Rockets

THE FUTURE OF TRAVEL BEYOND THE STRATOSPHERE

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ALSO BY WILLY LEY

THE LUNGFISH AND THE UNICORN
An Excursion into Romantic Zoology

THE DAYS OF CREATION
A Biography of Our Planet

BOMBS AND BOMBING

SHELLS AND SHOOTING

Rockets

THE FUTURE OF TRAVEL BEYOND
THE STRATOSPHERE

WILLY LEY

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CONTENTS

LIST OF DRAWINGS

LIST OF PHOTOGRAPHS

ALL OF THE PLATES ARE GROUPED FOLLOWING THE INTRODUCTION, PAGE 4

INTRODUCTION

THIS BOOK on rockets, devoted to their Past and Present as recorded by history and to their Future as indicated by theory, happens to go to print at a time when the general interest in rockets is greater than it has ever been before.

As will be seen in the book itself, the word "rocket," while always referring to the same principle of physics and most of the time to practically identical mechanical embodiments of that principle, evoked different ideas in the minds of people at different times. Two men speaking about rockets five hundred years ago discussed a weapon of war. Three hundred years ago a discussion of rockets was a discussion of a means to enrich a fireworks display. A hundred years ago it was war weapons again and fifty years ago it was again fireworks. At present it is war weapons once more.

This short recounting of habits of thought may make it seem as if the use of rockets can only fluctuate between these two extremes: the grim weapon of war and the instrument of amusement in a carefree period. And it may also give the impression that the more serious aspects of rockets will be gone again once the war is over.

But these two applications fail to comprise the theory. They coincide with the Past and the Present in the historical sense. Of course there will be war rockets and amusement rockets in the future too. But there will be bigger and more important applications than either of these two.

If you look at the future or, which is about the same thing, at rocket theory, the history of the rocket suddenly begins to look unimportant. Because the theory promises much more—new means of scientific research in several fields. It even holds the ultimate promise of the possibility of space travel, the fulfillment of an old dream.

I have occasionally been introduced to lecture audiences as a man who wants to fly to the moon. Or even as a man who wants to shoot to the moon.

Well, I don't.

Those statements, taken literally, are wrong.

But the implications are correct. If the word "moon" is taken to mean any planet other than the earth it is quite true that I am doing my best to help in producing the means of reaching whatever can conveniently be reached. But it will not be done by flying or shooting.

After centuries of steady and sometimes furious development of the physical sciences and after decades of theoretical research devoted to that particular problem, we definitely know two things. One of them is that at least some of the other planets—including, incidentally, our moon—are within reach, even though it cannot be done tomorrow or next year. The other thing we know is that the spaceship (to use a neutral term) has to be based on Sir Isaac Newton's Third Law of Motion.

That law states that every action must be accompanied by a reaction of equal force, pointing in the opposite direction. Such a reaction, we know, must take place anywhere and under any circumstances, under water or in the air or even in airless space. It is the natural law that makes a gun recoil when it is fired, and in that case the inevitability of the law is annoying most of the time. By the same token, however, we know that such a reaction will work in airless space and since this is the only thing we know will work in airless space outside the atmosphere of our planet, we know that a spaceship would have to be a vessel which moves by the reaction against something, most probably by the reaction against a stream of exhaust gases, generated in quantities for this specific purpose. It is the same application of the Third Law of Motion as that demonstrated by any ordinary skyrocket, which, after being ignited, rises a few hundred feet into air where it is then made to explode into a brilliant spectacle of colored fire.

The point I want to make here is that those skyrockets are not "shot" and that they do not "fly." They are "fired" (meaning ignited) and no initial motion is supplied to them; they do all their own propelling from that moment on. Rising they do not "fly," they cleave the air more or less in the manner of a projectile.

All this had to be said about that lecture platform introduction of flying or shooting to the moon. It is absolutely certain now that one cannot "fly" to the moon; the atmosphere of the earth extends for just about one per cent of the distance, and at best three per cent of the height of the atmosphere is suitable for flying: the three per cent closest to the ground. To "shoot" to the moon, in the manner employed by the heroes of Jules Verne's famous novel, is impossible too, although it is not so easy to explain why. At any event, even if it could be done, it would be useless.

But rockets, just because they neither fly nor are shot—to shoot a rocket of any type would ruin it, and whether a rocket can fly (with wings on) is one of the unsolved problems of modern aviation—are theoretically capable of reaching the moon. Not skyrockets of exaggerated size, but machines which have received the same name because they operate on the same principle, the principle stated in that Third Law of Motion.

What has been done with rockets in the past and what all these more or less distorted references to space rockets really mean is told on most of the pages of this book. And that brings me finally to the book itself.

It is the story of a great idea, a great dream, if you wish, which probably began many centuries ago on the islands off the coast of Greece. It has been dreamt again and again ever since, on meadows under a starry sky, behind the eyepieces of large telescopes in quiet observatories on top of a mountain in the Arizona desert or in the wooded hills near the European capitals. It has been dreamt all over the earth, in places ranging from quiet libraries to noisy machine shops. And everyone who thought about that dream added a little knowledge.

The thought assumed many shapes and facets. It was philosophic wonder whether the earth, and humanity on it, are alone in the universe or whether there are other earths with other humanities. It was astronomical research, trying to establish some knowledge about those other "earths" that were known to exist, the other planets of our sun. It was biological research which tortured the spores of bacteria with vacuum and cold, trying to see whether they would survive. It was an engineering problem, clothed in symbols and equations.

It is the story of the idea that we possibly could, and if so should, break away from our planet and go exploring to others, just as thousands of years ago men broke away from their islands and went exploring to other coasts.

It is a story with many ramifications, side issues, and blind alleys. But it is also a story of continuous progress, one small step here and another one there. It is a long story too. First the problem itself had to grow up, men had to realize—and then *prove*—that the luminous pin points in the sky were worlds, as large and usually larger than our own. After that . . . but the book will tell the story.

There are only a few personal remarks I have to add.

The problem of space travel, and incidentally of the scientific investigation of rocket propulsion, assumed prominence not quite two decades ago. I have been intimately connected with it since that time and I confess to two books in German about it, published in 1926 and 1928, respectively, along with a scholarly (and rather dry) book on the history of the powder rocket which has never been published except in abstract.

These two books—along with some twenty other similar books written and published during the period from 1925 to 1934, mostly in Germany and in Russia—are now obsolete. Little has been written since then and what has been written suffered from a curious kind of caution. Except for a few courageous British authors everybody suddenly began to abide by a tacit understanding which once was expressed to me in the form of a friendly admonition. "Don't mention the theory of space travel," I was told. "Speak about altitude rockets for meteorological research, stress the probable importance of reaction motors in aviation, and touch upon war weapons if you like. But don't say spaceship. People will scoff."

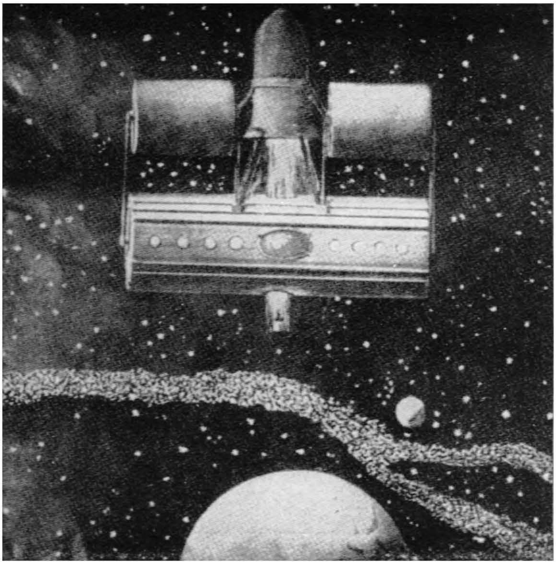
I never followed that advice.

The meteorological rocket, discussed in detail in Chapter 7, is a good thing and it will be the first to be realized, but it is only a beginning. The rocket airplane, as I said before, is a new problem in aviation and nobody can tell yet what form it will take and how valuable it will be. And as for war rockets, in spite of some spectacular applications in the present war most of their story lies in the past.

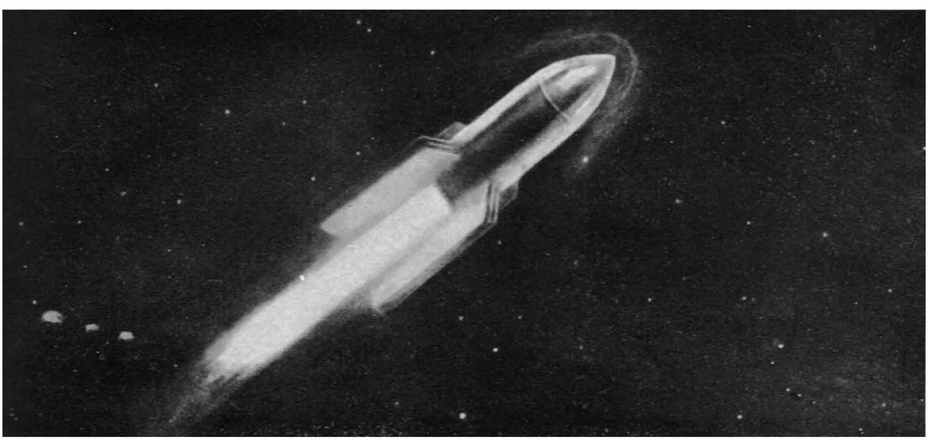
I do not feel responsible for the fact that some people follow an old practice as regards spaceships. In 1840 there were still very many people who did not believe in railroads and only a very few who believed in ocean-going steamships. The automobile was ridiculed and the Wright Brothers needed two years to convince people that they had actually flown. Of course neither of them had any commercial possibilities, a statement which at various times included the telephone, the electric light bulb, and the radio.

So, in disregard of the advice given to me some six years ago, I'm going to speak about spaceships.

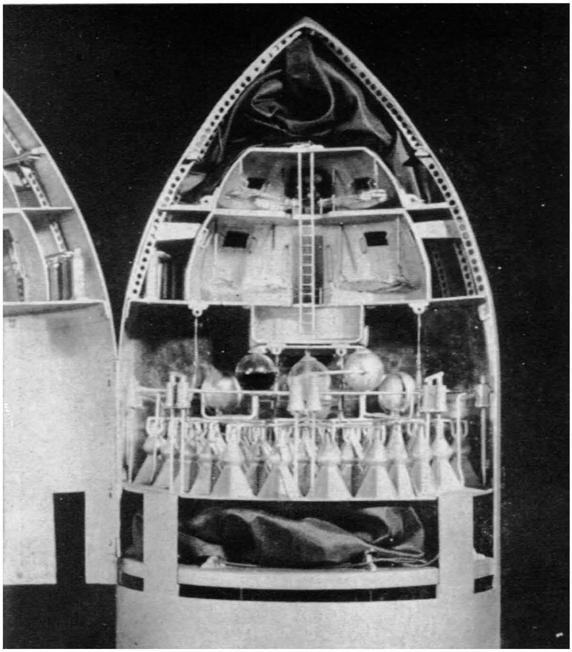
Some time in the future they'll exist.



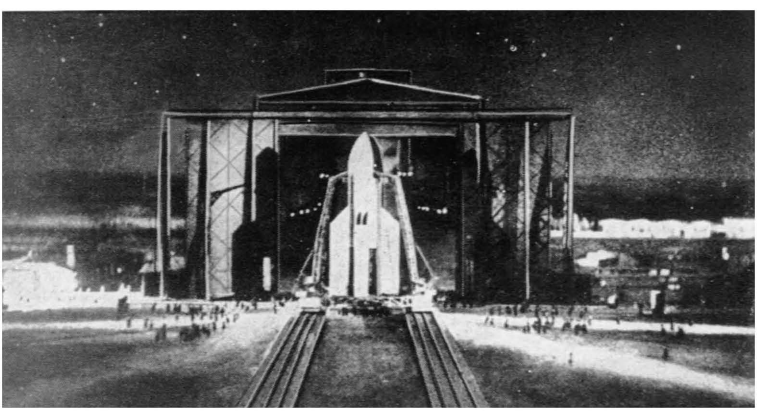
I. Hermann Ganswindt's Spaceship. The two cylindrical containers right and left of the bell-shaped explosion chamber were to hold the supply of explosion "pills." The long passenger cabin was provided with a center well to permit passage of the exhaust.



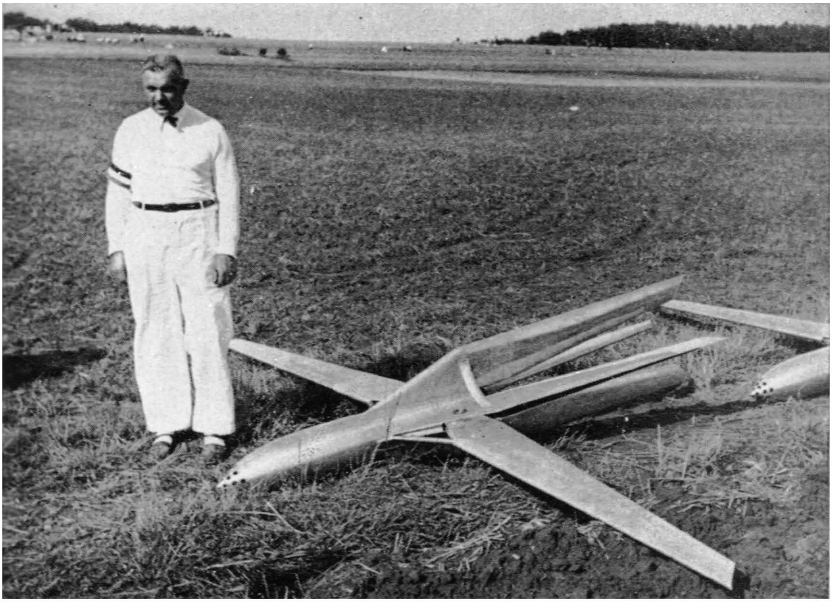
II. Spaceship, as conceived by Hermann Oberth, as it is leaving the atmosphere. From the Fritz Lang film, Frau im Mond.



III. Model of the upper portion of a spaceship built for the film, Frau im Mond. *From top to bottom: parachute, pilot cabin, passenger cabin, storage room, propulsion mechanism. The spheres are fuel pumps; the cones, exhaust nozzles. This model was later loaned to the* VfR *and was finally seized by the Gestapo.*



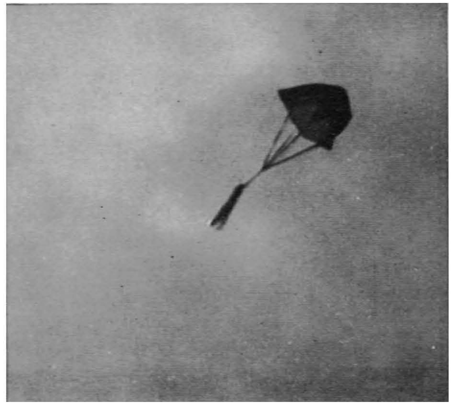
IV. Spaceship leaving its hangar. A scene from the Fritz Lang film, Frau im Mond.



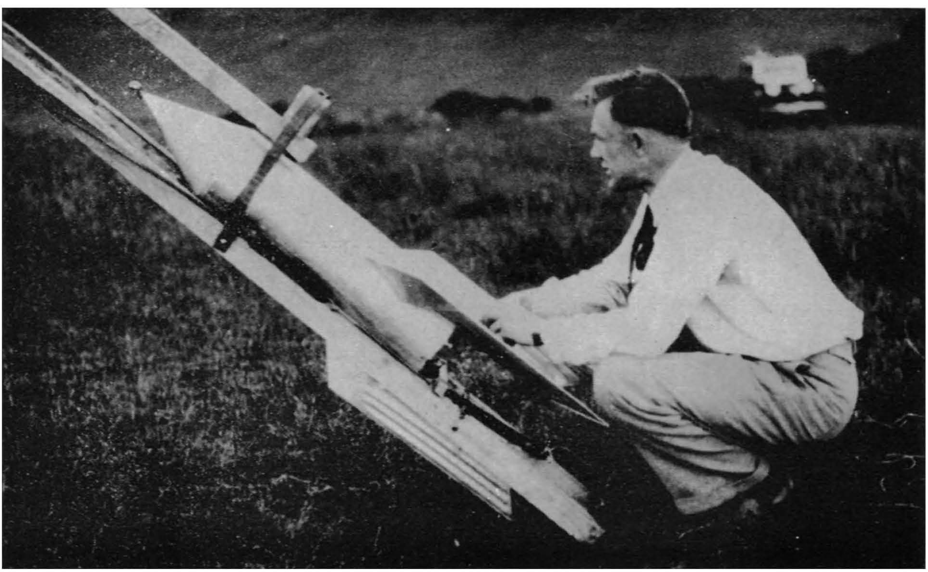
V. Reinhold Tiling, the inventor of winged rockets, during a demonstration at Hanover, Germany.

VI. Max Valier with his rocket sled on the ice of Starnberger Lake.

VII. Friedrich Schmiedl's Experimental Mail Rocket, V-12, taking off at Schöckel, Styria, on July 23, 1932.

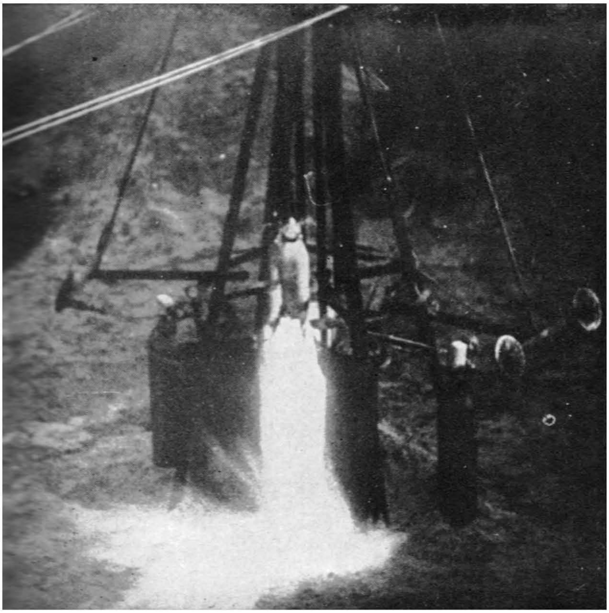


VIII. Descent of the V-12 which carried 231 pieces of mail.



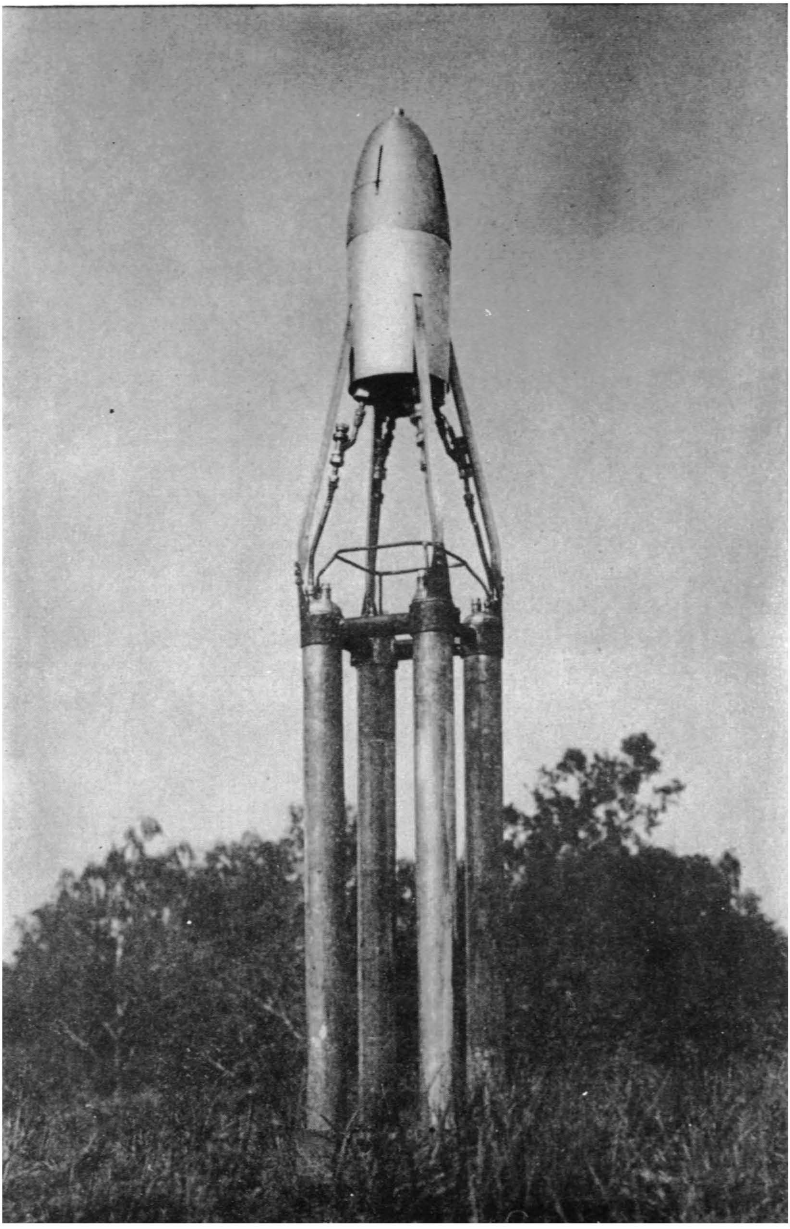
SCIENCE SERVICE

IX. Gerhard Zucker with his mail rocket in England. Zucker's rockets were of exceedingly simple construction, being merely a sheet metal hull with a steel tube in the center into which the rocket was inserted.



X. Test run of the "Aepyornis Egg." The "Aepyornis Egg," instead of producing a thrust of about 130 pounds, as expected, did not quite reach 100 pounds.

XI. Alcohol-oxygen rocket motor of the VfR, built in 1930. The photograph was taken from the observation dugout, about 25 feet from the test stand assembly. The thrust of the rocket blast was just above 130 pounds, and test runs were limited to thirty seconds because of the capacity of the oxygen tank. (See Fig. 29.)



XII. A big "Four-Stick Repulsor," one of the last experimental models of the German Rocket Society, at the Raketenflugplatz. *It weighed close to 150 pounds when fully fueled and made a successful although not very high ascent.*

Chapter 1:

THE BEGINNINGS OF AN IDEA

There are four several ways whereby this flying in the air hath been or may be attempted. Two of them by the strength of other things, and two of them by our own strength. (1) By spirits, or angels. (2) By the help of fowls. (3) By wings fastened immediately to the body. (4) By a flying chariot.—Bishop John Wilkins in Mathematicall Magick (1648).

INVENTIONS rarely have *a* history. Usually they have two or three—in some cases, even more. In that respect most inventions can be compared with a structure such as the Eiffel Tower. Surging up into the sky of achievement, they rest on several legs which lay astride the border lines of various fields of human thought and require a vast area as foundation.

Thus the invention of one Johann Gutenberg is, or was, the result (better: one of the results) of several histories—of the history of paper and of writing materials, of writing in general, of letter cutting, and several others. There might even be a history of the idea of printing, although here not much evidence is available.

Similarly the idea of space travel, of trips away from the earth, has more than one history. The history of astronomy and astronomical thought contributes much material, especially those parts dealing with the twenty centuries of philosophic battle over the concept of a "plurality of worlds." But, while the idea of space travel was identified for a long time with the "plurality of worlds" concept, the full stories of these two ideas are by no means identical. The history of the art of making powder rockets furnishes another line in the development of the concept of space travel, as does the history of certain physical laws, most especially Sir Isaac Newton's Third Law of Motion and Johannes Kepler's three laws governing the motions of the planets. Even the history of fantastic literature goes into the making of this story. Indeed, there seems to be hardly a field of human thought or human knowledge that is not somehow connected with the idea.

Its origin goes back a considerable number of centuries, though not to the dim days at the twilight of history as some writers on the subject, especially older ones, have asserted. As a matter of fact, it can be dated with considerable accuracy: it sprang up as soon as astronomical thought had attained a certain stage of development. It did not, for example, exist in the days of ancient Babylon.

We know that the Babylonians, by means of patient and long observation of the sky in a favorable climate, possessed an extensive knowledge of the apparent motions of the heavenly bodies. A modern man who, looking out of his window, notices a reddish star near the horizon, may wonder whether it might not be Mars. In thinking that he will remember that Mars is a planet farther away from the sun than the earth, that it is smaller than the earth, and that it takes about two of our years to revolve around the sun. He will wonder whether it might, after all, be "inhabited."

The train of thought of an astronomer-priest of ancient Babylon was different. He would have known at once that the red star *is* Mars, in fact he would have expected it. He would be able to trace its apparent movement across the sky; he would know after how many months and days it would reappear and where.

But Mars, to the priest, would not be the next planet outside the orbit of the earth, having about two-thirds the diameter of the earth and moving along its orbit at a steadily varying distance. Mars, to the priest, would not even be a solid body. To him it would be the abode of a certain god and his knowledge of that abode, as well as his *duty*, would consist of knowing the star's movements. Nothing else. There is not the smallest indication that the Babylonians, who possessed a patiently acquired and enormous knowledge of the movements of the sun, the moon, and the planets among the so-called fixed stars, ever attempted to determine their distance or their properties. It may be that they felt that such inquiries should not be made about the abodes of the gods; at any event, they never tried. Their astronomical knowledge was extensive and surprisingly reliable as far as the apparent movements of the lights in the sky went. Aside from that their astronomical knowledge was nil and their conceptions were childish. The absence of the idea that there were other worlds, somehow comparable in size to the size of the earth, precluded all further knowledge.

Ancient Chinese astronomy exhibits the same limitation. The ancient Chinese astronomers, again by patient observation, learned to recognize certain cycles. They knew what lights would be in the sky at what time and where. They predicted eclipses. They even invented a number of astronomical instruments—not telescopes, but instruments that are a great help in ascertaining the position of a planet or a star. But they believed that the earth was flat and they did not even guess that the lights in the sky which they observed so diligently might be other worlds.

It was left for the Greeks to invent better concepts, concepts which coincided to a large extent with reality and served as a starting point for future development.

Greek astronomy began to go its own ways about 540 B.C., a century after a Babylonian astronomer founded a school on the island of Cos. The most important "secret" the Babylonian taught was the so-called *Saros,* a cycle of 223 lunations or eighteen years and eleven days. After one such period the moon returns almost precisely to its original position in the sky. The knowledge of this period, of the *Saros,* permitted the making of astronomical predictions—the prediction of an eclipse, among other things. It was one of the first instances of a prediction that was not a prophecy—that is, something which may or may not come true—but a calculation giving exact information about the future. Thales of Miletus, who died in 548 B.C. and who is often called the Father of Greek Astronomy, may have been a pupil of that Babylonian.

Later, as the *Encyclopedia Britannica* has it:

> Pythagoras of Samos (fl. 540-10 B.C.) learned on his travels in Egypt and the East to identify the morning and evening stars, to recognize the obliquity of the ecliptic and to regard the earth as a sphere freely poised in space. . . . Heraclides of Pontus, who became a disciple of Plato in 360 B.C., taught in addition that the sun, while circulating around the earth, was the center of revolution to Venus and Mercury.

The Greeks almost succeeded in arriving at a true picture of the solar system; Aristarchus of Samos actually proposed what we now call the Copernican system, with the sun in the center and the planets revolving around it. The same Aristarchus tried to measure the relative distances of the sun and the moon from the earth. The attempt miscarried, partly because of the lack of magnifying instruments for observation, partly because his method was not quite adequate.

Six years after this attempt Eratosthenes was born at Cyrene.

He became a famous philosopher, so famous that Ptolemy Euergetes called him to Alexandria. He was given the post of Royal Librarian at Alexandria, the center of the cultural and intellectual life of the time. Eratosthenes decided to measure the earth. He did, and he found a figure surprisingly close to the truth. He had succeeded in establishing the size of the earth a little over two centuries before the birth of Christ.

The next great astronomer was Hipparchus who lived from about 180 B.C. to about 125 B.C. Hipparchus carefully verified a number of Babylonian discoveries that had to do with apparent motions; he determined the length of the year, the obliquity of the ecliptic, and many other things on the same order. His most important work was the cataloguing of 1080 "fixed" stars—he divided them into six magnitudes according to their apparent brightness, a system which is still in use.

These were great and valuable achievements but Hipparchus marred them, at least in our eyes, by making the bad mistake of discarding Aristarchus' correct conception of the sun as the center, or approximate center, of the movements of the planets. Eratosthenes' measurement of the earth may have frightened him—this was too big a globe to set in motion. Thus Hipparchus gave way to the emotionally and geometrically easier system of placing the earth in the center and of letting the planets, including the sun and moon, revolve around the earth.

This is what is usually called the Ptolemaic System, but Claudius Ptolemaeus, after whom it is named, did not invent it. Claudius Ptolemaeus, who came some 250 years after Hipparchus, rounded out the work of the earlier master. The result of this work was a book which preserved "the Hipparchus" for us, all the more important since only one early work by Hipparchus survived in its original form. The book by Claudius Ptolemaeus was called the *Mega Syntas* (Great Collection). Some seven hundred years later an unnamed translator was called upon by the astronomically inclined Caliph al-Mámun to translate it into Arabic. The translator did and, using the Greek word *megiste* (greatest) with the Arab prefix *al,* gave to it the title under which it has been known ever since: the *Almagest.*

While astronomy developed in this manner, philosophic commentary and speculations had not been idle. One of the main problems was what size and what constitution should be ascribed to the heavenly bodies. That question might never have come up, if it had not been for the sun and the moon, especially the latter.

The stars might seem to change their positions in the sky if one traveled in a north-south direction; the *planetes* (wanderers) as the Greeks called them might follow their own mysterious courses. Hesperus and Phosphorus (Venus) might shine so brightly that they made objects cast a shadow, but the stars and the planets and even Hesperus and Phosphorus were only luminous points in the firmament. The sun and the moon were more than luminous points; they had a definite size. Now the sun was obviously a searing fire—or, as later ideas went, the reflection of such a fire—but the moon had to be something else.

It looked, but for its spots, like a round shield of pure silver and, at a time when the earth was still thought to be flat, it was taken for just that. But there was a divergence of opinion as to the nature of those spots. One school of thought held that they were dirt—soot from the atmosphere of the earth, smoke, or fog that had condensed itself on Selene's shiny silver disk. Another school of thought held that the silver disk was in itself spotless and that those spots were just a reflection of land and water on the earth, that in studying the spots of the lunar disk you were really studying terrestrial geography.

We don't know just who held these opinions and when—they have been preserved for us by Pliny the Elder—but they must have preceded Thales of Miletus who discarded the silver disk theory and ascribed an "earthy nature" to the moon. If he actually did say that, he might have startled his listeners as much as Anaxagoras, somewhat later, startled the Court of Pericles by asserting that the sun might, after all, be larger than the whole mainland of Greece. The same Anaxagoras is also said to have asserted that "there are dwellings on the moon, and it contains hills and ravines." Since sun and moon are of the same apparent size, Anaxagoras probably believed that the moon also was somewhat larger than the whole mainland of Greece, and a "country" of that size would, naturally, be roomy enough for hills and ravines and rivers with dwellings on their banks.

One school of thought, however, went farther: the Pythagoreans. In order to bring the number of wandering celestial bodies to ten, a figure "holy" to the Pythagoreans, they invented the *Antikhthon*, the counter-earth. It was supposed to follow the same course around the "central fire" as the earth, having, like earth, an "uninhabitable hemisphere," namely, the one turned toward the "central fire." (The sun was only a reflection of that fire.) Since this assumed body was a counter-*earth,* it seemed likely that it was a counterpart of the earth in every respect, including inhabitants.

But the counter-earth was accepted only among Pythagoreans, not generally. Widespread belief in inhabited or at least inhabitable worlds centered mainly on the moon.[1] Flammarion and Linke, on the other hand, wrongly claimed that this belief was held for all the planets in general by early Greek philosophy.

The one man who definitely opposed all these speculations was Aristotle. It was only one of his many and often rather stupid mistakes to reject the idea of a "plurality of worlds." The unchanging sky, he stated, prevented the belief in other earths. Since all matter is contained in one world there can be no others and, since earths are heavy, they *must* come together in the center of the universe. Like Plato, Aristotle rejected both infinity and plurality.

Aristotle's attitude, in this and in other respects, would have handicapped science much less if he had not been so wholeheartedly accepted by Christian teachers a thousand years later. It literally came to the point where thinkers set out with the notion that all wisdom could be found in the Bible, all astronomy in the *Almagest,* and all science in the writings of Aristotle. Not only was it simply forbidden to teach anything that contradicted or diverged from Aristotle's statements, it was also denied that there was anything that Aristotle had not known.

But this attitude, which made life difficult for Giordano Bruno, Nicholas Copernicus, and Galileo Galilei, came much later. Those

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[1] "More current than the conception of an inhabited counter-earth was the belief that the moon is similar to our globe. Orpheus describes it as a 'celestial earth,' Thales is said to consider it of an earthly nature, and the Pythagoreans are recorded as believing 'the moon is terraneous, is inhabited as our earth is, and contains animals of a larger size and plants of a rarer beauty than our globe affords. The animals in their virtues and energy are fifteen degrees superior to ours, emit nothing excrementitious, and the days are fifteen times longer.' Philolaus considers the moon 'a body like the earth, with plants and animals,' and Xenophanes thinks of it as 'inhabited, and a land of many cities and mountains.' To Anaxagoras and Democritus it is 'a solid, condensed, and fiery body, in which there are countries, mountains, and valleys.' Heraclitus regards it as 'an earth covered with a bright cloud.' "—Dr. Grant McColley in *Annals of Science* (1936), Vol. I, No. 4.

who came soon after Aristotle considered him but one philosopher among several and they felt that they had learned a great deal since the time of his death.

Metrodorus remarked rather simply that "it seems absurd that in a large field only one stalk should grow and in infinite space only one world exist." And Plutarch poked fun at the notion that the earth should be situated in the middle of the universe, since the universe was infinite and without boundaries, hence also without a center. This same Plutarch, who is still well known in our times as author of the *Lives,* wrote a book *On the Face That Can Be Seen in the Orb of the Moon* (*De Facie in Orbe Lunae*).

It was a great summary of all the earlier ideas and thoughts and Plutarch emerged with the conviction that the moon is a second earth. Slightly smaller, yes, but very much like the earth in other respects. Of course it is inhabited—by the souls of the dead. This is a new thought and probably Plutarch's own. To us the thought of a world inhabited by the souls of the dead is apt to have some rather eerie connotations, but Plutarch probably wanted it to be taken as a matter-of-fact statement. I doubt whether it was meant as a weird fantasy.

The existence of Plutarch's book shows that in his time at least the moon was generally accepted as a solid body in the sky. The true nature of those luminous pin points might be debatable, but there was at least one other "earth." The fundamental conception necessary for the growth of the idea of space travel, that of other worlds besides our own, had been established.

Plutarch died in A.D. 120. Precisely forty years later the first novel of a voyage to the moon was written. Its author was the Greek sophist and satirist, Lucian (properly: Lukian) of Samosata.

Lukian called the book *True History*—it is often referred to under its Latin title *Vera Historia*—but warned the reader at the outset: "I write of things which I have neither seen nor suffered nor learned from another, things which are not and never could have been, and therefore my readers should by no means believe them."

The story itself, which was to exert great literary influence some fourteen centuries later, is the "missing adventure" of Odysseus—an adventure that could have been in the Odyssey and which, I believe, would have been in the Odyssey if the necessary astronomical knowledge had existed in Homer's time.

The *Vera Historia* begins with a number of adventures which still take place on earth, but in that strange and unknown region west of the Pillars of Hercules, west of Gibraltar, where adventures of incredible nature seemed the rule rather than the exception. It seems that the Phoenicians in their time had invented and told gruesome tales of that region in wholesale lots, presumably for the purpose of frightening possible competitors away from the West and especially from the Atlantic Ocean. These tales also enabled them to drive harder bargains for their trade goods; wares that had been acquired with so much personal danger naturally commanded higher prices. In Lukian's time many of these old tales were still lingering, at least to the extent that they could be used for literary purposes, even though they no longer frightened sailors and traders.

After these preliminary adventures, when the reader might expect that the vessel is ready to sail for home, the great adventure strikes. The ship is caught in a terrible whirlwind and lifted out of the sea. The wind carries it high above the ocean and for seven days and seven nights the travelers do not know what is going to happen to them. But on the eighth day, as the first English translation (Oxford, 1634) has it: "wee came in view of a great countrie in the aire, like to a shining Island."

The ship has reached the moon.

The travelers are soon surrounded by warriors riding on three-headed gigantic birds and are brought before the king who greets them in classic Greek since he is Endymion himself. The travelers are sufficiently astonished by this, but they are even more astonished when they learn that the moon is on the brink of a war with the sun. Both sides have prepared extensively for this war and both have acquired Allies so that their armies are very impressive. The infantry alone numbered 60,000,000 men. Then there were 80,000 men of the aerial cavalry, riding the three-headed birds, and 20,000 cabbage-bird riders, having mounts of enormous size covered with a dense growth of cabbage deep enough for a man to hide in. There also were giant spiders, the smallest of them larger than an island, there were garlic throwers, flea riders (30,000 of them), and gigantic ants, the latter in the army of the sun.

Lukian's satirical mind must have worked overtime when he invented these armies and their components, and outside the narrow globe of the earth he found real opportunities for enthusiastic satire. He seized upon anything he could find. Remember those ideas about the inhabitants of the moon who do not eject anything excrementitious? Lukian took that, but he went farther. Of course they did not die either since death, even the most decorous death, cannot help but be somewhat messy as an aftermath. Lukian's selenites don't die at all, nor are they immortal. When their time comes they dissolve into vapor and smoke, a quiet and terribly clean exit from life. Nor do they indulge in sex, as far as one can find out, nor in childbirth of the terrestrial variety. Being ultra-ultra in every respect, just as the old philosophers had demanded, the young one emerges with enormous cleanliness.

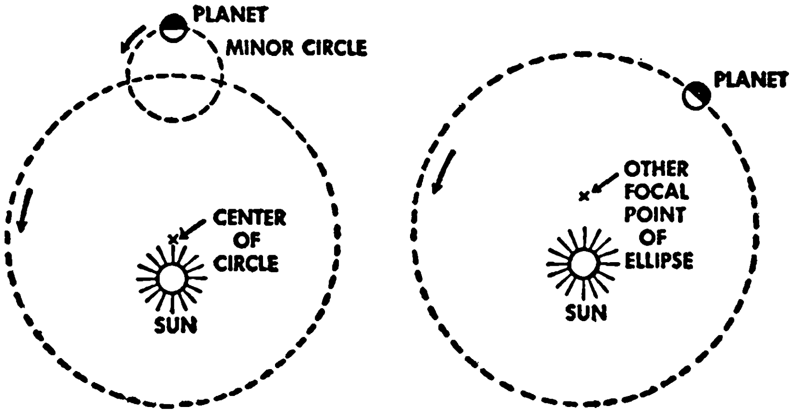
While the travelers of the *Vera Historia* made their trip to the moon accidentally, the hero of Lukian's other moon-travel story, *Icaromenippus,* plans his trip carefully. Observing the night sky for a long long time, and wondering about the matter that composes the radiant sun but being especially attracted by the moon, Lukian's second hero finally decides to go to the moon and to the stars. He provides himself with two wings, one of a vulture and one of an eagle, and begins to practice. He does learn how to fly and when he feels sure of himself in the new element he takes off for the moon from the summit of Mt. Olympus.

He does reach the moon, but that alone does not satisfy his curiosity. Now that he has gone so far, he strives to reach heaven itself. Taking off from the moon and leaving the sun to his right, he flies about among the stars and he arrives in heaven on the third day of that flight.

But the immortals resent the intrusion. Mercury is ordered to bring him back to earth and, while Icaromenippus is not punished for his audacity, his wings are taken away from him so that he may not reach the moon and the stars again.

For more than fourteen centuries no other book like Plutarch's *De Facie in Orbe Lunae* or Lukian's *Vera Historia* was written. For more than fourteen centuries no such book could be written, because philosophical teachings which opposed the idea of a plurality of worlds held sway. Once more the earth was flat and, even if it was not flat, it was the only solid globe. No other earth, no other world existed officially. For a time belief in other worlds than ours was expressly forbidden.

But then the astronomical revolution came, ushering in a new era of astronomy. That revolution consisted of three books: Nicholas Copernicus' *De Revolutionibus Orbium Coelesticum. (On the*

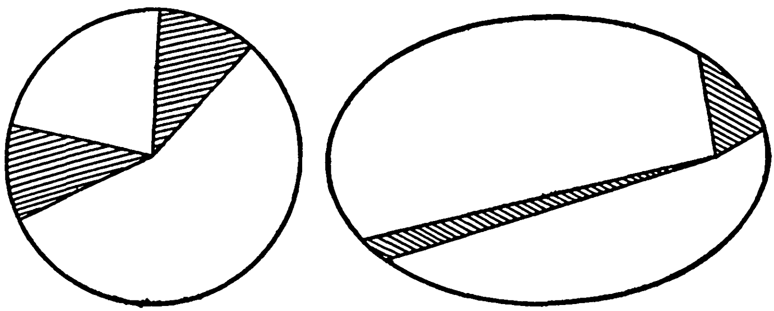


1. Copernicus's Picture and Kepler's Picture of Earth's Movement around the Sun.

Revolutions of the Celestial Orbs) in 1543; Johannes Kepler's *De Motibus Stellae Martis* (*On the Motions of Mars*) in 1609; and Galileo Galilei's *Sidereus Nuncius* (*Messenger of the Stars*) in 1610.

Each one of these books was of almost incredible importance, even when taken separately. Together they formed, in logical progression, a new picture of the world. Copernicus reversed the positions of sun and earth, placing the sun in the center and the earth among the planets, but his mechanism of movement was still the same as Hipparchus'. Kepler changed the mechanism; he replaced the circle on a circle by the elongated curve of the ellipse. This was the first of his "three laws"—the law that planets move in an elliptical orbit with the sun in one of the two focal points of the ellipse. The second law stated that the *radius vector* (the line connecting the center of the sun with the center of the planet) sweeps over equal areas in equal times. This meant that the planet, when closest to the sun, moves fastest, and moves slowest when farthest from the sun. (Fig. 2.) The third law, which he discovered later, dealt with the relationship between the distances of the planets and the amount of time needed to complete one full revolution around the sun.

Copernicus and Kepler put the mechanics of the solar system in order. Galileo Galilei, by means of a homemade telescope which he had virtually invented himself (after studying the principles on which the first "miracle tube," invented by the Dutchman Jan Lip-



2. Kepler's Second Law.

pershey, was based), put worlds into the solar system. He discovered that all the planets show disks when seen through the telescope and this proved that they were worlds comparable to the earth and the moon, even though they all differed in size.

Because of the fact that astrologers and philosophers of the old school succeeded in using the powers of the Church for their own ends, Copernicus' *De Revolutionibus* was put on the index of forbidden books in 1616 where it remained until 1835. Galilei was forced to recant—and the rapid development of astronomy in the next two centuries originated chiefly in Protestant countries.

In these countries the new developments in astronomy (based on the existence of the telescope), a revived interest in the problem of the plurality of worlds, and even a decided interest in the idea of space travel grew up hand in hand.

It began with a work by one of the great masters himself: Kepler's *Somnium.* This work cannot be dated accurately, because Kepler did not write his *Somnium* at any specific time. The book is the result of idle moments or, possibly, periods of sickness covering many years of his life. There is reason to believe that several hand-written copies of the manuscript existed, and one of them seems to have found its way to England. But Kepler hesitated to have it printed; he never considered it quite finished and ready for the printer. In 1630 Kepler died, not quite sixty years of age. Death came suddenly, in the form of an attack of pneumonia which he contracted while traveling long distances over poor roads and in bad weather, trying to collect debts long overdue. The *Somnium* was still not quite finished then and Kepler's son-in-law, Professor Bartsch, undertook the task of making it ready. But then Bartsch also died suddenly and the manuscript fell into the hands of Kepler's son Ludwig.

Ludwig considered it his duty to "leave to posterity the fame of my father without lacunae" and Kepler's heirs, impecunious as they were, shared the expense of the printing.

The *Somnium* is a fantasy, a fantasy with the little sad smile of a man whose good sense of humor is somewhat incapacitated by physical pain. It is full of interesting side lights, little humorous thoughts about Tycho Brahe, the garrulous, boisterous, conceited creator of the observatory of Uraniborg, the drunkard whose nose was made of silver (the original having been lost in a youthful brawl), the ox-strong nobleman without a home, the man who made the best and most reliable observations anybody ever made up to his time—observations that enabled Kepler to throw out the artificial circles of antiquity and of Copernicus and substitute his own ellipses. It is also tinged by Kepler's own desire for sleep and rest and it shows influences of the enforced restlessness of a Protestant in those times. "If they finally chase us from the Earth," he wrote in 1629 to a friend, "my book will be useful to emigrants and pilgrims as a guidebook of the moon."

The *Somnium* begins with Kepler lying in bed, asleep, resting from incessant labors over sheets filled with computations. Soon he is dreaming. He dreams that he has bought a book in a bookstall and is now reading it. That book tells of an Icelander who made the long pilgrimage to Tycho Brahe to learn what astronomers know about the moon. After several years he returns to his native island of glaciers and boiling springs. He finds his mother who spends her time in collecting strange herbs—a witch, as the son now realizes. He tells her about Tycho and his teachings and he learns, to his utmost surprise, that his mother knows much more about the moon than all astronomers in the world taken together. She has had a better teacher than her son, because her teacher is a demon—a demon from Levania.

It becomes clear immediately what "Levania" is; the demon himself provides the clue in the first sentence he speaks: "*Quinquaginta millibus miliarium Germanicorum in aetheris profundo sita est Levania insula* ("Fifty thousand German miles away in the deep ether there is the island of Levania").

Levania is not inaccessible, but there are certain difficulties. Little demons are rampant both on Levania and on Volva (the earth). But they shun the light of the sun and they cannot cross space because the rays of the sun would catch them there. They cannot cross space, that is, under ordinary circumstances. But when the shadow of the earth touches the moon, they are able to race across this temporary bridge. And they return when the shadow of the moon touches the earth.

It is clear what Kepler meant. The demons, the spirits of astronomy, must shun the sun's glare, for you cannot observe while the sun is blinding you. The spirits of astronomy thrive during the night when it is dark, and observations that are impossible otherwise can be made when the shadows of earth and moon reach across the void: during eclipses.

The spirits *can* take a mortal along, but it is hard work and it cannot be done at all if the mortal is too big and paunchy. (It seems that Kepler did not trust Tycho's abilities beyond that of making good observations.) Nor is the trip pleasant for any mortal—when the spirits pull him rapidly along the temporary bridge of the earth's shadow, he suffers from cold and lack of air. At the point where the "magnetic influence" of the moon becomes stronger than that of the earth the spirits let go and the mortal will then fall to the moon without their help. But at this point something strange takes place; the body of a mortal will curl up into itself "like a spider." Kepler had seen how certain spiders, when disturbed, pull all eight legs in and let themselves drop. He even explained in more detail what he meant: "When the magnetic attractions of the moon and of the earth equalize each other, it is as if neither of them exerted any attraction. Then the body itself, being the whole, attracts its minor parts, the limbs, because it is the whole."

Erase the word magnetism and you have a description of gravitational effects, long before Newton. As a matter of fact, Newton merely reported in sharp and clear language what Kepler describes in a playful mood, and I have often wondered whether Kepler may not have had such a sharp description with formulae somewhere among his notes.

As soon as the spirits arrive at the moon they hide in dark caves, knowing that the sun's rays will beat down upon the moon again at any moment. This, Kepler added, is a habit of astronomers too. "When I lived in Prague I had an apartment where there was no better place to observe the sun crossing the meridian than the beer cellar."

At this point Kepler stops playing. We now are on the moon and the astronomy lesson is about to begin. The *Volva* (earth) is large in the sky and the continents and seas are clearly visible. Because of the astronomical fact that the moon always presents the same face to the earth, Levania is divided into two permanent hemispheres and its inhabitants refer to themselves as *Subvolvani,* those who always have the *Volva* in the sky, and *Privolvani,* those who never see it unless they travel half around their world.

The mountains of Levania are generally higher and more rugged, the valleys and chasms deeper, than on earth. Since the days and nights are so long, each one lasting fourteen of our days and nights, the temperature differences are enormous. But fortunately there are many caves on the moon and they protect the inhabitants. Besides Nature helps; the bark of the trees and the fur of the animals—or what serves in lieu of fur—comprise the larger part of the mass of their bodies. It does happen that an animal is caught by the sun and seems to drop dead. In that case the outer layer of its fur or skin is singed by the sun and becomes hard. At night the animal revives and the singed portions slough off. In shape the inhabitants of the moon are mostly snake-like; a frequent variety looks like a singed pine cone during the day, while at night the pine cone opens and the animal emerges.

But while the Endymionides, as Kepler terms the inhabitants of the moon, have the shape of strange animals, their mental qualities and capacities resemble that of humans.

> Those hollows of the moon first seen by Galilei are . . . portions below the general level, like our oceans. But their appearance makes me judge that they are swampy for the greater part. It is there where the Endymionides find the sites for their fortified cities which protect them against the swampiness as well as against the heat of the sun, possibly also against enemies. They do it in the following manner: in the center of the chosen site they put a stout pole to which they attach ropes, their length depending on the size of the fortress to be built; the longest [rope] measures five German miles [about twenty miles]. Then they mark the periphery by walking around at the end of the rope. After that they amass to build the wall. . . . Whenever the inhabitants feel annoyed by the power of the sun those who live near the center move into the shadow of the outer wall . . . following the shadow for fifteen days they wander about and by this means endure the heat.

The new telescopic era which dawned during Kepler's lifetime shows in this description. Through the new "optick tube," crude and poor as it was, astronomers had now seen the round "craters" in the moon and Kepler, like everybody else, had wondered what caused them. This was his answer: the circular craters were artificial, they were erected by the inhabitants of the moon for the purpose of producing shaded places in which they could keep alive.

Kepler had read Lukian, but the influence went hardly farther than giving rise to the term Endymionides. Of course Lukian had not been serious when he invented his astonishing array of incredible creatures in the army of the moon. But Kepler was serious, in the sense of making a serious guess, and the biological features he invented surpassed the biological knowledge of most biologists of his time. As far as mathematics went Kepler was, needless to say, accurate and his conception of gravitational influences was virtually Newtonian. Even the dream device of getting to the moon was realistically conceived.

To Lukian, and also to many writers even long after Kepler, the problem of flying through the air and the problem of journeying to the moon were one and the same. There was nothing but a gradual difference—the trip to the moon was essentially the same as a flight from one mountain peak to another. It was merely a much longer trip, requiring preliminary practice, as explained for the first time in Lukian's *Icaromenippus.*

Kepler knew that it was not the same. To make flying and space travel alike there had to be a common atmosphere to earth and moon, an atmosphere which, probably, was denser near the surfaces of the two bodies, but an atmosphere which extended all the way from one to the other just the same. And Kepler realized what everybody else overlooked, probably without thinking about it at all: that this meant friction. Friction was the one thing Kepler, who had found the true laws of planetary motion, could not use. There could be no friction. Hence there could be no common atmosphere. Consequently man could not fly to the moon, even granting that he could fly at all. The only way out was a device which did not violate the laws of Nature since it was not subjected to these laws. Kepler, just because he had a better conception of the problem than anybody else for centuries to follow, had to use the dream method.

Even before the *Somnium* saw print, an English book had appeared which also dealt with a voyage to the moon. Unlike the *Somnium* that book, the first interplanetary voyage of English literature, saw several editions and translations. The first edition was printed in 1638 under the title: *The Man in the Moone: /* or / *A Discovrse of a Voyage thither* / By / Domingo Gonsales / *The speedy Messenger.*[2]

The author of the book was Bishop Francis Godwin, known to students of English literature mainly as the compiler of a voluminous and boring catalogue of English bishops. Bishop Godwin's book, which still affords amusing reading, shows many influences of the *Somnium,* and he must have read a manuscript copy of Kepler's posthumous work. In fact some of the early adventures of the fictitious hero Domingo Gonzales suggest that Bishop Godwin had the German astronomer in mind as a prototype for his hero. If true, it would be a nice little literary joke that the author of one moon journey is used as hero by the author of another moon journey. Taken purely as "literature" the *Man in the Moone* might outrank the *Somnium;* taken as a work mirroring the scientific knowledge of its period it is inferior.

Bishop Godwin was careful in his work. His hero, being a Catholic Spaniard, uses the Gregorian calendar, while the bishop himself still used the older Julian calendar. But Godwin was not a follower of Copernicus. He accepted the daily rotation of the earth around its axis, an old idea which had been accepted and rejected a few score times in the interval between Pythagoras and Copernicus. But Bishop Godwin did not accept the movement of the earth around the sun. Nor did he follow Kepler as regards the action of gravity and the presumed airlessness of the space between earth and moon. He termed the earth a big lodestone, and assumed that the "attractive force" does not reach very high, not much beyond the cloud zone. On the other hand, he stated quite explicitly that the attraction of the moon is much smaller, since the moon itself is smaller. As for the air above the zone of attraction, he described it as especially mild and pleasant, neither hot nor cold, with the

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[2] The French translation appeared in 1648 under the title: *L'Homme dans la Lune, ou le Voyage chimérique fait au Monde de la Lune, par* Dominique Gonzalès, *aventurier espagnol.* The German translation followed soon after under the title *Der fliegende Wandersmann.* A reprint of the first English edition appeared in 1937, in lieu of a tercentenary celebration, as Vol. XIX, No. 1, of *Smith College Studies in Modern Languages.*

miraculous property of preventing the sensations of hunger. But it is full of "devils and wicked spirits"; Kepler's spirits of astronomy return here in a disguised form.

The moon itself is a perfect paradise, and the rigors of climate that Kepler described are not affirmed. It is a place without want, unrest, or war. The inhabitants are humans, but tend to be of larger size than earthmen. Larger size denotes higher rank and, presumably, greater wisdom. Their language is so musical that it cannot be written in letters; notes have to be used and the bishop did not fail to give a few samples.

The trip itself is a flight. Domingo Gonzales, the hero, finds a "certain kind of wild Swans" which he calls *gansas* on St. Helena and trains them to carry weights and to obey orders. Finally he builds an "engine," which means a seat for himself, carried by a number of *gansas*. Still he only intends to fly, and the trip to the moon comes somewhat as a surprise. The birds fly in the direction of the moon in a straight line, as if it were the place to which they migrate every year. Their speed is great; Domingo estimates it as 50 leagues, about 175 miles, every hour. The flight takes twelve days—but twelve days at that rate of speed is only about 50,000 miles, about one fourth the actual distance to the moon. Godwin probably wanted to arrive at the figure fifty thousand given by Kepler, but he either overlooked the specifying *germanicorum* in his copy of the *Somnium*, or else the copyist had omitted the word.

The return trip back to earth—Domingo happened to land in China—was made in the same manner as the ascent, after enough time had been spent on the moon to make the *gansas* eager to fly back.

If Bishop Godwin's book influenced literature, especially English literature, it shared that influence with another book by another English bishop, which appeared within a few months of the first edition of the *Man in the Moone*. This was Bishop John Wilkins' *The Discovery of a World in the Moone: or, A Discovrse Tending to Prove, that 'tis probable there may be another habitable World in that Planet.*[8] This was not fiction, or a discussion disguised as

[8] The French book *Le Monde dans la Lune, divisé en deux Livres: le premier prouvant que la Lune peut être un Monde; le second que la Terre peut être une planète,* Par le Sieur de la Montagne (Rouen, 1655), is the same, but Wilkins' name is not mentioned. Another French edition appeared in London in 1640, a German translation in 1713.

fiction. It was a straightforward work on the moon, its similarity to the earth, and the possibility of its inhabitation.

> Two years later he added to the third edition of this work "The Discovery of a New World," a final chapter in which he seriously affirmed that it was possible to make a flying-chariot, wherein several men might sit, and, by means which he felt science would soon discover, might so motivate their ship that it would fly to any height and might at last reach the moon. His words were a stimulus to both science and literature and his influence in the Royal Society led that great body to turn its attention to the principles lying behind the flying-machine.—Marjorie Nicolson in the Introduction to *Navis Aeria of B. Zamagna.*

It seemed as if the good bishop's optimism was soon to be justified. Not even half a century after the first appearance of his *World in the Moone* the "flying chariot," the airship, was actually invented, though only on paper at first.

The inventor was a Jesuit priest who was professor of mathematics at the University of Ferrara from 1677-79. His name was Francesco de Lana-Terzi and the description of his airship can be found in the second volume of his main work.[4]

Francesco de Lana-Terzi could not have made his invention if others had not worked out experiments which dispelled one of the most unfounded but also most persistent beliefs of older philosophers, the *horror vacui.* "Nature abhors a vacuum" had been handed down like a sacred tradition, just as the other tradition that a body falls faster the heavier it is. That latter tradition had been destroyed by Galileo Galilei, by logic as well as by the experiment of dropping a cannon ball and a musket ball simultaneously from the leaning tower of Pisa and showing that both struck the ground at the same time.

The former tradition had been wounded severely by Torricelli when he invented his "Torricellean tube," the first barometer. Pascal had developed the theory of this instrument; Monsieur Perier, Pascal's brother-in-law, had carried one to the peak of the 4790-foot high Puy-de-Dôme in Auvergne, France, to show that there was less air pressure on mountain tops; and in 1650 the forty-eight-

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[4] Its title is *Magisterium Naturae et Artis,* in three volumes which were published in 1684, 1686, and 1692, the third posthumously since Lana-Terzi died shortly after the publication of Vol. II. (He lived from 1631-87.) The airship appears as *Artificum XLVI* in Vol. II.

year-old burgomaster of Magdeburg, Otto von Guericke, had invented the air pump and demonstrated that a vacuum is possible.

Lana-Terzi presented his ideas in a very logical and systematic manner. First of all he asserted that air has weight. Then he stated that it was possible to exhaust the air from a vessel. He emphasized that the cubic content of a given vessel, say a globe, increases at a much faster rate than its surface area, and arrived at the conclusion: "It is certain that one can construct a vessel of glass or other material which would weigh less than the air contained therein; if, then, one exhausted all the air . . . this vessel would be lighter than the air itself and . . . would float on the air and ascend."

The flaw in his reasoning was of a purely constructive nature; a vacuum globe light enough to weigh less than the air it replaces would be crushed by air pressure. The real solution consisted in substituting a lighter gas for the air inside the globes, thereby eliminating the unmanageable pressure difference—a solution found a few months after the Montgolfier Brothers had built their first hot air balloons in 1783. Professor Charles used hydrogen gas, not known during Lana-Terzi's lifetime, and Bishop Wilkins' "flying chariot" had finally been invented.

But, contrary to all hopes, it could not carry anybody to the moon.

While Perier climbed the Puy-de-Dôme to prove that air pressure diminishes on high mountains, while Otto von Guericke heaped glory on the city of which he was burgomaster by proving that not even several teams of horses could pull two well-fitting exhausted hemispheres apart, and while Lana-Terzi deduced the principle of lighter-than-air flight, philosophers and poets were busy acquainting the world with the rapidly spreading doctrine of the plurality of inhabited worlds and with tales that were based on this doctrine.

Cyrano de Bergerac wrote two novels of that type, the *Voyage dans la Lune* (1649) and *Histoire des États et Empires du Soleil* (1652). Some of it was heavily based on predecessors—the inhabitants of the moon talked music, not words. As for the means of transportation, Cyrano apparently could not make up his mind which should be given preference; consequently several heroes use several means. One is semi-mystical—bottles filled with dew lift the traveler; since dew disappeared in the rays of the morning sun, it was evidently drawn toward the sky. Two others were "flying chariot" devices: one an iron car lifted by means of pieces of lodestone thrown upward continuously; the other simply a box with a number of large powder rockets attached to it. Cyrano, by accident and of course without realizing it, had guessed the proper principle—the principle of reaction. But another half century was to pass until Sir Isaac Newton even stated what reaction really means.

Bernard de Fontenelle's *Entretiens sur la Pluralité des Mondes (Discourses on the Plurality of Worlds)* followed in 1686 and took Europe by storm. It was issued and re-issued, translated into several languages, and it even conferred upon its author the honor of being asked to take up residence in the palace of the monarch. He accepted and spent his time writing a book on geometry of which he said that it might be fully understood only by seven or eight mathematicians in Europe, he himself not being one of the eight.

The book, although intended to be a popular astronomy, has to be mentioned here because of its strongly speculative character. The leading idea was that every planet has to be inhabited, but by beings with constitutions conforming to their surroundings—a rather modern thought.

De Fontenelle, not handicapped by such trifles as instruments which can measure the surface temperature of another planet or which can tell the chemical composition of the top layers of their atmospheres, had only two things to go by: the temperature resulting from the distance from the sun and the sizes of the planets. As for Mercury, he asserted that the heat is so enormous that there are rivers of molten lead and silver (actually a river of molten lead is the best that temperature would permit). Its inhabitants cannot imagine a world where little discs of these metals can serve as money. Still, the inhabitants of Mercury endure the heat only because the planet spins rapidly around its axis (actually it turns once during its year, behaving with respect to the sun as the moon behaves with respect to the earth) and they enjoy themselves in anticipation of the coolness of the night which is soon to come. In general they are all hotheads and fools and enormously active because of the heat.

At this point de Fontenelle's German translator, Bode, could not help but interpolate: "Very strange! for with us in Berlin we find that great heat makes people lazy and sleepy instead of lively and active."

As for Venus, it is the planet of love, even though its inhabitants are not very beautiful. They have no time for the serious sciences because their time is taken up by constant flirtations. They do practice music, poetry, and dancing since these arts have their amorous uses. But, de Fontenelle added sadly, they cannot cook, because they live almost exclusively on air.

Mars is passed over and so is Jupiter to a large extent. De Fontenelle is somewhat embarrassed by the fact that the inhabitants of Jupiter, because of the size of that world, cannot possibly know each other, while on small Mercury everybody knows everybody else. However, the inhabitants of Jupiter have telescopes and one day somebody discovers a hitherto unknown small planet near the sun, the earth. "This is reported by their astronomical journal, but the population either does not hear about it or just laughs, the philosophers whose systems would be disturbed decide not to believe it, and all 'sensible people' harbor great doubts about this announcement."

As for Saturn, life is no pleasure because of the extreme cold. A Saturnian, brought to earth, would die because of the heat, even in the Arctic. Because of the cold, the Saturnians are slow and phlegmatic and remain all their lives in the places where they were born, just like oysters.

With Saturn, de Fontenelle had reached the limits of the solar system as it was then known, but he had to add a few remarks about the moon. Mercury and Venus, because of their proximity to the sun, do not need moons and therefore do not have any. The earth has one, Mars again none (the two small moons of Mars were not known until they were discovered by Asaph Hall in 1877), but luminous birds and luminous mountains illuminate the nights on Mars. Jupiter has, of course, its four large moons, and Saturn gets light from its rings. As for our moon, it might not be inhabited *à cause de la rareté de l'air.*

With all his nonsense, de Fontenelle did reflect some recent progress in astronomy. The moon, once loudly acclaimed as a sister planet of the earth, so similar that it might be difficult to tell the difference at first glance, had fallen into disgrace. The main reason for this remarkable and rapid cooling off was the great *Selenographia* of the astronomer, Johannes Hevelius of Danzig, which had been published in 1647. It was the first systematic work about observations of the moon and it abounded with fine and detailed maps, maps which made this world look rather strange and different. The rarity of the air was recognized and there were great doubts about the water supply. The moon did not look promising any more.

On the other hand the close approach of Mars in 1672 had been used to determine the true size of the solar system. While this was a truly international venture, most of the mathematical work was done by Giovanni Cassini who found, to his amazement, that the distance from the sun to the earth had to be more than 80 million miles (actually it is 93 million miles), which made the solar system at least twice as large as the most daring figures that had been advanced speculatively.

Things had suddenly grown too large, too impressive, for light-headed speculation on actual travel. And it also became clear to everybody what Kepler had taken for granted more than a century earlier: that the atmosphere formed only a thin shell around the earth, that even the possession of a flying chariot did not mean the possibility of a trip to the moon. It is significant that the first great poem on aviation, Bernard Zamagna's *Navis Aeria,* published for the first time in Rome in 1768, abstains from any mention of space travel.

The poem describes the building of an airship of the type invented on paper by Lana-Terzi, but the completed ship stays close to the ground; in fact, Zamagna even warns that it should not fly too high in the atmosphere because the air may become too thin.

Consequently, the two works of this period which deal with inhabitants of other worlds are carefully "non-material." These two works, as different from each other as is humanly possible, are Voltaire's *Micromégas* (1752) and Emanuel Swedenborg's *Arcana coelestia.* Voltaire's *Micromégas* relates the travels of a gigantic inhabitant of Sirius who is later accompanied by an inhabitant of Saturn. It is straight philosophical satire.

To be a philosopher and a satirist at the same time is not at all difficult, but Emanuel Swedenborg succeeded in combining the somewhat contradictory features of research scientist and mystic. As a research scientist he contributed a great deal to various sciences, especially mineralogy and geology. As a mystic he accepted the fundamental theorem that all worlds are inhabited. It seems, of course, that his "astral men" have to be taken "spiritually" which means, in plain language, that they are not to be taken literally. Nor are they very important in themselves; their importance lies in the fact that they prompted Immanuel Kant to devote a very large section of one of his works to an examination of these beliefs.

The realization that a means of flight was not simultaneously a means of cosmic travel[5] suggested that the latter would require a new principle, possibly the application of a new force. It is only natural that the vaguely known force of electricity suggested itself.

The same Otto von Guericke who had invented the air pump had also invented an "electric machine," consisting mainly of a large ball of sulphur which could be turned by means of a handle. The experimenter himself furnished friction by placing his hand upon the rotating sulphur sphere, and it was a beautiful toy for drawing room demonstrations and perfumed philosophical discussions with Madame la Marquise.

It was a Frenchman who expanded Guericke's sulphur ball into a spaceship, Louis-Guillaume de la Follie whose *Philosophe sans Prétention* was published at Paris in 1775. But the invention was not made on earth; it took place on Mercury where a young scientist asked for admission to the Mercurian equivalent of the *Académie* on the grounds that he had invented a flying machine. One of the members declared that such a machine could not possibly work and vowed that he himself would use it for a flight to Hermione (earth) in case that he should be wrong and the inventor be right. Of course the machine does fly, and the conservative philosopher, ashamed of his rashness, makes good his vow to fly to earth with it. The trip itself is uneventful, but an irreplaceable part breaks while landing, marooning the Mercurian philosopher on Hermione, the third planet from the sun.

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[5] Edgar Allan Poe's "Unparalleled Adventure of One Hans Pfaall," published in 1835 in the *Southern Literary Messenger*, which uses a balloon as a means of flight to the moon is, of course, in the spirit of banter.

Chapter 2:

THE DECADES OF THE GREAT DREAMS

In fact the two planets earth and Mars are the middle links of the planetary system, and it may be suspected with fair probability of their inhabitants that they stand in the center between the extremes as regards physiology as well as it regards morals.—Immanuel Kant in General Natural History and Theory of the Heavens (1755).

ON NOVEMBER 13, 1833, Sir John Herschel, the son of Sir William Herschel, embarked for Table Bay. He arrived at Capetown on January 15, 1834, and on March 4 he began the astronomical observations for which the long trip had been made. It was the first systematic attempt at exploration of the southern sky and not only professional astronomers but also the public knew well that Sir John had left for South Africa and why.

On August 25, 1835, the New York daily, *The Sun,* carried a front-page story about the discoveries made at the Cape by Sir John. It was, as may well be stated at the outset, the biggest and most successful scientific hoax ever perpetrated. While purporting to be a reprint from a special supplement of the *Edinburgh Journal of Science,* it had been written in New York by a staff member of *The Sun,* Richard Adams Locke, who by the very invention of this story proved to be a genius in his own right.

The hoax began with an editorial which called the attention of the readers to the first installment of the serialized reprint from the Scotch journal and promised the announcement of astounding discoveries.

But the first installment, contained in the same issue of *The Sun,* did not relate any of these discoveries. It merely spoke of the instrument which had made them possible. Even that, if true, would have been enormously important. In a dignified scientific style it was explained that opticians could easily increase the magnification achieved by a powerful telescope. As far as optics and mechanics go there is hardly a limit, but there exists one annoying fact which renders such an undertaking useless. That fact is that the image grows weaker the larger it is so that in the end it becomes so faint that nothing can be distinguished any more.

Actually this is only part of the truth. If it were the whole truth concerning the reasons why magnification beyond a certain level cannot be used, the problem would have been solved in the meantime by the invention of the photographic plate which accumulates impressions. The most important reason is that an astronomer on earth has to look through the atmosphere and that this atmosphere is never quiet all the way through. The sickle of Venus is apt to look like the flame of a candle in a draft because of that, and the faint image of a distant star may jump about in the field of vision. The trouble can be remedied somewhat by placing the telescope on top of a high mountain so that the densest and most disturbing section of the atmosphere is beneath, but there is always enough atmosphere left to annoy astronomers and to ruin many nights.

But *The Sun,* or Mr. Locke, went on to say that Sir John Herschel, while discussing this problem with Sir David Brewster, had found a way out. They discovered a method of "transfusing artificial light" into the image and thus brightened it sufficiently to allow for larger magnifications. Just in case some reader happened to see through this fallacy, several paragraphs were devoted to loose talk about microscopic reflectors, angles of incidence, properties of rays, etc., until the reader felt that he could not follow anyway and was, therefore, ready to accept anything he was told. Of course, the story continued, it needed a powerful telescope to begin with, and Sir John Herschel had a 24-foot mirror cast for this purpose. (The 200-inch mirror on Mt. Palomar measures 17 feet.) Theoretically this super-telescope, in combination with the new instrument for the "influx" of artificial light, should be powerful enough to see a butterfly on the moon, provided there were butterflies present.

The second installment described at length the journey to the Cape of Good Hope, the setting up of the telescope, and the observations of some distant stars and star clusters. Then, on January 10 (1835) the huge instrument was directed at the moon. The first thing that appeared on the projection screen was a huge basaltic formation. Everything was as clear as if the observers were floating over the moonscape in a balloon. Then they saw trees resembling yew trees, forests of firs, level grassy plains, and herds of animals. "Brown quadrupeds having all the external characteristics of the bison, but more diminutive." Soon after, another animal appeared on the screen, of bluish lead color, about the size of a goat, but with a single horn.

