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# ROCKETS AND SPACEFLIGHT

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# 2

# Theory

Before we can really concern ourselves with the first actual steps into space, we must equip ourselves with the necessary theoretical knowledge; without this it is not possible to understand what is going on. In contrast to those years when Oberth first announced his researches, the spaceflight concept is not nowadays regarded as something abstruse and academic. Rocket development over the last two decades has already confirmed many a theoretical assumption, and the man in the street has come to take the universe in his stride.

The most decisive obstacle which has impeded every plan for spaceflight so far is—as has already been mentioned—the Earth's gravitational pull. Like every other relationship between celestial bodies, its effect is explained by Newton's law of gravity. Gravitational attraction is one of the properties of mass, though the actual cause of this phenomenon has not yet been fully explained. One important fact established by Newton was that the force which at the Earth's surface causes an object to fall to the ground with an acceleration of 32 feet per second, and the force which causes the planets to circle the Sun in space, is in essence one and the same thing.

The attraction between two masses increases with their magnitude and diminishes with their distance from each other. It must be noted, however, that this latter decrease is not directly proportional, but varies with the square of the distance (like the intensity of light). The weight of any given object is the result of gravity acting upon it, and so the weight of an object which is situated at a distance of twice the Earth's radius from the centre of the Earth is now only one-quarter its value at ground level. At a distance of three times the Earth's





radius the value drops to one-ninth; at 10 radii, a hundredth; and at the distance of the Moon, which is approximately 60 radii away, 1/3,600. This shows that one of the main obstacles to spaceflight has to be overcome close to the Earth's surface. In actual fact there is no point at which the gravitational attraction of the Earth ceases to exist altogether; it merely becomes so infinitesimally small with increasing distance as to have little or no effect.

Another great obstacle is the resistance offered by the air, and although this problem is not of such prime importance as gravity it must nevertheless be taken into consideration. By air resistance we mean the resistance, or retarding effect, which the air offers to a body in motion through it; the result of pressure, friction and suction. The air is at its densest close to the ground, and becomes rapidly rarer with increasing altitude. Even so, there are still enough air particles at a height of 50–75 miles up to cause meteors plunging into our atmosphere at great speeds from outer space to become incandescent with the frictional resistance. For a long time it was thought that the last remnants of the air were to be found at an altitude of 300 miles. Recent observation of the orbits of artificial satellites, on the other hand, have shown that an appreciable atmosphere exists as far out as 600 miles and probably even further.

The greater the velocity at which an object is travelling, the greater becomes the resistance which the air offers. At take-off from the ground the skin of a vehicle travelling at a speed of 1·25 miles per second heats to a temperature of 160 deg. C. (320 deg. F.). If we were now to increase the speed to 6·2 miles per second the temperature would rise to more than 700 deg. C. (1,292 deg. F.). On account of the strong braking effect of air resistance, it is necessary to provide spacecraft with greater power, i.e. launching speed, than is theoretically required.

Here again rocket propulsion possesses certain advantages, for it builds up its speed gradually and reaches maximum velocity at cut-off, the moment when all the fuel has been consumed and the rocket ceases to fire. An artillery shell, on the other hand, is travelling at maximum speed almost immediately after being fired, more or less coasting to its target thereafter. By the time the rocket has accelerated to full speed, it is already far above the Earth's surface—that is to say, in the more rarefied region of the atmosphere. Even so it is essential to give rockets taking off from the ground an aerodynamic shape compatible with supersonic flight, as well as a heat-resistant skin.

Another precaution is to fire the rocket vertically upwards into the air, so that it passes through the denser layers as rapidly as possible, and then guide it into the desired trajectory (Oberth's 'Synergie-kurve').

