they walked upstairs, though a sufficiently sensitive barometer would show that the pressure in the bedroom is slightly lower than in the kitchen. . . .

Designers of the five-mile-long interstellar spaceships launched by the more ambitious science-fiction writers would certainly have to allow for this effect, since the atmospheric pressure difference between the prow and stern of such a vessel would be as great as that between base and summit of Everest. However, one fancies that this would be among the very least of their worries. . . .

We will end by reluctantly demolishing an illusion which everyone must be very sorry to lose—and that is the popular belief that on the Moon, even in daytime, the sky would be blazing with stars and that the Sun's corona would be seen stretching out from it like a glorious mantle of milky radiance. The lunar landscape by daylight will be spectacular enough—but it will be as starless as the day sky of Earth.

When a large amount of light enters it, as is normally the case during the daytime, the human eye automatically cuts down its sensitivity. At night, after a period of some minutes, it becomes about a thousand times as sensitive as during the day. It loses that sensitivity at once when it is flooded with light again—as any motorist who has been blinded by an approaching car will testify.

During daylight, on the Moon, the eye would be constantly picking up the glare from the surrounding landscape. It would never have a chance of switching over to its "high sensitivity" range, and the stars would thus remain invisible. Only if the eye was shielded from all other light sources would the stars slowly appear in the black sky.

You can put this to the test quite easily by standing well back from the window in a brilliantly lit room one night, and seeing how many stars you can observe in the sky outside. Then remember that the light reflected from the walls around you is less than a hundredth of the glare that the lunar rocks would throw back.

This situation poses a pretty problem to the artist attempting to illustrate lunar scenes. Shall he put in the stars or not? After all, they are there and can be seen if one looks for them in the right way. Besides, everybody *expects* to see them in the picture. . . .

The Sun's corona would be invisible to the naked eye for the simple reason that it would be impossible to look anywhere near the Sun without dark glasses. If they were sufficiently opaque to make the Sun endurable, they would cut out the million-times-fainter corona altogether. It could, however, be seen without difficulty if one made an artificial eclipse by holding up a circular disc that exactly covered the Sun.

The errors and misunderstandings discussed in this article have ranged from the trivial to the subtle, and some of them have involved important principles. The lesson that can be learned from them all is this—before we can conquer space, we must not only have a clear picture of all the factors involved, but we must also empty our minds of preconceived ideas which may colour our conclusions. We don't want any future astronauts looking at each other with blanched faces and saying: "Someone should have thought of that. . . ."

PERTURBATION MANOEUVRES

BY DEREK F. LAWDEN, M.A.

SUMMARY

The calculation of the velocity increment induced in a space ship due to its attraction by a large moving body and without expenditure of fuel is explained. Such a "perturbation manoeuvre" is seen as a means of economizing in the fuel requirement of an interplanetary journey.

1. Introduction

A number of writers have suggested that the fuel requirements of a journey between the Earth and the other planets might be reduced by taking advantage of the attractions of various bodies of the solar system, but the method of calculating such perturbing effects and the economies to be expected do not appear to be widely known. In the next section we shall consider this problem of a space ship attracted by a moving body and will show how to obtain the resulting velocity increment induced in the ship.

2. General Problem

Let $\mathbf{v}_0$ be a vector denoting the velocity of the ship relative to the Sun when it is still at a great distance from the moving body (planet or moon) whose perturbing effect is required. If $\mathbf{V}$ is the velocity of the body, $\mathbf{u} = \mathbf{v}_0 - \mathbf{V}$ is the velocity of the ship as observed from the body. Fig. 1 indicates the

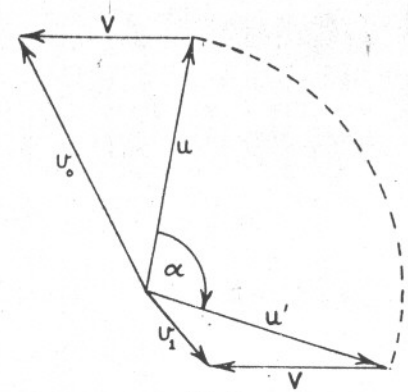

FIG. 1.

