Project MARS

A Technical Tale

by Dr. Wernher von Braun

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English translation by
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A fiery chariot, borne on buoyant pinions,
Sweeps near me now! I soon shall ready be
To pierce the ether's high, unknown dominions,
To reach new spheres of pure activity!
This godlike rapture, this supreme existence,
Do I, but now a worm, deserve to track?
Yes, resolute to reach some brighter distance,
On Earth's fair Sun I turn my back!
Yes, let me dare those gates to fling asunder,
Which every man would fain go slinking by!
'T is time, through deeds this word of truth to thunder:
That with the height of Gods Man's dignity may vie!

— Hohann Wolfgang von Goethe, "Faust."

Publisher's Introduction

Mankind's love affair with the planet Mars is certainly not new. It has long been recognized that Mars is the planet in our solar system most capable of supporting life. Until the 1970s, the existence of life on Mars remained an open question. We know today that there are no civilizations on Mars, but in 1949, when this story was written, the possibility had not yet been ruled out. In this story by Wernher von Braun, Mars has an underground civilization which is more or less on par with our own. And it is a peaceful civilization, neither bent on conquest nor paranoid about being attacked. In this story of man's first human mission to Mars, ten space ships make the journey. Upwards of 1,000 flights into Earth's orbit are required to build, supply and fuel these ten ships, and it is an international, cooperative project. In short, the undertaking is on a scale that would never happen in the real world. We tend to stick our toes in the water first, before diving in.

But neither of these issues takes anything away from the story. In fact, they add to its larger-than-life-adventure quality. All other aspects of the story are very realistic. The characters think and feel like real people; the science and rocket technology are accurate and are consistent with what is being used today; the mission timeline exactly matches reality; and so on. The mission plan does not include staying to colonize or setting up a Martian base, which, again, is realistic for a first mission. von Braun went to great lengths preparing the plot for this story. The calculations and technical drawings that he developed for a Mars mission, and on which he then based this story, are included in the 65-page appendix of this book.

The writing style of *Project MARS* is typical of an adventure story written in the 1940s. The translation from German to English and the publisher's editing have both retained the original styling, faithfully reproducing what von Braun created. What we have here is a genuine adventure story, created without the aid of special effects or sophisticated electronics. In contrast with much of what is written today, this story is highlighted by love and adventure, instead of sex and violence.

This is quite simply a story of ordinary people doing extraordinary things. Where *Project MARS* differs from most fiction of the mid-20th century is in its multiple main characters. Typical science fiction of that era involved one main character (perhaps with a side-kick) who beats the odds, saves the world, and gets the girl, pretty much all by himself. In von Braun's story there are many characters who make essential contributions, and the story will center for a time on each of them. This may be a throwback to von Braun's stated fascination with the works of Kurd Lasswitz, the father of German science fiction, whose book "On Two Planets" featured a host of characters, all contributing to the plot but with individual roles. This is also consistent with how the real world works – many people working together to accomplish what must be done; each affecting and being affected by the others. It's no accident that contemporary fiction predominantly relies on this "multiple protagonist" style.

You will find no ravaging monsters, terrorists or killing machines in this story; there is danger without a "dark side," and challenge without threat, just like the real world. However, it does differ from a "real" space mission in that there are no interfering politicians, lobby groups, trade unions, etc., repeatedly redefining the mission's goals, driving the cost up and the schedule out . . .

As much as *Project MARS* is entertainment, it can also be seen as a proposal – for international cooperation in a human mission to Mars. Von Braun clearly believed this was possible (this story takes place in the 1980s) and went to great lengths to prove as much, both in his professional life and in his writing. When this story was written, in 1949, a manned mission to Mars was considered fantasy by the man in the street, but today very few people would deny it was possible. The reasons that we haven't done it are economic, not technical.

There are minor social matters in the story that might be different from what would happen if this mission were flown today – such as the all-male crew – but they don't detract in any way from either the story or the idea of a manned mission to Mars. There are no miracle technologies or leaps of faith required to make this story believable, just a willingness to be entertained.

In this never-before-printed science fiction novel, Wernher von Braun, combines technical fact with a human story line in the way that only a true dreamer can realize.

Author's Preface

There are few dreams of the future which have woven so fascinating a web around human fantasy as flight through space. Since the first, epoch-making experiments of the great American pioneer of rocketry, Robert Goddard; since the days when Hermann Oberth, the German, and the Russian Constantin Eduardovitch Ziolkowsky published their startling writings on rocket propulsion, a veritable spate of literature has overwhelmed the public. This has covered the entire field ranging from serious, scientific dissertations to comic strips.

This literature is so voluminous as to render it difficult for even an engineer to sift the actual interplanetary premises of rocketry from idle conjecture, for in many minds there is a strong tendency to identify rocketry with space travel.

In the meantime, rocketry has become a recognized part of the science of armament and this tends to darken the glass through which one peers into its future. Much development has taken place since the first crude experiments of the path-finding pioneers, and much of this has been hidden from the public view for reasons of military security.

The object of this book is to assist the eye of the public to penetrate the thicket of confusion in which the future of rocket power now lies hidden. The following pages present a sketch of inter-planetary travel as visualized by one who for more than two decades has tumbled along the thorny path leading to the development of large rockets. The author has had his full share of bitter disappointments, nor does he underestimate the height and ruggedness of the barriers to be conquered before the first manned rocket shall be projected into illimitable space.

Despite our justified preoccupation with the problems of today, we must not neglect those of the morrow. It is the vision of tomorrow which breeds the power of action. Thousands of scientists and engineers are laboring constantly to perfect our knowledge of rocketry and rocket propulsion, and millions of dollars are spent yearly to advance such research. What the results will be is beyond the public ken, but they will surely exert a vital influence upon the future of the entire Earth and well beyond its present confines. Tens of thousands of young lads live their inner lives in dreams of a rocket-powered world. They envisage themselves circumnavigating the Earth in space ships, landing on the Moon and conversing on terms of familiarity with the inhabitants of Mars. The ease with which their comic strip heroes perform such feats leaves them no doubt that the actual reality lies not far away.

The author strongly feels that not only these boys but the public in general is entitled to know just how far and in what direction the science of rocketry now points and what the practical possibilities may be.

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I have used an unpretentious tale as a frame in which to paint the picture. The idea has been therewith to beguile the tedium which might be caused by the relative dryness of disquisitions concerning each problem in detail. The sum of these problems represents the barrier which as yet stands between us and our voyages into space. Nonetheless, all the mathematical data in the text are, without exception, the results of careful computations or tested scientific observations. This likewise applies to the assumptions as to the physical nature of the planet Mars, except for its canals and inhabitants. The subject of the latter is as controversial today as it was thirty years ago.

Errors may possibly have crept into my preparatory work for this book – it is my dearest hope that they may be but few. To him or her who may discover them will go my heartiest thanks, for every improvement will but serve to delineate more clearly our projected outline of future space travel. Truthfully, to project such an outline is the task of this book. My scientifically inclined readers will find in the appendix a certain amount of source material as well as the basic computations.

Putting the project in simple, narrative form permits me to outline the scientific, financial and organizational efforts which will be necessary before space travel can actually be brought into being. Few rocket enthusiasts have any idea of the inevitable scope of these efforts, nor are they mentioned in either scientific dissertations or in fiction.

The space ship will, I am confident, never emerge full-fledged from the mind of any solitary inventor who has constructed it with the help of a faithful assistant in his back yard. Only by the joint effort of thousands of engineers and scientists in a wide variety of fields can it become a reality. The list of these fields is almost all-inclusive, extending as it does from astronomy through medicine, safety, radio, mathematics, chemistry, physics, aviation, metallurgy, production engineering, and a host of others. To back up the technical development, there will be required farsighted industrialists, open-minded military men and daring financiers.

Part of the object of this book is to stimulate interest in space travel throughout these and even wider circles, for many readers will discover that their professions or trades have hitherto unsuspected applications to it. Not a few such readers will find themselves filling in details at which I have here not more that hinted.

Space travel's prime objective in the minds of its serious protagonists is to benefit mankind by extending his sphere of activity. It is with some regret that such protagonists find that wherever large rockets are tested today, it is done with military objectives. But rocketry, like aviation and atomic energy, has enormous military significance aside from its more noble and constructive task.

The stage setting for my narrative, therefore, is an Earth united after a final global conflict, in which are portrayed some of the terrifying aspects of future military rocketry. These aspects are inevitable concomitants of the finer phase, and I hope that they will not give offense. The military potentialities of the rocket are open to any technically-minded nation prepared to shoulder the burden of development. There's no mystery about it; it involves mainly a scaling up of existing designs. As far back as 1912 it was possible to accurately compute the requirements as to size, fuel and horsepower for transatlantic aircraft. It was many years, however, before the development work to put them into service could be completed.

It is therefore my desire that the reader should not remain ignorant of the tremendous impact on military science of the field of rocketry. My most earnest hope is that the world may be spared another conflict, but if such a conflict should be inevitable, as appears at times, I want the homeland of my free choice, America, to hold the weapon of rocketry against her adversaries, whoever they may be.

With the utmost care I have avoided delving into the realms of fantasy in describing physical conditions or phenomena encountered on the trip to Mars, nor have any assumptions based solely upon vague theories been used. No "miracle chest" from which the presiding genius produces at will "death rays" or "cosmic energy" will be found aboard my space ships. This is in contrast to so many science fiction stories which rely for their plausibility upon mysterious knowledge springing from the brains of some intellectual superman. My ships are propelled by compounds well known to the chemical fraternity. They are constructed of familiar materials. Even their equipment is built up around presently familiar methods and procedures. In other words, they are but a projection, an extrapolation, a natural development of a still youthful but solidly established technology.

For like reasons, my space ships are not atomic-powered on their trip to Mars. In the face of the considerable quantities of propellants required for space travel when using chemical fuels, it has become a custom for many quasi-scientific writers to promise future atomic fuels which can do the trick better. The nature of these mysterious fuels is tacitly bypassed or conveniently cloaked by vague hints at "military security."

The controlling of nuclear energies is but a recent achievement in physics and technology. It may still conceal a number of future surprises and I have no desire nor intention of decrying the eventual application of this source of power to navigation of interstellar space. When referring to technological advances, the word "impossible" must be used, if at all, with utmost caution... But I should like to state here that, within the framework of our present knowledge, atomic rocket fuels belong in the realm of wishful thinking.

The second part of our story lands us on the reddish surface of our neighbour Mars, thus completing the technical mission. From this point on, the solid, scientific platform upon which we have stood sinks beneath our feet and we tread upon the fairy bridge of fantasy, via which – and via which alone – the author has visited Mars. In his reluctant attempt to portray the conditions which faced the crews of the space ships, he was reminded that the fine Italian hand of Danté apparently did not tremble when penning a most detailed description of the Inferno; and yet Danté probably had not nearly as much infernal scientific data upon which to base his descriptions as the author has Martian data. Encouraged by this classical precedent, the author swallowed his scruples and passed the "Point of no Return."

And so he has portrayed the Martians as age-weary from super-civilization, thus affording him the opportunity to speculate contemplatively about the future of our own youthful, technology-ridden culture. For certain of our readers who may have gagged on the mass of technical detail upon which they fed during the long voyage through space, this part of the story may offer opportunities for ruminative philosophical reflection.

— Wernher von Braun, Fort Bliss, Texas, 1950

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A.D. 1980

Never before had men felt real confidence that peace was permanent.

The fear that a diplomatic cold war might metamorphose into a hot fight, with death and destruction to soldiers and civilians alike, was gone.

The final catastrophic conflict was over. The great Eastern Bloc, after five of the most frightful years in the history of the world, had finally succumbed to the last despairing blows of the almost exhausted Western Powers. The great Asiatic mass had become a group of smaller states, slowly digging out from under the ruins of the war. But they, too, were represented in the Congress of the World, which was in session in the great domed building overlooking Long Island Sound from the hills above Greenwich, Connecticut. They too voted Aye or Nay on the laws which were to assure the welfare and safety of all the peoples of Earth. At last the ancient prejudices and selfish insistences upon national sovereignty were no more. A brief ten years had seen the flames of war engulf anew the hopes for peace of uncounted millions, but now no votes could frustrate the decisions of the freely selected Representatives of all the People of the Earth. The President and his Cabinet faithfully carried out whatever was enacted into law by the Congress of the United States of Earth.

And each man knew in his heart that the Government of the United States of Earth no longer lacked the military power to enforce those laws. Fatal indeed had this lack been to the United Nations.

The Parachute Police of the United States of Earth could handle any minor trouble which might boil up in any latitude or longitude. Almost within minutes from the outbreak, Parachute Police would be on the spot to awe into civilized obedience the unruly burghers of the most remote village or hamlet. Trained to a tick and composed of elements drawn from every land and clime, they had at one time been the best soldiers in the world. In the event of more serious and organized trouble, the United States of Earth could reduce to rubble any community which refused to obey the verdict of the Congress. Enormous submarine cruisers could fire long range rockets thousands of miles inland if the appearance overhead of hundreds of destruction-laden bombers should have failed in its effect.

And above it all, invisible yet omnipresent Lunetta, the man-made Moon, circled silently far above the stratosphere.

Lunetta's acid test had taken place in the final World War. During the dread winter of 1974-75, the motorized forces of the Western allies had ground to a solid stop in the vastness of the Asian steppes. The chilling cold had numbed the blood and the courage of the most intrepid soldiers. Air attacks on the industrial centers of Siberia had almost eased by reason of the incredible accuracy and effectiveness of the adverse anti-aircraft rockets. But these rockets could not reach Lunetta in her dizzying heights, and the courageous crew of 440 men and women who manned her directed their atom bombs by remote control at the enemy's manufacturing plants to such good effect that the scales of victory could only incline towards the Allies.

And so Lunetta had become the Goddess of a new, strong peace, which was to deliver mankind from the morass of the foregoing century. But she was also the symbol of the final victory of man over space. She it was who was to point out the paths of the universe to the peoples of the Earth.

History recorded the dawn of 1980.

Listen, Holt," said Spencer pulling the picture away from him, "we've had our best men working on this and on a lot of other recent pictures which that new reflector on Lunetta gave us. And they're getting more and more convinced that the old hypothesis – that there's life on Mars – is true! And not only life, but intelligent life. Of course we haven't the faintest idea of what the Martians look like. Probably they're not human like you and me, but from what they've achieved, it seems they're not inferior to us in either intelligence or energy."

"Just look," he continued, "here's a bluish-green area so symmetrical in shape that we've got to take it as a cultivated patch of vegetation, planted in the middle of a desert otherwise as dry as a bone. Look at this dark green strip rimming the polar snow cap! That's a ring of vegetation, and it always appears just below the polar regions in Springtime, when the snow begins to melt. And see these bluish-green streaks, running in straight lines from the areas where the snow is melting, down to the temperate zones near the equator…"

"Those are the Martian canals we've all heard so much about, aren't they?"

"Right you are. But now it seems that they're not canals as we think of canals. Our astronomers have figured out that the Martian canals must be an irrigation system to drive the melted snow at the poles into the desert areas. So what you're looking at isn't open water, it's the vegetation growing along the banks of the waterways."

"But right at this point there seems to be some snow," remarked Holt peering at the photo.

"Sure enough. But you'll note that the canal leading through it suddenly disappears, and then emerges again on the other side. At that point the snow remains unmelted, and its color remains the exact same shade, as does the yellowish-red desert surrounding it."

"Here, at this other point, the canals radiate from a circular disk, like the rays of a star."

"Oh, you'll find those all over the place. Look at 'em. Here, and here, and here. Doesn't take much imagination to figure that they could be centers of civilization, as easy as not."

Spencer's voice was solemn. "Look, Holt," he said, "We've got other intelligent people out there in space, and not so very far away. Not too far, at any rate. The astronomical bunch showed these photos to the President in Greenwich the other day. And, of course, somebody got to talking about going for a look-see. So the President ordered a study made to find out whether the Space Forces could do the thing from a technical standpoint. So they've come to us to do the figuring of the preliminaries. If that figuring comes out positive, we'll get the job of building the ships and the equipment. What I want you for is the job of military advisor on our planning staff!"

"But…"

"But me no buts, Holt. Confidentially, you're the choice of the Space Forces for leader of the expedition, if it comes off."

Holt rose and stared silently out the window at the vast plant. His confusion at the thought was apparent.

Spencer walked up behind him and laid a hand gently on his shoulder.

"As a retired officer, Holt, you're, of course, under no obligation to take the job. But I know you'll do it, after working with you all these years."

There was assurance and yet pleading in Spencer's voice as he continued. "You've had a long time in the air and outside of it. Among all our people there are only a few who, like you, are equipped technically to take charge of such a job, and who at the same time have the necessary qualities of leadership. Above all, you possess balance without sacrificing a certain amount of zip. We're going to need both of those qualities in a large way."

Holt scratched his head reflectively.

"How about a couple of days to think it over?" he answered, "What you've cooked up is no half-hour hop to San Francisco, you know…"

He stood silently, his eyes still riveted on the vast buildings outside the window.

Finally he turned to Spencer with a wry smile. "You know perfectly well that a job like that intrigues me no end. But I'd rather not make up my mind until my wife and I have talked it over. I retired from active service two years ago because we didn't see each other, practically at all, for the five years the war lasted, nor for two years after that. She might think it rather unfair of me to go off on a wild Mars chase."

Spencer answered, "Your wife knew when she married you that you were also married to the sky, as men were married to the sea in bygone years. She knows that she'll have to put up with privations and long absences as long as you're any real good to her or to the world…"

"Well," said Holt, "I want to get General Braden's angle on the military and organization side of this thing before I jump, too. This is Tuesday, I'll let you know before Saturday noon."

"Right, I'll expect to hear from you Saturday."

They walked together to the door and there was a meaning in their handclasp as they parted.

With his car headed back towards Laguna Beach and Emerald Bay, Holt drove as in a dream. Passing the tall oil derricks of Huntington Beach, he pulled over to the side of the road where it runs close to the Pacific's sandy shore. Putting the ignition key in his pocket, he wandered off into the sand dunes and towards the ocean. For the moment, he needed solitude. Thoughtfully, he picked up a couple of seashells and gazed at them for a space. With his eyes seaward, he let them fall from his listless fingers.

So it was Mars, at last. He'd been in rocketry and space travel long enough to know that there'd be at least a year of concentrated planning and calculating. Then rocket ships would have to be designed, built, tested and improved. That, of course, was Spencer's specialty; he'd do it all right. But this was no fortnight's trip, like the lunar expedition; this was big, really big. He'd gone along on the lunar trip as a young, unattached Captain. And he'd had a magnificent Commanding Officer, a splendid fellow named Fitzgerald…

This voyage to Mars was something entirely different, and his astronomical knowledge, like that of all good space men, was sharp enough to tell him that the trip would require a time about half way between six months as we reckon them and six months as the Martians reckoned them. Quickly he did the sum in his head. One half of an Earth year is about 183 days. Add one-half of a Mars year, 343 days, and you get 526 days. Half of that is 263. Why, a one-way trip would be 263 days! They'd spend 526 days in outer space, just traveling. A lot more than a year! But then, too, they'd have to wait on Mars for the home planet to get into the right position before they could start back. That would call for yet another year at least. What a year that would be! It was the real objective of the whole expedition. During that time they would be finding out the nature of the inhabitants, and the circumstances and conditions in which they lived. There could be no doubt about it, he would spend not less than three years in outer space or upon a strange planet before he'd set foot upon Earth once more…

It was his job to figure out, as well as he could, what conditions on Mars would be and make all possible preparations to meet them. And the same for their return to Earth. Upon his success in so doing would depend the success or failure of the whole expedition…

Of course Spencer's reference to the probability of intelligent life on Mars hadn't been particularly startling. General ideas along that line had been rather common for decades. As a matter of fact, they dated from the time when Mars first focused in the objectives of improved telescopes. Such assumptions were but more strongly supported by the new photographs taken from the observatory on Lunetta.

Holt sank down on a convenient sand dune. As his eyes sought the horizon above the gentle Pacific rollers of the balmy Spring evening, exciting thoughts churned within his brain. The adventurer in him reawakened. This was no tame trip to a domesticated little satellite like the Moon! Once those trips were started, it was almost like driving to Death Valley – you can get an accurate map at any filling station. The astronomers had laid out every cranny and crater. He'd known exactly what to expect in the matter of atmosphere, temperature and such like. All the plans could be made with exact knowledge of what would be met. Since there wasn't any atmosphere, suitable pressure suits, with built-in breathing equipment, were provided. The footing would be hot during the 14 days of isolation which constitute a lunar day, and cold during the ensuing lunar night. So they worked up suitable heat retainers and temperature controls. It had been a matter of physics, technology, design, fabrication and testing in chambers where lunar conditions were reproduced. It had been a grand technical experiment. The dangers had lain in technical shortcomings or hiatuses in planning, Holt knew, for some minor slips of that nature had made him suffer physical agonies.

But this Mars business! What did we really know about the actual physical conditions there? His first step would be to pick the brains of the astronomers and get out every last bit of information to be found in them. The initial move would be a trip to Lunetta. There he would work out a detailed program of mensuration with the astronomers stationed there. This would provide many of the data required for organizing the expedition. Among others, they would need temperatures, density of the Martian atmosphere, its constituents, and so on. What is the nature of the surface of Mars? Do winds exist there? What will be the best procedure for landing? And what spot will be the most suitable?

There were other questions; in what form does life exist? The creatures must have intelligence and be thoroughly organized if they can set up such elaborate irrigation systems. And there must be a General Martian Government, indicated by the way that the irrigation system covers the entire planet in such astounding symmetry, from one pole to the other.

Holt wondered whether the inhabitants would be belligerent. After all, Mars was rather an elderly planet, he thought, and perhaps they've gotten over their period of wars in the thousands of centuries by which their planet is older than ours. Maybe they're even unfamiliar with armaments, because they've no more use for them…

But maybe their superior age and experience has put them in possession of atomic energy and perhaps something even more advanced, with which we're still unfamiliar? Will they receive an expedition from the Earth with kindness or not? Holt's mind whirled trying to imagine the variety of eventualities which might greet him on Mars. Not in the wildest flights of imagination could he convince himself that he had covered even a part of them.

It seemed reasonable to prepare for the worst. It might be foolhardy to explore the distant, unknown planet with a couple of companions waving only olive branches. There'd have to be a sort of commando detachment equipped with the latest in weapons. In that way, there'd be at least a chance of covering a retreat. But it would be far more important to affect an amicable approach, and to be able to get into communication with the inhabitants, assuming that the latter were also so inclined.

Holt's mind went back to his school days. He wondered how Hernando Cortez felt when he and his little band of followers found themselves on the coast of Mexico and face to face with the vast Empire of the Aztecs. Cortez had tackled a huge section of humanity which spoke an unknown tongue, adored strange Gods, and had curious and cruel customs springing from an ancient culture. Could this be more foolhardy than Cortez's invasion? Well, time would tell…

Holt ceased musing and he leaped to his feet. In his soul, he knew that he was already dedicated to Mars. He would be the Columbus of Space, the Admiral of the Universe, the Cortez of Mars. Hastily he regained his car and headed for Emerald Bay.

Catherine Holt was cooking dinner when her husband's car rolled into the little garage near the kitchen window. She saw him pull down the overhead door with an absent-minded gesture and walk into the living room, as in a dream, sit down in his favorite chair, and begin to drum his fingers on the leather chair-arm. After several minutes, he rose and came into the kitchen, putting his arm around her and kissing her, as was his wont after any absence. When they sat down to the table, she noticed that he put a pinch of salt into his coffee before reaching over to the sugar bowl. The conversation was desultory, but he did discuss for sometime how old man Spencer still had the same energy as ever. Humorously, he laid it to the odoriferousness of the Spencer cheroots.

"Gary," said Catherine, "come on; tell me what's up."

Oh," said he, "no hurry. Let's go out on the terrace and watch the sunset. I'll get your coat."

Putting her white sports coat around her shoulders, he gave her a gentle shove through the French doors onto the fieldstone terrace. Holt's glance went up into the darkening skies where the starts shone over the wide Pacific. He put his arm around her.

"Gee, this is a nice place," he said, "with you…"

"It is for me too, darling, so long as you're here."

"Do you think you could stand it for a while without me, if I were doing something really important? – something that would do the whole world a lot of good? Oh, I might as well tell you… See that red star up there? It's Mars, and they've decided they want me to take out the first trip; Flight One. Some new photos made from Lunetta make it pretty sure that it's inhabited, and the President of the Earth wants us to go and see if the people up there could possibly want to start a war."

There was a sobbing undertone in Catherine Holt's voice as she answered. "Just like you men! You'll never get over being children! You get this old Earth reasonably well regulated, you finally establish peace on Earth, and it begins to look as though there were no more enemies and no more wars. And just as we're getting settled in a place we both like and can afford, off you go, hunting for more trouble in Space…"

"But darling," he returned, "this isn't a simple, childish matter at all. Just suppose for a moment that these Mars people should suddenly drop down and take possession of Lunetta! Surely you realize that that might be fatal for all of us, since Lunetta can atom bomb any spot on Earth. All they'd have to do to dominate the whole Earth would be to control Lunetta. And from what we can find out from their operations on their own planet, they should be just as capable of coming to us as we are of going to them."

"Well," said she, "if they're as dangerous as all that, why haven't they come here long ago?"

"Perhaps they have been here… Ten thousand or one hundred thousand years isn't so very long, when you figure it cosmically. How far back do you think our history goes?"

With growing enthusiasm, Holt began to explain the significance of the Martian canals, the areas of vegetation, the seasonal variations and the conditions affecting living matter. These had probably forced the Martians to adopt extreme technical measures in order to survive at all upon a planet so old and so deprived of moisture. One could hardly tell, said he, whether the intelligent beings on Mars might not be gazing with envy upon the Earth, where conditions affecting life would appear so much more easy. There was no reason in the universe why such a condition might not have been pictured for them by their advanced astronomers… Why, they might even now be considering a general exodus towards Earth, and the results of anything like that upon humanity might well be incalculable.

Catherine Holt could hardly take in her husband's fantastic peroration. Despite his wanderings in and out of the atmosphere, she'd always kept her feet on the ground, forming a quiet and practical balance wheel which had steadied his sidereal gyrations. She loved him and the children and their home, and had always regarded with tolerant amusement the call of the wild blue yonder which so stirred the hearts of men. But her heart told her that no small part of the real love she felt for her husband was directly due to his devotion, infantile though it might seem, to the romance of flight. Like the love for the sea of a sailor who has "swallowed the anchor" too young, she saw Gary's yearning for the outer spaces reawaken after a few short years of rest and quiet. Torn by the knowledge that he would be gone for a long time, on an adventure of high daring and distant danger, she knew that she neither could nor should hold him back. His heart would break, were he to follow the exploits of some other leader through the papers and the radio, his body in his familiar armchair, but his soul winging through space. She'd be no true spaceman's wife were she to hinder him by so much as a thought. When she spoke, her voice had an aging quality in it.

"Gary, it's wonderful," she said. "I'll be the proudest woman on Earth…"

He felt her soft lips on his cheek and his arms instinctively went around her for a long time. He could not miss her brimming eyes as they separated.

"When do you expect to get started?" she asked.

"That's still indefinite, so far as I'm concerned. We've got a lot of checking to do to see whether it's practical at all. That will decide whether the attempt will be made. And after the decision, the date will depend upon a lot of things. First of all, Spencer will have to build the ships, which will take all of two years. Then we have to choose the proper apposition between the planets, and I'm entirely in the dark as to that. Don't worry, I'll be here for a long time yet, but I might be pretty busy and have to get around a lot…"

Her answer was what he had expected. "Just let me know what you want me to do…"

A tough-looking little man of fifty-five, in a Space Forces General's uniform, sat in an elaborate office in the Bureau of Earth Security in Garden City, Long Island. Humphrey L. Braden had the chiseled features and hawk-like profile which naturally went with the ex-Squadron-Leader of a supersonic jet-bombing outfit in the U.S. Air Force. Now he was Commanding General of the Space Forces, mainly because of the remarkable technical ability which had finally earned him a transfer to the Planning Staff of the Air Force. It was there that his dynamic driving power had urged slower minds on to the creation of the great, multi-stage rocket ships which had made the construction of Lunetta become an actual project. He it was who had visualized the military importance of a manned artificial satellite, circling the Earth like the Moon and requiring no power to do so. And it was he who had made it his life's task to overcome the objections of the doubters who had opposed the plan as visionary and impractical, and who had endeavored to frustrate it on that basis. Finally, he had established the Space Forces of the U.S.A. as coequal with the Air Force, Army and Navy. This happened when the last war proved that conventional bombing was no match for the Russian anti-aircraft rockets. Then the Jupiter-type space ships were beginning to successfully circle the Earth and prove that the construction of an artificial satellite, such as he had been advocating, was not only possible, but imperative. As the father of the Space Force of the U.S.A., he was appointed its Supreme Commander, and later, when the United States of the Earth became a reality, he succeeded to the new post of Commanding General of the Space Forces of the Earth, reporting to the Secretary for World Security. Such was the man awaiting Gary Holt.

When the latter entered, he was greeted like an old friend. They both sat down and Braden began the conversation.

"Spencer has let the cat out of the bag, or so I've heard," said the General. "What do you think of it?"

"Anything as big as that is mighty tempting, sir. But so far I've no very definite idea of how the whole thing will shape up, and I'm most anxious to hear how you've got it figured in detail..."

"Of course you would be; I can't blame you for that. So I might as well tell you that the planning part of the thing is still extremely sketchy. It's that part of it that's your pidgin. You're to carry on with the planning, and work it out in detail. Above all, I want you to balance the technical requirements against the materials and means that are available now. In other words, it's up to you to synchronize the whole business. But let me tell you our overall outline of the enterprise."

Braden reached for a document on his desk and began to read from it.

"Objective and Implementation of Operation Mars.

1. Operation Mars contemplates an expedition to the Planet Mars in order to determine whether the latter is inhabited by intelligent beings who might, now or at some later date, carry out any hostile design upon the Earth or any outpost thereof. Said expedition is simultaneously, if possible, to carry out an extensive program of research with regard to conditions on the Planet Mars.

2. Operation Mars will be carried out by the Space Forces under the direct supervision of the Commanding General. The Commanding Officer of the expedition will be an officer of the Space Forces appointed by the Commanding General."

At that point, Braden nodded at Holt, as much as to say, *You're it.*

"3. Estimated personnel: 70. Approximately 25% to be Commando troops in preparation for any armed resistance which might be met. The remaining 75% will consist of officers and technicians for the rocket ships, scientists, communicators and physicians, etc.

4. The expedition will be composed of ten space ships, of which seven will return to Earth, while three will be abandoned near Mars. Each of these three ships will be equipped with a landing boat to be used for landing upon the Martian surface and for taking off therefrom. The three ships will also serve as general cargo carriers for food and supplies; likewise for such supplementary equipment as special devices, committing boats, spare parts, repair equipment and so forth.

5. When the ten ships have reached the orbit of Mars and entered its gravitational field, any tendency to fall freely to the surface will be counteracted by a power maneuver. This will lead them into a satellite orbit. From this satellite orbit the surface of the planet will be carefully reconnoitered, photographed and studied, preliminary to the selection of a suitable landing area and the planning of the movements of the landing party upon the surface. Should this observation give grounds to believe that a landing might be impossible or inadvisable, none will be attempted. In this case, the squadron will await a suitable opposition between Mars and the Earth for the return trip and then undertake it.

6. Departure and return paths of the expedition will be those of a satellite orbit around the Earth. This orbit will lie in the plane of the ecliptic and will complete a full turn around the Earth in two hours at an altitude of approximately 1,040 miles. This orbit is almost identical with that of Lunetta, except for the fact that it lies at an angle thereto.

7. The Mars ships and the equipment pertaining thereto, including personnel, will be transported to the departure orbit by rocket ships of the *Sirius*-class. The Mars ships and equipment will be transported disassembled. Assembly and loading will take place in the orbit of departure. The landing boats will be assembled on Earth and flown up to the departure orbit under their own power.

8. A ferry service will be instituted whose main problem as to volume and mass will be to deliver the propellants for the Mars ships into the departure orbit. It is anticipated that the Space Forces will augment the number of *Sirius*-class rocket ships at their disposal in view of this exigency.

9. The landing on Mars is to be carried out, if possible, with avoidance of any hostile contact with inhabitants of Mars."

General Braden ceased reading for a moment, then he said, "There you have it, Holt. What's your opinion?"

"General, it's a wonderful plan."

The general went on, "It can hardly be called a plan, Holt. You might call it an outline for a plan. When the details are gone into, there are probably many changes to be made, but it will serve as a general directive."

"May I ask a few questions, sir?" said Holt.

"Shoot, Colonel," replied the General.

"Where is the money coming from?"

"Of course that's still one of the most important problems. President Vandenbosch intends to ask the United Congress for a special appropriation if our preliminary studies seem to justify it. Our astronomical division is working hard on a Special Report, as complete as they can make it, and profusely illustrated with the latest and best photographs of the planet. That ought to give the President's request enough power for him to put it over."

"Is that material available, sir?" said Holt. "I'd like very much to see it if I may…"

"Of course you may," said the General. "Tell you what you do. Drop up to Lunette in the next day or so and interview the astronomers. Mars is in opposition right now and in the most favorable phase for observation. We've taken advantage of it for the photographs you've seen, and you can get a good look at your planet in the new reflecting telescope."

"General, I'm sure we'll need a very considerable quantity of new information about Mars in order to have adequate basic data to work up a satisfactory plan for this undertaking." Holt looked at the General quizzically.

We surely shall," answered the latter, "and there is a lot more which is not covered by data on Mars alone. There are many other phases of this job which call for extensive research along many lines. Professor Ashley – you know, he's Head of the World Research Board – has promised us all the support and cooperation that the Board can give. That means that every University and Research Center in the whole world is at our disposal. And, of course, quite a lot of the funds appropriated by the Congress will have to be spent for such research."

"General, what's your guess as to the total amount of money required?"

"Our preliminary estimate is two billion dollars. But whether it'll be enough's another question…"

"How about personnel, general? Has anybody besides myself been selected to handle the planning and to go on the expedition?"

"Here's the setup on that, Holt: United Spacecraft will build the space ships and the landing boats. Spencer must have told you that, and I'm sure that you'll agree that he's the best man and his company is the best company for it. Spencer will also have to build the additional *Sirius*-class ships for the ferry work.

"For the planning job, we're going to form a committee composed of Spencer and some of his staff, one of Professor Ashley's men, and you and me. This committee will determine just what's to be done and will also distribute the work appropriately.

"We've made no plans as to the personnel of the expedition itself. If you head it, it seems best to give you the widest latitude as to who goes with you. But, of course, Ashley ought to have the say when it comes to picking the various scientific specialists, particularly for the research work on Mars itself."

The General smiled at Holt and continued, "You know you'll be gone from the Earth for almost three years, don't you? That's a very long time, and you'll run into a lot of surprises and technical difficulties. Not only that, but you're going to have some pretty psychological problems on your hands.

"Think it over for a minute… You and your crews will see the Earth only as another heavenly body for almost three years. It will not appear as a solid, homey disk, with the familiar continental outlines standing out and reminding you of where you live. You see it that way from Lunetta, or from the Moon…

"When you pick your people, you'd better see to it that every man jack understands that. You and they will have to know that everything that matters to you will seem to have shrunk to nothingness on the surface of a nasty little star in the dim distance. And you'd better be mighty careful about the bodily fitness and the psychological strength of every one of them. Ask yourself whether their initial enthusiasm will hold up after two and three years before you choose. I tell you, Holt, you're going to need men of steel for this job. And you, the leader, will have to be case-hardened."

The old soldier's words made a deep impression on Holt, and the fact that the grand old man of the Space Forces had found in him the qualities necessary for a task of such magnitude touched him profoundly. After a moment, he asked, "What about the publicity, sir? Is there to be any? I presume that it's all Top Secret so far…"

"Well," said the general, "so far, we've kept the new research data on Mars and the photos under wraps to prevent too much of a stir. But when President Vandenbosch forwards his request for the appropriation to Congress, that will be dropped. We then propose to put on a campaign in all the newspapers of the world. The idea is to publish the pictures and to discuss them technically; likewise to go into the plans for the expedition. Our hope is that we shall be able to steer the public reaction, which we expect will be enormous, into constructive and controllable channels."

The general grinned almost sheepishly, "Besides," he said, "it's more than possible that the right kind of publicity will make the United Congress feel quite generous..."

"Is it all right for me to approach some of the people I'd like to consider for the planning work, and maybe for the trip, before the thing is announced? Of course any such approach would be held confidential."

"I can't see where it would do any harm. You'll need a few men immediately, if we're to get on with this, anyway. And, of course, you'll discuss it only with thoroughly reliable people whom you can trust absolutely. It will be but a few weeks before the whole world will be standing on its head over the mere plans, anyway."

"I have a few people in mind already, General..."

"That would go to show that you'd decided to take the job before you even talked to me, wouldn't it?" laughed the General.

"General, I believe you know perfectly well that I couldn't have refused a job like this..."

"What's your wife got to say about it?"

"She's taking it beautifully. Half the time she's in tears, but the other half, she laughs over us men who can't stay quietly at home."

"You tell Catherine that my hat's off to her," answered the General as Holt opened the door to leave, "and one more thing. Of course you'll go back to active duty in the Space Forces. Colonel Maligny, our present Chief of Staff, will take care of that detail. Talk it over with him; he's had all the necessary instructions. Your preliminary post of duty will be Long Beach, so that you may collaborate as closely as possible with Spencer. But first, get away on your trip to Lunetta and have a good look at your new planet."

Chapter 2
A Flight to Lunetta

The Lunetta Ferry Squadron's Base was near Kahului on the Island of Maui. To Gary and Catherine Holt it was almost a second home, for they had been based there for a long time during the past war, when he had been flight instructor of Captains of Space Ships during the days of the old Jupiter class vessels. So he naturally took Catherine along to the base. Of this she was very fond, not the least reason for this fondness being that they had honeymooned there. To this had been added the first few years of their married life, and she proposed to look up a lot of old friends. When Holt got back from Lunetta, there'd probably be time for them to spend a day or so at Waikiki Beach, and that was a pleasant prospect.

There was an excellent reason for the selection of Kahului as a base for the Lunetta Ferry Service. First of all, any such base must of necessity lie close to the sea, for all space ships were given their primary acceleration by enormous rocket booster stages. After exhausting their propellants, these booster stages fell back to Earth, and could land only upon water without suffering irremediable damage. Water also was essential for practical salvage operations. On Hawaii, climatic conditions were especially favorable. It was also essential that the base be located at a great distance from the West Coast of America. This need was due to the fact that the relative movement of Lunetta to the Earth was in the same direction as the latter's rotation, although at a marked angle to the plane of the Equator. This meant that the boosters might drop as much as 1,000 miles East of the launching site. Logistically, all sorts of necessary supplies and equipment, such as rocket ships, parts, and particularly propellants, could be transported from the West coast by sea at low cost and with ease.

Catherine and Gary Holt had seated themselves in the cafeteria of the Flight Control Building at Kahului where they awaited the departure announcement of the space vessel in which the latter was scheduled to go to Lunetta. The time of departure was 9:12 p.m. Departures were calculated – somewhat in the manner of ocean liners with respect to tidal conditions – according to the seasonal date and the location of Lunetta in her orbit.

Holt was back in uniform, having been recalled to active duty with the rank of Colonel. The wings of his collar bore shiny rocket insignia, the specialty mark of the Space Forces. His appearance was somewhat weary, for he had slept but little during the last few days. He had spent the daytime in the public libraries of Los Angeles, gathering books and pamphlets on the subject of Mars, and had sat up into the wee small hours reading them. Finally, he had prepared an enormous questionnaire for the astronomers in Lunetta, to insure that he would not miss asking them any question which seemed to him important and primary with respect to Mars.

He and his wife had little to say to one another. She could feel how his mind was churning around the many unknown factors in the new plan. She hated to see him disappear once more into the infinity that lay between the stars, whose dim light shone into her eyes through sleepless night after sleepless night. When he was away in Space she could never so much as gaze through a window after nightfall without feeling a sort of humble horror of those distant stars.

Gratingly, the public address system interrupted her thoughts: "Passengers for Lunetta ferry *Sirius*, all aboard, please!" Holt, with overcoat, brief case and kit bag, rose and she followed him. Together they walked down a long, subterranean passage, brightly lighted and paneled. It led to a heavy, blast-proof door beyond which lay the launching site.

Here, centered in the gleaming rays of ten powerful searchlights, stood *Sirius*. Like a great black tower she loomed into the sky – a sky dark and lowering to Catherine, despite its serene stars. Of *Sirius*' 200 feet of height, the lower two thirds was cylindrical and 65 feet thick. The cylinder was necked down to about 30 feet at this point, somewhat above which stood the third stage. It oddly resembled a stubby artillery shell and was the heart of the vessel which alone would rise to escape the grasp of gravity. All the great mass of the lower part was made up of two booster stages, whose sole purpose was to bring the third stage to a speed from which its own much smaller thrust could whirl it into outer space and into Lunetta's satellitic orbit. From its sides protruded two arrow-head-shaped raking wing-stubs housing the retractable airfoils for use upon return to the atmosphere. Near these stubs, a ring of portholes shore dimly.

Sirius' vast bulk was supported vertically by four great stabilizing fins which provided flight stability on her passage up through the atmosphere. They rested upon a heavy iron annulus, itself standing upon four massive legs some distance above the ground. The raging torrent of fire which was to spout from the rocket nozzles would pass through the central aperture of this huge metal ring and would be equal in diameter to the full thickness of the ship. Just below the center of the aperture was the jet deflector, whose conical point would divide the great stream of fire emerging from the rocket nozzles in a vertically downward direction, and would fan it out horizontally. This would be necessary to protect the concrete underpinnings from the mighty blast of the fiery jet streams during the few seconds before the ship lifted high enough to reduce the terrific heat.

Beside the ship stood an enormous tower-like gantry mounted upon a heavy trailer with many wheels. A small open door in the third stage was accessible via this structure. The tiny figure of a man could be seen standing in the open door.

When Catherine and Gary reached the underground blast-proof door, a group of some fifteen men were crowded around a gateway leading to it. Among them were officers, soldiers and civilians, each with the necessary papers for passage to Lunetta. Holt joined them after a short and silent good-bye kiss. She saw him stride across the open space leading to the gantry, within which an elevator lifted him and his group of fellow passengers up towards the open door in the third stage. As he crossed the little walkway between the tower and the door, he waved to her, then he disappeared within.

It was by no means Catherine's first space ship launching from close up, but she could never master the awe that overcame her when she saw and heard – nay, felt through every fiber of her being – the might of that infernal stream of fire which so lightly lifted the clumsy ships and hurled them into the distant heavens.

As usual, she walked into the observation bunker from which the departure of loved ones could be observed in safety. Six-hundred feet from the launching platform, the bunker afforded an ideal view of the proceedings through a dome of armored glass. A giant clock showed that it was 9:05 p.m. A luminous red spot on the face of the clock marked the time of 9:12, and a huge second hand jerked around the dial.

Catherine could see the ship standing motionless, a dark, menacing column of blackness, despite the rays of the projectors focused upon it. Soon, a powerful tractor appeared out of the gloom and hooked onto the trailer bearing the elevator in which Gary and the others had mounted their lofty aerie. The coupling seemed to be a pretty involved business and the driver of the tractor signaled with his hand to the man who still stood in the open door. Finally the gantry moved ponderously off into the dark background and could be seen no more. The little door closed.

Within the observation bunker were two men enclosed in a glass booth. Telephone receivers covered their ears and before their mouths were microphones. These men were now the only Earth dwellers in communication with the pilot's cabin of the *Sirius*. Periodically, one of them pushed a switch button and the loudspeaker in the bunker rang out:

"Space ship *Sirius*, X minus two minutes!"

At short intervals, the commands succeeded one another:

"Ship-side power's cut in."

"Cut in tracking stations."

"Space ship *Sirius*, X minus one minute!"

Outside the bunker, a colored flare shot into the sky, whereupon all the searchlights died and a powerful siren wailed a warning note into the night.

The loudspeaker roared again:

"Set radio to send and receive!"

"X minus 30 seconds!"

"Ready, the *Sirius*! "Pre-launching time, 10 - 9 – 8 – 7 – 6 – 5 – 4"

A tongue of blue-green flame licked out from the stern of the ship, enwrapping the heavy iron table and the stabilizing fins. Then it spread out flat with a roaring rush! The bunker shivered as though in continuous thunder, and the flame issuing from the stern of the ship swelled to a column faster than lightning and more solid than steel. The whole ship and the surrounding landscape were lighted by its baleful glare. The flames spurted frantically across the ground, pouring from the jet deflector. Then the ship began to move slowly straight upwards, as pebbles flung by the mighty stream of fire rattled against the transparent observation dome of the bunker. The roar of the rocket exhaust increased almost beyond bearing as the discharge nozzles reached a height at which the observers could look directly into them. As the ship gained height, the din slackened until finally the great mass became invisible in the darkest sky; its position alone betrayed by the comet-like jet exhaust which soon began to curve off gracefully to the North and East. Growing smaller and smaller to the eye, now roaring like a remote thunderstorm, it soon crossed the star-spangled heavens like a man-made meteor. Then, after a minute and a half, it went out, like a star hiding behind a cloud.

No! There it was again! Like a migrating star, and with increasing speed, the flaming point swept across the sky, heading more and more towards the distant horizon.

The loudspeaker snarled, "First booster-stage released O.K. All's well." It was the voice of the Captain of the *Sirius*.

Now the flare of the rocket exhaust was but a tiny point of light in the distant reaches of the sky. Not very high above the dim horizon line, it blinked once more and finally lost itself among the constellations just above the edge of the sea.

Again the snarl came from the loudspeaker, but more softly this time: "Second booster stage released O.K.! All's well."

There was a minute of heavy silence, then, as though from another world, the loudspeaker whispered comfortingly, "Third stage cut-off correctly. All's well. Trajectory data, please."

The men in the glass booth sprang into action with their microphones and head-pieces. From various electrical triangulation stations, which had followed the ascent by radar, they correlated the flight data of the invisible ship.

"Terminal velocity, 8,260.3 meters per second," said the loudspeaker as though bored.

"Angle of elevation, 4 minutes of arc."

"Altitude of combustion cut-off, 101.98 kilometers."

"Plane of great circle inclined 66 degrees, 32 minutes, 2 seconds to plane of equator."

"Major semi-axis, 7,290 kilometers."

"Minor semi-axis, 7,2338 kilometers."

"Timing error, 2.45 seconds."

A short time passed, then the ship answered in a whisper, "Roger. Thanks. Have radio contact with Lunetta. Out."

When Colonel Holt stepped through the little door into the airlock of the *Sirius*, the cylindrical passenger cabin of the *Sirius* was bathed in light. He placed his equipment in the luggage rack and strapped it down. Then he lay down on one of the air-cushioned couches that were arranged circumferentially around the walls of the cabin. At the head of each couch was a small, round deadlight giving a view outside.

The roof of the cabin was equipped with a large clock having a second hand and showing a spot of red light at the scheduled moment of launching. Surrounding the clock face were four indirectly lighted instrument dials, one of which indicated acceleration, while the others gave altitude, speed, and horizontal distance made good. Luminous signs surrounded the instruments, all of which were dark, save one. The latter warned passengers to "Strap baggage – fasten safety belts."

A ladder ran up the cabin wall to a sliding hatch in the roof. This was the passage to the pilot's compartment. In the center of the deck was a circular manhole plate with a large hand-wheel in its center. Through it one could reach the cargo space, below which lay the propellant storage bay and the machinery spaces which were accessible in that way.

The clock showed X minus 3 when the ship's mechanic closed and dogged down the oval hermetic door of the air-lock, after shutting the outer door. Then he ascended the ladder and disappeared through the sliding hatch into the pilot's compartment.

Holt looked through his little deadlight and was able dimly to discern the movement away from the ship of the great elevator gentry, despite the blinding glare of the searchlights.

When the searchlights were switched off at X minus 1, there was a simultaneous dimming of the interior illumination. A deathly stillness filled the cabin, disturbed only by the hum of the directional gyroscopes and the buzzing of the inverters. He could hear through the cabin ceiling the muffled voices of the crew giving the last preparatory commands.

A luminous sign on the ceiling blazed up: "Caution! – X minus 30 seconds."

The "30" changed to "20" and to "10"...

Another sign bade "Heads on Headrests!"

Holt reclined his head on the soft pillow and followed tensely the leaping ciphers.

"8 -7 - 6 – 5 – 4 –"

The ship shivered slightly and Holt saw the neighboring buildings glow in the light of the ignition flame.

Then, amid a diapason roaring, as though the grandfather of all hurricanes had seized the vessel, an unseen force pressed Holt and his companions deep into the yielding softness of their couches. For a moment the Earth surrounding the ship seemed to be a sea of wild, concentric, horizontal flame. Then the sea shrank to a diminishing fiery disc and finally went black beneath the loom of the roaring column of fire spurting from the rocket exhaust. *Sirius* had lifted off and was thundering into space.

As the great vessel rose vertically, more and more lights in and around the station came into view. The brilliant lights of Honolulu blinked from across the water to dim and disappear in diffuse darkness. Below lay the night-steeped Pacific and above beckoned the star-studded ocean of space.

Holt, lying full length upon his couch, groaned as the almost unbearable load of the acceleration descended upon him. His breath labored as the menacing hand of the accelerometer crept past 3.2 g. The speed indicator and the altimeter hands hurried around their dials and the cabin was filled with the muffled growling of the rocket exhaust.

Still the accelerometer needle climbed… 5g… 6g… 7g… Holt was pushed into the supporting cushions almost viciously. It was as though every organ in his body had turned to lead. The acceleration rose to 8g.

Another luminous sign flared up on the ceiling: "Caution! Dropping first stage!"

There was an instant of relief from the dreadful pressure and the menacing accelerometer hand dropped back to 1.3g. Then the deep booming set up once more and the accelerometer increased to 1.8g. It continued slowly to the higher figures again, renewing the torture with which acceleration besets the human frame. The burning time of the second stage was 124 seconds, during which the acceleration once more reached 8g.

"Caution! Dropping second stage!" shone at the passengers from the ceiling sign; then came a moment of respite. But the experience was repeated as soon as the acceleration diminished to 1.3g. With a howl, the third stage combustion exerted its push upon the now tiny core of the erstwhile enormous rocket. There was a clicking sound and the accelerometer climbed again to 1.5g. Gone was the second stage which had brought them to the speed at which they could carry on towards Lunetta with the power packaged in the tip of the rocket. Vibration increased, for their own, undetachable rocket plant was thundering and roaring a scant fifteen feet below the floor of their cabin. It was the third and last stage of acceleration.

It was 84 seconds since the second stage had been jettisoned.

"Caution! Cut-off!" glared from the ceiling.

The accelerometer began to descend from 2.5g, the almost mercifully low figure which this time was its maximum. The cruel pressure melted, slowly at first, and then it was gone.

Holt closed his eyes for a moment. He had just come through that horrible second at the end of the acceleration ordeal, when the agony is over and the peculiar sensation of weightlessness begins. All people and all things in a rocket ship coasting through space are weightless, or seem to be, and this offers a feeling of release second to none. But the transition from the agonies of acceleration to the joys of weightlessness is ever accompanied by a dark moment of spiritual terror which besets everyone, no matter how often they have been through it.

He released his belt and found himself floating unsupported above his couch. Beyond the thick glass of his deadlight he could see the black sky with its stars projected in unnatural brilliance. Their Earth-familiar twinkle was gone.

Soon the sliding hatch in the ceiling opened and an officer who might be the copilot emerged head first, pulling himself along with his hands and with one foot hooked around the ladder rail, so as to remain parallel to the wall. Arriving at the bottom, he flicked himself into an upright position.

"Gentlemen," he said, "Those of you on your first trip to Lunetta may want to hear some details about our path of ascent, our present flight condition, and the maneuvers we shall undertake.

"Our vessel, *Sirius*, is the flagship of the Lunetta Ferry squadron. We reach a maximum velocity of 8,260 meters per second in ascent, in a direction horizontal to the Earth's surface. This is attained in three consecutive but separate propulsion periods.

"During the first period, lasting 84 seconds, the vessel is given a velocity of 2,350 meters per second by the first booster stage. The rocket motor of the first stage develops a thrust of 12,800 metric tons. During the 84 seconds of operation it consumes some 4,800 tons of propellants. While the angle of ascent is vertical at the beginning, the gyro gear gradually tilts it until, at the moment when the propellants of the first booster are exhausted, the ship has an angle of elevation with respect to the plane of the horizon of slightly more than 20 degrees. At the end of the propulsion period of the first booster, the ship has attained an altitude of approximately 40 kilometers above the Earth's surface and has made good a horizontal distance of some 50 kilometers from the launching platform.

"Shortly before the exhaustion of the first booster propellants, acceleration is diminished by throttling their admission to the motor, and this diminished acceleration permits the second booster stage to break free of the almost exhausted first booster stage by its own power.

"The second booster exerts a thrust of 1,600 tons, and as soon as it begins this, the first booster drops off. The latter is then decelerated by a large, specially designed parachute and descends to Earth supported by it. The second booster stage works for 124 seconds and consumes about 700 tons of propellants during this time, at the end of which the ship has attained a velocity of 6,420 meters per second, has climbed to 64 kilometers above the Earth and has reached a horizontal distance of 534 kilometers from the launching site. The gyroscopic steering gear has continued to tilt the angle of the ship during the operation of the second stage, so that the angle of elevation of the flight path to the plane of the horizon is only 2.5 degrees at the end of its combustion period.

"After the second booster is exhausted, the power plant of the third and final stage effects its release from the second stage in the same manner that the second stage is released form the first booster. The second stage, like the first, is decelerated by a parachute and descends to Earth.

"The thrust of the third stage rocket motor is but 200 tons and this thrust lasts for 84 seconds. During this period, the ship is brought up to her maximum velocity of 8,260 meters per second, after consuming 58.8 tons of propellants. This only partially exhausts the tankage of 83 tons, leaving a very considerable supply of propellants still available after ascent has been completed. This reserve is required for the maneuver of adaptation, which I shall shortly describe, as also for the return trip to Earth. There is still left a very considerable margin of safety as to propellants.

"During the propulsion period of the third stage, the ship rises to an altitude of 102 kilometers and at combustion cutoff has covered a horizontal distance from the launching site of about 1,135 kilometers. The angle of elevation of the flight path at combustion cutoff of the third stage is almost exactly zero. When referred to the plane of the horizon at the launching site, this angle is slightly negative, although with respect to the surface of the Earth directly below the rocket ship it is practically horizontal. This is due to the curvature of the Earth, which makes a spirit level, just below the momentary position of the ship, lie at an angle to a level at the launching site.

"When the third stage is moving horizontally at a rate of 8,260 meters per second, and is at an altitude of 102 kilometers above the ground, it is some 410 meters per second faster than the orbital velocity at that altitude. Were its speed exactly that of the orbital velocity, centrifugal force would balance its weight exactly and it would continue to orbit around the Earth at the altitude of 108 kilometers. But since the velocity imparted to the ship by the third stage is somewhat above the orbital velocity, centrifugal force is greater than the attraction of gravity and the ship recedes from the Earth.

"Our initial speed of 8,260 meters per second was selected in order that we might proceed along an elliptical path, the apogee of which is at 1,730 kilometers from the Earth's surface. This is the altitude at which Lunetta circles the Earth at the orbital speed corresponding to that altitude, namely 7,070 meters per second. We, however, lose a certain amount of our speed as a result of our climb to that altitude, so that our velocity will be but 6,610 meters per second at the time we intercept Lunetta's orbit. Thus we shall have to carry out a so-called "adaptation maneuver" in order to increase our velocity by the amount it lacks, to equal that of Lunetta. This is 460 meters per second. We fly unpropelled for a period of 50 minutes and 54 second after final combustion cutoff. At the end of this period we shall arrive at a point of tangency with Lunetta's orbit. The adaptation maneuver will begin at the end of this period and will require us to run our rocket motor for about 15 seconds. Until then, you gentlemen may do as you wish.

"The time of our launching was carefully selected so that we shall be flying close alongside Lunetta at Lunetta's velocity when the adaptation maneuver is completed. After that, we shall proceed to make actual contact.

"Gentlemen, you will note that you and everything else in the vessel is at present weightless, but please do not assume that this is due to our having passed beyond the influence of the gravitational field of the Earth, for this is not so. The condition is better explained by the fact that you and the other masses comprising the ship together received the identical initial velocity. We are now traversing the gravitational field of the Earth along a free trajectory. Every molecule of your bodies and all the parts of the ship obey the same laws of motion with respect to that trajectory. For that reason, no differential forces – which you might sense as gravity – are created between your bodies and the ship. The condition has been baptized "weightlessness" because we cannot perceive our own weight, nor that of anything else, although some linguistic purists question the accuracy of the word. We are, in point of fact, quite definitely under the influence of gravity, in that our trajectory is predetermined thereby. The reason why we cannot sense it lies in there being no opposing force nor solid ground beneath us, preventing us from yielding to the pull of gravity.

"During the portion of the flight when the weightless condition prevails, you may unsnap your belts and move freely around the cabin. I shall have to ask the inexperienced among you to be quite careful about it, so that you may not injure yourselves by bumping against the walls. You must realize that the slightest push will send you floating in any direction until you strike something. Some people have even learned to swim the air…

"When the adaptation maneuver is announced by the luminous sign, please return to your couches and put on your safety belts."

The copilot, after finishing his little speech, retired in the same mysterious manner through the sliding hatch from which he had emerged.

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Holt gazed drowsily through his porthole. He envisaged the long time during which he was going to be faced with naught but that sepia sky and its clear, untwinkling stars. No eye would ever see them thus so long as the owner stood deep at the bottom of the atmosphere. No Earthbound view would ever encompass his vision of the Milky Way, that diamond necklace of the sidereal depths spanning the firmament.

To him, Earth would appear much as Vega, that brilliant distant star that now stood forth against the black velvet background. His nearest and dearest would seem as remote as that, and for years. Katy, his boys, his bungalow, his Pacific, his beloved California, his native land, all would shrink down to a tiny point of light. To a nasty little star, as Braden had put it.

Fear overwhelmed him for a moment. Would he be able to maintain morale and discipline throughout the long, lonesome stretch, unbroken by day and night? The general had been right; his choice of companions must be restricted to men of steel. And he knew that he'd have to case-harden himself in order to do justice to them as their leader… Finally, he dozed off.

He was awakened by voices in the cabin and noticed that it had become brighter. The other passengers were crowded around the portholes across the cabin from his couch. Just inside the circle of couches lining the wall of the cabin was a balustrade of rope supported by stanchions rising from the floor. His body horizontal, he hauled himself along this balustrade and peered out.

At least one-half of the visible sky was covered by an enormous, luminous scimitar! Why, that was a dawn creeping over the Earth! It would not be long before *Sirius* would fly out of the penumbra of the Earth and into the sunlight.

The luminous scimitar became broader and broader, and soon the livid mantle of the solar corona flared up over the eastering curvature of the Earth. Painfully, his eyes received the first direct rays from the blistering surface of the orb of day, which soon emerged from behind the shelter of the Earth. Immediately below, their home planet was still wrapped in shadow, and the line marking the dawn crawled slowly towards the *Sirius*.

As he looked down, he seemed to descry a coastline, dim in the shadows just before Sun-up. Surely, there it was, clearly recognizable, the shore line of the Western Provinces of Canada. Hold drew his binoculars from his briefcase and peered tensely at the scene. Broad and easily identified, Vancouver Island defended the mainland, far to his right. It was unmistakable, despite the lividness of the morning light. Soon Athabaska Lake, crescent-shaped amid the vast forests, slid slowly by and before long Hudson's Bay loomed up at the extreme right.

Directly below them, full daylight enveloped the scene. It was easy to see that the ship had silently climbed higher and higher on its way to Lunetta's orbit, and it occurred to Holt that, if there were still any who doubted that Columbus was right when he announced that the Earth was round, this trip would surely carry conviction. The basic fact of the Earth's rotundity was incontrovertible to even the most skeptical eye.

The ship sped over Baffin's Land and the eternal glaciers of Greenland crept into view. It must have been an unusually clear day in those latitudes, for Holt was amazed at the definition with which his binoculars revealed the usually fog-bound fjords of Greenland's west coast.

The great circle course of the *Sirius* began to incline south at this point, and it was but half an hour after the rocket motor had been shut off that passengers on the opposite side of the cabin called out that they could distinguish Ireland. A few minutes later, the ship cut diagonally across the coast of Portugal. Lisbon, Gibraltar and its straights, Spanish Morocco and the Atlas Mountains passed as though projected on a strip of film, and soon the sandy vastness of the Sahara Desert lay below.

Just as they stood above the Cameroons and paralleled the Southern Atlantic coast of Africa, the luminous warning sign recalled them to their couches, where they tightened their straps. *Sirius* had attained the thousand miles of altitude of Lunetta in a long ellipse of ascent. Now for the adaptation maneuver.

Thrust was applied as the rocket motor screamed viciously, forcing the passengers painfully into their cushions. It lasted for 15 seconds, with the accelerometer rising to 2.8 and then to 5.3g. Then silence fell once more and the easy sensation of weightlessness was restored. Again the copilot's head appeared in the hatch.

"Gentlemen, our distance from Lunetta is now 800 yards. If you'll look to the left, you can see her clearly. Five minutes from now, we shall begin the contact action."

Holt peered out and the other passengers drew themselves to other portholes on his side. There swam Lunetta!

Of a glistening silver color, she seemed an enormous tire with spokes, suspended in space and slowly rotating about her central axis. Around the circumference of this gigantic inner tube were portholes like those of a ship. The spokes ended at the center in a cylindrical hub and were quite thin, like those of a Brobdignagian bicycle wheel, except for two much thicker ones that seemed to run straight through the hub from rim to rim. A large parabolic mirror was attached to one end of the hub and seemed not to rotate with the remainder of the huge fabric. In the focus of the mirror was a black ball.

Two of the civilian passengers floated themselves across the middle of the cabin and peered out of the port next to Holt's.

"There's your inner tube, Lussigny," Holt heard one of them say. "I hope you'll enjoy your stay in it. It will seem like a second home to you before you're through."

Holt glanced at the speaker from the corner of his eye. He was somewhat elderly, and had obviously neglected to have his gray hair cut. Intelligent gray-blue eyes twinkled behind rimless glasses. His companion's body seemed at least half a head longer than that of the speaker, although they hung at different angles beside the port. The companion's hair was bleached white and contrasted delightfully with the youthful curiosity with which he stared at the enormous wheel.

"It's certainly impressive," remarked the bleached giant, "but I'll have to admit that I don't quite understand it. Can't you tell me something about it before we connect?"

"I don't know quite as much about it as I'd like to," answered the man with the glasses, "but perhaps the colonel here wouldn't mind helping us out a bit?"

Turning to Holt, he introduced himself.

"My name's Hansen, Knut Hansen, of the Palomar observatory, and this is Doctor Francis Lussigny of M.I.T., who's visiting Lunetta for the first time. I'm sure you're an old spaceman who won't mind lecturing a couple of Earth-lubbers for a while…"

"I'm Colonel Holt. It'll be a pleasure."

"Oh, you'll be the Holt who was with Fitzgerald on the Moon! Of course, your picture was much in the papers at the time. You must feel at home in Lunetta."

"Well, I was on duty here for several months."

"How about a quick review of the most important things one should know about Lunetta? It would be so nice if I didn't have to bother the people here with foolish questions."

"O.K. Let's start with the orbit. Lunetta's orbit is almost exactly circular with respect to the Earth's center 8,110 kilometers away. That is to say, Lunetta flies in a circle at an altitude of 1,730 kilometers above the surface. Her velocity must be 7.07 kilometers per second in order that her weight may exactly counterbalance the pull of gravity by its centrifugal force in the orbit. Right now, our ship is momentarily at the same speed and we therefore follow Lunetta in her orbit without any need for power."

"What is the angle of the orbital plane to the plane of the equator?" Lussigny asked.

"It's exactly 66.5 degrees and exactly vertical to the ecliptic."

"Why was that angle chosen? Wouldn't it have been more practical to lay the orbit in the plane of the equator or in that of the ecliptic?"

"There would have been certain advantages if it had been done that way," said Holt, "but a compromise had to be made. You see, Lunetta was established during the last war and was primarily an observation post and a bomb-dropping station against Russia. That meant that her orbit must pass over some of the higher northern latitudes. Furthermore, to have the plane of the orbit perpendicular to that of the ecliptic affords the advantage that Lunetta is over daylighted ground during the longest possible time averaged over a year. The ground must be daylighted for effective observation or effective bomb-dropping."

"That I do not understand," said Lussigny curtly.

"If you will plot the angle of the Earth's polar axis in its orbit around the Sun, you'll see that the North Pole points most nearly towards the Sun on June 21st, while the South Pole does so on December 21st. This is the reason that Lunetta can make her girdle around the Earth on those two days exactly above the limits of dawn and dark. This means that the Sun never sets on the Earth directly below Lunetta. On the other hand, at the equinoxes Lunetta has night under her for one of the two hours which she requires to circle the Earth, and day for the other. Of course, you realize that the equinoxes are the most unfavorable periods for the operations of Lunetta so far as tactical considerations are concerned, for active work can only go on half the time. But averaged over the year, Lunetta's orbital plane permits her to be over daylighted areas 75% of the time; that's easy to see."

Holt pointed over at Lunetta, where a small circular door had opened in the bottom of the hub. A man in what seemed to be a diving suit stepped out into nothingness and seemed to float there. Suddenly, the distant figure began to move mysteriously towards the *Sirius* as though propelled by some invisible force. A thin line leading back to the hub of Lunetta followed him.

"He's bringing us the securing line," said Holt. "In ten minutes we'll have completed the contact operation."

"How does the fellow move himself?" questioned Lussigny.

"He's got a little reaction pistol in his hand. It's fed from a tank strapped to his back. Very simple, really. The tank holds hydrogen peroxide which is chemically dissociated in the pistol. This generates steam, which, spurting from the pistol, produces a couple of pounds of thrust. He can move himself in any direction by pointing the pistol just opposite from where he wants to go."

"Quite a business, quite a business, this pushing yourself around in space with pistols! But tell me, what is the diameter of this Lunetta anyway?

"It's exactly 200 feet, and it rotates once every 20 seconds on its axis. This rotation produces an acceleration at the rim equal to one third of the gravity on Earth, namely 0.3g. The crew, who spend most of their time in the rim, therefore feel themselves pressed against the outer wall of the periphery with one third of the force to which they are accustomed to press against the Earth at home. A spring balance would show that they weighed but one third of their normal weights." "Three-tenths g?" asked Lussigny in amazement. "Why do they not increase the RPM and produce an acceleration fully equivalent to the 1.0 g to which they are accustomed?"

"That seems quite reasonable at first thought," said Holt, "but there's an excellent reason for not going all the way with our synthetic gravity. In view of the relatively small diameter of Lunetta, her rotation tends to produce what are called Coriolis forces. If you are standing on the floor of the annular living space, which is, of course, where a nail would come through if you think of Lunetta as a tire being punctured, your head is pointed directly at the center of the hub. When you move peripherally in either direction your head must go more slowly then your feet to keep your body in line with the synthetic gravity. But since you are unaccustomed to such walking, because on Earth you must wander many miles before there is an appreciable convergence of the gravitational pull, here, where it happens rapidly you tend to fall in the direction of your movement. It turned out that for this particular diameter, a centrifugal acceleration at the rim of 0.3g was about right. It seems to be well above what we call the comfort level in the space business and yet the Coriolis forces are not high enough to affect equilibrium."

"That's certainly interesting… But how did you get that enormous wheel up here at all?"

"That wasn't so difficult. It consists, you know, of ten hollow sections of rubberized fabric. These were folded up small on Earth and brought up here on vessels like the one we are in. What am I saying – it was the old Jupiter class that did the job. Then men in space suits like this fellow out there assembled the sections to form a closed ring. Finally it was blown up with compressed air, like an automobile tire."

"Why that's wonderful! And the hub?"

"It's the same idea. The hub consists of a drum, likewise of rubberized fabric, inflated to the same pressure as the rim."

"What's the purpose of the spokes?"

"Please notice that there's a black sphere on the upper end of the hub. That is a steam boiler. It is heated by the parabolic mirror beside it. The diameter of this mirror is 10.6 meters and it concentrates the solar rays on the generator, permitting steam to be constantly drawn off from it. This steam drives a turbogenerator located within the Central Station, as the hub of Lunetta is called. Thus the whole structure is supplied with 35 kilowatts of electrical energy.

"You will notice that the mirror does not revolve with the wheel; instead, a photoelectric cell controls a mechanism which keeps it constantly directed at the Sun. Of course, this could not be done unless the rotation of the wheel was kept in the ecliptic. However, you must not confuse the plane in which the wheel rotates with the plane of Lunetta's orbit around the Earth, for the latter is at right angles to the ecliptic, as I already told you."

"What's the connection between the mirror and the spokes of the wheel?" asked Lussigny a bit confused.

"Ah, yes. Sorry I digressed from your last question. Those spokes are used as condensers for the exhaust steam of the turbine, and here we run into one of the more interesting anomalies. Despite the general belief that interstellar space is extremely frigid, it is very difficult indeed to achieve satisfactory cooling. There is, of course, no air, so we cannot resort to air cooling and are restricted entirely to radiation cooling. The turbine expands its steam down to 46 degrees Centigrade, and we're obliged to cool our condenser with what little radiant heat is still given off at that temperature. Even for the miserable 35 kilowatts that the generator puts out, we have to have 1,790 square feet of cooling surface, and the spokes are the condenser tubes. Since their combined length equals 1,300 feet and their diameter is 5.3 inches, they provide exactly the amount of radiating surface necessary."

"But how does it happen that these tubes are not heated by radiation from the sun?"

"That's quite simple," said Holt. "They're always shaded by the rim, because it rotates in the plane of the ecliptic."

Lussigny's curiosity was still unappeased, and he went on with his questioning. "That is certainly cleverly thought out, but tell me, just how the water gets back into the boiler from the tubes?"

"Simplest thing in – or out – of the world," said Holt. "It condenses on the inner walls of the tubes and runs outwards towards the rim by the centrifugal force brought into play by the rotation of Lunetta around the hub. There's a collector ring connecting the outer ends of the condenser spokes. From this ring, an electric pump feeds the condensate back to the boiler through one of the spokes reserved for that purpose."

"That's really wonderful! And now, what are the two thick spokes?"

"They're actually elevator shafts, if you can call a little car in which a man can ride – but which goes neither up nor down – an elevator. As a matter of fact, when you're riding in one, you feel like you're going down when you're moving towards the rim. Lunetta's rotation around her hub produces, as I think I told you, the effect of gravity in the rim. Anyhow, the crew can move between the hub and the rim in these elevators. But look, we're making fast."

The man in the space suit was now close to *Sirius*. At the end of the steel cable which he dragged behind him was a coupling device to be shackled to a fitting at the ship's nose. The man disappeared from the view of those at the portholes and could be heard moving around and connecting the shackle. Then he appeared in front of the entrance door of the passenger cabin.

Prior to this, the ship's mechanic had pulled himself down the ladder and was waiting near the door. He touched a switch button as the man in the space suit approached the outer door of the airlock, opening the latter. The man in the space suit drew himself in and the mechanic pressed another switch button after closing the outer door. There was a hissing sound which Holt described to Lussigny as the airlock being pressurized. Then the inner door was opened and the stranger drew himself in. After removing his transparent helmet and greeting the passengers with a cheery "Hello, folks!" he pulled himself along the ladder into the pilot's compartment.

There was a slight jerk.

"That's the winch taking hold," said Holt. "Lunetta has a little electric winch which is now winding in the cable the man just brought over and made fast on our nose."

Slowly, *Sirius* began to turn and the great wheel which was Lunetta disappeared from view, coming into sight again a few moments later. Its enormous, rotating circumference drew closer and closer to the portholes. Then there was a mild jar, followed by a sound as of a skidding auto tire. *Sirius* began to turn about her central axis.

When the mechanic opened the outer door without closing the inner one, there was no change of pressure, nor cracking in the ears of the passengers.

"That's the end and object of the contact maneuvers," said Holt. "We can now see how Lunetta looks from the inside."

Chapter 3
Interstellar Stop-Off

The Central Station of Lunetta was an elongated cylindrical space about 30 feet in diameter and 40 feet long and almost empty. Holt floated into its barrel-like interior through a door that opened in the mooring cone. At the apex of the mooring cone was a hand wheel that locked *Sirius*' nose against the hermetic seal.

Between the point of the cone and the opposite end of the station was a meshed shield of wire, behind which stood the turbogenerator.

In the center of the space was a sign reading "Welcome to Lunetta. Arriving personnel please report to Room 21 without delay."

There was a hand-rope leading to the door of one of the elevator shafts and Holt, Hansen and Lussigny held their luggage in their left hands as they pulled their bodies along this rope. Lussigny was having quite a bit of trouble, unaccustomed as he was to the weightlessness. With his luggage in one hand, he failed to pull himself exactly parallel to the rope, so that when he let go of it to get another grip, he found himself floating away and bumping into the wall. He then attempted to seize it with his left hand, thus relinquishing his grasp on his luggage. Before he knew it, the suitcase had escaped and floated away. Lussigny and his equipment were apparently hopelessly separated, despite the former's frantic wriggling, punctuated by mirth.

"Hold it! Here comes help" laughed Holt, pushing his own luggage against the wall of the cylinder where it remained, held by centrifugal force. Then Holt launched himself across the center with a powerful thrust, gripping the floating Lussigny as he passed. Together, they impinged lightly on the opposite wall, where Holt instructed Lussigny to make a similar leap back and then to hold on.

"I'll get that obstreperous suitcase of yours!" he said, laughing.

They then entered the cage.

"Now watch out," said Holt, grasping a pair of hand grips. "As soon as we move, you'll feel a push into the corner. This is a combined effect of the increasing centrifugal acceleration floorwards and the sideways acceleration which brings us up to the peripheral speed of the ring."

When the car stopped at what seemed the bottom, the old feeling of weight was restored, although it was definitely weaker than down on Earth. They found that they could both stand and walk, but Holt was the only one of the three who didn't tend to leap lightly from the floor at each step when they first arrived.

Holt immediately reported to Major General Riley, commanding Lunetta.

"I'm very happy to meet our Mars-man," said the General. "General Braden has radioed us to offer you every facility we have. What's your program?"

"My most important mission is to visit the observatory and to ask various questions about Mars of Dr. Bergmann and his assistants. After that, I'd like to discuss some of the astronomical measurement problems that are of vital importance to our planning work."

"Do you know that Professor Hansen from the Mount Palomar Observatory is to arrive?" asked the General.

"Certainly," said Holt. "We met on the way up and he's waiting in the outer office."

"Hansen is outstanding among the Mars specialists," said the General. "He's probably the best in his field. Perhaps you don't know that he's the man who sparked the whole Mars expedition scheme, and he's here to go over the final details for his report to the President with the collaboration of our astronomers. You'd better have him sit in on your deliberations."

"And who's this Dr. Lussigny?" asked Holt. "What's his line?"

"He's MIT's top-notch radio and radar man. Professor Ashley sent him up for indoctrination and I understand that he's making some preliminary studies for the design of the radio gear for your expedition."

Riley opened the door to the next compartment and invited Hansen and Lussigny, who were waiting, to come in.

"Welcome to Lunetta, gentlemen" said he. "May I introduce Colonel Holt? He's almost on his way to Mars."

"You – well, I declare!" exclaimed the professor. "But it's wonderful luck to find you here! Colonel, we've got so much to talk about that it had better wait until later..."

"Gentlemen, I know that no food is served aboard the *Sirius*, so let's go into the mess room for breakfast," invited General Riley.

Together they made their way along an apparently unending passage which curved upwards before them, although they had no sensation of climbing as they walked. This was the long corridor through which the various compartments of the rim of Lunetta communicated. It was interrupted every 60 feet or so by an air-tight door of circular section. These doors permitted any 60 foot section of the ten composing Lunetta's rim to be hermetically sealed in the event that one of them might spring an air leak.

While they were breakfasting, Holt and Hansen decided that they would visit the observatory together.

"How far is it from Lunetta to the observatory?" asked Lussigny.

"It's about ten miles," said Riley. "It precedes us in the same orbit."

"Why so far?"

"Ten miles isn't very far in interstellar space," answered Riley. "We've found it the best practice to keep all the auxiliary stations of Lunetta pretty far apart for a variety of reasons. For one thing, the orbits are less liable to disturbance by reciprocal attraction, and it also tends to avoid collisions which might result from minor differences in the orbital data of the various auxiliary stations. Each station must be in possession of its own orbital data as the basis for a great variety of purposes. Here in the main station we require them, for example, in order to determine the arrival conditions for the ferries with absolute precision. Our military auxiliaries, which are located at very considerable distances, need their orbital data with extreme exactness for ballistic purposes. And the observatory needs them for astronomical measurement."

"Would there be any breach of military secrecy if you were to tell me how bombs are dropped from here to the Earth, General?" asked Lussigny.

"Of course there are one or two details that are top secret," answered Riley. "But the basic principle is quite simple and there's no reason whatever why you shouldn't know it. There are two auxiliary stations flying in our orbit. One of them is 1,935 kilometers ahead and the other 1,935 kilometers astern of us. The one astern is the Bomb Bay and the one ahead is called the Control Station. When we bombed the Earth during the war, we really used rocket-powered missiles, which were fired from the Bomb Bay in the direction opposed to its rotation around the Earth. These missiles are gyro-controlled to maintain their set course during their short period of propulsion. Seen from the Earth, the rocket drive decreases the speed of the missile from the 7.07 kilometers per second which it had originally to 6.59 kilometers per second. This throws the missile into an elliptical path, the perigee of which is in the upper strata of the atmosphere after one half another circle around the Earth. The air drag gradually decelerates the missile, the tail of which is equipped with a special braking device. It then penetrates the lower atmospheric strata along a trajectory which is initially flat, but then grows steeper. Finally it falls onto the Earth.

In free flight, the missile requires nine minutes less than the hour the Bomb Bay does to half-circumnavigate the Earth, in order to reach the perigee of its semi-ellipse. This means that the Bomb Bay has lagged 26 degrees of arc behind the missile at the moment it enters the atmosphere. Even when it has entered on the decelerated trajectory, it still angularly precedes the Bomb Bay to a small extent. This is because the missile strikes the atmosphere at a considerably higher velocity than that of the Bomb Bay. Hence the Control Station is located some 3,870 kilometers ahead of the Bomb Bay in the same orbit so that the missiles can be easily seen from the Control Station while they are falling through the atmosphere, and may be guided to their targets by radio. The missiles are observed for this purpose with radar or powerful telescopes."

"It's not hard to understand that there can be no defense against that kind of attack," grunted Lussigny.

"The only effective one would be an attack on the Space Stations proper. During construction, we mounted quick-firing guns on Lunetta and her auxiliary stations because we always feared attacks form Russian space ships. But we fortunately succeeded in destroying their factories before they could get such ships into action. It wasn't until the war was over that we realized that it had been a matter of nip and tuck."

"You mentioned telescopes a few moments ago," said Lussigny, "with which the fall of the bombs was observed. How much detail of the Earth's surface can be recognized through them from as high as 1,000 miles?"

"Our new 100-inch reflector has good enough definition to let us distinguish two objects on Earth as little as 40 centimeters apart," answered Riley.

"Why then, you can make out individual people!" exclaimed Lussigny in amazement.

"No question about it. When we began to make observations during the last war, the Navy doubted whether we should be able to distinguish war ships. Not only could we distinguish them when weather and visibility were good, but we could make out their class and see the men on their weather decks."

"That's really incredible! What power do you use?"

"We can magnify up to 1,250 diameters. This brings the Earth 1,250 times as close as it appears to the naked eye, and we can see what goes on there as though we were 4,000 feet up instead of 1,000 miles."

"Why can't you step up your magnification?" asked Lussigny stubbornly.

This brought Professor Hansen into the argument.

"Magnification is limited by the diameter of the telescope reflector," he said. "As General Riley just explained, the reflector up here has a resolving power corresponding to a distance of 40 centimeters on Earth. If we were to increase the magnification beyond 1,250 diameters, we'd magnify the diffraction patterns around the objects observed. That would simply blur the image without revealing any more detail. We'd have to double the diameter of the reflector in order to increase the resolving power from 40 cm to 20 cm. Then we'd have a telescope as bulky as that on Mount Palomar. We simply haven't the means to produce anything like that, nor to freight it up here."

Lussigny wanted to know what the effect the atmosphere might have on observations, and Hansen continued. "We cannot, of course make any observations on zones covered by bad weather, but there's nothing like as much interference when the weather's good as is suffered by an Earth-bound astronomical telescope. This interference is quite serious. When you're looking into the heavens from the bottom of our sea of air, that air is both within and immediately before your optical system. Slight irregularities of ambient temperature cause refraction of the light rays very close to your optical system and tend to make the whole image flicker. But if you are looking Earthwards from here, any disturbances in the air are far distant. They are practically negligible."

Lussigny sank into a brown study. After a while, he spoke up. "When Professor Ashley gave me the first inkling of Operation Mars and asked me to comment on radio communication for the expedition across this wide, interstellar space, I'll have to admit that I thought the whole thing was just a crazy brainstorm. But since I've seen all this and heard the story, I'm getting awfully keen for it."

"Don't fool yourself, doctor, it's on its way" said Holt. After a glance at his watch, he touched Hansen's shoulder. "It's about time we got started towards the observatory."

"How do you get there?" asked Lussigny. "Is it in a space suit and with a reaction pistol?"

"No indeed," laughed the General. "That's a thing of the past for trips as long as this. Time has brought luxuries. They'll go in one of the busy bees and take off from the rim direct."

"You don't even have to go back to the Central Station?"

"Not a bit of it. The busy bee is a little space boat and it hangs in a bay on the rim, like a bomb. You get into it just as if you were entering any other compartment of Lunetta. The bee is pressurized by the same system as the whole. You simply close an inner and outer bulkhead door; the pilot pushes a button; and out of the bay you drop by centrifugal force. Once you're away from Lunetta's rim, he starts a little rocket motor and that gives you a push in whatever direction you want to go."

"So far, it's perfectly clear," marveled Lussigny, "but I'd like to know how the bee gets back into its nest in the rim."

"It's not so complicated. Perhaps you noticed that there's a rail running circumferentially around the rim. The bee has a snap hook which is pushed gently against the rail, engaging it in the hook. Since the rim of Lunetta is in rotation, the bee slides along the rail until one of the bays approaches. Shortly before the bay reaches the bee, a wedging action slows up the snap hook in its movement along the rail. This, of course, accelerates the bee in such a manner that its movement is integral with that of the rim at the moment it registers with the opening of the bay. This automatically closes an electric circuit which, by a suitable mechanism, pulls the bee into the bay. At the top of the bay is an automatic hermetic sealing device which connects the interior of the bee with that of Lunetta again. So, only two doors need be opened to get back into the rim of Lunetta."

"What an amazing gadget!" mused Lussigny. "But, General, that sort of thing must eventually slow down Lunetta's rotation."

"Certainly it does. But just imagine how great the effect must be of such things as the landing of something as massive as the *Sirius*! That not only affects our RPM and our planes of rotation, but it even does things to our orbit around the Earth, to some extent."

"How do you compensate for that?" asked Lussigny.

"We have a couple of swiveling rocket motors on the periphery of Lunetta and a couple more at opposite ends of the Control Station. When our prescribed rate or plane of rotation varies beyond certain limits, or we get somewhat out of orbit, all we have to do is to start these motors for a short time and restore our rates."

"Tell me," said Lussigny, "does the gravitation of the Moon affect Lunetta's orbit deleteriously?"

"Yes indeed; it's a very considerable factor in the corrections we have to make. As you know, the Moon and the Sun produce marked phenomena even on Earth by their gravitational effects – flood and ebb tides for example. They affect our orbit quite unpleasantly, particularly because the Moon circles the Earth in the plane of the ecliptic whereas our orbit is at right angles to that plane."

"It seems to me that these corrections must cost quite a lot of propellants, and you have to freight them up gallon for gallon."

"That's right, Doctor. But it isn't so bad, practically. We just steal a bit of the propellants from the ferry ships. Ships like the *Sirius* always, or almost always, have a full eight tons more propellants in their tanks than they require for the return trip to Earth. They all carry it, just in case... Well, we simply tap off the excess and keep up our supply in that way. It's not a complicated procedure. We have permanent hose connections at the mooring cone in the Control Station. The storage tanks are right under the walkways in the rim of Lunetta. All we have to do is to connect up, open a valve, and the propellants flow into the tanks by centrifugal force. The same stuff is used to drive the busy bees.

But I think, gentlemen, it's about time to get moving. How about my taking Dr. Lussigny to our radio station? Later you can have a quiet talk with our meteorologists. They report weather back to Earth every two hours and can give you much data on interference by weather, night effects and magnetic storms on our radio communications.

Colonel Holt and Professor Hansen might as well go right to the busy bee and take off for the observatory."

The inside of the busy bee was fitted out almost like an automobile. The pilot sat in the left front seat behind a steering wheel, but steering pedals like those of an aircraft replaced the familiar accelerator and clutch.

The controls operated like those of an aircraft in that the bee could be controlled around its longitudinal axis by turning the wheel, while forward and backward movements of the wheel lowered or raised the nose. To the right or left it was directed by the pedals. These controls were connected to a swiveling rocket motor in the tail. except for those affected by the turning of the steering wheel. That movement displaced a pair of vanes located in the jet exhaust of the motor.

The bee was also provided with another rocket motor in its nose, coupled to the same controls. Both motors were actuated by a single throttle from the center of the instrument panel. Pushing the handle of the throttle forward started the rear motor, while pulling it back from neutral gave thrust to the front one, after stopping the rear. Thus the bee could be accelerated ahead, or retarded at will. Neither motor operated with the throttle in neutral.

There were but two instruments on the panel. One showed acceleration and deceleration. The other was one of the so-called integrators that had for many years been part and parcel of rocketry. It indicated the relative velocity attained by the rocket drive as referred to some predetermined moment at which the integrator had been cut in.

The outside of the busy bee suggested a cylindrical drum, one side of which consisted of dark-tinted glass. Bees were exclusively for operation in space, outside the atmosphere, and hence needed neither streamlining nor stabilizing fins, such as are required by terrestrial rockets. The method of pressurizing the interior was similar to that used in submarines.

Holt and Hansen strapped themselves into the rear seats and the release allowed the bee to be flung out of its bay. The pilot pressed the throttle forward for a short period, after which the familiar weightlessness, which they had no longer felt while within the rim of Lunetta, reestablished itself. They remained in their seats only by reason of their safety belts. Over the pilot's shoulder they could see a tiny, shimmering disk which floated in space a few miles ahead.

"See the observatory?" asked Holt. "It's still about eight miles away according to my guess. We're making about 60 miles an hour with respect to Lunetta and we're approaching the observatory along an ellipsoidal path. If my guess is right, we ought to be there in about eight minutes."

"As an astronomer, I ought to understand that," said Hansen, "but there's a thing about these bee trips that puzzles me. Our additional speed of 60 mph above Lunetta's ought to increase our centrifugal force to keep the forces exactly balanced. On the other hand, the observatory precedes Lunetta exactly in her orbit. So it seems we might pass outside the observatory..."

"It's a good question," answered Holt. "Perhaps you didn't notice that we did not increase our speed exactly tangent to the Lunetta orbit, but slightly on a chord-line dipped towards Earth. We'll reach the perigee mid-point of our coasting flight and intersect the Lunetta orbit near the observatory."

"I understand," said Hansen. "But don't we have to compute our flight very accurately in advance so that we shall really hit the observatory and not go wandering off into space somewhere? I am always amazed when we get into these bees without any preparation whatever and push off into nothingness! It doesn't seem to be any different from getting into the car and driving to the market. Why, there isn't even any traffic problem!"

"Professor, you must remember that this is really a very short trip. Space navigation isn't so very different from water navigation. For a transatlantic journey, it's a good idea to do a lot of calculation before you get under way, and to plot your course on the chart. But you don't go to all that trouble to row across a pond. Our lads up here have soaked up Kepler's laws pretty thoroughly, and these little ferry trips are duck soup to them."

Hansen still wasn't satisfied. "How about the 2,000 kilometer jaunt to the two military stations about which Riley spoke, even if they are in the same orbit? Is that kind of ferry trip just a row across a pond, too? Or is 2,000 kilometers considered quite a respectable ocean voyage?"

"Oh, that's an ocean voyage all right," laughed Holt. "Ferry trips to those stations call for an entirely different brand of navigation from that used on this little hop.

"A busy bee enroute from Lunetta to the Control Station ahead of Lunetta reduces its orbital velocity by about 140 meters per second. This puts it into an elliptical orbit, the perigee of which is only 1,266 kilometers above the Earth's surface. Of course, that's still high enough to keep it clear of the atmosphere's upper limits. When the bee enters upon the second branch of this ellipse, it is again heading for Lunetta's orbit, which it intercepts after a full revolution around the Earth. But this elliptical path is, when averaged, somewhat closer to the center of the Earth than the orbit of Lunetta and her auxiliaries, and according to Kepler's Laws, the time the bee takes to circle the Earth is somewhat shorter than that taken by Lunetta and company.

"For a trip to the Control Station, the bee's ellipse is selected so as to require exactly 274 seconds less than the two hours that Lunetta requires for a complete encirclement. Thus the busy bee, contacting Lunetta's orbit after a complete encirclement of the Earth, is at the exact point to intercept the Control Station, 1,935 kilometers ahead of Lunetta. Then the bee must perform an adaptation maneuver, exactly like the one we experienced aboard the *Sirius*, in order to bring its velocity up by 140 meters per second, the amount required to equal the orbital velocity or the station.

"The principle used to reach the Bomb Bay trailing the Main Station is identical. Only, in this case, a complete ellipse is used which, rather than approach the Earth, becomes more distant from it. This causes the time of encirclement of the Earth to become somewhat longer than that in Lunetta's orbit, so that the bee intercepts the trailing Bomb Bay this time."

As Holt finished his explanation, they could see the enormous sickle-like arc of the Earth ahead of them and to the left. Despite the fact that their bee was bathed in the brightest sunlight, the Earth below them was still wrapped in darkness. So brilliant was the illumination of what they might well have referred to as the "crescent Earth" that they could make out no contrasts where the light fell.

Holt threw a glance at his watch. "We ought to be passing over Alaska in a moment," said he.

"Did you say Alaska?" asked Hansen incredulously.

"Sure, Alaska. We ought to be right over the Northeast Aleutians, headed for Anchorage, Alaska. Look, it's just 23:30, Hawaiian time. Two hours and fifteen minutes ago is just about when we started from Kahului. In the meantime, Lunetta's been around the world once, and a little more, but at the same time, the Earth's rotated to the Eastward some 34 degrees."

Hansen looked puzzled. "I may be an astronomer," said he, "but you'll have to go a little deeper into that one."

"Here's the way it is: the Earth rotates once every 24 hours – 360 degrees; that's 30 degrees for every bi-hourly encirclement by Lunetta. Lunetta makes 12 encirclements every 24 hours. If these were projected onto the Earth, they would make a spiral tracing across the Earth's whole surface between the Arctic and Antarctic circles. That's the joker in the military omnipresence of Lunetta! Lunetta will not be right over Kahului until some 12 hours after her last transit, and then she won't be moving on a Northeasterly course as she was when we took off, but on a Southeasterly one. Due to that, I cannot land back in Kahului until about 12 hours after leaving there.

"But speaking of Alaska, it's mostly heavily clouded over in this region. The sharp illumination you see on the Earth is only the reflection from the upper surfaces of the clouds.

"And did you notice that we were flying for almost an hour through the umbra of the Earth when we were breakfasting with Riley? Now the Sun's ahead of us once more, so we'll have daylight for the next hour."

The busy bee had approached within about a half mile of the observatory, and what had seemed to be a glittering little disc was now a silver sphere with a number of circular port holes. As they drew closer, there was another detail that heretofore had remained invisible against the sepia, star-spangled sky. This was a cylindrical object, apparently of latticework construction. It floated free in space, connected to the sphere only by a cable.

"So that's the 100-inch reflector," said Holt. "When I was stationed in Lunetta we had a dinky, little 60-incher out here. It was a pretty primitive gadget for some of the work."

"This is really a wonderful instrument," said Hansen. "Optically it's far more efficient than the old 60-incher and it's got a lot of other improvements. You'll notice that the 'scope is wholly detached from the observatory proper. We made this arrangement to avoid any shocks to the reflector from people moving in the observatory. With the integrally mounted 60-inch job, we had to keep the whole crew absolutely quiet and even shut off the blower during an observation. If we didn't, the image would flicker."

"Where's the seat for the observer in this case?" asked Holt.

"When an observation is being made, he's in a small cylindrical chamber that moves from the observatory to the 'scope. It has room for two observers and the necessary photographic and spectroscopic equipment. It has a small rocket plant like a bee. The chamber slips into guides attached to the 'scope so that the eye-piece, which is integral with one of the walls, registers properly and accurately with the optical axis. The observer simply replaces the eye-piece with a camera for photographic work."

"Having the 'scope and the observatory separate seems to me tremendously involved," remarked Holt.

"Look, Colonel," answered Hansen, "on Earth we're forced to keep our telescope foundations entirely separate from any other buildings or structures to avoid the transmission of vibrations. We have no heavy foundations here in space and our 'scope would vibrate fearfully if we didn't isolate it from any possible movement of the observatory.

"As you know, stellar observatories on the Earth require complicated suspension systems for their telescopes, and these suspensions are made to follow the apparent movements of the heavens by clockwork or electric drives. No such mechanisms are needed up here in space. When the observer seated in his tank has secured the latter to the telescope frame, he can turn the whole business in any desired direction by means of three electrically driven flywheels, and keep it pointed steadily at its object in the same way.

"The principle's simple enough. You know Newton's Law that to every action there's an equal and opposite reaction. So, if we start a wheel attached to a free-floating object in space turning clockwise, it exerts a rotating moment of equal power and makes the object rotate counterclockwise. If the wheel is much smaller than the object to which it is attached, it will, of course have to turn quite a number of times before the object proper makes one full turn in the opposite direction. Nevertheless, you can turn a body of considerable dimensions, when free-floating in space, with a relatively small, high-speed, electrically driven flywheel or disk. That is, if no very rapid rotation of the body itself is required.

"Our telescope here is equipped with three such inertia disks whose axes are at right angles to one another. This permits it to be turned arbitrarily to any angle in space and to be maintained there."

"We use the same principle in our space ships," said Holt, "to bring them to the proper heading for their various maneuvers. But look, we are making fast."

The pilot of the busy bee had cut in his decelerating motor and skillfully aimed his craft at the opening in a cylindrical shaft that protruded from the great, round ball in a radial direction. The bee slipped into a set of three guide-rails which diverged somewhat at their outer ends. There was a slight clicking sound and the light was blocked off from the great windows. The bee came to a stop with a slight jarring deceleration.

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The pilot rose and opened the circular door just above their heads. This was followed by the opening of a second door just above it in which the face of a blond youth appeared.

"Well, Bergmann, I'm glad to see you!" exclaimed Hansen.

"Good morning, Professor. It's good to see you up here with us again. We've a lot of new stuff for you. And you must be Colonel Holt, aren't you?"

"Right. Glad to know you..."

Since weightless conditions prevailed in the non-rotating sphere of the observatory, they drew themselves hand over hand along a rod which was axially located in the spherical chamber. It led to a room with circular walls which represented the middle floor of the observatory. This room was filled with all sorts of measurement gear and electrical switchboards, and gave the appearance of being a laboratory for electrical experiments. At one side of it there was an oblong table with a few low chairs near it. Dr. Bergmann introduced two of his youthful coworkers and then they drew themselves down onto the chairs and donned the belts which were necessary to hold them there.

On the table before them lay various documents and pictures which were carefully held onto the surface of the table by steel clamps. This was to prevent their drifting about the room as a result of their weightlessness.

Bergmann drew a large, colored photograph from a folder with the statement that it had been made but one week earlier and that it was the best one achieved so far. On this picture, the image of the planet Mars appeared about a foot in diameter. Of a raw whiteness, the famed south-polar cap of Mars stood out in the upper part of the picture. Below it and dull bluish-green in color was a large, similarly shaped area, the Mare Australe. As the eye moved towards the Martian equator, the picture became more confused. There were sharply rimmed spots and indefinitely outlined zones of all shadings from reddish brown to dark yellow, alternating with greenish-blue to grayish-blue areas. But throughout the whole region there ran a series of fine, dark green lines gracefully curved and following the vaulted shape of the Martian globe. These were the famous and controversial Martian canals.

The contrasts on the face of the disc were much paler near the edges. It was apparent that the light at these points had had to travel a much greater distance through the atmosphere of Mars than elsewhere before emerging into interstellar space. This gave an almost plastic and stereoscopic aspect to the photograph.

Holt regarded the image silently and reverentially for a long time, unable to conceal the emotional impact of his thoughts.

Finally he spoke. "It is really a second Earth. But what a mysterious, strange one… The continents float in no oceans. There are no rainy zones, shrouded in cloud. But the view of this picture leaves us almost no room to doubt the existence of intelligent inhabitants. No photograph of this size made from Earth would reveal such obvious testimony of the workings of intelligence."

"You're a member of the planning staff of Operation Mars, are you not, colonel?" asked Bergmann when Holt had again fallen silent.

"Colonel Holt will have command of the expedition!" interrupted Hansen solemnly.

The young astronomers present looked upon Holt with surprise followed by joyous enthusiasm. Their questions poured over him in a torrent which lasted until he had answered every one. When it was over, Hansen spoke again. "Dr. Bergmann, please tell Colonel Holt briefly the essential things which we know about Mars in relation to their importance to the expedition. Do not forget any aids to observation and methods of measurement which we have available. We propose to discuss an all-embracing new work plan in relation to what you will have reported."

Chapter 4
Let's Talk About Mars

Doctor Bergmann began his exposition. "Mars is the fourth of the nine major planets of the Sun. The orbits of Mercury, Venus and Earth lie closer to the Sun than its orbit, while those of Jupiter, Saturn, Uranus, Neptune and Pluto lie outside of it.

"The elliptical orbit of Mars around the Sun is of considerably greater eccentricity than that of the Earth. At perihelion, when Mars most closely approaches the Sun, it is 206 million kilometers away from it; at aphelion, however, the distance is 249 million kilometers. Hence its mean distance is 228 million kilometers. The Earth, whose orbit is nearly circular, has a mean distance of 149½ million kilometers from the Sun. The Earth's aphelion and perihelion differ from this mean distance by but five million kilometers, roughly.