Yet another method of minimising air resistance is to launch the rocket from a high altitude in the first place. The peaks of mountains are not suited for this for a number of reasons. One of the systems used is known as 'Rockair', where the rocket is carried aloft by an aircraft and is released when a certain altitude has been reached; from then on the rocket flies on under its own power. A further

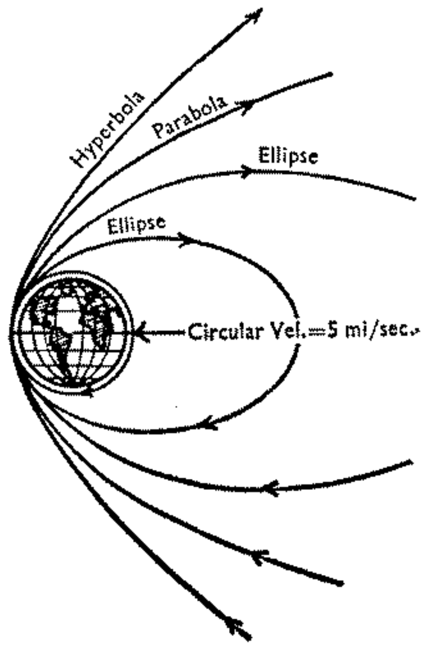



Fig. 5. Orbits from the Earth

principle of a similar nature is the 'Rockoon'; here the rocket is carried into the stratosphere by balloon; the rocket is then ignited and launched right through the balloon. This was the method used for launching the rockets of America's Project 'Farside'; having been carried to a height of 18 miles, the rocket itself penetrated 4,000 miles into space.

For actual spaceflight, ideal conditions will be reached when, at





some future time, extra-terrestrial launching platforms for journeys to the Moon and the planets have been built. Since these platforms will be situated outside the Earth's atmosphere, there will be no interference from air resistance.

As we have already seen, a space vehicle requires a considerable launching velocity in order to overcome the Earth's gravity. The conditions are best explained by means of an often quoted example. Figure 5 depicts the Earth. Let us now imagine that a gun is mounted on a very high mountain so that it will fire horizontally. For the purposes of this experiment we shall have to imagine also that there is no air resistance.

If the shot leaves the gun at a relatively slow speed, it will soon fall to the ground. If we now increase the launching velocity the shot will still fall to the ground, but this time further away from the point of firing. And so, as we increase the initial velocity, the projectile will land further and further away. Each time the trajectory is part of an ellipse with the Earth's centre as one of the foci. With increased velocity these ellipses tend to open out, but they will still cut the Earth's circumference at some point or other. It is only when the initial velocity reaches a value of 5 miles per second that the ellipse opens out into a circle. A projectile travelling along such a trajectory will not fall back to the ground again; for, relative to the Earth's centre, the distance through which the projectile falls each second, as a result of gravity, is now exactly the same as the amount by which the curved surface of the Earth deviates from the horizontal in the same period. Hence the projectile will not reach the ground and is literally 'falling round the Earth'.

This circular velocity of 5 miles per second plays a very important rôle in astronautics. A space vehicle which leaves the Earth at circular velocity will not return to the Earth, but will continue to circle it in the same orbit like an artificial moon so long as it receives no further impulse.

According to the law relating to the attraction of masses, we know that the closer to the Earth's surface the orbit lies, the greater the circular velocity has to be. Thus while the circular velocity close to the Earth is 5 miles per second, at the distance of the Moon the value is as low as 0·6 miles per second. In other words, a body at this distance from the Earth has to travel at a speed of 0·6 miles per second in order to prevent itself from falling towards the Earth. There is therefore a particular orbital velocity for any given distance from the Earth, at which the gravitational and centrifugal forces are held in balance.

If the velocity of our projectile is now increased beyond 5 miles per second, the orbit will no longer remain circular. We shall again have an ellipse, which with increasing initial velocity will extend further and further into space. When we reach an initial velocity of 7 miles per second the ellipse will 'come apart' at the far end and we now have a parabola. A space vehicle leaving the Earth at parabolic speed (7 miles per second) would continue out into space away from the Earth. Under the influence of the Earth's gravitational influence its speed would also diminish, but at the same time its distance from the Earth would be increasing. For these reasons 7 miles per second is often known as escape velocity, and a space vehicle which is to reach another body in the universe must therefore leave the Earth at this velocity.