relationship between these vectors. An observer on the body will see the ship approach from infinity with velocity $\mathbf{u}$ and, provided we may neglect the effect of the attractions of other bodies including the Sun during the short time the perturbing body's field is effective, he will observe that the ship follows a hyperbolic trajectory with its focus at the centre of attraction, eventually receding to infinity with a velocity $\mathbf{u}'$ having the same magnitude as $\mathbf{u}$ but a direction differing from that of $\mathbf{u}$ by some angle α (see Fig. 1). $\mathbf{u}'$ is the velocity of the ship relative to the perturbing body. $\mathbf{v}_1 = \mathbf{u}' + \mathbf{V}$ is the velocity of the ship relative to the Sun. The difference between the velocity vectors $\mathbf{v}_0$ and $\mathbf{v}_1$ represents the perturbing effect.

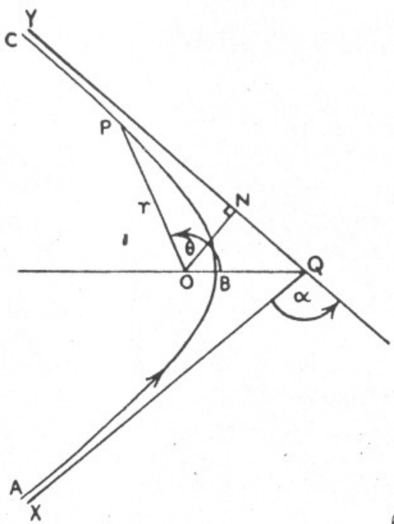

FIG. 2.

The magnitude of α will clearly depend upon the relative speed of approach **u** of the ship to the perturbing body and the closest distance of approach. If the latter is large, the body's attraction will have little effect and α will be very nearly zero. If, on the other hand, the ship approaches close to the surface of the body, α will be large and can take values up to a limit of 180°. The line of approach of the ship to the body can be varied, with negligible expenditure of fuel, by the application of small thrusts during the phase of the journey preceding the perturbation manoeuvre. The value taken by the angle α in the range (0°, 180°) can accordingly be regarded as under the control of the navigator. The sense of α (clockwise or anti-clockwise) may also be selected as required, since it depends only upon the side of the attracting body from which the approach is made. Given the value to be taken by α, the diagram of Fig. 1 can be drawn to scale in any particular case and the perturbation effect assessed. Alternatively, this diagram can be sketched and the problem solved by the use of trigonometry.

It remains to derive an equation exhibiting the dependence of α upon the relative speed and line of approach. Let O (Fig. 2) represent the centre of attraction and let ABC represent the track of the ship P as observed from the perturbing body. Let QX, QY be the asymptotes of this hyperbola and let α be that angle between them which represents the change in the direction of motion caused by the attracting body. Taking polar co-ordinates (r, θ) as shown, the equation of the hyperbola may be written.

$$\frac{a(e^2-1)}{r} = 1 + e\cos\theta, \quad \ldots \quad (1)$$

where $a = BQ$ and e is its eccentricity. When $r = \infty$, OP is parallel to QY

and hence $\theta = 90° + \frac{1}{2}\alpha$. Substituting this pair of values in equation (1), we find that

$$\operatorname{cosec}\tfrac{1}{2}\alpha = e. \quad \ldots \quad (2)$$

The closest approach of the ship to O occurs at B. Let $OB = c$. Clearly, c must always be larger than the radius of the attracting body. When $\theta = 0$, $r = c$ and hence, by substitution of these values in equation (1), we obtain

$$\frac{a(e^2-1)}{c} = 1 + e,$$

$$\text{or} \quad e = 1 + \frac{c}{a}. \quad \ldots \quad (3)$$

The speed v of the ship relative to O at any point of its hyperbolic trajectory is given by the energy equation

$$v^2 = \mu\left(\frac{2}{r} + \frac{1}{a}\right), \quad \ldots \quad (4)$$

where μ/r^2 is the attraction per unit mass at a distance r. If u is the relative speed of approach when the ship is at a great distance from O, $v = u$ when $r = \infty$. Hence

$$u^2 = \frac{\mu}{a}. \quad \ldots \quad (5)$$

Elimination of a between equations (3) and (5) yields

$$e = 1 + \frac{cu^2}{\mu}, \quad \ldots \quad (6)$$

and hence, by equation (2),

$$\alpha = 2\operatorname{cosec}^{-1}\left(1 + \frac{cu^2}{\mu}\right). \quad \ldots \quad (7)$$

Equation (7) determines α when the speed of approach u and the distance of closest approach c are known.