The unicorn climaxed the second installment.

As far as business was concerned, *The Sun* had every reason to be exhilarated. It had existed for only two years then, and it was the newspaper with the largest circulation in the world. It sold 19,360 copies, while the circulation of the *London Times* was only 17,000 copies!

The following installments described additional animals and winged bat-like creatures. The latter, when observed more closely, turned out to be the inhabitants of the moon, bat-men and bat-women, flying, sitting around, talking with many gesticulations, and behaving in general rather human.

Later installments told of temples with roofs "consisting of a yellow metal" and the last one wound up with a quick and not particularly inspired survey of the other planets of the solar system.[1]

Business remained splendid until the bitter end. A sheet of drawings of the things observed on the moon sold well. A reprint of the whole story in pamphlet form found very willing buyers. But the hoax could not be maintained indefinitely. The first editorial had stated, as did a postscript to the last installment, that the original report continued for another forty printed pages consisting of mathematical data and technical discussions of little or no interest to newspaper readers.

This remark brought Professors Olmstead and Loomis from Yale to New York. They did not blame the editor of *The Sun* for not printing these forty pages, but they were obviously in his possession and they wanted to see them. They were held at bay by Locke who told them to go to the printer. Locke himself raced ahead and instructed the printer where to send them next, racing ahead again, and again, and again, until the professors gave up. Then the *Journal of Commerce* wanted to reprint the whole story and sent a reporter to Locke to get the *Edinburgh Journal.* Locke at first tried to talk him out of reprinting the old stuff, then admitted that he had written it. The next day the *Journal of Commerce* gleefully informed its readers about the truth of *The Sun's* marvellous story.

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[1] The complete text of the moon hoax has been reprinted in *The Sky* in several installments, beginning in February 1937 with an introduction by William H. Barton, Jr.

For a while New Yorkers were indignant, then they began to laugh—as did Sir John Herschel who learned about it some time later—and the "Panorama" exhibits and the stage began capitalizing on Locke's great moon hoax.

It has been claimed that Locke had a collaborator when he wrote the moon hoax, a French astronomer by the name of Jean Nicolas Nicollet who had left his native country because of financial difficulties and who might have been susceptible to a profitable suggestion of that kind. Only Locke himself could have told whether Nicollet helped him or not, but Locke kept quiet about that point. But whether Locke had been helped along by a professional astronomer or not, the moon hoax portrayed better than any learned treatise the general attitude of the public—and of a large number of the scientists—toward the problems involved in that theme.

The nineteenth century had begun with a number of important scientific discoveries and more were confidently expected, an expectation which, as we know now, came true to an almost unbelievable extent. New astronomical discoveries were expected and there was a feeling (well exploited by Locke) that they might follow in the wake of the invention of a new instrument. This also came true in the latter part of the nineteenth century with the introduction of the camera and the spectroscope. Herschel's "light infiltration" was a guess at what might be invented.

Animals and inhabitants and dwellings on the moon were a guess at what might be discovered, and here again Locke merely expressed a prevalent belief, although the moon was not too well chosen as *locale*. One of the planets, except for its greater distance, might have been more convincing.

The "plurality of worlds" was no longer a matter of dispute. Venus and Mars and the other planets were acclaimed as "other earths," while the stars were now definitely taken as "other suns," each one presumably with a system of planets around it. And all the suns together formed the Milky Way, the galaxy. In addition, there was reason to suspect that the so-called nebulae, especially the big one in Andromeda, were other galaxies like ours. Sir John's trip to the Cape had as one of its main purposes the collection of more data on the existence of these additional galaxies.

But this growth of astronomical knowledge had also resulted, as we have seen in the preceding chapter, in a rather literal "growth" of the universe. The dimensions were now such that even a million miles were no more than an inch as applied to the dimensions of a city. Astronomers began to use bigger yardsticks. The distance between earth and sun, 93,000,000 miles, was chosen as an A.U. (astronomical unit), and the velocity of light, some 186,000 miles per second, furnished another yardstick. Astronomers began to say that the moon is a little over "one light-second" from the earth and the sun some eight light-minutes, meaning, of course, that the light from the sun needed about eight minutes to reach the earth. But even on that scale the *nearest* star was several light-*years* away.[2]

The feeling was that the universe was full of suns, each accompanied by planets most of which were probably inhabited. But all the various inhabitants could do, even those closest to each other in the same solar system, was to look at each other. A vacuum separated them and nothing could bridge it but gravitation, which was unchangingly ever-present and therefore quite useless, and light.

While the nineteenth century became the era of the greatest astronomical dreams, it took some time until it began to dream of direct communication. There were many books and articles on the inhabitants of other worlds, but nobody suggested for quite some time that they might visit us or that we might visit them. The early enthusiasm about the invention of the balloon had quickly changed into disappointment that it could not carry its pilot higher than a very few miles and even that distance with great danger to life and limb because of the cold and lack of oxygen experienced at higher altitudes.

The highest balloon ascent was no more of a departure from the native planet than the distance a fish may jump out of its tank. And it was fraught with the same dangers—suffocation and inclemency. As a matter of fact, the planets began to look like cosmic fish tanks and the various presumed humanities on them like self-contained little worlds in the well-kept tanks. They had been put there by the act of creation and sealed into their particular surroundings. Subject to catastrophes even in their own worlds—Monsieur Cuvier

[2] In modern astronomy the *parsec* is used along with the light-year. The term means a distance which produces a *par*allax of one *sec*ond of arc, an apparent yearly shift of 1/3600 of one degree. A parsec works out to 3.259 light-years; it is not much bigger as a unit, but it is more convenient to handle. A light-year is 5880 billion miles.

knew terrible things to tell about such catastrophes—they could do nothing but look out. Dependency on their surroundings forced them to remain at home, and the most they could hope for was to see other fish tanks and guess about those other surroundings.

This was, in approximation, the answer of the year 1830 to the problem of space travel.

But even if those fish could never possibly reach each other, they might—assuming that they had the necessary intelligence—signal each other. In fact this was the way to find out whether the "fish" in another tank were intelligent or not. If they understood a signal and replied to it, they were. If they did not reply, it meant that they did not exist or, if they did exist, that they were not quite bright enough. Of course one had to use a language for the signal which could not possibly be misunderstood, a language in which there was only right or wrong, but no misunderstanding.

It was, of necessity, the language of mathematical symbols, for example, the figure known as the "Pythagoras"—the figure which expresses the fact that the square of the longest side of a right-angled triangle is equal in area to the sum of the squares of the other two sides. If this figure were produced on earth on a scale large enough to be seen from another planet, intelligent beings of that other planet—provided they existed and provided they were intelligent enough to know elementary geometry—would know about humanity, and they would reply in a similar manner.

The Siberian tundra offered a "blackboard" of sufficient size. To "draw" the symbols was a job for farmers and foresters. The outlines would have to be planted in dark pine forest, each line 10 miles wide. And for contrast the interior of the triangle and of the three squares could be seeded with rye or wheat.

This was not a crackpot's idea; it was Karl Friedrich Gauss, the "Prince of Mathematicians," who advanced it.

And Littrow of Vienna, a name well known to any astronomer, professional or amateur, followed up with another similar idea. Use the Sahara as a blackboard and use large fires for signs. Arrange them in a circle, for example. Dig a circular trench several hundred yards in width and 20 miles or so in diameter, fill it with water, and pour kerosene on the water, enough kerosene to burn for six hours. Then ignite it. Use a quadratic trench the following night and a triangular trench the night after. This regular succession of regular mathematical symbols ought to convince the inhabitants of the nearest planets—convince them not only of our intelligence, which grasps the mathematics of simple figures, but also of our intentions to give signs to them since we would never need flaming signs of that size for teaching our own kind.

While Gauss and Littrow evolved these schemes for signaling the other planets, other astronomers frantically searched for signs they might send to us or at least for signs of their existence.

In July 1822 a Munich astronomer with the strange name of Franz von Paula Gruithuisen (*Khroyt-hoyzen*), who was also a somewhat strange man all around, announced that he had found a "walled city" on the moon. It is located near Schröter, a crater almost in the center of the half of the moon we can see. Gruithuisen described it as a regular grid of high walls and drew a picture which looks like a bird's-eye view of a multiple-walled fortress, partly submerged in a flood of mud which later hardened.

The announcement created a stir which can be traced through the whole literature of that time—it is even mentioned in some love stories written around 1830. Any definite building on the moon or elsewhere would be a sensation of the first class. And a kind of fortress would be a solid basis for quite a number of justified conclusions. It would be unmistakable evidence for the existence of intelligent beings, at least the former existence of intelligent beings if you want to be very careful. It would also prove that there is or was another and hostile life form about, presumably intelligent too. It would prove a whole lot of things—provided only that its nature were established.

Gruithuisen's walled city is *not* established. The German astronomer Mädler who, some time after Gruithuisen, produced maps of the moon which remained the best for many decades, drew the famous spot as an irregular pattern of small mountain chains. Modern observations seem to indicate that both exaggerated. The mysterious spot is not as regular as Gruithuisen drew it. Nor is it as irregular as Mädler made it out to be. At any event, it is something for which we don't know a counterpart on earth. If it is not a work of intelligent beings, there is no natural form on earth which is strictly comparable.

Nor, it may be added, do we have anything on earth which is comparable to the Great Valley of the Lunar Alps, or to the 70-mile long Straight Wall near the crater Thebit in Mare Nubium. As for the Great Valley, the only possible explanation is that it was caused by a very large meteorite, grazing the surface of the moon, while the Straight Wall, also called the Railway, is presumably a rocky fault, with one ledge higher than the other. The fact is that we don't have such things on earth. We don't have such a valley at all and our rocky faults are not only much smaller but also not as straight. Which, when applied to Gruithuisen's "walled city," means that the mere fact that no comparable natural form exists on earth does not imply that the lunar form has of necessity to be man-made.

The same Gruithuisen also found "life on Venus" in rather extreme manifestations. But before we go on to this, we must mention what is probably the wildest astronomical hypothesis ever advanced.

After Hevelius, as we have seen, the moon gradually fell into disrepute as an inhabited planet. The steadily improving telescopes left no doubt that there were no clouds on the moon. The darker areas which had been called *maria* (seas) with early enthusiasm, turned out to be just darker and generally smoother areas. They might still be the bottoms of old seas—although even that is by no means sure—but they certainly were not seas any more. There was, in short, no water on the moon. And there was no air to speak of; when the moon's disk covered a star that "occultation" occurred precisely at the proper second. If the moon had an appreciable atmosphere there would be a delay. Without air and water there could be no life as we know it. The lunarians, or selenites, or endymionides, if they ever existed, belonged to the past.

The nineteenth century made an attempt to "save" them.

The moon, by turning once around its axis while moving once around the earth, succeeds in keeping its opposite hemisphere permanently hidden from the interested eyes of our astronomers. That is, the moon almost succeeds, because there is a slight wobble known under the technical term of libration which permits seeing small portions near the rim on occasion. By accumulating such observations astronomers have succeeded in seeing about four-sevenths of the lunar surface. But the remaining three-sevenths simply have never been seen, nor can they ever be seen by observers stationed on earth.

Now the motion of the moon is peculiar, in fact it is one of the really difficult problems of mathematical astronomy. For a while it seemed as if the evidence pointed at a very peculiar solution. It seemed that the moon was not spherical as all other planets are—spherical, that is, within the customary deviations from the true mathematical sphere—but egg-shaped. The sharper end of the egg was the one pointing toward the earth, and it seemed as if the visible hemisphere was the enormous bulge of an irregularly shaped body—as if the whole hemisphere we can see, the whole hemisphere with all its craters and maria and mountains, was in itself an enormous mountain.

Then, if that were true, the other side would certainly be greatly different. The waterless and airless moon would be waterless and airless only where we could see it. It would be waterless and airless because it is an enormous mountain. The "back" might resemble earth much more; it might be an enormous tropical jungle with dense and steaming air. It would have to be a watery jungle, it was reasoned, because naturally all the water of the moon would be concentrated on that one hemisphere.

Suddenly it seemed as if this old Pythagorean idea of the "uninhabitable hemisphere" of earth, the hemisphere which cannot be inhabited because it has the "central fire" overhead, were illustrated in the sky. (The uninhabitable hemisphere was, of course, the Western Hemisphere.) The moon seemed to conform to this old fantasy with its enormous bulge sticking out into cold and airless space. From declaring that the other hemisphere was likely to be much more earth-like and inhabitable, it was only one step to saying that it was inhabited.

That hypothesis was never generally accepted by astronomers, but for some time it was an acceptable hypothesis; things *might* be that way. The moon "bubble" was pricked by Simon Newcomb who spent a great deal of his long and busy life investigating the orbital motion of the moon. It turned out that the moon is not precisely spherical, but the difference is too small to matter much. The gigantic earth-pointing "mountain" collapsed and with it collapsed the interesting idea of the watery and inhabitable "other hemisphere."

Decades later, when the dream was almost forgotten in astronomical circles, it was resurrected for literary purposes by the Polish poet, Jerczy von Zuławsky, in a novel *On Silvery Plains* [3] in which the crew of a spaceship from earth sets out on a long trek

[3] This is a translation of the title of the German edition, *Auf silbernen Gefilden*. As far as I know there are no other translations of Zulawsky's works.

across the visible hemisphere of the moon to reach the other hemisphere. Some of them succeed and a strange race grows up there, the children of the arrivals from earth.

As a matter of fact, the "other hemisphere" does not seem to differ in any respect from the hemisphere we can see. Certain mountain chains continue "over the rim" and the rims of other maria become visible when the libration is suitable.

If Gruithuisen felt certain of life on the moon—which, of course, meant intelligent life—he was more than certain of life on Venus.

It was well known in Gruithuisen's time that Venus is almost precisely a second earth as far as size and mass goes. But Venus, circling the sun inside the orbit of earth, would be generally warmer. It would be a tropical planet with a vegetation, to use Gruithuisen's own words, "incomparably more luxuriant than even the virgin forests of Brazil."

Now Venus exhibits a strange phenomenon from time to time. The dark parts, the parts where it is night on Venus, are not really dark, but glow with a faint luminosity, reminiscent of the so-called earth-light of the moon. The earth-light of the dark parts of the moon is, as the name implies, caused by the earth; these parts have night as far as their position in relation to the sun is concerned but they are illuminated by the *Volva* in the sky, to fall back on Kepler's name for the earth in the lunar sky. It is possible that the night side of the earth shows a similar faint light to an outside observer when there is a full moon illuminating it.

The very first observers of the Venus light explained it just that way—there was night on Venus with a full moon in the sky. But these first observers had a moon of Venus at their disposal to use for their explanation. We haven't. The "satellite of Venus," seen by several early astronomers, does not exist. We are perfectly certain now that Venus, like Mercury, does not have a moon; those early observers mistook a fixed star for a moon of Venus. There was, consequently, no explanation for the faint luminousness of Venus' night side.

Gruithuisen found one.

Going over astronomical records he noticed that "the principal observations of the ashen light on Venus are those of Mayer in 1759 and of Harding in 1806." There was an interval of 47 years or of 76 Venus years, an interval which makes no sense whatever from an astronomical point of view.

Gruithuisen agreed with this: "If this period has a religious character we cannot see any justification for that number of years. But," he continued, "it becomes more comprehensible if we assume that some Alexander or Napoleon then attained universal power. If we assume that the ordinary life of an inhabitant of Venus lasts 130 Venus-years, which amount to 80 earth-years, the reign of an Emperor of Venus might well last 76 Venus-years."

The ashen light of Venus, to Professor Franz von Paula Gruithuisen, was the astronomical result of a general festival illumination in honor of the ascension of a new emperor to the throne of the planet. Later Gruithuisen was apparently frightened by his own hypothesis and amended it in saying that it might simply be the burning of large stretches of jungle to produce new farm land—he just missed saying "new *Lebensraum*"—for the growing population of the evening star. "Large migrations of people would be prevented and the resulting wars would be avoided by abolishing the reason for them. Thus the race would be kept united."

To think of a phenomenon like our *aurora borealis* and *aurora australis* in order to explain the ashen light would have been *much* too simple.

It was, of course, difficult to surpass Gruithuisen, but the French inventor Charles Cros did his best. His *Moyens de communications avec les planètes* was published in Paris in 1869. The fact that luminous pin points had been occasionally observed on Venus and Mars—in all probability high clouds which were still struck by the light of the sun while the surface was already in darkness—was sufficient for him to state that the inhabitants of these two planets were trying to communicate with the earth. Cros proposed to answer by means of an enormous mirror, similar to the mirrors used in reflecting telescopes, but many many times as large and of a very shallow curvature.

It was to be so shallow that the focal point was no longer on earth at all but on the surface of the planet with which communication was to be established. If the mirror were large enough to collect a sufficient amount of sunlight, Cros reasoned, and if the focal point of it were near the surface of the Martian desert, the power of the sun's rays would fuse the sand there. Then it would be possible to "write" gigantic figures in the sands of the deserts of Mars: first simple symbols, like triangles and circles, then more complicated mathematical figures, and finally even simple pictures, the head of a man, the outline of a house, and so on.

Cros wanted the French government to pay for such a mirror and he spent many years of his life making petitions, writing memoranda, and pulling what strings he could. Nobody ever succeeded in convincing him that the existence of the Martians was, after all, not assured. Nobody ever succeeded in convincing him that no optician could build a mirror of sufficient size and precision. Cros stubbornly clung to his idea. He died disappointed and in extreme poverty.

The theme of devising means of communications with other planets has been a recurrent one ever since, although more in the spirit of intellectual curiosity. The German astronomer Plassmann once devoted a paper to the question of whether the Martians could see the light of our large cities. Plassmann wrote it around 1920 or 1925, when cities were much larger and much brighter than in Gruithuisen's and Cros' time. He came to the conclusion that the Martians, provided their eyes were as good as ours and provided that their instruments were as good (and not better) than ours, would never be quite certain whether they did or did not see pin points of light in those spots where terrestrial maps show the names of Moscow, Berlin, Paris, London, New York, Chicago, and Los Angeles. Somewhat better instruments would make that certain.

Plassmann disregarded the Venusians completely in his article and with good reason. Blanketed as they are by their eternal cloud layer, they certainly would not be astronomers and probably would never have invented the telescope. As a matter of fact, it would be easy to "prove" that the presumed Venusians in their presumed environment would not have been able to attain any intellectual level worth mentioning because their environment was not suitable for intellectual development. Intellectual or at any event scientific activity begins with the realization that effect follows cause, that the same cause always produces the same effect, and that there are natural laws. On earth, as far as we can find out, such activity was stirred or at least encouraged by the regularity of certain astronomical features. The moon went through its phases regularly, the seasons repeated regularly, the stars seemed to wander across the sky in a measured tread. The orderliness of the sky suggested orderliness in nature in general and investigation of nature was begun and finally progressed, in spite of many handicaps in the form of faulty analogies, mistakes, and misunderstandings. Without the starred sky as a starting point nothing like that may ever have taken place.

As for the selenites, if they exist, it may be said that their knowledge of the earth would be large in extent. Again, assuming that their eyes and instruments were as good but not better than ours, their maps of the earth should be excellent. In fact because of their favored position for the observation of the surface of the earth, their maps would surpass our own for a number of sections like some parts of Siberia, of Inner Australia, of Antarctica, and even sections of Alaska and South America. They would know the location of any town of more than a few thousand inhabitants and they could follow the maneuvers of a battle fleet and even of single large liners like the *Queen Mary*.

Some other aspects of interplanetary communication have also been re-examined more recently, of course again in the spirit of intellectual curiosity, not in the form of "projects," even if the newspapers occasionally called them that. An English engineer, for example, calculated the amount of flashlight powder needed to produce a flash that could be seen from Mars, provided the Martians knew where and when to look for it. I don't recall the figure, but it was enormous. Things would be somewhat better if the flashlight powder were not exploded on the ground but raised above the densest layers of the atmosphere by means of captive balloons which rise as high as they can possibly go and are exploded by electric ignition along with the flashlight powder. Under that assumption the figure for the amount needed looked somewhat better but it was still on the order of a trainload.

And finally some people have amused themselves in working out a "letter to the Martians." The purpose of that mental exercise was to find out whether it would be possible at all to establish a mutual understanding with beings of intelligence but of a completely alien race and environment. The "language" would have to be partly pictures and partly mathematics. The letter would begin with a single dot, accompanied by the figure 1. Then two dots accompanied by the figure 2. Then three dots with the figure 3, etc., until the meaning of the figures would be explained. Then the "letter" would progress to simple arithmetic and algebraic operations and to elementary geometry. The meaning of the symbol of an arrow (direction) would have to be explained and then a picture of the earth could be shown, with an arrow pointing to the picture of Mars. Of course there would be a diagram of the solar system with more arrows drawn in. It seems likely that a message of this type could tell that it came from earth to anybody who can think and see.

All these recent amusements, you may have noticed, spoke about the Martians as an example. This in itself is a modern thought. Around the middle of the nineteenth century Mars was still generally disregarded. It had not yet become important as a planet about which to speculate. If interest centered upon any specific planet it was, thanks to Gruithuisen's efforts, Venus. Naturally such an exciting thought could not fail to leave its mark upon literature and the first novel about a trip to Venus was not long in coming.

Its author was a Frenchman, Achille Eyraud. It was printed in Paris in 1865 and its title was simply *Voyage à Vénus.* Just how much Eyraud was influenced by Gruithuisen is something I'd like to know myself; I never succeeded in laying my hands upon a copy of Eyraud's novel. Wherever I lived I tried the local libraries, but the book seems to be rare. The following description is, therefore, based upon another source: the appendix of a late edition of Camille Flammarion's *Les mondes imaginaires et les mondes réels.*

Eyraud did something from which writers had shied away for more than a century: he "invented" a spaceship for his novel and described its engines. And he must have had a good working knowledge of theoretical physics or else the help of a professional physicist, because he found the only possible means. His ship was propelled by a *moteur à réaction.* Eyraud, according to Flammarion, described the known application of the action-reaction law which then was only the fireworks rocket. He also explained that the recoil of a gun originates in the same manner. And he stated that his *moteur à réaction* worked in the same manner. The remainder of the novel is not important; Flammarion says that on Venus the hero finds a society "hardly different from that of Paris or France." And since his terrestrial fiancée dies on Venus he finally marries *une jeune et belle Vénusienne.*

Achille Eyraud's *moteur à réaction* was important not so much because that writer used the theoretically correct means of accomplishing space travel, but because he was the first to express the belief that science, which had made the whole problem look impossible, also produced the means of a solution. If one branch of science had separated the worlds hopelessly by finding enormous distances and airless space, another branch of science pointed out that there were theoretical means of bridging those distances and of braving the nonexisting environment of a vacuum.

Seen from this point of view, Eyraud's novel simply expressed confidence in the powers of science and discovery, a confidence well fortified by the fact that during the preceding half century a number of important discoveries had been made and a number of important inventions had been put to work.

It was the same feeling which produced Jules Verne.

Kenneth Allott, in his excellent Jules Verne biography, has taken great pains to point out that Jules Verne's writings are romantic in sentiment. Of course they are, since explorations of the unknown and possibly also of distant things are by their very nature "romantic." But the more important thing is that Jules Verne represents a new attitude. Consistently his heroes (who are, of course, merely personifications of the scientists, engineers, and explorers of the nineteenth century) do things themselves. They do them in a novel way. They don't do things in a traditional and poor and inefficient manner for the sake of tradition. Nor do they look for "lost arts."

They are not even very romantic; they are mainly truthful. Instead of yielding to the traditional modesty of being "insignificant sons of great ancestors," they act with the full knowledge that their time has surpassed any preceding time. They know that they know more than their ancestors.

They expect their sons to be better than they are and they expect the future to be greater than the present. They don't hesitate to cruise under the seas or to fly through the air. And to them the problem of reaching the moon is what it really is: a question of attaining a sufficiently large velocity in the right direction at the proper time.

Jules Verne's *De la Terre à la Lune* appeared in 1865, the same year that Achille Eyraud's novel saw print. It was a prolific year for that sort of literature. Alexandre Dumas published his *Voyage à la Lune*, Henri de Parville published his *Un habitant de la planète Mars*, an anonymous French author published another *Voyage à la Lune*, an anonymous English writer published *A Journey in the Moon*, and, as if to round out the picture, Camille Flammarion published his *Mondes imaginaires et mondes réels,* which is essentially a description of all preceding works of literature that deal with astronomy, astronomical philosophy, plurality of the worlds, habitability of the planets, and attempts at interplanetary communication.

The books by Dumas and the anonymous English writer are unimportant. The anonymous *Voyage à la Lune* and de Parville's story are curiously alike in that they begin with the discovery of strange meteorites which are really messages. (Just a few decades earlier Chladni, in his work *Ueber Feuer-Meteore,* had convinced the scientific world that there really was such a thing as a meteorite.) The Mars story is essentially a treatise on the plurality of the worlds, but the *Voyage à la Lune* brings a new thought. It recounts the story of two men who went to the moon to live there. Their trip became possible because they invented or discovered a substance which is not attracted by the gravitational force of the earth but repelled by it.

Jules Verne spent the largest effort in trying to make his method credible. He had decided on a cannon as the proper means of bridging the gulf between earth and moon. He had calculated—and had his calculations checked by astronomical experts—just what muzzle velocity a cannon would have to have to throw a projectile to our satellite. He threw in a number of things then new: the propelling charge was to be guncotton, invented only some fifteen years before by Schönbein; the ball (which was to be large enough to be seen in flight by a new giant telescope) was to be of aluminum which, at that time, was still so rare that chemists made each other presents of little bars weighing a few ounces. In fact the whole book is the story of the preparations for the great event.

The locale of the story is America and the main characters are all members of a fictitious organization, the Gun Club, consisting of gunnery experts who served in and survived the Civil War, although not always complete in their anatomical make-up. The leaders of this club at first only want to send a projectile to the moon in order to show that it can be done. But then a young man by the name of Ardan appears and proposes to be a passenger of the projectile.

Jules Verne had his little joke with that name. Everybody in Paris at once recognized the anagram, Ardan was Nadar and Nadar was Felix Tournachon, a Paris journalist. "Nadar" had studied medicine, but then turned newspaperman and photographer. In 1852 he had opened a studio in Paris, but his puttering in the dark room did not prevent him from being active in aviation. He built a balloon, the *Géant*, which ascended for the first time in 1863—Jules Verne was in the gondola—and later he built the first of the balloons which left besieged Paris during the Franco-Prussian war of 1870-71. (One of the passengers in these balloons was a man who, as a boy, had almost made the first rocket flight, see page 83.) "Nadar" was also Lesseps' secretary for some time.

Well, Ardan-Nadar compels the Gun Club to revise the plans, the round ball has to be redesigned as an elongated projectile, padded and furnished inside, and equipped with "water buffers" to enable the passengers (they are three, in the end) to survive the shock of firing.

Two years after *De la Terre à la Lune* followed *Autour de la Lune,* the story of the three heroes imprisoned in the aluminum shell. As soon as they recover from the shock—actually it would have done more to them than just kill them—they begin to spout astronomical and mathematical wisdom in large doses. They get an additional reason for doing so because their projectile passes earth's "second moon" and slightly deflects its course. This proves to be their salvation for, instead of striking the moon, the shell misses and, caught by the force of lunar gravitation, circles around it. Unfortunately for Jules Verne's readers, the circumstances are such that the side of the moon which cannot be seen from earth is in darkness, and all that the three heroes can see is what appears to be a volcanic eruption. Finally they cross into the field of terrestrial attraction and fall back to earth, landing safely although tumultuously in an ocean to be rescued.

Although these two books are not easy to read, Jules Verne's two-volume story of a shot to the moon has become the classic moon-trip story and its fame is universal. This has had the rather unfortunate result of associating space travel with shooting in the minds of most people. But what Jules Verne really accomplished was to acquaint the public with the fact that a trip to the moon is a question of velocity. That he used a gun to produce that velocity is merely a literary device which is not to be taken seriously.

Just the same, this method has been examined critically more than once, and such an examination of Jules Verne's cannon shot is very interesting and teaches a lot about the actual problem. But because it involves too long a scientific discussion I am going to postpone it until it can be compared with modern conceptions. (See Chapter 8.)[4]

While the year 1865 had been prolific with novels about visits to other planets, it took some time until the next important book of this kind appeared. In my notes I have a long excerpt of a novel in four volumes, printed in German in 1882 and entitled *Beyond the Zodiac.* The title page of the book names Percy Greg as author and claims that it is a translation from the English. However I failed to find an English edition in all the libraries I consulted. Nor did any one of the many collectors of such books I know have any knowledge of an English edition or of the novel itself. Nor did I find it mentioned in various articles about interplanetary voyages, written by people who do not know German. Therefore I harbor the suspicion that it is not a translation but was written in Germany.

At any event it is a fairly interesting book. It begins again with the fall of a meteorite which buries itself in one of the South Sea islands. When the wreckage is examined, a strong box of an unknown metal is found in the meteor crater, containing a fat manuscript written in unknown characters. At first nobody believes that these characters can be read since they might be anything. But then the owner of the box reasons that the writer may have been an earthman who did not know, of course, in what country his vessel might land or crash. In that case he would not write in his native tongue, whichever that may be, but, if he is able to do so, in the one language which can be read by quite a number of people in every nation: Latin. Trying to decode the manuscript under this assumption proves easy. It is Latin, written in a different alphabet, just about as English would look using the Greek or Russian alphabets.

It turns out that an engineer who pondered about gravitation had the thought that there should be something like "negative gravity" which he calls *apergy.* After some experimentation he

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[4] Jules Verne's cannon shot is discussed in detail by Max Valier in *Der Vorstoss in den Weltenraum* and in *Raketenfahrt.* The calculations, incidentally, although not credited by Valier, were made by Hermann Oberth. Another discussion is that by Count Guido von Pirquet in my book *Die Möglichkeit der Weltraumfahrt* (1928) and a list of the mistakes may be found in *Popular Astronomy* (April 1942), Vol. L, No. 4, in the article "Marvelous Voyages—III" by Dr. Laurence J. Lafleur.

succeeds in discovering this apergy and sets out for a trip to Mars where he finds people greatly resembling those of earth, only somewhat smaller in stature. The remainder of the story is devoted to a description of Martian society, but the novel is not an utopia. That society is by no means an "ideal state," and there are a lot of things wrong with it. It is a different society, logically constructed.

The date of that novel is, as has been said, 1882. And we are now entering the period of speculations about Mars. After the "moon mountain" of Hansen's hypothesis had collapsed, the moon had finally been given up as dead. Venus was neglected and Mars was to rule supreme.

This shift in interest was not accidental; it was the logical result of scientific developments. The progression of these developments was about as follows: In 1828 Wöhler had shown that living substances consist of the same elements as non-living matter. In 1859 Kirchhoff and Bunsen had developed the spectroscope which, within its natural limitations, proved that the other stars and planets consisted of the same elements as earth, although the distribution of elements varied.

As if to make the case airtight as soon as possible, Dimitri Mendeleyeff and Lothar Meyer—working independently—produced the periodic system of the elements, showing that only a limited number of elements were possible at all. Mendeleyeff's work was published in 1869. Charles Darwin's *Origin of Species*, published for the first time in 1859, had to be added to these developments in the fields of physics and chemistry. The storm about Darwin did not break immediately, but around 1880 it was already clear who would win. Now Darwin's theory meant that all life was interrelated, not only in a symbolic manner of speaking, but actually. Wherever life started at all it was likely that it, given enough time, would produce intelligent beings in the end. And it seemed probable that life would start wherever conditions were suitable and that it would start soon after conditions became suitable.

On top of all this, astronomers believed they had a correct explanation of the formation of a planetary system of a sun. It was the so-called Kant-Laplace hypothesis—in spite of its name it was mainly Laplace's conception—which stated that the planets had condensed out of matter that had been thrown off their suns. Obviously then, the relative ages of the various planets could be read off their distances—those farthest away were the oldest.

Mars, therefore, was older than earth by an unknown number of years, probably a large number. Consequently life had started that much earlier on Mars; consequently Martian humanity was older and wiser than we are. By the same token Venus was younger and had probably not progressed to intelligent beings yet; Venus was a replica of the earth at the time of the carboniferous forests or at the time of the great dinosaurs. But Mars was a replica of the earth as it was to be later; looking at Mars one looked, actually and almost literally, into the future.

The year 1877 approached.

It was the year in which Asaph Hall discovered the two small moons of Mars. But it was also the year in which still more exciting news about Mars came from Italy, originating from an astronomer by the name of Giovanni Schiaparelli. The news said that Schiaparelli had seen *canali*.

Now the Italian word *canali* simply means "grooves" or "channels." The meaning of "canals" is secondary, although the word is used to mean artificial waterways too. But in all other languages the word "canal" means only that, and Schiaparelli's *canali* was quickly and emphatically translated into "canals." The jubilation was great; everything seemed to fit perfectly. The planet which had logically been pronounced the most likely abode of intelligent life in our solar system now showed by gigantic works of engineering that it really was.

Mars, as had been suspected from the combination of Kant-Laplace and Darwin, was older than the earth. Because of its age it had lost most of its water. But its inhabitants, also because of their greater age, had progressed in technological knowledge and in the spirit of mutual co-operation to the point where they could overcome that handicap. They had covered their planet with a network of canals which led the water from the melting polar icecaps over all the continents. Those Martian canals were waterways, but they served as means of transportation only secondarily; primarily they served as gigantic irrigation ditches, as center lines of irrigated farm land.

This conception also disposed of the first critical argument—the fact that a Martian canal, to be visible from earth, would have to be at least thirty miles wide and that many of them were three, five, and even ten times that wide. Of course the lines we saw were that wide or else we could not see them. But what we saw was not the canal itself; it was the wide ribbon of vegetation that stretched through the deserts alongside the canals. There was one river on earth which probably looked to the Martians like one of their canals, for the same reason and especially because it happened to be almost straight: the Nile!

Everybody knows that Schiaparelli's first announcement was followed by three decades of Mars enthusiasm, three decades during which reports from astronomical observatories were awaited and read as avidly as reports from the front in the middle of a war. Several amateur observers reported light signals from the Martians which mostly turned out to be high-flying whitish clouds. Astronomers made careful maps of the surface of Mars, and many who studied them looked for something on the order of the mathematical forest in Siberia proposed by Gauss. Such convictions were so strong that they led to a qualifying paragraph in the famous *Prix Guzman* which was deposited in Paris some time around 1900. The prize amounted to 100,000 francs, then $20,000, and the award was to fall to the person or persons who established interplanetary communication. But Madame Guzman, when founding the award, stipulated that Mars was excluded from it because communication with Mars would be too easy to deserve a prize.

It goes without saying that literature did not fail to contribute to these decades of the great dreams.

Much later, in 1927, the popular astronomical museum at Treptow near Berlin staged a "Mars Exhibit," consisting of maps of Mars, greatly enlarged photographs, and a large collection of books. And at that exhibit I met an elderly gentleman who swore that he had originally learned German for one reason only: to be able to read the novel *Auf zwei Planeten* by Kurd Lasswitz.

Kurd Lasswitz was a professor of mathematics in his private life, a great deal of which he spent quietly at Jena. *On Two Planets* was neither his only book nor his only work of fiction, but it was the one that made him famous, causing articles in the *Annals of Science* even now, forty years later.

Kurd Lasswitz had carried that logic about the older Martian race a few steps farther. If the Martians were so much older it would be a succession of Martian inventors and scientific institutions which would solve the difficult problem of space travel, and not a single terrestrial inventor. Consequently they would visit the earth, not the other way round. Also, these *canali* were really strips of vegetation through the deserts, wide bands of tall forests. (Under the lighter gravity of Mars trees would be higher.) Those forests shadowed the buildings of the loosely built cities and the moving roadways. (When traffic is too heavy in volume a moving roadway is superior to independent vehicles.) The precious water was carried in pipes to prevent it from evaporation, and none of the carefully preserved water was wasted on edible plants; food, under the Martians' advanced chemistry, would be synthetic and so inexpensive as to be virtually free.

It was partly a "utopia" portraying a higher society, partly it was simple prediction: engineers have often considered rolling roads for specific traffic problems. And there cannot be a better solution for the basic problem of sociology, eliminating hunger, than synthetic food which can be produced in any volume required at very short notice.[5] It was also basic psychology to show that the highly ethical Martians, when confronted with terrestrial stubbornness, quickly revert to war, fought in a highly efficient manner with a minimum of actual killing.

But the most interesting thing in Lasswitz' novel was his solution of the problem of space travel. Lasswitz saw to it that his readers got acquainted with it early in the book.

The novel began with a flight to the North Pole in a free balloon; the tragic attempt by Andrée to reach the Pole in this manner was still fresh in everybody's memory. When the Pole comes into sight, the men in the gondola see to their great surprise that there is an unmistakable building on the Pole, strange in shape, but not an Eskimo hut. At the same time the balloon begins to circle as if caught in a whirlpool, but it also begins to rise. Minutes later the balloon rises vertically, and the gondola rises faster than the gasbag. They are caught in a field of reversed gravity, induced by the connection between the building on the Pole and a structure high above the Pole, one earth-diameter from the center of the earth.

These are structures of the Martians, their first foothold on earth.

[5] Later, when synthetic food is introduced on earth, it becomes more than just a chemical problem. Lasswitz compresses the whole struggle in one scene, the scene where a man who has been out of touch with events, orders supper in a small restaurant, deciding on a liverwurst sandwich. The waiter asks whether he wants natural or synthetic.—"What, synthetic?"—"Yes, sir, Martian style, sir. You see, sir, 'grown' is considered patriotic, but synthetic is much less expensive and, really, it's much better."

The Martians get the travelers out of the field by turning it off as soon as the car which happened to be in transit between the Pole and the "outside station" has arrived on the latter. Revived, the three earthmen are informed about the accident that has happened to them. Later on they are taken to the outside station and asked to point out their homes, the Martians do have that kind of telescope that Locke ascribed to Sir John Herschel. But Lasswitz explains it better. The original image falls on a small screen consisting of millions of tiny photo-electric cells. Each cell operates an "optical relay," releasing visible radiation of precisely the same color but of much higher intensity, and these rays form the image on the large screen. (Lasswitz, incidentally, had astronomical experts check the precise range of such a presumed instrument in that presumed position.)

And then the earthmen learn how the Martians crossed space. They succeeded in developing a material which, although not weightless in itself, had the quality of becoming so as soon as it formed an unbroken shell. Lasswitz vaguely indicates that gravity will "flow around it" in this case. And all the things inside become "inaccessible" to gravity. Thus a Martian spaceship—they are spherical—becomes weightless as soon as the last door is closed. If that were done near earth the weightless ship would at once move away from earth's orbit along a tangent and in time reach the orbit of Mars, to land on Mars if the planet happens to be near that point of its orbit at that time. Or else the Martians can take off from the home planet in the same manner, wait until their planet is sufficiently far away, fall toward the sun until they have reached the orbit of earth, and then land on earth.

The first attempts, the earthmen are told, were unsuccessful and ended in disaster, partly because of the clumsiness of the method, partly because that marvellous substance, developed on Mars, disintegrated in the moist atmosphere of earth. They had to have two improvements. One was the station over the Pole—they have similar stations over their own poles because "you do not jump onto a train where it moves but where it stands still"—and secondly a method of steering, accelerating, and stopping their ships in space. The solution to the latter problem was *repulsit,* a substance somewhat beyond the grasp of terrestrial physicists, but essentially a highly explosive substance. The reaction of such an explosion would steer or stop or accelerate their ships, but they always needed quite a number of such "shots," each releasing a small dose of *repulsit,* since the jolt resulting from a dose of the proper magnitude would have killed every man aboard. Still, they could and did travel that way, finding only the earth inhabited by a race similar to them. But just recently a Martian engineer by the name of Fru has made the final invention they need, Fru's *repulsor* which releases the *repulsit* charge in a prolonged push instead of a sudden explosion.

Disregarding the marvellous but impossible (and what's more, actually useless, as we'll see later) substance which makes things inaccessible to gravity, Lasswitz presented a solution of the problem of space travel as mathematicians see it. Once free of the immediate gravitational influence of a planet, a spaceship would drift to the orbit of another planet in a time interval which can be calculated, and it is a question of timing the departure whether you meet the other planet at that point of its orbit or not. The reaction of a shot—preferably a pushing instead of jolting reaction —can be used as means to decelerate or accelerate in airless space. It was all worked out so well that most readers, as one critic put it, did not even notice that these pages of the book (only a score or so) presented a number of new thoughts.

One of the results of Lasswitz' novel was the reissue of Kepler's *Somnium,* and the *Somnium* greatly influenced H. G. Wells when he wrote his *First Men in the Moon* a year or two later. In this novel, as most readers will remember, Wells uses a substance very similar to Lasswitz' Martian invention, but ascribes it to an earthman, the engineer Cavor, and consequently refers to it as *cavorite.* Cavorite gets them to the moon and the two space-travelers are finally captured by the selenites who live in the numerous hollows and caves under the volcanoes.[6] The selenites are evolved from insects and Wells infuses these beings with the specialized nature of members of a termite colony. Finally one of the travelers escapes and returns to earth.

Wells' other early interplanetary novel appeared almost simultaneously, the *War of the Worlds,* and describes an invasion of the earth by the Martians. In this novel Wells used Jules Verne's

[6] Wells probably misread *subvolvani* as *subvolcani,* converting the "dwellers under the Volva" into "dwellers under the volcanoes."

method of shooting, but the book itself is devoted to the description of the attempted Martian conquest. The Martians are described as octopus-like creatures, rather frail, at least under the pull of terrestrial gravity. Consequently they move about mechanically, sitting in towering fighting machines equipped with heat rays and poison gas nozzles. Finally the Martians succumb, not to human opponents but to the "invisible devils" of which the terrestrial atmosphere is full. They die of bacterial infections—a pretty idea which has been imitated countless times since.

The two Wells novels were the last two important works of literature of this type produced by the decades of the great dreams of human life on Mars. Many more novels of this kind have been written and published during the last forty years, of course, but in most cases the authors have described the conquest of space as originating from earth. The Martians, by their very failure of visiting our planet, have proved that their intelligence has to be at a lower level than ours if they exist at all. Even that is now generally doubted and with many good reasons.

And with Mars out of the running, earth remains the only planet in our solar system which bears intelligent life. Little Mercury, the moon of the sun, has one hemisphere freezing in endless night while the other is scorched by endless day, an endless day in close proximity to a viciously radiating sun. Venus, sister planet of the earth as far as size and mass goes, is somewhat too warm—the estimates of its surface temperature range from 80 degrees Fahrenheit to the boiling point of water.

The moon is dead and without atmosphere. The atmosphere of Mars is thin, but dense enough to support the rare clouds. At noon in summer the Martian equator acquires a temperature which is comparable to a balmy spring day on earth in the temperate zone, but generally speaking the climate of Mars rather resembles the arctic zone of earth, or the icy cold of the high ranges of Inner Asia.

Still it is quite likely that there is plant and even animal life of some sort on Mars; the conditions are not such that life would be impossible. And the same can be said about Venus, provided that the surface temperature is sufficiently below the boiling point, something we are, at present, unable to determine.

As for the large outer planets, the present conception is that they are wrapped in miles upon countless miles of highly compressed ice under an enormously deep and dense atmosphere of extremely cold hydrogen gas, topped by layers of clouds of marsh gas and ammonia.

Being confronted with scientific evidence of this kind, newer novelists have had no other choice than to let the conquest of space originate from earth. The chances are overwhelming that future developments will prove them correct.

Chapter 3:

"THE ROCKET'S RED GLARE. . ."

Actioni contrariam semper et aequalem esse reactionem; sive corporum duorum actiones in se mutuo semper esse aequales et in partes contrarias dirigi.

Reaction is equal (in power) but opposite (in direction) to action; or the actions of two bodies are equal (in power) but point in opposite directions.—Sir Isaac Newton's Third Law of Motion.

THE story of the rocket is part and parcel of the story of flight as well as of space travel. While this connection may have been accidental in a number of early instances, it is anything but accidental today. The application of rocket power to theoretical devices for reaching outer space is solidly founded in scientific fact, as will become apparent later on.

If it were only a question of theory, the old powder rockets of several centuries ago could safely be neglected in a modern discussion. But the application of rocket power is also a problem of engineering design, and it is for this reason that the history of the rocket is important, mirroring, as it does, a long period of small achievements by the trial and error method and showing the limitations of the devices developed by the traditions of families of artisans.

With this remark I refer, of course, to the later European tradition of which we have knowledge. But the rocket is not a European invention; the Europeans got it from the Arabs and the Arabs, in turn, had it from the Chinese.

There has never been any doubt that the rocket, the ordinary skyrocket, is originally a Chinese invention. But for want of definite knowledge, its origin has often been shrouded in legend and its age has been vastly exaggerated.

Older books often state in an offhand manner that rockets and similar fireworks have been known to the Chinese since the earliest times, probably since 3000 B.C. Where the authors of these books got their information is something a historian with a talent for languages should investigate some day. There is no reason, and there never was a reason, to believe in such a high age. The oldest known Chinese source in which rockets are mentioned is a chronicle known to sinologists as the *T-hung-lian-kang-mu,* and that chronicle dates the first use of the invention—though not the invention itself—as having been made in A.D. 1232. The occasion was a siege laid to the city of Kai-fung-fu (Pien-king) by the Mongols. But the Chinese had two new weapons and the Mongols disliked them intensely. One of those weapons was a kind of bomb dropped from the walls of the city on the heads of the besiegers. The Chinese name for that weapon is *tchin-tien-lui* or "heaven-shaking thunder." The other new weapon goes under the name of *fe-ee-ho-tsiang* or "arrow of flying fire." These "arrows" are taken to have been rockets and the description supports that supposition.

That description, according to the French sinologist St. Julien, reads as follows:

> The defenders also had "arrows of flying fire." They attached an inflammable substance to the arrow. The arrow suddenly flew away in a straight line and spread its fire over an area measuring ten steps. The Mongols dreaded these arrows of fire very much.[1]

Those "arrows" are taken to be rockets because no mention is made of a bow or any other instrument for shooting them. It is merely stated that they flew away suddenly and in a straight line. It is quite possible that they were real arrows with a rocket tied to them. Drawings of such rocket-arrow combinations have been found in ancient Chinese manuscripts by the French Jesuit Father Amiot. And travelers who have paid attention to such minor matters have asserted that Chinese fireworks rockets, at least as late as the year 1900, were feathered at the lower end of their guiding sticks, just as if they were arrows and notwithstanding the fact that the feathers burned away very quickly when the rocket was ignited. The arrows of Pien-king were literally "arrows of flying fire," a term which, to a European, would mean something entirely different: a fire arrow.

Fire arrows or incendiary arrows consisted of a small package

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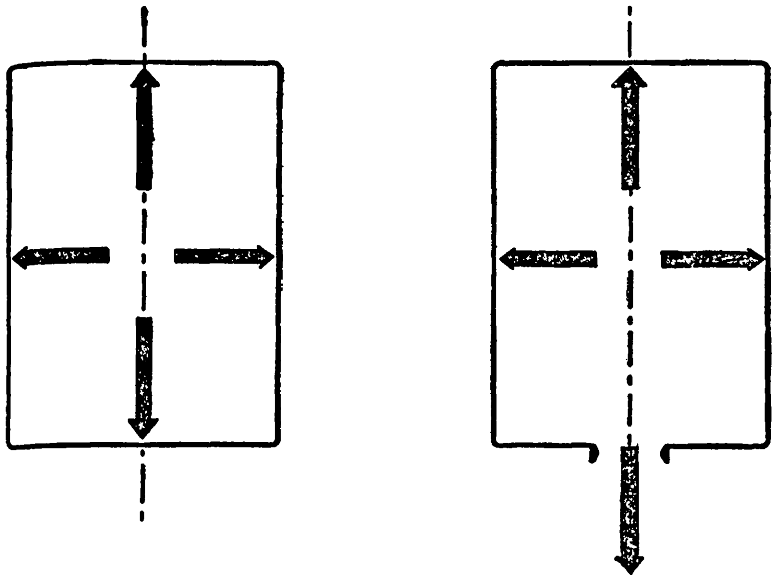
[1] In *Journal Asiatique* (1849). The original reads: "De plus, les assiégés avaient à leur disposition des 'flèches à feu volant.' On attachait à la flèche une matière susceptible de prendre feu; la flèche partit subitement en ligne droite, et répandait l'incendie sur une largeur de dix pas. Les flèches à feu volant étaient très redoutés des Mongols."

of incendiary materials tied to an arrow. Such arrows were dangerous weapons in times when most fortifications consisted of wood, and they were even more dangerous in later naval battles when sailing vessels had extensive tarred riggings. But rockets often substituted for fire arrows in these later naval battles and it seems that the two, the fire arrow and the fireworks rocket, are actually related to each other—in fact the one is the ancestor of the other.

The story of the fireworks rocket prior to the siege of Kai-fung-fu is not known, but more than half a century ago S. von Romocki evolved a brilliant conjecture about this unknown part of the rocket's history, a conjecture which has never been contradicted and which seems to be as close to actual truth as may be hoped for under the circumstances.

The fire arrow, the real fire arrow that was shot from a bow, was always an effective weapon in the wars of those days and it is only logical that many men sought to improve upon it. The main drawback of the fire arrow was its short range; it could not be shot from a fully drawn bow because that would extinguish the flame of the small package of incendiary materials tied to the shaft. Obviously it was necessary to find a material that would not be extinguished that easily. Now Greek philosophers held that salt, when added to an incendiary mixture, would make the flame hotter. The simple truth of the matter is that it merely makes the flame brighter, but since there was no way of measuring flame temperatures—or temperatures of any kind—in those days, the idea that the brighter flame was also the hotter flame was as obvious as it was beyond proof or disproof.

This "secret," the addition of salt to incendiary mixtures, seems to have traveled to China. And the Chinese seem to have substituted saltpeter for salt, either because they were not satisfied with the results of the "secret" or else because they accidentally discovered the properties of saltpeter. But when they added saltpeter they had a real improvement because then their incendiary mixture was well on the way to becoming gunpowder. Gunpowder, as every schoolboy knows nowadays, consists of a mixture of saltpeter (about three parts) and of pulverized charcoal and sulphur (constituting the fourth part in about even proportions). By about A.D. 1200 that process seems to have been completed. Hence the defenders of Kai-fung-fu had bombs which exploded with noise and violence and they also had fire arrows which had grown power-



3. *Elementary Principle of Rocket Motion.*

ful enough to depart of their own volition when ignited, without requiring a shooting instrument.

After the siege of Kai-fung-fu there is a little gap in the story of the rocket and, since it is necessary to understand the motive power of a rocket before we go on, that gap may be utilized for the necessary explanation.

A rocket is essentially a vessel filled with gas under pressure, gas meaning anything that is gaseous—compressed air, if you will, or steam under pressure, or carbon dioxide—any gas will do. As long as the vessel containing the compressed gas is without leaks or holes, nothing will happen; the gas will press against the walls of the container with equal force in any direction, up and down and left and right. But the picture changes when the container gets a hole through which the gas can escape. We'll assume that the hole appears suddenly in the bottom of the container. Then the gas still presses against the walls and the top, but it cannot press against the bottom because there is nothing to press against. Consequently the pressure pointing upward is not counteracted and the container rises. (Fig. 3.)

Abandoning historical sequence we find a perfect illustration of this principle in the steam rockets for which Mr. James Perkins of London was granted a British patent on May 15, 1824. Mr. Perkins' rocket consisted of a metal container which was partly filled with water. A round hole in the bottom was closed with a plug of a metal alloy which melted easily, probably a lead-tin alloy. Then the whole thing was placed into a blazing bonfire. The heat soon changed the water into steam which tried to get out of the confined space. But the container held together until the whole rocket had become hot enough for the plug to melt. Then the steam could push it out and suddenly, with a hole through which the steam could escape, the rocket shot up into the sky. I don't know whether Mr. Perkins knew precisely just what he was doing, nor do I know for what purpose he constructed these steam rockets and why he went to the trouble and expense of acquiring a patent, but I feel grateful for his efforts because he provided such a simple demonstration of the basic principle of rocket motion.

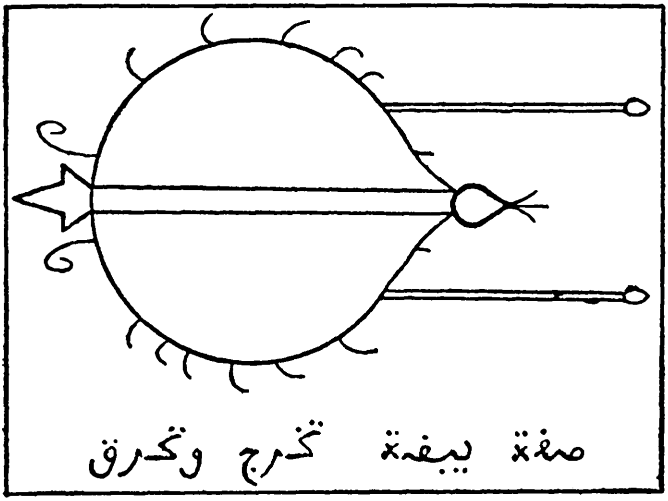
But to go back to the powder rocket.

Its principle is the same with only a minor difference of mechanics involved. Instead of being charged with a compressed gas, the powder rocket is charged with a mixture which, when burning, produces large quantities of compressed gas. Real gunpowder, incidentally, burns too fast for this purpose; it has to be slowed down—"made lazy" as the pyrotechnic term has it—by adding a large amount of pulverized charcoal. But those early gunpowders were all "lazy"; the weak mixture accidentally proved to be the right mixture.

The Chinese invention of the powder rocket, made some time around A.D. 1200, traveled back to the West with amazing speed. Just eight years after the battle of Kai-fung-fu an Arab scientist, usually referred to as Ibn Albaithar ("Son of the Horse Doctor"), wrote a book in which the important ingredient of gunpowder is mentioned.[2] Saltpeter, "the flower of the stone of Assos," as he has it, "is now called 'Snow from China' by the Egyptians," he stated, pointing to the influence of the Chinese discovery. As for the "people of the West" (the Arabs), he continued, the substance is called *barood*—but at that point he stopped; he did not say what they, or the Egyptians for that matter, did with *barood*.

We get more complete information about the things Ibn Albaithar may have been hiding from another Arab manuscript,

[2] His full name was Abu Mohammad Abdallah Ben Ahmad Almaliqi (from Malaga).



4. The Self-Moving and Combusting Egg.

the *Book of Fighting on Horseback and with War Engines.* It was written by one Hassan Alrammah, described as a brilliant hunchback whom his contemporaries adoringly called *Nedshm Eddin,* "Star of Faith," and who seems to have completed his manuscript in A.D. 1280. The book contains recipes for making gunpowder and directions for making rockets. And the rockets are still called *alsichem alkhatai,* Chinese Arrows.

But Hassan adds one unsuspected novelty: a rocket-propelled torpedo consisting of two flat pans, fastened together and filled with powder or an incendiary mixture, equipped with a kind of tail to insure movement in a straight line, and propelled by two large rockets. The whole was called the "self-moving and combusting egg," but no instances of its use are related. (Fig. 4.)

Some thirty years before Hassan finished his book, rockets and powder (which was not yet gunpowder because the guns were still to be invented) had been introduced in Europe. The rockets go under the Latin name of *ignis volans* (flying fire) or under the Germanic name of "wildfire," the latter being used later also for the old Greek fire which was a pure incendiary without explosive qualities.[3]

[3] I have told the story of gunpowder and rockets in Medieval Europe with more detail in my book *Shells and Shooting* (New York: Viking, 1942); see the chapters "Masters of the 'Black Art,'" "The Ancestors of Artillery," and "Rockets in Battle."

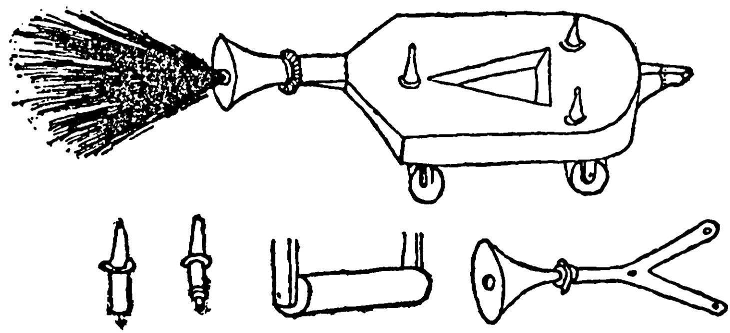
Shortly before 1249 the *Doctor mirabilis*, Roger Bacon, wrote his *Epistola;* some time between that date and 1280 (the year of his death) Roger Bacon's German counterpart, Albertus Magnus, wrote his *De Mirabilibus Mundi,* and the book of one Marchus Graecus, the *Liber ignium*, became known. All these books mention powder and rockets, and they all do so in the same words, proving a close interrelationship of the various books. Without going in for the rather difficult historical evaluation of the various manuscripts and works, it may be stated that the *Liber ignium* has been found to be the source for all the others. And the *Liber ignium* itself, of which only two apparently shortened and incomplete manuscripts were preserved in Paris, is probably a translation of a lost Arabic original.

That the introduction of rockets was not just a purely literary phenomenon is proved by occasional references to the thing itself. The chronicle of Cologne speaks about them in 1258 and the Italian historian Muratori credits a rocket with an important victory in the battle for the Isle of Chiozza in 1379. One defending tower resisted all assaults until it was set afire by a lucky hit.[4]

At that time firearms were already in existence, having been invented—according to the only source which gives a date—in 1313, but they were still crude and of poor performance so that rockets were a serious competitor. Naturally the military engineers of that period experimented with both, guns as well as rockets, trying to improve their power and range. Consequently there existed more than one type of rocket in 1400. The German military engineer, Konrad Kyeser von Eichstädt, mentions three types in his book *Bellifortis* (finished in 1405): vertically rising skyrockets, floating rockets, and rockets running along taut strings. The sketchbook of an Italian military engineer, Joanes de Fontana, which can be dated as having been finished in 1420, is full of much more ambitious projects.

This sketchbook, later called the *Bellicorum Instrumentorum Liber*, contains drawings of rockets disguised as flying pigeons, as floating fish, and as running hares, all of them supposed to set fire to the enemy's fortifications. The running hare, mounted on a wooden board, does not run on wheels but on wooden rollers—de Fontana was looking for a device that would enable his disguised rocket to cross uneven ground. The same idea, magnified

[4] The original reads: "Pure una rocchetta fu tirata nel tetto della torre de si fatto modo, que il tetto s'accese."

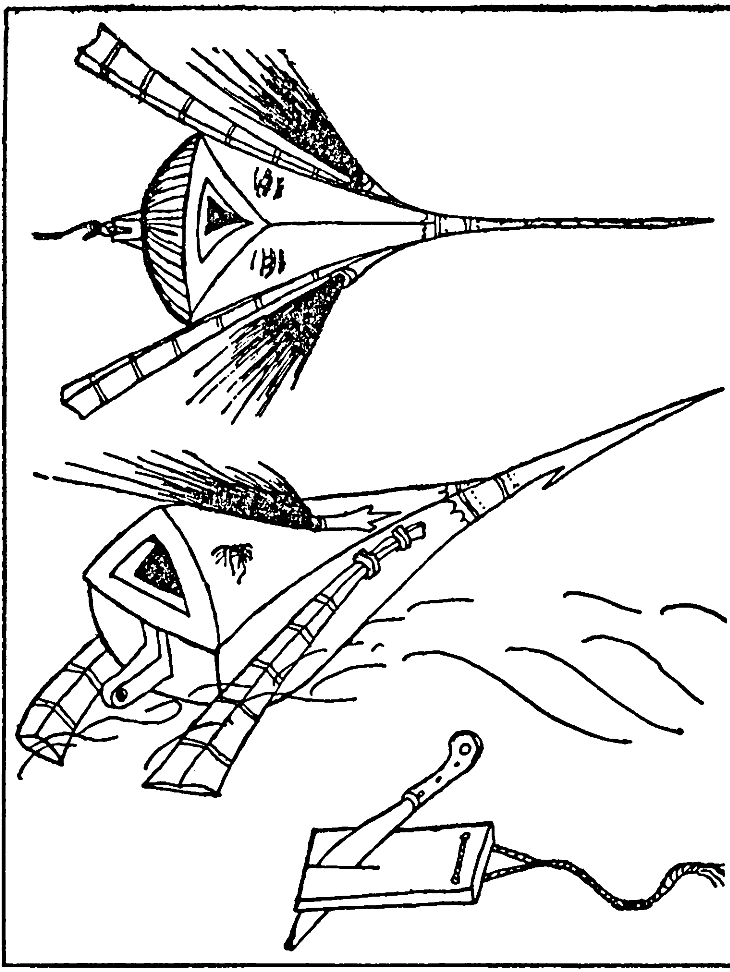


5. Fontana's Rocket Car.

in size, resulted in the sketch of the first rocket car, apparently expected to breach walls or at least gates. And finally de Fontana also sketched a wooden rocket torpedo, painted so as to resemble the head of a large sea monster. (Figs. 5 and 6.)

Most of these sketches were probably nothing but ideas which were never tried, but books on military matters which were published during the two centuries following de Fontana contain a number of ideas which look as if they resulted from actual experimentation. Rockets with crude parachutes are described in a heavy manuscript–it never saw print–compiled by Count Reinhart von Solms during the first part of the sixteenth century. A little later the Count of Nassau described a rocket which would dive and finally explode under water. Like that of the Count von Solms; the manuscript of the Count of Nassau was never printed. It is an enormous folio tome of 725 pages, completed in 1610.

But by then rockets were not weapons any more, except at sea where the riggings of sailing vessels offered large and highly inflammable targets. The book by Leonhart Fronsperger (important for its history of artillery), which was published in Frankfort-on-the-Main in 1557, speaks of rockets in connection with a description of fireworks for amusement. Only thirty-four years later one Johann Schmidlap published the first book to deal exclusively with non-military fireworks (Nuremberg, 1591). It is a thin folio volume and it begins with an interesting introduction in which the author states that the publication of his book may irk other fireworks experts. It seems that a number of trade secrets were published there for the first time. The manufacture of fireworks rockets had become a definite practice by then, a standard practice which must

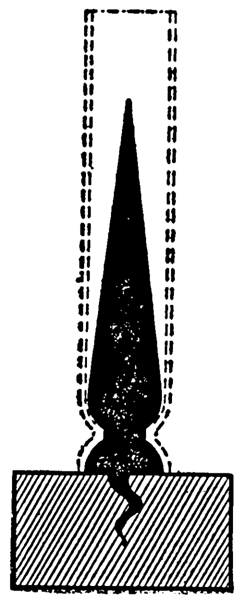


6. Fontana's Rocket Torpedo.
The dagger thrust through the tail piece indicates that the building material is wood.

be described because it has remained standard up to this day, with only minor modifications.

The raw material for the making of a rocket was "lazy" gunpowder and pasteboard, together with a few simple tools, mostly made of hardwood. The first step was the pasting of the tube which was shaped around a cylinder of hardwood that was rounded off at one end. Then, while the paste was still moist, the tube was

7. Mechanism for Making Powder Rockets. The rocket tube (dotted outline) is pushed over the "thorn" (solid black) and the powder charge is hammered in around it.

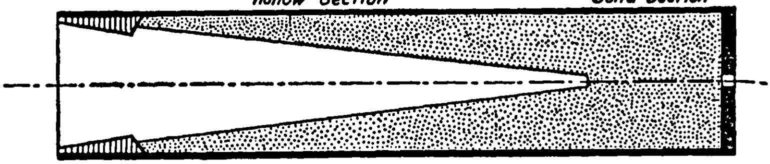


"throttled" by pulling the wooden cylinder out for a little more than the diameter of the tube so that the rounded-off end was at this point inside the tube. Another rounded-off plug was inserted and then a soaped string was looped around the moist tube at the point where the two rounded-off cylinders of wood met inside. By pulling the soaped string back and forth the tube was constricted to about two-thirds its full diameter. After that it was permitted to dry thoroughly.

When dry, the tube was filled with powder which was hammered in solidly, layer after layer, until the tube was filled to the top. The end which had been constricted formed the lower end of the rocket and the fuse was put in through the constriction or nozzle. The important point was that the powder was hammered around a "thorn" (see Fig. 7) so that the powder charge had a center hole, usually conical in shape, which reached almost all the way through. The purpose of this center hole—Konrad Kyeser was the first to mention it—was to provide a large burning surface for the powder so that a large amount of gases would be generated. For some reason this center hole was called the "soul" of the rocket, which set mystically inclined characters to speculating about the "power of the rocket soul."

This standard practice, which may even be an Arab invention, has survived until now—most fireworks rockets are still made in this manner. Only the larger factories have adopted some modifications, for example, hydraulic pressure in lieu of hammering. Such a "pressed rocket" is usually made solid, with a layer of clay at one end. The "soul" is then bored out through the layer of clay, the remains of which serve as a primitive nozzle, obviating the need for the tedious "throttling" of the tube.

The finished rocket, according to Schmidlap's description, is then tied to a straight stick "which must be about seven times as



8. Ordinary Powder Rocket.

long as the rocket itself. You then balance your rocket on your finger or on the back of a knife blade, placed just below the firing hole. If it balances well the stick is just right; if the stick be heavier, cut it until the rocket balances, but cut from its thickness only so that it have its full length."

This test, also, is still in use for handmade rockets.

But all the time, from the Chinese and Arabs on, none of the countless artisans who fashioned rockets had the slightest idea of what he was doing. Burning gunpowder produced a blast, that much was known. And an Italian, Vanoccio Biringuccio, had explained in fair detail just what happened. This is what he said:

> One part of fire takes up as much space as ten parts of air, and one part of air takes up the space of ten parts of water and one part of water as much as ten parts of earth. Now powder is earth, consisting of the four elementary principles, and when the sulphur conducts the fire into the dryest part of the powder, fire and air increase . . . the other elements also gird themselves for battle with each other and the rage of battle is changed by their heat and moisture into a strong wind. . . ."[5]

Biringuccio had observed the phenomenon correctly enough; it was not his fault that he had no better technical language at his disposal than Aristotelian nonsense.

The artisans who fashioned powder rockets knew, from Biringuccio's explanation as well as from direct observation, that something for which they had no better term than "a strong wind" emerged from the nozzle of a rocket. They lacked knowledge of the reason why this strong wind, which evidently was blowing downward, should carry the rocket upward. Another century and a half passed before Newton found out why this happened. But

[5] In *De la Pirotechnia,* published first in 1540. An English translation was published in 1943, while a German edition appeared some twenty years ago.

Newton's explanation, couched in a crisp Latin sentence, could not be understood well at first. There are still many people who don't understand it and help themselves with the essentially lazy explanation that the blast of the rocket pushes against the air.

An explanation why "every action is accompanied by an equal but opposite reaction" is now required. That explanation has been given many a time, clothed in similes involving exploding sticks, wooden balls that are pushed apart by expanding springs, and all kinds of other things that nobody has ever seen unless he has made them for the experiment.

Perhaps the simplest explanation of the Third Law of Motion is made by means of a frog and a piece of wood, floating on a quiet lake. The frog weighs one ounce and so does the piece of wood and nothing happens for some time. Then the frog sees a fly a short distance away and he jumps violently off the piece of wood. The frog, of course, gets to the fly and the piece of wood gets elsewhere—in the opposite direction. Assuming that the resistance of the water did not exist in this case, the wood gets as far as the frog. If the frog, in pushing himself off the piece of wood, acquired enough speed to sail through the air a distance of four feet, the wood also got a sufficiently strong push to move four feet in the opposite direction, both (because of their equal weight) moving with equal speed. (Fig. 9.)

When everything is over we will have the picture of a 1-ounce frog 4 feet from the original resting place due north, and a 1-ounce piece of wood 4 feet from the original position due south. If both had moved along the balance of a scale, the scale would not even have quivered because of the perfect distribution of the two weights to the right and to the left of the original center. This is the important point—the two components will balance each other perfectly at any given moment.

In the case of a rocket, the rocket itself is the piece of wood of our example and the powder gases are the frog. The gases, in "jumping" away from the rocket, "kick" it back—something that would happen in airless space as well as in air and that has nothing at all to do with "pushing" against the air.

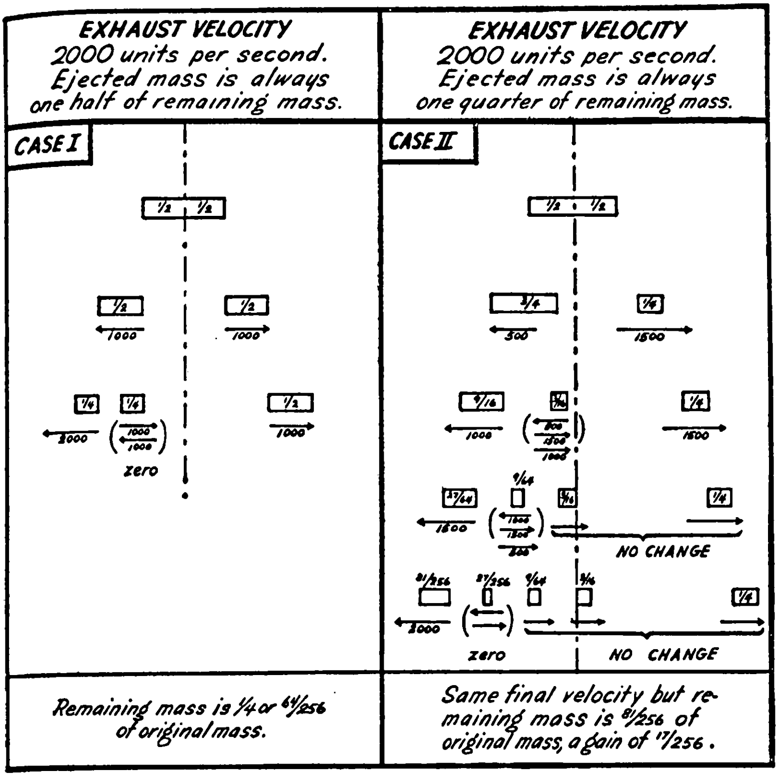
It is precisely the same force which kicks a gun barrel backward when the projectile and a stream of violently expanding explosive gases emerge from the muzzle. It is the same force which makes a chair topple over when a cat jumps from its back onto the book-

9. The Third Law of Motion.

shelf, the same force which kicks your canoe back into the river when you jump ashore.

The reason why it sounds so strange to the average man is that it is not noticed much in everyday life. Not because it is not there, but because it is not wanted. Ordinarily the action is the wanted part of the whole procedure; the reaction is a nuisance and therefore overlooked. But it can be utilized. You can, for example, propel a light canoe by throwing heavy stones with all your might over the stern. It is not very efficient and it is exhausting too, but it shows that you don't "push against the air."