"The orbit of Mars lies in a plane at an angle of 1 degree and 51 minutes of arc to the plane of the ecliptic, which means that Mars and the Earth rotate around the Sun almost in the same plane.

"Mars requires about 687 Earth days for a full revolution around the Sun, and this may be considered as a Martian year.

"Mars rotates around its own axis once in every 24 hours, 37 minutes and 22.7 seconds, making the Martian day only slightly longer than the Earth day, so that the Martian year has 569.6 Martian days.

"The rotational axis of Mars is inclined to the plane of its orbit by 24 degrees, which is very close to the inclination of the Earth's axis to her orbit, namely 23.5 degrees. This gives Mars seasons like those of the Earth.

"The diameter of Mars at the equator is 6,780 kilometers, while when measured along the polar axis, it is 35 kilometers shorter. This is a little more than half the diameter of Earth.

"The mean density of the planet is only 72% of that of the Earth. Its mass is proven to be approximately one tenth of that of the Earth, within close limits. These figures yield an acceleration due to gravity at the surface of Mars as equivalent to only 38% of that of the Earth, or 0.38g.

"Mars has two very small moons, Phobos and Deimos. Phobos is very close to its mother planet, its mean distance from the center of Mars being equivalent to only 2.77 radii of Mars. It circles the planet in 7 hours, 39 minutes and 14 seconds, doing so several times a day, somewhat similar to Lunetta circling the Earth. Viewed from the surface of Mars, it would rise in the west and set in the east. Its orbit is noticeably eccentric. Apparently its diameter is but a few kilometers.

"The other moon, Deimos, lies at a distance from Mars of a scant 7 radii of the latter and requires about 30 hours and 18 minutes to encircle it. We estimate its diameter at 10 kilometers and its orbit is circular within close limits."

Holt was making careful notes, but at this moment he glanced up. "What are the planes of the Phobos and Deimos orbits?" he asked.

"Both of them are, with great accuracy, in the plane of the equator of Mars," answered Bergmann.

"Thanks, but now what about the atmosphere of Mars, the climate and the general nature of the surface? I'd like to get some idea of conditions which we're apt to meet when we make a landing there."

"Certainly, Colonel. It is well proven that Mars has an atmosphere, although it's considerably less dense than that of the Earth. Once in a while, the formation of clouds has been noted. As to the surface, its formations are very clearly shown, particularly in infrared photography. At times, however, these formations are covered by some sort of diffuse white or yellow layer which registers particularly on ultraviolet photographs.

"Such layers must be considered cloud formations, and we take the white ones for water vapor and the yellow ones for sand clouds in all probability, whirled up by powerful storm conditions.

"Clouds containing water vapor must of necessity be present, in order to explain the regular appearance of snowfalls in the polar regions in Winter, and the occasional snowfalls in the temperate zones. There's no other possible explanation for regions of hundreds of thousands, or even millions, of square miles being concealed, sometimes in a very brief period, by a blinding white layer. The borders of the polar snowcaps also are frequently surrounded by a veil of clouds. We're inclined to interpret this veil as fog banks, developing over regions where snow is beginning to melt, rather than as clouds in the conventional sense. These fog banks develop in the cold Martian nights. Generally they are gone by noon."

"What is your guess for the atmospheric pressure on Mars?" asked Holt.

"A mercury barometer at sea level on Earth reads 760 millimeters where a corresponding one on Mars would read only 64 millimeters, if we've estimated correctly. That's only one twelfth of the terrestrial atmospheric pressure at sea level."

"Confound it! That means we'll have to wear pressure suits and employ artificial respiration on Mars!"

"There's no doubt of it, Colonel. Surface atmospheric pressure will be equivalent to that at 60,000 feet above the Earth."

"Then I imagine that the Martian atmosphere isn't nearly so lofty as that of Earth?" asked Holt.

"You might be a little careful about that deduction," said Bergmann. "Remember that increase of pressure at the lower altitudes of the terrestrial atmosphere is caused by terrestrial gravitation. The pressure is higher at low altitudes because the lower we descend, the heavier is the column of air above us. Now the acceleration of gravity on Mars is but 38% of ours on Earth. So any column of Martian air of equivalent mass would press upon the air below it with only 38% of the weight with which it would do so upon Earth. Consequently increase in density of Martian air with diminishing altitude necessarily takes place more slowly that upon Earth.

"Putting it another way, we can say that decrease of barometric pressure with increasing altitude takes place more slowly than at home. Expressed in figures, the atmospheric pressure of the terrestrial atmosphere decreases by a power of ten for every 18 kilometers of altitude; that is to say that ground level pressure is reduced at 18 kilometers altitude to a tenth, at 36 kilometers to one ten thousandth of an atmosphere. But on Mars, the pressure decreases by a power of ten only every 47 kilometers by reason of the weaker field of gravity. So, if we have but a twelfth of our terrestrial pressure at the surface, we shall have one hundred and twentieth of that pressure at 47 kilometers, one twelve hundredth at 94 kilometers…"

"Do you mean that at 94 kilometers above the surface of Mars, the atmospheric pressure is higher than it is 72 kilometers above the Earth?" asked Holt incredulously.

"That's what it is, strange as it may sound. It's got to be that way according to the inviolable laws of physics. Mars' weaker gravitational field just isn't able to compress its atmosphere to such a thin layer as the Earth's can do. Besides, we have visible proof that the Martian atmosphere must have just such a gradual pressure stratification, for we did some measurement on the clouds of Mars and found them to be at least 20 miles high."

"What's that?" exclaimed Holt, "do you mean that you can actually measure the cloud ceiling on Mars?"

"Surely," said Bergmann quietly. "It isn't even very difficult. Every now and then we observe luminous spots at the so-called terminator – the border-line between night and day on the planet. These spots remain luminescent when night has already fallen below them at the surface. Those spots are high-altitude clouds, and their height above the surface is calculated quite easily by their distance from the terminator at the time they occur."

"Well, that's most interesting. But what actually leads you to the conclusion that the pressure at the surface of Mars is one twelfth of that of the Earth? I can understand that the potency of the Martian field of gravitation throws light on the ratio of stratification of its atmospheric shell. But where do we get the absolute pressures themselves?"

Bergmann went on. "That's a bit more complicated. But there are several independent methods by which we determine these values, and their results correlate pretty well. Initially, all these methods give us only the entire mass of a column of air pressing upon a unit of area on the surface of Mars. The law of stratification already referred to then gives us the ground pressure.

"One of those methods is spectral analysis. Another comes via the reflective capacity of the surface of Mars, known as the "albedo" to astronomers. Perhaps you'd like to hear a more accurate description of this latter method…

"The albedo is the reflected percentage of the radiant energy of the entire visible region of the sun's spectrum intercepted by a planet. In the case of Mars, this is 27%. Now, we know from comparisons with similar objects on Earth, that the reradiation of the Martian desert areas, vegetated regions and snow fields accounts for only 10% thereof. Hence the remaining 17% must be accounted for by the reradiation of its practically cloudless atmosphere, which reflects 74% of what it receives. So we perceive that the albedo of the atmosphere of Mars is to that of a cloudless terrestrial atmosphere as 17 is to 74, or about 2 to 9.

"Let us now assume that the total mass of a cloudless shell of air increases in the same ratio as its power of reradiation. That should be approximately correct, because the power of reradiation is largely determined by particles suspended in the atmosphere, and the ability of the air to keep such particles in suspension increases as its total number of molecules increases. This leads us to the conclusion that Mars has an air mass above each square inch of surface equal to two ninths of that resting upon the same area on Earth. If we substitute this mass of air in the law of pressure stratification to which I referred, we arrive at a pressure at ground level of one-twelfth of an atmosphere."

Holt smiled. "It seems to me that you go all the way around Robin Hood's barn to reach that conclusion; but I suppose you know how much faith to put in it. In view of the importance to our enterprise of the structure of Mar's atmosphere, I almost think that those revelations, as I may well call them, urgently need a much more solid underpinning."

"No doubt, Colonel. Recently we've been trying to find the atmospheric pressure at ground level by another method, which might be called meteorological. We've set up a ratio between the presumptive air temperature and humidity of a certain section of the Martian atmosphere and the pressure. Using this ratio and the laws of meteorology, we have arrived at the atmospheric pressure at which clouds ought to form. We compared the results with the actually measured cloud height and postulated the computed pressure as existing at this height. By applying the law of pressure stratification, we computed the pressure at ground level as 79 mm of mercury. This is only slightly higher than the pressure obtained by the albedo method. Spectroanalytic results are perhaps the least reliable, because of the technical difficulties attending measurements, but they also are not far from this figure."

"You should be able to get data on the chemical composition of the Martian atmosphere by spectral analysis," said Holt. "Do you have anything definite on that subject?"

"So far our efforts along that line have produced reliable results for two components only, namely carbonic acid and water vapor. We're very certain that there is nitrogen, even though the latter is difficult to detect spectroscopically. We also have reason to believe there's a good deal of argon in Mars' atmosphere. There's difference of opinion as to the oxygen content; some observers insisting that they have proved that it exists. But if, indeed, oxygen is actually present, the quantity is considerably less than on Earth, even percentage-wise."

This remark brought a profound question from Holt. "On what do you predicate vegetation and animal life, if the oxygen content is so low that it cannot even be definitely traced?" he asked.

"There isn't the slightest doubt that plant life exists, and the botanists consider it well within the realm of credibility that Martian plants may live within a sort of 'internal oxygen atmosphere.' A plant applies photosynthesis in order to live, and generates new oxygen in the process, although it does require a certain amount of oxygen for recycling. If we assume that such a plant can store oxygen within its system, there's no reason why it cannot do without any free oxygen in the surrounding atmosphere.

"Now as to animal life, the answer doesn't come quite so easily. Animals, in the ordinary sense of the word, cannot live without oxygen. Nature, however, discovers the most extraordinarily manifold methods of providing animals with oxygen, even on Earth. Fish, for example, attract oxygen from the water through their gills. Monocellular organisms absorb oxygen through their exterior membranes, just as they do their food. Why shouldn't a Martian animal get its oxygen by eating plants which have stored oxygen produced by photosynthesis? It would, of course, demand that the lungs be more intimately connected with the digestive organs than are our own...

"Should you think this hypothesis a little far-fetched, there are other plausible explanations. Take, for example, the condition of symbiosis, which is quite familiar in natural history. Here animals and plants are able to survive jointly under conditions which would be fatal to either party alone. Corals, which are fauna rather than flora, are a case in point. We know that the oxygen content of the water within an extensive bank of coral is far too low to sustain life in the coral creatures inhabiting it. So Nature simply grows oxygen-producing algae throughout the coral bank. Thus it's quite reasonable to assume that Martian animals may live with oxygen-generating plants in some analogous symbiosis.

"We do have animals on Earth which require no oxygen at all to remain alive. Intestinal parasites, such as tapeworms, are typical of this class. Instead of relying on the chemical process of oxidation as do most other animals, they use fermentation to obtain the energy essential for the maintenance of life. Fermentation is the dissociation of sugar into alcohol and carbon dioxide, which is the process that transforms grape juice into wine or champagne. Fermentation, like oxidation, generates heat. Intestinal parasites exist amid a superfluity of sugar. They are beautifully protected against temperature variations by the bodies of their hosts, so they live extremely contentedly by fermentation without any oxygen whatsoever. Lest you think this example somewhat depraved, I employ it only to bring out Nature's inventiveness in finding ways and means for making life possible in the most inhospitable places."

"Well," said Holt reflectively, "it begins to look as though we might indeed be sticking our noses into a very strange world in this Mars business. But tapeworms or no tapeworms, what about the climate?"

"The average temperature throughout the year on Mars is somewhat lower than it is on Earth because of Mars' greater distance from the Sun, naturally. Nonetheless, it is not so low as this distance might lead one to expect. One of the most important reasons for this is the relatively low albedo of Mars; 60% of the total energy radiated to the planet from the Sun strikes the surface and is absorbed. in this case, not only the light radiation, but also the heat radiation. Then, too, there's little doubt that clouds form soon after sundown, preventing any very strong nocturnal reradiation. This cloud formation is doubtless due to the rapid cooling of the air after nightfall and the low atmospheric pressure. But the clouds quickly disperse when the Sun returns in the morning. Thus the mean yearly temperature on Mars is explained as being some 48° F, versus about 60° on Earth.

"The atmosphere of Mars is so thin that the temperature contrasts between day and ensuing night are very marked. This also applies to variations between seasons and latitudes. Such manifestations are familiar to us on Earth in regions of high mountains. On Mars, in regions where the Sun's rays fall vertically at noon, the early morning temperatures will be on the order on -20° C. These temperatures will rise to around +30° C at noon, and then decline to approximately zero near nightfall. We must anticipate temperatures of more than 100° below zero in the polar regions in Winter, when the Sun remains below the horizon for months, as it does in our own polar regions. During the polar Summer, when the Sun doesn't set at all, the temperature rises considerably above freezing. Otherwise the almost complete melting of the polar snow caps during this season would find no explanation."

Here Holt interrupted once more. "How do you explain that the melting of the polar snowcaps in Summer is so extensive? Our terrestrial snowcaps don't do that, despite the fact that the mean temperatures there are markedly higher than those on Mars."

"That's a mighty good question, Colonel. It is explained both by the nature of the Martian atmosphere and by the length of the year on that planet. Our spectroscopic determinations lead us to estimate that the average water vapor content of the Martian atmosphere is very low, not more than about 5% of that of the Earth's air. This low percentage is easily understandable in view of there being no oceans or large lakes from which quantities of water may rise into the atmosphere. The extreme thinness of the latter stimulates the evaporation of moisture from vegetation zones. The relatively cool air becomes saturated after absorbing small amounts of moisture, however, and this means naturally that any air reaching the polar regions will carry lesser amounts of water with it. Here it will be cooled down to extremely low temperatures in Winter, and will precipitate its water down to extremely low moisture contents. That is to say, it will precipitate its low moisture content considerably more completely than the Earth's atmosphere will. If we balance these conditions against one another, we're in all probability correctly concluding that the daily precipitation during the Winter months in the polar regions is noticeably less than that in those regions on Earth.

"Conversely, we shouldn't forget that a Martian Summer is nearly twice as long as ours, on account of the length of the Martian year. There's much more time available for solar rays to melt the snow of the Martian polar regions.

"These two effects explain the fact that the Martian poles have never formed such thick ice and snow caps as those of Earth.

"It is noteworthy that Summer at the South Pole of Mars is generally considerably warmer, although shorter than at the North Pole. This is related to the pronounced eccentricity of the planet's orbit. During Summer at the South Pole, Mars is near perihelion and closer to the Sun by 43 million kilometers than six Martian months later when it is Summer at the North Pole. It is at perihelion that Mars reaches its highest orbital velocity, being closest to the Sun. Thus Summer in the southern hemisphere is considerably shorter than in the northern, being only 158 days against 183."

"What's the size of the polar caps in Winter?" inquired Holt.

"They're largest towards Spring. The south polar cap extends as far as about the 42nd degree of latitude at this time, having a diameter of almost 5,700 kilometers. It shrinks gradually throughout the short but relatively hot Summer, and usually disappears completely before Fall. The cap at the North Pole does not grow quite so large. Due to the Winter being shorter, the amount of snow falling there is obviously somewhat less. The snow at the end of Winter doesn't usually go beyond the 51st parallel of latitude. In late Summer, this snow doesn't, as a rule, melt entirely due to the Northern Summer being cooler, though somewhat longer. It then shows as a small, white spot around the North Pole, reaching down to around the 87th parallel of latitude."

"What is your general concept of the total amount of water on Mars?" asked Holt. "This must have an important bearing on the vegetative regions and the canals."

"We've attacked that problem from various angles," answered Bergmann. "The most attractive one seems to be related to the probable amount of snow in the polar regions.

"Our approach is as follows: On Earth, the Sun is capable of melting about six meters of snow during the four months of Summer at and around the poles. Now Mars is more distant from the Sun and therefore receives less solar heat. On the other hand, however, its atmosphere reradiates a much smaller amount of this heat, so that a greater proportion reaches the surface. Furthermore, the Martian Summer is about twice as long as ours. It is hence reasonable to assume that the Sun probably melts about six meters of snow depth on Mars also. Since by the end of the Summer the snow on the polar caps is gone, we may conclude that the mean depth of snow at the polar regions is likewise six meters at the end of a Winter.

"Six meters of snow is equivalent to 60 centimeters of water, and at its maximum extension, the southern polar cap covers about 24 million square kilometers. From this we compute about 14 million millions of cubic meters of water. That's about twenty times the volume of Lake Erie, or a one-hundred-thousandth of the water in our terrestrial oceans.

"You might quite properly object that our assumptions concerning the depth of the snow caps are pretty arbitrary and that the quantity of water might well be one half of our estimated value. We won't take exception to that. An additional consideration is the fact that vegetative areas near the northerly latitudes are seen to be flowering and green when the south polar cap is largest. So we're sure that by no means all the water on Mars collects in the form of one polar snow cap or the other during the Winter in either hemisphere. My figures were intended to approximate the order of magnitude of the water on Mars. Just think, it's only one-hundred-thousandth of Earth's water supply, although the surface of the Earth is only about three and a half times greater than that of Mars! Makes it a pretty dry planet, doesn't it? Well, that figure alone, no matter how much you may question it, shows pretty plainly how arid Mars has become."

"What makes you think that Mars once was wetter?" inquired Holt.

"The huge zones of vegetation, particularly those in the southern hemisphere seem, for many and various reasons, to have been oceanic basins. The earlier astronomers even named them "Mare" because they thought that they were actually lakes. Today we know that open water bodies of any such size are unimaginable in view of the low atmospheric pressure of Mars – why, they'd evaporate in no time!

"What happened to the prehistoric Martian oceans and lakes is in prospect for our own, incidentally. We can follow on Earth the long process of their shrinkage through the various geological ages, and even through the short span of human history. Rome, for example, was a sea-side town when the Republic flourished, but since then the ocean has receded and Rome lies many miles inland. We find fossilized fish in all sorts of places in the mountains and deserts of the southwest states of America. These leave no doubt that large portions of the American continent were under water and only emerged by reason of the sinking of the oceans and inland lakes. The Great Salt Lake of Utah is a tiny remnant of the prehistoric Lake Bonneville, and even now its level is dropping at a rate which can be measured year by year.

"Planetary water loss is irrevocable and pitiless. On one side, the water sinks into the crevices of the solid crust. These crevices continue to gape open as long as the incandescent interior is undergoing a cooling process and shrinking. On the other hand, water evaporates into the air. This process becomes more rapid as the atmosphere is dissipated and its pressure drops."

"What's that about the atmosphere dissipating?" asked Holt curiously.

Bergmann went on coolly: "The molecules of the air are in motion, irregular and uncoordinated. Because they continuously collide, some of them may attain velocities sufficient to overcome gravity and thus escape from the atmosphere into the void. In the case of the Earth, this velocity of escape for a molecule must be not less than 6.9 miles per second, but on Mars, where gravity is much less potent, 3.1 miles per second suffices.

"Those two figures clearly show that the Martian atmosphere must have dissipated much more rapidly than that of the Earth. It's pretty safe to assume that there must have been about two fifths as much air over every square inch of Mars as there is over a square inch on Earth. That's plain from a very simple computation. But, as I said, the amount now present is only two ninths, and the difference is presumably that portion which has been dissipated."

"Now tell me, Doctor," said Holt, "if that much of the Martian atmosphere has been dissipated already, where is the moisture, the water vapor, which the air has absorbed from the evaporation of the erstwhile oceans? Did that fly out into space too?"

"Only a very small part of it," answered Bergmann. "Molecules can escape from the upper strata of the atmosphere only and these strata are necessarily very dry. The major portion of the water vapor must have combined its oxygen with the soil. For many millions of years, some moisture was precipitated on every cold Martian night in the form of dew, oxidizing the metals present in the soil. This split off the hydrogen, permitting it to rise into the upper atmosphere, from whence it dissipated gradually. We suspect," said Bergmann, with a gesture towards the photograph, "that this reddish coloration of the Martian deserts stems mainly from ferrous oxides which were thus formed at the expense of the oceans."

"Looking at this photograph," said Holt, "I find the great contrasts in coloration particularly striking. What conclusions do you draw from them?"

"Well," said Bergmann, taking a deep breath, "the reddish brown, ochre yellow, and orange zones are doubtless arid desert. But their coloration must be much affected by the position of the Sun, and they may therefore be somewhat "subjective" in every picture. Of course, we cannot tell what individual types of minerals make up the whole. If you contemplate taking a geologist along on your expedition to Mars, it ought to be a fascinating problem for him to examine the formations.

"Perhaps he'd find remnants of sea animals in the dried-up ocean beds, or maybe extensive salt deposits in the sinks where the last drops of the oceans lay. We're certain that he could do much to complete and supplement the theories we've built up on Mars' development.

"Now, it is our belief that the greenish zones represent vegetation. These tend to appear primarily around the polar caps at the time the melt begins. It is extremely impressive how the canals grow toward the equator out of these green melting regions, with water from the melted snow or ice.

"The artificiality of these canals is attested to by the fact that all canals hitherto known to us run in great circles across the surface of the planet, thus automatically achieving the shortest distance between the ends of any one canal. This alone lends considerable credence to the attestation, but the green areas at canal junctions, which are usually circular, tend to confirm it."

"My dear Dr. Bergmann," remarked Holt seriously as he put down the photograph, "you must know that the project before us is a very major one. We cannot possibly base our plans upon hypotheses and guesses, no matter how plausible they may be. We can only use clear, definite facts and results of such measurement as is entirely beyond doubt. These we must have. No effort must be spared to collect every bit of confirmed data available here. Our entire project can be endangered by a single erroneous conclusion or a set of figures which is not absolutely correct. Anything like that would distort the groundwork of our planning.

"Your dissertation was of immense interest to me and what you have said will be very useful. But I want to suggest that we drop any further attempts to line up further theories about the Martian civilization and what it may have created. It would be very kind of you to tell me something about the methods of observation and measurement that you have been using. You might also make a few suggestions about how to improve these methods, with respect to what we can do to perfect our applicable knowledge."

At this point Professor Hansen broke in. "We'll use this observatory as the main tool for all future work on Mars," he said. "I don't believe that we can use anything from the terrestrial observatories henceforward. Perhaps Dr. Bergmann will tell the Colonel why observations and measurements from here are so much better and more promising."

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"I'll begin by citing an example," continued Bergmann. "Let's take the composition of the Martian atmosphere. Spectroanalysis is the only method astronomy has for finding this composition. All the light coming from a planet is reflected sunlight which has traversed the planet's atmosphere twice – once when it strikes the planet's surface, and a second time when it is reflected back into space.

"The gases of which the atmosphere is composed produce certain characteristic dark lines in the planet's spectrum. The latter is otherwise a pure solar spectrum. This happens because every gas has the characteristic of absorbing light waves of certain quite definite frequencies. We can deduce what gases are present in the planet's atmosphere from the frequencies corresponding to certain dark lines in the spectrum, know as absorption lines.

"Now, when light must pass through the Earth's atmosphere before entering a telescope, black lines originating in the Earth's atmosphere superimpose themselves upon the other black lines. Let's take carbon dioxide and water vapor, for example. They are found in the atmospheres of both Mars and Earth. Therefore those lines which are caused by the carbon dioxide on Mars are superimposed on those caused by the carbon dioxide on Earth, and the same thing applies to water vapor, since the lines lie at very definite places in the spectrum. This dilemma is circumvented by photographing Mars' spectrum at a time when the two planets are receding from or approaching one another at the highest rate. Then the Doppler Effect displaces Mars' spectrum and it is possible to distinguish Martian absorption lines from those of our atmosphere.

"Unfortunately, this procedure calls for the photographs to be made at a time when Mars is rather distant and that is an unfavorable time for observation. Results thus obtained up to now have not been altogether satisfying.

"Working from Lunetta, there are no such difficulties, and we can take spectral photographs when Mars is very close to us. Another advantage is the absence of the flickering caused by the Earth's atmosphere. From the optical angle alone, our work is vastly better than can be done on Earth.

"Now let's take another example; just think of all the difficulties confronting a terrestrial observer who is trying to follow consecutively the burgeoning and fading of any given Martian vegetative region. Of course even on Lunetta, we cannot obviate the difficulties that the change of distance between observer and observed brings during a half year. But the astronomers on Earth must fight many handicaps from which we're free.

"Many observatories in the northern hemisphere, and particularly in highly developed regions such as Europe and America, work under such poor atmospheric conditions as to be almost unsuited for delicate observation work on planets. Local weather conditions often interfere just when astronomic ones are best.

"Even observatories near the equator, less bothered by weather, work against a handicap when it comes to consecutive observations of Mars over extended periods. Let's consider an opposition of Mars. The planet is then exactly opposite the Sun, and to all terrestrial observatories, it transits the southern branch of the meridian at midnight and may be observed from nightfall until daybreak. Since Mars rotates once in 24 hours and 37 minutes, any one spot on its face appears approximately in the same place on two consecutive nights at the same moment. An observer will see the same hemisphere of Mars each night, while the other hemisphere remains invisible. The latter, however, could be seen by an observer antipodally located, whose midnight is 12 hours later than that of the first observer.

"But the picture is gradually changed by the 37 minutes difference in the times of revolution. Any given spot on Mars appears at its western rim each night later, by 37 minutes. So fifteen or twenty days afterwards, it appears just before dawn, when daylight and the low altitude of the planet obstruct observation. Therefore, to get continuity of observation, an observatory located where it can see the subject at night must take over.

"You will not find it difficult to imagine what a lot of errors can thus creep in. There's the difference in personal reactions, without even bringing up the number of unsuccessful measurements and examinations in the past stemming from lack of accurate coordination between various observatories, widely separated geographically. This may not appear insuperable, but it's very difficult to get such coordination in practice.

"On Lunetta, we have none of these handicaps. With our bi-hourly orbiting time, Mars can never be hidden from us for more than an hour. We can always see it for a full hour or more. We can keep its entire sphere in sight so consecutively that we can check changes in certain regions throughout long periods quite easily and without interruption.

This is one of the more important keys to successful examination of Mars. Being free of atmospheric disturbances, we can observe Mars even when it is most distant from the Earth, unless, indeed, it is hidden by the Sun. Such observations, naturally, lack the quality obtainable in Mars oppositions, but no terrestrial observatory can make Mars out at all at these times, for it is obscured by the bright daylight.

"There are many more advantages of a space station like this as an observatory, but I suspect it might bore you to hear them all."

"Not at all, not at all," said Holt with a friendly grin. "As an old space man, even if I was military, I always get a kick when I hear that rocketry has done something for astronomy. You know, there's a natural relationship between our two trades, and a pretty close one at that. So we've got to pull together every time we can.

"But let's get back to business. What was that you were saying about temperatures on Mars? You gave the results, but I'd like to know how you get them."

"Here's the way it's done," said Bergmann. "There's a tiny thermocouple in the focal plane of the telescope with which we're working on Mars. The strength of the radiation is a measure of the temperature of that spot on the surface to which we have adjusted the thermocouple. It's not quite as simple as it sounds, for the total radiation of a planet consists of rather more than the heat radiated by the planet itself. The "more" is reflected solar radiation, and our conclusions must be drawn from the former only. So we've got to separate the two. This is done by interposing a layer of water about half an inch thick in the ray. This permits the short wave, reflected solar radiation to pass, slightly weakened. But it completely cuts off the long wave heat radiation which comes from the surface of the planet. There's a ratio between the current produced by the thermocouple with and without the water filter and this ratio enables us to determine the rate of the planetary radiation. With it, we can finally derive the temperature at the surface.

"Our thermocouple is hardly as big as a pin head, and you can guess what a job it is to run it to and fro over the tiny image of the planet. At points where radiation is strong enough, namely in the focal plane, the image itself measures but a few millimeters. When it is done in a terrestrial observatory, the tiny image also glimmers on account of the passage of the light through the atmosphere, so it is quite miraculous that measurement technique down there has advanced to the point where the required accuracy has been attained."

"You seem to imply," said Holt, "that we may anticipate improvements in work of that nature done from here."

"There's no doubt about it," assured Bergmann. "You have but to provide funds and scientific assistants, and induce the authorities to enlist the services of some of the more efficient research institutes to perfect our instrumentation. Then we'll be able to get readings up here on much of the data you'll require. Planetary examination presents one of the most difficult problems in measurement technique. But we can do much more than heretofore if we can tackle it with such means and resources as have been lavished on many industrial instrumentation efforts."

"If Operation Mars gets under way," said Holt, "you'll get what you need. I'm sure that Professor Hansen will concur in my request that you write an official memorandum for me on the procedure you would like to adopt. And here's a questionnaire covering everything I'd like to know about Mars, which I do not expect you to be able to fill in completely at this time, however.

"Please remember that every question that remains unanswered before we start is a source of danger to the whole enterprise, so put into your memo everything which might be important, even though there's no apparent immediate solution to some particular measurement problem. Include measurement methods which require original development, problems of that nature which you already face, and personnel and institutions you think should take part. Don't forget new instruments for this observatory, or anything which may facilitate the work. Give us an idea of how much time and how much money you'll need. Don't spare the horses, Mr. Bergmann. This is no place for economy drives."

Holt paused, noting Bergmann's gleeful face, for the latter was obviously overjoyed at the scientific windfall that had dropped at his feet. All his life he had yearned to probe the secrets of the Red Planet and here came the opportunity of a lifetime, free and unsolicited. Thoughts of applying then and there for a membership in the expedition raced through his mind, but to express them then he dare not…

At that moment, Hansen broke in with, "Do come and have a look at your planet, Colonel. You'll be here for a couple of hours, and we can go into your further questions later. And I'll stay for some days and have plenty of time to look through the great eyepiece."

Bergmann and Holt unstrapped their chair belts and reached for the fireman's pole which took the place of stairs or corridors in the weightless interior of the observatory. Hand over hand, they floated themselves to a circular manhole located diametrically opposite the bay in which they had been landed by their busy bee. Bergmann opened the plate to admit them into the observation chamber, much after the manner used with the bee. After closing the doors, Bergmann took the wheel and pressed a switch which caused the chamber to slide out of the bay and into space. Opening the throttle moved the chamber towards the telescope structure floating at the end of its connecting line. As they approached the guide rails, Bergmann reversed the thrust momentarily and, with a metallic click, the chamber entered the rails and locked fast at their inner limit stop.

The chamber had a hemispherical glass dome in whose center was a minuscule, swiveling telescope. Bergmann drew himself against it, turning it until it registered on Mars. When the latter was within his field of view, he threw a switch which audibly started electric motors somewhere in the fabric and ponderously the whole telescope structure, chamber, observers and all began to orient itself towards Mars. Now Bergmann fixed his eye to the ocular of the main 'scope.

"See what I'm doing?" he offered without looking away.

"I've got the idea," said Holt, "but I don't follow all the detail."

"The small sighting instrument is hung in gimbals which have sliding resistances or potentiometers as well call them, attached to the axes. Currents running through these are a measure of the angular difference between the instrument and the main tube. After the sighting 'scope has been bracketed on Mars, it is kept there by a light-sensitive cell, and two flywheels train the main 'scope until the two are parallel, thus bringing both 'scopes onto Mars. There comes our planet now, just sliding into the field of vision! Want to look?"

Holt traded places with him and applied his eye.

There it was, a huge disk treble the size of the Moon! Its coloration, indescribable in its variety, well-nigh overwhelmed him for a time. He could see the famed south polar cap, almost blinding in its stark whiteness. There was the rim from the melting edge of which the ever-thirsty Martians were supposed to draw their pitiful water supply. Below were the red, yellow, and dark-green zones – the deserts and vegetative regions. The longer he gazed, the more detail registered with him.

Suddenly, there they were! The canals! A whole hemisphere was almost covered by their fine, filigreed network, each meticulously following the bold sweep of a great circle. More and more seemed to appear from nowhere. What did they really mean? Here was no longer the Red Planet, but one like Joseph's coat. His it would be to plumb the distant mysteries by a dive into space deeper than any man had ever made.

Chapter 5
The "Sirius" Returns

Holt left the observatory full of admiration for the work going on there, and for the various adjuncts available to him for preparing his plans. His new knowledge, reinforced by the almost neighborly feeling of his close-up view of Mars, had given him a better sense of where he was headed. The busy bee shot him back to Lunetta's artificial gravity where he spent hour after hour with Riley indoctrinating the latter with the full magnitude of the coming effort. Then the time for him to drop back to Earth rolled around, and leaving the comfortable cabin which had been assigned him, he made his way to the elevator door from which he would rise against Lunetta's centrifugal force to reenter the conical nose of the *Sirius*.

A tall officer stood by the elevator door, suitcase in hand. "Why, if it isn't Tom Knight, my old copilot of war days! I've been stuck in this doughnut for two weeks, and now I'm going to fly the *Sirius* back to Kahului. You riding?"

"Well, I was going to ride," said Holt, "But now I'm a copilot, unless you want me to spring rank on you…"

Knight grinned, and ten minutes later, Holt took his place at Tom's right in the pilot's compartment. This was in the nose of the conical stump remaining after the release of the two enormous booster stages of the *Sirius*.

It was not unlike the cockpit of a large plane. The couches, previously necessary to enable the crew to withstand the high accelerations after Earth launching, had been set up as ordinary seats. There were four in the crew: Captain, copilot, mechanic and radio man. These men faced a task of skillful piloting on the return trip. When leaving the Earth, automatic devices had done everything – course-keeping, detachment of boosters at predetermined velocities – and the crew had merely reported the proper functioning of the incredible ingenious mechanical and electrical brain that had controlled the mighty, if short-lived power. Now the Captain would operate controls, like any pilot in the atmosphere.

Two oval ports permitted him and his helper to view whatever lay before the sharp nose of the ship, and below the ports was a mighty instrument panel. In the same plane as pilot and copilot sat mechanic and radio man, just below the operating seats. Each had an instrument panel, below which were two ports similar to those of the pilots.

With passengers and express aboard, the airlock to Lunetta was closed. The interior of the mooring cone was all that Holt could see through the glass of his port. *Sirius*' nose was still tightly held within it.

A green bulb flashed on the panel, signaling from Lunetta's flight controller that they were free to go. Knight closed a switch. A click showed that the toggle which had held them was open, then light began to filter around the rims of the ports. A compressed air piston was slowly expelling them from their snug berth. Lunetta gradually came into view, huge and glistening. Ponderously and silently, she receded. Knight started one of his flywheels and Holt had the impression that *Sirius* was slowly beginning to rotate around her longitudinal axis.

"Going to spin down?" he asked Knight with a laugh. Then he caught himself. "Don't bother. I must be getting rusty. Of course, you've just stopped us from turning with Lunetta. Before we were turning with her… I'd better get back into this space stuff!"

Still they floated not far from the great wheel. Knight drew a set of tables from the side pocket and turned its pages. He noted the hour on a large timepiece on the instrument panel. Then he reached for a periscope eyepiece which protruded from the ceiling and directed it at the star that he had identified from his tables. He set his cross-hairs onto the star with adjusting screws. Then he moved the switch once more and the flywheels buzzed. The ship began to orient itself away from Lunetta and Holt saw the huge disk of the Earth, brightly lighted by the Sun, swing into view. Knight was busy with his periscope, turning the adjusting screws to keep it bracketed on his star, despite the angular movement of the ship caused by the flywheels. He could see a set of changing figures, graduated in degrees, which showed that his ship was gradually coming parallel to the periscope. As the readings diminished, the tone of the flywheels dropped, stopping as the pointer hit zero. The ship was exactly lined up with the chosen star. Knight noted the time twice more, made an adjustment of the setting of his glass after a look at his tables, and then used his flywheels to add this correction to the angle of the ship.

Sirius was now orbiting around the Earth stern first. There was complete silence except for the rising whine of the steering gyros coming up to speed.

"Ten seconds to go," said Knight.

He advanced the throttle as the second hand touched ten, and there was a subdued hissing sound, followed by the vicious howl of the main jet. Acceleration pressed them back into their seats. The accelerometer went up to 3.1g. Knight was retarding the orbital velocity of the ship with a hundred tons of thrust, just half what the motor could develop. This would bring her into the upper atmospheric layers after half a revolution around the Earth. Once she had penetrated them, their drag and lift would serve to reduce the speed and make a landing possible. The application of thrust lasted some 15 seconds, whereupon silence again enveloped them and the heavy load imposed by the negative acceleration was gone. *Sirius* was now turning around the Earth at a rate of 480 meters per second lower than that of Lunetta. The latter, so far as they were concerned, was just another one of the myriad heavenly bodies in space.

Knight again started his flywheels, gradually rotating *Sirius* 180°, so that at the end of five minutes, her nose was pointing in the direction of flight. He continued to apply them from time to time in order to compensate for the curvature of their flight path.

Everything about the ship was still weightless, and the sunlit surface of the Earth glared up at them through the cabin portholes.

Knight pointed out a cloud-bank far to his right. "That's Hawaii," he remarked. "Just one turn more around the Earth and we'll be home."

The wide span of the Pacific shone up at them through the cloudless haze, for *Sirius* was still streaking along at over 1,000 miles altitude on the elliptical path leading to the landing. Her heading was southeast and a chain of woolly cloudlets bubbled past far below Holt's window. Their shadows on the shimmering surface of the immense ocean betrayed their height. Holt knew from experience that cloudlets of that sort indicated the presence of islands and he was soon able to coordinate them on his chart with the Marquesas. Those ahead would be over the Tuamotu Archipelago, that well-nigh forgotten legion of lonesome isles of the South Pacific.

Another fifteen minutes passed with naught but the waters of the ocean in view. Holt thought of Mars' water famine; less than one-hundred-thousandth of Earth's water… It seemed to him that we on Earth might do quite well with vastly less than we have, so why shouldn't the Martians manage one way or another?

Ahead and to starboard there appeared a glistening whiteness which Holt promptly identified as the southern barrier ice.

"We must be between Cape Horn and Antarctica…" he remarked to Knight.

"Correct," said the latter. "Our landing ellipse reaches its southernmost point just where the Antarctic Circle passes between North and South Graham Land.

By now *Sirius* was tearing into the rapidly approaching nightfall and the Sun popped out of sight on their port hand, so that all their senses could interpret of the shell-like trajectory was what was on the luminescent instrument board.

"It's getting about time to rig out the wings," remarked Knight and pressed a switch. There was the whine of a servomotor, and Holt, peering through his porthole, could see the telescopic wings slowly emerging by the light from the after cabin. Hitherto hidden by the stubs housing them, two thin, narrow wing panels now increased the span of the ship to triple what it had been.

Knight pulled the control wheel away from the instrument board where it had been latched and engaged it into the lateral and pitch control mechanism. The temperature indicator of the leading edges still read zero. He tried elevons and rudder, but they moved freely in his hands and the ship did not react. That meant they were still clear of the most tenuous layer of air.

"We ought to get some air soon," said he. It's been 46 minutes since we started to decelerate and we'll be at our perigee, 80 kilometers from the Earth, in five minutes."

He now moved the controls almost constantly, with an anxious eye on the leading edge temperature gauge. Soon slight movement of the ship began to follow the control movements. Very, very weak they were, but nonetheless perceptible. There was a light sensation of tripping, tending to draw them forward against their belts. At last air was reducing the 8,270 meters per second which showed on the airspeed meter.

The needle of the leading edge temperature gauge kicked and then rose slowly but steadily to 150°, 200°, 300° C. Higher and higher it moved.

Knight pushed the wheel slightly forward, keeping the altitude at an exact 80 kilometers. They were lifted slightly out of their seats and against their shoulder belts by acceleration in the vertical plane of about 0.1g. This came from the negative lift that Knight had imparted to the wings by his forward movement of the controls. Had he not done so, *Sirius* would have again emerged from atmosphere at perigee, and the second branch of her landing ellipse would have carried her back to Lunetta's orbit.

"What sort of skin temperatures do you get nowadays?" asked Holt.

"Oh, she'll take up to 1,100 degrees and more," answered Knight, "but the highest we're apt to get is around 730° C when we're at 5,000 meters per second at 60 kilometers altitude."

"Not much, is it?" asked Holt. "With the old Jupiters, we used to heat up to almost 900 degrees."

"These new vessels have a much lighter wing-loading. That lets us do our gliding considerably higher, and there's less heat transfer because the air's less dense. On some of our troop transfer trips, the boys got very jittery when they looked out the ports and saw the wings a bright, incandescent red."

Despite Knight's reassurances, it was getting uncomfortably warm in the cockpit. "I'll turn up the refrigeration a bit, so the boys back there won't get to cooking too much and be all nervous," he said.

He twisted the adjustment screw of the temperature regulator and the whine of the cooling turbine rose in pitch against the hissing and roaring of the onrushing air.

Above their heads, the star-strewn sky seemed motionless and below them was naught but pitch darkness. Their wings and nose had begun to glow with the color of old port wine, which penetrated the portholes with a ghostly glimmer and reflected from their faces. Their enormous velocity was betrayed only by the instruments and the incessant roaring as they split the air.

"There's the lighthouse on the Cape of Good Hope!" exclaimed Knight, "We'll be subsonic in another hour or so."

There was still very little sensible evidence of the slowing down of the *Sirius*. Not long before, they had been lifted into their shoulder belts by the centrifugal acceleration of the wings forcing the ship into a circular path, but this had slacked off and was no longer noticeable. It meant that the excess speed with which *Sirius*' had entered the atmosphere had sunk to approximately that of the local orbital speed. But the longitudinal deceleration still read less than 0.1g. Twenty minutes after they had passed the Cape of Good Hope, their speed was still above 7,000 meters per second and their altitude well over 70 kilometers.

All this time, the leading edge temperature gauge read but little under 700° C and the entire nose of the ship was heated by the air friction to a luminous cherry red. Holt's view of the wings revealed that their dark red incandescence progressively diminished towards the trailing edges. It was striking evidence that the boundary layer was growing thicker in chord and reducing the amount of heat transferred by the onrushing air.

It seemed a long time before they became aware of a sickle-shaped glimmering ahead of them. It grew rapidly on both sides of their nose, revealing that they were flying into the dawn. Above the horizon soon glared the livid mantle of the solar corona, to be followed rapidly by the orb of day itself, painfully contracting the pupils of their night-accustomed eyes.

Soon the advancing line of dawn on Earth had passed below them and Holt noticed that they were flying above an illimitable forest crossed by a silvery, serpentine line which could only be a river.

"That's the Ob," remarked Knight with a glance at the clock. "If our directional gear has been working properly, Novosibirsk ought to be out there to your right, then Tomsk, and the Yenissei River after a minute or so."

Sure enough, another mighty river, disguised from their height as a tiny, silvery thread, passed below them. Occasional patches of snow appeared in the forested Siberian wilderness, growing thicker as they advanced, until near Verhojansk, the "coldest city," the whole lonesome waste lay rigid under its icy frost. Here they had reached the limits of the Arctic, the Northernmost point of their great circle path.

Now headed towards the southeast, *Sirius* skimmed across the frozen Kolima River. Now, at last, the airspeed meter dropped to 6,000 meters per second, but the altitude was still above 65 kilometers. The wing temperature was on the upgrade and read slightly above 700° C.

But *Sirius* was now over the ocean once more. Holt saw Kamchatka's huge peninsula through a hole in a fog bank, thrusting out like a great barrier between Siberia and the Bearing Sea.

They could distinctly feel the increased deceleration imposed by the air upon the racing ship; they were drawn forward against their belts, as though seated in a car whose brakes are applied. When they passed the western outposts of the Aleutians the speed had dropped to 5,000 meters per second, and five minutes later it was only 4,000. The wing temperature, which had been stuck for a long time at around 730° C, had sunk to 670° and was now rapidly diminishing.

From below the pilot's seats, the radioman's hand appeared with a slip of paper.

"Here's the first bearing from Kahului," said Knight, twisting the knob of the course gyro and resetting the ship onto the corrected course. *Sirius* was cutting deeper and deeper into the atmosphere, whizzing diagonally downward. Knight checked speed and altitude with the figures on a tablet attached to the steering column. These showed him at what altitudes various speeds should be passed as *Sirius* rapidly lost velocity. When they hit the 1,000 meter per second mark at 33.3 kilometers height, according to plan, the wing temperature was only 237° C and Knight gave the order to tighten seat belts.

Five minutes elapsed without incident, then the deceleration suddenly increased noticeably for a few seconds. Knight's face grew tense as he manipulated the controls firmly. His eyes were glued to the Mach meter.

"Transonic speed," he said.

Sirius was still 24 kilometers high, but her deceleration again diminished. Gravity had been growing on them imperceptibly all along and was now wholly normal. It held them to their seats as Earth-dwellers have been held through the centuries. Soon the ship had also almost ceased to decelerate. At Knight's command the mechanic lowered the leading edge flaps a few degrees in order to adapt the supersonic airfoils to subsonic flight. The wings were now at almost the same temperature as the air.

The radio operator handed up course corrections in increasingly rapid succession and soon they could see the cloud caps above the Hawaiian Islands far below on their starboard bow.

Knight banked *Sirius* into a wide spiral glide which ended in a broad sweep across the airport. At his command the mechanic lowered the landing gear and flaps and he finally set the ship on the runway with no more fuss than some casual airliner coming in from Wake Island.

A tractor hooked onto them at the end of the runway and hauled them solemnly to the terminal building of Kahului Spaceport. It was almost 12 hours on the dot since they had been projected upwards towards Lunetta by the huge booster stages.

Catherine was waiting. She had spent the night with some old friends in Kahului, and as she and Gary got into a taxi, Knight gave them a friendly wave of the hand.

"Drop in on us, next time you're near Emerald Bay," shouted Holt.

Chapter 6
Is it Technically Possible to Reach Mars?

When President Vandenbosch's recommendation that an expedition to Mars be set afoot reached the newspapers and radio commentators, the Red Planet came alive in the minds and consciousness of people the world over. Speculation was rife as to the nature and makeup of the space vessels that would compose the fleet. Technicians and laymen flooded the press with both fanciful and serious comments and suggestions. Rocketry became overnight a word as familiar as television had been forty years before and was far more controversial. The names of Braden, Spencer and Holt ran from mouth to mouth like wildfire.

Catherine Holt immediately found herself called upon to redeem her promise to her husband to support his interplanetary plans, for the tremendous interest aroused by the project infallibly induced would-be participants and contributors to seek access to the leader by the domestic route. A California State Trooper was stationed outside the modest house on Emerald Bay to ward off the crowd of strange inventors who besieged its gates. Public relations requirements, however, indicated that inaccessibility, or at least the reputation of it, be avoided at all costs, so Catherine found herself interviewing a strange assortment of people ranging from gentle mystics to astrologers. The local postman brought daily a heavy sack of mail from which Catherine selected such letters as appeared to her to be true personal correspondence and forwarded the rest to Holt's office where they were processed by an especially engaged battery of secretaries and typists.

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The reaction of Congress to the President's message was anything but uniform, for the appropriation requested was two billion dollars and there were implications that this might not suffice. Many of the Representatives felt grave doubts as to the wisdom of devoting so great a sum to a project which, in their opinions, could contribute nothing immediate to a cure of the economic unbalance which was the main concern of every session of the World Legislature.

The past war had severely strained the resources of every country on Earth, united though they now were after finally building an enduring peace. Even the victors had strained their financial means to the breaking point, for they had been forced not only to repair their own war damage, but had also endeavored to succor the vanquished so that the heart-rending suffering among them might not break out into renewed unrest. The most strenuous efforts were being made all around the globe to establish a universal peace economy such as had not been known for more than two generations. And it was to taxpayers burdened with such an enormous load that the request was in the end directed – a request for billions with which to carry out a project of questionable value and of equally questionable technical feasibility!

The Congress appointed a special committee to study the matter and chose Senator Perucci, an Italian, as its chairman. Perucci was a physicist of note and had won the Nobel Prize for his epoch-making work on cosmic rays. Although he was now devoted to statesmanship, it was well known that no basic scientific error in the plan would escape his critical eye and caustic tongue.

Under his direction, the "Mars Committee" decided on a series of public hearings at which they would question those concerned with the management of the enterprise. Unless these men could give satisfying answers to every question, the appropriation would fail of the necessary votes in committee and never reach the floor.

Bruce Spencer was the first man called. His it was to defend the technical aspect of the planning and to report on the construction of the space ships for Operation Mars. He entered the committee room with a briefcase in one hand and a huge roll of drawings in the other. The witness stand was crowded with microphones. Reporters and spectators occupied every available space. At the long conference table sat the nine committee members with Senator Perucci at their head. He greeted Spencer heartily and invited him to display whatever material he had brought.

Spencer unrolled a large drawing and fastened it to a display board convenient to the witness stand. Brusquely and without preamble, as was his wont, he began.

"Gentlemen," his deep voice rumbled, "here in the middle of the drawing is the Sun. The outer circle represents the orbit of Mars, the inner one that of the Earth. You all know that the Earth requires a year, 365 days, to circle the Sun. It requires a certain speed to do this. It can easily be determined, since we know that we are 149½ million kilometers from the Sun. That speed has been computed as 29.8 kilometers per second. The orbit being curved, we may say that the Earth is in a continuous turn. This means that centrifugal force is generated, just as happens to you when you make a turn in your car. This force tends to urge the Earth away from the Sun, exactly in the same manner as you are forced outwards within your car. But the Sun also exerts a gravitational force upon the Earth which balances the centrifugal force to which I have just referred. This makes the Earth's path around the Sun a smooth, even circle.

"The same applies in principle to Mars, but its orbit is longer and its velocity along it is much lower, namely 24.1 kilometers per second. Hence it takes 687 days for a complete circle around the Sun, and this is the length of the Martian year.

"If you'll examine the drawing, you'll note that the orbit of Mars is not exactly circular. Here, at this point, Mars is evidently closer to the Sun than when at a point diametrically opposed to it. Doubtless you will desire an explanation of how this comes to be. As I told you, orbital centrifugal force and solar gravity are everywhere equal for the Earth, but this does not hold absolutely in the case of Mars. Take this point where Mars is remotest from the Sun. We call this point his "aphelion." Solar gravitation here exceeds centrifugal force because Mars' orbital velocity is lowest at this point. Hence Mars increases its speed towards the Sun. But it cannot move directly towards the Sun, being prevented from so doing by its orbital velocity. Mars, therefore, falls, as it were, around the Sun in curvilinear fashion and approaches closest at this point, called "perihelion," which is diametrically opposed to the aphelion. Now its orbital velocity has been considerably increased by this free fall. Therefore, at perihelion, centrifugal force exceeds solar gravitation and the planet begins to recede from the Sun. But there has been no dissipation of energy during the fall, so Mars is compelled to return to his point of origin, the aphelion.

"The whole procedure is a sort of oscillation, somewhat like that of a swing. There, at aphelion, when potential energy is greatest, kinetic energy is least, and vice versa.

"Far back in the middle ages, an astronomer named Johannes Kepler proved that these planetary orbits are elliptical. Hence the expression "Kepler ellipses." The center of attraction is always located in one of the foci of a Kepler ellipse. In the case of the solar system, it is the Sun. The foci are so close together in the Earth's ellipse that the latter is, to all intents and purposes, a circle. But Mars' orbit is markedly eccentric, as you've been shown.

"Gentlemen, it is Kepler's elliptical orbits that point out how we may journey from one planet to another.

"Let us assume that we could increase the orbital speed of the Earth at some arbitrary point of her orbit. That would increase the centrifugal force with which it would recede from the Sun. If we could increase Earth's orbital speed from 29.8 kilometers per second to 32.83, that is, by 3.03, she would intercept Mars's orbit after one-half a revolution along such an ellipse around the Sun.

"While we cannot do this with the entire Earth, it is quite possible to do so with a minute portion of it. A modern rocket ship finds it no great problem in attaining 3.03 kilometers per second, and such a ship may be considered as that minute portion.

"There's yet another factor which bears vitally upon the practicability of this kind of rocket voyage. I shall now cover it.

"So far, we have discussed the flight path of a ship enroute to Mars only as it is related to the solar system. But if we think of ourselves as looking at a rocket from some point on the Sun, and desire to increase its speed by 3.03 kilometers per second above the speed of the Earth, we must first overcome Earth's gravitation in order to do so. This is a much more difficult task.

"If we want to accelerate it enough to let it come to a standstill at the point where terrestrial gravitation has, to all intents and purposes, become zero, we must give it an initial velocity of 11.18 kilometers per second, an enormous figure. And if it is to depart from the Earth's gravitational field with a residual velocity of 3.03 km/sec, the initial velocity would have to be even higher, namely 11.6 km/sec. This is beyond our capabilities at this stage of development.

"But there are other means at our disposal. You are familiar with our artificial satellite Lunetta, circling the Earth these many years without any application of propulsive power. Her orbit around is subjected to the same Keplerian Laws that determine the movements of Earth and Mars around the Sun. The centrifugal force imparted to her components when they were freighted up to her orbit and assembled sustains her weight and prevents her from falling to Earth. Her orbital velocity of 7.07 km/sec just suffices to keep her centrifugal force adequate to maintain that situation.

"In order to retain the required residual velocity of 3.03 km/sec beyond the field of terrestrial gravitation, we should only be obliged to accelerate the ship by 3.31 km/sec along Lunetta's orbit and in the direction of her motion. This additional slight velocity increment to the orbital velocity, 7.07 kilometers per second, of Lunetta, will give us what we need. You will note that such a maneuver calls for only a minute fraction of the power of a ship designed to rise from Earth to Lunetta.

"There is, however, a regrettable catch in the Lunetta business, for Mars' orbit lies in the same plane as the ecliptic, whereas Lunetta's does not – a practical and economic drawback to launching from Lunetta. Thus we must effect the departure of Operation Mars from an orbit similar to that of Lunetta, except that it must lie in the plane of the ecliptic. We have actually selected a path of departure almost exactly equivalent to that of Lunetta and which, at the intersections of the planes, lies but a few miles from Lunetta's orbit."

Spencer paused and ran a flamboyant bandanna handkerchief over his hairless skull. Then he downed a glass of water and continued.

"We must remember that our problem is not limited to shooting our rocket ship to Mars on a one-way trip. You have doubtless realized from the foregoing that this might be done with our existing vessels if they were to depart from an orbital path around the Earth. But our expedition must not only reach Mars, it must remain there for quite a time and then return safely. This is much more difficult of achievement, so let us consider the demands made upon us by this problem.

"I have just shown you that 3.03 km/sec beyond the orbital velocity of the Earth is required to be imparted to a rocket ship after it has left the field of gravitation of the Earth, if it is to follow an elliptical free-flight path that will contact the orbit of Mars after one half a circle of the Sun, and that this velocity must be imparted in the same direction as that of Earth's orbital velocity. We also have learned that, if the start is made from an orbital path around the Earth in the plane of the ecliptic, in which path the ship has an initial velocity of 7.07 km/sec, we shall only have to accelerate it by 3.31 km/sec in order that it may leave the field of gravitation with the required residual velocity of 3.03 km/sec. To attain this velocity increment of 3.31 km/sec is the first propulsive problem of our trip. When it has been completed, the ship will coast on without power on a Keplerian ellipse through the solar system. After 260 days, at the time it reaches its aphelion, it will intercept the Martian orbit. Here I should note that all these figures are valid for the mean distance of Mars from the Sun. That is, I have assumed Mars' orbit to be circular for purposes of simplification.

"If we so arrange matters that Mars arrives at the point of contact of this ellipse with its orbit after 260 days, the ship will enter Mars' field of gravitation. We must remember that Mars has an orbital velocity of 24.1 km/sec., while the velocity of the ship at this point will have been reduced to 21.5 km/sec by its battle against solar attraction during the voyage. Mars will, therefore, overhaul the ship from astern with a differential speed of 2.6 km/sec. If the ship at its aphelion were exactly in Mars' orbit, it would be caught by his gravity and crash upon Martian soil.

"But we are in a position to locate the ship's aphelion just inside of Mars' orbit. Thus Mars would attract it hyperbolically, according to the laws of motion of heavenly bodies. The ship would approach most closely to Mars at the vertex of such hyperbola, and it would escape Martian gravity for all eternity on the second branch of the hyperbola. But, by the use of the rocket power plant, we may reduce the ship's velocity appropriately just before it reaches this vertex and cause it to enter a circular or slightly elliptical orbital path around Mars. Its radius around Mars will be about the same as the distance of the vertex of the hyperbola from the planet. The ship may orbit here indefinitely without propulsion. In effect, it will have become an artificial satellite of Mars and will so remain until the situation is again altered by a propulsive maneuver.

"We have selected for our purposes an orbit at 1,000 kilometers from the surface of Mars. In order to go into this satellite orbit, a change in velocity of 2.01 km/sec has been computed as necessary. If the trip to Mars involved only this entrance into a satellite orbit, our ship would have two velocity changes only: 3.31 km/sec to leave the satellite orbit around Earth, and 2.01 km/sec for entering the satellite orbit around Mars, a total of 5.32 km/sec. Even this is far less than the velocity change necessary to reach Lunetta from Earth.

"The return trip requires exactly the same velocity changes. 2.01 km/sec are required to depart from the Martian satellite orbit so that the residual velocity beyond Mars's gravitational field is again 2.6 km/sec. If we impart this residual velocity to the ship in a direction opposed to that of the travel of Mars around the Sun, it will eventually follow the latter at a rate 2.6 km/sec less than his own. The ship's orbital speed, being now less than that of Mars, reduces centrifugal force so that solar attraction outweighs the former. Thus the ship will move in a Keplerian ellipse which somewhat represents the continuation of the ellipse of arrival, and this ellipse contacts the orbit of the Earth at perihelion after 260 days. If the timing is such that the Earth reaches this point at the same time, the ship may be attracted into a hyperbolic path by the former. We can arrange matters so that this hyperbolic path will have its vertex at the same height as the circular path from which we originally took our departure. Now we must decelerate the ship just before it reaches this vertex and bring it down to the local orbital velocity, just as we did near Mars. We shall require a velocity change of exactly 3.31 km/sec for this purpose, identical with that of the departure. This is plain if the principle of the conservation of energy is considered. Once the ships are in such a satellite orbit, we can take off the crews with *Sirius*-class ships.

"To recapitulate: the trip to Mars and return will necessitate four propulsive maneuvers as follows:

1. Departure from satellite orbit around Earth.
   Velocity change: 3.31 km/sec.
2. Entrance into satellite orbit around Mars.
   Velocity change: 2.01 km/sec.
3. Departure from satellite orbit around Mars.
   Velocity change: 2.01 km/sec.
4. Entrance into satellite orbit around Earth.
   Velocity change: 3.31 km/sec.

"The sum of the velocity changes is therefore 10.64 km/sec.

"We need propellants to change the velocity of a rocket vessel, and their amount determines the size of the ships and their method of construction. Interplanetary filling stations, you'll agree, will be few and far between for some years, so we must carry along all propellants required, down to those for the final maneuver. Since the fuel which will be used in the last maneuvers represents ballast during the earlier ones, more propellant is required during the earlier maneuvers to achieve equal velocity increments.

"Before, however, I get to the actual quantities of propellants involved, I must acquaint you with some points of view which determine the structures of the vessels, and thus significantly affect the computations.

"You will have noted that the four maneuvers described do not involve surface landings, either on Earth or on Mars. This eliminates the determining factor for a surface-launched rocket ship, namely that the thrust must exceed the weight of the ship. We require thrust amounting to only fractions of the weights of the ships, by reason of their weights being constantly sustained by the centrifugal forces generated in their satellite orbits. We can get by with surprisingly small power plants, which will, however, be operated for relatively long periods during the initial maneuvers when large masses are still involved. These masses consist mainly of the propellants reserved for later maneuvers. We propose to use units of no more than 200 metric tons thrust, such as have long been employed in the top stages of *Sirius*-class vessels.

"Secondly: these Mars ships will always operate in a vacuum and that permits us to neglect all forms of streamlining, in contrast to our rocket ships, which must traverse the atmosphere. Nothing even remotely resembling the familiar hull is required. Propellant tankage will be supported in light, tubular, thin-skinned framing. Although the tankage volume, particularly for the first maneuvers, is very large, stresses are never very high, because the unvarying thrust of 200 tons cannot accelerate the ships rapidly when heavy. Therefore, all tanks can be of very light construction.

"In the third place, we shall be able to abandon the multi-stage principle. We shall rather jettison each tank, together with its supporting structure, as the propellants contained are exhausted.

"Fourthly: the tanks, as well as the crew spaces, will be made of thin-walled plastics. This will mean that tank shells and supporting structure will weigh but one seven-hundredth of the weight of the contents. Such tanks are collapsible, and will be freighted up to the orbit of departure all ready for assembly despite their bulk. Operation techniques of this nature were developed for Lunetta, so they are familiar to us.

"Fifthly: our rocket motors will be more efficient owing to their operation in vacuum. They will be more economical of propellants than those working in denser atmospheric layers. This improvement is accounted for by the so-called expansion ratio, which is particularly favorable in vacuum. In vacuum, the gases of combustion do not have to drive out of the nozzles against the back-pressure of the atmosphere, thus we can convert a greater proportion of the energy liberated during combustion into kinetic energy of movement of the gases. Of course, this is also done in the top stages of our present ships, so that their power plants are designed for just these conditions and there's nothing novel about it. The figures used in computing our propellant requirements include an exhaust velocity of 2,800 meters per second. You might be interested in the fact that the first booster of a *Sirius*-class vessel, designed for low altitude, attains an exhaust velocity of 22,550 m/sec.

"And now, I'd like you to bear with me for a moment on the subject of mathematics. I'll cut it as short as I can.

"One of the basic formulas of rocketry states that the velocity increment of a rocket in vacuum and beyond gravity is the product of the exhaust velocity and the natural logarithm of the ratio of initial-to-terminal weight. That sounds a bit more complicated than it really is. It simply means that it is possible to compute directly the initial weight of a rocket vessel before a propulsive maneuver if the change of velocity, the exhaust velocity and the final weight are known. The difference between the weights, of course, represents the propellants expended during the maneuver.

"This allows us to compose in tabular form the propellant requirements of the four maneuvers already discussed. Since the only figure that we can accurately predetermine is the final weight of the ship after the last maneuver, namely 50.5 metric tons, our purpose is best served by commencing with that figure. I will explain later how we reached this figure. Please note that in the following an allowance is made for a velocity reserve of 10% in each of the power maneuvers 2, 3 and 4. For maneuver 1 the computation of the required propellant weight is a bit more complicated because, in view of the extremely low accelerations, we have to take into consideration the climb against the Earth's gravitational field during the power maneuver proper. The velocity reserve for maneuver 1 amounts to but 3.5%, roughly."

Spencer turned to the blackboard and wrote upon it the following tabulation:

Maneuver	Change of Velocity (km/s)	Including Reserve (km/s)	Terminal Weight (tons)	Initial Weight (tons)	Propellant Weight (tons)
4	3.31	3.64	50.5	185	134.5
3	2.01	2.21	186.0	408	222.0
2	2.01	2.21	410.0	902	492.0
1	3.31	3.12	906.0	3,720	2,814.0
TOTAL	10.64	11.48	50.5	3,720	3,662.5

"There it is," he said with a gesture at the board. 3,720 metric tons total initial weight, 3662.5 of which are propellants used in the four maneuvers, is required so that the ship may weigh 50.5 tons when it is all over. The volumetric content of the propellant tankage for the initial maneuver of exit from the orbit of departure must suffice for 2,814 tons. Those tanks will be jettisoned before the second maneuver is undertaken, the latter requiring tankage for 492 tons. This will likewise be jettisoned before departure from the satellite orbit around Mars. 222 tons of propellants suffice for this departure and, when the corresponding tankage has again been disposed of, the final tankage for entering the terminal orbit around Earth need hold but 134.5 tons.

The above will give you a rough idea of the general dimensions of a space ship for a round trip to Mars."

"I have described only a part of the proposed journey, namely that between the two satellite orbits concerned. To effect safe and satisfactory landings on and departure from the surface of Mars poses an entirely novel set of problems. These cannot be solved by the vessels hitherto discussed. It would be worse than spendthrift to land all those propellants on the surface of Mars and then be faced with the tremendous power requirement for overcoming Martian gravity. Not only that, but the construction of the vessels utterly unsuits them to operate in any kind of atmosphere. They have no fuselages or hulls, nor are they winged, and their rocket motors wholly lack the power to lift them from the Martian surface. For that reason, we propose to make our landings in special craft which we shall call "landing boats," the space ships themselves continuing to orbit around Mars at the altitude of 1,000 kilometers. They will complete this orbit in about two hours and twenty six minutes at an orbital velocity of 3.14 km/sec.

"Now, the problem of descending from this orbit to the Martian surface is not dissimilar to that of descending from Lunetta to Earth. That is to say, the landing boat will decrease its velocity from that of its mother ship. This will throw it into an unpowered elliptical path touching the upper layers of the Martian atmosphere after one half of a revolution around the planet. Such a landing boat must of course be equipped with wings and controls permitting it to produce negative lift, in order to force it into a circular path within the atmosphere. The drag will then slow the boat down. The wings will eventually produce the positive lift required for a glide and a normal landing in airplane fashion.

"But a landing of this nature on Mars is accompanied by two novel problems when compared to its terrestrial counterpart. One is due to the Martian atmosphere being, at surface level at least, markedly less dense than that of Earth. This will diminish the obtainable aerodynamic lift. It is indeed fortunate that this drawback is to some extent counterbalanced by the weakness of Martian gravity, which decreases the weight to be supported by the wings. The atmospheric pressure at the surface of Mars is but one-twelfth of that on Earth, or not far from it. This, of course, reduces the load-carrying capacity of any given wing panel to one-twelfth at any given speed close to the surface. But gravity at the surface of Mars is but 38% of that of Earth, and this likewise reduces the weight and the required lift for any given landing boat to 38%.

"This is of great importance in the matter of landing speeds. Landing speed is the lowest speed at which the craft can be held in the air by the application of every possible aerodynamic expedient, such as flaps, slots, extreme angle of attack, etc. The figures indicate that any given landing boat will have just about double the landing speed on Mars that it would have on Earth. That means that our wings for a landing on Mars will have to be about quadruple their normal area, if we propose to maintain the same landing speed as on Earth.

"That, however, is but one half of our problem. Here's the other. When our *Sirius*-class ships return from Lunetta's orbit, we're accustomed to their being almost empty, for their propellants are nearly exhausted by the climb. This makes the ships light on their return to the atmosphere. The conditions of the landing craft for Mars will encounter this situation in reverse, for they will be obliged to later depart from the surface of the planet. To do this they must land with an adequate propellant supply."

Spencer grinned at his audience. "Mr. Hansen has praised the intelligence of the Martians very highly," he said. "But my engineers refuse to work on the basis that they'll have hydrazine and nitric acid in quantity ready for us… So, the landings will inevitably be made with rather heavily loaded craft.

"Of course this handicap is somewhat mitigated by the feeble gravity of Mars. This not only tends to decrease the effect of the mass of the landing boats and to reduce their landing speed, it also facilitates their return to the satellite orbit.

"It requires a terminal velocity of 8.26 km/sec for a *Sirius*-class vessel to reach Lunetta from Earth, and this must be gained in opposition to the powerful gravitation of the Earth. To reach the satellite orbit in which the space ships will be circling around Mars, however, our landing boats will have to be accelerated only to 3.70 km/sec and will be opposed only by that planet's much weaker gravitational field. Even the maneuver of adaptation by which the flight of the landing boats is made to conform to that of the circling space ships requires less power near Mars. 180 m/sec suffices in this case, versus 460 m/sec for a *Sirius*-class vessel approaching Lunetta. Another important factor is given by the fact that the takeoff weights of the landing boats also amount to only 38% of what they would be on Earth, and thus we can lift off an initially much greater mass with a reasonable rocket thrust and impart to it to a very satisfactory initial acceleration. The large area wings which will be required for safe landings must, of course, be abandoned on Mars before departure.

"The combination of advantageous circumstances referred to permits the use of a single-stage rocket to rise from Mars to the satellite orbit. This is in contradistinction to the triple stagers required to solve the analogous problem on Earth.

"But it is not my desire to bore you with too many details about the rather involved problem of the landing boats and their design and construction. Here are their main features in a nutshell: Each boat will have a 200 ton thrust unit, deviating from the conventional type only in so far as its expansion ratio will be somewhat reduced by the not inconsiderable density of the Martian atmosphere. In other words, the gases will not expand down to as low a terminal pressure as in the rocket motors used in our space ships. That means that we shall lose some exhaust velocity; the rocket motors of the boats will achieve exhaust velocities of about 2,600 m/sec versus 2,800 m/sec in vacuum.

"With full tanks, the boats will weigh 200 terrestrial tons at departure from the satellite orbit. This weight will decrease to 185 tons by the expenditure of propellants used to throw them into the elliptical landing path. These 185 tons will effectively amount to only 70 tons in the Martian field of gravity. The landing payload of 12 terrestrial tons will be decreased by 7 before departure from Mars, and both wings and landing gear, which together weigh about 40 terrestrial tons, will be abandoned. This will reduce the takeoff weight on Mars to but 138 terrestrial tons, namely 52.5 Martian tons. Their 200 tons of cut and dried rocket thrust is, therefore, capable of giving them a very respectable acceleration, permitting them to lift five tons of payload back to the satellite orbit of the space ships.

"Let us drop the landing boats and return to the loads the space ships will have to cope with.

"The initial weight of each landing boat, namely 200 tons, must be considered pure payload for those space ships which hauled them into the satellite orbit around Mars. But after the boats have served their purpose of landing and have returned their crews and payloads to the circling and waiting space ships, they have completed their tasks. Their value does not justify the expenditure of the propellants required to return them to Earth. Nor, as a matter of fact, is it practicable to return even their mother ships. Both, therefore, will simply be abandoned in the satellite orbit around Mars. The crew will return to the orbit of departure in the remaining ships, and from that orbit crews and load, if any, will be taken off by the good, old, reliable *Sirius*-class.

"If we assume that the landing boats will be transported to the Martian satellite orbit in mother ships of performance characteristics similar to the space ships designed for the round trip, you may note from my tabulation that the weight of such a space vessel after the second propulsive maneuver, that is, entrance into the Martian orbit, will be 410 tons. The tabulation also shows that 222 tons of propellants are required to depart from the Martian orbit and a further 134.5 tons must be used to enter a satellite orbit around the Earth. Therefore, such of the space ships as are to return home will be obliged to devote an overwhelming portion of their load-carrying capacity at arrival near Mars to propellants for the two homeward bound maneuvers, while these vessels to be abandoned can employ the major portion of the available 410 tons for payload. This reveals the trick by which we are able to get the 200-ton landing boats into Mars's orbit at all, despite our otherwise very tight situation with respect to weight.

"The empty weight of a mother ship on arrival in its Martian satellite orbit is about 15 tons, for it consists only of power plant, empty plastic tanks and a light connecting structure, once it has completed its one-way task. If we subtract the weight of a landing boat, 200 tons, plus the 15 tons from the available 410 tons, we get 195 tons for useful load of various sorts; and believe me, we can use it! So you will easily see that the trick of abandoning some of the space ships near Mars frees us to a large extent from our weight limitations."

"Let me now cover the technical overall planning of the voyage.

"We anticipate that the expedition will consist of seven passenger ships for the round trip, and three cargo vessels to be abandoned in Mars's orbit. Each of the latter will bear a landing boat plus 195 tons of useful load. This gives us a total of three landing boats and 585 tons of cargo in addition to the load carried by the passenger ships. The crews will be 70 in all.

"You have heard that the one-way trip to Mars will require 260 days. To this will be added a stay on Mars of 449 days, which I shall later explain. Let us refer to this as "waiting time," although the expedition will then fulfill its actual purpose. The waiting time will be followed by the return trip which will also require 260 days.

"Obviously the expedition as a whole can draw on the supply of the three cargo vessels during the trip out and during the waiting time. On the return voyage, the passenger vessels, bearing the personnel and whatever Martian cargo may be appropriate, will be on their own.

"This enables us to determine the payload requirements for the passenger ships. Each of the seven ships will carry a crew of ten on the way home. Those ten people have to be provided with food, drink and utility water, as well as breathing oxygen, for 260 days. Adding all these loads to the empty weight of the ship proper, we come to a total of 41.5 tons. Now I told you that, in effect, we based our calculations on a terminal weight of each passenger ship of 50.5 tons after completion of the last propulsive maneuver. So we still have a leeway of 9 tons per ship, or a total of 63 tons, which we have so far made no attempt to assign specifically. There are, of course, many uses for this reserve which are desirable although not vital. For example, busy bees will be extremely convenient, not only for visiting between ships, but also in the event of one or another ship getting into difficulties and requiring help. Long distance radio, borne on the trip out by the cargo vessels, could be taken over by one of the passenger ships for the run home. I can assure you that those 63 tons of available capacity for the trip back will gradually be filled up with various things as our plans and program take more definite shape. The final decision on the utilization of this reserve may be left to the discretion of the Command of the expedition.

"The situation is envisaged as being even somewhat more favorable than I have here represented to you. We may well assume that accurate navigation will render the 10% propellant reserve after propulsive maneuvers 2, 3 and 4 somewhat excessive. But we cannot exactly predict just how great this excess will be after each application of power and the corrective maneuvers that may follow it. Hence we propose to equip both passenger and cargo vessels with four reserve propellant storage tanks, each of 15 cubic meters capacity. Prior to any new maneuver, when it is desired to jettison the tankage of the previous one, any remaining liquid can be drained into the reserve tanks.

"During the earlier power applications, when large quantities of propellants are involved, accurate work on the part of the navigators and the control equipment makes possible the saving of very considerable quantities of propellants. If these savings be later applied, when the ships are relatively light, they mean large reserves for load carrying capacity or for changing velocity. It will largely be up to the Command of the expedition to apply these reserves at the times and in the manners which will do the most good, enabling them to choose whether they will bring back more payloads or save the reserves against possible unexpectedly large velocity change requirements.

"Let me now discuss the payload distribution of the cargo vessels. You know that, aside from the landing boats, there are still available some 195 tons aboard each vessel. We shall have to deduct from this the weight of the oxygen, water and food required for the voyage out and the waiting time together, 709 days. Each ship will require 25 tons of oxygen in liquid form, 35 tons of water and 20 tons of food. In addition, there's a reserve of 20 tons of water in the event that one entire cargo ship should be lost; but we still have 95 tons of available capacity. It would be a long task to convey to you all the articles which will comprise these thrice 95 tons, but here are the most important:

- Two heavy-duty radio sets for communication between the expedition and Lunetta.
- A large reflecting telescope with which to reconnoiter the surface of Mars from the satellite orbit. Such reconnoitering is a sine qua non before an attempt is made at landing.
- Three complete spare rocket power plants, each being applicable to either passenger or cargo vessels.
- Two spare tanks of each size, in the event of any of the regular ones springing a serious leak, will be kept ready at all times together with a lavish stock of all sorts of spares. Our damage control and repair equipment will even include two small lathes.
- There will be gravity cells, the busy bees for intership communication, as well as other things…"

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"And now, gentlemen, I must touch upon another point in my discussion – the timing of the expedition. It is, perhaps, the most critical problem of space shipping, and particularly so for a voyage through the solar system.

"We would profit but little by attaining Mars' orbit unless he is at the right time at the point where we intercept it. The same applies to meeting the Earth amid the vastnesses of space on the return trip. Let me now present the timing problem, in somewhat simplified guise, by assuming that the orbits of both Earth and Mars are circular. In actuality, of course, both orbits are elliptical – that of Mars in particular displaying a very considerable eccentricity – and when we perform the actual computations, this is, of course, considered.

"Mars makes a complete, 360° circle around the Sun in 687 days, equivalent to a segment of arc of 0.524° per day. Earth, on the contrary, takes only 365 days for a complete encirclement of the Sun and therefore accomplishes 0.987° in a single day. In view of the 260 day length of the trip to Mars, the latter must, at the moment of departure, be at a point 260 times 0.524° – 136° – ahead of the intersection of the path of the ships with the orbit. When observed from a hypothetical point on the Sun, this intersection will lie 180° behind the point of exit of the ship's elliptical path from the terrestrial orbit. Hence Mars, at the moment of departure, must be 180° minus 136° equals 44° ahead of the Earth in his orbit.

"Therefore, a departure for Mars on that type of elliptical path becomes a possibility only when Mars – as seen from the Sun – is 44° ahead of the Earth.

"During the outward voyage, the Earth will travel through 0.987 times 260° – 256° of arc. Once the ships have completed their full semi-ellipse of 180° and have arrived at Mars, the Earth – as seen from the Sun – will have advanced to 76° ahead of Mars.

"This gives us the key to the timing of the return voyage. Since the travel time is the same, it is apparent that at the moment of departure from Mars, Earth must be momentarily located 256° behind the intersection of the ellipse of return with her own orbit. That is to say, she must be at 256° minus 180° behind Mars, or 76°.

"Thus we have the following question with respect to how long the necessary waiting time on Mars will be: when the ships arrive at Mars, the Earth will be – as seen from the Sun – 76 degrees ahead of Mars, and the return cannot be undertaken until she is 76 degrees behind him. How long will it take for this condition to establish itself?

"The computation is relatively simple. On her shorter, inner orbit, Earth moves more rapidly in arc, and must cover 360 degrees minus twice 76, or 208 degrees with respect to Mars. The difference of movement in arc of the two planets is 0.987 minus 0.524 or 0.463

degrees per day. That is, Earth gains on Mars 0.463° each 24 hours. Thus 208° divided by 0.463 equals 449, the length of our waiting time in days."

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"Before I finish, I want to give you some idea of the extent of the financial and other efforts, which the expedition will require. There will be manifold special research and development operations, but the main effort will consist in freighting the ships, supplies and propellants, into the satellite orbit of departure. At this time, we have only a relatively modest number of *Sirius*-class vessels adapted to this purpose. Each requires 5,583, almost 5,600, tons of propellants, and can transport 25 tons of payload into the orbit of Lunetta. You've been shown that the 10 vessels destined for Mars will weigh 3,720 tons, a total of 37,200 tons of payload up to the satellite orbit of departure. That means 1,490 trips.

"The situation begins to appear somewhat less startling, however, if we consider the following factors. It is usual for a *Sirius*-class vessel to leave behind in Lunetta about eight tons of the reserve propellants she carries besides the regulation cargo. Furthermore, since our ellipse of departure lies in the ecliptic, ascent to it will be somewhat more economical of propellants than the trip to Lunetta, because we can utilize for the climb a greater component of the circumferential velocity of the Earth. This, we believe, will permit each shipload on the ferry trips to deposit some six additional tons of propellants in the orbit of departure. Thus we anticipate that each *Sirius*-class ferry will leave there either 39 tons of propellants, or solid cargo amounting to 25 tons, plus 14 tons of residual propellants. This would reduce the number of ferry trips to about 950.

"Each ferry flight will, however, consume 5,600 tons of propellants or thereabouts – a total of 5,320,000 tons – which is the product of 950 and 5,600. It would take 443 tank steamers, each of 12,000 tons capacity, to hold this amount. This is about the equivalent of the fuel for six months in one of the theaters of World War III.

"Both the Mars vessels and the *Sirius*-class ferries will use highly concentrated hydrazine and nitric acid as propellants. These chemicals are produced by the suppliers of the Space Forces at an average price of about $100.00 per ton. The quantity envisaged will presumably necessitate some plant expansion. Thus the cost of the propellants for the ferry trips to the orbit of departure will be around $500 million. The same item with respect to the Mars vessels and their landing boats is almost negligible in comparison; the cost will be but three and a half million dollars, roughly.

"Just about one fourth of the entire two billion dollars will be expended in propellants for the ferry flights! We believe that the remaining three quarters will suffice for the solution of the other problems."

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Spencer closed his speech abruptly. Sitting down on a chair in front of the witness box, he produced his cigar case and lit one of his villainous stogies after his usual elaborate preparations. Not a sound came from his listeners. Even the Mars Committee held its peace.

After some time, Perucci's white head rose into prominence as its owner addressed Spencer with a strong Italian accent.

"Mr. Spencer," he remarked, "please accept the gratitude of the committee from my lips. You have certainly cleared many matters in our minds. Many of us, I know, felt the same way about it as I, but you have removed many doubts and explained many hitherto moot points. Let us now proceed to a question session, for I know that not only I, but many other members of the committee have much to ask, judging from the busy pencils I saw during your address. I shall begin with one or two questions of my own.

"If I'm right, you stated that the aphelion of the elliptical path of a ship approaching Mars would be located just short of the orbit of Mars instead of right on it. This, I understand, is to prevent the ship from crashing vertically to the surface of the planet, overhauling it from astern. Rather the ship should be drawn into a curved hyperbolic path by the gravitation of Mars. Then when it approaches closest to the planet at the vertex of this hyperbola, the ship's velocity is to be slowed until it corresponds to the orbital velocity appropriate to its location. Have I understood you aright so far?"

"That's correct, Senator."

"There's something about it which I do not quite grasp. Apparently you have assumed the ellipse of interplanetary travel to result exclusively from the combined effect of the motion imparted to the ship in the form of kinetic energy and the gravitation of the Sun until such time as the ship approaches the field of gravity of Mars. But it would seem that the ensuing hyperbolic flight path is produced by Mars' gravitation alone. The orbit of Mars itself is certainly determined by the gravitation of the Sun, and so the hyperbolic flight path under discussion must, in some way, also be affected by solar gravity, even within the sphere of Martian gravity?"

"You're quite correct, sir," answered Spencer. "Perhaps I oversimplified my method of presentation on this detail to some extent, as also on other matters. In actuality, the business of entering a satellite orbit around Mars is quite a bit more involved than I have pictured it, and gravitation, both solar and Martian, must be used in the computations. Poinoare, a French mathematician, evolved the mathematical methods he used when he solved the so-called "probleme restraint du probleme des trois corps." The same applies, furthermore, not only to the entry into a satellite orbit around Mars, but also to all four maneuvers and to unpowered interplanetary coasting, insofar as these take place not too remote from Mars or the Earth. The gravitation of our Moon adds a few complications to the mathematical aspect close to the Earth. None of these effects are quantitatively very large, nor do they affect the figures I quoted to any material extent; nonetheless, they must be taken into account in working out the navigation, both prior to and during the voyage."

"That brings up another question," said Perucci. "According to your drawing, the intersection of the ellipse of the voyage and the Martian orbit is at about 377 million kilometers from the point of departure from the Earth's orbit. Then you propose to effect the manpower of adaptation at Mars in such manner that the resulting satellite orbit shall be 1,000 kilometers distant from the surface. Should your departure data at the termination of the first thrust maneuver be even minutely in error as to velocity or direction, you might easily be many thousands or even millions of kilometers off when you approach the orbit of Mars. I can imagine that navigation will have to be kept current with extreme accuracy and that any errors will be subject to running corrections."

"That's quite so," replied Spencer. "But there's plenty of time enroute for meticulous navigation. Throughout the 260 days of the voyage there will be constant checks on the position of the ships and any aberrations from the predetermined track will be computed and corrected. As I informed you, there is available a certain propellant reserve, and this can be used for any corrective maneuver found necessary."

From the serried ranks of the committee an elderly gentleman wearing nose glasses rose and inquired how positions could be plotted in space.

"That's relatively simple," answered Spencer waving his cheroot. "The navigating officer will simply take the stadimetric angle between any planet in the plane of the ecliptic and some star in the same plane. Since the voyage takes place in that plane and since the Ephemeris gives the positions of both planets and stars, this angle will immediately fix the position of the ship. Our experienced spacemen call this procedure the 'determination of planetary parallax.' The same measurement may be taken perpendicular to the plane of the ecliptic by finding the angle between some fixed star and a planet when a line drawn between them cuts the plane of the ecliptic at right angles. This will also give a check on whether the vessel has strayed from the plane of the ecliptic, and the data for the appropriate corrective maneuver."

Spencer looked around for further questioners, whereupon a spare, gray man looking somewhat like a retired cowman spoke up. "You mentioned that food, water and oxygen for the crews is an important factor in the cargo requirement of your space ships. That is quite plausible in the face of the long duration of the voyage. Can you tell us something about the rations on which your weight calculations are based?"

"With pleasure," said Spencer. "I hope you will excuse me if I don't have all these figures in my head, so let me just look into my papers."

He sank his ham-like paws into his briefcase and, after some digging, produced a folder.

"Now let's see," he said, leafing through the pages. "First of all, we're allowing to each of the 70 men 120 kilograms for personal baggage. This baggage included, we reckon that all in all, crew weight will be 14 metric tons. This makes two tons apiece for each of the seven returning passenger ships.

Each man will require 1.235 kg of breathing oxygen per day on the average, as has been confirmed by practical experience in Lunetta. Since both on the outbound leg of the voyage and during the waiting time oxygen can be drawn from the cargo vessels, the oxygen supply of the passenger ships can be limited to the needs of the return trip, 260 days. Each of the passenger ships will therefore need for its crew of ten an absolute minimum of 10 times 1.235 times 260, equals 3,220 kg of oxygen. Each ship will actually be provided with 5 tons.

"Water will be needed to the extent of 2 kg per person per day. For the passenger ships, that's twice 10 times 260, equals 5,200 kg. We're providing 5.5 tons. We're also supplying an extra 2 tons of non-potable water. It will be stored in a special system and used for cleaning purposes and the like. Oddly enough, this utility water will increase daily as the result of water recuperated from the air-drying plant. This recuperation will amount to about 1.62 kg per person per day. It comes from perspiration and moisture in the breath of the personnel, and there's no reason at all why it cannot be employed for utility purposes, after thorough treatment, of course. Thus the utility water will increase during the return trip to 6.2 tons from the original 2 tons. Of course, the drinking supply will be correspondingly diminished.

"Where food's concerned, we reckon with a daily consumption per person of 1.2 kg – that's about Army standard – and each passenger vessel will require about 3.12 tons of food as a minimum. We shall provide 3.5 tons. Food containers will weigh around one ton, making 4.5 tons in all.

"When all this is added up, each of the seven passengers ships will haul 2 tons of payload composed of the crew and their personal belongings, 5 tons of oxygen, 5.5 tons of potable water, 2 tons of utility water and 4.5 tons of food, or 19 tons altogether.

"In this connection let me give you the remaining figures affecting the terminal weight of the passenger ships. Personnel spaces of each ship will be spherical and have an empty weight of 3 tons, more or less. Furnishing and fittings will raise this to around 4 tons. Air and water recuperation equipment calls for another 3 tons; navigational and course-keeping gear, 2 tons; while the electrical generating plant weighs another 2 tons. That's 30 tons altogether.

"Now, the rocket power plant, as presently used in the top stage of the *Sirius*-class, weighs almost exactly 10 tons, and we expect to use it without alteration. This includes rocket motor, gas turbine-driven propellant pumps, and gas generator for the turbine, as well as valves, tubing and all the various components. The tanks for the final thrust maneuver weigh a scant half-ton and the required structure, after jettisoning the other tanks, weighs not quite one ton. And so we reach a total empty weight for each passenger vessel of 41.5 tons, including the entire useful load. You will recall that this gives us a leeway of 9 tons per ship, since we actually based all performance calculations on a terminal weight of 50.5 tons."

Spencer seated himself once more and looked expectantly at the cowman. "Seems all right to me," said the latter. "I get the idea that you've gone far enough into this thing to start right in building your strange gadgets the moment the appropriation's through. And I guess it wouldn't be long before the whole outfit would go busting off into space..."

Spencer hurriedly got to his feet.

"Hold on a moment, sir" he protested solemnly. "It's not as simple as that. When you get down to the details of a job of this kind, it is so involved and varied that it will call for years of work on the part of a veritable army of scientists and engineers, not to mention production men in every imaginable field. That will have to be gone through before we can even dream of launching the convoy into space.

"Let us not deceive ourselves, gentlemen. There are enormous problems ahead of us. It will be much like an attempt to climb some very high and rugged mountain. Often we shall see what we believe to be its summit clearly before us, not far away. But when we reach it, we shall find that it is not the true summit and that a strenuous climb still lies ahead.

"All I had hoped to accomplish today was to convince you that it is even now technically possible to fly to Mars using means, materials and methods which are presently available to us. In no way do I desire to minimize the difficulties facing the project. But I am absolutely certain that if our work is begun with adequate facilities, Mars will soon conceal no more mysteries than Moscow."

Chapter 7
What of Life on Other Planets

When Spencer had finished, not a man in the Mars Committee doubted that a voyage to Mars was technically possible, and the effect of his presentation was a lasting one. But in the public press, and even among the members of the committee, there were those who vociferously questioned the value of the objectives of the undertaking, and furiously opposed the expenditure of the vast sums which the enterprise could not fail to demand. After acrid oratory it was finally determined to interview Professor Hansen, the foremost astronomer of the day. His opinion that Mars was inhabited by creatures of intelligence was important, and likewise, what he thought would be encountered by an expedition after landing upon the surface of the distant planet was valued.

The whole city of New York was in a turmoil of anticipation when Hansen appeared before the Mars Committee. As he left his car, at the door of the great cupola of the Capital of the World in Greenwich, reporters by the hundred swarmed around him, vainly seeking advance information as to his testimony.

After he had taken the stand, he looked solemnly at his hearers and began.

"Before touching the practical phase of the astronomical aspect of Operation Mars, I feel it my duty to pay tribute to a great man. For several decades, the turn of a forested peak near Flagstaff, Arizona, has covered all that was mortal of Percival Lowell. Beside his grave rises his beloved observatory where, over eighty years ago, he pronounced to the world certain truths, which have now been confirmed by the perfecting of our methods of research. He had seen almost all of it through the eyes of genius, his gift of observation and his ability to combine the seen with the felt. By fellow observers he was often ridiculed because they, lacking his keen eye and even keener perceptiveness, could discover no confirmation of the vital findings at which he had arrived after many years of laborious work. It would seem that his very eyes had been so trained by the labor of the years that they could clearly discern what others thought too dim for credence.

"You, gentlemen, might well open Percival Lowell's books written in 1903 and 1905 and in those musty tomes find everything which I propose to lay before you today. In point of fact, all I have to tell you is that photographs and measurements taken from the Lunetta observatory, under the direction of its distinguished chief observer, Dr. Hans Bergmann, fully confirm all the theories advanced many years ago by Percival Lowell.

"Astronomers today generally hold that the origin of most stars is as follows:

"Empty space no longer is thought to be really empty. Rather is it believed permeated with cosmic dust. The distribution of this dust is so unbelievably fine that it does not appreciably affect either the passage of light or the movement of the stars.

"In the illimitable reaches of space between the fixed stars, this dust is subject to radiation pressure from the surrounding heavenly bodies. As eons pass, the combined action of some of the closer and powerfully radiating stars, omnilaterally surrounding any given sidereal space, drives this dust together and condenses it into the shape of the well-known cosmic clouds. As the particles of dust are heaped together, they develop a common center of gravity, to which other particles are attracted with increasing velocity. Such a cosmic cloud finally collapses on itself with protean violence and the sudden deceleration of the particles manifests itself in incredibly high temperatures. This phenomenon becomes visible as a new star in the heavens. We have reason to believe that this is the way in which our Sun came into being.

"Hitherto, there has been no completely satisfactory hypothesis as to the creation of the planets in the solar system. Theory after theory has been advanced, only to be found wanting in one respect or another. The presently favored explanation postulates that the Sun at one time was circled by a very large satellite, with which it formed a double star. Then it is thought that some wandering star appeared from the depths of space and collided with the satellite after entering the Sun's gravitational field. Quite possibly the planets as we know them are the remnants of the incandescent wreckage of that sidereal cataclysm.

"The molten character of the new-born planets allowed them to assume spherical shapes under the influence of the gravity of their own mass. They cooled more or less rapidly, according to their magnitudes, the larger ones remaining hot longer. Heavier components concentrated in the center, forming a core, while the lighter, gaseous ones surrounded them as atmosphere. The core of a planet would first become cool at the surface, due to the continuous loss of heat by radiation into space. This formed a crust while the liquid center shrank more and more. Then the crust, already solidified, became too large for the shrinking core and began to develop folds and crevices, exactly as does the skin of a drying apple. Mountains and valleys were thus formed, and basins for seas and lakes. In these, water collected, precipitated by the cooling of the vapor in the atmosphere.

"A heavy, impenetrable layer of clouds still hovered above the permanent gloaming of the surface. This shielded off any direct sunlight and reduced the loss of heat during the nights.

"Our planet was like this when life made its first appearance, and the experience of Mars must have been the same, although it seems to have taken place sooner, in view of Mars' smaller size. For his smaller size contributed to his cooling process occurring more rapidly than ours.

"Our scientists no longer believe that life came to Earth in the form of bacteria or living cells from somewhere in space. Meteorites could hardly have brought such life, for they glow red-hot when they enter the atmosphere and would kill any germs. Radiation pressure from the Sun might have brought life germs, but from where? Hardly from its incandescent surface…

"So we are forced to believe that our life originated here.

"When the water had cooled below its boiling point, protoplasm appeared within it. The reason why it did, only the Creator knows, but protoplasm is the foundation of what we call life. At first it was the lowest, monocellular beings which were protected and given the uniform conditions and food they required by the naturally thermostatic oceans. Then life evolved from monocellular creatures into the incredible variety of marine plants and animals – algae, trilobites, fish, and marine reptiles.

Water, however, is a poor medium for the development of the higher forms of life, ideal as it may be for its generation in primitive form. Fish, for example, deposit their thousands of eggs in it and leave their posterity to the tender mercies of chance. In the higher forms of life, the parents must supervise the growth of their young, must warn them of dangers and instruct them.

"And so we may visualize how one fine day, some reptile crawled out of the water and established a new home on terra firma. The great lizards of the Saurian period originated in the development of higher forms of life brought about by this step to solid ground. But the saurians later became extinct and bequeathed the mammals supremacy on dry land.

"Life out of water, however, brought combat with the asperity of nature. The water vapor content of the atmosphere had decreased and this caused temperatures varying between roasting sunlit days and frigid starlit nights. As the battle against the increasing obstacles grew fiercer, nature developed her most powerful weapon, intelligence. This led to the mastery of man.

"Intelligence enabled man to inhabit regions entirely unsuited to his bodily constitution. Had he not invented such things as clothing and housing, and discovered the power of fire, he would never have been able to extend his dominion far into the icy Northern latitudes. Without his intelligence and these fruits of his creative imagination, he would miserably have perished there."

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"Now," Hansen continued, "let us take a look at Mars.

"Here is an aging planet, much further along his life's path than we. The protecting clouds of his earlier days are gone very nearly entirely. His oceans have dried up. His mountains have eroded away. Five-eighths of his area is bare desert with no signs of fruitfulness throughout the Martian year. The temperature variations between day and night are tremendous according to our standards. This comes from the almost total absence of protective cloud covering and the fact that the Martian atmosphere has become as tenuous as our own stratosphere throughout the passage of thousands of years. A few figures will be illuminating. Near the Martian equator, sunrise temperatures are of the order of -20° C; near noon they are from 20 to 30° C above freezing; and at sunrise they fall to zero. During the night they go as low as -30° C.

"Gentlemen, even the Winter temperature range in my home state of New Mexico pales into insignificance beside that sort of variation! It's common knowledge that it takes a very smart man to survive in New Mexico, so you can figure out for yourselves how smart the Martians must be..."

A roar of laughter at this sally burst from Hansen's hearers and several reporters elbowed their way to the door in order that the world might know of Professor Hansen's culminating bit of evidence for the existence of intelligence on Mars.

The Chairman banged his gavel for several minutes before he could silence the guffaws which burst from the erstwhile solemn listeners, and when he at length succeeded, Hansen continued. "We have reason to believe that Mars once had oceans like ours. Certain wide, dark spaces lie at a lower level that the surrounding deserts. This suggests that they may have been oceanic basins at one time. Hence we have the same basic conditions for a parallel development of the simpler forms of life on Mars as upon Earth. There can be no doubt that, as the seas receded, life moved likewise onto solid ground. Conditions grew more and more difficult, thus stimulating nature mightily to develop intelligence as a means of protecting life.

"It seems reasonable that on Mars, too, only one species of living creature can wear the crown of creation. If this is so, the history of Mars should reveal that conditions there favored the creation of a community of living creatures which dominated the planet after man's fashion here.

"Let us consider the evidence on the face of Mars which tells us that such creatures once existed and that they still exist. We cannot, of course, observe them in person, but their intelligence has left traces upon the surface of their smaller world, and these traces we believe we can interpret.

"There is a dense, spider-web-like tracing of dark lines all over the surface of Mars. Giovanni Schiaparelli, the Italian astronomer who first discovered them, called them "canals." Until quite recently, this method of designation has caused much confusion, for the general public concluded that it referred to canals in the common meaning of navigable waterways. The idea is wholly erroneous and I would ask you to consider the word "canal" in the Martian sense to be but a label for those peculiar lines.

"All these canals are not visible simultaneously, for, as we shall see, they are subject to marked seasonal changes. So far, 437 of these lines have been definitely catalogued. They may be from five to fifteen miles wide and from 200 to 3,000 miles long. The longest known to us is called Eumenidus-Orcus and extends 3,450 miles from a region known as Phoenix Lake to a large, accurately triangular zone named Trivium Charontis.

"The system of canals exhibits certain peculiarities which I shall now recount for you. First: all canals, long or short, are accurate great circles. That is, they follow the shortest distance between their terminal points.

"Second: the aspect of the canals is intimately connected with the seasons on the planet. When the Antarctic snow cap begins to melt in springtime, a blue-green zone develops around its white edges. From this the canals seem slowly to grow towards the Martian equator. Such canals as were invisible or inconspicuous increase in breadth and definition and then stand out in stronger relief against the ochre-brown or reddish deserts they traverse. As the Spring advances in the Southern hemisphere, this widening of the canals extends over further towards the equator. Our observations have timed the advance from the 72nd parallel of Martian latitude to the equator at 52 days. The distance is 2,650 miles. The rate of advance is remarkably uniform, namely 51 miles per day, or 2.1 mph.

"Third: the widening of the canals extends across the equator, far into the Northern hemisphere, and is accompanied by a change of color of good-sized areas from matte to lush blue-green. These areas are frequently geometrically shaped and the change requires only a few days.

"Fourth: Six months later, the same phenomenon is observed in the other hemisphere. Remember, gentlemen – Mars is in a continuous drought, and water is as valuable as in our Sahara…

"We cannot but conclude, with Lowell, that the system of canals is the creation, the mighty creation, of beings of intelligence. Its purpose is to utilize the water of the polar melts for rendering fruitful the arid wastes of the planet. We hold that the blue-green areas I mentioned are not open water, but zones of vegetation which spring into bloom when water flows through the "canals" from the poles. The canals themselves, as we see them through telescopes, are strips of vegetation whose flowering and withering is caused by water or lack of it in the subterranean water courses below them. Nor does the low atmospheric pressure of Mars permit us to assume that water could reach the equator at all, unless the veins of water lay below ground. Otherwise it would evaporate during its long journey.

