ARTIFICIAL EARTH SATELLITES*

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ABSTRACT

A general discussion is given of the scientific and technological problems involved in the launching of earth satellites, covering various aspects such as the dynamical relationships involved, the propulsion and guidance systems, tracking and data transmission etc. The possible uses of satellites for scientific research as well as some of the likely future developments are also briefly indicated.

Introduction

The twentieth century has witnessed some of the greatest advances in Science and Technology—wireless, aeronautics, atomic energy, to mention only a few. The recent launchings of artificial earth satellites mark the latest step in the triumphant march of science. The achievement of flight and of space-travel has been an age old dream of Man, as is evidenced by the mention it finds in many ancient mythologies. It was reserved for the 20th century to see the actual achievement of the first of these (flight) and of the first successful step towards the second (space travel). The idea of space travel and methods of achieving the same have been the subject of speculative thought throughout the ages and many popular books were written on the subject by science-fiction writers. Although the idea of using rocket-propelled vehicles had been mooted in many of these popular writings, as a subject of serious scientific import, it was conceived almost simultaneously by two men—Zialkowsky of Russia and Hermann Ganswindt of East Prussia. Ganswindt was probably the first to propose the conception of a reaction-propelled space ship. Zialkowsky also arrived at the same idea and besides put forward the idea of using liquid fuels of the kerosene type. The feasibility of attaining great altitude by means of rockets was studied in great scientific detail by R.H. Goddard, whose report "A method of reaching great altitudes," published in 1920, marks the first great advance in modern rocket techniques. While Goddard's researches were primarily devoted to developing suitable means for the study of the physical properties of the atmosphere at very high altitudes, the feasibility of applying the same techniques to achieve space-travel was carefully discussed by Hermann Oberth and his conclusions were published in his important book, "The Rocket into interplanetary space" (1923). The following is a quotation from the introduction to this book :

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"(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 may develop within a few decades. In this book I wish to prove these four assertions". It may be added that Oberth established these assertions (excepting, of course, the fourth) in his book. Like Goddard and Zialkowsky, Oberth also placed great emphasis on the use of liquid fuels for rockets intended to reach outer space.

Although the rocket was developed in the earlier stages as a military weapon it soon lost its importance in this role on account of its inherent inaccuracy in comparison with the highly accurate spin-stabilised artillery shell. Interest in rocket research became largely confined to a few private scientific organisations until the beginning of World War II, when intensive research on rocket weapons was undertaken by governments of several countries, culminating in the appearance of the celebrated German V-2, which ranks as one of the great scientific and engineering achievements of all time. Since the last war, many of these V-2's (captured from the Germans and shipped to America) have been used in a continuing programme of high altitude research. The first step into outer space was taken on February 24, 1949, when a WAC-Corporal mounted on a V-2 climbed to an altitude of 250 miles. High altitude research has been pursued vigorously since then. However, the development of long range missiles has been the major factor contributing to the tremendous progress achieved in rocketry. In October 1952, leading scientists from all over the world agreed to hold the first International Geophysical Year from July 1, 1957 to December 31, 1958, the object of which was to expand man's geophysical knowledge through joint research and experiment. On July 29, 1955, the President of the U.S.A. announced that, as part of the U.S. contribution to the IGY programme, the U.S. would launch a series of artificial earth satellites. The first U.S. satellite was expected to be launched sometime in 1958 but, in the meanwhile, the Russians startled the world by successfully launching into orbit their first Sputnik on October 4, 1957 and a second, much heavier, Sputnik (with a live dog in it) on November 3, 1957. Since then in quick succession four American satellites and a third Sputnik from Russia have been put into orbit. More ambitious projects like rockets to the Moon, satellites carrying humans, etc. may achieve success in the not-too-distant future.