The real rocket does not throw stones. It ejects gas molecules instead. The effect is, naturally, the same, but there is a certain advantage connected with the ejection of very tiny particles. In the case of our frog, both parts of the whole system were halves.



10. The remaining mass of a rocket-like mechanism increases as the size of the particles ejected decreases.

The result was that half of the total mass attained half the total jumping speed. If there had been several smaller frogs on that piece of wood, the final result would have been better.

Fig. 10 shows what happens to the original mass if you eject halves—"halves" (and later "quarters") always means halves, or quarters, of the mass that is still available after one ejection has taken place. If you eject halves you attain total exhaust velocity, as the mechanical equivalent of the jumping speed is called, and you have, in the end, one quarter of the original mass left. If you eject quarters, you attain full exhaust velocity with 81/256 of your original mass left. Since one quarter is 64/256, you have "saved" 17/256 or roughly 1/15 of the original mass.

It is obvious that the amount "saved" increases as the size of the ejected particles decreases. The limit is reached when the particles become infinitesimally small. With such small particles you can attain full exhaust velocity if your original mass is 2.72 times as large as your remaining mass, whereas in the case of ejecting halves it had to be four times as large as your remaining mass.

We now come to a very important point. There is, of course, no reason why the ejection of particles should not be carried on even after the rocket has reached full exhaust speed. Naturally it is possible to go on, provided only that there is still some ammunition left. And that means that a well-built rocket *can attain a velocity which is higher than the exhaust velocity.*

The foregoing discussion—which is repeated in the form of tables and formulae in the *Addenda*—has brought out several important facts that may be summarized as follows:

(1) The motion of a rocket is essentially independent of the surrounding medium—a rocket can move under water as well as in air or in a vacuum. The surrounding medium appears only in the form of resistance against both, the motion of the exhaust as well as the motion of the rocket. The attainable velocities and efficiencies will, therefore, be higher the thinner the medium in which the motion takes place.

(2) The exhaust of the rocket should consist of very small particles, which is normally an accomplished fact since the exhaust usually consists of a gas.

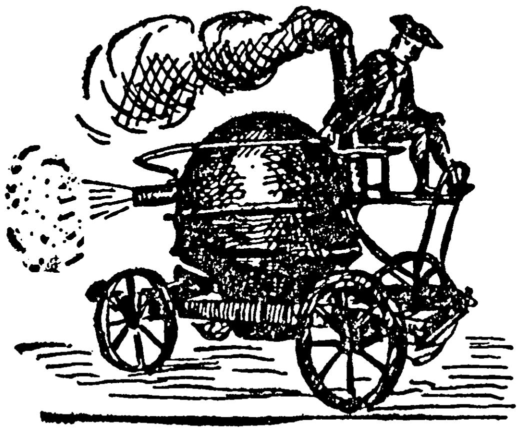
(3) The velocity of a rocket might be increased either by increasing the mass of the exhaust or by increasing its velocity. If a choice is possible, the latter method is superior.

(4) The velocity of a rocket can exceed the velocity of its own exhaust. The velocity of the rocket is limited only by the amount of mass (fuel) which can be ejected.

All this is contained in the simple statement which has become known as Newton's Third Law of Motion. Other physicists began to understand these possibilities after Newton had pointed the way. While most of it was, at first, of purely academic interest, one fact of possible practical usefulness was realized quickly: rocket motion did not depend on some mysterious quality of gunpowder; it was solely a question of ejecting a mass of some sort at high speed.

It seemed possible to propel a vehicle that way—a thought which was highly intriguing at a time when no motor of any kind existed.

Experimenters began to wonder about direct reaction for vehi-



11. Steam Reaction Car.

cles and a Dutch professor succeeded to a certain extent. His name was Jacob Willem s'Gravesande and one of his works gives explanations and illustrations of Newton's natural laws. The book had the title *Physica elementa mathematica* and it appeared in two volumes, the second in 1721 at Leyden. In this second volume Professor s'Gravesande pictured and described a model car which moved under its own power. The miracle was accomplished by mounting a small spherical metal container on the car with a little fire underneath. The steam produced in the small boiler escaped through a long tube pointing rearward and the model moved.

There are rumors that Professor s'Gravesande later tried to build such a steam reaction car on a large scale, and there even exist some drawings of this vehicle. But since the drawings look as if they were made later and since no direct report of the attempted construction has been preserved, it is uncertain whether s'Gravesande ever really tried, although he may have toyed with the idea. (Fig. 11.)

The description of the small working models was to give rise to a large number of different plans later on—Mr. Perkins' steam rockets of 1824 were only one of them—but at first there was a military interlude. The war rocket was revived with great initial success and for quite some time the words "rocket" and "war rocket" became synonymous. It was what is now called the "Congreve period," after Sir William Congreve, the creator of the British war rockets.

However, the direct cause for that revival did not lie in Europe; it was an unsuccessful military campaign in India, related in a book with the title: *A Narrative of the Military Operations on the Coromandel Coast against the combined Forces of the French, Dutch and Hyder Ally Cawn from the Year 1780 to the Peace in 1784,* by one Innes Munroe, *Esq*. It was published in London in 1789 and it confirmed other stories that had reached England somewhat earlier. The stories said that the Indian troops employed large rockets to fight the British, rockets similar to those used in England for amusement, but much larger. They consisted of an iron tube instead of the customary pasteboard, their weight ranged from 6 to 12 pounds, and they were guided by a 10-foot bamboo pole. Their range was estimated to be a mile and a half and they were not very accurate, but they did much damage through mass application, especially among the British cavalry.

The Hydar Ali—this is the proper spelling—mentioned in the title of the book, was then Prince of Mysore and the father of the idea of attaching a rocket corps to his regular army. It numbered 1200 men and since the "new" weapon had proved to be so successful, Hydar Ali's son, Tippoo Sahib, increased the strength of the rocket corps to 5000 men. The British suffered badly from these rockets, especially at Seringapatam in 1792 and 1799.

The news aroused the curiosity of the military in Europe. It looked as if a promising possibility had been overlooked, and the barely noticed experiments of a Frenchman, Citizen Chevalier, suddenly began to look important too. That Frenchman had fired incendiary rockets of a large size against a large target fashioned from an old sail which he intended to set afire. It had not worked simply because the rockets had torn through the old sail so fast that the target had no time to catch fire.

But perhaps there was something to Chevalier's idea after all. Several military men and scientists began to experiment in a modest way but only one of them was really successful, the British Colonel William Congreve, M.A. (the "Sir" was not added until several years later). Contrary to a statement that can be found in many books, Congreve had never seen the Indian war rockets in action for the simple reason that he never went to India. His only information came from books and journals, available to anybody interested in the matter.

In 1801 or 1802 Congreve bought the biggest skyrockets available in London, paying for them out of his own pocket, and began to indulge in some private long-range practice, or rather in firing practice which had the purpose of establishing the possible range. He found it to be between 500 and 600 yards, less than half the range of the Indian war rockets. Then he took the idea to the authorities, apparently aided by his father, Lieutenant General Sir William Congreve, comptroller of the Royal Laboratory at Woolwich. Lord Chatham granted permission to use the laboratories and the firing ranges, and Congreve soon obtained a range of 2000 yards. In 1805 the new weapon was demonstrated to the Prince Regent, and later in the same year Congreve accompanied Sir Sidney Smith in a naval attack against Boulogne.

What happened during that first expedition is not quite clear; some military historians say that the weather prevented the use of the rockets, others state that about two hundred rockets were fired which damaged only three houses and that the French soldiers marched around in the city after the attack, carrying the empty shells of the rockets and making unprintable jokes about them. It is unimportant whether the one or the other claim is correct, because the rockets proved their effectiveness in the years to come. Boulogne underwent a terribly devastating fire raid in 1806, and in 1807 the greater part of the city of Copenhagen burned to the ground, set aflame by a mass expenditure of about twenty-five thousand rockets.

Danzig, in 1813, was very much a repetition of the Boulogne bombardment. The first barrage, fired on August 26, failed to do any harm and the empty burned-out rockets were carried around in the streets and bought by people who exhibited them in stores for a small fee. The second bombardment in September set twenty-three buildings afire, among them the hospital of the Dominican monks. And the third bombardment on October 20 fired the food stores so that the city had to surrender on November 27.

During the days immediately preceding the effective October bombardment of Danzig, the British "Rocket Corps" distinguished itself during the Battle of Leipzig (October 16-19, 1813) which broke Napoleon's power. The Corps had no part in the actual taking of the city, but it had served effectively during the preliminary actions and was granted permission to display the word Leipzig on its standards.

Congreve had started out with incendiary rockets of about 30 pounds which carried a "carcass" filled with incendiary mixtures. But he steadily increased the size and weight, the stability and also the variety of his rockets, and in 1817 he published the following list of the various types:

WEIGHT AND DESIGNATION	TYPE OF PROJECTILE CARRIED	EXTREME RANGE IN YARDS	ELEVATION FOR EXTREME RANGE —ABOVE
42-lb. Carcass Rocket	Large: 18-lb. Carcass		
	Small: 12-lb. Carcass		
42-lb. Shell Rocket	Large: 12-lb. Spherical bomb	3000	60°
	Small: 5.5-lb. Spherical bomb		
32-lb. Carcass Rocket	Large: 18-lb. Carcass	2000	60°
	Medium: 12-lb. Carcass	2500	55-60°
	Small: 8-lb. Carcass	3000	55°
32-lb. Shell Rocket	9-lb. Spherical bomb	3000	50°
32-lb. Case Shot Rocket	Large: 200 Carbine balls	2500	55°
	Small: 100 Carbine balls	3000	50°
32-lb. Explosive Rocket	5-12 lbs. of powder	2500-3000	55°
12-lb. Case Shot Rocket	Large: 72 Carbine balls	2000	45°
	Small: 48 Carbine balls	2500	45°

Flare Rockets equipped with parachutes.

These rockets represented all types of artillery ammunition then in use, save for the solid round shot. It was Congreve's firm belief that his rockets would replace artillery, except for naval warfare, within a few decades. His favorite term in speaking about his rockets was "the soul of artillery without the body" and in a sense he was right. His rockets surpassed all the easily movable artillery pieces of his time in range. They were about even as far as accuracy was concerned which, from our point of view, was nothing to boast about. His rockets were cheaper; he calculated a saving of 8 pence per round when comparing the 10-inch mortar with a rocket of equal effectiveness, neglecting the cost for the mortar itself. But the main advantage was lighter weight; Congreve's rockets did not need strong and heavy barrels to give them direction. He used thin-walled launching tubes made of copper. And for mass bombardments he needed only collapsible wooden frames which looked like very wide stepladders.

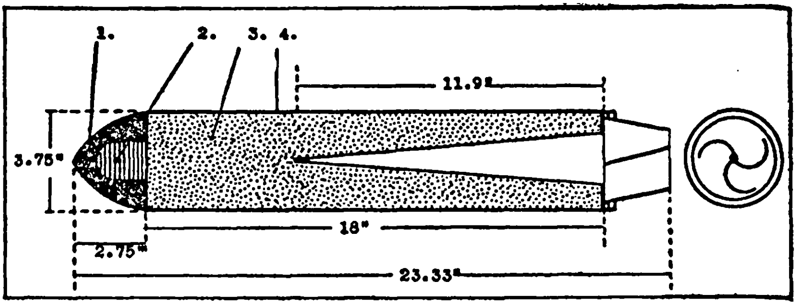
What Congreve did not know—and what he could hardly be expected to know—was that the artillery pieces of his time were crude and clumsy devices which, in spite of their age of some five hundred years, were still in the earliest stages of their development. His rockets, on the other hand, were just about as large and as powerful as a black powder rocket can be. Since he could not know this, it was only natural that his conclusions were wrong. Artillery soon began to outrange, outshoot, and out-perform rockets in every respect, and the later invention of the internal combustion engine made even the weight of the guns unimportant.

Congreve died May 16, 1826. Among his papers plans for a rocket with a diameter of 8 inches were found, as well as some notes relating to rockets weighing 500 and even 1000 pounds.

Congreve's influence was enormous. Denmark, Egypt, France, Italy, the Netherlands, Poland, Prussia, Sardinia, Spain, and Sweden attached rocket batteries to their artillery. Austria, England, Greece, and Russia had rocket corps which were independent units. So had Switzerland, but only on paper. The United States formed rocket units—there is some doubt whether they were independent or artillery units—some time later when William Hale had made a new invention which will be described shortly. At least twenty books on war rockets appeared during as many years, written in English, French, and German (the Russians wrote French at that time).

Congreve's war rockets gave rise to two or three useful and ten times as many useless inventions. And they are responsible for allusions which are still known to practically everybody, even though people do not know the reference any more. Everybody knows, for example, that one of the famous early locomotives was named the *Rocket.* No direct allusion to the speed was intended; the name grew out of an article in a British engineering journal. George Stephenson had promised a locomotive of twice the speed of a mail coach. And a critic exploded into words like "silly and ridiculous . . . twice the speed of a horse-drawn coach. It may just as well be expected that the inhabitants of Woolwich will consent to a ride on a Congreve war rocket than trust their lives to such a machine." Whereupon Stephenson called his new locomotive *Rocket.*

And every American sings about "the rockets' red glare, the bombs bursting in air . . ." which refers to the bombardment rockets launched in quantities against the bastions of Fort McHenry.



12. Late British War Rocket (1905).
An example of the stickless Hale rocket. 1.—Cast iron; 2.—Hardwood; 3.—Propelling charge; 4.—Steel tubing.

But it is necessary to finish the story of the military interlude first. All those rocket corps and rocket units did not live very long; by 1850 most of them were gone. The Austrian corps was not dissolved until it had failed badly against the Prussians in 1866. The British Rocket Corps had disappeared rather early as an independent unit, but war rockets continued to be an issue weapon in the British Colonial Services for a long time. They are still listed as such in the official *Treatise on Ammunition,* edition of 1905. (Fig. 12.)

The American war rockets as well as the later British war rockets of the Colonial Services were no longer Congreve rockets. As soon as the general construction of Congreve's rockets had become known to other technicians (after the first bombardment of Boulogne), they had decided that the heavy guiding stick should be abolished if possible. The stick was needed to keep the rocket from moving erratically, but it also looked like a lot of dead weight.

There were two possible ways to eliminate this dead weight. One was to find a substitute for it, some less ponderous mechanism which would perform the same service of keeping the rocket on a straight course. The other was to thrust another function on the guiding stick. French experimenters decided in favor of the latter method; they designed or at least drew pictures of war rockets where the projectile was elongated to the extent of serving as a guiding stick at the same time.

But the real solution was the first method, and William Hale, around the middle of the last century, succeeded in finding it.

It consisted of three small metal vanes placed in the exhaust nozzle, vanes which would make the rocket rotate furiously along its longitudinal axis, making it spin in the same manner a rifle bullet spins. The American rockets were Hale rockets and so were the late Colonial Service rockets of the British.

During the latter half of the nineteenth century quite a number of inventors, military and naval engineers as well as landlubbers, tried to invent rocket torpedoes. It was generally known through Robert Fulton's demonstrations in Great Britain and in America that an underwater explosion inflicted much more severe damage on a vessel than any above-water explosion could possibly do. The mine and the so-called spar torpedo had been invented and used rather extensively during the Civil War. It remained to create a real torpedo, to provide a mine with mobility of its own.

Some of these inventions were actually tested, but just as cannon soon outranged war rockets on dry land, mechanical torpedoes like the Whitehead soon outranged the rocket-propelled models. No rocket torpedo was ever actually used in battle.

But in the meantime the rocket had gained a place in naval life, although not as a weapon.

The life of a seaman often required something resembling shooting but less violent than real shooting. The Congreve rocket fitted perfectly into this picture. And in 1821 Captain Scoresby, on the good ship *The Fane,* began to hunt whales with rocket harpoons. It was a good idea and it is likely that rocket harpoons would have endured to this day if it had not been for the fact that a rocket is not quite accurate enough. Because of this the first real harpoon gun replaced the rocket harpoon.

But rockets could throw lines, and that feature was utilized. Small vessels the size of lifeboats that had to negotiate a heavy surf did so by using a rocket to throw a small anchor across the surf. Then they pulled themselves to safety along the anchor rope.

This method, of course, worked both ways and resulted in the most useful rocket invention that was to follow the Congreve war rocket.

This was the so-called lifesaving rocket, used to rescue the crews of stranded vessels. It works in this fashion: a rocket carries a thin line from the shore to the stranded vessel. By means of this thin line the crew of the vessel hauls a heavier rope across and leaves the vessel one by one in a so-called breeches-buoy, a saddle-like affair suspended from the rope and pulled back and forth by means of thinner lines.

The first plan of this kind originated in the mind of a tradesman, the Prussian Master Weaver Ehrgott Friedrich Schaefer. This was before Congreve, and Schaefer did not think of rockets; he wanted to shoot the first line from a small siege mortar. He drew up his plans and submitted them in 1784 to the commander of the artillery of Frederick the Great. A committee of ordnance officers was entrusted with the evaluation of the idea, but most of them seem to have known the sea only from books; they decided that the invention was impractical.

Thirteen years after Schaefer a British Lieutenant of the Royal Artillery by the name of Cell advanced the same suggestion. The performance was the same, with the minor difference that the idea was not actually rejected. Instead no action was taken. A few years later, however, George William Manby, Royal Military Inspector, witnessed the stranding of a ship on which 67 people perished in plain sight of the horrified but helpless spectators ashore. After that Lieutenant Cell's suggestion was revived, Manby himself constructed the mortar, and the invention saved 332 lives during the years from 1807 to 1823 on the coast of Norfolk.

When Manby's mortar proved successful the Prussians remembered Schaefer's suggestion and went to work building a line-throwing mortar. It was tried for the first time in the harbor of Pillau on the shores of the Baltic Sea and in July 1819 the provincial government officially permitted "the use of this new means of saving lives, although the Government is aware of the fact that this means might be dangerous in itself."

Meanwhile a Captain by the name of Treugrouse had substituted Congreve war rockets for the line-throwing mortar in private experiments made in 1807. The experiments were successful, but remained almost unknown until John Dennet of Newport on the Isle of Wight repeated them in 1824. It was Dennet who applied for and was granted the first British patent for such an apparatus. It is dated August 2, 1838. Four years after Dennet's first experiments the Prussian Major Stiehler demonstrated line-throwing rockets for the same purpose near Memel, using a Continental (possibly Polish) imitation of the Congreve rockets as a missile. Major Stiehler's experiments attracted much attention and led to the introduction of that method on the European Continent.

Another military chapter has to be added to the story of the powder-propelled rocket: the modern war rocket.

Although rockets had been expected by some to play an important role in the First World War, actually they hardly put in an appearance, save for their use as signals. The Germans made some use of large powder rockets by sending them across barbed-wire defenses. The rocket carried a small boat anchor and the barbed-wire entanglements were pulled out by the roots in hauling the anchor back. The Russians as well as the French used powder rockets, attached to the upright struts of their biplanes and ignited electrically from the cockpit, to set fire to German observation balloons. But aside from these isolated cases no war rockets appeared then.

It is different in World War II.

The description of the rocket weapons used cannot be complete at this point for obvious reasons, but the main types may be mentioned. There are three that are used on the ground: the American *Launcher, Rocket, AT. Mk. I.* (AT stands for anti-tank), better known as the "Bazooka"; the Russian rocket thrower called the *Katyusha;* and the German "Whistlin' Willie" as American soldiers call it, officially named *Nebelwerfer 41.*

The American Bazooka is an anti-tank weapon which can be handled by one man although it is usually operated by two, the second man doing the loading while the first man does the aiming and firing. The launching tube is around 50 inches long, the projectile itself about 24 inches.

The Russian *Katyusha* is a multiple rocket thrower of which nothing is known except what can be seen on released photographs. It comes in two forms, either as a ladder-like multiple rack which is put on the ground much in the same manner as the Congreve launching racks were, or mounted on a truck for mobility. Each salvo seems to consist of a dozen heavy rockets. Of course their accuracy is inferior to artillery fire, but since there are about a dozen projectiles released by each discharge the *Katyusha* makes up in volume what it lacks in accuracy.

The German type, the six-barreled "Whistlin' Willie," is best known. It was captured by the Russians for the first time when they retook Velikiye Luki in 1942.

To the German soldier the six-barreled rocket mortar is known as the *Nebelwerfer 41*, which means "Fog (or Smoke) Thrower, Model 1941." The name indicates that it was originally intended as a chemical weapon for laying smoke screens. It consists of six barrels or rather launching tubes 150 millimeters or about 6 inches in diameter. These six tubes are mounted in such a manner that they can be elevated as a unit. The carriage is the same as that of the German 37 mm. anti-tank gun, with minor modifications.

The firing tubes are open at both ends, but a finger-like projection in the rear prevents the rocket shell from sliding out when the tubes are elevated. Inside the tubes there are three straight guide rails, about 1/3 of an inch deep. The rocket shells are fired, which means ignited, electrically; the fastest rate of fire observed by the Russians was the discharge of all six barrels in as many seconds. The rocket shells are almost as long as the launching tubes and they weigh 25 kilograms or about 55 pounds each. The range was observed to be around 6000 yards, the accuracy of fire was fair but, of course, much inferior to artillery under similar conditions.

These German rocket shells are not a new invention. They go back in a straight line to the so-called "aerial torpedoes" invented forty years ago by the Swedish Baron von Unge. At first Baron von Unge formed a special company, the firm "Mars" of Stockholm, for his invention. A few years later Krupp bought the patents and all the equipment and continued experimentation with von Unge's aerial torpedoes on its own. In 1910 it was announced that the work on this invention had been discontinued. Nobody believed it then, but it was probably true.

The experimental projectiles had a diameter of 4 inches, weighed about 55 pounds, and had an extreme range of 5500 yards.

The sudden reappearance of the war rocket does not mean that Congreve's old prophecy might still come true. The modern war rockets do not replace artillery in any way; they merely augment it.

Chapter 4:

PROPHETS WITH SOME HONOR

It is not the gray, cold, naked objective truth that counts in the history of mankind and will advance the cause of civilization, but it is the flight of human imagination, the impulses and visions of a genius, very often his errors and miscalculations, which have stimulated inventions and progress.—Berthold Laufer in The Prehistory of Aviation.

The history of science is science itself, the history of the individual, the individual.—Johann Wolfgang von Goethe in Mineralogie.

PARALLEL to the story of the use of rockets there runs another story: that of the application of rocket power to machinery in general and to vehicles in particular. No systematic attempts were made prior to the days when Professor s'Gravesande astonished his pupils by demonstrating a steam-spitting small vehicle that scampered across the floor.

Consequently some of the early instances in that story stand alone in splendid isolation in space and time.

The earliest of all seems to have been the apparatus which later became known as the Flying Pigeon of Archytas, dating back to about 360 B.C. For many centuries the wooden pigeon has been praised as one of the most ingenious inventions ever made by man and practically every writer who praised it added that the secret had been lost. While the praise was justified in view of the early date, the lament was not. A Roman author, Aulus Gellius, had described it quite clearly, clearly enough to permit its reconstruction.

According to Aulus Gellius the pigeon of Archytas was suspended from strings with counterweights "which preserved the equilibrium and the pigeon was propelled by the blowing of the air mysteriously encased therein." This means that the wooden bird model did not fly at all, as is usually asserted, but that it merely moved in circles around the point of suspension, motivated by air blowing from its body. If such a model were to be constructed today, the simplest way of accomplishing such a performance would consist in placing a small container of compressed air inside the body. Archytas must have used another method, easier to handle with the means at his disposal. In all probability he used steam, unless all the descriptions we have are misleading, and it may be assumed that the bird model was moved around by the reaction of a steam jet.

This would make it an earlier edition of another ancient invention, models of which are still shown and operated in elementary physics classes: the aeolipile, invented, according to tradition, by Heron of Alexandria.

Unfortunately we don't know just how the original aeolipile looked. Nor do we know just when it was invented. The one definite clue is that the inventor, Heron, is stated to have been a pupil of Ktesibios. Just to make things easier there was more than one Ktesibios, but Heron's teacher most likely was *Ktesibios mechanicus* who lived in the third century B.C., fairly soon after Archytas.

The aeolipile probably consisted of a bowl-shaped container which was filled with boiling water and then placed over the fire on an altar. The steam rose through a tube into a spherical chamber and escaped through two narrow tubes bent backward near their tips. The reaction whirled the tubes and the spherical chamber around as long as fresh steam came from the boiler. (Fig. 13.)

About two thousand years after its original invention, a physicist by the name of Segener had the idea of turning such an aeolipile upside down and forcing water into it under pressure. This invention is now in general use—turned right side up again—and known to everybody as a rotating lawn sprinkler.

Another such isolated instance of the application of rocket power is a story which may be legendary or it may be true—there is no way of telling. It centers around the otherwise completely unknown person of a Chinese official whose name is given as Wan-Hoo.

This Wan-Hoo, the story goes, committed a rather spectacular suicide in or around A.D. 1500 by inventing and testing a rocket airplane. He took two large kites and connected them with a framework in the center of which a saddle was fastened. Forty-seven large powder rockets had been attached beneath the kites in strategic places and forty-seven coolies stood ready with flaming torches to ignite these rockets at a prearranged signal. When everything seemed ready, the learned and daring Wan-Hoo seated himself in the saddle and finally signaled to the waiting coolies. They rushed at the machine, each one applying his torch to the rocket

13. Heron's Aeolipile.

he was to ignite, and Wan-Hoo and his machine disappeared in a noisy cloud of black smoke.

Precisely the same can be said about the second known attempt to combine the principles of flight and of propulsion by reaction.

In 1782 the Montgolfier brothers succeeded in making their first hot-air balloons rise. Just one year later two Frenchmen, the Abbé Miollan and one Monsieur Janninet, announced that they had solved the problem of making such balloons fly in the desired direction. Their idea was simple. The bag of the balloon was filled with hot air or smoke which had the tendency to expand if permitted to do so. If there were a hole in the side of the bag the hot air would escape through that hole, naturally causing a reaction in the opposite direction which would propel the balloon sideways. All that was required was to have several holes around the circumference of the bag, kept shut by valves which could be operated from the gondola.

It was decided to make the first attempt with a balloon which had only one exhaust hole. Subscriptions for this balloon were offered and were sold to an eager populace. The ascent, of course, was public and, equally of course, an admission was charged for the privilege of witnessing the epochal event.

The balloon was ready in midsummer 1783, the attendance was good, but Miollan and Janninet had the particularly tough luck to pick a day which turned out to be unusually hot. Because of that the most frantic stoking resulted in only a partial inflation of the bag. It looked weak and wrinkled and did not even have enough lifting power to lift itself and the gondola, to say nothing of two passengers. Finally two things happened almost simultaneously: the balloon burst into flames and the spectators lost their patience which was strained by the hot weather anyway. They rushed to the balloon and tore off smoldering pieces to be kept as souvenirs, shouting, meanwhile, for the two unlucky inventors.

Janninet merely disappeared, it seems, while Abbé Miollan proved a little more resourceful: he grabbed the box containing the admission money and left Paris with a speed that by far surpassed anything he had promised as the probable speed of his balloon.

The third attempt at rocket flight ended even more ingloriously: it was forbidden by the police.

In the early decades of the nineteenth century there lived in Paris a rocket maker by the name of Claude Ruggieri, obviously an Italian. It was a period which was full of stories of balloon ascents on the one hand and of Congreve war rockets and their exploits on the other hand. Ruggieri profited from the news by staging demonstrations in which small animals like mice and rats were carried aloft by large rockets and brought back to earth safe and sound by small parachutes.

Claude Ruggieri's rockets grew in size and power and around the year 1830 the resourceful artisan announced that a large combination-rocket, as it was called, would carry a ram aloft. On the day after the announcement Ruggieri received an offer from a young man who wanted to take the place of the ram. Ruggieri accepted the offer and the rocket ascent was announced to take place on a certain date from the *Champs de Mars*. But the police intervened, probably because the "young man" turned out to be a small boy. I don't know whether the whole project collapsed because of this or whether Ruggieri used his ram after all.

Dr. Robert Paganini of Zweisimmen, Switzerland, informed me several years ago that the boy's name was Wilfried de Fonvielle who must have been at the most eleven years of age when he offered his person for the venture. Later on he became a balloonist and was one of those who left Paris by air when the city was besieged by the Prussians in 1871. Wilfried de Fonvielle died in 1914, just a little over ninety years old.

In 1843 the daily press of Russia devoted a great deal of space to the invention of one Emil Jir who claimed to have solved the problem of the dirigible balloon by the invention of a mechanism which would permit balloons to find favorable winds by rising or falling, without the necessity of sacrificing either ballast or lifting gas. The mere mention of this project brings to mind the *Five Weeks in a Balloon* of Jules Verne, but Verne's and Emil Jir's methods were not alike. Jir planned to accomplish the rising and falling by means of reaction; he wanted to carry compressed air along for this purpose, probably also a hand-operated compressor. The modern verdict on this idea would be: "theoretically sound but quantitatively insufficient."

This verdict applies to most of the "daring inventions" of this type.

Six years after Emil Jir, a member of the engineer corps of the Russian Army submitted a manuscript of 208 pages to the Governor of the Caucasian provinces, Prince Vorontzov in Tiflis. The manuscript had the title: "On the methods of guiding an airship," and was signed by "Engineer Tretesskij."

Tretesskij planned to equip the airship with exhaust nozzles pointing in all directions; if movement in a certain direction was desired, the proper nozzle was to be connected with the "blast generator," to use a modern term. The blast was to consist of compressed air or steam or, possibly, of air heated by an alcohol blowtorch.

Both these projects may have been influenced by a British patent which had been granted on January 4, 1841, to one Charles Golightly. Unfortunately the patent itself is lost and no description or picture of Golightly's project is known. All we do know is a cartoon on Golightly's project which bears the jeering title: "Steam-

14. Caricature of Golightly's Projected "Aerial Steam-Horse."

Horse, on which one may ride in one hour from Paris to St. Petersburg." If the caricaturist expressed the idea correctly the Golightly project was a steam reaction airplane. (Fig. 14.)

Strangely enough, this cartoon had more influence than the original invention. It set quite a number of people to thinking about reaction planes. A few short paragraphs from a German book seem to express the state of mind of the leading mentalities of the middle nineteenth century quite significantly.

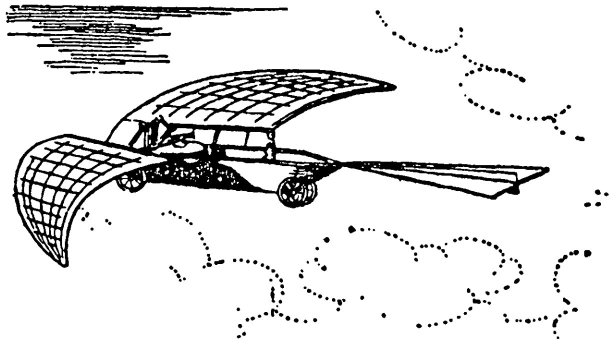
> In the diaries of my mother, Elisabeth Lepsius, née Klein, I find under the date of November 12, 1846, a description of a house party where a friend of the family, the naturalist Ehrenberg, was one of the guests. He was the famous professor Christian Gottfried Ehrenberg (1794-1876) whose discovery of the *infusoria* had populated all the waters and even the air with the smallest living things then known.

After talking about Ehrenberg's own line of research:

> a great deal of the conversation was devoted to guncotton. Ehrenberg was highly excited about the discovery and declared that it would exert an enormous influence on the development of aviation and that we would soon come to the point where we are able to propel airships vertically as well as horizontally by means of rockets.[1]

Guncotton, it may be explained here, had been discovered just one year earlier (1845) by the German chemist Christian Friedrich Schönbein who had tried to dissolve cotton in a mixture of nitric and sulphuric acids. Of course the cotton had refused to dissolve

[1] B. Lepsius in *Lili Parthey, Tagebücher aus der Berliner Biedermeierzeit* (Berlin, 1926).

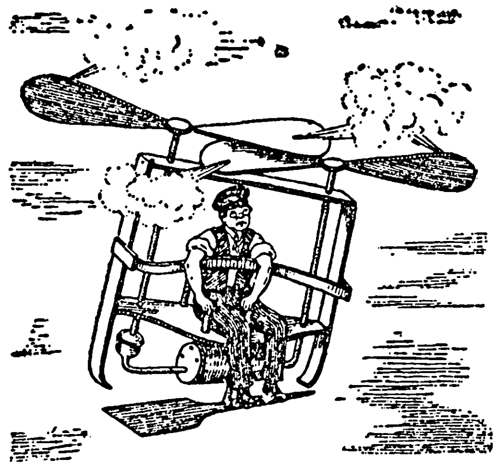


15. German Drawing of a Rocket Airplane.
Said to be by Werner von Siemens some time from 1845-55.

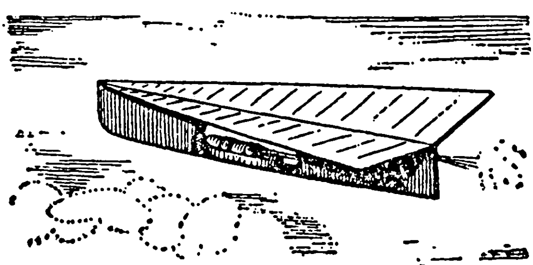
and Schönbein, writing off the experiment as a failure, had gone home for supper, after putting the still wet strands on top of the hot stove to dry. Schönbein lost his laboratory that way, but discovered guncotton in the process.

Another well-known man who became interested in the idea of guncotton-propelled airplanes was Werner von Siemens, the founder of the enormous Siemens Works near Berlin. Siemens drew a sketch of such a plane and had it published. Because he was then holding an army commission he did not use his name but labeled the sketch "a proposal coming from an officer." (In Russian books on rockets this project is erroneously ascribed to a Nuremberg mechanic by the name of Rebenstein.) (Fig. 15.)

And finally there was the Phillips helicopter. Phillips built a functioning model, running on steam. It was, in fact, an aeolipile with helicopter blades. The model was demonstrated to learned societies in Paris in 1842 and it worked. According to contemporary descriptions, it was made of metal and weighed around two pounds, the center of the apparatus being, of course, the boiler. The rotor had four blades, tilted at an angle of 20 degrees and supported by four struts. The four exhausts of the aeolipile part were connected with these four struts. The reports do not give figures about the performance, but state that the small helicopter "rose to considerable height and traveled a long distance horizontally until it touched the ground again." As in the case of the Golightly patent, the demonstration of the Phillips helicopter gave rise to a caricature. (Fig. 16.)



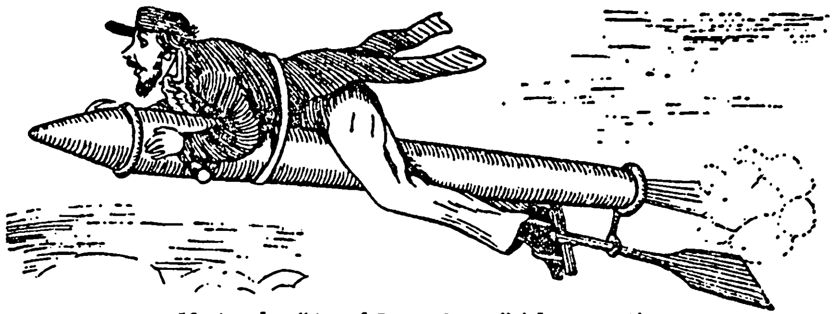
16. Cartoon of a Helicopter (about 1860).



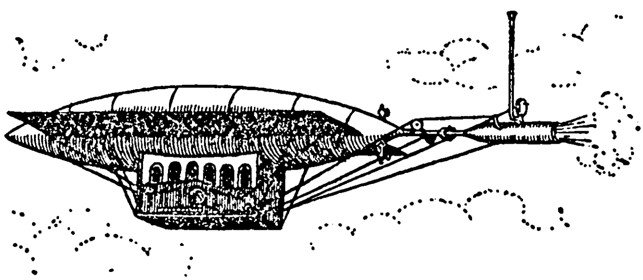
17. Steam Reaction Airplane of 1867.

Three other names that have to be added to the list of the early inventors of rocket-propelled aircraft are those of General Russell Ihayer of Philadelphia, of engineer Nicholas Petersen of Mexico City, and of the inventor Sumter B. Battey. The dates are, in the same order, 1884, 1892, and 1893. All three inventions relate to the propulsion of elongated airships, not round balloons.

General Ihayer had, of course, a military application in mind. His airship was a war vessel, equipped with cannon. Propulsion was to be accomplished by a jet of compressed air, and the air was carried along in steel cylinders, but the compressors were stationary on the ground. The aeronautical general was careful to point out that the recoil of the cannon would counteract the recoil of the air jet and, in consequence, suggested that the gunfire should be directed toward the rear of the vessel if at all possible.



18. Another "Aerial Steam-Horse" (about 1860).



19. Battey's Rocket Airship.

The other two suggestions were fairly much alike in several respects. Nicholas Petersen equipped his vessel with a mechanism closely resembling the old but then very common Colt revolver except that it was much larger and large rockets were to be used instead of cartridges. The chamber was to turn around automatically as soon as one rocket was exhausted, and the ignition of the new rocket also was to take place automatically. The engineer only had to keep the revolving chamber loaded and to steer the airship by pointing the universally mounted exhaust in the proper direction.

Sumter B. Battey, who was granted a U.S. patent on his invention, had a more machine-gun-like mechanism in mind. His reaction motor worked with a large number of small explosive fills which were fed into the chamber automatically. (Fig. 19.)

In judging all these ideas and projects, one thought has to be kept paramount. The choice of rocket or steam reaction as a means of propulsion was not a free choice, it was a matter of necessity. No other prime movers except the steam engine and the clock-

20. Nikolai I. Kibaltchitch.

work existed then. The one was obviously too heavy and the other was, equally obviously, too weak. Rockets, on the other hand, had proven successful in certain applications and, as long as there was no proof that they could *not* perform as a prime mover for aircraft, they were worth considering.

It was precisely this kind of reasoning which caused the conception of a project that, because of the circumstances under which it was born, remained unknown for more than thirty years. It was safely locked away in the archives of the Imperial Russian Secret Police.

The inventor was one Nikolai Ivanovitch Kibaltchitch and the invention had been made, or at least put on paper, in a cell of the Peter-Paul Citadel while the inventor was awaiting the day of his execution.

Nikolai Ivanovitch Kibaltchitch was one among six members of the *Narodnaya volya,* the revolutionary party called "Will of the People," who were charged with the "major crime," the assassination of Czar Alexander II. The trial took place at St. Petersburg, then capital of the Russian Empire, from the 7th to the 9th of

April 1882, ending, as was to be expected, with death sentences for all except one of the defendants who was a woman.

The leader of the group was Alexander Shyelyabov who, when in court, would not miss any opportunity of inserting a political speech into the record. The actual assassin, the man who had thrown the bomb that killed the Czar, was one Nikolai Ryssakov, a young man who was extremely nervous all through the proceedings and hysterically voluble when asked to answer a question. Kibaltchitch had taken part in only one respect: he had made the bombs and had instructed Ryssakov and others how to use them.

Kibaltchitch had been arrested on March 29, 1882. Two days later he had been confronted with Ryssakov who recognized him at once as the bomb instructor. According to court procedure an attorney was then assigned to defend him.

When the attorney went to Kibaltchitch's cell on one of the first days in April, he probably expected to find either a fanatical revolutionary or the proverbial broken-down offender. What he actually found was a well-dressed, quiet young man who was deep in thought when the cell door opened. But Kibaltchitch did not think about his personal fate, which he knew was decided; he was busy inventing a rocket airplane. Literally his first question was whether his attorney might be able to obtain permission for him to write in his cell.

The attorney realized soon that the case was hopeless from the legal point of view. Kibaltchitch not only refused to go through the legal routine, he also did not comply with any of the established rules. When in court he sat as if he were paid for attending, but were not obliged to listen to the proceedings. He came to life only when the explosives experts were called to testify. Then he would enter into a discussion, argue about fine points of the manufacture of a detonator, ask questions about facts which he had failed to find in literature, and be deeply gratified when the experts asserted that the bombs he had made had been good, professional, reliable bombs.

He also called public attention to the fact that he had just finished a manuscript which bore the title "Preliminary design of a rocket airplane" and that he had asked his attorney to submit it through the prison authorities to a committee of technical experts.

That had actually been done, but the manuscript had not gone beyond the prison administration. The officials in charge decided that a public discussion of Kibaltchitch's manuscript would stir up too much interest in the person of the defendant—the newspaper accounts of Kibaltchitch's short remarks in court had done too much harm already in their opinion. The manuscript was simply attached to the documents of the trial and locked away in the archives, until the latter were systematically searched by the Tcheka in 1918. It was then published, with comments by historians and engineers, in the Russian journal *Byloje* (*The Past*), October-November 1918.

Kibaltchitch had visualized his rocket airplane as a platform with a hole in the center. Mounted above this hole was a cylindrical explosion chamber into which "candles" of compressed powder were to be fed. The apparatus was to rise vertically at first, then the chamber was to be tilted for horizontal motion; the speed was to be regulated either by the dimensions of the powder "candles" used, or by their number.

Kibaltchitch died in the belief that a committee was still debating his plans.

None of all these inventors of rocket aircraft thought of his projected vehicle as a possible means of leaving the earth. Although this idea had been voiced in novels by that time, as we have seen, it was still not a subject of serious consideration. But the first project for a rocket propelled vessel for ascents beyond the outer layers of the earth's atmosphere was not long in coming.

As such things often go, the idea was conceived by two men almost simultaneously, two men of different backgrounds and different characters, of different habits and different nationalities.

Both were strange and, each in his own way, colorful characters. Both were independent in their thoughts and stood alone with them. Both were, which is also interesting, self-taught and both failed to be very successful. But their similarities end with these statements; everything else about them was different. The Russian school teacher Konstantin Edouardovitch Ziolkovsky (pronounced *Tsee-oll-kóvs-key*), handicapped by the same physical ailment that did not handicap Thomas Alva Edison at all, lived a long quiet life in a rather unimportant and, to the outside world, practically unknown corner of the Russian Empire, near Kaluga. The German law student Hermann Ganswindt, who never got to be a lawyer or a judge as his parents had dreamed he would be, also lived a long life, but a stormy one, battering his way through almost four-score years in a manner which could not possibly be used as a plot for a story. Any self-respecting editor would reject it as "unnatural and improbable."

Of the two, Ganswindt was more impetuous and less scientific. And, since he was Ziolkovsky's senior by the narrow margin of one year, I'll begin with him.

He was born in a small town in East Prussia on June 12, 1856. His parents, well-to-do people, decided that little Hermann was to study law, acquire a doctor's degree, and then settle down to a successful and "reputable" life in the legal profession. Filial rebellion was not a part of the program, but young Hermann rebelled. He decided in an upsurge of revolutionary spirit that "justice" and "right" were not always identical, and this decision quickly condensed into the belief that the courts by administering the law could not do other than dispense "injustice and law" instead of "right." Hermann Ganswindt wanted no part of that, and he wrote a book about his worries, or rather a book in which these worries were expressed vehemently along with other things. It was thoroughly misunderstood, of course, but Ganswindt would never admit that he had written a book which could be misunderstood; he only blamed the others for not understanding it.

Having turned his back on the legal profession, Ganswindt turned toward his real love: mechanical gadgets. All his inventions had to do with transportation in one form or another. He invented (not in that order): bicycles, horseless carriages, "motor" boats, fire engines, airships, and spaceships. Some of his inventions remained on paper, but most of them were actually built; in the majority of cases the inventor was his own craftsman.

His first attempt was the airship. There were some airships on record at this time: Giffard in Paris had built one with a small steam engine in the gondola (it was too weak). Dupuy de Lôme, also in Paris, had made one for propulsion by muscle power. Hänlein had completed an airship in December 1872, and it had been the largest of the three—all of 165 feet long. Ganswindt wondered why they had all been unsuccessful and found an answer which he incorporated in a patent that was granted to him in 1883 by the Patent Office in Berlin. (It was D.R.P. No. 29014.) The main mistake, according to Ganswindt, had been the semi-logical idea that you had to build a small airship before you can build a large one.

In the case of the airship that was wrong, said Ganswindt. In order to be really a "dirigible," a ship must be able to maintain some 30 miles per hour. Nothing less would do or any breeze could change the dirigible back into a free balloon. Adequate speed would require an engine of at least 100 horsepower, but a steam engine—there was no other kind—of such power would be too heavy for an airship. Too heavy, that is, unless you build an airship of sufficient size; natural laws see to it that things improve with size in that case. If you enlarge a given airship ten times in every dimension, its volume and hence its carrying capacity are a thousand times as large as before. But its cross section and its air resistance are only ten times as large. *Ergo* an airship will become a true dirigible if only you make it large enough. The proper size for a 100 horsepower ship would be a length of 500 feet with a diameter of 50 feet.

His reasoning was somewhat crude as far as air resistance is concerned, but essentially he was right—such a ship could have been built then. Everybody knew, of course, that airships would have a great military value if they could only be built, hence Ganswindt submitted his ideas, copy of patent attached, to the Minister of War. The answer came quickly. It was no.

In retrospect we can only say that Ganswindt's conception of the problem was sound. But that was not so obvious to his contemporaries. Besides who was that man Ganswindt? Oh, a student of law who had interrupted his studies before he was even halfway through. And now he wants to be an inventor and travel through the air, the crank, and not only that, but he wants to travel through the air with structures twice the height of a church steeple. Ridiculous! If the small airships did not work how could a large one be any better?

Ganswindt had expected something like this. He wrote a book devoted exclusively to the problem of the dirigible airship, had it printed at his own expense, and submitted his suggestion again, this time accompanied by a copy of the book. But the Ministry of War was thoroughly weary of airships. The Ministry of War, the officers in charge said to themselves, has funds to buy inventions which are of military usefulness. But it has no funds to smooth the way for inventions that at present are only projects. Anyway, the best military inventions have been made in the research laboratories of the Army and not by outsiders. Besides, if we grant funds for the invention of a dirigible today, we will get somebody else tomorrow who wants to have a cruiser with full complement in order to catch the Great Sea Serpent. Again the answer was no.

But Ganswindt had mailed copies of his book to everybody in the social register by then. Among the recipients was, of course, the Crown Prince, the same who was to rule later for 99 days as Kaiser Friedrich III. The Crown Prince was interested in intellectual matters; he also was dutifully interested in military matters. He read the book, he agreed with Ganswindt, and he ordered that an investigation be made.

The Ministry of War was displeased, not openly, of course. Ganswindt again! The officers in charge suddenly hated their high positions. The Crown Prince had ordered that the matter be looked into. The technical experts questioned agreed with Ganswindt. And Ganswindt, if rejected, might scream in print. The officers felt a triple noose around their necks; whatever they did was bound to be wrong. Japanese officers in the same position would have committed honorable suicide. The Prussians suddenly remembered that there was such a thing as diplomacy.

"To Hermann Ganswindt, Inventor: Sir, with utmost regret we beg to state that airships of a length of five hundred feet far surpass military requirements."

The Crown Prince, poor of health, was satisfied. Too bad, it had sounded interesting. The War Ministry was rid of Ganswindt, but they had rounded one cliff only to run into the next. Only a few years later they got another airship, projected by Ferdinand Graf Zeppelin. That was worse. Count Zeppelin was, in the first place, nobility. He was wealthy too. He had lived for quite some time in America which made him a widely traveled man. He had served as a colonel in the cavalry during the Franco-Prussian War and the records said that he had distinguished himself in an extraordinary manner. But the War Department had laid down its rules; Zeppelin received a "no" too. He was not accepted until he had spent his own money and that of a few wealthy friends proving the possibility of airships by building them.

Before Count Zeppelin's first ship was even completely designed, Ganswindt had become a well-known character in Berlin, delighting in being called the "Edison of Schöneberg." He had founded a small factory for his inventions, combined with a permanent Ganswindt Exhibit with all the characteristics of a Fair, including large and brightly colored posters all over Berlin. The factory built a free-wheeling mechanism for bicycles and a new type of wheel hubs which were advertised as "practically frictionless." The factory built what Ganswindt called the *Tretmotor*. It was an engine ersatz, consisting of an ingenious arrangement of levers and pieces of rope. Two small platforms, slightly larger than a man's foot, were on top or behind the mechanism. The driver stood on these platforms and by alternately shifting his weight from one leg to the other made the mechanism whir. Ganswindt built a well-functioning "motor" boat that was propelled in that manner—he added a small artificial lake to his Fair for demonstrating it—and he built a carriage for two people, with the driver standing behind them. It worked well and Ganswindt rode around in it in the city. The result was astonishing; all other carriages followed him to see how it worked and after two or three rides the police asked Ganswindt to announce every trip in advance to them so that they could take the proper measure. Traffic was too much disturbed by the unexpected appearance of his horseless carriage.

The Fire Department of the City of Schöneberg accepted a carriage of that type for its own use, on trial. This was in 1894. It ran for several months and the reports were more than enthusiastic. Ganswindt felt that he could make the fortune required for the airship by manufacturing such cars. But then it was returned to him, still accompanied by reports praising its performance to the skies. But the Fire Department could not pay 4000 marks; it offered 2000. Ganswindt replied that this first model had cost him more than 2000 marks and took his carriage back. It did not occur to him that the cost price of later cars would be much lower; he had no sense for business, he only demanded his "right." And his "right," in this case, was to make a profit from the first carriage on. When I asked him later why he had not accepted the price offered to him, since that would have resulted in more orders and later profits, he failed to understand my reasoning. "But I would have lost money on that car," he insisted. "If, as you say, later cars would have cost less money to build, and I agree with you on that, I would of course have reduced the sales price."

In between he built a large helicopter with seats for two people.

The machine lacked only the motor, nothing else. Newspaper reports said that there was an internal combustion engine of sufficient horsepower on display at the Paris Fair. Ganswindt went to Paris and offered to buy the motor, provided that it developed the necessary power. That was promised and weeks later a crate arrived at Schöneberg. Ganswindt tested the motor and it lagged by a full third behind the promise. He returned it and thought about a way out. He found one. The helicopter had been assembled around a central axis; Ganswindt replaced the central axis by a length of steel tubing. Through this tube he threaded a steel rope which was attached to the ground as well as to the projecting roof of the factory building. Then he wound a second rope around the central tube and attached it to a heavy weight which, when released, would drop into a well dug for this purpose. It was an adaptation of the well-known trick of winding up a top.

The helicopter actually flew with two people in it. Not high, because of the short duration of the impulse it received, but it flew. And one of the early inventors of the movie, Max Skladanowsky, took a film of the performance. Together with other similar "shots" it made one of the first newsreels. The film was taken in June 1901 and the newsreel was shown in the *Wintergarten* in November of the same year. I have seen a copy of the program for the night of November 5, 1901. The last feature of the program was *Max Skladanowsky's Biograph* and one of the features of the Biograph newsreel was Hermann Ganswindt's Flying Machine.

By then Ganswindt had many enemies who claimed that the wire rope through the central tube was actually used to pull the flying machine up. Actually its purpose was to prevent side slips and accidents. The enemies also stated that "any blacksmith can duplicate the contraption at an expense of 500 marks." Ganswindt's friends replied with a bond of 35,000 marks, to be paid to the blacksmith who did. Nobody ever claimed the money. Ganswindt's enemies dug up yellowed copies of his first book with its indiscreet remarks about justice and right and "proved" that he was a Social Democrat in disguise. Ganswindt produced a testimonial about his helicopter, written by Count Schlieffen, the implication being that *Count* Schlieffen would not support a Social Democrat.

The fight ended dramatically in April 1902. A high official of the Police Department informed Ganswindt that he would like to see the helicopter himself the next morning. Ganswindt was up early on that morning of April 17, 1902, in full dress with top hat, expecting the visitor. The visitor did not come; instead a plainclothesman appeared with a warrant for Ganswindt's arrest. Three days later he learned why he had been arrested: he had accepted money from trusting investors in order to build things that were impossible to build. Since he had often displayed a sufficient knowledge of physics and chemistry to know that such things were impossible, he was guilty of fraudulent claims.

The trial, which included a court visit to Ganswindt's exhibits, ended with acquittal, but as far as public repercussions went Ganswindt might as well have been convicted. The company that rented poster space refused his posters, the newspapers refused his ads.

Ganswindt, embittered and hurt—all the more hurt, probably, because he felt that he was not entirely blameless—went berserk and turned against his numerous enemies. Ironically he turned against them by dragging them into court. If the world consisted of injustice he would administer some injustice too. The courts were embarrassed. There was a grain of justification in these lawsuits, but more often than not it was too slight to be noticed. The courts dragged the proceedings out—and Ganswindt complained to higher courts. The storm was completely quieted only by the war. Then Ganswindt turned to the Ministry of War again, offering his airship once more and stating loudly that the Zeppelin ship was an inferior imitation. He asked the Ministry for a sum of several millions as damages for the suppression of his invention, but promised that he would use the money to build his airship and put it at the disposal of Germany.

It was the German Minister of War—von Stein was his name—who voiced the general sentiment in one sentence. When, in 1917, another one of Ganswindt's innumerable petitions arrived, he wrote in red pencil on the cover page: *"Lebt denn dieser Unglücksrabe immer noch?"* ("Is that bird-of-woe still among the living?")

He was correct in the sense that Ganswindt, the Ganswindt of 1917, was no longer the Ganswindt of the period from 1883 to 1901. He was no longer an inventor who wanted to create something; he was a quarrelsome person who fought only to redeem an injustice done to him. He wanted it redeemed with money and public recognition. He wanted to hear "officially" what he put on his stationery and envelopes: "Hermann Ganswindt, original inventor of the free-wheeling mechanism, the automobile, the airplane, the airship, and the spaceship."

He did get some kind of recognition in the end. Articles about him began to appear in newspapers and magazines and the general feeling was that he had been condemned too hastily. Some people even sent him anonymous gifts of money when they learned that the monetary inflation had left him impecunious and that he was supported by welfare agencies and by the elder of his twenty-three children. And in 1934 a semi-official government agency sent Dr. Stark with a gift of 1000 marks to Ganswindt.

Ganswindt was sick with a cold on that day and received the money and the official recognition which he thought it implied—actually it was one of the Nazi's propaganda gestures intended for domestic consumption—with deep gratitude. A week later he died (October 25, 1934). He had lived to fight for recognition; recognition achieved, he had nothing left to live for. He had received his "right."

Ganswindt received his long-awaited share of public attention in the late Twenties and early Thirties because of one of his early "inventions" to which he himself had never paid much attention: his conception of the spaceship.

It was actually the first I know of. I have seen the program of one of his lectures, delivered at the *Philharmonie*—the name indicates a concert hall in Berlin—on May 27, 1891. It was during this lecture, which was devoted mainly to aviation, that Ganswindt expounded his theory of the possibility of space travel.

Fairly early in his career he had come across reaction as a means of propulsion. He had realized that a reaction has to work in empty space. But while he intuitively grasped that, he never quite understood the mathematics of the problem, as I later discovered through much questioning. It was his contention that a gas jet could not produce reaction of sufficient magnitude, that it was necessary to throw off solid bodies, weighing at least two or three pounds apiece. Because of this preconceived notion, his "fuel" consisted of heavy steel cartridges containing a charge of dynamite. He wanted to feed those cartridges into a bell-shaped steel explosion chamber. One half of the cartridge would be thrown out by the explosion of the charge inside; the other half would hit the top of the explosion chamber and, after transmitting its kinetic energy to the chamber, drop out. The chamber was rigidly connected with two cylindrical fuel drums on either side.

This assembly constituted the "motor." The passenger cabin was suspended from the motor on springs to ease the shocks. Naturally it was provided with a center well through which the steel pieces could pass. Once a sufficiently high velocity was reached, Ganswindt wanted to stop feeding cartridges into the explosion chamber. Then, he knew, the passengers would undergo the experience of apparent weightlessness which he wanted to combat by rotating the long and cylindrical cabin around its center well. This way he planned to substitute centrifugal force for gravity, making the two ends of the cabin the floors. That idea was correct too, but Ganswindt lacked either the ability or the patience —probably both—to work the plan out in detail.

Now for Ziolkovsky, the other early spaceship inventor.

Unlike Ganswindt, he was a patient and quiet man. Unlike Ganswindt, he never overlooked a single detail. Unlike Ganswindt, he never had any enemies. And unlike Ganswindt, he had considerable trouble speaking about himself and his work. When, about 1930, Professor Nikolai A. Rynin of Leningrad wrote to Ziolkovsky for a complete autobiography for his forthcoming seventy-fifth birthday, he received only a thin manuscript of a few pages, accompanied by a letter stating: "this, Nikolai Alexeyevitch, is the best I have to offer." Ziolkovsky also enclosed a collection of photographs and it is typical that he did not even mention the fact that he got married in his autobiography, although some of the later photographs show him surrounded by grandchildren.

He was born September 5, 1857, at Ijevsk in the District of Ryasan. His father was a forester by profession and an unsuccessful inventor and philosopher by avocation, while his mother came from a family of artisans. Ziolkovsky remembered these facts and he also remembered that his first toy, which he got at the age of eight or nine, was a small balloon, a rare toy in those days. Soon after, at the age of ten, Ziolkovsky got dangerously ill with scarlet fever which caused deafness; his hearing never returned. "At eleven I wrote the foulest verses."

His deafness made it difficult for him to attend school—even for what little schooling there was in Ryasan in 1870—but he studied zealously, especially elementary mathematics and physics. Even that was difficult because there were only "a few doubtful books." But he managed to absorb the basic principles of science and those few fundamental facts he could find in the books he had. He not only satisfied the small requirements of a pupil; soon afterward he even satisfied those of a teacher and began to teach in 1876. In 1882 he was offered a position at the school in Borovsk in the District of Kaluga, and ten years later he became a teacher at the school of Kaluga, a position he held until he resigned because of ill health in 1920.

Most of the time he got up at dawn, went to school, and hurried home as quickly as possible to do his private work. The latter mainly concerned problems in physics, but he also worked on some inventions. At the age of twenty-three he submitted a few scientific papers to the St. Petersburg Society for Physics and Chemistry.

When his papers were received there they caused not a little consternation; the reaction was partly incredulous and partly indignant. The papers dealt with some aspects of the theory of gases. Those formulae had been worked out by others twenty-four years earlier. They dealt with methods of measuring the velocity of light, methods that had been in use decades before that. At first glance it seemed as if somebody with a restricted mentality had tried to gain some doubtful fame by doubtful methods. But a careful reading of the manuscripts made it clear that their author, the teacher Konstantin Eduardovitch Ziolkovsky, simply had not known that these formulae and methods existed.

One of the leading men of the Society took it upon himself to write to Ziolkovsky, to inform him about his strange misfortune, and to express the interest of the Society in his future work. The man who wrote that letter was Dimitri Mendeleyeff, the famous discoverer of the periodic system of the elements.

Ziolkovsky passed over his disappointment later with the remark that it had been "good practice," but he concentrated on inventions from then on. He also became interested in airships and he came to the same conclusion as Ganswindt—Ganswindt would have sued him if he had known—that airships were too small to work well. He began to work on a large all-metal ship.

But there was something that was not known: how much skin friction would a metallic ship create at a certain speed? Ziolkovsky thought about the problem, but it could be decided only by experiments with models. For these experiments he built a small wind tunnel in 1891, possibly not the first in the world but certainly the first in Russia. Mendeleyeff was interested in Ziolkovsky's airship plans and helped as much as he could. It was probably mainly his influence that made the Academy of Science in St. Petersburg contribute 470 roubles to Ziolkovsky's work. Ziolkovsky also had a friendly press, and newspaper readers from various parts of the country contributed small amounts, all in all 55 roubles. Ziolkovsky was perfectly aware of the fact that they were meant as alms. But he did not return them in indignation as most people of his period would have done; he used the money for his research work.

One night in Moscow, when he was still a boy, he had looked up to the sky and tried to visualize what he had learned: the spinning earth in space, racing around the sun along its orbit. Spinning suggested centrifugal force with the familiar picture of a weight whirled around on a piece of string. Such strings occasionally snap —and young Ziolkovsky found no more sleep during that night. He was, as Columbus' son said about his father—although in another sense—"drunk with the stars." The idea of space travel had caught him and never let go again.

In 1895, many years later, Ziolkovsky dared to mention space travel cautiously in an article for the first time. To his surprise the article was printed (in *Nature and Man*) and from then on the idea of space travel crowded everything else from his mind. After that first publication, he really began to think about the problem, or rather the complex of problems, taking them up one by one.

Between the planets there was mostly empty space, hence the space vessel would have to have a completely sealed cabin with oxygen reserves and air purification. Because of that empty space only a mode of propulsion which would work in empty space could be considered: that was the principle of recoil, the rocket. But rockets were not efficient enough, they needed higher efficiency. Higher efficiency could be obtained best by using fuels with a higher exhaust speed. Hence Ziolkovsky decided on liquid fuels of the gasoline type for the spaceship. He went over the whole problem step by step and in 1898 he had something that could be called a preliminary study. He submitted it to the editors of a journal called *Science Survey* (*Na-ootchnoye Obozreniye*) and the editors, apparently after hesitating for quite a while, finally published it in 1903.

Nobody paid much attention to it. Outside of Russia it remained unknown because of the language in which it was written and inside of Russia those who may have felt intrigued by Ziolkovsky's reasoning probably waited for comments from other scientists, comments which were not forthcoming. But Ziolkovsky had now found his field. He did get some encouragement from readers and he also saw that his airship plans were crowded into virtual oblivion by the large-scale experiments of Count Zeppelin upon whom all attention began to center.

Consequently Ziolkovsky devoted all his energies and probably all his spare time to the problem where such competition did not exist. A series of articles appeared during the years from 1911 to 1913 in a technical magazine with the title *Aviation Reports*. This was a magazine that was widely read in Imperial Russia (it folded with the revolution) and it brought Ziolkovsky a disciple who proved very valuable, a writer on scientific subjects, mainly physics, by the name of Dr. Jakov I. Perelman. Perelman, who was later to become the science editor of the *Krassnaya Gazyeta* in Leningrad, devoted several chapters in his *Entertaining Physics* books to Ziolkovsky and to rockets in general. But he also wrote a straight popularization of Ziolkovsky's more severe works, and it was Perelman's eloquence which made Ziolkovsky's name known to the Russians.

There are many legends connected with that early period which unfortunately acquired some permanence because a German-writing Russian by the name of Aleksander Borissovitch Shershevsky uncritically put hearsay into some of his articles and into his one and only book. One of the legends is that Ziolkovsky and the Frenchman Robert Esnault-Pelterie (one of the French pioneer aviators who later became an ardent devotee of space travel problems) held a debate on space travel in the presence of the Czar. Determined to set the record straight, I asked both of them by mail about this assertion. Robert Esnault-Pelterie wrote at once saying that the legend may have originated with the fact that he, a year or two before the First World War, had delivered a lecture at St. Petersburg. But the Czar had not been there. Nor had he ever seen him. Nor had he ever met *le Monsieur Ziolkovsky*. And his lecture had been *pas sur l'astronautique mais sur l'aviation*.

Ziolkovsky's letter, written in longhand and in German, arrived a week or two later. The story simply wasn't true.

Another legend, originating from the same source, stated that the well-known Russian astronomer Tikhov had devoted much of his time to problems of space travel. Perelman assured me that all that Tikhov had ever done along that line had been to be chairman during one of Perelman's lectures.

The First World War, naturally, put a stop to Ziolkovsky's and Perelman's endeavors. But the Russian revolution did not touch them; in fact the Soviet government, before it was completely stabilized, put a protecting hand over Ziolkoysky's head. He mentioned in a letter to me that he received sums of money "quite frequently," probably by way of honorariums for reprints of his former articles which were published in the form of pamphlets by the Kaluga Branch of the Government Publishing Office. The first publication by Ziolkovsky under the new regime was not a straight scientific work, however. It was a novel with the title *Outside of the Earth*, a fictionalized account of a journey away from the earth. Such books always sold well in Russia and the commissar in charge may well have thought that Ziolkovsky's novel was just one more of that type, even though he was probably informed that every sentence was the result of painstaking research.

My reason for assuming this is the fact that none of Ziolkovsky's "straight" works was reprinted until after the year 1923 when the German-writing professor Hermann Oberth published a work on the theoretical possibility of space travel in Munich. One year later the Government Publishing Office in Kaluga reprinted the long article that had originally appeared in *Na-ootchnoye Obozreniye* in 1903. The title was changed for republication and now read: "*Rakyeta v kosmeetcheskoye prostranstvo*" ("The Rocket into Cosmic Space"). The title page of the octavo pamphlet of thirty-two pages was bilingual, a German translation of the title ("*Eine Rakete in den kosmischen Raum*") being at the head of the title page. It also carried a preface in German by Aleksander L. Tchijevsky, stating that the Russians, after a short review of Oberth's book had been printed in the official Russian dailies, remembered that their compatriot Ziolskovsky had expounded the same theory thirty years earlier. The whole preface, while written in German, was actually an emphatic appeal for patriotism, closing with the words: "Do we always have to get from foreigners what originated in our boundless homeland and died in loneliness from neglect?"

The other articles appeared in quick succession after that; Ziolkovsky found himself honored beyond his most ambitious expectations and when he rounded his seventy-fifth year in 1932, official agencies prepared articles about him which were published in all the official newspapers. The *Osoaviakhim,* the Russian aviation organization, prepared a large-scale celebration of his birthday.

He died four years later, in 1936.

Chapter 5:

THE BATTLE OF THE FORMULAE

To believe that everything has been discovered is just as profound an error as it would be to accept the horizon as the world's boundary.—Lemierre.

BY THE end of 1913 a noticeable amount of printed matter about rocket propulsion had accumulated in the dozen really large libraries in the world. But although the total amount was comparatively large, it would have been hard to find. There were, of course, some twenty books and pamphlets on the old war rockets, mostly in English, French, and German. The remainder consisted, aside from a few privately printed pamphlets, of articles in French and Russian aviation magazines and, except for those by Ziolkovsky, all these articles dealt with a side issue: the application of rocket propulsion to airplanes.

By the middle of 1914 the First World War broke out and all active thought stopped. By the end of 1918 everything that had once been planned was forgotten.

It is true that in the following year, 1919, the Smithsonian Institution published a valuable paper, written by a then unknown college professor by the name of Robert Hutchins Goddard and bearing the somewhat noncommittal title of *A Method of Reaching Extreme Altitudes.* It was a good paper, based on carefully conducted experiments, clearly written, and full of interesting implications. But title and treatment may have caused the impression that its contents were of interest only to physicists and meteorologists. At any event it did not quite create as much of a stir at first as one should think. And although a few copies of it reached European libraries, it remained virtually unknown in Europe for a number of years.

But Europe, for some reason which is hard to evaluate, was to become the center of rocket research and of the idea of space travel for a full decade. And the Europe of 1919 still had other worries, worries of wars and civil wars, of unstable currency, and of political strife. A book published in happy America was only too likely to be overlooked.

By 1923 a good deal of the political troubles had run their course. The Russian revolution had passed through its wildest phases and the German monetary inflation had ended with suspicious suddenness. Precisely at that moment the great problem was revived.

It was done in what may be called a particularly ineffective manner. The publishing firm of R. Oldenbourg in Munich published a paper-covered pamphlet of less than a hundred pages (I learned later that its author had to pay the larger part of the printer's bill out of his own pocket) with the title *Die Rakete zu den Planetenräumen* (*The Rocket into Interplanetary Space*) by H. Oberth.[1] Nobody knew who "H. Oberth" was and the book itself did not shed any light on that question.

The introduction began with four numbered paragraphs which read as follows:

> (1) The present state of science and of technological knowledge permits the building of machines that can rise beyond the limits of the atmosphere of the earth.
>
> (2) After further development these machines will be capable of attaining such velocities that they—left undisturbed in the void of the ether space—will not fall back to earth; furthermore, they will even be able to leave the zone of terrestrial attraction.
>
> (3) Such machines can be built in such a way that they will be able to carry men (probably without endangering their health).
>
> (4) Under certain conditions the manufacture of such machines might be profitable. Such conditions might develop within a few decades.
>
> In this book I wish to prove these four assertions. . . .

The rest of the book sounded exactly like those four paragraphs. The four "assertions" were subjected to a mathematical analysis that progressed step by step. A rocket ascent to realms beyond the stratosphere was dissected mathematically and turned out to be a problem in fuel consumption. That, of course, led to an investigation of the rate of fuel consumption which, in turn, depended on the velocity which brought up the problem of "optimal velocity."

[1] The pronunciation of the name is *O-bert*, with the stress on the O. Hermann Oberth was born in Hermannstadt, Transylvania, on June 25, 1894.

It is almost superfluous to mention that proof of those four assertions was established, but it was such that only mathematicians, astronomers, and engineers could read it. As far as the general, even the interested, public was concerned, the book might just as well have been printed in Sumerian characters.

There is a good reason for writing of this type. It is simply that the originator of a new thought tries to convince the professionals first, that he seeks professional criticism of his thesis. It happens every day in science and fulfills its purpose with only rare exceptions. Oberth's book, for some reason, turned out to be such an exception. It became, incredible as that may seem, a limited public success; the first edition was sold out in a short time and the orders that piled in at the publisher's office almost exhausted the second edition before it was even printed. While the small book was successful in that respect, it did not do so well in the other. It sought the professional criticism of the professionals—but, of course, there was no such profession. Many of those who should have read it carefully did not do it at first because they felt that this was something beyond their ken, that it was not really a problem in their own profession.

Since this book proved to be so important, it may be useful to give a short outline of its contents. It was divided into three parts. The first part dealt with more or less general questions of rocket motion and contained a lot of things that people—meaning physicists, etc.—should have known but didn't, for example, the statement that a rocket can surpass the velocity of its own exhaust. It emphasized the importance of the "free ascent" (without power, after the supply of fuels has been exhausted). To repeat in bulk at this point what the first part of the book said would result in a long chapter full of technicalities; it will be easier and better to explain these things one by one as we come across them later on.

The second part consisted of the description of an assumed altitude rocket called *Model B*. This description was not supposed to be taken as literally as many critics took it. It mainly had the purpose of discussing the whole problem in its applications to one particular instance. The third part—incidentally the only one that could be read without getting caught in the barbed wire of equations every two seconds—dealt with general prophecies about the probable achievements. Oberth described a theoretical spaceship, discussed the possible objections, and developed the first sketchy theory of a station in space.