The next problem is how to obtain this fantastic speed with our rocket. Here we must consider some of the basic equations of rocket technology. Their exact calculation is of course a matter for skilled mathematicians, but it is not very difficult for the uninitiated to see what they are all about.

The fundamental equation, which, in this form, is strictly speaking only really applicable to empty space, reads as follows:

$$v = c.\ \ln\frac{M_0}{M_1}$$

where $v =$ velocity of rocket
$c =$ exhaust velocity of combustion gases
$M_0 =$ initial mass of rocket
$M_1 =$ final mass of rocket after consumption of propellents.
In is the 'natural Logarithm'

$\frac{M_0}{M_1}$ represents what is called the 'mass ratio' which is an extremely important factor in all astronautical calculations. It indicates how much heavier the fully fuelled rocket must be than the empty shell in order to obtain a given cut-off velocity. If one wishes to calculate the relevant mass ratio for a particular cut-off velocity one can write the equation thus:





$$\frac{M_0}{M_1} = e^{v/c}$$

In this equation 'e' is what is known as the base for natural logarithms, 2·71828 . . .

If we now look again at the equation for the velocity 'v', we can see at once that the value of 'v' increases with the value of either the exhaust velocity 'c' or the mass ratio $M_0/M_1$. The exhaust velocities attained nowadays by burning alcohol in liquid oxygen are something like 1·4 miles per second, and there seems little likelihood that this will be raised in the foreseeable future. True, the combustion of a mixture of liquid hydrogen and liquid oxygen would yield an exhaust velocity of 2·5 miles per second, but the use of liquid hydrogen which vaporises at a temperature of —253 deg. C. (—423·4 deg. F.), only 20 deg. C. (36 deg. F.) above absolute zero, brings with it a whole lot of additional technical difficulties. Even the mass ratio has a limit. Using the formula let us examine the mass ratio as if it were an ordinary mathematical problem. We shall assume that the exhaust velocity 'c' remains constant, i.e. keeps the same value throughout.

Now $M_0/M_1 = e^{v/c}$ can also be expressed in other forms according to which of the symbols is unknown. We are trying at this stage to discover the value of the initial mass $M_0$ and so we shall write the equation thus: $M_0 = e^{v/c}.\ M_1$.

It does not need an extensive knowledge of mathematics to see that when maximum velocity attained at cut-off 'v' equals the exhaust velocity 'c', the mass ratio $M_0/M_1$ is equal to 'e', that is approximately 2·72 as mentioned previously.

When $v = c \quad M_0 = e^{1/1}.\ M_1 = 2{\cdot}72^1.\ M_1 = 2{\cdot}72\ M_1$
$v = 2c \quad M_0 = e^{2/1}.\ M_1 = 2{\cdot}72^2.\ M_1 = 7{\cdot}4\ M_1$
$v = 4c \quad M_0 = e^{4/1}.\ M_1 = 2{\cdot}72^4.\ M_1 = 54{\cdot}6\ M_1$
$v = 6c \quad M_0 = e^{6/1}.\ M_1 = 2{\cdot}72^6.\ M_1 = 403\ M_1$
etc.

Suppose now that the exhaust velocity 'c' is 1·4 miles per second; this means that the rocket will have to attain almost four times this speed if it is to remain in orbit round the Earth. Referring to the above equation we find that when $v = 4c$, $M_0 = 54{\cdot}6\ M_1$, or, in other words, the initial mass at take-off is practically 55 times the final mass, with which the rocket will travel in orbit as a satellite after it has spent all its fuel. The mass ratio is thus 55:1. In order to reach escape velocity which in our example is represented by roughly $v = 6c$, the mass ratio would have to be in the nature of 400:1. Clearly the construction of a rocket whose initial mass is 400 times the final mass is just not feasible.