Celestial Mechanics of Satellites

The successful launching of earth satellites may be regarded, in one sense as a triumph of Celestial Mechanics. It virtually amounts to putting into practice, so to say, the laws discovered nearly 300 years ago by Kepler and Newton relating to the dependence of the orbit of a satellite on its launching conditions. Precise calculations based on these laws of Kepler and Newton were necessary in order to shoot the satellites into their orbits around the earth. Of course the satellite projects were not undertaken merely to verify the well known laws of celestial mechanics. These man-made satellites enable us to probe into the far reaches of our atmosphere, the borders of space and even the depths of the earth itself. In the first few weeks of their flight they have told us more about the shape of the earth than 2000 years of observation of our natural satellite, the moon. Since a satellite's orbit alone and changes in it can tell us a great deal about the earth, it is necessary to establish the orbit with very high precision. Precise calculation of the orbit is also necessary in order to predict the position of the satellite at any time. We therefore begin with a brief consideration of how the orbit is found and then what information this furnishes in regard to the earth itself.

The laws governing the motion of a light satellite around a massive particle are summarised in the three famous 'laws of Kepler'. Kepler formulated these laws with reference to the motions of the planets around the Sun, but Newton showed that these laws are of universal application and could be applied to the motion of a satellite round the earth, provided that the gravitational attractive force between the earth and the satellite varies inversely as the square of the distance between them and is always along the line join ing their centres. Under these circumstances, Kepler's first law states that the orbit of the satellite will be a conic section with the earth at one focus, and unless the launching velocity is too large, the orbit will be an ellipse. More precisely, if the satellite is launched with an initial velocity V_o at a distance R from the centre of the earth in a direction making an angle α with the line joining their centres, then the orbit of the satellite will be a conic section whose eccentricity is

$$e^2 = 1 - \frac{2V_o^2 R \sin^2\alpha}{\mu} + \frac{V_o^4 R^2 \sin^2\alpha}{\mu^2} \quad \ldots \quad \ldots \quad (1)$$

where μ is the product: mass of the earth $\times$ constant of gravitation. By writing the above equation in the form

$$e^2 - 1 = \frac{V_o^2 R^2 \sin^2\alpha}{\mu^2}\left(V_o^2 - \frac{2\mu}{R}\right)$$

we see that $e^2 \gtreqless 1$ according as $V_o^2 \gtreqless 2\mu/R$. Thus the orbit is a hyperbola, a parabola or an ellipse according as $V_o^2 >, =$ or $< 2\mu/R$. We can also deduce from the above equation the condition for a circular orbit (for which e=o). Putting e=o and replacing 1 by $\cos^2\alpha + \sin^2\alpha$ the equation becomes

$$-\cos^2\alpha = \sin^2\alpha\left[1 - \frac{2V_o^2 R}{\mu} + \frac{V_o^4 R^2}{\mu^2}\right]$$

or

$$-\cos^2\alpha = \sin^2\alpha\left(1 - \frac{V_o^2 R}{\mu}\right)^2$$

Now the left hand side is a negative quantity while the right hand side is obviously a positive quantity. The equality can therefore be only maintained if both sides are zero, *i.e.*

$$\alpha = \pi/2, \; V_o^2 = \mu/R$$

Thus a circular orbit can only be attained if the satellite is launched with an initial velocity $V_o = (\mu/R)^{1/2}$ *and* in a direction at right angles to the line joining it to the earth's centre. If the speed of projection is exactly that required for a circular orbit at the projection height and if the velocity vector is truly horizontal, then the orbit will be circular. If there should be a slight departure from either of these conditions the orbit will be an ellipse. The point of the elliptic orbit nearest the centre of the earth is called the *perigee* and the point furthest from the centre of the earth is called the *apogee*. Obviously the perigee and the apogee are the two extremities of the major axis of the orbit. The length a of the semi-major axis is determined in terms of the initial conditions by the relation

$$V_o^2 = \mu\left(\frac{2}{R} - \frac{1}{a}\right) \qquad . \quad . \quad . \quad (2)$$

If P is the period of revolution in the orbit, the quantity $N = 2\pi/P$, called the "mean motion," is related to the semi-major axis a by the equation

$$n^2 a^3 = \mu \qquad . \quad . \quad . \quad (3)$$

which expresses Kepler's third law.