There was just enough of it "readable" to intrigue a comparatively large number of people. But the professional critics, the people for whom the book had really been written, did not do so well. Some just announced it, a few others wrote articles which were a condensation of Oberth's statements. Some, finally, criticized it, as they were expected to do. But what they said was, for the most part, surprising—in one of the more uncomplimentary shades of meaning of that word.

Two or three well-reputed astronomers, men who certainly should have known better, simply "killed" the whole idea—or so they thought—by stating that all these things are very nice and interesting but lacking in foundation since everybody knows that there can be no recoil in empty space. Another critic, physician by profession, added some more devastation. Not only was there no recoil in empty space; the idea of manned rockets was preposterous for all times to come because people, as soon as they left the atmosphere of the earth (provided it could be done), would be subjected to the gravity of the sun which is powerful enough to squash their bodies.

The good doctor had taken his figures from tables in an astronomical book. Unfortunately the figure for the sun's attraction in that table *referred to the surface of the sun itself* and not to a distant place such as the orbit of the earth or a point near that orbit.

Another critic, an aviation expert, stated in a puzzled manner that he was inclined to believe Oberth, but that he could not understand, try as he might, why the exhaust gases should follow the rocket if the latter, after some time, surpassed its own exhaust velocity. That the exhaust velocity, *seen from the rocket,* never changes, apparently did not occur to him. The whole puzzle which he could not solve was caused only by the (unconscious) mental change of viewpoint: by looking at the exhaust once from the rocket and then from the ground.

Another one, by his profession as a physicist more given to precise statements, said that the rocket, of necessity, could not surpass the velocity of its own exhaust because the efficiency would surpass 100 per cent in that case. And an efficiency of more than 100 per cent is, obviously, not possible. This was a strange mixture of correct and incorrect conclusions. It is true that the efficiency of a rocket which moves, say, twice as fast as its own exhaust velocity, seems to be far above 100 per cent, if you consider only the time interval when that condition takes place. But it is wrong to do that. The apparently impossible efficiency occurs, in a manner of speaking, at the expense of the very low efficiency at the beginning of the ascent when the rocket moves very slowly. If you look at the whole performance, the efficiency never even approaches 100 per cent, which is what should be expected in the first place.

What could happen if you went off on a tangent somewhere in the middle of the whole problem was nicely demonstrated by another mathematician and physicist who calculated with gusto that the most powerful explosive known could not even lift its own weight to a greater height than about 400 kilometers (250 miles). He forgot that the fuel is not carried along but only its energy.[3]

Oberth, as can be gathered from these criticisms, had merely expounded the simple theories mentioned in the chapter "Rockets": that reaction does not depend on the presence of an atmosphere; that a rocket can surpass its own exhaust speed; and that the easiest way to achieve a good performance is to attain a high velocity which, in turn, implies the use of a fuel with high exhaust velocity. This theoretical reason alone is sufficient to decide in favor of liquid fuels (mechanical considerations all point in the same direction) the most ordinary of which, gasoline, has more than twice the exhaust velocity of ordinary rocket powder.

Oberth did not know about Ziolkovsky's then forgotten articles in which the Russian schoolteacher had come to the same conclusions. It would not have helped him even if he had received a complete file of these old aviation magazines, because he could not

[3] Dr. Otto Steinitz, who later worked with Oberth on some patents, nicely explained this mistake by the use of an analogy. When shooting an arrow muscular energy is stored in the wood of the bow. It amounts to about 20 kilogram/meters for every kilogram the bow weighs. Twenty kilogram/meters would be just enough to lift the bow 20 meters or about 66 feet and the conclusion would be that an arrow cannot be shot higher than 66 feet, no matter how large the bow, since you cannot store more than 20 kilogram/meters of energy per kilogram of weight. But you don't shoot the bow, you shoot the much lighter arrow, weighing, say, one tenth of the weight of the bow. Consequently it can rise ten times as high as the bow could lift itself. In the case of a rocket, the rocket itself represents the arrow and the fuel the bow, and the altitude is not limited by the weight (mass) of the exhaust gases—the product of the fuel—since these are left behind.

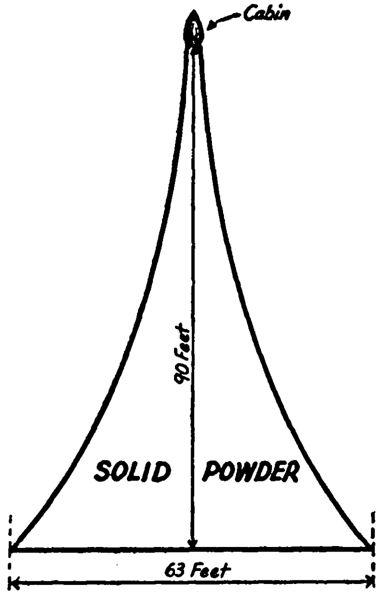
read a single word of Russian. Nor did Oberth, or anybody else, know that Professor Goddard was actually experimenting with liquid fuels at that time, under enormous and unnecessary secrecy which has become a standard joke in interested circles.

But Oberth's book did more than confuse the critics. It encouraged others who had similar ideas to appear with them before a surprised public. One of the most important publications, following close on the heels of Oberth's book, was another tall thin volume of similar external appearance and written in a similar manner. As a matter of fact, it looked so forbidding to prospective buyers who leafed through it in the bookstores that the first edition of only fifteen hundred copies was never completely sold.

Its author was Dr. Walter Hohmann, city architect of the City of Essen-on-the-Ruhr, and the title was *Die Erreichbarkeit der Himmelskörper* (*The Attainability of the Celestial Bodies*). The title does not sound quite as clumsy in German as it does in English, but it is severe enough. As for the table of contents, it read: "I. Departure from the Earth; II. Return to Earth; III. Free Coasting in Space; IV. Circular Orbits Around Other Celestial Bodies; V. Landing on Other Celestial Bodies."

If that sounded intriguing, a reader was subjected to a cold plunge when he opened the book, say, at Chapter 2 and began to read: "In order to reduce the velocity of a vehicle of the type described in the preceding chapter from v_1 to zero, if that vehicle is falling toward the earth from a very great distance, we require the same time of operation t_1 as calculated by means of equation (10) but the stream of the exhaust dm/dt has to point in the direction of the movement." The whole book read like that and years later the editor of a large newspaper came to my office, pulled a copy of Hohmann's book from his brief case and said: "I want to write a feature article about you people and you, Mr. Ley, have written that Hohmann's contribution is important. All right, I believe you and I want to say something nice about him . . . *but what does it all mean?*"

I can understand why Hohmann's book was even more obscure to people like that newspaper editor than Oberth's book. Oberth, at least, had spoken about a rocket called Model B and about another one called Model E. He had calculated their performance and stated what they ought to be able to do. To the engineer these models B and E were only examples, sketches supplied for the



21. The So-Called Hohmann Spaceship.

purpose of making a definite calculation. To the layman—and that was practically everybody except engineers and, possibly, astronomers—the models B and E were not examples but projects, something that could somehow, even though with difficulties, be visualized.

Hohmann, as he wrote me later, had thought about actual constructions but had not come to a presentable conclusion. Consequently, he had restricted himself to a mathematical investigation of the quantities of a given or assumed fuel which would be required for an assumed operation. It was all highly interesting and of great scientific value, but it read very much like a prescription.

Just for the purposes of illustration Hohmann had drawn a powder tower (Fig. 21) which, of course, made no sense unless explained. It is by no means a "design," as some people thought; it is one more of these abstract examples. If you imagine that this powder tower burned at the base only and needed eight minutes to be consumed completely, you could draw eight parallel lines through it. You would then get eight disks of powder, of equal thickness but of different diameter. Also of different weight, of course. These eight slices, or rather the mass of these eight slices, illustrated the amount of fuel required per minute. The biggest slice at the bottom was the amount for the first minute of operation and so on. You could also subdivide it into seconds of operation and find the amount required from second to second.

After these two books there was clearly need for some understandable writing. If the whole thing was to be of any value the matter must not rest with theoretical findings. Something had to be built or Oberth and Hohmann would be merely repetitions of Ziolkovsky, possibly to be revived again another twenty years later in another repetition of the same thing. The idea had to leave the study to enter the laboratory and later the workshop. But people who could unlock laboratory doors had to be interested first, and that required non-technical language not only for those who could not understand the technical language, but also for those who could, but did not know of the existence of these formal treatises or who needed an interest-rouser.

It was reasoning of this kind which prompted a man by the name of Max Valier, known as a popular writer on scientific subjects, to approach Oberth with the proposal of emulating Dr. Perelman. Of course he did not put it that way, since neither of them knew either of Ziolkovsky or of Perelman, but the idea was the same.

Oberth accepted the proposal. He had had the idea of a popular book himself, as he told me later, but he was overburdened with work. His own studies for a teaching job were not quite completed. He worked on extensions of his own rocket theory and he also spent quite some time in discussions with financiers and in working out simple demonstrations for them.

The discussions about financial support came to nothing.

The financier or financiers had apparently held the customary conception of professors who invent things, the conception you can find in print in innumerable stories.

They had expected an old or at least elderly man who had labored over one idea all his life and who carried battered manuscripts around with him, manuscripts wrapped up in newspapers and tied around by strings with many knots in them. They probably had had secret hopes concerning complete models which would fly around in the conference room. They had quite definitely expected that the investments they were—perhaps—going to make would bear fruit in not more than two years.

Then they saw that the professor was a slender man who looked taller than he was because of his gangling build, a young man who had just rounded the third decade of his life. The long matted hair and big beard they had visualized turned out to be a short crop of black hair and a small moustache. The only thing that was "professorial" about him was his manner of speaking—whenever Oberth opened his mouth you got the feeling that you were in a classroom and there was no way of leaving, not even on that famous urgent errand, until the lesson was over.

They learned that Oberth had not kept any great secrets to himself, as they had expected, but that everything could be found in his book (which they couldn't read), that the program of carrying out what Oberth had visualized was a program of decades and not of years. They learned that the demonstration models were rigged up at home and were not even patented! Like many people they did not know what a patent was, but they labored under the belief that a patent is an expression of official approval of an invention. Actually it only certifies that the idea was new on the day it was submitted, carrying with it a license to sue imitators.

After having wasted a good deal of time and effort, Oberth returned to the country of his birth, Transylvania, an old German-speaking colony of German Saxons wedged in between Hungarian and Rumanian territories and politically belonging, at that time, to Rumania. More specifically Oberth went to Schässburg in January 1925, leaving it in February to take a post as professor of mathematics at the High School of Mediash, also in Transylvania.

By that time Max Valier's book was about ready and it appeared soon afterward. But it failed to be what the author had promised. It was full of well-meant but ridiculous illustrations. When it came to difficult points, Valier resorted to flippancy which he took to be humor. A great deal of the book was in fine print ("to be skipped by the lay reader") full of calculations, most of them made by Oberth. In spite of all these faults it sold at a fair and steady rate, a reprint became necessary roughly once a year, and some of the most glaring faults were remedied in these reprints. Some others were added later by Valier in an effort to display independent thinking.

As a matter of fact it was the poor quality of Valier's book which made me enter into competition with him although I was not quite twenty years old at that time. With the enthusiasm peculiar to that age I decided that I could do better than Valier. I sat down and wrote a small and formula-free book on the same subject. It was printed in 1926 and sold some six thousand copies during the following six years. To my surprise many people, including Oberth, said that it was actually better than Valier's—at any event it did what Valier had failed to do, it told the whole story understandably and in as few words as possible.

It was then that the problem began to assume international dimensions. In Russia, as has been told in the preceding chapter, Ziolkovsky's old articles were reprinted, along with new editions of Dr. Perelman's book. In Moscow even a student society was formed with the purpose of advancing the problem of space travel. It was short-lived which was just as well since it had not been too serious to begin with. It was not until November 1929 that a serious student society was founded in Russia, with one group in Moscow and another in Leningrad, the latter under the experienced leadership of Professor Rynin and Dr. Perelman.

The same Professor Rynin had then just begun to publish the first parts of his enormous nine-volume work *Interplanetary Travel.* And in France one of the French pioneer aviators, Robert Esnault-Pelterie, delivered a lecture on the problems of space travel, addressing the *Société Astronomique,* created originally by Camille Flammarion. The lecture was published in 1928 in book form. The date of the lecture had been the 8th of June 1927—precisely three days after several gentlemen, living in and near the comparatively small provincial town of Breslau in Germany, had met in the back room of a restaurant to found a society for the purpose of spreading the thought that the planets were within reach of humanity if humanity was only willing to struggle a bit for that goal.

The name of that society was *Verein für Raumschiffahrt* (Society for Space Travel). But people later referred to it as the *VfR*, while the common appellation in English-speaking countries became The German Rocket Society.

If I remember correctly, German law provided that the minimum number of people who can legally found a society is seven; I don't think the assembly exceeded that number by more than two. One of those present at the meeting, a man by the name of Johannes Winkler, agreed to accept the presidency of the society—Valier had refused because of his almost continuous lecture tours—and to publish a small monthly magazine which was to be the mouthpiece of the society. This monthly magazine, called *Die Rakete* (*The Rocket*), was actually published immediately afterward and appeared regularly until December 1929. Winkler invited Oberth and Hohmann to join and they did. Winkler also undertook the task of registering the society with the courts in Breslau. This was required for business reasons: only a society registered with a court of law existed legally and that fact was indicated by adding the letters *e.V.* (*eingetragener Verein* or "registered society," implying about the same as "Inc."). There was a little trouble with this particular incorporation; the court found that the word *Raumschiffahrt* (space travel) was not defined in any dictionary and that the public, therefore, would not be able to judge the purpose of the society. A change of name was suggested. However, the court finally relented and, since new inventions require new words, it accepted the registration of the society under the condition that the document of registration itself define the name in an unmistakable manner.

The growth of the *VfR* was rapid. Within a year it acquired almost five hundred members, among them everybody who had ever written about the problem in Germany and in neighboring countries. Oberth and Hohmann, Dr. von Hoefft and Guido von Pirquet in Vienna, Professor Rynin and Robert Esnault-Pelterie—all had joined. The program was, in outline, to interest as many people as possible, to collect membership dues and extra contributions, and to create a fund for experimental work. And since existing literature in the field was already obsolescent to a certain extent, I began to plan another book, to be written in collaboration by all the leading men of the society. My publisher promised to publish it and to advertise the *VfR* in the process, and the *VfR*, in turn, promised to advertise the book. It appeared under the title *Die Möglichkeit der Weltraumfahrt* (*The Possibility of Space Travel*) in the spring of 1928.

But meanwhile several other developments had taken place, some of them good, others less so. One of the more important ones was a series of articles attacking Oberth in a rather vehement manner. They were published in the very important journal of the *VDI* (*Verein deutscher Ingenieure,* Society of German Engineers) and they were signed by Privy Councilor Professor Dr. Lorenz of Danzig. Privy Councilor Lorenz did not make any elementary mistakes; he simply proved that Oberth's spaceship could not acquire the famous velocity of escape of about 7 miles per second. His arguments and calculations boiled down to the statement that a rocket fueled by known fuels, if it were to acquire the necessary escape velocity, would have to weigh thirty-four times as much when fueled as it weighed when empty. The conclusion drawn from these calculations read: therefore it cannot be done.

Oberth, naturally, wrote a reply. It was rejected. Dr. Hohmann, being a member of the *VDI* as well as the *VfR*, also wrote a reply. It was rejected. The excuse given was lack of space. The real reason, which I learned through a personal conversation years later, was: "We cannot permit people half his age to contradict the Privy Councilor!"

But another society, the *WGL* (*Wissenschaftliche Gesellschaft für Luftschiffahrt,* Scientific Society for Aeronautics) was not so narrow-minded. That society held annual meetings and the meeting for the year 1928 had been scheduled to be held in Zoppot near Danzig. The *WGL* invited Lorenz to attack Oberth and it invited Oberth to defend himself. Lorenz spoke at length; Oberth answered with a very short speech. He pointed out that he had followed the Privy Councilor's arguments and that one could arrive at the ratio of 34 to 1. Personally, by knowing that one factor was more advantageous than the Privy Councilor had assumed, he had arrived at the ratio of 20 to 1, as the Privy Councilor would have seen if he had finished reading Oberth's book. But in any case Oberth could not help it if the Privy Councilor refused to believe that it is possible to build an aluminum pot into which one could pour enough water so that the full pot would weigh twenty times as much as the empty pot.

I may add that Lorenz never wrote about rockets again.

After the meeting, Oberth, Mrs. Oberth, and I sat together and complained bitterly about fate. The big book, the *Möglichkeit,* had been published just in time for the meeting in Zoppot. But something else had happened too. The headlines of every newspaper in Europe told about "the successful trial run of the world's first rocket-propelled vehicle." They referred, of course, to Opel's rocket car which had just been demonstrated to the public in a big, carefully staged show. And that was, to put it mildly, exasperating. These rocket cars and the stories around them embodied the greatest possible misunderstanding and stupidity.

The instigator of all this colossal nonsense had been Max Valier.

For some time Valier had hinted in various articles and lectures that great developments could be expected in the very near future. In January 1928 we had learned just what this great development was going to be—it was such that I had sent the manuscript of the *Möglichkeit* to my publisher without waiting for the chapter Valier had promised to contribute to it.

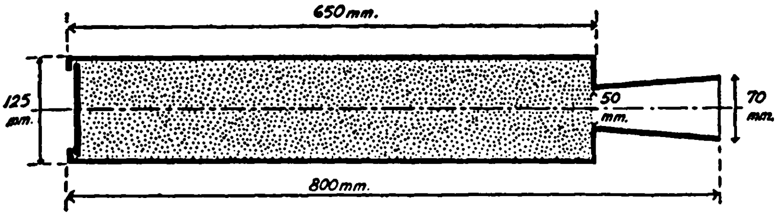
Max Valier, as he put it himself, had "succeeded in interesting Fritz von Opel in rockets." This, of course, was a very euphemistic way of putting things. It was one of those statements that are correct and truthful as far as the wording goes, but which are, in fact, untruthful because they lack the implications that may reasonably be expected.

The fact was that Max Valier had one day had an opportunity to see Fritz von Opel who was the owner of a large factory manufacturing cheap cars. Although he always denied it, nothing flattered Opel so much as hearing people refer to him as the German Henry Ford. When listening to whatever it was Valier told him, Fritz von Opel had a brilliant idea. He saw an opportunity of purchasing unlimited amounts of publicity with what was for him small change. He and Valier were to build a rocket automobile. How long would it take to develop a rocket motor? Valier assured him that there was no need to wait for anything; such experiments would be just as valuable from the scientific point of view if they were made with large powder rockets, and large powder rockets could be purchased on short notice. Of course the experiments had no value either way, but Opel did not probe that question. That was not what he was interested in. Being a shrewd businessman, he answered reluctantly that he might consider it if Valier knew where to get the powder rockets.

Valier did—there was a factory making powder rockets in Wesermünde near Bremen, owned and run by an engineer by the name of Friedrich Wilhelm Sander. Sander did not manufacture ordinary fireworks rockets for amusement; he specialized in practical types. He made line-throwing rockets for the coastal rescue societies, signal rockets for the merchant marine and the German naval units, and other pyrotechnic devices connected with navigation. Sander's rockets were acclaimed in seafaring circles for their good performance and that good performance was due to a special process of manufacture which Sander had developed. By means of this process Sander was able to compress the powder mixture to a much higher degree than "possible"—which is to say "customary"—and since he succeeded in doing that without blowing up both the machinery and the laboratory, it was quite a feat.

Valier and Sander, when talking about the proposed use of the rockets, decided to employ "mixed batteries," consisting of both bored and solid rockets. The largest bored rockets delivered a thrust of close to 400 pounds for not quite three seconds while specially made large solid *branders*, as they were called, delivered a thrust of about 45 pounds for thirty seconds. The rockets were to be used to give the initial impulse and accelerate the car to a fair speed; the *branders* were to maintain that speed. (Fig. 22.)

Valier wanted to make a private test at Wesermünde before



22. Cross-Section of Steel-Cased, Solid Powder Sander Rocket. 125 mm. is not quite 5 inches; 650 mm. is not quite 26 inches.

going to Fritz von Opel's race track at Rüsselsheim. But Sander refused to lend his car for the experiment and Valier did not own a car. Their arguments resulted in a draw and they compromised by going to Rüsselsheim without a preliminary test. The rockets were shipped by truck—the railroad refused to transport them—and the first secret test was made on March 15, 1928. It consisted in attaching one bored rocket and one solid *brander* to a small Opel car. Opel's test driver Kurt Volckhart took the wheel, released the brakes, and ignited the rockets. The car moved very slowly and came to a stop after about half a minute—450 feet in 35 seconds!

Both Volckhart and Opel were greatly disappointed and Opel wanted to give up then and there. Sander felt insulted because Opel had said that the rockets "obviously did not work" and took one of his bored rockets, tied a long pole to it, and set it off for a vertical ascent. Opel was sufficiently impressed with this demonstration to agree to another test. This time Volckhart used the motor of the car for the initial push. When the car was moving at about 30 miles per hour, he disconnected the motor and ignited the rockets simultaneously. They accelerated the car to 45 miles per hour. Opel, somewhat pacified, ordered a special car built.

The new car was not so very special; it was an ordinary racing model without an engine and with a mixed battery of Sander rockets attached to the back of the car. The first run (April 11, 1928) was made with six rockets. One of them failed to ignite, the other five propelled the car for about 2000 feet. The next run was made with eight rockets. Again one of them failed to ignite, two others exploded without doing any harm, but the car ran some 3000 feet with an average speed of 55 miles per hour.

The next test, officially called the First Test Run, was made the following day. Five of the battery of twelve rockets did not ignite, but the speed exceeded 70 miles per hour and the newspaper reporters present wrote enthusiastic stories keyed to a patriotic note: German science and German industry had created the first rocket vehicle in the world. Opel saw that his publicity scheme had worked after all, and while his advertising department placed full-page ads in the better magazines,[3] his engineering department designed a special rocket car.

It was a long streamlined car with stubby wings mounted upside down so that they would press the car against the road. After a secret test run, Fritz von Opel himself demonstrated the car—called the *Opel Rak II*—on the *Avus* Speedway near Berlin on May 23, 1928. This run was a complete success, all twenty-four rockets ignited without any trouble, none of them exploded, and the speed of the car came close to 125 miles per hour. Opel, photographed from all sides, delivered a speech over the radio, promising an even more astounding *Opel Rak III*.

This was the run that had taken place near Berlin while Oberth defended himself against Professor Lorenz in Zoppot. Small wonder that this victory did not make us very happy.

After the *VfR* had worked itself to exhaustion explaining the difference between liquid and powder fuels, after pointing out scores upon scores of times that rockets could never be efficient unless they moved at high velocities—some 800 miles per hour or higher, after all this one of the founders of the *VfR* had gone and played around with powder rockets of commercial manufacture to pave the way for the biggest publicity stunt of all history.

The efficiency of these runs had been below 1 per cent! The expense had been fantastic.

Max Valier came close to being publicly expelled from the *VfR*. It did not happen only because the procedure would have been rather tedious, requiring a lot of correspondence since by then hardly two of the members of the board of directors resided in the same city.

Of course Opel did not stop with this. He produced the promised *Opel Rak III* which was a railroad car, built along the general lines of *Opel Rak II* but with a small battery of rockets in its nose, generally referred to as brake rockets. They were to stop the car at

[3] They showed a couple in evening dress sitting in an Opel car watching a display of fireworks with the following conversation: "Rockets were not important before Opel." Answer: "Neither were automobiles."

the end of its test run, being ignited automatically. The German government had granted permission to use the track from Burgwedel to Celle (near Hanover) for this experiment. That particular track had been chosen because it was perfectly straight and level. The first run was made on June 23, 1928, with a battery of ten rockets. The ignition was timed by a clockwork device, as were the brake rockets, and the car was not manned. It attained a top speed of about 180 miles per hour, the brake rockets failed to perform properly, they shot up into the air when ignited, and the car coasted for several miles.

Retrieved and towed back to the starting point, it was charged with a battery of thirty rockets—all speed records were to be broken. But the acceleration was too high, the car derailed almost immediately and was destroyed. The fate of *Opel Rak IV* was similar. One rocket of the first series exploded and a splinter short-circuited the ignition system which made all the remaining rockets go off at once. The car jumped off the tracks and was totally destroyed. *Opel Rak V* was ready to replace it, but the railroad officials had enough; they did not permit further experiments which might ruin their best track.

Some time later Fritz von Opel switched to rocket airplanes, but gave up after one fairly successful flight near Frankfort-on-the-Main on September 30, 1929.

Nor were Opel's rocket vehicles the only specimens of their kind. His former test driver, Kurt Volckhart, had made himself independent with a rocket car of his own design. Valier had found another manufacturer of powder rockets who lent his support for the construction of railroad cars that lost all four wheels under too violent acceleration. Finally Valier even built a rocket sled and a manufacturer of small airplanes tried his hand on a rocket glider.

What had started out as a kind of scientific movement was almost smothered under a series of publicity stunts. Almost, but not quite. One of the serious attempts at furthering the progress of the idea was made in Paris with the creation of the Annual Award for Astronautics, somewhat reminiscent of the old *Prix Guzman*. But unlike the Guzman Prize, this one did not involve a large fortune nor were the requirements as high as stipulated by the far too optimistic founder of that old award. Robert Esnault-Pelterie and the Paris banker André Hirsch set aside the sum of 5000 francs each year, to be given to the author or experimenter who had done most in furthering the idea of space travel during that year.

Oberth, meanwhile, had begun to rewrite his book for a needed third edition. It was planned on a grand scale and was to consist of two volumes, but only the first, entitled *Wege zur Raumschiffahrt (Road to Space Travel)* appeared in Munich in 1929.[4] It is still the most valuable theoretical work, and it won for Oberth the first "REP-Hirsch Prize" which, as a special compliment, was doubled.[5]

That was in the autumn of 1929. Oberth was in Berlin then, having arrived in the fall of 1928. But this time he had not come for personal reasons, or for a scientific debate, or for more or less vague discussions about financial support. This time he had come for a definite purpose—he had been called by Fritz Lang to serve as scientific advisor for a movie. It was the film *Frau im Mond* which ran in English-speaking countries under the title *By Rocket to the Moon* and *The Girl in the Moon,* the latter being the translation of the German title.

The manuscript for the film had been written by Thea von Harbou (then Mrs. Fritz Lang). The book credited Oberth's first publication and my second book as scientific source material.

The news that Fritz Lang was going to make a film on space travel was very good news indeed. It is almost impossible to relate what magic that name had in Germany at that time. The first showing of a Fritz Lang film was something for which there was no equivalent anywhere as a social event. The audience—it was an unwritten but rigid rule that one had to wear full evening dress, not just a dinner jacket—comprised literally everybody of importance in the realm of arts and letters, with a heavy sprinkling of high government officials. It is not an exaggeration to say that a sudden collapse of the theater building during a Fritz Lang

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[4] I mention the planned second volume only because the first contains some references to it. The second volume never was finished.

[5] The Prize was not awarded in 1929, 1931, and 1932. In 1930 it fell to the French engineer Pierre Montagne for a paper on "Gaseous Mixtures Utilizable in the Propulsion of Rockets." Montagne received a renewal in 1933 for a similar paper, but the real prize was not awarded in that year nor in 1934 when the French engineer Louis Damblanc received a "prize of encouragement" of 2000 francs for an exhaustive treatise on the tests and performance of powder rockets. The 1936 award fell jointly to the American Rocket Society and to Alfred Africano who was then its president. The prizewinning paper was a design for a high altitude rocket. This was the last award made.

premiere would have deprived Germany of all intellectual leadership in one blow, leaving only those who for some urgent reason had been unable to attend.

A Fritz Lang film on space travel, consequently, meant a means of spreading the idea which could hardly be surpassed in intensity and effectiveness. More than that, this connection might also mean funds, sizeable funds, for experimental work on liquid fuel rockets.

I remember that I began to needle Oberth about this during our very first meeting, but it took months until Oberth got up enough courage to press the point.

In the end it was mainly Fritz Lang himself who brought the matter to pass, dragging the reluctant and sceptical business directors of the UFA Film Company along with him. He pledged a rather large sum of money for experimental work and put pressure on the management to do the same. Of course there was a business angle to the transaction too. Oberth was to get the money for experimental work, for the construction of a rocket similar to the Model B described in his book, and for the preliminary experiments that might be required. That rocket was to be finished and ready for an ascent on the day of the premiere of the film so that it could be used for publicity. The idea was to say that this actual rocket represented the first step toward the solution of the problem shown in the movie.

The scheme might have worked out as beautifully as it was conceived if the proper men had been available to do the work involved and if there had been sufficient time for it. The time interval was impossibly short, only about twelve weeks, maybe thirteen or fourteen—nobody realized then how ridiculously short that was. And Oberth, I regret to say, was not the proper man to do it. As a matter of fact, such a man did not exist at all. There was nobody at that time who had sufficient experience with liquid fuel rockets.

Never having organized such a job before, Oberth had no idea of how to go about it. He was, a point I wish to emphasize, the greatest authority on rocket propulsion at that time (he still is, in certain respects, or rather his work is still the most authoritative of all), but he was a theorist, not an engineer. He completely lacked the ability of an experienced engineer to say in advance what can be done and what probably cannot be done. Nor did he know how to instruct a mechanic or workman who would ask how this or that should be done.

On top of all that he was greatly confused by his surroundings. He had grown up in the small towns of Transylvania and he had studied in the leisurely atmosphere of Heidelberg and of Munich.

Now he was suddenly plunged into the strange atmosphere of fast-moving, efficient, flippant, and sophisticated Berlin. Not only was he a stranger in that city of four million inhabitants, but he found himself in the very spot where the apparent turmoil of a big city appears wildest. People spoke to him in a dialect which was strange and, to him, ultra-rapid. Instead of the company of unhurried small-town intellectuals in semi-retirement, he found himself on a movie lot in the company of film stars and directors. He ate his lunch in a canteen where Russian and English and French were as common as German; the only foreign languages in which he had a slight degree of fluency were Hungarian and Rumanian. He sat next to internationally known people, he had to speak to chairmen of huge enterprises of all kinds, he was beset by newspaper columnists and magazine writers with imposing names.

That would have been bearable, but what mainly confused him were habits which he could not understand. He was used to his bicycle and simply could not see why he had to use the subway or a taxi instead. He missed appointments because of his afternoon nap, told the truth about it, and was laughed at. Once he refused to meet a busy man who would not be free before midnight. Oberth simply answered that he went to bed at eleven. When I remarked that "busy people in Berlin sleep when they get around to it," he angrily declared that that was the wrong attitude, wrong from the medical point of view.

He was generally angry with me because I tried to advise him. He would have nothing to do with "the behavior of these soulless, money-making, German-speaking Americans who call themselves Berliners."

While he deliberately failed to conform to "habits and attitudes alien to the German soul," [6] he did realize that he was no engineer and that he needed an assistant who was one. He could

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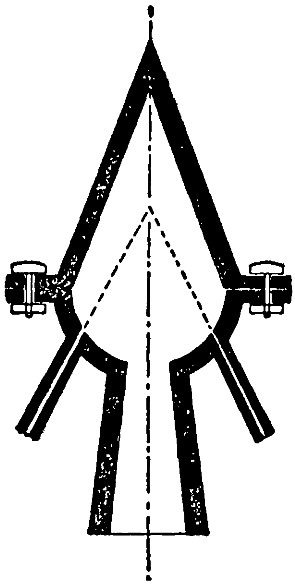
[6] This mystic inclination naturally transformed Oberth into a Nazi in due course. In 1934 he joined the Transylvanian Nazi organization although he was, in his capacity as a high-school teacher, a Rumanian government official. I have it in writing from his own hand that he denounced me to his Nazi superior, stressing the fact that I was in correspondence with Ziolkovsky, Rynin, and Dr. Perelman.

have phoned any one of a dozen specialized employment agencies, he could have asked any one of innumerable people he had met for an able assistant. There were many unemployed and there were many able men among them, and almost anybody knew somebody else who needed a job. But Oberth put an ad into the classified section of one or several newspapers—he had come to the point where he would show people that he did not need their advice. The ad brought a number of applicants, several capable men among them, no doubt.

One of them was a small man with a strangely accented voice and a hard face, meticulously dressed and with precise military posture. He had introduced himself: "Name is Rudolf Nebel, engineer with diploma, member of oldest Bavarian student corps, World War combat pilot with rank of lieutenant and eleven enemy planes to my credit." And Oberth, who always stated his opposition to "Prussian militarism" hired Rudolf Nebel at once!

He did not make certain whether Nebel had the qualifications he needed so desperately, whether he knew the town and its smaller and larger industrial establishments well, whether he had practice in working with aluminum and magnesium alloys or at least with liquefied gases. Nebel himself told me later, without regarding it as a personal secret, that he had been graduated in a hurry during the war because he had volunteered for the air arm, and that after the war he had never worked as a designing engineer but for some time as a salesman of mechanical kitchen gadgets instead. Since jobs were almost impossible to find, all this was probably not his fault—but he certainly was not the man Oberth needed.

Thus Nebel became Oberth's first assistant. The name of the second assistant was Alexander Borissovitch Shershevsky, a Russian aviation student. Oberth had come across his name because it had appeared as a by-line under several articles in aviation magazines, articles which had found Oberth's approval. Via the editor of one magazine, Oberth had contacted Shershevsky who was simply destitute at the time. Shershevsky had been sent to Germany to study gliders, but had overstayed his *kommandirovka* and dared not go home again. Lazy by nature (and very proud of it), he earned just enough money for room and board by writing for professional journals. He could have done better if he had written about Russia but he didn't; he felt that what could be said



23. *Oberth's* Kegeldüse.

at that time would not be considered too favorable by the Western mind and he was genuinely in favor of the Soviet government. He was a refugee by accident.

The trio, consisting of a more than slightly bewildered theorist, a professed militarist, and a Bolshevist accidentally in disgrace, worked together or tried to. Shershevsky was not too eager to work, Nebel was eager and waited for orders, and Oberth was not quite certain where he should start.

He did not build a rocket to be used at a certain date—which was impossible, but nobody knew it—he researched. Some of his critics had stated that Oberth's whole theory was useless because of one single fact. You could not bring liquid oxygen and a fuel, say gasoline, together for continuous combustion. Such a mixture would never burn; it would always explode.

This was a serious criticism and it came from people who had long experience in handling liquid gases. It was a point to be investigated, and Oberth was perfectly correct in making its investigation his first experiment. Liquid air was poured into an open bowl (liquid oxygen was considered too dangerous) and a very fine stream of gasoline was shot into the bowl and ignited at the same time. It had been a little bit too much and a minor explosion resulted. It did small damage; it also gently pushed out a windowpane. The experiment was repeated and the result was that the critics had been wrong. It did work or, rather, it could be made to work. As a matter of fact, Oberth was quick to see that something took place which had never been observed but which was very advantageous: the burning droplets tore themselves apart and were consumed much faster than had been assumed. This discovery meant that much larger amounts of fuel could be burned in a given space and during a given interval of time than had been believed possible. For one thing, it made the still theoretical rocket motors much smaller and lighter.

During one of these experiments another explosion occurred; this one was worse and came close to destroying Oberth's eyesight in one eye. It laid him up for several days, but there have been worse rocket explosions since. Oberth spent some time figuring out a theoretically ideal combustion chamber. In general shape it was conical (Fig. 23) and Oberth called it *Kegeldüse, Kegel* being the German word for cone. He had several specimens of it built somewhere—I don't recall whether in one batch or one after the other, but I suspect the latter.

While Oberth had stressed the advantages of gasoline as a rocket fuel in lectures, he did not want to use gasoline for his own experiments but looked around for methane (CH_4, known also as marsh gas) because of a slight theoretical advantage. It could not be had easily in Berlin, which disappointed him because "home in Mediash we have it in commercially pure form from gas wells."

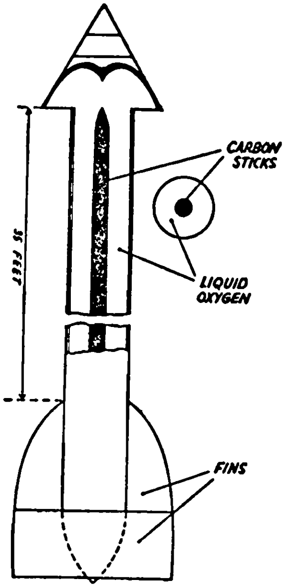
The rocket was to be torpedo-shaped and about 6 feet long, the construction material an aluminum alloy. Nebel took the plans to a factory where the parts were made and after his return they began to work on a parachute release which they wanted to test by means of powder rockets. When they got in touch with a factory of powder rockets, they found that the mechanism developed by the factory for the ejection of complicated starlights was completely satisfactory for their purposes.

All this consumed time.

Most of the delays would have been avoided if Oberth had had an assistant who knew the industrial establishments of Berlin. But even the most ideal assistant could not have accomplished the job in time. The program, as a program, was not so bad, but it was one for a whole year, with four months added for safety's sake. They did not even have four months.

The public waited for the experiment with an enthusiasm that looks incredible even in retrospect. The demand for information was so great that I had to write an article about rockets literally every day for several weeks. The enthusiasm was such that even a photograph of the spot on the Baltic coast rented for the experiment sold well as a picture postcard.

The UFA Film Co. had announced that the Oberth Rocket



24. Oberth's Rocket for Carbon and Liquid Oxygen.

would probably rise to 70 kilometers, say 45 miles. The place chosen originally had been the *Greifswalder Oie,* a small and perfectly flat island in the Baltic off the coast near the city of Greifswald. But the authorities had refused permission because there is a lighthouse on the *Oie* and the possibility existed that the returning rocket might touch the lighthouse. It was a perfectly idiotic attitude, considering the probable radius of descent from a height of 40 miles. Within that radius the whole *Oie* is only a small speck and in looking at the lighthouse I found it sturdy enough to stand a hit from a field gun. And the "danger" was a light empty metal shell dangling from a parachute. In view of the adamant attitude of the officials in charge, the *Oie* was finally abandoned and a spot on the coast of the mainland was chosen. We did not tell anybody that the *Oie* was still within the probable radius of descent from 40 miles.

Suddenly Oberth realized, or was made to realize, that he had only a few weeks left, although he had had more time than originally planned. Fortunately for Oberth, Fritz Lang takes time in editing and cutting his movies—on one occasion in the past he was still cutting the last reel while the first was running in the premiere.

Oberth had to change his plans. He designed a special demonstration model. It consisted of a long aluminum tube with several sticks of coal in its center, surrounded by liquid oxygen. The coal sticks were to burn from the top down. Theoretically they were dimensioned in such a way that the consumption of 5 inches of coal would just use up 5 inches of oxygen level. The gases were to be ejected through a system of nozzles at the top of the rocket; the nozzles were to pull the rocket upward, instead of pushing it upward as planned in the original Oberth Rocket. (Fig. 24.)

This system, known as "nose drive"—as distinct from the pushing "tail drive"—offered a great number of advantages. The rocket did not have to be constructed as sturdily nor did it require an elaborate steering mechanism with gyroscope, relays, and movable vanes. It was better and simpler all around and in all experiments subsequently made the nose-drive rockets performed best. Oberth told me that he had always had that idea in mind, but that he had wanted to keep the nose-drive method to himself. He had sacrificed it only because of the great hurry.

Oberth made more experiments, failed to find a "carbon carrier" which would burn with just the proper speed, and rapidly approached a nervous breakdown. He left town for a week or so—not announcing it beforehand so that Shershevsky called me up to say laconically: "He ran away"—but came back to attend the premiere of the film (October 15, 1929). The UFA Film Co. released a statement that the rocket ascent had to be postponed indefinitely, hinting that the season had too far progressed for reliable weather. Nothing happened for some weeks after that, then Oberth suddenly left for home, releasing a statement that he would sue the UFA Film Co.

Years later, in 1934, he explained in a letter to the new president of the *VfR* that he had not been accountable for his actions at that time. The explosion, he claimed, had given him all the symptoms of shell shock and he had never completely recovered.

Chapter 6:

SUCCESS, FAILURE, AND POLITICS

History has been charged with the duty to judge the past and to educate the present for the benefit of the future. This work does not attempt to do anything as important as that, it only wants to state what really happened.—Leopold von Ranke.

ALTHOUGH the film episode looked like a hopeless failure as far as the practical advance of rocket research was concerned, something good did come of it after all. It came about in a rather devious method, but the focal point of the actual work was the *VfR,* as had been planned all along.

There had been some changes in the structure of the *VfR* during the year preceding the non-materialization of the Oberth rocket. Johannes Winkler had resigned as president because of a job of confidential nature; Oberth had been made president and I, vice-president. An office in Berlin had been opened under the direction of a patent attorney by the name of Wurm and the society had flourished. A talley in September 1929 showed a membership of 870 and new members were coming in every day.

By the end of 1929 Winkler had discontinued the publication of *Die Rakete,* but arrangements were made to mail out an information bulletin from Wurm's office so that contact with the members would not be lost. It was this information bulletin which informed the members, a short time later, that the *VfR* had acquired the Oberth Rocket and that experimentation would be continued by the society.

It would have come to that at any event. The way it actually happened was that I met Nebel on the street one day, by pure accident. Nebel had been wondering whether his recently acquired experience could not be put to some use and he had toyed with the idea of founding a society for the advancement of rocket research. When he told me that I was somewhat dumbfounded. I could not see any reason why he should want to compete with the *VfR,* but on the other hand he did not sound as if he wanted to. I asked him outright and learned that he did not know of the existence of the society; Oberth—then president of the *VfR*—had never mentioned it to him. Nor had Oberth ever called Nebel's attention to any of the numerous books on the subject, save for his own which Nebel had begun to read dutifully only to give up on page 20 or so.

Naturally I brought Nebel and Wurm together. Oberth returned, and a general meeting took place in Wurm's office. Aside from Wurm and me there were Nebel and Oberth, glowering at each other across the conference table, and a young engineer by the name of Klaus Riedel (pronounced *Ree*-del) who had just joined the *VfR* and wanted to help.

That first meeting resulted in one decision: the Oberth Rocket existed in parts, but some bills had still to be paid and without payment of these bills we could not get the parts. We voted that the *VfR* should try to pay these bills and have the rocket assembled. That was done and we also acquired Oberth's equipment which was still on the movie lot, the heaviest piece being the launching rack that had been built for the Oberth Rocket.

As soon as it was assembled disagreement began. We all were sure that it would not work; even Oberth agreed. That was the point where agreement ended. Nebel revived a suggestion he had made before, during the last days of the UFA episode. He wanted to put one of Sander's most powerful powder rockets inside for a faked ascent—or for an explosion—just as long as something could be shown to the public. When we all yelled at him in utter indignation, he was mainly surprised; he did not understand such a reaction. Nor did Oberth understand the equally violent reaction that greeted his proposal. He wanted to sell the rocket to a circus in Mediash and use the money to build a better one. It was finally decided not to do anything with it.

Then Nebel revived his old idea of a rocket for liquid fuels, not designed for any performance in particular, but merely designed to function. And that rocket was to be of the smallest possible size. For this reason Nebel called it the *Minimumrakete* or, abbreviated, *Mirak*. Oberth did not like this idea very much—he had rejected it previously, during the UFA experiments—because he was of the opinion that a liquid fuel rocket should show its superiority by having a better performance than any existing powder rocket. But in this case he was overruled; we all agreed that a small rocket that worked was far preferable to a large one that didn't, and Nebel was charged with the job of drawing a preliminary design.

By this time the funds of the *VfR* were exhausted and Oberth and Nebel spent several weeks trying to raise funds from scientific foundations. The final result was nil; those societies or foundations either had empty coffers or else what funds they had were earmarked for specific purposes. But that unsuccessful treasure hunt yielded an unexpected result.

There existed a government-sponsored institute by the name of *Chemisch-Technische Reichsanstalt*, the Reich Institute for Chemistry and Technology. This institute did some work of its own along the lines of the Bureau of Standards. But it also tested industrial inventions and processes and testified as to their value. Originally the *Reichsanstalt* had been approached for money. It did not have any funds available but its director, Dr. Ritter, suggested that a rocket motor for liquid fuels be demonstrated to him. If the demonstration turned out well, he would issue a certificate and that should be a great help in approaching other institutions.

It was a good suggestion and we lost no time in accepting Dr. Ritter's offer. Oberth's *Kegeldüse* was made ready for the test and Nebel hoped to get his *Mirak* in too, but it was still incomplete when the day of the test came. I am tempted to say that it was just as well, because the day of the test was one of terrible weather. All through the day it poured; it had poured the day before and it was still pouring the next day. The test was made in the open, in a clearing in the pine forest close to a small shack which offered some protection. But it was as wet inside the shack as out because everything was permeated with moisture; the clouds were hanging so low that they obscured the boughs of the trees.

The *Kegeldüse* had been rigged up on a registering scale and the whole assembly had been placed in a shallow slit-trench. Handling liquid oxygen under these conditions was pretty much a sleight-of-hand trick. Liquid oxygen, having a temperature of close to 200 degrees below freezing Centigrade, rapidly draws all moisture within reach out of the air and freezes it around pipelines, valves, and other points which should not be covered with ice. There was much moisture in the air on that day, clouds of ice crystals formed wherever liquid oxygen was poured from one container into another, and I saw one pipe collect a quarter-inch layer of ice in less than a minute. But, despite the great waste of liquid oxygen, Riedel—who did most of the actual handling of the equipment—finally got the rocket motor going and the press photographers somehow succeeded in getting a few pictures in spite of the raindrops on their lenses.

Dr. Ritter certified that the *Kegeldüse* "had performed without mishap on July 23, 1930, for 90 seconds, consuming 6 kilograms of liquid oxygen and 1 kilogram of gasoline, and delivering a constant thrust of about 7 kilograms." (One kilogram equals 2.2 pounds.)

The demonstration at the *Reichsanstalt* was Oberth's last experiment in Germany. Officially he was still a teacher of mathematics at the high school at Mediash, and as far as that high school was concerned the whole year of work for the UFA Film Co. had been simply a leave of absence. While Oberth's endeavors were appreciated by his superiors, there was a limit to the time a man could be on leave and still retain his job. He now had to return and he did it gladly. Pocketing the certificate Dr. Ritter had issued and thinking nasty thoughts about everybody he had met, Oberth went happily home to Mediash.

Those six months between Christmas 1929 and the official test run of the *Kegeldüse* had not been idle by any means. The first *Mirak* had been built during that time and a good deal of publicity work had been done. Unfortunately a tragic and actually dangerous note had crept into that work.

It had begun with a public meeting in the lecture hall of the General Post Office in Berlin. On that night, April 11, 1930, the completed Oberth Rocket was displayed for the first time. Among those present were not only representatives of large firms and institutions but also Hermann Ganswindt, Johannes Winkler, and Max Valier.

Valier told me that night that he had "said good-by to powder rockets" as I would see soon, and I did see it about a week later, on April 19. Early in that year Valier had come to terms with Dr. Heyland, the director of a firm with the clumsy title Association for the Utilization of Industrial Gases. Among other things this firm manufactured liquid oxygen and Valier had built a car which was propelled by a liquid fuel motor for liquid oxygen and gasoline. The large vehicle made a long and lumbering run; it was evident that the motor did not work well and the flame was reddish and smoky, certain signs of poor combustion.

But Valier was sure that he could improve matters soon. He wanted to have the car ready for a demonstration during "Aviation Week" which had been scheduled in Berlin for the week from May 25-31, 1930. The Week consisted of public lectures, documentary films, some inexpensive air hops over the city, and an exhibit on Berlin's most important square, the Potsdamer Platz. The *VfR* was supposed to take part in that exhibit; unfortunately it kept raining most of the week and we therefore moved our Oberth Rocket, the *Mirak*, the *Kegeldüse*, and our other exhibits to the large department store of Wertheim's, situated on the same square. The weather being what it was, our exhibit found many more visitors than the rain-soaked sports planes and gliders outside.

Valier and I met once more on May 14 or 15. He was confident that his improved car would draw a record crowd.

Two days later when I came home at night I found a wire on my desk: Max Valier was dead! It was a Saturday and he had worked late in Dr. Heyland's empty factory. Apparently he had made several test runs of his motor—"idling" it without actually letting the car run—which had turned out well and he had observed another run at close range. Suddenly the motor exploded and a large steel splinter cut the aorta; he bled to death before anybody could do anything about it.[1]

It was especially tragic in view of the fact that nothing had ever happened to him during all his dangerous and useless experiments with powder rockets. He died while engaged in his first really useful experiment, although the idea of mounting his motor in a car was, of course, ridiculous. And it was even more tragic since Valier's death gave rise to cries to outlaw rocket research. It may have been these cries that influenced Dr. Heyland to break off negotiations concerning collaboration with the *VfR*.

The demonstration run of the *Kegeldüse* at the *Reichsanstalt*, which we made soon afterward, was a "test" in another respect too. We wanted to see whether reports on that run would cause these cries to be renewed. It did not happen, but we decided "to keep further casualties secret."

For this reason the experiments with the *Mirak* were not made in Berlin. It so happened that the grandparents of the young engi-

[1] Valier was not the first victim. About a year earlier an adolescent boy had been killed by the explosion of a homemade powder rocket while trying to build a large model of the Opel rocket car.

neer Klaus Riedel, mentioned in the preceding chapter, owned a farm near the small city of Bernstadt in Saxony. We made sure that liquid oxygen could be had within easy driving distance and then Riedel and Nebel left with the *Mirak*, a set of tools, and a box of spare parts. Their reports read about as follows: "The *Mirak* burns, but the recoil is too small to be measured with our home-made thrust meter, probably a pound or so." Then: "The *Mirak* now produces a recoil of three or four pounds." Some time later: "The recoil of the *Mirak* is slightly higher than its own weight; it would rise if we released it." And in September 1930: "The *Mirak* has exploded, no harm done; we'll come back and build a new one."

When we put these reports into our mimeographed bulletins by means of which we held the *VfR* together, two members saw fit to reveal that they were wealthy. One of them, an engineer by the name of Dilthey, donated approximately $1000 in cash, in two installments. Another one, a manufacturer by the name of Hugo A. Hückel, sent only $100, but he promised the equivalent of about $150 every month, provided that none of it would be used for anything but experimental work. He absolutely refused to pay postage or carfare or delivery charges—nothing but bills for machinery, tools, gasoline, and oxygen could be charged to him.

It does (and did) sound somewhat funny, but it was a basis to build on. What was needed now was a permanent proving ground, an equivalent of the shack and the open field at Bernstadt. Nebel drove around in the outskirts of Berlin looking for inaccessible places and he found several—an abandoned factory here, an unused tract of land there, a small island in a lake elsewhere. One of these places looked best and he checked on its ownership, etc. Then it looked ideal.

It was a tract of land about 2 square miles in area, difficult to find, and situated in the district of Reinickendorf near the northern periphery of the city, a typical worker's suburb. Two roads led into the vicinity, but one of them was so bad that a city ordinance forbade its use by motor vehicles. I still wonder why the use of the other one was permitted. At the point where these two roads met an old army garrison stood; it was used as local police headquarters.

The place chosen was across the street from the police garrison, but did not border the road. A secondary dirt road branched off there, leading for 1000 feet or so through a conglomeration of small single-family houses, minor manufacturing establishments half of which were idle, truck garages, and shacks of uncertain purpose and use. After you had negotiated that dirt road you came to a wire fence which enclosed the 2-square-mile tract.

The owner was the City of Berlin and to the municipal officials in charge it must have been something in the nature of a white elephant. To make it usable for manufacturing or settlement purposes would have required an enormous capital investment. Not only that, but a new road was urgently needed.

The place itself was hardly suitable for anything. Half of it was hilly and covered with trees, and some of the depressions between the hills were swampy. To make it worse from a businessman's point of view, the jurisdiction was somewhat doubtful. During the First World War, when the police garrison had been an army garrison, the place had been used to store ammunition and the War Ministry had erected storage buildings. These were massive concrete barracks with walls a foot thick, surrounded by blast guards in the form of earth walls, 40 feet high and about 60 feet thick at the base.

The earth walls had slits to make the buildings accessible for vehicles, but the slits were a little too narrow for large motor trucks. The roads connecting the various buildings could hardly be seen any more and the buildings themselves had only a very few windows.

While the ground itself belonged to the city, the concrete buildings and earth walls belonged to and were under the jurisdiction of the War Ministry. The city might have liked to rent the place, but the War Ministry insisted that no damage of any kind must be done to its buildings and earth walls and that, of course, prevented any business deal.

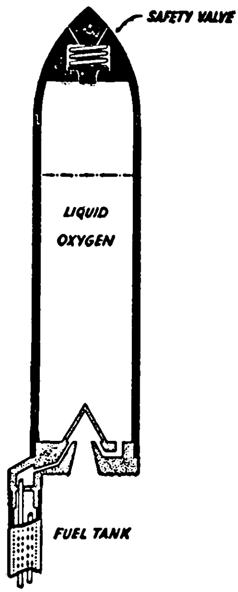
We had to make an enormous number of promises. We were to use only one of the two gates, we were to occupy only two of the buildings and were not to enter any of the others (there were five or six more, all perfectly empty as we quickly found out), we were not to make any changes in the two buildings we were permitted to use, and we were not to move in machinery and/or equipment which could not be moved out within forty-eight hours. We promised everything and then rented the place for a nominal sum —some $4 per year—and received the key to the smaller building on September 27, 1930, which date we proclaimed to be the "birthday" of our testing ground. Nebel called it the *Raketenflugplatz* (rocket airdrome) and it became known in interested circles all over the world.

The smaller building next to the gate, not surrounded by an earth wall, had only one storey. It was an oblong of about 30 by 45 feet, divided into two sections by a massive partition, one section being about twice as large as the other. The smaller section was subdivided again so that it had three rooms, the large one being four times as large as either of the two small ones. It had obviously been the guardhouse, with a rest room and an office for the officer in charge and a room for the soldiers of the guard. A replica of this building could be found near the other gate. During the interval between the time the guard had moved out and we had moved in, somebody had used it to store lumber which was afterwards forgotten. When we finally got the door open we found a solid layer of thoroughly rotted wood, a yard thick. It was a full day's work to drag this wood out into the open, to burn it, and to clean the house.

After that Nebel and Riedel set up a bachelor household in the two small rooms and used the larger room as temporary storage space for our equipment. It consisted of the Oberth Rocket and a full-size wooden model of it, as well as the iron launching rack for the Oberth Rocket. The wooden model was later mounted on a pole near the road, pointing in the direction of the testing ground. Then we had the second *Mirak*, which had been completed in the meantime, and the stand in which the first *Mirak* had been tested at Bernstadt. The rest was odds and ends.

This room later became a combination office, reception, conference, and board of directors' meeting room; I called it the *chambre à tout faire*. But during the winter it became an incredible jungle of machinery and raw materials. We wrote hundreds of letters to any firm manufacturing something we could use, explaining what we wanted to do and asking for contributions which would help us a lot and not hurt the contributor. We did not ask for cash, we asked for raw materials, unused machinery (unused, that is, by the man or firm who owned it), for tools and similar things. And we got them: boxes of hand tools, aluminum in sheets and rods, magnesium alloy in rods and seamless tubes, angle iron, screws, nuts, bolts, pots of paint, a drill press, and a small lathe—a whole machine shop came in piecemeal.

Somebody, in an hilarious moment, even wrote a letter to the



25. Cross-Section of the "Head" of Mirak 2. *Solid black indicates aluminum; dotted area indicates copper.*

Department of Internal Revenue asking for a waiver of the tax on the gasoline we would use for our experiments, transportation, etc. To our great surprise it worked, bringing the price of gasoline down from about 80 cents per gallon to something like 13 cents per gallon.

Our program was as simple as it was definite.

There was to be no nonsense about rocket cars. We had made up our minds that a rocket could be good only as a rocket and we were going to build rockets. Oberth had been perfectly right in that respect. But we also decided that there was no use tinkering any longer with the Oberth Rocket. We wanted to keep it as a museum piece. It later stood like a big gleaming airplane bomb in the *Chambre à tout faire,* causing visitors to throw away their cigarettes in a hurry.

Our first job was to make the second *Mirak* work.

It was a replica of the first, except that it was slightly larger in size. When Nebel had drawn up the design of the first *Mirak* he had followed the pattern of a powder rocket as closely as he could. Like a powder rocket it consisted of a "head" and a "guiding stick." The latter was a long thin aluminum tube which served as gasoline tank. The "head" was made of cast aluminum and machined to size; it looked like an artillery projectile. The nose could be removed to fill in the liquid oxygen and it contained a safety valve. (Fig. 25.) The bottom of the head was made of copper and carried a combustion chamber in the center, a small replica of the *Kegeldüse.* The combustion chamber, therefore, formed the bottom of the liquid oxygen tank. It was assumed that in this way it would serve two purposes: the liquid oxygen would cool the rocket motor while the heat from the rocket motor would evaporate some of the liquid oxygen, thereby creating sufficient pressure to feed the liquid into the combustion chamber. The gasoline was to be fed into the combustion chamber by means of carbon dioxide pressure, produced by a carbon dioxide cartridge of the same type that is used for making soda water. That cartridge was carried in the end of the tail.

The launching rack of the *Mirak* was equipped with a simple gear which could be turned from a distance. By turning that gear the carbon dioxide cartridge was discharged in the customary manner.[2] But the launching rack was also provided with a clamp that held the *Mirak* tightly so that it did not rise when fired but only pulled that clamp. And the pull could be measured.

The second *Mirak* performed like the first: it would have been just powerful enough to lift itself off the ground. Finally, like the first, it exploded. The hot combustion chamber made the oxygen develop more pressure than the tank could stand or the safety valve could handle. We came to the conclusion—which was also verified mathematically—that the liquid oxygen could not be used to cool the rocket motor; that had to be done either by the fuel or by a separate cooling water-jacket.

The second *Mirak* blew up in the spring of 1931.

It was decided to do two things simultaneously. A third *Mirak* was to be built, with the rocket motor below the bottom of the liquid oxygen tank. For better balance it was to have two tails; the second tail was to hold compressed nitrogen gas so that the carbon dioxide cartridge could be discarded. The parts for this third *Mirak* were made except for the motor. To build a better motor was the other thing we had decided to do and that had to be done first.

There was some delay because that job needed much preparation. Now that spring and better weather had come, we began to occupy one of the large buildings and change it into a laboratory and machine shop. This larger building had a second floor; not

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[2] In some English and American books and magazine articles it is stated that the second *Mirak* differed in various respects from the first, mainly in having a ceramic-lined combustion chamber. This is due to a series of misunderstandings which occurred when I explained the story of the *Miraks* to G. Edward Pendray, one of the founders of the American Interplanetary Society (later the American Rocket Society), when he visited the *Raketenflugplatz*. The misunderstandings were due to the fact that Pendray did not speak German and that my English was very poor. What I meant to say, but apparently didn't, was that one specimen of the *Kegeldüse* had been tested with a ceramic lining. As was to be expected the lining cracked and one piece of it blocked the exhaust nozzle, causing the combustion chamber to explode. That had been before the first *Mirak* existed even on paper.

far below the roof a ceiling of 2-inch planks, resting on 8 x 8-inch wooden beams, had been built in. This ceiling was at the same level as the crest of the earth wall around the building, and a door led to a narrow bridge which ended on the crest of the earth wall. Walking over the bridge and down the earth wall we came to a small depression in the ground and this was chosen as the site for the testing stand.

The testing stand was the old iron launching rack for the Oberth Rocket, fitted with a balance. The rocket motor was attached to one end of the balance and the tilt of the balance registered on a revolving drum. An insulated oxygen tank and a gasoline tank were buried in the ground at either side of the test stand, each with a nitrogen steel bottle for pressure. The valves were operated by thin wire ropes which led into the top floor of the machine shop. They were connected to large railroad switches and operated by a man standing behind the doorway. The same man also ignited the rocket motor by closing an electric switch. The operator was perfectly safe, but he could not see the test stand either; he followed orders shouted by the man standing on the crest of the earth wall and directing the test.

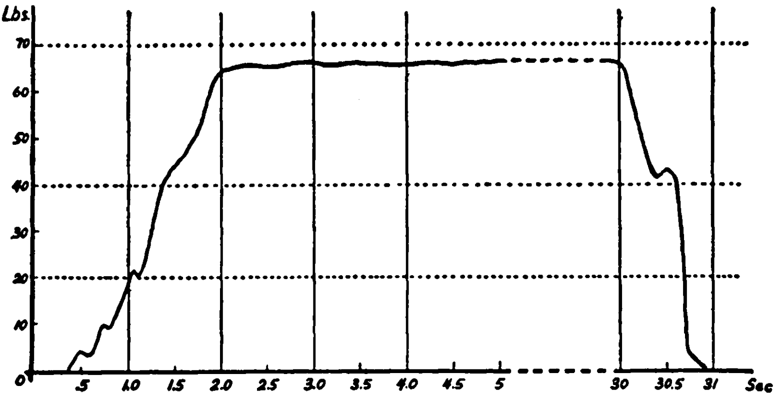
The procedure was as follows: the rocket motor, which will be described soon, was water-cooled during the test stand runs. It was fitted into a metal container which, in turn, was attached to the balance of the test stand. The cooling water came from a large water barrel standing on the ground just outside that small depression into which the test stand was placed. The water was drained off through a pipe fitted into a hole near the bottom of the container; the pipe ended on the ground a few yards away.

The ground crew's job, after the water barrel and the fuel tank had been filled and the motor had been attached to the balance, consisted of the following procedure: The ignition device was attached to the muzzle of the exhaust nozzle; it was actually a kind of small powder rocket but with strange qualities. The powder had been compounded by the chief chemist of a large pyrotechnic factory near Berlin, and it required a specialized chemist's specialized knowledge to produce a powder that did just what we wanted it to do. The main point was that it had to produce a very hot flame, but it also had to burn for at least ten seconds and with little generation of exhaust gases; the ignition device was not supposed to have any recoil. In addition to that, the flame was not to be extinguished either by water or by a jet of cold compressed gas. A thermite cartridge approximately filled our needs but was too hard to ignite; we wanted electric ignition too. The chemist, Dr. Feistl, after hearing all these requirements said that it could be done, and he delivered a dozen capsules only a week later. They proved excellent.

After that device was attached, the clockwork of the registering drum was wound up, and after that the liquid oxygen was poured into the oxygen tank. Then the ground crew scrambled to safety, leaving only one man behind who turned the stop cock in the cooling water line. When he too was under cover the test really started. There was a definite sequence in the orders shouted by the observer. It went: *"Feuer!—Benzin!—Sauerstoff!"* "Fire!—Gasoline!—Oxygen!"

At "Fire" the electric switch was closed, and it ignited the small powder tube which jetted its flame horizontally across the mouth of the exhaust nozzle. When that flame was well established the shout for gasoline was answered by a spout of yellow fire from the rocket motor. The call for oxygen followed immediately. The flame grew first bright and then bluish, shortening rapidly at the same time. The sound produced by that short and sometimes hardly visible flame resembled the roar of an enormous waterfall which kept up until the switches were closed or the fuel gave out. Test runs varied in length from thirty to ninety seconds. When Mr. and Mrs. Pendray of the American Interplanetary Society visited the *Raketenflugplatz* in April 1931 we could demonstrate a fine test run.

By that time the preliminary experiments had settled down to a standard fuel—gasoline—and a standard motor which was generally referred to as "the egg" because it was about the size and shape of an egg. It was made of two sections of spun aluminum—almost pure aluminum—which were welded together. The two liquids were jetted in through attachments in the lower end of the combustion chamber. (For diagram see Fig. 28.) The complete motor without the cooling water-jacket weighed not quite 3 ounces, and it produced a thrust of 32 kilograms (70 pounds) after the first run. The first run was usually poorer, producing from 28-30 kilograms, but the motors improved with use. Since they consumed around 160 grams of gasoline and liquid oxygen per second, the exhaust velocity of the blast must have been almost precisely 2000

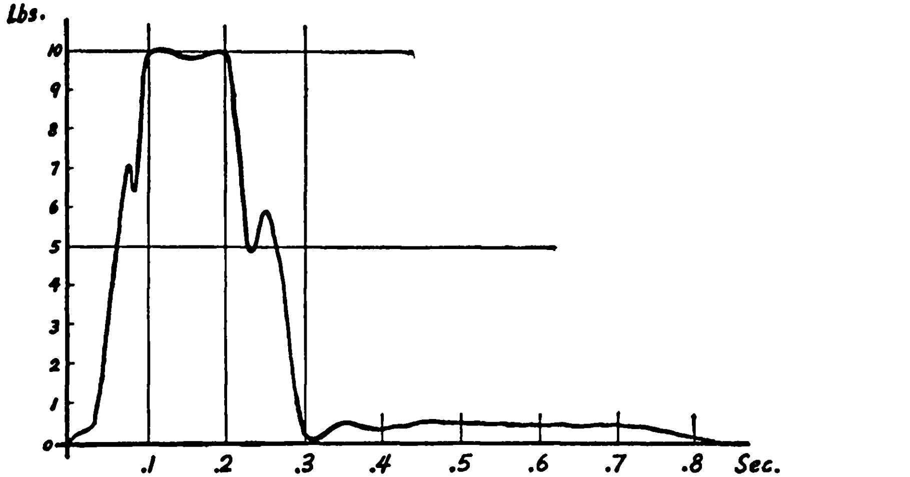


26. Thrust Diagram of a Liquid Fuel Motor.

meters—some 6600 feet—per second. For this reason the "egg" was officially called the "160/32 standard motor." (Figs. 26 and 27.)

I cannot say who invented it; it is almost impossible to tell who invented anything at the *Raketenflugplatz*. The *Kegeldüse* was Oberth's invention and the first *Mirak* was Nebel's, but after that almost any device or development was the result of informal talks and conferences between three or four or even five or six people. We never paid any attention to the question of who had thought of what, knowing that it was a long way from our experiments to definite shapes, and knowing also that our glory was a collective glory. If the question of who invented the standard motor were important, I'd feel inclined to give most of the credit to Riedel.

The standard motor was not only powerful, it could also be regarded as safe after it had been through one or two test runs. We had just enough accidents to keep us from getting careless. Once a motor burned through at a faulty place in the welding seam with the weird effect that there were two jets of fire, one vertical and one horizontal, the latter carrying a steaming spray of water with it. Once the man at the controls pulled the oxygen switch first by mistake and the whole motor blew up—a piece of it deeply imbedded itself in a spade handle which I kept for years as a souvenir. It would have penetrated two inches in living flesh. Another time the whole welding seam broke and the top of the motor shot skyward. The violent explosive combustion resulting from the jets of oxygen, gasoline, and water meeting in midair



27. Thrust Diagram of a Small Commercial Skyrocket.
The thrust reaches 10 pounds, but lasts for only one-tenth of a second. The latter part of the curve shows the thrust produced by the solid section of the powder charge.

almost tore the test stand apart before the man at the controls could turn the pressure off.

But practically all of these accidents happened during first runs and even then we sometimes knew that they were coming. If the motor roared like a waterfall with a steady and fairly small darkish flame everything was fine. When we suddenly got a bright flame and machine-gun staccato it was better to duck quickly and with a great disregard for curiosity.

This was the motor that was to go into the third *Mirak*. But the third *Mirak* was never built, or rather it was never assembled.

It was not assembled in the end because we had something better. But at first it was simply because we had too many other things to do. Nebel, when asking prospective donors of machinery and tools for a donation, had had to promise occasionally that he would invite them for a demonstration when ready. When we could fulfill this promise, Nebel had the idea that these demonstrations could be used to augment our income for which we were dependent on membership fees and on Hückel's generosity. We would invite engineering societies of various kinds to witness test runs for a flat fee of say $50 regardless of attendance. When these visitors came we would usually test one or two new motors and hold a tested one in reserve, in case something went wrong. The scheme greatly helped to improve our finances, but it prevented us from doing something with the third *Mirak.*

It also helped to deprive us of the honor of having sent the first liquid fuel rocket in Europe up into the air.[3] That first European liquid fuel rocket took off on March 14, 1931, but it was not ours; it was Winkler's. The rocket stood about 2 feet high and weighed 11 pounds of which 3¾ pounds were fuels. It looked like a prism placed on end and consisted of three tubular tanks, partly covered with sheet aluminum much in the manner of the old box kites. One tube held liquefied marsh gas, the other liquid oxygen, and the third "an inert gas under pressure," which was Winkler's way of saying "compressed nitrogen." The motor consisted very simply of an 18-inch piece of seamless steel tubing, placed near the center line of the system. The rocket rose, according to Winkler, to an altitude of about 2000 feet (600 meters) from a field near Dessau. Hückel had paid for the experiment and, although we felt a bit foolish that Winkler's private tinkering had built a rocket before we had, we liked the news. A liquid fuel rocket had performed well. It could be done. That meant that we could do it too.

After quite a number of demonstration runs and after the visit of the Pendrays, Nebel felt that he could do with a vacation. There was an Aviation Week of some kind in Kiel and Nebel decided to go there, taking the Oberth Rocket along for exhibition. There were no demonstration runs for several weeks and Riedel and I had time to straighten out odds and ends and talk things over. It had been vaguely agreed upon that the third *Mirak* should be assembled, but that was no definite promise.

Riedel had another test in mind which we had planned together quite some time earlier but had not been able to perform, partly because of the pressure of other work, partly because Nebel would have frowned upon anything that was not directly connected with his third *Mirak.* The idea was to take two pieces of magnesium tubing of the same capacity as the *Mirak* tails, put one of the standard motors between them, and measure the thrust that would be developed under those conditions. We talked for a while about

[3] Actually liquid fuel rockets built by Professor Robert H. Goddard had taken off before that date, but Goddard did not release anything about his experiments until 1935.

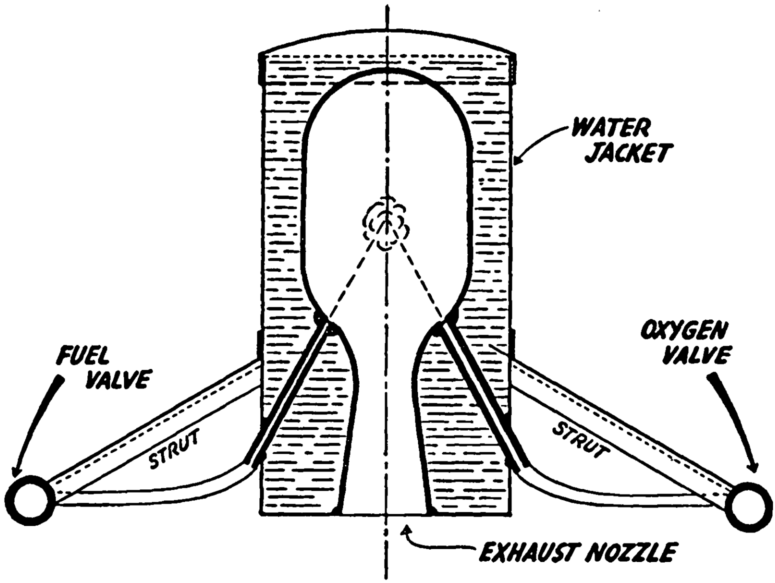
the simplest possible arrangement for such a test and then just sat and looked over our *Raketenflugplatz* which had grown very beautiful with the coming of spring. The hilly part was covered with the young green of pine shoots and new beech leaves, the depressions between the hills were full of young birch. Crickets sang in the high grass and frogs croaked somewhere in the distance.