If therefore we still wish to venture out into space and travel to other planets, we must look round for some suitable aids to our project, in order to circumvent this difficulty. Luckily two solutions at once present themselves: the step system and the cosmic space station.

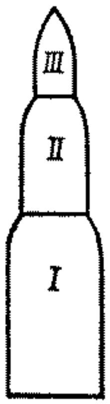



Fig. 6. The principle of the 'Step Rocket'

The application of the step principle is based on the idea of fixing a number of rockets together, say one on top of another, so that only one is firing at any one time and is discarded immediately its fuel has been expended. Figure 6 shows a rocket consisting of three steps, or stages. The largest rocket at the base ignites first and carries stages II and III as its payload. At cut-off, the moment when the rocket ceases to fire having run out of fuel, it will have accelerated the whole system to a speed of '$v_1$'. The empty shell of the first stage is now discarded and the second stage engine begins to operate. This develops a cut-off velocity of '$v_2$' and is in turn abandoned. Stage III fires immediately. This stage carries the actual payload and reaches a speed of '$v_3$'. The speed finally attained by the third and last stage





can be calculated by adding together the three individual speeds:

$$v = v_1 + v_2 + v_3$$

Theoretically any desired speed could be built up in this way. In practice, however, constructional difficulties soon limit the number of steps which can be successfully employed. The real advantage of the system lies in the improved mass ratio, since various useless components are discarded *en route* and so very little unnecessary weight has to be carried.

Long before the first artificial satellite was launched, the step principle had been used with success. One example, the German 'Rheinbote', has already been mentioned. Perhaps a better known application of the principle was the U.S. 'Bumper' project. The 'Bumper-WAC' was constructed by the General Electric Co. of North America for research work. It consisted of two steps; the first was a specially adapted A-4 and the second a WAC-Corporal rocket. During the course of the programme, in February 1949, one of the WAC-Corporals reached an altitude of 244 miles, a record at the time. The rockets used in Project Farside were also multi-stage affairs, in which the last step reached an altitude of almost 4,000 miles. In the present state of science, therefore, the step principle would seem to provide the means of travel through space.

The other possibility for the accomplishment of space travel is still very much in the future, even though serious preparations for its realisation are already in hand. This project concerns the construction of manned space-stations to orbit the Earth beyond the last remnants of the atmosphere. We shall, however, have more to say about present plans for these devices in chapter VII. One particular advantage of a space-station lies in the fact that it would also form an astronomical observatory free from atmospheric interference, though above all else it could be used as a transit centre on journeys from the Earth to the Moon and planets.

Space craft starting off from a space-station would not have air resistance to contend with; consequently their design and shape would not be influenced by the aerodynamic aspect, but would be on a purely functional basis. Owing to the distance of the station from the Earth, the latter's gravitational attraction would be considerably diminished. Finally, the inherent orbital velocity of the space-station would assist in reaching the necessary speed, as we shall see later in our example of a lunar journey.

One of the better known space-station projects is that of Wernher von Braun. He suggests a space-station orbiting the Earth at an altitude of about 1,075 miles at a velocity of 15,773 m.p.h. completing one revolution round the Earth every two hours. It would be constructed in orbit by men wearing space-suits, the various components having been carried aloft in freight rockets.

The ascent of a three-stage freight rocket to the celestial building site would take place in much the following manner. The engines of the first stage develop a thrust of 12,800 tons and accelerate the vehicle to a speed of 5,250 m.p.h. within a matter of 84 seconds. At stage I cut-off the rocket is at a height of 25 miles and a lateral distance of 30 miles from the launching pad. When the second stage, which has a thrust of 1,600 tons and a duration of 124 seconds, cuts out the speed has reached 14,280 m.p.h.; height 40 miles and horizontal distance 330 miles. Next comes stage III (thrust 200 tons; duration 84 seconds) and at cut-off the speed has grown to 18,400 m.p.h.; the altitude is 63 miles and the horizontal distance 700 miles. The rest of the ascent occurs in free flight and the speed gradually diminishes. Finally it is manœuvred into the correct orbit. The whole process assumes very reasonable mass ratios; 4·0 for stage I; 4·5 for the second and 1·85 for the final stage.