We have seen that the orbit is completely determined by the initial conditions at projection. The plane of the orbit will be the plane determined by the line joining the point of projection to the earth's centre and the direction of the initial velocity vector. In order to specify the position of the orbit in space, we take a rectangular coordinate system with the origin at the centre of the earth, the Z-axis pointing towards the celestial pole, the X-axis towards the vernal equinox, the plane XOY being the plane of the earth's equator with the Y-axis (OY) drawn in such a way that OXYZ forms a right-handed system. The orbit intersects the equatorial plane XOY in two points called the 'nodes' of the orbit. The node N at which the orbit passes from the negative to the positive side of the Z-axis is called the *ascending node* and its right ascension is denoted by Ω. The normal to the plane of the orbit makes with the Z-axis an angle i, "the inclination". The two quantities Ω and i serve to determine the orientation of the orbit in space (see Fig. 1).

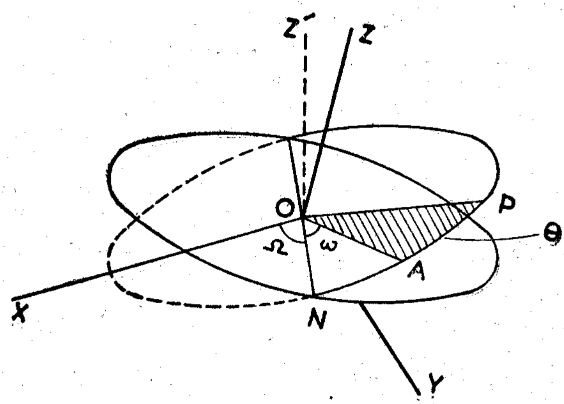

FIG. 1

The orientation of the orbital plane having been fixed by giving i and Ω, the orbit itself is now fixed by giving a, e and the position of one point on the orbit, say the perigee A. Let ω be the angle NOA (see Fig. 1) and T the time of perigee passage of the satellite. Then the six quantities i, Ω, a, e, ω, and T determine the orbit completely and are called the "elements of the orbit". Once the elements are known, the right ascension α, the declination δ and the distance r of the satellite (from the centre of the earth) can be predicted for any time t.

$$\left.\begin{aligned} \alpha &= \Omega + \tan^{-1}\Big[\cos i \tan(\omega + \theta)\Big] \\ \sin\delta &= \sin i \sin(\omega + \theta) \\ r &= a\,(1 - e\cos E) \end{aligned}\right\} \quad . \quad . \quad (4, a)$$

Here E, the so-called "eccentric anomaly" and θ ($=\hat{AOP}$) the "true anomaly", are determined by the relations

$$\left.\begin{aligned} E - \sin E &= n\,(t - T) \\ \tan\frac{\theta}{2} &= \sqrt{\frac{1+e}{1-e}}\tan\frac{E}{2} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (4, b)$$

The above formulae are applicable to an observer at the centre of the earth. Given the latitude and the local time of an observer at any time at any selected place on the earth's surface, it is not difficult to obtain formulae giving the apparent right ascension, the apparent declination and the distance of the satellite from the observer.

Perturbations of Satellite orbit—Effects of Earth's oblateness

In the discussion of the satellite orbit it was assumed that the only force on the satellite was that due to the gravitational attraction of the earth. Further the earth was assumed to be perfectly spherical, so that this gravitational force on the satellite was always directed along the line joining the centres of the earth and the satellite and inversely proportional to the square of the distance between them. Actually the earth is not exactly spherical; it is more nearly an oblate spheroid, the polar diameter being shorter than the equatorial diameter by about 1 part in 297. Further, the atmosphere surrounding the earth offers resistance to the motion of a satellite through it. Other effects such as the attractions of the moon, the other planets and the Sun may be neglected in the case of a small satellite with a relatively close orbit. But the effects of the oblateness of the earth and of the air resistance cannot be neglected. Consider the effect of the oblateness first. The flattening at the poles and the bulge at the equator may be envisaged as a removal of mass from the polar regions and a corresponding increase of mass in the equatorial region. One effect of this redistribution of mass on the attractive force experienced by the satellite is that this force is no longer directed towards the centre of the earth but towards a point on the farther half of the polar axis, giving rise to a component of the force at right angles to the plane of the orbit and hence tending to pull it towards the equator. But the revolving satellite has the property of a gyroscope. If to a whirling gyroscope we apply a force tending to tip its axis, the gyroscope responds by a precession of its axis of rotation in a direction at right angles to the axis and to the applied force. In the case of the satellite the corresponding effect is a precession of the normal to the plane of the orbit round the polar axis or, equivalently, a regression of the line of nodes in the equatorial plane. For example, the orbit of Sputnik I, soon after its launching, was regressing rapidly westwards, at the rate of 3·1 degrees per day or three complete revolutions of the line of nodes per year. In the case of the far more distant natural moon, the rate of regression is one full revolution in eighteen years. This westward regression of the line of nodes manifests itself as a gradual decrease in the right ascension Ω of the node N.