Only a few days later Riedel called me up in the office, telling me that he had "taken the secret baby out for a test run" the day before. He did not expect anything to happen; it was well weighed down with oversized valves, a large cooling water-jacket, and heavy struts. "But the beast flew! Went up like an elevator, very slowly, to sixty feet. Then it fell down and broke a leg."

I inquired just what "a leg" meant. "A fuel line," chuckled Riedel. "Home in Mediash that wouldn't have happened." This accidental flight had taken place on the 10th of May; on the 14th the rocket was repaired, lightened, and ready for the first planned ascent. The only thing lacking was a parachute. We did not have one ready and we were much too eager to wait. The two tubular tanks of the rocket were inserted into two stovepipes which served in lieu of a launching rack. The spring-operated valves we had were too heavy so we used light turn cocks which had to be opened by means of "keys" mounted on broomsticks. It was done through the open and sand-bagged window of one of the buildings.

In spite of all the makeshift the "flying test stand" took off with a wild roar. It hit the roof of the building and raced up slantwise at an angle of about 70 degrees. After two seconds or so it began to loop the loop, rose some more, spilled all the water out of the cooling jacket, and came down in a power dive. While it was diving the wall of the combustion chamber—being no longer cooled—gave way in one place, and with two jets twirling it the thing went completely crazy. It did not crash because the fuel happened to run out just as it pulled out of a power dive near the ground; actually it almost made a landing. Examination showed that it was intact save for the hole in the motor. We could not examine it at once since we were dizzy from watching and jumping out of the way and had to sit down in the grass for a moment. In retrospect it seemed as if all this took place very close to the ground, but my notes say that we estimated maximum altitude as about 200 feet immediately afterward.

This was the beginning and end of Repulsor No. 1 (Fig. 28). We



28. Original Sketch for Riedel's First Repulsor.
The two tubular tanks were to be attached to the struts outside of the two valves. In actual construction the struts were placed below the fuel lines.

took that term straight from Lasswitz's novel since we wanted to avoid the word rocket because it implied powder. And we could not call these machines *Miraks* any more; they were something else.

Work on Repulsor No. 2 began the same night. We used the same tanks but substituted another motor. The struts were eliminated and better valves were substituted. We decided to do once more without a parachute, but we connected the tanks by circular aluminum hoops and took a large circular disk of sheet aluminum and cut it into four quarters. These were attached to the lower hoop to serve as fins. The repulsor was to stand on these fins on the ground so that no launching rack would be needed.

No. 2 was ready on Saturday, May 23, 1931. It happened to be an exceptionally beautiful day. At first the repulsor was fueled with oxygen only since we had to find out how long it would take to build up the necessary pressure of 300 pounds per square inch in that particular tank on that particular day. The time required was just short of four and one-half minutes. One of the mechanics then opened the valve which let the oxygen escape through the motor and the exhaust nozzle. He swore that he felt a noticeable recoil.

In this and in all later repulsors the oxygen was fed into the rocket motor by its own gas pressure; a short waiting time of a few minutes was all that was required. The gasoline was fed into the motor by means of compressed nitrogen. Since a fuel tank was filled to only one third of its full capacity at the most, there was enough empty space on top of the fuel for the compressed nitrogen.

After the oxygen pressure test we had some coffee and butter-cake in the open before we got the repulsor ready in earnest. While Riedel waited, wristwatch in hand, for the oxygen to build up pressure, I climbed a low hill to have a vantage point from which I could not only see the repulsor but also look over most of the *Raketenflugplatz*. From down below I heard the shouts of "Ready! —Fire!" and saw a white flame shoot out of the nozzle. It shortened quickly, became less bright, and began to roar. At the same instant the repulsor rose off the ground, slowly at first but accelerating rapidly. It climbed to about 200 feet and then turned sideways, like a car taking a curve. In that position it raced across the whole place, still under full power. It slowly lost altitude and it also slowly turned around its longitudinal axis while in flight. The four aluminum fins reflected the red rays of the setting sun like mirrors.

We saw that the repulsor would land outside the *Raketenflugplatz* and started on a wild pursuit, by car, motorcycle, and bicycle. We knew that people often walked in the forest outside the fence and we had visions of horrible slaughter. Fortunately the repulsor had not done any other harm than breaking off a 2-inch branch of a stout tree. When we found it, it was hanging in the smaller branches some 30 feet above the ground, totally smashed. The distance from take-off to tree was 600 meters, about 2000 feet.

That night we wrote two very triumphant letters, one to the American Rocket Society in New York and one to Nebel in Kiel. And then we quietly put the parts of the third *Mirak* in a big wooden box. After that it was repulsors.

No. 3 was built within a few days, and it was a greatly improved model. The two fuel tanks were placed much closer to each other than previously. They were only about 4 inches apart and were held in place by two sets of aluminum braces that jutted out for an inch on either side, fitting into U-channels of aluminum screwed to a wooden launching rack. The bottom braces also carried the parachute container, a vaned can some 3 inches in diameter. It had a fairly loosely fitting lid with a hole in the center through which the main shroud of the parachute was threaded, and in this way the lid was not lost when the parachute was ejected from the container.

The actual ejection was produced by a thick disk of cork which carried a small charge of ordinary black gunpowder. The charge, in turn, was ignited by a timing device of the type used by photographers. The timing device was started by the rocket itself when it pulled out of the launching rack; it was set for the time interval that was calculated to elapse until the repulsor reached peak altitude. This solution, presenting as it did a mixture of mechanical and pyrotechnic principles, was not quite satisfactory from a theoretical point of view. It was, I am tempted to say, theoretically unclean. But it was reliable.

Repulsor No. 3 was tested on a beautiful afternoon early in June. It quickly climbed to 1500 feet. About then the fuel was exhausted and about then something went wrong: the parachute was ejected but much too early. Either there had been more fuel in the repulsor than we had thought or else the timing mechanism had been set wrong. At any event the rocket was still climbing at a fast rate when the parachute blossomed out. It was effortlessly torn off, the repulsor rose for at least another 600 feet, but because of the momentary pull of the parachute it rose at an angle of about 60 degrees while it had climbed almost vertically before. Describing an enormous arc, the repulsor landed outside the *Raketenflugplatz* like a howitzer shell—by coincidence in the same clump of trees where No. 2 had found its end. It buried itself more than a foot deep in the hard forest soil, completely smashed.

These early experiments decided two very important questions: the proper position for the rocket motor and the proper place for the parachute container. The nose drive, with the rocket being pulled by the motor, proved far superior to the originally contemplated tail drive in every respect. The rocket was not only more stable during the ascent, it was also easier to design. The nose drive eliminated, at least for experimental models, the clumsy, expensive, heavy, and mechanically difficult steering mechanism. As a matter of fact, only two tail drive rockets so far have made fair (but not good) ascents.[4] The nose drive also allowed us to put

[4] See Notes and Addenda.

the parachute in its proper place: the extreme tail end. Oberth had thought of putting it in the nose compartment. One night, when making a diagram of a trajectory, I realized why it did not belong there.

The ideal case was, of course, that the parachute should be ejected at precisely the instant when the rocket begins to fall back to the ground. But a timing device might be somewhat off and eject the parachute a few seconds too early or a few seconds too late. If it were ejected too early the still rising rocket would run into its own parachute. If it were ejected too late, after the rocket had turned over in the air because of its stabilizing fins, the same thing was likely to happen. In either case it was likely to crash. But if the parachute were located in the rear that would not occur. If it were ejected a little too early it would merely halt the still moving rocket. If it were ejected too late the rocket would fall for a few dozen feet without a parachute. For similar reasons I had advocated that the timing device should be set for "too late."

Riedel had placed the parachute in the tail in No. 3 because of my insistence and against Nebel's wishes, but he had given in to Nebel in setting the timer "on time." If it had been delayed No. 3 would not have crashed.

But that was unimportant; three more of No. 3 were built during the next few weeks and one or two more later. They all made fine ascents, but there were a few more parachute accidents of the same kind. The next step was Repulsor No. 4 which turned out to be the perfect model. It was essentially Repulsor No. 3 taken apart and reassembled differently. The motor, enclosed in a small cooling water-jacket, was placed on top as usual; two struts and two fuel lines, forming a four-pronged fork, held it in place. The handle of that fork was the oxygen tank. The gasoline tank was placed in line below the oxygen tank and the vaned parachute container below the gasoline tank.

We called this model the "One-Stick Repulsor" and the older types, consequently, were referred to as "Two-Stick Repulsors." The first of them was tested in August 1931 and reached an altitude of about 1 kilometer, roughly 3300 feet. At that altitude it was only a small dot in the sky. Suddenly we saw a tiny white parachute against the blue background and the repulsor drifted gracefully back to the ground. Several more were built, two of them larger in size but with the same standard motor. The One-Stick Repulsors, not fueled to capacity (which we did not dare to do because it would have caused trouble with the authorities), reached altitudes of around 1 mile; one that by accident took off at an angle covered a distance of more than 3 miles. Often we released them half fueled because they were sent up for demonstrations and they presented a better spectacle when the ejection of the parachute was clearly visible from the ground.

All the time progress was steady with hardly any disappointments. We had only one partial failure—the test runs of a larger motor. It had been designed as early as April and since we called the small ones eggs I referred to the big model as the "*Aepyornis* Egg," in reference to the gigantic eggs of the extinct "Madagascar ostrich" *Aepyornis*, which are still found in swamps on occasion.

The *Aepyornis* Egg was expected to yield a thrust of 64 kilograms or 140 pounds; actually it barely made 50 kilograms or about 110 pounds. This partial failure was not conclusive, however, since it might well have been a partial failure of that particular motor. It happened occasionally that one of the standard motors did not perform so well. The tentative designing of a still larger model seemed justified.

There was no further progress during the remainder of that year of success, but things still went well. The UFA Film Co. devoted a large portion of its sixtieth newsreel[5] to the first year of work in the *Raketenflugplatz*, showing a test run of the *Aepyornis* Egg and the ascent of a One-Stick Repulsor. By that time 87 ascents and 270 test stand runs of rocket motors had been made, not counting the *Miraks* at all.

During the filming of the newsreel one repulsor tore off its parachute and landed on top of a shack, setting the roof afire with the last remaining drops of gasoline. It was an old shack and there was nothing of value stored in it, but it belonged to the property of the police garrison across the road. The police descended on the *Raketenflugplatz* like an invading army and any further experimentation was forbidden then and there.

Long discussions and hearings followed, revolving around the question: "When is an accident just an accident and when is an accident a symptom that something is essentially dangerous?" We

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[5] They were numbered and there was one every week. Number one had been the first UFA newsreel with a soundtrack.

quoted airplane crashes and train derailments, bus collisions and fires from short circuits. Finally a demonstration was staged just for the police, and the order was withdrawn, with five provisions that read:

A. The weight of the rocket with fuel must not exceed 11 pounds.

B. The rocket motor used must have made three flawless test runs.

C. Heavier rockets require special permits.

D. Flights must be made only on workdays between 7 a.m. and 3 p.m.

E. No rocket flights are permitted on windy days.

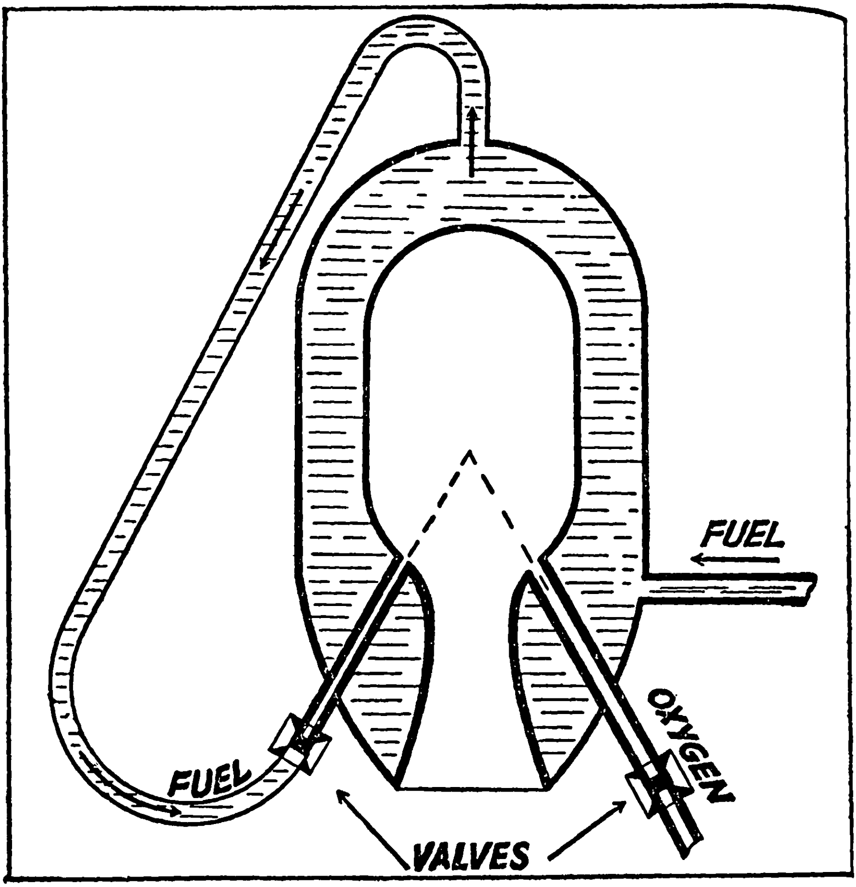
Considering that we worked within the city limits, these provisions were sensible enough.

The newsreel and the victory over the police were our last triumphs. What followed afterward was a hopeless struggle against political tension and economic misery. It was a hard winter climatically. And it was the fatal winter under Chancellor Bruening when Adolf Hitler suddenly assumed prominence. It was a winter during which the roster of members shrank to less than three hundred, most of them deprived of their livelihood. It was a winter during which there came many letters saying that no further dues would be forthcoming because "all money belongs to the Führer." Hückel wrote that he could not help us any more and Dilthey disappeared. Six months later his body was found in a narrow cliff-bounded valley. He had met with an accident while vacationing in the mountains.

In order to raise money I went on a lecture tour in East Prussia. At the *Raketenflugplatz* the men struggled along.

In spring the testing arrangement was completely overhauled. A dugout was placed in the earth wall, only 30 feet from the test stand. The pressure bottles were placed in that dugout, to be operated by the observers who were protected by thick wooden planks, peering through a slit less than an inch wide. A number of larger motors were tested, some of them burning alcohol instead of gasoline. The results were, on the whole, satisfactory. (Fig. 29.) A score of repulsor ascents were made too, but things did not look rosy any more.

There were continuous clashes during the meetings of the board of directors except on the two occasions when Nebel was not pres-



29. Alcohol-Oxygen Rocket Motor.
This model circulated the fuel around the combustion chamber before injecting it, thus obviating the need for cooling water. (See Plate XI.)

ent. When he was he attacked everything and everybody. He attacked me for having kept an agreement about mutual information which I had signed on the occasion of Pendray's visit to Berlin. He attacked the new president of the *VfR*, Major Hanns-Wolff von Dickhuth-Harrach, a retired officer, for having signed a congratulatory letter to Ziolkovsky on the occasion of Ziolkovsky's seventy-fifth birthday. Speaking with a careful imitation of Hitler's mannerisms—they had the same hard southern accent to begin with—he declared that he would leave the *VfR* to die and join the army.

The latter did not mean that he wanted to enlist; it meant that he wanted to turn the *Raketenflugplatz* over to the army. The trend to rearmament was very apparent then and it was not kept secret in any noticeable degree.

Nebel seized upon one of Oberth's early thoughtless claims: that a long distance rocket could be made to hit within a 200-yard circle over a distance of 1300 miles. The whole board of directors opposed him, if for no other reason than that this claim was unfounded. Nebel brushed all our arguments aside: "If we say that it can be done, we'll get the money to try it." The board of directors voted not to take any such action. Nebel sat down and wrote a perfectly senseless "confidential memo on long-range rocket artillery" and went to see Captain Becker, the co-author of *Cranz-Becker: Ballistics,* the most used handbook on ballistics.

The results were maddening and it was small consolation that I could say "I told you so." I had warned Nebel once more—after that meeting which had decided against him—and had told him what the inventor of a new airplane engine had recently experienced. He had approached the War Ministry with his invention and had not heard anything for a long time. Then he was informed, without a word about the engine, that he had to submit to the following orders: he had to make lists of all of his and his wife's relatives and friends and lists of the restaurants and theaters they frequented. The purpose of these lists was that he would receive orders as to what friends to drop, what relatives to avoid, and what restaurants he had to regard as forbidden. This was before Hitler, in peacetime, "disarmed" Germany.

If something like that happened to Nebel, he was careful not to tell anybody about it. But there were enough things we could see. Soon afterward a burglary attempt was made at the *Raketenflugplatz* and that attempt, which was in all probability faked, was used as an excuse to fingerprint everybody present. Then Count von Braun, a member of the board of directors of the *VfR*, was made to resign and to accept a commission. Then a demonstration was ordered, to be made at the army's testing ground at Kummersdorf. The repulsor—it was one of the slightly larger one-stick types—had to eject a red flare at the peak of its trajectory, and it was because of this provision that the members of the board of directors learned about the test at all after it had taken place. One of the mechanics complained to us about the unnecessary work!

All of those who knew about it, except Nebel, prayed for failure. It turned out to be a brilliant success.

Since Nebel had failed to notify the board of directors about the demonstration, he naturally could not notify us about the result. But we learned about it through his highly informative complaints. He had been treated in the customary manner which consisted in regarding anybody of a lesser rank than a full colonel as a moron and a useless moron to boot. Further research would, of course, be conducted by competent officers. But Nebel, for bringing the subject to their attention, would be rewarded; he would be regarded as a manufacturer and would receive contracts for the manufacture of a specific part, probably the parachute container.

Shortly after Count von Braun complained too. His tale, pieced together and condensed, ran like this: the army had discarded liquid fuels at once because of their non-storability. The army had attained 30,000 yards—von Braun did not specify whether horizontally or vertically. And finally, the army had stopped research completely and given him a dull routine job which he did not like. I believe the first and the last of these three claims; the second is obviously a lie. That was late in 1932.

During that winter, the winter preceding Hitler's assumption of power, Nebel got the big opportunity he had been waiting for. It was the so-called Magdeburg Project. The chief provision, or so he said, was that the Project would be entrusted to him personally, not to the *VfR*. Major von Dickhuth and I agreed readily. It looked like something in which we did not like to see the *VfR* involved. Much of our worry was groundless because Nebel had accidentally kept the society in the clear. When talking to Captain Becker and other army officers he had insisted that there was no other connection between *VfR* and *Raketenflugplatz* than the fact that he, Nebel, also was secretary of the *VfR*, or rather had been in the past. When talking to the representatives of the Magdeburg interests, he had said the same. He could say so with impunity because, if anybody thought of checking up with the Court of Registry, he would receive the answer that the *VfR*, through its secretary Mr. Rudolf Nebel, had filed under oath a voluntary petition of bankruptcy in February 1930.

Nebel had not asked anybody about that; he had never even told anybody—and when Major von Dickhuth and I learned about that fact (in the spring of 1933), we had the ledgers and correspondence seized and went through those things that were not in the book. It became clear that a sum of some 2000 marks, if not more, was missing. It became clear that Nebel had resold the tax-free gasoline and had not even paid the gasoline bills. Knowing this we were obliged to act—which we would have done anyway—and we submitted the facts to the District Attorney.

But meanwhile the Nazis had come to power and the ensuing conversation ran something like this: "Herr Major, I hesitate to do anything. The man has lived to be forty years without any other record than a case of fast driving. . . . Herr Major, you are accusing a former fellow officer. . . . Herr Major, I have noticed that he wears the Party Armband [the Assistant District Attorney did not]. . . . Herr Major, I can only advise withdrawal of your complaints. These are revolutionary times." The Assistant District Attorney was thoroughly frightened.

Von Dickhuth removed Nebel from the board of directors; later we both resigned. The *VfR* was dead. Just before it died the Nazis had come to us "to give us directives." As far as we were concerned the "reborn Germany" consisted of two or three meticulously booted and uniformed young men who gave the impression of being homosexuals. Being of the ripe old age of nineteen or thereabouts they carefully patterned their speech after the Führer's, unless they grew excited and forgot to do it.

They were going to reorganize the *VfR*, but their luck was poor. There were no bribes to be had and by sheer accident the members of the board of directors all happened to be "Aryans." What made life worse for them was that von Dickhuth remembered certain psychological principles and rummaged through his trunks prior to the meeting. He appeared in uniform, with half a dozen high decorations, dress saber clanking against high officer's boots. He literally shouted them out of the house.

The New Order then descended upon the *Raketenflugplatz* where Nebel quickly pledged 500 marks for the "Adolf Hitler Sacrifice"—sending them back to us to collect. The *VfR* still had 34 marks at that point.

For a while von Dickhuth and I tried to keep the interested *VfR* members together in another society, but it was a slow death. There was no opportunity for doing anything useful, nor any hope for such an opportunity. Late in 1934 I prepared to leave Germany.

The story of the Magdeburg Project still remains to be told.

It began like a story by Jules Verne. A mentally somewhat decrepit philosopher had written a pamphlet about the true shape of the universe. He tried to prove that the earth is the universe, that we live *inside* a hollow globe of the dimensions of the earth, that there is nothing outside that globe, and that the universe of the astronomers is only an optical illusion. Since every crank can find some fellow cranks, the "hollow earth philosophy" had found some too, among them an engineer by the name of Mengering who was somehow connected with the municipal government of the City of Magdeburg. Being an engineer he conceived the idea of testing the hollow earth theory by means of a rocket. If a rocket going vertically upward crashed among the antipodes, proof would be established.

Now Magdeburg is a proud city. It was a burgomaster of Magdeburg, Otto von Guericke, who performed that famous experiment with the evacuated hemispheres which could not be pulled apart by several teams of horses. Magdeburg would welcome another great scientific achievement of that kind. Mengering offered his idea. The municipal officials did not believe any of the "hollow earth" trimmings, but they were interested in a spectacular rocket ascent, a man-carrying rocket, if possible.

Mengering talked to Nebel and Nebel at once agreed. He would be ready at Easter 1933 or, better, at Pentecost or, if they did not want a holiday (Pentecost was an official holiday in Germany), the Sunday after Pentecost. They agreed on the latter date, which was the 11th of June 1933. It was agreed that the rocket could cost 25,000 marks and it was to be shown as the crowning feature of a kind of citywide holiday which would require another 15,000 marks.

Mengering did not succeed in getting pledges for the whole amount, and since Nebel did not fulfill the contract he got only a part of this. Mengering later spoke of 3200 marks.

But for this story I'll leave the telling to my friend Herbert Schaefer, who worked some sixty hours per week on that project.

> The man-carrying rocket, called the "Pilot Rocket," was to be a huge monster about 25 feet high with a rocket motor of 600 kilograms (1300 pounds) thrust. The passenger cabin and the fuel tanks were to be one unit, shaped like a huge artillery shell, while the other unit, comprising the rocket motor and the para-

chute, was a smaller "shell" topping the bigger one. The rocket was supposed to reach an altitude of one kilometer (1100 yards) at which point the parachute was to be ejected while the passenger—he was not a "pilot" since he did not do anything—was to jump out with his own parachute.

A smaller rocket of the same shape was to be built first; except for size it differed from the large one by having its parachute where the large one would have the passenger. This rocket was 15 feet high and equipped with a rocket motor of 200 kilograms (440 pounds) thrust.

We all began to work feverishly although we knew that it would be impossible to get such rockets ready in the time interval agreed upon. But it meant an opportunity to build large rockets without being handicapped by lack of funds. The actual work began around Christmas 1932, 440-pound thrust motors were designed and built, and also a new test stand was designed to "take" 1000-kilogram (2200-pound) rockets. That stand was ready in March 1933, but one of the new motors was ready earlier and was tested on a provisional test stand on March 9.

It could be heard for miles. The big new stand actually worked for the first time on March 22. It worked to our full satisfaction. Three days later one of the motors exploded at the instant of ignition; the concussion was so bad that the eyeballs of the observers pained considerably. We had expected some such mishap and had eight such motors scheduled. For a week I spent all my time in the welding shop supervising the construction of them. The second motor exploded, also on ignition, on April 3. This was the last real explosion, but on three successive tests the exhaust nozzles burned through at the throat (the narrowest part). Some twenty test runs were made in April; the thrusts obtained varied between 150 and 200 kilograms, depending on the fuel-oxygen ratios. Finally we considered that type of motor reliable.

The City of Magdeburg hurried us and it was agreed to let the big rocket (but not the man-carrying) ascend on June 9. A large launching rack was built in a cow pasture at Wolmirstedt near Magdeburg. It was 30 feet high. Then a series of mishaps began. The rocket could not be attended properly so far away from the workshops. On the morning of June 9 it was fired, the rocket began to rise slowly, but before she reached the top of the rack she began to slide down again, very slowly. The thrust was insufficient and the reason could not be found. Another attempt two days later was spoiled by a leaky gasket. The motor got only one quarter of the fuel it was supposed to get, the rocket roared for two minutes instead of 30 seconds, and we approached to within 10 feet. Of course the rocket did not move. Another test on June 13 also ended prematurely. When the rocket was 6 feet high a vent screw popped out and the rocket fell back, getting no more fuel.

We decided on a complete overhaul. After that new tests with all kinds of little mishaps; once a valve froze tight, another time the ignition capsule was blown out before it ignited the rocket, a diaphragm in the fuel line burst, etc. Heavy rains interfered and warped the wooden launching rack, not enough to be noticed, unfortunately. The city accountants had not granted the expenditure of a metal rack. Thus, when the rocket finally did take off on June 29, one of the rollers derailed and became stuck. The rocket just stripped it but took off almost horizontally because of that. Losing altitude rapidly, the rocket made a belly landing 1000 feet from the rack, the motor still going full blast. It slithered for another 30 feet. It looked totally smashed, but the motor and the tanks were unhurt. Only the casing, fuel lines, etc., had been smashed.

This was the Magdeburg Project itself. It had an aftermath which is still of interest. Schaefer's shorthand notes describe it as follows:

We decided not to wait for another casing but converted the motor and the tanks into a four-stick-repulsor, 7.5 feet high. This repulsor was tested on "Lover's Island" (official name on maps is Lindwerder) in Tegeler Lake near Berlin. She rose with terrific velocity to about 3000 feet, suddenly tilted over up there, made a few loops, and came down in a power dive, landing some 300 feet from the island in the water. The parachute was ejected at the last moment before striking, thus only minor damage was sustained. Another repulsor, with minor modifications, was tested from same island on July 21. The first try was unsuccessful; the valve burst, but after replacement and refueling the repulsor took off. One oxygen valve failed to open, and the repulsor rose slowly and off balance to about 200 feet. It landed in water with only minor damage.

The captain who owned "Lover's Island" objected—we scared his summer campers. We went to Schwielow Lake, using a motor launch instead of an island. Same type of repulsors. Test on Saturday, August 5, 1933. Exploded soon after take-off. Next test same type repulsor, same place, August 11. Seems that one valve did not open, horizontal flight, touching water. Sank in steam-

> boat channel, the only dredged and deep section of the whole shallow lake. Rescue impossible. August 31, same type, same place. Flew away, could not be found again.
>
> September 9 and 18. Two tests with new design, two-sticker with very long tanks and 200 kilogram motor. Same place. Both poor.

And another one of Schaefer's shorthand notes:

> Nebel had hoped that by stringing along with a uniformed organization he could achieve something. All he achieved was that they "took over"; the sound of marching boots became common on the proving grounds and we were asked to join the organization (I and some others refused which caused a lot of friction). A young man with high boots, a blue uniform, and an arrogant bearing became some sort of an overseer. Most of us looked right through him.

Finally the Gestapo seized the journals, papers, books, and all the records—probably the equipment too. The men who worked at the *Raketenflugplatz* were given jobs, mostly in industrial firms like Siemens. I left Germany during the very first days of the year 1935, coming to the United States via England and unwittingly following the same route Fritz Lang had taken when he quietly vanished overnight after Goebbels had offered to make him "Führer of the German Film Industry."

Some three months later a daring editor wrote me that the press had been forbidden to even mention the word "rocket," no matter in what connection. Four weeks after that somebody overheard somebody else's telephone conversation with the War Ministry. It contained the sentence: "Now I've all the rocket people safely on ice around here and can watch what they're doing."

In 1936 Schaefer joined me in New York.

Chapter 7:

THE METEOROLOGICAL ROCKET

In order to go higher, and man will want to go higher, it will be necessary to adopt a different principle. The principle of the rocket is indicated which will lead to a reaction motor.—Capitaine F. Ferber (de Rue) (1911).

THE question is justified now: Why were all these experiments made?

There were various goals in our minds. The first of these will be discussed and described in this chapter, but the experiments were not specifically directed toward it. It was more important to find out, at first, how much of what theory required in the line of improvement upon the ordinary powder rocket could actually be carried out in engineering practice.

As regards that question, the experiments of the *VfR* as well as some of the other experiments listed in the *Addenda* were highly encouraging. The accomplishments demanded by the theory were: higher exhaust velocities through the use of liquid fuels, perfect control of the rate of combustion, longer burning times for higher efficiency. The experiments with liquid fuels proved that these could be achieved.

The Opel experiments, on the other hand, in spite of all their foolishness, proved something too. They affirmed what the theory had stated to begin with: that the rocket is not a "motor" in the sense in which this word has come to be used, even though experimenters speak of their devices as "rocket motors."

The rocket, in any shape or form, is absolutely worthless as a prime mover for wheeled vehicles.

The rocket is almost worthless as a prime mover for aircraft, at least in the sense of not being able to replace the internal combustion engine for any known type of aircraft. Whether special types of aircraft using rocket propulsion can be developed is another story. (See *Addenda*, pp. 258-60, 269-71.)

The rocket does not even replace with any great success the propelling charge in a gun barrel. There are some military uses for rockets, but they are additions to other weapons, not their successors.

What, then, is a rocket, if it is no replacement for any other type of engine? And what, then, is the use of rockets?

To the first question: a rocket is, simply and unconditionally, a rocket. It cannot function efficiently if one tries to make it something else. A rocket is good only as a rocket.

And to the second question: the rocket finds its usefulness in the limitless space which is above the reach of anything else. And this is, literally, a bigger field than anything else.

At the beginning of this great future development of rockets stands one type or application which is known as the "meteorological rocket." The name, as has been explained earlier, refers to a type of rocket which ascends vertically, carrying a number of meteorological instruments. After the rocket has reached the peak of its ascent both rocket and instruments return by means of a parachute.

The idea is not new by any means. Dr. Goddard clearly had this purpose in mind all along and Oberth devoted a good portion of his first book to the description of such a proposed rocket which he called *Model B*. Farther back, in the days before the First World War, the United States Patent Office even granted a patent on an "instrument-carrying rocket" (powder rocket).[1] And meteorologists have repeatedly stated the need for such a device and their desire to see it developed.[2] The science of meteorology relies on the knowledge of conditions in the upper atmosphere. And navigation and aviation, and to a large extent agriculture too, rely, in turn, on meteorology.

It can be said without reservation that meteorologists have always been quick to see how their own science can be benefited by new inventions. The very first hydrogen balloon that took to the air, on December 1, 1783, carried a barometer and a thermometer. One year later, almost to the day (on November 30, 1784), followed the first balloon ascent specifically devoted to meteorological research. That vertical expedition had been fathered by an American, Dr. John Jeffries of Boston, who then resided in London.

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[1] U.S. patent No. 847,198, granted to Alfred Maul of Dresden on March 12, 1907.

[2] For example, Gordon M. B. Dobson of Oxford University, in his "Halley Lecture" of May 5, 1926.

He carried six bottles filled with distilled water along with him; they were emptied at various heights and sealed. The samples of air thus obtained were analyzed later. Along with these six bottles the gondola was cluttered with a thermometer, a barometer, a hygrometer, an electroscope, and a mariner's compass.

Other such vertical expeditions followed, and in some cases the balloons went so high that the lives of the men in the gondola were seriously endangered. But in spite of this danger it took almost a full century until somebody conceived the idea that such research work might well be done by means of small and unmanned balloons, carrying automatic self-recording instruments. The earliest suggestion of this kind seems to have been made by Brissonet in 1879. Brissonet's suggestion was fine; it had only one drawback—self-registering and sufficiently light meteorological instruments did not exist then. This was still true a few years later when the German meteorologist Assmann made the same suggestion.

Assmann then drew the conclusion that such instruments should be developed if they did not exist and began doing so in 1891. At the same time two Frenchmen, Gustave Hermite and Georges Besançon, had drawn the same conclusion from the answers Brissonet's suggestion had evoked, and they began designing and building the same tiny instruments over which Assmann was sweating. They won the race; on March 21, 1893, the first *ballon sonde* or sounding balloon was released in France. It reached an altitude of 15,000 meters or about 49,200 feet. A German sounding balloon, released on April 27, 1894, reached 21,800 meters or 71,500 feet. Assmann and his associates had the satisfaction of having gone higher, even if they had lost the glory of being the first. This is about the same altitude as that attained many years later by manned stratosphere balloons, the American *Explorer II* and the Russian *Stratostat*. (The latter does not count officially because it did not land safely.) In the interim sounding balloons had broken their own early records again and again, and at present the altitude record for a sounding balloon belongs to one that was released near Hamburg on September 8, 1930. It attained 35,900 meters or 117,750 feet (22.4 miles). (There exist several slightly higher claims for other sounding balloons but they are, as far as I know, not officially recognized.)

These instrument-carrying balloons have gathered a great many valuable data (see *Addenda*). They have, among other things, taught us that the atmosphere has several distinct layers. The one nearest the surface is known to meteorologists and aviators as the Troposphere. This is the turbulent layer with cloud formations, vertical currents, and "weather." It is characterized by steadily decreasing density and temperature the higher the altitude. At sea level air pressure averages 760 millimeters or 29.92 inches of mercury. At 11 kilometers (about 6.8 miles or 36,000 feet), which is the approximate upper limit of the troposphere, the pressure is only 165 millimeters or a little over 6½ inches.

Higher up, at 15 kilometers or about 9.4 miles, the pressure is only a little over 3½ inches or 90 millimeters. This means that the volume of a cubic foot contains only 11.7 per cent of the air which can be found in a cubic foot at sea level. The corresponding figure for an altitude of 11 kilometers is 22 per cent. But the composition of the thinner air at 11 kilometers differs from that of the dense air near sea level in only one respect: all water vapor has disappeared and oxygen and nitrogen have gained correspondingly.

During the first 11 kilometers the temperature falls off at the rate of about 1 degree Fahrenheit per 300 feet of ascent, or 6 degrees Centigrade per kilometer. It reaches a low of minus 55 degrees Centigrade or minus 67 degrees Fahrenheit. From then on it remains the same and even has a slight tendency to rise. This means that we have now entered another layer where only the density continues to fall off, but no longer the temperature. This less turbulent and therefore more "stratified" layer is known as the Stratosphere, and the imaginary dividing line or rather dividing shell between the troposphere and the stratosphere goes under the name of Tropopause. The tropopause, generally said to be at about 11 kilometers or 7 miles (it varies from 9-19 kilometers with latitude and season), is not a layer in itself but only the dividing line.

We know very little about the higher stratosphere, simply because it has not yet been possible to take any direct measurements high above the tropopause. For these higher layers meteorologists have to depend on indirect observations which are often enough chance observations:

After the sun sets, light is still reflected toward the earth by the higher layers of the atmosphere. Calculation has shown that the highest layers capable of diffusing sunlight occur at about 60

> kilometers. Luminous or pearl clouds, whose altitudes have been definitely established by triangulation, have been observed at night at altitudes of 80 kilometers. Shooting stars appear at about 300 kilometers. . . . The Aurora Borealis have a maximum frequency at about 100 kilometers, while some rays reach to altitudes of 1000 kilometers. The study of the propagation of radio waves has led to the conclusion that an ionized zone called the Heaviside Layer exists at an elevation of more than 80 kilometers.[3]

All these facts taken together permit the conclusion that the atmosphere has a total height of about 400 kilometers while a highly attenuated outer shell—if we had made it in the laboratory we'd call it a hard vacuum—reaches to about 1000 kilometers. But that is about all that can be said with any degree of certainty. Any figures for the density of the air at, say, 200 kilometers which you may find in scientific literature will differ with each other to an enormous extent. The reason is simple. To calculate the density we should know the temperature and the amount of hydrogen gas present. As for the temperature: we don't know. As for the amount of hydrogen: it is certainly small, but nobody can say whether it is one part in a hundred thousand or one part in a hundred million, and the result of the calculation will differ greatly depending on whether the one or the other value is used.

But the conditions in higher layers of the atmosphere are not only worth knowing for the sake of knowledge, they are of great practical importance. Aviation is forging higher and higher, but if you want to fly safely at 40,000 feet you should know conditions well up to 60,000 feet. And if later rocket airplanes want to go up to 60,000 feet it would be useful to have a good picture of conditions up to 100,000 feet.

The balloon *Explorer II* reached an altitude of 72,395 feet on November 11, 1935, and remained at its ceiling for one hour and a half. It was the biggest and most expensive balloon ever built and it carried a full ton of scientific equipment. When at the ceiling, the men in the spherical gondola had 24/25 of the total mass of the earth's atmosphere under their feet and the sky, of a normal blue near the horizon, looked darkish near the zenith. The zenith

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[3] *Weather Manual for Pilots* (War Department, May 27, 1940), Technical Manual TM 1-230.

itself was presumably black, but could not be observed because of the gas bag.

Outside of the spherical gondola a small propeller was mounted at the end of a long strut. The gondola was painted white on one side and black on the other, and the propeller was to turn gondola and balloon around so that either the white or the black side were exposed to the sun, depending on whether it was too warm or too cold in the gondola. At peak altitude the propeller worked with 5000 revolutions per minute, but it had no noticeable effect. The air was too thin for propellers!

The balloon *Explorer II* brought very valuable data back to the ground and the flight was a great success in every respect. But stratosphere research cannot depend entirely on balloon flights of this kind. Such balloons are of enormous size and need a very large ground crew to handle them. They are too expensive in themselves too, especially since the bag cannot be expected to last for more than one flight.

Sounding balloons are inexpensive, but that does not mean that they are ideal. The bag of a sounding balloon consists of rubber and the lifting hydrogen or helium inside keeps expanding the bag at a rate equal to the drop of outside pressure. This goes on until the bag bursts; the instruments then return by parachute. It sounds like a neat trick, but it has its drawbacks. The balloon may drift for a long time until it bursts and the instruments returning by parachute experience another drift, although of shorter duration. Consequently the ratio of instrument losses is high, so high that it is useless to release balloons on days with zero visibility.

More important than the high ratio of losses and the interruptions of series of data because of "grounding" in zero visibility is the fact that sounding balloons rarely ascend to the normal ceiling of aircraft equipped with superchargers. Those records of 70,000 and 100,000 feet are very definitely records far above the average performance. Not even 30,000 feet can be counted on every time.

The meteorological rocket will be able to take over from that point on, carrying instruments to any desired altitude in any kind of weather without an important amount of drift during the ascent.

A meteorological rocket able to duplicate the feats of the most successful sounding balloons can be achieved in the *near* future. The One-Stick Repulsors of the *VfR* were the prototype, and it would take no more than two years of intensive work to make the meteorological rocket a reality. (Fig. 30.) It is so close to reality that it can be described even now.[4]

The rocket, looking almost precisely like a One-Stick Repulsor, would be of the nose-drive type, i. e., the rocket motor would be located on top in a fork formed of fuel lines and struts and would pull the rocket. The whole rocket would weigh 20 kilograms (44 pounds) when ready for the take-off. Of this total weight half goes for liquid oxygen and fuel, 1 kilogram is the allowance made for the instruments, while the rocket with parachute weighs 9 kilograms. Its total height, not counting the "fork" and the rocket motor at its end, would be close to 3 meters or about 10 feet.

To begin with the motor: it would have to deliver a thrust of 60 kilograms (132 pounds) and develop an exhaust velocity of 2500 meters per second. Burning 236 grams of fuel and oxygen per second, it would use up the whole available supply of 10 kilograms in 42.5 seconds. The material for the motor would be aluminum or another metal characterized by a high heat conductivity factor. It would be water-cooled or fuel-cooled in the manner employed by Dr. Sänger.

Air-cooled, or rather uncooled, motors are unlikely to stand up for that length of time. I remember that Krupp engineers, visiting the *Raketenflugplatz,* told long stories about a marvellous new steel for safety deposit boxes which had been developed by their firm. They claimed that it was virtually burglar-proof, not because it would not yield to a cutting torch in the end, but because cutting it would take so long and require so much oxygen that a burglar could not carry the necessary amount. They later mailed us a sample of that steel, a sheet of the proper thickness which we soon made into a rocket motor of the "standard" type.

It looked a sinister dull grey when it was screwed to the test stand. It still looked dull grey a second after the beginning of the test run. Then it turned dull red, grew a bright cherry red, and a split second later the experiment ended in a beautiful display of bright sparks.

As I said before, the motor would have to be water- or fuel-cooled.

The tanks of the meteorological rocket would consist of seam-

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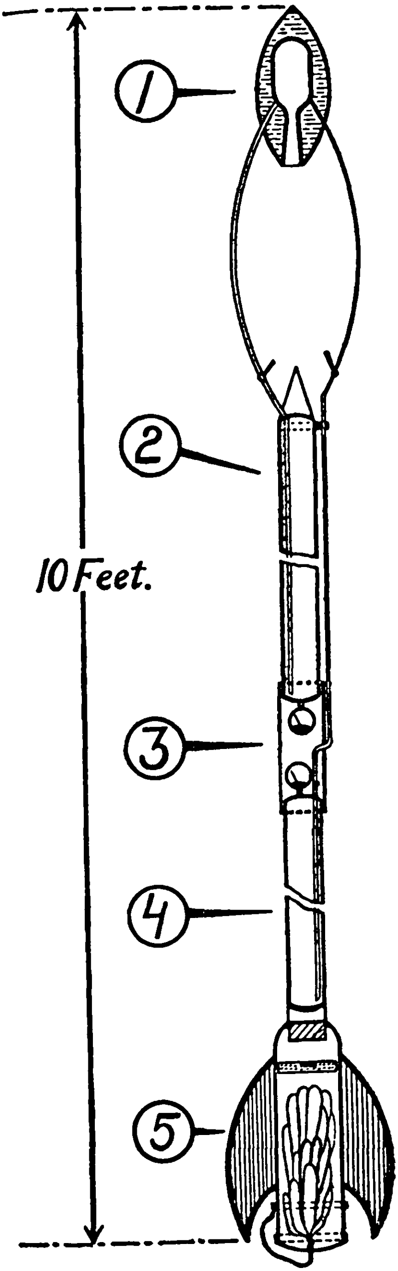
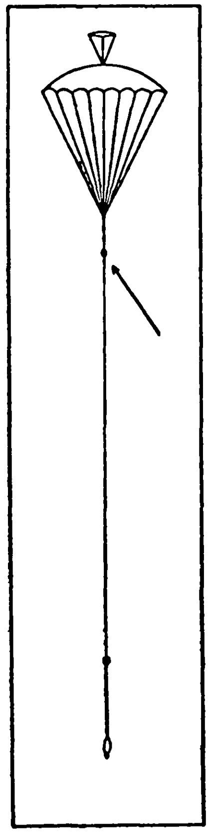
[4] This description is based on two articles by Ley and Schaefer: "Les Fusées volantes météorologiques" in *l'Aérophile* (Paris, October 1936), and "Meteorological Research by Means of High Altitude Rockets" in *The Military Engineer* (Washington D. C., November 1943).





30. Diagram of the One-Stick Repulsor. 1.—Motor with cooling water-jacket; 2. —Oxygen tank; 3.—Connecting piece with pressure gauges; 4.—Fuel tank; 5.—Vaned parachute container. This compartment would be elongated to hold meteorological instruments.
The inset shows the returning rocket; the arrow indicates the meteorological instruments. The empty rocket touches the ground first, thus relieving the parachute of all weight but the instruments for the remaining 40 or 50 feet.

less tubing of light metal alloys. A lightly coppered magnesium alloy would be preferable because of its lesser specific weight, but the better grades of aluminum alloys (for example, the type 17 ST) could be used just as well, since the weight margin is not as narrow as is believed by a number of rocket enthusiasts. The outside diameter of the tanks would be 100 millimeters or about 4 inches; their inside diameter would depend on the material used. The tanks should be able to stand an internal pressure of around 550 pounds per square inch.

The total length of both tanks together would be 2500 millimeters or about 100 inches which allows for "empty" space above the fuel and oxygen levels. How the tank length is divided between the fuel tank and the oxygen tank (the latter would be on top) would depend upon the fuel used.

There are no "secret" rocket fuels. Anything that is liquid and will burn can be used. The question is merely which one will perform best and is most advantageous all around. Benzene, for example, while excellent in many respects, is barred because its freezing point is too high, and freezing, because of the vicinity of the super-cold liquid oxygen, is a factor to be considered. Other hydro-carbons which might be good are barred because they are either too expensive or not readily available or both. Liquid methane is an excellent fuel, but I am opposed to it because I have discovered that one liquefied gas is enough trouble. Why bother with two?

The best and cheapest fuels are simply gasoline and alcohol. The advantage of gasoline is that it is even more readily available than alcohol; the advantage of alcohol is that it is chemically uniform. It has the further advantage of requiring less liquid oxygen; the ratio of oxygen to alcohol for complete combustion is 2.08 to 1, while for gasoline it is 3.5 to 1 (the "1" represents the fuel in both cases). The length ratio between fuel tank and oxygen tank would correspond with the weight ratio for complete combustion, but the choice of fuel would not affect the total length of both tanks taken together.

Below the fuel tank, tubular space of the same diameter would be provided for the steering mechanism, the instruments to be carried, and, finally, for the parachute and its release mechanism. The total length of this space would be 500 millimeters or about 20 inches—5 or 6 inches more would be nothing to worry about.

There is little to be said about the parachute and its release mechanism. Whether a steering mechanism will be required or not cannot be decided without full-scale experiments; so far it looks as if there is a good chance that the rocket can do without it.

If it is needed, it would be a small gyroscopic instrument that produces the proper movement of steering vanes which prevent the rocket from veering off the vertical path. The type of instrument required exists, but only in an application for airplanes. The existing type would, of course, be much too heavy for a rocket. It also would be—which may seem strange—too accurate. The existing variety or varieties are useless for this purpose. But instrument designers feel confident that the design of a small and light mechanism of that type will not present any great problems. The job is simplified by the fact that such a mechanism will not have to run for more than a few minutes at a time and that it will not have to do more than prevent deviations of more than 5 degrees from the vertical.

But, as I said, it looks as if it can be done without such an instrument which, although it would not be a very difficult problem, would increase the cost of such rockets.

In order to find out how such a rocket would perform it was necessary to calculate the theoretical performances of a number of rockets. The method of calculation and tables of the final results are given in the *Addenda* at the end of this book, but the problem itself can be explained at this point.

The rocket, at the moment of the take-off, weighs 44 pounds. If the rocket motor developed a thrust of only 44 pounds, nothing would happen at first. But then the rocket would begin to grow lighter because of the steady fuel consumption, while the thrust of the rocket motor would remain the same. The rocket would begin to rise slowly, gathering speed, until the fuel supply was exhausted. At that instant it would attain the highest velocity of its ascent and would continue until its kinetic energy has been eaten up by the action of gravity and by air resistance.

We'll now assume that the rocket motor has a thrust of 88 pounds, twice the weight of the fully loaded rocket. Then the rocket would ascend with an acceleration of 32 feet per second for every second elapsed. It would be like a fall in reverse on general principles, but with a few minor modifications.

These modifications are, I hasten to add, minor only in this particular example. It is easy to imagine cases where they would become major modifications.

The modifications are these: It would be a reversed fall if the rocket motor had a thrust of precisely twice the weight of the rocket at any instant during the ascent. Since the weight of the rocket goes down as fuel is consumed, the thrust of the motor should go down too to fulfill this condition. But the thrust remains practically the same throughout the burning time. Because of this not only does the speed of the rocket mount, the acceleration increases also. In other words, the rocket does better than merely demonstrate a reversed fall. But now another complication sets in: air resistance. It gets worse the higher the speed becomes.

The initial acceleration of a rocket is expressed in terms of *g*. The rocket of the first example which has only as much thrust as it weighs itself—and which begins to rise only when it weighs less—has an acceleration of 1*g*. That one *g* is spent fighting gravity and therefore does not count really. The second rocket, with a thrust of twice its weight, has an acceleration of 2*g* or, since one of them is counteracted by gravity, of 1*g* effective. It has become customary to talk only of the effective acceleration. If you wanted to be strict, you'd have to say that a given rocket has an acceleration of 5*g* or 4*g* effective. But it is simply called a 4*g* rocket.

The rocket designer now finds himself in the following dilemma. (We'll assume that he has no trouble building a rocket with as many *g* as he likes.) If he builds a 1*g* rocket, everything is nice and moderate. The acceleration is 1*g* in the beginning and goes up slowly to around 2*g* for the last few seconds of burning. The velocity mounts accordingly, never reaching very high values and, therefore, never causing any excessive air resistance. But such a low-acceleration rocket is apt to be unstable in air. It might require a stabilizing gyro-instrument.

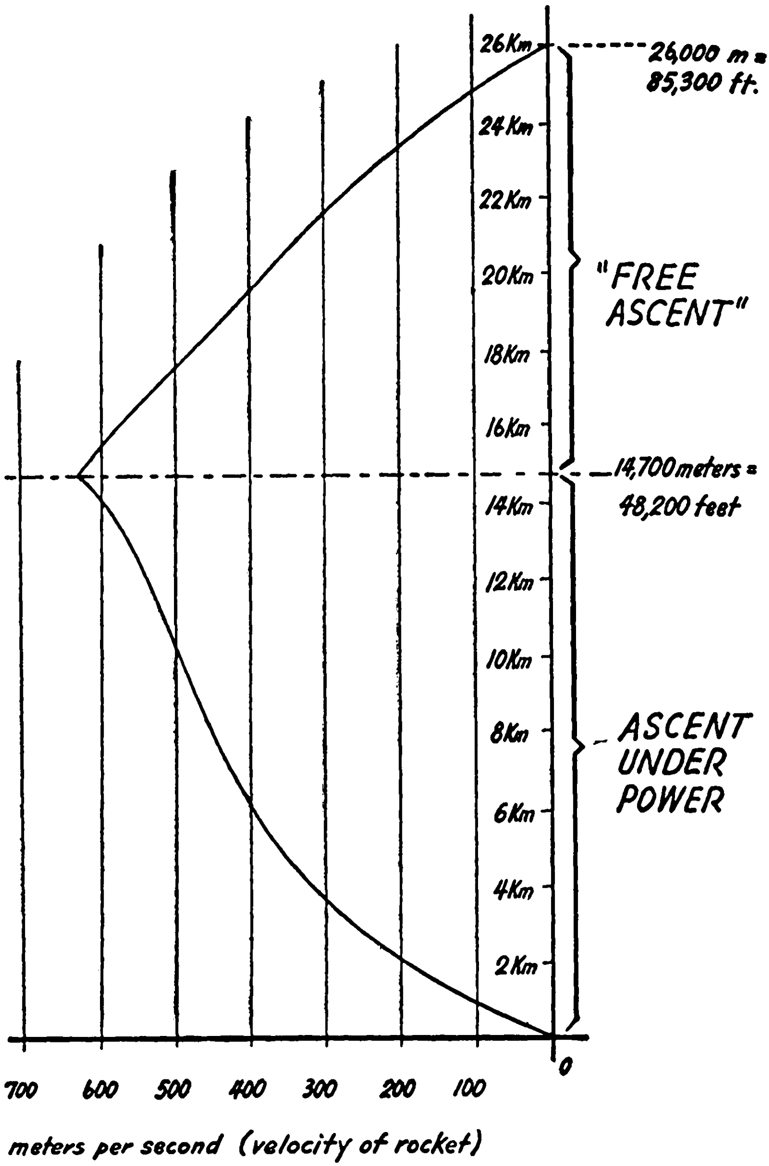
So the designer goes to the other extreme. He builds a rocket with 10*g*. It accelerates like mad and produces proportionate velocities. Or rather, it wants to, but fails because the air resistance very quickly goes up to such a value that the rocket spends most of its energy fighting air resistance instead of climbing.

At this point I am pleased to introduce two more complications, both of which, for a change, are favorable. One of them is that gravitational attraction falls off at great heights. But this is not much comfort in reality, because the heights where this begins to help are immense; it doesn't begin to show until after the first 600 miles. The other complication, which *is* a comfort, is that the density of the atmosphere, and hence the air resistance, falls off too. And that shows very soon; it begins to be really helpful after the first 6 miles. Clearly, then, a rocket should accelerate fairly slowly so that the velocities do not become high until above the 6-mile level. In this way the rocket will spend more time fighting gravity, it is true, but it will not fight unnecessary air resistance, which happens to be a more important factor in meteorological rockets.

The problem is now to find an acceleration where the air resistance encountered stays within reasonable limits but which is high enough to make the rocket stable without a special stabilizer. There is no definite theoretical answer to that problem. Schaefer and I are inclined to believe that even a 1*g* rocket might be able to do without a stabilizer. It is not quite certain, but it is very likely. For a 2*g* rocket, the type I have been describing all the time, it may safely be assumed. Fig. 31 shows its velocity diagram.

It can be seen that the velocity goes up fairly rapidly until it passes the mark of 300 meters or about 1000 feet per second, which is about the speed of sound in air. Then, although the velocity continues to increase, the rate of increase falls off. Only near the end, when the rocket is above 30,000 feet, does the velocity increase again at a greater rate. There are two reasons for this. One is that the rocket is now very light, having used up most of its fuel. The thrust is now relatively higher, and the rocket acts like a rocket with higher acceleration which, of course, is the case. The other reason is that the density of the air has decreased greatly at that altitude, and the air resistance is less even at higher speeds. The top speed of this particular rocket is roughly twice the speed of sound. It is attained at the instant the fuel supply gives out, which takes place after 42.5 seconds at an altitude of 14,700 meters or 48,200 feet.

Now, with the rocket motor silent, air resistance and gravity can really go to work. With combined efforts they manage to kill the speed of the rocket in a little over another minute or so. The rocket, of course, keeps climbing until the speed becomes zero. This takes place at an altitude of 26,000 meters or 85,300 feet, roughly 10,000 feet above the peak of *Explorer II*. Then it begins to fall back.



31. Speed Diagram of a Meteorological Rocket.
The curve shows the speed of the rocket at any moment during its ascent under power until the supply of fuels is exhausted. This point lies at 48,200 feet, but the rocket at that moment has a speed of about 620 meters per second (1985 feet per second) which is sufficient to carry it upward for another 37,000 feet to a total altitude of 85,300 feet.

The curve shown in Fig. 31 is based on calculation, but the actual curve will be very much like this calculated curve. And such a rocket can be built.

But there are a few things to be added here before we go on. The curve for the 1*g* rocket shows a higher altitude (almost 31,000 meters), but it might need a stabilizer. The curve for the 4*g* rocket, which was also computed for comparison, shows a peak altitude of only 20,600 meters; that rocket is too fast too early and spends too much energy fighting air resistance.

On an airless planet, say when taking off from the moon, the rocket with the highest acceleration would go the highest, since it spends less time fighting gravity. But in our atmosphere the fight against air resistance is much more important than the fight against gravity.

However, there is a way of avoiding the most troublesome layer of the atmosphere. It consists in letting the rocket take off from the top of a high mountain, where air density is less. Just to find out what would happen, the 2*g* rocket described was calculated to take off from two mountains, one 4000 and the other 5000 meters high (about 13,000 and 16,000 feet). From the top of the 4000-meter mountain the rocket attained 43,400 meters, instead of 26,000 + 4000 meters—a clear gain of more than 13,000 meters, accomplished by moving through rarefied air from the outset. From the top of the 5000-meter mountain the rocket attained 48,700 meters, a gain of close to 18,000 meters because it was still more rarefied air.

After that question had been settled, another question had to be investigated. What would happen if the instruments turned out to be rather heavy, if a stabilizer should be needed even for the 2*g* rocket, and if the whole construction turned out to be much heavier than (by comparison) the One-Stick Repulsors of the *VfR*?

It was assumed that the rocket would weigh 46 kilograms when fully fueled, not only 20 kilograms as in the first example. Of the 46 kilograms 20 kilograms were assigned as the dead weight, the other 26 kilograms being fuels. The rocket was assumed to have the same proportions as the first one, but thicker and larger all around.

The heavier 2*g* rocket was found to attain a peak altitude of 27,300 meters instead of 26,000 meters. That proved that a greater weight would not matter very much if necessary. Each ascent would cost only 2.6 times as much in fuel, not an important amount in dollars and cents.

But something else was proved by that calculation. The lighter 2g rocket attained 14,700 meters under power and coasted upward for another 11,300 meters. The heavier 2g rocket attained 12,800 meters under power, 1900 meters less than the first. But the heavier rocket then managed to ascend another 14,500 meters without power, 3200 meters more than the lighter one. In other words, what it lost under powered ascent it more than made up under free ascent. The heavier rocket, due to its greater weight, had more penetration than the lighter one.

This is the reason why, as I said before, the weight margins do not have to be watched as carefully as, for example, Winkler did.

As regards the instruments, it is unlikely that they will be responsible for a greater weight. Instrument builders have performed great feats since the days of Assmann, Besançon, and Hermite. They have, in particular, succeeded in eliminating a good deal of the annoyance caused by the high loss in equipment. This has been done by incorporating a small short-wave radio sender which relays the data to a station on the ground as it is registered on the instruments. By that means the data will go on record even though the instruments themselves may be lost.

A commercial model, the *Friez Ray Sonde*, weighs about 2.5 pounds. It comes in a box measuring 8½ inches in width and in height and 4¼ inches in depth. The radio sending set can transmit over an estimated maximum distance of more than 100 miles. It contains, aside from the radio transmitter and the battery, a baro switch measuring barometric pressure, a humidity element which has a range from 5 per cent to 100 per cent, and a precision resistance element with a range from + 30 degrees to — 70 degrees Centigrade with a sensitivity of less than one degree.

In order for this equipment to be used in a rocket, nothing would have to be done except to rearrange the units so that they would fit into the available space. The allowance made for the weight of the instruments in the calculations was 1 kilogram, only about 2 ounces less than they actually weigh. But since weight is not so important within small limits, it would be possible to carry additional instruments, for example an air sampler and a spore collector.

The main advantages of the meteorological rocket, when compared with a sounding balloon, are:

(1) The rocket can regularly attain the highest record altitudes of sounding balloons.

(2) It has less drift because of the rapid ascent, between one minute and ninety seconds for those altitudes normally reached by sounding balloons, while the sounding balloon requires between two and two and a half hours, rising at best only 200 meters per minute.

(3) The parachute drift of the rocket will be smaller too since the rocket descends somewhat faster than the instruments of a sounding balloon. The instruments of the rocket are, however, less apt to suffer damage because they are still some 30 feet or more above the ground when the rocket itself touches ground and relieves the parachute of its weight. The instruments would sink down very slowly during these remaining 30 feet.

(4) The batteries and the radio transmitter can be used to broadcast a monotone (using the rocket as an aerial) for as long as the batteries last (a period of several hours) after the mission is completed. This monotone will facilitate finding the rocket by means of triangulation.

The meteorological rocket can be realized soon. I know that after all this I will be expected to make an estimate of some kind and, although I am reluctant to do so, I don't want to disappoint this expectation. It is my estimate that the realization of the meteorological rocket, as described, will require an expenditure of around $2000-$3000 per month for a period of not less than two but not more than three years. (No overhead included.)

The meteorological rocket, the first goal of scientific rocket research, is definitely in view, thanks mainly to the work done many years ago on the proving ground of the *VfR*. But the theory goes farther. The theory says (and proves, as far as it is possible mathematically) that the space rocket, the rocket which ascends beyond the last traces of the atmosphere, will come after the meteorological rocket. The theory says too that the famous, much discussed and also much ridiculed "rocket to the moon" is possible too.

And I wish to affirm with great seriousness that the rocket to the moon *is* possible. Whether it has any practical value is another question and whether the experiment will actually be made is still another story. But these "higher" rockets are as possible as the meteorological rocket.

They are only farther in the future.

Chapter 8:

THE ROCKET INTO COSMIC SPACE

Alter erit tum Tiphys, et altera quae vehat Argo
Delectos heroas. . . .

There shall be another Tiphys and another Argo to carry
Chosen heroes. . . .—Virgil (Eclogues IV).

ONCE the meteorological rocket has become a fact of reality it will be possible to go on. The altitude to which a rocket can ascend is not limited by any natural law; it is limited only by engineering considerations. The theorist has little trouble in arriving at and writing down a set of figures and saying that these figures are the requirements for a rocket which is to attain an altitude of, say, 600 miles, just to name a figure. The problem is to realize that set of figures in actual engineering practice.

In a problem like this scepticism is not only permissible, it is desirable. The whole slump in scientific progress between A.D. 300 and A.D. 1400 was due to the fact that there was not enough scepticism in the world. On the other hand blind scepticism will not do. It must be scepticism of the "scientific" variety, which permits itself to be dispelled if proof, or at least probability, can be established.

In the case of the space rocket, by which term I mean an unmanned rocket capable of ascending beyond the 400-kilometer level to which our atmosphere extends, proof cannot consist of words. It can consist only of those figures which the theory demands, plus an investigation of their engineering feasibility. It will be necessary to go in for some figures now, but fortunately the problem, while difficult, is not even half as difficult as most people imagine.

Needless to say, the space rocket cannot be described in as much detail as the meteorological rocket at the present state of research. But it is quite possible to state the requirements and to give a number of general hints and ideas.

Essentially the space rocket will be an improved meteorological rocket. It will be of larger size, naturally, and it will require a more powerful rocket motor which is capable of furnishing an initial acceleration of around 2*g* for this heavier rocket.

The first engineering problem would be to create such a higher-powered rocket motor. All the other engineering problems, while rather diversified, can be grouped together under a common denominator: the "mass-ratio."

So far this term has not been used, but we are already familiar with its meaning—it is the ratio between rocket weight or dead weight, which, however, includes the so-called payload, and the weight of the fuels. In the case of the meteorological rocket described in the preceding chapter that mass-ratio was 2 to 1, the weight of the rocket at the instant of ignition (usually written M_0) was twice as high as the weight of the rocket plus instruments, etc., after all the fuel had been used up. (This empty weight is written M_1.)

It is obvious that it is the mass-ratio which, other things being equal, determines the altitude to which a rocket can ascend. If you have two rockets of the same weight when fully fueled, and alike in every respect except for the fact that one can hold more fuel than the other, that second rocket will have a longer burning time and consequently rise longer and higher.

The main problem, consequently, is the establishment of a high mass-ratio. How high? That depends on what you want to do. Many authors have stated in print that a moon rocket, an unmanned rocket which is to crash on the moon, would have to have a mass-ratio of about 20 to 1 which means that it would have to be 95 per cent fuel at the instant of take-off. This figure must not be accepted too readily for reasons which will soon become apparent, but it does give a good idea of the requirements which may have to be faced.

But first we have to study the natural laws which govern these requirements. There are only two that are really important—one deals with the velocity that has to be attained, the second deals with the mass-ratio required to attain a given velocity.

The first of these two laws is easy. It states that the velocity of impact *from* a given altitude and the velocity of departure *for* that altitude are equal. If there were no air resistance that law would mean that a bomb dropped upon an anti-aircraft battery from 30,000 feet would strike the ground with the same speed with which the anti-aircraft shell fired against the bomber leaves the muzzle of the gun. The law does not appear to hold true in the atmosphere because of the slowing action of air resistance which prevents the bomb from reaching a really high speed and which cuts the speed of the anti-aircraft shell down very quickly.

But this does not make the law invalid; it is only a complication which calls for a correction. For a purely theoretical investigation the complication caused by air resistance can be neglected at first; afterward corrections have to be put in, which is an awkward and tedious job. Forgetting about those corrections for a moment we get the first step in the procedure of investigating the problem of a space rocket. We determine, at first, how high we want to go in an example. Having agreed upon a figure for the height to be attained, we calculate the velocity with which a body dropped from that height would strike the ground. We get a figure which says that it would be so and so many feet per second. That is the velocity of impact. The velocity which the rocket has to acquire to rise to that altitude is the same.

The next step is to find out what mass-ratio would be required for that velocity and with that we run into the first minor complication. Suppose we found that the velocity should be 1 mile per second. If we used that figure we would not get one figure for the mass-ratio, but a dozen of them. The mass-ratio also depends on the fuel used or, more specifically, on the exhaust velocity of the rocket motor. Unless we agreed on an exhaust velocity first, we would never get anywhere with our calculation. But if we have to agree on a specific exhaust velocity we don't get a general answer.

The way out of this dilemma is simplicity itself. It consists in using the exhaust velocity itself, whatever it may be, as a yardstick. To be able to do that we only need to know what mass-ratio a rocket needs to attain its own exhaust velocity. That ratio is clearly always the same—if you have a higher exhaust velocity the rocket will have a higher velocity too after this ratio has been used up. If you have a lower exhaust velocity you will get a lower rocket velocity. But the ratio between the weight (mass) of the fueled and the empty rocket will be the same in both cases.

That ratio is 2.72 to 1. A rocket weighing 272 pounds at take-off and 100 pounds empty will acquire a velocity equal to its own exhaust velocity. This figure has been mentioned before (in the chapter "The Rocket's Red Glare, . . ."); it is familiar to any student of mathematics and mathematicians call it e. Its correct value is 2.71828183 . . . ; it is easier to call it 2.72. And it is still easier to call it e.

So the rocket, provided its mass-ratio is e, will attain its own exhaust velocity. Fine. But what if that is not high enough? We know already that a rocket can move faster than its own exhaust speed, provided it has still fuel left when it reaches that velocity. Provided, in other words, that it has a higher mass-ratio than 2.72. How much higher does the mass-ratio have to be for the rocket to attain twice its own exhaust speed? The answer to that question is that the mass-ratio has to be the square of e, in figures approximately 7.4. The cube of e is 20.1 and a rocket with that mass-ratio can and will attain thrice its own exhaust velocity.

Theoretically you can go on in that manner: e^4 would give you four times the exhaust velocity, e^5 would give you five times the exhaust velocity, and so on. But it seems extremely unlikely that it will ever be possible to build a rocket with a higher mass-ratio than 20.1 to 1 (the cube of e) and even that will be a very difficult job.

Now we have all the rules we need for a preliminary investigation of the problem of the space rocket. These rules will provide us with figures which will not check to seven decimals with actual conditions but which will be sufficiently accurate to determine what can and what cannot be done. And now we'll try our hand on a first example, an example in which we do not care about attaining a specific height, but in which our sole interest is to see how high we could go with a given exhaust velocity.

Supposing you know that an exhaust velocity of 2000 meters per second (6560 feet per second) is the best that can be achieved at a given time—the "standard" motors of the *VfR* did approximately that—so you use this value for the exhaust velocity. By careful trimming of every superfluous ounce of metal on your rocket you achieve a mass-ratio of the square of e or 7.4 to 1. Your rocket will then attain a velocity of 4000 meters per second. Now 4000 meters per second is the theoretical impact velocity of a body falling from a height of 1310 kilometers (roughly 820 miles). Your rocket would ascend 820 miles.

It would ascend to 820 miles, that is, if you cast a spell which creates an airless shaft a few hundred yards in diameter in which your rocket can climb against the pull of gravity without the unfair interference of air resistance. Or else, if you are not good at casting such spells, you may find a non-miraculous method of transporting your rocket to a height of 25 miles first. In that case the figures given would hold approximately true without the aid of additional miracles.

Meanwhile, of course, your worst competitor for the *Prix Guzman* has succeeded in coaxing an exhaust velocity of 3000 meters per second out of his rocket motors without resorting to a "secret fuel." Three thousand meters per second is a great achievement, but it is not impossible. By filing off a quarter of an ounce of metal here and sawing off an ounce of metal there the same way you did, he also accomplishes a mass-ratio of *e* square. This gets him a final velocity of 6000 meters per second instead of the 4000 you accomplished. Theoretically his rocket will rise to 3820 kilometers or about 2400 miles.

The two examples not only show how important a high exhaust velocity is—we know that already—they also show that high exhaust velocity and high mass-ratio can be exchanged to a certain extent. This is important for one reason: high exhaust velocity is, of course, preferable, but there are limits to the exhaust velocities that are available—or should I say attainable—and these limits are, unfortunately, rather low. There are limits to possible mass-ratios too, but they are not quite as narrow.

Exhaust velocities are limited by the amount of energy imprisoned in the fuels that exist. Theoretically alcohol and oxygen in proper proportion can produce a top exhaust velocity of 4180 meters per second (for gasoline the figure is 4450 meters per second). But no rocket motor can be 100 per cent efficient. The top velocity that can be reliably expected for either one of these two fuels is about 2500 meters per second; 3000 meters per second may be possible, but it is not as certain. That value, when obtained, will really represent the limit for these fuels.

A more powerful fuel is known. It is hydrogen with a theoretical exhaust velocity of 5170 meters per second. Only one isolated experiment with hydrogen has been made so far (by Oberth) and it seemed to indicate that 4000 meters per second may actually be obtained.

But hydrogen is not as ideal a rocket fuel as this figure may lead one to believe. It has quite a number of unpleasant characteristics which are, to say the least, annoying. One of these characteristics is that even the temperature of liquid oxygen is still some 70 degrees

Centigrade too warm for liquid hydrogen, which is to say that hydrogen is still colder than oxygen when liquefied and proportionately more difficult to handle and to control. Anything of even approximately normal temperature will set it boiling furiously.