Later there will be further ascents of ferry rockets both to maintain the station and to carry aloft the crews of the deep space craft which will be launched from the platform.

As soon as the station itself is in commission, the construction of the actual deep space craft can begin. There can be little doubt that the first objective of manned spaceflight will be the Moon, whose mean distance from the Earth is only 238,840 miles, less than ten times round the world at the equator, and as such is our nearest neighbour in space. In order to escape from the Earth, the vehicle will require to reach a velocity of 19,500 m.p.h. Since the orbital velocity of the station is already 15,773 m.p.h., vehicles launched from it will need to raise a speed of only 3,727 m.p.h. from their own power. According to von Braun's calculations this will be reached within 33 minutes of the launching. Then after cut-off the space craft will continue their flight in elliptical paths under their own impetus at gradually diminishing speed until—with still a little impetus in hand—they pass the point of neutrality. This lies some nine-tenths of the distance from the Earth to the Moon, and at this point the gravitational fields of the two bodies are in equilibrium. From here on the Moon's gravitational attraction is the stronger, because of its





proximity. The space craft now begin to gather speed again as they fall towards the Moon. Six hours and forty minutes after passing the line of equilibrium the craft will have to turn through an angle of 180 deg. by means of built-in gyros, so that the next part of the descent will be made tail first. 550 miles above the lunar surface the rocket engines will leap into life once more; this time opposed to the direction of flight, so that the speed will be reduced to zero some ten minutes later when the surface of the Moon is reached. In von Braun's concept the journey from the space-station to the Moon would take 5 days in all.

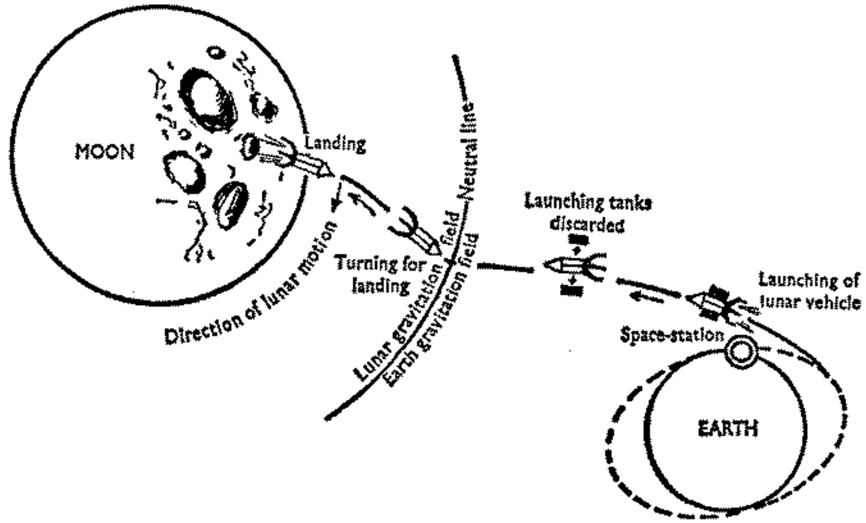



Fig. 7. Trajectory of a space-ship travelling from a space-station to the Moon (proposed by W. v. Braun)

Mars will probably be the second objective of space exploration after the Moon. Although Mars never comes as close to the Earth as does the planet Venus, it is probably the most 'Earth-like' of all the planets. The main point about a journey to Mars is that the power, i.e. velocity, of the space craft is added to the orbital velocity of the Earth. In general the various aspects of such a trip are much the same as for the lunar journey; take-off from the space-station; next powered flight for a short period until escape velocity is reached; free flight in an elliptical trajectory which would touch the orbits of both Mars and Earth (Fig. 8); braking manœuvre in the vicinity of Mars and subsequent guidance into a spiral path about the planet.