Another effect of the earth's oblateness is to cause the perigee point A to move along the orbit, so that ω is not constant. For the orbit of Sputnik I the rate of change of ω is about two fifths of a degree per day. Still a third effect of the equatorial bulge is a periodical flattening of the satellite's orbit slightly at the north and south ends.

Thus a satellite has three different periods associated with its motion:

(*i*) *Radial or anomalistic period*, from one perigee passage to the next.

(*ii*) *Nodical period*, between successive passages of the satellite through the ascending node,

(*iii*) *Sidereal period* of one complete revolution in right ascension.

There are two methods for calculating the effects of disturbing forces on the motion of a satellite or a planet. In the first method the exact equations of motion including the perturbing forces are integrated step-by-step by numerical methods. This method makes no use of the theory of the unperturbed elliptic orbit and entails a large amount of labour (unless one employs one of the large electronic computers). The second method makes effective use of the theory of the elliptic orbit. Without disturbing forces the orbital elements would be true constants but when such forces are present, the elements vary with time. If at a certain instant (called the instant of osculation) all disturbing forces were removed the satellite would describe an elliptic orbit and the elements specifying this orbit are called *the osculating elements.* In reality the continued action of disturbing forces causes the osculating elements to fail to represent the actual motion, but the theory allows us to calculate the changes in the elements with time due to the action of the disturbing force. Thus the position of the satellite at a later time can be computed by the usual formulae using the changed values of the elements. Some of the changes are periodical, others gradual. For example, the apogee and perigee distances exhibit a periodic (*i.e.* oscillatory) variation while the right ascension of the ascending node decreases steadily. For the 3rd stage rocket of Sputnik I the predicted change in Ω is $-3{\cdot}25^{\circ}$ per day, assuming that the earth's flattening is 1/297. A discrepancy between claculated and observed behaviour would indicate that this value for the flattening could be improved. It will be noted that the predicted rate of regression for Sputnik I is in good agreement with the observed value (mentioned earlier).

Perturbations due to Air Resistance

The air resistance or drag can also have marked effects on the satellite orbit. In the absence of air resistance it follows from equation (3) above that an increase in the value of a will result in a decrease in the value of n and hence an increase in the value of the orbital period P. Thus a larger orbit corresponds to a larger period of revolution. The larger orbit also corresponds to a larger value of the total energy (kinetic + potential). Now in the presence of air resistance, part of this total energy is dissipated in overcoming this resistance, so that corresponding to the smaller net value of the total orbital energy, the orbit will be smaller. Thus the effect of the air resistance is to continually force the satellite into a smaller orbit with a shorter period. During the first month after its launching, the nodical period of Sputnik I was decreasing by approximately 4 seconds per day. The apogee and perigee distances both decrease continually but owing to the decrease in atmospheric density with elevation, the decrease in apogee distance is more marked than that in perigee distance. The apogee and perigee distances will continually diminish (the former much faster than the latter) until eventually the orbit becomes circular, after which both should decrease at nearly equal rates. The satellite will then spiral towards the earth and the end of its career would be near (see Fig 2). Details of these progressive changes would give valuable information on air density at great altitudes.