Another drawback is that hydrogen, even when liquid, is very light and consequently bulky. This means larger tanks which, of course, means greater weight. A rocket that will have a nice mass-ratio for heavier fuels will not have that same nice mass-ratio for hydrogen. And to make that factor even worse, hydrogen does not behave quite "properly" in the combustion chamber. It will be necessary to have a considerable hydrogen surplus so that the exhaust consists of water vapor (burned hydrogen) and unburned hydrogen. This, of course, means still bigger and consequently still heavier tanks. As a matter of fact, Oberth decided that hydrogen would not do for rockets at all as long as the rockets were still in the atmosphere. Hydrogen, in short, cannot be counted upon as a rocket fuel right now.[1]

For the present, and for the near future, the rocket fuels will be gasoline or alcohol. The early space rockets, for all these reasons, will be rather similar to meteorological rockets; in fact there will not be much difference between improved meteorological rockets for the highest layers of the atmosphere and rockets which are to go beyond these highest layers.

[1] For the more distant future one may speculate on monatomic hydrogen as a rocket fuel. Monatomic hydrogen is hydrogen in which each atom is independent instead of being tied to another hydrogen atom to form a normal hydrogen molecule (H_2). Purely on paper monatomic hydrogen will yield a theoretical exhaust velocity of 21,000 meters per second, actually a little more than half of that might be attainable. So far, however, this is pure speculation; it is not even certain whether monatomic hydrogen could be manufactured and stored in appreciable quantities. This also holds true for the famous "fission" of the atoms of Uranium U-235. At present nobody can manufacture U-235 in lots visible without a microscope. And while U-235 releases enormous amounts of energy, that energy appears simply as heat and it is hard to see how it could be applied in rockets.

Just to forestall possible false hopes, I wish to point out that high explosives like nitro-glycerine, guncotton, TNT, etc., are *far weaker* than gasoline or alcohol. They are destructive by virtue of the rapidity of their combustion; if they could be slowed down to useful speeds they would be inferior fuels. The theoretical exhaust velocity of nitro-glycerine is 3880 meters per second, that of dynamite 3300 meters per second, that of picric acid 2600 meters per second. Compare this with the values for alcohol (4180 meters per second) and for gasoline (4450 meters per second).

High explosives, to repeat, are weaker than ordinary fuels, and they would be inferior even if they could be used.

While the higher mass-ratio of these rockets will be the main improvement, a few other improvements are possible which may be termed "minor" by comparison, but which are rather important by themselves.

The example of the meteorological rocket has shown that the natural combination of constant thrust and diminishing weight produces an increase of the acceleration. That increase is not advantageous if it takes place too early or rather too near the earth where the density of the atmosphere is still considerable. But that increase is a decided advantage if it takes place at a high altitude, say after the 10-mile level has been passed. It would be desirable to increase the thrust of the rocket motor from then on. Since the exhaust velocity is given, the thrust can be increased only by burning a larger amount of fuel per second.

This could be accomplished in more than one way. One solution would be to have a second set of fuel and oxygen lines from the tanks to the motor, and this would be opened by a timing device after the calculated number of seconds had elapsed. Another possibility is this: It is likely that a rocket of such size will have several fuel and several oxygen tanks. We'll assume that the motor draws from one set of tanks only during the ascent to 10 miles. The capacities of the tanks may be such that they are emptied when an altitude of 10 miles has been reached. The same timing device that was previously used will then switch on the second set of tanks, tanks with wider fuel lines and larger valves which deliver a larger amount of fuel to the rocket motor.

It would be an additional improvement if a design could be arranged which completely disconnected the empty first set of tanks so that they fell off. (The tanks would, of course, have a parachute attached to them so that they would neither be damaged nor cause damage.) This would improve the mass-ratio further since the rocket would not have to carry the dead weight of the empty tanks all the way up. The higher power of penetration due to greater weight, which was so comforting in the case of the meteorological rocket, no longer plays a role in the really rarefied layers above the Heaviside layer.

The idea of dropping empty tanks leads to the conception of the so-called "step rocket" where a large rocket serves as the "lower step" for a small rocket. This would be the "non-miraculous method" of transporting a rocket to an altitude of 25 miles. It has an additional advantage in that the "lower step" not only transports the small rocket to that height, but also endows it with a considerable velocity before it even begins to work itself.

But we have not yet exhausted the list of possible improvements of a single rocket.

There are no better fuels for the present and for quite some time to come than the very ordinary liquids known as alcohol and gasoline. But there is, there conceivably is, something better than liquid oxygen. Theoretically, at any event, there *is* something better: liquid ozone.

Ozone, discovered by the same chemist Schönbein, who had that adventure with guncotton mentioned in Chapter 4, is a modification of oxygen. Ordinary oxygen has two oxygen atoms per molecule and is called O_2 for that reason. Ozone has three oxygen atoms per molecule, hence is called O_3. It is, to all intents and purposes, a kind of concentrated oxygen. It has a higher specific gravity—a tank which can hold 6 pounds of liquid oxygen can hold almost 10 pounds of liquid ozone. This alone, as can easily be seen, will increase the mass-ratio, since the tank itself weighs the same, no matter what it contains.

Connected with the higher specific gravity is the fact that liquid ozone does not have to be quite as cold as liquid oxygen to stay a liquid. Liquid oxygen boils at —183 degrees Centigrade; liquid ozone boils at —119 degrees Centigrade.

As far as tank capacity goes, liquid ozone simply means more oxygen in a given space. As far as the combustion chamber is concerned, liquid ozone means even more. It means more energy and a higher exhaust velocity. Liquid ozone can be formed only if it can absorb energy (719 calories per gram) which may be supplied by ultra-violet radiation, electric discharges, or heat. But when the ozone enters the combustion chamber it reverts to ordinary O_2, releasing the energy it absorbed before. Alcohol with ozone, for this reason, develops a theoretical exhaust velocity of 4630 meters per second (4180 with oxygen), gasoline develops 4960 meters per second (4450 with oxygen), and hydrogen 5670 meters per second instead of 5170. Burned with ozone alcohol may deliver 3500 meters per second instead of the 3000 meters per second which appeared to be the possible maximum.

But ozone, a dark blue liquid, is unstable. If it gets a bit too warm it may revert to ordinary oxygen with explosive suddenness. This, as the handbook on chemistry puts it, "will be accelerated catalytically by the presence of water, alkalies, metal oxides, metals of the platinum group, organic substances, and chlorine." It is a thoroughly untrustworthy substance.

However, the case is not yet hopeless.

The transformation of ozone into oxygen apparently is not only brought about by catalysts, of which there are many in this particular case, but the ozone reaction also seems to take place occasionally without a catalyst around.

The point I am trying to make is that the latter is not absolutely certain. For the simple reason that many different substances *can* serve as catalysts for this particular reaction, it is extremely likely that there *was* a catalyst around every time the reaction took place. It is quite possible—though of course not certain—that liquid ozone which is free of all impurities (at least of those that can act as catalysts) will be stable and reliable. Not enough research has been done on that question yet to permit judgment.

But if it should be found that the number of possible catalysts is so large and so widespread that contamination is impossible to avoid, there is still another hope left. There are not only catalysts, there are also anti-catalysts, substances which prevent the catalysts from making their presence felt. If a reliable anti-catalyst for the ozone reaction could be found, the problem would be solved. Until then ozone in lieu of liquid oxygen is a beautiful but unreliable hope.

Let's see now how far we have progressed.

Fuels: still alcohol or gasoline, with a top exhaust velocity of 3000 meters per second, approximately 500 meters per second more if ozone can be tamed.

Tanks: of maximum size and capacity, but not larger than compatible with an initial acceleration of about 2g.

Other changes: thrust increase above 10 miles, coupled with possible dropping of empty tanks.

Probable altitude to be expected from all this after sufficient research and preliminary experimentation: around 600 miles.

What else can we do? So far everything has been merely a development of things already done in the past, but now we do have to make a new invention.

The tanks of our rocket are sturdy magnesium or aluminum alloy tubes with an internal pressure that forces the fuels into the combustion chamber as soon as the valves click open. Naturally such tanks are fairly heavy. They could be built much lighter only if they held the fuel in the manner of a gasoline tank in a car or in an airplane. But in that case you would need an additional mechanism to get the fuels into the motor. You would need a pressure pump. If you succeeded in making the pump light enough so that its added weight did not surpass the weight saved by lightening the tanks, fuel pumps would be advantageous.

It is obvious that you cannot have pumps in a small rocket such as the 10-foot meteorological type. But for larger rockets the use of pumps does promise a reduction of "dead weight."

But the requirements for these pumps are difficult, to say the least. They must be light and not bulky. They do not have to pump the fuels under very high pressure (only around 400 pounds per square inch), but they must pump large quantities in a short time. On the other hand, they will have to be in operation for only about two minutes.

So far a good design for such pumps does not exist, but Oberth outlined an idea for them. Inside the large thin-walled tanks he placed small sturdy pressure tanks. A valve in the pressure tank permitted the fuel to run in. When the valve closed, a tiny amount of oxygen was injected into the pressure tank and ignited. The oxygen burned a small amount of the fuel and thus generated pressure in the small tank. This pressure forced the remaining fuel into the motor. Of course Oberth's design would require a pair of pumps working alternately—one running full of fuel while the other ejects it. In the oxygen tank the arrangement would be the same, except that a small amount of fuel would be injected into the oxygen.

Some critics, for example Doctor von Hoefft, have called these pumps "suicide contraptions." This is not necessarily so. By carefully limiting the amount of oxygen to be injected, you can be sure not to create a higher pressure than the tank will stand. On paper, at any event, it looks like a possible solution and it is also likely to work in reality. So far it hasn't been tried.

The objection is not so much the probable danger as the complicated design and the probable weight. You have to have several valves which open and shut in perfect synchronization. One of the valves has to do the dosing. The ignition has to come just at the proper moment. And one set of these pumps has to work immersed in liquid oxygen. These pumps, in short, require a lot of auxiliary apparatus and moving parts, while the ordinary high-altitude rocket has absolutely no auxiliary parts. It has, as a matter of fact, no moving parts at all.

It might be easier to use Oberth's pumping scheme without the injection of small amounts of fuel or oxygen. A small flask of compressed gas could be used instead. This flask could periodically inject a certain amount of compressed gas (nitrogen in the fuel tank and helium in the oxygen tank) into the small pressure tank. It would serve the same purpose without any danger of explosion and it also might weigh less. At any event, it is easier to build.

It was the pet theory of some of the engineers at the *Raketenflugplatz* that a sufficiently large rocket motor would not require pumps but would get its fuels from the tanks by suction, provided it had been running for a few seconds under pressure first. One accident seemed to indicate that these hopes might be justified to a certain extent. In the middle of the test run of a large rocket motor, the pressure valves snapped shut but the motor continued to run. Doubtless there was a loss of thrust for the remainder of that test run, but doubtless the motor kept on burning. The thrust measuring device must have been influenced by the accident too; it had stopped registering when the valves clicked shut. (I did not see that test run myself.)

This happened during the preparations for the Magdeburg experiment, and there was no time to make deliberate tests. If this last theory should work, the solution would be to build a set of small, strong tanks to start the motor going, in addition to the actual fuel tanks. If it should not work, pumps will be needed.

After a suitable pump has been invented by somebody, we may expect the mass-ratio of a rocket to go up to about 10 to 1, resulting in a velocity of about 2.3 times the velocity of the exhaust. But exhaust velocities being what they are, even such a rocket would still be chained to our planet, although with a rather flexible chain. Still, it is not enough to get away from the earth entirely.

This is a good place to go back to Jules Verne and his moon gun and to examine the scientific background of his famous novel. The principle involved is what in physics textbooks goes under the name of "velocity of liberation," sometimes also called "velocity of escape" or "escape velocity."

Everybody has learned at some time that all bodies fall with the same speed—first demonstrated by Galilei—and that the power of gravitation diminishes with the square of the distance. The latter part of that sentence is usually not quite clearly understood, while the early part of it is not even quite correct.

One should say that all bodies fall with the same acceleration. A ball of lead and a ball of hardwood, both dropped from the height of 1 mile, will fall under equal acceleration and, since they both fall for the same distance and the same length of time, they'll both arrive with the same velocity. If one of them were dropped from an altitude of 2 miles, it would arrive with a higher impact velocity than the other. But it would not arrive twice as fast.

The power of gravitation decreases with height or, more precisely speaking, with distance from the center of the earth. If it has a certain value at the distance of one full diameter from the center—or a half diameter of the earth from the earth's surface—it will have only one quarter of this value at the distance of a full diameter from the earth's surface. It will have only one ninth of this value at the distance of three half diameters from the surface (three radii), one sixteenth of that value at the distance of four radii, one twenty-fifth at the distance of five radii. It can easily be seen that the earth loses its grip rapidly.

Keeping this fact in mind, it is easy to understand why a fall from a distance of four radii does not produce twice the impact velocity of a fall from a distance of two radii. While the distance may increase by leaps and bounds, the impact velocity will increase comparatively slowly. And even if the distance is infinite, the impact velocity will by no means be infinite.

A body striking the earth after a straight fall from infinity (which means any distance you wish to name just so long as it is big enough) will strike the earth with a velocity of about 11,200 meters per second which is almost the same as 7 miles per second. The gravitational might of the earth cannot produce a higher velocity than that.[2]

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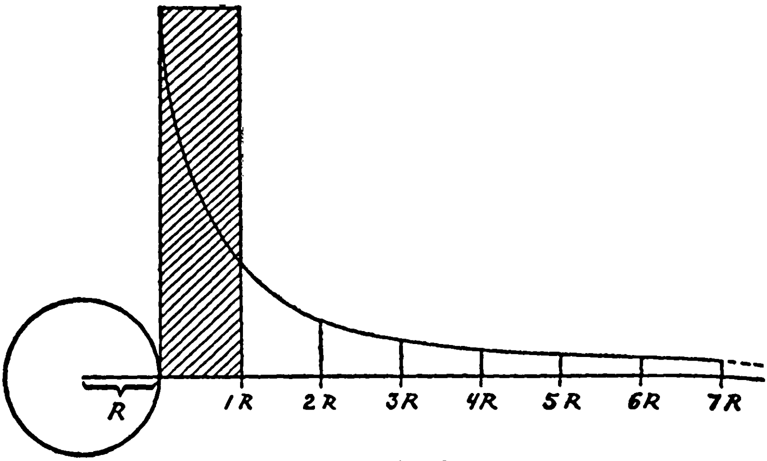
[2] Meteorites frequently enter the atmosphere of our planet with a higher velocity than that, but this is not due to attraction. The meteorites have a high velocity of their own which may be added to the orbital velocity of the earth when earth and meteorite run into each other. And the orbital velocity of the earth alone is much higher than the velocity of liberation, amounting to 18.5 miles per second.



32. *The Gravitational Field of a Planet.*
The curved line indicates the falling off of intensity with increasing distance. The total field (the area under the curved line) equals an imaginary field which extends for the distance of one semi-diameter at surface intensity.

This is the *velocity of liberation.*

It receives its name from the general rule that you need a velocity equal to the impact velocity to throw a body back to the height from which it dropped. The work required to do this, incidentally, is the same as if that body had to be lifted for the distance of one radius from the surface in a gravitational field that keeps the same intensity throughout that distance. (Fig. 32.)

The basic idea of Jules Verne's novel is to fire a projectile vertically with a muzzle velocity of a little over 36,000 feet or about 7 miles per second. While the projectile ascends, gravity, pulling constantly, will reduce the speed of the shell more and more. But if it started out with 36,000 feet per second, it would reach the so-called neutral point between the earth and the moon in eighty-three hours and twenty minutes. In spite of all the efforts of gravity, it will have a speed of a few feet per second left, enough to crawl across the neutral point. Then it would be attracted by the moon and simply fall down upon its surface which would require another thirteen hours and fifty-three minutes, making ninety-seven hours and thirteen minutes for the whole trip.

So far everything is very nearly correct.

But then things begin to go wrong. The projectile is to be a hollow aluminum ball, 9 feet in diameter with walls 1 foot thick. The cannon, 900 feet long, is poured into a well dug for this purpose. Actually the cannon is only the lining of a barrel with walls of indeterminate thickness, formed by the soil of Florida. An arbitrary amount of guncotton (400,000 pounds) is put into the barrel, filling about 200 feet of it. This is supposed to produce a muzzle velocity of 54,000 feet since the president of the Gun Club, or rather Jules Verne, expects to lose the difference to air resistance. All this, as may be expected, is somewhat vague. Elsewhere in the novel it is stated that air resistance will not be important because the projectile, with its high speed, will require only a few seconds to traverse the atmosphere.

The latter statement is like saying that a slab of armor plate 3 feet thick cannot very well be expected to stop a 16-inch shell since the shell traverses the distance of 1 yard in a thousandth of a second.

If the experiment had actually been made, the experimenters would have found, to their great surprise, that their ball would have landed 100 feet from the muzzle after rising not much higher. And the shell would have been flattened and partly volatilized. The reason is that Jules Verne, who did worry a little about air resistance in the open air, forgot to think of the resistance encountered in the 700 feet of gun barrel. That column of air, 700 feet high and 9 feet in diameter, could not possibly get out of the way of a projectile moving much faster than sound. It would have to be compressed and the hollow ball or shell, as later redesigned in the novel, would have found itself between two very hot and enormously powerful pistons: the furiously expanding gases of the guncotton underneath and the column of air, heated by compression, above. The passengers, if everything had worked as Verne wanted it to work, would have been spread out into a thin film by the enormous acceleration of the projectile.

But even the shot itself would not have worked. As I stated in Chapter 2, a modified moon gun has been computed by Oberth and Valier for their own amusement. The results were as follows:

The projectile must consist of a high-grade steel alloy—for example tungsten steel—and must be practically solid. Its caliber must be 1200 millimeters (about 48 inches) and its length six times its caliber. The gun must be 3000 feet long and must be built into a mountain near the equator so that the muzzle is at least 16,000 feet above sea level. Before firing, the air has to be exhausted from the barrel and the muzzle has to be closed with a metal lid—padded with rubber around its rim—which is strong enough to resist the air pressure from above. Since the vacuum in the barrel cannot possibly be perfect, there will be a small amount of air left which is then compressed by the moving projectile and which will push the lid off just before the projectile itself reaches the muzzle.

Some years later Count von Pirquet went over the problem again and came to the conclusion that even this improved moon gun would fail to perform fully as required. In the first place, von Pirquet made the mountain 3000 feet higher so that the muzzle of the gun would be at an elevation close to 20,000 feet. Furthermore, Pirquet found that the gases of the propelling charge would not expand rapidly enough if the whole charge were packed at the bottom. He rectified this by attaching a considerable portion of the charge to the bottom of the shell and by furnishing a number of extra firing chambers along the length of the barrel, their mouths leading into the barrel from the side. But even after all this we cannot say whether the gun itself could be built and whether the national budget for an average war would be sufficient to pay for it.

You cannot shoot into space through an atmosphere like the earth's and against a gravitational field like ours. The moon gun on the moon—it would then be an earth gun—working against a lesser gravity and without any perceptible atmosphere would be possible. On earth it cannot work.

But while it is impossible to send a projectile into space, it is quite possible to send a rocket into space. Even without fuel pumps rockets could just attain open space above the atmosphere. And there is one additional trick that still is to be discussed: the step rocket. Oberth and Goddard both thought of it in their first theoretical studies. Even then the idea was not new; a Belgian patent, granted to Dr. André Bing in 1911, described that invention. You can find pictures and descriptions of step rockets in books on fireworks dating back to 1700 and earlier. The fireworks makers did not do it to gain an especially high altitude; they did it to obtain an impressive display. But the idea was there.

The step rocket consists in having a smaller rocket carried aloft by a larger one. The smaller rocket, when it is ignited, starts off from whatever altitude it was carried to by the larger rocket. But that is not the most important advantage. The important advantage is that the smaller rocket does not start with zero velocity but with the velocity attained by the larger rocket.

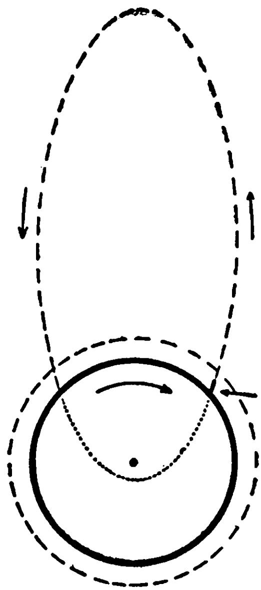
Again figures show much better how this works out than mere words. And in order to simplify our example, we are going to use a letter to designate the exhaust velocity. The letter customarily used for this is *c*, while *v* (velocity) is reserved for the velocity of the rocket itself.

For the purpose of our example we'll assume that we can build rockets with a mass-ratio of 10 to 1 and that we can build a rocket which weighs 1000 pounds when fueled and ready to take off. When empty its weight is assumed to be 100 pounds. Paying no attention to air resistance, we find that this rocket will attain a velocity of 2.3 times *c*. This, of course, would still be an ordinary rocket with a nice high mass-ratio. But then we build two rockets of this mass-ratio, one weighing 800 pounds (80 pounds when empty) and one weighing 200 pounds (20 pounds when empty). The larger rocket will carry the smaller one aloft. The total weight at the take-off is still 1000 pounds.

When the larger rocket which burns first is exhausted, it will have attained a velocity of 1.27 times *c*. The figure is less than the 2.3 times *c* mentioned above because this rocket does not have the full weight ratio of 10 to 1. It has that weight ratio when considered alone, but it carries the smaller 200-pound rocket and, as far as the performance of the first rocket goes, these 200 pounds are additional dead weight.

To repeat: the larger rocket, carrying the small one but otherwise empty, has attained a velocity of about 1.27 times *c*. Now the smaller rocket starts burning and the empty hulk of the first rocket drops off. For our private amusement we'll assume first that something goes wrong and that the empty shell of the first rocket does not drop off, although the design is such that the smaller rocket can function in spite of this handicap. Since both rockets together have the "overall" mass-ratio of 10 to 1, the final result will again be 2.3 times *c*. The imagined mishap, in other words, left the whole performance unchanged so that we might as well have had just one rocket of that mass-ratio.

But now we remedy whatever went wrong and then we get something better. Unhampered by the empty hulk of the large rocket, the small rocket by itself can attain a velocity of 2.3 times *c*. But when it began burning it already had a velocity of 1.27 times *c* from the efforts of the lower step. As a result, its final velocity becomes 1.27 plus 2.3 or 3.57 times *c*.



33. Orbit of a Space Rocket.
The orbit of a space rocket, although released vertically, would assume this form. The trajectory would be an ellipse with the center of the earth in one of its focal points. Save for the drift in the troposphere during the return, the trajectory could be calculated with great accuracy. The whole orbit would be traversed in "free fall," and only a short section of the ascent (marked by an arrow pointing to it) would be under power.

If you had wanted to attain a velocity of 3.57 times *c* with a single rocket you would have needed a mass-ratio of roughly 30 to 1. That a mass-ratio of 30 to 1 can actually be built is most unlikely. But it is not at all unlikely that a mass-ratio of 10 to 1 can be built. By building two rockets of the smaller mass-ratio and putting one on top of the other, you can achieve the higher ratio.

The step principle, in other words, makes it possible to achieve mass-ratios which cannot possibly be achieved by single rockets. If we assume that such a "two-step rocket" as described in the foregoing is powered by rocket motors capable of delivering an exhaust velocity of 2500 meters per second, it should reach an altitude of about 20,000 miles provided that all the little tricks to cut down air resistance, such as a take-off from a high mountain, were used properly. (Fig. 33.)

Twenty thousand miles from the surface of the earth is no longer "altitude"; it begins to be "distance" in the sense in which we speak about the distance at which a comet or a meteorite passes the earth. It is still a very short distance as astronomical distances go, but by the same token it is an astronomical distance, if only a short one.

Now we can talk about the moon rocket. You want to know how it could be done and how large it would have to be and whether it could carry a pilot and a million other things.

At the end of Chapter 7 I said that the moon rocket has to be considered as possible and I stick to this statement. It is possible, but it must not be expected to become a reality during the next decade. And it cannot be expected at all if meteorological rockets have not done their duty first for quite a length of time, and if space rockets have not been sent beyond the stratosphere in quite impressive numbers.

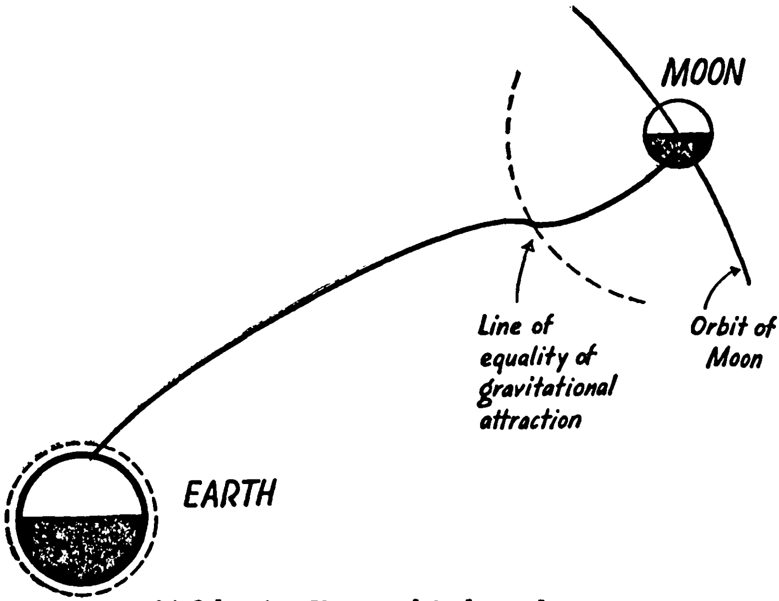
Logically as well as technologically the moon rocket is a specific variety of the space rocket. It is an especially large space rocket which follows a path through the void different from that taken by other space rockets.

The path followed by any ordinary space rocket which is to return to earth, whether it departs vertically or at a lesser angle, may vary in appearance. But it is always the same geometric figure: it is always and invariably an ellipse, with the center of the earth in one of its two focal points.

It obeys Kepler's laws with respect to the earth as a planet obeys these laws with respect to the sun. The path is, therefore, referred to as a Keplerian Ellipse. (Fig. 33.) The rocket travels almost the whole of that Keplerian Ellipse, except for the section below the surface of the earth. This same orbit, incidentally, applies to any artillery shell. The so-called trajectory of a projectile is simply the part of a very short Keplerian Ellipse that is above ground. In this case it is only a very short section of the complete ellipse, but it is a section of an ellipse, not a parabola as most instruction booklets state for the sake of simplicity.

Some sixteen years ago it was suggested that a space rocket be used for the rapid transportation of mail. It is true that such rockets, especially when departing at a lesser angle, would traverse very long distances in surprisingly short times, needing less than an hour to cross the Atlantic, for example. But this idea, theoretically correct as it is, may be considered dead by now. The accuracy would be poor. Even if it were less than 1 per cent of the distance, which I doubt, it would amount to a great deal because of the long distances. The place of descent would be within a circle with a diameter of about 50 miles over a distance of 3000 miles. A dispersion of this magnitude would imply the descent of the rocket on water where the watchers could see over great distances without the obstruction of buildings and natural formations. This then would necessitate retrieving the rocket by motor boat or helicopter and dispatching the mail to the addressees by ordinary means.

Even so the gain in time would be impressive when compared



34. Orbit of an Unmanned Rocket to the Moon.
The earth and the moon are drawn to scale, but should be eight times as far apart. The orbit would then look like a straight line. The rocket would need close to one hundred hours for the trip, but only seven or eight minutes would be under power.

with steamer mail. But if the competition is against transatlantic airlines, the gain in time would not be several days but only several hours, not enough to make the venture worth while.

The space rocket, to return to the theme, ascends along a Keplerian Ellipse, most of the ascent being, of course, "free ascent" after a few minutes of burning time. The gravitation of the earth gradually kills the upward momentum of the rocket until it comes to a standstill. Then it begins to fall back.

If we imagine that ellipse to be more and more elongated, the point farthest from the earth—technically known as the *apogee*—may fall beyond that imaginary line where the gravitational influences of the earth and the moon are equal. If that happens, if the *apogee* falls beyond that line, the rocket will not return. It will fall toward the moon.

The path described by it is shown in Fig. 34; it is curve-shaped, somewhat like a capital "S" which somebody tried to straighten out by pulling at both ends without very noticeable success. The curve consists of two sections of two different Keplerian Ellipses joined together, one section belonging to an ellipse with its focal point in the center of the earth, the other section belonging to an ellipse with its focal point in the center of the moon.

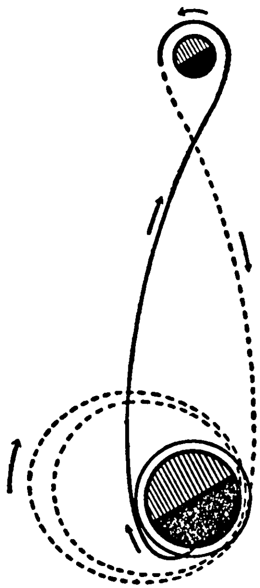
That, then, would be the moon rocket.

Naturally it would crash on the moon and one of Dr. Goddard's early suggestions was to do just that, putting a "payload" of flashlight powder into the nose of the rocket so as to create a flash which could be seen in a telescope and thus prove that the rocket actually did reach the moon.

But there are disadvantages to this idea. Oberth stated repeatedly that the only mistake he had been able to find in Dr. Goddard's first publication was the underestimation of the amount of flash powder required. I don't intend to mix into this discussion since I dislike the idea of a single flash that may be missed merely because the observatories, which are favorably situated for the observation of the flash, are having a period of bad weather or poor visibility.

If the rocket "crawled" across the line of equal gravitational attraction, it would strike the surface of the moon with a velocity of just about 2 miles per second, the "velocity of liberation" for the moon. If it had some velocity left when crossing the line, its velocity of impact would be proportionately higher. At any event it would be considerable and cause the formation of a new small "crater." This tendency can be increased considerably if we substituted some 10 pounds of *tetryl* (which is more powerful than TNT) for the flashlight powder. That would cause a permanent marking which could be searched for at leisure.

It can be made even more conspicuous if only half a pound of tetryl were used (it would be set off by the impact) and if the other 9½ pounds were Plaster of Paris or a similar fine white powder which would be scattered over a visible area by the explosion. Since the surface of the moon is rather dark, on the average as dark as darkish terrestrial rocks or lava, the white powder, no matter how thinly spread, would show in an unmistakable manner. It would look bright when seen from earth even if it might be so sparsely spread that it would be unnoticeable to a man walking over that area.



35. The Trip around the Moon.
The final landing on earth is accomplished by means of "braking ellipses."

The mass-ratio required for the experiment would be high, as can be seen from the following table:

ASSUMED EXHAUST VELOCITY	MASS-RATIO REQUIRED
3,000 meters per second	237
4,000 meters per second	60
5,000 meters per second	26
10,000 meters per second	5.5

If we optimistically assume that some day an exhaust velocity of 5000 meters per second will be reliably obtained, the moon rocket would still have to weigh 26 pounds at the take-off for every pound that gets to the moon. But that, once such exhaust velocity has been attained, is within the realm of possibility.

We may go one step further now.

If we increase the mass-ratio still more, we may get a rocket to go around the moon and fall back to the earth, either in a straight ellipse with an *apogee* considerably beyond the orbit of the moon or in the somewhat preferable curve shown on Fig. 35. In that case, we might equip the rocket with automatic film cameras and get pictures of the "other side" of the moon.

Yes, but. . . .

Such a trip would be a rather complicated maneuver, requiring delicate control. Theoretically it might be accomplished by throwing the rocket into just the proper orbit with the proper velocity at the proper time. Or else, if you are not quite so punctilious in the beginning, you can correct the mistakes later on, say by a set of robot pilots hooked up with "electric eyes" which perform some minor feats of celestial navigation. The first method, Oberth estimated, would imply that you master the exhaust velocity within a range of less than a foot per second, which is obviously impossible. The second method would require a great deal of fairly delicate machinery, weighing, at a guess, some 800 pounds or more.

The remedy obviously consists in finding a robot pilot which would weigh less than 800 pounds, say between 150 and 200. There is such a light-weight "robot pilot" in existence that is also fairly rugged within reasonable limits and which has the additional advantage of being very versatile and adaptable. Its designation is *Homo sapiens.*

This "remedy," which eventually will become necessary, automatically alters the designation of the rocket. The space rocket which crashes on the moon is still just a space rocket. The space rocket which needs a human pilot because of the necessity of a few adjustments of velocity and direction—but mainly for the purpose of determining the need for these adjustments—is a spaceship.

Chapter 9:

THE SPACESHIP

Illi robur et æs triplex
Circa pectus erat, qui fragilem truci
Commissit pelago ratem primus.

Oak and brass of triple fold
Encompassed sure the heart, which first made bold
To the raging sea to trust a fragile bark.
—*Quintus Horatius Flaccus* (Odes I).

NOBODY doubts the meteorological rocket. Everybody grants, after having acquainted himself with the requirements, the space rocket. And almost everybody will concede the unmanned moon rocket. But when it comes to spaceships, all heads begin to shake and objections begin to come forth in a thick stream.

How are you going to land? How are you going to return? What are you going to use for a fuel? How do you expect the pilot to stand the strain? What kind of food are you going to carry? How about water for drinking and washing? What about oxygen for breathing and fuel for heating the cabin?

Occasionally these questions are not uttered as questions but take the form of a plain statement, such as can be found in the book *Consider the Heavens* by Forest Ray Moulton, which says:

> It must be stated that there is not the slightest possibility of such a journey. There is not in sight any source of energy that would be a fair start toward that which would be necessary to get us beyond the gravitative control of the earth. There is no theory that would guide us through interplanetary space to another world even if we could control our departure from the earth; there is no means of carrying the large amount of oxygen, water and food that would be necessary for such a long journey; and there is no known way of easing our ether ship down on the surface of another world, if we could get there.[1]

And there is no reason to make any of these statements!

[1] Written in 1935, more than ten years after Oberth and Hohmann furnished that theory which Dr. Moulton finds lacking. These sentences have also been quoted with glee by Mary Proctor in one of her books.

Going into a discussion of such questions as water and food, oxygen and heat are obviously useless until we have a clear idea of the requirements, and these hinge without exception on one factor—time. Before we can say anything about the possibility of a journey into space, we have to know how long it will last.

Fortunately this is something we can predict. We can say, for example, that a trip to Venus and back would last two years, one month, and a few days. Nor is this prediction idle.

I admit that, when seen at first glance, a discussion of a trip to Venus—or to Mars, or to the moon, for that matter—at the present stage of development in rocket research may look as if it were comparable to a conversation about transatlantic flights between Wilbur and Orville Wright on the day after the first hop at Kitty Hawk. But there are differences.

A transatlantic flight depends essentially on the steady generation of so and so many horsepower for so and so many hours. The motors have to maintain their power output to keep the plane in the air and to overcome air resistance. A trip into space depends essentially on the generation of a particular high velocity which does not need constant fuel expenditure to be maintained to the required degree. Once that velocity has been attained—and that must be done in a matter of several minutes—the motors keep silent, no matter how long the trip itself may last. The theory of space travel does not operate with "quantities of work" but with "quantities of motion."

I do not say that the one or the other is easier to accomplish; I am just pointing out the difference. And a transatlantic flight leads through atmosphere, through weather, a proverbially unreliable commodity. A trip into or through interplanetary space has nothing at all to do with weather. It leads through the gravitational fields of various celestial bodies, a thoroughly reliable proposition.

There are very many things about spaceships which nobody knows at the present moment, which could not even be determined at the present moment, no matter what efforts were spent in this direction. But the orbits those spaceships, once they exist, will have to travel are not among them. These routes are not arbitrary by any means and because of that—and because it is essentially a problem in astronomy—they can be predicted now. Nor is that prediction of the kind that says that the next President will be a Republican if he is not a Democrat. The prediction is rather of the type of those you find in the calendar on those pages which state when the sun will rise and set on a certain day, when the moon will be full and when an eclipse is due to occur and where it will be visible—in short, astronomical information about the future.

But we were talking about substituting a live pilot for a robot pilot. The case in question was the moon rocket. And while I am postponing everything that has to do with the bodily welfare of the pilot, there is one point that has to be taken up at once because it also influences the technical requirements. That is the question of acceleration.

Plain speed has no influence at all on the human body. We are traveling around the sun at a rate of almost 20 miles per second, but we don't even feel it. We are traveling with the sun with a similar velocity in a direction which is almost at right angles to the direction of the earth's movement. It took us hundreds of years even to find it. We are traveling in still another direction, with much smaller velocity, due to the rotation of the earth. We are probably traveling at a very high rate with our whole galaxy.

Plain speed does not matter at all.

What does matter are changes in speed, called acceleration and deceleration. The proper question is, therefore, what amount of acceleration the human body can stand without being harmed. The war has provided an enormous amount of material because every airplane pilot who pulls out of a dive or makes a sharp turn is subjected to a strain which, although caused by centrifugal force in the majority of the cases, is precisely the same as would be caused by acceleration or deceleration in a straight line.

We know that the pilot should not surpass 6*g*, that he should not surpass 4*g* without training. We know that some people stand the strain better than others, though there are few outward signs that tell us who will and who won't. Winkler put a man on a new electric carrousel which he rented for this experiment and let it run at full speed for almost ten minutes, causing the sole passenger to stand a strain of 4*g* for almost this length of time. When he came out he was dizzy because it had been a rotary motion, but he felt all right otherwise.

It can be concluded, therefore, that an acceleration of 4*g* (or 3*g* *effective*) could be used. In fact, Oberth suggested that the pilot be tested several times by means of a large centrifuge producing the equivalent of this acceleration; moreover, the instrument could also be used for practice. There is little doubt that the strain will be endured best in a supine position, but it must not be imagined that it will feel as if three times the weight of the body were piled on top of his body. The tissues near the back will take more of the strain and it will probably feel as if about half the expected weight were resting on the body. These things can be investigated in detail when required; so far there is no reason to believe that an acceleration of 4g for a period of ten minutes (which is the maximum possible duration of ascent under power) will prove harmful to a healthy person.

It may be well to mention at this point that it would not matter greatly if the pilot did "black out" during the period of initial acceleration. Just because of that possibility, the spaceship has to be designed for automatic performance during this period anyway. This would not be difficult at all, and the pilot is not required for the ascent; he is needed for observations and correction later on.

You are at liberty to have some doubts about these points. The discussion's main purpose was to find out what acceleration should be inserted in the equations for a first survey of the requirements.

Although I am getting ahead of the proper sequence of discussion, at this point I feel obliged to give the figures for the moonship now. The figures I am going to present are Oberth's and they can be found on page 376 of *Wege zur Raumschiffahrt.* Needless to say, the moon voyage has been calculated by others too, but the divergence between the results of various computers is comparatively small so that one set of figures will do.

Oberth assumed that the trip from the earth to the moon would be made by acquiring just enough momentum to pass the line of equal attraction. Then it would be necessary, of course, to stop the velocity of about 2 miles per second which is acquired by the ship when falling toward the moon. It can be stopped only by turning the ship around in the direction of its fall and by using the rocket motors to reduce the falling speed so that the ship touches the surface of the moon with the velocity reduced to zero. After some time the pilot would wish to return and has to take off from the moon, again by using the rocket motors. Fuel for all these maneuvers would have to be brought from earth, of course. But the landing on earth can be accomplished without using fuel at all, at least theoretically. Actually a small amount of rocket firing may be required.

The example, therefore, looks like this:

MANEUVER	"IDEAL" VELOCITY REQUIRED FOR THIS MANEUVER (meters per second)
(1) Take-off from the earth	11,200
(2) Reduction of velocity of arrival to zero	3,030
(3) Losses sustained during execution of maneuver No. 2 (owing to too much caution)	870
(4) Take-off from the moon	3,030
(5) Allowance for corrections and mistakes	1,000
Total	19,130

This total, assuming the exhaust velocity to be 4000 meters per second (hydrogen and oxygen), represents a mass-ratio of 134 to 1. The periods of acceleration are as follows: for maneuvers (1) and (2) eight and nine minutes respectively—the long period of nine minutes is what causes the losses listed under (3); for maneuver (4) ninety seconds. Maneuver (5) is, of course, indeterminate, taking only a few seconds at a time.

The trip to the moon would take around ninety-eight hours. The return trip would take the same time plus an estimated twenty-four hours for the landing on earth plus whatever time the pilot spends on the moon. Either way the trip can be started at almost any time. There is not much reason to wait for an especially opportune time unless the pilot wishes to land at a certain spot on the moon, say near crater Copernicus, at the time of sunrise for Copernicus.

The mass-ratio of 134 to 1 would require at least a three-step rocket; the venture is clearly much farther in the future than the plain moon rocket.[2] If you imagine that the shape of the moonship is that of a huge artillery projectile, which seems to be the most likely shape, it would tower to about one third of the height of the Empire State Building.

The mass-ratio of 134 to 1 is unpleasantly high, but it is certainly closer to the realm of possibility than the fantastic figures that were computed several years ago by the Canadian astronomer Dr. J. W. Campbell of the University of Alberta. Dr. Campbell stated that a moonship would have to be about as massive as Mt. Everest, that its mass would be such that it could form a ball 5 miles in diameter. Dr. Campbell's mathematics were, of course, correct, but

[2] That is, if a slow and tedious development is taken for granted. Actually such developments have a habit of progressing in sudden spurts.

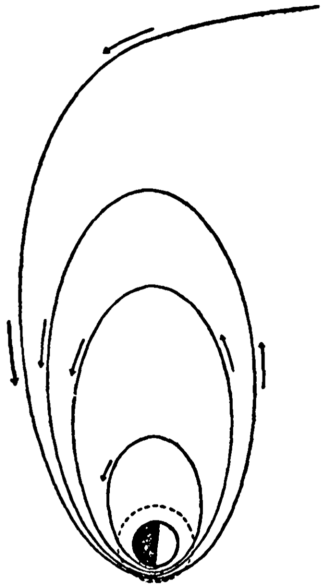
he made the wrong assumptions. The returning ship, he assumed, would weigh 500 tons, and the exhaust velocity was estimated, if I remember correctly, at less than 1 mile per second. With these assumptions you do arrive at such figures. But these figures do not prove that the problem cannot be solved. They only prove that the problem cannot be solved for a 500-ton ship and an exhaust velocity of some 3000 feet or about 1000 meters per second.

As a matter of fact Oberth even exaggerated a bit with his mass-ratio of 134 to 1 for an exhaust velocity of 4000 meters per second. He deliberately ignored the fact that the gravitational attractions of the moon and of the earth compensate each other to a slight extent all along the way. Taking this into account you arrive at a mass-ratio of 120 to 1 for an exhaust velocity of 4000 meters per second and of 44 to 1 for an exhaust velocity of 5000 meters per second.

The mass-ratio for the rocket around the moon, without landing there, will come out to about 80 to 1 for an exhaust velocity of 4000 meters per second and about 55 to 1 for an exhaust velocity of 5000 meters per second. If we assume the higher exhaust velocity, a two-step rocket would be sufficient to accomplish this trip which, if nothing else, would yield photographs of the unknown "other side" of the moon, photographs of the sun as it appears without the interference of the earth's atmosphere, and photographs of the earth itself. The latter two things, however, could also be accomplished by the unmanned space rocket.

The returning moonship, naturally, has to land. If this has to be done by reducing the falling speed of the ship—again that famous velocity of liberation of 11,200 meters or 7 miles per second—all the mass-ratios mentioned would have to be multiplied by about thirty and would, in consequence, loom even more forbidding. But rocket power, fortunately, is not needed for the landing on earth. In this case the atmosphere, which generally causes so much trouble, proves to be useful.

The returning moonship, audiences have been informed by careful characters time and again, would burn up in the atmosphere just as a meteorite burns up. There are some differences, however. In the first place, the moonship returns with about 7 miles per second, about one fifth of the velocity with which the average meteorite runs into the earth. The heating is the result of the compression of air molecules in the path of the meteorite (or ship),



36. "Braking Ellipses." The drawing is to scale, except that the atmosphere (broken circle) is about four times too deep. The length of the directional arrows indicates the velocity.

and the compression takes place in a cylindrical space having the same diameter as the entering body. Obviously it makes a great difference whether the path, the "cylinder," is 1 or 5 miles in length for a given interval of time. And even the meteorites are not heated up all at once. The outermost fringes of the atmosphere prove too tenuous for that even at high cosmic velocities.

Still, the moonship *would* be heated to incandescence if it entered the atmosphere vertically. Consequently the theory requires that it doesn't.

The pilot of the returning moonship will see to it that his vessel misses the earth by, say, 250 miles. The actual figure may be a little more or a little less—at present we lack the precise data needed for proper calculation, but these data will be furnished by the larger types of meteorological rockets. The idea is, at any event, that the ship *grazes* the fringes of the atmosphere. It will shoot out of the atmosphere again, but with reduced speed. After the first grazing its velocity will be below the velocity of liberation; the ship is no longer independent, but has become another satellite of the earth. That satellite travels around the earth in an elliptical orbit, one of its focal points coinciding with the center of the earth as usual. The *apogee* of that orbit is somewhere out in space and does not interest us very much; the decisive point is that the *perigee* [3] is just inside the atmosphere. When the ship returns to its *perigee,* it is slowed down again. Again it leaves the atmosphere, and again its speed is reduced. The ellipse is smaller now, the *apogee* is closer to earth, but the *perigee* is still at about the same

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[3] The point of the orbit which is closest to the earth.

altitude above the ground, probably only some 10 or 15 miles lower.

The fourth grazing is likely to reduce the velocity to such an extent that the ship does not leave the atmosphere any more. It now spirals down and finally lands by means of a large parachute. (Fig. 36.)

Russian and German rocket literature is full of discussions of this landing maneuver. The velocities at each point have been computed and for a time a heated discussion raged on whether an additional parachute should be used for the first two grazings or not. This is one of the questions that simply cannot be decided at present. We have to know a lot more about the density and composition of the atmosphere at these altitudes before we can really settle down to a detailed computation. But the maneuver itself has survived all criticism. Essentially that is the way the landing can be accomplished without large fuel expenditure. It would take about twenty-four hours from the first grazing to the final landing.

It may be useful to say something about gravity at this point.

The whole problem is a fight against gravity and in all these discussions the fight against gravity has been waged on the basis of brute force. The gravitational power of the earth amounts to a velocity of 7 miles per second. We answer with an investigation of methods supposed to create a velocity of 7 and a fraction miles per second. The moon can produce 2 miles per second. We get ready to fight back with 2.1 miles per second.

But those novelists who wrote about voyages to the moon and to other planets during the latter part of the nineteenth century did, as a rule, forego brute force in the fight with gravity. They used subtler means, substances which were not affected by gravity, substances which produced gravitational shadows, like Mr. Wells' *Cavorite*. Is there no possibility that such a substance may be found and utilized before rocket research has progressed to exhaust velocities of 5000 meters per second and to step rockets with a combined mass-ratio of 60 or even 80 to 1?

There are two answers to that question. One is not greatly in favor of that solution. The other is against such a solution.

Just what—to begin with the first answer—do we know about gravity? We do know that gravity decreases with the square of the distance which is the result of the geometrical fact that the area of a sphere is proportional to the square of its radius. This, then, is not a special gravitative phenomenon and we know, as a matter of fact, that other natural phenomena work in the same manner—for example, light. To know this fact is useful enough; all ballistic and astronomical calculations are based on it and they work out nicely. As far as those disciplines are concerned, no knowledge of the nature of gravity is needed. All we have to know is its general behavior and its intensity at a given point. And we know that.

Otherwise we mainly know what gravity does *not* do. It does *not* change with the nature of the matter involved. It does *not* change with temperature. It is *not* influenced by light or darkness, by electricity or magnetism, by ultra-violet rays, radio or X-rays. There is *no* way of screening it. Small wonder that Dr. Paul R. Heyl of the National Bureau of Standards called it an "intractable phenomenon" in the *Scientific Monthly* (August 1938), and continued:

> Gravitation appears to be a function of nothing but the masses involved and their space co-ordinates. As to all other properties the evidence is negative, in most cases of a high degree of precision, reaching a few parts in a billion. The cause of gravitation is hidden in a protective armor on which there is not even a projection upon which to hang a hypothesis.

As may be expected under these circumstances, all so-called "explanations" of gravity suffer from the common defect that they don't work. They all try to account for some of the observed facts by neglecting others or even by neglecting the very consequences arising from the explanation itself. Or else they try to explain the observed facts by explaining them away.

What may be called the "classic" explanation is the one Le Sage of Geneva proposed in 1750. According to him the whole universe was filled with "ultra-mundane corpuscles" moving at high speeds and exerting a steady pressure on the surfaces of all bodies, pressing, for example, humans to the surface of the earth. The obvious present-day answer is to inquire about the heat generated by the impact of the corpuscles, but in 1750, when Le Sage advanced his hypothesis, the law of the conservation of energy was still to be discovered.

The general idea of the Le Sage hypothesis remained a favorite with gravity explainers for a large number of decades. Later elaborations stated that the corpuscles, of course, penetrate all solid bodies, but that they lose some speed while doing so. For this reason the push from below (at the surface of the earth) does not quite match the push from above, the difference being called "attraction." Again it does not work because of the law of the conservation of energy. And none of all these theories—by now the Le Sage hypothesis has been advanced about fifty times, each time as a "new" explanation of gravity—can be true because a screening effect would invariably result and it should be measurable. If there were a screening effect, the moons of Jupiter would betray its presence. The actual behavior of the moons shows that no screening exists.

When Albert Einstein became interested in this problem he looked about for a similar untractable phenomenon and found it, inertia, especially in the form of centrifugal force. An observer in a rotating circular room, he said, would find himself in a kind of gravitational field turned inside out, forcing him away from the center and becoming more powerful with distance. In that case the observer would know what is happening to him. He would not look to the center or to the rim of the room for the "origin" of the force, but would know that it originated in the objects themselves and that no screening of any kind can be expected.

Einstein then proceeded to say that a "gravitational field is equivalent to an inertial field produced by a suitable change of coordinates." To the layman he then promptly disappeared from view in a forest of equations.

His idea is usually explained by comparing matter in space to stones forming cusps in the otherwise flat surface of a frozen lake. Another stone set in motion on that surface which is, by definition, frictionless, would follow a straight line in a given direction until it grazed one of these cusps. Then it would continue in an altered direction. If it got fairly deep into the cusp it would not leave again at all but would revolve around the larger stone. That would look like gravity, being the effect of a three-dimensional cusp in a two-dimensional world. Similarly, popularizers used to state sonorously, real gravity is the cusp made by matter in four-dimensional space—which was neither understandable nor a precise rendering of Einstein's equations.

Actually we have as little reason to believe in four-dimensional space (or in the expanding universe, for that matter) as we have to believe in the two-dimensional world which was assumed to explain four-dimensional space. Higher and lower dimensions have a certain *raison d'être* in equations on paper but must not be taken literally. Recent astronomical evidence seems to indicate that this idea is as much a blind alley as the Le Sage hypothesis, although for other reasons.

When Aristotle was confronted with the same problem he "explained" it by ascribing the "property of heaviness" to matter. We still have to do the same—gravity seems to be the most fundamental property of matter. And therefore it is practically impossible even to imagine a gravity screen.

This is what I meant in saying that the first answer to the question about gravity screens is not greatly in favor of such a device. The second answer is even more devastating.

If we did have a substance like *cavorite,* it would be useless. The point is this: speaking in terms of physics we live under a certain gravitational potential at the surface of the earth. If we go away from earth we arrive gradually at lesser potentials until the potential finally becomes zero, at an infinite distance from the earth.[4]

To lift 1 kilogram (2.2 pounds) to a height of 1 meter (40 inches) under normal gravity at the surface of earth we have to expend a certain energy which has received the logical name of kilogram-meter and which is used as a unit for measurement. To lift 1 kilogram to the zero potential (to an infinite distance) requires 6,378,000 kilogram-meters, and the gravitational potential of the earth is expressed by that figure.

Cavorite is supposed to create the zero potential. Consequently a man who steps onto a sheet of *cavorite* has to overcome the whole gravitational potential of earth. Supposing he weighs 165 pounds or 75 kilograms. His muscles have to produce a mere 6,378,000 times 75 kilogram-meters for this purpose. It does not matter that he walks only one step. Distance is unimportant; it is the difference in potential that counts.

Now this puts the lucky inventor of *cavorite* in a very curious predicament. Either his muscles are not powerful enough to enable him to enter his spaceship, in which case the marvellous invention is wasted because he cannot use it, or else his muscles are powerful

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[4] It is a deeply ingrained popular misconception that the "gravitational zone" of the earth is somehow limited in extent. This belief makes as little sense as, for example, the belief that a star shines only to a certain distance. What actually happens is that the light of a star may become too faint to be seen if the distance is too large. Similarly a gravitational field may become too faint to be noticeable.

enough for the task, in which case the invention is useless too, but for another reason: the inventor would not need the ship because he could jump to the moon directly!

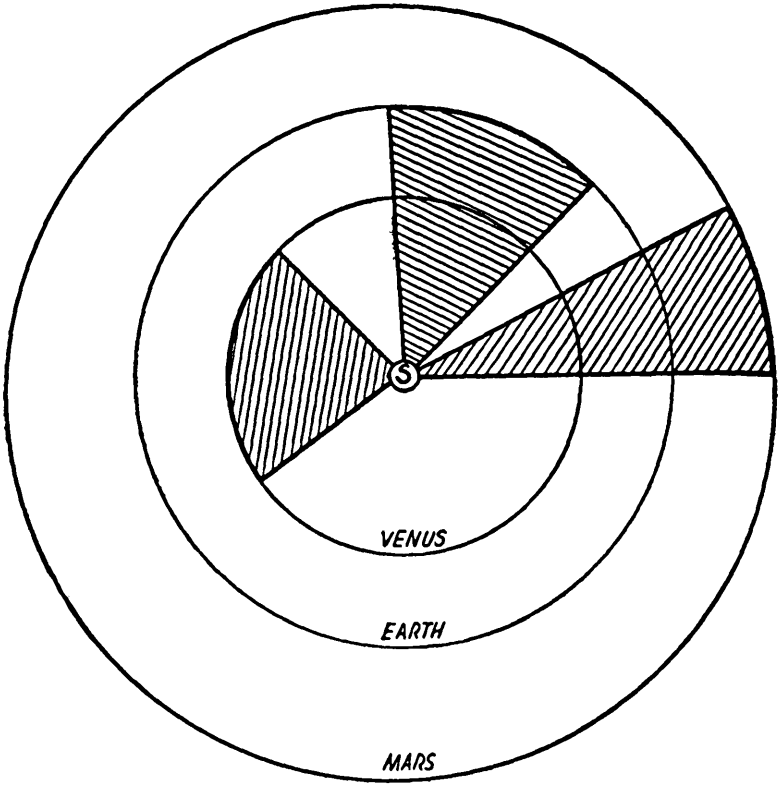
After this interlude we can return to rocket theory with the comforting knowledge that there is no other way of conquering gravity or space. It can be done only by superior force.

We are not yet finished with the theory of interplanetary travel merely because we have discussed the fundamentals of the moon rocket and of the moonship. The moonship is not the whole theory. In fact it is only a special case, a footnote to the theory itself. It is in a subclass of its own because the moon trip pays no attention to the gravitational influence of the sun and to the orbital motion of the earth. Not that the attraction of the sun is unnoticeable at our distance of 93,000,000 miles. It is extremely powerful, but it does not matter since the earth, the moon, and the ship are all subjected to it in the same manner. They are on the same potential of the sun's gravitational field. With regard to the sun all three move with about the same velocity and within narrow limits in the same direction, and because of that the presence of the sun can be disregarded.

An everyday example may make this clear. The straight ascent of a space rocket with an immediate return to earth is like getting up from your seat in a railroad car, going to the window, and coming back. The ascent with a subsequent fall to the moon is like going to another car in the same train. For all these restricted movements it does not matter whether the train is standing still or is traveling at full speed because your seat, the window, and the next car all move with the same speed. But setting out for Venus or Mars means leaving the train and then the speed of the train becomes an important consideration.

The planets of our solar system all move in the same direction around the sun. They also move in almost the same plane; not quite the same plane, but with differences which are not large compared to the enormous size of the whole. Only the orbits of some comets are tilted at a high angle.

But the planets do not move with the same speed; the inner planets are faster by far (Fig. 37). They need the higher velocities to stay in their orbits—to counterbalance the more powerful attrac-



87. The Movements of Venus, Earth, and Mars during a Fifty-Day Period. (Cf. Fig. 2.)

tion of the sun. The whole may be visualized as a whirlpool with sloping sides, the sun being in the center at the very deepest point. The innermost sections rotate at the highest speed, at some distance from the center the speed of rotation is perceptibly slower, while the outer portions, where the whirlpool slopes least, move rather slowly. At each point the speed of rotation is just sufficient to counteract the attraction of the sun, to prevent the bodies that are at that point from sliding down toward the center.

Actually the solar system is flat. The sloping whirlpool is just a device to visualize the action of the sun's attraction.

If a body moving in one of the outer slow parts were suddenly slowed down still more by an outward force, it would slide toward the center. Gaining speed while sliding down it might acquire a new balance, but the important point right now is that it would be drawn toward the center if it lost some of its normal speed. Conversely one of the faster bodies, pushed to a still higher speed by an outside force, would move outward, overcoming the attraction of the central body.

This picture can be applied to actual conditions in the solar system with little alteration. We'll say that we have a large rocket, capable of attaining considerable velocity of its own, and we'll let it take off from earth. The result would depend on the time of day. If the rocket takes off at such a time that its own speed is added to the speed of the earth in its orbit, it will have more speed than is required to counteract the gravitational attraction of the sun at our distance. The rocket would drift outward in the solar system, climbing against the gravity of the sun. Naturally that gravity would gradually reduce its "surplus" speed, so that there would come a point when the rocket would no longer recede from the sun. If the rocket took off at a time of the day when its speed would subtract from the orbital speed of the earth—as seen from the sun—it would not have enough speed to counterbalance the sun's attraction. It would drift inward in the solar system, approaching the sun. In this case the sun's attraction would increase its speed so that, at one point, the sun itself will have made up for the "deficiency."

That rocket would approach either the orbit of Mars or the orbit of Venus, depending simply on the question of whether its own speed were added to or subtracted from the orbital speed of the earth.

The movements in either case would again be Keplerian Ellipses, but this time the focal point of the ellipse would be the center of the sun. The rocket would move along an ellipse which touches the orbit of the earth at one end, and the other end would be elsewhere in space, either outside or inside the orbit of earth. This is general astronomy. There are comets and minor planets which have such orbits—elongated orbits that touch or cross one or several planetary orbits.

The application of this general astronomical knowledge is a question of timing and a question of dosing. It is clear now what a spaceship would have to do to go to Mars: it would have to add its own velocity to that of the earth. Then it would drift outward in the solar system until the orbit of Mars is reached. But the goal is, after all, not the *orbit* of Mars, but the planet itself. It is a question of timing to arrive at a given point of the orbit of Mars when the plane itself is in that point too.

If the timing is important the dosing is even more so.

If the spaceship added too much speed to the orbital speed of the earth, it might acquire the tendency to drift across the orbit of Mars instead of just to the orbit of Mars. In such a case its own orbit and that of Mars would cross. If it had just enough speed to drift to the orbit of Mars, the two orbits would only touch.

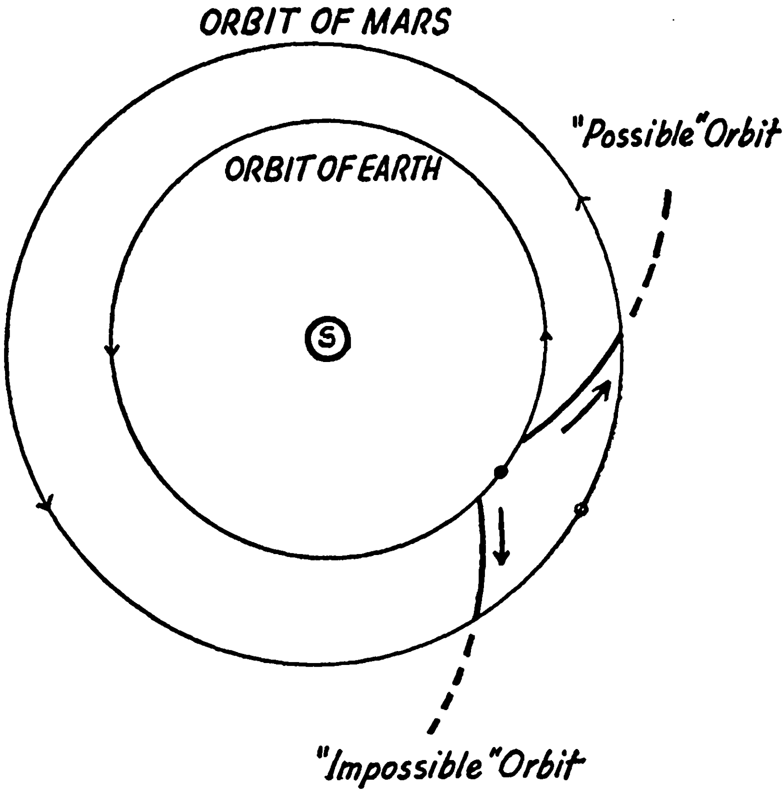
That is the difference between economical and uneconomical orbits. If the orbits of ship and planet *touch,* both move around the sun in precisely the same direction, although not quite with the same speed. But if the orbits of ship and planet *cross,* the ship not only has to change direction but it also has to eliminate a greater difference in velocities than in the case of touching orbits where the difference to be eliminated is not very large as cosmic velocities go. Naturally a much larger amount of fuel would have to be expended in the case of crossing orbits and, since this fuel had to be lifted from earth first, it does mean *much* more fuel—a much larger mass-ratio—at the beginning of the trip. It is easy to see why touching orbits are more economical than crossing orbits.

One cannot ask at this point whether such a thing could be done or not. The possibility or impossibility, the improbability or probability, if you prefer, depends mainly on the figures which result from definite calculations. There is no way of passing judgment until we know the figures for the velocities (or rather their changes) and the masses involved.

We can now proceed to some figures from which that answer may be derived. I'm going to follow the exposition of the problem as it was given in 1928 by Dr. Walter Hohmann in my book *Die Möglichkeit der Weltraumfahrt.* I am not going to repeat Dr. Hohmann's calculations, but only state the problems and give his results.

All the Hohmann orbits, as they have come to be called, are, as is natural, Keplerian Ellipses which lie in the plane of the ecliptic (the earth's orbit), and which follow the general rotation of the solar system and touch or cross at least two planetary orbits.

I have inserted the phrase "follow the general rotation of the solar system" advisedly. Naturally one can imagine and calculate a Keplerian Ellipse pointing in the opposite direction, but this



38. "Possible" and "Impossible" Spaceship Orbits.

would be a non-economical orbit *par excellence.* It would mean the acquisition of more than the orbital velocity of the earth *against* the orbital velocity of the earth (the ship, being a part of the earth before the take-off, naturally has earth's orbital velocity at the outset), and it would again mean reducing all this velocity to zero and acquiring a high velocity in the opposite direction to catch up with the orbital velocity of the target planet, all this leading up to a landing against that planet's gravitation. This is something that clearly cannot be done, and orbits which do not follow the general rotation of the solar system are therefore ruled out as "impossible orbits." (Fig. 38.)

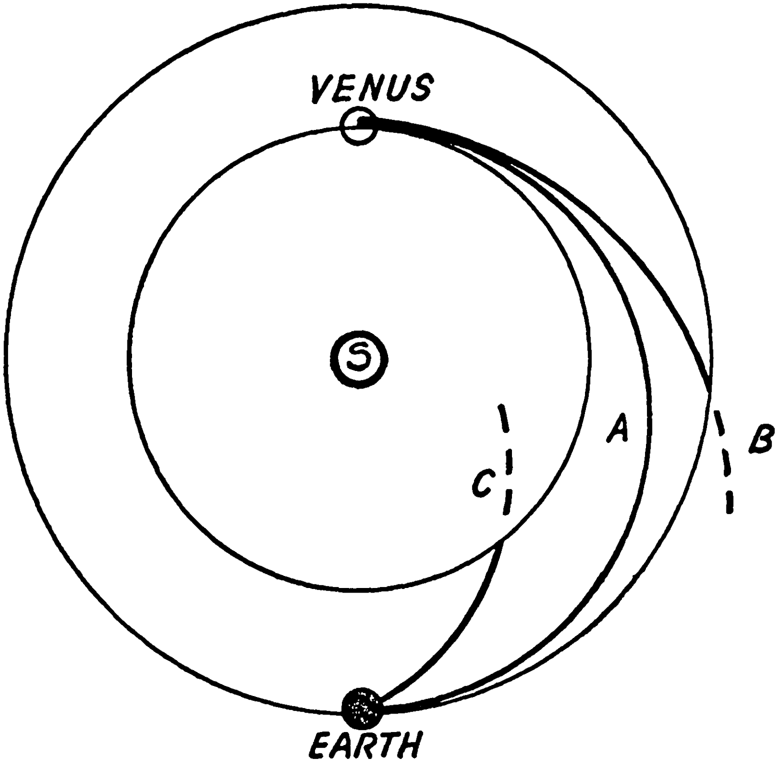
As regards the "possible" orbits, Dr. Hohmann simplified the calculations somewhat by making two assumptions about the orbits of the planets. We know that they are elliptical but to such a small extent that they look like circles on a small drawing. And we also know that they are tilted against the plane of the earth's orbit to a very slight degree. Dr. Hohmann made the two assumptions that the orbits of the inner planets lie precisely in the same plane and that they are circular. The latter assumption has the purpose of getting rid of the complication that would otherwise arise from the fact that the planets travel somewhat faster at perihelion than at aphelion. He assumed that the *average* orbital velocity of a planet held true for every point of the orbit. Expressed in slightly more technical language he assumed that the *radius vector* does not only sweep over equal areas during equal time intervals, but that it also describes equal angles. The difference between this simplified picture and actual conditions is such that it would spell doom for a spaceship whose navigator lightens his duties in a similar manner. But it is not large enough to change the figures to an important extent and at present we only want some general figures which can serve as a basis for conclusions about the probability of the whole venture.

Dr. Hohmann's first example is a trip to Venus and he started out by drawing five possible orbits called A, B, C, D, and E. Orbit A *touches* the orbits of *both* Venus and the earth, orbit B crosses the orbit of earth but touches the orbit of Venus, while orbit C touches the orbit of earth but crosses that of Venus. Orbit D is similar to C, only less abrupt, while orbit E is of the same type as orbit B. The spaceship was supposed to arrive at Venus and adjust its velocity, but not to land. Its final weight, at that moment, was assumed to be 6 tons, including three passengers. The allowance for the passengers during the trip had been 10 kilograms or 22 pounds per man per day which is, at any event, ample. (Fig. 39.)

The results are condensed in the following table which should be studied carefully:

ORBIT USED	DURATION OF TRIP	ORIGINAL MASS OF SHIP IN TONS * (1)	(2)	(3)	(4)
A	146 days	49	34	27	18
B	75 days	530	200	104	31
C	69 days	5,900	1,060	417	60
D	109 days	141	70	48	22
E	102 days	172	83	55	24

* *The term "ton" always means 1000 kilograms or 2200 pounds.*



39. Hohmann Orbits.

Now we can see in figures how economical the A orbit turns out to be, even though it takes twice as long to complete as the B or C orbit. That there are four columns of figures for the original weight of the ship is explained by the assumption of four different exhaust velocities. The figures in column (1) refer to an exhaust velocity of 3000 meters per second, the best that can be expected from gasoline and oxygen. The figures in column (2) refer to an exhaust velocity of 4000 meters per second which may be expected from hydrogen and oxygen. Those in column (3) are for an exhaust velocity of 5000 meters per second, the best that can be expected from hydrogen and ozone. The figures in the last column (4) are based upon an exhaust velocity of 10,000 meters per second; we have no idea at present how that could be done.

This first table settles one point: only A orbits can be considered at all. Any orbit that crosses a planetary orbit and involves a change of direction has to be ruled out almost as strictly as an orbit that does not follow the general rotation of the solar system.

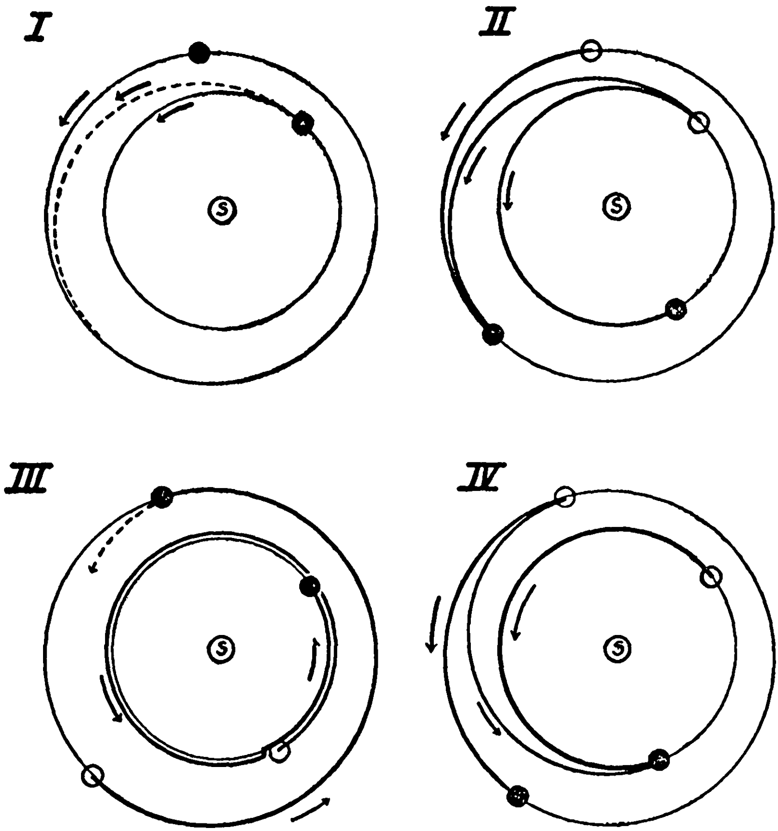
But those figures must not be misunderstood. They do not mean that a 6-ton ship, burning hydrogen and ozone (and having an exhaust velocity of 5000 meters per second) would need 21 tons of fuel to get to Venus in 146 days. Or that, burning gasoline and oxygen, it would need 43 tons of fuel for the trip. If that were the whole of the story, we might seriously think about the construction of a spaceship some time next week.

