CHAPTER 4

ORBITS AND DESTINATIONS

WERE the earth isolated in space, once a rocket vessel had attained the velocity of escape it would be able to travel in any direction for any distance, always providing that the duration of the voyage was of no concern to the occupants. But while a journey to infinity could be expected to be not a little prolonged, it may be noted in passing that within the confines of the solar system, very considerable reductions in transit times are obtainable by increasing the speed of take-off. Thus the despatch of a rocket to the moon, a journey which would require 116 hours if it began at the minimum velocity of somewhat less than 7 miles a second necessary to achieve it, could be completed in far less time if additional supplies of fuel were available:

Initial velocity miles/second	*Transit time hours*
7	28
8	14
9	$10\frac{1}{3}$
10	$8\frac{1}{4}$

From Newton's first Law of Motion we know that a rocket will continue in a state of rest, or of uniform motion in a straight line, unless it is acted upon by an external force. This proviso clearly applies to interplanetary space, in which gravity-filled domain no vessel would be able to pursue a course which was a straight line, thanks to the ever-present attraction of the sun, not to mention the lesser pull of the planets. In effect, a spaceship must of necessity follow a curved course, specifically one that is circular, elliptical, parabolic, or hyperbolic. And, surprising though it may seem, these

cosmic paths were studied by the ancient Greeks more than 2,000 years ago, in the guise of the familiar conic sections, the metric treatment of which by the famed geometer Apollonius of Perge (c. 262 B.C.) and his successors has been hailed in modern times as one of the outstanding mathematical achievements of antiquity.

The conic sections are so-called, reasonably enough, because they can be obtained by cutting (sectioning) a cone. If the cut be made in a plane perpendicular to the axis of the

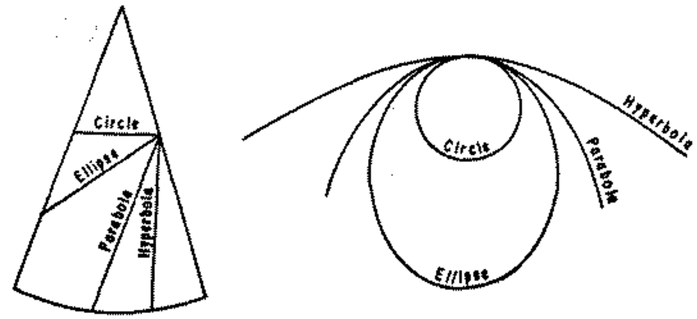

FIG. 19. The conic sections (left). Defined in terms of half the distance between the foci divided by half the major axis, the eccentricity (degree of flattening) of these curves ranges from 0 in the circle and < 1 (read, "less than 1") of the ellipse to 1 of the parabola and > 1 (read, "greater than 1") of the hyperbola. The various sections are shown (on right) as orbits having the same perihelion distance, the size and eccentricity of the orbit increasing with the speed of the revolving body at this point.

cone (*i.e.*, straight across), the resulting shape will be a circle, whereas if the cutting instrument deviates from the horizontal in such a way that the plane is more inclined to the axis of the cone than to one of its edges, the outline will be an ellipse. For a parabola, the plane of intersection must lie parallel to a line down the opposite edge of the cone, while, if the plane is more nearly parallel to the cone's axis than to its edge, it will cut the cone in a hyperbola (Fig. 19).

Now in the presence of an external force, the orbit of a rocket (or of any other body moving in space) may be one of captivity or of freedom. If captive, its path will be a closed curve, either a circle or an ellipse; if free, it will move in an open curve, either a parabola or a hyperbola. Such, at all events, is the theoretical aspect of the situation. In practice, however, the choice is likely to be between an ellipse and a hyperbola, as the slightest alteration in the velocity of a body that is moving in a circular orbit suffices to change its course to an ellipse—of which the circle is a special case. The parabola is also unique, in that it forms the dividing line between closed and open curves, the smallest deviation at once transforming it into an ellipse or a hyperbola, as the case may be. Nor is this all, for an important relationship exists between the two transient states, in that it can be shown that if the