The line of approach may be specified for the navigator by the length of the perpendicular from O upon it. This is $ON = p$ in Fig. 2. Clearly

$$\begin{aligned} p &= (a + c)\cos\tfrac{1}{2}\alpha = ae\cos\tfrac{1}{2}\alpha \text{ (equation (3))} \\ &= a\cot\tfrac{1}{2}\alpha \text{ (equation (2))} \\ &= \frac{\mu}{u^2}\cot\tfrac{1}{2}\alpha \text{ (equation (5))}. \quad \ldots \quad (8) \end{aligned}$$

Equation (8) permits the navigator to calculate the value of p he must aim for corresponding to any assigned manoeuvre.

3. Perturbation by the Moon

In this section we will calculate the economy to be expected from a perturbation manoeuvre involving the Moon. Let us suppose that a ship leaves a circular orbit about the Earth by applying a thrust which is only just sufficient to effect escape. The ship will recede along a parabolic arc and when at a

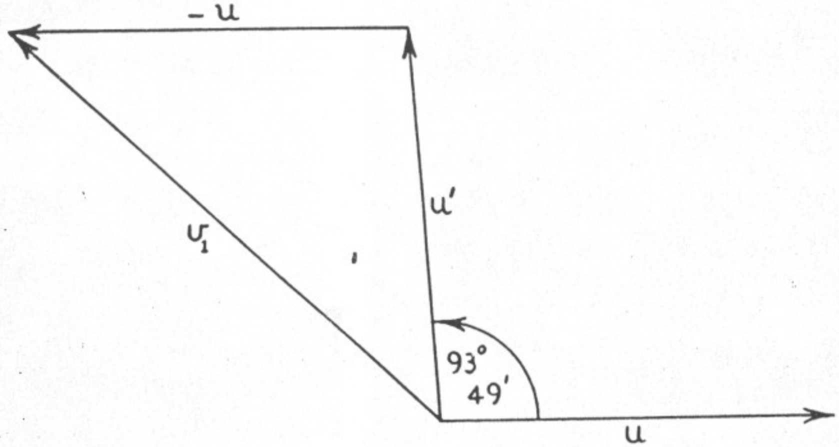

FIG. 3.

great distance from the Earth its velocity will be almost zero. Unless a further thrust is applied, or it is perturbed by another body, it will move around the Sun in the Earth's orbit. Suppose, however, that it is eventually attracted by the Moon. Its velocity relative to the Earth is zero and hence its velocity relative to the Moon is the same, apart from sense, as the velocity of this body in its orbit about the Earth, viz. $1{\cdot}02 \times 10^5$ cm./sec. The line of approach with this speed as seen by an observer on the Moon will depend upon the position of the Moon in her orbit at the instant we regard the ship as entering within her sphere of influence. By careful timing in the manoeuvre, the navigator will be able to choose this line of approach to suit his purposes. Let us suppose that he plans to graze the Moon's surface in order to take maximum advantage of her attraction. Then, in the notation of the previous section, c is equal to the radius of the Moon. Hence $c = 1{\cdot}74 \times 10^8$ cm. Also $u = 1{\cdot}02 \times 10^5$ cm/sec., $\mu = 4{\cdot}90 \times 10^{18}$ c.g.s. units. Substituting in equation (7), we find that $\alpha = 93{\cdot}49'$. $\mathbf{u}'$ makes this angle with the vector $\mathbf{u}$ as shown in Fig. 3. Adding the Moon's velocity (which is equal and opposite to $\mathbf{u}$) vectorially to $\mathbf{u}'$, we obtain the ship's velocity relative to the Earth at the termination of the perturbation manoeuvre, $\mathbf{v}_1$. A little trigonometry shows that the magnitude of $\mathbf{v}_1$ is $1{\cdot}49 \times 10^5$ cm./sec. At the commencement of the manoeuvre the ship had zero velocity relative to the Earth. The perturbation has accordingly resulted in a velocity increment of 1·49 km./sec. By choosing the time of take-off appropriately, this increment can be arranged to augment that component of the ship's velocity due to the motion of the Earth in its orbit or, alternatively, to act in the opposite sense. To reach the orbit of Mars, a velocity increment of 2·95 km./sec must be given to the ship after release from the Earth's field, whereas the orbit of Venus can be reached after a velocity decrement of 2·50 km./sec. It will be noted that about 50 per cent. of these velocity changes can be acquired by making use of the Moon's attraction with no expenditure of fuel. No violation of the law of conservation of energy is involved, since a gain in

energy of the ship is exactly compensated by a corresponding loss on the part of the Moon (which will hardly be aware of the deprivation !). In the case of Mars, much of the velocity increment required by the ship at the end of its journey along the Hohmann ellipse can similarly be made up by a perturbation manoeuvre based upon Deimos or Phobos.