Naturally the exact moment of launching would have to be carefully chosen, so that the spaceship would arrive in the Martian orbit when the planet itself had reached the same point.

Wernher von Braun has also worked out the details connected with a Mars project of this kind, entirely with methods and materials available today. The outward and return journeys would each take 260 days, he calculates, but it would be wrong to assume that the total duration of a Mars expedition could be as short as 520 days,

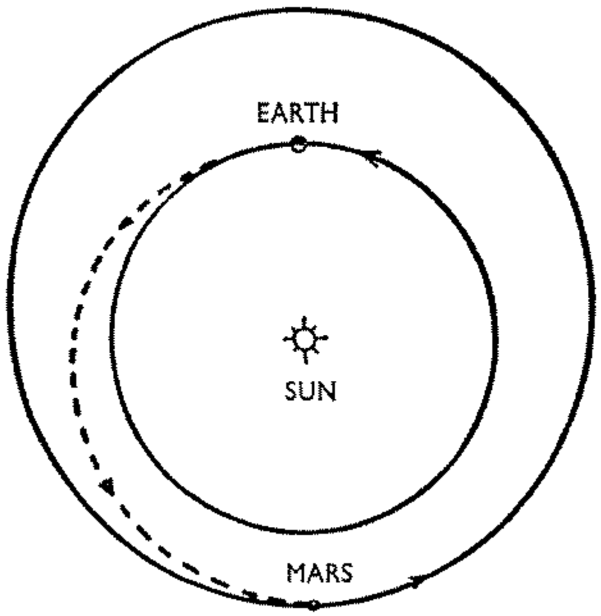



Fig. 8. Trajectory of a vehicle travelling from Earth to Mars

for we must take into consideration a waiting period of 449 days on Mars until it and the Earth again come into suitable opposition. Hence the whole of the tour would be 260 + 449 + 260 = 969 days, i.e. 2 years and 239 days.

For a journey to Venus, on the other hand, once the spaceship has escaped from the Earth, the important thing is to slow it down relative to the Earth's orbital velocity. It will then describe a path which will take it towards the centre of the solar system. The order of the various orbital manœuvres is similar to the Martian journey. Again most of the trip will be accomplished in free flight and the trajectory will be part of an ellipse which touches the orbits of Earth





and Venus. Naturally, it would be quite feasible to arrive on target along different paths, the ellipse formed could well be such as to intersect the orbit of Earth, or Venus, or even both, but this would entail a greater expenditure of fuel and this fact in turn would affect the mass ratio. Journeys to the planets in free fall ellipses, which touch but do not intersect the orbits of Earth and the planet in question, certainly take longer to accomplish, but against this they are by far more economical in fuel consumption. In the light of present progress this is a most important factor.

Outward and return journeys to Venus will each take 146 days, which is less than the Mars expedition, but in contrast the waiting period on Venus will be longer, 470 days. The total duration of a Venus expedition is thus 146 + 470 + 146 = 762 (2 years and 32 days).

Some readers may be wondering how the various manœuvres—guidance into the desired orbit, course corrections and steering in general—can be carried out in empty space. In the old A-4, where the air at great altitude was already too rarefied to use conventional rudders, devices called 'jet rudders' were employed. Here deflection plates of heat-resistant material were placed in the path of the exhaust stream. In modern rockets, however, a different technique is used; usually the rocket engine is mounted in a system of gimbals, so that the direction of thrust can be altered.

Finally a word or two about the return and landing of space vehicles. So far as landing on a body such as the Moon, which does not possess an atmosphere, is concerned, the only possible procedure is to slow down the flight, i.e. fall, velocity of the space craft by means of rockets operating in a direction opposed to the direction of fall (retro-rockets), so that the craft may reach the ground at zero velocity. This is a manœuvre which will require absolute accuracy and split-second timing.