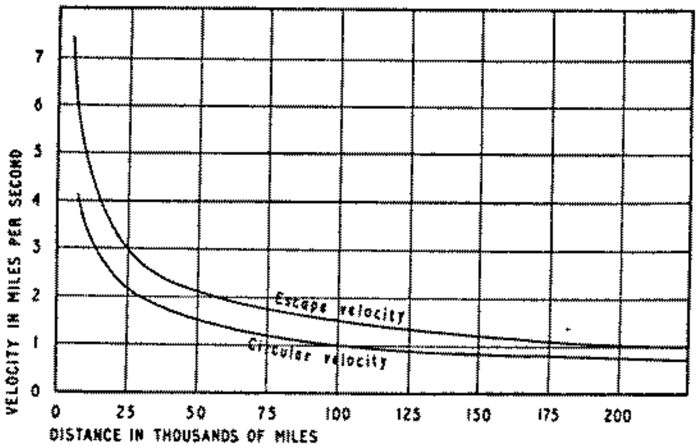

FIG. 20. Variation of escape and circular velocities with distance from the earth's centre. At any given point, circular velocity multiplied by $\sqrt{2}$ equals escape velocity.

speed of a body in a circular orbit is multiplied by $\sqrt{2}$ (about 1·41), its course will become that of a parabola, so enabling it to escape from its primary. Conversely, the parabolic escape velocity at any given point, when multiplied by 0·707, gives the associated circular velocity (Fig. 20).

A trip to the moon will be the least difficult of all extra-terrestrial visitations, in part because it calls for a voyage of thousands rather than the millions of miles which a journey to any of the planets will entail. Thus the earth and its satellite are separated by no more than 252,710 miles, and because of the ellipticity of the lunar orbit, this distance is reduced

during the month to 221,464 miles. The moon's orbital velocity is likewise subject to constant change, and, apart from the added complication that the departure platform is spinning rapidly, it will be evident that to take-off in the direction of a distant target which is itself travelling at some 2,290 miles an hour would be to ensure missing it altogether. A departing spaceship, in other words, must be aimed ahead of the moon, and its movements so timed that the two bodies duly meet at some predetermined point along the lunar path. Nor is it enough that the vessel should depart at exactly the right time in precisely the required direction. Its capabilities must also be such that its performance can be predicted with considerable accuracy, for, if the launching speed in any way differs from that calculated, not only will the shape of the trajectory be affected, but an error in flight time will inevitably be introduced.

On a manned flight, it is not to be expected that reliance will be placed entirely on a ballistic launch, as this would leave little enough room for error, especially on an interplanetary voyage. Instead, steering rockets will be used should the vessel be found to be off course in the light of information radioed to it from earth—computations relating to its movements will be so complicated that an electronic computer will need to be employed, and there would be no point in burdening the ship with such a mechanism.

Some idea of the mathematical complexities of the situation may be gathered from the multiplicity of calculations which preceded the firing of the American lunar probe Pioneer IV. On each of successive days there was a choice of several possible launching times, firing directions and speeds for which a different trajectory had to be computed (Fig. 21). In the event, Pioneer IV was sent on its way on 3 March, 1959, exceeding the velocity of escape within 4½ minutes. It was intended that the rocket's payload should pass within 5,000 miles of the moon between 29 and 37 hours after take-off, but, owing to minor errors in speed and aiming direction, it missed the moon by more than 37,000 miles after a flight time of 41 hours. But that the required degree of accuracy is attainable was convincingly demonstrated a few months later by Lunik II, which reached the moon within a few seconds of its estimated time of arrival.

Without in any way seeking to detract from this outstanding Russian achievement, it will be apparent that the feat of crash-landing several pounds of instruments on the moon is an undertaking far easier of accomplishment than that of sending men and equipment there, not so much because of

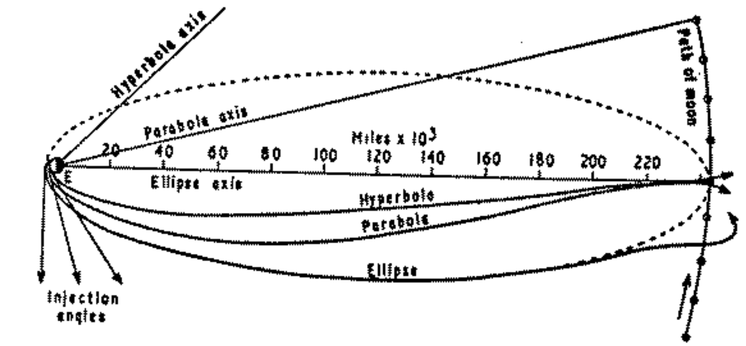

FIG. 21. Elliptical, parabolic and hyperbolic paths from the earth to the moon, with calculated launch speeds of 24,000, 24,600 and 25,000 miles an hour respectively.