These figures merely express the tribute that has to be paid to the sun for moving from the orbit of earth to the orbit of Venus and regulating the velocities so that they agree with those of the planets at both ends. So far the two planets have been treated as if they had no gravitational power of their own. The figures in the table do *not* include the departure from earth. Nor has anything been said about the return. So far the only thing that can be kept in mind as definite is the duration of the trip: 146 days. Similarly the duration of the trip to Mars along an A orbit would require 258 days.

Before we try to establish the true mass-ratios required—the mass-ratios which include departure from the earth, landing, and similar problems—we have to find out the true duration of the trip which means the duration of a *round trip*. It is not simply twice 146 days in the case of Venus or twice 258 days in the case of Mars. The planets move.

Supposing we have completed an A orbit to Mars and have, for some reason, decided not to land but to return at once. The thing to do, it would seem, would be not to adjust the ship's velocity to the velocity of Mars at all but simply to stay in the same orbit. Without requiring the expenditure of any fuel the orbit would carry us back without fail, back to the orbit of the earth. But the earth itself would be elsewhere.

When we departed from the earth, the slower Mars was far ahead. The time of departure was calculated in such a manner that the ship would catch up with the planet. But during the 258 days the relatively fast earth raced ahead. At the end of the trip the earth would be far from the point touched by the return orbit. There is no other way out but to linger on or near Mars until Mars is ahead of the earth which means, of course, until the earth is behind by having completed more than one full revolution around



40. A Trip to Mars and Back.
I.—Position of planets (black circles) at beginning of trip (broken line shows orbit traveled by spaceship); II.—Position at moment of arrival on Mars (previous position shown by white circles); III.—Position at date of departure from Mars (Mars has completed the whole journey from the white to black circle and the earth has traveled around its whole orbit almost one and one quarter times); IV.—Position at date of spaceship's arrival on earth.

the sun. This waiting period is unfortunately rather long; it amounts to 455 days. Thus the round trip to Mars requires 258 + 455 + 258 = 971 days or about two years and eight months. (Fig. 40.)

On a round trip to Venus conditions are reversed since Venus is faster than the earth, but the net result is again a waiting period on or near Venus. It is even a little longer: 470 days. The duration of the whole round trip is, consequently, 146 + 470 + 146 = 762 days, or two years and a month. It is seven months shorter than the round trip to Mars, simply because of the shorter duration of the trips themselves, even though the waiting period is two weeks longer.

Now for the mass-ratios required. The table of mass-ratios for the departure from earth looks like this:

	EXHAUST VELOCITY			
	3000 m/sec.	4000 m/sec.	5000 m/sec.	10,000 m/sec.
EARTH	95	30	15	4

Air resistance and mild acceleration for the sake of the pilot are included in this table. These figures are not tons, they are ratios. If you would like to find out for yourself what initial masses you have to count on for going to Venus, you can make a choice of exhaust velocity, pick the proper figure for the Venus trip from the table on page 217, and multiply it with the figure for the same exhaust velocity in the table just given. This is not the proper way of making the calculation and it is impossibly bad from the point of view of a mathematician, but it will give you approximate results.

Things begin to look very dark now. The mass-ratios become enormous. And with all that expenditure you just manage to get off the earth, drift to Venus, adjust your velocity there, and make a landing of the type described for the returning moonship.

If you had picked Mars you would need additional fuel to effect a landing against the gravity of Mars, since the Martian atmosphere cannot be counted upon to serve in the same manner as the atmospheres of the earth and of Venus. (The proper figures will follow in a moment.)

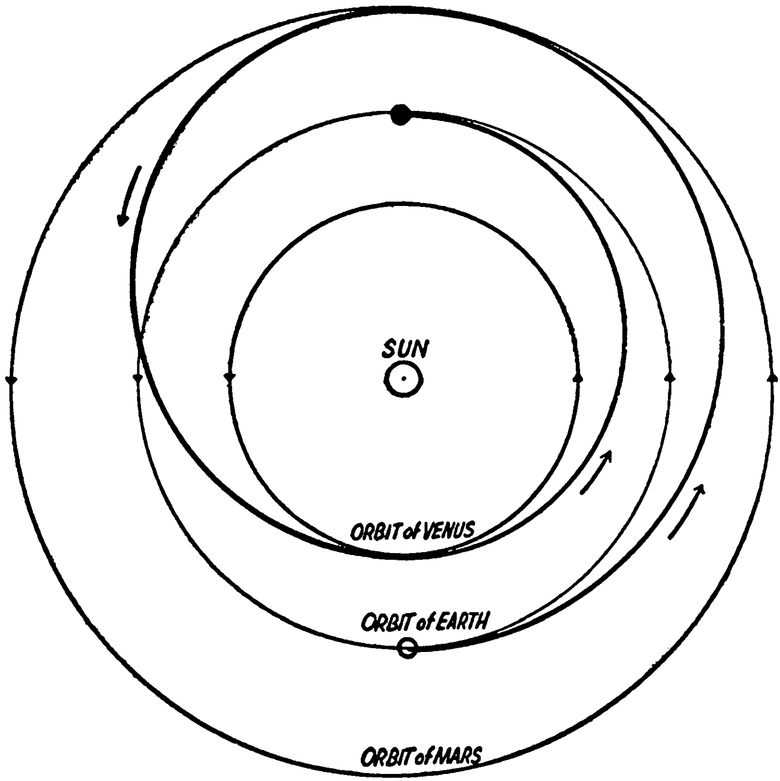
The procedure of the trip, as outlined by Hohmann, would be to ascend from the earth vertically in an arbitrary direction, until the ship is 500,000 miles from the surface. At this distance the gravitational field of the earth can be neglected. The ship is now independent of the earth, but still has the same orbital velocity as the earth. Now change the orbital velocity of the ship, a change of some 2 miles per second. The ship is now on its way, drifting inward in the solar system along an A orbit. During the initial ascent, which takes a few days, the rocket motors work for about eight minutes; in order to change the orbital velocity they work for another two minutes. From then on they are silent until the orbit of Venus and Venus itself are reached. But the ship during the inward drift, which is really a fall toward the sun, has gathered speed; it is now somewhat faster than Venus. That difference has to be adjusted; Venus and the ship are then really in the same orbit, moving with the same velocity. This is, of course, an unstable condition. The gravity of the planet will draw the ship down ("down" as seen from the planet) and the landing maneuver will have to begin. The landing maneuver is again designed to kill speed, but this time it is the speed resulting from the attraction of the planet. All this holds true for a trip to Mars too, except that the landing would require the expenditure of fuel to kill the falling speed of the ship.

Here are the figures I promised, all neatly condensed into one table. They are valid for a 6-ton ship with three passengers, each of whom has a food-water-oxygen allowance of 22 pounds per day.

EXHAUST VELOCITY AVAILABLE	INITIAL MASS OF SHIP REQUIRED (in tons)			
	TRIP		RETURN (independent)	
(meters per second)	to Venus	to Mars	from Venus	from Mars
3,000	4,680	29,500	2,510	382
4,000	1,020	4,180	690	182
5,000	410	1,260	276	110
10,000	73	135	64	41

It can be seen that it is, comparatively speaking, easier to go to Venus, but it is easier to return from Mars. The figures really are not bearable except for those which refer to the 10,000-meter-per-second exhaust velocity which we don't know how to achieve at the present moment. And there is another unpleasantness in that table; the figures for the return trip are for an *independent return*, which means that the fuel supply for the return trip is not carried along but is taken on (or manufactured) on the other planet. The idea of manufacturing the fuel for the return trip is not quite as farfetched as it may seem; the raw materials or rather the raw material for all oxygen-hydrogen or ozone-hydrogen combinations is simply water. And the energy needed for the manufacturing might well be solar energy—we are just now beginning to learn how it may be used. And the waiting period does provide time.

The first trip, of course, would not be one with a landing on the planet, especially since it is likely that all the information needed for future plans can be gathered by way of prolonged close observation of the planet. This then would be a round trip during which the waiting period is spent circling the planet.



41. The So-Called Hohmann Round Trip.

The mass-ratios for such a venture, again for a 6-ton ship with the usual assumptions, are given in the following table:

EXHAUST VELOCITY AVAILABLE (meters per second)	INITIAL MASS OF SHIP (in tons) EARTH-MARS-EARTH, with circling of planet	EARTH-VENUS-EARTH, with circling of planet	SPECIAL ROUND TRIP
3,000	65,500	40,000	46,300
4,000	9,400	6,330	6,700
5,000	3,100	2,160	2,160
10,000	356	284	244

Again only the figures in the bottom line look bearable, but it is always amazing to see how just a slight increase in exhaust speed slashes away at the mass-ratio requirements.

The figures in the last column, labeled "special round trip," need some explanation and a diagram (Fig. 41). It is assumed here that the ship goes to Mars and that it does not land. But neither does it spend the whole waiting period circling Mars. After several weeks the pilot decreases the orbital velocity and begins to drift inward along an A orbit which leads directly from the orbit of Mars to that of Venus; earth's orbit is naturally crossed on the way, but the earth is nowhere in sight. Venus, however, is at the meeting place and is circled for a while. Then the orbital speed is increased so that the ship is flung into an A orbit to the earth, reaching the earth one and a half years after the original departure and having accomplished a survey of both planets in a shorter time and with slightly less fuel expenditure than that required for a no-landing round trip to Venus alone.

Although I know that I severely disappointed everyone who expected great predictions and dramatic suspense—or even a fictional description of a trip through space—in this chapter, I do not feel the need for apologizing for the hail of figures I produced instead. Flowing and lurid talk about spaceships may sound nice, but does not impress anybody for a reasonable length of time. If talk about spaceships is to be sensible talk, it has to be done in figures. And Hohmann's figures do talk.

They show, better than fifty pages of words, how every increase in exhaust velocity makes the solution of the problem more likely. They also show that trips to the two neighboring planets are not in the nature of hit-or-miss daredevil ventures, but are cold-blooded proceedings based on well-established natural laws. They also show that the question of time is not of the order of that famous schoolbook example of the cannon ball which, "if it could be fired at the sun would need two centuries to get there." The trips are of the order of the average duration of extended expeditions on earth. All this is very satisfying indeed.

But the mass-ratios are disappointing. They are much too high to be pleasing and many of them are clearly beyond possible accomplishment. At this present moment it looks as if no higher goals than the unmanned rocket to the moon and the manned trip around the moon can be predicted.

I think, however, that these goals are big enough to satisfy. At least until a method is found which permits whittling down Hohmann's mass-ratios. Some whittling, as the concluding chapter will show, can be done even now.

Chapter 10:

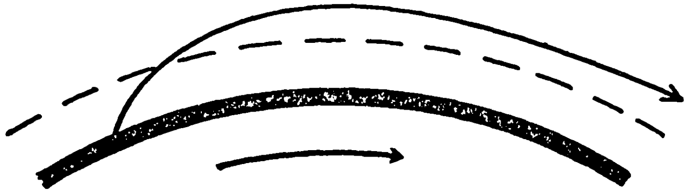
TERMINAL IN SPACE

Space travel is not a problem of "quantities of work," but a problem of "quantities of movement."—Dr. Franz von Hoefft (1928); paraphrased by Robert Esnault-Pelterie (1930).

I AM convinced that later, a few centuries from now, Dr. Hohmann's figures will be quoted in books in much the same manner as we now quote Eratosthenes' attempt to measure the size of the earth. We admire his conception of a usable method, we marvel at the accuracy of the results obtained—considering the assumptions on which they were based—but we don't use his method and we no longer rely on his figures.

To Hohmann's quiet way of thinking and working goes the credit of having established the basic conceptions of routes to be followed and of maneuvers to be carried out; it is certainly not his fault that the mass-ratios he found are too high to be pleasant. Oberth and Pirquet set out at once to find ways and means of whittling them down and they did succeed in finding some. Hohmann himself was the first to acknowledge that fact, stating that his mass-ratios for interplanetary trips—as distinct from a trip to the moon or a trip around the moon—might be reduced by approximately one third if the ship is handled skillfully.

In rocket literature the "skillful handling" goes under the rather clumsy but appropriate name of "the problem of the condensation of power application." It amounts to this: in Hohmann's calculations the hypothetical spaceship bound, say, for Mars first ascends to a distance of some 500,000 miles. This accomplishes nothing but the separation of earth and ship—astronomically speaking, the ship is now a "companion" of earth. It still moves approximately in the earth's orbit and approximately with the same orbital velocity. Then the ship accelerates in the direction of its movement, thus creating the higher orbital velocity which causes it to drift outward toward the orbit of Mars. Having arrived in the vicinity of the planet the velocity of the ship is adjusted to that of the planet. And then the landing follows. This means (not



42. Oberth's "Synergy Curve."

counting the possible need for corrections) four burning periods: one for the initial ascent, one for the change in orbital velocity, and two more at the end of the trip.

Condensing the four burning periods into two will save a lot of fuel. Oberth, applying the maxim "first things first," especially interested himself in the problem of the initial ascent. He found that a vertical ascent is wasteful; the ideal ascent would be almost horizontal in the direction of the earth's rotation (the speed of the earth's rotation would thus be utilized by the ship, a final gift from Mother Earth to its departing child). This is, of course, impossible because of air resistance. Therefore the ascent must be vertical for the first 60 miles, but should then tilt toward the east. Once outside the atmosphere, the ship would go on increasing its velocity so that the necessary change of orbital velocity is a part of the same maneuver. In some cases it might be necessary to go half around the earth outside its atmosphere, but this would not involve any losses.

The compromise between the most efficient ascent, utilization of the earth's rotation, and avoidance of air resistance was called the "curve of synergy" by Oberth (Fig. 42). Similarly, at the other end, part of the difference in velocities between planet and ship could be utilized too. It may look surprising at first glance, but the substitution of the condensations for the separate phases of acceleration does slash a full third off the mass-ratios listed in the preceding chapter.

This helps a great deal. But the figures for the mass-ratios are still far beyond the ken of engineering even with that reduction. Hohmann calculated a mass-ratio of 2,160 tons (for a 6-ton ship) for a round trip to Venus without landing. Reduced by one third it would be 1440 tons, and one is as impossible as the other. Of course if we could count on a fuel with an exhaust velocity of 10,000 meters per second things would look more promising. For such a fuel Hohmann's figure, for the same trip, reads 284 tons or, reduced by one third, 189 tons. Since a 6-ton ship is always assumed, the ratio is only about 30 to 1, which might be possible to achieve with some experience. However, I wish to repeat here for emphasis: so far we don't know such a fuel and without it we are not apt to get any farther than around the moon.

The need for such a high exhaust velocity fuel was confirmed by Count von Pirquet. Count von Pirquet is an ardent devotee of space travel problems, putting all his Viennese enthusiasm to the task. But Count von Pirquet makes (or made—I don't know what has happened to him since the Nazis seized power in Austria) his living as a practical engineer. Consequently he attacked the problem from an angle which had virtually escaped the attention of the others. Other authors had moaned about the high initial mass of the ship; Pirquet perceived an engineering impossibility connected with that high initial mass.

In the first place the rocket motors had to adjust their thrust throughout the period of acceleration to the diminishing weight of the ship. We have seen that the acceleration goes up while the motor works with a constant thrust, as it naturally does. For our meteorological rockets we even counted on that feature and we found it advantageous that the acceleration increased at higher altitudes. But for a spaceship, with a man or men aboard, such steadily increasing acceleration won't do. An acceleration which starts out with, say, 3g and goes up to 10g is fine for the performance of the ship, but the men inside won't be able to stand it. Consequently the thrust has to diminish along with the diminishing weight of the ship, which is an engineering problem in itself. Since the exhaust velocity is always the same—and since it would be the peak of foolishness to cut the exhaust velocity, say, by means of deliberately faulty mixtures—the adjustment can be accomplished only by diminishing the rate of fuel feed.

But it was not the aspect of cutting the power of the motors gradually which really worried Pirquet. It was, on the contrary, the problem of fuel supply for the first few seconds of ascent. The ship is enormously heavy at the take-off. Consequently the amount of fuel to be burned to lift it off the ground while it is so heavy is simply fantastic.

Pirquet took an exhaust velocity of 4000 meters per second, the figure used by Oberth for the calculation of the moonship, and calculated the initial weight of a Mars ship. And then he tried to determine the amount of fuel that ship would have to burn during the first second of the take-off.

One hundred and five tons for the first second!

It is no consolation to know that it will be much less only fifteen seconds later. It has to be that much for the first second, and almost as much for the three or four seconds after the first. And, needless to say, the rocket motors have to handle that amount. Only for a very few seconds, it is true, but they must be able to handle it for these few seconds.

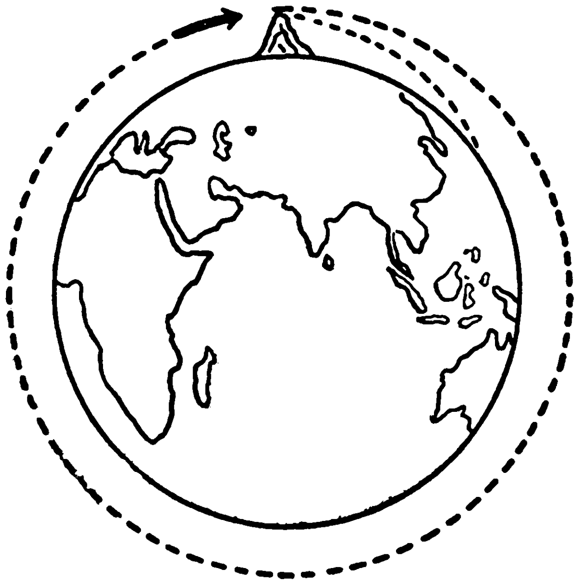
Pirquet calculated the size of a rocket motor which could handle that amount. The area of the throat—the narrowest part of the nozzle—would have to be 150 square meters (1615 square feet). And the area of the mouth of the exhaust nozzle would have to be 1500 square meters (16,146 square feet). No matter how many motors and exhaust nozzles you use to split up these figures, they remain fantastic even on paper. And nobody can build anything like that.

The direct take-off for Mars from the earth is made impossible by these dimensions. With an exhaust velocity of only 4000 meters per second it simply cannot be done at all. If there were a 10,000-meter-per-second fuel, you could divide the figures just given by twenty—then they might begin to look reasonable.

Before that we can only build meteorological rockets and space rockets, try for the unmanned rocket to the moon, and toy with the idea of a trip around the moon. But we can do something else. We can try for a trip around the earth.

In most physics books you can find an illustration looking more or less like Fig. 43. It shows the earth with an imaginary mountain of colossal dimensions—its peak being out in empty space—with an imaginary gun on top of it. In connection with this picture it is stated that the horizontal range of that gun would vary with the muzzle velocity of the projectile, but that the gun could also fire around the earth—and presumably hit itself—if the muzzle velocity were large enough. The muzzle velocity required for this experiment, the book goes on to say, is 8000 meters or just about 5 miles per second. And this velocity is called the "circular velocity," because the projectile would continue to circle the earth indefinitely.

All these statements are correct, of course, but experience has



43. *"Circular Velocity."*

taught me that many people never quite stop wondering why the projectile does not "fall." The answer is that it does, but that it falls *around* the earth.

This strange statement may become clear if we look at it this way: for any kind of shot the projectile describes two motions at the same time. The first of the two is due to muzzle velocity. If the second motion, caused by gravitational attraction, did not interfere, the first motion would be horizontal in a straight line. If the projectile had no muzzle velocity, it would describe only the second motion—a straight fall to the ground. Together the two motions produce a curve—the projectile moves sidewise and falls downward simultaneously. The speed of fall does not vary from shot to shot, but the muzzle velocity can be changed. If the muzzle velocity is high, the curve will be shallow; if it is low, the curve will be steep.

If the muzzle velocity gets very high, the range is increased by another factor: the curvature of the earth. For low muzzle velocities (such as are actually in use) that factor does not show. The curvature of the earth, compared with the curvature of the projectile's trajectory, is so "shallow" that it can be taken for a straight line. But if the trajectory's curvature is shallow too, the curvature of the earth's surface will become more apparent. And in the end one curve will be as shallow as the other; the projectile, while falling, will never reach the ground. The earth's surface, in a manner of speaking, curves downward as fast as gravity causes the projectile to approach it.

This takes place when the sidewise motion is about 5 miles per second. No gun could ever do it—nor would it be of any use to anybody if it could be done.

But a spaceship, taking off along a synergic curve, could get into such a circular orbit much more easily than it could get to the moon. Since the velocity required to establish an orbit around the earth (say at an altitude of 500 miles to be safely outside the atmosphere) is much less than that required to produce a circumnavigation of the moon, it is obvious that the mass-ratios required will be much smaller too.

While in that orbit, no fuel would need to be expended. As far as fuel requirements go, it does not matter whether the ship circles the earth once, twice, or fifty times; the requirements are always the same: zero. Expenditure of fuel is needed only when the pilot wants to return—then it is necessary to slow the velocity of the ship so that it finally touches the atmosphere and carries out the landing maneuver described previously.

This, obviously, will be done before anybody even sets out for the trip around the moon. Circling the earth in such a manner, ship and pilot will experience all the sensations of coasting in free space. I hardly need to mention that there are many misconceptions about the healthfulness of this experience, a question which is yet to be discussed.

Oberth had mentioned the possibility of a spaceship circling earth for a considerable length of time in his first publication. He had hinted at experiments in the field of physics, especially radiation physics, and at astronomical work that could be done from such a vantage point. The Austrian Captain Potočnic, writing under the pen name of Hermann Noordung, devoted a whole book to the station in space which could be developed on this basis. But it was Pirquet who recognized the true importance of this idea.

First he satisfied his pet worry, that of the amount of fuel to be expended during the first second. He emerged with a smile from his calculations. Assuming the worst possible figure at every step and making rather generous allowances for safety, he found that a 2-ton ship en route to this station would have to weigh 140 tons at the take-off. This figure applies to an exhaust velocity of 4000 meters per second. A more optimistic estimate of the exhaust velocity would, of course, give much lower mass-ratios.

The maximum ejection required for such a ship would be 1.5 tons per second which can be handled by a rocket motor with a nozzle area of 2.1 square meters or about 23 square feet at the narrowest point. It is still a big figure, but no longer impossible. There is good reason to believe that this can be accomplished in time, not in the form of one gigantic motor, of course, but in the form of a number of smaller motors with an aggregate exhaust of 1.5 tons for the first second. A ship of such a mass-ratio would have to be a two-step ship. Pirquet naturally preferred a one-step ship, a unit which stays a unit, and this would be possible if somebody should succeed in attaining an exhaust velocity of roughly 4 miles per second. With an exhaust velocity of just slightly above 4 miles per second (6700 meters per second, to be precise) a one-step or one-unit ship could bring 3 tons of materials and provisions to the station with an initial weight of 40 tons and a maximum fuel expenditure of 300 kilograms or 660 pounds per second. But this hopeful calculation was only a side issue. Pirquet wanted mainly to find out at what point it would be possible to abandon two-step ships. The important discovery was that the circling spaceship can be established in its closed orbit with present-day fuels: oxygen and hydrogen with an exhaust velocity of 4000 meters per second.

The idea is, logically, to leave the ship in its orbit, to supply building materials—at the expense of a maximum of 68 tons of fuel for every ton of equipment and supplies that gets there—and to build a permanent station, observatory, outpost, or whatever you want to call it, around the first ship. Oberth had had the idea before Pirquet—even Ganswindt, incidentally, had had something similar in mind—but Pirquet expounded certain aspects in greater detail.

Writing in *Die Rakete* ([1928], Vol. II, pp. 134-40), he stated in no uncertain terms that the idea of space travel directly from earth to another planet might as well be dropped completely since it would lead to problems of design which will be as insoluble fifty years from now as they are at present. You simply cannot eject masses on the order of 100 tons in a second. But you can eject 1.5

tons per second, and with that you can realize the station in space.

For some psychological reason the idea of a station in space seems more farfetched than a trip to the moon. Actually it is simpler. Jules Verne, in his second novel, had the crew of his projectile encounter a second small moon of the earth, circling the earth 4700 miles above the surface in three hours and twenty minutes. This incident is based upon the now forgotten calculation of a French astronomer by the name of Petit.[1] Some searches for the "Second Moon" were made, all fruitless, as could be expected for a case of a tiny body moving close to earth with great rapidity. It is quite possible that some small or large meteorites circle the earth in closed orbits, but Petit's "Second Moon" has simply been filed away.

I mention it here only because the hypothesis of such a small moon will be useful to understand why the problem of the station in space is the easiest of all space travel problems after the plain space rocket. It is many times as difficult as the problem of the space rocket, but it is still easier than the moon trip. Naturally it would be easier to reach a close (and incidentally small) moon than it would be to reach the distant (and incidentally large) moon which the earth actually has. That the ship does not attempt to reach a small body actually moving in an orbit around earth, but attempts to reach one of the many possible orbits of this kind, does not make any difference.

The first point in Pirquet's argument was what we have been discussing all the time, that the realization of the station in space is the least difficult problem of all. His conclusion was that—once things have developed to that point—this problem should be attacked first, even before the trip around the moon. The second point in Pirquet's argument—and that comprises its main value—was to show that this first step solves all the following steps automatically, that the realization of the station in space is the realization of space travel in general.

Trips to the moon, around the moon, and even to the other planets are no longer difficult if they are made from that station. That the gravitational potential of the earth is somewhat smaller for the distance at which the station circles our planet—at an altitude of between 500 and 600 miles—is helpful, but it is not important. It is far more important that no air resistance has to be

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[1] It took me almost a week's intensive search even to locate it.

overcome. But the most valuable factor is the high velocity of the station itself, amounting, as it does, to roughly 5 miles per second. And since the station circles the earth within a few hours, you can have that velocity pointing "forward" or "backward" as compared with the movement of earth. The waiting period from "forward" to "backward" is on the order of about one hour.

All in all, the conditions for a spaceship take-off are pretty nearly ideal. A velocity of about 5 miles per second to start with, no air resistance, plenty of room for maneuvering (and mistakes). The ship itself does not need to acquire much more velocity on its own —about 1.5 to 2.5 miles per second additional would suffice, depending on the target planet.

"Of course it could be said here," wrote Pirquet, "that you don't 'really' gain anything by relying on the station in space and the following example could be constructed: 68 tons of take-off weight are required for the transportation of each ton from the surface to the station in space. Consequently, if a trip to Mars from the station is contemplated, with a ship of 3 × 170 = 510 tons, the primary requirement is an expenditure of 500 × 68 = 34,000 tons which, of course, are transported piecemeal, most of it being used up for the transportation. But if you depart directly from earth, intending to return with a 3-ton ship, only 4800 × 3 = 14,400 tons are required, or only about 10,000 tons if you have a ship of 2 tons final weight. The latter is, of course, less expensive; the question is whether it can be done at all."

And the answer to that was that it couldn't be done.

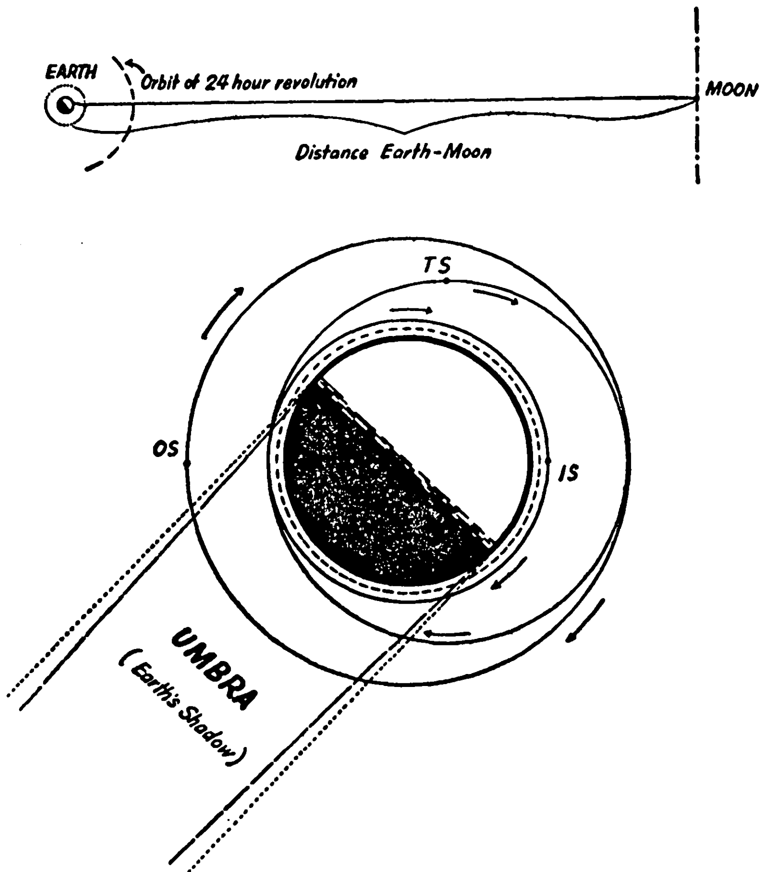
You will have noticed that Pirquet arrived at a take-off weight of 170 tons (from the station) for a 3-ton Mars ship, a mass-ratio of about 57 to 1. With that mass-ratio, especially since the acceleration can be kept lower in free space, there is no need for excessively large motors. It might indeed be possible to reduce the mass-ratio some more by placing the curve of departure in such a manner that the ship at first approaches earth to a certain extent, falling in the general direction of the planet and thus gaining velocity. That gain does not count directly; naturally it is eaten up again by earth's gravity when the ship recedes after passing the point closest to it. Even in empty space you don't get something for nothing. But you do gain a little in such a maneuver: the motors work more efficiently when burning at a higher velocity. For those who, at this instant, are apt to bring forth the law of the conservation of energy, I hasten to remark that even that gain does not come out of "nothing"; it is some of the energy expended by lifting fuel to the station which you get back in this manner. I also have to add that the fuel expenditure per second for take-offs from the station is on the order of about 400 pounds.

All of which justified Count von Pirquet's statement that space travel with present-day fuels may be regarded as impossible, but that present-day fuels permit the realization of the station in space and that the station in space, in turn, facilitates space travel to an almost incredible extent.

Oberth and many others agreed with Pirquet, only Max Valier never fully subscribed to the theory of the station in space "since the moon is a natural station of this kind." This statement is about as valuable a contribution to the problem as Opel's rocket cars. The moon is much farther away and, as has been shown, much more expensive to reach. In addition to that, it has a gravitational field which needs an escape velocity of 1½ miles or about 2.4 kilometers per second to overcome. And the gain in speed is anything but impressive; the orbital motion of the moon is not even two-thirds of a mile per second. The only real gain, which may outweigh all these disadvantages, would be manufacture of the fuel on the spot, provided that the raw materials could be found in sufficient quantities.

Professor Oberth wanted to place the station some 600 miles above sea level so that it would circle earth once in about four hours. The late Captain Potočnik, who has already been mentioned, was in favor of a station 35,900 kilometers or about 22,300 miles above sea level. At that altitude—or distance—the station would need precisely twenty-four hours to circle earth once which would mean, of course, that it would remain stationary over the same point. Potočnik even drew very elaborate plans showing how the station should look and how it should be designed. They were such that, immediately after the publication of his book, I wrote to Pirquet that "Noordung's plans are of great historical interest even now."

Pirquet, in turn, developed a kind of design of his own. It was not a design for the station itself—that can wait until we know more—but an "orbital design." Such a station, as we'll see soon, would have to serve for several purposes and for some of these purposes it would be desirable to have it as close to earth as pos-



44. The Three-Unit Station.
The Inner Station (IS) circles the planet just above the upper limits of the atmosphere (indicated by broken line). On top the distance earth-moon is drawn to scale. The dotted line around the earth is the orbit of the Outer Station and the broken line indicates the orbit of a station which would circle the earth once in twenty-four hours.

sible. For others a slightly larger distance would be preferable. The result is that more than one station, or a station consisting of more than one unit, seems indicated. Consequently Pirquet developed his "three-unit station," shown diagrammatically in Fig. 44.

The "Inner Station" (IS) would be 760 kilometers (about 475 miles) above sea level. The "Outer Station" (OS) would be 5000 kilometers (about 3125 miles) above sea level. Both would revolve around the earth in practically circular orbits. A third unit, called the "Transit Station" (TS), running on an elongated elliptic orbit, is to connect the two, and the TS would be in the nature of a small spaceship. The interplay of motions of the three units was expressed by Pirquet as follows:

	ALTITUDE ABOVE SEA LEVEL (kilometers)	TIME REQUIRED FOR ONE COMPLETE REVOLUTION AROUND THE EARTH (minutes)
IS	760	100
TS	760-5,000	150
OS	5,000	200

This, according to Pirquet, is the optimum arrangement possible to satisfy all requirements. The TS is not to touch the orbits of the other two but only to approach them at the closest by little less than a mile. The difference in velocity between TS and either OS or IS at the moment of closest approach will be around three quarters of a mile per second, which would have to be adjusted if an actual transfer of men or materials is to take place. The TS is, so to speak, on a permanent "A" orbit between the two others. The gravitational attraction of even very large and massive stations will not be enough to disturb their mutual orbits seriously. Minor corrections, involving the expenditure of a few pounds of fuel, may become necessary from time to time.

The station in space, as evolved in theory by Pirquet, is mainly a terminal in space. Pirquet wanted to create a suitable base for exploratory trips through the solar system, a base which, by virtue of its own movements, facilitates the movements of vessels, and a base which serves as a fuel depot since liquefied gases, if they are only shielded against the rays of the sun, will keep indefinitely out there.

But there are many other things the station in space can do, things which would make it valuable even if no spaceship ever took off from there.

Conditions on the station differ from those on earth in three important respects:

(A) The station moves in a vacuum which is better or, as it is usually called, "harder" than any vacuum we can produce on earth. And even if we could produce a vacuum as hard as that, it would be small in size indeed, while the vacuum surrounding the station is, for any practical purpose, infinite in extent.

(B) Any desired extremes of temperature can be produced easily on the station. Any object which is shielded against the direct radiation of the sun by a mirroring surface—for example, by thin sheets of sodium metal—will lose its own heat by radiation and within a few hours it will cool off to a temperature close to absolute zero, probably closer to absolute zero by fractions of a degree than can be accomplished in the laboratory. On the other hand it will be easy to concentrate the sun's rays upon an object, heating it to temperatures far surpassing the temperature of an electric arc.

(C) The station is under no gravitational strain whatever, even though it is comparatively close to our massive home planet. This is a condition which can be duplicated on earth only in a very restricted space for only a very short time by dropping bodies into an evacuated tube. The absence of gravitational strain is the result of the condition of "permanent free fall" (around the earth) prevailing on the station. If a body can freely follow the pull of gravity it is, of course, under no gravitational strain, since the strain is the result of the prevention of free fall.

Because of these three fundamentally different conditions, the station lends itself to experiments which cannot be performed, or cannot be performed well, on earth.

Condition (A)—the large hard vacuum—would produce a perfect laboratory for electronics engineers, and I am fairly certain that any electronics engineer reading this can think of a program of experimentation sufficient to keep a dozen researchers busy for years on the spur of the moment. Condition (B)—the accessibility of the whole temperature range—will be of special interest to physicists of any description. It may be added here that Condition (A) also implies the presence of an infinite pressureless space which might be of interest on many occasions, while Condition (B) implies the presence of radiations about which we know very little because they have trouble penetrating our atmosphere which is remarkably opaque to any but visible radiations. As a footnote to space-travel plans, it can be said here that ultra-violet radiation from the sun, useful for converting oxygen into ozone, is present in large amounts.

But the most important novelty is Condition (C) because it is something which virtually does not exist on earth. Physicists and chemists will be greatly interested to learn how molecular arrangements take place under the apparent absence of gravity. We may find that this makes no difference, or it may make a great deal. We simply don't know at all whether a chemical reaction would proceed in the familiar manner under that condition. Just because gravitational strain is ever present on the surface, we have no idea what role, if any, it plays in everyday chemistry.

Biologists would like to investigate tissue growth under that condition. It would be interesting to find out, for example, whether an amoeba would split into two or not when it reaches the size where that usually happens. An amoeba of a thousand times its normal bulk would be absolutely helpless at the surface of the earth, would not be able to function, and would probably die. But at the station it may be able to grow to such a size, and such an experiment may lead to investigations about the nature of "life" which would be more successful than those made on the ground.

The lack of gravitational strain not only permits absolutely new experiments of all kinds; it also permits new ways of constructing known types of equipment and instruments. An astronomical telescope, for example, is a very massive instrument because of the gravitational strain. The tube of the telescope has the optical purpose of keeping stray light out of the instrument, but it has also the mechanical purpose of holding the main lens (in a refracting telescope) in place. The main lens is heavy but it must be perfectly "in line"; consequently the tube has to be very massive. At the station, with everything apparently weightless, the tube has to perform its optical duties only. Once the lens has been moved to its proper place, it stays there without exerting any mechanical strain on anything, and it can, therefore, weigh a great deal less.

This means, of course, that optical instruments can be much larger than those on earth. (The design would follow somewhat different principles, too, since nobody expects to move a heavy 200-inch mirror out into space.) They can also become much more effective.

The trouble with astronomical observatories, as Dr. R. S. Richardson of Mt. Wilson Observatory put it some time ago, is that their location condemns them to operate with only about 30 per cent of their possible efficiency—they have all been built on earth.[2] The

[2] Following this lament, Dr. Richardson described how he would build an observatory on the moon, with unimpeded vision. The amusing and interesting article appeared in Street & Smith's *Astounding* (February 1940).

reason for their low efficiency is, of course, the atmosphere which prevents astronomers from using the magnifications which are optically at their disposal. A comparatively small telescope—of a special design much too flimsy to hold together on the earth even for minutes—when used from the station could solve many of the problems which are so dear to the layman.

It could see the "fine detail" supposed to make up the optical illusion of the *canali* on Mars; we would find out whether they are an optical illusion or not. It could investigate certain areas on the moon, for example, those mysterious moving darkish spots in the "crater" Eratosthenes, discovered and described by Pickering. Since there is no dispersion of light, it would be easy to block out the sun and to observe Mercury at almost any time. As a matter of fact, the station would serve well to decide which places might be of interest for a visit to be planned. So far *everything* looks interesting because we don't know enough; the improved knowledge of an astronomy operating from a station in space will do considerable sifting in that respect.

Of course the station would permit taking spectrograms of the earth which would be of immense value for comparison with the spectrograms of other planets. It would also solve an important problem in astrophysics about which few laymen may even have heard: whether the so-called "red-shift" of distant bodies might not be caused in part or in toto by a secondary action of our atmosphere.[3]

Naturally observers on the station would have an excellent view of the earth. The airplane has taught us how advantageous it is to see things from above—how many things that cannot be seen at all on the ground appear clearly, such as shadings of the color of vegetation caused by the presence of certain minerals or elements.

The view of earth from the station will offer similar advantages on a larger scale. A trained observer could greatly assist weather bureaus all over the earth. He could, as far as the warning service is concerned, replace the ships of the North Atlantic Iceberg Patrol. He could observe ship movements of any kind (the term "ship" includes, of course, large aircraft), keep track of the movements

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[3] I wonder whether astronomers would not prefer the more distant station which revolves around the earth once in twenty-four hours. It would enable them to combine all the advantages of the station with established points, times, and methods of reference.

of expeditions, locate wrecks—in short he could render a large number of services of definite financial value. And this is the result of the first and, by comparison, easiest step on the road to interplanetary travel.

I am at the end of my story now, the story of the development of the idea of space travel from earliest to modern times. But I know that there are a large number of questions in the minds of my readers. Most of these questions do not concern the straight technical aspects of these problems; they are concerned with the welfare of the people who may undertake these ventures, who may travel outside the atmosphere in large space rockets, possibly embark on a trip around the moon, and finally man the station in space. These questions are very natural because they are very human and for this reason they cannot be simply dismissed with the otherwise perfectly correct statement that a science capable of producing a spaceship, or rather the science which will produce the spaceship, will also be capable of taking care of its pilots.

But this answer has to be kept in mind from a somewhat different point of view. The questions about the welfare of the men in a spaceship can be answered today, but with today's answers. A few decades hence, when things will probably have progressed to the first manned space rocket, the answers will be different. Other and presumably better solutions will have been found in the meantime.

The first question usually concerns temperature. It is still in most people's minds that space is cold. Actually space is not "cold"; it does not have any temperature at all. Only material bodies can have a temperature. The spaceship, of course, will assume one—a temperature which strikes a balance between the heat absorbed and the heat radiated. The heat absorption depends mostly on the distance from the sun which for quite some time to come may be called "somewhere between Venus and Mars," or somewhere in the "temperate belt."

The balance between absorption and radiation can be influenced by artificial means; the simplest and easiest way would be to have one half of the passenger cabin painted dull black while the other half is polished to the greatest possible mirror brightness. (The fuel tanks have to be mirror bright all around.) If the shining (reflecting) half were turned to the sun, virtually no heat would be absorbed. If the dull black half were turned to the sun, all available heat would be absorbed. Intermediate positions would produce intermediate results. Generally speaking it is apt to be rather too warm than too cold.[4] Only when the ship is in the shadow (umbra) of a planet would a drop in temperature be expected, but such periods would be short.

The turning of the ship around on its long axis to regulate internal temperature as well as the turning of the ship around on its short axis to point the exhaust nozzles in the desired direction prior to a maneuver or correction could be accomplished in a very simple and somewhat surprising manner. If a wheel is turned inside the ship, the ship itself would begin to turn against the momentum of the wheel in the opposite direction. The proportion of turns would be in accordance with the masses involved. A wheel whose rim weighs, say, 10 pounds would have to make one thousand complete revolutions to cause the ship (which at that instant is supposed to weigh 10,000 pounds) to make one complete revolution in the opposite direction. A practical wheel for this purpose would be built like a bicycle wheel with a heavy metal rim, equipped with a hand crank, a differential gear, and a revolution counter. Three such wheels, mounted in such a manner that the three axes come together like the edges of a box would make it possible to turn and point the ship in any direction and position desired. Naturally this would not have the slightest influence on the direction of the movement of the ship; it would serve merely to swing the ship in the proper position. Of course one single wheel, universally mounted, would do the same, but would cause only one kind of turn at a time.

An important question concerning the welfare of the men in a spaceship is one that is usually not asked: the reaction of the human body to a prolonged absence of gravitational strain. Whenever the motors are silent, which is practically all of the time, the spaceship is in a "free fall" which may be directed toward the earth, away from the earth, toward the sun, or away from the sun —almost anything. But it is always a free fall, an unrestrained following of the orbit caused by the various gravitational fields and the rocket's action. What we called Condition (C) with regard to the station in space prevails in any spaceship as soon as the initial

[4] According to a rough calculation it is apt to be some 75 degrees Fahrenheit.

ascent has been completed—roughly after ten minutes—and it keeps prevailing until landing maneuvers begin.

Since this condition occurs so rarely on earth, and only for very short intervals of time, we know very little about the physiological reaction to be expected. Oberth once undertook an experiment which consisted of taking certain drugs and then immersing his body into water of body temperature, and he found that the experience was not even unpleasant. But this experiment, of course, caused only the sensation of complete weightlessness and not the actual physical conditions, hence the reaction or rather lack of reaction of his body is not conclusive.

There is little doubt about the extremes as far as time intervals go. Short periods, a few minutes up to half an hour, are not likely to cause any reaction at all. It is also likely that this period may be prolonged by practice if some reaction should occur after several hours. There is also no doubt that a very prolonged period of weightlessness, lasting for many months or even years, will cause the muscle tissue to deteriorate since the muscles, at least the voluntary muscles, are not used.

The involuntary muscles are not likely to be affected. The job of the heart, circulating the blood through the body, will be about the same. The resistance which the heart finds in circulating the blood is mostly due to the friction of the liquid against the walls of the blood vessels, not to gravity. The same, with obvious modifications, goes for breathing, and the peristaltic movements of the stomach have nothing to do with gravity.

Some authors have worried about swallowing of food and drink and about the more delicate bodily functions, an unnecessary worry since none of these functions relies on gravity. One can eat lying flat, where gravity hardly plays a role, and it is not even unpleasant. One can even eat and drink upside down, swallowing against gravity. It is not pleasant, but it can be done. As for ejected waste matter, it actually is an ejection which also does not depend on gravity.

It is quite possible that the absence of gravitational strain will not cause anything more serious than a temporary nausea. But in case it does cause troublesome or even serious physiological reactions, a countermeasure can be designed. There exists a perfect substitute for gravity: centrifugal force.

It could be done in about the following manner: As soon as it has been established that the ship is in the proper orbit and that no corrections will be necessary for quite some time to come, the ship is divided into two parts of pretty nearly equal weight. One strong push, produced in any manner practicable, will make the two parts drift apart, and they are then connected only by a long steel rope. A sidewise push (rocket action) will send the two parts spinning around the common center of gravity which is located half-way between them if they are of equal weight. The resulting centrifugal force will replace gravity, and the spinning neither affects the orbit of the ship nor does it necessitate fuel expenditure until it is to be stopped.

However, there are some drawbacks connected with this. If we want to produce a centrifugal force equal to earth's gravity at the surface and if we use a 3-mile long rope, each part would have to travel 12 feet per second. A complete rotation would require 4335 seconds or 72¼ minutes, far too slow to produce dizziness from spinning. Observations, of course, would be difficult, if not impossible.

So far everything looks fine, but a 3-mile steel rope cannot be put away in a small locker. If we assume that each of the two parts weighs 20 tons, which would be correct for a large number of cases, the strain upon the rope would be half the total weight. A steel cable capable of bearing this strain—with a fair safety factor added—would have to be about ¾ inches thick and 3 miles of it would weigh around 13,000 pounds. If the cable were shorter, the two parts would have to spin more rapidly, but the strain on the cable would be less because it weighs less itself.

By making the cable only 1 mile long, by using a more suitable alloy than ordinary steel, and by paring down the safety factor—since the rope weighs less—you might be able to slash three quarters off those 13,000 pounds. But even 3000 pounds of dead weight are very unpleasant in any mass-ratio calculation. If we could do without the rope and without spinning, things would be much better. In that case only the gradual weakening of the tissue of the voluntary muscles over long periods would have to be prevented which can be done by regular exercise periods. Of course the exercises cannot be of the type involving weight lifting (the weight is the weight of your own body, or parts of it, if you use a "gadgetless" system) since weight does not appear. But steel springs and rubber bands retain their resistance and one can still play one set of muscles against another.

The objection to 3000 pounds or more of dead weight obviously applies only to the rocket vessels. There is no reason why the sleeping and recreation rooms of the station should not be designed that way.

Before I go into the rather complex question of eating, drinking, and breathing, the known dangers have to be mentioned. "Known" dangers means just that—the dangers we know of and can think of. If there are others, they have to be of a type which so far have escaped detection completely—chances are decidedly in favor of the assumption that there are no such "other" dangers.

One known danger comes from the short radiations, ultra-violet and shorter, of the sun and meteorites. The metal hull of the ship —or of the station—will protect the crew from all short radiations.[5] The weak points are the windows. It is significant that all the "early" books about the problem, those written between 1925 and 1930, are evasive about that question. I remember that I was once asked about it after a lecture and that I had to reply that one would have to wait for favorable developments in that respect.

In the meantime these favorable developments have taken place. High-altitude flying has taught a number of valuable lessons and has stimulated chemical research to solve the problem.

In the first place, glass has been replaced by transparent plastics which are far superior mechanically. But the customary transparent plastics list it as one of their advantages that they do *not* shut out ultra-violet rays. This *is* an advantage at and near sea level, where the dosage is small. But in high altitudes, where the thickest part of the atmospheric blanket is lacking, there is far too much ultra-violet for good health. It did not take long, after this was realized, to develop a special type of transparent plastic which is almost opaque to ultra-violet without impeding the passage of visible radiations. For use in open space even this new compound is not opaque enough, but the quick partial solution of the problem indicates that a full solution is possible.

The danger from meteorites is far more substantial and cannot be combatted in so easy a manner as the ultra-violet. In fact there is little that can be done about meteorites at all. Detection of a

[5] The very penetrating "cosmic rays" are excluded from this statement, but there are not enough of them to present a problem.

large meteorite might be possible by a radar-type instrument, but it would probably miss the small and much more numerous meteorites.

Even if the instrument did not miss them, the detection would not be of any help. Detection does not mean that the orbit of the meteorite has been established. It would be a major job to find out whether the orbits of the meteorite and of the ship intersect at a point where both will be at the same time.

Thus the value of a detecting instrument begins to look analogous to the value of books according to one certain old Caliph. He said that he could not see any value in books. Either they contradict the *Koran,* in which case they are evil, or else they don't contradict the *Koran,* in which case they are not needed. Either the meteorite misses the ship, in which case it is just as well not to know it, or else it does not miss, in which case foreknowledge of the event is useless because the ship cannot swerve. And the station could swerve even less than a ship.

No doubt there *is* a danger factor there and all we can do is to estimate the probable frequency of such an event. The earth, astronomers estimate, is hit by some two million meteorites every twenty-four hours. The vast majority of them burns up in the atmosphere; an average of two out of the two million reach the ground. To a spaceship, or to the station, even the small ones would constitute a danger, but that figure cannot be applied to a spaceship as some critical authors have done in the past. The earth presents a target several thousand billion times as large as the largest conceivable ship. And although most meteorites do not so much fall onto the earth as they run into it or the earth runs into them, the gravity of our planet plays a role too. This second factor is missing completely in the case of a ship.

The figure given for the earth is, therefore, only misleading and should be discarded. But another way of estimating the danger can be tried.

In astronomical books it is mentioned that the fall of the Leonids was unusually beautiful in 1866. This simply means that in that year the earth ran into an unusually dense sector of that swarm of meteorites. But it could be calculated that, by terrestrial standards, even the densest sections of that dense sector were simply "empty." The minimum distance between two particles exceeded 110 kilometers or about 70 miles.

In order to get a more recent estimate, one of the members of the *VfR* approached Professor Graff of the Observatory near Hamburg in 1928. Graff replied: "Even in very dense swarms there is hardly one particle weighing less than a gram [1/28 of an ounce] in a space of 100 cubic kilometers, a space immense beyond imagination. As far as large meteorites are concerned, the danger of collision becomes zero."

Making some unfavorable assumptions, one can calculate that we would have to send about five hundred thousand rockets around the moon to be sure that one of them would be hit by a meteorite. The danger factor, it may safely be concluded, is quite small.

However, it does exist, and it is the only danger that is not due mostly to the imagination. But since when do we live in an age where no ship is ever wrecked in a storm, no railroad train ever suffers an accident, and no airplane ever crashes?

If a meteorite did hit the passenger cabin of a ship, it would pass through the metal walls—probably consisting of an aluminum-beryllium alloy—as easily as a high velocity rifle bullet passes through an empty cardboard box. Still this does not necessarily mean the death of the whole crew. Because of its rapid passage, the meteorite would produce two holes of exactly the size of its own diameter. Naturally the air would escape through these holes, but it would not happen instantaneously. In fact the drop in air pressure may be the first warning sign.

Now we get into a whole complex of questions. The mechanical part is comparatively simple. If the walls of the cabin are comparatively bare, as they should be, the holes will not be too difficult to locate. A small patch of sheet rubber would close the hole; the air pressure in the cabin itself would hold the patch in place until a real repair job can be undertaken. But such an event has physiological implications. Supposing that the air pressure drops to half its normal amount between the accident and the emergency repair with small slabs of sheet rubber. There would still be air enough left for breathing (uncomfortable breathing) but the rapid decompression might have serious consequences. The occupants may come down with a case of "diver's sickness," commonly called "bends."

"Bends" is caused by rapid decompression of any description, but the real cause may be described as "bubbles in the blood," nitrogen bubbles, to be precise. The nitrogen of the atmosphere has the habit of dissolving in the tissues and in the blood. As long as the pressure stays normal this saturation with nitrogen is of no consequence whatever. But when the pressure is released, or better relaxed, the nitrogen emerges and forms the dangerous bubbles constituting the cause of the bends. Elaborate tests (a summary of which was published in *Science* [February 27, 1942], No. 2461) have shown that the bends might be avoided if the body is saturated with oxygen for a period of time before the decompression occurs. Unfortunately the "period of time" is long, at least five hours, and breathing too much oxygen is not at all healthy either. But there exists another and better substitute for nitrogen: helium.

Helium, chemically even more inert than nitrogen, does dissolve in the body to a certain extent, but it is much less soluble than oxygen, roughly one fifth. Conversely, the process of bubble formation under decompression is much milder; in fact it needs an extreme case to occur to a health-impairing extent. Diving tests with rapid ascent have shown that experienced divers at least, emerging in a helium-oxygen atmosphere, can sustain decompressions which would have killed them if the atmosphere had been a nitrogen-oxygen mixture. It becomes clear, then, that the atmosphere inside a spaceship cabin should be a helium-oxygen instead of a nitrogen-oxygen mixture.

This again is a point where recent developments evolved for high-altitude flying permit us to say more than could be said ten years ago. Supposing the meteorite which pierced the cabin was very small, so that the holes it made were like pinpricks? Air would escape slowly through these holes and the decompression would be so slight that it might pass unnoticed for a long time. A great deal of oxygen atmosphere could be lost in this way.

A small gadget, worn in the ear, answers this problem. The gadget operates by sending a tiny beam of light through the ear lobe. The color of the blood changes very slightly with the varying oxygen content of the atmosphere, far too slightly to be discovered by the eye. But the photoelectric tube connected with the gadget can see and distinguish two million shades of color, and it announces these changes of shades by means of a pointer on an instrument dial. In that manner small losses would be discovered very soon, and not only losses, but also any other changes in the spaceship's atmosphere.

Now we come to the problem of fueling the body of the pilot.

The human body needs three things: air with oxygen in it, water, and food. And when it comes to spaceships most people invariably assume, as Dr. Moulton did, that a full supply of oxygen, food, and water has to be carried along. This conception leads to a short calculation and the calculation leads to the verdict that it is too much to be carried. Even under this assumption the verdict is not quite justified, and all of Dr. Hohmann's calculations were made with such an assumption. But the assumption is wrong too, especially as applied to one of the three factors: food.

It is amusing to see that fiction writers also tripped up on this problem. They considered that so and so much oxygen had to be carried, plus a fair amount of soda-lime to absorb the carbon dioxide and the moisture. They decided that so and so much water was needed. But they started the idea of a "meal in a pill" to save at least the room which would be occupied by a decent food supply.

The meal in a pill does not work. As far as the essentials of human nutrition go, you can go down to pill size only for the things that are usually in pills anyway: vitamins and minerals. But the amount of carbohydrates needed per man and day is around 2 pounds, and 2 pounds is 2 pounds and does not get smaller by saying so. There are some other things besides carbohydrates, minerals, and vitamins which have to be supplied, so that it is a good bet to say that meals will continue to be meals as we know them. Of course you can save a great amount of bulk and weight first by trimming off nonessential parts as is done anyway for canning. A large variety of foodstuffs can be dehydrated which saves even more weight. And the dehydrated foods should be somewhat compressed as has recently been learned, since this not only saves additional bulk (though no weight), it also makes the food keep better since the oxygen of the air has no longer easy access to the interior.

Food, as I said above, will have to be taken along—a full measure of it. But that does not apply to the water and to the oxygen. In these respects the spaceship is, or can be made to be, a "closed system"—the equivalent of a well-balanced aquarium with fish and plants in it. Only the ship would take on a more "scientific" and less "natural" shape—in some respects.

An allotment of 1 gallon of water per man per day would be more than enough under any circumstances that may be encountered. But while the body does need that water desperately, it does not keep it. It throws it off as a matter of course. As a matter of fact, the body produces some additional water of its own. The "combustion" of food in the body proceeds along a long series of complicated chemical reactions, but some water is one of the end products. The water leaves the body in various ways: roughly half of it by way of natural discharge, the other half by way of expiration and skin evaporation. If it is hot, the skin evaporation grabs a much higher percentage of the total.

The water lost by skin evaporation and expiration enters the air and has to be removed, but there is no need for clumsy chemical methods out in space. Oberth suggested a simple mechanism, consisting in the main of a long tube leading from the cabin to the outside. The tube was to go in a tight zigzag along the dark side of the ship, then pass around to the illuminated side, describe another zigzag line of the same length as before, and return to the interior. The reason for this device is simply that it is very cold inside that tube on the dark side, cold enough to freeze the moisture out of the air and to condense the carbon dioxide gas into "dry ice." The oxygen and nitrogen (now replaced by helium) would not lose their gaseous state, would be heated to ordinary temperature in the other zigzag, and would return to the cabin. Only additional oxygen and an occasional cleaning of the tube would be required.

Oberth did not say so—possibly because he described that mechanism in an example of a moon journey which would be too short to go in for elaborate "saving"—but it would be wasteful to throw the ice and "dry ice" away. The ice could be melted, distilled, and washed and it would then be very pure distilled water which can go through the same process again, and again, and again. The water allotment could be cut down to about a quart per day per person. The water fits perfectly into the closed system.

The carbon dioxide does too, to a certain extent. If the trip is a question of many man-days, there exists a mechanism which is much lighter than liquid oxygen that can be carried along for breathing purposes. That mechanism is the living plant. Plants use carbon dioxide and exhale oxygen; they form the other half of the closed system started by man's breathing of oxygen and exhalation of carbon dioxide. The question is whether plants produce enough, say by weight or bulk, to compete with the weight and bulk of liquid oxygen. The answer is that they do, provided the period under consideration is not too short. For one, two, or even three weeks liquid oxygen is superior; from then on plants win.

But there are some specifications: not plants in general. Growing plants, fast-growing plants, especially starch-producing plants, are best. They do a little better if the atmosphere in which they grow contains more carbon dioxide than the atmosphere of earth, but the percentage used in experiments would still not hurt human beings. German plant physiologists singled one plant out as being especially effective: a growing pumpkin. They found that 1 square meter, or about 11 square feet, of leaf surface can supply the oxygen needs of a resting person. Other botanists, to whom I talked about this, swore that certain water plants must be more effective. It probably would not take much experimentation to find a plant which is the best all around: fast growing, with large leaf surface (that does not mean large leaves), and unaffected by its surroundings.

The current minimum estimate is that each cubic meter of plants can supply the oxygen needs of at least two people doing a normal amount of non-strenuous work. And they could do it, not for any limited time, but indefinitely, as long as they stay alive.

Liquid oxygen for breathing, therefore, would need to be carried only for emergency purposes and for use in what has become known as a "space suit" which is a pressure-proof diving suit with an electric heating and a small reaction mechanism, to be used for "outdoor work" around the station or for inspections of the outer hull in the case of a spaceship. And for leaving the ship on the moon, if a landing should be in the plans.

These are the answers I promised to give. They are, I repeat, the answers of today and they will probably not be the same fifteen years or so from now. But they show that these questions can be answered.

There is one more answer which I separated from the others because it will *not* be subject to change. The problem of navigation, or astrogation if you prefer the term. A spaceship, once launched into an orbit, is not in danger of straying from its course; there is no weather in space and the equivalent of currents are the gravitational fields in and among which the ship is coasting. While there is absolutely no chance for "straying" in that sense, there exists the chance, of course, that the ship is not quite in the proper orbit, and that point will have to be checked. It can be checked very easily—easy in principle, at least—by means of celestial navigation, used today on every airplane.

The principle, as used by aviators, is this: at a given moment a certain star must be vertically over one point of earth. This point is called the "substellar point" and if an airplane found a star directly overhead, the whole problem would be solved; the plane would be over that substellar point which can be looked up in a table. Most of the time, however, the star is not overhead but at an angle which has to be measured. The first measurement results in a circle, drawn on a globe around the substellar point, with the angular distance found by measurement. The plane is, must be, at one point along that circle. Then the maneuver is repeated with another star which produces a second circle, crossing the first one in two points. The plane is in one of these two points and, since they are usually a thousand or more miles apart, there can be no doubt which one of the two it is.

Actually the navigator, just because he knows approximately where he is, does not draw full circles but only two short straight lines on a map. The two lines represent short sections of the two circles. Their crossing marks the position of the plane and is called a "fix."

In that form, celestial navigation cannot be used for purposes of space travel, but it can be easily adapted. The recipe was written some time ago by a professional astronomer, Dr. R. S. Richardson.[6] It works like this: First the astrogator finds the star Regulus which happens to be large and which also happens to be situated nicely in the plane of the solar system. He measures the angle formed by the sun, the ship, and the star Regulus. Since Regulus, to all practical purposes, is motionless, the angle sun-ship-star informs the astrogator about his position in space. The astrogator now knows the position of his own, or rather his vessel's *radius vector.* What he needs to find out next is the length of the *radius vector* and this is established by constructing a triangle of sun, ship, and a planet, usually the target planet. Of that triangle he knows one side, the distance of that planet from the sun for that day—it will be in his *almanac*—and he can measure or deduce all three of its angles.

[6] In an article "Space Fix," in Street & Smith's *Astounding* (March 1943). This magazine, although classified as a "pulp," carries quite a number of articles by professionals, dealing with matters somewhat outside the scope of professional journals.

It is easy to calculate the length of that side which represents his distance from the sun.

It is quite likely that special instruments will be developed to guarantee high accuracy of these measurements, but the principle just explained will not be subject to change because of its great simplicity.

The idea of space travel has by now reached a rather high state of perfection. There is not the slightest doubt any more about the requirements and the principles for their fulfillment. The strategy, so to speak, is established. What the tactics will look like is another question. Some "tactical maneuvers" are rather well established too, while the ideas about some others are, of necessity, somewhat hazy at present.

The important point is, however, that nowhere in the vast expanse of that problem could anything be found which looks like a really insurmountable obstacle. Difficult points, yes. Troublesome corners, yes. Stiff requirements, yes. But nothing that cannot, in one way or another, be approached and be brought more closely to a solution.

It looks as if that great old dream is not a dream after all. It is something that can be done.

CONCLUSION

THE man who calls himself a "hard-headed businessman" now looks up from the book and frames a big question in a single syllable. The syllable is "Why?"

Why should we try for space travel?

Those semi-philosophic statements like Ziolkovsky's about the inescapable logic of man's conquest of space after all of the earth has been conquered do sound very nice. They are possibly correct too, but that question remains, with a slight shift in emphasis.

Why should *we* try for space travel? Why not later generations who find the job easier?

The answer to that question may not be convincing if you don't want to be convinced, but it is a simple answer. Somebody has got to start at some time, and we may as well get the glory for our own century.

It can be added here that developments of this type very often progress much more smoothly than expected as soon as the initial difficulties have been overcome. In this particular case the reasons for harboring this belief are good indeed. Some of the initial difficulties are not just a figure of speech for a lot of undefinable things. They are actual, they appear in the equations and in the diagrams. We know about them and we know *when* they will be overcome. The space rocket will be simple once the meteorological rocket has passed the 200,000-foot altitude mark. So much is certain right now. And there is little, if any, reason to doubt Pirquet's statement that the exploration of the inner solar system will be easy once the station in space has been established.

The question beginning with "Why" still persists, but the emphasis has shifted again. This time the speaker himself is the emphasis, the fact that that question comes from a businessman.

It is now voiced not as a question of the possibility. The businessman, once he finds twenty engineering experts and astronomers in agreement that this or that can be done, will accept their combined word for it. Nor is the question voiced as a doubt of the glory that will descend upon the century that begins to work on the great problem. The businessman is willing to accept that honor rather than leave it to anybody else. He is even ready and willing to buy it, provided it can be bought at a reasonable price.

"Reasonable" means either "small," or it means a price which yields financial returns. The first is certainly not the case. How about the financial returns?

I don't mean the meteorological rocket here. The commercial usefulness of that will be admitted readily.

I mean actual space travel, space travel with its long period of development and with its incredible amounts of money involved, all called "initial outlay." What are the financial returns that can be expected from that?

The first trip may expect to pay part of its cost out of curiosity value. Pieces of lunar rocks, samples of lunar sands, anything lunar at all will bring fabulous prices. But only once.

Later on commercial possibilities of that kind are nil. We cannot expect to find anything on the moon, generally speaking, that cannot be found on the earth. We cannot expect to find anything valuable enough, barring pure platinum and highly concentrated radium salts (and there is not much hope for either of these things) that can pay for its incredible haulage.

It cannot be a substance of any kind that can be expected to pay. It can only be something intangible, not involving haulage, which is, at the same time, more valuable.

There is something like that: Knowledge.

The station in space, the spaceship circling the earth, is, as we have seen, a super-laboratory for any branch of physics and chemistry and for some branches of the biological sciences. It is a laboratory with completely new facilities, offering absolutely new conditions. It offers a temperature range from the intensity of concentrated sunbeams to cold near that lower limit which scientists call absolute zero. It offers a vacuum better than any that can be made on earth, literally limitless in size. It is free from gravitational strain, but you can produce any gravitational strain you want to have for some reason.

Since the conditions are new, new results are certain to be obtained. It is a place where pure research can be counted upon to furnish new discoveries. And new discoveries, the discoveries of pure research, are the most valuable asset of any industry.

The station in space promises many new discoveries. It is not impossible that a single one of them will pay for everything.

NOTES AND ADDENDA

ADDENDUM TO CHAPTER 3.

Page 65.

Written in the form of an equation, the Third Law of Motion reads $MV = mv$, where M and m are the masses involved and V and v the velocities. It is customary, however, to use v for the velocity of the rocket and c for the velocity of the exhaust. Likewise it has become customary to refer to the mass of the rocket before working (burning) as M_0 and to the mass of the rocket afterwards as M_1.

The differential equation governing rocket motion is

$$m \times dv + c \times dm = 0.$$

The most important relationship which can be derived from this formula is the expression for the velocity v which states that v equals c multiplied by the "natural logarithm" of the mass-ratio M_0/M_1. Natural logarithms are those which are based on e which equals 2.71828183..., the result of the series $1 + 1/1! + 1/2! + 1/3! + 1/4! +++\ldots$

Using the factor e, the mass-ratio can be expressed in a very simple manner as $e^{v/c}$. This factor, multiplied with the remaining mass of a rocket, permits establishing its take-off mass without difficulties. Of course v (velocity) and c (exhaust velocity) have to be known. A table which permits the finding of the proper value for the mass-ratio will follow at the end of this "note," and several examples of the use of this factor will be discussed in the "Note on Rocket Artillery."

But it is also possible to arrive at e in an elementary manner, by calculating the remaining mass for several assumed rockets, ejecting definite proportions (like halves, quarters, hundredths, etc.) of their mass. An example of this has already been given in Fig. 10 on page 67. Carrying the same method further, one may obtain a number of results that can be tabulated in the following manner:

$v = c$ when the mass-ratio equals	4	(expelling	halves)
	3.375	"	thirds
	3.165	"	quarters
	2.868	"	tenths
	2.729	"	hundredths
	2.723	"	thousandths
	2.720	"	ten thousandths

When "infinitely small" parts are expelled the ratio drops to 2.7182... which is e. This case holds true for actual rockets of any type, powder or liquid fuel, since gas molecules may be considered as infinitely small as compared to the size of the rocket.

The following table, worked out by Professor Oberth, permits instant finding of the proper mass-ratio within wide limits.

	v =	500	1,000	2,000	3,000	4,000	5,000 m/sec.
c =	1.000	1.64	2.72	7.39	20.0	54.5	148
m/sec.	2.000	1.29	1.64	2.72	4.48	7.39	12.2
	3.000	1.18	1.39	1.94	2.72	3.78	5.29
	4.000	1.13	1.29	1.64	2.11	2.72	3.49
	5.000	1.10	1.22	1.49	1.82	2.22	2.72

	v =	6,000	7,000	8,000	9,000	10,000	11,000 m/sec.
c =	1.000	405	1089	2987	8060	22,070	60,000
m/sec.	2.000	20.0	33.0	54.5	89.6	148.7	243.5
	3.000	7.39	10.25	14.35	20.0	27.95	39.0
	4.000	4.48	5.76	7.39	9.5	12.20	15.75
	5.000	3.32	4.06	4.95	6.06	7.39	9.02

	v =	12,000	13,000	14,000	15,000 m/sec.
c =	1.000	163,100	444,000	1,200,000	3,290,000
m/sec.	2.000	402	662	1,091	1,805
	3.000	54.6	76.1	106.3	148.7
	4.000	20.0	25.8	33.2	42.7
	5.000	11.0	13.47	16.42	20.0

From Die Möglichkeit der Weltraumfahrt.

Page 78.

Note on Rocket Artillery

The conception of the mass-ratio also permits judging the advisability of rocket propulsion for artillery projectiles. Since the take-off mass of any rocket has to be $e^{v/c}$ times the remaining mass (which consists of the empty rocket plus the projectile carried), the only values that have to be known are the exhaust velocity of a given fuel and the highest velocity (here called v) which the projectile-carrying rocket would have to attain to span the desired range, i. e., the distance between the take-off point and the target.

Since storability is the prime requirement for military rocket fuels, the factor c may be assumed to be 1000 yards per second on the average. This is the value that is valid for the *best* known types of commercial powder rockets. Liquid fuels, because of their non-storability, will hardly be considered for military applications.

If we apply this factor to a few known gun performances, we get very interesting results. The German *Paris Gun* of 1918 discharged a 260-pound projectile with a muzzle velocity of 1 mile or 1760 yards per second. The mass-ratio then becomes $e^{1.75}$, or $e^{7/4}$, or $\sqrt[4]{e^7}$ which is 5.76. Since it could hardly be assumed that the empty rocket could weigh less than 240 pounds, the "remaining mass" of such a shell, when rocket-propelled, would be around 500 pounds, and the initial mass about 3000 pounds. The propelling charge in the *Paris Gun* was about 650 pounds maximum. This charge propelled the shell over a distance of 80 miles. It would need a 3000-pound rocket to accomplish the same result.

For a 600-mile shot the mass-ratio would have to be $e^{3.52}$ (if v is 2 miles per second). This is roughly $e^{7/2}$ or $\sqrt{e^7}$ or about 33.

As has been shown in the book in Chapter 8, such a mass-ratio cannot be accomplished except with the step principle, and even then only when liquid fuels are used. Similar disadvantages exist at the other end of the scale of artillery ranges. The French 220-mm. mortar Model 1887 fired 260-pound projectiles. With an elevation of about 66 degrees the minimum range attained was 600 meters, the maximum range 3200 meters. The muzzle velocity for the minimum range was 90 meters per second, the propelling charge 2.5 pounds. The muzzle velocity for the maximum range was 230 meters per second, the propelling charge required 13.5 pounds.

If the mortar were to be replaced by rockets with projectiles of the same weight, the following figures would apply: for maximum range the mass-ratio would be $e^{1/3}$ or about 1.4, the take-off mass 260 pounds (projectile) + 25 pounds (empty rocket casing) times $1.4 = 399$ pounds. For minimum range the mass-ratio would have to be 1.15, the take-off mass $260 + 25 \times 1.15 = 328$ (pounds).