"You will have noticed that there is a remarkable distinction between Springtime on Earth and on Mars. As seen from Lunetta, Earth's polar snow cap recedes gradually, followed by the growth of the surrounding vegetation towards the Pole. On Mars, however, vegetation begins to grow in the melting zones around the Pole and then extends gradually equatorwards.

"As you know, the awakening of vegetation from its hibernal sleep requires warmth and water. On Earth, water is constantly available everywhere except in deserts, and the plants are brought to life by the extension of the temperate heat belt towards the Poles during Springtime. In the cloudless atmosphere of Mars, daytime temperatures rise more rapidly in Spring that do our own, but the plants cannot react to them until the irrigation system built by the Martians provides the necessary water.

"There is ample evidence to prove that this system is definitely artificial, aside from the mathematical precision of its layout. For instance, it has been disproved that the equatorward movement of the water results from centrifugal force generated by the rotation of the planet on its axis; such force would be zero at the poles and maximum at the equator, but it cannot explain how the water extends beyond the equatorial line when coming from either pole. Likewise, Mars is an oblate spheroid with flattened poles, like Earth. His diameter is 35 kilometers less at the poles than at the equator. Thus water would be forced to run uphill 17 kilometers on its journey from either pole to the equator. On the other hand, we know that a plumb bob hangs exactly vertical to the plane of the local horizon at any latitude on any planetary oblate spheroid. There is, therefore, no possible explanation of the movement of the water through the canals of Mars except that it is artificially pumped!

"We can estimate from other data that the amount of water frozen each year at the polar caps is about one one-hundred-thousandth of the water on our Earth. That is approximately twenty times the content of Lake Erie. How many millions of horsepower it must take to pump such an enormous quantity through the canal system, twice yearly, for thousands of miles, I'll leave to your imagination, but the pumping stations must be very powerful…

"It appears to me that three basic conclusions may be drawn from these facts. First: Mars must be inhabited by intelligent beings who have built a tremendous irrigation system over their whole globe. They keep it constantly in operation, and in order to do so, they must have a political organization of a global nature and be subject to some central authority.

Second: they equal us technologically, and have perhaps surpassed us, or they could have built no such system of canals and pumping stations.

Third: Mars is an aging planet and his inhabitants can keep alive only by the exertion of extreme intelligence. They would not have survived at all, had they not applied that intelligence, their technological capabilities, and their strength to a far greater degree than have we."

"Of course you'll want me to tell you what these creatures look like, in view of my predictions that they at least equal us in intelligence and may be immeasurably ahead of us in knowledge and capabilities.

"But here, gentlemen, you will ask in vain.

"We know that the atmospheric sheath of Mars has become thinner and thinner with the passing years and today has but a fraction of the pressure of our terrestrial air. Our space men will be obliged to wear pressure suits while on Mars, and would suffocate without artificial respiration. From that we may deduce that Martians are differently constituted. But of their actual appearance we are totally ignorant. They might be mammals with specialized lungs… Could it be that some form of gigantic insects or reptiles have performed those technological miracles? We cannot tell.

"The mathematical precision of the layout of the canals must fill us with awe. But does not the bee produce the comb with marvelous mathematical precision, storing it with food against the winter? And is not the hive an example of social cooperation which permits amazing communal achievement along technological lines?

"We are baffled by the problem of how intelligent beings survive in the thin Martian air and among his violent temperature variations. But here on our own Earth, there are animals which marvelously survive under conditions lethal to humans. May not frogs become frozen in the ice all Winter long, only to awaken unharmed when Spring comes? Do not fish of the profoundest ocean deeps live under a pressure of hundreds of atmospheres, dying when brought to the surface?

"We must believe that God's will that there should be life in nature cannot easily be frustrated by physical obstacles. And when He wills that the characteristics with which He has endowed them shall no longer withstand the environment which His will imposes upon them, He selects special favorites for the gift of intelligence with which to alter their environment.

"No, gentlemen, it would be fallacious to assume that we sentient begins stand alone in the universe; nor should we arrogate to our Earth the distinction of being the only planet to bear higher forms of life.

"So let us reach out! Let us fare forth to seek our fellow beings in the depth of space! Perhaps we too can learn from God's creatures on our sister planet. For on its countenance are clearly written the symbols of creative and intelligent works wrought by them…"

Chapter 8
The Mission of Space Travel

A number of speakers were to come before the Mars Committee after Spencer and Hansen had had their day. Holt was required to outline his plans for preparing the organization and Lussigny went deeply into the subject of radio communications. Dick Peyton, Chief Designer of United Spacecraft, told them many of the details of the construction of the Mars vessels. Finally, Professor Ashley related what the World Research Board proposed to undertake in the matter of preparatory research.

After long study and debate the Mars Committee unanimously concluded that Operation Mars presented no insuperable difficulties to an energetic and determined attack. It proclaimed without a dissenting voice that it believed that the enormous sums of money required would indeed be well spent for the general benefit of humanity. Not one of their signatures was missing on the favorable report in which they advocated consideration of the Mars Exploration Act by the World Senate and House.

It was on the floor of the Senate that the initial victory of the proponents of Operation Mars proved to be but a first battle in what was to be a lengthly war, for both Senate and House were composed of a congeries of people whose primary interests lay anywhere else rather than in a costly excursion into deep space. A very considerable number of the delegates held their positions below the vaulted dome in Connecticut, with the avowed intention of devoting their full time and effort to ameliorating the lot of their particular constituents, and to the neglect of all else.

All too many were obsessed with the desire to cater exclusively to such feelings, desires and needs as might animate those who had elected them. Narrow, provincial points of view frequently dominated the thoughts of those whose votes held away over the welfare of all the inhabitants of Earth. Nor were such men backward about emphasizing what they felt to be their duties along such lines.

Countless regions still suffered dreadfully from the aftermath of the ultimate war. Wounds suffered in direct combat still bled copiously and even the quasi-neutrals in many cases existed precariously at the very brink of an economic precipice, created by the almost complete stagnation of world trade which had accompanied the destructive conflict. It was small wonder that the United Congress had become a sounding board for the plaints of those impoverished countries whose primary objective it was to pick the pockets of the more opulent.

The price exacted of the victors for a global democratic government had indeed been high, for it was not long before the poor but populous regions of South and East Asia began to throw their numerically superior representatives into the scales within the great, domed structure of the Congressional building. More and more the scales inclined towards the indigent populations and to the detriment of the erstwhile Western powers. The 800 million voters in India and China weighed heavily behind the efforts of their representatives to tap the remaining resources of the West and to ameliorate the sufferings caused by the civil wars which had torn them during the global conflict. With oriental guile they set about the task of piping a flood of gold and goods into their insatiable maws.

When Operation Mars reached the Congress it was promptly projected into the maelstrom of these conflicting interests. The appropriation of two billion dollars called for by President Vandenbosch represented an outlay which loomed large beside the funds for the World Recovery Plan, to which America was contributing the largest part. And so it was not long before a block of great power was formed in opposition to Operation Mars. It was composed, significantly enough, of representatives of regions from which few, if any, contributions to it could be expected.

The leader and mouthpiece of the opposition was a Chinese Senator named Chi-Lau-Hen. The dignity and pomposity of his appearance in no wise obstructed the cunning machinations he aimed at the obliteration of Operation Mars. Chi-Lau-Hen meticulously and skillfully avoided any mention of the financial aspect in his speeches on the floor, or when he buttonholed prospective supporters of his stand in private. Rather would he quote impressively from the writings of Buddha and Confucius, emphasizing their admonitions towards economy and salutary moderation in all things. With oriental adroitness, he warned against the dangers of passionately plunging into the unknown. Chi-Lau-Hen explained to all and sundry how the past war, with its horrors, might have been avoided if only mankind had abjured the "intoxication" of dynamic ideals and had devoted itself to self-sufficient, God-fearing contemplation of the Karma. He was wont to fortify his arguments with references to "eternal China" and "timeless India." Solemnly he recounted how often both had been raided throughout history by belligerent and dynamic neighbors, and how the invaders had inevitably succumbed and been absorbed by non-resistance and the very inertia of their almost stoic inhabitants. "Do not, I beg of you, violate the Tao!" was the culmination of his great speech before the Senate, "God is eternally on the side of those who serve Him and are subservient to Him on the land where He created them. In His anger He will surely castigate men who, with impious hands, would reach into His Heavens!"

Rhetorical appeals of such fervor did not go unheeded. Chi-Lau-Hen struck a chord in the very hearts of Chinese and Indian voters, where it resounded ever louder and deeper. On such a high plane did his verbal crusade proceed that the actual critical aspect, the procurement of funds, was completely obscured form view. It was not long before the powerful Asiatic block in the Senate stood united in purposeful and almost devotional opposition to further exploration of space. Even in the weary and tax-ridden Western countries there were those to whom Chi-Lau-Hen's blandishments were not without a profound appeal.

The supporters of the measure, those on the other side of the fence, were drawn from very heterogeneous groups.

Scientists were almost unanimously in favor of the plan, for almost every man or woman of science could not but be titillated by the almost illimitable extension of research in many fields that such a grandiose scheme would engender. The Congress was literally flooded with pleas and challenges from the men of science to show itself equal to the great task before it. The Space Forces had launched a campaign of publicity which united behind the scientists a very large section of the forward-looking and progressive public.

The press of the world in general, with all its power to mold public opinion, espoused the cause of Operation Mars. Whether or not the prospect of future headlines motivated much editorial thought did not affect the energy with which they supported the crusade.

It was in industrial circles that the strongest proponents of Operation Mars made their appearance, for many were the producers of armaments and related products who found themselves with plant facilities swollen by the war demand and now facing the almost hopeless problems of conversion to peaceful production. The military organization maintained by the World Government for police purposes more than sufficed to suppress any internecine strife which could be humanly foreseen, but it was still infinitesimal in comparison to the great armies, fleets, air and space forces created and supplied by the huge munitions plants during the war. Many of such plants were so highly specialized that conversion to the manufacture of such things as vacuum cleaners and bath tubs proved literally impossible. Plants so specialized viewed Operation Mars with the billions to be expended therein as a God-sent substitute for the armament contracts without which they could not hope to maintain the technical levels and the skills they had so long labored to achieve.

As diverse as were the motives of the proponents of the Operation, they soon welded together a solid front against the Orientals, manipulating their best weapon, the World News Services, with consummate skill.

At the head of this group stood a Senator from America by the name of McLee. In furthering his cause, he moved in a direction diametrically opposite to that of his celestial opponent. McLee made no bones about avoiding the involutions of the pseudo-ethical arguments with which Chi-Lau-Hen attempted to enmesh him and concentrated his fire directly upon the real crux of the situation, the finances. His strategy was to satirize and minimize, with dry and humorous comment, the oriental urges towards bucolic laissez-faire which beset him. With sardonic wit, he sent shaft after shaft of biting comment winging through the public press with such skill that those who supported the project did so with a smile upon their lips.

"Did you ever realize that short drinks in America cost more in one year than we ask for Operation Mars?" This was one of his innocent, yet effective gambits.

In one of his speeches before the full Senate, he referred with a gentle bitterness to the cost of women who had reached what he called the "cosmetic age." Following each item with the amount of yearly expenditure devoted to it, he listed permanent waves, eyelash curlers, skin rejuvenators, falsies, girdles, lipstick and all the myriad adjuncts of the beauty business. He showed that Operation Mars would cost far less than they, sadly and gently wondering whether a lesser expenditure might not be justified to bring the "cosmic age" to mankind.

As McLee listed feminine accouterments in meticulous detail, many a worthy Senator would cast a comprehending glance at some fellow domestic sufferer. The glaring contrast between the costs of "cosmic" and "cosmetic" achievement made the headlines to the vast detriment of Chi-Lau-Hen's sanctimony.

In Holt's sitting room at Emerald Bay, Spencer sat behind a cloud of acrid tobacco smoke and vented his rage at the stalemate in Congress.

"There they sit, on their fat bottoms," said he. "A bunch of Asiatic mystics who want to persuade us to squat there, gazing into our navels and musing on the virtues of inaction as a Way of Life! Forty long years I've been battling for space travel. I've worn every last hair off my head for it; I've talked myself deaf, dumb and blind for it; I've just about written my fingers off for it; Hundreds of fine young fellows have lost their lives for it! And here comes some sanctimonious, sententious son of a Mandarin blatting about how Confucius wouldn't like it!"

Holt was no less perturbed at the possible frustration of the enterprise than Spencer. "Confucius has been dead a long time," he said, "and I think the assumption that he would have been against it is entirely unwarranted. I know that General Eraden's conviction that we should carry out this plan is fervent, and there's a lot of religion in that fervor! Isn't there someone who could upset that oriental mysticism?"

Spencer shook his head wearily. "Braden would be the man, of course, but I've argued vainly with him to go before the Congress. He says everybody identifies him with "high brass," and claims that people don't want to have anything to do with "brass" ever since the war ended. He thinks that anything he said would only make matters worse.

"And, of course, he's quite wrong, for the whole world – including our former enemies – recognizes him as the man who put an end to the war before civilization was entirely destroyed. He's stuck his neck out for every one of the space developments that really form the basic groundwork of our peace. And every time he did it, he invited unpopularity, criticism and opprobrium. Nevertheless, he overcame ridicule, doubt, bureaucracy and every single obstacle that could be put in his way. Even our sit-down strikers from East Asia know they wouldn't be where they could make their opposition felt if it weren't for him! He's the only man I know to whom even they might listen…"

"If only he wasn't so modest and retiring!" sighed Holt. "He just can't get it out of his head that he's anything but just another soldier serving the people."

While Holt and Spencer were bewailing the threatening hiatus in their long-cherished undertaking, Catherine Holt had been in the kitchen preparing a snack for the dispirited conferees. None of their remarks had escaped her. For several weeks she had noticed that Gary's usually high spirits had been drooping and had wondered whether this could be attributed only to the delays caused by the celestial longwindedness in Congress. She entered the sitting room bearing her offering of food upon a tray, and with a quiet little smile on her face.

"Catherine, my dear," said Spencer, "if it wasn't for you and people like you, we'd never be able to keep up our morale during times like these. You keep your man's courage up the way you always have, and we'll find some way out of this dilemma sooner or later."

"That's very kind of you, Mr. Spencer," said Catherine. "I'll do what I can. By the way, Gary, didn't I hear that you two were going to fly out to Kahului for a few days? I was thinking I'd like to take a trip to New York for a visit to mother while you're gone. What would you think of that?"

An audacious idea had begun to whirl around in Catherine's head, for it had suddenly occurred to her that she might do more than simply keep up Gary's courage. But to put it into effect, she must go to New York, and she must go without Gary's knowing the real purpose she had in mind.

"It's a grand idea, Katy," said Gary. "You pop along to New York and take a breather from handling all these queer creatures who want to go to Mars. You need a rest probably much more than I do."

When Spencer had departed, Catherine opened all the doors and windows to rid the house of the pestilence which his stogies had left floating in the air, but her heart was unaccountably light. She felt sure that her plan would succeed.

General Braden drew nervously on a cigarette and worried. A call from Catherine Holt seemed to add to the myriad difficulties in which Operation Mars had entwined him. From the insistence with which Catherine had sought the interview, he anticipated that she was going to attempt to influence him to find some other man than Gary Holt to command the expedition. The mere fact that she felt that way about it half inclined him to accede to her request when she presented it, for he had his doubts about the effectiveness of a leader whose loyalties might be torn between an unwilling wife and even the greatest objective. He wanted every last man of the expedition to be heart and soul in it and not to have the slightest misgiving. Perhaps it might be well to appoint a different leader…

On the other hand, what would be the effect on Congress and the general public? Might not a change in the command prove a boon to the opponents of the plan in Congress and elsewhere? Rumors of dissension within the directorship of the enterprise would begin to fly; talk of cold feet would become rife. Perhaps the integrity of the whole business might be called into question.

He was engrossed in such thoughts when Catherine was shown in. Rising to meet her, he perceived her with a quizzical glance. There was no doubt that her hair was grayer than when he had last seen it a year ago. He summoned up the courage he always needed to talk to a woman.

"How nice to see you, Katy my dear," was his not entirely sincere greeting. "How's everything in Emerald Bay? And how's your good husband?"

"He's not well, General," answered Catherine with a wan smile.

"Is he really sick? *Here it comes*, thought Braden. He offered her a chair and seated himself beside her.

Catherine looked at him fixedly. "He's sick at heart, General," she almost whispered. Then the floodgates of her speech almost washed Braden off his feet.

"General, you are what is making him sick! He idolizes you! Everything is held up by Buddhism and Confucionism and all sorts of isms and he can't get through his head why you sit inactive and silent! You, the man who fought like a tiger when people wouldn't believe that men could ride in rockets! You, who really created Lunetta and the space ships, seem to him to have slumped back into a narrow, military mentality when the whole world awaits your open advocacy of Operation Mars! He simply cannot understand how the man who sparked the enthusiasm of all those who are working day and night can sit in silence behind the screen of a soldier's preference for avoiding politics. He feels that it's as much your duty to fight for Operation Mars as it is his to command it. If you want him to get well, you'll get in there and bowl over these oriental objections like a set of ninepins!"

Catherine had risen and was practically pounding her small fists on Braden's desk. As for the General, he was momentarily incapable of answering. So violent was the reversal of thought within his mind that no words came. The graying woman had turned the tables on him, for he could not but admire the self-sacrificial tenor of her speech, despite the embarrassing situation into which it put him. Her deep loyalty to her husband in coming here to reproach him with remissness aroused unbounded admiration.

"Katy, you're wonderful," he finally brought out. "If that's the way you feel, everything's fine!"

"Everything's fine?" she said, "What do you mean by that?"

"As unjust as it may have been, Katy, I thought you were coming to persuade me to replace Gary with another man, because you wanted to keep him at home. But after what I've heard, I know that you're braver than I. I'm going to match your courage and appear before Congress, although I'd much rather take Gary's place and lead the expedition..."

"General, you can't get one member of this family all worked up over something and then let him stew in his own juice without hearing from the other Holt!" Katy's eyes were moist above the relieved smile with which she looked back through the half-opened door at the astounded Braden.

Not many days later, Braden put on his best suit of civilian clothes and mounted the steps leading to the podium in the Capitol at Greenwich. The hopes of thousands were on his lips as he began his address.

"Gentlemen, as an old soldier obeying the orders of the President, I come before you to give an opinion on Operation Mars.

"I am too much of a realist to attempt to predict what might happen in the event of a surprise attack on us by intelligent enemies from some other planet. The results might well be so fantastic as to be incredible, and I'll leave prognostications of that nature to the authors of dime science fiction.

"But as a military man, I cannot but be concerned with our old Earth's vulnerability to external threat, and we must remember that Lunetta, our most potent concentration of military power, floats unprotected and unarmed in neighboring space. Any interplanetary attacker would be able to reduce that outer bastion with little or no effort, compared to taking effective possession of even the tiniest section of the Earth itself.

"A most venerable military principle states that the best protection for an isolated outpost is good reconnaissance. Should such reconnaissance reveal that there's no menace to our outpost, we may contain our souls in peace. If so, we at least have gained some time in which to devise protective measures.

"Professor Hansen laid before you the cogent reasons why we must be convinced that Mars is inhabited by a race of intelligent creatures, and we may well assume that they are potential enemies until the contrary is ascertained. I'm sure I need not emphasize this simple principle with any fanciful horror stories.

"The history of our planet up to the present has always been that of two or more armed camps. To our great good fortune, all these camps are now united, and conflict can only come from somewhere in space and be directed against each and every one of us, just as we are preparing to enjoy the fruits of our dearly won peace. In my opinion, the future happiness of our good old Earth has too much at stake to neglect any precautions whatsoever against some raid from space.

"That, gentlemen, represents my professional viewpoint. But there are a number of remarks I'd like to make about the general value of Operation Mars, and I offer for them your very serious consideration.

"From my earliest youth, I have despised the Greek proverb which claims that 'War is the father of Events.' Nonetheless, my whole life has been one consecutive revelation of the core of truth that lies within that proverb.

"Since the dawn of time, man has sought wings; but no sooner had they taken their first, faltering strokes than the new-born aircraft was swept into the capacious maw of the military. It required the immense expenditures of money which bred bombers and fighters throughout the whole Earth to evolve the useful and reliable airliner of our present day.

"Let me ask you whether any scientist could dedicate himself to a more fruitful task than to freeing nuclear energy for the liberation of mankind from the yoke of physical labor? Nevertheless, only the dire need for an all-destructive weapon, the atom bomb, could have raised the fantastic sums needed for the nobler concept.

"Rocketry has followed a similar path. Do you believe that the thousands of scientists, engineers and craftsmen who labored for decades on rocket aircraft, guided missiles, and finally, on our great satellite vessels, envisaged in their loving work and ingenuity the diabolical ends to which their creations were often put? I tell you No! gentlemen. Those men were animated by secret visions of reaching into the heavens, of bringing their fellow men closer to what all our primitive ancestors felt was the outward manifestation of the Deity, and which was by them so worshipped – the stars, great and small. But the vast appropriations which were applied to the development of our present-day rocket ships could not be pried from the public purse save by the cogency of their overwhelming potency in war! During the last conflict it was quite plain that he who held control of space over the heads of his enemy held victory in his hands!

"We are today at peace, thanks be to God. Well may we apply advances in fighting aircraft to civil aviation. Well may we work frantically to convert the war-born destruction of atomic energy into a blessing for all mankind. And by all means, we should apply the billions spent on space travel and our little, war-baby satellites to actualize that most ancient of dreams, flight into and among the stars of the heavens.

"Do not think that nowadays it is but a dream, nor that military necessity is that which gives Operation Mars its main right to be considered a valuable and practical enterprise. We must, I tell you, face up to the driving forces which heretofore have goaded civilization forward.

"Why did men yearn to sail the seas, generation after generation? The answer might be that seafaring is an economic necessity, because through it alone can world trade exist. Your real seaman, however, cares not a whit whether the cargo of his vessel upon the high seas be gold or grain. We may well doubt whether Columbus, on the quarter deck for the *Santa Maria*, was animated by a burning desire to reduce the freight rates on Indian tea, when he sought a new passage to Cathay and found America athwart his hawse. The great adventurers, Marco Polo, Magellan, and Henry Hudson did not sail forth upon distant and dangerous oceans on occasions of economic urgency, nor of closely reasoned logic. Theirs was the fire of genius, the divine urge, the response to the challenge of the unknown…

"Again, why has the desire to fly plagued us humans since the days of Icarus and Daedalus? The mail bags and the passengers in their pressurized cabin are of small concern to your true pilot. He took to the air because, when he was a small boy, he had seen an eagle circling in the empyrean blue, and because since that day some mystic longing constantly drew him upwards into the depths and distances of the sky.

"Explorers, seamen and flyers live their lives by certain elementary rules with which the Creator endowed them. Economic advantages to the generality of humanity come only in the train of their fundamental, basic drive.

"Gentlemen, if we really face it, we might find that it is actually unwise to inquire too stubbornly into the reasons that urge us to set afoot this expedition to Mars… You have all heard, quite clearly, that we have the necessary technical means to carry it out. Were we now to send out a call for volunteers, we should be swamped with applications from enthusiastic, enterprising youths, ready and eager to embark on the great voyage.

"When Isabella the Catholic granted Christopher Columbus' request for the ships of his westering voyage, she little knew what amazing results would follow in its wake. But there was no question in her mind that any but the Creator of all things had imbued his children with that urge into the unknown which distinguishes the pioneer. After prayerful watching, she fell in with the plan, secure in the knowledge that He knew the purpose of His endowment of Columbus with the spirit of adventure.

"Only through God has the door to our neighbors in space been opened! Shall we slam it in His face?"

Chapter 9
Headaches of a Space Ship Designer

Holt's first task was the selection of his crews.

His old war buddy, Tom Knight, had signed up without hesitation and Holt appointed him Deputy Commander and Captain of his flagship.

John Wiegand, the man with whom Holt had spent many thirsty days in a pneumatic boat under the burning sun of the Indian Ocean, had immediately agreed to abandon his profitable automobile agency in Fort Worth as soon as the project took tangible shape. John was an old timer in space shipping, with an engineering background. He had been through the teething troubles of the *Jupiter*-class and then directed the assembly of Lunetta personally and in situ. Holt knew his merciless meticulousness about the smallest detail, and for this reason had picked him out as Chief Engineer.

Since geology promised to one of the most fruitful fields for investigation on Mars, Holt had succumbed to the blandishments of a solemn, spectacle-wearing scientist by the name of Samuel Woolf. A well-known geologist of middle age, he had dreamed of the intentions of making an expedition along his professional lines, and had pestered Professor Ashley with applications to a point where he gave him a letter of recommendation to Holt. The latter interviewed him and was much impressed by the way Woolf had combined his plans for geological studies of the structure of Mars with various other objectives on the planet.

Dr. Bergmann, the light-haired astronomer, assented immediately when Professor Hansen let him know that Holt desired him to be in the party. Hansen did not tell him that he had long since guessed that his secret dream was to go along, and had spoken strongly in his behalf. Since Holt's visit to Lunetta, Bergmann had increased his efforts to the limit of human capabilities in order to squeeze every conceivable advantage form the existing opposition of Mars, when conditions favored observations and measurements. Bergmann's equipment was kept busy to its ultimate capacity during this time. For six solid weeks he had lived in the observatory, returning only occasionally to Lunetta for sleep. He had kept the busy bees busy indeed, bringing his meals over from Lunetta to the observatory. Each returning Lunetta ferry carried a thick sheaf of data for Holt back to Kahului, as Bergmann compiled what he thought might assist the planning.

Then there was Glen Hubbard of Los Angeles. For years he had been a civilian test pilot in the service of United Spacecraft, until the flight surgeons began to hint that he would last longer and enjoy himself more in a swivel chair behind a desk. He then became technical assistant to Spencer, but his wide experience when testing the *Jupiter*-class, particularly because it was he who had worked out their landing procedure, had been of inestimable value to every new design put out by the company. When Operation Mars was first announced, he immersed himself immediately in study of the glide characteristics and landing procedures which would face the landing boats in Mars' peculiar atmospheric structure, and came up with many valuable design tips. This aroused in him such enthusiasm for the whole project that he asked Holt if he might have a command. He wanted to strike a final blow for the cause to which he had dedicated his life, for flight in space, in which he had often risked his neck. The trip would be a high point for him ere he must retire into innocuous inactivity.

Another captain was Charles Laroche, the French underground fighter in the last great war against the overrunning of Western Europe by Bolshevism. Unknown at first, he had finally emerged to fight the barbarians in the air, becoming the ace of the French aces who, at the peak of his powers, had joined the United States Space Forces to become one of the first great space ship masters. Since the war had ended, Laroche had found no satisfactory outlet for his boiling energy, despite his fondness for social frippery and his many feminine conquests. Visiting with some wealthy acquaintances, he had accompanied them on an African hunting safari, but when his old friend Knight hinted that there was to be an Operation Mars, his request to Holt for a part in it figuratively burned up the mails.

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Holt called a conference of his key men at the plant of United Spacecraft, that they might be apprised of the state of advancement of the planning. He gathered them in the study of Richard Peyton, the chief Designer, for a report by the latter on the manifold questions relative to the details of the designs.

Dick Peyton was an old-timer at the business. When he and Spencer began their work together in the days of the early long-range rockets, it was his engineering conscience which had provided the balance-wheel for Spencer's almost pestilent fantasy and furious creative drive. If Spencer was the man whose wide vision could connect seemingly unrelated factors and discover new solutions when no progress seemed possible, if he could win an argument with his own engineers with the same assurance that he could overpersuade a board of directors or a Pentagon party, Peyton was the lover of detail, paternal to his designers, never allowing an error in a drawing, no matter how insignificant. He had a strange gift with subcontractors, coordinating their efforts in producing the hundreds of special parts and auxiliary equipment which went into the building of great rocket ships.

When the meeting was called to order, Peyton began with a report on the requirements for steering the great ships on their long voyage through space. He made it clear that steering could only be applied during the relatively short power applications. Between these power maneuvers, the ships would coast through space for weeks on end, like wandering meteorites, their flight paths predetermined by the direction and energy imparted to them during the preceding application of thrust. But, if the running position checks by star angle should show any departure from the precomputed course, it would, of course, be necessary to enter a corrective maneuver, during which accurate steering would be as necessary as during the main maneuvers.

No one needed to be told that the steering problem of the Mars vessels would be attacked by automatic mechanism, as was that of the mighty triple stagers on their departures from Earth. Manual steering, as used in busy bees, could not be considered for any such high degree of accuracy as the navigation of the Mars vessels required.

A gyroscopic plane of reference was to be established by a system of control gyros, rigid in space. So-called "program devices" were slowly to displace this plane in angle during applications of power. Any deviation of the vessel from the attitude imposed by the gyros would then call into being the angle-changing moments which would bring back the set attitude.

Such control moments were to be generated by four relatively small rocket motors. These were to be mounted symmetrically at four opposite points on the periphery of the main motor. Each could be rotated around one axis. When all were set to zero, their jets would parallel the jet of the main motor. Yaw and pitch control would be given by changing the angles of one or the other pair of opposite jets, each moving conjointly in angle. Rotation of the vessel around her own longitudinal axis could be initiated or stopped by deflecting all jets clockwise or counterclockwise. The angular displacement of each steering jet was to be produced by a small electric motor whose motion was controlled by rheostatic devices coupled to the gyros.

"Up to this point," remarked Peyton, "attitude control of space ships is a routine problem.

"But the actuators of these control jets now are called upon to fulfill a novel function, for we are steering not a single ship, but a whole convoy. We shall hardly be able to produce mechanisms uniform enough so that there will not be very slight divergences in track and velocity at combustion cutoff. In the course of a long coast through space, the ships will therefore diverge more or less. The busy bees will find their trips from ship to ship growing longer and longer. Therefore, it will be necessary to close up the convoy from time to time. To do this with the main motors would call for a laborious turning of each vessel in space by its directional flywheels, so that the thrust of the main motor, even though applied but momentarily, would be in exactly the right direction. That would be quite an elaborate procedure for what is, after all, a very minor correction.

"We are therefore making provision to cut out the automatic gyro control devices temporarily, and are equipping the steering rocket jets with manual electric remote controls which permit them to be directed anywhere within a full 360 degrees around their axes of rotation. Thus, should it be found that a ship is moving too fast in line with its longitudinal axis, all four steering jets can be turned to face forward, and their thrust will decelerate the vessel directly. Similarly, we can swing any ship into or out of the convoy column. The main advantage is that we can make really fine corrections with these fractional thrusts when compared to the main motors. Corrections can be made by small thrusts over extended periods rather than by short, but violent ones. You will, I think, easily appreciate the advantages of this modification."

Next to come up was the question of waste disposal. To eliminate every pound of weight possible prior to each new power maneuver meant fuel saving and increased reserves of power. Such reserves might be of vital importance if a navigation check should show that any maneuver had not turned out entirely according to plan.

The problem was to expel waste matter from the pressurized living spaces into the surrounding vacuum of space and simultaneously to prevent the accumulation of masses of such matter in the immediate proximity of the ships. Nothing, as a matter of fact, would prevent some discarded tin can from following faithfully throughout any portion of the voyage between power maneuvers. Peyton described a clever dodge which might solve this problem. It was planned to place waste matter in an airlock through a small door. The door would then be closed, and a piston impelled by the internal air pressure would project the waste with considerable velocity into the outer vacuum. It became plain that one of Peyton's pet projects was to connect this gadget with the ship's sewage system. He discoursed pridefully and solemnly at some length on the problems attending the use of the latter during long, unpowered stretches of the voyage under weightless conditions. So serious and detailed was his presentation that howls of laughter burst from his auditors.

Peyton further reported that Untied Spacecraft was already in negotiations with the American Blower Corporation of Detroit for air regeneration equipment. This company had pioneered in the development of machinery of this kind for the pressurization of Lunetta, but here too, was a knotty problem.

First, the air would have to be freed of the carbon dioxide developed in the lungs by breathing. Air continuously exhausted from the living spaces would first pass through a dust filter and then traverse, under increased pressure, a tank into which water was simultaneously sprayed. The carbon dioxide would combine with the water under this increased pressure and form carbonic acid. Then, when the water was subsequently decompressed, the carbonic acid would bubble out, as it does from the contents of a bottle of soda-water, and be exhausted into the vacuum of space between the worlds. The air, now free of carbon dioxide, would be passed through a bone charcoal filter for deodorizing. Then it would be replenished with oxygen, the latter being carried in liquid form and hence requiring to be gasified. After this treatment, and before being readmitted to the living spaces, the air thus regenerated would require conditioning to the exact temperature, pressure and humidity desired for breathing purposes.

The air regeneration system was closely integrated with the water recuperation system. Breath and perspiration would liberate more than one and one half liters of water daily per man, to be extracted by the system. This recuperated water, added to the utility water carried for cooking, dish washing and the laundry machines, would increase the utility at the expense of the slowly shrinking potable water. It would be necessary to sterilize such water by distillation, recondensation and germicidal additives, for it would be unthinkable to jeopardize hygienic standards on a lonely, year-long trip, where so many people would live in such restricted space and have access to such limited medical assistance. Measures to this end were considerably handicapped by the weight limitations which Peyton had found it necessary to impose upon the developing company.

But this was not all, for the constituency of the air was closely tied in with the type of glass to be used in the portholes. Experience on Lunetta had confirmed this. There was a high concentration of ultraviolet in the light impinging on these windows, being unaffected in its passage through empty space by any atmospheric filtering effects. This not only caused malignant conjunctivitis but also led to the formation of ozone in the living spaces. The Lunetta crews had frequently complained that she smelled of "artificial mountain sun," and that it eventually gave them headaches. For some time, development of special window glass had been under way. Such glass was to absorb a considerable proportion of the ultraviolet radiation and likewise to reduce somewhat the glare of the sunlight. It was a tough assignment, for most glasses slowly disintegrated under the strong ultraviolet light.

All this was completely novel to Dr. Woolf, who followed Peyton's remarks with rapt attention. But the longer he listened to the latter's dissertations on toilet problems and odors of ozone in space vessels, the more his mind concentrated upon a burning question which seemed to him vastly more important than all this detail, and to which he could find no answer with all the will in the world. Finally, he burst out when Peyton paused for a moment.

"Mr. Peyton," said he anxiously, "what about the temperature in these space ships? Away back in school, I learned that the temperature in space is absolute zero, or minus 273 degrees Centigrade. With an outside temperature like that, how in the world are we going to keep warm?"

"Solar heating's the answer, Mr. Woolf," answered Peyton. "You're obviously under some misapprehension about maintaining temperatures in space ships. Space, you see, really has no temperature. What is temperature, anyway? It's only a way of expressing the rate of movement of molecules. The faster the molecules composing a body whirl about within it, the higher is its temperature. But space is composed of absolute vacuum and might as well have no molecules. So how can empty space have temperature?"

"Aren't you splitting hairs, Mr. Peyton?"

"Certainly not, although I must admit that right now we're interested in a somewhat different problem, namely, what temperature does a body suspended in empty space assume? The body, of course, consists of molecules, and these may have motion and therefore temperature.

"Let's consider the simplest case, namely a sphere floating somewhere in space, remote from the Earth and equidistant from the Sun. One half will be irradiated by the sun, the other will be shaded. Thus one side will absorb heat radiation and the sphere will become warm. From the shady side, heat will be lost by reradiation. The sphere will continue to grow warmer until the rate of radiation equals that of absorption. At the temperature where this occurs equilibrium is established. This temperature of equilibrium is primarily dependent upon the distance of the sphere from the Sun – the nearer it is to the latter, the more solar radiation is absorbed and the higher is the equilibrium temperature at which the sphere can reradiate the increased amount of heat absorbed."

"But does not the temperature attained by the sphere also depend upon the nature of its surface and above all on its color? A mirror finish reflects all radiation, while a black surface swallows it all."

"Quite right. But what applies to the irradiated surface also applies to the shaded side. A mirror finish does not reradiate, while a black one greatly furthers reradiation. If the sphere is completely shiny, it absorbs no heat on the sunny side and radiates none on the shady side. An entirely black sphere absorbs much and reradiates much. Either is the same with respect to the temperature of equilibrium.

"It's not quite so simple when intermediate colorations between mirror and black are concerned, for then the so-called spectral absorbtivity and emissivity play a considerable role. Solar radiation has a considerable portion of short wavelength energy, that is, visible and ultraviolet light, while the sphere, warmed but to moderate temperatures, radiates long wave, invisible infrared only. The absorptive capacity of some particular paint for short wave radiation may differ materially from its ability to reradiate long waves. Thus there are different temperatures of equilibrium for the sphere at identical distances from the Sun, and these vary according to the nature of the sphere's surface characteristics. But for a sphere whose surface is either completely reflective throughout the whole spectrum, or completely black in the absorptive sense, the temperature of equilibrium would be the same at the same distance from the Sun."

"You seem to be telling me," wondered Woolf, "that whether a space ship be painted with black or with reflecting paint, its temperature is wholly and solely dependent upon its distance from the Sun? Why then, the interior of the vessels ought to get colder and colder! Because our distance from the Sun will increase constantly during our trip out to Mars."

"Now wait a minute," said Peyton, "that's another reason why we must take steps continuously to adjust our temperature of the sphere; we'll assume that it's black on one side and mirror-reflecting on the other. That will make its equilibrium temperature at any given distance from the Sun also dependent upon its attitude to the solar rays. If the black side is turned sunwards while the other is shaded, the sphere will heat up several hundred degrees, because it is absorbing much heat and can give off but little of it. But if we reverse its position and face the mirrored surface to the Sun, the mirrored hemisphere will permit no heat to be absorbed, while the black side will be radiating the accumulated heat into space. Under those conditions, and, make no mistake about it, under those conditions only, the sphere may finally reach absolute zero."

"What is done in practice?"

"Most of the exterior of the ship is polished to a mirror finish. Then the temperature simply remains exactly as it is, for there is neither heat absorption nor radiation to any extent. Being surrounded by vacuum, the vessels may be regarded as Brobdignagian thermos flasks, for in such flasks, that which was cold remains cold and that which was hot, hot.

"We regulate temperature accurately as follows: the reflecting surfaces of the ship are spotted by small, black areas, shielded by silvered venetian blinds; the black surfaces under them are exposed and absorb heat when the blinds are open. When the blinds are closed, their reflecting surfaces prevent the absorption of radiation by the black areas. In practice, there's an automatic thermostatic control system which operates the blinds jointly with the air conditioning plant."

"Now I understand it. But tell me, how about the propellants stored aboard the vessels? Do we not also have to maintain them somewhere within a limited temperature range? Wouldn't they otherwise boil or congeal?"

"Quite right, they must be held quite accurately at one temperature. One factor is that the thin balloon fabric tanks could hardly withstand any such pressures as might be produced by extensive evaporation of the propellants. Another is the problem of maintaining accurately the predetermined mixture ratio between the two propellant components. This necessitates each of them being fed to the thrust unit at rather definite temperatures. The tanks will be painted aluminum. The propellant temperature will also be controlled by venetian blinds, automatically operated by thermostats.

"There's quite a variation in the preferred temperatures of different parts of such a ship, incidentally. Think, for instance, of the liquid oxygen tanks for cabin pressurization. The oxygen in them shouldn't boil – despite its low boiling point of -183° Centigrade – in order not to produce any undesired pressure in the storage tank or leak losses through the safety valve above it. Then we have the food storage bays in which the food should lie deep frozen. And of course, we should like to spare ourselves the weight of refrigeration equipment with a capacity for almost three year's store of comestibles. That can all be done with this method of blinds operated by thermostats. It's a simple and relatively trouble-free expedient and involves a low weight penalty."

"All this seems to me most intelligible," remarked Woolf, "but I'm somewhat surprised that the Mars vessels will have this bright, mirror finish, when all the pictures I've seen of the *Sirius* ferries to Lunetta show them as black as ink."

Peyton smiled tolerantly. "There's quite another reason for that," said he. "Don't forget that the *Sirius*es have to traverse Earth's atmosphere at such high flight speeds as to cause great heating of their skins by air friction. By coloring that skin black, the friction-generated heat is dissipated by better radiation, and the skin does not reach such high temperatures as would otherwise be the case.

"The pilot's compartment and the disposable interior of a *Sirius* vessel are temperature insulated within the outer shell, and their temperature regulation is exclusively taken care of by the air conditioning system. But the Mars vessels have, as you know, no outer sheathing. That means that radiation balance must play the premier role in temperature control."

At this point Holt injected himself into the conversation. "If you'll excuse me, Sam, perhaps I can add a little illustrative touch to this Mars vessel temperature subject," he said. "Lunetta remains in the umbra of the Earth for almost one half of each of her revolutions around it, during the equinoxes at least. She too is painted silver and uses the same method of temperature regulation which Dick has just described. Now we've noticed that the regulating blinds hardly change their angle even when passing through the umbra, when there is no sunlight at all. That happens because the heat capacity of the station is so great compared to the slight amount of reradiation through the usually half-opened blinds, that a single hour is hardly enough for the interior temperatures to react to the absence of solar radiation and to affect the thermostats.

"Dick also forgot to mention another factor, namely the heat which is constantly being liberated in the operating spaces. In the case of Lunetta, there's a continuous utilization of some 15 kilowatts of electrical energy. This is converted into heat via lighting units, hot plates, motors, and the like. Then too, there are some 80 men in Lunetta's peacetime complement. You'd hardly believe what a lot of heat 80 men, each eating 4,000 calories of food per day, can put out! They alone are a very efficient heating plant! In point of fact, the blinds on the shady side are almost constantly wide open in order to expel all that heat. Otherwise I can assure you that it would gradually get uncomfortably warm."

John Wiegand decided to put his oar in at this point. "Speaking of electricity, what are you going to do about that in these Mars ships? Will it be the same setup as in Lunetta?" John had been intimately associated with assembling the power station in Lunetta and was vaguely remembering a lot of almost forgotten difficulties.

"No indeed, Johnny," answered Peyton. "Not only the problem, but the whole build-up of our Mars ship power plants differs in several respects from those of Lunetta. Her current requirement is a relatively steady 15 kilowatts, more or less. When she's in the umbra, her steam generator naturally cuts out because there's no solar radiation reaching her reflector, and that's about half the time at the equinoxes. The load is taken over by accumulators, so the generator, when it's operating, has to furnish 15 kilowatts to the mains and another fifteen to recharge the batteries so that they can carry the load during the next passage through the umbra.

"The picture on the Mars ships is quite different, for there are no repeated passages through the shadow of the Earth. On the other hand, when power maneuvers are in effect, each ship calls for some 70 kW for steering purposes. The earlier propulsive maneuvers last much longer than the later ones, so we shall draw the major part of the electric current from batteries and jettison a part of the batteries afterwards, which will economize on propellants by decreasing the mass of the ship when the next maneuver comes up.

"The intervals between maneuvers will be very long, so that a trickle charge can easily bring back batteries pretty well run down by a power maneuver. All in all, it means that, even with the heavy currents called for during the relatively short periods when the rocket motors run, we can get by with generators of moderate capacity.

"Lunetta needs a minimum generator capacity of 20 kW and we have actually installed 35 kW; but on the Mars ships, 16 kW generators will do. During the long, unpowered flight periods, most of the current will be used by the blowers and pumps for water and air regeneration and recuperation. All of these together will call for about 6 kW, leaving ample current available for such auxiliaries as electric stoves, washing machines, remote annunciators, thermostatic controls and the like. We shall not need, except to a small extent, electric lighting; for unlike Lunetta, our ships will almost always fly in sunlight. Of course the batteries will stand an occasional peak load of 40 or 50 kW if it is not applied just prior to a power maneuver.

"The power-plants of the Mars vessels will be operated by turbogenerators fed by sun-heated boilers. We shall require solar reflectors of 94 square meters surface to produce the required 16 kW, and oddly enough, that's more surface than is used for Lunetta's 35 kW. The apparent discrepancy is explained by the need to keep up our 16 kW even when near Mars, where the solar energy caught by the reflector is less than half of that near the Earth's orbit.

"After the vessels have been drawn in by Mars's gravitation, they will circle him and be in his umbra during one third of the time required for each circle. Then the problem will become much like Lunetta's. The mean output of our 16 kW generators will be reduced to 11 kW per vessel, and that's getting close to the tenuous current requirements of the air and water regeneration systems. It is, in a sense, fortunate that the crews of the ships awaiting in their satellite orbits the return of the landing craft will be reduced by the number of the landing party. This will diminish our current requirements during this critical period.

"Exhaust steam condensers present a particular problem in the Mars vessels. Those of you who have visited Lunetta will remember the spokes connecting her rim with the central station. These serve as condenser tubes reducing the aqueous vapor to liquid which the feed pumps can return to the boiler. It was possible to use this expedient on Lunetta because the spokes are shaded by the rim, due to Lunetta's rotating in the plane of the ecliptic. But the Mars vessels are not wheel-shaped, and their attitude in space with respect to the Sun may change continually. Hence we propose to locate the condensers behind the reflectors, because, since the reflectors must always face sunwards when the turbines are running, there will invariably be shadow behind them.

"But here we encounter a rather ugly difficulty. Our power plant has an overall efficiency of 30% only. Thus 70% of the solar energy from the reflector must be dissipated into space by the condenser. For the low exhaust steam temperature of 46°C, the condensing surface must be double that of the reflector.

"You may argue that there'd be no particular problem in placing a condenser with twice as much surface as the reflector in the latter's shadow. The design of such a condenser would be elongated and extending to the rear, so that it would radiate heat not only directly away from the Sun, but also laterally. But that configuration would be rather bulky and unhandy, and we must not forget that the reflector with the condenser must be swivel-mounted so that, for any attitude of the ship in space, it can face the Sun directly.

"For all these reasons, we have decided to substitute mercury vapor for the more conventional steam. Such turbines are not a new departure and have the advantage of permitting higher admission temperatures to the turbine than steam and consequently the exhaust is hotter. That will give us a temperature of 120°C in the condenser. This, of course, will make the surfaces radiate much more actively and we can get by with relatively compact condensers which will easily fit within the shadow of the reflector."

"Say, Dick," said Holt when Peyton stopped talking for a moment, "what about the electrical energy for radio communication? Have we got any figures on that?"

Peyton drew a deep breath and plunged on. "Here's the communication story. According to the plan, we must consider three separate types of radio communication.

"The first type is for intership work. There's not much to that. It's short range stuff, not much different from the two-way command sets used between airplanes in formation. Each unit will use only a couple of watts and draws practically nothing from the mains.

"The second type is for middle distances of about 10 to 20,000 miles. It will be needed primarily for communication with the landing party when the space ships are circling Mars. Likewise, it will be useful for contact with Lunetta or terrestrial stations after return to Earth's orbit. We propose to equip three ships with transmitters for this middle distance service, and also one transmitter for each landing craft and ground vehicle. All vessels, landing craft and vehicles will of course have appropriate receivers. These middle distance transmitters will draw about 5 kW each, and since the times during which they will transmit are short, the mains of the vessels will take care of it nicely.

"But the third and most problematical radio is for long, interplanetary ranges. These will be covered by the so-called High Duty Radio Sets, and these will have to be constructed as wholly separate structural entities, independent of the structures of the vessels. Two of the three cargo ships will each carry one of these sets. As a matter of fact, if the navigation should not be accurate enough to allow the Command of the expedition to effect notable savings in propellants, the Command may well be forced to abandon both these sets in the Martian satellite orbit, for we have been unable definitely to assign any portion of the payload of the passenger vessels to these radios.

"The idea is to erect a similar station on Earth with which they will communicate, although the boys are not yet quite sure of its configuration. It's not impossible that one exactly like those of the Mars vessels will operate from Lunetta's orbit... The range of these stations must suffice for two-way communication throughout the entire trip.

"As a matter of fact, this radio communication problem is giving us about as much trouble as any of them. You probably all know that we've been working with Old Man Lussigny, and he's running this show. I don't know as much about radio as I'd like to, considering how my problems tie in with it. Communication across hundreds of millions of kilometers apparently calls for concentrating the radio energy into a ray-pencil of small divergence. The radio boys are still pretty much puzzled over this. If they reduce their wavelength, the same size of directional antennas will give better concentration, but then they cannot build transmitters with enough output. On the other hand, longer wavelengths ease the transmitter problem, but require such large and cumbersome antennas that they give us acceleration troubles during power maneuvers. Right now, I'm still a little vague as to the outcome of this tail-chasing, but it seems quite definite that these High Duty Radio Sets will have to be separate from the ships, not only structurally, but as to sources of power."

Peyton had hardly closed his mouth after this speech than the door was flung open and Spencer burst in waving a newspaper. His usually solemn countenance was wreathed in smiles. "Hey! Read this!" he shouted joyously, "It's all in the papers! The Congress has voted us our whole two billion dollars! Boys, we're off in a cloud of dust! Cosmic dust, at that!"

Chapter 10
How an Army of Technicians Works

All through 1981 and 1982 the key men of Operation Mars had been enmeshed in tremendous intricacies of problems and work, for the astronomers had set the date of departure at March 21, 1985, and there could be no tampering with it.

The assembly shops of United Spacecraft were filled with purposeful bustle.

The three landing craft stood nearly completed in a wide, spacious, but low-roofed hangar, one behind the other. At first glance, they resembled enormous flying wings, but closer examination revealed individual peculiarities.

Their wings were very much swept back. Throughout their span of 153 meters they were exceptionally thin in section and had the familiar sharp leading edges which point to supersonics. Those leading edges were on hinges like the flapped trailing edges, except that they could not be depressed to the same extent. United Spacecraft had developed this expedient many years before and it was in use on the telescoping wings of the *Sirius* vessels. Its purpose was to improve the slow flight characteristics of the thin supersonic airfoils which, after descending through the sonic barrier, were unsuited for the lengthly subsonic glide and the ensuing landing. "Elevons," the well-known combination elevators and ailerons, were located at the trailing edges on the outboard ends of the wings.

The cylindrical hulls, almost insignificant beside the huge wings, protruded but little fore and aft of the central wing section. They were 22 meters long, 4.7 meters in diameter and sharp-nosed, while the afterbody terminated in the familiar flat base of rockets. Behind this was a cruciform empennage, so tiny in comparison with the wings as to arouse curiosity concerning its purpose. In actuality, it was proposed to control the craft within the Martian atmosphere by means of the rudders atop the wings and with the elevons only. The cruciform empennages with their own small control surfaces would serve when the wings had been shed on the surface of Mars. Then the landing craft would assume the guise of rockets pure and simple, and would launch themselves from a vertical position, standing on their stabilizing fins, in order to return wingless to the satellite orbit in which their mother ships awaited them.

One of the three boats had retractable skis, in contrast to her sisters' conventional tricycle landing gear.

Peyton and Spencer had scratched their heads for many a weary hour over the problem of landing these craft on Mars. Dr. Bergmann had said that he couldn't assure them that there was any place large enough, hard enough and smooth enough for a landing with wheels at the computed speed of 197 kilometers per hour. So they accepted Bergmann's suggestion that the first landing be made on skis in the snow-covered south polar region, and conveyed it to the Space Forces.

This suggestion, as appealing as it might appear at first blush, added no inconsiderable additional difficulties to the landing problem. Holt and Braden hesitated long before finally acceding to it, for it meant that the first echelon would be down in a region from which they could never return to the satellitic orbit under their own steam. This was because the satellitic orbit in the plane of the ecliptic could not be reached from that latitude. Hence, the first echelon after debarking would have to set out in their land vehicles towards the equator, in the hope of discovering a suitable landing area for the two remaining wheeled craft, or, if worse came to worst, preparing one. Such a surface voyage would most certainly face them with a passage through a zone of thaw and moisture, where the ground characteristics would be unknown. Holt and Braden's acceptance of this proposal made the enterprise of the first landing party an adventure upon whose outcome depended the success of the whole expedition, and which might bring all sorts of surprises.

The hulls of the landing craft were arranged with the pilot's compartment far forward, with seats for pilot, copilot, flight engineer and radioman. It had wheel controls and a mighty instrument panel. Hidden by the latter and jammed forward into the nose section were various electrical devices and the automatic course-keeping equipment, which would come into play when the wingless hull took off rocket-fashion to return to a satellite orbit.

Abaft of a small radio bay was a large cabin for the personnel and equipment of the landing party. It was about four meters long and filled the whole cross-section of the hull, thus exhibiting no marked distinctions from the cargo space of a medium-sized transport. In its center, just atop a hermetic loading hatch, was the location for a special caterpillar for Mars. This could be passed through the hatch after landing by means of lowering tackle attached to the ceiling. Surrounding the vehicle there was ample room for food and other supplies. Flat couches for some 18 persons lined the walls, which had two rows of port holes for exterior vision of the occupants of the couches.

Still further aft were two large propellant tanks, most of whose contents would be required for the rocket takeoff from Mars. The tankage bay was some 7.5 meters long.

In the afterbody were located the turbopump, the gas generator, and the valves and tubing of the rocket propulsion unit, with the motor proper at the extreme tip. Despite this motor's ability to develop the same 200 ton thrust as the top stage of a *Sirius* ship, the diameter of its discharge nozzle was but half the latter's. This smaller diameter pointed to the contemplated use of the motor in the Martian atmosphere.

There had been an early decision to fly the landing craft into the terrestrial satellite orbit without disassembling, unlike the space vessels proper. This could be done by putting them in the place of the top stage of a *Sirius* vessel, and permitting the two *Sirius* boosters to lift them to a point where their own rocket plants could take over and provide the final velocity increment for attainment of the orbit. Their enormous wings, of course, would be dismounted, being freighted up in sections in the course of the regular supply operations. Then they would be reassembled in space and mounted on the hulls prior to the final departure.

The master plan called for a special expedient applying to the ski-equipped landing craft only. This craft would, of course, need the same propellant capacity as the others in order to reach the orbit of departure. But since it was to be abandoned after landing near the Martian South Pole, it would need no propellants for the return. It had been computed that each landing craft would expend but 15 tons of its total propellant tankage of 128 tons to depart from the satellite orbit around Mars and to land on his surface, the remainder being needed for return to the orbit. The 113 tons in the ski-equipped craft would thus be available for other purposes. Holt suggested that considerable supplementary equipment to ease the exceptionally difficult problems of the first landing party be made available to them in the extra load thus disposable.

It was decided to remove the large plastic tanks of the ski-equipped craft in the terrestrial orbit and to replace them with smaller ones which would suffice for the landing maneuver on Mars. That made available a volumetic capacity of some 12 meters by 4.5 meters in diameter which could carry a weight of not less than 125 tons of payload, where the other landing craft had but 12. Three big caterpillars would be the key equipment of this cargo, and with them the landing party would find itself with adequate transportation for the long trip towards the Martian equator.

The Mars vessels themselves were under construction in one of the other buildings, but the onlooker could as yet discern but little of the clumsy outlines of these, the backbones of the expedition. Here and there isolated groups were being check-assembled and then taken apart again for shipment into the orbit of departure.

A casual glance into the great building conveyed the impression that one of the old harbingers of the air age was being resurrected, to wit, a rigid dirigible like those which successfully attacked the Kingdom of the Air some eighty-odd years before. The enormous propellant tanks of plastic fabric, thin, folded and empty, lay in stacks one upon the other and were reminiscent of hydrogen or helium ballonets from the tanks of the long departed Zeppelins. Not far distant, the noise of riveting hammers echoed through the filigree tracery of tubular trusses like those of some arched bridge. Eventually the tanks would be suspended in these structures. All long frames were sectional, connected by screw joints at certain intervals, for easy stowage in the holds of Sirius vessels.

One of the spherical personnel nacelles for a passenger vessel was inflated in one corner of the great assembly hall. It was blocked up on a flat, wooden stand, appearing for all the world like a glistening, silver balloon some ten meters in diameter. Within it, a crew of men were working on the interior fittings, having entered by the already completed entrance airlock by which the moderate internal pressure was prevented from escaping. The job in hand was to adapt and fit the electrical wiring and the rubber tubes for the air circulation system. When completed, these, like all the other fittings, would again be removed so that the nacelles might be freighted up to the departure orbit collapsed, like the propellant tanks. There it was that the final assembly was to take place.

In the upper part of the nacelle was the control room. This would be the foremost element of a Mars ship after final assembly and would contain a bewildering assortment of gauges, gyro gear, radio equipment and operating panels. The uppermost segment, which would form the extreme nose of the space vessel, was the forward astrodome. Through it or through one of the seven others strategically arranged around the sphere, all angles could be visually covered. Each astrodome was a hemispherical glass bowl about one meter in diameter, through which the navigators might take the stadimetric angles of heavenly bodies required for running fixes. Light could enter the nacelle through a large number of smaller portholes liberally interspersed between the astrodomes.

The deck below the control room in the spherical nacelle contained four sleeping compartments segmentally arranged around its periphery, as was the Captain's cubicle. The next lower deck was composed of two large living compartments, a radio office and a small library which might also be used as a chartroom. On this same deck, air and water regeneration equipment was located, and space was left for a sick bay, a toilet and Peyton's famous garbage gun. The part of the great sphere that would be closest to the propellant tanks after final assembly contained the galley, the food storage and a water tank. The entrance airlock was at the very bottom. Communication between the various decks was through central and concentric openings through which ran a fireman's pole, for the weightless condition which would obtain throughout the voyage rendered any sort of ladder or stairs superfluous.

Rocket-minded visitors often expressed wonderment that there was no sign of propulsive power plants in evidence and there was an interesting and ingenious answer to their questions.

Long before, the designers had decided to use the well-tested *Sirius* cargo spaces. The rocket motors themselves were welded on and the diameter of their nozzles filled out the whole after-section of the ferry vessels which they conventionally propelled.

It was at this point that old Spencer's flexible ingenuity had saved the day.

"When you're assembling in the orbit of departure, just rob the *Sirius*es of their rocket motors and install 'em in the Mars vessels," he had said.

Peyton had objected to leaving a lot of valuable ferry ships circling indefinitely and impotently around the Earth, whereupon Spencer went on:

"You won't have to do that at all. A Sirius doesn't need 200 tons of thrust to get back to Earth. She can do it with a couple of thousand kilos if they work a bit longer. So you just ship up a few propulsion plants from the old rocket fighters and install them in place of the cannibalized thrust units. They are so small that they will not fill out the openings in the sterns of the ships, but we can have some sheet metal cover plates made up in sections to be installed around their little nozzles to cover the open wounds. The plates will go into the cargo spaces without difficulty."

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Not long after the World Congress handed down its historical decision, Professor Ashley the wise, graying head of the World Research Board lived up to his promise and assigned suitable research institutes, university facilities and specialized companies to a vast number of partial research and development problems related to Operation Mars. The difficult task of coordinating this worldwide program with the constantly changing design and construction work going on in Long Beach came under the cognizance of the Development Commission appointed by Braden. This commission drew the contracts in detail and supervised the distribution of work; Holt, Spencer and Peyton were members.

When Operation Mars began to take tangible shape, a veritable army of engineers and technicians went to work on a wide variety of problems of which instrumentation for Martian conditions was not the least difficult.

Pressure altimeters for the Martian atmosphere were developed in conjunction with other types and special gyro-compasses for the caterpillars replaced magnetic instruments in view of the lack of information on Mars's magnetism.

In order to set the control gyros on the ships and to adjust the ship's attitude in space for a power maneuver, a new and ingenious device had been developed. The problem was to adjust the gimbal system of the attitude gyros to a direction established in each individual case by the navigators for both the main power maneuvers proper, and the corrective maneuvers as obtained by the running navigational fixes. This being accomplished the ship had to be brought into the same attitude in space. The Sperry Company in Great Neck had developed a device for this purpose which worked as follows. Two small telescopes were mounted on a gimbal system in which the position gyros were suspended. These telescopes were to be centered on two fixed stars and kept on them by light-sensitive cells. This established a plane in space upon which an arbitrary system of reference with three coordinates could be built up, having the vessel itself as a center. Three scales attached to the prime axes of the gimbal system could be set to the angularity of the desired three-dimensional heading as referred to this arbitrary system of reference.

After this had been done, the gyros were started, and this brought the entire gimbal system automatically into the prescribed special attitude. When, after several minutes of operation, this attitude was attained, the triple attitude flywheels of the ship were set in motion and continued to run until the ship itself coincided with the special attitude of the control-gyro system.

The purpose of this device was to eliminate lengthy adjusting to and fro, and to bring the Mars vessels more rapidly and more accurately to the desired headings for any power maneuvers.

There were a great number of mathematical labors to be performed aside from such technical developments as those described.

First there was the task of recomputing the voyaging ellipses to comply with the departure date and time selected. As a navigational essential, it called for the utmost precision, although not affecting the basic layout of the ships. Into these computations would enter accurate elliptical orbits for both Earth and Mars, the complicated interaction between solar and planetary gravities when the vessels approached either planet, not to mention aberrations in the flight paths produced by other heavenly bodies such as Jupiter and the terrestrial and Martian moons. This last mentioned factor called for the closest scrutiny.

Furthermore, it was necessary to run another set of computations for the four main power maneuvers as affected by these more accurately worked out data. The periods of power application would be long, particularly the earlier ones, and it would be necessary that the ships' attitudes coincide with their curved, powered flight paths. This could only be done by gradual alteration of the spatial attitudes, such alteration being impressed by the control gyros in accordance with a set time program. The initial power maneuver of departure from the terrestrial orbit would last 66 minutes – more than a full hour; and during that time a ship would more than half circumnavigate the Earth along the departure orbit. The velocity would change but slowly until the final hyperbolic escape velocity was reached, and this would give the track of departure a marked curvature, to be accurately complied with by the control gyros. All the other power maneuvers posed the same problem, although to a continually lessening degree.

Bitter experience had taught the Space Forces that captains and navigators must be freed as far as possible from involved computations while under the stresses of a voyage. Burck's adventure with *Hercules* had redoubled the efforts to furnish ship commanders with flight data already prepared for all eventualities and unforeseen deviations from the prescribed track, from which they could determine proper procedures immediately and without lengthly calculations.

The high accuracy required for navigation in interplanetary space even made a further step necessary to prepare the Mars expedition. The vast program of the many thousands of flight path calculations required to cover the multitude of variations encountered by the most minute deviation from the predetermined track could only be handled with the help of huge electronic computers, which, since 1940, had begun to relieve mathematicians of the burden of tedious numerical calculations. These electronic super-brains supplied their results in the form of a magnetic tape, on which the solution was imprinted in a magnetic pattern. The hieroglyphs on the tape were usually decoded by a separate printing machine which retransformed them into ordinary figures.

What was more obvious, then, than to utilize the magnetic tape itself for the guidance and control of the ship, rather than to have the navigator first take figures from a table and adjust the control devices accordingly? It was comparable to running a punched tape printed with musical notes directly through an electric piano, which played the symphony, although without expression, yet with absolute assurance against discords.

Several thousand magnetic tapes were compiled from the many computations and each ship was to carry such a collection for its navigation. A handbook, crammed with diagrams and auxiliary tables, served the navigator as a key for picking the proper tape once a certain deviation from the prescribed track had been ascertained by running fixes.

Notwithstanding all these preparations, it had been thought necessary to develop a novel type of electronic computer, small and light enough to be taken along by each of the expedition's ships. These computers were to stand by for entirely unforeseen events and were capable of producing guidance tapes while enroute.

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A particularly broad program was the development of synthetic training devices and synthetic testers. Both faced the problem of reproducing as accurately as possible the circumstances under which certain vital components would operate, and also those which would affect the humans who would take part in the expedition.

Synthetic testers were typified by the control simulating device. The weight of the Mars vessels would be reduced from 3,720 tons to almost 50 tons during the voyage, by the exhaustion of propellants, and this reduction in weight would reduce the so-called mass moment of inertia, profoundly affecting the operation of the automatic controls. The control simulating device permitted an accurate laboratory test of the functioning of the control mechanisms under a broad variety of operating conditions. This would greatly reduce the risks attending any mechanical malfunction or some unpleasant surprise or other in the physical behavior of the control gear during the voyage itself.

In order to study the behavior of the control system on such a device, the oscillation-susceptible system of the automatically controlled ship was simulated by a complicated electronic hook-up. This permitted an exact determination of the way an initial angular displacement impressed upon the vessel would be corrected by the automatic controls. It would show whether the attitude adjustment was rapid or deliberate, whether or not there was over-correction, and how many corrective oscillations took place; or finally, whether the controls might throw the ship into that dreaded "flutter" which might break it to pieces. At the same time, the control simulating device afforded a splendid means of regulating the control mechanism to its most favorable setting for each of the greatly variable operating conditions.

The synthetic training devices, on the other hand, were evolved with the idea of giving to the crews advance preparation in meeting and overcoming the problems they would meet on the voyage, even before it started.

There were special training devices which duplicated the entire electrical system of the Mars vessels. These were especially for the training of the troubleshooters. Such devices afforded a field for the malicious talents of the instructors, in that they could produce intentional malfunctions to test the ingenuity and handiness of their victims. They might tear a single wire out of one of the hundreds of jack plugs or shove a burned match between the contacts of some inconspicuous relay. Stop watch in hand, they stood around the great masses of wiring and switches while the troubleshooters labored to find and repair the defect in the shortest possible time.

Then there was a complete, working mock-up of the air and water regeneration plant. Here the routine maintenance jobs, such as filter cleaning, gasket changing and valve-replacing, could be practiced. The more serious malfunctions were, of course, not neglected, especially those where speed of repair was of the essence. The crews were trained in blower troubles, "no juice" problems, defects in the water pump of the carbonic acid absorption tank, plugging of the oxygen supply and similar emergencies which might make the air unbreathable. Each and every emergency could be synthetically reproduced in all its natural horror.

There was also a synthetic flight training device for the landing craft crews. It consisted of a pilot's cockpit from a landing craft, complete with all instruments. In it the pilot and his helpers could undergo the whole gamut of the landing procedures from the departure out of the orbit to the touch down. Here they could be trained in coordinating altitude and speed. An elaborate electronic flight path simulator on the instrument panel accurately reflected the craft's response to control movements. Even a Martian landscape was portrayed on the rolling carpet that passed before the eyes of the pilot as he synthetically flew along.

The presentation piece among the training devices was the "Command Post." It consisted of a complete personnel nacelle of a passenger vessel situated centrally in a specially-built planetarium. A practice run in the Command Post was almost uncanny in the verisimilitude with which it reproduced the conditions under which the crew of a Mars vessel would some day work and live and have their being.

Of course the pilot's cabin was equipped with the same maze of operating panels, warning lights, gauges and radios as the actual cabin. Through the astrodomes could be seen the brilliant reaches of the firmament. The Sun, the Earth, the Moon, not to mention Mars with his dual attendants, could be projected in any desired dimensions upon the dome of the planetarium. They and the other planets could be made to move against the background of the fixed stars.

No crew ever went through the dry run of the voyage which this simulator offered without being deeply affected. The difficult final maneuver, the maneuver of adaptation upon return to the terrestrial orbit, when practiced in the simulator, took place as follows.

The great, sunlit shape of the Earth's sphere appeared on the velvet-black backdrop of the planetarium's dome. As the vessel gradually drew nearer, accompanied by an accurate portrayal of the increasing velocity, this great shape covered and uncovered various fixed stars as it moved along, seeming to grow in size to the eyes of the anxious navigator as he lay within his astrodome. He measured the angle between Earth and certain of her neighbor stars, thus getting a fix from his precomputed parallax tables. Chronometer in hand, he read the seconds at which certain of the stars near the Earth's rim were obscured by it and compared these times with what they should have been according to his tables. Then, as a check, he made a parallax measurement on the Moon. When he was satisfied with his observations and had good coordination between his fixes as found by different means, he would again consult his tables and then, through the interphone, would pass on to the Command the complete data on how to set up the necessary maneuver for entering the orbit of arrival.

The Captain would then aim his two telescopes, mounted on the gyro gimbals, at two reference stars on the dome of the planetarium and fix their positions by means of his photocells. He would set the course the navigator had given and start his gyros and flywheels. But where the course change would have turned the ship in reality, here it was the planetarium that moved around the nacelle, causing the entire firmament, Sun, Moon, Earth and stars, to parade across its dome so that it appeared that the "ship" was acquiring its new attitude in space. Finally, when they had reached the position called for by the ship's new attitude, the motion stopped and the navigator would continue his observations from one of the other astrodomes.

When the time came to apply thrust, the preparatory motions and the maneuver itself in the simulator called for exactly the same manipulation of switches and levers as in actuality. The same warning lamps flashed, the same gauge hands trembled over their dials as though the flight were real. Even the muffled thunder of the rocket exhaust could be heard. Dim and distant, it would only reach the occupants by transmission through the metal parts of the ship, for the vacuum of space cannot carry sound.

But there was one control panel in the mock-up which in reality would be absent. Behind it sat John Wiegand with a diabolical grin on his face. He could hear distinctly the piteous conversation between the Engineer and the Captain as he produced instrument readings on their panels calculated to drive them to desperation. Hearing their planned corrective measures, he could block their success by a turn of the wrist. One after another, he conjured up malfunctions to plague them. Suddenly, in the midst of a power maneuver, the respiration blower might stop. One of the four motors of the steering gear would show suspiciously high amperage. The worst and emotionally most disturbing trick he would play would be to indicate on several instruments simultaneously a malfunctioning of the main rocket motor. This would include a most lifelike imitation of stuttering or howling in the otherwise steady growl of the exhaust. Then there was a matter of only seconds in which the captain had to do the right thing or else endanger the entire vessel.

Every now and then, John would succeed in proving to some captain that his presence of mind wasn't all it ought to be. Looking at the victim with a cynical grin, he would remark, "there are some mistakes a man makes but once in a lifetime – and not because he learns a lesson from the first one, either. He only makes the one because he hasn't the chance to make any more..."

Of course the Command Post Simulator had no real danger attached to its operation – it wasn't a life or death matter. But it served to fill Holt's record book on his personnel with vital data. An error and its consequences could be thoroughly discussed when committed here. Errors made could be countered later by the unhurried processes of logic, and the best means of preventing or correcting could be thought out at leisure. Some definite "sequences of events" could be repeated and repeated until the correct response had been drilled into the command to a point where it became a conditioned reflex. The Command Post Simulator proved to be an invaluable aid in preparing crews for the mass of difficulties which technological troubles might foist upon them during the trip, and its high cost was more than justified thereby.

As the training proceeded, the Command Post Simulator was to undergo a fate which had not been predicted by either Spencer or Holt, both of whom had shared in its basic conception. Nor did any of the many scientists and engineers who had brought it to a state of highly ingenious perfection have any suspicion of its eventual lot.

The closer the date of eventual departure of the expedition approached, and the more millions were swallowed up in Operation Mars, the greater became the number of Very Important Persons who could not refrain from getting a peep behind the scenes of this most titillating of all projects. Mostly they were driven by a combination of sense of responsibility and just plain curiosity. In ever-increasing numbers they swarmed around the building slips of United Spacecraft for inspections of the landing craft and the components of the Mars vessels. Almost all of them wanted a trip up to the orbit of departure to watch the final assemble, but at that point, General Braden called a very decided halt indeed.

This made the Command Post Simulator a favorite spot for cigar-bearing senators and efficient looking executives. All sorts of dignitaries could be found in it, including Indian potentates and venerable, clever old Chinese, who were frequently said to be influential members of the United Congress. Gray-headed generals renewed their youth in the Simulator as they envisaged realistically what would face the expedition. Braden had found a smooth and satisfactory treatment for these gentry, for, while they often cluttered his efficient plans, he did not feel it wise to risk their displeasure by neglect. And so it came about that John Wiegand often found it necessary to restrict his tender ministrations in the matter of producing synthetic interstellar disasters. Whenever a practice run for once went off without incident, the otherwise tortured crews would remark, "well, that was a V.I.P. run, all right…"

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Meanwhile, Sam Woolf had not been idle and had lined up his program of geological studies on Mars under the supervision of Ashley's organization. Holt had promised him a detail of 12 men for excavation and similar geological purposes. This stimulated a veritable flurry of enthusiasm in the development and preparation of suitable digging and drilling tools. The latter presented no small problem in view of the limited tonnage assigned to Woolf's equipment, and particularly because they would have to operate under wide temperature variations in Mars's thin air and be manipulated by men encumbered by space suits. Among other things, Woolf procured a series of colored photographs of terrestrial rock formations of great variety in order to promptly recognize and classify those of Mars, so that he might purposefully lay out his work.

The World Research Board took over in its psychological section a weird assortment of gifts which from all directions were pressed upon Holt for transmission to the Martians. Each giver wished to dispose the Martian recipients favorably towards Earthmen and to acquaint them with the beauties, achievements and peculiarities of life on this terrestrial sphere.

There was a marvelous collection of colored photographs showing every aspect of the Earth's vast countenance. Some were taken from Lunetta and showed Earth as an enormous disc of oceans, clouds and continents. There were pictures of towns and cities in all regions, landscapes, mountains, forests, factories, observatories, ships, railways, automobiles, aircraft and people of all races and colors at work and at home. Flora and fauna were not missing. But of all the photographic subject matter, the ocean was the most prolific. Surf, calm and storm in all their infinite variety seemed to be counted upon to make the greatest impression upon the liquid-lacking Martians.

Not neglected was a sample collection of artistic and handicraft products from different regions. Reproductions of famous paintings, sculptures, memorials and architectural masterpieces; phonograph records of symphonic music, opera and modern music came, along with films of plays and extracts from daily life. There were artistic Chinese silks, Belgian embroideries, French jewelry, German optical work, English porcelain. Finally there were important varieties of woods and metals, ceramics and plastics, together with pictures typifying the advancement of arts and sciences, including a chemistry set with which simple experiments might be demonstrated.

It seemed well for Holt to carry with him under lock and key a folder showing the war potential upon Earth. Atomic explosions, men of war, bombers, space vessels, radar gear, tanks and battle scenes were here depicted in the unhoped-for event that the Martian mentality might exhibit inimical inclinations towards the sister planet. But it was the deepest hope of Holt and of all his collaborators that even a discussion of eventual hostilities would never be called for.

Chapter 11
The Cosmic Rays

One of the training phases for the great expedition consisted of a month's course of lectures in the old rocket pilot's school in Kahului. It had the further objective of welding the participants into an integrated unit which should be capable of withstanding the physical and psychological hardships of a three years' trip through space. Consequently, it likewise acted as a screening operation, subjecting its members to the most severe type of character test, including absolute sequestration from the outside world. Three candidates in all actually failed to meet the requirements by mockingly belittling Holt's Spartan regulations.

The physical capabilities of the future spacefarers were also tested to the limit under the supervision of a small army of medical and psychological specialists who allowed no defect, whether of body or of personality, to escape. Particular attention was paid to equilibrium and respiration. Even the scientists were made to undergo an exhausting course of athletic exercise to fit them for the great adventure.

The lecture course included every possible phase of interstellar hypothesis and knowledge, it being one of Holt's cherished theories that no member of the expedition should ever pose any question which must remain unanswered within the knowledge possessed by the science of the day. Among the relatively unfamiliar subjects was the effect of cosmic radiation upon the human frame. The Lunetta crews were exposed to it but for short periods, since no man ever spent more than 14 days on duty in the artificial satellite, followed by not less than a month deep within the sheltering shell of the atmosphere. There was much discussion as to what would happen on the trip to Mars, when even the favored ones who would descend to the planet would be exposed to cosmic rays for almost a year and a half, while the shipkeepers who would circle in the Martian orbit would find no shelter from the rays for a full three years. There were those who insisted that members of the expedition would return to Earth, if indeed they returned at all, with severe damage to their organic systems.

Even Holt's tougher lads became somewhat affected by the gloomy prognostications of some of the amateurs who made such dire predictions. Well aware though they were of the more obvious dangers of the mission, and as intrepidly prepared as they might be to face them, the idea of possibly returning to their homes with manhood impaired by treacherous, invisible rays, or that their posterity might be endangered by mysterious "mutation changes," was depressing to even the least sensitive.

To lay the ghost of such fears and trepidations, Holt turned to the foremost radiation physicist, who was no other than Senator Perucci and to whose sympathetic understanding much of the money and facilities available to Operation Mars might be ascribed. Perucci found time to keep up with the study of cosmic radiation, despite his political activity, and was not long in responding favorably to Holt's request that he come to Kahului for a lecture on cosmic rays and their physiological effects, in order that the fears of the spacefarers might authoritatively be allayed.

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"We refer," Perucci began his lecture, "to tiny particles, moving with enormous velocity from the depths of the cosmos into more proximate space, as cosmic rays. Most of these tiny particles are protons, that is, atomic nuclei of the hydrogen atom. About 0.4% of them, however, represent atomic nuclei of heavier elements, of which the heaviest particles hitherto observed possessed a mass 96 times heavier than that of protons, thus corresponding to the weight of the nuclei of molybdenum.

"When such particles penetrate our atmosphere, they not infrequently collide with its atoms. Such collisions may occur after two fashions, according to whether the penetrating particle is decelerated only by the electrical field of the atomic nucleus, or collides head-on with the latter. In the first case, only ionization takes place along the paths of the incident particles. Their energy loss by ionization is low. However, the probability is considerable for every oncoming particle to impinge directly upon an atomic nucleus within the uppermost layers of the atmosphere. In this case, a so-called 'explosion shower' is generated, in which protons, neutrons, mesons electrons, positrons, photons, as well as heavy atomic fragments consisting of nuclei of elements like carbon or nitrogen, are hurled out.

"The more energetic electrons and photons created in such an explosion shower are of particular interest. Electrons are rigorously slowed down by the fields of atomic nuclei, thereby generating additional radiation quanta or photons. These photons, while traversing the strong electric fields of other atoms, are able to materialize by forming pairs of electrons and positrons which then fly off. If these electrons and positrons enter the fields of further atoms, they are retarded and again create photons. Thus the so-called 'cascade showers' develop.

"Mesons, which have a mass some two hundred times greater than the electronic mass and have one positive or negative charge, are but slowly absorbed in the atmosphere and even in the solid crust of the Earth. They have been found thousands of feet under water and even at the bottom of deep mines. Nonetheless, their number decreases rapidly during their travel through the atmosphere due to their inherent instability: Mesons are subject to radioactive decay; after an average lifetime of one millionth of a second, they disintegrate into a common electron and a neutron.

"Decay and transmutation products thus induced, together with fragments, now have the effect of secondary radiation. The secondary particles are subjected to further collisions which give rise to tertiary radiation, and the chain continues. Thus we, at the bottom of our sea of air, and anywhere within it, are constantly exposed to a continuous hail shower composed of an already much weakened primary radiation, largely very fast protons, plus a whole family of collision products. Among these collision products are secondary protons, electrons, positrons, neutrons, photons, mesons and heavy atomic fragments.

"Experience has shown that our human organism is very capable of long withstanding this shower of radiation, at any rate insofar as its strength and composition at ground level are concerned.

"Science is still largely in the dark as to the true origin of primary cosmic radiation. The mean quantitative distribution of primary particles in protons and heavier nuclei seems to reflect quite accurately the quantitative distribution of the chemical elements in the cosmos, as derived from spectroscopic examinations of fixed stars. The latter show hydrogen to predominate to a marked extent. There is, therefore, a tendency to regard cosmic radiation as a product of atomic explosive catastrophes within the universe, although we unfortunately are as yet unable to conceive of the mechanism of such explosions. The energy of the fastest particles hitting the top of our atmosphere has been estimated to be as much as one thousand million million electron-volts. Most particles, however, have lower energies, their abundance being inversely proportional to about the square of their energy. The average energy of the incident particles amounts to ten thousand million electron-volts. If we consider that the famous splitting of the uranium atom produces only some 200 million electron-volts, and that this would be multiplied only by about one thousand were the mass of the uranium atom wholly to be converted into energy, the origin of the huge energy of some primary particles remains a moot question. It is thought at the present time that there are pulsating magnetic fields in the vastnesses of space, created by cosmic clouds, streams of ions or clusters of fixed stars. The original, slow, energy-lacking protons fly through such fields and are accelerated. They move from one field to another with increasing velocity, as in a betatron. But this theory is unable to explain many phenomena and certainly requires further perfecting.

"For our particular purposes, however, we may well omit further theorizing on the origins of cosmic radiation. Let it suffice that such rays exist and let us examine whether, and if so, how dangerous they may be to the human frame during extended space travel.

"We are justified in considering primary cosmic radiation particles, as well as their secondary and tertiary offspring resulting from collisions with atmospheric particles, as tiny projectiles constantly traversing our bodies. Since the human organism is also constructed of atoms and molecules, collisions occasionally take place between these projectiles and the building blocks of our bodies. Such collisions induce decay and transmutation products as well as fragments, just as did collisions in the atmosphere, representing a new family of secondary rays. There's no doubt that the body-molecules involved may be damaged in such collisions.

"On the other hand, the probability of one of these tiny projectiles contacting a body molecule during its passage is but small. The atomic nuclei with their circling electrons of which our body is composed, are separated by such wide spaces that most particles pass through without any contact or disturbance, as though through a coarse sieve. In order to visualize this we must remember that the size and interval relationships between the building blocks of our bodies have the same relationship to one another as size and interval relationships between the Sun and planets in our solar system. Thousands of such particles pass through us every minute and we can compute the probabilities of hits over any given period.

"While our bodies are slowly destroyed in this manner, the process is opposed by what we may call the natural rejuvenation factor of living substance. Experiments with radioactive isotopes as tracers show that, in a cycle of a few years, all the atoms constituting our organism are replaced by new ones. That means that there's not a single atom in us today which was there a few years ago! This not only renews the building blocks of cells which have died in any fashion, but also continuously eliminates the detritus caused by the bombardment of cosmic radiation particles.

"We can envisage a relatively simple image of the dangers of cosmic radiation in open space if we set up a frequency of occurrence comparison for primary particles plus the secondary and subsequent collision products as occurring in various altitude layers of our atmosphere.

"For some time – and the figure has been confirmed by measurements in Lunetta – we have known that every square foot of the upper atmosphere receives per minute some 21,500 primary protons and 79 heavier nuclei. These figures give us a measure of the density of cosmic rays in empty space which you and your Mars vessels will traverse.

"At 60,000 feet, the primary particles have been reduced to 6,400 by collisions with the atoms of the atmosphere. But the collisions have the effect of producing at this height a supplementary stream of radiation consisting of 17,000 secondary protons, 15,000 neutrons and 12,000 mesons. Additionally, every square foot at this altitude is penetrated by 48,000 electrons and positrons, produced by the collisions, per minute.

"At about 14,000 feet, an altitude exceeded by but a few of our mountains, the number of primary particles is reduced to a very small, not accurately known figure. But there are still some 300 secondary protons, an equal number of neutrons, and about 2,500 mesons.

"At sea level, these figures are down to 20, 20 and 1,100, respectively.

"What may we deduce from these figures?

"The first thing is that the comparison shows indubitably that the total density of radiation at 60,000 feet altitude is much higher than in empty space; the number of particles at 60,000 feet is about 86 times as great as at sea level, while in empty space it is only about 19 times as great! If we choose to consider secondary particles of cosmic radiation to be as dangerous as the faster primary particles – which may not necessarily be quite correct – it is obviously far more dangerous to fly in the atmosphere at 60,000 feet than to remain in empty space for an equal period.

"In neither case, however, do we need to be much concerned about our health. The natural regenerative processes of our organism are competent to remove the detritus of the cosmic ray bombardment and to provide new atoms as they work their continuous miracle of cell rejuvenation.

"The problem of the effects of the bombardment upon our posterity is a different and perhaps a more serious matter. In the rapid succession of generations, in the continual disappearance and regeneration of our cellular structure there is a something which is as unalterable as the Rock of Ages. This something is the "genes," the bearers of hereditary qualities transmitted from parents to children. Genes supervise the continuity of the species; they explain hereditary family traits and determine the inherited dowry which is laid with each child into the cradle. The characteristics of the one and a half million genes which actively participate in one act of fertilization determine not only the character of the infant, but they also determine each and every physical detail, down to color of eyes, facial expression and skin pigmentation.

"Genes are also constructed of atoms and molecules, so that any damage to them by cosmic radiation must be far more fateful than damage to our organism itself. Changes in the structure of the genes, such as have been proved may occur under the affect of radiation, affect not only the characteristics of immediate offspring, but are fundamentally inheritable. Such permanent alterations of inheritance are known as 'mutations.'

"We may compute the probability that a gene, a unit of our inheritance, will be damaged by cosmic radiation, for it may be statistically treated, since we know the shot-density and the size of the target. If we assume radiation density as that of ground level and apply it to the period extending from birth to the termination of reproductively of the average man or woman, the computation shows that a gene will be struck about ten times within the many generative cells generated over that period. But only a very tiny fraction of the generative cells of a person have the opportunity to participate in determining the characteristics of a child. Hence the probability of mutations affecting the individual family is minute.

"Due to the fact that there are some 2 billion inhabitants on our Earth, there is a goodly chance for a number of hereditary changes in each generation, despite the small likelihood of a mutation in any given family.

"A mutation is by no means always negative, for we have both good and bad inheritances. While some inherited diseases, such as the hemophilia of the Russian Czars, may turn up, improvements in heritage are also possible.

"It seems to me that the Darwinian doctrine of the survival of the fittest should here be introduced. A more intelligent, stronger, better species in the long run has a better chance of survival that the obtuse, weaker and poorer. Perhaps we can interpret the development of man from Homo primigenius to modern Homo sapiens as the combined effect of mutations on one side and Darwin's selective survival on the other. This may even be a tiny peep-hole into God's mysterious laboratory…

"Whatever our attitude towards such interpretation, one thing is certain, and that is that every living thing on Earth is subject to a certain, definite, but small prospect of a mutational change by cosmic radiation. The prospect is immeasurably small for any individual, as has been strongly attested to by the amazing uniformity with which human, animal and plant species have continued themselves through the ages.

"The total cosmic radiation density in empty space is some 19 times greater than on Earth, according to the figures just presented. A gene, however, cannot be exposed to particles penetrating the body until a certain layer of the body had been traversed. The thickness of this layer will, of course, be affected by the angle at which the particle impinges. In space, the particles approach from any direction, so statistically we shall do well to figure a certain mean layer thickness. This is about equivalent to 20 centimeters of water surrounding the genes. Collisions may of course occur in this layer, preventing primary particles from reaching the genes to some extent, but also increasing the danger of their being struck by secondary products from these collisions. You will see that the body provides a shield for the genes similar to that of a thin atmospheric layer and that the density of particles is somewhat higher than that produced by the primary radiation alone. It can be estimated that in empty space the genes are not subject to 19 times the surface level cosmic bombardment, but to one 40 times as heavy.

"On the other hand, cosmic rays are by no means the only sources of mutations. It has been scientifically confirmed that certain chemicals, of which colchicines is one, can also affect the genes. Botanists have found in experiments with plants that exposing the genes to marked changes of temperature, in particular shortly prior to the fertilization process, has much the same effect. Mutations are sometimes caused by radiation emitted by lighting. There may even be arbitrary reorientations within the complicated molecular structure of the genes.

"Therefore there are quite a variety of additional causes of mutation aside from cosmic radiation. Some of these causes, such as lightning, do not occur in empty space. Under these circumstances, it is difficult to say to what extent a mutation is more likely to take place in space than on Earth. We may, however, state that the factor of cosmic radiation will not be multiplied by more than 40.

"When applied to any individual, this factor of 40 is negligible. After all, gentlemen, you do not propose to expose yourselves for the rest of your lives to this radiation, but only for some three years. We believe that millions of people would have to expose themselves in empty space for a lifetime before we scientists could confirm an increased number of mutations in succeeding generations.

"Now, you might like to know whether the nacelles of the Mars vessels might not be shielded to a point which would reduce the cosmic radiation density within them to that of the Earth's surface.

"The absorptive capacity of our atmosphere corresponds to that of a leaden wall some 40 inches thick. I need not tell you that anything even approximating such a thickness would render the Mars vessels incapable of fulfilling their functions. Anything thinner would be worse than useless, for as you have learned, the total radiation density at 60,000 feet is higher than in empty space by reason of the collisions between the atoms of the atmosphere and the particles. It is the atmospheric layers below this altitude which absorb the secondary radiation to an extent which reduces the total radiation density at sea level to less than that of empty space. Therefore a shield of a few centimeters of lead would only make matters worse and offer no protection whatsoever. It would simply increase the probability of collisions without being thick enough to absorb the secondary radiation.

"Thus, the thinnest wall remains the best, and the organic outer skins of your nacelles are favorable to the protective issue. The organic plastics of which the nacelles will be composed contain primarily hydrogen, carbon and oxygen atoms and are highly porous to the primary particles. Thus collisions, with their resulting secondary radiation, will be reduced to a minimum and the radiation density within will be no higher than in empty space, while metal walls of moderate thickness would increase it.

"In short, gentlemen, I believe that I can assure you that there is hardly any danger to which you will be called to expose yourselves that will be of less consequence than the cosmic rays, as infamous as they may be thought to be.

"There's no doubt in my mind that you risk yourselves and your posterity to a far greater extent each time you get into a motor car than you will be doing by exposing yourselves to cosmic rays in the nacelles of your space vessels."

Chapter 12
The Great Space Lift

General Braden concentrated his personal attention on the organization of the ferry service which would freight Operation Mars up to the orbit of departure. Already he had reduced the rocket vessels which served Lunetta from 30 to 12. Those 18 ships which he assigned to Operation Mars were immediately sent to United Spacecraft for the necessary modifications, which included complete removal of the passenger accommodations and the relatively small cargo bays from the top stages. Fifteen of the vessels were equipped with cargo tanks for the hydrazine and nitric acid propellants of the Mars vessels. The other three ships were rebuilt with wide doors and large, roomy cargo spaces for the bulky components of the Mars vessels to be assembled in the orbit. United Spacecraft further completed 28 more *Sirius*es as propellant freighters exclusively, giving Braden a fleet of 43 tankers and three cargo vessels.

The ferry plan provided that each vessel should average a trip every ten days, and actually, the top stage of each ship required but 12 hours or so for a round trip. The problem of salvaging the booster stages, particularly the second stage, with its drop into the ocean a full thousand miles from the launching site, was complicated by reason of the three days required by the salvage steamer to get back to the base. There were, nonetheless, some seven days available for inspection, repairs and reassembly of the various stages to prepare each ship for its next departure. Experience with the Lunetta ferry system indicated that such a schedule could be safely complied with, and matters were so arranged that the 950 Mars ferry flights could be carried out within about eighth months, even if as many as six ships should be concurrently out of commission for major repairs.

Braden's plans were synchronized exactly with spacecrafts' delivery schedule for the components of the Mars vessels and with the assembly schedule for the orbit of departure. Accordingly, a few cargo flights delivered a number of tank frames and tanks, followed by one of the nacelles for the passenger vessels. This cabin was to serve as a primitive shelter for the assembly gang during their labors in space. Working in space suits, the men assembled the frames and located the tanks within them, ready to receive propellants. This permitted the propellant loading operation to begin without delay, during which the tankers pumped their hydrazine and nitric acid into the prepared receptacles of the as yet incomplete Mars vessels. Two tankers were to be launched simultaneously every 12 hours and to lay alongside the storage tanks which they would fill through their delivery hoses within the ten hours preceding the arrival of the next shipment. Then they were to uncouple their hoses and apply to themselves a brief decelerative thrust in order to reenter the elliptical plunging path whose perigee would touch the atmosphere after the ship had gone half around the Earth. After another half circle in extended gliding flight they would return to their point of departure. During the elapsed 12 hours, this point would have slowly advanced 180° by the Earth's rotation, and would hence again be below the orbit of departure.

The cargo vessels were intermittently to deliver the other Mars ship components as the fueling proceeded. The last movement was to be that of the landing craft, whose wide wings would already be awaiting them in the departure orbit. Using their own rocket motors atop *Sirius*-class booster stages, they would fly up to orbit to have their wings attached, and would themselves then be clamped to their mother ships in anticipation of the long voyage through space.

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This was an enormous logistical effort, the greatest ever undertaken by the Space Forces. Establishing Lunetta had been child's play in comparison. But before Braden could begin it, he was faced with another important problem.

The plane of the orbit of departure lying, as it did, in the ecliptic, had eliminated Kahului as a practical base of operations for the ferry vessels, for the Hawaiian Islands are approximately in the latitude of the Tropic of Cancer. The latter represents the northernmost latitude attained by the orbit. Nor could more than one launching operation every 24 hours be carried out from Kahului, and this would have delayed the entire ferry operation. In addition, there was the matter of utilizing the maximum payload, and the location of Kahului was unsuited to this.

Braden therefore was forced to establish an entirely new base for the ferry vessels at Christmas Island, a huge atoll of more than 100 miles circumference rising from the Pacific to bare the ring of its palm-fronded islets 1,200 miles South of Hawaii. Since Christmas Island was almost exactly on the Equator, it was from there that the maximum peripheral velocity produced by the Earth's rotation could most effectively be utilized for ascent. At the Equator, this velocity is 464 meters per second, and since the direction of movement in the orbit of departure was identical, a velocity of 464 m/sec was no mean contribution to the required total velocity of 8,260 m/sec. In actuality, only 425 of those 464 meters per second would be saved, and this was because of the angle between the ecliptic and the Equator. Nevertheless, some six tons of propellants per trip would remain in the tanks of the ferry vessels over and above what would have been there had the trip been made from Kahului to Lunetta. Since the propellants were the same as those used in the Mars vessels, this represented a considerable net gain of available payload. Only by this gain had it been possible to reckon with but 950 flights for the whole ferry operations.

The base on Christmas Island shared with Kahului the advantage that there was direct sea transportation between it and the plant of United Spacecraft at Long Beach, for very nearly all the material to be shipped was either manufactured there, or passed through there for testing or adaptation. The problem of loading propellants was far easier in steamer ships than in tank cars. It would require more than 500 shiploads, so that this aspect alone was a determining factor in the selection of a new island base. The Dupont Corporation expanded for the Space Forces large propellant plants in both Oakland and San Diego, and nothing was easier than for the tankers to go alongside the loading piers in these harbors, load up, steam to Christmas, and discharge into its storage tanks.

Early in January, 1983, eighteen months work had put the Christmas Island base into temporary operating shape.

It was a rude shock which awaited the crews detached from the Lunetta ferry service and their comfortable quarters in Hawaii. The grousing was like the grousing in every army since Caesar's, to the effect that when a base was picked by the Space Forces, it was at the most God-forsaken spot on the map. When they got there, Braden took their worries off their minds by delaying the ferry flights to the orbit of departure as little as possible. To keep soldiers busy was also an old Roman custom.

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A number of salvage steamers were always within the Christmas Island atoll while the tankers were unloading propellants into the tank farm near the docks. These salvage ships sought out the exhausted booster stages as they dropped into the ocean. Like returning whalers, they carried the great bulk of the boosters on their low-lying after-decks when they entered the atoll's protected waters through the channel which had been blasted through the barrier reef. They always flew a victory pennant from the fore truck, somewhat like that flown by a successful sail fisherman.

Salvaging boosters had become a science since the first modest space ships were developed; it had become so important that a number of special devices for it had come into being.

The enormous first booster of a *Sirius* ship produced a thrust of not less than 12,800 tons and imparted to the upper two stages a velocity of 2,350 meters per second in 84 seconds. At the 84th second, when the initially vertical flight path had curved to a little more than 20° from the horizontal, the ship would be 40 kilometers high and about 50 kilometers horizontally from the launching site. Then the second stage began to exert its thrust, separating from the empty first booster below it. With its tanks empty, the latter still weighed 700 tons.

There is still considerable drag at 2,350 m/sec, even at an altitude of 40 kilometers, and at the moment of separation, a large parachute of wire mesh emerged from the after end of the exhausted booster. The parachute slowly decelerated the great bulk on its still rising path, attaining several hundred degrees of heat in the process, by reason of the high velocity. The metal of which it was constructed, however, could easily withstand this. The booster continued upward to about 64 kilometers altitude from which it descended to the sea, its velocity having dropped to 1,250 m/sec when it passed the 40 kilometer altitude. Now the booster's flight path began to grow steeper, until it finally reached sea level some 190 miles from the launching site, approaching the water at 50 meters per second. It had flown for seven minutes.

When the huge bulk was still 50 meters above the sea, a ground proximity fuse went into action, igniting the braking rockets. These were mounted in the nose section of the booster and now pointed downwards due to the pull of the parachute on the other end. Their ten streams of fire, generated by powder, exerted an upward thrust of almost 2,500 tons for two seconds. Had the booster continued seawards at the same rate, it would have been destroyed by the impact, but the rockets, pouring their violence against the water, reduced the speed left by the parachute to almost zero. Thus the booster landed softly in the water, roiled by the rockets, and submerged.

Before long it emerged once more, rolling like a wounded whale as the flotation of the great, empty tanks turned the huge stabilizing fins downwards. Finally it floated supinely, its empty powder rocket tubes pointing at the sky and the heavy rocket plant acting as ballast.

A salvage steamer had been waiting in the vicinity, tracking the booster's descent with radar. Now she hastened to the spot where the great, buoy-like mass rolled amid the frothing seas. She approached it cautiously, with much backing and filling, for to hoist aboard such a clumsy object was no child's play. Specially trained teams had been developed for the purpose, for any slight contact between the hull of the steamer and the delicate structure of the booster might well result in damage which would mean long and costly repairs.

The ship moved stern first towards the booster with the jib of a crane mounted at the taffrail extending above it. From the outer end of the jib hung a bridle with a heavy spreader, upon each end of which sat a man. The bridle was lowered and the two men skillfully shackled the ends of the bridle onto two fittings located atop the booster especially for this purpose.

It was a majestic sight when the crane began to hoist the dripping black monster clear of the sea. The twenty meters of diameter and its 29-meter length, adorned by the huge stabilizing fins, finally hung above the water as the ship's stern sank several feet because of the added weight.

Before the jib of the crane was swung around, a second great stream of water poured out of the belly of the suspended monster. A fresh water hose had been part of the suspension bridle, so that all parts of the valuable booster might be sprayed down to prevent damage by the corrosive sea water to its complicated equipment and delicate structure. When this was completed, the crane swung around slowly and deposited its load upon an open section of the steamer's deck, forward of the crane. Here the stabilizing fins were promptly secured by screws to fittings prepared for them.

But the steel cable leading to the parachute still hung over the side of the ship. It was attached at its inboard end to a ring inside a large containing drum located in the center of the rocket combustion chamber and its nozzle system. The latter covered the whole cross section of the booster. The metallic parachute, of course, had sunk.

To salvage this 'chute with its 85 tons of weight and its diameter of 64.5 meters was almost as much of a problem as to salvage the booster itself.