the far greater payload concerned, but because it involves a double journey. As aggravated by the fuel problem and the question of making a return, manned space missions may be listed in the following order of increasing difficulty:

	Miles per second
1. Earth–moon–earth, no lunar landing	16
2. Earth–moon–earth, with lunar landing	20
3. Earth–Venus–earth, no Venusian landing	24
4. Earth–Mars–earth, no Martian landing	24
5. Earth–Mars–earth, with Martian landing	32
6. Earth–Venus–earth, with Venusian landing	38

The figures in the right-hand column give the total or so-called characteristic velocity requirement of each mission in miles per second, due allowance having been made for possible navigational corrections, and for gravitational and other losses. In terms of fuel expenditure, it will be observed that items 3 and 4 are the same, and the trip to Venus is placed ahead of that to Mars because of its shorter duration.

But when it comes to the question of a landing, Mars offers the advantage of a smaller mass, an inducement which, however, the presence of a dense atmosphere on Venus, in a manner shortly to be described, may more than offset. Be it noted, meanwhile, that the characteristic velocity is merely a summation, indicative of fuel requirements, which the spaceship is at no time called upon to attain. For example, the total of 20 miles a second attributed to the earth–moon–earth trip, with power-assisted lunar and terrestrial landings, is arrived at as follows:

	Miles per second
Escape from earth	8
Landing on moon	2
Escape from moon	2
Landing on earth	8
	20

Thus, far from being used to accelerate the vessel to 20 miles a second, half the allocated fuel consumption is for decelerative purposes during the making of lunar and terrestrial landings.

It will be recollected that the first part of the outward journey (the escape from earth) was likened to a motorist ascending a long hill by rushing towards it at high speed and then switching off his engine. This analogy may be extended to the remainder of the lunar journey if the vehicle, after coursing up the gradient, be pictured as reaching the crest of the incline with sufficient momentum to pass over it, whereafter it at once begins rolling down the opposite slope, gaining speed all the while. In such circumstances, to avoid colliding head-on with an obstruction at the bottom, the driver would need to apply his brakes. And in the same way, a rocket vessel which, having crossed the imaginary line where terrestrial and lunar gravitational fields neutralise one another, and so begun a 24,000-mile fall to the moon, would need to counter the lunar attraction by using its motors in reverse.

Apart from the question of the distances involved, another reason for the relative simplicity of the lunar voyage is the circumstance that, throughout it, the solar pull is to all intents and purposes exerted equally on earth, spaceship, and moon alike, so that its influence can be ignored. On an interplanetary journey, however, this is no longer the case, and a rocket which barely succeeded in overcoming the attraction of the earth would do so only to find itself a prisoner of the sun, pursuing an elliptical orbit astronomically not far removed from that of the earth itself—as did Pioneer IV (Fig. 22).

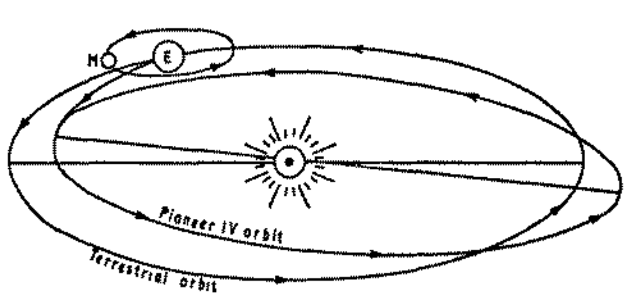

FIG. 22. The orbit of Pioneer IV in relation to that of the earth. After passing the moon, the rocket travelled to within 91·7 million miles of the sun, a distance which was increased at aphelion, some $6\frac{1}{2}$ months later, to 106 million miles. A complete circuit requires 395 days.