It can be seen that artillery is superior for any range as far as efficiency goes. But the use of rockets permits the substitution of a light launching rack for a heavy gun or howitzer. Similarly the disadvantage of lesser accuracy is made up by the greater volume of fire. The rockets in use in World War II, consequently, are all operating over comparatively short ranges (up to about 5000 yards) and achieve success by heavy volume of fire.

Addendum to Chapter 5.

Page 118.

The efficiency ot a rocket cannot be expressed in the same manner as that of another type of engine because it is the product of two different "efficiencies," usually referred to as "inner" or "thermal" efficiency and "outer" or "ballistic" efficiency. The former is equivalent to the efficiency of, say, an internal combustion engine, referring to the percentage of theoretical energy in the fuel which is actually utilized. Except for electrical machinery, this efficiency varies from about 25 to about 35 per cent in the various types of prime movers; in the case of a rocket it is rather high, between 50 and 60 per cent, due to the lack of moving parts and the small amount of friction. This thermal efficiency has to be multiplied with the ballistic efficiency. But while the thermal efficiency is substantially the same under any condition, the ballistic efficiency depends solely on the velocity of the rocket at a given instant. It is zero when the velocity of the rocket is zero. When $v = c$ the ballistic efficiency is 100 per cent, and in that case the overall efficiency would be equal to the thermal efficiency of the motor. The formula given by Dr. Sänger for the ballistic efficiency is

$$E_{ball} = \frac{2cv}{c^2 + v^2}$$

It can easily be seen why the ballistic efficiency—and with it the overall efficiency—of rockets forced to move at much less than their own exhaust velocity is poor, so poor as to be useless.

Page 119.

The danger of premature explosion is almost inherent in powder rockets of this size. Sander succeeded in compressing the powder mixture to a higher extent than customary, but that higher compression also caused the resulting powder cylinder to be much more brittle than customary. If such brittle rockets are subjected to changes of temperature while stored, or if they are transported, fine cracks are apt to form in the charge, cracks which cannot possibly be detected. When such a rocket is used the performance will be normal until the flame reaches the crack. Then the surface of the crack will also become a burning surface, causing a sudden large increase in gas generation. In comparatively harmless cases unburned lumps of composition—those between crack and nozzle—will be thrown out. But usually the tube cannot stand the sudden increase in pressure, which may be aggravated by the blocking of the exhaust nozzle by a still unburned lump of powder. Unless it is possible to use a type of composition which, while highly condensed, stays somewhat flexible and does not crack, there is no way of avoiding such explosions.

Page 128.

Note on Other Rocket Societies

In the wake of the founding of the *VfR* a number of other rocket societies were formed. The Russian society mentioned was called *GIRD*, a name formed from the initials of the Russian words for "Group for the Study of Reactive Motion." The Moscow branch and the Leningrad branch were called *Mosgird* and *Lengird*, respectively. In Austria Pirquet and Zwerina founded the *Oesterreichische Gesellschaft für Raketentechnik* (Austrian Society for Rocket Technology). In Great Britain the British Interplanetary Society was founded in 1933 by P. E. Cleator in Liverpool. It was later transferred to London and has been suspended by its board of directors for the duration of the war. There also exists a Manchester Interplanetary Society. In the U.S.A. several societies existed at some time or another. One of them was the "Cleveland Rocket Society" under Ernest Loebell which ceased to exist in 1937. A proving ground had been established but was used for only a very few experiments.

Oldest of the American societies is the American Rocket Society in New York, which was founded in March 1930 by G. Edward Pendray and David Lasser under the name of the American Interplanetary Society. This society is the only one in this country which actually built a rocket, or rather several. The first was a two-stick repulsor patterned frankly after the *VfR* model. It was damaged during its first test run in autumn 1932. Most of its parts, especially the tanks and the motor, could be salvaged, and the new rocket, called "No. 2," was tested at Marine Park, Great Kills, Staten Island, in May 1933. The society's journal, *Astronautics* (No. 26.), reported on the test as follows:

> Experimental Rocket No. 2 of the American Interplanetary Society was shot at twenty minutes past eleven o'clock, Sunday, May 14. It reached an altitude of approximately 250 feet after firing a trifle more than two seconds. At that height the flight was brought to an abrupt end by the bursting of the oxygen tank.

After this three more rockets, called No. 3, 4, and 5, were planned. No. 5 turned out to be hopeless nonsense; No. 3 was built but could not be fueled and was therefore useless. No. 4, a one-stick repulsor, was tested September 9, 1934. It took off with high acceleration and rose almost vertically to about 300 feet. At that point one of the four nozzles of the motor burned out and the rocket assumed a strange weaving motion. The peak altitude is estimated to have been 382 feet. It covered a horizontal distance of 1300-1400 feet. The rocket struck the water with great violence and was so badly smashed that it could not be repaired. The newly devised parachute release had no chance to function.

Since that experiment only ground tests have been performed. The record is a twelve-second run on June 22, 1941, when a ceramic-lined motor designed by Alfred Africano produced a recoil of more than 260 pounds for the duration of about two seconds. Lack of a permanent workshop and proving ground, combined with an almost frantic desire to avoid "conventional methods," resulted in a rather erratic program and may explain the comparatively small amount of work done since 1935.

Addendum to Chapter 6.

Page 142.

Winkler later built a second rocket which failed to perform. Resembling the Oberth Rocket in size and shape, it had a tail drive, a nose parachute, and two spherical tanks for liquid oxygen and methane. It was a little over 5 feet high and weighed around 110 pounds. The trouble with this rocket was that it, like the Oberth Rocket, was based on a large amount of computation with only a very slight seasoning of experience. Winkler had made just one full test run in the course of which most of the exhaust nozzle had burned away.

Like the Oberth Rocket the *HW-2* (Hückel-Winkler 2—Hückel had provided the cash) was to take off from the Greifswalder Oie. But the lighthouse was still there and the same officials were still in charge—at least the same kind of officials. After months of waiting, Winkler had to leave the unfriendly isle and took his rocket to East Prussia where he finally got permission to test it on the beach not far from the harbor of Pillau. He made his first attempt on September 29, 1932. Nothing happened; icing around and probably inside the valves prevented the fuels from entering the combustion chamber. This turned out to be the lesser evil. During the next attempt on October 6, the valves apparently leaked and permitted a trickle of gases to accumulate somewhere between the tanks and the outer skin of the rocket. When the rocket was ignited this mixture caught fire too and threw the rocket which had barely lifted itself for 6 or 10 feet to the ground. It was an extraordinary smashup. Winkler complained afterward that not a single part was usable.

Page 142.

Note on Dr. Goddard's Experiments

Although Dr. Goddard was actually the first to build a liquid fuel rocket, this fact remained completely unknown until 1936 when the Smithsonian Institution published his second report. Since Dr. Goddard is unwilling to have his work discussed, I'll quote only a few facts from this report which establish some dates.

On November 1, 1923, a rocket motor operated in the testing frame, using liquid oxygen and gasoline, both supplied by pumps to the rocket.

The first flight of a liquid oxygen-gasoline rocket was obtained on March 16, 1926, in Auburn, Mass., and was reported to the Smithsonian Institution May 5, 1926.*

The rocket traveled a distance of 184 feet in 2.5 seconds, as timed by stop watch, making the speed along the trajectory about 60 m.p.h. Other short flights of liquid oxygen-gasoline rockets were made in Auburn, that of July 17, 1929, happening to attract public attention owing to a report from someone who witnessed the flight from a distance and mistook the rocket for a flaming airplane.

Later Dr. Goddard established a proving ground near Roswell, New Mexico. The rockets were equipped with a gyroscope stabilizer. (First test March 28, 1935.) Some films of these rockets were shown later. One ascent was made on May 31, 1935 (ceiling 7500 feet), another on October 14, 1935 (ceiling 4000 feet). The gyro stabilizers worked well, but the performance of the rocket motors cannot have been very good. The rockets left a smoke trail and occasional flashes of exploding gasoline vapor. It is stated that the weight "varied from 58 to 85 pounds" but it remains unclear whether this is the weight ratio, or the weight of two different rockets. Nothing has been stated about work carried out since then.

Note about the Experiments of Reinhold Tiling

In April 1931 a German engineer by the name of Reinhold Tiling (pronounced *Tee-link*) of Osnabrück demonstrated for the first time a new kind

* *Dr. Goddard refused permission to republish the photograph of this rocket.*

of powder rocket which found a great deal of public acclaim. The date of the first public demonstration was April 15, 1931, the place a lake near Osnabrück. Tiling, who had the financial backing of one Count von Ledebour, must have worked in secret for a long time because the rockets he displayed then were a finished product.

They consisted of a streamlined aluminum body, housing the rocket proper, and four long fins. There was no parachute. The functioning of Tiling's landing mechanism is reported wrongly with annoying consistency, mainly because Tiling patented a misleading description. (U.S. patent No. 1,880,586 of Oct. 4, 1932.) The patent reads, in essence:

> This invention relates to a flying rocket with foldable tail fins, the feature of which consists in that the tail fins . . . are hinged . . . so that, during the propelled flight they serve as guide fins, and, when changing into free fall over the point aimed at, become released and thus spread out and impart a torsion to the rocket body.

In less cumbersome language that means that the four fins will spread out at the peak of the ascent and act like the blades of an autogiro.

Actually Tiling's rockets did not use that system at all. Two of the fins remained fins, while the two others snapped out like the blade of a pocket knife. The two fins transformed the rocket into a glider, not into an autogiro. The arrangement worked well, provided the air was calm. It was better looking but much less effective and much less versatile than a parachute. The Tiling rockets had an overall length of about 6 feet, and they rose to altitudes varying from 1500 to 2500 feet. They never showed any improvement, just because Tiling had demonstrated a finished product to begin with. Later on he even had bad luck occasionally. During the demonstration at Tempelhof airdrome near Berlin one almost smashed into the grandstand so that the police forbade further attempts on that day, which happened to be gusty and rainy.

Undaunted, Tiling set out to build rockets capable of crossing the British Channel. This, at least, is what he announced. But whatever it was he had really in mind did not come to pass. On October 11, 1933, the newspapers reported that Tiling's laboratory had exploded the previous night. Tiling was dead, as was his laboratory assistant Miss Angelika Buddenböhmer, while his mechanic, Friedrich Kuhr, lived for another day.

It turned out to be the result of great carelessness, just as Valier's death. They had been working late the previous night, compressing not less than 40 pounds of powder into compact tablets. In the middle of that work the catastrophe occurred. It seems that the powder press exploded; pieces of the heavy cast iron press were found all over the ruins. The flame of that explosion reached a large supply of processed and unprocessed powder which was *stored in the same room.* The whole laboratory caught fire instantly, but Tiling and his two helpers succeeded in leaving the burning ruins, their clothes on fire. They threw themselves into a nearby pond. Then Kuhr, who was the least injured, ran to Count von Ledebour's castle to give the alarm. Nothing could be salvaged and medical aid came too late for all concerned.

Page 132.

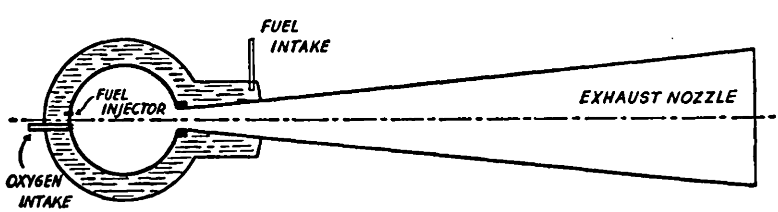
Valier's last rocket car was overhauled later by chief engineer Pietsch of the factory owned by Dr. Heyland. Pietsch designed and built a rocket motor capable of delivering a thrust of 160 kilograms (about 350 pounds) for a period of a few minutes. The weight of the motor was 18 kilograms. The car made two public (and probably several secret) test runs on April 11 and on May 3, 1931. While the thrust of this rocket motor was unusually high and the duration of the test remarkable, the efficiency must have been poor. The flame was red and smoky, signifying incomplete combustion.

Note on Dr. Sänger's Experiments

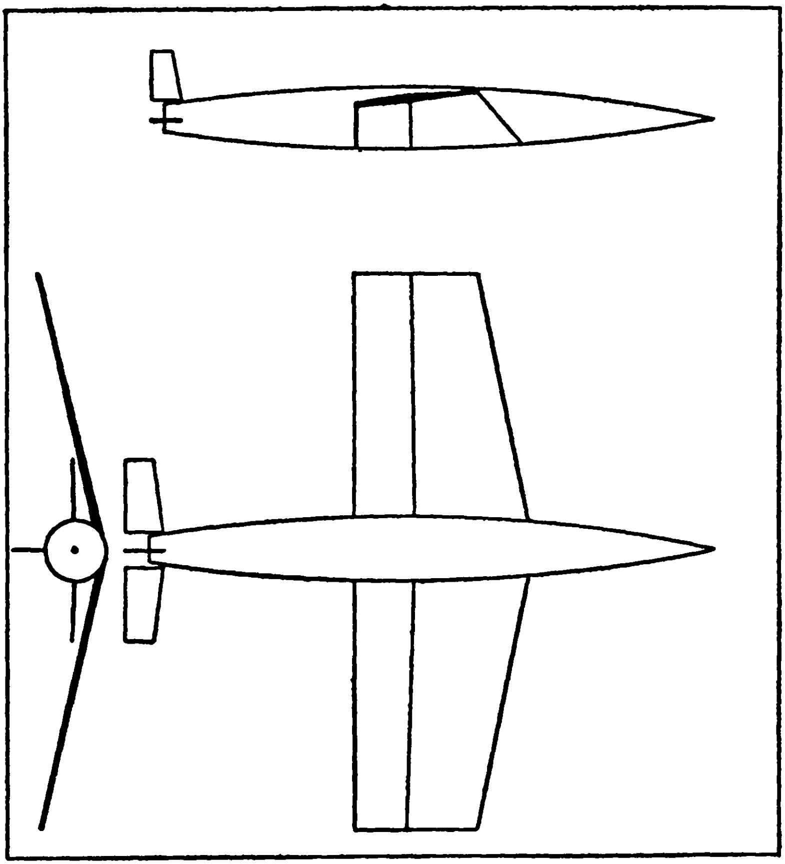
In 1931 and early in 1932 Dr. Eugen Sänger performed a long series of rocket tests using the facilities of the University of Vienna. Doctor Sänger's standard model was spherical, with a diameter of about 2 inches. The exhaust nozzle was some 10 inches long, with a muzzle diameter equaling the diameter of the spherical combustion chamber. The combustion chamber itself and the part of the exhaust nozzle next to it were surrounded by a cooling liquid jacket. (Fig. 45.) The oxygen was fed in directly under high pressure, the fuel was fed into the space between the combustion chamber and the cooling liquid jacket and thereby served a double purpose: it not only cooled the combustion chamber but also relieved it of the pressure created by the combustion by producing a somewhat higher counterpressure. It was the outer jacket which really took the strain, which it could do all the more easily since it remained cold.

Because of this arrangement, Doctor Sänger could follow the practice of the *VfR* and keep the walls of the combustion chamber thin. The injection of the fuel was done by means of a Bosch injection pump of the same type that is used in Diesel engines. The injection pressures were very high, ranging from 30 to about 150 atmospheres. The fuel used was light fuel oil; in a number of cases gaseous oxygen under pressure was substituted for liquid oxygen. The rocket motor itself was suspended in a horizontal position in a framework of steel tubing which could swing horizontally only, pressing against a spring device which measured the thrust.

Doctor Sänger achieved astonishingly long burning times. His normal test run lasted fifteen minutes; in many cases they lasted twenty minutes and once



45. Dr. Sänger's Experimental Rocket Motor.



46. Dr. Sänger's Sketch of a Stratosphere Rocket Plane.

even half an hour. The thrust of the motor was around 55 pounds, the exhaust velocity was estimated to have varied between 2000 and 3500 meters per second (about 6600 to 11,500 feet per second). But the flame of the exhaust was of the type called "fox tail flame," indicating that the combustion was not quite complete.

After these tests, Dr. Sänger arrived at the following conclusions:

(1) The exhaust speed of the combustion gases will become much higher than the main translatoric value for the speed of the gas molecules when the motor is correctly shaped.

(2) The dissociation which occurs during the combustion does not lead to important losses (of energy) in rocket motors.

(3) The explosion-like combustion of liquid hydrocarbons in the presence of liquid oxygen occurs with reliable steadiness provided the feed is steady.

(4) The problem of suitable materials for combustion chamber and exhaust nozzle is most certainly soluble.

He then investigated the possibility of atmospheric and stratospheric flight by means of rocket power and arrived at the conclusion that the use of rockets is only possible if a new principle of flight is adopted. The method is about this: the rocket plane climbs at an angle of about 30 degrees under power until the desired high altitude is attained. Then it levels off. The rocket motor will be switched off (the fuel is likely to be about exhausted by then) so that the plane will travel in the manner of a projectile, slowly losing both speed and altitude until it is time to land. Under these conditions a burning time of twenty minutes should result in a flight of about seventy minutes with an average speed of 1600 miles per hour. The probable appearance of such a strato-speedster as visualized by Dr. Sänger is shown in Fig. 46.

General Remarks on Rocket Airplanes

The problem of the rocket airplane has to be considered as a specialized application of the rocket problem, and the invention of a rocket plane as a by-product of rocket research. The problem, about which a very considerable number of articles and papers have been written since 1905, is made difficult because the laws of aerodynamics and the laws of rocket propulsion are mutually exclusive as long as the atmosphere has appreciable density. Rocket propulsion demands velocities of such a magnitude for efficiency that this condition usually cannot be fulfilled. While some of the ideas advanced are rather interesting, there is no need to recount them in detail since most of them remained on paper. Only a few progressed to the model stage. The main idea was always to add atmospheric air to the rocket blast in some manner in order to increase the mass of the blast and decrease its velocity at the same time, thus producing a better "outer" efficiency. The Frenchman Henri F. Melot in 1917 (and later) simply added air to the blast by means of a number of so-called Venturi nozzles. The German Wilhelm Goldau operated with very large combustion chambers, containing a great surplus of air. These two methods worked experimentally; a host of others remained paper work. The so-called "jet-propelled" planes do not belong to the same category and will be discussed at the end of these Notes.

Note about the "Fischer Hoax"

The Magdeburg Project had another afterlude, the so-called Fischer Hoax which claimed that on October 29, 1933, a man by the name of Fischer risked his life in a 6-mile rocket ascent, the rocket being the work of his brother. The account seems to have originated in the London weekly *Sunday Referee*; at least a copy of that weekly shows the earliest date of all the numerous versions of the story. It also had the most complete account which read, somewhat condensed, as follows:

> A sensational secret demonstration of the practicability of the rocket principle applied to flight was made here last Sunday, when Herr Otto Fischer was shot 6 miles into the air within a 24-foot steel rocket and returned to earth safe and sound, though shaken. The pilot who risked his life in this experiment is the brother of the designer and constructor of the rocket, Herr Bruno Fischer.

Owing to the disastrous results of a similar experiment made on Rügen in the spring of last year, when the original inventor was killed, the demonstration was made under the cover of absolute secrecy, under the auspices of the Reichswehr, the German War Ministry. The inhabitants of the island knew nothing of the proposed experiment, and no members of the press were called to witness it. For some months the two brothers had been working day and night in Barmbeck, a small village near Hamburg, to complete the rocket, Bruno Fischer having been an assistant in the building of the first projectile. When the projectile was completed it was transported to Rügen with great secrecy. On Sunday morning, at six o'clock, Otto Fischer shook hands with his brother and the small group of Reichswehr officials present to witness the experiment, and crawled into the rocket through the small steel door.

Bruno Fischer and the three officials then retired to a small hollow in the ground about 200 yards away and Fischer closed the switch that sent the rocket on its journey. There was a blinding flash and a deafening explosion and the slim torpedo-shaped body was gone from the steel framework in which it had rested.

A few minutes later it came into sight again, floating nose upward from a large parachute that had automatically been released when it had begun to descend. As it drifted nearer, the steel fins on the outside of the body could be seen moving as its pilot manipulated the rocket so that it would land on the island. A few seconds later it came to rest on the sands a few yards away and Fischer crawled through the door of the rocket, white and shaken, but smiling triumphantly. The journey through space had lasted ten minutes and twenty-six seconds.

"It was a tremendous sensation," he said to the men who had rushed forward to congratulate him. "When the rocket left the ground I was conscious of a deafening roar and an unbearable weight seemed to be crushing me against the floor of the rocket. Then I lost consciousness for a moment, due to the tremendous acceleration which drained the blood from my head. When I came to my senses and looked at the altimeter before my face, it flickered at 32,000 feet—a fraction over 6 miles—and then began to drop rapidly. I had completed my climb and was descending. Peering through the little glass window in the side of the compartment I could just see the tip of the parachute billowing above me. The next thing that occupied my attention was the tremendous heat of the asbestos floor on which I was standing. The reason was that the rocket had merely been propelled about 200 yards by the initial explosion, and had been driven the remainder of the distance by the rockets in its tail. . . ."

Further experiments will be conducted by the German War Ministry.

The flood of mail I received proved that this alleged report looked convincing enough to the average reader. It cleverly combined features which could be counted upon to revive some vague memories about rocket experiments in Germany in the reader's mind. It also confirmed more or less vague suspicions about German rearmament. Small wonder that it was uncritically believed at once.

But to anybody familiar with German rocket research it contained a large number of glaring errors. In the first place, the choice of steel for a building material was startling, to say the least. Since a rocket does not undergo great strains and stresses, there is no reason to build it of such heavy materials. The "asbestos floor" was another error; a German engineer would be likely to use another kind of insulating material.

Then there were a few typical layman's mistakes, proving definitely that the writer of that article had not only not seen the secret Fischer rocket but had never seen any kind of a rocket except fireworks powder rockets. The "initial explosion which propelled the rocket for 200 yards" is a case in point;

there is no such thing as an initial explosion. And large rockets, naturally, never disappear in a flash. They always take off slowly and can be seen clearly. They may "disappear" later, when they are too high to be easily seen. The masterpiece was, of course, the description of the moving steel vanes supposed to steer the rocket to a certain spot. The vanes could move as much as one wanted, but they would not noticeably influence the angle of descent of a load carried by a parachute. The proper way of steering such a load—whether it be a rocket or a man or anything else—would be to tilt the parachute by pulling the shrouds on one side.

The editor of the *Sunday Referee*, when informed about these facts, explained that his policy of editorial secrecy prevented him from disclosing his source of information and he passed lightly over the technological points, saying that his reporter, not being a trained engineer, might have made a few minor mistakes. The point was that these mistakes were not minor; they were of the order of saying that a Flying Fortress took off from Shangri-La airdrome by flapping its huge wings.

Since a glamorous lie is often more attractive than a simple truth, most people could not be convinced that the story was a hoax. Just to make sure I checked up on possible rocket experimenters by the name of Fischer. Although Fischer is a fairly common German name it so happened that the *VfR* did not have a member by that name. And while a search of the correspondence files of non-members did bring to light two or three Fischers, they did not live in or near Hamburg.

It was comparatively easy to piece the implied references together. The performance itself was, naturally, an elaboration on the announced performance of the Magdeburg "Pilot Rocket" with the minor change that passenger and rocket descended together in one parachute instead of separately. The "slim torpedo-shaped body" was, no doubt, a description of the Oberth Rocket, and the steel launching rack also pointed to the 7-foot Oberth Rocket. Whether the writer of the "report" had any knowledge of Nebel's attempt to interest the German War Ministry or whether he thought of it as a literary device to produce the conditions of utmost secrecy required for his purposes remained uncertain.

But the unknown reporter of the *Sunday Referee* was bested by another writer—or was he the same?—who signed himself as W. J. Makin and published an article entitled "Space Explorers" in the May 1935 issue of *Nash's Pall Mall Magazine* in London. In that article "Mr. Makin" explained that he had heard that there were some doubts about the secret Rügen ascent and that he set out to investigate it:

> I decided to begin my investigations by flying to the first most elaborately equipped rocket aerodrome, the *Raketenflugplatz*. A young engineer led me to the records chamber, where not only the work of the *Raketenflugplatz* is carefully recorded, but scientific results from rocket aerodromes in other parts of the world are collected. [There were no others. *W. L.*]
>
> But even as I was combing these records, a heavily built man with a charming smile and a curiously soft voice was introduced to me.
>
> "Herr Otto Fischer."
>
> Even as I shook hands with him I realized that I was meeting the one man who had traveled through space inside a rocket and lived to tell the tale—the

first passenger to enclose himself in a steel rocket of some 24 feet, which was shot 6 miles into the air. The rocket was designed and constructed by his brother, Herr Bruno Fischer. In great secrecy it was transported to the island of Rügen. . . .

Later on in that same article I am mentioned too, although "Mr. Makin" does not make it clear whether he met me at that occasion or at another one. As a matter of fact I never met him. "Mr. Makin's" visit to the *Raketenflugplatz* some time between November 1933 and March or April 1935 is just one more embellishment of the same hoax. At that time the *Raketenflugplatz* was no longer active.

Addendum to Chapter 7.

Page 161.

Humphrey's Table on the Variation of Temperature, Pressure and Density with Altitude.

(Compiled from actual records obtained by sounding balloons in flights made near Paris, Brussels, Munich, and Strassburg.)

760 mm Hg = 29.921 inches = 1,013.3 millibars.

altitude km	C°	mm Hg	density of dry air in gram/cm³
20.0	—51 (—57)*	44.1 (39.5)	0.000092 (0.000085)
19.0	—51 (—57)	51.5 (46.3)	0.000108 (0.000100)
18.0	—51 (—57)	60.0 (54.2)	0.000126 (0.000117)
17.0	—51 (—57)	70.0 (63.5)	0.000146 (0.000137)
16.0	—51 (—57)	81.7 (74.0)	0.000171 (0.000160)
15.0	—51 (—57)	95.3 (87.1)	0.000199 (0.000187)
14.0	—51 (—57)	111.1 (102.1)	0.000232 (0.000220)
13.0	—51 (—57)	129.6 (119.5)	0.000270 (0.000257)
12.0	—51 (—57)	151.2 (140.0)	0.000316 (0.000301)
11.0	—49.5 (—57)	176.2 (164.0)	0.000366 (0.000353)
10.0	—45.5 (—54.5)	205.1 (192.0)	0.000419 (0.000408)
9.0	—37.8 (—49.5)	237.8 (224.1)	0.000470 (0.000466)
8.0	—29.7 (—43.0)	274.3 (260.6)	0.000524 (0.000526)
7.0	—22.1 (—35.4)	314.9 (301.6)	0.000583 (0.000590)
6.0	—15.1 (—28.1)	360.2 (347.5)	0.000649 (0.000659)
5.0	— 8.9 (—21.2)	410.6 (398.7)	0.000722 (0.000735)
4.0	— 3.0 (—15.0)	466.6 (455.9)	0.000803 (0.000821)
3.0	+ 2.4 (— 9.3)	528.9 (519.7)	0.000892 (0.000915)
2.5	+ 5.0 (— 6.7)	562.5 (554.3)	0.000942 (0.000967)
2.0	+ 7.5 (— 4.7)	598.0 (590.8)	0.000990 (0.001023)
1.5	+10.0 (— 3.0)	635.4 (629.6)	0.001043 (0.001083)
1.0	+12.0 (— 1.3)	674.8 (670.6)	0.001100 (0.001146)
0.5	+14.5 (— 0.0)	716.3 (714.0)	0.001157 (0.001215)
0.0	+15.7 (+ 0.7)	760.0 (760.0)	0.001223 (0.001290)

* *The figures in parentheses refer to winter conditions.*

Page 167.

Method of Calculation of Rocket Ascents

It was assumed that the thrust P is constant. The air resistance F was calculated as $338 \times R^2 \times i \times \gamma \times f(v)$ (as given by Siacci in Cranz-Becker: *Ballistics*). For the air density (γ) the Hohmann formula was used. (See table at the end of this note.) The factor i was assumed to be 1.2, much higher than for artillery projectiles where it only equals 0.865.

The formulae used follow:

Ascent under power:

$$\text{Acceleration } a = \frac{(P - W - D)}{W} \times g.$$

$$\text{Speed } v_2 = v_1 + \frac{(P - W - D)\,g}{W} \times \Delta t$$

$$\text{Altitude } s_2 = s_1 + \frac{v_1 + v_2}{2} \times \Delta t$$

Free Ascent:

$$v_2 = \sqrt{v_1^2 - \frac{2\,g}{W_1}(h_2 - h_1) \times (D + W_1)}$$

Explanation of symbols:

D in kilograms	Air resistance.
R in meters	Radius of rocket.
$i = 1.2$	
γ in kg/m^3	Density of the air.
$f(v)$	According to Siacci (Cranz-Becker: *Ballistics*).
a in m/sec^2	Acceleration.
a_e in m/sec^2	Effective acceleration at beginning of ascent.
v in m/sec	Speed of rocket at any given moment.
s in meters	Altitude attained under power.
h in meters	Altitude attained "free."
$H = s + h$	Total altitude.
P in kilograms	Thrust.
W in kilograms	Weight of rocket at any given moment.
W_o in kilograms	"Take-off weight" of rocket.
W_1 in kilograms	Weight empty, but including instruments.
t in seconds	Time.
g	Assumed to be the same at any altitude attained by rocket with the value of 9.81 m/sec^2.

The computation of the ascent under power was made with intervals of $\Delta t = 2$ seconds. For this interval W, γ and $f(v)$ were assumed to be constant with the value which is correct for the first instant of this interval. The error thus created is very small and has the tendency to cancel out during the computation. The free ascent was calculated with intervals (of altitude) of $(h_2 - h_1) = 500$ meters. The variables were treated in the same manner.

The results of these rather tedious computations are condensed in the following two tables:

TABLE I

$W_o = 20$ kg; $W_1 = 10$ kg; $W_F = 10$ kg; $R = .05$ m.

The symbols are the same as those used in the formulae, with the following additions:

W_F—Weight of fuel and liquid oxygen
W_s—Fuel (and oxygen) consumption per second
v_{max}—Highest velocity attained by the rocket during the ascent
T—Time required for complete consumption of fuel and oxygen.

	c (m/sec)	a_s (m/sec²)	P (kg)	W_s (kg/sec)	T (sec)	v_{max} (m/sec)	s (km)	h (km)	$H=s+h$ (km)
1.	2000	1 g	40	.196	51.0	460	12.9	7.2	20.1
2.	2000	2 g	60	.294	34.0	515	10.2	7.1	17.3
3.	20υ0	4 g	100	.491	20.4	590	7.2	7.0	14.2
4.	2500	1 g	40	.157	63.7	575	18.7	12.2	30.9
5.	2500	2 g	60	.236	42.5	625	14.7	11.3	26.0
6.	2500	4 g	100	.392	25.5	695	10.3	10.3	20.6

TABLE Ia

Case No. 5 under the assumption that the rocket is fired from the top of a high mountain instead of sea level.
Height of mountain assumed to be 4 km in case No. 5a
5 km in case No. 5b

5a	2500	2 g	60	.236	42.5	790	20.8	22.6	43.4
5b	2500	2 g	60	.236	42.5	830	22.3	26.4	48.7

TABLE II

$W_o = 46$ kg; $W_1 = 26$ kg; $W_F = 20$ kg; $R = .06$ m.

	c (m/sec)	a_s (m/sec²)	P (kg)	W_s (kg/sec)	T (sec)	v_{max} (m/sec)	s (km)	h (km)	$H=s+h$ (km)
1.	2000	1 g	92	.451	44.4	465	10.8	7.8	18.6
2.	2000	2 g	138	.676	29.6	545	8.8	9.1	17.9
3.	2000	4 g	230	1.130	17.7	640	6.2	9.5	15.7
4.	2500	1 g	92	.361	55.4	560	15.8	12.3	28.1
5.	2500	2 g	138	.541	57.0	650	12.8	14.5	27.3
6.	2500	4 g	230	.902	22.2	745	9.0	14.0	23.0

TABLE III

Air pressure, etc., in high altitudes according to Dr. Hohmann's formula:
$\gamma/\gamma_0 = (1 - h/400{,}000)^{49}$.

altitude km	g, m/sec^2	mm Hg	weight of 1 m^3 air in kg.
0	9.8100	760.0	1.30
1	9.8068	675.0	1.15
2	9.8042	598.0	1.00
3	9.8010	528.0	0.90
4	9.7978	466.0	0.80
5	9.7945	410.0	0.70
6	9.7915	360.0	0.62
8	9.7857	277.0	0.48
10	9.7794	210.0	0.375
15	9.7640	89.66	0.215
20	9.7498	40.99	0.105
30	9.7182	8.63	0.0283
40	9.6880	1.84	0.00740
50	9.6580	0.40	0.00187
60	9.6278	0.094	0.000448
70	9.5982	0.0274	0.0001025
80	9.5682	0.0123	0.0000230
90	9.5388	0.0081	0.0000049
100	9.5094	0.0067	0.98×10^{-6}
200	9.2220	0.0001	0.23×10^{-15}
400	8.6874	0.0000	0.00000

ADDENDA TO CHAPTER 8.

Page 179.

Note on Usable Fuels *

The following table shows the chemical reactions taking place in the combustion of various liquid fuels and the theoretical exhaust velocities. The equation for pure carbon has been included for comparison.

NAME	REACTION	THEORETICAL EXHAUST VELOCITY (meters per second)
Oxygen in the form of oxygen:		
Hydrogen:	1 kg H_2 + 8 kg O_2 = 9 kg H_2O	5170
Methane:	1 kg CH_4 + 4 kg O_2 = 5 kg CO_2 and H_2O	4490
Gasoline:	1 kg C_8H_{18} + 3.5 kg O_2 = 4.5 kg CO_2 and H_2O	4450

* *The tables in this Note are condensations of more extensive tables published in Dr. Eugen Sänger's book* Raketenflugtechnik.

Benzene:	1 kg C_6H_6 + 3.4 kg O_2 = 4.4 kg CO_2 and H_2O	4270
Alcohol:	1 kg C_2H_6O + 2.08 kg O_2 = 3.08 kg CO_2 and H_2O	4180
Carbon:	1 kg C + 2.67 kg O_2 = 3.67 kg CO_2	4320

Oxygen in the form of ozone:

Hydrogen:	1 kg H_2 + 8 kg O_3 = 9 kg H_2O	5670
Methane:	1 kg CH_4 + 4 kg O_3 = 5 kg CO_2 and H_2O	5000
Gasoline:	1 kg C_8H_{18} + 3.5 kg O_3 = 4.5 kg CO_2 and H_2O	4960
Benzene:	1 kg C_6H_6 + 3.4 kg O_3 = 4.4 kg CO_2 and H_2O	4800
Alcohol:	1 kg C_2H_6O + 2.08 kg O_3 = 3.08 kg CO_2 and H_2O	4630
Carbon:	1 kg C + 2.67 kg O_3 = 3.67 kg CO_2	4800

The products of the combustion are always either water (in the form of vapor) or carbon dioxide or a mixture of both.

Hydrogen and oxygen with hydrogen surplus:

1 kg H_2 + 8 kg O_2	5170
1 kg H_2 + 8 kg O_2 + 0.5 kg H_2	5030
1 kg H_2 + 8 kg O_2 + 1.0 kg H_2	4890
1 kg H_2 + 8 kg O_2 + 1.5 kg H_2	4770
1 kg H_2 + 8 kg O_2 + 2.0 kg H_2	4680
1 kg H_2 + 8 kg O_2 + 2.5 kg H_2	4570
1 kg H_2 + 8 kg O_2 + 3.0 kg H_2	4470

Explosives:

Nitro-glycerine $C_3H_5(ONO_2)_3$	3880
Nitro-cellulose $C_6H_{10}O_5$ + 4 NO_3	3660
Dynamite	3300
Smokeless Powder	3240
Picric Acid $C_6H_2(NO_2)_3OH$	2600
Black Powder	2420

Most of these substances are not usable for obvious reasons. The *measured* exhaust velocity of ordinary rocket powder (black powder with carbon surplus) averages 600 meters per second.

Addendum to Chapter 9.

Page 212.

It may have been noticed that Professor Oberth and Dr. Hohmann do not use the same method for the determination of the mass-ratio required for a given interplanetary trip. Oberth's method consists in ascertaining the change in velocity required for the various maneuvers. These changes, expressed in meters per second, are called "ideal velocities." They are then added up and the total mass-ratio can be determined from the total of the changes in velocity. Hohmann ascertains the mass-ratio for each maneuver separately. The total mass-ratio is the product of the multiplication of the various mass-ratios with each other. Each method has advantages and disadvantages of its own. Oberth's method is simpler in operation; Hohmann's is more graphic.

Examples of Oberth's method may be found in his book *Wege zur Raumschiffahrt;* examples of Dr. Hohmann's method in his *Erreichbarkeit der*

Himmelskörper and in his chapter in my *Möglichkeit der Weltraumfahrt.* To quote an example in full would, unfortunately, require a great deal more space than is available.

Page 229.

Although the moon would be far inferior to the Outer Station as a base for space travel, Dr. Hohmann calculated a number of trips *from* the moon, in consideration of the possibility that water might be found there so that the manufacture of fuels would be possible. The following table shows the results, under the usual assumptions:

INITIAL MASS IN TONS, WITH 6 TONS AS FINAL WEIGHT

TRIP:	DURATION (in days)	EXHAUST VELOCITY AVAILABLE (meters per second)			
		3000	4000	5000	10,000
Earth to Moon	4	1420	360	153	31
Moon to earth	3	15	12	10	8
Moon to Venus	146	123	68	46.5	24
Moon to Mars	258	780	278	142	44
Venus to earth	146	2510	690	276	64
Mars to earth	258	382	182	110	41
Moon, circling of Venus, earth	762	1060	423	244	92
Moon, circling of Mars, earth	971	1720	630	352	116
Round trip: Moon→orbit of Mars→orbit of Venus→earth.	546	1220	446	245	80

Landing on the planet with a small rocket for one passenger with a final weight of 1 ton, while ship is circling planet; small rocket is left behind after return of its pilot to the ship (final weight 6 tons, as usual):

Moon—Venus—earth	762	1870	601	299	101
Moon—Mars—earth	971	2432	790	410	125

TABLE OF ESCAPE VELOCITIES, ETC.

PLANET	MASS earth = 1	g AT SURFACE earth = 1	ESCAPE VELOCITY		ORBITAL VELOCITY	
			miles per second	kilo-meters per second	miles per second	kilo-meters per second
Mercury	0.04	0.27	2.2	4.3	29.7	47.7
Venus	0.81	0.85	6.3	10.3	21.7	35.1
Earth	1.00	1.00	7.0	11.2	18.5	29.7
Mars	0.11	0.38	3.1	5.04	15.0	24.1
Jupiter	317.0	2.64	37.0	59.5	8.1	13.0
Saturn	95.0	1.17	22.0	35.4	6.0	9.6
Uranus	14.7	0.92	13.0	21.6	4.2	6.8
Neptune	17.2	1.12	14.0	22.8	3.4	5.4
Moon	0.012	0.16	1.47	2.37	0.64	1.03

Note on the Caproni-Campini Jet-Propelled Plane

In December 1940 reports emanating from Italy claimed that a new type of propellerless airplane had proved very successful. These reports referred to the C.C. 2, the second of a type invented by the Italian engineer Secondo Campini and built by the firm of Caproni.

Photographs of the C.C. 2 showed a plane of fairly ordinary appearance, save for a wide hole in the nose of the fuselage. This hole represents the air intake. Through it atmospheric air is sucked into the fuselage by a two-stage compressor located about amidships and driven by an ordinary radial engine. After passing the engine, the condensed air is injected with fuel which is ignited at the next stage. The resulting jet, consisting of the combustion products of the fuel, surplus air, and the exhaust from the radial engine is exhausted through a large rear nozzle in the center of which one can see a cone. This cone, by being pulled in or pushed out, controls the effective area of the rear nozzle. The pilot cabin is placed on top of the fuselage so that it does not interfere with the airflow inside.

The first of these craft, the C.C. 1, made a ten-minute flight in August 1940 at Taliedo airdrome near Milan, piloted by Colonel Mario de Bernardi, the Italian Schneider Trophy pilot. Apparently Colonel Bernardi had a whole list of critical remarks ready when he landed after that ten-minute hop because the C.C. 1 was abandoned and the C.C. 2 built. Just how much the C.C. 2 differs from the C.C. 1 has not become known yet, except that the C.C. 2 is a two-seater.

It is also known that the C.C. 1 took off by means of a propeller and did not switch to jet propulsion until it was in flight. It weighed about 8000 pounds while the weight of the C.C. 2 is estimated at 11,000 pounds. The C.C. 2 may have made a few test flights but nothing became known about them until the plane was flown from Taliedo airdrome near Milan to Linate airdrome, Guidonia, near Rome. The pilot was again Colonel de Bernardi, the co-pilot (or passenger) was Captain Pedace of the Regia Aeronautica. The distance from airport to airport is 168 miles and the flight, which was made on December 1, 1940, took two hours and twenty minutes with a stop of unspecified duration at Pisa, probably for refueling. The average speed, according to Colonel de Bernardi, was 130 miles per hour.

One may well wonder what the speed would have been if the motor which was used to drive the compressor had been used to drive a propeller. One may also wonder what the efficiency of the jet really was. If the rumor is true that the landing in Pisa was necessary for purposes of fuel replenishment, that efficiency must have been low indeed.

Note on the Whittle Jet-Propelled Plane

In January 1944 the news was released that the Allies possessed a jet-propelled plane originally developed in England by Group Captain Frank Whittle. It was announced that the Whittle jet-propelled plane had performed a large number of successful test flights, the first of them several weeks before the flight of the C.C. 2. The British public, frightened at first by the loud whistling noise which was taken to be the sound of a large bomb, called it *The Squirt* and British observers said that it "makes Spitfires seem slow."

No performance data have yet been released but it has been stated that the fuel used is kerosene. While the type of engine actually in use is also secret, the original Whittle design had been published earlier: in 1938 in the German aviation magazine, *Flugsport,* and in 1941 by G. Geoffrey Smith in the British aviation magazine, *Flight.* According to these publications the Whittle engine of that time worked as follows: Atmospheric air is sucked in by a compressor and forced into a duct, leading to a turbine wheel. Just before meeting the turbine, fuel is sprayed into the air duct and ignited. The resulting mixture of combustion products and heated air is drained of part of its energy by the turbine which is required to turn the compressor. Then the gaseous mixture is ejected through the exhaust nozzle, propelling the plane.

This system is, as can easily be seen, much simpler than that of Secondo Campini. Present experience indicates that such jet-propelled planes are likely to be very useful as interceptors. But the high fuel consumption (officially admitted by British air experts) makes the use of jet-propelled planes for long-distance flights very doubtful. As far as can be judged at the present moment, jet-propelled planes are unlikely to have a commercial future. They seem to be as exclusively military as any other interceptor and fighter design.

Nor should the success of the Whittle plane give rise to the belief that the problem of the rocket airplane has been solved by way of the jet-propelled plane. It is true that in both cases it is the Third Law of Motion which accounts for the movement of the plane, but the similarity ends with that statement.

The jet-propelled plane depends on at least reasonably dense air for its operation. Consequently it is incapable of attaining the altitudes where air resistance is so low that the plane is able to fly at a speed approaching the velocity of its exhaust. The latter is the hope of rocket airplane inventors, but it cannot be the hope of jet-plane designers, because their engine needs air for its operation.

The German "Secret Weapon"

In the middle of June 1944, not quite two weeks after the landing of Allied troops on the Normandy peninsula of northern France, a new German weapon was put into action. It had been heralded for a long time by frantic propaganda releases from all kinds of German propaganda agencies as a gigantic long-distance rocket supposed to carry more than 100 miles and containing a high-explosive charge weighing several tons. The German agencies even went so far as to quote spurious "eyewitness accounts" which were broadcast from Zurich, Stockholm, and Istanbul.

A simple calculation (*see* Note on Rocket Artillery) showed that such a long-range rocket, assuming powder as a fuel, would have to have a mass-ratio of at least 7 to 1, which at present does not seem possible. The general tenor of the propaganda broadcasts made it evident that the claims for the *Wunderwaffe* (miracle weapon) were deliberately distorted and not to be taken literally. On the other hand it was clear that a new German weapon had been installed along the French coast, especially in the Pas-de-Calais area, since both the RAF and the 8th U.S. Army Air Force bombed that sector very thoroughly and for a long time.

The *Wunderwaffe,* conforming to the formula for mass-ratios, turned out not to be a rocket. It also turned out not to be very miraculous in any respect. The weapon was a torpedo-shaped fuselage about 22 feet in length, carrying a high-explosive charge of 1000 kilograms (2200 pounds) with a 16-foot wing, directed by a robot pilot and propelled by a simple jet-motor. Its average speed was between 300 and 350 miles per hour (on rare occasions a larger and faster type was seen). The average height above the ground was between 2000 and 3000 feet, and the maximum range around 150 miles, corresponding to a burning time of about twenty minutes.

The projectiles were, in strict classification, "jet-propelled robot-controlled aerial torpedoes," but the British public quickly referred to them as "doodlebugs" and generally failed to be impressed with Nazi ingenuity. The accuracy of the weapon was very poor, in fact it was negligible from a military point of view, and it had to be regarded rather as a terror and propaganda measure than as a military weapon. The "robot bombs," as they were also called, were intercepted by heavy anti-aircraft fire from the ground, by heavily gunned interceptor planes, and by dense balloon barrages. Naturally a weapon that flies at a constant speed and is kept on a straight course by a robot pilot offers a comparatively easy target; the only difficulty presenting itself was the small size of the "doodlebugs." The most effective countermeasure, of course, was heavy bombardment of the take-off platforms.

Since the projectiles had a high wing-loading, they could not take off under their own power. Their take-off had to be assisted by a launching device, either by a conventional catapult or else by a number of take-off rockets which dropped off after they had done their duty.

Quite naturally I have often been asked about my guess as to the inventor of these weapons, especially since the "doodlebugs," when photographed in flight, seemed to bear a strong resemblance to Dr. Sänger's conception of a rocket airplane as pictured on page 259. Of course it is quite likely that the Nazis made use of Dr. Sänger's theoretical work for the development of these weapons, but I believe that this similarity was mostly superficial. In fact the large jet-motor, roughly 10 feet long, which was mounted on top of the fuselage, rather spoiled what resemblance existed.

As to the inventor of that jet-motor, I can only offer a guess. In 1931 a member of the *VfR*, Wilhelm Goldau of Diusburg-Meiderich, sent me a working model of a jet-motor invented by him. He later acquired two German patents for it. Goldau's system differed from all other jet-propulsion suggestions by restricting itself to very low operating pressures. His combustion chambers were large and thin-walled and generally barrel-shaped. They were closed at both ends by valves and operated in cycles. First, both valves were opened to permit air to flow through the chamber. Then the rear valve was closed; the front valve clicked shut an instant later. Then fuel (benzene) was injected into the chamber, the rear valve was opened, and the fuel-air mixture ignited simultaneously. After that the front valve was opened again while the rear valve still remained open, and then the next cycle began. Wilhelm Goldau wrote me later that he had a well-functioning model. That was in 1937 and I have not heard from him since. It is quite possible that this work was the beginning of the large and simple jet-motor used on the "doodlebugs."

BIBLIOGRAPHY

Section I

WORKS ON ROCKETS, APPLICATION AND THEORY

NOTE TO THE SECTION ON ROCKET LITERATURE:

The following bibliography is, to the best of my knowledge, complete as far as publications in book or pamphlet form are concerned. It does not contain articles published in periodicals since most of these articles are by now either obsolete or have been duplicated in books. Some articles that were for some reason significant, as well as some patents, have been mentioned in the text of the book; they have not been listed again in the bibliography.

Listings of articles on rocket research and allied fields can be found in two places. One of them is the ninth volume of Professor Nikolai A. Rynin's *Myeshplanyetniye Soöbshtcheniya*. This volume (*Astronavigatsiya*) contains a virtually complete list of all articles written about rockets in any language up to 1931. The list comprises pp. 110-89 of the book. Another not quite so voluminous a list was published in 1937 under the auspices of the W.P.A. as *Part 49, Rocket Propulsion* of the *Bibliography of Aeronautics*. *Part 49* comprises twenty-seven double-spaced mimeographed pages. A second edition of this list, enlarged by an index of the articles published in *Astronautics*, was issued by the American Rocket Society some time later.

Both these lists contain references to two small Italian pamphlets I have never seen and did not include in the following bibliography. Those books in the following bibliography which I have not read myself are marked with a dagger (†).

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Goddard, Robert H. *A Method of Reaching Extreme Altitudes*. Smithson. Misc. Coll., LXXI (1919), No. 2. 69 p.

———. *Liquid-Propellant Rocket Development*. Smithson. Misc. Coll. XCV (1936), No. 3. 10 p. and plates.

Lasser, David. *The Conquest of Space*. New York, 1931. 271 p.
This book was published by Penguin Press, Inc., a firm which does not exist any more. It is *not* the same as Penguin Books.

Philp, Charles G. *Stratosphere and Rocket Flight*. London, 1935; a second edition, revised and somewhat enlarged, was published later the same year. 118 p. Unreliable in detail.

Smith, G. Geoffrey. *Gas Turbines and Jet Propulsion for Aircraft.* London, 1942. 56 p.

Deals mainly with gas turbines and jet propulsion for airplanes of the type of the Italian Caproni-Campini. It also contains a description of the engine of Captain Whittle's jet-propelled plane, but almost nothing about rockets. Most of the material in this book appeared first in the British aviation magazine *Flight* of which Mr. Smith is editor. A second enlarged edition was published in 1943.

Astronautics, Bulletin of the American Rocket Society, originally called *Bulletin of the American Interplanetary Society.* Started in 1931, at first monthly, then irregularly; now quarterly, printed, mimeographed, and offset.

The Journal of the British Interplanetary Society, since 1933, at first quarterly, then more or less irregular. Publication was stopped with the outbreak of World War II.

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Eastman, Jacobs, and Shoemaker. *Tests on Thrust Augmentors for Jet Propulsion.* N.A.C.A. Techn. Notes No. 431.

Roy, Maurice. *Propulsion by Reaction.* Translated from *La Technique Aéronautique.* N.A.C.A. Techn. Mem. No. 571.

Schubauer, G. B. *Jet Propulsion with Special References to Thrust Augmentors.* N.A.C.A. Techn. Notes No. 442.

(*See also under German books,* Dr. Eugen Sänger.)

BOOKS IN GERMAN:

Biermann, Gerd. *Weltraumschiffahrt?* Bremen, 1931. 43 p.

Brügel, Werner. *Männer der Rakete.* Leipzig, 1933. 144 p.

A collection of essays, autobiographical and pertaining to their work in rocket research, by the following: Hanns-Wolf von Dickhuth-Harrach, Robert Esnault-Pelterie, Robert H. Goddard, Franz von Hoefft, Willy Ley (report on the *Verein für Raumschiffahrt*), C. P. Mason (report on the American Rocket Society), Hermann Oberth, Guido von Pirquet, N. A. Rynin, Friedrich Schmiedl, Johannes Winkler, and Konstantin E. Ziolkovsky.

Gail, Otto Willi. *Mit Raketenkraft ins Weltenall.* Stuttgart, 1928. 106 p.

Hohmann, Walter. *Die Erreichbarkeit der Himmelskörper.* Munich, 1925. 88 p.

Ley, Willy. *Die Fahrt ins Weltall.* Leipzig, 1926; 2nd ed., somewhat enlarged, Leipzig, 1929. 83 p.

———. *Die Möglichkeit der Weltraumfahrt.* Leipzig, 1928. 344 p.

With chapters by Karl Debus, Franz von Hoefft, Walter Hohmann, Willy Ley, Hermann Oberth, Guido von Pirquet, and Friedrich Wilhelm Sander.

———. *Grundriss einer Geschichte der Rakete.* Leipzig, 1931. 16 p.

Linke, Felix. *Das Raketen-Weltraumschiff.* Hamburg, 1928. 100 p.

Mandl, Vladimír. *Das Weltraum Recht.* Mannheim, 1932. 48 p.

———. *Die Rakete zur Höhenforschung.* Leipzig, 1934. 16 p.

The same author published a popular book in Czech under the title *Problém mezihvězdné dopravy.* Prague, 1932. 100 p.

Nebel, Rudolf. *Raketenflug.* Privately printed, 1932. 47 p.

Noordung, Hermann. *Das Problem der Befahrung des Weltraums.* Berlin, 1928. 188 p.
Hermann Noordung is a pseudonym for Captain Potočnik of the old Austrian Imperial Army.

Oberth, Hermann. *Die Rakete zu den Planetenräumen.* Munich, 1923; 2nd ed., Munich, 1925. 92 p.

———. *Wege zur Raumschiffahrt.* Munich, 1929. 431 p. Greatly enlarged third edition of *Die Rakete. . . .*

Sänger, Eugen. *Raketenflugtechnik.* Munich, 1933. 222 p.

———. *Neuere Ergebnisse der Raketenflugtechnik.* 22 p.
This is the December 1934 "special issue" of the magazine *Flug,* published in Vienna. Dr. Sänger's article comprises the entire issue. An English translation appeared in April 1942 under the title *Recent Results of Rocket Flight Technique.* (N.A.C.A. Tech. Mem. No. 1012.)

Schrenk, Martin, and Schiller, Melitta. *Die Rakete als Kraftmaschine.* 12 + 13 p.
This is *Tech. Mem. No. Vf. 24/3,* published October 13, 1928, by the *DVL* or *Deutsche Versuchsanstalt für Luftfahrt* in a small and restricted edition.

Shershevsky, Alexander B. *Die Rakete für Fahrt und Flug.* Berlin, 1928. 134 p.

Valier, Max. *Der Vorstoss in den Weltenraum.* Munich, 1924. 95 p.
From 1925 to 1929 this book went through five printings without important changes; in 1930 a revised and greatly enlarged edition was published under the title *Raketenfahrt.* 240 p.

Die Rakete, monthly magazine of the *Verein für Raumschiffahrt,* edited by Johannes Winkler and later by Winkler and Ley. First issue was July 1927, from then on monthly until the end of 1929. A special issue representing January to June 1927 was published at the end of 1927. This magazine had the character of a semi-professional journal. In the years following 1930 until about the end of 1937 it was replaced by irregularly appearing bulletins, called *Mitteilungsblatt* (Bulletin), *Raketenflug, Das neue Fahrzeug,* and finally *Weltraum.*

BOOKS IN FRENCH:

Ananoff, Alexandre. *Le problème des voyages interplanétaires.* Paris, 1934. 24 p.

———. *La navigation interplanétaire.* Paris, 1935. 32 p.

———. *La Fusée de Guerre.* Paris, 1934. 12 p.

Damblanc, Louis. *Les fusées autopropulsives à explosifs.* Paris: *Ministère de l'éducation nationale,* 1935. 36 p.

Esnault-Pelterie, Robert. *L'exploration par fusées de la très haute atmosphère et la possibilité des voyages interplanétaires.* Paris, 1928. 96 p.
Originally a lecture before the French Astronomical Society.

———. *L'Astronautique.* Paris, 1930. 248 p.
A much revised and greatly enlarged second edition of *L'exploration . . .*

———. *L'Astronautique, Complément.* Paris, 1935. 102 p.

†Marquis, Raoul. *Irons-nous dans la lune?* Paris, 1932. 188 p.

Roy, Maurice. *Recherches théoretiques sur le rendement et les conditions de réalisation des systèmes motorpropulseurs à réaction.* Paris, 1930. 214 p.

RUSSIAN BOOKS:

Бобров, Н. Н. Большая Жизнь (Циолковский). 1933.

Грабе, Сергей Людвигович. Путешествие на Луну. Ленинград, 1926. Popularization written for children.

Кондратюк, Юрій Васильевич. Завоевание Межпланетных Пространств. Новосибирск, 1929.

ОСОАВИАХИМ, Стратосферный Комитет, Реактивная Секция. Реактивное Движение. Ленинград и Москва, 1925. Два тома.

Перельман, Яков Исидорович. Межпланетные Путешествия. Первое издание 1915; восьмое издание 1933.

———. Полет на Луну. 1924.

———. Ракетой на Луну. Первое издание 1930; третье издание 1933.

———. Циолковский, его жизнь, изобретения и научные труды. 1932.

———. К звездам на ракете. 1933.

Рынин, Николай Алексеевич. Межпланетные Сообщения; Ленинград. Девять томов.

I. Мечты, легенды и первые фантазии. 1928.
II. Космические корабли в фантазиях романистов. 1928.
III. Лучистая энергия в фантазиях романистов и в проектах ученых. 1931.
IV. Ракеты. 1929.
V. Теория реактивного движения. 1929.
VI. Суперавиация и Суперартиллерия. 1929.
VII. К. Э. Циолковский. Его жизнь, работы и ракеты. 1931.
VIII. Теория космического полета. 1932.
IX. Астронавигация. Летопись, Библиография и Указатель. 1932.

———. Методы освоения стратосферы. 1931.

———. Propulsione e reazione senze utilizzazione dell'aria esterna. Roma (Reale Accademia d'Italia), 1935. This and Professor Rynin's chapter in Brügel's book *Männer der Rakete* are the only writings of this author that have been translated from the Russian.

Цандер, Фридрих Артурович. Проблема полета при помощи реактивных аппаратов. Москва, 1932.

Циолковский, Константин Эдуардович. «На Луне» (in: Вокруг света). 1893.

———. «Исследование мировых пространств реактивными приборами.» 1903. This article was published in Научное Обозрение. Several others, bearing the same title, followed during the years 1911-14 in the now defunct aviation magazine Вестник Воздухоплавания.

———. Вне земли; Научно-фантастическая повесть. Parts of this work were written in 1896. It was first serialized in Природа и Люди. and published in book form in 1920.

———. Ракета в космическое пространство. 1924. Reprint of the publication of 1903, somewhat enlarged and with a new title. The title page is bilingual, with German title *Eine Rakete in den kosmischen Raum* and German preface by A. L. Tchiyevsky.

———. Исследование мировых пространств. 1926. Essentially a reprint, revised and enlarged, of the articles in Вестник Воздухоплавания.

———. Космическая Ракета. 1927.

———. Космические реактивные поезда, 1929.

———. «Цели звездоплавания» (in: Авиация и Химия), 1929.

———. Звездоплавателям. 1930.

———. Реактивный аэроплан. 1930.

———. Стратоплан полуреактивный. 1930.

BOOKS ON WAR ROCKETS (HISTORICAL):

d'Arcet. *Notice sur les fusées incendiaires de Congrève.* Paris, 1814.

Barber, F. M. *Lecture on Drifting and Automatic Movable Torpedoes, Submarine Guns and Rockets.* Newport, R. I.: U. S. Torpedo Station, Decembei 1874.

Bem, Joseph. *Erfahrungen über die Congrev'schen Brand-Raketen, bis zum Jahre 1819 in der Königl. Polnischen Artillerie gesammelt und an seine Kaiserliche Hoheit, den Grossfürst Constantin, Général-en-Chef aller Königl. Polnischen Truppen, berichtet von Joseph Bem, . . . neben dem Französischen Original-Text in Teutscher Uebersetzung . . . herausgegeben von M. Schuh.* Weimar, 1820. In German and French.

Congreve, William. *A Concise Account on the Origin and Progress of the Rocket System.* Dublin, 1817.

Congreve's name does not appear on the title page.

———. *The Details of the Rocket System.* London, 1814.

———. *A Treatise on the Congreve Rocket System.* London, 1827.

Crusius, Artur von Baumgarten. *Die Rakete als Weltfriedenstaube.* Leipzig, 1931. 174 p.

This book is mentioned only as a curiosum. It is generally not serious and more often than not even ridiculous in its assertions, although its author probably expressed his sincere opinions. It credits an unknown German inventor with the perfection of long-distance bombardment rockets of enormous magnitude. The photograph of one of these "rockets" shows clearly, however, that it is constructed of wood and sailcloth, modeled closely along the lines of the spaceship in Fritz Lang's film *Frau im Mond.* The leading thought of the book is that such long-distance bombardment rockets would be so enormous a threat to civilization that the existence of such rockets and the idea of war are mutually exclusive. Another German book, published about a year earlier with a title which I remember as something like *Vengeance 193?,* was presumably written by the same author. It is virtually a carbon copy of the other, thinly disguised as "prophetic fiction." It contains a lucid account of the destruction of Paris and the consequent downfall of France, brought about by such rockets, secretly developed and manufactured in enormous quantities. It is an adaptation of the old Air Power theme which is rooted in the erroneous but fanatical belief that a war can be fought and won with one new weapon. The author's political beliefs are as simple as his technological and military ideas—with the "evil influence" of France eliminated, permanent world peace is brought about automatically.

Goddard, Calvin. "Rockets," *Army Ordnance.* Washington, D. C.: May-June—September-October 1939.

Hale, William. *A Treatise on the Comparative Merits of a Rifle Gun and a Rotary Rocket.* London, 1863.

Hime, Henry W. L. *Gunpowder and Ammunition.* London, 1904.

———. *The Origin of Artillery.* London, 1915. 2nd ed. of *Gunpowder and Ammunition.*

von Hoyer, J. G. *System der Brandraketen nach Congreve und Anderen.* Leipzig, 1827.

Hume, J. *Remarks on Military Rockets.* London, 1811.

Jähns, O. *Geschichte der Explosivstoffe.* Vol. I. Berlin, 1897. This gives the history of war rockets in general.

Konstantinoff, M. *Mémoire* and *Lectures sur les Fusées de Guerre.* Paris, 1858-1861. 2 vols.

Latham, H. B. "The Rocket Service and the Award of the Swedish Decorations for Leipzig," *Journal of the Royal Artillery,* LVI (January 1930) No. 4.

Ley, Willy. *Shells and Shooting.* New York, 1942.

Montgéry. *Traité des Fusées de Guerre, nommées autrefois rochettes et maintenant fusées à la Congrève.* Paris, 1825.

Moore, W. *On the Motion of Rockets.* London, 1810.

Nye, T. *Thoughts on Aerial Traveling and on the Best Means of Propelling Balloons.* London, 1852.

Pictet, Adolph. *Essai sur les propriétés et la tactique des Fusées de Guerre.* Turin, 1848.

Rogier, Charles. *A Word for My King and Country: A treatise on the utility of a rocket armament, assisted by balloons where ships of war cannot be accessible; both defensive and offensive, to the annoying of the enemy's harbour.* Macclesfield, 1818.

Scoffern, J. *Projectile Weapons of War.* 1859.

This is one of the large numbers of books on weapons and military matters published during the nineteenth century which contain a description of war rockets. Similar articles can be found in many others, for example, in J. Frost's *Book of the Army of the United States* (1845), in E. S. Farrow's *Military Encyclopedia* (1885) and in the British *Treatise on Ammunition* (His Majesty's Stationery Office), in several editions. The articles on war rockets are not the same in the various editions; generally speaking they are shorter the more recent the edition. The last one is in the edition of 1905. The articles on war rockets in these books and manuals deal with types contemporary or recent at the time these books were printed; they pay no attention to the earlier history.

Fireworks and Signal Rockets:

Brock, A. St. H. *Pyrotechnics.* London, 1922.

Busch and Hoffmann. *Die Kriegsfeuerwerkerei der Königlich Preussischen Artillery.* Berlin, 1851.

Jones, Robert. *Artificial Fireworks.* London, 1776.

Nye, Nathanael. *A Treatise of Artificiall Fire-Works for Warre and Recreation etc. . . .* London, 1647.

Simienowicz, Kasimir. *Vollkommene Geschütz/Feuerwerk vnd Büchsenmeysterey Kunst.* Frankfort (Main), 1676.

Simienowicz was commander of the Polish Army; his book was written in Latin and published in that language, but the Latin text is only a part of the whole plan. The German edition, listed here, is a larger work, finished according to Simienowicz' original plan by Daniel Elrich, Ordnance Master of the city of Frankfort-on-the-Main. The Latin section was translated into German by Leonhard Beer.

Miscellaneous:

Crassus, Ing. *Der gefahrlose Menschenflug.* Hamburg, 1912. 37 p.

The author's real name is Wilhelm Gaedicke; the book deals with the project of a helicopter with jet-driven rotor. Only of historical interest.

Gussalli, Luigi. *Si può già tentare un viaggio dalla terra alla luna.* Milan, 1923.

The book is devoted to several inventions and ideas of the author. The section on rocket propulsion forms only one chapter.

Jacobs, H. *Schwanzlose Segelflugmodelle.* Ravensburg, 1937. 60 p.

Advice on the design and construction of glider models, among them some powered by powder rockets; also photographs of the latter.

Lorin, René. *L'Air et la vitesse.* Paris, 1919. 94 p.

Contains several chapters on rocket torpedoes, rocket power for airplanes, etc.

Papp, Desiderius. *Was lebt auf den Sternen?* Vienna, 1931. 345 p.

While the title sounds as if the book dealt only with the possibility of life on other planets, a great deal of it is devoted to the problems of interplanetary travel, conjectures about the inhabitants of the planet Mars, etc. It contains a great deal of material but has to be read with many reservations.

Pseudoman, Akkas. *Zero to Eighty*. Princeton, 1937. 283 p.
The book has the subtitle: "Being my lifetime doings, reflections and inventions, also my journey around the moon." Akkas Pseudoman is the pseudonym of Dr. E. F. Northrup, inventor of the Ajax-Northrup high-frequency induction furnace, who died May 1, 1940. For an obituary see the *New York Times* of May 2, 1940. The book, a semi-fictional autobiography, contains a great deal about the author's experiments with solenoid guns, including photographs, and a résumé of the theory of space travel which Dr. Northrup wanted to accomplish by means of rockets initially accelerated in large solenoid guns.

Section II.

LITERARY HISTORY OF IMAGINATIVE LITERATURE

A complete literary history of that variety of imaginative literature which is based on facts and theories of a scientific nature—so-called "science-fiction"—still remains to be written. The existing books deal mostly with Jules Verne, the first outstanding representative of that field, while some essays are devoted to specific phases.

Books on Jules Verne:

Allott, Kenneth. *Jules Verne*. New York, 1941. 282 p.
The first biography of Jules Verne in English, with a good bibliography of his numerous works, fiction, factual, and stage writings.
Claretin, Jules, *Jules Verne. Célébrités Contemporaines*, No. 33. 1883. 32 p.
de la Fuÿe, Marguerite Allotte. *Jules Verne—Sa vie, son œuvre*. Kra, 1928. 292 p.
Biography of Jules Verne by his niece.
Lemire, Charles. *Jules Verne 1828–1905*. Paris, 1908. 185 p.
Marcucci, Edmondo. *Giulio Verne et la sua Opera*. 1930. 129 p.
Contains a good bibliography of Jules Verne's works and a section on his Italian imitators.
Popp, Max. *Julius Verne und sein Werk*. Hartleben, 1909. 213 p.
Devotes a good deal of space to Verne's imitators, mainly those writing in or translated into German.
Waltz, George H. *Jules Verne, the Biography of an Imagination*. New York, 1943. 223 p.
Shorter than Allott's book, contains interesting notes about the influence of Jules Verne's books.

Books:

Flammarion, Camille. *Les mondes imaginaires et les mondes réels*. Paris, 1865.
The book consists of two sections: the first dealing with the conditions on the surfaces of the planets of our solar system as they were then assumed to be; the second, almost three times as voluminous as the first, consists of a survey of everything ever written about other planets

(except strictly astronomical works of then recent date), philosophical as well as theological, including novelistic attempts, like Godwin's *Man in the Moone*. I own a copy of the 1892 edition of this book (21st ed. 12mo. 598 p.) which contains an added section about books published during the interval from 1865 to 1892. Flammarion, in a preface, stated that he then considered the first part of the book obsolete, but did not change it because he had meanwhile rewritten that part in a greatly enlarged form as *Les terres du ciel* (8vo. 600 p.) published for the first time in 1876.

Essays:

Debus, Karl. "Raumschiffahrtsdichtung und Bewohnbarkeitsphantasien seit der Renaissance," *Hochland* (Munich, 1926-27), No. 10. Reprinted in a revised and enlarged form as Chapter III of my *Möglichkeit der Weltraumfahrt.*

Günther, Ludwig. *Kepler's Traum vom Mond.* Leipzig, 1898. Translated from the Latin and with an introduction by Dr. L. Günther. The introduction contains a survey of similar literature in concise and condensed form. The original Latin work was first printed at Frankfort in 1634 as *Joh. Keppleri Mathematici olim imperatorii SOMNIUM seu Opus posthumum de astronomia lunari.* It was republished at Frankfort in 1870 as Vol. VIII of *Joannis Kepleri Astronomia Opera Omnia.* Dr. Günther's German translation is the only translation of this work. Kepler's many "notes" are appended.

Kretzmann, Edwin M. J. "German Technological Utopias of the Pre-War Period, *Annals of Science,* III (October 1938), No. 4. A great portion of the essay is devoted to Kurd Lasswitz.

Lafleur, Laurence J. "Marvelous Voyages," *Popular Astronomy,* L— (January 1942), No. 1—.

McColley, Grant. *Introduction* to Bishop Francis Godwin's *The Man in the Moone* and *Nuncius Inanimatus. Smith College Studies in Modern Languages,* XIX (October 1937), No. 1. The reprint of *The Man in the Moone* is from the first edition (London, 1629) and that of the *Nuncius Inanimatus* is from the first edition published in London in 1638. The first editions were both represented by unique copies before the reprint was made. The *Nuncius Inanimatus* is accompanied (on opposite pages) by the English translation of Dr. Thomas Smith of Magdalen College, Oxford, which accompanied the Latin text in the second edition (London, 1657).

Nicolson, Marjorie Hope. *A World in the Moon. Smith College Studies in Modern Languages,* XVIII (1936), No. 2. An essay on the influences of astronomical discoveries on English literature during the seventeenth and eighteenth centuries.

———. *Cosmic Voyages. ELH, A Journal of English Literary History,* VII (June 1940), No. 2.

Nicolson, Marjorie, and Mohler, Nora M. "Swift's 'Flying Island' in the Voyage to Laputa," *Annals of Science,* II (October 1937), No. 4.

———. *The First "Electrical" Flying Machine. Smith College Studies in Modern Languages* (October 1939).

Navis Aeria of B. Zamagna. Rome 1786. Translated from the Latin by Mary B. McElwain. With introduction by Marjorie Hope Nicolson. *Smith College Classical Studies,* No. 12. Northampton, Mass., March 1939.

INDEX