A completely different technique will have to be used to approach a planet, such as the Earth, which does possess an atmosphere. In view of the air resistance a vehicle which is designed for operation in deep space, and thus does not have an aerodynamic shape, would not itself be able to make land, since in its passage through the atmosphere the friction would inevitably cause it to become white-hot and finally vaporise. If a space-station already existed, the crew could disembark and change over to a ferry rocket. Failing this the deep space vehicle would have to remain in orbit while the crew

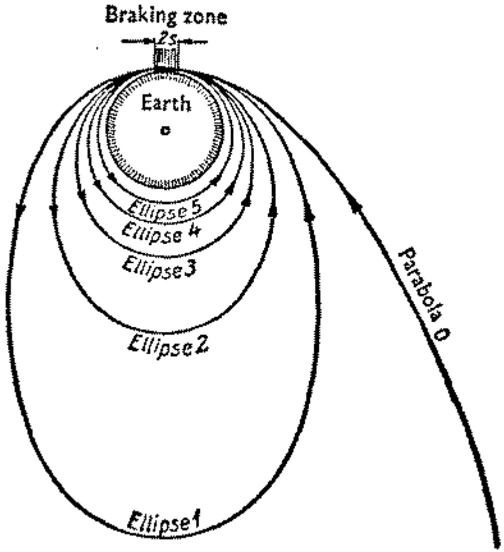
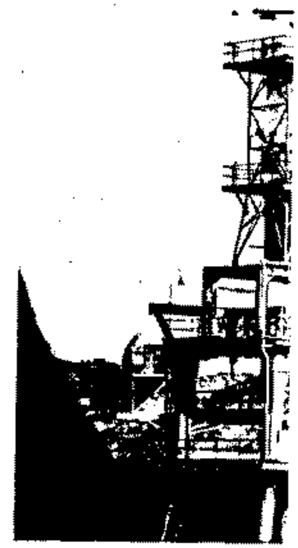



Fig. 9. Braking ellipses on return to Earth (W. Hohmann)

attempted a landing in specially designed winged rockets. The re-entry into the atmosphere is a problem to which scientists are still giving a great deal of thought. The point is to use the air resistance so as to reduce the speed of the vehicle very gradually. Figure 9 shows the landing manœuvre suggested by W. Hohmann, whom we mentioned in the previous chapter. It is calculated for a craft returning from space in a parabolic trajectory. At the closest point of its orbit to Earth, the ship passes through the outermost layers of the atmosphere. The resultant friction will bring about a certain amount of reduction in speed; owing to its slightly slower motion the ship will now enter an elliptical orbit, ellipse 1. From now on every time the vehicle makes contact with the atmosphere it will be slowed down even further and the ellipses will become ever tighter (2–5). Eventually comes the landing proper in an extended glide. In Hohmann's reckoning the whole landing procedure would take 22·6 hours.

Let us now leave the purely theoretical considerations and examine the results which have so far been achieved in practice along the road into space.