Now a body which is encircling the sun in the neighbourhood of the terrestrial orbit must, like the earth, be travelling at an average of $18\frac{1}{2}$ miles a second or so, a figure which, when multiplied by $\sqrt{2}$, gives the solar velocity of escape at this point. So that to free itself entirely from the hold of the sun, the encircling rocket would need to increase its speed from $18\frac{1}{2}$ to 26 miles a second, though the total escape requirement of $14\frac{1}{2}$ miles a second (made up of 7 m.p.s. in respect of the earth and $26-18\frac{1}{2}=7\frac{1}{2}$ m.p.s. on account of the sun) could be reduced somewhat (to the root of the sum of the squares) by employing one period of acceleration only. But in any case, the possibility of forsaking the solar system appears likely to remain one of academic interest for many years to come, if only because the nearest galactic destination is the star Proxima Centauri, at a distance of some 25,000,000,000,000 miles!

A less exacting interplanetary journey, meanwhile, evidently requires that the spaceship should be transferred from the vicinity of the orbital path of one planet to that of another, an operation governed by the fact that the nearer an orbiting body is to the sun, the faster it must be travelling in order to neutralise the solar pull. From this, it will be apparent that the departure time of such a journey, carefully calculated with reference to its estimated duration, cannot be chosen at random, as the distance between starting point and destination is subject to constant change. When Mars and the

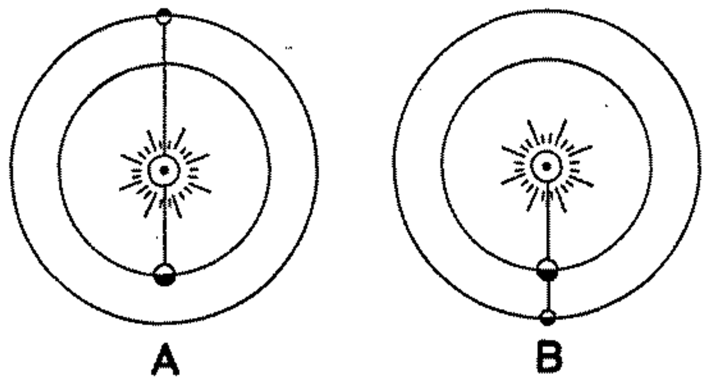

FIG. 23. The earth and an outer planet in (A) conjunction and (B) opposition.

earth, for instance, are in what is termed conjunction—to be found on opposite sides of the sun—they may be as much as 250,000,000 miles apart (Fig. 23A). This position, however, is only momentarily maintained, because the two bodies are travelling at different rates. The faster earth, moreover, has a shorter circuit, so that it will steadily overtake its companion until they are both once again in line with the sun, but on the same side of it. They are now said to be in opposition, and the distance separating the two bodies (which, as at times of conjunction, is subject to considerable variation because of the ellipticity of the two planetary orbits) may on occasion (every 15–17 years) be no more than 35,000,000 miles (Fig. 23B). The interval between the occurrence of one opposition (or conjunction) and the next is known as the synodic period of the planet concerned. It amounts to 780 days in the case of Mars, this planet and the earth most closely approaching one another every 2·137 terrestrial years.

Similar considerations apply to the inner planets Venus and Mercury, though neither of these bodies can be in opposition, as the earth can at no time assume a position between them and the sun. The earth and Venus (or Mercury) are said to be in superior conjunction when Venus is in line with the earth, but with the sun between, and at such a time they may be 160,000,000 miles apart (Fig. 24A). In due course,

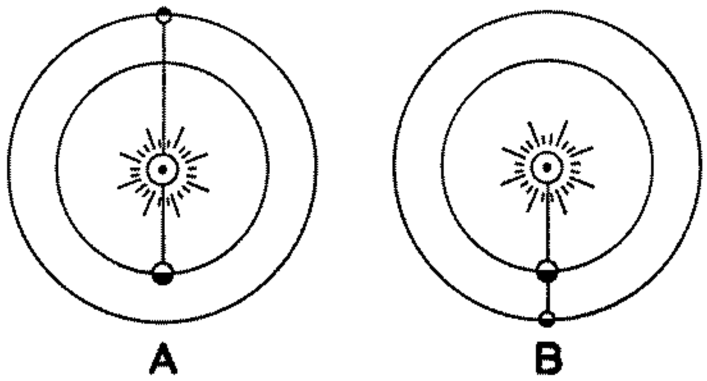

Fig. 24. The earth and an inner planet in (A) superior conjunction and (B) inferior conjunction.

however, the faster moving Venus will overtake the earth and so assume a position in line with, but between it and the sun (Fig. 24B). The planets will then be in inferior conjunction, and as little as 26,000,000 miles may separate them. Such an approach takes place every 584 days, so that the synodic period of Venus amounts to a little more than 1½ years.