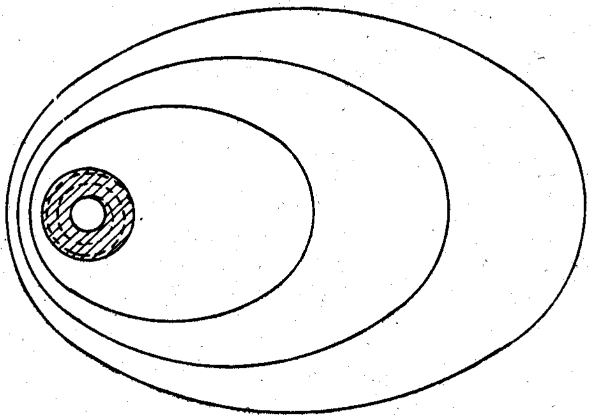

FIG. 2

Observations of the period changes for the Sputniks have already revealed that the air density at some 150 miles above the ground is about 5×10^{-13} gm/c.c. a figure much higher than that hitherto supposed.

If we consider together the effects of both the oblateness of the earth and the air resistance, the continual decrease in apogee and perigee distances will be of an oscillatory character. These oscillatory changes are similar to those produced by the oblateness alone, except that now after each oscillation the apogee and perigee distances will be less than their initial values, corresponding to the continued loss of energy due to air drag.

Satellite Life-time

On account of the rapid diminution of air density with height, for a satellite orbit whose eccentricity is not too small, most of the airdrag is encountered near perigee so that the factor of chief significance as regards the satellite's life-time will be the air density in the region of the original perigee. Consequently, there is considerable retardation near perigee leading to a reduction in height at the next apogee but very little decrease in perigee height. For strongly accentric orbits this difference will be very marked and the changes in the orbit shape will, during a considerable period of time, reduce practically to a decrease of apogee height alone with a nearly constant perigee height. Since the life time of the satellite is approximately the time for its orbit to become circular (as explained above) we can thus obtain an estimate of the lifetime provided we know from observation the initial rate of loss of apogee height. A more reliable estimate of the lifetime can be obtained by analytically solving the equations of motion of the satellite by including in these equations the terms due to the air resistance. In thus calculating the lifetime, we can neglect the effects of the oblateness of the earth since it produces no secular changes in the size and shape of the orbit. However, we have to make some assumption about the variation of atmospheric density with height, since at present we have no precise information on the physical parameters of the atmosphere at high altitudes. Because of the lack of reliable information in this respect, the results derived from the calculations can only be regarded as tentative and orientative. Nevertheless, such calculations will be useful in deriving atmospheric density data from observed lifetimes. The actual air density in the initial perigee region can be calculated from the known initial heights at perigee and apogee and the observed lifetime of the satellite in its orbit. Analysis of the results from a number of satellite launchings with different initial heights of perigee will make it possible to calculate the actual distribution of the atmosphere in altitude.

Another interesting conclusion that can be drawn from the calculations may be mentioned here. The lifetime of the satellite is more effectively increased by incresaing the initial perigee height, and less effectively by increasing the initial apogee height. This is indeed to be expected. Since establishing satellite orbits of great initial perigee height obviously presents many difficulties, it is important to find that a considerable increase of satellite lifetime may be secured, without changing the perigee height, by increasing the initial height of the apogee which requires only a comparatively small increase of the velocity at perigee. This result indicates the advantage of using elongated orbits, which make it possible to secure a considerable increase in satellite lifetime in a relatively simple way. If sufficiently large values of the perigee and apogee heights are selected then the lifetime of the satellite may be quite considerable.

Propulsion into orbit

The launching vehicle must impart sufficient energy to lift the satellite to the given height above the earth and then give it the kinetic energy requisite to maintain it in the orbit. On the other hand the lifetime of the satellite must be sufficiently large (about a fortnight at least) in order to allow adequate time for conducting significant geophysical and astrophysical researches. It has been estimated that a minimum initial orbital height of about 150 miles would be necessary. Another important consideration is that of accuracy. We have seen that the character of the orbit is determined by the satellite's position and velocity vectors when it is projected into its orbit, and that the orbit will be circular only if the velocity vector at projection is truly horizontal and the speed has the correct value. If the initial velocity vector is directed slightly upward or downward from the horizontal, the orbit will be an ellipse and the perigee height will be lower (see Fig 3).