In earlier days, this complicated job had been done with a large net lowered from the jib crane into the water astern of the steamer. Four steam winches had wound in cables with grapnels at their ends which had engaged in the bulky metallic 'chute and pulled it into the net, piece by piece. Finally the crane had hoisted the net, 'chute and all, inboard. The salvage was too primitive to avoid frequent damage to the delicate parachutes, and such damage was always followed by extensive repair work.

But now the ferry trips of the Mars vessels were greatly facilitated by a new procedure which had been worked out by the Space Forces for this salvage activity. It had been proved superior to the older method by extensive testing.

A roll of reinforced sailcloth was suspended just aft of the stern of the ship between two outriggers. The roll was about 10 feet thick and as wide as the beam of the ship. The whole thing was somewhat like a roll of carpet. The roll began to turn under the power of an electric winch and the sailcloth dipped into the water with its ends delimited by two thick, round disks. Under the weight of the wire reinforcement, the sailcloth unrolled ever faster until stopped by a brake on the roller. Thus the full 180 meters of the sailcloth was submerged, the 'chute hanging almost collapsed, its depth nearly that of the sailcloth.

There was a switch hidden behind a plate at the base of one of the four stabilizing fins of the booster. This closed an electrical circuit running through a conducting core concealed within the lay of the parachute cable. When current flowed, it set in motion a reefing motor located in a watertight casing at the open end of the parachute. The motor reeled in a thin steel cable which closed the bight of the parachute down to a few meters as it hung deep under water at the end of its cable.

Now the steamer's engines went slow ahead and the great parachute began to open as far as the draw-line tightened by the reefing motor would permit, but still creating much drag behind the slowly moving vessels. As the speed of the steamer increased, the parachute on the end of its cable, now secured to bits at the stern of the ship, began to approach the surface. It streamed out behind the ship at an ever flatter angle, until some fifty meters astern, the first visible meshes of the 'chute appeared above the boiling wake.

Soon, almost the whole pocket of the great mass of metal ribbons was whirling and flashing near the surface like a school of flying fish. The long sailcloth roll had been pushed up beneath the parachute by the dynamics of the water and was raising the whole thing above the surface, much as a man on an aquaplane is supported by it.

At last, the parachute lay with its whole length clear of the water and was kept narrow within the width of its supporting sail by the drawstring.

Now a man on deck pushed a button and a solenoid in each of the two disk-like affairs at the far end of the sail pushed off two can-shaped covers. This revealed on each disc a little water wheel with spoon-shaped paddles. Promptly beginning to revolve in the wake of the advancing steamer, these wheels began to roll up the sail and the parachute within it around their common axle. It seemed that the towed sail was growing shorter as the roll it made at its after end grew thicker and thicker.

Some 40 meters astern of the steamer, this rolling-up process stopped due to the weight of the axle and its burden being too great to be supported above water by the now shortened sail. At this point an electric motor began to rotate the huge drum upon which the towing sail had been stowed. The sail was wound back onto it until the great mass, nearly 12 feet in diameter, between whose folds lay the dual layers of sail and parachute, was clear of the water. Just before this emerged, there appeared an enormous swivel weighing some two tons. This swivel, joining the parachute suspension line to the shroud lines of the great canopy, was to prevent any fouling of the latter if the body of the booster should begin to rotate while in descent.

The carpet-like roll of parachute and towing sail was not hauled inboard, but secured to the after section of the hull, well above the waterline. Then, as the steamer's screw began to turn in earnest and her course was set for Christmas Island, the radio flashed the welcome news of another successful booster salvage to the Ferry Command.

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The spacious inspection and repair building for recovered boosters stood close by the bulkhead of the inner basin of Christmas Island. As the Steamer came alongside, the ship's crane deposited the booster gently on a wide trailer which was then promptly hauled into the building.

Here the reconditioning procedure began immediately, starting with the drying process by blasts of hot air. These removed any remaining traces of water from the booster's ducting within a few hours. Still on its trailer, the booster next went into one of the test chambers, where it was thoroughly inspected for dents, damage and sprung rivets. The electricians connected the plugs on either end to their multipoled testing circuits which terminated in a profusion of test panels upon which glittered masses of switches, gauges, meters and test lamps. This revealed any defect in the magnetic valves, switching relays, servomotors and the rest of the complicated equipment which rendered the launching of a *Sirius* well-nigh automatic. Other mechanics connected compressed air mains to the tubing of the propulsion unit, verifying its leakproofness and the operation of its multiplicity of valves.

Any defects revealed during these inspections were immediately made good by specially trained crews carrying appropriate replacement parts.

Usually there were a few minor elements whose operation might be considered unsatisfactory, such as a sticky relay or a recalcitrant valve. All such commonly required parts were kept in stock in the building itself and could be obtained without delay. But occasionally there was major damage to be repaired. In such cases, which might vary from a crack in a seam weld on the rocket motor to a defective turbopump, the entire hull section of the booster might be hoisted by the overhead crane, as an undershirt is stripped from a patient in a hospital. The workmen would swarm around the inner structure like bees and remove the defective unit, installing a new motor or turbopump in laborious hours or even days of effort.

One of the regular operations in preparing a salvaged booster for a new flight was the replacement of the exhausted deceleration powder rockets. Each of these ten rockets, as it checked the descent of the great booster a few meters above the ocean, developed a full 250 tons of thrust. It was a little more than 1½ meters in diameter and was about two meters long. The powder charge weighed 2.5 tons and was loaded in steel drums weighing almost 1.5 tons empty. When the powder was ignited, it burned for two seconds, expelling its gas in a violent jet of flame at a pressure of 200 atmospheres to produce the upward thrust which slowed the downward motion of the plunging booster.

When this work was completed and the test section had certified the booster as ready for service, a tractor hooked on to the trailer and dragged it over a pit where the parachute was installed. This pit was just outside the building. The parachutes themselves were taken directly from the salvage steamer to a separate shop where they were removed from the rolled towing sails, thoroughly inspected, and finally given a new coating of corrosion-proofing. Then they were skillfully loaded into special metal containers and sent to the installation pit. Here a hydraulic ram pushed the container upwards into the parachute housing of the booster. It was locked in, and the suspension cable was attached.

Two assembly sheds were located some eight miles away along the ring of the atoll, on which a wide concrete road had been constructed. The trailer was towed to the sheds not far from the launching site. Each shed was an enormous, tower-like structure some 70 meters high and each could contain four complete *Sirius*es at a time.

Within each shed there was a mighty overhead traveling crane which lifted the complete booster slightly from its trailer as it came in, while the trailer was removed. The heavy metal annulus from which the launch would be made was on rails and was run under the booster which the crane gently lowered onto it.

It was not time to mount the second, or "baby," booster, as the Space Forces called it. Looking somewhat like an egg truncated at one end and in the middle, it was brought into the shed and made ready. It was 20 meters in diameter at one end, thus matching that of the "big" booster. At the upper end it tapered roundingly to 10 meters, above which section the third stage would find its place. The whole baby booster was about 14 meters high.

Now the traveling crane lifted the baby and set it in place atop the stumpy taper of the "big" booster's upper level. The taper also served as jet deflector for the baby when the latter's rocket motor began to spew flames after the propellants of the larger and lower rocket stage were exhausted. Around the taper there were four vertical guide rails into which the baby was now carefully fitted. A bare meter above the tip of the jet deflector cone, the lower part of the small booster came to a stop. Four mechanical couplings which provided the rigid connection between the stages clicked shut. They would part electromagnetically only in flight, when the big booster was to drop off. As the couplings snapped shut, the multiple-pole electric jacks and plugs also connected firmly.

Now the crane fetched four large rectangular cover plates. These would close the annular gap between the two stages. Just before the baby booster's motor fired, these cover plates would be released by explosive bolts so that the jet might freely emerge around the lower stage's conical top. The ignition cable leading to the explosive bolts was plugged in, and thus the first part of the assembly was complete.

When the top stages had completed their trip to the orbit of departure and returned, after discharging their freight they landed on a runway not far from the assembly shed. The runway stood on piles within the protected waters of the atoll, and the date of completion had been a masterpiece of coordination between the Space Forces and the contractors.

Like the others, the top stages also were thoroughly checked after each landing. A hangar was available for this purpose, nor were they approved for other flights until the inspection had been completed.

When their retractable wings were spread, they looked rather more like conventional all-wing aircraft than rockets. Their wings were highly raked, and had two conspicuous steps where the thinner retractable outer wings protruded from the thicker mid-sections. The span was 52 meters. Approximately where the first step of the telescoping retraction took place, were two vertical stabilizers with rudders behind them.

In comparison with the Martian landing craft, with their much greater span, their hulls appeared rather fat and stubby. This was largely due to the huge flat bases, 9.8 meters across. Without this great area, the top stages could not have expanded their gases of combustion down to almost one hundredth of an atmosphere. Thus with their length of but 15 meters the hulls appeared rather like short artillery projectiles.

The top stages, when belonging to cargo vessels, received their loads of non-fluid cargo immediately after their inspections, and were towed to the assembly sheds on their own landing gear. Their wings were hydraulically retracted as the tractor drew them into the shed. Here two thick, round steel tubes were inserted transversely fore and aft, so that each protruded from both ends. The four ends were picked up by slings from the crane, the ship was hoisted horizontally and the landing gear was retracted. When the ship had been hoisted halfway, the stern was lowered and finally swung into position above the double booster and lowered into its seat. Thus the third stage, once in place, comprised the forward point of the whole enormous rocket.

When the three stages had been joined, two men entered the pilot's cabin in the top stage and thoroughly checked the various flight mechanisms. If everything worked well, the ship was declared in flight condition.

There were four separate launching sites on Christmas Island, two of them being operated in conjunction with each assembly shed. When a ship was to be launched, one of the great sliding doors in the building opened to permit its 60 meters of height to pass out. The powered launching platform, complete with jet deflector and running upon wide-gauge tracks, bore the vertical rocket ship to the takeoff site, located a scant mile from the building. The site itself was no more than a wide concrete platform permitting various auxiliary vehicles to approach the waiting rocket ship and eliminating, as far as possible, any damage from the pelting of the surroundings with rocks and pebbles that would take place if the mighty blast of the jet were to impinge upon unprepared ground.

When the site was reached, the launching car was immovably anchored by tong-like brake shoes to the rails and a web-like series of propellant hoses was attached. Each of the three stages was filled with two propellants independently through separate hose lines.

A system of pipelines connected the filling stations at the launching sites with the storage tanks near the harbor. There was a fuel meter on each outlet, permitting maximum accuracy during the tanking procedure.

When the filling was over, the elevator gantry on its trailer was brought alongside the ship and the crew went aboard. All was ready for another takeoff for the orbit of departure.

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Braden's schedule called for the departure of two ships every twelve hours. They would be launched almost simultaneously and proceed in formation to the orbit of departure. This cycle of 12 hours was determined by the positions of the growing Mars vessels in their orbit, for there were only certain moments at which a *Sirius* ship could take off from Christmas and reach them. The orbit of departure lay in the plane of the ecliptic, namely at an angle of 23.5 degrees to the plane of the Equator; it is in the plane of the ecliptic that both Earth and Mars circle around the Sun. The group of vessels on which the assembly work was being done circled the Earth once every two hours and this made them cross the equator once every hour. In the meantime, the Earth was slowly rotating under the orbit of departure, making a complete revolution every 24 hours. Hence, after every half revolution, or 180 degrees, the same point on the equator which was now just under the vessels, would again be exactly under them, they having meanwhile made six full circles around the Earth.

Therefore it was always possible to launch a second flight just twelve hours after one launching had been made from Christmas Island. But if one flight had reached the orbit of departure in a northeasterly direction, the succeeding flight 12 hours later would be obliged to depart southeast, for only after a further 12 hours could the orbit of departure be attained via the northerly track.

Chapter 13
Incidents and Adventures

No great achievement of a technical nature has ever taken place without exacting a tribute of sacrifice, and Braden's magnificent spacelift was not long in following suit.

It was noon on a March day in 1983 when the two ferry vessels, *Andromeda* and *Max Valier*, took off at the regulation interval of 3 seconds. *Valier* was the leader, with *Andromeda* close astern. Hardly had the ships begun to respond in velocity to the ear-splitting roar of their great boosters than the ground crews noticed that *Andromeda*'s comet-like propulsive jet suddenly collapsed to nothing. A few seconds later the enormous ship came to a standstill directly over their heads ...

Contrary to orders, they had become so accustomed to uneventful launchings that they had left the protection of their bunkers as soon as the danger of fire and pounding rocks was over. Now they rushed madly back into cover, there to spend a few seconds of tortured waiting until what seemed a minor earthquake shook the solid bunker, flinging them from side to side. It was followed by a violent explosion, which died away in a series of smaller ones. Then all was silence.

They opened their steel doors to hear the wail of a siren which somehow injected a note of belated absurdity into the tragedy, as though anyone might have missed the earthquake; for some thousand feet distant from the launching platform a great mushroom of brown smoke ascended out of what seemed a volcano of roaring white flame. Above it all could be heard the diminishing thunder of the *Valier* on her path to Heaven. So intense was the heat from the pyre that not until some fifteen minutes had elapsed could the firefighters and their equipment approach close enough to spread their blankets of foam over what had once been the proud *Andromeda*.

She lay at the center of a shallow crater some 200 feet in diameter, where hydrazine was still burning with its acrid odor of ammonia. Pieces of the huge rocket combustion chamber could still be recognized, strewn over the bottom of the crater. The ruins of the second and top stages lay in a line along the walls of the bowl, indicating that at the moment of impact the great ship had already begin to turn her nose downwards. All around the crater were bits of shattered steel and sheet metal, interspersed with carbonized pieces of electrical equipment. It was quite plain that none of the crew of four had succeeded in leaving the vessel before the catastrophe, although the intense heat had destroyed all traces of their bodies.

The sad news brought general Braden to Christmas Island immediately. Shortly after his arrival, a board of inquiry began a search for the causes of the accident. But such was the destruction, and so completely burned and crushed were the pieces of wreckage, that the board was unable to assign any reason to the disaster beyond a wholly hypothetical conclusion that a certain relay must have failed. The particular one selected was the relay which shuts off the flow of propellants to the main booster motor when the second stage is ready to take over. It was assumed that this relay had functioned prematurely, thus depriving the ship of power at the most critical phase of the ascent.

Immediately the launching of ferry vessels was interrupted for a week, and every switching relay of every *Sirius* vessel was carefully examined. The old space men on Christmas Island muttered that the board of inquiry might have done better to call the thing an act of God, for they knew that relays are always the scapegoats in the rocket business when obscurity cloaks the unforeseen. Ever since the first liquid rocket flew, the relay has suffered criticism despite its reputation for reliability and its manifold uses in telephones, power stations and aircraft.

Considerable damage to the project was caused by the loss of *Andromeda*, chiefly in that four able men had perished. These men's vast experience in space would long be missed by the Space Forces, while their many companions and friends sorrowed greatly. The absence of the ship itself was easier to compensate, for production of *Sirius* vessels was in full swing at United Spacecraft, and there was no difficulty in adding one more vessel to the line of production. It was, in a sense, fortunate that *Andromeda* had been a propellant carrier rather than ferrying dry cargo, for no scarce component of a Mars vessel had been lost.

But considerable damage had been done to the installations on Christmas Island by the shock wave engendered by the huge explosion.

The hangar where the returned top stages were overhauled and inspected looked as though a blockbuster had struck close to it. Fortunately there had been but one top stage in work at the time, but this was so badly distorted as to be fit only for the junk pile.

In the repair shed, where baby boosters were overhauled, a traveling overhead crane had jumped its rails and descended upon two boosters that lay below it, damaging them severely. As though by a miracle, the working crews had survived without a scratch.

The nitric acid supply line from the harbor storage tanks to the launching sites was kinked by the shock in several places and leaked considerably. Several filling pumps and their motors were destroyed by acid corrosion.

A test of the complicated wiring system connecting the launching sites with the operating bunker showed a wide variety of malfunctions. It had to be laid up for extensive repairs.

The big assembly building near *Andromeda*'s launching site, where the three stages of *Sirius* vessels were fitted together, had all its windows blown out, and several of the men working there suffered glass cuts.

Even at the relatively distant harbor, ceilings had dropped, windows had been broken, and door frames had been sprung.

Aside from the loss of *Andromeda* herself, there was several hundred thousand dollars damage and a delay of two weeks for the whole operation.

Andromeda's, however, was not to be the only accident to cause loss of life in Braden's ferry operation. Some three months later, *Orion* fell victim to a sorry fate.

Orion had passed the transonic speed range and was approaching the velocity of 1,000 m/sec without incident. Suddenly the flight path began to fluctuate. Observers later reported that she had yawed to the left and that the contrail behind her fiery jet then became wavy. A few seconds later, the vessel broke apart. The aftermost portion blew up in an explosion whose shock wave was audible at the launching site much later. The smaller forepart of the ship continued upwards in a steep ballistic parabola, passed its maximum ordinate, and fell with still increasing velocity into the sea. There had been no radio calls from *Orion*.

Flight Control immediately dispatched aircraft and rescue boats to the point of impact given by the radar stations, but not a trace of the ship could be found before it was engulfed by the ocean. After several hours of search, a survivor was picked up in an exhausted condition by a rescue boat, his rubber raft having functioned in the nick of time.

Sergeant Kenneth R. Andrews had been the radio operator of the unfortunate *Orion* and reported the accident as follows. The gyroscopic steering gear of the big booster had malfunctioned for no ascertainable reason. Andrews had noticed a sudden sharp tilt of the vessel from her programmed heading, accompanied by a disagreeable centrifugal acceleration. This motion was arrested by a returning couple, followed by a swing in the opposite direction and three or four violent oscillations. The skipper had punched the emergency cutoff button in fear that the high angle of attack might rupture the whole ship. Then he released the big booster which was at once decelerated and separated by its huge 'chute. He ordered the crew to don the helmets of their pressure suits and to attempt to abandon ship at maximum ordinate. Here the stagnation air pressure would be a minimum and thus offer the least hindrance to exit from the still upward-bound ship.

After receiving the order, there was but a minute before the maximum ordinate was reached. The preparations for abandonment took place hurriedly. Andrews himself was shot out by his ejection seat into the thin atmosphere like a champagne cork. This moved him well away from the ship. He allowed himself to fall from the 40 km altitude of the maximum ordinate to 5 km before opening his 'chute to avoid congealing himself. Whether anyone else got out he could not report. The rescue planes and boats continued the search for two days without further results.

Operation Mars had three more victims.

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Captain Henry Burck of the *Hercules* was to experience an adventure sensational even to a veteran spaceman. *Hercules* had been climbing for 207 seconds and it was time for the speed indicator to throttle the thrust of the baby booster and ignite the top stage, which would then force itself away from the baby under its own power. The impulse signal was given correctly, and the painful acceleration of the baby booster diminished, the cover plates detached themselves, the top stage ignited properly.

Then it happened! The magnetic disconnector between the stages malfunctioned and no separation took place! Burck immediately pulled the emergency baby booster release, but the booster did not fall off.

Then Burck cut off the propellants to the top stage motor and waited tensely. A few seconds later the already weak thrust of the baby booster died entirely and, as the last propellants burned, a jar ran through the vessel flinging the men forward. The decelerating 'chute of the baby booster had opened! And the propellant-laden top stage was still clinging to it like a leech!

The crew glanced nervously at the Captain who, feigning indifference, was cudgeling his brains for a solution.

The ship's instruments showed a velocity of 6,420 meters per second, an altitude of 64 kilometers, and an angle of elevation to the horizon of 2.5 degrees. The weight of the baby booster, now exhausted of propellants, was 70 tons. It clung insistently to the top stage. The open deceleration 'chute was calculated for this weight only and was expected gradually to reduce velocity in the thin upper atmosphere. The top stage, still loaded with propellants, weighed 130 tons, so that the little 'chute was now attached to a full 200 tons. Such a weight could not be slowed down by the 'chute in the time available, and the ship would tend to remain at relatively high altitudes for but a limited period as a result of her small angle of elevation. Soon she would tilt downwards and enter denser air with too high a velocity; thus the 'chute would inevitably tear away from her.

The first step was obviously to lighten the top stage by dumping the propellants!

Burck closed the servo operated hydrazine valve and whipped his turbopump to its full delivery. This forced nitric acid alone into the rocket motor from which it emerged through the areas uncovered by the jettisoning of the side plates, to be sucked out and dissipated in the rushing air. After less than a minute the tank emptied. Burck closed the nitric acid valve and opened the hydrazine. This drained the other tank, thus reducing the weight of the top stage to 47 tons by expelling 83 tons of propellants. The 'chute was then laden with 117 tons rather than the 70 for which it had been designed.

The situation was much improved over that of the former load of 200 tons, but there was still great danger of descending too rapidly into lower and denser air. To make matters worse, the vessel was beginning to roll slowly around her longitudinal axis to the right.

Burck undertook the risk of rigging out the telescoping wing panels of the top stage, whereupon he applied full left aileron. This stopped the roll and he pulled back on the flippers.

Then began a weird and wonderful flight, for the 'chute of the baby booster was still slowing them down gradually. The 'chute was extended behind an almost conventional aircraft whose wings were producing lift and could extend the time during which the odd and unforeseen configuration could remain at altitude, compared to what this time would have been had the wingless rocket followed a natural descent path dragging the 'chute. At the controls of the queer craft sat a pilot bemused by the apparent ease with which things had gone up to that point.

Burck was grubbing in his memory to remember the correlation of altitude and velocity which corresponded to the flight path of the baby booster and it's 'chute alone. He wanted to try to fly the weird combination of rocket and aircraft according to that data, and he cursed silently the paucity of information in his flight data folder. At the moment, he was entirely out of sympathy with the Space Force pen-pushers who hadn't foreseen that a captain might some day have to make a landing with his baby booster still attached! Had they really envisaged every emergency as they claimed, he would not now find himself without that vital curve sheet.

So he simply hauled back on his slipper controls as far as he could without tearing off the wings, coaxing every possible bit of lift out of the straining panels. For his own life and the lives of his crew, he must enter the lower air strata as slowly as possible. That would reduce the deceleration which endangered the parachute.

Two and one half minutes had elapsed before *Hercules*' velocity was down to 5,300 m/sec. At just under 70 km altitude, the great vessel soared east-northeast across the deserted Pacific. The deceleration of the 'chute had been reduced from 1.8g at the time of 'chute release to about 0.7g by reason of the gain in altitude and the decrease in velocity.

Burck became conscious of a new worry; he might be able to use his wings to prevent too rapid a descent, but the mass of his vessel was greater than that of the baby booster alone, and he could not prevent her from descending to a point far beyond where the baby booster would normally have taken to the ocean. Salvage ships would be awaiting the solitary booster, and away beyond that point there would be none. Furthermore, the baby booster's deceleration rockets were not calculated to check the fall of such a great mass as now composed of their odd aircraft. The cabin might well be crushed by the impact on the sea and bar their exit, and the empty propellant tanks of the booster might admit water and sink them below the pitiless waves of the Pacific. He hated the thought of making a half-way decent landing with the prospect of drowning with his crew like rats in a trap.

Burck grasped the intercom. "Radio! S.O.S. to Christmas Island from *Hercules*. Top stage not separated form baby booster. Now gliding, wings extended, on projection of great circle of ascent track. Send cross-bearings and locations any sea vessels in this region. Anticipate landing 1,970 km distant from launching site. Prefer to land near any vessel in that area."

Another thought came to him with a shiver. "P.S.," he said over the intercom, "Hope nitric acid dumped doesn't corrode my 'chute too fast!"

After a couple of minutes their cross-bearings began to come in. 500 km ahead and slightly to port, the tanker *Patrick* was steaming towards San Diego. Burck would attempt to land alongside her.

Hercules' velocity was now down to 3,000 m/sec and her altitude to about 48 km, but the deceleration had become almost unbearable with the descent into denser air. Five g's pressed Burck against his shoulder belt where he gasped for breath, barely able to read the instruments and to keep his craft in the flight attitude. Slowly the nose began to point downwards, and when it reached 30 degrees, the agony relented. With this angle and 31 km high, they slipped below the 500 m/sec mark and the copilot with his binoculars reported a steamer diagonally beneath them. It could only be the *Patrick* and Burck, still able somewhat to control the winged parachute bomb which the *Hercules* now was, headed in the direction of the tanker.

At 10 km altitude, *Hercules* pointed vertically downwards like a parabomb before impact. Her crew hung forward in their belts, gazing terrorized at the up-rushing ocean. Already they could make out the white caps and the bone in the teeth of the *Patrick* steaming under forced draft towards the point of their prospective dunking.

Fifty meters above the water, the circumferential checking rockets in the baby booster above them roared out and the deceleration again threw them into their belts with violence. The jets from the rockets screamed past their portholes in a mantle of flame.

Then the greenish darkness of the sea veiled the ports, breaking some of them and compressing the air into the crew's Eustachian tubes. Their ears cracked. This must be the end... But there was a rolling and twisting of their cabin, and sunlight burst through the broken ports, reviving their flagging spirits. *Hercules* stood like a can buoy upon her fractious baby booster and they were safe.

An hour later, Burck and his crew watched from the tanker the great mass riding safely on the ground swell of the Pacific, the great wings torn and twisted by the impact. The *Patrick* stood by until the arrival of the salvage ship *Sea Lion*. The latter, after considerable difficulty, got the badly damaged rocket aboard and, with its crew, steamed off for Christmas Island.

Braden reacted typically to the report of the accident. His radio to Burck read tersely: "Congrats. More luck than brains. Braden."

Holt, who had been about to leave Christmas Island, delayed his departure and interviewed Burck in detail. When he had heard the whole tale, he was convinced that Braden had been unjust to Burck, to whose presence of mind, Holt felt, was not only responsible for the survival of the crew, but had also provided valuable information on how to avoid future troubles of the same nature.

Holt's wire to Braden read, "Burck's brains beat bad luck."

A few weeks later, Burck's dearest wish came true when he read his orders to command one of the Mars vessels.

Chapter 14
Farewell to Earth

It was past noon on March 1, 1985 in San Diego. The morning fog had gone and the sidewalks were crowded as they had not been since the day of the Armistice which ended the great war. Police held back the enormous crowds thronging every street leading to the harbor. The city was gaily decorated with star-spangled bunting and the rainbow colors of the United States of the Earth. Greetings to the Mars adventurers hung in great transparencies across the wide thoroughfares.

The steamer *Queen of Hawaii* lay alongside the string-piece of San Diego's waterfront wall. It was in her that the personnel of Operation Mars would sail for Christmas Island at slack tide in the evening.

Four years had passed since a memorable session of the Congress of Earth had passed the appropriations bill which was to make into a reality the exploration of interstellar space, and had loaded upon the shoulders of its protagonists the enormous burden which such an extension of a man's realm implied. The preparatory work had been unspectacular and quiet, and the general public had become almost unconscious of the mighty deeds which were preparing in their midst. But the departure of these intrepid men had again concentrated the light of publicity upon the enterprise, and Mars again was a familiar word upon the lips of all and sundry. Once more a spate of curiosity welled up as to his mysteries. America left no stone unturned to send forth her sons into illimitable space with proper honors and the proud pomp which was their due.

The great cruising steamer was full dressed with signal flags. Her ample decks swarmed with visitors and voyagers whose families had come to bid them farewell. Fathers and mothers crowded the companionways. Aunts, uncles, cousins, brothers and sisters of the intrepid explorers cluttered every available space. Here and there lovers made plans for reunions when the three years demanded by the expedition should be over.

Gary and Catherine Holt stood on the boat deck looking at the harbor with its flotillas of submarines and destroyers nested beside their stodgy mother ships.

"Gary, I know you'll do it," she said without looking at him.

"Everything is as ready as we could make it," he answered. "God will have to do the rest."

The deep-toned whistle called those ashore who were not to depart. With a quiet kiss, Catherine descended the long, covered gangplank. The Space Forces band on the deck struck up a merry air and paper serpentines flew between the ship's rail and the pier. With a last loud blast from the whistle, moorings were cast off and the water between the white steel side of the vessel and the shore grew wider. Catherine held up her crossed fingers to Gary's receding figure. He could not see her brimming eyes above her smile fading into the distance and the crowd surrounding her as the ship pulled away...

As the *Queen of Hawaii* drew clear, every whistle, siren, horn and bell in the city of San Diego blasted its cheering fanfare to Holt and Knight and their enterprising band of spacefarers on the after-deck of the tall ship.

"This is it, Tom," said Holt quietly.

Coronado lay astern and the vessel had begun to lift and descend to the mild swell of the Pacific when the call to dinner rang from the ship's melodious gongs. The great dining hall was bright as the Mars crews seated themselves, to their full number of seventy, at long tables, one of which was occupied by the leaders who had done the planning. Braden, Spencer, Peyton and Holt took their seats with the ten captains of the space ships waiting in the orbit of departure.

The captains were Henry Burck, whose adventure with the *Hercules* had earned him the sobriquet of "Captain Marvel"; Anthony Haynes, United Spacecraft's recent chief pilot, whose imperturbability had become legendary; and Frank Sherman who had been a space ship captain in the last war. He had emerged from retirement as a major in the Space Forces when the Mars expedition was activated. Another reactivated Major was fat, cheerful Freddy Duncan with his inexhaustible fund of salty and passable anecdotes. Trygve Nordenskjold was a Norwegian lieutenant. A slim and silent fellow, he had made more than 60 ferry trips to the departure orbit in *Sirius* without the slightest incident. He'd been insistent that he could make as good landings on Mars as he could at home. Herbert Steinmetz, Lieutenant Colonel, Space Forces, an old-time space skipper. Fred van Newman, a young, intrepid looking captain. Lieutenant Colonel Tom Knight, with his light hair and winning ways; quiet, contemplative Glen Hubbard and the effervescent, smart Frenchman Charlie Laroche.

Little persiflage passed between them as they sat. Each man was too much affected by thoughts of the great adventure ahead. They had bidden farewell to their loved ones, to wander forth into the emptinesses of space for years; perhaps, indeed, for ever. They would stand on the brink of the unknown.

At a table to the right sat Hal Royer, navigator-in-chief, surrounded by the ten who were to work at that trade and simultaneously copilot their space ships. The next table was for the engineers; to the last man experienced "burner boys" from the war or the Lunetta Ferry. Their dean, tough, grizzled John Wiegand, vainly attempted to draw them into a discussion of specific impulse and the hypergolic propellants which eliminated the complicated machinery formerly required to induce combustion between fuels and oxygen-carriers. John had almost assembled the circling and waiting Mars ships with his own hands during the fifteen trips he had made to the departure orbit. Blindfolded, he could have laid his hand upon any tool in any space vessel. He knew more of the coming problems than any other engineer. But his attempts to lecture them fell on deaf ears. Their minds were elsewhere.

On the other side of the dining room sat the scientists. Dr. Marion Gudunek was a swarthy Yugoslavian research linguist whose fluent seventeen languages might enable him to establish verbal communication with Martians and permit his to study and codify their speech, if any. Near him sat John Henry Billingsley, as British as Brixton with his R.A.F. mustache. He had abandoned his archeological diggings in India and China and left his book on the Ming dynasty incomplete so that he might plumb the depths of historical development on Mars. Douglas McRae would record zoological facts; Howard Ross would botanize. Sam Woolf's geological hammer was ready. Dr. Hans Bergmann knew Mars' geography better than he did that of the Earth.

James Barret, M.D. was the surgeon of the expedition and certainly the world's most distinguished practitioner of space medicine. Hardly had he graduated from Medical School than his keen mind apprehended the variety of medical problems which attended flight through space. It was not long before he had made the solution of these problems his main life's work. The effect of high accelerations upon the body caused him to perform studies with the human centrifuge which provided the ground work for his solution to the difficulty in breathing called forth by the inability of the chest muscles to expand the breast under high g's.

His discovery that hyperventilation during the low-g periods would store enough oxygen in the blood of a spacefarer to allow him to withstand the short periods of high g's without breathing at all had made him the medical advisor of the Space Forces, entirely aside from the many other medical innovations he pioneered.

During Lunetta's trial period, Barrett was her surgeon and was able to investigate the physiological and psychological effects of the absence of any acceleration, even that of gravity – the one "g" to which all creatures of Earth are subjected. Of these, the sense of equilibrium was the most affected and the most difficult of solution. When the war was over, he set up his famous Institute of Space Medicine and left it for a time only because of his devotion to the Mars project.

Not far from the scientists sat the radio men, headed by their boss, spare, snowy-haired Francis Lussigny of Canada. It was he who had designed the High-Duty radio sets which were to bridge the unfathomable distances which would soon separate them from the Lunetta orbit. He was one of the doubters until he met Holt in Lunetta. But the darkness and solitude of the deep heavens bewitched him during his long struggle to perfect satisfactory interplanetary radio in the orbit. Then he sought and was granted the opportunity to communicate personally across the multi-million-mile radio bridge his genius had conceived.

Lieutenant Hempstead and his military troop of 18 sat at another table. It was they who would guard and guide the landing party. John Wiegand would keep them employed during the extended coasting flight through space, and they had been trained to a tick along many lines. Some of them would preside in the ships' galleys with their electric stoves. Others would operate the busy bees from ship to ship or apply the damage control knowledge they had acquired in the simulators for repair personnel. All of them were to be of the landing party except Jimmy Cox, the heavyweight chief cook and storekeeper, and his two helpers. Once on solid Mars, they would drive the caterpillars and, if necessary, employ their light weapons to protect the others. They would taste all the surprises the Red Planet might hold in store.

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In the orbit of departure, the Mars vessels had been abandoned by their ship-keepers and were manned by their regular crews. All the ferry vessels had returned to Christmas Island except *Astroliner*, the luxurious command vessel of the Space forces. In her cabin, Braden, Spencer and Dick Peyton awaited the final departure of the strange agglomeration of cumbersome shapes apparently floating motionless in space some few hundred yards form their observation ports.

Braden terminated a short valedictory radio talk, reminding the crews of the scope and intrepidity of the enterprise. He stressed the responsibility to the peoples of Earth resting upon them and emphasized the importance of Spartan discipline. Lack of the latter might jeopardize not only success, but their own lives.

Six journalists scribbled tensely at notes, reporting the great departure while two newsreel men worked their cameras under the unaccustomed handicaps of weightlessness.

Outside the observation ports, Holt's flagship, *Polaris*, hung motionless at the head of the column of Mars craft. She bore the spherical control and living nacelle at her fore. Silvery in color, it exhibited the seven astrodomes and sundry portholes. Behind it and vertical to the longitudinal axis of the vessel was the framework of the cruciform "forward tank retainer." The fat-bellied dual hydrazine tanks for the first propulsive maneuver hung swollen and silver from its outer ends. Each contained 540 cubic meters of the liquid. Below them and supported from below by a second tank retainer were the nitric acid tanks for the maneuvers, tanks of almost equivalent dimensions.

In the other plane of the cruciform tank retainers hung the elongated tanks for the second and third maneuvers. In the center, almost obscured by the latticework backbone of the vessel, were the attenuated pipe-like storages for the ultimate maneuver of adaptation to the terrestrial orbit when the expedition should return. The reserve tanks for propellants left over from prior maneuvers were cramped between them and the huge spheres for the maneuver of departure. Their filling would begin with any excess which might remain when the first maneuver was complete.

There was a long extension protruding transversely from the after tank retainer. A universal joint at its end supported the long, gutter-like solar reflector for the power plant. The mercury vapor turbine and its electric generator could be seen beside it.

Behind the after tank retainer were the serpentines of the propellant piping leading from the tanks to the feed pumps. Abaft the latter was the enormous rocket motor, flat, and in appearance not unlike a huge cake. Around its rim were the four movable steering rockets for flight path control.

Echeloned astern of the *Polaris* floated the cargo vessel *Robert H. Goddard*.

The *Goddard*'s appearance was dominated by the enormous wings of the landing boat constituting her fore-part and serving as crew nacelle. Behind the stern of the boat, almost concealed by the great struts of the connecting structure of the ship, was a spare propulsion plant intended to replace any which might prove defective in the *Goddard* or some other Mars vessel. *Goddard* carried no tanks or propellants for the last tow maneuvers, for she would never make them. She was to be left circling Mars. But to make up for it, she was laden like a Mexican burro with all sorts of tanks and equipment for the easement of the tasks of her sister ships. Among her burdens were the large telescope, the solar reflector and the circular reflecting antenna of the High-Duty radio set. She also carried two busy bees, oxygen tanks, the water supply and many objects whose applications were not immediately apparent.

In *Astroliner*, the loudspeaker had been hooked up to intercept communications between the ships.

"Colonel Holt in Command of *Polaris* speaking. X minus six minutes. Send ready reports as called. Nordenskjold!"

"Nordenskjold, cargo ship *Goddard*, ready!"

Ponderously came the other reports.

"Sherman, passenger ship *Aldebaran*, ready."

"Van Newman, passenger ship *Arcturus*, ready."

"Duncan, passenger ship *Regulus*, ready."

"Hubbard, cargo ship *Oberth*, ready."

"Burck, passenger ship, *Capella*, ready."

"Laroche, passenger ship *Vega*, ready."

"Haynes, cargo ship *Ziolkowsky*, ready."

"Steinmetz, passenger ship *Antares*, ready."

"To squadron from *Polaris*; Time X minus 3. At X equals zero, beginning with *Polaris* and in order of reporting, ships will apply thrust at 30 second intervals."

The seconds dragged wearily as tension among the men in *Astroliner* waxed, their eyes glued to the ports.

Then Holt's voice spoke calmly, "X minus 10, 9, 8, –"

At the word "three," a tiny flame leaped from the motor of *Polaris*, to be followed by a long trail of fire. The thunder of the jet was imperceptible, for this was no rocket launch from Earth. There was no air to transmit the sound even across the short span between *Astroliner* and the convoy.

Slowly, very slowly, the colossal vessel began to move across their field of vision and disappeared.

Then the *Goddard*'s flaming jet lashed out and she too bore away majestically with her outthrust wide wings.

Aldebaran, *Arcturus*, *Regulus* – one after another, they forged into the illimitable distances by the consecutive ignition of their fiery tails. Amid a silence in which the buzzing of a gnat might have been heard, the cumbersome craft departed from view.

The cabin of *Astroliner* resounded to a mechanical buzzing as the pilot ran up his flywheels and twisted his vessel in space so that Braden might again see the convoy.

There they were against the velvet black sky with its unwinking stars. An orderly line of ten man-made comets trailed ten flaming exhausts laterally across the heavens and Braden's heart swelled within him. This was truly a departure on man's proudest exploration; a departure in flaming confidence! He was still musing upon the incalculable possibilities facing the space crews when *Astroliner*'s jet roared out to start him and the other stay-at-homes back to Christmas Island.

Chapter 15
Killing Time Between the Worlds

Five days of the voyage to Mars were behind the ten ships of the convoy.

After the initial impulse away from Earth, their intervals had slowly become greater. After three days, at the exact end of which each ship had fixed her position by stellar parallax, Hal Royer, the head navigator, reported to Holt that *Ziolkowsky* was the only vessel to have applied her thrust so accurately as to both direction and amount that she needed no correction. Duncan, the solid fellow in command of *Regulus* had slipped ahead so far that the sunlight on her glittering tanks appeared but like one of the fixed stars in the dim distance. Burck in *Capella* brought up the tail of the procession, some 40 miles astern of *Ziolokowsky*. *Polaris* held her position well and was but little ahead of *Ziolkowsky*.

Holt radioed orders for corrective maneuvers to return the nine stragglers to *Ziolkowsky*'s track.

Extreme concern for economy of propellants might have dictated that closing up the convoy should be conducted so that the ships would be in close formation only when near Mars, but Holt had his reasons for reassembling them without delay. He felt that a few thousand kilograms of propellants would be well expended in keeping the ships near enough so that in case of damage mutual help would be at hand in a minimum of time. So the ships started their steering rockets and maneuvered themselves towards *Ziolkowsky*. Within ten days no more than ten miles separated them.

By now, the Earth was some one and one half million kilometers distant and appeared about as large as the Moon does to Earth dwellers. She reminded the observers of the waxing half-Moon, due to her right half alone being illuminated by the Sun. But that half shone more brightly than ever the Moon, so brightly indeed that no contrasts upon it could be distinguished with the naked eye.

Some distance from the Earth, they could see a luminous disclet of about one quarter Earth's diameter. This was the Moon itself, faithfully following Earth on her path around the Sun.

The sight brought the men of Operation Mars to full appreciation of the significance of their departure into the planetary world; they could see Earth and her companion actually submerging in the depths of space. Glances at the spectacle filled them with a kind of humble pride at their privilege of being the first to witness it.

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Not long after the maneuver, a stiff watch list and work program was instituted in order to accustom the men to the even and uninterrupted passage of time. Since there was no natural sequence of day and night, the good old military principle of invoking authority to determine which was which went into effect. At exactly 2000, expedition time, blinds were pulled over all ports except those of the pilot's cabin and astrodomes, to be opened only at 0700.

Meals, of course, were served on the dot. Weightlessness even proved a problem for the old Space Force veterans when it came to eating. *Sirius* trips had been so short that there had never been a question of more than an odd sandwich or so, while aboard Lunetta the synthetic gravity had brought the business of food down to Earth, so to speak. The consumption of a full meal under weightless conditions was an exciting novelty for almost everyone.

Food was served in pannikins with spring-loaded covers and no knives were used. Edibles requiring cutting were chopped up in the kitchen. Nor were there forks or spoons. The interstellar voyagers reached cautiously underneath the covers of their pannikins with tong-like devices to prevent the whole meal from floating unsupported before them.

Soups and other fluids required even more inventive treatment, being served in flexible containers with nipples not unlike those used for infants. By taking the nipple in the mouth and squeezing the container, the fluid could be expressed and sucked to a point where the muscles of the esophagus could begin their work. Nothing could be poured as it could when gravitation exerts its helpful influence.

At 2000 every day, each crew would assemble to listen to a radio broadcast from Earth, perhaps the most welcome event of the 24 hours.

Oberth had a receiver which caught a special program for them from the High-Duty radio set near Lunetta which Lussigny had spent two years developing and assembling to assure communication between the expedition and the Earth. This was then rebroadcast by *Oberth* on the intership frequency. It usually brought news, a lecture or so, and music; although from time to time, some regular American program was retransmitted. The Mars crews might hear of hostilities of a minor nature between Hindus and Moslems flickering and dying, or even reports of their own doings. When a "commercial" would emphasize the availability of some new toothpaste in the drugstore just around the corner, roars of laughter would go up over the assertions concerning just how essential to civilized existence such products had become.

The scientists kept themselves busy with studies and writings on their own specialties, and the captains, navigators and engineers relieved one another on watch. The main duty of such a watch while coasting unpowered through space was to keep all the auxiliary machinery operating at highest efficiency, and to see that no part of the complicated installation suffered from neglect.

This called for rather more activity than appeared superficially. One important item was the temperature of the propellants. Each passenger ship had four tanks for each maneuver except the last, for which there were but two. In addition, there were the four reserve containers. It had proved necessary to distribute the propellant over so many tanks to establish a proper symmetry of masses during each maneuver.

Temperatures in the 18 tanks were kept constant by thermostats operating the reflecting venetian blinds. The angular attitudes of the ships tended to vary considerably by movements of the personnel within, so that the inner tanks were shaded by the outer ones in very irregular fashion. Early design studies had showed that certain attitudes of the vessels would permit supercooling of the inner tanks, because in such attitudes, no sunlight could reach them. Hence, from time to time the watch keeper had to start the flywheels and move the vessel out of the "prohibited" attitude.

Then there was the air conditioning system. Although temperatures, humidities, pressures and oxygen content were automatically regulated, there were tests to be made and regularly logged. An ingenious device constantly showed the ratio between the flows of treated and untreated air. It would reveal immediately whether there was any tiny escape of the precious respiration gas into the great void outside.

Temperatures of water and oxygen storage tanks had to be read and recorded, as also were those of the food storage.

The electrical power supply required the most constant supervision. It was the heart of the whole complicated system of annunciators, remote-reading gauges and such which kept the man on watch informed on the condition of the entire vessel. It further worked the various automatic regulators which alone permitted the involved system to maintain the life within it. Electricity fed the gauges and the instrumentation, and turned the temperature-controlling blinds to their appropriate angles. Above all, it whirled the pumps and blowers which fed air to the lungs of those few lonesome humans far into the reaches of airless sky. Should the mercury vapor turbine halt, it would be but a few hours before the batteries' exhaustion would bring the life-giving air circulation to a stop.

Should the current supply fail, the watch keeper would sound the general alarm and awaken the crew. Then he would radio one of the cargo ships for a power bee whose powerful accumulators would keep the blowers and pumps running while repairs were made by the damage control party called in for assistance from other ships.

Two weeks from the day of departure, John Wiegard began a series of monthly inspections. From ship to ship he went in his busy bee, accompanied by three crewmen specially trained by United Spacecraft in troubleshooting and damage control techniques. No detail of the involved structure or machinery escaped his eagle eye and the prying hands of his assistants. Generally he would spend up to three days on each vessel. His three minions, together with the engineer of the ship and John himself would don space suits and climb out to the propulsion feed pumps at their station between the rocket motor and the huge tanks. Here his electrician began to pull plugs and seek scorched contracts or cracked plug bodies which had been allowed to overcool. His plumber might check tubing for hairline cracks caused by excessive heat stresses or the long vibrating of the initial maneuver. His tank expert would search for punctures with a magnifying glass. He would patch the tiniest rift such as was occasionally caused by meteoric dust, lest the self-sealing tank lining fail to plug it. John himself, with the help of the ship's engineer, might lift the turbine cover of the great 5,000 hp pump and perhaps decide to replace a wiped bushing.

After thoroughly examining the ship externally for as much as a whole day, they would proceed to functional tests. Pressures were applied to parts of the propulsive mechanism to discover leaks. Trial switching operations were run so that the electro-pneumatic gear might not escape the inquisition.

Finally, Wiegand and his gang would go over the pilot's compartment with a fine-tooth comb. He and his electrician checked inverters, gyros, computers, switchboards and instrumentation, using portable test panels. They would open relay covers to ascertain the contact pressures or to try the soldering on a cable terminal.

Wiegand recorded his findings in a red notebook of evil repute, where he also laid out the repair work to be done, with some assistance from his troubleshooters, by the crew of the ship just victimized. The latter would procure any required parts from one of the cargo ships.

His reports to Holt on the mechanical state of affairs kept the engineers and captains under constant pressure, for he never hesitated to lay the blame for any unsatisfactory condition exactly where he thought it belonged. It was not long before they were so intensive in their own inspections that "Trouble John" (as they called him) found trouble in finding trouble that he might enter in his horrid red book.

Holt discovered that Wiegand's tireless X-ray eyes slowly but surely brought him the assurance that he need no longer fear that human mental inertia would prove a Satanic factor in his computations. This it might easily have happened, lulled as were the men by the monotony of their seemingly endless voyage, and as susceptible as were the involved mechanisms to neglect. Holt had enough to worry about without that.

Chapter 16
Interplanetary Radio

Holt found much of his diversion in listening to the tales of adventures on the five continents related by the three interplanetary hitchhikers, Billingsley, McRae and Ross. One day, however, they professed boredom with the confined cabin of *Polaris* and Holt happily sent them off on a visit to Lussigny in *Oberth*. Here the old radio man lived in monastic seclusion, completely preoccupied with his High-Duty radio set. The adventurous three had no particular technical background, but they hoped that the sour Canadian might explain to them how he managed to maintain unbroken communication across so many million miles of sky. The Earth and Moon appeared no more distinctly that a bright dual star, but the newscasts and music which sprang from the loudspeakers were as clear and undistorted as though they came from a local station around the corner.

As Billingsley and company approached *Oberth* in a busy bee, they could see beyond one of the wide wings of her landing craft hanging obliquely in space, an odd structure some 1,000 feet away from her and wholly separate from the bulky cargo ship. It looked like a silver drum, with hemispherical heads, from which extended two four-legged frames on opposite sides. One frame had at its terminal a circular, parabolic, opaque reflector like those of war-time radars, while the other bore a gutter-like, elongated mirroring surface within which was a thick, black tube.

The odd device was one of the two High-duty radio sets borne by the cargo vessels, although only this one from *Oberth* had been put into operation. The bee slipped into the guides at the side of the drum and the men floated inside through the rapidly opened doors. After greeting Lussigny, who crouched in front of an enormous instrument panel, they managed to inveigle themselves into such open spaces as could be found amid the electrical apparatus that filled the compartment.

"Frank," said Billingsley, "it's jolly good of you to let three radio ignoramuses into your high-voltage jigsaw puzzle. If you're not too busy playing radio-footsie with Venus, or something equally abstruse, give us a bit of a lecture on how your interplanetary hook-up works!"

Lussigny did not deign to respond to this sally beyond stating that they were in direct, two-way communication with a similar station in Lunetta's orbit.

"It's just like any two radio stations talking to one another," he remarked, "only the distances are greater. There are no innovations nor peculiarities about the sets themselves."

"You talk as though all these millions of kilometers were a secondary consideration," bellowed Billingsley.

"As a matter of fact, they're only one of many, equally important factors," answered Lussigny. "When we began to work out this set, all the radio people argued that we couldn't radio across interplanetary distances. So we just worked up some calculations and proved to the doubters that for forty years they've had the technological means for radioing reliably clear across the solar system."

"What!" shouted the three visitors, amazed.

"Certainly, right across the whole 12 billion kilometers of Pluto's orbital diameter. Actually, we might transmit almost twice that far, if you want real accuracy, for the figures showed 23 billion."

"Must call for almost infinite power to transmit that far…"

"Not at all. 60 kilowatts is all we need and we get them quite easily at the frequency we've selected for this example. For this limiting case, in which we sought to demonstrate to the experts the performance of today's radio equipment, we left out such fancy trimmings as music or voice transmission. At those extreme ranges, we only claim to do business with the simplest and crudest type of communication, namely dot and dash.

"Music and voice transmissions are rather tricky, for we have to have what radio people know as "bandwidth." Bandwidth means that the receiver, when tuned to a certain wavelength, must also receive a band of longer and shorter waves at the same time, if it is to pick up the modulations with which speech or music affects the carrier wave. When you want to transmit all the finer points of music from an instrument like a violin or cello, the tonal quality of which is determined by its overtones, the truer the transmission is to be, the greater the bandwidth required.

"But there is an unpleasant obverse to the case of great bandwidth. When you turn up the volume on your domestic receiver, you've all noticed that there's a background noise which increases and largely blurs the reception of distant stations, and this noise is caused by unavoidable heat effects in the tubes of the receiver. In radio technology, there's an inevitable relationship between the noise level and the bandwidth, in that the noise level increases in the same ratio as the latter.

"Reasonably good reception requires that the useful "signal power" of the reception be a multiple of the noise power. But the noise level is entirely a vice of the receiving equipment, and has no connection with the distance from which the signal comes. On the other hand, the power of the signal itself decreases as the square of the distance of the receiver from the transmitter, so that, if the distance is doubled, the signal strength is diminished to one fourth, and so on. So you see that if we wish to radio over great distances, we must reduce the bandwidth so that the noise level is correspondingly reduced. This is the most important viewpoint in setting up interplanetary radio sets. In the arithmetical example to which I referred concerning radio transmission right across the solar system, we assumed that the bandwidth was reduced to 120 cycles per second. In our computation, we picked a wavelength of 50 centimeters, corresponding to a frequency of 600 megacycles, or 600 million oscillations per second. This means practically that the receiver accurately tuned to a 120 cycle bandwidth can only receive such wavelengths as do not vary by more than 60 oscillations from the 600 million.

"Based on this wavelength and this narrow bandwidth, communication across 23 billion kilometers with 60 kW of power, and directional reflectors for both transmitting and receiving of 100 square meters, we should still have a signal power exactly equal to the noise power. If these dots and dashes are slow and are visually observed on the screen of an oscilloscope, they can just be distinguished from the grass of the background noises."

"That's a little dim to me," said McRae, the animal trainer. "According to you, the secret of long ranges is to reduce the bandwidth sufficiently; then you say that a wide bandwidth is necessary for music and voice. Nevertheless, we hear beautiful music and speech every evening... How does that fit together?"

"At present we're nothing like 23 billion kilometers away from the transmitter. It's only about 20 million, and we've enough reserve range capacity to set our bandwidth for music and voice. But it won't be long before you'll notice a distinct deterioration in the quality of the reception, for we shall continually have to cut down on our bandwidth as we recede from Earth, so as to prevent the background noise from overwhelming the decreasing signals.

"But you wanted to know how our system really works, so here's the principle of it. Not far from Lunetta and in her orbit, there's a radio station much like the two we have with us. But instead of our reflecting antenna's 3.56 meter diameter and 10 square meters, the Lunetta station has one of quadruple that area. It is seven meters in diameter, and would be somewhat cumbersome for our circumstances.

"Power actually radiated from both our transmitter and from that of Lunetta is 10 kilowatts. It is the maximum present day transmitters can put out at our operating wavelength of 10 cm.

"If we base good voice reception upon signal strength of 100 times that of the noise level and if we demand a bandwidth of 5,000 cycles for reasonable clarity in voice reception, this means that our system has a range limit for voice communication of about 100 million kilometers. We shall reach this limit on the 160th day of our journey. Then we'll slowly have to dispense with direct voice and music reception from Lunetta.

"Of course, our actual range of communication will then in no wise be used up. If we limit ourselves to fast code, transmitted automatically, we can reduce our bandwidth from 5,000 to 1,000 cycles. Since a receiver for automatic telegraphy still operates well when the signal strength is about 20 times that of the noise, the limit of our range for automatic telegraphy is more than 500 million kilometers.

"Our greatest distance from Earth will be when we are waiting in the Martian orbit and the Earth passes behind the Sun. Our radio transmissions will have to overcome a distance of about 377 million kilometers. So you'll see that we never get beyond the range of automatic telegraphy. We shall never in this voyage utilize the extreme ranges which we could attain by "brass pounding" our dots and dashes slowly, in which case we could further cut down on both bandwidth and surplus signal strength."

Billingsley spoke up once more. "When Earth is hidden behind the Sun, it would seem that radio transmission to our home planet would be blanked off by the Sun?"

"That's right, but the period will be short, for the Earth will soon reappear."

"Do I understand that the reflecting antenna is used for both transmitting and receiving?" asked Ross.

"Yes indeed, Doctor. It works like the reflector of a searchlight, for the actual transmitting rod-antenna lies in its focus. Radio emission emanates from this short rod and is reflected into space as are the light rays from a searchlight. When the rod is connected to the receiving set, arriving radio emanations are concentrated upon it by the reflector, rather like the way a shaving mirror can concentrate sunrays to burn paper."

"Then the directive qualities of the antenna reflectors must be an effective means of increasing range," mused Ross.

"Very much so," answered Lussigny. "If we were to operate the rod-antenna without the reflector, the emanations would spread about spherically into space, so that only an infinitesimal part of them would strike the distant receiving antenna. With the directive reflector, we concentrate the radio emission preferably in the direction of the receiver. Then the receiving reflector picks up a goodly part of the impinging energy and concentrates it upon the receiving antenna, providing a further gain. Mathematically, the total effect is given by the product of the transmitting and receiving reflectors' areas."

"You just said that Lunetta's reflector has four times the area of our own," objected Billingsley. "Then Lunetta ought to receive our transmissions better than we can get hers..."

"No, that isn't quite correct. We do not concentrate our transmissions quite so effectively with our smaller reflector, but Lunetta is able, with her larger one, to intercept a larger cross section of our beam. So the effective energy caught by her larger reflector from our less concentrated beam is exactly equal to our lesser amount from her highly concentrated emission. Either way, it's the product of the reflector surfaces that counts."

"How sharp is our beam?" asked Ross.

"It's some 1½ degrees. Generally this kind of beam is sharper, the greater the diameter of the reflector is in relation to the wavelength employed."

"Just a moment; why, then, don't we shorten the wavelength? Three or 4 centimeters instead of 10 ought to give better results."

"Theoretically you're right, but in practice, our wavelength is affected by other factors as well. The main problem is that it is still difficult to build transmitters for powers of the order of magnitude of 10 kilowatts and wavelengths of less than 10 cm, although it is thought that it may be done some day. If we reduce power, we sacrifice some of our range, while the narrowing of the beam achieved by shorter wavelengths would lose its value."

"One more question, please," asked McRae. "You said that there was no difficulty in reducing the bandwidth for achieving long range. But that means that the receiver must be tuned very accurately to the transmitter's wavelength. How can you find the frequency at all? I have trouble on my set at home finding the frequency of a certain short wave station…"

"Now you've hit on a touchy question," said Lussigny. "In our case, tuning to the transmitter is complicated by some special factors.

"First of all, there's no way of building a transmitter which will not fluctuate to some extent in the emitted wavelength. Ours are stabilized by crystals whose natural frequencies are sharply defined and which prevent any broad variation of the design frequency. But even these crystals are subject to temperature and other variations which prevent complete steadiness in the frequency. We have the same difficulty in our receivers, for, if we wish to tune to a definite frequency with such high exactitude, we must use superheterodyne circuits. In the latter, we do not tune the carrier frequency proper, but rather its difference from a frequency standard generated in an oscillator in the receiver. The accuracy of this oscillator, however, depends on a crystal. The sum of the irregularities thus introduced by inevitable variations between receiver tuning and transmitting frequency forces us to stay above a certain minimum bandwidth. Otherwise the transmitter may "wander" out of the reception band for which our receiver is set. Fortunately, the minimum bandwidth needed for these reasons is only a fraction of what we require for voice transmission or automatic telegraphy.

"We have still another bugbear which is characteristic of our cosmic radio problem. This is the effect of the relative motion between our ships and the station with which we communicate. It makes the frequency actually received different from that transmitted. This phenomenon is called the Doppler effect. It becomes positive or negative as we approach or recede from the station we are working.

"In actuality, the Doppler effect during our voyage is composed of four independent motional effects. The first is produced by the presently increasing distance of our vessels from Earth and will be reversed during the return trip. The second motional effect is caused by the rotation around the Earth of the station we are working. The third motional effect will be caused by our circling around Mars after we enter the satellitic orbit there. At that time, the fourth the most powerful motional effect will be caused by the relative motion between Earth and Mars.

"Let me outline for you how the Doppler effect is produced. Let's assume for the moment that the distance between us and the station with which we work is increasing. Waves emitted by that station must overhaul the ship as it tries to get away from them with its own velocity. Therefore the waves strike our antenna in slower sequence than if we were at rest with respect to the transmitting station. You may think of the simile of an ocean liner: a head sea strikes the vessel more frequently than a following sea.

"The extent of the role played by the Doppler effect is exemplified if you'll forget for the moment our motion relative to the Earth and consider only the periodic rotation of the Lunetta station around the Earth. This produces a very powerful Doppler effect. If, at one moment, the Lunetta station is approaching us at her orbital velocity of 7 km per second, an hour later, it will be receding from us at the same speed. That means that inside of an hour a speed difference of 14 km per second may take place, and thus the frequency which we are now receiving is 140,000 cycles per second higher than that we shall receive within the hour. You remember that we wish to reduce out bandwidth to 1,000 cycles, so you can see how important it is to keep our receiver constantly tuned to the transmitter.

"It's not quite as difficult in practice as you might think. We might use a search receiver sweeping periodically over a wide frequency band in addition to the working receiver. The searching receiver would detect the frequency at which the messages were arriving each time it passed them on its scale, and would periodically tune the working receiver accordingly. Actually, we use a single receiver with "automatic frequency control." The Lunetta station is similarly equipped, and it is not difficult to reestablish communication even after lengthy interruptions."

"How do the Lunetta operators know where to direct their radio beams?" asked Billingsley. "I can see that we simply aim ours at the Earth. But Lunetta surely cannot see our vessels at present."

"Their tables give them our exact bearing in space and since they have our coordinates daily they always know whether we're on our prescribed track or not."

"I'm only a child when it comes to radio," remarked Ross, "and I want to ask what might be a foolish question. Could we communicate by radar?"

"The question is by no means foolish. What you have in mind is obviously "pulse radar," because the simple term "radar" is not clearly distinguished from the term "radio." We checked and found that it would be quite possible to use pulse radar, although it offered no particular advantages over radio. Perhaps you'd like to hear the reasons.

"Pulse radar technique differs from radio in that the continuous waves used in radio are supplanted by momentary radio flashes or "pulses." The output of radio transmitters is generally limited by temperature rises, mainly in the tubes. In pulse radar we have the advantage of being able to overload tubes mightily during the short times that pulses last, for they can cool off between them. Actually, we can multiply the power of emission on the order of magnitude of 1,000 as compared with continuous waves, if the pulses are short enough. So, if we were working with pulse radar, we could multiply the output of transmitters such as this one by a thousand without any greatly increased effort.

"It sounds quite appealing, but there's a catch to it, for such a powerful emission extends over a considerable bandwidth.

"There's an interesting analogy in acoustics; fire a pistol near a piano when the damping pedal is depressed, and all the strings will vibrate. Why? Because the sound of the shot is composed of tonal vibrations of innumerable frequencies or tones, as the acousticians call them. Each individual string reacts to the air vibration from the pistol shot that corresponds to its natural frequency, and gets in resonance with it. You might say that the explosion has a wide acoustic bandwidth.

"A radar pulse is just such an explosion, so we'd have to set our receiver for a wide range of frequencies if we wanted to extract a lot of energy from it. That would mean a wide bandwidth.

"There's the answer to your question. A pulse receiver needs a bandwidth that is greater; the shorter the pulses it is to receive are, the greater the necessary bandwidth. But the noise level increases in the same ratio as the bandwidth. So, as we shorten our pulses for a radar receiver, we get more "grass" as opposed to our continuous wave receiver. On the other hand, we cannot increase our output power without shortening the pulses. So you'll see that what we gain on the swings, we lose on the roundabouts and vice versa. Transmitter efficiency goes up, but receiving efficiency goes down. So the pulse method has no advantages, and we stick to continuous wave radio for maximum range."

"I say, Francis," said Billingsley, "why did you take the trouble to set up a station in the Lunetta orbit? Why could we not communicate direct with Earth?"

"We thought about it a good deal, and there's not much doubt but that we might have done so under favorable conditions," answered Lussigny. "But there were a lot of practical reasons which induced us to set up the Lunetta station.

"First there's the problem of Earth's rotation on her axis. We could communicate with a single station on Earth for a maximum of a half a day at a time, for that station would be blanked by the Earth's mass for the remaining 12 hours. That would have meant several terrestrial radio stations for continuous contact. These stations would have had to work in relays with continual intercommunication between themselves, and the whole world-girdling organization would have had to be set up for three years. The Lunetta station permits us to work at least once every hour, by reason of its bi-hourly circling of the Earth.

"Then too, radio communication directly to and from Earth would be affected by the atmosphere.

"The lower atmosphere would have made communication hinge on local weather conditions. Sandstorms and thunderstorms might have upset communications. Clouds tend to reflect some of the energy radiated at them by our short waves, and we often would not have known whether we'd been received correctly or why the other station didn't come in at the agreed times.

"When I went to General Braden with this idea and kept going back to him with new problems and demands for perfecting such an involved net of communication stations, he wasn't pleased. Finally he pounded the table and said, 'You'll get one ferry flight to the Lunetta orbit! Fix up something to take up there which will do the job our side of all this atmospheric blockage! We want reliable communication with the expedition, not a scientific circus which will be flopping intermittently so that the wise boys can give a thousand reasons from advanced physics for the flops…'

"So we built up another set just like those we have with us now. There was some extra disposable load in the *Sirius* which took the set to the orbit, and this allowed us to haul up the big, 40-square-meter reflector. That's the story of the station which we work."

McRae looked puzzled. "You imply that the Lunetta station is a Chinese copy of our own. I've believed that it was the other way around and thought that our station was independent of the Mars vessels because such an independent station had proved its efficacy in the Lunetta orbit. But if the design was first worked out for the voyage, why wouldn't it have been simpler to have made the radio set integral with the ship?"

"There are mighty good reasons for the radio station being a self-contained unit separate from the ships. First of all, cargo vessels do not have comfortable living spaces like that yacht you're living in, the *Polaris*. They have a pilot's cabin, a tiny radio shack, and the crowded cargo bay of the landing boat, and that's all. Our transmitting and receiving spaces would have had to be built separate from the landing boat anyway.

"Then Peyton insisted that the attitudes of the ships be controlled, even while coasting, so as to avoid any propellant tank becoming too cold by being shaded for an excessive period. This would have prevented us radio people from setting the ship's attitude in accordance with the desired angularity for our reflectors.

"You'll understand, of course, that not only must our reflecting antenna be constantly directed at the Earth during the actual voyage and while circling in the Martian satellitic orbit, but the reflector of the generating plant must be directed at the Sun. It would be quite a trick to do that from a space ship whose attitude is determined by entirely different considerations. Right now, it's difficult enough to keep the ship's own power-producing reflector pointing at the Sun and still permit the skipper adequate freedom to position the vessel as he wishes. With our two reflectors, that would be a geometrical impossibility, for the angular relationship between Earth and Sun changes much during our voyage.

"The self-contained and separate characteristics of our station eliminate these difficulties entirely. After the maneuver of departure, we had two busy bees tow this station away from the *Oberth* and leave it some 1,000 feet from the vessel. We can stay here until the old man decides that we have to make another power maneuver. Here we can keep the transmitter compartment in whatever attitude will permit the reflectors to be appropriately directed."

"How do you control the reflectors?" asked McRae.

"With triple flywheels and in the same manner that the attitudes of the ships are controlled. There's a set of such flywheels here in the transmitter compartment. With them, we set the whole radio station, leaving the reflectors locked in position. Then we unlock the solar reflector which is swiveled at its center of gravity on an outrigger. The solar reflector has two flywheels with which we direct it at the Sun, after which a photoelectric cell automatically cuts the flywheels on and off to keep the direction. In the same manner we rivet the reflecting antenna to the Earth."

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"Your current supply here is doubtless based on the same principle as the power plants in the ships?" remarked Billingsley.

"Yes, it's the same idea; solar reflector, mercury vapor boiler, turbine, and condenser, the latter being in the shadow of the solar reflector. The reflector is smaller than those on the ships, having an area of but 15 square meters. It collects solar energy to the amount of 8½ kilowatts and feeds it to the boiler. This figure holds near Mars, but increases to 20 kilowatts near the Earth where solar rays are much stronger.

"Such kilowattage is not adequate for our transmitter, and besides, our turbogenerator is only about 30% efficient. In the Martian orbit, we shall only extract some 2½ kw of power from our 8½ kw of solar energy, the remainder being reradiated to space by the condenser.

"Thus you see that our reflector only provides a quarter of the energy emitted by our transmitter. Moreover, to radiate ten kilowatts from the antenna, we must have an input into the transmitter of 30 kilowatts. For these reasons we must store energy in batteries. We charge the accumulators with 2½ kw for the full 24 hours, say 60 kilowatt-hours, and that allows us to operate the transmitting set about two hours daily. Our outgoing messages are handled during the ten minutes, occurring every two hours, when the station we are working is between us and the Earth. Of course, we can receive for much longer period because the receiver needs very little current."

"I suppose you just shift your antenna appropriately from transmitting to receiving when you're working the other station," said Billingsley. "Rather like talking over the telephone."

Lussigny smiled. "I'm afraid it's not quite as simple as that. Were you to try it, you'd find that all those millions of kilometers are rather more than just abstract figures. Radio waves move with the speed of light, 300,000 kilometers per second, and we are now about 20 million kilometers from Earth.

"Now, if I ask my friend Donald Flip in the Lunetta station, 'How's tricks where you are?' it'll take about a minute before my question reaches him, and I'll have to wait another minute before his, 'Just fine, Francis,' gets back to me. When we reach Mars, and when during the waiting time, Earth passes behind the Sun as seen from where we shall be, it will require almost 42 minutes for a radio wave to make a two-way trip between us and Earth. So we'll have to "bunch" our questions and answers if we expect to be understood."

"How horrible!" groaned Billingsley. "It makes me homesick. How about it, boys, shouldn't we be getting back to *Polaris*?"

"I've another question for Dr. Lussigny," said McRae. "There's one thing about the power plant I've never quite understood. Every time I think of our flexible baby bottles, I cannot figure how a steam boiler can work in weightlessness. Liquid has to be evaporated in the boiler, and nothing but the steam is supposed to reach the turbine. It would seem to me that there might be frightful priming troubles. How is that avoided in weightlessness?"

Lussigny smiled again. "What you've just brought up has been one of the critical problems in the development not only of the radio power plant, but of the other plants in the ships. Here's the way it's done in principle. The condenser liquefies the mercury vapor along its walls, where it takes the shape of small globules, driven along by the still uncondensed vapor moving past. These globules are caught in a small chamber in which the condenser tubes terminate tangentially. The heavy liquid mercury whirls around the sides of this chamber from whence it can be returned to the boiler by the feed pump. Residual mercury vapor, which keeps up the whirling motion, is recirculated to the admission side of the condenser by a small blower. Thus separation of mercury and vapor is done centrifugally, although in the boiler itself there is no sharp division between the liquid and the vapor phase. In principle the boiler is nothing but a tube set in the focal line of the gutter-like reflector. Mercury enters one side of the tube in liquid form and leaves the other side as vapor at 700 degrees Centigrade, being piped directly to the turbine.

"It all sounds a good deal simpler than it really is. We made preliminary experiments in the Lunetta orbit for months before the thing was working in principle. And it took more months to get the bugs out of the first trial power plants. Then we gave these a service test in the orbit. But finally we were successful, and I feel that we can consider this mercury vapor power plant as entirely reliable and functional."

Chapter 17
A Nasty Little Aster

On the second of June, 1985, the voyagers to Mars had been under way for seventy-three days. Their routine gave no indication to their senses that they were not floating idly in space, while they were moving actually towards their distant goal at a rate many times exceeding the muzzle velocity of a bullet. Today they would see the Earth pass across the brilliantly flaming surface of the Sun!

At first, the ship's elliptical path had kept them advancing away from the Earth at a rate of more than three kilometers per second, as soon as they escaped from her gravitation and began wandering through space like a swarm of tiny, independent planets, drifting through the solar system. Then the Sun's gravitation had begun to act, and they were still swinging away from its source, although working against it. Their velocity along their elliptical path had day by day diminished, until their angular velocity around the Sun had been reduced to less than that of the Earth. The Earth had begun to overhaul them on her solar orbit, and would pass between them and the Sun at a distance of some 20 million kilometers. Thenceforth she would outdistance them more and more.

This day would offer the lonely crews of the Mars vessels a celestial spectacle never before beheld by the eye of man. They would see the Earth and the Moon transit the Sun's disk. It would be a farewell to Earth until they should again return towards the close of their sidereal journey.

Smoked glasses before their eyes, they hung at the ports, gazing at the Sun's blinding splendor. They could not see the luminous double planet with which they had become so familiar during the past weeks, for both Earth and Moon had turned towards them their nocturnal sides, and these did not detach themselves from the surrounding blackness of the sky.

At last a tiny black dot appeared against the enormous corona surrounding the blinding white Sun sphere like a robe of flames. It was, to begin with, sickle-shaped, gradually becoming circular in appearance. Deliberately, very deliberately, it moved from left to right into the full glare of the fiery ball. An hour or so later, another tiny spot appeared, even tinier than the first. It followed towards the Sun's center.

To the navigators, this was far more than a spectacular sidereal slide show or sorrowful leave-taking from a midget dark spot that called itself the center of life, and which its inhabitants were wont to refer to as The World. The navigators could use it for a thorough-going check on the accuracy with which the convoy had maintained its velocity and track. In their astrodomes, they held filtered telescopes before their eyes, took the exact instants and measured exactly the points at which Earth and Moon transited the left and right edges of the Sun's disc. Then they computed to the fraction of a second just how much time had elapsed since they had shut off the rocket motors some 2½ months earlier and begun the long coast through space.

The transit of the Earth lasted eight hours and five minutes, and in two hours she disappeared from sight beyond the flaming edges of the corona. One hour later, the Moon followed suit.

The navigators compared notes and data by radio, consulted their tables, and came to the conclusion that their track was little, if at all, in error, and that no corrective maneuver need be undertaken.

Chapter 18
The *Aldebaran* calls "Mayday!"

Three more months passed, and Holt and his faithful band still faced an equal period before they would reach their mysterious Red Planet.

Weariness and extended inactivity made themselves felt. Personalities were beginning to wear on one another with resulting tensions. The cook and the engineer of *Antares* had gotten into a fist fight, which might have had serious results had it not been for the handicaps imposed by weightlessness on physical combat.

This was no particular surprise to Holt, familiar as he was with the effects of restricted living quarters on the occupants. He therefore undertook an exchange of personnel between the space vessels so as to afford some variety in the human contacts between his men. It was, indeed, time to alleviate the unbearable monotony which supervenes when the same wisecrack has been worked over as many as ten times. Even Billingsley had seemingly exhausted his ample store of amusing anecdotes concerning English globetrotters and dead Chinese emperors. That had been the danger signal. *Even if there are no new tales*, thought Holt, *we can improve things by getting a new set of listeners.*

Captains, navigators and engineers had to stick it out, for it would not have done to throw away the intimate familiarity they had developed with the complicated mechanics under their charge. Tom Knight, captain of Holt's *Polaris*, remained of course, and none of the tensions had occurred between the two. Their friendship actually became deeper, despite the over-intricate contact in which they were obliged to live.

Tom's appearance had altered considerably since they had stood together at the rail of the *Queen of Hawaii* and watched the lights of San Diego melt into the distance. In accordance with a custom which sprang up in the whole Mars fleet a few weeks after departure, he had let his beard grow. With his smoothly parted blond hair, his bright blue eyes and his long blond beard, he looked like an ancient Viking sailing forth to Ultima Thule.

Holt himself remained clean-shaven. He insisted that no beard could "hang properly" without gravity and that it would interfere with eating. No matter how convincing the arguments of the beard-wearers that their experience proved the opposite, he stuck to his theory. But in the interest of the psychological welfare of his crews and to prevent them from becoming prey to depressive thinking, he instituted a broad program of activity.

Every passenger ship held a movie show at least twice a week. Sam Woolf and Howard Ross circulated from vessel to vessel and ran the projector. Those not on watch in the cargo ships we allowed to attend, since the limited spaces where they lived would not permit of such luxuries. This they called "getting out into the great world."

Dr. Gudunek would give radio lectures in English, French, German, Russian and Spanish for those who desired to improve their education during the long days of inactivity. He announced that he would include Martian during the return trip. He saw to it that there was an active interchange of books between the vessels, thus providing himself with an opportunity for extensive visiting, and he was always welcome.

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The expedition's gravity cells offered one of the gratefully accepted escapes from boredom.

Early in the planning stage, Dr. Barrett and the specialists of the Institute of Space Medicine had expressed grave concern as to the effects of the weightless condition upon the crews, when protracted for months on end. Even Bergmann and his assistants, the champions in long-time weightlessness, had been able frequently to return to Lunetta during their extended observations and there to expose themselves to her synthetic gravity for several hours.

Many problems had been posed to the space doctors. What would be the effect of extended weightlessness upon body fluids? Would, perchance, the sensitivity of the organs of equilibrium of the inner ear, weight-sensitive as they are, suffer? It was these organs which for ages had told men and animals what was up and what was down – where Heaven and Hell were. In space flight their system of reference was gone... Would a general degeneration of the muscular and vascular systems not threaten organs such as arms and legs and heart, when, accustomed to working against gravity, they would be able to function with so little effort? In weightlessness, violent motion involved the danger of the mover's colliding with any of the six walls surrounding him, forcing him to use his physical strength with utmost caution! The muscles and limbs of the crews might well shrink as though in plaster casts, incapacitating them for their duties when they reached the surface of the distant Red Planet.

The answers to all such problems were the gravity cells, for it was impractical to provide the expedition with so bulky a doughnut as Lunetta. Peyton's designing genius evolved the dumbbell-shaped affairs which floated not far from the ships, whirling about the center points of their handles like giant maple keys.

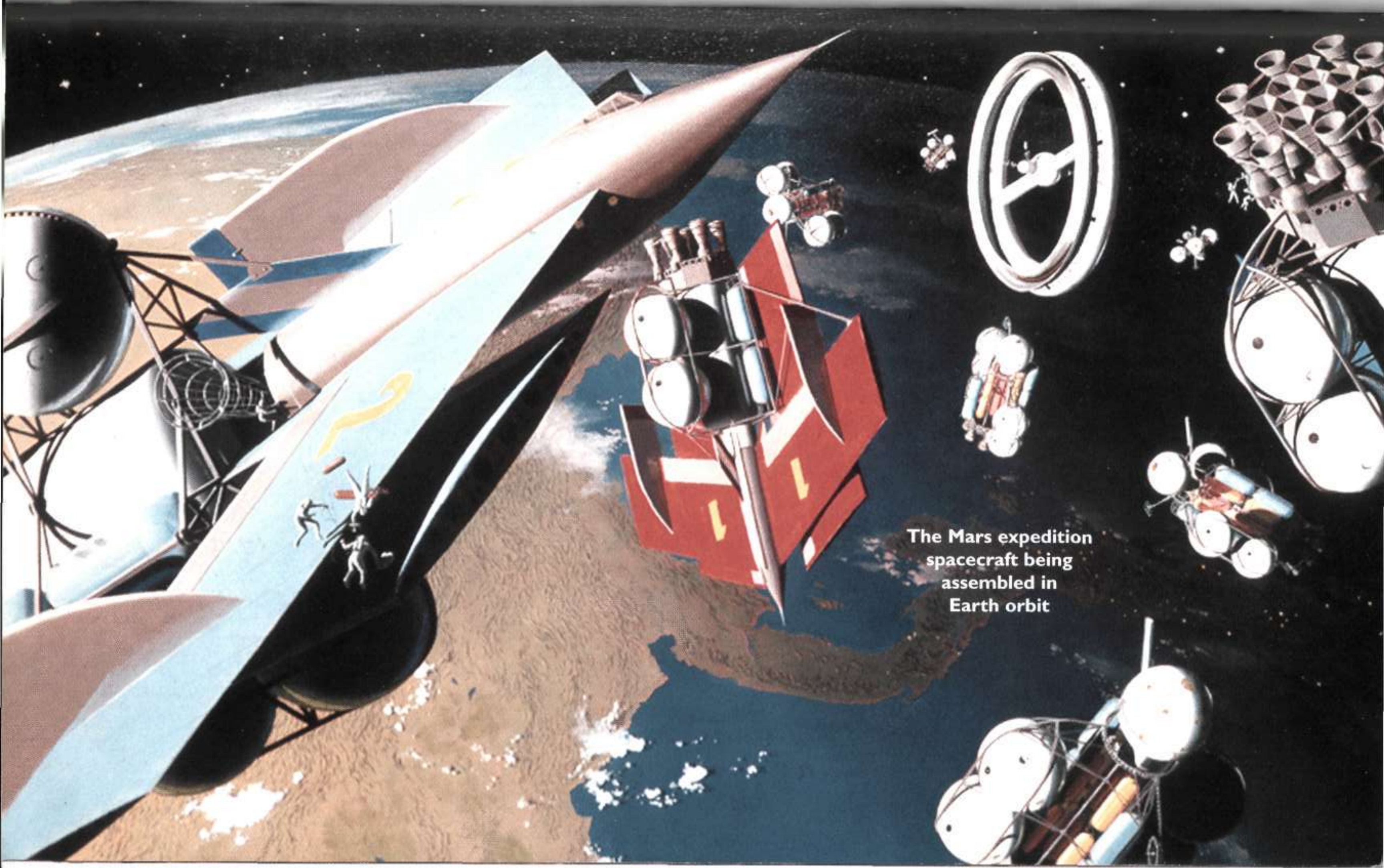
Holt issued a squadron order that each crew member must pass not less than two hours in the gravity cells twice a week. Busy bees ferried the men in groups of four to the huge dumbbells, which they entered through the central chamber, a spacious metal drum, via bulkhead doors directly from the bees. From the central chamber the men descended to either of the great bells through air-impervious hoses one hundred feet long and three in diameter. The two diametrically opposed spheres, the hoses and the central chamber were inflated by an air conditioning unit to a pressure of one atmosphere for respiration and to maintain the dumbbell's shape.

The four sometimes unwilling athletes distributed themselves into opposite gravity cells by seating themselves upon a board attached to a rope, one of whose ends was made fast in the central chamber while the other was rolled around a drum on the board. When a snubbing device was released, centrifugal force pulled the man on his board into the cell proper. To return to the central chamber, he would pull himself back by a handle attached to the drum.

Within the cells were a few simple gymnastic implements with which the men worked their unaccustomed muscles back to suppleness, accompanied by many a humorous curse and gripe at the now loathsome synthetic gravity.

When propulsion maneuvers were undertaken, the gravity cells were secured, as was Lussigny's radio set and Bergmann's telescope. This was done by allowing the internal pressure to escape, after which men in space suits folded the spheres and their connecting hoses and stowed them in the metallic drums of the central chambers. The chambers were then towed back to their cargo vessels.

Officially it was night and Holt was sleeping peacefully in the air of the living compartment of the *Polaris*. Two safety pins through the coat and trousers of his pajamas held him gently moored to a pair of cords which kept sleepers steady during the hours



The Mars expedition spacecraft being assembled in Earth orbit

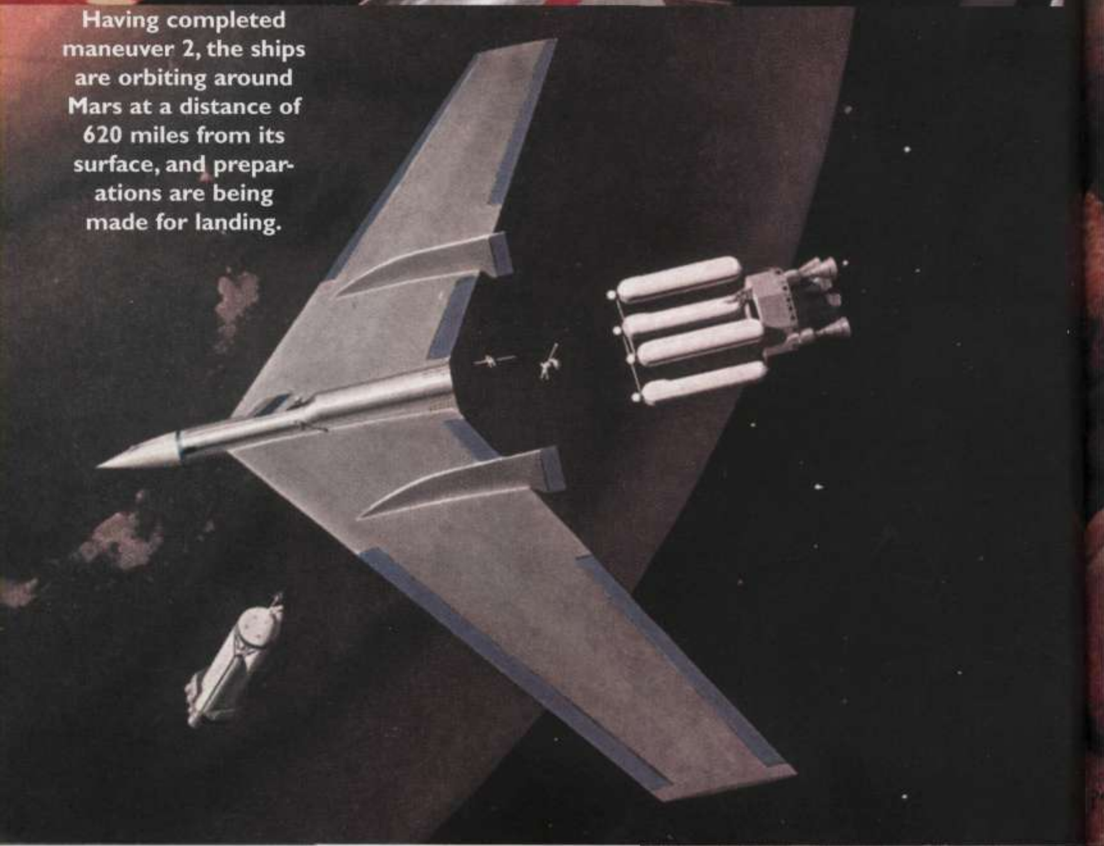
Assembling the ships for the Mars expedition, 1075 miles above the west coast of South America. The group of islands left of center is the Galápagos.

Maneuver 1: The two ships leave for Mars, traveling east in the plane of the ecliptic. They are shown 1330 miles from Earth. Part of the visible portion of Earth is the South American continent.

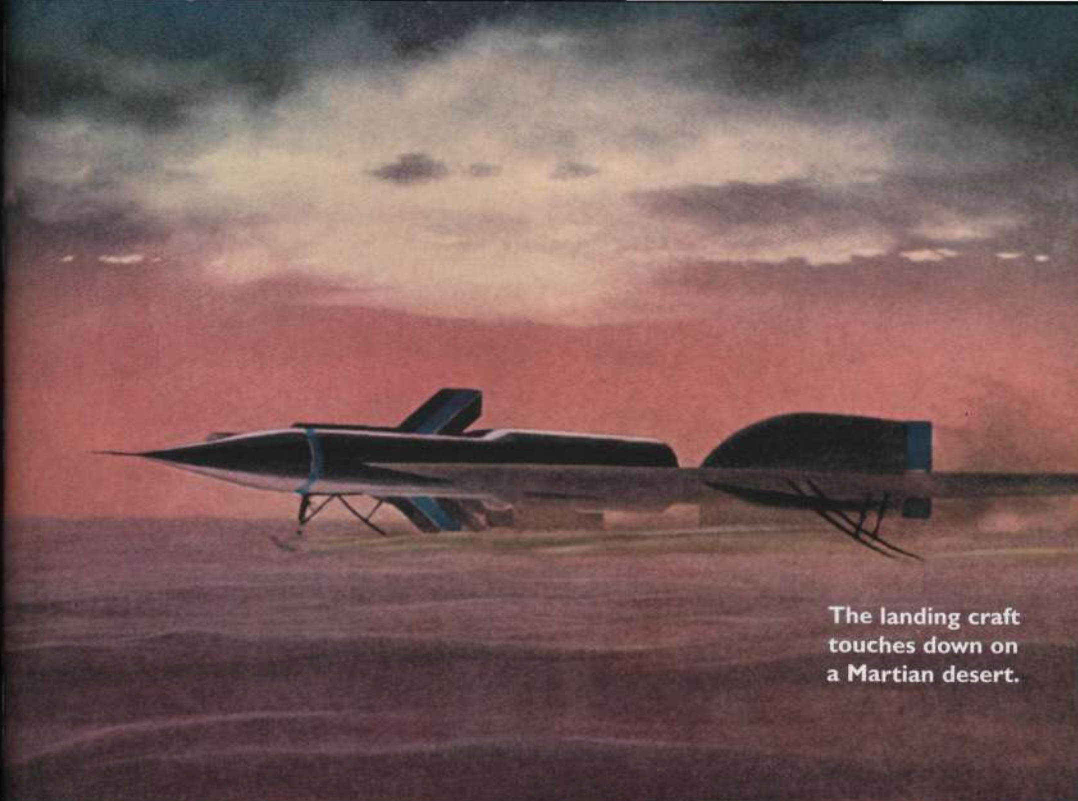
The Mars expedition, 8600 miles from its goal. The ships are approaching tail first.

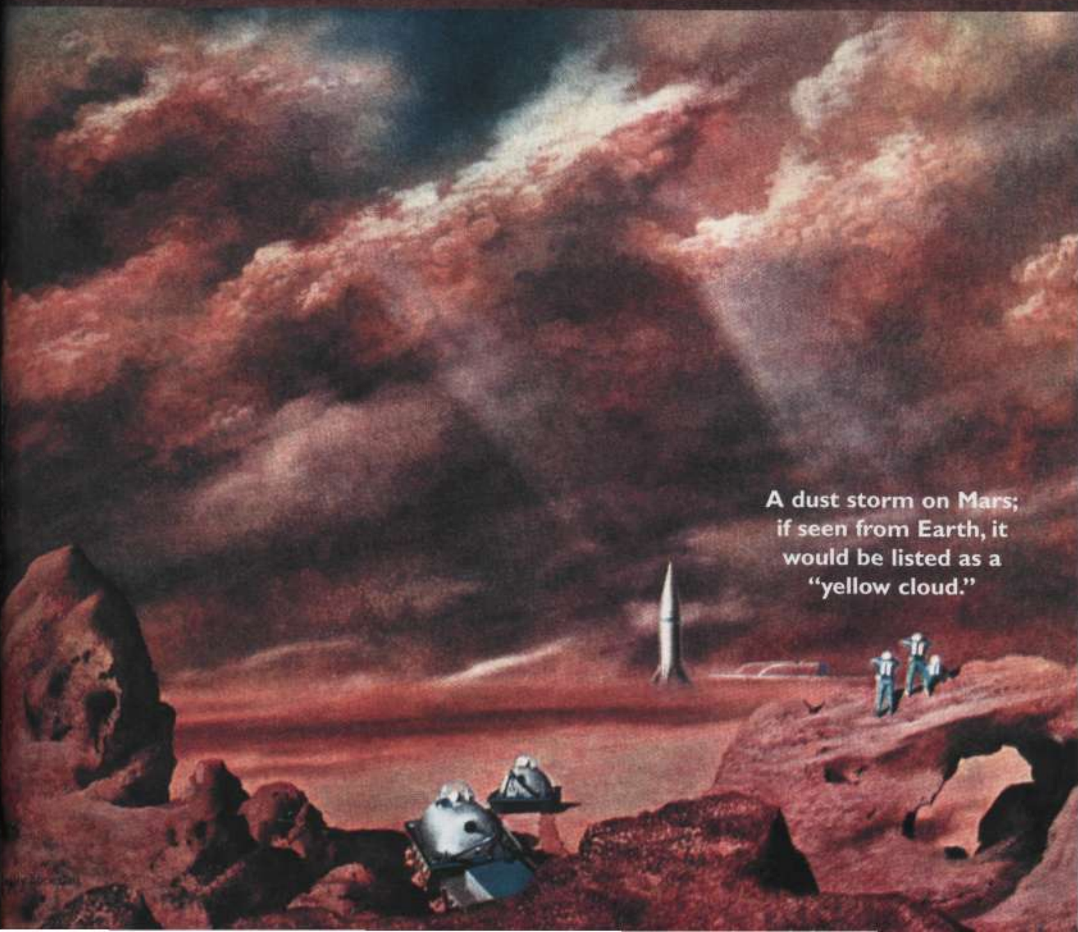
Mars as it appears to the naked eye when seen from its inner moon Phobos.

The Earth fleet arrives in Mars orbit



Having completed maneuver 2, the ships are orbiting around Mars at a distance of 620 miles from its surface, and preparations are being made for landing.

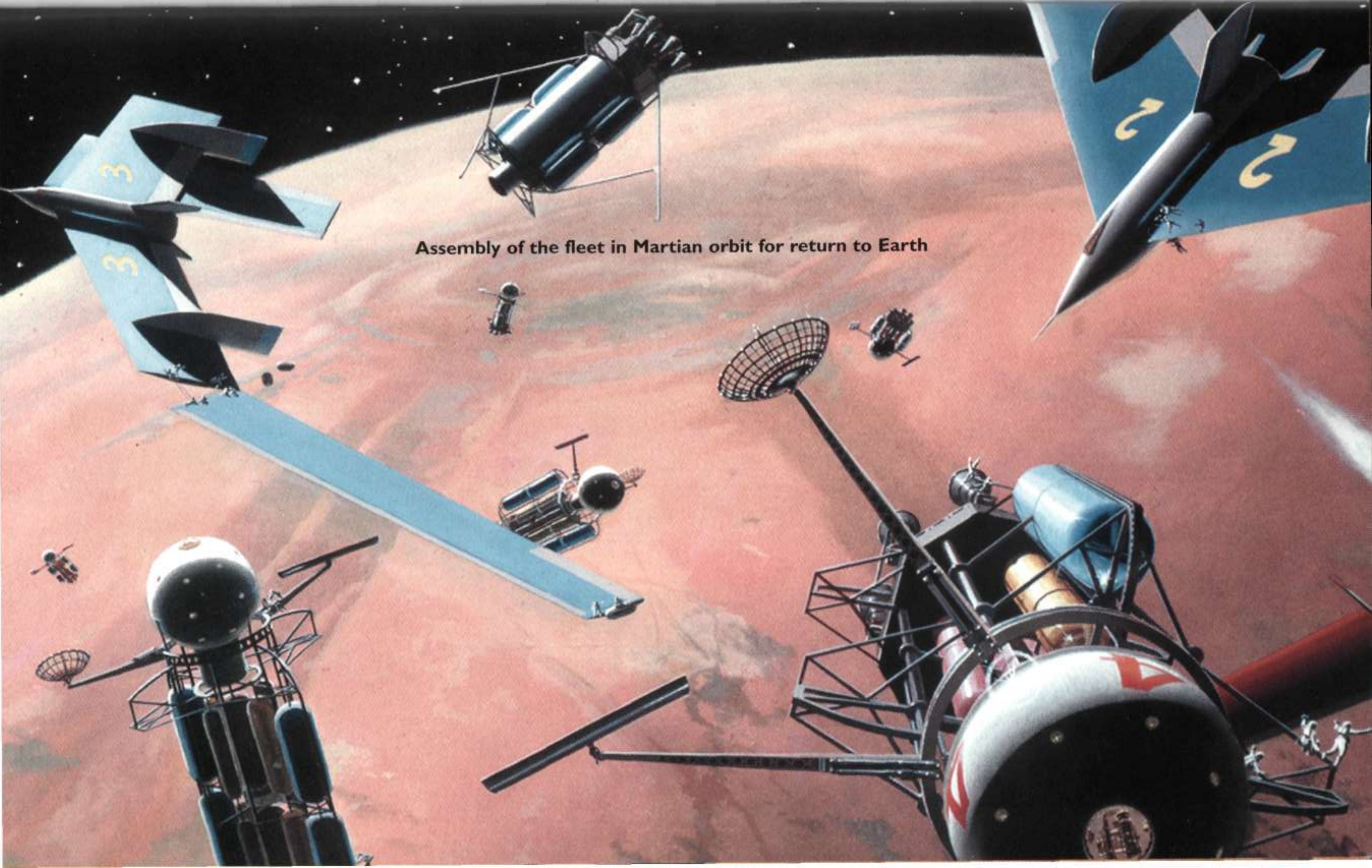

The landing craft touches down on a Martian desert.


A dust storm on Mars; if seen from Earth, it would be listed as a "yellow cloud."

The ground station has been set up on Mars,
and the explorers are beginning to
investigate the vicinity of the landing site.

A human colony beginning to take shape on the surface of Mars.

After landing, the wings and undercarriage are disengaged, and the rocket is raised into take-off position.



Assembly of the fleet in Martian orbit for return to Earth appointed for slumber. His dreams were rudely interrupted by a twitching of one of the cords. It was Tom Knight who had recently gone on watch.

"We've had two Maydays from *Aldebaran*!" shouted Knight, "No response to our acknowledgment!"

Holt ripped the safety pins out of his night clothing and swam with Knight into an astrodome from which *Aldebaran* was visible. Field glasses showed nothing abnormal. She hung there about eight miles away, as she had for weeks, motionless and glistening against the velvet sky. Holt slipped into a uniform, snapping out commands as he did so.

"Waken Dr. Barrett and two Corpsmen. Clear away a busy bee with four space suits. Radio *Ziolkowsky* to send a power bee to *Aldebaran*. Same to *Goddard*. Radio *Capella* to send Wiegand and a damage control party to *Aldebaran*. I'm off with Barrett and the two Corpsmen."

A few minutes later, Holt and his party, already dressed in their space suits, entered the busy bee secured at *Polaris*' airlock and the forward tank retainer. Holt himself took the helm and swung out towards the motionless and apparently unaffected *Aldebaran*.

As they neared the vessel, his glasses revealed several figures moving outside the nacelle and apparently busy near the forward portion of the tankage system. Still no apparent damage was visible. Holt reversed his thrust so as to stop the bee some 200 feet off. Opening the hatch, he spoke into the microphone contained in his transparent space helmet.

"What's up, Sherman?"

One of the figures lifted an arm in acknowledgment and then, drawing his reaction pistol, projected himself in their direction. As he neared the bee, he reported via his individual radio set.

"We took a meteor through the nacelle just now. No personnel losses. Repairs are underway."

Holt drew him into the busy bee. He closed the hatch, pressurized the little cabin and they removed their helmets.

"Tell me about it, Sherman."

"We were hit by a meteor about one fourth of an inch in diameter through the forward wall of the control room, just alongside the bow astrodome. It passed through the captain's cubicle and through my laundry chest. Then it knocked a hole in the position chart in the navigating room and went on out through the sick bay aft. It cut the corner of one of the hydrazine tanks for the second maneuver, and I'm afraid we've lost some propellant. But the patch is just about on, and the loss is small."

"Were you aware of what happened?"

"Sergeant Bock was on duty in the control room and I was strapped down in my cubicle, reading. The thing missed Bock's head by a foot or so. The others were asleep. All I heard was a bang in my laundry chest and then some smoke came out of it. There was a hissing sound, followed by the alarm horn. Then I knew we'd been hit. I ordered Bock to send an SOS, although he was a little fuzzy from the shock wave of the meteor.

"When the nacelle pressure began to go down and the drop-out in the smoke producer gave us a clue to the location of the entrance and exit holes. We had hard rubber patches over them in about three minutes. The blower system went into automatic high delivery just as it is supposed to, although we lost about a half an atmosphere of pressure before the patches began to hold. Then the pressure climbed right back to the full one atmosphere. The system worked beautifully. Made my ears snap, the pressure came back so fast."

"How about the hydrazine tank?" asked Holt.

"We didn't notice that in the excitement until Corporal Blacksmith went to make a check on whether any of his medical gear had suffered. He opened the port cover and took a look out at the tanks when he saw that the wake of the meteor might be near them. When he saw the hydrazine pouring out, we put on space suits and climbed out with patches."

"Do you think you've lost much?"

"I don't think it's a great deal. It was pouring out of the aftermost leak like a half-opened spigot. It began to spread over the skin of the tank because of its adhesive properties, and then evaporated rapidly in the vacuum. The forward leak just dribbled. Weightlessness is what saved us. I hope and believe that we didn't lose more than 50 gallons."

"Well, that's not as bad as it might have been," said Holt, "but why didn't you answer us after you sent the "Mayday"?

"Until we stopped the leaks in the nacelle, I didn't know how long we could maintain our pressure. It was dropping despite the emergency power on the blowers. So I ordered the crew into space suits and shut off the juice from everything except the blowers so that the batteries could keep them running at full power as long as possible. Our radio transmitter was shut off too. I believed it was vital to keep the pressure up at all costs, or else the nacelle might collapse when the batteries went dead. A collapse like that would play havoc with the entire installation. We reported as soon as the holes were plugged, but you'd gone. Colonel Knight took the message."