It transpires that Mars and Venus, the two planets which most closely approach the earth, have the longest synodic periods of all (those of the planets next in order of distance, Mercury and Jupiter, are respectively 116 and 399 days), and it will be seen that if one favourable opportunity for making a departure is missed, there will be a considerable delay before the occurrence of the next. Again, as in the case of a lunar journey, due allowance must be made for the fact that

the planetary destination is not stationary, the aiming point on the orbital path being located ahead of the moving target. There is, nevertheless, an infinite number of alternative trajectories from which to choose, and the question thus arises as to which of these is the most suitable. On the face of it, the answer might appear to be the one associated with

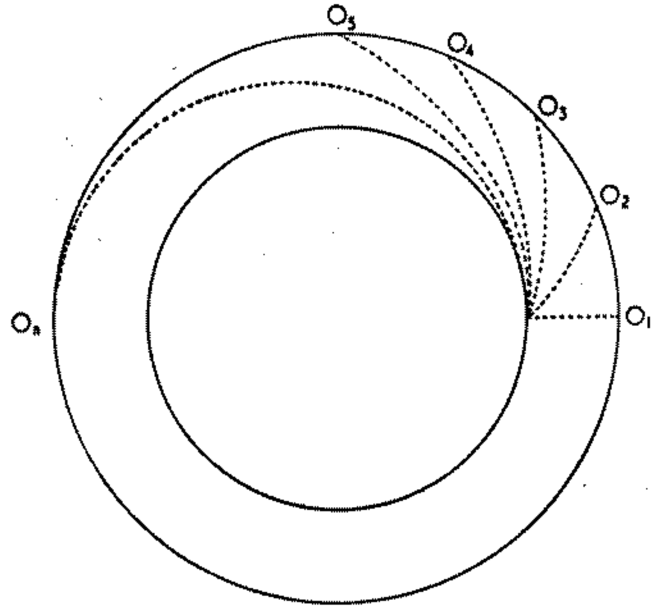

Fig. 25. Interplanetary orbits. O_H is the Hohmann or minimum energy orbit.

times of opposition (in the case of Mars) or of inferior conjunction (as applicable to Venus), a course which would entail the shortest possible journey, thus saving time and reducing to a minimum exposure to the attendant hazards. But this, though an important consideration, is not the overriding one, which is the need to conserve fuel, and the exigencies of interplanetary travel are such that the longer journey O_H (Fig. 25) is more economical in this respect than shorter routes.

This seeming paradox is simply explained, for the more direct routes tend to cut across the two planetary orbits, whereas the tangential path of the extended journey merely grazes them. In consequence, the spaceship is enabled to derive the maximum advantage from the orbital motion which it possesses at the time of its departure, a gift not lightly to be cast aside. Indeed, the importance of these minimum energy interplanetary orbits is such that, with the propellants at present available, they appear to offer the only real hope of the planets being reached at all, as Walter Hohmann realised more than a quarter of a century ago when he first suggested their use, in commemoration of which advocacy they now bear his name.

An evident drawback to the Hohmann orbits, however, is the roundabout nature of the journeys they involve, coupled with the length of time they require, so much so, that in the case of the outermost planets, a more direct approach will need to be made if too many years are not to be spent in travelling to them. As it is, the Hohmann orbit from earth to Mars (and vice versa) extends for a distance of some 345,000,000 miles, as against the 35,000,000 miles which separate the two bodies when a favourable opposition occurs (thanks to the ellipticity of the orbits aforementioned, the opposition distance may, on occasion, be as great as 63,000,000 miles).

In order to pursue its elongated course, the spaceship, after overcoming the attraction of the earth, will add $1\frac{3}{4}$ miles a second to its inherited orbital velocity of $18\frac{1}{2}$ miles a second and so begin to move outwards, away from the sun and towards the path of Mars, coasting for the remainder of the way until it nears its destination. The speed of the vessel (relative to the sun) will by this time have fallen to about $13\frac{1}{4}$ miles a second, some $1\frac{3}{4}$ miles a second less than the rate at which the approaching Mars is travelling. By making good this difference, the vessel will effect a transfer from the Hohmann to the planetary orbit, so enabling it to accompany Mars on its journey round the sun, either as a satellite or (if the fuel situation permits) after having landed upon the planet's surface.