It will be appreciated that the foregoing calculation has been of an approximate nature only. For one thing the fields of the Earth and Moon have been treated as though their spheres of influence are entirely separate, whereas in fact they will both be operative on the ship at all times. However, the results obtained may be accepted as a good guide to the magnitude of the effect to be expected.

4. Further Numerical Illustration

As a second example of the method, we will calculate the perturbing effect of Mars in the case of a ship which follows the Hohmann ellipse connecting the orbits of the Earth and Mars and chooses a line of approach to Mars which causes it to graze the surface of the planet. The velocity of the ship, as it approaches Mars, is less than that of the planet in its orbit by 2·65 km./sec. Its velocity relative to Mars is accordingly 2·65 km./sec in a direction opposite to that of the motion of Mars in its orbit. The radius of Mars is $3{\cdot}4 \times 10^8$ cm. In equation (7) we therefore put $u = 2{\cdot}65 \times 10^5$, $c = 3{\cdot}4 \times 10^8$, $\mu = 4{\cdot}30 \times 10^{19}$ and obtain $\alpha = 80°$. The relationship between the relative velocity of the ship to Mars before the perturbation $\mathbf{u}$ and afterwards $\mathbf{u}'$, is shown in Fig. 4.

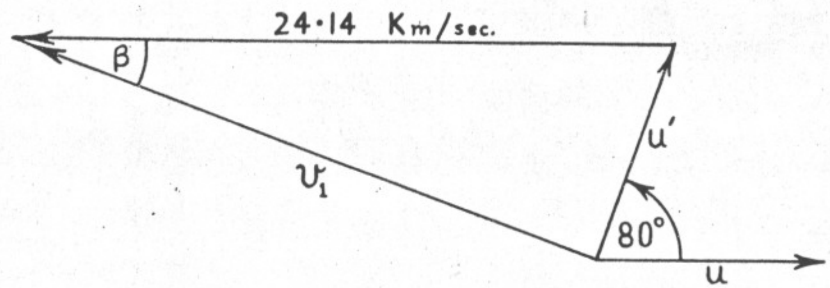

FIG. 4.

Adding vectorially to $\mathbf{u}'$ the velocity of Mars in its orbit (24·14 km./sec. in a direction opposite to that of $\mathbf{u}$) we obtain the velocity $\mathbf{v}_1$ of the ship relative to the Sun at the termination of the manoeuvre. A little trigonometry proves that $\mathbf{v}_1$ has a magnitude of 23·82 km./sec. and makes an angle of $\beta = 6°\ 17'$ with the direction of the motion of Mars. This shows that there has been a net velocity increment of 2·33 km./sec due to the perturbation.

5. Conclusions and Recommendations

By judicious planning of a journey between two planets, taking advantage of the possible perturbing effects of the many asteroids, a considerable saving in fuel can almost certainly be effected. The manner in which maximum advantage may be taken of the attraction of any such body in the case of a particular journey may be calculated by employing the technique for the discovery of optimal trajectories which has been described by the author elsewhere. This will be the subject of a future investigation. However, a series of numerical investigations of the type explained in this article would act as a very useful basis for this more theoretical research and such work is recommended to those interested in orbital computations.

SOME COMMENTS ON STRUGHOLD'S IDEAS ON MARTIAN VEGETATION

By A. E. Slater, M.A., M.R.C.S., L.R.C.P., F.R.Met.S.

Dr. Hubertus Strughold's most interesting book *The Green and Red Planet*, the American edition of which was reviewed by Mr. E. R. Nye in the January issue of this journal (page 58), has now been published in England by Messrs. Sidgwick and Jackson at 7s. 6d.—a mere fraction of its original price of 4 dollars. Since this is bound to increase its circulation, the time seems opportune for a few comments on Dr. Strughold's ideas which appear to be called for.