"You handled the situation very well, Sherman," said Holt. "Let's have a look at the damage while Dr. Barrett gives Sergeant Bock the once over."

They replaced their helmets, depressurized the interior of the bee and pushed themselves clear of the little vessel. With their reaction pistols they shoved themselves towards the silver nacelle of *Aldebaran*.

The holes made by the speeding meteor were insignificant. The edges of the punctures showed signs of carbonization due to its velocity. The hard rubber patches within the nacelle were still held tightly by the interior air pressure. Wiegand and his repair experts were already busy cementing them in place from the outside for permanence. The *Aldebaran* people had completed this detail on the hydrazine tank.

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The encounter between the meteor and the *Aldebaran* promptly became a welcome and enduring subject of conversation among the Mars crews. Bergmann the astronomer had drawn Laroche's *Vega* in the personnel shift and found himself foregathering with the loquacious Billingsley. Meteors in general had become a matter of very considerable importance and Bergmann's sidereal knowledge was much in demand. Heretofore he had not been able to utilize his fine, large telescope, for Mars was still at a greater distance than during his most favorable oppositions and Bergmann was unable to find a refuge from the hail of questions with which he was bombarded.

"I had no idea that these meteors were such dangerous fellows," remarked Billingsley on the day after *Aldebaran* had been struck. "It would seem that our ships are so tiny compared to all this space that there should be plenty of room for us without any real danger of colliding with the wretched things, you know. D'you think there's much chance of its happening again?"

"I'm afraid there is," answered Bergmann cautiously." I believe, however, that the *Aldebaran* incident permits us to discount any major danger from collisions of this sort."

"But I say, old chap, what if a bloody great meteor knocks a whole ship to bits and pieces?" bellowed Billingsley.

"That would be very tough luck indeed," answered Bergmann, "but the big fellows are fortunately few and far between in anything as vast as the universe. It's the small fry that give us the headaches.

"Judged by the size of the hole it made in *Aldebaran*, the meteor must have been about a quarter of an inch in diameter. Not very large, you'd say, but it's quite respectable for a meteor. The risk of a nacelle being hit by another is about once in 10,000 years."

"My dear fellow, you seem shockingly definite," retorted Billingsley with some skepticism, "how on Earth – in space, I mean – can you know that?"

"It's quite simple in principle, although that type of calculation is apt to be somewhat rough. The frequency of shooting stars as we observe them from Earth gives us a point of departure."

"Really, old fellow! How jolly interesting! Won't you elaborate a bit?"

"A meteor one quarter of an inch in diameter is visible as a shooting star of zero magnitude when it strikes Earth's atmosphere and becomes incandescent by air friction. That is to say that its luminosity is equal to such bright, fixed stars as Vega or Capella. A statistical compilation of the observations of star gazers scattered all over the Earth indicates that about 500,000 shooting stars of zero magnitude and higher strike Earth's atmospheric shell per 24 hours. When this is referred to the tiny globes of our nacelles, it comes out to the figure I gave you: one probable hit every 10,000 years."

"That would seem to settle the matter for the quarter-inch giants, right enough. I shan't worry too much about them. But what about the smaller bits? Our recent visitor went right through two walls of our nacelle, tore and burned my good friend Sherman's undies, and punched two bloody great holes in the hydrazine tank. Can't one of his baby brothers burst through the nacelle some day and knock my breakfast pannikin galley-west?"

"As I told you, it's the smaller ones that give us the headaches, for they become more frequent as they decrease in size, and it is indeed fortunate that their penetration also decreases. This permits us to count on the three-quarter inch walls of the nacelles to protect us from all meteors smaller than the tenth magnitude.

"That size can only be perceived through powerful telescopes when it strikes the atmosphere, for the diameter is not far from one hundredth of an inch. We should call them "grains of meteoric dust" rather than meteors. Should such a grain penetrate the walls of one of our nacelles, the tiny puncture can be repaired with far less fuss than *Aldebaran*'s trouble.

As to probabilities of such punctures, meteors down to the tenth magnitude strike Earth's atmosphere five billion times per day, or ten thousand times as often as those of zero magnitude and larger. The probability of a hit by such a large meteor is, as I said, one in 10,000 years; therefore the likelihood of a hit by a meteoric grain is one per year. On our three year's trip, we might expect about three punctures per nacelle."

"What about armor plating the nacelles?" asked Billingsley.

"To get effective protection against meteors up to and including the eighth magnitude," answered Bergmann, "we should have to plate our nacelles with one tenth of an inch of steel and that would amount to five tons per nacelle. The planning staff felt that the risk did not justify the sacrifice in payload in order to cut down the chances of puncture to 20 per cent. Whether they were wise or not is a matter of educated guesswork rather than a scientific question. We shall know when we get home."

"That's all very well of the nacelles," pursued Billingsley, "but our propellant tanks are remarkably thin, so I'm told. Aren't we apt to dribble like sieves?"

"It's not as bad as that," went on Bergmann. "The large tanks for the initial maneuver are but one tenth of an inch thick and can presumably be holed by meteors as small as the fifteenth magnitude, which are about one four-hundredth of an inch in diameter. The tanks are roughly the size of the nacelles, and of the same material. Fifteenth magnitude meteors are about one hundred times as frequent as those of the tenth magnitude, so we anticipate roughly one hundred punctures per year. By the time we jettison our presently empty tanks, they'll probably average 70 punctures apiece. We're far more concerned over the smaller tanks for later maneuvers, since they will be exposed to meteoric grain bombardment for a much longer time."

"It seems to me a jolly great miracle that we've a drop of fuel left…"

Bergmann smiled confidently. "You've heard of puncture-proofing, have you not? It was used in automobile tires as early as 1920 and in bulletproof aircraft fuel tanks before that. Our tanks contain a chemical which immediately flows to the tiniest wound and stanches it then and there. Nor is it often called upon to heal anything as large as a 0.50 caliber hole, as it used to do quite regularly when men fought airplanes. It will be 10,000 years before there's another puncture like *Aldebaran*'s, you might remember."

"Really, Bergmann, you're the most accommodating and patient science fellow it's ever been my good fortune to travel to Mars with. They do have meteoric swarms if the tabloid journals are right," persisted Billingsley.

"They are relatively dense, to be sure," answered Bergmann, "but the nice thing about them is that we're on familiar terms and know where to expect them.

"Meteors may be classified as hyperbolic or elliptical. The hyperbolic type enter the solar system from elsewhere and when they enter the solar field of gravitation, they have an initial velocity which tends to increase the closer they approach to the Sun. When their distance from the Sun is equal to the distance of Mars's orbit, they are traveling more than 34.3 km/sec, and at the distance of Earth's orbit more than 42.1 km/sec, for they would have attained this velocity by solar gravity alone, even without any initial velocity.

"Such meteors are 'strangers' and they describe a hyperbola around the Sun and disappear for ever from the solar system, unless they fall into the Sun or onto a planet. We have no way of predicting their appearance, whether as to time or location, for they visit us but once and for a short time. It is assumed that 70% of meteors are hyperbolic.

"Elliptical meteors must basically be slower than the figures I've quoted, and the whole situation is different. Like planets, they gravitate around the Sun in elliptical orbits which are frequently very eccentric. They cross Earth's orbit at regular intervals and this permits us to become relatively familiar with their paths. The track of this voyage avoids such paths by a safe margin, if our computations have been effective."

"Jolly interesting, you know," mused Billingsley. "Then the swarms of meteors which return regularly on certain days belong to the elliptical brotherhood, et?"

Bergmann nodded.

"And how do they come into being?"

"We figure that the elliptical brotherhood, as you call them, are the wreckage of comets which may have come too close to the Sun and burst from the heat. When a swarm of such small particles following the same path – but considerably separated from one another – arrives at the inner regions of the solar system as they fly around the Sun, there are minor differences in the attraction exercised by the latter upon the nearer and more distant particles. This, and planetary gravity, produces small differences in their orbital periods which in time become cumulative. Thus the wreckage of the erstwhile comet is distributed along the orbit, and we see a swarm of shooting stars.

"Within the thickest of such swarms hitherto observed, meteoric density is about 35 times that of a normal night. If this figure, which applies to visible shooting stars larger than the sixth magnitude, can be extrapolated for the smaller ones, our chance of taking a hit when traversing a swarm would be 35 times greater than normal. We should remain in it for only a few hours, so even this additional risk is not very great."

"I don't suppose there's any way we could protect ourselves from one of your bally sidereal bombardments outside of armor plate, is there?" asked Billingsley.

"Not much, I'm sorry to say," continued Bergmann seriously. "Maybe you're dreaming of some sort of radar warning device which might enable us to start the rocket motors and duck out of the way. But if you'll remember that meteors are often not much bigger than a grain of sand and are only a few seconds – but quite a few scores of kilometers – distant when radar could pick them up, you'll agree that we couldn't even get the propellant pumps up to speed before the nasty little visitor would have come and gone. You might as well ask a battleship captain to steam away from a 16 inch shell."

Billingsley gave himself a push against the bulkhead and floated across the little room to where the sleeping cords ran from one wall to the other. As he removed his shirt, it was caught in the draft of the blower discharge and floated just out of reach.

"Getting jolly well bored with this space travel," he yawned. "Can't even hand up my bally shirt. And you, Bergmann, with your blooming high velocity meteors… First thing you know, you've made a chap quite nervous. Turn out the light like a good fellow, will you?"

Chapter 19
The Approach Path to Mars

Ten days remained before the maneuver of adaptation to the satellite orbit around Mars, and the excitement among the crews waxed visibly. Their distance from the planetary goal had diminished to the paltry figure of 2.2 million kilometers and they could see him as a prominent half-disk, one third of the diameter of the Sun. The sunny side glowed intense orange-red and green, and even the naked eye could distinguish the white spot of the southern polar cap melting in the sunlight of the Martian Summer. The opposite half was shrouded in night, and its outline could be made out only when approached by a star which began to twinkle as its light passed through the Martian atmosphere. It would finally occult when it reached the invisible rim of the planet.

Not much more distant from it than the diameter of the Martian half-disk there was a softly glowing starlet whose relation to Mars visibly changed if observed for some time. It was Phobos, Mars' inner moon, on its seven-and-a-half-hourly chase around the planet. Double the distance away and on the opposite side of the luminous semi-disk was Deimos, the other and more distant moon. Inconspicuous against the fixed stars, it made a leisurely circuit of its lord and master in an exterior orbit requiring thirty hours for completion.

Hitherto the navigators had been content with a stellar parallax every 24 hours, but they now floated into the astrodomes every third hour and determined the apparent motion of the red planet against the fixed stars behind him. Two days remained before a corrective maneuver was scheduled to bring the convoy into a more exact elliptical path from which the actual hyperbolic approach to the planet might begin. Mars' solar orbit would then pass outside the aphelion of their improved ellipse and at exactly 8,800 kilometers from it. He was coming up behind them, overhauling them at the rate of 2.55 km/sec and bringing them subject to his gravitation. Then they would fall towards him in a hyperbola having its vertex about 1,000 km above the surface. 2,900 km before reaching this vertex, a propulsive maneuver was to reduce their velocity to that of the local orbital speed. The navigators figured that, if no such maneuver took place, they would shoot out into space again at an angle of exactly 106 degrees and 12 minutes of arc to the initial direction of approach.

Holt had instructed Bergmann to secure the big telescope through which he had been scrutinizing their rapidly approaching goal. It was fastened to the *Goddard*, and Lussigny's radio station likewise became a part of the *Oberth* after the last reports on Bergmann's observations had gone forth to Earth. The gravity cells were collapsed and hauled in; then Wiegand made a quick but thorough check that all was in readiness for the vital maneuvers. A full 24 hours before the signal was to be given, each ship was as much in readiness for it as human hands and eyes could make her.

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The correction maneuvers had taken place without incident and the velocity of the squadron had been changed by 22 meters per second, exactly in the direction which the Chief Navigator figured would bring about the required 8,800 kilometers distance from the Martian orbit and provide proper timing with respect to the now rapidly approaching planet. Observations of Mars' disk in relation to fixed stars confirmed the correctness of the calculations and the outcome of the maneuver.

There was now no further use for the great propellant containers from which had been drawn the power for the departure maneuver and the ensuing corrections. They must be jettisoned in order to save weight during the coming maneuver of adaptation to the circum-Martian orbit. Preparations for abandoning them included forcing all residual propellants into the reserve tanks.

This done, the engineers in space suits emerged from the nacelles and broke the connections to the propellant pumps, then unscrewed the helium lines which pressurized the tanks. Finally they pulled the plugs and interrupted the electrical connections to the quantity gauges and remote-indicating thermometers in the control room.

There were other useless loads besides the empty tanks to be dispensed with. The superfluous storage batteries provided for steering during the extra long initial maneuvers were now useless, since the smaller regular bank of batteries would be adequate for the coming shorter propulsion periods. Spent food containers, broken tools and instruments and similar accumulated debris was to be eliminated. Carried along as useless ballast, it would cause waste of propellants. Packed in what might be called sidereal garbage cans, the debris was bolted to the tank retainers to be jettisoned. Then the engineers reentered the nacelles.

Flywheels were started to bring the vessels into slow rotation around their longitudinal axes. Then the closing of electrical circuits detonated explosive bolts holding the outer arms of the tank retainers to their center pieces. The centrifugal force generated by the rotation then flung the arms with their great silver globes out into space, where they continued to recede slowly into the infinite distance. There could now be no danger of their interfering with the coming maneuver of adaptation.

Holt ordered his convoy into echelon with an interval between ships of some 1,000 feet, with instructions that their captains should keep station with the utmost accuracy, using the four rotatable steering jets only.

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Events now came in such rapid succession, almost taking away the breath of the Mars crews after the weary boredom of their months in space.

The apparent diameter of Mars two days before the maneuver of retardation had been equivalent to about twice that of the Sun, and twenty-four hours later it had increased to nearly quadruple. Now, just four hours before the vertex of the hyperbola was to be passed, the enormous multicolored disk, more than half of which was brightly illuminated, subtended an arc of vision of over seven degrees, or fourteen times the angle subtended by the Sun. The now compact flotilla of space ships was only 55,000 kilometers from the center of Mars's enormous sphere.

All navigators lay strapped into their astrodomes, recording the times of occultation behind Mars of various stars and reporting results to Holt immediately by radio telephone as he and his Chief Navigator, Hal Royer, studied the flight path chart in the navigation room of the *Polaris*. As Royer read positions from the tables with each incoming report, Holt would mark the spot on the chart with a round-headed, colored pin. Thus he could keep track of any small divergences of the convoy from the prescribed track's thick red line. Holt was well content, for the many careful observations of star occultations were now bearing fruit, proving the last correction maneuver to be accurate. There was no reason to anticipate any unforeseen alteration of the flight path by extraneous or unpredicted factors.

Two hours and fifteen minutes remained before they would reach the hyperbolic vertex where they were to convert their precipitous drop into a definite circular orbit. In the meantime, their velocity relative to Mars had increased from 2.55 kilometers per second to 3.1 km/sec and the rapid increase of the disk of Mars in their eyes impressively confirmed it. The distance to Mars' center was 27,500 km, and almost three-quarters of the great sphere was bright with sunlight.

There was a brilliant star close to the inky edge of Mars' nocturnal side, sliding rapidly towards the planet. Instead of disappearing behind the somber edge it remained visible on the night-steeped face of the planet, and passed across the orange-red deserts, finally moving off into the world of stars with increasing pace. It was Phobos, the fast-moving inner satellite of Mars, crossing their course! Field glasses revealed that the 10 kilometer sphere was misshapen in contrast to the perfected rotundity of larger heavenly bodies.

At X minus 85 minutes, their distance from the center of Mars had been clipped down to 13,750 kilometers and their relative velocity had risen to 3.57 km/sec. Mars himself, with his glowing red, white and green shadings, subtended a full 30 degrees of angular vision in the eyes of the tense crewmen.

Holt now gave the order to turn the ships to the attitude for the maneuvers. Royer selected two fixed stars on which the directional 'scopes of the new Sperry instruments were bracketed. Then the desired relative attitude of each vessel to this system of reference was set, and when the control gyros had leveled themselves, the flywheels were started. Ponderously, the ships gyrated in space until their rocket motors faced in the direction of flight. There was no disturbance of their orderly echelon. Within minutes Holt received the reports that each ship occupied the proper attitude and was ready to apply thrust.

At X minus twenty-three minutes and sixteen seconds, their relative velocity had mounted to 4.37 km/sec, they were but 6,875 km from Mars' center, and the planet's colored surface seemed to rotate with ever-increasing speed. This evidenced that they would not crash perpendicularly upon his surface, but were racing towards him tangentially in a graceful sweep which would permit them to use his gravity to convert their movement into the satellite path which was their objective.

No more than 3,500 km separated them from the planet's surface at X minus eleven minutes! His entire surface was bathed in brilliant sunlight.

The maneuver of retardation which would swing them into the orbit of a satellite around Mars was to be simultaneous for all ships, unlike the maneuver of departure, for it was not desired that there should be the slightest divergence between them when the maneuver was completed. Minor differences in angle or speed would have been much more difficult to correct in an orbit than during the long, elliptical interstellar passage.

The Space Forces had developed a technique for simultaneity during the ferry operations, when it had been found desirable to launch two *Sirius* ships in a time interval of but a few seconds toward the assembly operations going on in the orbit of departure.

The technique used a flagship as "master." Other ships were "slaved" to her angular attitude. This was done by automatic, continuous registry of the flagship's angle in relation to her three control gyros and impressing the three error angles upon three continuously emitted tones which modulated a radio carrier wave. A fourth tone conveyed the acceleration factor of the flagship. Thus any special attitude of the flagship and her acceleration would be reflected in the pitch of the tones emitted by her radio transmitter. On the slave vessel, the corresponding four tones were generated, and comparison of the pitches of these four tones with those emitted by the flagship indicated whether the slave ship deviated in spatial angularity and in acceleration from the master. If one tone varied in pitch, it produced a beat with that of the flagship. This beat induced a corrective signal in the automatic control equipment of the erring vessel, and her angle or thrust was corrected until the beat disappeared.

This method had been used by two ships only in the ferry activity, but near Mars it was proposed to slave the whole flotilla of nine to *Polaris*. Ten captains lay strapped in their control rooms, ready to make corrections by hand if the automatics should fail or an alteration in the ships' relative positions should prove necessary. Thus there could be no danger of the vessels being drawn together in a mass collision, or by any malfunction in the flagship's mechanism.

Polaris was now the last in line, astern of all the others. Next ahead was Sherman in his completely repaired *Aldebaran*. Haynes' *Ziolkowsky* spread her wide wings in the next position and at the head of the column flew Laroche in *Vega*.

Two minutes before the maneuver, Holt ordered the navigators out of their astrodomes and to their acceleration couches, for Royer had informed him that the vertex of the hyperbola would be missed by but 12 kilometers, and this could easily be allowed for by a slight change in the length of the thrust application. Computation was now to be laid on the shelf. The proper guidance tapes were inserted so that the automatic mechanisms could take over. The next minutes would show whether the various ingenious devices had survived the rigors of the long, idle voyage and whether John Wiegand's precision was to bear its fruit. A malfunction of the most insignificant part of the machinery might bring disaster upon the ship where it took place. Each vessel was faced with a passage between the Scylla of an all-shattering crash on Mars and the Charbdis of losing herself in space forevermore on the second branch of the hyperbola.

"X minus one minute...," came Holt's voice through the bull horns.

The once weary hours spent in the synthetic trainers returned to the crews. Captains and navigators checked the spatial attitudes of their commands. Engineers went over the checklists of control gyro planes, automatic steering gear, and the readiness of rocket motors. Each and every gauge and indicator seemed to smile encouragingly at them. They lay back on their couches. The fateful second hands of the clocks jerked towards the deciding moment.

"6 – 5 – 4– ," came Holt's quiet voice.

Knight firmly pushed *Polaris* igniter button. On Holt's panel a red bulb glowed, to be followed by the nine others showing that ignition had been all but simultaneous on the other vessels.

" – 2 – 1 – "

The thrust roared out and a column of green bulbs lit up across Holt's panel. The whole convoy was now pushing against their self-created gases to reduce the precipitous speed!

But weak indeed was the deceleration! The indicators showed a bare 0.2g – only a miserable one-fifth of Earth's gravitational force. The oldest space men in the crews could not but realize how different was a true voyage through space from an Earth launching, where they were almost crushed by acceleration at the end of the booster thrusts.

"Convoy from *Polaris*. Reports from Laroche, please."

"*Polaris* from *Vega*. Formation's good, except for 20 percent lateral between numbers 3 and 4. First three ships are a little too far inside."

"Roger, thank you. Burck, did you hear?"

"Roger."

"Haul out 60 meters. Over"

"Roger, willco. Over"

A little later, Burck called, "Now on station. Out."

Holt instructed *Oberth* and *Vega* to follow suit, then Laroche reported the station-keeping above reproach.

The thrust maneuver was to last 10 minutes and 58 seconds, and the accelerometer rose slowly to the figure of 0.45g. Holt's eyes flickered between the clock and the integrating velocimeter where was registered the speed reduction produced by the thrust working against their direction of travel. When it read 2.01 km/sec there was silence, and the hand of the accelerometer snapped to zero. The roar of the rocket motor, transmitted by the structure of *Polaris*, had suddenly ceased, as the ten green bulbs on Holt's panel went out – *Polaris*' integration gear had simultaneously cut off the thrust in the whole convoy by radio.

Holt called for reports in a dry, tense voice. When Laroche's French accent pronounced the final, "All's well," a shout of joy came from all the bull horns.

Cutting off reception from the other ships, Holt relaxed above his couch with closed eyes. A mumbled prayer rose from his lips. "Thanks to Thee, O Lord, we've done it. Be Thou with us henceforward. Amen."

Chapter 20
The Red Planet Bares His Secrets

Hardly had the maneuver of retardation been completed than Bergmann called from *Vega* to ask Holt if he might have *Goddard* send him a busy bee so that he might get his telescope working. His request was turned down until two hours later, when Royer reported that they were making good their satellitic orbit with excellent accuracy. They were whirling around Mars in an almost perfectly circular path at an average of 1,009 kilometers from his surface. Holt then put the formation back into line and told Bergmann to go ahead with his observation work, for he himself was only too curious about the fantastic scene below them.

The naked eye could easily distinguish the canals with their green, symmetrical intersections, and no sooner had Bergmann reported from *Goddard* that he was in full swing with his observing than Holt's busy bee was on its way to the free-floating observation chamber of the telescope.

Bergmann opened the hatch and emerged in his space suit to greet him. "What's the latest news from Mars?" asked Holt through his microphone. His curiosity was almost getting the better of him.

Bergmann shook his head. "So far, it's mighty scarce," he answered. "No towns, no streets, no movement anywhere. The whole planet seems dead as a doornail. But somehow there's an impression of symmetry entirely uncharacteristic of death. Quite frankly, I'm just as dumb as ever."

Inside the observation chamber, they removed their helmets.

"Let me have a look," said Holt.

"Wait until I set the 'scope at a point just West of Syrtis Minor in the region we call Libya."

Bergmann arranged himself in front of the eyepiece and twirled the leveling controls, continuing meanwhile, "this zone lies South of and close to the equator, between the famous Syrtis Major and Syrtis Minor. It is surrounded on the south, east, and west by vegetation and is bounded on the north by the broad Canal of Nepenthes, which there leads through Moeris Lake, a small, circular spot of vegetation.

"Libya stretches about 300 km north and south and 500 km east and west. I'm using low power at present, so that you can see the whole area. Take a look."

Holt drew himself to the eye-piece. In the center of the bright orange-red desert which Bergmann had called Libya, there was a circular, green speck into which not less than seven canals of varying breadth terminated radially. Some of the canals connected with the large vegetal areas of Syrtis Minor and Major. Two of them proceeded with admirable parallelism from the great, green circle of Moeris Lake, cut rectilinearally by the broad Napenthes Canal.

Holt gazed reflectively for a long time into the telescope. Then he withdrew and looked inquiringly at Bergmann. "It's incomprehensible," he said.

"Try 2,000 diameters magnification. Then it will seem as though we are only 500 meters above it, although the field of vision will be smaller."

When Holt looked again, the circular edge of the green island cut half way through the field of view. Holt was forced continuously to adjust the telescope setting to prevent their motion in the satellitic orbit and the rotation of the planet from losing the location on which he was focused.

atmosphere. The drag of the air, heightened by brake flaps at their tails, would decelerate them and bring them to Earth with diminishing velocity.

The sounding bomb was equipped with a parachute opening automatically at an altitude of some 125 kilometers, while the atom bombs had continued at high speed until their proximity fuses detonated them not far above the ground. The 'chute was intended to delay it, particularly in the little-known lower layers of the Martian atmosphere, which were of such vital importance to the landing.

Elaborate instrumentation replaced the war head of the atomic missile. This radioed its determinations back to the ships circling the planet.

The telemetering technique employed was in no way novel, for it had long before been used in reverse in rocket instrument vehicles which explored the mysteries of the upper atmosphere on Earth.

Holt transferred his flag temporarily to the *Ziolkowsky* in order to be present at the launching of the first of the three bombs from her launching mount. The latter was a simple affair of steel sections with two interior guide rails; two feet in diameter and some twenty long, the bomb lay ready between them. In order not to endanger the ship by the jet of the bomb, the mount was attached longitudinally to an out-jutting member of the tank retainer, and was some ten feet clear of the ship. Being parallel with the keel of the vessel, it could be directed much as the stern torpedo tubes of a submarine are directed by swinging the whole craft.

John Wiegand and Lussigny, with the help of some of the technical ratings, had spent the last 24 hours calibrating and inspecting the complicated instrumentation and the telemetering gear which would radio back the data. Aside from the relatively simple problems of securing and sending simple readings such as pressure, temperature, humidity and instantaneous altitude as found by electric altimeter, the bomb was also equipped to analyze automatically the composition of the Martian atmosphere and to transmit it by radio.

As John Wiegand often remarked, "Measuring is no great trick! But to measure correctly... Ay, there's the rub!"

A busy bee moored to *Ziolokowsky* served as launching station. Lussigny's High-Duty radio set aboard the *Ziolkowsky* was still in reserve and was equipped with a special receiver for the bomb's telemeter transmitter, together with the oscillographs which would record the vital data. Wiegand in the busy bee was to attend to the firing, with Holt as an interested but inactive spectator, while Lussigny sat before his automatic receiver and Haynes, in the control room of *Ziolkowsky*, would lay the vessel to the correct angularity. All three parties were in permanent contact via the ship's interphone.

John Wiegand spoke into his microphone. "Attitude set?"

"Attitude set!" came Haynes' voice.

"Receiver tuned?"

"Receiver tuned!" said Lussigny

"Ready on the firing line: FIRE!"

Flame shot from the tail of the bomb, urging it rapidly out of the mount. Like a torpedo, steered by its small gyros, the sounding bomb passes close to *Aldebaran* and *Polaris*. The flame contracted to nothingness after four seconds, for the bomb's speed had been reduced to 130 m/sec less than the 3.14 km/sec with which *Ziolkowsky* was circling Mars.

After nearly an hour, one half its time to circle Mars, the bomb would reach the atmosphere tangentially at the lowest point of its ellipse. Then it would dive deeper and begin to take its measurements and to send them back to the anxiously waiting Mars crews.

Tensely the men waited. Every ten seconds a signal impulse flitted across Lussigny's check instrument, showing that the telemeter transmitter in the bomb was "alive" and at the ready. At the sixtieth minute, the multiple indicators on his receiver came to life, proving that the instrumentation of the bomb had armed itself faithfully.

Lussigny switched on the oscillographs which would record the many readings radioed by the precipitously falling transmitter in the bomb. Slowly the light-sensitive strips of paper wound themselves through the recording instruments. From the tracings which would later appear would come the final word whether the design of the landing boats had been based upon solid facts, or whether guesswork had made a landing on the long-sought planet too risky.

Now the tiny specks of light on the instruments began to register, for the bomb had entered the atmosphere and was beginning to telegraph the vital information. For twenty drawn-out minutes the luminous points danced across the observation screen. Then they suddenly vanished. The bomb had reached Martian ground!

Hardly had the light specks disappeared than Lussigny feverishly began to develop the paper strips. Twenty-four hours later Holt addressed his anxious crews by radio to tell them that he proposed to take the landing boat of the *Oberth* down to Mars within three days, with Glen Hubbard as pilot.

Chapter 21
Down to Mars

Tom Knight took over the command of the vessels circling Mars with strict injunctions not to risk any foolhardy efforts with other landing boats until Holt so ordered by radio from the surface. Should he crash in the attempt, Knight was to keep the space vessels in the satellitic orbit until a suitable opposition for a return should occur between Mars and the Earth, employing his time with such observations as might be made from the orbit.

A series of eight radio relay bombs was then fired off into the Martian atmosphere after the manner of the sounding bomb. The radio relay bombs contained automatic transmitters and receivers which could receive short waves from the circling space vessels and retransmit them on long wave. They could also receive long waves and retransmit them as short waves. The object of these devices was to permit constant communication between the landing party and the circling convoy, for a line-of-sight between the two would exist for only very short stretches at a time, due to the rotation around Mars of the space ships. Such line-of-sight is essential to short wave communication. But Lussigny had predicated his design of the radio relay bombs on a Martian ionosphere which would reflect long waves and permit radio communication between any points upon the surface. Thus several radio relay bombs would always react to long wave signals from the landing party, while one or more of them would always be in line-of-sight with the convoy.

After they had been eased to ground by their parachutes, Lussigny "questioned" them as to their readiness and no less than six responded, to his great delight. He reported to Holt that uninterrupted two-way communication was assured when the latter should have made his landing.

John Wiegand and his inspectors went busily to work on the *Oberth*'s landing boat, seeking not only defects in its involved mechanism, but subjecting the three caterpillars, the respirators, the pressure suits, the radio, and even the food and water supply to the most exacting scrutiny.

"The devil," said John, "is a squirrel. Wouldn't it be silly to go through all this and have one of the boys die on Mars of ptomaine poisoning?"

Eighteen composed the first landing party and Holt was unwilling to shift the burden of its leadership to anyone. Glen Hubbard, his executive and pilot, had vast experience as former Chief Test Pilot of United Spacecraft in supersonic glides and landing techniques of experimental craft. No other captain could compare with him.

Dr. Gudunek, the linguist, was a member, in the hope that he would be able to initiate conversations with the Martians, whose intelligence was by now a foregone conclusion. Sam Woolf's geological knowledge would be of inestimable value in getting out of the polar melting zone and in finding a suitable area in which to lay out landing strips for the wheeled landing boats. John H. Billingsley's experience with strange races and peoples Holt thought might be extremely important. As engineer, there was First Sergeant Clark E. Winslow, whose tireless efforts had kept the *Oberth* in Wiegand's good graces throughout the trip. Harry Brooks was radio man, and Lieutenant Hempstead, with a detail of 10 soldiers, was there to do odd jobs, including the operation of the caterpillars and their radio sets. These men would also undertake the building of landing strips, once the equatorial zone had been reached, or, if need be, hold off any unhoped-for Martian attacks with tank ordnance and small arms.

Holt seated himself beside Hubbard in the *Oberth*'s landing boat's copilot seat, while the others floated into the well-packed cargo space. Then the boat was cast off and hauled by two busy bees some 300 meters to the side of the orderly column of space ships. The three hundred meters increased the boat's distance from Mars above that of the column of the convoy, and the bees had to reduce slightly the boat's velocity around the planet to keep the orbit exactly circular. Since *Oberth* had been number two ship near the head of the line, the boat now passed in review beside the circling vessels, drifting slowly astern of them, while their crews floated in their astrodomes and waved farewell. Then the boat hung solitary above the vast Martian surfaces.

Deceleration for descent was to take place at the southernmost point of their orbit. They would then make a half circle of Mars to enter his atmosphere just before reaching the point where their northing flight would again turn southward. Detailed computations had shown that the boat could then glide down to the selected landing spot near the south pole in a long, gentle right hand spiral and with minimum alteration of course. Hubbard brought his flywheels up to speed and turned the boat to maneuvering position. The rocket nozzles were now opposed to the direction of the satellite orbit. Hubbard glanced at the clock and signaled the passengers to strap down. He touched the ignition switch and the jet roared into space, snapping the accelerometer to 1g. Slowly it climbed to 1.03 –1.05 – 1.07 – 1.08g. At 17.2 seconds, the thrust cut off. It had reduced their orbital velocity by 173 m/sec. Quiet again reigned in the boat.

Hubbard again rotated his vessel to coincide with the flight direction, occasionally correcting to keep their centerline coincident with the line of flight.

"That must be Lucus Solis," he remarked to Holt, pointing at a geometrically circular, large green area in the desert just below them. "Even with all the study of this scenery and the many months in the simulator, it still looks pretty strange when you actually see it."

"Ahead of us must be Aurorae Sinus," said Holt with a glance at his knee-held chart. "Then the Margaritifer Sinus. Who do you suppose doped out all these crazy Latin names? I'll bet the Martians name them differently."

"Maybe they call it Greenland because it's green," ventured Hubbard.

"Hardly," grinned Holt. "If their logic works the way logic works on Earth, Greenland would be white!"

They had been coasting for half an hour without power when night fled below them across the planet's wastes. In their control room it remained bright for 15 more minutes, then they too were shrouded in blackness. Their radar altimeter, sending its pulses to ground and measuring the time of return, had begun to register, showing their altitude as 200 kilometers. There were no responses to Hubbard's control movements, nor did the wing temperature indicators even flicker.

"What a queer atmosphere this planet has," remarked Hubbard. "Near Earth, we wouldn't even be expecting any air at this height. But if the scientific boys are right, we'll have stratospheric conditions right at the surface when it comes to the landing."

"According to the sounding bomb," answered Holt, "you ought to feel something when the altimeter reads 180 kilometers. That's quite amazing when you remember that we're moving much slower than we would be this high over Earth."

"That's right," said Hubbard. "If this were a landing from Lunetta, we'd have a velocity of 8.27 km/sec at the perigee of our landing ellipse. Here it's only 3.67 km/sec, notwithstanding this perigee's being 155 kilometers high, while the one from Lunetta is only 80. Hmm… seems to me I can feel something…"

As he twisted the wheel to and fro, the wide wings began to rock slightly under the influence of the elevons and there began the first audible signs of the passing air in the shape of a gentle hissing.

The pressure altimeter's hand began to kick around the dial which had been covered with a rough, hand-drawn scale computed from the results radioed back by the sounding bomb. It went from 165 to 160 to 159 kilometers and then settled at 158. Hubbard thrust the control wheel ahead.

"We seem to have gotten into this funny stuff a little high," he remarked. "I'd better nose down a little so as not to sail right out of it again."

They were lifted softly out of their seats by the negative lift of the great wings.

"The ship's doing all right," said Holt with an eye on the altimeter. "Here we go down again."

The wing temperature began to rise. 100 – 200 – 300 degrees registered in succession. Then it stopped at 370 degrees Centigrade.

"Wing temperatures are no problem here," said Hubbard. "What with our low wing loading and low speed, we won't even get to 400 degrees."

"Do you remember how Dick Peyton wanted to skin those things with dural instead of steel? He might almost have gotten away with it so far as the temperature's concerned. But discretion's the better part of valor."

Holt kept an anxious eye on the leading edge, but the familiar glow of a landing on Earth failed to materialize. This was less ghostly than a return home from Lunetta. The tiny light ray from the cabin lost itself along the length of the somber wing surface. There was no tendency to float out of their seats now.

Harry Brooks handed up a radio chit from his cubby hole. "Hope you are doing fine – Tom," it read.

Holt wondered whether Knight, circling above them, was worrying while they sat as comfortably as in any airliner and split the air of the second planet to feel the foot of man… Here they went, through a mad sort of atmosphere, which nevertheless reacted to controls as if their aircraft were in the familiar air of their home planet.

Showing Hubbard the chit, he scrawled upon its reverse the familiar words: "Having wonderful time. Wish you were here," and gave it to Brooks. Doubtless the very banality of the response would help to quiet any undue nervousness in the distant space ships.

Hubbard now cut in the automatic pilot, setting the ship in a long, right-hand gliding turn, carefully worked out beforehand. It would steer them out of the plane of the ecliptic and towards the south polar cap, the aiming point of their descent.

Holt kept looking out at the dark surface below them in the hope of discovering some gleam of light similar to what he had seen through Bergmann's telescope. At times he felt that it had again appeared, but on each occasion the enveloping darkness swallowed it before he could be sure, or the wide wing interrupted his vision.

Finally the first livid glare of the solar corona came up over the dark edge of the horizon. The heavy boat's speed had been reduced only to 3,400 m/sec by the tenuous Martian air, despite the 20 minutes which had elapsed since the perigee of their landing ellipse. They were still 150 kilometers high, and the electric and pressure altimeters coincided almost exactly, thanks to the calibration of the latter permitted by the sounding bomb readings.

The first rays of the Sun penetrated the bow windows of their cabin, although the darkness still spread its mantle over the scene below. Slowly, very slowly, the dawn crept toward them, revealing vague outlines on the surface. Holt consulted his watch, the chart and what he could see through his port.

"That elongated area ahead and to the right must be the Mare Cimmerium. Our flight time corresponds with our passage across the 220th meridian and the equator."

"Yes," answered Hubbard, "and that broad canal just under us must be Cyclopus."

Still at vast altitude, they followed the Antaeus Canal from northwest to southeast, and passed Mare Chronium, looking like a fertile, green meadow, fifteen minutes later. There was a broad bridge of vegetation joining the bleak deserts of Thyle I and Thyle II, and after they had whipped across it, the glistening white of the south polar snows rose over the horizon.

Holt took his field glasses and inspected the surface below, that extensive vegetal area which so strikingly surrounds the polar caps, even when seen from the Earth. It was Mare Australe. After landing, their caterpillars would crawl through it to the point Bergmann had selected as most suitable for the landing of the other two boats.

In the steep sunshine, the land appeared dry, for no puddles sent up their reflected shimmers. From 80 kilometers, he could not distinguish the nature of the vegetation. As they approached the snow, Holt examined the line of demarcation between it and the green surroundings. At that line it would be easiest to discover the depth of the snow and the nature of the white covering concealing the southernmost part of the planet.

Spreading along the wide verge of the Antarctic snow field was a band of shimmering water, extending into the distance like a great river. As they flew above it, they could see its vast extent and recognize its shallowness from the tops of the plants emerging.

"I believe we'd better go further south where the snow may be firmer," said Hubbard. "To land in the melting zone might get us upon a surface so soft that we and the whole business would sink as in a quicksand."

There was a change in the reaction of the ship to Hubbard's neat control movements.

"Martian transonic conditions are about the same as those at home," he called to Holt as the altimeter hung for a moment at 38 kilometers. Hubbard cautiously lowered the leading-edge flaps of the wings.

Holt scanned the surface attentively through his binoculars. Suddenly he gave Hubbard a punch in the ribs and handed him the glasses. "Give me the controls," he said, "and take a look at that long, gray thing down there!"

He banked into a smooth curve so that Hubbard might see better.

"It certainly looks artificial," said the latter. "Rather like concrete! I wonder what it can be?"

Holt returned the controls and began taking photographs of the strange object with his telecamera. Hubbard made several 360 degree turns around the mysterious structure while his companion again studied it with the glasses.

"There's no doubt about it, that thing's artificial," he said. "A mass as regular as that in the middle of a stoneless region didn't just happen. It looks rather like a concrete Quonset hut, with a domed roof and no windows. Perhaps we can tell more from the photographs after they're developed."

Hubbard marked the location of the object on his chart and glided further over the snow, meanwhile descending to 1,000 meters.

"Ready with the wind bomb?" he asked the mechanic below him.

"Ready!" came the answer.

"Does the surface look good?" he asked Holt.

Upon Holt's affirmative, the bomb was dropped, and Hubbard piloted the ship into a left turn, his eyes on the spot where the bomb would fall. A huge column of black smoke arose from it, drifting slowly to the northeast. As the trailing edge flaps went down and the skis were lowered, Holt radioed Knight that they would land immediately. The ship was now heading upwind towards the smoke bomb, close to the glittering surface of the snow. The skis touched softly and they sped like a sleigh along the smooth white plain. The friction brakes reduced their speed with an unpleasant scratching and grinding, and their motion stopped.

"Nice landing, Glen," said Holt with a pat on the shoulder.

"Looks like the finale of the second act," commented Hubbard.

"Do you think we've got a Happy Ending coming too?" asked Holt with a smile which couldn't quite hide the obvious concern he felt.

"Never been to a movie yet that didn't have one. And you know this must be a movie, for people don't get to Mars except in movies. So I, for one, am counting on a happy ending!"

Chapter 22
A Grayish Mass

The first eighteen human beings to land on Mars were grouped around the door leading to the upper surface of the huge wing. They listened intently to the hiss of the escaping air as the cabin was brought down to the low pressure outside. Then the door opened and they stepped out, Holt in the lead. Clad in their pressure suits and spherical, transparent helmets, they grouped themselves around him on the wing.

Curiously, and with mixed feelings, they gazed upon the wide expanse of snow surrounding their motionless vessel. Although encumbered with their space suits and not yet accustomed to walking and standing in the long-unfamiliar gravity, there was a feeling of release at no longer being cooped up within the small confines of the vessels in which they had made their long and silent journey. The scene before them might well have been that presented by a snow-covered plateau of their own familiar Earth, glistening in the sunlight from a dark blue, cloudless sky. Yet they beheld the scenery of a strange place, which to their loved ones at home appeared hardly different from any of the myriad denizens of the heavens.

Holt and Hubbard walked to the trailing edge from which the landing flap sloped towards the snow, six meters away.

"Go ahead, jump!" shouted Holt gleefully into his microphone and pointing downward.

Hubbard looked sheepish.

"How about the boss being the first man on Mars?" he asked.

"You're the fellow who got us here safely," returned Holt. "Get on with it!"

Hubbard, without further ado, sprang down, landing no harder than if the jump had been two meters or so, for Mars' weak gravity seemed barely to pull him through the six meters between the wing and the surface. He gathered a handful of snow in the clumsy mitts of his pressure suit and tried to toss it up. It broke in the air, returning as powder to dust the transparent top of his helmet.

"We've got powder snow," he called into his microphone. "Did we bring any skis?"

As soon as the excitement of the arrival subsided, unloading operations were begun by opening the belly hatch and lowering the first of the caterpillars. The Chrysler Corporation had developed them especially for conditions on the Red Planet, and they varied considerably from familiar patterns on Earth.

The power plants in particular had been designed to be independent of the atmosphere, except for cooling, for it had been thought unwise to rely upon burning any fuel in the relatively low oxygen concentration of the Martian atmosphere. Supercharging, similar to that used in aircraft engines for high altitudes, might have been effective, but Holt's judgment was that this would be a questionable expedient in view of the refusal of the spectroscope operators on Lunetta to commit themselves.

The caterpillars, therefore, were driven by two propellants, concentrated hydrogen peroxide, as used in the reaction pistols, and common fuel oil. The hydrogen peroxide was first dissociated into water vapor and oxygen in a catalyzing chamber. This mixture evolved steam at high temperature by the energy of dissociation. Into it was injected a metered quantity of fuel oil, which promptly burned in the oxygen portion of the mixture. A row of successive nozzles injected water into the flame, thus producing steam of moderate heat, only slightly contaminated by carbon dioxide and carbon monoxide from the combustion of the oil.

The flow of this steam could be regulated by throttling the admission of its three constituents. It turned a turbine which provided power for the caterpillar.

The steam was condensed in a low-pressure condenser, cooled by a blower, after passing through the turbine. The carbon dioxide and carbon monoxide remained in the vapor phase and were drawn off and expelled by a second and smaller blower, while the water in liquid phase was recirculated from the condenser to the combustion chamber. The water loss of the system, therefore, was limited to the portions affected by dissociation of the peroxide and the combustion of the oil, by being ejected into the atmosphere as withdrawn from circulation.

The efficiency of this system was quite high in view of the necessity for providing artificially the oxygen which an ordinary engine would extract from the atmosphere, and considering that this oxygen formed part of the propellants and so tankage had to be provided for it. In order to conserve supplies, the cruising speed of the land vehicles was restricted to 13 mph.

The tracks of the caterpillars extended across their whole lower surface and their twelve foot length in order to diminish their surface loading and give maximum traction on the softest ground. In the weak Martian gravity, the vehicles weighted but 28% of their terrestrial tonnage. This reduced the danger of becoming mired, but it also diminished the traction to the same extent. Thus the maximum obtainable length tended to prevent non-propulsive "churning" of the tracks.

Directional control was obtained by braking one or the other of the tracks, their low ground pressures permitting this despite their great width.

The power plant was located between the tracks, and above it was an elongated cylindrical body which could be pressurized and which provided space for passengers and lading. Forward it had two large, oval windows through which the driver might view the ground, and several circular ports along the sides for the passengers. Two hemispherical, plastic gun turrets stood above the forward and after ends of the cylinder. Just behind it, mounted on the framework of the strange vehicle, was a small crane such as is used on wrecking tow cars. From the crane's jib to the forward end of the cylinder ran the radio antenna which was to aid communication via the radio bombs.

When all three caterpillars had been lowered and given a short test run to insure that their power plants were working properly, Holt deployed them around the helpless landing boat in the untoward event that the hitherto invisible Martians might undertake some hostile action. But nothing happened.

After the removal of the three huge caterpillars, unloading began in earnest. Three folding trailers were dropped through the hatch and assembled on the snow beneath the belly of the boat. The first one completed, standing upon its wide wheels, was placed beneath the hatch while busy hands under the expert direction of Clark Winslow piled it with a vast assortment of cases and equipment. As each was hauled away with its load, the reserve fuel tanks to supplement the tankage of the caterpillars were filled by gravity hoses from wing tanks of the landing boat. The long voyage ahead precluded the tractor-caterpillars from carrying adequate fuel supplies in their own tanks.

For twelve hours the landing party bent its united energies to the accomplishment of the seemingly endless task, but when the work was done, no restful night came to induce sleep in their wearied limbs. It was Summer at the Martian south pole and the midnight Sun remained visible in undiminished splendor. It made but a sweep at the horizon, returning in a great circle in the sky to a point due south.

All hands were much relieved when Holt ordered the hatch closed on their boat and the air valves opened to bring up the pressure. Wearily they had trooped through the door and divested themselves of their space suits to seat themselves around a table hastily constructed from various bits and pieces of the stowage gear. One of the soldiers proved himself to be no mean cook, and it was a novel experience for them all to eat and drink in the old familiar fashion from open plates and glasses. That night, when the shades were drawn over the landing boat's ports to keep out the brilliant glare reflected from the snow, the men retired to their acceleration couches, somehow grateful not to be floating in space, despite the sometimes painful pressure which even the light Martian gravity inflicted upon them.

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They arose next day to find the Sun shining as brightly as before. Donning their space suits and releasing the pressure in their abandoned landing boat, Billingsley, Gudunek and Woolf stamped their way through the powdery snow to the *Panther*, Holt's caterpillar, which was to head the column moving northwards. The driver was Sergeant Regand, a tough farmer from North Dakota, Brooks, *Oberth*'s radio man, would attend to communications. Holt himself would man the forward gun if things got tough, while Brooks would take the after one.

The *Jaguar*, under Glen Hubbard, was manned by Clark Winslow and four soldiers, while *Leopard* was to bring up the rear under Lieutenant Hampstead and the remaining five men of his guard.

After each caterpillar had picked up its trailer, Holt sent Winslow back to assure himself that the abandoned landing boat was as well moored as circumstances permitted, lest she capsize in some storm or blow away across the limitless wilderness of snow. The thought of burning the boat as Cortez had done with his ships ran through Holt's head. Both the lack of propellants in her tanks and her station near the pole effectively prohibited any return to the orbit where their friends still circled Mars. But finally Holt's natural conservatism prevailed upon him to preserve what few material possessions he had brought to this distant goal.

As the caterpillars rattled and snorted northward with their trailers, Holt stood in the gun turret of the *Panther* and surveyed the vast snow field ahead. In the pressurized interior, he had removed his helmet and laid it upon the breech of the gun. Like the others, he still wore his pressure suit. As the mileages were called up to him from below, he entered each odometer reading on the chart where he kept track of their progress along the 190th meridian to which the gyrocompass held their course. If he had estimated correctly, some 25 miles should bring them to the mysterious, concrete Quonset hut which had so attracted his attention during the landing approach.

Tom Knight, whirling around Mars high overhead, had been kept closely in touch by radio with all that occurred. He had returned a description of the joy of the Mars-circlers at the successful landing on the 82nd parallel of latitude, and was fully aware of their course towards the mysterious building Holt had described. Shortly before, he reported that he was able to make out the three dark spots of the caterpillars on the blind snow through Bergmann's great telescope, and that he had located the mysterious gray building during the half hour that his vessels were able to view the region where the landing party was making its slow progress.

The northward trek had continued for two hours at 12 mph when Holt saw the previously clear horizon become misty and blurred. This he took to be the effect of the melting zone and the haze which would naturally form above it. He turned to look astern. The tracks left by their caterpillars, which had theretofore been almost indistinguishable in the mixture of hoar frost and powder snow, were now clear and distinct, indicating that the snow must be growing stiff and sticky. Sure enough, the thermometer outside his glass dome showed 30° Fahrenheit: just under freezing.

As he meditated upon the rapid increase in temperature, a rounded silhouette rose out of the haze ahead. It could only be the mysterious building!

Quickly he called *Jaguar* and *Leopard* with orders to man the guns, again bracketing his binoculars on the projection above the monotonous expanse of snow. There was no movement, no sign of life. But with surprise, he beheld at each end of the strange structure two small turrets protruding from its smoothly rounded roof. Had there been smoke, he would have taken them for chimneys. The heavy machines clattered towards the mystery and stopped 200 yards away at Holt's radioed command.

The lenses of his glasses revealed nothing. There was no path nor road leading to the building. Around it, crevices in the now melting snow showed green vegetation, apparently thick and mossy. There were no windows nor other apertures in the great, gray block 300 by 100 yards square. The rounded roof met the ground hemispherically at either end. Nor did the two turrets help to uncover the mystery. Their twelve feet of height and nine or ten of diameter were topped off by hemispherical, smooth caps. They could not be chimneys.

No snow was on the rounded roof, but the light northerly wind bringing the haze towards them might have blown it away. That was quite possible... Could there be heat inside?

Staring through the glasses, Holt's eyes burned with curiosity and concern. Now they seemed to tell him that the upper portion was more lightly shaded than the gray of the lower. Sure enough, he detected a marked line of separation running horizontally around the roof at mid-height. Where the building ended hemispherically, the line ran upward and across the rotund gable. The central portion of the roof was unmistakably of a different material and seemed to have been let into the main structure.

Holt ordered the caterpillars to disperse, one at each end of the weird building, while he with the *Panther* took position fifty yards from the long, curved southern wall. Useless as they seemed, the tiny gun barrels swung around toward the giant mass.

Calling to Billingsley in the compartment behind him, Holt suggested a little sally to the placid Briton.

"Quite so.. Might be rather fun, you know," came back the imperturbable voice.

Slipping on their pressure helmets, they airlocked themselves out into the wet snow and took a tall ladder from the loaded trailer. Dragging it behind them, they approached the curving wall with the floating step which characterized the light Martian weights of their bodies. Holt drew a heavy knife from his belt and scratched at the strange material.

"Harder than concrete," he remarked with a shake of his head.

They pushed the ladder carefully up the sloping surface before them and mounted to a point at which the angle was flat enough to prevent their slipping on the roof itself. As they reached the mysterious line, the waiting crews saw them throw themselves down with their heads just across it, gazing fixedly at the surface.

What they saw took away their breath, for the whole upper part of the roof was of transparent, glass-like material! Below it was a huge engine room, reminiscent of a giant terrestrial power plant! They counted fourteen huge, circular, red-painted shapes, neatly ranged within the silver-glittering hall!

"Pumps, or I'm a Chinaman!" said Holt after getting his breath again. "Old man Hansen was right…"

"And your Percival Lowell, God rest his soul," chimed in Billingsley.

Holt pressed his helmet to the glass.

"Feel it? The machinery's running."

"Look, old fellow," grunted Billingsley, "I'm sure I just saw one of their chaps running about down there."

A diminutive, dark-haired figure of human bearing and carriage was walking down the length of the great room. He stopped and inspected one pump after another as he gradually approached the spot above which they kept their watch.

The Martian wore a white garment reminiscent of a Japanese kimono with multi-colored ornamentation. The man, for no other name could be applied to him, was beardless. His face was swarthy, with warm and friendly eyes and delicate features. His arms and legs showed nothing different from those of homo sapiens, as exemplified by the quaking observers on the transparent roof.

"Almighty God must have found that our species has some good points, if He chooses to plant something so much like us on Mars," meditated Holt.

"But look at the enormous skull the fellow has!" whispered Billingsley as though he feared eavesdroppers. "My dear chap, if what that skull contains is all intelligence, we may be able to learn something yet from these bally Martians!"

Holt gazed solemnly at the creature below who still seemed unaware of his brethren from another planet.

"John," he finally remarked, "now I think I've got my theory working. These Martians are undoubtedly subterranean, and cannot live in the open. The whole pumping station is pressurized. Why else the curvature of this roof? Their whole civilization is pressurized and air conditioned! Otherwise, how to explain the rest of it? No streets, no cities, no life above the surface but this huge pumping station, and the radio music Lussigny picked up the other day?"

Billingsley brought his hand up as though to scratch his head through the plastic of his hermetic helmet.

"Bergmann," he said, "once confided to me that he believed this to be the answer. But he was a bit bashful about declaring it openly. Probably thought it rather on the fantastic side, you know. But I don't see why they shouldn't have done it judging from this…"

"Do you think we should try and communicate with the lad down there?" asked Holt. "If we're right about their civilization, we shall run into similar structures anywhere we go and have similar difficulties. We can't get in, and they may not come out! Wouldn't that be a joke on us, if we sailed half-way through the solar system to find that we can do no more than look at a Martian through several inches of glass!"

"I jolly well don't see why the blighter shouldn't come out," huffed Billingsley. "If his bally job is to pump water, he must look southward once in a while to see how the melting snow is holding out, and how much more water he can expect before the pumping season is over. Or do you think that might be a blooming terrestrial point of view?"

"You're probably quite right about it. We'll dash back to our caterpillar and make a report to Tom Knight who ought to be hanging around somewhere above us right now. He can retransmit what we've seen to Earth. Our voyage will have had some value, no matter what happens from here on. We'll tell him to bracket the big 'scope on us while we make a racket which the fellow down there'll be bound to notice. Then we'll see what happens."

"Jolly good idea," said Billingsley. "Perhaps our Martian here in the frozen south will be a bit more pleased with interplanetary visitors than the authorities of some large town. They might be frightfully annoyed if we were to drop in on them unannounced."

"Well," concluded Holt, "if our friend down there should have some kind of death ray, or otherwise make it hot for us, the caterpillars can always retreat in a hurry and send the bad news to Knight. Let's go."

Chapter 23
Contact

Holt, after having heard the circling convoy in the satellite orbit confirm his exciting report, ordered *Jaguar* and *Leopard* to station themselves a thousand yards to the west of the Martian pumping station. Sam Woolf took over the command of *Panther*, which remained where she was, close to the station's well. Her living compartment was depressurized and the crew sat within in pressure suits, ready to respond to any call for help. Woolf had connected his walkie talkie to the antenna of the caterpillars so that he could speak with the men outside.

Gudunek accompanied Holt and Billingsley back to the pumping station and up the ladder. The white-clad figure below still stood before one of the great pieces of machinery. The great moment had come.

Holt moved two steps onto the transparent roof and then stamped thrice upon the thick pane.

The Martian glanced up, a look of amazement flooding across his features. In a moment, his face reassumed its calm and he waved up at them as though interplanetary visitors were an everyday occurrence. Holt waved back, pointing to himself and his companions, then down into the hall. The Martian stared, then passed his hand horizontally before his forehead in an indescribably graceful gesture and walked to a small doorway through which he disappeared.

Ten tense minutes passed.

Suddenly they became aware that a door in the chimney-like turret at the end of the building had opened. Looking through, they could see a second, unopened door of glass, some five feet inside. Behind it was their Martian, inviting them with easy gestures to enter what was evidently an airlock. They could now see him clearly. Aside from his stature, which was shorter than their own by a foot or so, and his large cranium, he exhibited no major differences from terrestrial man.

Entering, they stood before the transparent bulkhead, awaiting the Martian's next move. With some perturbation, they saw him push a button which closed behind them a semi-cylindrical sliding door of metal, confining them within a cylinder whose other half was composed of the curved pane behind which the Martian stood. A hissing sound indicated that the airlock was being filled so that they might pass into a larger pressurized compartment without major discomfort.

The three Earthlings gazed with attentive concern at the Martian's doings at a small switchboard. There was no backing out now; they could not even radio to the waiting Sam Woolf. With apparent unconcern, the Martian continued to pull switches and push buttons.

Holt's exterior pressure meter in his helmet now indicated 4 pounds per square inch; the interior of his suit held 7 psi. A glance at the gas analyzer from his pocket showed 40% oxygen and 3% carbon dioxide. The rest was inert gas of some unknown kind.

Should this be nitrogen, which his analyzer could not show, the prospects were good indeed. Even other noble gases such as helium or argon would offer no hindrance to satisfactory respiration. He could, however, by no means be certain that their Martian was flooding them with something safely respirable by terrestrial human lungs.

Holt's space suit inflation collapsed and the pressure gauge now showed 10 psi. This corresponded to an altitude of 25,000 feet altitude on Earth, where 40% oxygen may be breathed with impunity without fear of intoxication. Breathing masks commonly used by aviators furnished a higher oxygen percentage than the 21% of the terrestrial atmosphere.

As the pressures equalized, the inner glass door slid back. The Martian's face lit with a friendly smile as he pressed the palm of his right hand over the spot where his heart was – if the inner anatomy of Martians resembled that of terrestrial humans as much as did their exteriors. Holt and his companions followed suit and then stepped towards him in the elevator which he evidently occupied. Silently, the Martian pushed a button, and the lift descended to the floor of the great pump house.

On the way down, Holt removed his helmet and took a deep breath. Aside from a great feeling of relief at the presence of relatively vast quantities of breathable air of adequate oxygen content, he felt no effects. A silent prayer of gratitude that the Martians had created an artificial atmosphere suitable to their brethren from Earth arose within his heart. Few things could so favorably affect the coming effort to reach an understanding with them.

The terrestrial trio, bearing their helmets under their arms, followed the silent Martian down a long corridor lined on both sides with beautifully ornamented metal doors. The corridor glowed with a clear, warm light, although there were no lamps or other apparent sources of illumination. Holt cudgeled his brains for an understanding of this phenomenon. Then he realized that the walls themselves were luminescent, like the symbols on a watch dial, though vastly brighter! Here the ancient dream of illumination engineers had become real – light without heat! No incandescent wire nor flaming arc threw out vast heat losses while producing limited light. Martian engineers had solved the mystery of the firefly and applied the solution to practical illumination problems!

A feeling of infinite satisfaction overwhelmed Holt, for he could see that on the economic side alone, he might return to Earth with an infinite variety of technological and economic advances to be applied to the amelioration of human living conditions. The initial friendliness of their reception gave ground for hope that the Martians would not hesitate to part with their formulae and methods.

The guide stopped by one of the metal doors lining the corridor, opened it, and ushered them into a large, windowless room decorated with carmine red patterns of pleasing outline. Opposite the door sat a venerable, dignified Martian at a long, ebonite table from which he arose at their entrance and laid his hand upon his heart. When they had countered his greeting in like manner, he motioned them to be seated upon a long, cushioned bench across the table from him.

Their Martian guide thereupon intoned a melodious speech in words without significance to any of the visitors. From time to time the dignified, elderly person interrupted smoothly with what could only be questions. Gudunek listened intently to every inflection and syllable, attempting to coordinate the words with the remarkably restrained gestures accompanying them. He could not get even an inkling of the Martians' reactions to the arrival of Earthlings upon their transparent rooftop.

There was a pause in the smooth flow of language and both looked at Holt with expressions of amicable interrogation. Drawing from his briefcase a diagram prepared for the first interview with any authorities they might meet, Holt placed it upon the table before the elderly Martian.

Clearly and unmistakably portrayed was the Solar system with the five inner planets, Mercury, Venus, Earth, Mars and Jupiter. Each orbit was marked with its astronomical signs and the direction of rotation of its planet. The route of the expedition stood out in brilliant red, with an arrow marking the direction of travel. The ancient art of astronomy was surely the most likely ground upon which to base a set of semantic symbols capable of development into broader means of communication between the denizens of separate planets.

The senior of the two Martians bent over the diagram with evident interest and understanding. Holt's finger point to his own group and then to the Earth, followed the flight path; then indicated their hosts and their planets. He then arose and placed his hand upon his heart after the Martian method of greeting. The senior Martian followed suit, turning thereafter with a wry smile to a small cabinet in the wall. He opened the cabinet and adjusted two knobs within. No sooner had he done so than the blood of the visitors suffused their faces with embarrassment, for a voice in colloquial English sounded forth:

"Can you still hear me, Tom" it questioned. "If we don't get out of that building within 24 hours, the caterpillars will proceed northward along the 190th meridian to the equator where they'll start preparing the landing strip."

It was Holt's own voice, evidently intercepted and recorded by the Martian radio system. While it was likely that the significance of the words entirely escaped their hosts, it was at least entirely clear that the latter were anything but ignorant of what was going on in an interplanetary way. It would be well to be careful in dealing with people of that sort…

The Martian shut off the record and smiled tolerantly at Holt and his party whose answering grins held no small portion of embarrassment. Holt felt that matters were progressing rather better than expected, despite the evident lack of privacy of their communications.

The elderly Martian now extracted a large sheet from a drawer in the wall and spread it before Holt. It seemed an organization chart, being covered with circles arranged in pyramidal form and containing mysterious symbols.

The Martian selected one of the small circles in the bottom row and placed his finger upon it. He put a finger of his other hand upon his breast and nodded as much as to say, "This is where I am." Then, with a finger on the larger circle at the top of the pyramid, he gestured into the room and said something which sounded like "Ahla."

"By Jove," spoke Billingsley with a perfectly straight face but with a trace of roguishness in his voice, "Looks rather as though the British Labor Party had gotten here before us! Mars seems almost as bureaucratic as jolly Old England!"

Holt produced his map of the Red Planet, showing the mark he had made to locate the pumping station in which they were being entertained. Then he pointed at the ground below them. Saying "Ahla" in a rising and questioning inflection, he offered the Martian his pencil. Accepting it promptly, the latter poised it above the circular, vegetal area over which they had flown when approaching the landing and made a cross in the center. It was Lacus Solis, and the repetition of the word "Ahla" convinced the visitors that here must be the center of Martian civilization.

Although Lacus Solis was 2,600 miles away from them and quite distant from the spot which Bergmann had selected for their landing strip, it became apparent to Holt that a landing of the other boats near Lacus Solis might well be sensible, for it was plain that the Martian Government was anything but unprepared for the visitation by the Earthlings. Even the most distant outposts had evidently received instructions for the treatment of the interplanetary visitors. "Send them to Headquarters immediately," was quite plainly the tenor of the policy. Holt could see no reason for doing otherwise than comply with alacrity.

It was a question whether he should attempt to make clear that he would proceed there in his own vehicles, or seek Martian transportation, which he knew must exist in view of the technical perfection attained along other lines.

Martian transportation, whatever it might be, would doubtless offer the quickest answer to the question of the attitudes of the inhabitants of the planet. On the other hand, he and such members of his group as might accompany him would be separating themselves from what little equipment they possessed.

The other alternative, to undertake the long drive with his own vehicles, at the rate of 120 miles a day, would require almost a full month, and during that time the Martian authorities, to whom his presence was known, might well grow suspicious of his intentions and perhaps take unpleasant countermeasures.

Holt put the question to Billingsley and Gudunek while their hosts listened politely if perhaps uncomprehendingly.

"No doubt about it," said the former. "We'd best thrust our unprotected heads right into the lion's mouth as soon as possible. He'll be much less likely to bite than if we delay the business."

Gudunek expressed the same sentiments and brought up the question of how many men should accompany Holt.

"If we take too many," said he, "we shall have difficulty keeping them together."

"Quite right," answered Holt. "We three will do it and leave the rest of the party with the caterpillars to await word from us. Hubbard will wait seven days, and if he doesn't hear from us, he'll drive on to the location already selected for the landing strip, prepare it, and arrange anything further according to his judgment and Knight's."

After some difficulty in convincing the elderly Martian that they must depart from the pumping station in order to communicate with the waiting landing party outside before accompanying him to Ahla, they were politely ushered out of the airlock, from which the old gentleman observed with interest their return to the vehicle. Exactly what his feelings were when the other caterpillars rolled up and their helmeted crews crowded into one of them, they could not tell. His greeting was nonetheless cordial when Holt, Billingsley and Gudunek returned dragging heavy boxes which they took with them into the airlock and to the floor of the pumping station.

Following the Martian, the three Earthlings and their burdens entered another elevator which plunged yet deeper into the mysterious planet. At the bottom, the Martian opened the door and they stepped out into a bright, vaulted space of some sixty feet in length and twelve in height. Both lateral walls were interrupted by circular glass windows reaching to the floor. Looking through one of them, Holt saw a wide tube of some 12 feet in diameter gleaming brightly, as did all other rooms or corridors, by reason of the luminous paint.

"That looks rather like a subway tunnel," he remarked to Billingsley, "except for there being no rails."

"There's a sort of slot at the top," commented the latter. "Perhaps it's a kind of hanging railway, by Jove!"

They advanced to one of the round windows somewhat further down the sixty-foot platform and saw through it a compartment containing a number of low, but comfortable-looking seats.

"The Mars Express!" whistled Gudunek.

"The Ahla Limited, so help me" cracked Billingsley.

The Martians pressed a switch button beside the window, which promptly slid up, much after the manner of the windows of the more expensive terrestrial motor cars. With his help, they stowed their baggage behind their seats, and seated themselves at his inviting gesture. He went to the other end of the compartment and began to work the switches on a panel located there. Beyond him was a transparent sheet which permitted Holt and his companions to see the luminous tube in which their small compartment lay, extending indefinitely ahead of them. As the Martian worked, the door through which they had entered slid closed, as did a second one hitherto concealed in the walls of the compartment. The Martian returned and seated himself beside Holt, but nothing moved.

Then there were three flashes, one after another, at the forward window! The Martian gestured that they should remain seated. At a double flash, the Martian raised his arm aloft. Then came a third, long-extended orange flash; the arm came down and the vehicle, for such it evidently was, moved noiselessly and smoothly into the tunnel with rapidly increasing speed.

The Earthlings were pressed back into their chairs with an acceleration reminiscent of that of a *Sirius* launching. Holt's hands clutched the arms of his seat, his head against the headrest. He could just see the watch on his wrist which indicated that they had been moving for 20 seconds at an acceleration which he was convinced could not be less than 3g! It almost frightened him to realize that already they must have reached supersonic speed, for their vehicle was in no way streamlined, having blunt, hemispherical ends and fitting the inner diameter of the tunnel so tightly that there was but an inch or so of clearance! There could be but one explanation for the terrific speed with which they shot down the tunnel – there must be a vacuum within it!

Holt's curiosity as to the mode of propulsion of this fantastic vehicle plagued him like a rash. There was no familiar clicking of rail joints every thirty feet, nor could he hear the hum of an electric motor or any other source of power.

Finally he determined to attempt to elicit the information from the silent Martian. From his briefcase he drew a colored photograph of one of his native American streamlined trains which he had brought for the dignitaries of Ahla. The old gentleman examined the picture minutely while Holt pointed at the rails ahead of the locomotive and then made circular movements to suggest the rotation of the driving wheels. Then, with an interrogatory gesture at the roof of their car, he offered the Martian a pencil and the reverse side of the photograph as a place to sketch.

As the lines flowed from the Martian's fingers, Holt recognized a fellow engineer in the old man. Martian railways knew no wheels! At the front and rear of the roof of their car were two horseshoe shaped permanent magnets which were poised around a bearing rail at the top of the tunnel and within the slot running along its center. The magnetic flux which passed through the bearing rail from one pole of the magnets to the other suspended their light vehicle without metal-to-metal contact! The secret of the absence of such contact and therewith of the suspension lay in a device which prevented the free-floating supporting magnet from sliding to one side and contacting the rail with one of the poles. The device was located behind each of the powerful supporting magnets and consisted of two condenser plates arranged on either side of the supporting rail and whose capacity changed as they approached or receded from the rail. This change in capacity was apparently utilized to energize two electromagnets arranged laterally to the rail through an electronic amplifier. According to whether one or the other of the two electromagnets received more or less amperage, the position of the large permanent magnet was displaced to the right or left by a small increment. The control was so adjusted that the bearer magnet was balanced in a free-floating central position.

That's a problem of getting sufficient sensitivity and damping in the control system, thought Holt. *Actually, there was no reason why an electronic control with sufficiently fast action shouldn't solve it…*

The handy sketch produced by the Martian also revealed the secret of the power driving their fleet car.

In principle, it was nothing more nor less than the famous, or infamous, solenoid gun, which for many years had ghosted in the minds of terrestrial engineers without ever reaching the practical stage. Above the suspension rail was a chain of electrical windings, interrupted at regular intervals. These coils were energized consecutively from an exterior source of current so that a cylindrical permanent magnet located centrally in the car roof was attracted from one coil to the next, rushing the car with it. This permanent magnet represented in some sense the armature of an electric motor which, instead of rotating, dashed along the extended sequence of the coils. It seemed that once the period of acceleration was past, strong current impulses no longer were required through the coils, for there remained but friction to be overcome.

Friction? ran through Holt's mind, *what sort of friction?* There were no wheels whose bearings and rims could produce friction. In order to use wheels, the Martians would have had to possess materials of strength many times superior to the best terrestrial steels, if they were to withstand the centrifugal forces produced by such tremendous speeds! *Air drag?* There was a vacuum in the tunnel... So there was only hysteresis created in those sections of the suspension rail gripped by the vehicle's magnets. But if the suspension rail were laminated, as is the custom in terrestrial transformers and generators, even the hysteresis caused by eddy currents could not be great...

Every now and then a brief row of round lights flashed at them as they whizzed down the straight tunnel. They were obviously entrance doors of stations lining the underground passage through which they were shooting like a projectile.

It occurred to Holt that it might be embarrassing if another car happened to be stopped to receive passengers at any of these stations. There was no engineer or motorman, and he had seen nobody except their small party on the platform from which they had departed. The elderly Martian sat unconcerned beside him, immersed in the pictures Holt had handed him. He paid not the slightest attention to their bullet-like speed. The only explanation was a completely automatic system.

Suddenly there seemed to be an application of brakes, for they were gently urged forwards in their seats. Far, far ahead, a slight change of direction in the tunnel could be seen. They were on top of it and could feel the centrifugal force as the car swung slightly outward, despite the reduction in their velocity as they made the turn. Then the acceleration came on again and brought them back to speed.

Twice their vehicle came to a full stop for a few seconds, then the invisible and automatic signals controlling this underground miracle of transportation sent them on their way once more.

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After a brief two hours, their Martian companion signaled that their journey was approaching its end. With reduced speed, they slid through switches at forks in the tunnel and finally halted before the round glass doors of a station.

Here a festive scene awaited them, for the tiny platform was decorated with multicolored and tasteful draperies and occupied by 80 or 100 Martians of both sexes. The clothing of the Martians had a silken-metallic sheen and was beautifully ornamented in the most varied colors, lending a solemn, almost reverentially antique flavor to the occasion. The Earthlings could not but contrast this with the marvelous practicality of the technical miracles achieved by the same people.

At the signaled invitation of their guide, Holt stepped out at the head of his companions upon a thick carpet which led from the door of the car to a group of Martians centered around a venerable man in a violet kimono embroidered with tiny golden stars. Holt approached him and gave the Martian greeting with his hand on his heart. Billingsley and Gudunek, a few paces behind him, followed his example to right and left.

The old gentleman returned the greeting, followed by the surrounding dignitaries.

Harp-like musk filled the air with a cheerful lilt in which a joyous greeting was somehow reflected, and the chief dignitary advanced towards Holt holding out in both hands a massive and glittering ornamental chain which he ceremoniously placed over Holt's bowed head. Then, after the manner of a South American "abrazo," he embraced him.

The hospitality of this reception surprised Holt no little, despite the very complete equipment he carried with which to reciprocate kindness. With a grandiose gesture he motioned Billingsley to his side. The latter stepped forward, ceremoniously opening a gold-embossed jewel case in which lay a ruby-studded arrangement in the shape of a star. As though he had spent a lifetime pinning royal decorations upon the breasts of faithful servitors, Holt gravely attached the glittering bauble to the Martian's upper garment. Next he returned the embrace.

Apparently satisfied, the old Martian made a gesture of mutual departure and stepped forth with Holt at his side. Holt was no little concerned about the baggage with the radio transmitter, a signal from which his comrades in the frozen south were anxiously awaiting. A turn of his head revealed Gudunek engrossed in a sign language conversation with their erstwhile guide and evidently relating to the baggage which had been left in the underground car.

Coolly he turned back to his dignified companion, somewhat restrained by the obvious impossibility of initiating any small talk, and they walked together, decorations jingling, to the exit.

Chapter 24
How Mars is Governed

Long and exhausting were the official receptions of the three Earthlings by the Martian authorities. Holt and his two companions finally found enough leisure to make themselves a consecutive picture of the vast variety of novel impressions which the week of greetings had poured upon them.

At no time did they sense any suspicion that their arrival out of the depths of space might be motivated by anything but the most friendly of feelings and intentions. At first they had thought that perhaps the Martian consciousness of absolute technical superiority over Earthlings had been the foundation of the dignified courtesy and consideration shown to them by the personalities in authority. After all, an interplanetary visitation could be no ordinary event, even in their lives. But slowly Holt and his companions began to realize that they were acting from primarily quite different motives; the pictures of life on Earth with which they had been regaled were to them but final confirmation of the universally held, deep, religious conviction that God had created Man in His own image, wherever Man was to be found. The efforts of Earthlings to subjugate Nature on their richly endowed planet seemed to the Martians technically extremely primitive, but again they drew the conclusion that these pitiful efforts were but an additional proof that God had inspired the doers, and that this inspiration was inseparably linked with that inner urge to action which had been the driving power of Martian civilization.

The Martian government was directed by ten men, the leader of whom was elected by universal suffrage for five years and entitled "Elon." Two houses of Parliament enacted the laws to be administered by the Elon and his cabinet.

The Upper House was called the Council of the Elders and was limited to a membership of 60 persons, each being appointed for life by the Elon as vacancies occurred by death. In principle, the method was not unlike that by which the College of Cardinals of the Roman Catholic Church is appointed. Usually the Elon chose historians, churchmen, former cabinet members or successful economic leaders who could offer lifetimes of valuable experience. The Council of Elders, however, had but limited authority. Proposed laws could be approved or disapproved as presented, but no riders, amendments or alterations could be voted. The Council of the Elders could stimulate, suggest and test legislation. Its main purpose was not action, but rather to assure the continuity of the basic thought on legislation, as also the protection of that thought.

A lower house, the Assembly of Deputies, was devoted to action, for here demands were made and wordy battles were fought.

The main distinction between the Martian Assembly and analogous terrestrial legislatures was the electoral system. The United Congress of the Earth was composed of representatives regionally elected after the tried and true examples of the formerly great democratic nations. The Martian Assembly of Deputies, on the other hand, consisted of representatives of certain occupational groups.

This peculiar electoral system originated in the structure of the entire Martian community which, despite the close relationship between the thinking and feeling of the individual and that of his Earthling brother, yet differed profoundly from the community of Earth. The ancient culture had long since emerged from the age when the welfare of the inhabitants of any region depended upon their being well and powerfully represented in the machinery of government.

The Earth had not yet cast aside the concept that the riches of any particular region, whether in natural resources or skill and energy of its inhabitants, should be devoted primarily to the welfare and comfort of those same inhabitants. Thus each country of Earth attempted energetically to elect such representatives as would most effectively further its own, immediate welfare and interests.

Thousands of years of civilization on Mars had permitted refined technology completely to remove all regional concepts. Racial prejudice, national and local patriotism had not existed since time out of mind. Conditions of life on Mars, vastly different from those of Earth, made it possible for the planet to be governed without any form of regional representation. It was possible to make any conceivable journey within the confines of the planet in less than four hours in the high-velocity subways. This, and the fact that the very concept of nostalgia was unknown, due to subterranean existence which prevented Martians from developing attachment to local scenery or dwellings, together with the standardization of all ideas and desires, had much to do with it. Other factors were mass production of all consumer goods, and synthetics had replaced organic and inorganic natural materials and foodstuffs. This, of course, abolished the distinction between naturally rich and naturally poor regions, so that there no longer existed "have" and "have-not" regional groupings with conflicting interests.

The aging planet offered its inhabitants very few natural riches, and they had found that their individual lots could not be improved by attempting to bring their particular regions to the fore, either politically or economically. So integrated had their economy become that any trouble afflicting one locality was immediately painful to the entire planet.

This, however, did not mean that utter peace and unity existed among the Martians, for there was only a displacement in the points at issue. Instead of geographical differences of opinion, political debates went on between the representatives of various branches of science, technology and administration concerned with maintenance and improvement of living conditions. Traders and transportation people would differ with sociologists; physicians could not agree with ventilation engineers; private industry would argue with government; employees had grievances against employers; and so on, ad infinitum.

The ultimate result of these differences was a congress of professionals from each of the complicated branches upon which the highly involved society of Mars was dependent, and each branch was represented in proportion to its importance. Mars appeared to be doing extremely well with this system.

There were, of course, local authorities to handle local problems. The fairy underground city of Ahla was the capital of Mars and had a mayor, as did New York. But the City Council was composed of elected professionalists, exactly parallel to the Assembly of Deputies.

Towards the end of the week of receptions and festivities with which Holt and his two companions had been welcomed, Glen Hubbard and the rest of the first landing party arrived in Ahla.

Holt had followed a suggestion of the Elon and instructed him to move his caterpillars to one of the great power stations at the southern rim of Thyle I, where there was a terminal of the underground freight system which spanned the planet. This freight system was wholly independent of the passenger transportation net and differed considerably from the latter, except as to being subterranean. The cars were extremely spacious and were coupled one to another as on Earth, and operated in tunnels no less than thirty feet in diameter. Unlike the passenger vehicles, they were suspended from wheels running on a monorail at the top of the tunnels. Movement was much slower than that of the passenger system, for extensive switching operations had to be undertaken to classify cars with different destinations. Nor would the monorail wheel suspension permit anything like the speed of the magnetically suspended passenger vehicles.

The freight tunnel to Thyle I carried primarily drainage pipe and earth-moving equipment for the pumping station of the region. The evacuated tunnel had airlocks at its terminals which permitted bulky freight to be moved into the atmosphere where the drainage pipe was installed. This was done by special ditch digging machines which did the excavating, laid the pipe, and then covered it, being manipulated by Martians in pressurized cabins atop the huge machines.

Hubbard had reached the station after three days of hard driving, sixteen hours a day. Lieutenant Hempstead's *Leopard* had mired twice in the soft ground of the melting zone. But Hubbard and Woolf had each time succeeded in towing him out. Finally they had reached the great concrete station, worn out and muddy.

The Martian attendants at the Thyle I station greeted Hubbard with the utmost courtesy and consideration, inviting him to step into the great building in advance of the rest of the party. With great politeness, they ushered him into a small, quadrilateral room and seated him at a table where they left him.

No sooner had the door closed than the light went out, greatly to Hubbard's consternation, for he felt that this might be some sort of trap. He was about to make a rush for the door when Holt suddenly appeared across the table from him against a milky, luminous background.

"Hello Glen, how goes it?"

"How on Earth – I mean Mars – did you get here so fast, Colonel?"

"I'm not really here at all," grinned Holt. "What you see is my astral body. We're talking by Martian telephone, and that includes television..."

Hubbard was almost speechless with amazement at the full-sized, colored, stereoscopic telepicture, for he would have bet his bottom dollar that Holt was really present. It was some time before he could get hold of himself enough to make notes from Holt's instructions as to the mode of behavior he should inculcate into his men so that no offense might be given the Martians. Then he had returned to the caterpillars, which he directed into the air lock. Here, they were lowered to the tunnel level and driven directly into the waiting freight cars. Since the latter were not pressurized, the Earthling crews remained in the caterpillars and kept their air conditioning running until they reached Ahla after a journey of some 12 hours.

Chapter 25
How the Martians Live

When Hubbard and his caterpillar crews debarked from their machines in the roomy freight station of Ahla, Holt, Billingsley and Gudunek were on hand to greet them beside the Martian reception committee. The new arrivals were honored, with but little less ceremony than had been proffered their commander. Gudunek's uncanny semantic sense had already breached the difficulties caused by the lack of a common language, and he was able to distribute a rudimentary glossary in which he had reproduced as closely as possible the musical sounds of the single Martian language in Earthling phonetics. He himself could already chatter easily with the people of Ahla, while Holt and his two original companions were no longer limited to the sign language, although they were by no means as fluent as the linguist.

Preparations had been made for the weary Earthlings to be lodged in Ahla's finest hotel, on one of the upper levels of the circular, subterranean city. Although daylight never penetrated their apartments, they soon lost the pallor they had acquired during their wide voyage through space, for the luminosity produced by the miraculous Martian interior paint in no way lacked health-giving invisible rays.

Invitations to the visitors from the distant planet poured in upon them and the hospitable Ahlians spared no pains to make them feel the sincerity of their welcome. The strangeness of their whole surroundings, and the puzzling inability of the Earthlings to grasp the nature of the truly inconceivable three-dimensional city, were mitigated when they were invited to the underground office building which fulfilled the functions of a city hall.

Here was displayed a model of the amazing, bright, cheerful catacomb in which they were to live for more than a year. It was a huge, circular, conical mass of drifts, stopes, halls and galleries, some twenty miles in diameter and half a mile deep in full scale. The central shaft held forty round, open levels, one above the other, each about one thousand feet in diameter. Around them were ranged the spacious quarters of the Martian government and the administration offices of the important companies.

The tubes of the metropolitan high-speed transit system proceeded radially from each of these levels to the sections of the city devoted to dwellings. From whatever level he happened to be occupying, the homeward-bound Martian had but to walk around the circle of the spacious shaft level where he was, and enter the station which served the sector to which he wished to go. One after the other, small, six-seat cars continued to pass the platform at a walking pace. Selecting an unoccupied car, the Martian would step into it and dial a three-letter combination on a device not unlike a telephone. The residence of each Ahla-dweller had such a letter combination. The little car would continue to move slowly to the end of the platform from which unoccupied cars were switched back into the column passing the platform. Any car with one or more passengers and a dialed combination would fly down the open tunnel ahead of it to the circular gallery corresponding to the first letter of the dialed combination. Here it slipped into an elevator which carried it up or down to the level prescribed by the second dialed letter. Then the car would slide right or left within its sector until it stopped at the dwelling coded by the third letter. The Martian would step out onto the tiny platform in front of his home door, while the car returned automatically to the central station.

Should the Martian or some member of his family wish to make a visit somewhere in Ahla after the departure of the car, he had but to push a button beside the doorbell. Within three minutes an automatic mechanism at the central station would dispatch the same or similar car, after which dialing the appropriate three-letter combination would take them to any desired destination on any level and in any sector.

There were no streets, automobiles, pedestrians, traffic lights, collisions, parking problems or crowded trains. Ahla suffered from none of the nerve-wracking imperfections of an Earthly metropolis. When a Martian family desired a walk, the button near the door would summon a car in which they could ride in comfort to one of the many beautiful subterranean parks in which grew the most amazing, never-wilting trees and shrubs, and through whose maze of branches the Sun shone by day and the stars by night.

A most immaculate cleanliness was the hallmark of the huge, underground metropolis. There was no such thing as dust, for the air was cleaned, refreshed and even given the qualities of different times of year by a central air conditioning system. Individual preferences as to temperatures could be catered to if that selected by the operators of the municipal plant failed to please. Each dwelling had its own supplementary heating and cooling system, which could be adjusted to suit the occupant. Water, televisephone, news, purchases – everything was done by wall plugs, spigots or cabinets in which the articles desired were taken out of one of the walls.

It had required some time for Holt and his companions to accustom themselves to this automatically operating subterranean existence, but as soon as they mastered it and became sufficiently familiar with the language to communicate without undue difficulty, they began to take part in the private social life of the great city.

The dean of Martian astronomers was an elderly scientist named Oraze who took great pleasure in extending to Holt one of the first invitations to a Martian home. The Orazes, with their two daughters and a grown son, lived in a handsome, capacious apartment in one of the exterior Ahlian sectors. For many years Oraze had devoted himself to research of Earth's conditions; indeed, his devotion to that type of discovery greatly resembled that of a kindred spirit on Earth, Percival Lowell.

When Holt and Hubbard, to whom the invitation had also been extended, arrived at the Orazes' hospitable door in their little car, they were greeted by the whole family with the cordiality which had marked all their contacts with Martians. The old gentleman adorned them with the customary chain-like decoration about the neck while Holt returned the compliment in the shape of a fine, large, terrestrial globe. Hubbard presented the ladies with flowers he had ordered from one of the large forcing greenhouses. Chattering as gaily as their still limited knowledge of the language permitted, Holt and Hubbard took their seats with the family around a bare, but graceful table in the living room. No sooner were they seated than the lady of the dwelling – for "house" it could not be called – extinguished the light and flipped on the television. One after the other, a procession of delectably prepared dishes flowed past their hungry eyes. When the final dish had melted into the darkness, the procession was repeated; this time a little faster, and during the second presentation, the diners pushed a button handed to them on a long cord as each course of which they desired to partake passed upon the screen. The screen became blank and the room again was bathed in the soft Martian interior light.

For the space of five minutes, Holt and Hubbard were given an opportunity to exercise their growing knowledge of Martian, then there was a clicking sound from somewhere and the lady of the dwelling arose and removed from a cabinet door in the wall seven shining silver containers, which she graciously placed before the diners. Cooking and serving was a lost art in Ahla, for the huge catering firms of the city were able to display their wares by television and to accept orders at the simple push of an electric button. Whenever such a button was pushed, the dwelling letter-combination appeared upon the order board of the company patronized, at a moment corresponding to the passage of a given dish across the television screen. Electronic cookers prepared it in a flash and, together with the trimmings, it was rushed into vacuum jars which were in turn loaded, complete with utensils, into metal containers and forwarded to the diner via the pneumatic tube delivery system which connected all portions of the city. Nor did dish washing plague the lives of Martians, for the remnants of the meal were simply replaced in the containers and pneumatically returned to the caterers.

When the meal had been completed, Oraze began to relate his observations of Earth, not minimizing the difficulties which he had encountered in achieving satisfactory results, for it had, indeed, been much more difficult to observe the Earth from a Martian observatory than the reverse.

During the closest approach of the two planets and when Mars was in the full rays of the Sun and easiest to observe, Earth was between Mars and the Sun and turned a pitch-black surface towards the Martian astronomer. To a Martian, Earth was the morning and evening star, as Venus is to the Earth. Only when at a considerable angular distance from the Sun could Earth be successfully observed. The naked Martian eye then saw her as a bright double star, due to her large Moon, in the morning or evening twilight. In a telescope, however, she showed as a fine sickle which grew finer the closer the planet approached the Sun in angle. Only when Earth had receded almost as far from Mars as the Sun himself, did she reveal a half illuminated disc. The extent of her illumination increased as she continued to recede on her more rapid voyage, but when her face was almost completely lighted, she was so far distant and so close to occulting behind the glare of the Sun that but little of value came from observing her.

Despite this handicap, and the frequent and extensive cloud banks which often obscured Earth, Oraze related some remarkable results. Martian astronomers were well up on terrestrial climates, seasons and temperatures. They knew the composition of the atmosphere far better than Holt had known the Martian one, and they were entirely convinced that a Martian could live easily on Earth's surface without the elaborate pressurization to which he was accustomed. They had no doubt that Earth was inhabited, and inhabited by surface creatures who could move freely around their planet as the Martians had been able to do in former ages, before the oxygen in their air was reduced and their water began to disappear. But in general, Martian researchers had held no very high opinion of the intelligence of Earthlings.

Nothing they could see on the surface had betrayed traces of intelligent creatures. There were mountains, zones of snow which melted in Spring, vegetation which bloomed when the snows melted, but there were also vast deserts, even near huge supplies of water, which never changed. To the Martians, for whom water was the most priceless of all natural gifts, a planet rich in moisture could not be inhabited by creatures of intelligence if deserts were allowed to exist year-in and year-out!

Holt was but little edified by the poor reputation of his fellow Earthlings and with a trace of asperity changed the subject by asking Oraze just how an impending visit by a deputation of such ignorant creatures became known in Ahla, not forgetting to mention his own surprise when the Martian in the southern pumping station played him the record of the radio conversation with Knight.

Oraze informed him that intercepted radio messages had in fact been the first intimations of the Earthlings' nearness. Holt concluded that this must have taken place as early as the final adaptation maneuver. The Martians had caught no more mysterious messages for the following two days, and the rumors that radio messages had been received from space thereupon sank beneath the waves of public ridicule. Subsequently, however, the great observatory of Nibilo on the Gigas Canal had reported ten fast-moving stars in an orderly row which slid into the early dawn against the background of the fixed stars. When the observatory computed their orbits, it was realized that the luminous objects were quite small and were circling the planet along an orbital path, their luminosity stemming from their reflection of solar rays against the dark background of the twilight heavens. Other observatories confirmed Nibilo's conclusions the following day.

According to Oraze, suspicion that the novel phenomenon might resolve itself into space ships was strengthened by their orbital path being in the plane of the ecliptic, and it was generally assumed that they must come from Earth. Then directional radio-receiving antennae had been bracketed upon the mysterious objects. This immediately and entirely confirmed the source of the radio emanations as intercommunication between the stranger space ships. The flight path of the landing boat had been followed quite accurately by the same method and the outlying south polar pumping stations had been advised of the impending visitation.

Holt inquired whether they had nurtured any suspicions that the visitors might have hostile intentions. At this the old man smiled tolerantly.

"I hope you'll forgive us if we doubted the intelligence of Earthlings until we came together with you. But we really never thought you could be stupid enough to attack a whole planet with a handful of men..."

This sally brought good-humored laughter from all the listeners, including Holt himself, who felt that this might be an appropriate moment to put out feelers as to any Martian urges to visit the Earth.

Oraze immediately penetrated the meaning of the delicately put question. "You may set your mind at rest on that subject," said he. "We Martians have no desire to storm the heavens. Troglodytic as we have become through the centuries, we seldom indulge in stargazing, either actually or spiritually."

"Nevertheless, you are a religious folk in whom Heaven has kindled a powerful light..."

"Our Martian God does not live in Heaven. His abode is in the hearts of our more worthy people, but I regret to say that He leads a sorrowful existence in the minds of the majority, for the God of the Martians is old and weary."

Holt tried once more. "But your whole planet abounds with creative power," said he, "and the people seem to rejoice greatly in each technical achievement as it comes to fruition. It would seem to me that your adventurers might well be tempted by a neighboring star which might, in many ways, offer greatly improved living conditions..."

"Adventurers are an infrequent manifestation of the culture of Mars," answered Oraze in a tone of regretful resignation. "During the short time you and your friends have been here, I know that you have been deeply impressed by many of the superficial things. When you have observed our people for some time, you will realize that an age-weary, languid, satiated culture lies hidden behind all the mechanical refinements with which our technicians have overwhelmed us.

"Not long ago, it was my privilege to hear you describe how a few Earthling pioneer races extended civilization over your planet only a few centuries ago, and then, consumed from within by the ardor of their mission, prepared the way for new races.

"Tens of thousands of years ago, the same development took place here also. Here, too, there were battles and wars until there arose a planetary government. Then came the long flowering of a beautiful culture. Standards of living rose higher and higher, despite the increasing depredations of global drought and erosion. Fine arts progressed to unthought-of perfection. Production of consumer goods on a vast scale well-nigh leveled the difference between rich and poor.

"But the extirpation of contrasts and of the asperities of life decreased those tensions which theretofore had supported the ebullience of our inner drives. Now our planet is the home of a peace-seeking and easeful race, reposing upon the deeds of their ancestors. Everything is well organized; too well, indeed, to breed adventurous thoughts or actions."

Oraze fell silent for a space. Then he added contemplatively, "perhaps the arrival of you young heroes may shake our languid minds awake one more. Perhaps..."

"So you believe that this spiritual lassitude was caused by the necessities of life being satisfied in too great a measure by the perfection of the means of production?" inquired Hubbard. "On our own Earth we are now attempting to fight poverty along identical lines. And hitherto we've held to the belief that when dire need is banished, mankind will be able to turn to higher and nobler things than the fight for bare existence."

"Natural laws are inexorable," returned Oraze. "You Earthlings too will enter a period of wonderful cultural development, once the political unification of your planets is complete – and I envy you. But you will also have to pay the piper. It is impossible to satisfy the demands of the millions unless you adopt methods of production which produce identical goods likewise by the million, and true mass production means not only the standardizing of the goods produced, but also the standardization of requirements and tastes.

As an example, the identical dishes we ate this evening were eaten at the same time by millions of others here in Ahla, and identical tablecloths lie upon millions of identical tables. Even the shoes my daughter wears..."

"Father, you know I've cut my initials in the heels!" objected the young woman.

Oraze smiled bitterly. "You've just seen a very tiny example of what represents our greatest tragedy. It presses upon us all like a horrible nightmare, and those of us who have any feeling are fighting tooth and nail against an ever-increasing, gray uniformity which besets our lives. That uniformity is, I fear, too powerful ever to be overcome.

"Throughout thousands of years our people battled for personal freedom. Usurper after usurper who attempted to suppress freedom in the name of his own conceit was overthrown, and a free political system was established which covered the entire planet and has provided an unheard-of degree of stability for more than five thousand years.

"Our technicians liberated us from bodily need. That's right... But their methods, the horrible uniformity with which they invest everything, has literally scorched our souls."

The old man choked in his excitement. "My son Imo, there, is a physician. Mura, my eldest daughter is a teacher. Our hospitals are no more that anatomical repair shops and the schools simply pack minds as mechanically as machinery fills and seals food cans! You will have to see them to understand what I mean!"

Chapter 26
All Hands Ashore on Mars

Woolf and Hempstead set about their task of preparing the landing strip for the boats from the *Goddard* and *Ziolkowsky* within a few days of the termination of the welcoming festivities. With Gudunek's able linguistic assistance, they agreed with the Martian authorities upon a location exactly on the equator and just north of the great vegetated Aurorae Sinus. The crews of the space ships which still circled in their orbits had been kept informed of all the exciting events on the Red Planet below them and were eager to escape the narrow confines of their inflated nacelles, and experience for themselves the wonders of the fairy, subterranean existence of which they had heard so much.

The site of the landing strip had the advantage of lying only 1,600 miles from Ahla, and was distant but 430 miles from Suguli, a large city hidden beneath the verdant carpet of Aurorae sinus. Woolf and Hempstead shipped the *Panther* to Suguli by underground freight and drove her around the region in the company of several Martian employees of the Ministry of Irrigation. Near the Jamuna Canal, and just west of it, where it connects Aurorae Sinus with Lacus Niliacus, they found an open plateau with satisfactory ground consistency where they proposed to lay out the landing strip. The Martian Irrigation authorities provided earth-moving machinery with which the work was accomplished within a very few days.

One of the aspects of life in Mars which had astounded Holt was the relative unimportance of aviation, despite the tremendous progressiveness of the highly technological civilization. It was not that aviation was unknown or unpracticed on Mars, for the museums were full of all sorts of highly developed transport aircraft which once had been in extensive use. Subterranean existence and the increasing perfection of the bullet-fast underground transportation system had banned the aircraft as obsolete and no longer adapted to modern transit problems. It was occasionally used to observe the waters of the polar melts and for surveying, but almost all remaining aircraft were helicopters, requiring no landing strips. Hence there were none available for the high landing speeds of the eagerly awaited boats.

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In the course of the explorations in search of suitable landing terrain, Sam Woolf was able to throw considerable light upon the secret Martian vegetal regions and canals. Nowhere did he discover any signs of farming or plantation. It was simply that a sort of moss proceeded to grow anywhere sufficient moisture was provided, and to cover the bare ground with a carpet of varying thickness. The Martians themselves paid not the slightest attention to any utilization of this moss.

Sam found himself before an apparent enigma, for it hardly seemed reasonable that the vast and complicated system of irrigation had been engineered and developed merely to further the growth of unharvested moss over enormous areas. The thousands of miles of "canals" were also covered with moss, and Sam Woolf kept expecting that he would discover plantations from which the Martian would derive vegetable nourishment.

Slowly there awoke in him a realization that there must be some other solution to the riddle than could be suggested to him by his Earth-trained mentality. In Ahla he had become aware of the great synthetic food manufactories which shot appetizing, torpedo-like meals into the swellings. There could, of course, be no farm industry! Highly developed chemicals satisfied the Martian hunger just as synthetic fertilizers nourished plant life on Earth!

But any industry calls for a certain amount of raw material, of which the most elemental is water, and water on Mars came only from the poles. Thence it was pumped during the vernal melts. How did the water return to the polar regions? Of course, snow fell there during the Winters, but whence came the snow? Nowhere but from the atmosphere's moisture – and how could the atmosphere gather moisture, if industry and the cities consumed all the water pumped to them?

Nothing is lost in nature even when she is abused after the manner of modern chemistry; therefore, what once was water must again become water. It was quite plain that the subterranean cities must drain away the same amount as was pumped to them. If this were not so, they would drown in their hermetic capsules.

Sam Woolf discovered that the city sewage was distributed to an extensive net of porous tubes which ran slightly below the surface in the vicinity of the population centers. Thus the liquid soaked the ground and caused the moss to sprout. Millions of tiny roots absorbed it, through which it rose above the surface as sap and returned to the air sucking greedily at the stems and leaflets of the plants. By the grace of autumnal winds, the moisture returned to the poles, where it again began its cycle. This insignificant moss played an important role in the life of the whole planet!

Woolf was also able to explain why the green of the vegetal areas wilted in Winter, although the urban water consumption did not vary the year around, the flow being constant into the drains. The ground froze solid during the Winter season and thus was unable to absorb. The cities accordingly stored their sewage and waster water in enormous sumps from which it was pumped when the warmth of Springtime softened the ground once more. Then the life-giving moss awakened again.