The travelling time from earth to Mars is 258 days, and a like period is needed for the return journey. This will be begun by the spaceship reducing, instead of adding to, its

(Martian) orbital speed, so that it is no longer able to resist the solar pull. As a result, the vessel begins to coast inwards and earthwards, so increasing its velocity in the process that in the vicinity of the earth a further reduction is required to enable a transfer to be made to the terrestrial orbit. But this is not to suggest that the entire trip could be undertaken in $2 \times 258 = 516$ days. At the start of the journey, the relative position of the two planets needs to be such that, after departing from the earth and travelling half-way round the sun, the spaceship encounters Mars at the appointed place at the prearranged time. Similar considerations apply to the making of the return trip, and the circumstances are such that the two planets do not assume the required position until 455 days after Mars has been reached, for the whole of which period the vessel must, perforce, linger on or near the planet. The round trip thus requires 971 days, or nearly 3 years.

The Venusian journey calls for a repetition of the Martian procedure, the several manœuvres being carried out in reverse order, *i.e.*, after the ascent from earth, there will first be a reduction of orbital velocity and the initiation of a drift sunwards, followed by further braking so as to bring about a transfer to the Venusian orbit at the journey's end; while on the return, an addition to the (Venusian) orbital velocity will enable the vessel to coast outwards and earthwards. The inward and outward stages of the journey will each require 146 days, interrupted by a stay of 470 days, a total of 762 days —more than 2 years.

In round figures, the total velocity requirement of 32 and 38 miles a second of these two interplanetary excursions is made up as follows:

	Mars miles per second	*Venus miles per second*
Escape from earth	8	8
Transfer to Hohmann orbit	2	2
Transfer to planetary orbit	2	2
Landing on planet	4	7
Escape from planet	4	7
Transfer to Hohmann orbit	2	2
Transfer to terrestrial orbit	2	2
Landing on earth	8	8
	32	38

It will be seen that even if the voyagers were content to hover in the vicinity of their planetary destination throughout the waiting period, and made no attempt to descend to the surface, the characteristic velocity would still not fall below 24 miles a second. This calls for a fuel consumption far in excess of anything that is at present available and so, indeed, do the more modest requirements of the lunar journey. But the matter does not necessarily end here, for the figures concerned can be brought down to more realistic levels by resort to various expedients.

Is it essential, for instance, to expend precious fuel while making a descent to the earth's surface? Instead, could not

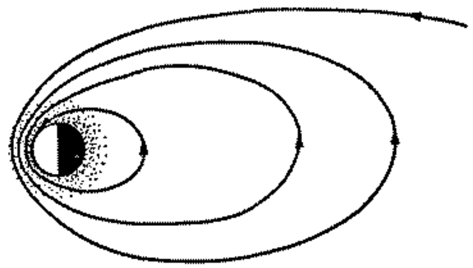

FIG. 26. Braking ellipses. In carrying out this landing manœuvre, it is envisaged that a spaceship will graze the upper layers of a planet's atmosphere in a series of decelerative loops, each successive one passing through air of greater density, until the vessel has been slowed down sufficiently to enable a descent to the surface to be made by parachute.

advantage be taken of the presence of a dense atmosphere to employ some form of aerodynamic braking? A number of proposals to this end have been advanced, notably that use could be made of braking ellipses. As its name suggests, in carrying out this manœuvre, the returning spaceship would approach the earth in a series of ever-diminishing loops, slowing itself down by skimming through the upper air layers and, after having become overheated by the friction thus engendered, soaring out into space, there to lose the unwanted warmth before turning earthwards once again (Fig. 26). Were the ship to be fitted with wings, the procedure could terminate in a prolonged glide, or the final descent to the surface could be made with the aid of a parachute.

It has been suggested that there are good prospects that a landing could be accomplished entirely by such means, without the need to burn any fuel at all, in which event an appreciable reduction in the velocity requirements considered earlier would be brought about. The total of that for the lunar trip (with landing) would be lowered by 8 miles a second, while that of the Venusian journey (again with landing) would fall from 38 to 23 miles a second, there being a corresponding saving during the descent to the planet's surface. To what extent aerodynamic braking could be employed on a visit to Mars remains to be seen, for that planet's atmosphere is known to be somewhat tenuous.