My reading of the purpose of the book is that it is not just a general review of the possibilities of life on Mars, but that the general aspect serves as a setting for a highly original suggestion which Strughold first propounded in the symposium *Space Medicine* (reviewed in *J.B.I.S.*, September, 1952, p. 239), but which Mr. Nye's review does not mention. The suggestion is that the Martian vegetation keeps within its tissues the oxygen it produces by photosynthesis* and then uses this oxygen for respiration, instead of taking it from the air, as earthly plants are able to do. Thus does Strughold dispose neatly of the argument that there cannot be life on Mars because oxygen is virtually absent from the atmosphere.

Strughold devotes the whole of his Chapter 7, "A Hidden Store of Oxygen," to this idea. But there is one point on which he seems to have gone astray, and by coincidence it comes on the same page as the one about ice crystals in air spaces which Mr. Nye criticized in his review.

On page 72 of the American edition, Strughold says that:—"On such a planet as Mars a plant presumably could produce no oxygen to speak of beyond its own needs, because of the limited supply of water and the reduced amount of energy available from sunlight. Therefore it would not be constantly increasing the hoard of free oxygen in the air, as our plants do. Although there would actually be enough oxygen within the vegetation to maintain life, no visible trace of it would be found in the atmosphere. And this is in fact the case on Mars."

Actually, the question whether the hoard of oxygen would increase has nothing to do with the strength of the sunlight, but would depend solely on whether the plant as a whole was growing or not. Strughold himself gives the

* *The process by which the energy of sunlight, trapped by the green chlorophyll, is used to build up organic substance out of carbon dioxide and water, giving off oxygen as a by-product.*

relevant chemical reactions earlier in his book. On page 14 the formula for photosynthesis is given:

$$6CO_2 + 6H_2O + \text{light energy} \longrightarrow C_6H_{12}O_6 + 6O_2$$

and on page 17 the formula for respiration:

$$C_6H_{12}O_2 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}.$$

Thus, in photosynthesis 6 molecules of oxygen are liberated for every molecule of carbohydrate built up; while in respiration the same amount of oxygen, 6 molecules, is needed to oxidize the one molecule of carbohydrate—i.e. to burn up the fuel to provide the energy the plant needs in order to live.

If the plant is to grow, then more carbohydrate must be built up by photosynthesis than is burnt up by respiration, so that more oxygen must be liberated than is used up again, and the store of oxygen must necessarily increase. (If proteins or oils are built up, the proportions are slightly different, but the main argument is not affected.)

However, this process cannot go on indefinitely, unless the Martian plants are immortal. On the Earth, when plants die, they usually become oxidized, either in the bodies of animals, or by decaying where they fall, and it will be seen from the formulae that the surplus oxygen they have put into the air while growing will be exactly used up when the same amount of tissue decays by oxidation.

But not always. On the Earth, during past geological ages, a vast amount of vegetation has been buried under water in swamps, etc., before it had time to be oxidized by decay, and has turned into coal; and other organisms have similarly been buried unoxidized and turned into oil. The surplus oxygen, which might have been used to oxidize them but was not, must have remained in the atmosphere, and according to a theory widely held for many years, this explains why the Earth's atmosphere contains such a lot of oxygen. (The only plausible rival theory is that water molecules in the atmosphere are dissociated by light energy, the oxygen remaining in the air and the hydrogen flying off into space.)

Thus the virtual absence of oxygen in the atmosphere of Mars can be explained on the assumption that none of the vegetation has been buried unoxidized after death, possibly because of the scarcity of water; and incidentally it follows that future colonists will find no coal or oil below ground. But if we accept Strughold's suggestion, we still have to explain how surplus oxygen stored in the growing plants can be transferred to the dying ones to help them to decay. Are animals the answer? It seems to me that Strughold, having made such an ingenious suggestion, might well have followed it through to its logical conclusion.

Another question for which room might well have been found in a book on Martian vegetation concerns the changes in colour with the seasons. The main force of the classic argument in favour of life on Mars is not merely that the dusky areas are greenish, but that this colour changes in various regions into a wide variety of browns, reds, purples and yellows, covering the same range of hues to be found in different species of autumn leaves on the Earth. But this

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