The verdure covering the canals was explained in the same way, for the underground waterways could be pumped full only when the heat of Spring or Summer melted the polar snows. During such times, the huge pumping stations delivered water sufficient for the entire year to cities and industries, where it was stored against the future, as the waste water.

In view of the vast, straight-line distances, the Martians had forborne to install piping and had simply dug series of parallel ditches with enormous earth-movers. The ditches were covered over to prevent undue evaporation losses, and between them the moss tended to grow whenever they were full. This was in Spring when the pumping began, and the moss withered away when it ceased in the Autumn.

Woolf's research into the Martian water circulation did not impede the work of preparing the landing strip, and Holt radioed *Goddard* to launch her landing boat. An hour before it was due, the entire Earthling landing party stationed itself at the end of the runway. The three caterpillars, from which Hempstead had tactfully removed the ordnance, were manned by drivers and radio men, while a pressurized, transparent Martian vehicle loaded with journalists and television newsmen stood by to immortalize the epic-making landing of an interplanetary space vessel.

The usually imperturbable Holt showed signs of nervousness, for the success or failure of his expedition was at stake in the landings of the two boats. He suffered at the thought of being only a spectator at this decisive moment, and longed to be in the copilot's seat of Nordenskjold's craft, where he might perform a bit of discrete back seat driving. It distressed him to know that his men were in danger that he could not share.

As they scanned the northwesterly sky through field glasses, a signal flare drifted down out of the somber, crystal blue. Soon they could see the wide sweep of the raked pinions centered by the pod-like hull. The great wing swept across them at 6,000 feet, made two descending spirals and a wide, left turn into the approach leg. Holt saw the two landing wheels drop into place before the start of the turn hid them under the wings.

An agitated voice came out of his helmet receiver. "Colonel Holt, this is Brooks in *Panther*. Reporting Mayday from *Goddard*. Lieutenant Nordenskjold reports nose wheel stuck. Minor fire in propulsion compartment caused a short circuit. Over."

"Damnation!" Holt exploded into his microphone. "Clear away the caterpillar fire equipment, Nordenskjold will have to work it out for himself. Transmit to me any further reports. Over."

"I had a hunch something would happen," he growled to himself. He could see the absence of the nose wheel between the extended main wheels as the boat leveled off.

"Full stall landing will be made. Over," now came through his receiver.

"That's the only thing he can do," said Holt, more to himself than to the radio man. "Hope the tanks don't burst and the ship doesn't catch fire!"

With the nose high in the air, the wheels touched the landing strip. Holt crossed his fingers as well as he could in his clumsy gauntlets. The heavy boat rolled a hundred yards or more with the nose still high and a cloud of dust rising from the short, cruciform empennage, where the emergency tail-skid was tearing up the ground and tossing pebbles and sparks into the air. Slowly the nose dropped as the speed diminished until, in a cloud of dust and with a grinding of metal, the craft came to rest directly in front of the waiting group without sending up any fatal plume of fire.

Holt rushed to the stern, pale and trembling. Sure enough, the emergency skid had torn off! The diagonal cross of the stabilizing fins, which were so essential for the eventual relaunching, had been ground down to half their span by contact with the landing strip. The whole stern appeared to have suffered and the skin was torn away in places through which protruded bent and broken struts.

A repair job of the first magnitude would give John Wiegand a chance really to demonstrate his skill, and Holt experienced a moment of satisfaction in the knowledge that the invaluable John would rejoice in his visit to Mars, instead of remaining in the circling orbit as originally intended.

The door of the boat opened and the inflated, helmeted figures filed out upon the inclining wing and leapt down.

"Sorry about that," said Nordenskjold as Holt held out his hand. "It might have been far worse," answered Holt, "and it's mighty good to have you here. You did your part splendidly."

Twenty-four hours later, *Ziolkowsky*'s boat descended from the orbit, and in the hands of the experienced Haynes landed as though on the home field of United Spacecraft. John Wiegand was with him, somewhat sketchily equipped with a toothbrush for the coming year on Mars. This lack of impedimenta did not disturb him, and he immediately crawled under the *Goddard*'s boat for an inspection.

"It shouldn't be too much of a job, if we can remove the stern from *Oberth*'s boat and replace this damaged one," said he. "Do you think we can get that done?"

Chapter 27
Body Repair and Brain Filling Stations

After the landings of *Goddard*'s and *Ziolkowsky*'s boats and when the various scientists were well started on their tasks of discovery, Holt and Hubbard decided to take advantage of Oraze's invitation to visit a Martian hospital. Dr. Barrett had arrived and, with Woolf and Billingsley, they made their way to the surgery clinic headed by Oraze's son, Imo.

Oraze's lamentations concerning the seedy side of their civilization had made a profound impression on his hearers, and Doctor Barret was consumed with curiosity as to medical and surgical procedures on the Red Planet. Notwithstanding his devotion to space medicine, he had retained a high degree of surgical skill and a good familiarity with internal medicine.

The group of Earthlings was greeted at the entrance to the municipal hospital where the clinic was located by the youthful, swarthy Imo, who promptly led them down a wide corridor behind whose transparent walls was displayed a grim collection of human organs preserved in glass containers. Livers, hearts, lungs, eyes, legs, hands and feet were stored in nutritive fluids or kept in states of activity by complicated glass pumping devices.

"Here you see our stock pile," commented Imo. "All these organs are willed to us by people who have died and who, in their lifetime, declared their willingness to devote any still usable parts of their bodies to the healing of the sick. You may be interested to know that it is socially good form so to specify in one's testament.

When such a person dies, we immediately remove surgically those organs for which there is the greatest demand. They are then made sterile and preserved against future use in the machines you see before you, under conditions which permit us to keep the organs usable for a considerable time."

"How horrible!" whispered Holt to Dr. Barrett. "Hyper-civilized cannibalism disguised as brotherly love and humanitarianism..."

Dr. Barrett chewed somewhat dubiously at his ragged mustache. "I'm not so sure," said he. "Our own medical science seems to be headed in the same direction. If blood banks, and eye banks, and bone and skin grafts are acceptable, why shouldn't a heart for which the owner has no more use, or an arm or leg fall into the same category?"

Imo ushered them into an elevator which descended to a circular gallery whence they could look down into a bright operating theater. On the table lay a patient completely enveloped in what seemed to be a white, celluloid skin. He was conversing freely with the masked surgeons and assistants through his transparent head enclosure. Ultraviolet lamps for sterilizing the air shone from the ceiling.

Imo began to describe the operation. "This patient is a musician and yesterday his arm was crushed in an accident. Fortunately for him, his accident coincided with the death of a noted violinist, so that his new arm will require little, if any training when he returns to practice his profession. It might even happen that his skill will improve measurable."

As Imo continued with his gruesome lecture, the crushed arm was removed and placed in a dish. One of the surgeons removed the new arm from its preservative solution and held it close to the socket, while another began connecting up the various nerves, muscles, sinews and blood vessels. For greater convenience, these were identified by small, colored tags, like the wiring of a switchboard. Finally the ball was fitted into the socket and the wound closed. During the whole process, the patient lay with open and interested eyes, conversing loquaciously with the operators.

"Getting a tire changed on my car seems more of a job than that," commented Woolf.

In the next operating theater, an eye was being removed from a woman.

"This lady has been getting very myopic, and we once replaced her cornea, but this failed to effect a permanent cure. Not long ago, we received an eye which would fit her, and she decided on an exchange. Eye operations are among our more difficult surgical problems. Shall we move on to physiotherapy?"

In a long, half dark room, patients lay on elongated apparatuses and watched a television show on the ceiling. Peculiar arrangements of levers and wheels moved legs, fingers or arms to and fro.

"Most of these people have received new members or had serious operations," explained Imo. "We apply local anesthetic to the joint or affected part and then use mechanical movement to restore suppleness. The movements are initially slow and small, to be increased in size and speed after a few days."

"Gosh, it's like running-in a car!" whispered Woolf. "Not over forty for the first five hundred miles; then increase speed gradually…"

They left the half-lit room and Holt questioned the young surgeon. "I saw some hearts on glass pumps in your stock room. Can you really exchange a heart without losing the patient?"

"I see at what you're driving," was the answer. "My father's remark about God living in the hearts of the few good Martians and suffering in the minds of the others… Perhaps the old gentleman is right.

"But you might as well know that medically the heart is neither more nor less than a pump with a particular aspiration pressure, and an optimum delivery pressure. It delivers per second an accurately defined quantity of a reddish liquid called blood.

"Of course we exchange hearts! First we shunt a sterile electric pump into the blood circuit and dam off the old heart; next we excise it and connect and insert the new one. Finally we set the new heart in motion by mechanical massage, and after it takes up the load, we shut off and remove the electric pump. No patient has ever asked us what happens to his God during an operation."

Holt was having difficulty concealing his distaste and explained to Imo that other business called him urgently. When they got outside, he addressed Billingsley. "I'm beginning to understand what old Oraze meant. It seems impossible that men who pretend to serve a science should be capable of such sacrilegious cynicism."

A few days later they paid a visit to Imo's sister Mura at her school and heard a description of the Martian educational system.

Martian children entered school at the age of three, which was approximately equivalent to six on Earth. The first two years were devoted to reading, writing and arithmetic, together with a broad, illustrative coverage of the physical aspects of Martian civilization. Then the curriculum became more specialized.

It included mathematics, physics, engineering and electrotechnics, not to mention chemistry, sociology and jurisprudence. There was also a short course in the history of Martian development and civilization.

When the children attained their eighth year, there came a most confusing elaboration of the educational field. Metallurgy, food chemistry, atomic physics, transportation, communications, pressurizing and air conditioning, domestic economy, domestic troubleshooting, automatic registration and management, anatomy, medicinal properties, social hygiene, labor jurisprudence, vitamin studies, hydraulic installation, water rights, and ten or more other subjects, including the study of tunnel building, as abstruse as it might be to the average citizen, were thrown at the young students. The curriculum was designed to familiarize them with the inordinate complications of their future life and simultaneously to impress them with their responsibilities as vital, if undistinguished, cogs in the mighty machine.

At the age of 12, both boys and girls entered universities or technical schools to prepare for their actual professional or business activities. Mura explained proudly that for many generations, sex equality had been the foremost law and tenet of the Martian social order.

Under her guidance, the visitors then entered a classroom where six year olds were studying chemistry.

The instructor was brushing through his subject at a terrifying rate. Within 30 minutes he covered the periodic system of elements and the secret of electrical adhesion which binds atoms into molecules in chemical combinations. Lightly, he tapped the subject of natural radioactivity of heavy atoms and included some remarks on the variety of behaviors of noble gasses in their splendid isolation, as compared to such clinging vines as the halogens.

On leaving the classroom, Holt spoke to their guide. "The speed with which all that involved material was presented to those children is really bewildering, and surely, even if those boys and girls understood it at all, it's out of the question that they should remember it!"

"Oh," answered Mura with a disarming smile, "they're not expected to. The children learn no detail matter in school. It's done at home at night."

"You mean in the evening, as homework?"

"No indeed. I mean at night, when they're asleep!"

"How on Mars can that be?"

"Our entire system of instruction is so arranged that lectures at school merely provide the children with a very general concept of the interrelation of things. In the classroom they are not expected to absorb detail, but only to comprehend indicative viewpoints and general systematics. We can instill detail much more simply in the absence of waking consciousness, when the brain is not distracted by other external stimuli.

"Here you will see a large collection of phonograph records relating to every professional subject. When they return from school, the children carry home records appropriate to the subjects they have just heard discussed. They fill their record changers and connect the pickup to their pillow receivers. During sleep, the substance of the instructional matter on the records flows into their subconscious and, according to our experience, it is absorbed much more reliably than if we had hammered knowledge into them in the classroom."

"How can a child get to sleep with a voice chattering from the pillow?" inquired Hubbard.

"The phonograph does not cut in until the encephalograph shows that the child is asleep."

"That's beyond me," answered Hubbard, with a shake of his head.

"Let's go to the repose chamber," said Mura, "and I'll give you a demonstration."

Nearby there was a dimly lighted room containing several couches, on one of which Mura invited Hubbard to recline. When he had done so, she produced a piece of apparatus like a radiophonograph on small, rubber-tired wheels. From a neighboring closet she took a record and placed it on the turntable.

"How much do you know of the periodic system of elements?" asked Mura.

"No more than I was able to pick up from that high-speed lecture we heard just now, and furthermore, my Martian is too limited for me to have understood it all anyway."

"You shall know much more very shortly," answered Mura confidently.

Dipping an absorbent pad into a liquid which smelled like acetone, she wiped several spots on Hubbard's scalp and then placed a number of shining metal disks on the spots, retaining them with an adhesive. Each disc was connected to the apparatus by a thin wire. Then she pushed a button on the machine and a monotone buzzing reached Hubbard's ears from the pillow where his head reclined.

"Soon you'll go to sleep," said Mura. "These disks are sensitive to the waves of your brain and conduct them to the amplifier. Can you hear a loud ticking in this receiver? That is the high frequency of your waking consciousness. As soon as you fall asleep, slow oscillations will indicate that your conscious mind is submerged, and when the amplifier registers this, your lesson in chemistry will begin."

Five minutes of listening to the monotone sound coming from the pillow put Hubbard into a sound sleep. The amplifier ticked slower and slower. Then there was the click of a switch and the phonograph began to revolve.

An insistently persuasive voice whispered from the pillow:

"The first nine elements of the periodic system: Hydrogen, Helium, Lithium, Beryllium, Boron, Carbon, Nitrogen, Oxygen, Flourine…

Hydrogen – Helium – Lithium – Beryllium…

Hydrogen – Helium – Lithium – Beryllium…

Boron – Carbon – Nitrogen – Oxygen – Flourine…

Boron – Carbon – Nitrogen – Oxygen – Flourine…"

For several minutes the insistent list was repeated. Then Mura shut off the machine and wakened Hubbard.

"Well Glen, can you tell us the first nine elements of the periodic system now?" laughed Holt.

Hubbard sat up with a yawn and then repeated his lesson mechanically in Martian just as he had received it from the phonograph record.

"Hydrogen – Helium – Lithium – Beryllium – Boron – Carbon – Nitrogen – Oxygen – Flourine. If I only knew what the devil it all means in English!"

At this, Gudunek, who had been standing skeptically in the background, exploded joyously, "What a wonderful thing for my Martian language teaching!"

Holt shook his head dubiously. What was it that Oraze had said? Canned knowledge? It was an excellent tag for this horrible intervention of technology in the sacred mysteries of the human mind…

"When I was a small boy," he said, "I used to sleep with my Latin primer under the pillow because I couldn't remember the words. How many thousands of hours I put into learning mechanical things, and how difficult it was! It doesn't seem possible that it can be so simple…"

"I say, Doctor Barrett," remarked Billingsley, "doesn't this jolly well explain why our Martian friends all have outsized heads? Surely if continued overeating puts a fine round belly on a man, this stuffing the brain with wisdom must enlarge the good, old cranium if it's not to burst, you know…"

Chapter 28
The Machinery of a Super Civilization

As Holt and his little band penetrated further and further into the details of Martian civilization and culture, the 449 days of "waiting time" which they originally contemplated with considerable dread began to fly like the wind.

Rather did they fear that the apposition necessary for the start of the return journey to Earth would take place long before they could thoroughly examine and record all the surprises offered by the extreme ingenuity of these members of an overripe civilization.

Among these surprises were great atomic power plants whose millions of horsepower kept the bloodstream of the huge, unified technical organism in circulation. Almost equally impressive was the chemical industry of Mars and the manner in which it was able to integrate the scarce but vital planetary store of water, oxygen and ore in such manner that its cycle sustained the inhabitants' general welfare.

The chemical industry was faced with three major problems:

Air conditioning and pressurization of the subterranean cities and installations.
Feeding the hundreds of millions of people.
Producing enough steel to extend the underground structures and to provide for consumer goods.

To fulfill these functions, around which gravitated a whole series of other industrial activities, the managing mentalities were faced with

Almost entirely exhausted natural coal deposits, which had been ruthlessly exploited by earlier generations of Martians, much as Earthlings presently exploit their coal mines.
Very limited water supplies, which were required to be pumped from the polar regions during Springtime.
A good supply of electrical energy, generated by atomic power.
Finally, an inexhaustible supply of relatively low-concentration iron oxide, adulterated by various minerals in the ferrous soil of the deserts.

The Martian chemists had gone about their work in the most admirable fashion, attacking the triple problem with a model degree of integration.

They electrolyzed a certain proportion of the water as it arrived from the polar regions by passing powerful electric currents through it and thus disassociating it into hydrogen and oxygen. The oxygen was piped to the air conditioning and pressurizing plants, and there was used to regenerate the air of respiration, a continuous process. The hydrogen was used in the steelworks, where it was passed over beds of incandescent iron oxide, combining with the oxygen in them. This converted the ferrous oxides into metallic iron, to be worked into structural and other steels by ensuing processes of varying sorts. Simultaneously, the hydrogen burned to water vapor by taking up the oxygen from the ferrous oxide, and the water produced by condensing the vapor returned to the cycle.

In the air conditioning and regenerating plants, only half of their function was completed by the addition of oxygen to the air of respiration, for the carbon dioxide produced by breathing had to be eliminated to an equivalent extent. This was done in the same manner as in Holt's space vessels, where the exhaust air was pumped into pressure air washers and sprayed with water. Under the high pressure of these sprayers, the carbon dioxide was absorbed into the water droplets, thus separating itself from such air constituents as were insoluble in water. The carbonized water was expelled from the bottoms of the pressure washers and then, when depressurized, it rendered up its carbon dioxide in bubbles. The latter was then piped to food manufactories.

Martian food manufacture was one of the more extraordinary chemical miracles, although it was more biochemical than chemical, in the strict terrestrial sense of the word. Here the mystery of natural vegetable growth was duplicated by artificial means in retorts.

The biochemical establishments made practical use of that marvelous process which manifests itself in the growth of every plant and which Earthly scientists, in their inability fully to explain it, have called photosynthesis, an empty and non-significant title.

Photosynthesis is the word designating the ability of plants to produce fat, sugar and protein for their nourishment from carbon dioxide, water and a few chemicals which they ordinarily extract from the ground, and they do this by the mere presence of light.

The Martians in their food factories utilized the simplest form of vegetable growth known in nature, namely microscopic algae.

The water supplied to the factories was first heat sterilized in order to destroy alien and undesired germs. Then it was "inoculated" with a relatively small amount of algae and was enriched by the necessary nutritive materials, in the main, carbon dioxide, magnesium, nitrogen and phosphorus. Water thus prepared was passed slowly under batteries of powerful artificial lights within glass tubes which allowed the ultraviolet rays to pass freely. The algae grew both in size and numbers by the mysterious process of photosynthesis, forming, in accordance with the modifications of the process by minor supplementary chemical additives, primarily fats, sugars or proteins. When the light had taken effect and the water flowed out of the transparent piping, the augmented algae growth was centrifuged from the water and taken to extraction presses where the useful products were recovered and sent on to refineries to become food for the Martians.

Electricity was the mainstay of the hyper-refined Martian technological setup. Only by electricity was it possible to replace the complicated interplay between plant and animal life, the atmospheric processes and the farms and industrial production which on Earth permitted civilized life to be maintained and improved.

It was, therefore, quite natural that electricity had attained an almost mythical quality on Mars, for it not only helped transmute the waste products of the lungs into rich and tasty foodstuffs and permitted air of respiration and structural steel to be manufactured from desert dust and polar snow, it kept the infinitely involved gearing of the entire civilization in rotation.

Hundreds of horsepower were invisibly at work for every Martian, day and night; and to them alone Martians owed the high state of their material welfare, which were, in effect, the air they breathed, the food they ate, and the clothes they wore. Electricity bore the voice and image of distant friends into homes whenever people might wish. By that horsepower people were borne to any point of the red globe within the space of a few hours. It kept in motion the huge productive machine whereby they were able to earn in a short four hours daily their portions of whatever joys material accomplishment could offer.

Such conditions naturally brought in their train the establishment of energy as a standard of monetary value. Since nearly all production was almost fully automatic, the number of kilowatts used in manufacturing any sort of goods became the determining factor of their price and valuation. More energy per person meant more riches for everyone. Thus, on Mars, kilowatt-hours took the place of Earth's gold standard of values.

Each time a new generating station was built, the amount of money in circulation increased, but no danger of inflation was incurred by this continual increase in the currency. Industries operated by the new source of power increased in productivity in the same measure as did the currency in circulation, thus maintaining a well-proportioned balance between the values of goods and money.

In bygone days, improvement of the general welfare and increase in productivity, together with medical and surgical advances, had combined to induce a marked rise in the population, exactly as had taken place on Earth since the dawn of the industrial and technical age.

For an extended period, the population grew faster than did the housing facilities and industrial production. During this time, decreased infant mortality in combination with greater general longevity prevented the Martians from benefiting from the increasing productivity of their industries. At one time the authorities were even obliged to impose taxes on children, for the rapid increase in population threatened to outrun the available respiration air, food and housing. Such a tax, brutal as it was, offered the only means of limiting the population below the danger point.

Later, the pendulum swung back again, and in a most interesting manner.

Industry had, by reason of sharp competition, tended to eliminate the human element in production and to utilize automatic machines as much as possible, with resultant savings. This development brought with it an increasing degree of standardization with the consequent dullness of uniformity about which Oraze complained so bitterly. Nonetheless, it elevated human labor more and more into the regions of creativeness and utilized man's spirit rather than his muscles.

Throughout the lifetime of several generations, Man's liberation from bodily labor remained a Pyrrhic victory of very doubtful value, for the proud and experienced craftsman was replaced by a miserable machine watcher, who saw to it that the automatics did not stop, with a box of uninspiring index cards before him. But this unhappy stage was eventually overcome by the development of self-activating methods of registration. An electronic equivalent to the punched card method of Earth, these methods gradually dammed the flood of paper.

Phonetic notation of the Martian language was introduced, thus allowing the typewriter to die a natural death and to liberate an army of unhappy girls. A dictating machine replaced it and transcribed the text directly from the spoken word.

When all this had happened, the last and lowest Martian became free of the major portion of any physical burden, and could devote himself to work of a creative nature, no matter what his profession or trade might be. The pendulum of increasing population reversed itself.

Every Martian who desired to earn his living in such a complicated scientific and technical world by creative contribution was faced with enormous demands on his professional knowledge by reason of the high scientific level of all professions. The breadth of knowledge to be transmitted to the youth by schools and colleges was beyond conception, and as this breadth increased, so did the costs of education.

The average age expectancy of a Martian man or woman was some 50 Martian years, or about 94 terrestrial years. It was not possible for the universities to graduate their students, fit to live their way of life, a day younger than fifteen to eighteen Martian years, despite their specialized methods of instruction. Thus the young folk were financially dependent upon their parents up to that age, in addition to the costs of their education. Marriage prior to graduation was out of the question for all but a fortunate few.

Having babies had become an expensive luxury, even without considering the underhanded tax situation. Not unnaturally, the danger of overpopulation died aborning. It had been created by technical civilization's advent and was strangled by its growth.

Ahla and the neighboring city of Sugili were bitter rivals in athletics, and athletics played a vastly important role in the life of the Martians. Sport in general was not merely a safety valve for the ebulliency of youth as it is on Earth, where the exuberance of youthful spirits is offered an outlet, yet held in check by carefully thought out rules and limitations.

Rather was sport on Mars an elemental rebelling against the slavery of the troglodytic existence which bound the natural instincts and physicals energies of the young of both sexes, and deprived them of contact with nature and of the beauties of life in the open. It was also a revolt of their bodies against the danger with which mental overdevelopment threatened them. It was a broad revulsion against the push-button civilization where physical labor had been turned over to machines and electrical gadgets. Martian athletics were also a forum where the combative instincts of the younger Martians could find vent in constructive rather than destructive activity, now that the former warlike eras lay far in the past. Finally, they had become a favorite mode of indulging the long leisure granted the Martians by the four-hour workday.

Holt and a group of his companions sat in the stadium of Ahla under a huge dome of glass which maintained the artificial atmospheric pressure, the life of the planet. The arena was oval and surrounded by four rows of seats after the fashion of a Greek amphitheater. Natural sunlight irradiated the festive scene through the vast dome.

As the last day of the competition was reserved for the decathlon between the young men of Suguli and Ahla, Holt had felt that he could not miss the important event.

The brown bodies of the Martian youths were almost naked. Sinuous and beautifully knit, they went through the events of running, jumping, swimming, discus-throwing, shot-putting and other sports with a grace and ease beyond all praise. The high and distance jumps positively astounded the Earthling visitors, despite their familiarity with the weakness of the Martian field of gravity.

As they scrutinized the gay festivities, the observers from Earth could not but be reminded of the spirit of the ancient Greek Olympiads, for no individual victory in running or jumping counted here; it was the development of the entire body which was sought. No misshapen wrestlers or biceps-bulging weight lifters were to be seen. Any distortion of the human form by over specialization was carefully avoided.

The decathlon was an ideal means for producing true bodily perfection and balance, for it demanded an extensive proficiency of the body along a wide variety of exercises, and simultaneously evolved the aesthetic satisfaction which a broadly trained body offers to the eye. In the Martian decathlon, the ultimate object was not so much the highest record as it was to bring forth the most versatile and perfect, the "Kalos," as the Greeks had it.

Despite the emphasis on beauty and bodily perfection, there was no lack of strenuous effort in the competition between the males. The final event, a sort of marathon lasting a half hour, brought most of them to the verge of exhaustion. The winner received an ovation which reechoed from the glass dome above when he stepped to the front to receive the prize of a purple neck chain. The enthusiasm of the spectators was no more for the wonderful performance which he had put up than for the harmonious physique which his long training had developed.

As a finale, there were ball games and gymnastics for girls, for whom beauty and grace also were prime objectives. The Earthlings marveled at the enthusiasm with which the maidens engaged in the various exercises and the pride with which they displayed their charms. There was none of the languor which so often tinges an Earthly stage show with the obscene. On the other hand, there was none of the prudery which ugliness so often drapes around itself as a form of moral cloak.

The whole festivity was an unforgettable tribute to the living strength and will to beauty of the healthy youth, offering to a Nature banished by technology the honor and veneration which was her due.

Chapter 29
The Expedition Bears Fruit

Douglas McRae and Howard Ross were the zoologist and botanist of the Mars expedition. Great indeed was their disappointment when Holt's first radio reports from the surface to the circling vessels indicated that, to his eye at least, there was but little plant or animal life on Mars. Holt had flirted with the idea of directing both McRae and Ross to remain in the space vessels and to continue to circle in the orbit in order to devote the lifting capacity of the landing boats on takeoff to objects of greater importance to Earthlings than the reports and specimens of a zoologist and botanist. It seemed that such reports would consist of the solemn conclusion that Martian fauna was limited to a few species of ants and worms, while flora consisted of a limited variety of mosses.

Holt's point of view changed when he was introduced to the elaborate Martian underground gardens, bathed in a combination of filtered natural and artificial light. Parks produced a luxuriant growth of trees, shrubs and flowers beneath the sun rays that penetrated the enormous glass domes above them. When he had spent some time browsing in the Natural History Museum of Ahla, he revoked his intention of keeping McRae and Ross circling in space and radioed them to descend in the *Goddard*'s boat.

Ahla's natural history museum, like many others in various cities, contained inexhaustible treasure troves for seekers of answers to developmental questions. How, for example, had Mars come to present the picture of today? How may the Red Planet have appeared thousands or millions of years ago? What had become of the oceans and mountains which once must have existed? How long had it taken for the atmosphere to dissipate to a point where the Martians fled to a subterranean, pressurized existence? When and why did higher forms of animal life die out? What had such forms actually been? How did the Martians breed the marvelous plants of their subterranean world?

Sam Woolf had haunted the museum from the moment that he was free of his duties as airport engineer, and he found so rich the collections and specimens that he was able to dispense with the geological equipment he had brought to the orbit. He promptly abandoned any thought of digging for specimens himself and devoted his time to studying the exhibits in the museum. Here, the Martians had correlated all he desired to know in the most extensive manner, while the curators were always at his beck and call to explain anything he might not fully understand.

Hans Bergmann was another scientist to benefit from the Martian penchant for thoroughly documenting and recording the astronomical phase of the development of their planet. Bergmann enjoyed the astronomical bliss of seeing the history of a planet pass in review in full scale photography – and it was his planet, to which he had devoted his professional life. He found the complete answers to his years of patient, tireless research, passing the planet's red rays through the torture of the spectroscope. Now he had no need to correlate one vague theory with another equally vague in order to make his observations agree with one another. Mars' life story lay before him, an open book. He could even compare it with that of Earth and thereby set up a series of generalizations for basic laws which must underlie the developments of all planets.

Thus the Earthling scientists abandoned the primitive research equipment with which they had hoped to solve the mystery of the Red Planet's life and history. They were able to benefit by the efforts of generations of Martian scientists as collection after collection, specimen after specimen, was presented to their eager eyes.

The expedition's scientists had been a glum lot when the first message from Mars' surface reached them in their orbit, but their gloom rapidly dissipated when they plunged into the stimulating flow of revelations of natural science with their Martian confreres. So vast was the treasure of information that it threatened to overwhelm their mental capacity, and they loudly boasted that a mere visit to the Natural History Museum of the City of Ahla would alone more than justify in the minds of Earthling taxpayers the billions of dollars expended on Operation Mars.

The unfortunate Tom Knight continued to command and maintain as best he could the interplanetary vessels as they circled the Red Planet. The tedium of his faithful watch was relieved by the daily reports radioed up by Holt for retransmission to Earth. Lussigny sent them forth into the ether until they reached the grasping antenna of the High-Duty station in the Lunetta orbit. From there they were poured into the ears of the Space Force communicators and to Braden's desk, from which eager reporters and radio commentators passed them on to the news-hungry people of Earth.

Not long after his arrival, Holt came to the realization that Mars' boiling economy and scientific advancement might well represent an extremely valuable outlet for Earthling trade and the industry behind it, while there could be no doubt that along certain lines an interchange not only of knowledge and culture, but also of material goods, should be envisaged. Using the code designated for confidential matters, Holt asked Braden what his attitude on this subject should officially be. He asked for instructions whether to foment plans for closer interchange of experiences and permanent economic cooperation, if the general idea should seem to appeal to the Martians.

Braden's usually prompt response to any message from Holt was long delayed on this subject, for he did not fail to recognize the solar system-shaking importance of such a decision. He characteristically felt that it was beyond his province. During a personal interview, he laid it before the newly elected President of Earth, but that worthy official likewise declined to rule on so far-reaching a subject, preferring, as was more than natural, to submit the matter to a session of the United Congress.

The quandary in which the President found himself was indeed no light one. To undertake trade relationships with another planet could have unforeseeable consequences. It might open infinitely rich fields of knowledge of incalculable benefit to suffering humanity, but it might also carry the microbe of possible future cosmic conflict.

Holt's fateful question was, therefore, tossed into the ravening maw of a special session of the United Congress, which flung it from one tongue to another in impassioned debate. The elder politicians viewed it with alarm and were strongly supported by the lobbies of some of the major industrial concerns, in mortal fear that the comfortable practical monopolies they enjoyed might be threatened by revolutionary methods descending on them like a blight from Mars. Some few of the more progressive and open-minded interests publicly announced that they proposed to organize a joint, private expedition in order that various technical advances described in Holt's radio messages might be studied in situ by their own experts. Lobbying flowered as never before and the representatives of both persuasions exerted gigantic efforts to win legislators to their points of view.

The debate raged for month after month until the Congress uttered its historic decision that cosmic isolation could be no more successful than terrestrial isolation had proven in the past. If Mars had developed an advanced situation, it would simply be the worst form of retardationism not to enter into full relations with the representatives of this civilization. The approval of the scheme contained very few reservations, carefully masked in some of the minor clauses.

In the meantime, Holt became aware that desire for a permanent relationship with Earthlings and their science and industry was anything but one-sided. Oraze's hopes that the "young heroes from Earth" would shake some of the Martian mentalities out of their lethargic channels of thought seemed to have been granted. A new spirit seemed to pervade them and to blow away the cobwebs from their rigid minds, revealing that there was another and a different world outside the pressure locks of their underground culture. They began to sense that in a free and open world with a free and open sky, simple human happiness might be more attainable than in their troglodytic existence of gadgets and tawdry ornamentation.

Holt telecast to the entire population a series of pictures and explanations of the technical advances of Earth, but the Martian engineers and chemists displayed little more than an extremely patronizing interest. Certainly the great liners plowing the seas were to them an amazing prehistoric manifestation and aroused their admiration, as did the skyscrapers of terrestrial cities, although it seemed to them somewhat illogical to build upwards when an underground structure could so easily be expanded indefinitely simply be digging and bracing another stope or tunnel.

Their disdain, however, of the primitive mechanical art which still drove wheels by diesel and turbine power was unbounded, and human mining methods seemed to them but little advanced beyond the Neanderthal man's scratching for minerals with a fire-hardened stick. They thought very little of a race which depended for its food upon surface agriculture and the breeding of edible animals. Their final conclusion, reached with many expressions of self-appreciative sympathy, was to the effect that they had little to learn from any fledgling civilization, as curious as it might be in its primitive way.

Other branches of Martian science adopted a radically different point of view, particularly those who saw in Holt's pictures much of value and interest, although not contributing to any immediate advancement of their planet. For them, Earth was a planet in the first flush of youth; a planet populated by people of natural intelligence who had mobilized all the mighty forces God had given His favorite creatures, men. And those forces varied from the farmer rooted on his land to the spacefarers plumbing the depths of the Heavens. On Earth, they might still see the plant and animal life which had long since been extinct upon their own planet. Fossil forms of life in a Martian museum could still be studied as it lived and breathed upon the sister planet. Martians knew that their globe had once rejoiced in mountains, seas, swamps and forests; their natural histories told them so with an abundance of colorful detail. But such phenomena were now as remote from their own days and times as the Pliocene era is to an Earthling of the 20th century. If they could study Earth in the flower of her development, well might they discover the source of that monotonous artificiality which was the bane of their own poverty-stricken planet.

The mainspring of any true scientist is curiosity, and the Martians were no exceptions. Holt wound that mainspring to its utmost limit and held before them an Olympic torch of truth-seeking from which they caught the fire of enthusiasm.

There were many factual discussions with Woolf, McRae, Bergmann, Ross and others, and no Martian ever departed without an aroused interest in an exchange of experiences. Societies in support of scientific cooperation with Earth grew like mushrooms. During the most bloody wars on Earth, scientists had always found a common denominator on which they could heartily concur and agree, irrespective of their national loyalties. Theirs was a community of soul in the search for the Truth in God's own nature, and it was now to extend its unifying bond across the vastnesses of space.

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Holt was overjoyed when the radio message containing Earth's decision to take up interplanetary relations with Mars reached him in the office he occupied in the Martian government lodgements around the deep, central plaza of Ahla. Without delay, he communicated to the President of the Martian Academy his desire to lay before the outstanding men of science of the planet an offer to have three of them accompany the expedition on its return to Earth. These men would be guests of the government of Earth for the duration of their stay and would be returned to the satellitic orbit around Mars at the next suitable apposition between the two planets and to their subterranean civilization by a landing boat carried by a cargo vessel to be built for the purpose.

A special session of the Martian Academy of Science was called to select from the huge number of candidates those who should be distinguished by making the voyage.

Election to, or even a call to speak before, the Academy of Science was the highest honor within the aspiration of any Martian scientist, for the significance of the Academy far exceeded that of a mere association of honorable graybeards distinguished in their chosen fields. The Academy was, in point of fact, a sort of General Staff of Research, set up with the perfected skill in organization which characterized Martian civilization. It organized and planned all-embracing and systematic campaigns against ignorance wherever found. It discovered breaches in the linked chain of knowledge and forged new links. It appointed liaison officers whenever it discovered that some advance in one branch of science might be of importance to another branch. It offered training to any scientist whose position at the forefront of research required that his work be correlated with the general welfare. When some new horizon was discovered in any field of knowledge, the Academy immediately proceeded to evaluate not only its practical application, but also the effects it might have on social, hygienic, psychological, economic or other circumstances. In its studies, the Academy was some fifty or one hundred years ahead of the present, and it planned the strategy of research accordingly.

Notwithstanding the regimentation and systematization of Martian scientific thought, the Martian Academy was fully aware that basic research must wither and die without freedom. It was the custom of centuries that the Academy should be apportioned some fifteen per cent of the public budget for research purposes. Oddly enough, this figure was astoundingly close to that devoted to armament by terrestrial nations before they settled their differences, even in piping times of peace. Much of this money went to research institutes and universities without strings as to its disbursement and without an accounting. All that was required of the beneficiaries was that they should report with the minimum of delay to the Academy any new discoveries made by them.

Ancient custom dictated that the President of the Martian Academy be a teacher of philosophy, the queen of spiritual sciences. The high esteem in which the Academy was held was reflected in that its President ranked, together with the Senior Justice of the Supreme Court, immediately behind the Elon, despite the general lack of social distinctions throughout the planet. Even the cabinet officers occupied the next lower rung of the social ladder.

Ansanto, the "Sage of Laroni," was president of the Martian Academy of Science when Holt's epic-making proposal was submitted for deliberation. As presiding officer, it was he who introduced the subject in the presence of Holt and the scientific leaders and officers of the expedition. He appealed to the Academy to draw inspiration from the Earthlings' splendid interplanetary pioneering. He adjured them to pursue without hesitancy or vacillation the path of cosmic cooperation thus courageously opened.

"Life below ground, to which our aging planet has condemned us," said he, "has made us forget that another and a greater world lies without the hermetic capsule wherein we perforce must live.

"Until our Earthling friends and brethren came to us through the airless reaches of the solar system, we were in danger of entirely forgetting that there is a heaven wherein God guides the courses of the stars of His creation. We awoke to the joyous discovery that we are not alone in the infinite ocean of the stars. We rejoice that our kindred from across space think, feel, hope and believe as we do.

For eons we have sought the answer to the final question, the great, hitherto insoluble question of the purpose of the cosmic creation – why did God make the magnificent machinery of the universe? To this day, our natural scientists have stood perplexed but gripped in the fascination of its endless complexities and bemused by the infinity of its riddles. Our Earthling companions have brought us the answer: it is Life! Joyful, pulsating Life, everlastingly sustained by the two divine urges, Love and Hunger!

We may well still wish to know what is the purpose of this life, and to that question, too, they have brought us an answer full and complete: it is the quest of perfection! In this quest, life has evolved from the amoeba to the thinking, sentiment being, following the dictates of the conscience with which God in His own good time endowed it, so that it might seek Him and strive for His perfection in the full knowledge that never can it fully be attained.

The inspiration of your cosmos-shaking journey, my Earthling brothers, cannot have been that of a purely technical experiment, despite the magnificence of its conception. You have come to us on a mission whose ultimate object was planned by God Himself, for it is you who have brought together the germ plasms of rational creation in our solar system that they may thrive and grow into a higher and more noble organism, which shall envelope the depths of space. In no other manner than by the joining of individual cells did the higher forms of life evolve at the beginnings of time!

Let no man here, whether Earthling or Martian," cried Ansanto prophetically, "misapprehend the significance of this mission! Let us follow in the path it so clearly defines for us, and may the generations which shall come after us never deviate! Then, and then only, may we be assured that we have seen God's plans and aims, and that we follow His Holy Will towards His cosmic ends."

Chapter 30
The Sage of Laroni

The Sage of Laroni's speech in no way failed of its effect upon the highly intelligent and basically religious members of the Martian Academy of Science. Three prominent and able men from among their number were appointed to make the voyage which Holt scheduled to begin by a launching of the two landing boats, some two weeks before the expiration of the 449 day long "waiting time." He had no intention of allowing any last-minute difficulty to prevent him and his men from being snugly ensconced in their space ships when the crucial hour of departure from the Martian orbit should arrive. To miss that figurative split second by reason of some minor malfunction would mean the loss of the expedition by exhaustion of food and oxygen in the orbit. Nor could refuge be taken on the friendly Red Planet, for the landing boats no longer had the wings necessary for the descent.

With the entire expedition gathered in the seven passenger vessels for a solid two weeks prior to the final departure from the orbit, Wiegand would have ample time for a thorough inspection of the equipment, so that the months of the return trip would be begun with every possible assurance of mechanical perfection. Tom Knight's reports from the orbit showed that there had been no serious damage nor malfunctions in the waiting vessels, for he had been able to carry out all running repairs with the supplies at hand. Holt, however, proposed to run no chances. The damage to Nordenskjold's landing boat caused by the stuck nose wheel had proved once again the importance of keeping everything in apple pie order. Failing this, the whole expedition might be endangered, with incalculable loss not only to Earth, but perhaps to a universe into which man had just taken his first, faltering steps.

Most of John Wiegand's time on the Red Planet had been devoted to the repair of *Goddard*'s landing boat. With the generous assistance of the Martian authorities, he had dismounted the necessary parts from *Oberth*'s boat in the snowy south polar region and transported them to the landing strip near Suguli. Here the damaged craft was staked down alongside her sister ship from *Ziolkowsky*. Wiegand even found a small machine shop near Suguli where he fabricated some of the material needed.

As soon as the repairs were completed, Wiegand and Hempstead's detachment busied themselves with task of removing the great wings from the landing boats. The next step was to set the huge, torpedo-like hulls erect upon the steel launching tables which had formed part of their cargo. Their sections were bolted together and mounted on the wheels destined for them. Then began the actual process of erection, a by no means simple matter on which Wiegand had spent much time before departure from Earth.

The tail of the still horizontal boat was first jacked up sufficiently so that the table on its wheels could be pushed under it. Then the wheels of the table were removed and it was lowered to the ground and the stern of the boat was let down upon it. During the procedure, two protrusions on the empennage rested on two bearings of the table, forming a sort of hinge around which the boat's hull would rotate when brought from the horizontal to the vertical. The table was then firmly staked to the ground.

The next step was to erect upon the top of the still horizontal hull a vertical strut over which passed a steel cable fastened to the nose of the vessel and extending out over the stern where it was attached to one of the caterpillars, standing stern to stern with the still recumbent landing boat. When the caterpillar wound in the cable on its winch, the huge hull began to rise, turning about the hinge joint of the launching table. Another cable from the nose led to a second caterpillar stationed forward of the boat. The second cable was slacked as the first one was wound in, thus avoiding a sudden, jarring adoption of the vertical position after the point of neutral equilibrium had passed as the boat approached the vertical.

The principle employed in this delicate operation was simple and by no means new. It somewhat resembled the method applied to the erection of telegraph poles. The landing boat hulls, however, were easily damaged, so that a high degree of skill and experience in handling heavy and bulky equipment was essential.

With the boats safely in their launching positions and secured against the treacherous Martian windstorms by wire guys, John Wiegand applied to them his most rigid inspection technique. A few minor parts were found defective and these he replaced from stock. Ten days before the date of departure, he reported to Holt that both boats were in complete readiness to ascend to the orbit, where Tom Knight awaited the crews and their Martian guests, and where the wingless boat hulls would circle forevermore as manmade satellites of Mars.

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It was the last evening Holt was to pass in the pressurized passages of the Red Planet. He esteemed it a great honor to be the guest of Ansanto, the Sage of Laroni, where the Dean of Martian scientists dwelt in company with many artists, writers and philosophers of the planet. The little town exhibited distinct differences from the larger cities such as Ahla and Suguli, for the liberal attitudes of its inhabitants reflected themselves in vagaries of taste and decoration beyond the scope of more conventional Martians. Laroni lay beneath the verdant moss of Lacus Lunse.

Ansanto was by no means limited to the scientific aspect of his proud position in the Academy, and it was as much over the cultural phases of the evening that Holt rejoiced as over the more familiar scientific and technical ones. Ansanto's vast historical and philosophical studies had given him a perspective extending over truly cosmic ages of Martian development.

When they sat down together after a simple but satisfying meal, Ansanto urged Holt to talk about the recent war on Earth, for he himself had never experienced such a cataclysm and greatly desired to complete the impressions he had derived from Martian history by a first-hand, vivid report.

Holt launched into a description of the titanic struggle between the Western and the Eastern powers and told how a unified goyernment had eventually resulted, but that the cruelties of the conflict had brought terrestrial mankind so close to the abyss of universal cultural suicide that the damage could hardly be repaired in less than several centuries. He spoke of the desperation of those horrible years and of the misfortunes with which technology had flooded mankind instead of with her highly touted blessings. Nor did he neglect the increasingly frequent and insistent warnings of the many Earthling thinkers who proclaimed that technology bore an eternal curse and that naught but a return to a simple bucolic existence of self-determination could preserve humanity from utter self-destruction.

Ansanto listened silently for a long time until Holt finished.

"There can," said he, "be no turning back for any civilization which has once pinned its faith to the advance of technology. Any such turning back would conjure up such a terrible economic and social crises as to reduce the civilization itself to wrack and ruin.

"Nor is there any inner justification or rightness whatsoever in turning back. Man is responsible for the dangers and unbalance of technology, not technology itself.

"During one of your lectures, so greatly appreciated by our students of history, you recounted how all the ancient cultures of Earth were based on slavery. You expressed amazement that the great thinkers of those ages found nothing objectionable therein. I, for one, am no whit amazed, for our own earlier cultures were likewise based upon slavery. Every culture is an organism, analogous to a plant unable to flower towards the light if the roots, the source of strength, do not dig into the soil.

"Subjugation of the forces of nature by technology is the only means offered us by God whereby we may strip off the curse of slavery. By this means only can we create a social system where each and every man may unfurl his capabilities to the breeze of freedom rather than permit a chosen few to blossom and bloom while supported by the weary shoulders of the multitude.

Here on our venerable and weary planet we have moved far ahead of your youthful Earth towards the manumission of our slaves by technology. The difficulties you are presently encountering have a familiar ring in the ears of Martian historians, for we too have suffered them. But you may be assured that you also will master those difficulties, not, of course, without paying a certain price for the freedom thus achieved. This price in part will consist in the leveling of consumer goods which is followed by a general leveling of tastes, modes, and even of human attitudes. These inevitable concomitants of the technical age affect sensitive souls as does cruel tyranny. It is the luxuriant glory of jungle flowers being transmuted into an orderly garden where each plant is assigned its place in accordance with its size, its color and its form. No longer is it privileged to grow according to its own sweet will. To me, the manumission of humanity is well worth the price."

"Tell me, my friend," Holt said after a pause, "what you believe to be the main obstructions to making technology operate for the benefit of mankind rather than to its destruction?"

Ansanto smiled. "I will try to formulate it for you. Technology is by nature dynamic, while political order, created by man for orderly social living, is fundamentally static. Continually renewed conflict arises between the static social order, unable as it is to grow with dynamically progressing demands, and the technical advances which create the latter. A new invention is capable of changing the basis of many lives to a far greater extent than any novel social or political concept. The explosions which have plagued your planet during the last few decades cannot, in the last analysis, have been caused merely by clashes between opposing political ideologies. The fact is that limited and sovereign states cannot live next to one another on the same planet, once technology has attained a certain definite advancement. You may be very sure that technology was the real architect of your present government of Earth and that your politicians were only subordinate artisans.

As technical developments progress, political conflict becomes increasingly destructive. This is not simply accounted for by the increased effectiveness of the weapons employed; no less important is the inevitable increase of governmental authority and bureaucracy, which supervenes to direct the complicated social order brought by more mechanization in living. The personal responsibility of political leaders becomes infinite with such advances in mechanization."

"On a smaller scale," chuckled Holt, "I can drive a buggy along a country road with a few drinks too many under my belt, and nobody gets hurt. But if I drive a high-powered car on a highway in the same condition, those drinks may be fatal, not only to me, but to others."

"I've never seen a motor car," answered Ansanto, "but we still have humor on Mars, even without cars; and your amusing analogy goes to the root of the matter. Ethical progress must keep up with technical progress. But ethics wither and die without self-control and without humility and religion."

"Do you believe," Holt asked, "that increasing scientific insight undermines religions belief? Back on Earth, I know so many who seem convinced that they know and no longer need believe. Here too, I have encountered not a few of the same turn of mind."

Ansanto smiled tolerantly. "When I was a young student," he remarked, "I thought myself very wise indeed. Natural science was my passion, and to some extent it still is. The universe seemed to me to be a relatively simple, if rather large mechanism, whose laws of operation I thought I understood quite well. As our technicians applied identical laws to their own purposes with ever-increasing success, I became more and more convinced that it was idle to seek a transcendental director of fate behind the transparent cosmic machinery. To me, there could be no God, except as identified with the laws of nature.

"As time went on and I matured, I began to realize the blank areas in our picture of the universe. What I had previously seen as a wide expanse of beautifully clear perceptions began to be choked in the underbrush of vague attempts at explaining the unexplainable. Slogans and catchwords covered the thickets which the spirit could not penetrate. The simplest things no longer could withstand critical scrutiny. Consider the concept of infinity, which is no more comprehensible than its opposite, finiteness. What is behind either or both these concepts? Or consider the mutual relationship between matter and energy. We know and can use the formulae, and their potency serves us in our atomic power plants. The inner secret of their mechanisms will, however, remain a sealed book for all eternity. What of the miracle of heredity? By what mysteries does a great-grandchild carry some touching trait of his forebear? Are we not deluding ourselves if we pretend to explain such mysteries on a scientific basis?

"A period of profound depression followed my youthful exuberance over our scientific achievements. The fundamentals of my cosmic beliefs were profoundly shaken. I lost myself amid the distances of the theory of cognition, where I vainly sought to delimit the capacity of our minds to solve these problems. I sought the key to the ultimate revelations in the history of our planet and in the lives of our great men.

"And it was here that the genius of great thinkers and inspired artists pointed the path out of desperation. For I sought for some law which should direct the hearts of these men. Was there, I asked myself, some equation working in their minds as they advanced beyond the frontiers of knowledge, or created immortal music or paintings? But there was no regularity, nothing resembling our so-called laws of nature behind their genius. By no repetitive series of experiments could a mathematical causal relationship be established. Inspiration put into effect the will of God Himself through the thoughts and deeds of these men. There could only be one answer: it was God, acting through His creatures.

"It was a soul-satisfying illumination of my spiritual darkness to find the transcendental deity manifesting Himself in the creativeness of the spiritual and artistic great. My discovery convinced me that whatsoever is good and desirable is sired by the holy search for perfection and dammed by the receptivity of humility.

"That the majority in their search for truth do not go beyond the material is the greatest of human tragedies. Our schools crowd the minds of our children with knowledge which intoxicates them, perhaps broadening their horizons, notwithstanding. At the gates of the mysteries our schools balk. 'We cannot teach what we do not know' is the slogan. Thus our youth is deprived of humility, their most valuable dowry for the future.

"As an example, the schools enlighten the children at a tender age as to the physiological and medical aspects of sex. It is claimed that such biological enlightenment protects and strengthens the morality of youth. Not a word is said to them of the ethical aspects of love, nor of any factor which might awaken in those children respect for the divine mysteries of propagation of the race, and of birth.

"No, I say. As medical lectures on sex cannot promote morality, scientific enlightenment cannot promote ethics. Rather, is the reverse true, for each scientific advance brings the danger of blasphemous self-glorification. The most important and never-ending social task of our churches is to keep awake humility for the curbing of overweening pride in our knowledge and accomplishments.

"We may learn from the history of our planet that idolatry of our own deeds and achievements is the greatest, most dangerous blight with which humanity threatens both itself and its civilization. It renders mankind completely sterile in the face of the challenge of the future. If scientific achievement be deified, humility suffers, and there can be no further true science without her mother, humility. If mankind worships ideology, symbols, or its own history, it forfeits the ability to adapt the structure of the state to the demands of technological advancement.

"God, and God alone must be worshipped, if man would complete his mission in this world. He cannot overcome his pride of accomplishment except by his humility before the Deity. Such humility, however, frees him to adapt to the constantly varying demands of the future and fits him to better the inheritance of his forefathers and such of his own works as require betterment. Thus man may achieve submission to God's will by recognizing the imperfections of the present, and develop a will of his own to follow God's way as it opens before him.

"Thus, and not otherwise, can he create the basic ethic which must bear up technology and transmute her dangers into benefits for mankind."

Chapter 31
Immortal Man

The launching of the now wingless landing boats was a major event in Martial scientific and cultural circles. Towering on the launching platforms, the boats were miniatures of the massive *Sirius* vessels, ready to ascend from Earth on their voyages to the orbit. A large number of Martians witnessed the unprecedented spectacle. When all was in readiness, Holt led his little group to their respective landing boats and then, clad in his space suit, marched slowly around the circle of observers who were seated in the great pressurized vehicles which several Martian irrigation companies had furnished for the great event. Holt placed his hand upon his heart in the Martian farewell, then mounted to the cabin of *Goddard*'s boat. The door closed and a few minutes later the two boats shot upwards a few seconds apart. As the condensation trails gradually dissolved in the thin atmosphere, the huge land vehicles rattled to the concrete airlocks through which the Martians would return to the galleries of their pressurized world.

The Earthlings were on the first stage of their journey home.

No incident disturbed the climb to the orbit, where the interplanetary ships awaited the boats. When the short maneuver of adaptation terminated, Holt's party and their three Martian guests beheld through their circular ports the clumsy structures hanging without apparent motion against the black heavens. To the three Martians, the sight was so moving that they could hardly be dragged from their windows. Almost reluctantly they entered the busy bees which came to transfer the landing party and the various gifts and souvenirs to the passenger ships for the long drift to Earth. Finally, the remnants of propellants unused by the landing boats were emptied into the reserve tanks of the returning vessels.

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"X minus 1 minute," resounded from the bull horns.

Holt, from his acceleration couch in *Polaris*' pilot's cabin, viewed the six echeloned passenger ships in front of him. The final test had come. Would the complicated mechanisms still function to a fraction of a second? Had the crews properly maintained them despite the psychic load to which they had so long been subject? Could, perhaps, this at long last have frustrated John Wiegand's tireless insistence upon perfection? Within 60 short seconds, he would know – perhaps the last knowledge he would ever acquire…

"X minus 30 seconds."

Copilot and engineer rapidly scanned the complicated instrument panels, nodding approvingly, yet gravely. The rising pitch of the direction gyros rose above the monotonous rustle of the respiration blowers.

"X minus 20 seconds."

The tenseness of the moment reflected itself in the exchanged glances of the three men…

"X minus 10 - 9 – 8 – 7 – 6 – 5 – 4 –"

"Number 6 prestage light's missing!" Hal Royer's voice roared through the bullhorn. The navigator had been checking the warning lights of the squadron from the navigation room. Hardly had the words left his mouth than the main stage of *Polaris* ignited, as simultaneous streams of fire shot from the rocket motors of all ships except Holt's immediate leader, *Regulus*.

"*Regulus*, report!" shouted Holt into his microphone.

The answer came in a thunderous bang in the intercom and a blinding flash from *Regulus*' rocket motor, where there should have been a steady jet of smooth flame.

Holt flicked the emergency cutoff switch and *Polaris*' jet collapsed into silence. Quietly, the commander spoke into the microphone.

"*Polaris* to *Vega*. Take over expedition command. Proceed as planned. *Polaris* will stand by to help *Regulus*."

He gazed at the five rocket jets receding into the vastnesses of space as Knight's voice answered, "Roger. Wilco. God keep you. Over. Out."

With a word to the copilot to return *Polaris* to her original position relative to *Regulus*, Holt moved down the central shaft of *Polaris*' nacelle and entered the airlock leading to the busy bee. He went forth to assess the extent of the damage and to bring what help he could.

As the bee approached the damaged vessel, Holt saw the after flames of the explosion fade and die at the stern of *Regulus*. He knew from this that the propellant control valves had not suffered and had shut off the flow. The great cylindrical rocket motor itself, however, was completely shattered, together with its tubing, wiring, and other accessories.

He steered his bee into the guide rails of *Regulus*' nacelle and was greeted by her commander's plump face grinning a bit shamefacedly through the port. Major Freddy Duncan was a calm soul and far less subject to edgy nerves than some of his fellow commanders. With the knowledge that the latter were receding into the distance at many miles per second, Holt rejoiced in his confidence in Duncan's stability. The airlock opened and the visitor entered a bluish haze and heard the hissing of escaping air.

"Splinter punctures?" he asked calmly.

"A few," answered Duncan imperturbably, "but they're all located and we'll have them plugged pronto."

"Anybody hurt?"

"Poor Nordenskjold got a splinter in his right thigh, which smashed his femur. He lost a lot of blood. Our medic's working on him now."

"I hope he's up to the job! Barrett's over a thousand miles away in space by now and we can't call him back!"

Duncan rubbed his cheek. "He's a good boy, but this looks like a large order for his amount of medical training, Colonel. Haven't you got a Martian in *Polaris* who's supposed to be a surgical whiz?"

"We'll get Svetla on the intercom and see if he can help," said Holt. "In the meantime, let's see how Trygve's feeling..."

Nordenskjold was strapped to the bunk in the captain's cabin, his upper right leg swathed in bandages. As Holt pulled himself into the tiny space Nordenskjold smiled wanly.

"It seems that I'm always making trouble for you, Colonel," he said.

"Don't worry about that, son," answered Holt. "We'll get you out of this all right. You're needed back on Earth, you know. Not every pilot can make good landings without nose wheels..."

He patted the youth's shoulder, then sent for Royer, the navigator, and retired to the pilot's compartment with him and the captain of *Regulus*.

Duncan looked quizzically at his commander. "Colonel," he said, "it seems as though we've missed the bus. If we try to install a propulsion system from one of those cargo vessels still floating out there, it will take so long that Earth will be way past the point on her orbit where our voyaging ellipse intercepts it. You can't take us down and introduce us to your friends on Mars because you forgot to bring the wings back with the landing boats. It looks as though we were in the permanent Martian satellite business."

With a smile at Duncan's imperturbable humor, Holt answered, "We can't repair *Regulus*, but there's still a chance. The mathematical planning section and their electronic brains figure out a solution for just this kind of situation. We'll take a set of tanks from one of the cargo vessels, attach them to *Polaris*, and fill them with what's left of your *Regulus* propellants. That will give us a velocity reserve permitting *Polaris* to make a faster trip back to Earth, even with your *Regulus* crew aboard. Of course, we'll be down to a bare minimum of food and essentials. Royer, how does it look from the figure standpoint?"

The navigator studies his tables. "There's no time to be lost," said he. "We'll have to be on our way in not more than 104 hours. That's just a little more than four days. If we can tank up with *Regulus*' full supply, we can pick a returning ellipse which will have a perihelion at a distance of 140 million kilometers from the Sun. That is about nine million kilometers less than the distance of Earth's orbit from the Sun, and this ellipse will intersect Earth's orbit at an angle of 8 degrees and 40 seconds after a voyaging time of 233 days. Fortunately, the Earth will be at that intersection at that time. But if we are to enter such an ellipse, we shall have to give our ship a velocity change of 2.275 kilometers per second when we leave the Martian orbit, as compared to only 2.01 kilometers per second for the other five ships. And when we attempt to reenter our former departure orbit around the Earth, we'll need a velocity change of 4.28 kilometers per second instead of the 3.31 called for by the original calculations. What with the crew of *Regulus* and the necessary oxygen, food and water, *Polaris*' load will be increased by 19 tons, and with *Regulus*' propellants, we'll just be able to make it along the ellipse of which I've spoken. If we add our four days to the 233 days, we can be back near Earth 213 days from now, while the other ships will need 260 days. We can be home 47 days before them, if all goes well."

The four days of grace were hectic and the three available busy bees worked constantly, even through the hours of darkness, when the great mass of Mars shielded the workers from the light and heat-giving rays of the Sun. The three cargo vessels which had been stripped of their landing boats still hung near the lonely Earthlings as they whirled around Mars, and Holt selected the four empty tanks still attached to *Goddard* as those to be used. They were first towed to *Regulus* and temporarily suspended from her structure in order to facilitate their filling with the available propellants. *Regulus* had lost 32 tons through the rips caused by the explosion of her rocket motor, so that only 326 tons were still available for *Polaris*' desperate venture.

The next problem was to bring the partially filled tanks over to *Polaris* and to attach them properly. Each of the four was filled to only two-thirds of its capacity, so that it was necessary to top them off with helium under slight pressure in order to distend and facilitate handling. With a busy bee at each tank header, the unwieldy shapes were carefully towed to a position close to *Polaris*, from which all hands in pressure suits gently inched them into position and bolted their suspension nets to the cruciform tank supports.

When the tanks were attached, the crews connected the aspiration tubes leading to the propellant pumps, and the pressurizing lines. Finally, they adjusted the temperature control blinds and the liquidometers. The last beeloads of food and supplies were loaded into *Polaris*, the final checks and tests were made, and the engineer reported to Holt that they could depart a scant five hours before the elapse of the critical 104 hour period.

Oberth's High-Duty radio station still swam near them in the velvet darkness, and Holt had kept it manned and in communication with the distant convoy, so that both the departing crews and Earth itself might be kept informed of the desperate struggle for preservation.

The last message announced that *Polaris*' rocket motor would be started within the hour, and that the laggards would enter a satellite orbit around Earth in 209 days. Until then – silence, for the High-Duty station must be left circling in the Martian orbit along with the remnants of the landing boats and cargo vessels.

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Holt touched the prestage ignition switch and waited tensely. A few seconds later the main jet roared its deep-throated song of power. A silent prayer of thanksgiving rose to the lips of all in the crowded nacelle as they felt the familiar thrust. Svetla, their Martian guest and fellow traveler, relayed their belated farewells to his home planet and assured them that Mars, no less than Earth, accompanied them in prayer. Tired but hopeful, they settled themselves against the weary, weightless coast through space.

There were now none of the amenities which had mitigated the hardships of the outward journey, for neither Earth nor Mars radio programs could be received, nor were there any movies or intership visits to break the monotony. The most careful movement through the weightless spaces of *Polaris*' nacelle brought collisions with sleeping men suspended between the bulkheads or with someone attempting to beguile the time in desultory conversation with a listless neighbor. The tiny library's short stock of books were read and reread so often that the only exercise for the mind was to learn some classic by heart. The only physical exercise was that provided by a venerable spring-exerciser, for Holt had been forced to abandon *Polaris*' gravity cell.

The forty-second day of their lonesome voyage saw Nordenskjold in a sinking condition. Three days before, the ship's medic and Svetla, the Martian, had been compelled to amputate the injured leg. Svetla performed the operation and Holt acted as anesthetist; but the youth failed to rally. He died in Holt's arms.

Holt moved from the sickbay into the crowded living space and called for silence, after closing the oval door upon all that remained of the intrepid pilot.

"Men of *Polaris*, he said quietly, "our friend, Trygve Nordenskjold, has left us forever. Many of you owe your lives to his skill and coolness on that unforgettable day when he set down *Goddard*' damaged boat without injury to a man. None of us can ever forget what a man he was, either on our home planet, through the long reaches of the sky, or in the hospitable underground galleries of Mars.

Nordenskjold was a true Viking of the Heavens, and we shall give him a Viking's burial in the infinite vastness of space, a burial not unlike those which honored his knightly forebears upon the wide and stormy ocean. At 0400 tomorrow, our last remaining busy bee will be launched into space, never to return. In it will rest all that is mortal of Trygve Nordenskjold. When you hear the call, 'All hands to bury the dead,' let each man send a heartfelt prayer out into space with our departed comrade."

With reverent hands, the remains of the dead hero were strapped into the pilot's seat of the bee as it lay moored before the airlock. A strong spring was attached to the throttle, which was held closed by an explosive bolt. The latter was connected by a cable with an electrical socket outside the nacelle. As the clock struck four, Holt raised the microphone to his lips. "All hands to bury the dead," he said hoarsely. "Since it has pleased God in his almighty wisdom to take from this space ship the soul of our true comrade and brother, we now commit his body to the depths of space..." With the final word he touched the switch under his hand. There was a flash of blue-green flame outside the stern ports and the dead pilot sped forth into eternity, impelled by a fiery jet which, in an atomic and interstellar age, still was symbolic of the floating pyres in which his Viking ancestors had journeyed to Valhalla.

In the Administration Building on Christmas Island, Catherine Holt and General Braden sat amid wreaths of stale cigarette smoke and between piles of burnt-out stubs.

Polaris had been overdue for three nights, and neither man nor woman had closed an eye for twenty four hours.

Had the ship's maneuver of departure failed, so that she was still circling Mars, unable to descend to its hospitable surface and hopelessly exhausting the last supplies of nourishment and oxygen? Could some mischance have carried the bold vessel into the path of some big meteor, unlikely though this contingency was? Countless possibilities of disaster existed, particularly for a space ship alone amid the vastnesses of space. A navigation error might have swept the solitary craft far from her home planet. Perhaps *Polaris* had missed her meeting with Earth, or failed to develop the thrust required to convert her voyaging ellipse to a satellite path around her home planet… None could tell.

Lunetta had been alerted for several days. Her radio stations were continuously manned in the hope that their directive searching antennae might pick up some weak signal from *Polaris*' feeble transmitter. The convoy itself regularly sent in Knight's bi-hourly reports, but as to *Polaris*, all was silence.

The tropic dawn began to spread over the island. Catherine Holt slept the sleep of exhaustion with her head on the conference table, while Braden was just about to ignite his fiftieth or sixtieth cigarette. Suddenly, a high-pitched buzzing split the silence. Braden snatched the telephone.

"Braden speaking."

"Report for you, sir, from Central Radio, Christmas."

"Go ahead, damn it! What are you waiting for?"

"Lunetta's observatory reports blinker signals apparently reading, 'SOS, Polaris.' Lunetta reports blinker signals apparently from a satellite orbit considerably distant from, but encircling Earth. Is now attempting to get its coordinates."

"Hold everything," said Braden, "I'll be in your station in a jiffy…"

Catherine awakened and gazed anxiously at the general, who returned her look half quizzically, although tears rolled down his lean cheeks.

"It's Gary." He said. "Seems he's bored because we haven't come to drag him out of his orbit and wants to put in a kick about it…"

Two hours later, *Astroliner*, with Braden and his staff on board, was underway to the departure orbit, where her top stage was retanked from a reserve held there for just such a contingency. Picking up two busy bees, the great space ship again started her rocket motor and entered upon an extended ellipse leading further into space. This ellipse was computed so that its apogee might contact the distant satellite orbit now followed by *Polaris* and determined by Lunetta's observatory. Arrived at apogee, *Astroliner* carried out a short maneuver of adaptation to the local orbital velocity.

Her crew soon beheld *Polaris*, a scant ten miles distant. She was reduced to a skeleton by the absence of the great spherical tanks and was hardly recognizable, but reassuring blinker signals conveyed the welcome news that there was life aboard.

Braden hastened into one of the busy bees picked up by *Astroliner* in the orbit of departure and fairly hurled himself across the intervening distance. Within twenty minutes of sighting the lost space ship, he entered her airlock and ordered her exhausted occupants to prepare to disembark into the busy bees which now shuttled excitedly between the two space vessels.

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The radioed report that *Astroliner* was alongside the lone *Polaris* brought not only Catherine Holt, but a swarm of reporters, workers, and relatives of the long-lost spacefarers to the great landing strip of Christmas Island, and soon the flagship of the Space Forces could be seen making her calculated approach over the runway markers. Her wheels already in rapid motion, she touched down and slowed to a dignified stop alongside the tractor which hauled the massive vessel with her raking wings to the Terminal Building. The door in the ship's nose was thrown open and in it appeared a bent, gray-haired figure supported on either side by Braden and his Chief of Staff. It was Gary Holt.

Tenderly, the general and his companion half led, half carried him to one of the nineteen litters which had been hurried to *Astroliner*' exit gangway. With a sign of complete exhaustion, and breathing heavily, Gary Holt lay motionless as Catherine enfolded him in her arms, covering his face with tears and begging him to answer her caresses.

"Darling, all I've wanted was you, and now I have you, I find I need weightlessness to do more than look at you! It seems impossible now that during most of my life, such a pressure as I now feel has oppressed me..."

A rapid health check at the Station Hospital revealed that the weakness of Holt and his companions was of a nature which only time and slow, careful exercise of the muscular faculties could cure. The doctors in each case decided that home influences would soonest overcome the psychic handicaps imposed upon their patients' mental and spiritual functionings. Oddly enough, Svetla, the Martian, had withstood the ordeal with less disturbance than his Earthling companions. This was attributed to his lifetime having been passed under weaker gravity conditions than they, as well as to the enormous inner resources of his highly developed brain and spirit. The notes he had made of his observations of the actions and behavior of his companions were for many months thereafter a fruitful source of psychological data concerning maturity coefficients as affected by the most stressful conditions.

Gary Holt, in the capacious quarters occupied by Braden, began towards evening to recover his spirits and energies enough to relate to Catherine some of the details of the journey of his lone ship back towards her home planet.

As they coasted through the solar system, it had become apparent to the navigator, Royer, that the original track had not been followed with sufficient accuracy to bring them to their vital goal. Three corrective maneuvers had been necessary, largely straining their scanty reserves of propellants. When it came to the maneuver of adaptation to the Earth orbit, it had been essential to jettison everything not absolutely necessary to sustain life within the desperate *Polaris*. This had included much food, books, instruments, pressure suits, water, radio equipment, and even much of reserve oxygen supply. Even then, they lacked enough propellant to put them back into the bi-hourly orbit around Earth, which had so ideally served for the departure. They had to choose the cheapest maneuver possible and this proved to be an entry into a satellite orbit some 30,000 kilometers distant. The velocity change required for this maneuver was some 500 meters per second lower than that which would have put her into the original orbit of departure. With radio equipment jettisoned, *Polaris*' despairing crew was reduced to employing their solar reflector, ordinarily used for electric current generation, as a heliograph. It had been largely a matter of luck that Lunetta had intercepted the blinker signals. The most dreadful hours of his life, Gary said, were the three days they had spent on reduced rations and with their oxygen supply dwindling while they circled helplessly the home planet for which they longed so intensely.

Gradually recovering his energies under his wife's tender ministrations, Holt stubbornly resisted all reporters and other influences which would have beguiled him from the restful solitude of Christmas Island until Knight and his five Mars vessels reentered the orbit from which *Sirius* rockets would ferry their crews and Martian guests back to the base. For Catherine, the 43 restful days were all too short, although much of the time, her husband's thoughts remained with the space crews in their lonely nacelles. When, a day or so before the increasingly strong radio signals from Knight's squadron set the exact day and hour of their entrance into the orbit, four *Sirius* ships climbed aloft for the joyous task of picking up the spacefarers, Holt's strength of both body and spirit had so far returned that he insisted upon a last voyage with one of the vessels into the outer marches of Earth's gravitational influence and to bid a final adieu to the interstellar void which had been the fateful arbiter of his life. With his own eyes, he witnessed Knight's five Mars ships sweep into their Earth orbit in a neat squadron maneuver of about a minute's duration.

No sooner did the busy bees from the four *Sirius* vessels snap into the guide rails of the returning squadron than busy and enthusiastic hands loaded the various Martian mementos into them. Immediately thereafter, and with their two Martian guests in the lead, the homesick but cheerful men were urging the captains of the ferries to make all haste to the Christmas Island landing strip.

Once aground, ovation after ovation, celebration after celebration was their log. Soon Holt was on the road with his Martian passengers, but as the wife of a VIP, Katy was urged to taste his triumph with him, and uncomplainingly and gaily did so.

Triumphal entry after triumphal entry to towns and cities, banquet after banquet overwhelmed Braden, Spencer, Holt, and their companions.

It was during one of the more festive of the banquets that it happened.

Spencer, cigar in hand, had just responded to the conventional toast to the future of interplanetary commerce. He slumped, rather than seated himself. His bald skull fell forward upon the table. The last of his villainous cigars dropped from his failing fingers, for the fighting heart which had borne him through the interplanetary battle had stopped. The spark was extinguished which had lit the fire of enthusiasm for space travel more than a generation ago.

A few days later, Spencer was buried in the National Cemetery at Arlington. Holt stood with Catherine beside the open grave, his now grizzled locks shaken by the Autumn wind. Again he paid a tribute to a coworker in space, this time to the man who had also been a paternal friend: "Bruce Spencer's restless spirit and his life of combat opened the reaches of Heaven to mankind. It was he who forged those wondrous tools which bore us safely among the stars. It was his vision which opened our eyes to life in the universe.

"His restless spirit has now returned to the God who inspired Bruce Spencer's creations.

"His ships will sail on through space and their bridge with our outer brethren will become strong and great. A new community of fate will overcome space and we and our outer brethren will become one.

"Bruce Spencer's ships carried us safely to the Moon's dead landscapes, where we saw a heavenly body which cannot support life. They bore us to the fervid culture of Mars, where we learned the full capabilities of man to survive when his planet ages and he can no longer enjoy a life in nature. There we saw the declining glory of a setting civilization.

"Eons from today, Bruce Spencer's ships will carry our descendants from an aging Earth, no longer capable of sheltering them, to a young, new home star where they may found a new future.

"His immortal creations will have given mortal man an immortal future."

THE END

SCIENTIFIC APPENDIX

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A. THE *SIRIUS* VESSELS

1. Summary of Principal Data

Table I: Principal Data – First Stage

	Symbol	Eng. Units	Physical Units
Thrust (at expansion to ambient pressure $P_a = P_{e,I}$)	F_I	12,800 t	$12.8 \cdot 10^9$ g
Take-off weight	$W_{0,I}$	6,400 t	$6.4 \cdot 10^9$ g
Empty weight of booster 1 ·	$W_{E,I}$	700 t	$0.7 \cdot 10^9$ g
Final weight (booster 1 empty, stages 2 and 3 full)	$W_{1,I}$	1,600 t	$1.6 \cdot 10^9$ g
Weight ratio	E_I	4	4
Propellants booster 1	$W_{p,I}$	4,800 t	$4.8 \cdot 10^9$ g
Rate of propellant consumption	$\dot{W}_{p,I}$	55,808 t/sec	$55.808 \cdot 10^6$ g/sec
Exhaust velocity	$U_{e,I}$	7,400 ft/sec	$2.250 \cdot 10^5$ cm^2
Nozzle exit pressure	$P_{e,I}$	9.96 psi	700 g/cm^2
Nozzle exit area	$A_{e,I}$	2,418 sq ft	$2.240 \cdot 10^3$ cm^2
Initial acceleration (absolute)	$A_{0,I}$	61.2 ft/sec^2	$18.64 \cdot 10^2$ cm/sec^2
Take-off acceleration (relative)	$A_{0',I}$	29 ft/sec^2	$8.83 \cdot 10^2$ cm/sec^2
Final acceleration (absolute)	$a_{1,I}$	286 ft/sec^2	$87.0 \cdot 10^2$ cm/sec^2
Burning time	T_I	84 sec	84 sec
Altitude at cut-off	Y_I	24.9 mi	$40 \cdot 10^5$ cm
Velocity at cut-off	V_I	1.46 mi/sec	$2.35 \cdot 10^5$ cm/sec
Horizontal distance at cut-off	X_I	31.1 mi	$50 \cdot 10^5$ cm
Angle of elevation at cut-off	Φ_I	20.5°	20.5°
Distance between take-off and landing (booster1)	$X_{L,I}$	189 mi	$304 \cdot 10^5$ cm
Length booster 1 (without fins)	L_I	95.2 ft	$29 \cdot 10^2$ cm
Diameter booster 1	D_I	65.6 ft	$20 \cdot 10^2$ cm

Table II: Principal Data – Second Stage

	Symbol	Eng. Units	Physical Units
Thrust	F_{II}	1,600 t	$16 \cdot 10^8$ g
Initial weight	$W_{0,II}$	900 t	$9 \cdot 10^8$ g
Empty weight of booster 2	$W_{E,II}$	70 t	$0.7 \cdot 10^8$ g
Final weight (booster 2 empty, stage 3 full)	$W_{1,II}$	200 t	$2 \cdot 10^8$ g
Weight ratio	E_{II}	4.5	4.5
Propellants booster 2	$W_{p,II}$	700 t	$7 \cdot 10^8$ g
Rate of propellant consumption	$\dot{W}_{p,II}$	5.6 t/sec	$5.6 \cdot 10^6$ g/sec
Exhaust velocity	$U_{e,II}$	9,200 ft/sec	$2.8 \cdot 10^6$ cm sec
Nozzle exit pressure	$p_{e,II}$	0.342 psi	24.1 g/cm^2
Nozzle exit area	$A_{e\,II}$	3230 sq ft	$3,000 \cdot 10^3$ cm^2
Initial acceleration (absolute)	$a_{0,II}$	57.1 ft/sec^2	$17.4 \cdot 10^2$cm/sec^2
Final acceleration (absolute)	$a_{1,II}$	258 ft/sec^2	$78.5 \cdot 10^2$ cm/sec^2

Table II: Principal Data – Second Stage (continued)

	Symbol	Eng. Units	Physical Units
Burning time	T_{II}	124 sec	124 sec
Altitude at cut-off	Y^{II}	39.8 mi	$64 \cdot 10^5$ cm
Velocity at cut-off	V_{II}	3.99 mi/sec	$6.42 \cdot 10^5$ cm/sec
Horizontal distance at cut-off	X_{II}	332 mi	$534 \cdot 10^5$ cm
Angle of elevation at cut-off	Φ_{II}	2.5°	2.5°
Distance between take-off and landing (booster 2)	$X_{L,II}$	906 mi	$1,459 \cdot 10^5$ cm
Length booster 2	L_{II}	46 ft	$14 \cdot 10^2$ cm
Aft diameter booster 2	D_{II}	65.6 ft	$20 \cdot 10^2$ cm
Forward diameter booster 2	D_{III}	32.1 ft	$9.8 \cdot 10^2$ cm

Table III: Principal Data – Third Stage (Maneuver of Ascent)

	Symbol	Eng. Units	Physical Units
Thrust	F_{III}	200 t	$20 \cdot 10^7$ g
Initial weight	$W_{0,III}$	130 t	$13 \cdot 10^7$ g
Final weight after maneuver of ascent			
a. From Kahului to Lunetta	$W_1{}^I{}_{,III}$	71.5 t	$71.5 \cdot 10^6$ g
b. From Christmas Island to orbit of departure	$W_1{}^{II}{}_{,III}$	78.5 t	$78.5 \cdot 10^6$ g
Propellant consumption for maneuver of ascent			
a. From Kahului to Lunetta	$W_p{}^I{}_{,III\cdot a}$	58.5 t	$58.5 \cdot 10^6$ g
b. From Christmas Island to orbit of departure	$W_p{}^{II}{}_{,III\cdot a}$	51.5 t	$51.5 \cdot 10^6$ g
Total propellant supply third stage	$W_{p,III}$	83 t	$83 \cdot 10^6$ g
Empty weight without payload	$W_{E,III}$	22 t	$22 \cdot 10^6$ g
Rate of propellant consumption	$\dot{W}_{p,III}$	0.702 t/sec	$0.702 \cdot 10^6$ g/sec
Exhaust velocity	$U_{e,III}$	9,200 ft/sec	$2.8 \cdot 10^5$ cm/sec
Nozzle exit pressure	$p_{e,III}$	0.142 psi	10 g/cm^2
Nozzle exit area	$A_{e,III}$	798 sq ft	$740 \cdot 10^3$ cm^2
Initial acceleration (absolute)	$a_{0,III}$	49.6 ft/sec^2	$15.1 \cdot 10^2$ cm/sec^2
Final acceleration (absolute)			
a. From Kahului to Lunetta	$a_1{}^I{}_{,III}$	90.4 ft/sec^2	$27.5 \cdot 10^2$ cm/sec^2
b. From Christmas Island to orbit of departure	$a_1{}^{II}{}_{,III}$	82 ft/sec^2	$25.0 \cdot 10^2$ cm/sec^2
Burning time			
a. From Kahului to Lunetta	$t^I{}_{III,a}$	84 sec	84 sec
b. From Christmas Island to orbit of departure	$t^{II}{}_{III,a}$	73 sec	73 sec
Altitude at cut-off	Y^{III}	63.3 mi	$102 \cdot 10^5$ cm
Velocity at cut-off	V_{III}	5.13 mi/sec	$8.26 \cdot 10^5$ cm/sec
Horizontal distance at cut-off			
a. From Kahului to Lunetta	$X^I{}_{III}$	705 mi	$1135 \cdot 10^5$ cm
b. From Christmas Island to orbit of departure	$X^{II}{}_{III}$	655 mi	$1054 \cdot 10^5$ cm
Velocity increment to be furnished be third stage during ascent			
a. From Kahului to Lunetta	$\Delta V^I{}_{III}$	1.049 mi/sec	$1.688 \cdot 10^5$ cm/sec
b. From Christmas Island to orbit of departure	$\Delta V^{II}{}_{III}$	0.879 mi/sec	$1.415 \cdot 10^5$ cm/sec
Angle of elevation at cut-off	Φ_{III}	0°	0°

Table IV: Principal Data – Third Stage (Maneuver of Adaptation)

	Symbol	Eng. Units	Physical Units
Thrust	F_{III}	200 t	$20 \cdot 10^7$ g
Initial weight for flight			
a. From Kahului to Lunetta	$W_1{}^I{}_{,III}$	71.2 t	$71.2 \cdot 10^6$ g
b. From Christmas Island to orbit of departure	$W_1{}^{II}{}_{,III}$	78.5 t	$78.5 \cdot 10^6$ g
Final weight after maneuver of adaptation for flight			
a. From Kahului to Lunetta	$W_2{}^I{}_{,III}$	60.4 t	$60.4 \cdot 10^6$ g
b. From Christmas Island to orbit of departure	$W_2{}^{II}{}_{,II}$	66.6 t	$60.6 \cdot 10^6$ g
Burning time, for flight			
a. From Kahului to Lunetta	$t^I{}_{III,ad}$	15.4 sec	15.4 sec
b. From Christmas Island to orbit of departure	$t^{II}{}_{III,ad}$	17 sec	17 sec
Apogean velocity of the ellipse of ascent	$V_{a,a}$	4.11 mi/sec	$6.61 \cdot 10^5$ cm/sec
Circular velocity in the apogee of the ellipse of ascent	$V_{circ,1}$	4.40 mi/sec	$7.07 \cdot 10^5$ cm/sec
Velocity increment for adaptation	ΔV_{ad}	0.29 mi/sec	$0.46 \cdot 10^5$ cm/sec

Table V: Principal Data – Third Stage (Entering Maneuver for the Landing Ellipse)

	Symbol	Eng. Units	Physical Units
Thrust (half throttle)	$F_{III,L}$	100 t	$10 \cdot 10^7$ g
Initial weight	$W_{3,III}$	32.2 t	$32.2 \cdot 10^6$ g
Final weight (landing weight)	$W_{4,III}$	27 t	$27 \cdot 10^6$ g
Empty weight (without payload)	$W_{E,III}$	22 t	$22 \cdot 10^6$ g
Useful landing payload	$W_{U,L}$	5 t	$5 \cdot 10^6$ g
Propellant consumption for landing maneuver	$W_{p,III,L}$	5.2 t	$5.2 \cdot 10^6$ g
Initial acceleration	$a_{3,III}$	100 ft/sec^2	$30.5 \cdot 10^2$ cm/sec^2
Final acceleration	$a_{4,III}$	120 ft/sec^2	$36.4 \cdot 10^2$ cm/sec^2
Burning time	$t_{III,L}$	14.8 sec	14.8 sec
Perigee altitude of the landing ellipse	y_p	49.7 mi	$80 \cdot 10^5$ cm
Apogean velocity of the landing ellipse	$V_{a,L}$	4.09 mi/sec	$6.59 \cdot 10^5$ cm/sec
Velocity increment for entering the landing ellipse	ΔV_L	0.297 mi/sec	$0.48 \cdot 10^5$ cm/sec

Table VI: Principal Data – Third Stage (Dimensions)

	Symbol	Eng. Units	Physical Units
Length of body	L_{III}	49.3 ft	$15 \cdot 10^2$ cm
Aftermost diameter	D_{III}	32.1 ft	$9.8 \cdot 10^2$ cm
Wing area	S_W	3960 sq ft	$3.68 \cdot 10^6$ cm^2
Wing span	b_W	171 ft	$52 \cdot 10^2$ cm

Table VII: Principal Data – Total Ship

	Symbol	Eng. Units	Physical Units
Overall-length (without fins)	L_{tot}	190.5 ft	$58 \cdot 10^2$ cm
Maximum diameter	D_I	65.6 ft	$20 \cdot 10^2$ cm
Nominal payload for ascent	$W_{u,a}$*	25 t	$25 \cdot 10^6$ g
Total useful load for ascent (incl. propellant reserves that can be delivered to the satellite orbit)			
a. Flight from Kahului to Lunetta	$W_u{}^I{}_{,a}$	33.2 t	$33.2 \cdot 10^6$ g
b. Flight from Christmas Island to orbit of departure	$W_u{}^{II}{}_{,a}$	39.4 t	$39.4 \cdot 10^6$ g

* Weight data listed in the second column are given in metric tons.
(1 metric ton = 1 long ton = 1 t = 1000 kg = 10^6 g).

2. Terminal Velocity of Third Stage

The final velocity of the third stage required to reach Lunetta (or the orbit of departure of the Mars expedition) is derived as follows (see fig. 3):

Let $y_{III} = 0.102 \cdot 10^8$ cm be the cut-off altitude at which the third stage attains peak velocity horizontally. Then

$$R_p = R_E + y_{III} = (6.380 + 0.102) \cdot 10^8 = 6.482 \cdot 10^8 \text{ cm} \qquad (2.1)$$

represents the geocentric distance of the perigee of the ellipse of ascent succeeding powered flight. The apogee of this ellipse is to have the same geocentric distance as Lunetta's orbit. For the latter, Equation 16.2 yields $R_{S,E} = 8 \cdot 110 \cdot 10^8$ cm. Thus, the length of the major semi-axis of the ellipse of ascent equals

$$a = (R_p + R_{S,E})/2 = 7.290 \cdot 10^8 \text{ cm} \qquad (2.2)$$

The circular velocity at cut-off altitude is determined by the relation

$$V_{circ}{}^2 = R_E/(2 \cdot R_P) \cdot V_{p,E}{}^2 \qquad (2.3)$$

where $V_{p,E} = 11.18 \cdot 10^5$ cm/sec is the parabolic escape velocity at the Earth's surface. Hence $V_{circ} = \sqrt{(6.380/(2 \cdot 6.482)) \cdot 11.18^2 \cdot 10^{10}} = 7.850 \cdot 10^5$ cm/sec.

The perigean velocity of the ellipse of ascent must be equal to the required cut-off velocity of the third stage and is therefore

$$V_{III} = V_{circ} \cdot \sqrt{2\text{-}(R_P/a)} = 8.260 \cdot 10^5 \text{ cm/sec} \qquad (2.4)$$

3. Track of Powered Ascent

a. First Stage

The most favorable track of ascent for the first stage is determined by the following requirements:

- maximum possible terminal velocity
- vertical take-off
- angles of attack prevailing during tilting must remain within structurally safe limits. This is assured as long as acceleration normal to the flight path $n = V \cdot \dot{\phi}$ does not exceed 2 g.
- cut-off velocity, cut-off altitude, and angle of elevation φ_I at cut-off must be chosen so as to assure moderate loads during first booster's parachute descent.

To calculate the ascent track, we have the following equation for the acceleration in direction of the flight path

$$\dot{V} = \Delta V/dt = [(F_I + A_{e,I} \cdot (p_{e,I} - p_a) - C_D \cdot A_I \cdot V^2 \cdot (\gamma/2g_0))/(1/g_0) \cdot (W_{0,I} - \dot{W}_{p,I} \cdot t)] - g_0 \cos\vartheta \qquad (3.1)$$

where: $F_I = 12.8 \cdot 10^9$ g thrust of the first booster at an altitude at which ambient air pressure

P_a = nozzle exit pressure $P_{e,I}$;

$A_{e,I} = 1940 \cdot 10^3$ cm^2 nozzle exit area:

$p_{e,I} = 700$ g/cm^2 exit pressure:

C_D = drag coefficient of the three-stage ship (see Table VIII);

$A_I = 3140 \cdot 10^3$ cm^2 projected frontal area of the ship;

γ = specific weight of air;

g_0= 981 cm/sec^2 gravitational acceleration;

V = velocity;

$W_{0,I} = 6.4 \cdot 10^9$ g take-off weight of the ship;

$\dot{W}_{p,I} = 55.808 \cdot 10^6$ g/sec rate of propellant flow of the first booster;

t = time;

ϑ = flight path angle against local vertical direction;

This differential equation has been integrated numerically after Runge and Kutts. The vertical and horizontal components of the velocity are as follows:

$$\dot{y} = V \cdot \cos\vartheta$$
$$\dot{x} = V \cdot \sin\vartheta$$

Table VIII (right): Drag Coefficient of Sirius as Function of Mach Number

M	C_D
5	0.55
5	0.55
4	0.57
3	0.59
2	0.69
1 - 1.4	0.80
Subsonic	0.40

After each step of the integration, the increments of altitudes y and horizontal displacements X are determined accordingly.

The dependency of the drag coefficient C_D on the Mach number M has been determined by a rough estimate of the pressure distribution around a *Sirius* configuration. Numerical values have been compiled in Table VIII.

The characteristics of the ascent track thus calculated are listed in Table IX.

Table IX: Characteristics of Ascent Track of First Stage

Step	$\Sigma \Delta t$ sec	$\dot{V} \cdot 10^{-2}$ cm/sec	$V \cdot 10^{-2}$ cm/sec	$y \cdot 10^{-2}$ cm	$X \cdot 10^{-2}$ cm	ϑ degrees:minutes
0	0	8.8321	0	0	0	0:0
1	4	9.5164	36.74	72.4	0	0:0
2	8	10.2724	76.23	297.2	0	0:0
3	16	12.0320	165.18	1252.5	21.5	2:58
4	24	13.9157	269.31	2971.5	190.5	8:02
5	32	15.7022	385.94	5528.9	706.4	14:39
6	40	19.3283	524.52	8949.4	1883.8	23:19
7	48	25.1416	700.60	13197.8	4245.1	34:43
8	56	32.3347	924.82	18068.7	8476.5	46:08
9	64	40.8963	1216.72	23423.9	15080.9	54:48
10	72	51.7102	1585.23	29260.8	24574.2	61:25
11	80	66.5597	2054.96	35565.3	37606.3	66:29
12	80	82.3034	2498.78	40644.7	50235.6	69:30

Consequently, if the first booster completely consumed its propellants it would reach a terminal velocity of $2.498 \cdot 10^5$ cm/sec after a burning period of 86 seconds. If the cut-off velocity is reduced to $V_I = 2.350 \cdot 10^5$ cm/sec, a rest of $103 \cdot 10^6$ g of propellant will remain, corresponding to a reserve in burning time of 1.85 seconds. This reserve is provided for safety reasons, in order to assure the required cut-off velocity even in case of a deviation from the standard mixture ratio of the propellants. After separation of the first booster any residual propellants may be expelled by fuel pump to reduce weight for the parachute landing.

The cut-off altitude of the first stage is approximately $y_I = 400 \cdot 10^5$ cm, and the horizontal cut-off distance is $X_I = 50 \cdot 10^5$ cm. During the ascent the track has been tilted by ϑ_I 69.5° against the initial vertical; hence the angle of elevation at cut-off is $\varphi_I = 90 - \vartheta_I = 20.5°$.

b. <u>Second Stage</u>

For the second stage cut-off altitude of $y_{II} = 64 \cdot 10^5$ cm and a cut-off angle of elevation of $\varphi_{II} = 2.5°$ have been chosen. These data offer advantageous initial conditions for the parachute landing of the second booster (see Section 15d).

Since aerodynamic drag during the burning time of the second stage may be disregarded, the latter's velocity increment and horizontal flight distance may be obtained be analytical integration. In the case of complete exhaustion of propellants, the terminal velocity of the second stage equals

$$\begin{aligned} V_{II}^* &= U_{e,II} \cdot \log_e E_{II} - g \cdot \sin \varphi_m \cdot [W_{0,II}/\dot{W}_{p,II}] \cdot [(E_{II} - 1)/E_{II}] \cdot C_r + V_I \\ &= 2.8 \cdot 10^5 \cdot \log_e 4.5 - 970 \cdot 0.0497 \cdot 900/5.6 \cdot (4.5 - 1)/4.5 \cdot 0.678 + 2.35 \cdot 10^5 \\ &= 6.51 \cdot 10^5 \text{ cm/sec} \end{aligned} \tag{3.2}$$

where: $C_r = 0.678$ the "centrifugal reduction factor," as defined in Equation 10.2, for the average velocity of the second stage;

$g = 970$ cm/sec^2 gravitational acceleration at the average altitude of the flight path of the second stage;

$\varphi_m = 2° 51'$ the average angle of elevation of the flight path of the second stage, as found by iteration.

The meaning of the other symbols may be taken from Table II.

The horizontal flight path of the second stage equals

$$\Delta X_{II}^* = (W_{0,II}/\dot{W}_{p,II}) \cdot \cos\varphi_m \cdot [U_{e,II} \cdot (1/E_{II}) \cdot (E_{II} - 1 - \log e\, E_{II}) - C_r \cdot (g/2) \cdot \sin\varphi_m (W_{0,II}/\dot{W}_{p,II}) \cdot ((E_{II} - 1)/E_{II})^2 + V_I \cdot ((E_{II} - 1)/E_{II})] = 491 \cdot 10^5 \text{ cm.} \quad (3.3)$$

However, we may assume a somewhat lower cut-off velocity, viz., $V_{II} = 6.42 \cdot 10^5$ cm/sec. This gives us a leeway of $6.45 \cdot 10^6$ g of propellants, corresponding to a reserve of burning time of 1.15 sec, which is available for failure to maintain standard mixture ratios. The horizontal distance covered by the second stage is here reduced to $\Delta X_{II} = 484 \cdot 10^5$ cm.

The total horizontal distance made by the second stage, as reckoned from the launching site, then amounts to

$$X_{II} = X_I + \Delta X_{II} = (50 + 484) \cdot 10^5 = 534 \cdot 10^5 \text{ cm.} \quad (3.4)$$

The burning time until complete exhaustion of the tank age equals

$$T_{II} = (W_{0,II} - E_{1,II})/\dot{W}_{p,II} = (900 - 200)/5.6 = 123 \text{ sec} \quad (3.5)$$

c. Third Stage

From Equation 2.4 it follows that the required cut-off velocity of the third stage is $V_{III} = 8.26 \cdot 10^5$ cm/sec. Since the cut-off velocity of the second stage is as high as $V_{II} = 6.42 \cdot 10^5$ cm/sec, the power plant of the third stage must provide the balance,

$$\Delta V_{III} = V_{III} - V_{II} = 1.84 \cdot 10^5 \text{ cm/sec.} \quad (3.6)$$

A portion of this velocity is contributed by the circumferential velocity of the launching site due to the Earth's rotation. This portion depends on the geographical latitude δ of the launching site and, moreover, on the angle ζ between the plane of the target satellite orbit and the equator.

For an ascent from Kuhului, Hawaii to Lunetta we have $V'_r = V_A \cdot \cos\delta = 0.464 \cdot 10^5 \cdot \cos 21° = 0.433 \cdot 10^5$ cm/sec where $V_A = 0.464 \cdot 10^5$ cm/sec the circumferential velocity at the equator. Since Lunetta's orbit is inclined by $\zeta = 66.5°$ towards the equator, only a fraction,

$$V'_{rot} = V'_r \cdot \cos 66.5° = 0.173 \cdot 10^5 \text{ cm/sec} \quad (3.7)$$

will actually be utilized for the ascent. Hence, the third stage must furnish a velocity increment

$$\Delta V'_{III} = \Delta V_{III} - V'_{rot} = 1.667 \cdot 10^5 \text{ cm/sec} \quad (3.8)$$

by its own power.

The increase of potential energy due to climbing of the third stage may be disregarded owing to the fact that at the prevailing velocities gravitation, on the average, is completely balanced by centrifugal acceleration along the path ($c_r = 0$). The required weight ratio may therefore be simply computed as follows (see Equations 23.1 and 23.2):

$$W_{0,III}/W'_{1,III} = \exp(\Delta V_{III}/U_{e,III}) = \exp(1.667/2.8) = 1.82 \quad (3.9)$$

For an initial weight of the third stage of $W_{0,III} = 130 \cdot 10^6$ g we obtain the final weight

$$W'_{1,III} = 71.5 \cdot 10^6 \text{ g} \quad (3.10)$$

after completing the maneuver of ascent. It follows that the propellant consumption is

$$W'_{p,III,a} = W_{0,III} - W'_{1,III} = 58.5 \cdot 10^6 \text{ g} \quad (3.11)$$

and the burning time

$$t'_{III,\partial} = W'_{p,III,\partial}/\dot{W}_{p,III} = 558.5/0.702 = 84 \text{ sec} \quad (3.12)$$

For an ascent from Christmas Island to the orbit of departure we find

$$V''_r = V_A = 0.464 \cdot 10^5 \text{ cm/sec}$$

$$V''_{rot} = V''_r \cdot \cos 23.5° = 0.425 \cdot 10^5 \text{ cm/sec} \quad (3.13)$$

$$\Delta V''_{III} = \Delta V_{III} - V''_{rot} = 1.415 \cdot 10^5 \text{ cm/sec} \quad (3.14)$$

$W_{0,III}/W''_{1,III} = \exp(\Delta V''_{III} / U_{e,III}) = 1.66$ (3.15)

$W''_{1,III} = 78.5 \cdot 10^6$ g (3.16)

$W''_{P,III,a} = 51.5 \cdot 10^6$ g (3.17)

$t''_{III,a} = 73$ sec (3.18)

4. Maneuver of Adaptation

From the Second Law of Kepler it follows that

$$R_p \cdot V_{III} = R_{S,E} \cdot V_{\partial,\partial} \quad (4.1)$$

where $V_{\partial,\partial}$ is the velocity at the apogee of the ellipse of ascent (see Fig. 3). Hence $V_{\partial,\partial} = R_p/R_{S,E} \cdot V_{III} = (6.482/8.110) \cdot 8.260 \cdot 10^5 = 6.610 \cdot 10^5$ cm/sec.