There is also the question of the ascent, and in the case of the earth, some slight reduction in the velocity of escape could be achieved by despatching the rocket from the summit of a high mountain on the equator, though the inconveniences attendant upon the use of so elevated a departure platform might well offset the advantage to be gained. An equatorial launching in an eastward direction, however, would provide a useful addition to the spaceship's final velocity, at no extra cost, simply by virtue of the fact that the speed of rotation of the earth's spinning is here slightly more than 1,000 miles an hour. Even more promising is the prospect of making the escape from the earth with fuel tanks nearly full instead of almost empty, for, given the relationship which exists between parabolic and circular velocities, it follows that in the vicinity of the earth's surface the last-named will amount to $7 \times 0{\cdot}707$ or almost exactly 5 miles a second, a figure well within existing capabilities. Hence, if worthwhile payloads consisting of supplies of rocket propellants were placed in orbit, a departing spaceship, after expending most of its fuel in duplicating this manœuvre, could refill its tanks and thereafter make good its escape merely by adding $7-5=2$ miles a second to the velocity it had earlier acquired.

The procedure may be likened to the method which could be adopted by the bearer of a heavy burden: that of apportioning the load and making a double journey with it. The space traveller, however, is not in the happy position of a carrier who is able to divide his load into two equal parts, for the velocity assignments of 5 and 2 miles a second cannot be improved upon. It is true that orbital speed diminishes with distance from the centre of attraction, from which it might appear that it would be advantageous to place the refuelling depot at an altitude of some 4,000 miles, at which height it would satellite the earth at precisely half the velocity of escape. Nature, however, is not to be cheated in this fashion, and a greater expenditure of energy would, in fact, be required to achieve the slower but higher orbital path than one which was faster but lower. In short, the closer the selected orbit is to the surface of the earth, the more economical will it be to reach and enter it, though care must be taken, of course, to ensure that it does not impinge upon the outermost layers of the atmosphere.

All the indications at present are that, pending the harnessing of nuclear energy to the propulsion requirements of space travel, manned flights to the moon and beyond will need to have recourse to orbital refuelling, in conjunction with a judicious use of the step principle, even after making allowance for some improvement in existing mass ratio and specific impulse figures. Much of the importance of the procedure resides in the variety of the applications to which it lends itself, and if for any reason aerodynamic braking proves to be unsuitable for making the descent to earth, the refuelling technique can just as readily be employed on an inward as on an outward journey, while some advocates have carried the idea further still. Thus a plan put forward some years ago by H. E. Ross and R. A. Smith envisaged the simultaneous placing in orbit of three spaceships, of relatively modest dimensions, which may be designated A, B, and C. The vessels, each weighing 442 tons and containing a solitary occupant, would rendezvous at a height of 500 miles, from where ship A, after taking on board all C's remaining fuel and some from B, would head for the moon with the three men as passengers. While in orbit about the moon, excess fuel tanks would be unloaded into space and left circling, while the ship, thus lightened, made its way to the lunar surface. On the return journey, the discarded fuel tanks would be

retrieved, thus enabling the ship to reach and re-enter the terrestrial orbit from which it had earlier departed. Here, the three voyagers would transfer to the still partly-fuelled ship B, in which vessel they would make the descent to earth. Variations of this ingenious scheme are, of course, possible, the essence of the matter being the ability of several spaceships to achieve orbital velocity with appreciable quantities of fuel to spare.

Another interesting possibility which would arise is that of transfer, when in orbit, to a vessel which was restricted to use in space, *i.e.*, one which was incapable of making a planetary landing or escape, and would thus need to be conveyed aloft or constructed *in situ* from component parts ferried into position and there assembled. Such a proposal offers a number of advantages. As the ship would be confined to the vacuum of space, it could assume any odd shape that happened to be convenient, for streamlining would be unnecessary. Again, all the stresses and strains associated with the attaining of normal escape velocities would be absent, so that a correspondingly light structural design could be used —fuel tanks, for example, could consist of plastic containers, retained by a flimsy lattice of metal-work. More important still, their power requirements would be so low as to open up the possibility of dispensing with the conventional rocket motor in favour of some novel form of propulsion.