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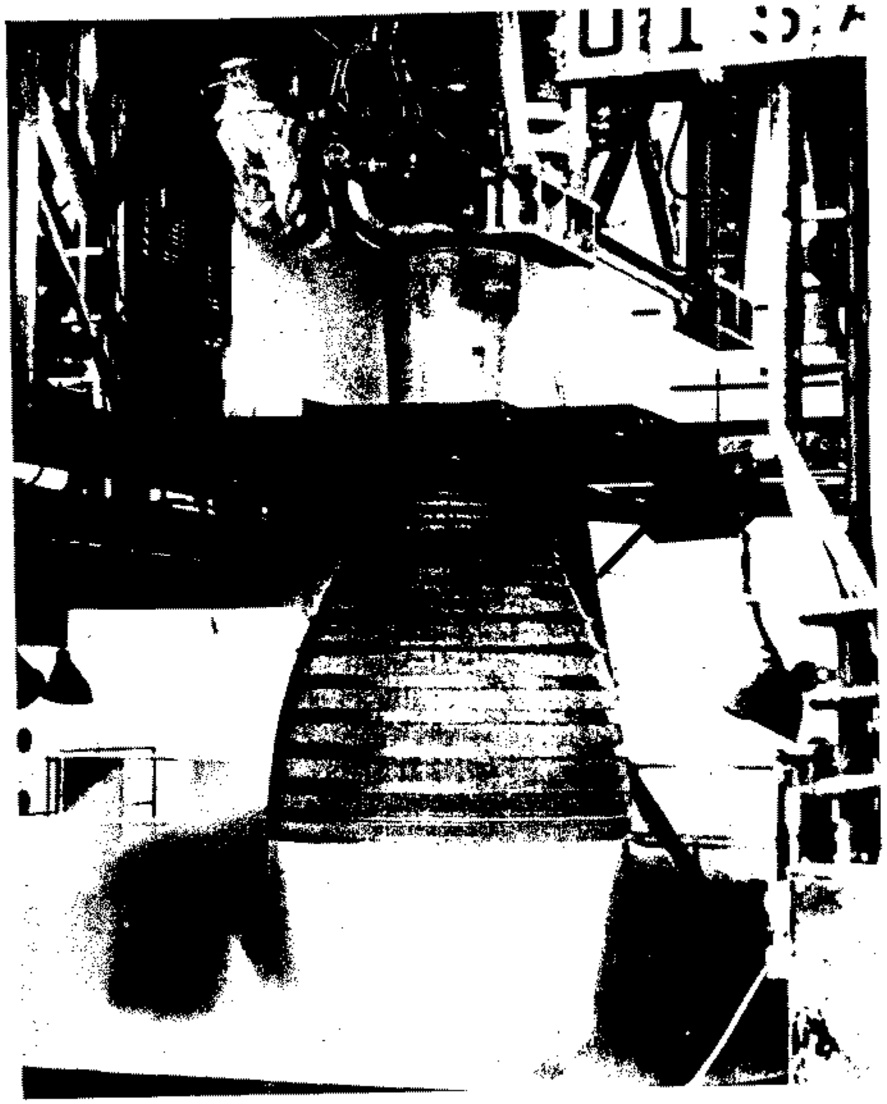

4. Photograph of the Rocketdyne 400,000-lb. thrust class research and development rocket engine being test fired at Propulsion Field Laboratory in Santa Susana Mountains. It was developed by Rocketdyne, a division of North American Aviation, Inc., under a development contract with the U.S. Air Force. This engine is contributing information on combustion, turbo machinery design and systems operation for very high thrust engines

# 3

# Practice: Rockets and Artificial Satellites

The end of World War II heralded renewed efforts for a peaceful onslaught on space. For, with the removal of a number of weapons from the secret list, an astonished world learnt of the amazing strides which had been accomplished within a few years in the field of rocket research. To those whose interests lay in spaceflight it meant even more: up to that time they had been concerned with the matter, more or less, on a purely theoretical basis; now the A–4 represented the break-through into reality.

The astronautical organisations in various countries resumed their activities. Connections which had been broken off on account of the war were once more re-established. In Germany a number of regional groups grew from the remnants of the original GfW as a result of the different occupation zones. Some of these, for example in Berlin, Frankfurt-on-Main and Leipzig were but short-lived. The N-W German GfW, founded by the author and H. J. Rueckert in Stade in 1946, which was also one of the founder members of the International Astronautical Federation, continued its activities until the autumn of 1952 when it merged with the Stuttgart GfW as part of the general amalgamation of all the German rocket societies. This amalgamation which came into being in 1948 led to the German Society for Rocketry and Spaceflight which is today the strongest of these societies in Germany.

The German Rocket Society (DRG) led by A. F. Staats, which was