According to Equation 16.3 the orbital velocity of Lunetta and also of the ships in the orbit of departure is $V_{circ,1} = 7.07 \cdot 10^5$ cm/sec. At the apogee, the velocity of the third stage must therefore be increased by

$$\Delta V_{ad} = V_{circ,1} - V_{\partial,\partial} = 0.460 \cdot 10^5 \text{ cm/sec.} \quad (4.2)$$

The weight ratio required for this maneuver is as follows

$$W_{1,III}/W_{2,III} = \exp(V_{ad}/U_{e,III}) = \exp(0.46/2.8) = 1.79 \quad (4.3)$$

Inserting for $W_{1,III}$ the values calculated in the foregoing section, the terminal weight with which the third stage reaches Lunetta on its ascent from Kaului is

$$W'_{2,III} = W'_{1,III}/1.79 = 71.5 \cdot 10^6 = 60.6 \cdot 10^6 \text{ g} \quad (4.4)$$

The orbit of departure will be reached in an ascent from Christmas Island with a terminal weight of

$$W''_{2,III} = W''_{1,III}/1.179 = (78.5 \cdot 10^6)/1.79 = 66.6 \cdot 10^6 \text{ g} \quad (4.5)$$

The better utilization of the Earth's rotation in the latter case yields a net gain in payload of

$$(66.6 - 60.6) \cdot 10^6 = 6.0 \cdot 10^6 \text{ g} \quad (4.6)$$

Burning times for the adaptation maneuver in each case are

$$t'_{III,ad} = (71.5\text{-}60.6)/0.72 = 15.5 \text{ sec} \quad (4.7)$$

$$t''_{III,ad} = (78.5\text{-}66.6)/0.702 = 17.0 \text{ sec} \quad (4.8)$$

5. Coasting Time in the Half-Ellipse of Ascent

Kepler's Third Law stated that

$$T^2/a^3 = \text{const} \quad (5.1)$$

where T is the period of revolution, and "a" the length of the major semi-axis of the orbit. For the terrestrial Moon we have $T_{moon} = 2.36 \cdot 10^6$ sec and $a_{moon} = 3.84 \cdot 10^{10}$ cm.

Hence the period of revolution for any orbit around the Earth becomes

$$T = 3.13 \cdot 10^{-10} \cdot \sqrt{a^3} \quad (5.2)$$

Upon substitution of the numerical value of "a" given in Equation 2.2, the complete period of revolution of the ellipse of ascent results as $T_{ell} = 3.13 \cdot 10^{-10} \cdot \sqrt{(7.29 \cdot 10^8)^3} = 6140$ sec.

The coasting time in the half-ellipse of *Sirius*'s third stage is one half that long, minus the burning time of the adaptation maneuver,

$$T_{C,a} = (T_{ell}/2) - t_{III,ad} = 3054 \text{ sec} = 50 \text{ min } 64 \text{ sec} \quad (5.3)$$

6. Wing Area of Third Stage

The required wing area of the third stage is determined by the desired landing speed $V_{L,}$

$$S_W = (2 \cdot g\ W_{4,III})/(C_{L,max} \cdot \gamma_0 \cdot V_L^2) \quad (6.1)$$

where: $C_{\pi,max} = 1.3$ is the maximum lift coefficient obtainable with lift-increasing devices such as leading edge flaps and landing flaps;

$\gamma_0 = 1.293 \cdot 10^{-3}$ g/cm³ the specific weight of air at sea level;

$g_0 = 981$ cm/sec² gravitational acceleration;

$W_{4,III} = 27 \cdot 10^6$ g the landing weight.

For a landing speed, V_L = 65 MPH = 2925 cm/sec, we obtain:

$$S_W = (2 \cdot 981 \cdot 27 \cdot 10^6)/(1.3 \cdot 1.293 \cdot 10^{-3} \cdot 0.2925^2)$$
$$= 3.68 \cdot 10^6 \text{ cm}^2 = 3960 \text{ sq ft} \qquad (6.2)$$

7. Negative Lift at the Perigee of the Landing Ellipse Required for Inducement of Circular Path. The circular velocity at an altitude $y_P = 8 \cdot 10^6$ cm (corresponding to distance of $6.46 \cdot 10^8$ cm from the Earth's center) equals $V_{circ} = 7.85 \cdot 10^5$ cm/sec as follows by the same reasoning as indicated in Equation 2.3.

The acceleration due to gravity, which must be equal to the centrifugal acceleration in such a circular orbit, is at this altitude $g_p = V_{circ}^2/(6.46 \cdot 10^8) = 955$ cm/sec^2.

In analogy to Equation 2.4 we obtain the perigean velocity of the landing ellipse as follows

$$V_p = 7.85 \cdot 10^5 \cdot \sqrt{2} - (6.46/7.285) = 8.27 \cdot 10^5 \text{ cm/sec.}$$

The centrifugal acceleration in a circular path involving this speed at an altitude $y_P = 8 \cdot 10^6$ cm is $A_p = V_p^2/(6.46 \cdot 10^8) = 1052$ cm/sec^2.

Hence, the negative lift must generate a centripetal acceleration $a_{cp} = a_p - g_p = 97$ cm/sec^2 in order to induce the circular path. Since the landing weight of the third stage is $W_{4,III} = 27 \cdot 10^6$ g, the required negative lift becomes

$$-L_r = ((27 \cdot 10^6)/981) \cdot 0.97 = 2.67 \cdot 10^6 \text{ g.} \qquad (7.1)$$

At an altitude $y_P = 8 \cdot 10^6$ cm the specific weight of air is $\gamma = 2.5 \cdot 10^{-8}$ cm^{-3}. At these extremely high Mach numbers a lift coefficient $C_L = 0.1$ may be assumed. The wing area $S_W = 3.68 \cdot 10^6$ cm^2, as derived for the desired landing speed, can produce a negative lift

$$-L_\partial = (C_L \cdot S_W \cdot V_p^2 \cdot \gamma)/(2g_0) = 3.2 \cdot 10^6 \text{ g.} \qquad (7.2)$$

This comparison shows that at a perigean altitude $y_P = 8 \cdot 10^6$ cm the elliptical approach can easily be transformed into a circular path.

8. Entering Maneuver for the Landing Ellipse

The apogean velocity, which corresponds to a perigean velocity $V_P = 8.27 \cdot 10^5$ cm/sec at an altitude $y_P = 8 \cdot 10^6$ cm, is $V_{aL} = (R_E + y_p)/R_{s,E} \cdot V_p = 6.59 \cdot 10^5$ cm/sec as follows from Equation 4.1. In the satellite orbit, in order to enter the landing ellipse, a reduction in speed

$$\Delta V_L = V_{circ,4} - V_{a,L} = 0.480 \cdot 10^5 \text{ cm/sec} \qquad (8.1)$$

is required. The weight ratio for this maneuver equals

$$W_{3,III}/W_{4,III} = \exp(\Delta V_L/U_{e,III}) = \exp(0.48/2.8) = 1.1 \text{ g.} \qquad (8.2)$$

We assume an empty weight of the third stage of $W_{E,III} = 22 \cdot 10^6$ g and a useful landing payload $W_{U,L} = 5 \cdot 10^6$ g. The total landing weight becomes $W_{4,III} = W_{E,III} + W_{U,L} = 27 \cdot 10^6$ g whence the departure weight from the satellite orbit becomes in view of Equation 8.2

$$W_{3,III} = 1.19 \cdot W_{4,III} = 32.2 \cdot 10^6 \text{ g.} \qquad (8.3)$$

The propellant weight required for the entering maneuver is

$$W_{p,III,L} = W_{3,III} - W_{4,III} = 5.2 \cdot 10^6 \text{ g.} \qquad (8.4)$$

We assume, that each third stage can draw this propellant only from the supply remaining after the ascent, which means that no refueling in orbit is provided. We furthermore assume that the landing payload $W_{U,L} = 5 \cdot 10^6$ g consists exclusively of cargo taken aboard in the orbit (i.g., homebound crews from Lunetta or orbit of departure). Then the available payload for the ascent $W_{U,a}$ may be determined as follows.

$$W'_{U,a} = W'_{2,III} - W_{3,III} + W_{U,L} = (60.6 - 32.2 + 5) \cdot 10^6 = 33.4 \cdot 10^6 \text{ g} \qquad (8.5)$$

and correspondingly for a flight from Christmas Island to the orbit of departure

$$W''_{U,a} = W''_{2,III} - W_{3,III} + W_{U,L} = 39.4 \cdot 10^6 \text{ g.} \qquad (8.6)$$

$W_{U,a}^* = 25$ t $= 25 \cdot 10^6$ g might be labeled as "nominal cargo". Then, in the first case, an additional propellant supply of 8.4 t, in the latter case one of 14.4 t, can be delivered to the satellite orbit.

The burning time of the entering maneuver for a thrust of $10 \cdot 10^7$ g (half-throttle) is

$$t_{III,L} = 2 \cdot (W_{p,III,L}/\dot{W}_{p,III}) = 2 \cdot (5.2/0.702) = 14.8 \text{ sec.} \tag{8.7}$$

The coasting time through the half-ellipse preceding the glide is approximately equal to that of the half-ellipse of ascent, 51 minutes.

9. Aerodynamic Assumptions for the Third Stage with Extended Telescoping Wings

Above Mach number $M = 8$ the following aerodynamic coefficients, referred to the wing area S_W, may be assumed: coefficient of lift $C_L = 0.1$ and coefficient of drag $C_D = 0.05$.

These coefficient correspond to a quotient

$$1/\varepsilon = C_L/C_D = 1/0.5 = 2. \tag{9.1}$$

For lower Mach numbers the values listed in Table X have been assumed.

Remarks:

a. These assumptions are based on crude extrapolations and accuracy is not claimed for them. Since they serve merely as a basis for a tentative calculation of the glide path of the third stage; even a major deviation of actual wind tunnel results from these figures would not render a glide from the satellite orbit impracticable.

Table X: Aerodynamic Assumptions for Third Stage

M	ε	C_L	C_D
5	0.38	0.14	0.06
3	0.28	0.24	0.06
2	0.24	0.34	0.08
1	0.19	0.34	0.07
Subsonic	0.17	0.32	0.05

b. From the structural angle it might appear objectionable to propose telescoping wings for the glide of the third stage, because it is generally taken for granted that supersonic airfoils must be very thin. Unlike supersonic aircraft, which need excellent aerodynamic qualities for economic reasons, however, drag plays a minor part in a decelerating glide from a satellite orbit. Thicker airfoils allowing a telescoping wing design have higher drag which tends to shorten the unnecessarily lengthy glide path.

c. The main purpose of a telescoping wing design is to reduce the structural load in the comparison to the load which would be imposed on fixed wings during and subsequent to launching. The reduction of drag during the ascent is almost negligible in view of the large thrusts of the two boosters.

d. The telescoping design is not a "must" for satellite rocket vessels. It is possible to build a third stage with fixed wings. It is also conceivable to stow the disassembled wings in the cargo space of the third stage and to assemble and mount them in the satellite orbit before returning to Earth.

10. Glide Path of the Third Stage between Perigee and Landing Ellipse and Landing Procedure of Calculation

a. The weight of the third stage is partially sustained during the glide by centrifugal forces, particularly when the velocity is still high. Instead of the total weight $W_{4,III}$, only the fraction

$$W = w_{4,III}(1 - (a_{cf}/g_0)) = W_{4,III}(1 - (V^2/(g_0 \cdot (R_E + y)))) = W_{4,III} \cdot C_r \tag{10.1}$$

need be borne by the wings. Table XI gives the relation between the "centrifugal reduction factor"

$$C_r = W/W_{4,III} = 1 - (V^2/(g_0 \cdot (R_E + y))) \tag{10.2}$$

and velocity V.

Table XI: Centrifugal Reduction Factor for a Mean Altitude $y = 50 \cdot 10^5$ cm

$V \cdot 10^{-5}$ cm/sec	C_r
8	-0.100
7	0.227
6	0.428
5	0.603
4	0.746
3	0.857
2	0.936
1	0.983

Table XII: Glide Values

$V \cdot 10^{-5}$ cm/sec	$Y \cdot 10^{-5}$ cm
8.27	80
7	72.9
6	65.8
5	60.5
4	55.7
3	50.3
2	43.8
1	33.3
sonic	24.0

b. The minimum air density capable of affording sufficient lift to carry the "reduced" weight of the third stage is

$$\gamma = (W_{4,III}/S_W) \cdot C_r \cdot (2g_0/C_L) \cdot (1/V^2). \quad (10.3)$$

Under the simplifying assumption of a constant temperature, the density distribution of the atmosphere is given by the relation

$$\gamma/\gamma_0 = \exp(-y/y^*) \quad (10.4)$$

where $y^* = 7 \cdot 8 \cdot 10^5$ cm is the altitude increment which causes a decrease of air density by the factor e = 2.718.

$\gamma_0 = 1.293 \cdot 10^{-3}$ g/cm^3 is the density at sea level.

Hence, the altitude y corresponding to a density γ in Equation 10.4 may be calculated.

c. Multiplying the lift $L = W = W_{4,III} \cdot C_r$ by D yields the drag D at any time (see Equation 9.1). Hence the longitudinal deceleration equals

$$- dv/dt = D \cdot g_0/W_{4,III} = C_r \cdot \varepsilon \cdot g_0 \quad (10.5)$$

d. The glide may now be determined by numerical integration after Runge and Kutta. Results are compiled in Table XII.

Table XIII: Glide Path of Third Stage

$-\frac{dv}{dt} \cdot 10^{-2}$ cm/sec	Δt sec	$\Delta X \cdot 10^{-5}$ cm	$R/D \cdot 10^{-2}$ cm/sec	$\Sigma\ \Delta$t sec	$\Sigma\Delta X \cdot 10^{-5}$ cm
0.79	1,610	12,300	4.4	1,610	12,300
1.61	622	4,050	10.4	2,232	16,350
2.54	394	2,170	13.5	2,626	18,520
3.30	303	1,365	15.8	2,929	19,885
3.94	254	888	21.2	3,183	20,773
4.42	226	565	28.8	3,409	21,338
3.43	292	438	16.4	3,701	21,776
2.33	300	195	50	4,001	21,971

The total time of flight from the perigee of the landing ellipse down to sonic speed is $\Sigma\Delta t = 4001$ sec = 1 hour 6 minutes 41 seconds. The horizontal distance covered to this time is $\Sigma\Delta X = 21971 \cdot 10^5$ cm = 13,650 miles, equal to 55 percent of the Earth's circumference. Sonic speed will be passed at an altitude $24 \cdot 10^5$ cm = 14.9 miles.

11. Skin Heating During the Glide of the Third Stage

When a body is placed in a high-velocity air stream, it assumes a temperature higher than static temperature T_a of ambient air. In case no heat is re-radiated and a stationary state is reached, the temperature of the body is called "natural temperature" T_n, which is somewhat lower than the stagnation temperature T_{st}. For landing cone or wedge angles between 15° and 50° we have the relation

$$T_n - T_a = 0.89\,(T_{st} - T_a). \quad (11.1)$$

Values of $T_n - T_a$ are compiled in the table at the right. These values have been calculated with the help of enthalpy formulas but regardless of dissociation.

$V \cdot 10^{-5}$ cm/sec	$T_n - T_a$ °K
8.27	22,673
7	16,256
6	12,518
5	8,995
4	5,548
3	3,161
2	1,581
1	442

The altitudes y, at which these velocities are passed, may be taken from Table XIV. The atmospheric temperatures T_a at these altitudes are known measurements of the pressure distribution and other methods.

In this manner, we obtain the natural temperatures T_n for the flight conditions during the glide of the third stage (see Table XIV.)

The heat flow per unit area boundary layer to skin is given by the equation

$$Q_i = h \cdot (T_n - T_s)\ (\text{cal/cm}^2\text{sec}) \quad (11.2)$$

where T_s is the temperature and h the heat transfer coefficient.

Table XIV: Skin Heating During Glide of Third Stage

$V \cdot 10^{-5}$ cm sec^{-1}	$y \cdot 10^{-5}$ cm	T_a °K	T_n °K	h cal/cm sec^{-10} K^{-1}	T_S °K	t_S °K
8.27	80	200	22,873	0.456	933	1,220
7	72.9	217	16,473	0.795	983	1,310
6	65.8	270	12,788	1.069	989	1,320
5	60.5	300	9,295	1.627	1005	1,350
4	55.7	320	5,868	2.139	945	1,240
3	50.3	322	3,483	2.682	855	1,080
2	43.8	300	1,881	3.790	754	900
1	33.3	225	667	5.692	510	460

For moderate supersonic speeds and a cone-shaped body we have according to Eber:

$$h = (0.0071 + 0.0154 \cdot \beta^{0.5}) \cdot 1/l^{0.2} \cdot (\gamma/g_0) \cdot K/\mu^{0.8} \cdot V^{0.8} \qquad (11.3)$$

where: β = leading cone angle,

l = downstream distance from nose,

γ = local specific weight of ambient air,

K = heat conductivity of air,

μ = dynamic viscosity of air.

This equation also represents a fair approximation for a wedge-shaped wing.

The local value of γ may be computed from Equation 10.4. To illustrate, we assume a wing cord l = 32 cm = 1 ft downstream of the leading edge and a leading-edge angle $\beta = 20°$. The resulting heat transfer coefficients are compiled in Table XIV.

According to the Table XII changes of flight conditions occur rather slowly. Therefore the heat capacity of the skin may be disregarded and in essentials a steady-state temperature will prevail.

The instantaneous heat flow Q_i from boundary layer to skin will be re-radiated from the skin.

$$Q_i = Q_r \qquad (11.4)$$

Heat conduction into the interior of the vessel may be disregarded. The latter must be reduced to the greatest possible extent by efficient temperature insulation to keep within the capacity of the cabin air-conditioning plant.

According to the Stefan-Boltzmann Law, the radiation equals

$$Q_r = 1.38 \cdot 10^{-12} \cdot \varepsilon \cdot T_s^4 \text{ (cal/cm}^2\text{sec).} \qquad (11.5)$$

The emissivity of sheet steel is $\varepsilon = 0.96$. Upon combining Equations 11.2, 11.4 and 11.5 it follows that $h(T_n - T_s) = 1.32 \cdot 10^{-12} \cdot T_S^4$.

Inserting numerical values of T_n and h the steady-state temperature T_S of the skin for all flight conditions may be calculated. Results are compiled in Table XIV.

Remarks:

a. The forgoing calculations involve several objectionable assumptions and serve merely to outline the problem of a glide from a satellite orbit. Very little information is available as to heat transfer coefficients at extremely high Mach numbers. Various authors have recently suggested modified formulas for the heat transfer coefficient h, which may result in skin temperatures as much as 300 °K higher than those computed above. In principle, however, it is always possible to reduce skin temperatures by decreasing the wing loading. This allows glides to be made at higher altitudes.

b. Gas dissociation in the boundary layer may also affect heat transfer at high Mach numbers. This effect has been disregarded herein.

c. The factor $1/l^{0.2}$ in Equation 11.3 indicates that the heat transfer coefficient and therefore the skin temperature is highest at the leading edge of the wing or nose end and decreases progressively downstream.

d. The foregoing calculations apply, in principle at least, to both the wing and the hull of the third stage.

12. Nozzle Exit Areas

The required nozzle exit area determines the caliber of any large rocket vessel. This may be calculated from the throat area and the expansion ratio.

The throat area for a specific heat ratio n = cp / cv = 1.2 is given by

$$A_{th} = \dot{W}_p/(2.09 \cdot p_i) \cdot \sqrt{(r \cdot T_i)} \tag{12.1}$$

where: $\dot{W}_p$ = weight rate of propellants (g/sec)

$r = 484/M_a$ specific gas constant of combustion gas

M_a = average molecular weight of combustion gas

T_i = combustion temperature (°K)

p_i = pressure in the combustion chamber (g/cm^2).

For combustion of equivalent quantities of hydrazine and nitric acid corresponding to the idealized stoichiometric equation

$$1.25\ N_2N_4 + HNO_3\ 3H_2O + 1.75\ N_2 \tag{12.2}$$

we obtain with the aid of the method described in section 40 a combustion temperature T_i = 2850 °K and an average molecular weight of the combustion products M_a = 21.7. The combustion pressure for all three *Sirius* stages may be assumed to be p_i = 214 psi = 15 • 10^3 g/cm^2. Throat areas calculated from Equation 12.1 are given in Table XV.

Table XV: Throat and Exit Areas for the Three Sirius Stages

Stage	$A_{th} \cdot 10^{-3}$ cm^{-2}	$A_e \cdot 10^{-3}$ cm^{-2}
1	595	2,240
2	59.8	3,000
3	7.5	740

Exit area A_e and throat area A_{th} are related to the equation

$$A_{th}/A_e = ((x+1)/2)^{1/(x-1)} \cdot (p_e/p_i)^{1/n} \cdot \sqrt{((n+1/n-1)) \cdot (1-(p_2/p_i)^{(n-1)/x})} \tag{12.3}$$

where p_e represents the exit pressure to which the combustion gas expands within the exhaust nozzle.

a. First Stage

The rocket motor of the first stage starts working at sea level, i.e., at an ambient pressure p_a = 1000 g/cm^2. If we assume for the take-off proper a slight over-expansion down to p_e = 700 g/cm^2, Equation 12.3 yields $A_{th,I}/A_{e,I}$ = 0.265 whence

$$A_{e,I} = 595 \cdot 10^3/0.265 = 2240 \cdot 10^3\ cm^2 \tag{12.4}$$

corresponding to a circular cross section with a diameter of 1690 cm. However, the housing for the large decelerating parachute is to be inserted in the center of this cross section. Assuming a diameter of 1070 cm for the latter, we obtain for the first stage a diameter of

$$D_I = 2000\ cm = 65.6\ ft. \tag{12.5}$$

b. Second Stage

The rocket motor of the second stage begins to operate at an altitude of 40 • 10^5 cm, where the ambient air pressure amounts to 4 g/cm^2.

If one would expand the combustion gas down to so low a pressure, the required exit area of the second stage would call for a diameter larger than that of the first stage. This is undesirable both for aerodynamic and design reasons. It is therefore assumed that the aftermost diameter of the second stage is equal to that of the first. If we cut out a circular cross section with a diameter of 422 cm for the housing of the 'chute of the second stage, we obtain a useable nozzle exit area of

$$A_{e,II} = 3000 \cdot 10^3\ cm^2. \tag{12.6}$$

In view of the value of A_{th} listed in Table XV we obtain $A_{th,II}/A_{e,II}$ = 59.8/3000 = 0.01995. According to Equation 12.3 this area ratio corresponds to an expansion ratio $p_i/p_{e,II}$ = 622. If p_i = 15 • 10^3 g/cm^2, the nozzle exit pressure becomes $p_{e,II}$ = 15000/622 = 24.1 g/cm^2, which is about six times the ambient pressure at the ignition altitude of the second stage.

Remarks: A lower combustion pressure might be chosen for the second stage, because even then an expansion ratio of 622 could be maintained so long that no loss of exhaust velocity would occur.

Such a measure is, however, unfavorable owing to the increase in combustion chamber size necessary for the lower pressure.

c. Third Stage

The power plant of the third stage takes over at an altitude of $64 \cdot 10^5$ cm, where the ambient air pressure is down to about 0.2 g/cm^2.

It is impossible to expand the combustion gas down to so low a pressure because this would lead to an excessively large nozzle diameter. The third stage must have a somewhat suitable configuration for the glide, which, however, needs by no means be perfect. Therefore, its diameter is chiefly determined by aerodynamic considerations.

For a nozzle exit pressure $p_{e,III} = 10$ g/cm^2, Equation 12.3 yields $A_{th,III}/A_{e,III} = 0.0101$ and

$$A_{e,III} = 7.5 \cdot 10^3/0.0101 = 740 \cdot 10^3 \text{ cm}^2, \qquad (12.7)$$

corresponding to a diameter

$$D_{III}^* = 972 \text{ cm} = 31.8 \text{ ft}. \qquad (12.8)$$

This should be about the maximum practical diameter.

Throat and exit areas for the three *Sirius* stages are compiled in Table XV.

13. Diameters

The dimensions of the three stages are mainly determined by their supply of propellants.

The weight ratio of the two propellant components results for the reaction in Equation 12.2 as

$$W = \dot{W}_{NA}/\dot{W}_{Hy} = 1.57; \qquad (13.1)$$

$$\sigma_{NA} = 1.58 \text{ g/cm}^3;$$

$$\sigma_{Hy} = 1.011 \text{ g/cm}^3.$$

Thus the volume ratio of tankages for the two propellants assumes the convenient value

$$V_{NR}/V_{Hy} = 1.57 \cdot 1.011/1.58 = 1. \qquad (13.2)$$

The average mixture density, i.e., the ratio of total propellant weight to total tankage volume, becomes

$$\sigma_{av} = 1.295 \text{ g/cm}^3. \qquad (13.3)$$

a. First Booster

The diameter of the first booster has been found to be $D_I = 2000$ cm. Its propellant weight is $W_{p,I} = 4.8 \cdot 10^9$ g. If we chose for the diameter of the tanks a value slightly smaller than the caliber, $D_{T,L} = 1950$ cm, we obtain for cylindrical tanks a length $L_{T,I} = (4 \cdot W_{p,I})/(D_{T,I}^2 \cdot \pi \cdot \sigma_{av}) = 1240$ cm.

Since the total tankage is to be subdivided into two separate units for the two propellants, length of 260 cm will be allowed for domed tank headers. The length of the rocket motor may be 600 cm, the height of the pump and valve component 500 cm. The jet deflector at the upper end of the first booster which protect the tanks from the blast of the second booster may have a height of 300 cm. Thus, for a diameter of the first booster equal to

$$D_I = 2000 \text{ cm} = 65.6 \text{ ft}, \qquad (13.4)$$

a total length

$$L_I = 2900 \text{ cm} = 95.2 \text{ ft} \qquad (13.5)$$

results.

b. Second Booster

The after diameter of the second booster will likewise be

$$D_{III} = D_I = 2000 \text{ cm} \qquad (13.6)$$

Its forward diameter will be equal to that of the third stage, $D_{III} = 980$ cm. Hence the second booster has the form of a truncated ogive. The volume of its tankage is $W_{p,II}/\sigma_{av} = 7 \cdot 10^8/1.295 = 5.4 \cdot 10^8$ cm^3 which requires a length of tank bay of 500 cm. We further assume that the rocket motor has a length of 450 cm, the pump and valve component of 250 cm and that the jet deflector for the blast of the third stage has a height of 200 cm. Then we compute a total length of the second stage

$$L_{II} = 1400 \text{ cm} = 46 \text{ ft}. \qquad (13.7)$$

c. Third Stage

The body of the third stage has the configuration of a stubby artillery shell of

$$D_{III} = 980 \text{ cm} = 32.1 \text{ ft} \quad (13.8)$$

in caliber (after diameter) and

$$L_{III} = 1500 \text{ cm} = 49.3 \text{ ft} \quad (13.9)$$

in length.

The propellant tanks have a volume $W_{p,III}/\sigma_{av} = 8.3 \cdot 10^7/1.295 = 6.4 \cdot 10^7$ cm^3 and occupy a body section of approximately 150 cm = 4.9 ft in length. We assume a length of the rocket motor of 300 cm and a length of the pump and valve compartment of 200 cm. Then there remains an ogival component with a length of 1500 - 150 - 300 - 200 = 850 cm = 27.9 ft and a bottom diameter of 750 cm = 24.6 ft for the cargo and pilot's compartments.

The wing area has been determined in Section 6 as follows

$$S_W = 3.68 \cdot 10^6 \text{ cm}^2 = 3960 \text{ sq ft.} \quad (13.10)$$

An "all-wing" design offers the most favorable solution to reconcile these wing dimensions with the hull configuration as determined above. For a cord length equal to 80 percent of the hull length and a trapezoidal wing shape we compute the span as

$$b_W = 5200 \text{ cm} = 171 \text{ ft.} \quad (13.11)$$

14. Buoyancy

All three stages float when empty, as may be shown by a simple comparison between their tank volumes and their empty weights.

15. Landing of the Boosters

a. Parachutes

To keep the 'chutes for the two boosters within reasonable dimensions, it is advisable to permit a high velocity of descent and to annihilate by power rockets the residual velocity immediately prior to impact. This measure also proves favorable from the weight standpoint.

For terminal velocity of descent for both boosters of

$$V_t = 5 \cdot 10^3 \text{ cm/sec} \quad (15.1)$$

the required projected 'chute area for the first booster is computed as

$$A_{p,I} = (2 \cdot g_0 \cdot W_{E,I})/(C_D \cdot \gamma_0 \cdot V_t^2) = (2.981 \cdot 7 \cdot 10^8)/(1.3 \cdot 1.293 \cdot 10^{-3} \cdot 52 \cdot 10^{-6})$$
$$= 3.26 \cdot 10^7 \text{ cm}^2 = 35000 \text{ sq ft} \quad (15.2)$$

corresponding to a 'chute diameter

$$D_{p,I} = 6.45 \cdot 10^3 \text{ cm} = 212 \text{ ft.} \quad (15.3)$$

The drag coefficient assumed in this case is $C_D = 1.3$.

Likewise the 'chute area for the second booster is

$$A_{p,II} = (2 \cdot g_0 \cdot W_{E,II})/(C_D \cdot \gamma_0 \cdot V_0^2) = 3.26 \cdot 10^7 \text{ cm}^2 = 35000 \text{ sq ft} \quad (15.4)$$

and the 'chute diameter is

$$D_{p,II} = 2.04 \cdot 10^3 \text{ cm} = 67 \text{ ft.} \quad (15.5)$$

A computation of the deceleration paths shows that the 'chute for the first booster requires a maximum load factor $N_{max} = 6.03$ g, and for the second booster $N_{max} = 8.1$ g (see Table XVI and XVII). For temperature reasons the canopies of both 'chutes must be of steel mesh and parachute shroud lines of steel cable. With the aforementioned load factors the weight of the first booster is

$$W_{p,I} = 85 \text{ t} = 85 \cdot 10^6 \text{ g} \quad (15.6)$$

and that for the second booster

$$W_{p,II} = 3.8 \text{ t} = 3.8 \cdot 10^6 \text{ g.} \quad (15.7)$$

The surprisingly small weight for the chute of the "baby" booster is due to its much shorter shroud lines, the weight of the shroud lines being the critical factor in 'chutes of this size. The sizes of the two 'chutes also reflect on their stowage (see Section 12, a and b).

b. Braking Rockets

It proves advantageous to keep the burning time of the powder rocket brakes as short as possible in order to eliminate losses due to gravity. The required thrust is

$$F_r = (W_E/g_0) \cdot (a_r + g_0) \qquad (15.8)$$

For a burning time $t_r = 2$ sec, the required deceleration is

$$A_r = V_t/t_r = 5 \cdot 10^3/2 = 25 \cdot 10^2 \text{ cm/sec}^2. \qquad (15.9)$$

Hence, we need a thrust for the brake rockets of the first booster equal to

$$F_{r,I} = (7 \cdot 10^8/981) \cdot (25 \cdot 10^2 + 981) = 24 \cdot 10^8 \text{ g} = 2480 \text{ t} \qquad (15.10)$$

and likewise for the second booster

$$F_{r,II} = 24.8 \cdot 10^7 \text{ g} - 248 \text{ t}. \qquad (15.11)$$

Under the assumption of an exhaust velocity of the powder rockets $U_{e,r} = 2 \cdot 10^5$ cm/sec the weight of the powder rocket charge for the first booster becomes $W_{c,I} = (F_{r,I} \cdot g_0 \cdot t_r)/U_{e,r} = 24.36 \cdot 10^6$ g = 24.36 t and that for the second booster $W_{c,II} = 24.36 \cdot 10^5$ g = 2.436 t.

Under the conservative assumption that the steel tubes and nozzles require 65 percent of the weight of the charges, the total weight of the rocket brakes for the first booster becomes

$$W_{r,I} = 1.65 \cdot W_{c,I} = 40 \cdot 10^6 \text{ g} = 40 \text{ t}. \qquad (15.12)$$

For the second booster it is

$$W_{r,II} = 1.65 \cdot W_{c,II} = 4 \cdot 10^6 \text{ g} = 4 \text{ t}. \qquad (15.13)$$

The entire landing auxiliaries ('chutes plus rockets) of the first booster therefore requires weight-wise

$$W_{a,I} = 85 + 40 = 125 \text{ t} = 125 \cdot 10^6 \text{ g} \qquad (15.14)$$

equal to 18 percent of its empty weight of 700 t.

The landing auxiliaries of the second booster preempt

$$W_{a,II} = 3.8 + 4 = 7.8 \text{ t} = 7.8 \cdot 10^6 \text{ g} \qquad (15.15)$$

equal to 11 percent of its empty weight of 70 t.

c. Deceleration Paths (Procedure of Calculation)

The paths of deceleration of both boosters are to be determined by numerical integration.
The deceleration in the horizontal plane X is

$$\ddot{X} = [(C_D \cdot A_p)/(2 \cdot W_E)] \cdot \gamma \cdot V^2 \cdot (V_X/\sqrt{V_X^2 + V_y^2}) \qquad (15.16)$$

and in the vertical plans y

$$\ddot{y} = [(C_D \cdot A_p)/(2 \cdot W_E)] \cdot \gamma \cdot V^2 \cdot [(V_y/\sqrt{V_X^2 + V_y^2}) \pm (g_0 \cdot C_r)] \qquad (15.17)$$

where C_r the "centrifugal reduction factor", Equation 10.2.

The ratio of 'chute area A_p to empty weight W_E is identical for both boosters. Thus, for a drag coefficient $C_D = 1.4$, valid in the supersonic regime, we have for both deceleration paths

$$\ddot{X} = 3.26 \cdot 10^{-2} \cdot \gamma \cdot V^2 \cdot (V_X/\sqrt{V_X^2 + V_y^2}) \qquad (15.18)$$

$$\ddot{y} = 3.26 \cdot 10^{-2} \cdot \gamma \cdot V^2 \cdot [(V_y/\sqrt{V_X^2 + V_y^2}) \pm (g_0 \cdot C_r)] \qquad (15.19)$$

The relation

$$N = (3.26 \cdot 10^{-2} \cdot \gamma \cdot V^2)/g_0 \qquad (15.20)$$

gives the load factor of the 'chutes.

d. Deceleration Paths (Results)

Differential equations (15.18) and (15.19) have been integrated numerically after Runge and Kutta. Results are compiled in Table XVI and XVII.

First Booster

Initial conditions:

Cut-off velocity $V_I = 2.35 \cdot 10^5$ cm/sec
Cut-off altitude $y_I = 4 \cdot 10^6$ cm

Flight path angle at cut-off $\varphi_I = 20.5°$

Table XVI: Deceleration Path of First Booster

Step	$\Sigma\,\Delta t$ sec	$V \cdot 10^{-2}$ cm/sec	$y \cdot 10^{-5}$ cm	φ degrees:minutes	N g	$X \cdot 10^{-5}$ cm	Remarks
1	10	2,350	40.60	20:30	6.03	20.28	$N_{max} = 6.03$ g
2	20	1,994	47.69	18:3	1.87	38.56	
3	30	1,837	53.17	15:17	0.90	55.82	
4	40	1,741	57.42	12:16	0.61	72.58	
5	50	1,675	60.58	9:5	0.42	88.94	
6	60	1,626	62.72	5:46	0.32	104.97	
7	70	1,591	63.85	2:20	0.27	120.74	
8	90	1,564	64.02	-1:10	0.26	151.50	$y_{max} = 64.02 \cdot 10^{-5}$ cm
9	110	1,524	61.49	8:16	0.31	180.99	
10	130	1,484	55.42	15:26	0.52	208.42	
11	150	1,397	45.97	22:39	1.10	231.34	
12	160	1,095	34.76	30:23	3.13	239.27	
13	170	793	29.70	35:27	3.99	244.28	
14	180	504	25.71	42:17	3.02	247.10	
15	190	324	22.71	51:35	2.01	248.61	
16	200	232	20.38	62:28	1.48	249.00	

Continuation of this computation leads to impact at a time

$$\Sigma\Delta t = 400 \text{ sec} = 6 \text{ min } 40 \text{ sec} \tag{15.21}$$

after take-off, at a horizontal distance of $X_{tot,I} = 254 \cdot 10^5$ cm at the point of cut-off.

The cut-off distance being $X_L = 50 \cdot 10^5$ cm, the total distance between take-off and landing of the first booster is found to be

$$X_{L,I} = X_{tot,L} + X_I = 304 \cdot 10^5 \text{ cm} = 189 \text{ miles.} \tag{15.22}$$

Second Booster

Initial condition:

Cut-off velocity $V_{II} = 6.42 \cdot 10^5$ cm/sec

Cut-off altitude $y_{II} = 6.4 \cdot 10^6$ cm

Flight path angle at cut-off $\varphi_{II} = 2.5°$

Table XVII: Deceleration Path of Second Booster

Step	$\Sigma\Delta t$ sec	$V \cdot 10^{-2}$ cm/sec	$y \cdot 10^{-5}$ cm	φ deg.:min.	N G	$X \cdot 10^{-5}$ cm	Remarks
1	5	6,420	64.0	+2:30	2.74	31.8	
2	10	6,289	65.3	2:25	2.23	63.0	
3	15	6,183	66.4	2:16	1.85	93.4	
4	20	6,086	67.5	2:5	1.59	123.4	
5	30	6,008	68.5	1:55	1.19	182.3	
6	40	5,891	70.2	1:37	0.97	240.2	
7	50	5,796	71.4	1:11	0.83	297.3	
8	60	5,714	72.1	0:43	0.78	353.7	
9	70	5,638	72.3	0:0	0.76	409.3	$Y_{max} = 72.3 \cdot 10^5$ cm
10	80	5,565	72.0	-0:16	0.78	464.2	
11	90	5,489	71.2	0:47	0.88	518.2	
12	100	5,402	69.9	1:20	1.07	571.2	
13	110	5,300	68.1	1:55	1.40	622.8	
14	120	5,173	65.8	2:31	1.86	672.5	

Table XVII: Deceleration Path of Second Booster (continued)

Step	$\Sigma\Delta t$ sec	$V \cdot 10^{-2}$ cm/sec	$y \cdot 10^{-5}$ cm	φ deg.:min.	N G	$X \cdot 10^{-5}$ cm	Remarks
15	130	4,984	63.1	3:11	2.48	719.8	
16	140	4,745	59.9	3:55	3.58	763.6	
17	150	4,339	56.2	4:47	5.12	802.0	
18	160	3,861	52.2	5:56	6.93	833.6	
19	170	3,194	48.1	7:28	8.10	857.3	$N_{max} = 8.1$ g
20	180	2,402	44.1	9:40	7.86	873.4	
21	190	1,642	40.4	13:7	6.02	883.7	
22	200	1,080	37.1	17:57	3.88	890.4	
23	210	731	34.1	24:20	2.65	894.7	

Continuation of this computation leads to impact at a time $\Sigma\Delta t = 480$ sec = 8 minutes after take-off, at a horizontal distance of $X_{tot,II} = 925 \cdot 10^5$ cm from the point of cut-off.

The cut-off distance being $X_{II} = 534 \cdot 10^5$ cm, the total distance between take-off and landing of the second booster is found to be $X_{L,II} = X_{tot,II} + X_{II} = 1459 \cdot 10^5$ cm = 906 miles.

Fig. 4 shows the tracks of powered ascent of all three *Sirius* stages and the deceleration path of the two boosters.

B. LUNETTA

16. Lunetta's Orbit (Also Orbit of Departure for Operation Mars)

To facilitate a scheduled ferry service, it is necessary to chose a period of revolution which is a unit fraction of 24 hours. Thus

$$T_1 = 2 \text{ hours} = 7200 \text{ sec} \qquad (16.1)$$

has been chosen.

Equation (5.2) yields $\sqrt{R_{s,E}{}^3} = (7.2 \cdot 10^3)/(3.13 \cdot 10^{-10}) = 2.3 \cdot 10^{-13}$ and

$$R_{s,E} = 8.11 \cdot 10^8 \text{ cm} = 5040 \text{ miles} \qquad (16.2)$$

as the distance of the orbit from the Earth's center. The altitude of the orbit above the Earth's surface is

$$y_{s,E} = R_{s,E} - R_E = 173 \cdot 10^8 \text{ cm} = 1075 \text{ miles.} \qquad (16.3)$$

The circular velocity in the orbit is

$$V_{circ,1} = (2 \cdot R_{s,E} \cdot \pi)/T_1 = 7.07 \cdot 10^5 \text{ cm/sec} = 4.40 \text{ miles/sec.} \qquad (16.4)$$

17. Wheel Size and RPM

The centrifugal acceleration in the rim is to be 0.3 g = 294 cm/sec^2.

Thus $V_r{}^2/r_L = 294$ cm/sec^2.

Since the peripheral velocity of the rim is $V_r = (2 \cdot r_L \cdot \pi)/\tau_L$, the period of revolution becomes $\tau_L = (2\pi/\sqrt{294}) \cdot \sqrt{r_L} = 0.365 \cdot \sqrt{r_L}$.

For a wheel radius $r_L = 3 \cdot 10^3$ cm, thus

$$\tau_L = 20 \text{ sec.} \qquad (17.1)$$

The wheel diameter at the flooring of the rim is $D_L{}^* = 2 \cdot r_L = 6 \cdot 10^3$ cm = 191 ft and the total diameter approximately

$$D_L = 200 \text{ ft} \qquad (17.2)$$

18. Power Generating Plant

The generator is to furnish 35 kw. If an overall efficiency of turbine and generator of $\eta_T = 30$ percent is assumed, the steam boiler must be continually heated by a solar radiation

$$P_i = 35/0.3 = 117 \text{ kw} = 117 \cdot 10^3 \text{ watts.} \qquad (18.1)$$

The solar constant in the Earth's orbit is

$S_E = 0.1325$ Watts/cm^2. (18.2)

Hence the required reflecting surface becomes

$A_r = P_i/S_E = 8.84 \cdot 10^5$ cm = 950 sq ft. (18.3)

If this parabolic mirror is circular in cross section, its diameter is

$D_r = 1.06 \cdot 10^3$ cm * 35 ft (18.4)

The amount of 70 percent of the radiation energy not being transformed into useful electrical power is to be re-radiated into space from the surface of the condenser. Thus

$P_0 = 0.7 \cdot 117 \cdot 10^3 = 82 \cdot 10^3$ Watts. (18.5)

For a condenser pressure $p_k = 100$ g/cm^2 the temperature of saturated steam is $T_s = 319$ °K. To maintain continuous heat transfer, the condenser walls must be slightly cooler than the steam, e.g., $T_k = 313$ °K. According to the Stefan-Boltzmann Law, we have $P_0 = 5.76 \cdot 10^{-12} \cdot \varepsilon \cdot T_k^4 A_k = 82 \cdot 10^3$ Watts and the required condenser surface for an emissivity $\varepsilon = 0.9$ becomes

$A_K = (82 \cdot 10^3)/(5.76 \cdot 10^{-12} \cdot 0.9 \cdot 313^4) = 1.66 \cdot 10^6$ cm^2 = 1790 sq ft. (18.6)

If this condenser surface is distributed over 20 tubular spokes of total length of 1300 ft, the outer diameter of each spoke must be

$D_s = 1790/(1300 \cdot \pi) = 0.44$ ft = 13.4 cm = 5.3 in. (18.7)

19. Communications Trips of the "Busy Bees" along Lunetta's Orbit

Communication trips between two stations circling in Lunetta's orbit must be conducted along elliptical orbits, one focus of which is located in the Earth's center. In principle, such trips can also be made along parabolic or hyperbolic segments of arc, but such routs require very large velocity increments and are extremely uneconomical.

Elliptical communication trips can be conducted according to the following four methods:

a. Over an elliptical segment of arc whose perigee is located at the mid-point between the loci of departure and arrival and which lies inside the orbit of the stations (see Fig. 6). Since the coasting time through such an elliptical segment is, according to Kepler's Third Law, less than the flight time of the two stations through the same radius vector angle, such routs are suitable for communication trips to a leading station (e.g., from Lunetta to the Observatory).

b. Over an elliptical segment of arc whose apogee is located at the mid-point between departure and arrival points and outside the orbit of the two stations. The coasting time through such an elliptical segment is necessarily longer than the flight time of the two stations through the same radius vector angle, hence such routs are suitable for communication trips to a trailing station (e.g., from Observatory to Lunetta).

c. and d. Over a full ellipse

If the stations orbit intercepts this ellipse at its apogee, so that its perigee lies inside the circular orbit, the ellipse has a shorter period of revolution than the orbit. Consequently, it leads the busy bee after one complete revolution to a leading station, (see Fig 5, track A).

If the stations orbit intercepts the ellipse at the perigee, so that its apogee lies outside the circular orbit, the ellipse has a longer period of revolution than the orbit. Hence it leads the bee after one complete revolution to a trailing station (see Fig. 5, track B).

Trips according to scheme c.) and d.) require always slightly more or less than two hours which is the period of revolution in the circular orbit, and they are suitable particularly for communication between two remote stations.

For trips in accordance with schemes a.) and b.), the coasting time depends chiefly on the eccentricity of the chosen ellipse. The faster the trip is to be made, the greater are the velocity increments required at departure and arrival.

Example 1:

Communication trip according to scheme a.) from Lunetta to the Observatory traveling 10 miles ahead of Lunetta.

The distance between the two stations is assumed to be

$$S = 10 \text{ miles} = 16.2 \cdot 10^5 \text{ cm} \tag{19.1}$$

i.e., the Observatory would pass any given point in the orbit

$$t = s/V_{circ,1} = 16.2/7.07 - 2.989 \text{ sec} \tag{19.2}$$

prior to the passing of Lunetta.

At departure ($\tau = 0$), Lunetta is located at point I_0, and the Observatory at point II_0, (see Fig. 6). After a flight time τ of the busy bee, Lunetta will be at $I\tau$ and the Observatory at $II\tau$. The elliptical track of the bee must intersect the circular orbit at I_0 and $II\tau$.

The coasting time τ of the bee will be 10 minutes = 600 sec. The radius vector angle of the elliptical segment of arc is

$$\theta = (V_{circ,1}/R_{s,E}) \cdot (\tau + t) = 0.5256 \text{ radians} = 30.144^{\circ}. \tag{19.3}$$

Flight time through the elliptical segment is determined by the general equation

$$\tau = \sqrt{[(1 + e\cos(\theta/2))/(g \cdot R_E^2)] \cdot [R_{s,E}/(1 - e^2)]^3} \cdot [\pi \cdot (1 + e\cos(\theta/2)) - 2e\sqrt{1 - e^2} \cdot \sin(\theta/2) - 2(1 + e\cos(\theta/2)) \cdot \arcsin((e + \cos(\theta/2))/(1 + e\cos(\theta/2)))] \tag{19.4}$$

where e represents the numerical eccentricity. For $\theta = 30.144^{\circ}$, the relationship between τ and e is shown in Table XVIII.

Table XVIII: Eccentricity e as Function of Flight Time t

e	0	0.005	0.01	0.015	0.02	—
τ	602.28	600.69	599.11	597.57	596.42	sec

Upon graphical interpolation of these figures, it follows that a numerical eccentricity $e = 0.0072$ is required for the desired flight time $\tau = 600$ sec.

The velocity in the ellipse at points I_0 and $II\tau$ is

$$V_{I,0} = V_{II,\tau} = \sqrt{(g_0 + R_E^2/R_{S,E}) \cdot [((e^2 - 1)/(1 + e\cos(\theta/2))) + 2]} \tag{19.5}$$

The angle α, at which orbit and ellipse intersect at these points, is given by the equation

$$\cos\alpha = \sqrt{(g_0 \cdot R_E^2 \cdot p)/(R_{S,E}^2 \cdot V_{I,0}^2)} \tag{19.6}$$

where

$$p = R_{S,E} \cdot [1 + e\cos(\theta/2)] = 8.16 \cdot 10^8 \text{ cm} \tag{19.7}$$

represents the parameter of the ellipse. Thus $\alpha = 0.086^{\circ}$.

We can now draft a vector diagram of the circular and the elliptical velocities at point I_0, (Fig. 6). In this manner we find that for throwing the bee into the elliptical path a velocity increment

$$\Delta V = 26.59 \cdot 10^2 \text{ cm/sec} = 59.5 \text{ MPH} \tag{19.8}$$

is necessary. This increment is to be imposed at an angularity of

$$\beta = 23.46^{\circ} \tag{19.9}$$

toward the Earth's surface.

The same figures apply to the arrival at the Observatory at point $II\tau$.

Example 2:

Communication trip of a Bee from Lunetta to the Control Station, coasting 1200 miles ahead of Lunetta.

Distance between the two stations is

$$S = 1200 \text{ miles} = 1935 \cdot 10^5 \text{ cm} \tag{19.10}$$

Hence, the Control Station would pass any fixed point in orbit

$$T = S/V_{circ,1} = 1935/7.07 = 274 \text{ sec} \tag{19.11}$$

prior to the passing of Lunetta.

By this amount the period of revolution of the communication ellipse must be shorter than that in the circular orbit. The period of revolution of the ellipse must therefore be

$$T = 7200 - 274 = 6926 \text{ sec.} \tag{19.12}$$

In view of Equation 5.2, $\sqrt{a^3} = T/(3.13 \cdot 10^{-10}) = 2213 \cdot 10^{10}$ and the length of the major semi-axis becomes

$$a = 7.878 \cdot 10^{10} \text{ cm}. \quad (19.13)$$

Eq. (2.2) gives $a = (R_p + R_{S,E})/2$.

Hence the perigeeal distance from the Earth's center equals

$$R_p = 2a - R_{S,E} = 7.646 \cdot 10^8 \text{ cm} \quad (19.14)$$

Corresponding to an altitude of the perigee of

$$y_P = R_p - R_E = 1.266 \cdot 10^8 \text{ cm} = 786 \text{ miles} \quad (19.15)$$

above the Earth's surface.

Eq. (2.4) and (4.1) yield an apogeal velocity of this ellipse, equal to $V_a = 6.93 \cdot 10^5$ cm/sec.

For entering the ellipse at the point of departure, the velocity in the circular orbit must be reduced by

$$\Delta V = V_{circ,4} - V_a = 0.14 \cdot 10^5 \text{ cm/sec}. \quad (19.16)$$

When approaching the Control Station, the bee must readapt to the circular velocity in the orbit. Hence, the communication trip requires a total velocity increment

$$2 \cdot \Delta V = 0.28 \cdot 10^5 \text{ cm/sec}. \quad (19.17)$$

Remarks: A noteworthy peculiarity of this traveling technique is that the busy bee leaves Lunetta in a direction directly away from the destination.

C. PHYSICAL DATA FOR MARS VOYAGE

Table XIX: Physical Data for Mars Voyage

	Earth			Mars		
	Symbol	English Units	Physical Units	Symbol	English Units	Physical Units
Average distance from sun	a_E	92.9 Mill mi	$1.495 \cdot 10^{13}$cm	a_M	141.5 Mill mi	$2.28 \cdot 10^{13}$ cm
Distance from Sun at perihelion	$a_{E,min}$	91.3 Mill mi	$1.47 \cdot 10^{13}$ cm	$A_{M,min}$	128.3 mill mi	$2.06 \cdot 10^{13}$ cm
Distance from Sun at aphelion	$a_{E,max}$	*94.4 Mill mi*	$1.52 \cdot 10^{13}$ *cm*	$A_{M,max}$	*154.8 mill mi*	$2.49 \cdot 10^{13}$ cm
Period of revolution	T_E	365 days	$3.156 \cdot 10^7$ sec	T_M	687 days	$5.94 \cdot 10^7$ sec
Mean orbital velocity	V_E	18.5 mi/sec	$29.8 \cdot 10^5$ cm/sec	V_M	15.0 mi/sec	$24.1 \cdot 10^5$ cm/sec
Radius of planet	R_E	3,963 mi	$6.380 \cdot 10^8$ cm	R_M	2,110 mi	$3.390 \cdot 10^8$ cm
Parabolic escape velocity at surface	$V_{P,E}$	6.95 mi/sec	$11.18 \cdot 10^5$ cm/sec	$V_{P,M}$	3.13 mi/sec	$5.04 \cdot 10^5$ cm/sec
Circular velocity at surface	$V_{circ,E}$	4.91 mi/sec	$7.90 \cdot 10^5$ cm/sec	$V_{circ,M}$	2.21 mi/sec	$3.56 \cdot 10^5$ cm/sec
Radius of satellite orbit	$R_{S,E}$	5,040 mi	$8.110 \cdot 10^8$ cm	$R_{S,M}$	2,730 mi	$4.39 \cdot 10^8$ cm
Circular velocity of this satellite orbit	$V_{cir,1}$	4.40 mi/sec	$7.07 \cdot 10^5$ cm/sec	$V_{circ,2}$	1.95 mi/sec	$3.14 \cdot 10^5$cm/sec
Period of revolution of satellite orbit	T_1	2 h 0 min 0 sec	$7.2 \cdot 10^3$ sec	T_2	2 h 26 min 24 sec	$8.78 \cdot 10^3$ sec
Gravitational acceleration at surface	g_0	$1 g_0$	981 cm/sec²	g_M	0.38 g_0	373 cm/sec²
Solar constant	S_E	0.1325 W/cm²	0.1325 W/cm²	S_M	0.0568 W/cm²	0.0568 W/cm²
Planet's albedo	Alb_E	?	?	Alb_M	27 percent	0.27
Albedo of planet's atmosphere*	$Alb_{a,E}$	74 percent	0.74	$Alb_{a,M}$	17 percent	0.17
Atmospheric pressure at surface*	p_0	760 mm Hg	1000 g/cm²	$P_{0,M}$	64 mm Hg	84 g/cm²
Atmospheric density at surface*	γ_0	0.0806 lb/c ft	$1.293 \cdot 10^{-3}$ g/cm³	γ_{0M}	0.0067 lb/c ft	$1.1 \cdot 10^{-4}$ g/cm³
Boiling point of water at surface*	—	212 °F	100 °C	—	111 °F	44 °C
*Mean yearly temperature**	—	*60 °F*	*16 °C*	—	48 °F	9 °C
Altitude increment, at which atmospheric pressure decreases by a factor of 10*	—	11.2 mi	$18 \cdot 10^5$ cm	—	29.3 mi	$47.15 \cdot 10^5$ cm

* Values for Mars are based on indirect conclusions from available measuring data and require corroboration.

D. THE MARS VESSELS

20. Summary of Principle Data

Table XX: Summary of Principle Data, Mars Vessels

	Symbol	Eng. Units	Physical Units
Thrust	F	200 t	$20 \cdot 10^7$ g
Total Propellant Supply:			
Passenger Vessels	$W_{p,tot,p}$	3,662.5 t	$3.6625 \cdot 10^9$ g
Cargo Vessels	$W_{p,tot,c}$	3,306 t	$3.306 \cdot 10^9$ g
Rate of Propellant Consumption	6_p	0.702 t/sec	$0.702 \cdot 10^6$ g/sec
Exhaust Velocity	V_e	9,200 ft/sec	$2.8 \cdot 10^5$ cm/sec
Nozzle Exit Pressure	P_e	0.142 lbs/sq in	10 g/cm
Nozzle Exit Area	A_e	798 sq ft	$740 \cdot 10^3$ cm^2
Overall Length:			
Passenger Vessels	$L_{tot,p}$	134 ft	$41 \cdot 10^2$ cm
Cargo Vessels (incl boats)	$L_{tot,c}$	210 ft	$64 \cdot 10^2$ cm
Maximum Diameter:			
Passenger Vessels	$D_{tot,p}$	95 ft	$29 \cdot 10^2$ cm
Maneuver 1:			
Initial Weight	$W_{0,1}$	3,720 t	$3.720 \cdot 10^9$ g
Propellant Supply (incl. 3.5% velocity reserve)	$W_{p,1}$	2,814 t	$2.814 \cdot 10^9$ g
Final Weight	$W_{1,1}$	906 t	$9.06 \cdot 10^8$ g
Burning Time	t_1	66 min 5 sec	3,965 sec
Maneuver 2:			
Initial weight	$W_{0,2}$	902 t	$9.02 \cdot 10^8$ g
Propellant supply (incl 10% velocity reserve)	$W_{p,2}$	492 t	$4.92 \cdot 10^8$ g
Final weight	$W_{1,2}$	410 t	$4.10 \cdot 10^8$ g
Burning time	t_2	10 min 58 sec	658 sec
Maneuver 3: (passenger vessels only)			
Initial Weight	$W_{0,3}$	408 t	$4.08 \cdot 10^8$ g
Propellant supply (incl. 10% velocity reserve)	$W_{p,3}$	222 t	$2.22 \cdot 10^8$ g
Final weight	$W_{1,3}$	186 t	$1.86 \cdot 10^8$ g
Burning time	t_3	4 min 58 sec	298 sec
Maneuver 4: (passenger vessels only)			
Initial Weight	$W_{0,4}$	185 t	$1.85 \cdot 10^8$ g
Propellant Supply (inc 10% velocity reserve)	$W_{p,4}$	134.5 t	$1.345 \cdot 10^8$ g
Final Weight	$W_{1,4}$	50.5 t	$0.505 \cdot 10^8$ g
Burning Time	t_4	2 min 43 sec	163 sec

21. Departure from Earth (Maneuver 1)

The major semi-axis of the outbound and homebound voyaging ellipses is (See Fig. 7)

$$a = (a_E + a_M)/2 = 1.8875 \cdot 10^{13} \text{ cm.} \tag{21.1}$$

From Equation 2.4 it follows that the perihelion velocity of these ellipses equals

$$V_p = V_E\sqrt{2 - (a_E/a)} = 29.8 \cdot 10^5 \sqrt{2 - (1.495/1.8875)} = 32.83 \cdot 10^5 \text{ cm/sec.} \tag{21.2}$$

The velocity difference, by which the outbound ship must exceed Earth's speed is, therefore

$$V_{d,1} = V_p - V_E = 3.03 \cdot 10^5 \text{ cm/sec} \tag{21.3}$$

With this residual velocity in the direction of Earth's orbiting around the Sun, the ship must leave the Earth's gravitational field. The velocity increment to be produced in the orbit of departure in order to do this may be determined from the following principle.

The kinetic energy per unit of mass at leaving the orbit of departure $\frac{1}{2} \cdot V_{tot,1}^2$ must be equal to the sum of the residual energy $\frac{1}{2} \cdot V_{d,1}^2$ and the parabolic escape energy $\frac{1}{2} \cdot V_{p,1}^2$ referring to the geocentric distance of the departure orbit. Since

$$V_{p,1}^2 = 2 \cdot V_{circ,1}^2 \tag{21.4}$$

we obtain

$$(V'_{tot,1})^2 = V_{p,1}^2 + V_{d,1}^2 = 2 \cdot 7.07^2 \cdot 10^{10} + 3.03^2 \cdot 10^{10} = 108 \cdot 10^{10}\ \text{cm}^2/\text{sec}^2 \tag{21.5}$$

and

$$V'_{tot,1} = 10.38 \cdot 10^5\ \text{cm/sec} \tag{21.6}$$

The velocity of the ship in the departure orbit prior to maneuver 1 is as high as $V_{circ,1} = 7.07 \cdot 10^5$ cm/sec. Hence, the rocket motor is called upon to produce a velocity increment

$$V'_4 = V'_{tot,1} - V_{circ,1} = 3.31 \cdot 10^5\ \text{cm/sec} \tag{21.7}$$

With a cut-off velocity $V'_{tot,1}$ the ship commences coasting along an "escape hyperbola" whose asymptote must be parallel to the orbital flight direction of the Earth in order to induce the ship into the succeeding voyaging ellipse. Such hyperbolic tracks result both after the two departure maneuvers 1 and 3 and prior to the two adaptation maneuvers 2 and 4.

a. The Power Track

The computation of $V'_{tot,1}$ and V'_1 was based upon the simplifying assumption that the velocity increment V'_1 is achieved instantaneously, so that no climbing against the Earth's gravitational field is performed during the power maneuver proper. It can be shown that this simplification is admissible for an approximate calculation of maneuvers 2, 3 and 4, where accelerations have already markedly increased and burring times and power tracks are accordingly short. For maneuver 1, however, with its huge initial weight, such a calculation leads to considerable errors. Hence, the length of the powered track is to be taken into consideration.

The powered flight path of maneuver 1 has been determined by numerical integration in the following manner:

According to Lagrange's Equation of Energy we have

$$d/dt \cdot \partial_E/\partial_{\dot{q}i} - \partial_E/\partial_{qi} = K_q \tag{21.8}$$

where: q is a "general coordinate"

i is subscript of the current coordinate number

E is energy

For the kinetic energy we have (see Fig. 8)

$$E = \tfrac{1}{2}\, mV^2 = \tfrac{1}{2}\, [r^2 \cdot \dot{\theta}^2 \cdot \dot{r}^2)]. \tag{21.9}$$

Hence

$$\partial E/\partial r = mr\dot{\theta}^2 \qquad \partial E/\partial \dot{r} = m\dot{r} \qquad d/dt\ (\partial E/\partial \dot{r}) = m\ddot{r} \tag{21.10}$$

$$\partial E/\partial \theta = 0 \qquad \partial E/\partial \dot{\theta} = mr^2\dot{\theta} \qquad d/dt\ (\partial E/\partial \dot{\theta}) = mr^2\ddot{\theta} + m\dot{r}\dot{\theta}. \tag{21.11}$$

For the forces we have

$$\delta \cdot W_r = F_r \cdot \delta_r \tag{21.12}$$

$$\delta \cdot W_\theta = F_\theta \cdot r \cdot \delta_\theta \tag{21.13}$$

where: δW_r and δW_θ are the "virtual work" in r and θ directions,

δ_r and δ_θ are the "virtual displacements."

F_r and F_θ are the generalized forces acting upon the ship in the direction indicated by a local plumb-bob and normal thereto.

Hence

$$\ddot{r} - r\dot{\theta}^2 = F_r/m \tag{21.14}$$

$$r\ddot{\theta} = 2\dot{r}\dot{\theta} = F_\theta/m \tag{21.15}$$

where m represents the instantaneous mass of the ship.

Let F be the rocket thrust, then (see Fig. 8)

$$F_r = F \bullet \cos\vartheta - mg_r = F\dot{r}/V - mg_r \tag{21.16}$$

$$F_\theta = F \bullet \sin\vartheta = Fr\dot{\theta}/V \tag{21.17}$$

where

$$g_r = g_0 \bullet R_E^2/r_2 \tag{21.18}$$

the local value of gravitational acceleration.

Thus we obtain the equations of motion for the calculation steps

$$\ddot{r} = (P\dot{r}/mV) - g_r + r\dot{\theta}^2 \tag{21.19}$$

$$r\ddot{\theta} = (Pr\dot{\theta}/mV) - 2\dot{r}\dot{\theta} \tag{21.20}$$

$$V = \sqrt{(r\dot{\theta}^2) + \dot{r}^2} \tag{21.21}$$

Herein it has been assumed that the gyro control system keeps the thrust axis of the ship currently in the flight path tangent, what is easily possible by means of a suitable programming device.

The numerical integration has to start with the conditions given by the departure orbit:

$$t_0 = 0 \qquad r_0 = R_{s,E} \qquad \dot{r}_0 = 0 \qquad \theta_0 = 0 \qquad \dot{\theta}_0 = V_{circ,1}/R_{S,E} \tag{21.22}$$

Furthermore, the following data for the ship proper have been used:

Initial weight: $W_{0,1} = 3.720 \bullet 10^9$ g

Propellant supply for maneuver: $W_{p,1} = 2.814 \bullet 10^9$ g

Rate of propellant flow: $\dot{W}_p = 0.702 \bullet 10^6$ g/sec

Thrust: $F = 20 \bullet 10^7$ g

The thus resulting characteristics of the flight track are compiled in Table XXI. Herein represent (see Fig. 9):

T = time

V = velocity

R = distance from the Earth's center

θ = polar angle, measured against the direction indicated by a plumb-bob at the departure point

φ = flight path angle against the local horizontal

Table XXI: Characteristics of Powered Flight Track Maneuver I

$\Sigma\ \Delta t$ sec	$V \bullet 10^{-5}$ cm/sec	$r \bullet 10^{-8}$ cm	θ degrees	Φ degrees
0	7.07	8.11	0	0
500	7.32	8.13	25.6	1.4
1,000	7.49	8.33	51.5	4.3
1,500	7.53	8.72	76.7	8.5
2,000	7.46	9.45	99.8	13.5
2,500	7.36	10.49	120.2	19.0
3,000	7.31	11.85	137.9	24.9
3,500	7.42	13.56	152.6	31.0
4,000	7.80	15.68	165.0	37.3

It is noteworthy that there is a transitory decrease in V. This is accounted for by the variable ratio of the ship's acceleration to the retarding component of the gravitational acceleration.

The total available burning time for maneuver 1 is

$$T_1{}^* = W_{P,1}/\dot{W}_P = (2.814/0.702) \bullet 10^3 = 4008 \text{ sec.} \tag{21.23}$$

The velocity thus attainable is secured by continuation of above calculation, and is equal to $V^*_{tot,1} = 7.805 \cdot 10^5$ cm/sec. The required terminal velocity $V_{tot,1}$ is already reached at a geocentric distance

$$r_c = 15.56 \cdot 10^8 \text{ cm} \tag{21.24}$$

which is passed after

$$t_c = 3965 \text{ sec.} \tag{21.25}$$

At this time the ship has a polar angle

$$\theta_c = 164.0° \tag{21.26}$$

and a flight path angle

$$\varphi_c = 36.8° \tag{21.27}$$

Owing to the considerable increase of potential energy during the powered flight, $V_{tot,1}$ is markedly less than the terminal velocity which would be required in the orbit of departure proper, where $V'_{tot,1} = 10.38 \cdot 10^5$ cm/sec (see Equation 21.6). It follows from Equations 21.4 and 21.5 that at a geocentric distance $r_c = 15.56 \cdot 10^8$ cm the required terminal velocity equals

$$V_{tot,1} = 7.780 \cdot 10^5 \text{ cm/sec.} \tag{21.28}$$

The propellant reserve for maneuver 1 therefore corresponds to a burning time $t_{res,1} = 4008 - 3965 = 43$ sec and the reserve in terms of potential velocity increment is

$$V_{res,1} = (7.805 - 7.780) \cdot 10^5 = 25.10^2 \text{ cm/sec} \tag{21.29}$$

Corresponding

$$0.025/(7.780 - 7.07) = 25/710 = 3.5 \text{ percent} \tag{21.30}$$

Fig. 9 shows the power track of maneuver 1 with the subsequent escape hyperbola.

Remark: It can be shown that maneuver 1 could be carried out with a somewhat smaller initial weight, if the thrust were increased. For example, it is possible to add four additional 200-ton power plants, thereby increasing the total thrust to 1000 tons. These additional power plants could be jettisoned after maneuver 1. This measure leads, of course, to a dead weight increased by the additional power plants and by the reinforcement of tanks and of the ship's structure appropriate to the higher acceleration. But the propellant saving is sufficiently significant, so that despite this additional dead weight, the initial weight of each Mars ship could be reduced by about 10 percent. To the same extent, the volume of the entire "Space lift" could be reduced. For the sake of simplicity, this stratagem was not applied in our story.

b. The Escape Hyperbola

At the cut-off point the ship enters the un-powered escape hyperbola. (see Fig. 9). The data of this hyperbola may be determined from the four significant figures of the cut-off point as computed in the foregoing section:

$r_c = 15.56 \cdot 10^8$ cm
$V_{tot,1} = 7.780 \cdot 10^5$ cm/sec
$\theta_c = 164.0°$
$\varphi_c = 36.8°$

The polar equation of the hyperbola reads

$$r_c = p/(1 + e \cos \beta) \tag{21.31}$$

where p the parameter of the hyperbola, i.e., its ordinate in the focus β the angle between the radius vector of the cut-off point and the principle axis of the hyperbola, which is to be determined.

$$g_c = g_0 \cdot R_E^2/r_C{}^2{}^2 = 981 \cdot 6.380^2/15.56^2 = 165 \text{ cm/sec}^2 \tag{21.32}$$

is the gravitational acceleration at the cut-off point. Then the length of the parameter is

$$\rho = V_{tot,1}{}^2 \cdot \cos^2\varphi_c/g_c = (7.780^2 \cdot 10^{10} \cdot \cos^2 36.8°)/165 = 23.5 \cdot 10^8 \text{ cm.} \tag{21.33}$$

The numerical eccentricity e is

$$e = \sqrt{1 + (V_{tot,1}{}^2 - 2g_c \cdot r_c) \cdot [(V_{tot,1}{}^2 \cdot \cos^2\varphi_c)/(g_c{}^2 \cdot r_c{}^2)]} = 1.239, \tag{21.34}$$

the linear eccentricity

$$C = [e/(e^2 - 1)] \cdot \rho = 54.45 \cdot 10^8 \text{ cm,} \tag{21.35}$$

the length of the major semi-axis

$$a = [1/(e^2 - 1)] \cdot p = 43.9 \cdot 10^8 \text{ cm,} \tag{21.36}$$

and the length of the minor semi-axis

$$b = \sqrt{1/(e^2 - 1)} = \sqrt{a \cdot p} = 32.1 \cdot 10^8 \text{ cm.} \tag{21.37}$$

The angle between asymptote and principle axis is

$$\tan \alpha = b/a = 0.731; \qquad \alpha = 36° \, 10' \tag{21.38}$$

and finally the angle β

$$\cos \beta = (1/e) \cdot [(p/r_c) - 1] = 0.412; \qquad \beta = 36° \, 40'. \tag{21.39}$$

The ignition point for maneuver 1 is determined by the requirement that the asymptote of the escape hyperbola must be parallel to the Earth's orbital direction. Fig 9 gives the geometrical relation

$$\xi = \theta_c + 90 - \beta + 90 - \alpha = 242° \, 10'. \tag{21.40}$$

22. Maneuvers 2, 3 and 4

For these maneuvers the length of the power track may be disregarded in the first approximation.

a. <u>Approach to Mars (Maneuver 2)</u>

The aphelion velocity of the voyaging ellipse becomes in view of Equation 4.1

$$V_a = (a_E/a_M) \cdot V_\rho = (1.495/2.28) \cdot 32.83 \cdot 10^5 = 21.55 \cdot 10^5 \text{ cm/sec.} \tag{22.1}$$

Hence, Mars will overhaul the ship at the aphelion with a differential speed

$$V_{d,2} = V_M - V_a = 2.55 \cdot 10^5 \text{ cm/sec} \tag{22.2}$$

Since the aphelion of the voyaging ellipse is located several thousand miles inside the Martian orbit, the ship will enter a hyperbolic loop around Mars with this initial speed relative to Mars's center. The distance of the vertex of this hyperbola from the latter will be $R_{S,M} = 4.390 \cdot 10^8$ cm. According to Equation 2.3, the circular velocity at this distance becomes

$$V_{circ,2} = \sqrt{[R_M/(2 \cdot R_{S,M})] \cdot V_{\rho,M}^2} = \sqrt{(3.390/2.4390) \cdot 5.04^2 \cdot 10^{10}} = 3.140 \cdot 10^5 \text{ cm/sec} \tag{22.3}$$

where: $V_{p,M} = 5.04 \cdot 10^5$ cm/sec the parabolic escape velocity at the planet's surface;
R_m is the radius of Mars.

From Equations 21.4 and 21.5 we obtain

$$V_{tot,2} = \sqrt{2V_{circ,2}^2 \cdot V_{d,2}^2} = 5.15 \cdot 10^5 \text{ cm/sec} \tag{22.4}$$

where $V_{tot,2}$ is the velocity at the vertex of the hyperbola.

To transform the hyperbolic path into a circular orbit, this vertical velocity must be reduced to the local orbits velocity (maneuver 2). Hence, the rocket motor must decrease the ship's velocity at the vertex by the amount

$$V'_2 = V_{tot,2} - V_{circ,2} = 2.01 \cdot 10^5 \text{ cm/sec.} \tag{22.5}$$

If we provide a velocity reserve of 10 percent for maneuver 2, the weight ratio and the propellant supply must be laid out for a velocity increment

$$V_2 = 2.21 \cdot 10^5 \text{ cm/sec.} \tag{22.6}$$

The data of the approach hyperbola are determined by the initial velocity $V_{d,2}$ and the desired distance of the vertex from Mars's center. The latter is approximately equal to the radius of the satellite orbit,

$$R_{S,M} = 4.390 \cdot 10^8 \text{ cm} \tag{22.7}$$

corresponding to a height above the planet's surface of

$$y_{S,M} = R_{S,M} - R_M = 1 \cdot 10^8 \text{ cm.} \tag{22.8}$$

From the foregoing data the following values are to be determined: (See Fig. 10):

1. the distance b of the asymptote from Mars's center necessary to enter an approach hyperbola with the vertical distance $R_{S,M}$. This distance b equals the distance between the aphelion of the voyaging ellipse and Mars's orbit. The aphelion must lie inside Mars's orbit to accomplish that the

flight direction through the vertex is in the same general direction as the circumferential motion of Mars's surface facing the vertex. This measure is expedient for the re-ascent from Mars to the satellite orbit.

2. The angle α between the principle axis of the hyperbola and the asymptote.

The angle α may be determined from the relation

$$\tan \alpha = b/a = 2 \cdot V_{d,2}^2/V_{\rho,b}^2 \tag{22.9}$$

as shown in Equations 22.18 to 22.28.

Eq. (22.2) gives $V_{d,2} = 2.55 \cdot 10^5$ cm/sec.

The parabolic escape velocity at the distance b equals

$$V_{\rho,b} = V_{\rho,M} \cdot \sqrt{R_M/b} = 5.04 \cdot 10^5 \cdot \sqrt{R_M/b}. \tag{22.10}$$

If we choose tentatively

$$b = 8.80 \cdot 10^8 \text{ cm}, \tag{22.11}$$

Eq. (22.10) yields

$$V_{\rho,b} = 5.04 \cdot 10^5 \cdot \sqrt{3.390/8.80} = 3.122 \cdot 10^5 \text{ cm/sec}. \tag{22.12}$$

Hence in view of Equation 22.9

$$\tan \alpha = 2 \cdot 2.55^2/3.122^2 = 1.322; \qquad \alpha = 533^\circ\, 6'. \tag{22.13}$$

The angle between escape asymptote and approach asymptote equals

$$2\alpha = 106^\circ\, 12'. \tag{22.14}$$

The length of the major semi-axis is

$$a = b/\tan \alpha = 6.60 \cdot 10^8 \text{ cm}. \tag{22.15}$$

The linear eccentricity is

$$C = \sqrt{a^2 + b^2} = 11.00 \cdot 10^8 \text{ cm}. \tag{22.16}$$

Hence the distance of the vertex from Mars's center equals

$$R_{S,M} = C - a = (11.00 - 6.60) \cdot 10^8 = 4.40 \cdot 10^8 \text{ cm}. \tag{22.17}$$

This value checks satisfactorily with the distance of the vertex according to Equation 22.7. Consequently, the tentatively assumed value of b in Equation 22.11 is confirmed.

Remark: As has been shown by von Pirquet, Equation 22.9 may be derived as follows:
According to the principle of energy and Newton's Attraction Law

$$V_{r,V}^2 = V_{\rho,b}^2 \cdot b/R_{S,M} \tag{22.18}$$

where $V_{p,V}$ the parabolic escape velocity for the vertical distance $R_{S,M}$. Upon combining Equations 21.4 and 22.4

$$V_{tot,2}^2 = V_{p,V}^2 + V_{d,2}^2 \tag{22.19}$$

where $V_{tot,2}$ the vertical velocity. Hence

$$V_{tot,2}^2/V_{p,V}^2 = 1 + (V_{d,2}^2/V_{p,V}^2) = 1 + [\,(V_{d,2}^2/V_{p,b}^2) \cdot b/R_{S,M}]. \tag{22.20}$$

From Equations 22.16 and 22.17 it follows that

$$C^2 = a^2 + b^2 = (a + R_{S,M})^2 = a^2 + 2aR_{S,M} + R^2_{S,M} \tag{22.21}$$

and

$$b^2 = 2aR_{S,M} \cdot\ [1 + (R_{S,M}/2a)]. \tag{22.22}$$

The radius of curvature at the vertex is

$$\zeta_V = b^2/a = 2R_{S,M} \cdot\ [1 + (R_{S,M}/2a)] \tag{22.23}$$

Since

$$\zeta_V \cdot V^2_{p,V} = 2R_{S,M} \cdot V^2_{tot,2} \tag{22.24}$$

it follows from Equations 22.20 and 22.23 that

$$V_{tot,2}^2/V_{p,V}^2 = 1 + [(V_{d,2}^2/V_{p,b}^2) \cdot (R_{S,M}/b)] = 1 + R_{S,M}/2a. \tag{22.25}$$

Hence

$$(V_{d,2}^2/V_{p,b}^2) \cdot (R_{S,M}/b) = R_{S,M}/2a. \tag{22.26}$$

Thus we obtain

$$b/a = 2 \cdot (V_{d,2}^2/V_{p,b}^2) \tag{22.27}$$

and finally

$$\tan \alpha = b/a = 2 \cdot (V_{d,2}^2/V_{p,b}^2). \tag{22.28}$$

b. <u>Departure from Mars (Maneuver 3)</u>

Eqs. (22.1) to (22.6) are based on energy considerations only and therefore apply likewise to the departure from the satellite orbit around Mars. The total velocity increment determining the weight ratio and propellant supply for maneuver 3 is therefore the same as for the approach,

$$V_3 = 2.21 \cdot 10^5 \text{ cm/sec} \tag{22.29}$$

which includes a 10 percent velocity reserve.

The escape hyperbola succeeding maneuver 3 is very closely equal to the approach hyperbola of maneuver 2. The escape asymptote must be parallel to Mars's orbit but pointing in the opposite direction.

c. <u>Approach to Earth (Maneuver 4)</u>

According to Equation 21.7 a velocity increment, including a 10 percent velocity reserve, of

$$V_4 = V'_1 + 10\,\% = 3.64 \cdot 10^5 \text{ cm/sec} \tag{22.30}$$

is required. The approach hyperbola (fig. 11) is determined by the demand that the orbit of return equal the orbit of departure, i.e.,

$$R_{s.E} = 8.11 \cdot 10^8 \text{ cm}. \tag{22.31}$$

This is also the distance from the hyperbolic vertex to the Earth's center.

The velocity difference with which the returning ship overhauls the Earth at the perihelion of the voyaging ellipse is according to Equation 21.3

$$V_{d,4} = V_{d,1} = 3.03 \cdot 10^5 \text{ cm/sec}. \tag{22.32}$$

If we choose tentatively a distance of the asymptote from the Earth's center

$$b = 27.75 \cdot 10^8 \text{ cm}, \tag{22.33}$$

we obtain a parabolic escape velocity at the distance

$$V_{p,b} = V_{p,E} \cdot \sqrt{R_E/b} = 11.8 \cdot 10^5 \cdot \sqrt{6.380/27.75} = 5.36 \cdot 10^5 \text{ cm/sec}. \tag{22.34}$$

Eq. (22.28) yields

$$\tan \alpha = 2 \cdot V_{d,4}^2/V_{p,b}^2 = 2 \cdot 3.03^2/5.36^2 = 0.640; \qquad \alpha = 32^\circ\, 37'. \tag{22.35}$$

The escape asymptote intersects the approach asymptote at an angle

$$2\alpha = 65^\circ\, 14'. \tag{22.36}$$

The length of the major semi-axis is

$$a = b/\tan \alpha = 43.35 \cdot 10^8 \text{ cm} \tag{22.37}$$

and the numerical eccentricity

$$C = \sqrt{a^2 + b^2} = 51.45 \cdot 10^8 \text{ cm}. \tag{22.38}$$

Hence

$$R_{S,E} = C\text{-}a = 8.10 \cdot 10^8 \text{ cm} \tag{22.39}$$

This value checks satisfactorily with the distance of the vertex according to Equation 22.31. The value $b = 27.75 \cdot 10^8$ cm represents the required distance by which the perihelion of the ellipse of return must lie outside the Earth's orbit. The perihelion must lie outside the terrestrial orbit to accomplish that the flight direction through the vertex is in the same general direction as the circumferential motion of the Earth's surface facing the vertex. This is also the orbital direction in the orbit of departure. (See Fig. 11).

23. Weight Ratios and Propellant Requirements

According to the Principle of Conservation of Momentum

$$m \cdot dV = U_e \cdot dm \tag{23.1}$$

i.e., by projecting a mass particle dm with the exhaust velocity U_e, the mass m of the ship acquires a velocity increment dV.

Integration yields

$$V = \int dV = U_e \int_0^1 dm/m = U_e \cdot \log_e m_0/m_1 = U_e \cdot \log_e W_0/W_1 \tag{23.2}$$

or

$$W_0/W_1 = \exp(V/U_e). \tag{23.3}$$

The following computations are based upon an exhaust velocity $U_e = 2.8 \cdot 10^5$ cm/sec as calculated in Section 40.

If we want to determine the required initial weight of the ship we must commence with the terminal weight after completion of the last maneuver.

a. Approach to Earth (Maneuver 4)

Eqs. (22.30) and (23.3) yield

$$W_{0,4}/W_{1,4} = \exp(V_4/U_e) = \exp(3.64/2.8) = 3.67. \tag{23.4}$$

For a terminal weight after maneuver 4

$$W_{1,4} = 50.5 \cdot 10^6 \text{ g} \tag{23.5}$$

the initial weight prior to the same maneuver becomes

$$W_{0,4} = 3.67 \cdot W_{1,4} = 185 \cdot 10^6 \text{ g} \tag{23.6}$$

and the propellant requirement

$$W_{p,4} = W_{0,4} - W_{1,4} = 134.5 \cdot 10^6 \text{ g} \tag{23.7}$$

b. Departure from Mars (Maneuver 3)

Eqs. (22.29) and (23.3) yield

$$W_{0,3}/W_{1,3} = \exp(V_3/U_e) = 2.2. \tag{23.8}$$

$W_{1,3}$ exceeds $W_{0,4}$ by the weight of the tankage jettisoned after maneuver 3, which amounts to 1 t. Thus

$$W_{1,3} = (185 + 1) \cdot 10^6 = 186 \cdot 10^6 \text{ g}. \tag{23.9}$$

Consequently

$$W_{0,3} = 2.2 \cdot W_{1,3} = 408 \cdot 10^6 \text{ g} \tag{23.10}$$

and the propellant requirement

$$W_{p,3} = W_{0,3} - W_{1,3} = 222 \cdot 10^6 \text{ g}. \tag{23.11}$$

c. Approach to Mars (Maneuver 2)

For maneuver 2 Equations 22.6 and 23.8 yield likewise

$$W_{0,2}/W_{1,2} = \exp(V_2/U_e) = 2.2. \tag{23.12}$$

Tankage jettisoned after maneuver 2 weighs 2 t. Hence

$$W_{1,2} = W_{0,3} + 2 \cdot 10^6 = 410 \cdot 10^6 \text{ g}. \tag{23.13}$$

Consequently

$$W_{0,2} = 2.2 \cdot W_{1,2} = 902 \cdot 10^6 \text{ g} \tag{23.14}$$

and the propellant requirement

$$W_{p,2} = W_{0,2} - W_{1,2} = 492 \cdot 10^6 \text{ g}. \tag{23.15}$$

d. Departure from Earth (Maneuver 1)

The computation of the powered track for the maneuver of departure (See Section 21,a) was based on an initial weight

$$W_{0,1} = 3.720 \cdot 10^9 \text{ g} \tag{23.16}$$

and on a propellant supply for the same maneuver, including a 3.5 percent velocity reserve,

$$W_{p,1} = 2.814 \cdot 10^9 \text{ g}. \tag{23.17}$$

The final weight of the ship with completely exhausted tanks for maneuver 1 is therefore

$$W_{1,1} = (3.720 - 2.814) \cdot 10^9 = 906 \cdot 10^6 \text{ g} \tag{23.18}$$

which is $4 \cdot 10^6$ g more than $W_{0,2}$. This excess weight of 4 t is provided for the tankage of maneuver 1 to be jettisoned prior to maneuver 2.

24. Burning Time and Accelerations

The thrust of the Mars vessels will be

$$F = 20 \cdot 10^7 \text{ g} \tag{24.1}$$

for all four principle maneuvers. The rate flow of propellant consumption is

$$\dot{W}_p = F \cdot g_0/U_e = 0.72 \cdot 10^6 \text{ g/sec}. \tag{24.2}$$

The burning time for each maneuver follows from relation

$$t = W_p/\dot{W}_p. \tag{24.3}$$

Since the propellant requirements W_p determined in the foregoing section include a velocity reserve of 3.5 percent for maneuver 1 and 10 percent for all subsequent maneuvers, the actual propellant consumptions are somewhat less if the maneuvers are conducted "correctly." Table XXII refers to "correct maneuvers" in which the reserves are not utilized. However, it has been assumed that the corrective maneuvers following each principle maneuver during the ensuing coasting period consumes the savings, so that each principle maneuver is started with its "nominal" initial weight as indicated in Equations 23.6, 23.10, 23.14 and 23.16.

Table XXII: Burning Time and Accelerations of the Four Principle Maneuvers

Maneuver	1	2	3	4
Burning time (sec)	3,965	658	298	163
Initial acceleration (g)	0.054	0.22	0.49	1.08
Terminal acceleration (g)	0.214	0.45	1.00	2.84

25. Dimensions of Tankage

From Equations 13.1 and 13.2 there results the general relation $V_{Hy} = V_{NA} = W_p/2.6$ for the required volumes of the hydrazine and nitric acid tanks.

a. Maneuver 1

$$V_{Hy,1} = V_{NA,1} = W_{p,1}/2.6 = 2814 \cdot 10^6/2.6 = 1080 \cdot 10^6 \text{ cm}^3 \tag{25.1}$$

If, for symmetry reasons, this supply is subdivided onto two spherical containers for each propellant, located at two opposite sides from the ship's central axis (See Fig. 12), we obtain a diameter

$$D_4 = \sqrt[3]{(6 \cdot 540 \cdot 10^6)/\pi} = 1010 \text{ cm} \tag{25.2}$$

for each of these spherical tanks of $540 \cdot 10^6$ cm^3 volume.

b. Maneuver 2

The diameter of the four spherical containers for maneuver 1, arranged in pairs one behind the other, determines the total length of the ship's tank compartment (Fig 12). It seems expedient to provide the smaller tanks with the same length of 1010 cm and to make them cylindrical with semi-spherical bottoms.

For the four cylindrical containers of maneuver 2 the diameters then become

$$D_2 = 368 \text{ cm}. \tag{25.3}$$

c. Maneuver 3

For the four containers of maneuver 3 we have

$$D_3 = 240 \text{ cm}. \tag{25.4}$$

d. Maneuver 4

For maneuver 4 it is expedient to provide only two tanks, arranged in the ship's central axis, because they need not be jettisoned. Their diameter is

$$D_4 = 266 \text{ cm.} \tag{25.5}$$

e. Reserve tanks

The size of the reserve tank is determined by the requirement that they must be capable of holding the maximum amount of propellants which can possibly be saved if all principle maneuvers are conducted "correctly" and no corrective maneuvers are necessary between the principle maneuvers. A closer investigation shows that a maximum amount

$$W_{p,res} = 45 \cdot 10^6 \text{ g} \tag{25.6}$$

of propellants could be saved after completion of maneuver 2, and that this amount would decrease during subsequent maneuvers even if the latter are also conducted "correctly." It follows from Equation 25.1, that this propellant weight requires volumes for the hydrazine and nitric acid tanks of $V'_{Hy,res} = V'_{NA,res} = 45 \cdot 10^6/2.6 = 17.3 \cdot 10^6 \text{ cm}^3$.

However, if we make an allowance for a possible deviation of 1.7 percent from the design mixture ratio, the required tank volumes increase to $30 \cdot 10^6 \text{ cm}^3$ for each propellant. Since there are two reserve tanks for each propellant (Fig. 12), each tank has a volume of $15 \cdot 10^6 \text{ cm}^3$, corresponding to a diameter

$$D_{res} = 140 \text{ cm} \tag{25.7}$$

26. Empty Weight of the Propellant Containers

The tank ballonets of the Mars ships can be built very light as will be illustrated by the example of the large spherical containers for maneuver 1.

The initial acceleration in maneuver 1 is, according to Table XXII, 0.054 g. For the nitric-acid tank we find a bottom pressure $P_B = D_1 \cdot \delta_{NA} \cdot 0.054 = 1010 \cdot 1.58 \cdot 0.054 = 86 \text{ g/cm}^2$.

This pressure can be safely withstood by a fabric of a weight of 0.065 g/cm^2. For a container with a surface $D_1{}^2\pi = 1010^2\,\pi = 320 \cdot 10^4 \text{ cm}^2$, a weight of $0.065 \cdot 320 \cdot 10^4 = 20.8 \cdot 10^4$ g would result.

Prior to departure, a slight pressurization of the tank is necessary in order to start the propellant flow into the feed pump, since in the orbit of departure there is neither gravity nor ambient air pressure. To prevent the pressurizing gas, helium, from entering the intake pipe in absence of gravity, a displacement bag is required. If we provide a pressurization of 200 g/cm^2, the weight of the fabric will be higher, viz., 0.22 g/cm^2, and the weight of each container becomes $70 \cdot 10^4$ g. The four tanks for maneuver 1 then have a total weight $W_{T,1} = 4.70 \cdot 10^4 = 2.8 \cdot 10^6$ g.

In section 23d, a weight reduction by jettisoning the tankage for maneuver 1 of $4 \cdot 10^6$ g has been assumed. The balance of $1.2 \cdot 10^6$ g is more than sufficient for the outer girders of the "cruciform tank retainers" and the helium flasks for the pressurization, which will be jettisoned with the tanks.

The state of affairs is similar for the containers, tank retainers and flasks for the other maneuvers. Both "cruciform tank retainers" can be built with a weight of about $4.5 \cdot 10^6$ g, which will be gradually reduced with each jettisoning of tanks.

27. Coasting Time and Main Data of the Outbound and Homebound Voyaging Ellipses between Earth and Mars

The length of the major semi-axis of both ellipses becomes in view of Equation 21.1 $a = 1.8875 \cdot 10^{13}$ cm. The linear eccentricity is

$$C = a - a_E = (1.8875 - 1.495) \cdot 10^{13} = 0.3925 \cdot 10^{13} \text{ cm.} \tag{27.1}$$

The numerical eccentricity is

$$e = C/a = 0.208 \tag{27.2}$$

and the length of the minor semi-axis

$$b = \sqrt{a^2 - C^2} = 1.848 \cdot 10^{13} \text{ cm.} \tag{27.3}$$

The period of revolution in this ellipse can be determined with the help of the data of the terrestrial orbit

$$T_E{}^2/a_E{}^3 = (3.156^2 \cdot 10^{14})/(1.495^3 \cdot 10^{39}) = 29.7 \cdot 10^{-26} = (5.47 \cdot 10^{-13})^2 \tag{27.4}$$

and Kepler's Third Law. Thus

$$T = 5.47 \cdot 10^{-13} \cdot \sqrt{a^3} = 44.8 \cdot 10^6 \text{ sec} = 510 \text{ days.} \tag{27.5}$$

The coasting time through the half-ellipse is therefore

$$T_h = 520/2 = 260 \text{ days.} \tag{27.6}$$

Flight time through an elliptical segment of arc, as defined by the angle θ swept by the radius vector, is given by

$$t = (E - e \sin E) \cdot T/2\pi. \tag{27.7}$$

The relation between the "eccentric anomaly" E and the angle θ reads

$$\tan(\theta/2) = \sqrt{(1+e)/(1-e)} \cdot \tan(E/2) = \sqrt{(1+0.208)/(1-0.208)} \cdot \tan(E/2)$$
$$= 1.235 \tan(E/2). \tag{27.8}$$

We next consider the following special case. When the ship has covered a radius vector angle θ = 72°, we have tan(E/2) = tan 36°/1.235 = 0.589. Hence E/2 = 30° 30', E = 61° or E = 1.062 radians.

Eq. (27.7) yields for the flight time up to this point

$$E = (1.062 - 0.208 \cdot \sin 61°) \cdot 44.8 \cdot 10^6/2\pi = 6.28 \cdot 10^6 \text{ sec} = 73 \text{ days.} \tag{27.9}$$

The Earth covers a segment of arc of 360° /365 - 0.987° per day, and thus after 73 days,

$$\theta = 0.987 \cdot 73 = 72°. \tag{27.10}$$

Consequently, on the 73rd day of the outboard voyage, the ship's crews will observe a transit of the Earth across the Sun (Fig 2). The same event will happen 73 days prior to arrival at the Earth on the homebound voyage.

28. Eccentricity of Mars's Orbit

The velocity requirements for the four principle maneuvers, as determined in Sections 21 and 22, and the flight time as computed in section 27 are based on a circular Martian orbit with a radius equal to Mars's average distance from the Sun, $a_M = 2.28 \cdot 10^{13}$ cm. While an accurate computation of a voyaging ellipse to any arbitrary point of Mars's elliptical orbit is somewhat more intricate, it is simple to investigate the velocity requirements for trips to the two extreme positions of Mars in his orbit, viz., aphelion ($a_{M,max} = 2.49 \cdot 10^{13}$ cm) and perihelion ($a_{M,min} = 2.06 \cdot 10^{13}$ cm).

A comparison of these two cases with the "mean" voyage hitherto investigated leads to the results compiled in Table XXIII.

Table XXIII: Voyage to Aphelion and Perihelion of Mars

Mars's distance from Sun at arrival	2.28	2.49	2.06	10^{13} cm
Mars's orbital velocity at arrival	24.10	21.83	26.40	10^5 cm/sec
Major semi-axis of voyaging ellipse	1.8875	1.990	1.775	10^{13} cm
Perihelion velocity of voyaging ellipse	32.83	33.38	32.10	10^5 cm/sec
Aphelion velocity of voyaging ellipse	21.55	19.98	23.22	10^5 cm/sec
Residual velocity in terrestrial orbit	3.03	3.58	2.30	10^5 cm/sec
Differential velocity in Mars's orbit	2.55	1.85	3.18	10^5 cm/sec
Velocity increments for maneuvers 1 and 4	3.31	3.55	3.19	10^5 cm/sec
Velocity increments for maneuvers 2 and 3	2.01	1.67	2.32	10^5 cm/sec
Total velocity increment for round trip	10.64	10.44	11.02	10^5 cm/sec
Coasting time through half-ellipse	260	281	237	Days

One readily recognizes:

a. The additional requirement of the aphelion trip for maneuvers 1 and 4, as compared to the "mean" voyage, is more than balanced by the lower velocity increments for maneuvers 2 and 3. Indeed, contrary to a guess at first sight, the aphelion trip is the most economic and the perihelion trip the most expensive.

b. The differences in the total velocity increments are not significant and do not affect the dimensions of the ships to any considerable extent. However, in view of the large differences between the velocity increments for the individual maneuvers, a change in the propellant distribution in the tankage of the four principle maneuvers is necessary, if the actual trip deviates from the "mean" voyage.

c. The aphelion trip lasts 44 days longer than the perihelion trip.

Remarks:

a. In the above comparison the effect of the long burning time during maneuver 1 (see Section 21) has been disregarded. Therefore, the figures for the total velocity increments will be used for purposes of comparison only.

b. In practice it is not possible to fly a pure aphelion or perihelion route on both the outbound and homebound legs of the voyage. Once the time of departure is selected, the conditions for the return trip are predetermined by the "waiting time."

29. "Fast" Voyages

Apart from using voyage ellipses which kiss the Martian orbit at their aphelions, it is possible to select elliptical routes which lead far beyond Mars's orbit, intersecting the latter before the ship has traveled through a complete half-ellipse.

If, for example, an ellipse is chosen whose aphelion lies in Jupiter's orbit ($a_j = 7.79 \cdot 10^{13}$ cm), we have (see Fig. 13):

Length of the major semi-axis

$$a = (a_E + a_j)/2 = [(1.495 + 7.79)/2] \cdot 10^{13} = 4.6425 \cdot 10^{13} \text{ cm}. \quad (29.1)$$

Period of one complete revolution with the help of Equation 27.5

$$T = 5.47 \cdot 10^{-13} \cdot \sqrt{4.6425^3 \cdot 10^{39}} = 17.3 \cdot 10^7 \text{ sec} = 3003 \text{ days}. \quad (29.2)$$

The numerical eccentricity is

$$e = (a - a_E)/a = (4.6425 - 1.495)/4.6425 = 0.679 \quad (29.3)$$

The single θ swept by the radius vector up to the point where the ship intersects the Martian orbit in this ellipse follows from the polar equation of the ellipse. Thus

$$\cos\theta = [a \cdot (1 - e^2) - a_M]/(a_M \cdot e) = 0.1455; \quad \theta = 81° 389 \quad (29.4)$$

Eq. (27.8) gives $\tan(E/2) = \sqrt{(1 - e)/(1 + e)} \cdot \tan(\theta/2) = 0.3774$. Hence, $E/2 = 20° 419$ or $E = 41° 229$ or $E = 0.772$ radians.

The coasting time from the perihelion (Earth's orbit) to the point of intersection between ellipse and Mars's orbit becomes in view of Equations 27.7 and 29.2

$$t = (E - e \text{ sine}E) \cdot T/2\pi = 7.545 \cdot 10^6 \text{ sec} = 87.4 \text{ days}. \quad (29.5)$$

The perihelion velocity (in the Earth's orbit) is according to Equation 2.4

$$V_p = V_E\sqrt{2 - (a_E/a)} = 29.8 \cdot 10^5 \sqrt{2 - (1.495/4.6425)} = 38.60 \cdot 10^5 \text{ cm/sec}. \quad (29.6)$$

The ship must therefore leave the field of terrestrial gravitation with a residual velocity

$$V_{d,1} = V_p - V_E = (38.60 - 29.80) \cdot 10^5 = 8.80 \cdot 10^5 \text{ cm/sec}. \quad (29.7)$$

Eqs. (21.4) and (21.5) give

$$V_{tot,1} = \sqrt{2V_{circ,1}^2 + V_{d,1}^2} = \sqrt{2 \cdot 7.07^2 \cdot 10^{10} + 8.80^2 \cdot 10^{10}} = 13.31 \cdot 10^5 \text{ cm/sec}. \quad (29.8)$$

The velocity increment necessary for the maneuver of departure is

$$V'_1 = V_{tot,1} - V_{circ,1} = 6.24 \cdot 10^5 \text{ cm/sec} \quad (29.9)$$

if sufficient thrust is applied to keep the burning time short.

The angle of intersection between voyaging ellipse and Mars's orbit must, for geometric reasons, equal half the angle included by the lines drawn from the point of intersection to the two foci of the ellipse (see Fig 13). This angle is a = 31° 259.