Thus it has been suggested that use could be made of the fact that electrically unbalanced atoms can be accelerated to speeds up to that of light, so that thrust could be provided by a beam of ions. Such a thrust would, of course, be very small, able to provide an acceleration which was no more than a fraction of 1 gravity. But, unlike the thrust of an ordinary chemical rocket, it could be applied continuously, so that over long periods quite respectable terminal velocities would be attained. Ernst Stuhlinger has outlined a Mars ship propelled by this means, the total mass of which is a modest 435 tons, of which no less than 150 tons is payload, in part made up of chemically operated landing craft for use when the destination is reached. At the onset of the voyage, the vessel would gradually leave its terrestrial orbit by circling the earth until it had built up sufficient velocity to free itself, whereafter it would spiral outwards round the sun. At the halfway mark, the thrust would be reversed, the vessel entering a satellite orbit on reaching Mars after a journey of some 300 days—a time not very much greater than that required by a conventional spaceship following the Hohmann orbit.

Ion propulsion for rockets (the possibilities of which were noted by R. H. Goddard as early as 1906!) now has a rival in the conception, recently put forward by T. S. Tsu, of a vessel fitted with a solar sail, by means of which it would be enabled to utilise radiation pressure from the sun. The essentials of this novel spaceship are a gondola-like life container and (attached to it by shroud lines) a huge parachute-shaped sail, made of aluminium foil or lightweight plastic. Such a contrivance would, of course, be incapable of making an escape from the earth's surface, but, once it had been placed in orbit with the assistance of chemical rockets, the voyagers would unfurl their sail, which could be so manipulated that the forces acting upon it would carry the vessel in any desired direction, even towards the source of radiation itself. As in the case of the ion rocket, the propelling force would be small, but continuously applied, and departing from the vicinity of the earth would necessitate a continuous circling operation lasting several weeks. But, once the ship was under way, it is estimated that Mars could be reached in as little as 118 days, as the course of the vessel would be a logarithmic spiral, a much shorter path than the tangential ellipse.

CHAPTER 5

EXTRA-TERRESTRIAL SURVIVAL

TWENTY-FIVE years ago, only a few enthusiasts were sufficiently misguided to express the belief that a rocket would one day succeed in overcoming the pull of the earth, while the idea of manned flights at speeds in excess of 25,000 miles an hour was everywhere dismissed as hardly less fantastic than the notion of making an interplanetary journey itself. But what was here overlooked was the disconcerting fact that we are all seasoned space travellers already, in that the entire human race has spent the past million years or so unconcernedly hurtling through the void at some 66,000 miles an hour on account of the earth's orbital motion alone!

That, until comparatively recently, mankind remained blissfully unaware of this movement, strongly suggests that mere speed, of itself, is of no account, and such is, in fact, the case. It is *change* in velocity—acceleration or deceleration—which is of vital concern, and there must be few who have not experienced the last-named when the driver of a conveyance has suddenly applied his brakes. At all events, these effects are likely to be greatly magnified in space travel, particularly at the onset of a voyage, when the demands of economic fuel consumption will call for the attainment of escape (or circular) velocity as quickly as human endurance and atmospheric friction will permit. Allowing a time limit of not more than 10 minutes for this, the crew of a spaceship will face the prospect of submitting to accelerations of from 3–5*g*—the extent of their ordeal, that is to say, ranging from the lesser inconveniences of 3 times gravity over a period of nearly 10 minutes to the greater discomforts of 5 times gravity, maintained for about half as long (Fig. 27).

The other side of the moon, an historic picture televised to earth from the Russian Lunik III in October, 1959. The continuous line represents the lunar equator, the dotted line the border between the visible (on left) and invisible (on right) hemispheres as viewed from the earth. Familiar landmarks (Roman numerals) are: (I) Mare Humboldt; (II) Mare Crisium; (III) Mare Marginis; (IV) Mare Underum; (V) Mare Smythii; (VI) Mare Foecunditatis; and (VII) Mare Australe. Hitherto unseen features (Arabic numerals) have been named: (1) Sea of Moscow; (2) Gulf of Astronauts; (4) Tsiolkovsky Crater; (5) Lomonosov Crater; (6) Joliot-Curie Crater; (7) Sovietsky Mountain Range; and (8) Sea of Dreams. The area marked (3) is a continuation of the Mare Australe.

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by

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