The velocity V of the ship at the point of intersection can be determined with the help of equation

$$V^2 = V_\rho^2 - 2\mu/a_E + 2\mu/a_M \quad (29.10)$$

where

$$\mu = g_s \cdot r^2 \quad (29.11)$$

is the product of local gravitational acceleration due to the solar field and the square of the distance r from the Sun. The constant μ characterizes the entire gravitational field of the Sun. With the orbital data of the Earth we find

$$\mu = g_s \cdot a_E^2 = (V_E^2/a_E) \cdot a_E^2 = V_E^2 \cdot a_E = 29.8^2 \cdot 10^{10} \cdot 1.495 \cdot 10^{13}$$
$$= 1.33 \cdot 10^{26}\ \text{cm}^3/\text{sec}^2. \quad (29.12)$$

With the Equations 29.6 and 29.11 we obtain

$$V = \sqrt{38.60^2 \cdot 10^{10} - [(2 \cdot 1.33 \cdot 10^{26})/(1.495 \cdot 10^{13})] + [(2 \cdot 1.33 \cdot 10^{26})/(2/28 \cdot 10^{13})]}$$
$$= 29.7 \cdot 10^5\ \text{cm/sec}. \quad (29.13)$$

The orbital velocity of Mars is $V_M = 24.10 \cdot 10^5$ cm/sec. Since voyaging ellipse and Mars's orbit intersect at an angle $\alpha = 31^\circ\ 259$, we can now draft a parallelogram of velocities from which we can immediately read the relative velocity $V_{d,2}$ and the angle β at which the ship enters Mars's gravitational field. Thus

$$V_{d,2} = 15.53 \cdot 10^5\ \text{cm/sec and } \beta = 54^\circ. \quad (29.14)$$

From Equation 22.4 it follows that

$$V_{tot,2} = \sqrt{2V_{circ,2}^2 + V_{d,2}^2} = \sqrt{2 \cdot 3.14^2 \cdot 10^{10} + 15.53^2 \cdot 10^{10}}$$
$$= 16.18 \cdot 10^5\ \text{cm/sec}. \quad (29.15)$$

Hence, the velocity increment required for entering the satellite orbit becomes

$$V'_2 = V_{tot,2} - V_{circ,2} = 13.04 \cdot 10^5\ \text{cm/sec}. \quad (29.16)$$

In Table XXIV the data for this "fast" voyage are contrasted with the data of the "mean" voyage.

Table XXIV: "Fast" Voyage

	"Fast" Voyage	"Mean" Voyage	Dimension
Coasting time (cut-and homebound)	87.4	260	days
Velocity increments for maneuvers 1 and 4	6.24	3.31	10^5 cm/sec
Velocity increments for maneuvers 2 and 3	13.04	2.01	10^5 cm/sec

It is evident that the additional propellant requirements incident to shortening the voyage are excessive.

E. THE LANDING BOATS

30. Summary of Principle Data

Table XXV: Summary of Principle Data

Thrust	F	200 t	$20 \cdot 10^7$ g
Exhaust velocity	U_e	8,550 ft/sec	$2.60 \cdot 10^5$ cm/sec
Rate of propellant consumption	$\dot{W}_p$	0.755 t/sec	$0.755 \cdot 10^6$ g/sec
Radius of satellite orbit	R_{SM}	2,730 mi	$4.390 \cdot 10^8$ cm
Circular velocity in satellite orbit	$V_{circ,2}$	1.95 mi/sec	$3.14 \cdot 10^5$ cm/sec
Apogeal velocity of landing ellipse	$V_{a,L}$	1.84 mi/sec	$2.967 \cdot 10^5$ cm/sec
Perigeeal altitude of landing ellipse	Y_p	96.3 mi	$0.155 \cdot 10^8$ cm
Initial weight in satellite orbit	W_o	200 t	$20 \cdot 10^7$ g
Propellant consumption for landing maneuver	$W_{p,L}$	13 t	$13 \cdot 10^6$ g
Propellant reserve for landing maneuver	$W_{P,L,res}$	2 t	$2 \cdot 10^6$ g
Burning time of landing maneuver	T_L	17.2 sec	17.2 sec
Landing weight	W_L	185 t	$185 \cdot 10^6$ g
Useful landing payload (wheeled boats)	$W_{U,L}$	12 t	$12 \cdot 10^6$ g
Useful landing payload (ski boat)	$W^1_{U,L}$	125 t	$125 \cdot 10^6$ g
Wing area	S_w	30,400 sq ft	$2.82 \cdot 10^7$ cm²
Weight of wings (abandoned on Mars)	W_W	33 t	$33 \cdot 10^6$ g
Weight of landing gear (abandoned on Mars)	W_g	7 t	$7 \cdot 10^6$ g
Take-off weight for re-ascent to orbit	$W_{O,R}$	138 t	$138 \cdot 10^6$ g

Table XXV: Summary of Principle Data (continued)

Cut-off velocity (re-ascent)	$V_{p,c}$	2.3 mi/sec	$3.70 \cdot 10^5$ cm/sec
Cut-off altitude (re-ascent)	Y_c	77.8 mi	$0.125 \cdot 10^8$ cm
Burning time (re-ascent)	t_a	147 sec	147 sec
Terminal weight after ascent	$W_{o,ad}$	26.8 t	$26.8 \cdot 10^6$ g
Terminal weight after adaptation maneuver (re-ascent)	$W_{1,ad}$	25 t	$25 \cdot 10^6$ g
Useful payload (re-ascent)	$W_{U,a}$	5 t	$5 \cdot 10^6$ g
Apogeal velocity of ellipse of ascent	$V_{a,c}$	1.84 mi/sec	$2.960 \cdot 10^5$ cm/sec
Velocity of increment for adaptation maneuver	$V_{a,d}$	0.112 mi/sec	$0.180 \cdot 10^5$ cm/sec
Length of hull	L	72 ft	$22 \cdot 10^2$ cm
Diameter of hull	D_e	15.5 ft	473 cm
Wing span	b_W	500 ft	$153 \cdot 10^2$ cm

31. Structure of the Martian Atmosphere

Mars albedo is

$$Alb_M = 0.27. \tag{31.1}$$

On the seasonal average, the planet's visible surface comprises

61 percent of desert with an albedo of 0.16

37 percent of vegetated areas with an albedo of 0.07

1.6 percent of snow with an albedo of 0.75

This yields a mean albedo of the surface of 0.135.

Only 75 percent of the sunlight intercepted by Mars reaches his surface. Hence the fraction reflected by the surface is only $0.135 \cdot 0.75 = 0.10$.

The actual albedo of 0.27, minus the share of 0.10 accounted for by the surface, equal 0.17, must therefore originate from reflection by the Martian atmosphere.

In regard to the Earth's albedo: Let the total brightness of the Sun outside the Earth's atmosphere and for the visible range of the spectrum be 100 percent. Here from 79 percent is diffracted and only 21 percent reaches the surface directly. A part of the diffracted light, however, also reaches the surface of the Earth. Its amount is given by the brightness of the sky. The following relative figures are known:

Brightness of the Sun (visible region) 80

Brightness of blue sky (visible region) 19.

The total intensity at the Earth's surface is therefore $19/80 = 0.24$ greater that the intensity directly received from the Sun. Hence, on account of the diffraction in the Earth's atmospheric shell a portion $1.24 \cdot 21 = 26$ percent of the total brightness of 100 percent reaches the surface. Therefore a portion $100 - 26 = 74$ percent must be re-radiated into space. In other words, the albedo of the cloudless terrestrial atmosphere is

$$Alb_{a,E} = 0.74. \tag{31.2}$$

Under the assumption of proportionality between albedo and air mass, we find the mass per unit surface area on Mars to be $0.17 / 0.74 = 2/9$ of that on Earth.

If we suppose a similar composition of both atmospheres and equal temperatures, we find a surface density of the Martian atmosphere equal to

$$\gamma_{0,M} = (g_M/g_0) \cdot (2/g) \cdot \gamma_0 = 0.38 \cdot 0.222 \cdot 1.293 \cdot 10^{-3} = 1.1 \cdot 10^{-4} \text{ g/cm}^3 \tag{31.3}$$

and a surface pressure

$$p_{o,M} = 0.38 \cdot 0.222 \cdot 760 = 64 \text{ mm Hg} = 84 \text{ g/cm}^2. \tag{31.4}$$

The corresponding boiling point of water is 44°C = 111 °F.

For the density and pressure distribution of the Martian atmosphere it follows from Equation 10.4 and in view of the weaker gravitational field

$$\gamma/\gamma_{0,M} = p/p_{0,M} = \exp[-(0.38 \cdot y)/y^*] = 10 - y/(47.15 \cdot 10^5 \text{ cm}). \tag{31.5}$$

We recognize that the pressure of the Martian atmosphere decreases by the factor of 10 for each $47.15 \cdot 10^5$ cm = 29.3 miles increase in altitude.

Remark: Figures presented in this section may serve merely to portray the general structure of the Martian atmosphere. An actual design of landing boats would call for much more solid underpinning of these data.

32. Wing Area

Let the landing weight of the boat be $W_L = 185 \cdot 10^6$ (terrestrial) grams. For a landing speed of

$$V_L = 120 \text{ MPH} = 54.5 \cdot 10^2 \text{ cm/sec} \tag{32.1}$$

we obtain from Equations 6.1 and 31.3 the necessary wing area as follows

$$\begin{aligned} S_W &= (2 \cdot 0.38 \cdot g_0 \cdot W_L)/(C_{L,max} \cdot \gamma_{0,M} \cdot V_L^2) \\ &= (2 \cdot 0.38 \cdot 981 \cdot 185 \cdot 10^6)/(1.5 \cdot 1.1 \cdot 10^{-4} \cdot 54.5^2 \cdot 10^4) = 2.82 \cdot 10^7 \text{ cm}^2 \\ &= 30{,}400 \text{ sq ft.} \end{aligned} \tag{32.2}$$

33. Perigeal Altitude of the Landing Ellipse

The perigeal altitude of the landing ellipse is to be chosen in such manner that air density is sufficient to constrain the boat into a circular path (see the analogous calculation for the third *Sirius* stage in section 7).

For a perigeal altitude

$$y_p = 0.155 \cdot 10^8 \text{ cm} = 96.3 \text{ miles} \tag{33.1}$$

corresponding to a distance

$$R_p = (3.390 + 0.155) \cdot 10^8 = 3.545 \cdot 10^8 \text{ cm} \tag{33.2}$$

from Mars's center, Equation 22.3 yields a circular velocity

$$V_{circ} = \sqrt{(R_M/2R_p) \cdot V_{p,M}^2} = 3.488 \cdot 10^5 \text{ cm/sec.} \tag{33.3}$$

The local gravitational acceleration, which must equal the centrifugal acceleration in such a circular path, is

$$g_p = V_{circ}^2/R_p = 343.5 \text{ cm/sec}^2. \tag{33.4}$$

The apogee of the landing ellipse lies in the satellite orbit, i.e., at a distance $R_{S,M} = 4.390 \cdot 10^8$ cm from Mars's center. Thus we find for the length of the major semi-axis of the landing ellipse

$$a = (R_p + R_{S,M})/2 = 3.967 \cdot 10^8 \text{ cm} \tag{33.5}$$

and for the perigeal velocity with the help of Equation 2.4

$$V_{p,L} = V_{circ}\sqrt{2 - (R_p/a)} = 3.671 \cdot 10^5 \text{ cm/sec.} \tag{33.6}$$

The centrifugal acceleration in a circular flight path with this velocity at a perigeal distance R_p is

$$a_p = V_{p,L}^2/R_p = 380.0 \text{ cm/sec}^2. \tag{33.7}$$

Hence, the negative lift of the wings must be capable of generating a centripetal acceleration

$$a_{cp} = a_p - g_p = 36.5 \text{ cm/sec}^2. \tag{33.8}$$

Since the landing weight of the boat is $W_L = 185 \cdot 10^6$ g, the required negative lift becomes

$$- L_r = (W_L)/\gamma_0 \cdot 36.5 = 6.890 \cdot 10^6 \text{ g.} \tag{33.9}$$

Eq. (31.5) yields for an altitude $y_p = 0.155 \cdot 10^8$ cm an atmospheric density $\gamma_p = 5.6 \cdot 10^{-8}$ g/cm^3. Under the conservative assumption that for moderate angles of attack in the high supersonic region a lift coefficient $C_L = 0.1$ may be realized, we find that the negative lift actually attainable with the wing area determined in Equation 32.2 is

$$-L_a = (C_L \cdot S_W \cdot g_p \cdot V_{r,L}^2)/(2 \cdot g_0) = 10.6 \cdot 10^6 \text{ g.} \tag{33.10}$$

Consequently, at the chosen perigeeal altitude $y_p = 0.155 \cdot 10^8$ cm the required negative lift is easily attainable.

34. Initial Weight of the Landing Boat in the Satellite Orbit

The landing weight of the boat was hitherto arbitrarily assumed to be $W_L = 185 \cdot 10^6$ g. What is the boat's weight when leaving the satellite orbit?

Eq. (4.1) yields an apogeeal velocity in the landing ellipse

$$V_{a,L} = (R_p/R_{S,M}) \cdot V_{p,L} = (3.545/4.390) \cdot 3.671 \cdot 10^5 = 2.967 \cdot 10^5 \text{ cm/sec.} \quad (34.1)$$

According to Equation 22.3 the circular velocity in the satellite orbit is $V_{circ,2} = 3.140 \cdot 10^5$ cm/sec. To throw the boat into the landing ellipse, its velocity must therefore be reduced by the difference

$$\Delta V_L = V_{circ,2} - V_{a,L} = 0.173 \cdot 10^5 \text{ cm/sec.} \quad (34.2)$$

For this velocity increment and an exhaust velocity $U_e = 2.6 \cdot 10^5$ cm/sec (see Sections 40 and 42), Equation 23.3 yields the following weight ratio

$$W'_0/W_L = \exp(\Delta V_L/U_e) = \exp(0.173/2.6 = 1.069) \quad (34.3)$$

whence

$$W'_0 = 1.069 \cdot W_L = 198 \cdot 10^6 \text{ g.} \quad (34.4)$$

To assure a small propellant reserve, we round off to

$$W_0 = 200 \cdot 10^6 \text{ g.} \quad (34.5)$$

The propellant consumption for entering the landing ellipse is

$$W_{p,L} = W'_0 - W_L = 13 \cdot 10^6 \text{ g.} \quad (34.6)$$

For a thrust $F = 20 \cdot 10^7$ g the rate of propellant flow becomes

$$\dot{W}_p = (F \cdot g_0)/U_e = (20.10^7 \cdot 981)/(2.6 \cdot 10^5) = 0.755 \cdot 10^6 \text{ g/sec} \quad (34.7)$$

and the burning time of the landing maneuver

$$t_L = W_{p,L}/\dot{W}_p = 13/0.755 = 17.2 \text{ sec.} \quad (34.8)$$

35. Return into the Satellite Orbit

In section 32 it has been calculated that a wing area of $S_W = 29{,}700$ sq ft is required. These wings must be built of steel. Their weight has been estimated to be $W_W = 33$ (terrestrial) tons $= 33 \cdot 10^6$ g. Let the landing gear weigh $W_g = 7 \cdot 10^6$ g. Since both landing gear and wings are abandoned on Mars's surface prior to return to the satellite orbit, the take-off weight will be $40 \cdot 10^6$ g less than the landing weight. If we furthermore limit the return payload to $W_{U,a} = 5 \cdot 10^6$ g as compared to the landing payload of $W_{U,L} = 12 \cdot 10^6$ g, another reduction of the take-off weight by $7 \cdot 10^6$ g results. The take-off weight of the boat is therefore

$$W_{0,R} = W_L - 47 \cdot 10^6 = 138 \cdot 10^6 \text{ g} \quad (35.1)$$

when measured in the terrestrial field of gravitation, or

$$W_{0,R,M} = 0.38 \cdot 138 \cdot 10^6 = 52.5 \cdot 10^6 \text{ g} \quad (35.2)$$

in the Martian field. With a thrust $F = 20 \cdot 10^7$ g we obtain a relative take-off acceleration

$$a'_0 = (F \cdot g_0/W_{0,R}) - g_M = (20 \cdot 10^7 \cdot 981/138 \cdot 10^6) - 373$$
$$= 1048 \text{ cm/sec}^2 = 1.07\, g_0. \quad (35.3)$$

This is a little more than the take-off acceleration of a *Sirius* from the Earth.

Let us now assume that the boat is capable of attaining the required velocity for return into the satellite orbit at an altitude

$$y_c = 0.125 \cdot 10^8 \text{ cm} \quad (35.4)$$

and that the flight at this altitude is horizontal. For this altitude Equation 33.6 yields a perigeeal velocity of the ellipse of ascent

$$V_{p,a} = 3.70 \cdot 10^5 \text{ cm/sec.} \quad (35.5)$$

The apogeal velocity of this ellipse is

$$V_{a,a} = [(R_M + y_C)/R_{S,M}] \cdot V_{p,\partial} = 2.960 \cdot 10^5 \text{ cm/sec.} \quad (35.6)$$

The maneuver of adaptation in the satellite orbit requires therefore a velocity increase

$$V_{ad} = V_{circ,2} - V_{a,a} = 0.180 \cdot 10^5 \text{ cm/sec.} \quad (35.7)$$

The weight ratio for the adaptation maneuver is given by

$$W_{0,\partial d}/W_{1,\partial d} = \exp(V_{\partial d}/U_e) = \exp(0.180/2.6) = 1.072. \quad (35.8)$$

The terminal weight $W_{1,ad}$ represents the empty weight of the wingless boat including the return payload of $W_{U,a} = 5 \cdot 10^6$ g. Putting

$$W_{1,ad} = 25 \cdot 10^6 \text{ g} \quad (35.9)$$

we obtain

$$W_{0,ad} = 1.072 \cdot W_{1,ad} = 26.8 \cdot 10^6 \text{ g}. \quad (35.10)$$

This is the boat's terminal weight after the maneuver of ascent proper. Hence, for the ascent a weight ratio

$$E = W_{0,R}/W_{0,\partial d} = 138/26.8 = 5.15 \quad (35.11)$$

remains available.

Eq. (3.2) enables us to make a crude check as to whether the perigeeal velocity $V_{p,a} = 3.70 \cdot 10^5$ cm/sec, as demanded in Equation 35.5 can actually be attained with this weight ratio. If, for the sake of simplicity, we introduce a mean flight path angle $\varphi_M = 45°$, Equation 3.2 yields a cut-off velocity

$$\begin{aligned} V^*_{p,C} &= U_e \cdot \log_e E - g_M \cdot \sin \varphi_M \cdot [W_{0,R}/6_p] \cdot [((E - 1)/E)] \\ &= 2.6 \cdot 10^5 \cdot 1.64 - 0.38 \cdot 981 \cdot 0.7071 \cdot [138/0.755] \cdot [(5.15 - 1)/5.15] \\ &= 3.877 \cdot 10^5 \text{ cm/sec.} \end{aligned} \quad (35.12)$$

The cut-off altitude and the cut-off distance for a 45° ascent would be with the help of Equation 3.3

$$\begin{aligned} y_C^* &= (W_{0,R}/\dot{W}_p) \cdot \sin \varphi_m \cdot [U_e \cdot (1/E) \cdot (E - 1 - \log_e E) \\ &\quad - (g_m/2) \cdot \sin \varphi_m \cdot (W_{0,R}/\dot{W}_p) \cdot ((E - 1)/E)^2] = 0.1455 \cdot 10^8 \text{ cm.} \end{aligned} \quad (35.13)$$

Finally the burning time for the ascent, if the available propellants are completely consumed,

$$t_a = (W_{0,R} - W_{0,\partial d})/\dot{W}_p = (138 - 26.8)/0.755 = 147 \text{ sec.} \quad (35.14)$$

It may be recognized from this rough estimate that the required perigeeal velocity can easily be reached at the envisaged altitude.

Actually, even more favorable results are to be expected, if all factors disregarded herein are taken into account. Such factors are decrease of the gravitational acceleration with increasing altitude, actual trajectory configuration, periphery velocity of the Martian equator, centrifugal reduction of weight, aerodynamic drag and static thrust gain due to decreasing ambient pressure. See Section 3.

36. Use of Landing Boats as Third *Sirius* Stage

The weight of the empty, wingless boat including a return payload $W_{U,a} = 5 \cdot 10^6$ g is according to Equation 35.9 $W_{1,ad} = 25 \cdot 10^6$ g. The payload during landing on Mars will be greater by $7 \cdot 10^6$ g. The terminal weight of the wingless boat with full landing lading after completion of ascent and adaptation maneuver in the terrestrial orbit of departure is therefore $W_1 = 32 \cdot 10^6$ g.

The initial weight of the boat when used as third *Sirius* stage must not exceed the initial weight of the latter, since the ascent tracks of the first and second boosters are computed on this basis. Thus $W_0 = W_{0,III} = 130 \cdot 10^6$ g.

A comparison with the third *Sirius* stage shows that the weight ratio thus available by far exceeds that of the latter. Hence the total tankage of the boat of $W_{p,tot} = 128 \cdot 10^6$ g (see Equation 37.4) must not and needs not even be fully utilized when the boat is launched into the orbit of departure.

37. Dimensions

The landing boat will have the same thrust as the third *Sirius* stage. Owing to its lower exhaust velocity the rate of propellant flow is 7 percent higher than in the *Sirius* top stage. According to Equation 12.1 the throat area of its rocket motor must be enlarged in the same ratio. Thus

$$A_{th} = 1.07 \cdot 7.5 \cdot 10^3 = 8 \cdot 10^3 \text{ cm}^2. \quad (37.1)$$

Let the combustion chamber pressure also be pi = 15000 g/cm^2 and let the gas expand down to an exit pressure $p_e = 66$ g/cm^2, corresponding to 78 percent of the surface pressure of the Martian atmosphere. Then Equation 12.3 yields a nozzle exit area

$$A_e = A_{th}/0.0453 = 176 \cdot 10^3 \text{ cm}^2 \quad (37.2)$$

corresponding to a nozzle exit diameter

$$D_e = 473 \text{ cm} = 15.5 \text{ ft.} \quad (37.3)$$

It is expedient to make the hull's caliber equal to this diameter. From Equations 34.4, 34.5, 34.6, 35.1 and 35.9 there results a total propellant capacity

$$W_{p,tot} = (138 - 25 + 13 + 2) \cdot 10^6 = 128 \cdot 10^6 \text{ g} \quad (37.4)$$

With the help of Equation 13.3 we find a total volumetric tankage

$$V_{p,tot} = 128 \cdot 10^6/1.295 = 99 \cdot 10^6 \text{ cm}^3. \quad (37.5)$$

The tank diameter might be somewhat less than the caliber as determined in Equation 37.3, e.g.,

$$D_T = 440 \text{ cm}. \quad (37.6)$$

Then we find the length of the cylindrical tank bay

$$L_T = (V_{p,tot} \cdot 4)/(D_T^2 \cdot p) = 650 \text{ cm}. \quad (37.7)$$

For the length of the power plant we may make the same assumptions as for the third *Sirius* stage, viz.,

- length of rocket motor 300 cm
- height of pump and valve compartment 200 cm
- addition for domed tank bottoms 100 cm.

Thus we have a total of 1250 cm for the entire propulsion system of the boat including the tanks. The ogival space in front of the tanks may be provided for pilot's compartment, radio room, instrument compartment for automatic guidance during re-ascent and for the cargo space. These may occupy an additional length of 950 cm. The overall-length of the boat's hull then becomes

$$L = 2200 \text{ cm} = 72.3 \text{ ft}. \quad (37.8)$$

If the wings are attached to this hull in the "all-wing" fashion, the boat's span becomes approximately

$$b_W = 15300 \text{ cm} = 500 \text{ ft}. \quad (37.9)$$

Remark: The boat of the first landing party will not return to the satellite orbit. According to Equations 34.4, 34.5, and 34.6 it needs only $15 \cdot 10^6$ g propellants to enter the landing ellipse. The bulk of the tank bay, occupied by propellants in the two other boats, therefore becomes available for additional cargo. The landing payload of this boat increases by the weight of the propellants required for ascent and adaptation maneuver (together approx. $113 \cdot 10^6$ g), i.e., its amounts to $125 \cdot 10^6$ g instead of the $12 \cdot 10^6$ g in the case of the two other boats.

38. Glide Path from Perigee of Landing Ellipse to Landing

With the help of Equation 31.5 and the same scheme as outlined in Section 10 we may determine the landing boat's glide path. The computation has been based on the same assumption for aerodynamic coefficients as used for the third *Sirius* stage (See section 9). Table XXVI applies to a wing area according to Equation 32.2 and a landing weight $W_L = 185 \cdot 10^6$ g.

Table XXVI: Glide Path of the Landing Boat

$V \cdot 10^{-5}$ cm/sec	$Y \cdot 10^{-5}$ cm	$-dv/dt \cdot 10^{-2}$ cm/sec^2	Δt sec	$\Delta X \cdot 10^{-5}$ cm	Rate of Descent R/D $\cdot 10^{-2}$ cm/sec	$\Sigma\Delta t$ sec	$\Sigma\Delta X \cdot 10^{-5}$ cm
3.67	155						
3.5	155	0.183	930	3,330	0	930	3,330
3	133	0.336	1,490	4,830	14.8	2,420	8,160
2	99	0.955	1,046	2,620	32.4	3,466	10,780
1	82	1.105	905	1,360	18.7	4,371	12,140
sonic	39	0.867	808	525	53.3	5,179	12,665

The total flight time from perigee to sonic speed at slowly diminishing flight velocity is $\Sigma\Delta t = 5179$ sec = 1 hour 26 minutes 19 seconds

The distance covered during the glide is $\Sigma\Delta X = 12665 \cdot 10^5$ cm = 7,880 miles, which is about 60 percent of the circumference of Mars.

Sonic speed will be passed at an altitude of $39 \cdot 10^5$ m = 24.2 miles

39. Skin Heating During Glide

Skin temperatures during the glide of the landing boat have been calculated in the same manner as in section 11. Results are compiled in Table XXVII.

Table XXVII Skin temperatures of landing boats during glide through Martian atmosphere

The skin temperatures are so low that use of light metal may seriously be envisaged.

Table XXVII: Skin Temperatures of Landing Boats

$V \cdot 10^{-5}$ cm/sec	$y \cdot 10^{-5}$ cm	T_s °K	t_s °F
3.67	155	643	700
3.5	155	625	665
3	133	649	710
2	99	605	630
1	82	416	290

F. EXHAUST VELOCITY AND SPECIFIC IMPULSE

40. Thermodynamic Calculation

The quotient

$$I_{sp} = F/\dot{W}_p \text{ (sec)} \tag{40.1}$$

i.e., the ratio of thrust to rate of propellant consumption per second is generally referred to as "specific impulse." It represents a convenient measure for the efficiency of a rocket motor.

The Law of Conservation of Momentum

$$F = \dot{m} \cdot U_E = (\dot{W}_p/g_0) \cdot U_e \tag{40.2}$$

yields the simple relation between I_{sp} and exhaust velocity U_e

$$U_e = g \cdot I_{sp} = 981 \cdot I_{sp} \text{ (cm/sec)} \tag{40.3}$$

The "theoretical specific impulse" $I_{sp,th}$ is defined as the specific impulse in the case of complete chemical equilibrium inside combustion chamber and isentropic expansion. It can be calculated from the relation

$$I_{sp,th} = 9.323 \cdot \sqrt{H_0 - H_e} \tag{40.4}$$

where H_o represents the enthalpy per unit mass of propellants, H_e the enthalpy in the nozzle exit after isentropic expansion of the combustion gas, provided chemical equilibrium prevails in the combustion chamber. Practically, enthalpy-entropy charts are used.

The stoichiometric equation for the reaction of hydrazine with nitric acid regardless of dissociation reads 1.25 N_2H_4 (liquid) + HNO_3 (liquid) 3 H_2O (gas) + 1.75N_2 (gas);

$$\Delta H = -\ 1424.5 \text{ cal/g} \tag{40.5}$$

where ΔH represents the enthalpy increase, equal to the negative amount of heat released. At temperatures above 2000°K, as occurring in this reaction, the dissociation of the combustion products must be taken into account. This may be done as follows:

One computes the dissociation equilibrium and the corresponding total enthalpies (chemical plus temperature enthalpy) for a number arbitrarily chosen temperatures in the vicinity of the expected combustion temperature T_i, for example, for T = 3000, 2900, and 2800°K. By comparing the thus determined enthalpies with the available enthalpy of the propellants, the actual combustion temperature T_i is found by interpolation.

For the selected combustion pressure $p_i = 15000$ g/cm^2 we obtain in this manner

$$T_i = 2850\ °K \tag{40.6}$$

and the equation for the actual combustion becomes

$$\begin{aligned}&1.25\ N_2H_4 + HNO_3\ 2.624\ H_2O + 0.2328\ OH + 0.2413\ H_2 + 0.063\ O_2\\ &\quad + 0.0017410 + 0.014156\ H + 1.75\ N_2.\end{aligned} \tag{40.7}$$

Next we determine the entropy S_o of the gas mixture at the temperature T_i and the combustion pressure p_i. The expansion being isentropic, this entropy must also prevail in the nozzle exit area:

$$S_e = S_o. \tag{40.8}$$

For the selected nozzle exit pressure we can now determine the entropies belonging to a series of arbitrary exit temperatures. By comparing these entropies with $S_e = S_o$, the actual exit temperature may be found by interpolation.

The enthalpy H_e in the nozzle exit area is then easily computed. For exit temperatures below 2000 °K dissociation may be disregarded.

H_o and H_e being known, Equation 40.4 yields the "theoretical specific impulse" and Equation 40.3 the "theoretical exhaust velocity."

Both these values are labeled "theoretical," because no allowances are made for

- incomplete combustion and non-uniform mixing
- incomplete recombination of dissociated molecules
- divergence losses (streamlines in nozzle exit area have a small velocity component normal to nozzle axis.)

All these losses can be allowed for by a loss factor X. According to experimental results it is possible to attain in carefully tuned rocket motors of moderate expansion ratio a loss factor X = 0.95. In the case of high expansion ratio we have X = 0.90.

For a combustion of equivalent quantities of hydrazine and nitric acid, results are compiled in Table XXVIII.

Table XXVIII: Specific Impulses and Exhaust Velocities

	Symbol	1	2	3	4	Dimension
Nozzle exit pressure	p_e	700	24.1	10	66	g/cm^2
Expansion ratio	p_i/p_e	21.4	622	1,500	227	—
Nozzle exit temperature	T_e	2,005	1,165	983	1415	°K
"Theoret. specific impulse"	$I_{sp.th}$	242	307	318	291	Sec
"Theoret. exhaust velocity"	$U_{e.th}$	2.374	3.010	3.120	2.850	10^5 cm/sec
Loss factor	X	0.95	0.93	0.90	0.93	—
Specific Impulse	I_{sp}	230	285	286	271	sec
Exhaust velocity	U_e	2.250	2.80	2.81	2.65	10^5 m/sec

Column 1 applies to the first *Sirius* stage
Column 2 applies to the second *Sirius* stage
Column 3 applies to the third *Sirius* stage and to the Mars vessels
Column 4 applies to the Landing Boats

Remarks: The foregoing method of computation is superior to the well-known and frequently used formula of St. Venant and Wantzel, because it takes into account variation of specific heats with temperature and dissociation effects. The formula of St. Venant and Wantzel yields in general too favorable results.

41. Static Thrust Forces

The specific impulses listed in Table XXVIII are based on the assumption that the pressure of the ambient air equals the pressure at the nozzle exit, which is determined by the pressure in the combustion chamber and the ratio of exit area to throat area. If the exit pressure is greater or less than the ambient pressure, the so-called "static" thrust increases or decreases the "nominal" thrust as determined from the foregoing thermodynamic calculations. The static thrust is given by the product of nozzle exit area and the difference between exit pressure P_e and ambient pressure P_a.

$$\Delta F = A_e \cdot (p_e - p_a) \qquad (41.1)$$

Depending on whether the ambient pressure is less or greater than the exit pressure, the static thrust is positive or negative.

In Table XXIX, the gains and losses due to static thrust are listed for operating conditions of the rocket ships which are of particular interest.

Table XXIX: Gains and Losses Due to Static Thrust

"Sirius"	$A_e \cdot 10^{-3}$ cm^2	p_e g/cm^2	p_a g/cm^2	**Static Thrust** ΔF (absolute)	**Percent Gain or Loss**
First Booster:					
Take-off	2,240	700	1,000	$-673 \cdot 10^6$ g	5.25% loss
Cut-off	2,240	700	4	$1.56 \cdot 10^9$ g	12.20% gain
Second Booster:					
Ignition	3,000	24.1	4	$60.3 \cdot 10^6$ g	3.77% gain
Cut-off	3,000	24.1	0.2	$71.6 \cdot 10^6$ g	4.48% gain
Third Stage:					
Ignition	740	10	0.2	$7.25 \cdot 10^6$ g	3.63% gain
Cut-off (and all maneuvers in empty space)	740	10	0	$7.40 \cdot 10^6$ g	3.70% gain
Mars Vessels:	740	10	0.2	$7.40 \cdot 10^6$ g	3.70% gain
Landing Boats:					
Take-off (re-ascent)	176	66	84	$-3.17 \cdot 10^6$ g	1.58% loss
Cut-off (re-ascent)	176	66	0.2	$11.6 \cdot 10^6$ g	5.8% gain
Maneuver empty space	176	66	0	$11.6 \cdot 10^6$ g	5.8% gain

42. Values Used in Computations

For the numerical integration of the ascent of the first *Sirius* stage, an exhaust velocity $U_{e,I} = 2.25 \cdot 10^5$ cm/sec as indicated in Table XXVIII has been used. The static thrust has been determined for each step of the calculation with the aid of Equation 41.1 and has been added or subtracted to or from the nominal thrust. Air drag has been taken into account separately (See Equation 3.1).

In all other instances, the contribution of static thrust has been disregarded. Since, according to Table XXIX, static thrust means a higher total thrust without increase in propellant consumption, except during the first flight seconds of the ascent of the landing boats from Mars, disregard of static thrust is a conservative assumption corresponding to a tacit propellant reserve between 3 and 6 percent in addition to the reserves referred to in the computations of the maneuvers proper. The exhaust velocities used in computations are

Second and third *Sirius* stage $U_{e,II} = U_{e,III} = 2.80 \cdot 10^5$ cm/sec
Mars vessels $U_{e,} = 2.80 \cdot 10^5$ cm/sec
Landing boats $U_{e,} = 2.60 \cdot 10^5$ cm/sec

G. INTERPLANETARY RADIO

43. Evaluation of the Well-Known Experiment of a Radio Contact with the Moon

In 1946, American experimenters succeeded for the first time to receive and to record radio signals emitted by a transmitter located on Earth and reflected by the Moon.

Only a small sector of the directed intensity of the transmitter was intercepted by the Moon, and only a fraction of the impinging energy was reflected. The power of the "Moon transmitter," corresponding to the actually reflected power, was therefore very small. It is evident that a powerful transmitter in space could be received on Earth, if its distance would be many times greater than the distance from Earth to the Moon.

Let

P = the power concentrated in the Moon's direction
$r = 4 \cdot 10^{10}$ cm the distance from Earth to the Moon
$A = 9.5 \cdot 10^{16}$ cm^2 the projected area of the Moon facing the Earth

The power intercepted by the Moon's surface then equals

$$P_{moom} = (P \cdot A)/(4 \cdot \pi \cdot r^2) \cong 5 \cdot 10^{-6} \cdot P \quad (43.1)$$

Only a scant 20 percent of this power is spherically reflected by the Moon,

$$P_{refl} \cong 1 \cdot 10^{-6} \cdot P \quad (43.2)$$

which is one millionth of the power transmitted from Earth in the direction of the Moon. The power received from a given transmitter is inversely proportional to the square of distance. In the case of one-way transmittance, a transmitter such as that actually used in the Moon experiment would therefore produce the same power input in a receiver such as that actually used in the Moon experiment, if the distance is one thousand times greater than the distance from Earth to the Moon. This consideration shows that a one-way communication over a distance of roughly $4 \cdot 10^{13}$ cm would be possible. This distance equals nearly the maximum possible distance between Earth and Mars ($3.77 \cdot 10^{13}$ cm), prevailing when the Sun stands between Earth and Mars.

Consequently, radio communication between Earth and Mars and vice versa is possible with equipment nowadays available at all astronomical appositions.

44. Maximum Distance which can be Bridged with Present Radio Means

By and large, the greater output power of a transmitter; the greater directivities of transmitting and receiving antennae; and the less the noise level at the receiver input; the greater are the distances which can be bridged.

a. Transmitter Output Power Attainable in the Regime of High Frequencies

Table XXX: Transmitter Output Power

Frequency f megacycles per second (mc)	**Wavelength** λ cm	**Method**	**Average Power P** (continuous wave-cw) Watts	**Peak Power** (pulses) Watts
100	300	Triode amplifier (Moon experiment)	$15 \cdot 10^3$	—
350 - 500	85 - 60	Magnetron	$10 \cdot 10^3$	—
340 - 625	88 - 48	Resnatron	$60 \cdot 10^3$	—
500 - 10,000	60 - 3	Magnetron	$1 \cdot 10^3$	—
1,000	30	Magnetron	—	$1{,}000 \cdot 10^3$
3,000	10	Magnetron	$10 \cdot 10^3$	$2{,}500 \cdot 10^3$
10,000	3	Magnetron	—	$1{,}000 \cdot 10^3$
30,000	1	Magnetron	—	$50 \cdot 10^3$

The remarkably high output power attainable at lower frequencies are not listed, because space radio at these frequencies is not expedient as will be shown later. It may be noted that outstanding power values are reached by the Resnatron in the wavelength range from 48 to 88 cm and by the Magnetron at a wavelength of 10 cm (S-band). Both are the result of extensive development during World War II.

b. Directional Antennae

The larger the dimension of an antenna in comparison to the wavelength, the higher is the directional affect for transmitting and receiving. The advantage of high transmitter output power available for longer waves (e.g., broadcast band) is thus more than compensated by the reduced directivity imposed by the limitations of practicable antennae.

A directional antenna of an area A brings a gain in the receiving antenna, as compared to a spherical radiator, by the factor G. This gain can be computed as

$$G = (A \cdot 4\pi/\lambda^2) \cdot \eta \qquad (44.1)$$

where: $\eta > 0.75$ the "antenna utilization factor,"
λ is the wavelength

The receiver antenna power absorption is determined by the area of the receiving antenna and, if the latter is given, independent of the wavelength. For any given distance and wavelength, Equation 44.1 shows that the received signal power is proportional to the product of transmitter and receiver antenna areas. Power input must thereby remain unaffected, even when the parabolic antennae of transmitter and receiver are interchanged.

The antenna gain at the transmitting side is, according to Equation 44.1, for a given antenna area A inversely proportional to the square of the wavelength. If this area A is limited and given by practical reasons, the shortest wavelength would therefore yield optimum results.

Let $A = 10^6$ cm^2 be the maximum possible size of a space antenna. If such an antenna had a mechanical inaccuracy of one thousandth of its linear dimension, this inaccuracy is of the order of one tenth of the wavelength for the 10 cm wave. A wavelength of 10 cm would therefore be the lower limit for such a maximum-size antenna. According to Table XXX, we have for a wavelength of 10 cm an output power which cannot be reached with shorter waves. The latter are, for those two reasons, less suitable for obtaining maximum range.

The beam width of the 10^6 cm^2 antenna for a wavelength of 10 cm is computed for a circular parabolic antenna as follows

$$\vartheta = \lambda/D = \lambda \cdot \sqrt{\pi/4A} = 0.885 \cdot 10^{-2} \text{ radians} = 0.5° \tag{44.2}$$

c. Noise Level

Thermal agitation noise of an antenna directed towards empty space is negligible, because the temperature of the space at which the beam is directed is close to absolute zero.

The antenna intercepts, however, "cosmic noise," which, averaged over the celestial globe, equals

$$N_c = 1.8 \cdot 10^6/f^3 \text{ (Watts)} \tag{44.3}$$

where f represents the frequency in megacycles per second. Equation 44.3 holds for the frequency region between 18 and 200 Mc. For higher frequencies, cosmic noise is negligible, anyway.

The noise level of the receiver can be computed from the relation

$$N_r = \overline{NF} \cdot K \cdot T \cdot \beta \text{ (Watts)} \tag{44.4}$$

where: $\overline{NF}$ = noise factor,

$K \cdot T = 4.11 \cdot 10^{-21}$ joules at $T = 300$ °K,

β = bandwidth of the receiver.

Values of the noise factor $\overline{NF}$ are compiled in Table XXXI.

Eq. (44.4) shows that the noise level of the receiver increases linearly with the receiver's bandwidth.

Table XXXI: Noise Factors

Frequency f (mc)	**Method**	$\overline{NF}$
50	Lighthouse	2.1
100	Tube amplifier	2.5
200	Tube amplifier	3.0
600	Tube amplifier	5.0
1,000	Crystal	10
10,000	Crystal	10

If only noise level is taken into account, the optimum frequency for interplanetary communication over maximum distance is given by the condition that the sum of cosmic noise and noise of the receiver is a minimum. This minimum proves to be between frequencies of 100 and 200 megacycles per second, corresponding to wavelengths between 300 and 150 cm. Frequencies below 100 Mc are not advisable for communication in space owing to the rapidly increasing cosmic noise. Above 200 Mc, receiver noise is predominate, whereas cosmic noise becomes negligible.

d. Range Increase by Pulse-Radar

The transmitter output power can be greatly increased during short pulses, if, by providing sufficiently large intervals between pulses, the power loss (plate dissipation) is kept within such limits as can be handled by the tube heat-wise. For example a tube of 10^3 Watts continuous wave operation could handle a peak power in the order of 10^6 Watts in 1000 pulses per second of one microsecond length each (See Table XXX).

However, optimum reception of pulses of a duration t requires a receiver bandwidth

$$\beta = 1/\tau \tag{44.5}$$

For great increase in peak power by application of short impulses, the average energy given off by the transmitter is nearly constant:

$$E = P \cdot \tau \cong \text{const.} \tag{44.6}$$

In view of Equations 44.5 and 44.6 the useful signal power therefore is

$$P_r = \text{const} \cdot \beta \quad (44.7)$$

i.e., the received signal power is proportional to the bandwidth. But according to Equation 44.4 the noise power in the receiver is likewise proportional to the bandwidth. Hence, for the assumptions made in deriving Equations 44.5 and 44.6, the signal-to-noise ratio is in the first approximation independent of power increase by pulses.

In other words, the appealingly high peak power attainable with pulse-radar is not beneficial to extend the maximum range.

e. Narrow-Band Operation

According to Equation 44.4, the noise power decreases to the same extent as the bandwidth is reduced. If, as a theoretical limiting case, the bandwidth were reduced to zero, the noise power would likewise become zero and the transmitter would be perceptible (without signal communication) over any distance, for the signal need not compete with any noise at all.

In practice, the narrowing of the bandwidth is limited for reasons explicated in what follows. The speed and versatility in radio communication attainable with these smallest possible bandwidths then results necessarily.

f. Frequency Constancy

The receiver bandwidth must be sufficient to intercept the transmitter's carrier despite its fluctuations and those of the receiver's intermediate frequency.

Crystal-controlled oscillators of a constancy of 10^{-8} are not only in practical use on Earth, but can no doubt be employed in space ships also. Let us therefore assume that frequencies of this constancy are at disposal for stabilizing both the transmitter and the receiver. Let us furthermore assume that it is possible to stabilize a high-powered transmitter of an inherent frequency constancy of 10^{-4} by automatic frequency control with such a 10^{-8} crystal oscillator, so that an overall stability of the transmitter's carrier of 10^{-7} results. In the receiver, intermediate frequencies of a stability10^{-8} may be available. The required minimum bandwidth can be read from the third column of Table XXXII.

Table XXXII: Minimum Bandwidth

Frequency f mc	**Maximum Differences Frequency caused by Fluctuations of Transmitter and Receiver** ($f \cdot 10^{-7}$) cycles per second	**Required Minimum Bandwidth β_{min}** cps
100	10	20
300	30	60
600	60	120
3,000	300	600

If no special precautions are provided to suppress the image frequency, the double value of the minimum bandwidth β_{min} is to be applied. Hence, the bandwidth determining the noise becomes in the present case

$$\beta_n = 4 \cdot 10^{-7} \cdot f \quad (44.8)$$

We see that the noise power, proportional to β_n, increases linearly with the used frequency, owing to the lack in perfection of the frequency constancy.

The very marked frequency shifts between receiver and transmitter occurring in space radio because of the Doppler effect (see Sec. 46) have no bearing on the required minimum bandwidth. These Doppler shifts occur so slowly, that, unless extremely narrow bandwidths are employed, a current tuning of the receiver by automatic frequency control is easily possible.

g. Frequency Choice for Maximum Range

The useful receiver input is

$$P_r = (P \cdot G \cdot A \cdot \eta)/(4 \cdot \pi \cdot r^2) \quad (44.9)$$

The range r reaches its maximum value r_{max}, when this signal power input equals the noise power, as referred to the receiver input. With the aid of Equation 44.4 it follows that

$$P_{r,min} = (P \cdot G \cdot A \cdot \eta)/(4 \cdot \pi \cdot r_{max}^2) = \overline{NF} \cdot K \cdot T \cdot \beta \quad (44.10)$$

where $A \cdot \eta = A_C$ the "collecting antenna area." This is in the first approximation independent of the frequency, $G = const \cdot 1/l^2 = const \cdot f^2$ (See Equation 44.1), $\beta = const \cdot f$ (see Equation 44.8).

From Equation 44.10 we obtain the general relation

$$r_{max} = const \sqrt{P/\overline{NF} \cdot f}. \tag{44.11}$$

Substituting the available transmitter powers P (continuous wave, column 4) from Table XXX and the noise factors $\overline{NF}$ for the various frequencies from Table XXXI, we find with the aid of Equation 44.11 that there is no marked frequency optimum for reaching a maximum range r_{max}. In the frequency band of the Resnatron r_{max} slightly increases, and, therefore, the absolute maximum in range is found to be a frequency of 600 Megacycles per second. It may be noted, however, that the range obtainable with 3000 Megacycles per second is only slightly shorter despite a six times less powerful transmitter.

While, therefore, the overall maximum range can be reached with a Resnatron transmitter in the 50 cm band (see Sec. 44 h), the 10 cm band and proves superior on account of its smaller power requirement and its inherently greater bandwidth (See Table XXXII).

h. Maximum Range

We shall now investigate the maximum range obtainable with a transmitter and receiver arrangement which, from the angle of antennae dimensions and power, represents about the maximum of what can be realized with present-day means.

The following specifications are introduced:

Frequency $f = 600$ Megacycles per second (Resnatron)
Wavelength $\lambda = 50$ cm
Power $P = 6 \cdot 10^4$ Watts (continuous wave)
Antenna areas $A = 10^6$ cm^2 (physical size, both on receiving and transmitting side)
Collective antennae areas $A_c = A \cdot \eta = 7.5 \cdot 10^5$ cm^2
Receiver noise factor $\overline{NF} = 5$
Receiver bandwidth $\beta = 120$ cps (image frequency suppressed).

With the aid of Equation 44.10 we find

$$r_{max} = \sqrt{(P \cdot G \cdot A_C)/(4\pi \cdot \overline{NF} \cdot K \cdot T \cdot \beta)} \tag{44.12}$$

whence we obtain with the foregoing numerical values a limiting range

$$r_{max} = 2.35 \cdot 10^{15} \text{ cm.} \tag{44.13}$$

The orbital diameter of the outmost planet of our solar system, Pluto, is, for comparison, $1.2 \cdot 10^{15}$ cm.

Eq. (44.13) gives the absolute, upper limit for the range which can be covered with present-day radio means. Differentiation between signals (long, slow pulses) and noise of equal intensity is feasible by means of visual observation on an oscilloscope screen.

45. Layout and Range of the "High Duty Radio Sets"

The limiting range found in the forgoing Section exceeds the maximum distance between Earth and Mars by a factor of 62. In terms of power, this means that even in this most unfavorable apposition an excess of 36 decibels is available. When Mars in his opposition is closest to Earth ($77 \cdot 10^{11}$ cm), the excess is even as high as 49 decibels.

Thus considerable reserves are available which may be utilized for the following purposes.

a. Reduction of transmitter power, whereby also the dimensions of the sun mirrors for the power-generating plant can be reduced
b. Reduction of the dimensions of the directional antennae
c. Widening of the bandwidth whereby music and voice communication becomes possible.

Which of these possibilities are preferred, depends merely upon the expenditure which one wants to afford in order to increase the limit in range for voice transmission.

The High-duty sets in our story are based on the following specifications:

Frequency $f = 3000$ Megacycles per second (Magnetron)
Wavelength $\lambda = 10$ cm

Power $P = 10^4$ Watts (both ship's station and Lunetta Station)

Antenna area

Ship's station $A_s = 10^5$ cm^2

Lunetta station $A_L = 4 \cdot 10^5$ cm^2

Collective antenna area

Ship's station $A_{c,s} = 7.5 \cdot 10^4$ cm^2

Directivity of antenna

Lunetta station $G_L = 3.78 \cdot 10^4$ (see Equation 44.1)

Receiver noise factor $\overline{NF} = 10$ (see Table XXXI)

We furthermore assume that adequate voice transmission requires a signal-to-noise ratio greater than a = 100 (corresponding to 20 decibel), and good voice transmission requires a minimum bandwidth $\beta = 5000$ cps. Then we find the limiting range for voice transmission with the aforementioned equipment as follows

$$\begin{aligned} r_{max} &= \sqrt{(P \cdot G \cdot A_{C,S})/(4\pi \cdot a \cdot \overline{NF} \cdot K \cdot T \cdot \beta)} \\ &= \sqrt{(10^4 \cdot 3.78 \cdot 10^4 \cdot 7.5 \cdot 10^4)/(4\pi \cdot 100 \cdot 10 \cdot 4.11 \cdot 10^{-21} \cdot 5000)} \\ &= 1.05 \cdot 10^{13} \text{ cm} \end{aligned} \tag{45.1}$$

This limiting range, i.e., distance between Earth and expedition, will be reached about 160 days after leaving the orbit of departure. In Equation 45.1 we have once more tacitly assumed that measures to suppress the image frequency were provided, see Sec. 44 f. The circuit required for this purpose is relatively simple and effective.

After discontinuation of voice communication, operation can be continued by automatic telegraphy. Assuming a required bandwidth of $\beta = 1000$ cps and a necessary signal-to-noise ratio of a = 20 (i.e., 13 decibel), we find a limiting range

$$r_{max} = 5.24 \cdot 10^{13} \text{ cm} \tag{45.2}$$

The greatest distance between Earth and Mars is $3.77 \cdot 10^{13}$ cm. Hence, during the entire length of the expedition, radio communication even with automatic telegraphy is possible. The limiting range for slow telegraphy ("brass pounding"), of course, is very much greater, for a smaller bandwidth is required and the signal-to-noise ratio can also be reduced if receiving of acoustical or optical signals (earphones or oscilloscope) is provided.

46. Doppler Effect

Any increase or decrease of distance between transmitter and receiver causes a Doppler effect, i.e., a shift between the emitted and the received frequency.

During our Mars voyage, radio communication between the space ships and Lunetta is affected by Doppler shifts owing to the following kinds of motion:

a. Rotation of Lunetta about Earth,

b. Relative motion between ships and Earth on the outward-bound and homeward-bound voyaging ellipses,

c. Revolution of the ships about Mars after entering the satellite orbit,

d. Relative motion of Mars and Earth during the "waiting time."

The amount of the respective Doppler shifts can be calculated from the relation

$$\Delta g = \Delta V/\lambda \tag{46.1}$$

where: $\Delta\gamma$ the frequency shift,

Δ V the component of the relative velocity between transmitter and receiver in the direction of wave propagation, i.e., in the direction of the line of sight, λ the wavelength.

For instance, the orbital motion of Lunetta with a velocity $V_{circ,1} \approx 7 \cdot 10^5$ cm/sec causes a maximum differential velocity $\Delta V = 14 \cdot 10^5$ cm/sec with a frequency of one hour. For a wavelength $\lambda = 10$ cm, we obtain a Doppler effect

$$\Delta\gamma = 14 \cdot 10^5/10 = 140{,}000 \text{ cps} \tag{46.2}$$

The relative motion between Earth and Mars brings about a maximum Doppler effect, when the angle Sun - Earth - Mars is a right one. Then the Doppler effect is almost entirely determined by the orbital velocity of Earth. Thus

$$\Delta\gamma = 29.8 \cdot 10^5/10 = 298{,}000 \text{ cps} \tag{46.3}$$

47. Remark on to Mercury-Vapor Power Plant of the High Duty Radio Set

The merits of mercury-vapor turbines for power generation in space ships become evident from the following two figures:

Vapor pressure of Mercury at 120 °C: 0.7557 mm Hg = 1 g/cm^2
Vapor pressure of Mercury at 700 °C: 700 psi = $50 \cdot 10^3$ g/cm^2

In contrast to steam turbines, it is therefore possible to operate mercury-vapor turbines economically with a condenser temperature as high as 120 °C.

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D. Special References

Magnetically Suspended Railway with Solenoid Drive

A ballistic test range with magnetical suspension and solenoid drive was in development at the Ballistische Versuchsanstalt, Gatow and Goettingen, Germany, under the direction of Dr. Schardin.

Sleep Teaching

The story on sleep teaching in our tale has been based on work conducted by Max Sherover, president of the Bingusphone Institute, and experiments by Dr. C.E. Elliot, University of North Carolina.

Brain Waves

The electro-encephalograph (brain wave recorder) was pioneered by Prof. Hans Berger, Psychiatric Institute at the University of Jena, Germany and Dr. E.D. Adrian, world-famous neurologist, Cambridge University, England. Modern experiments were conducted by Dr. C.E. Elliot, University of North Carolina.

Fat Algae Cultures

Use of algae for production of fats, sugars and proteins was pioneered by Sam Ruben, University of California. After Ruben's death his work was continued by Drs. Melvin Calvin and Andrew Benson. Dr. Herman A. Spoehr of the Carnegie Institution's Division of Plant Biology at Palo Alto, California, recently succeeded in developing a species of algae containing 85 percent fat. Dr. Spoehr believes in utilization of algae for mass production of fats.

See Lester Velie, "Bread Within the Waters," Colliers Magazine, Sept. 11, 1948.

Diagrams – Drawn by Dr. Wernher von Braun

The 14 diagrams on the following pages were hand-drawn by Dr. Wernher von Braun. They are part of the contents of this appendix, and are referenced within.

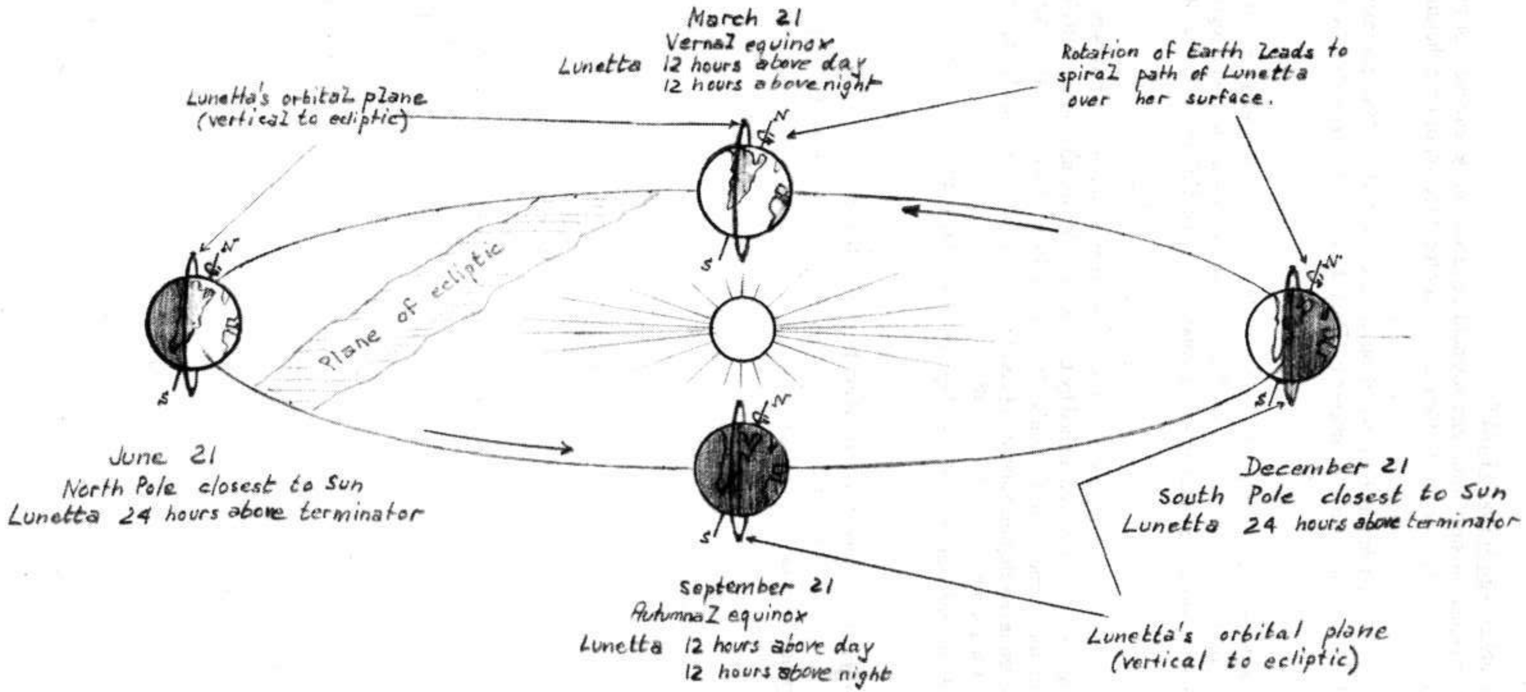


Fig. 0

Location and features
of Lunetta's orbital plane
(see page)

Wernher von Braun 10-5-49

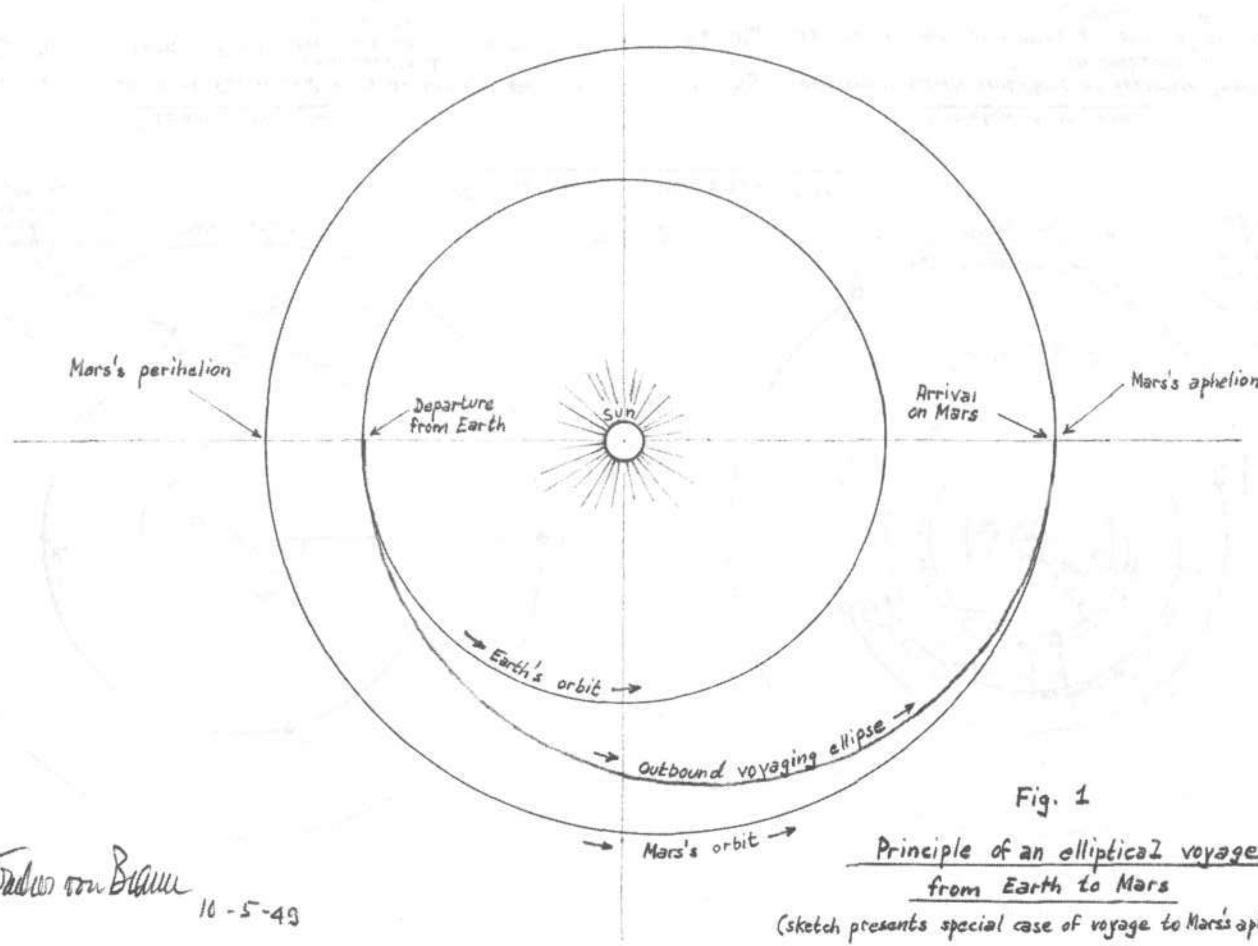


Fig. 1

Principle of an elliptical voyage from Earth to Mars

(sketch presents special case of voyage to Mars's aphelion)

Wernher von Braun 10-5-49

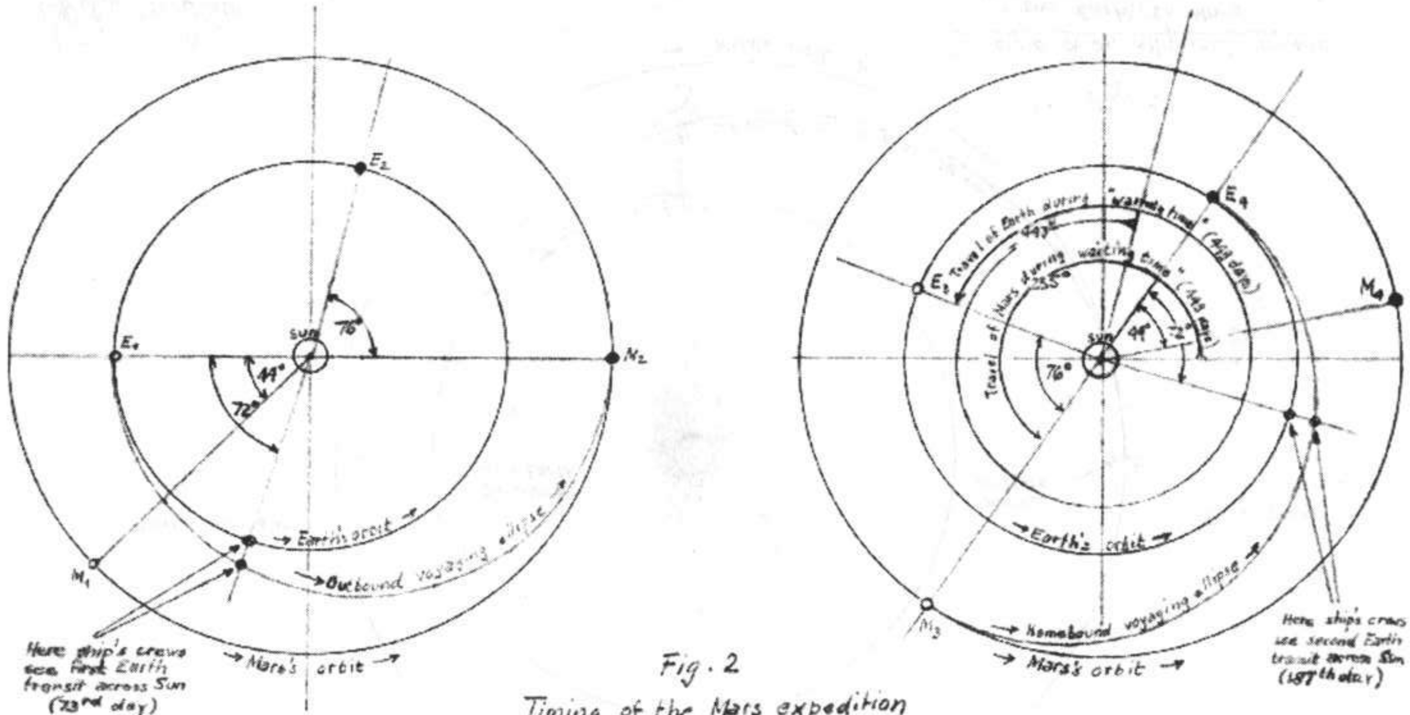


Fig. 2

Timing of the Mars expedition

(see page)

Outbound voyage

E_1, M_1 : positions of Earth and Mars at time of departure (manoeuvre 1)

E_2, M_2 : positions of Earth and Mars at arrival on Mars (manoeuvre 2)

Homebound voyage

E_3, M_3 : positions of Earth and Mars at departure from Mars (manoeuvre 3)

E_4, M_4 : positions of Earth and Mars at arrival on Earth (manoeuvre 4)

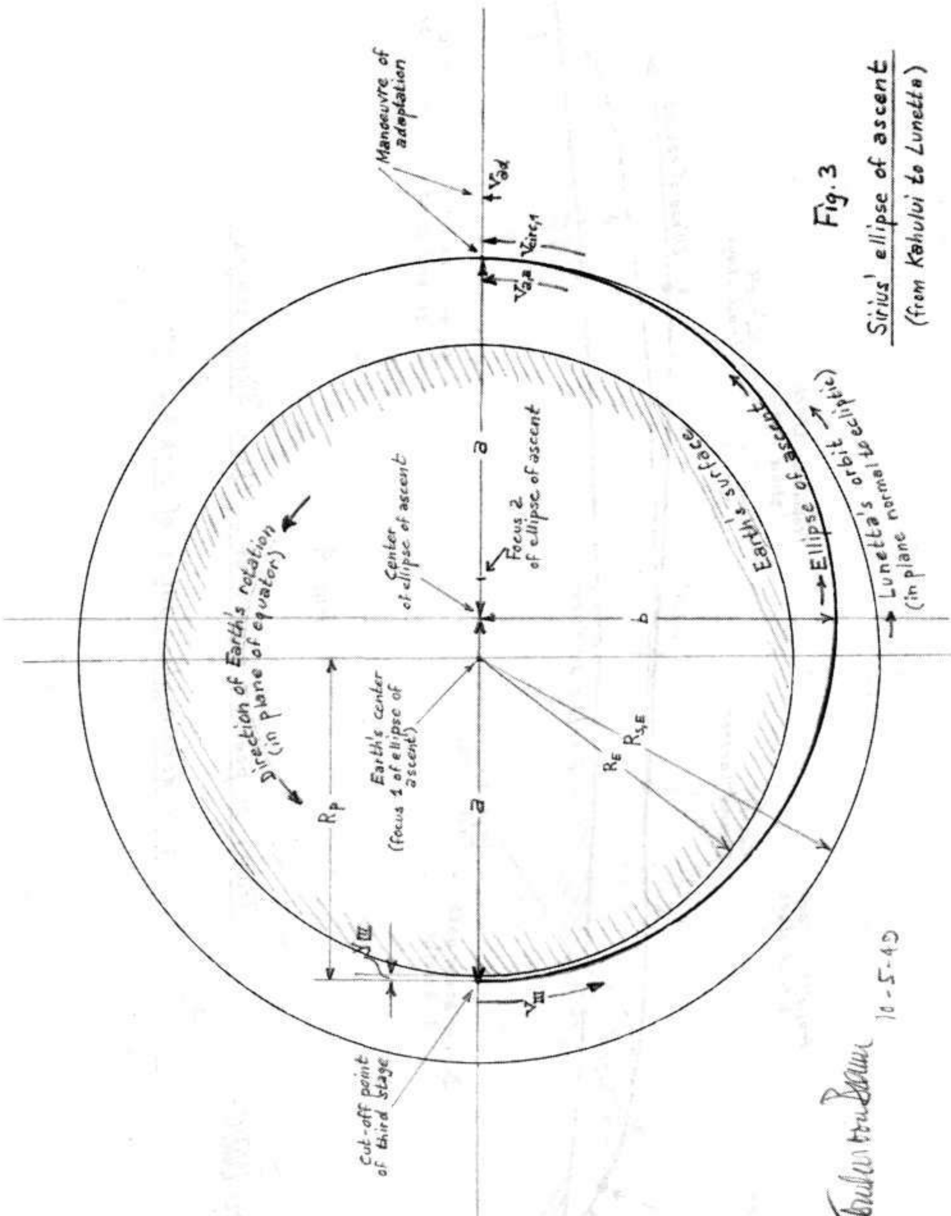


Fig. 3

Sirius' ellipse of ascent

(from Kahului to Lunetta)

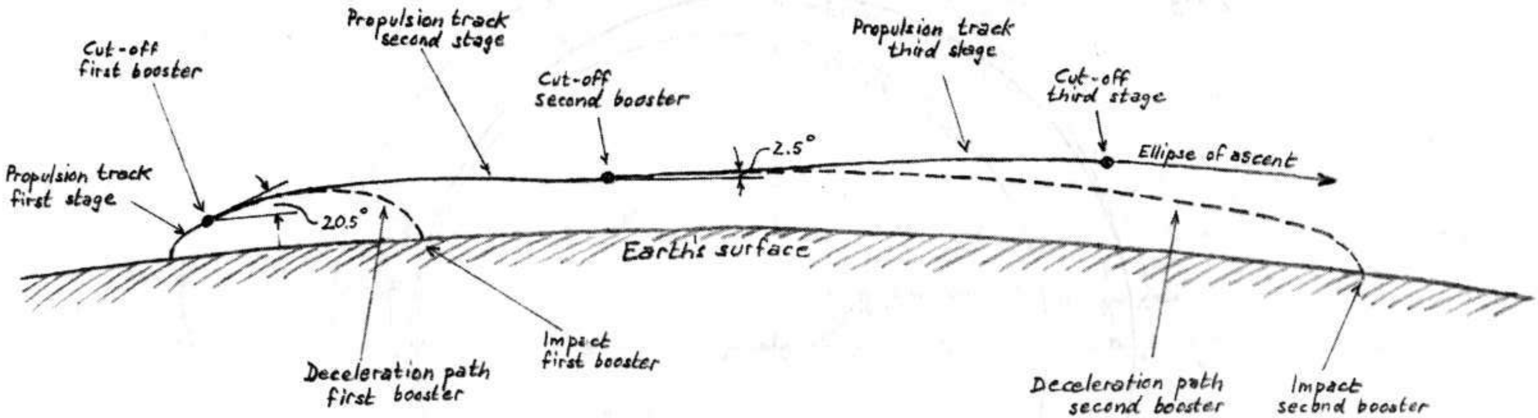


Fig. 4

Tracks of powered ascent of all three "Sirius" stages

and deceleration paths of both boosters.

10-5-49

Track A: Ellipse with apogee in the satellitic orbit. Period of revolution is shorter than that of Lunetta's orbit. This ellipse takes busy bee from Lunetta (L) after one complete revolution to advanced station S_1.
At departure bee's circular velocity must be decreased.

Track B: Ellipse with perigee in the satellitic orbit. Period of revolution is longer than that of Lunetta's orbit. This ellipse takes busy bee from Lunetta (L) after one complete revolution to trailing station S'_2.
At departure bee's circular velocity must be increased

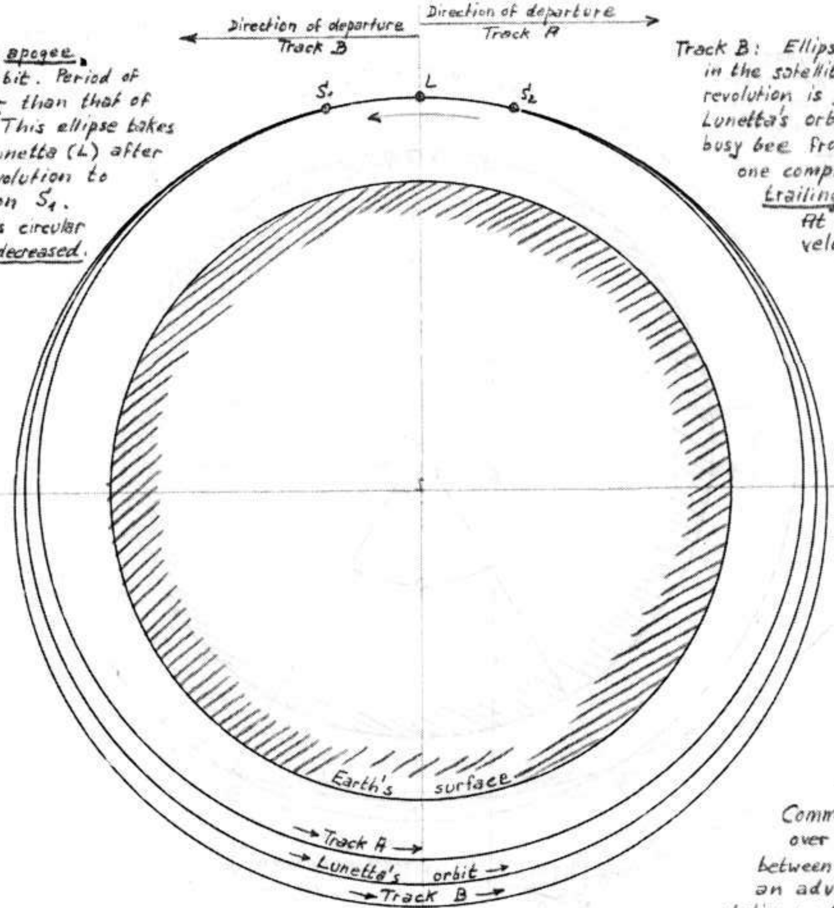


Fig. 5

Communication trips over full ellipses between Lunetta and an advanced and trailing station on the same circular orbit.

Wernher von Braun 10-5-49

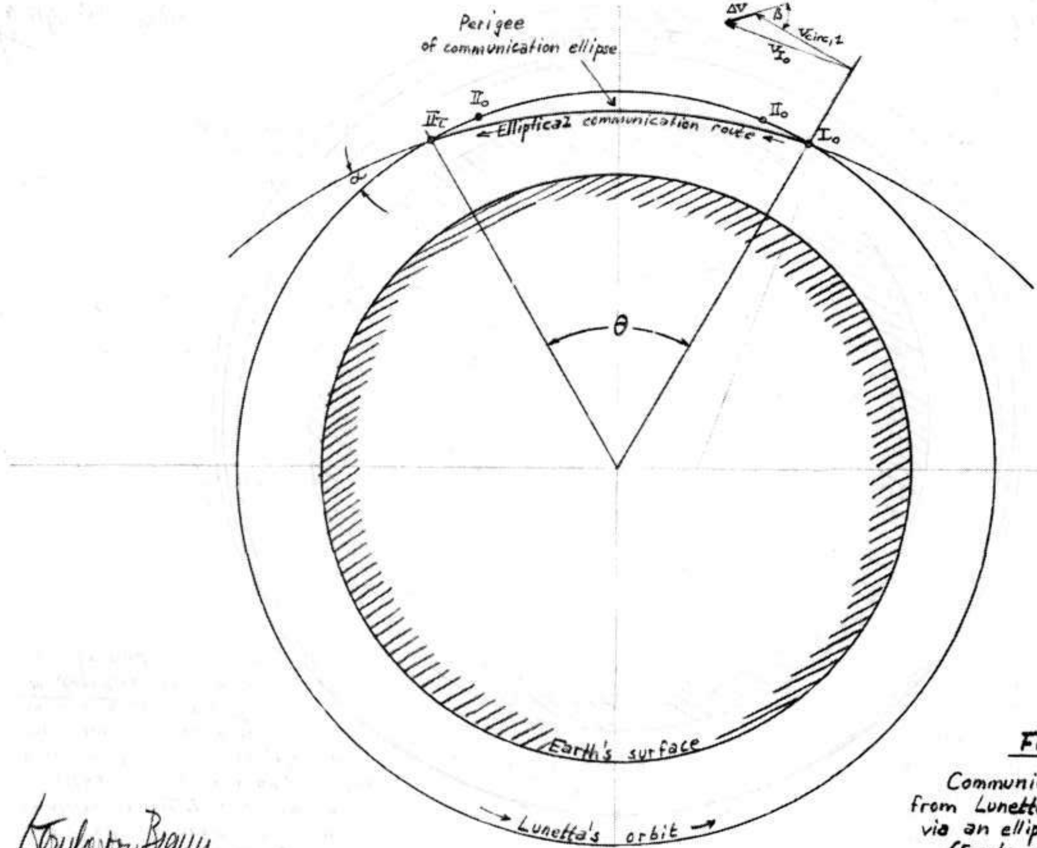


Fig. 6

Communication trip
from Lunetta to Observatory
via an elliptic arc.
(Scale distorted)

Wernher von Braun
10-5-49

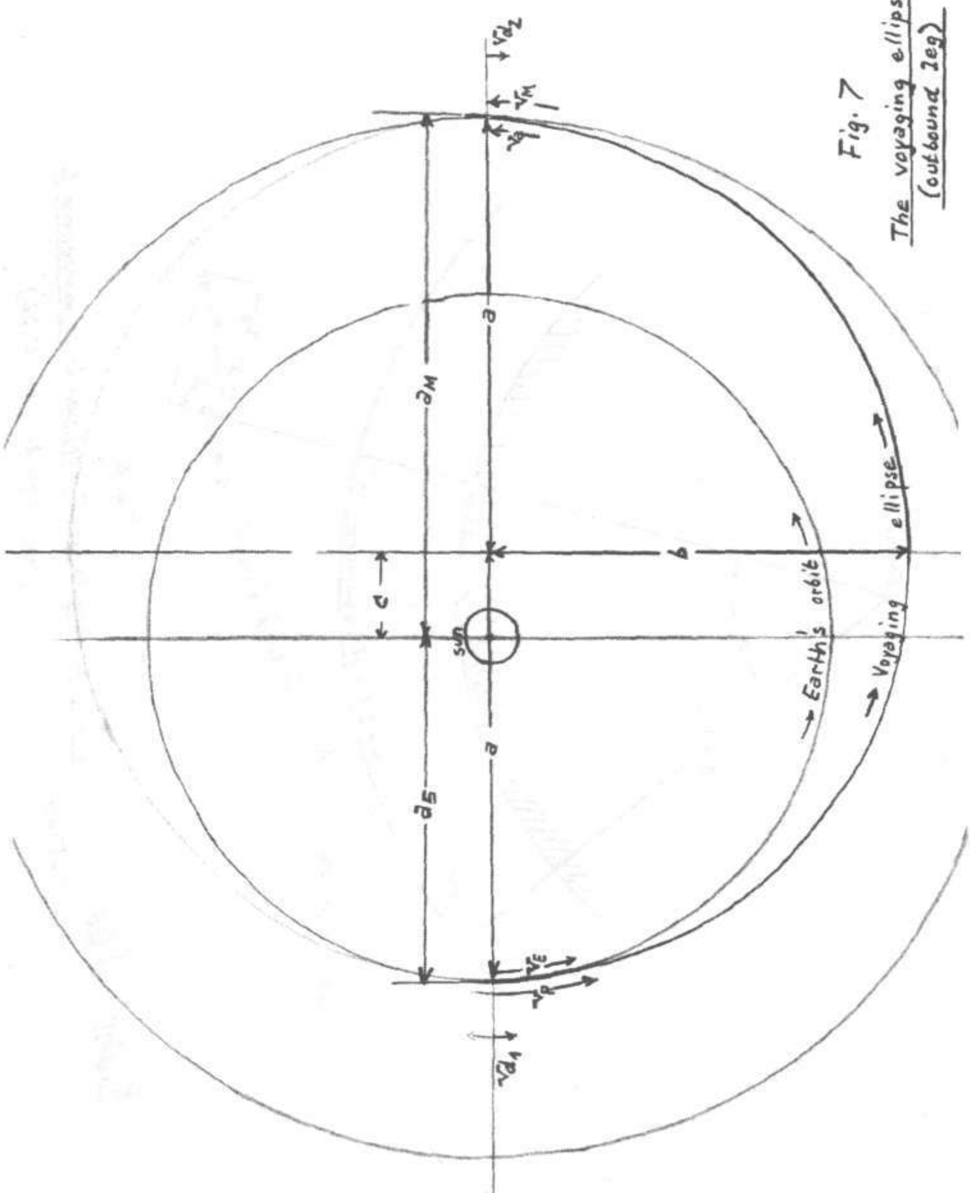


Fig. 7
The voyaging ellipse
(outbound leg)

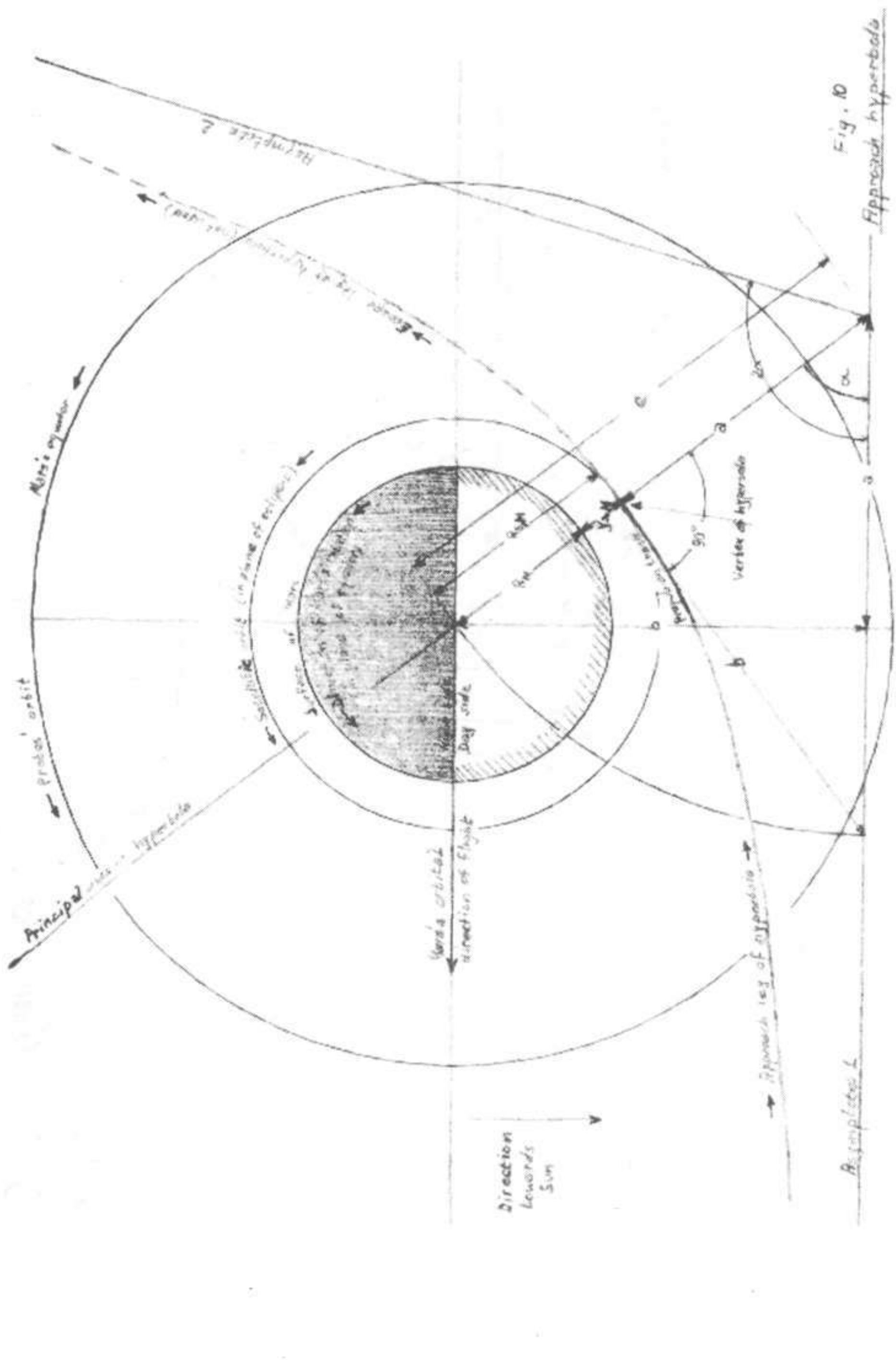


Fig. 10
Approach hyperbola

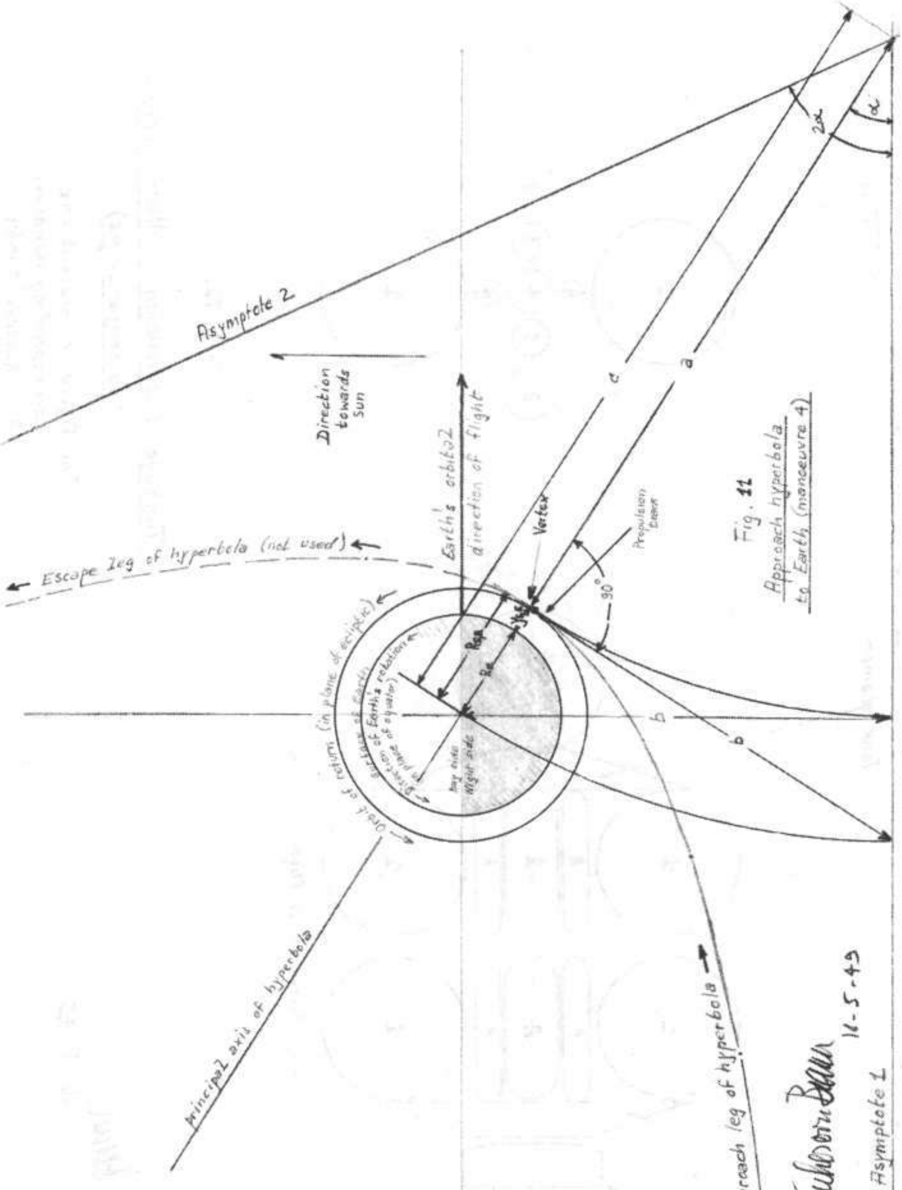


Fig. 11
Approach hyperbola to Earth (manoeuvre 4)

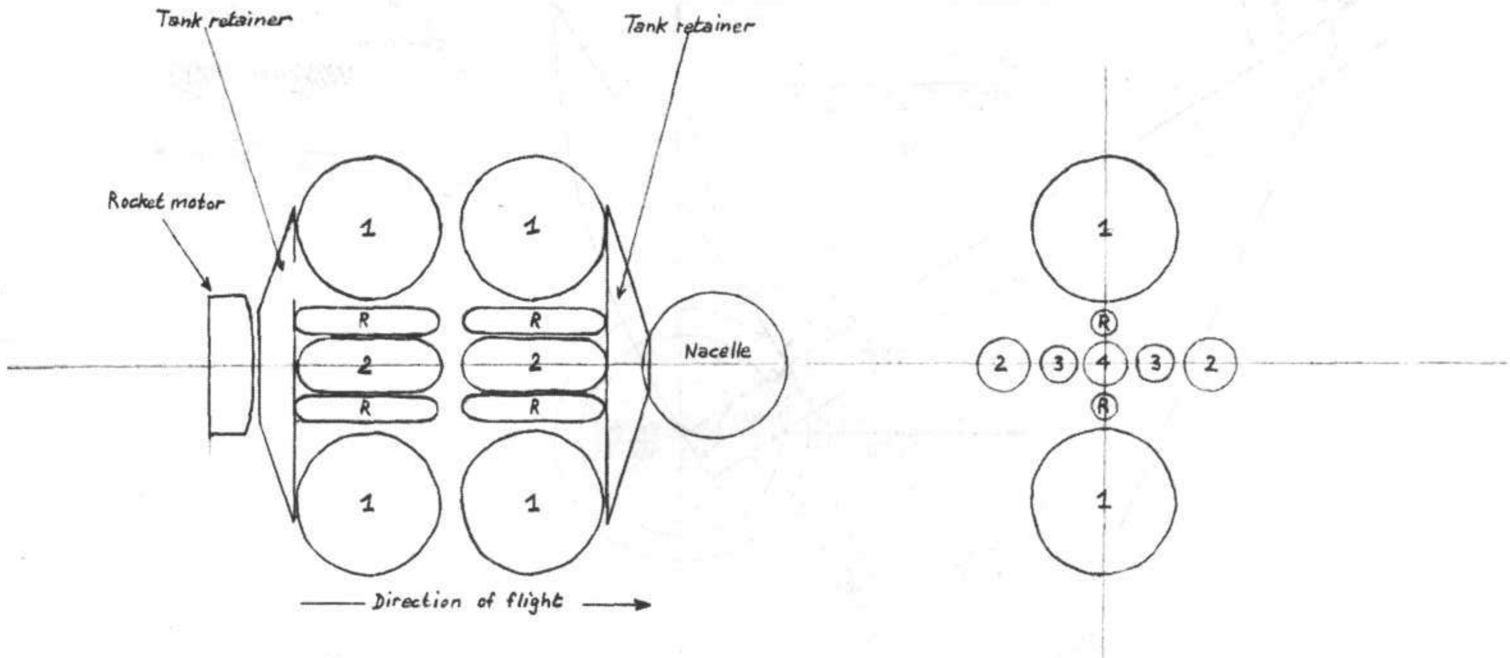


Fig. 12

Tankage distribution in Mars vessels

(passenger ships)

The figures respresent the corresponding manoeuvre.
R = Reserve tanks

10-5-49

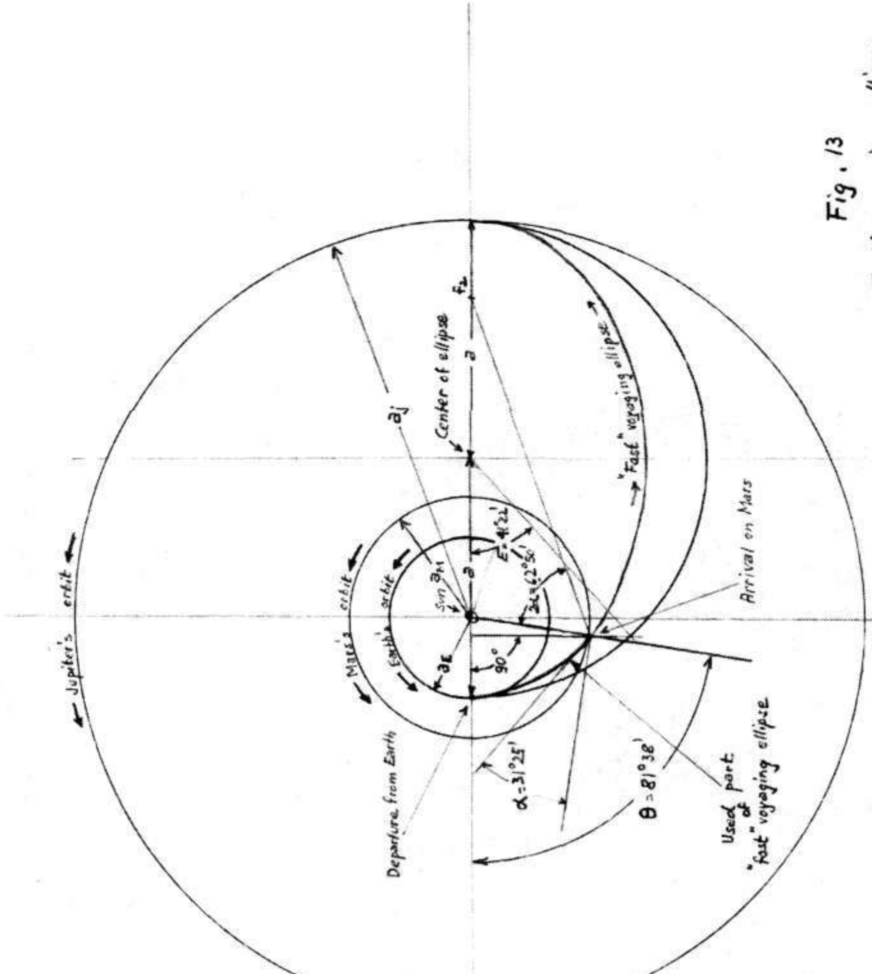


Fig. 13
"Fast" voyaging ellipse

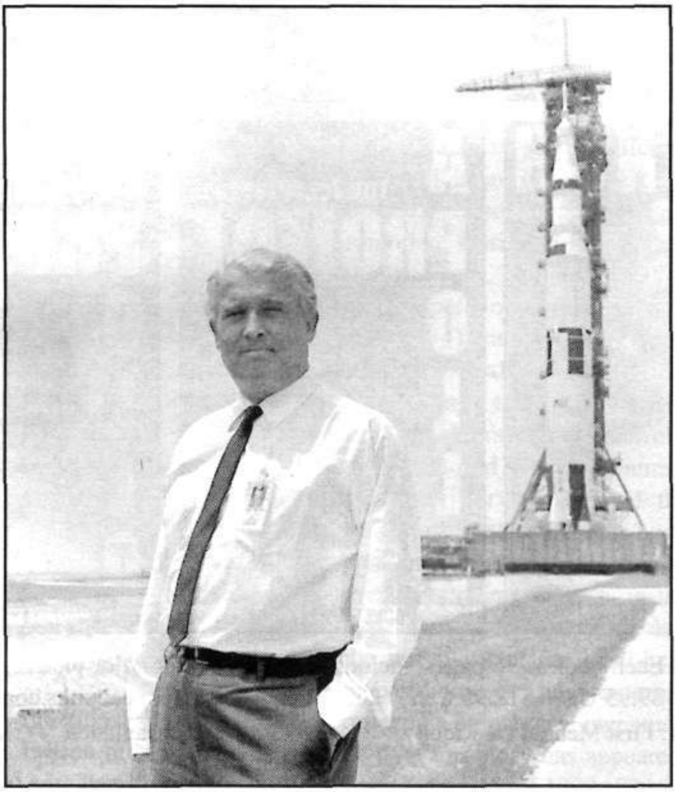
Wernher von Braun
10-5-49

About the Author

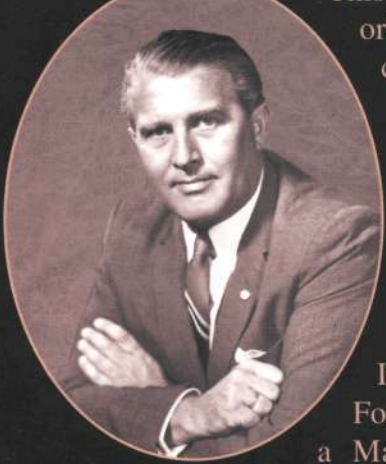
Dr. Wernher von Braun is best known as NASA's "rocket man." His team designed and developed, among other large rockets, the Redstone booster, which launched America's first satellite and astronauts, and the giant Saturn V, which launched the Apollo missions to the Moon.

Although he worked on military rocket development during the first half of his career, Wernher von Braun dreamed of a world in which rockets were used for space exploration, and this, he claimed, was his primary motivation. In a series of articles in *Collier's Weekly* magazine in 1952, von Braun presented a concept for an Earth-orbiting space station. He also worked as a technical director at Disney studios, preparing three television films about space exploration.

In 1949 von Braun penned a science fiction story, *Project Mars: A Technical Tale*, a story based on detailed and accurate science, yet presented as a very human undertaking. Clearly intended as a way to infect others with his enthusiasm for human space exploration, this forgotten tale lingered in his personal files until being published in 2006, nearly 30 years after his death and 57 years after it was written.



Dr. von Braun pauses in front of the Saturn V vehicle being readied for the historic Apollo 11 lunar landing mission at the Kennedy Space Center (KSC). The Saturn V vehicle was developed by the Marshall Space Flight Center under the direction of Dr. von Braun. Photo Credit: NASA Marshall Space Flight Center



This never-before-printed science fiction novel by the original "rocket man," Dr. Wernher von Braun, combines technical fact with a human story line in the way that only a true dreamer can realize.

This novel takes the reader through the entire adventure—the planning for a Mars mission, the building of the mighty space ships, the long journey, the amazing discoveries made on Mars, and the return home. Gary Holt, former Chief Instructor of Rocket Pilots for the U.S. Space Force, leads a 10-ship multinational team to Mars—a Mars with one surprising difference from our Mars!—and after spending months exploring the red planet, brings his mission home a complete success.

The author's detailed attention to the actions and feelings of the characters—both those who went and those who stayed behind—makes this an adventure of human proportions, rather than merely another fanciful tale.

Written more than half a century ago, this enthusiastic tale of human space exploration, based on detailed and accurate science, has lingered unpublished in von Braun's personal files until now, nearly 30 years after his death and 57 years after it was written.

This exclusive von Braun treasure comes complete with an appendix of his original calculations and technical drawings, made in the late 1940s, on which the story's journey is based.

Following the end of World War II, Wernher von Braun emigrated to the United States and became the driving force behind America's space launch vehicles. Dr. von Braun's team at NASA developed the Redstone booster that launched America's first astronauts, and the mighty Saturn V launch vehicles that sent the Apollo spacecraft to the Moon.

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