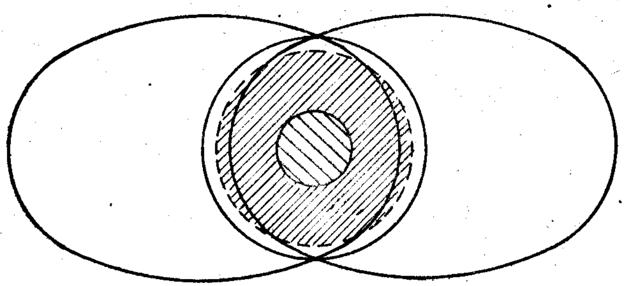

Fig. 3

Hence an accurate control system for accurately aiming the final stage velocity vector is essential. The allowable error in launching angle rapidly increases as the launching speed increases so that when the launching speed is 5 per cent above the circular speed an error of approximately 4° in either direction can be tolerated.

At the present time rocket propulsion offers the only means of attaining the altitudes and velocities required for establishing a satellite in its orbit. On account of their high exhaust velocities, liquid fuels are preferred at the present, but recent developments in the field of solid fuels indicate that the latter may become a serious competitor. Whatever the fuel employed the maximum velocity v attained by a rocket is given by (neglecting gravity and air resistance)

$$v = c \log_e (M_0/M_1) \quad \dots \quad (5)$$

where M_0 is the initial mass of the rocket, M_1 is the mass remaining when the fuel is all burnt and c is the exhaust velocity which is determined by the energy content of the fuel. The ratio M_0/M_1 is called the 'mass-ratio'. It is clear from the above relation that high performance (*i.e.*, high velocity) can be realised either by working with a high exhaust velocity or high mass ratio. The first is the field of fuel chemistry. Table I shows the properties of some commonly employed liquid fuels.

High exhaust velocities are obtained with a high flame temperature and low molecular weight of the fuel, but often these two qualities do not coexist. At the present time straight LOX (liquid oxygen) seems to be the choice of all large missile systems. Liquid Fluorine (or Fluorine compounds) is closest to displacing LOX. Fluorine offers a good balance between high flame temperature and low molecular weight. For smaller systems nitric acid will continue to be a popular propellant. A big advance in the field of liquid fuels is the development of the so-called "exotic" fuels. Known under the name of "Zip" or "Highcal"

TABLE I

Specific Impulse of some typical liquid propellants

Oxidizer	Fuel	Combustion temperature (°F)	Mean molecular wt. of exhaust products	Specific impulse (sec)
Hydrogen Peroxide	Gasolene	4,830	21	248
Do.	Hydrazine	4,690	19	262
Nitric acid	Gasolene	5,150	25	240
Oxygen	Alcohol	5,560	22	259
Do.	Hydrazine	5,370	18	280
Do.	Hydrogen	4,500	9	364
Fluorine	Hydrazine	7,940	19	318
Do.	Hydrogen	5,100	8·9	373

the exotics apparently are hydrides of boron. Three important raw materials used in current developments of high energy fuels are—Boron, Lithium & Ammonium perchlorate. The biggest single solid propellant development has been concerned with scale-up for producting really large single grains. Both single and double base castable propellants have been evolved which permit grains of almost any size. It is probable that present solid propellant technology can give grains of about 1 million lb.-sec. The Russians apparently have high performance solid propellants. The last stage rocket in both Sputnik I and Sputnik II used a large composite grain that delivered 0·75-1·00 million lb.-sec. The sea-level specific impulse is estimated at 273 sec. The average high-energy solid propellant now in use in the U.S. yields a sea-level specific impulse of about 225 sec. The next propulsion plateau above chemical propellants will probably be the use of nuclear energy. As at present envisaged the method of using nuclear energy for propulsion is to utilise the reactor as a source of heat for raising the working fluid (in the form of a gas) to a high temperature and then exhaust it through conventional nozzles. As before a fluid with low molecular weight would be preferable and this points to hydrogen as a possible choice. But the nuclear rocket is still an idea yet to be realised. Fusion energy for rockets is a hope, although distant. There is a great deal of interest in non-heat engines. Ion propulsion is one of the techniques being studied.

A very interesting idea is the application of concepts of magneto-aerodynamics to achieve the acceleration of a gas stream to extremely high speeds. The air surrounding a body moving at high speed is partially ionised (by heat due to friction and compression) and the conductivity of the ionised air can be further increased by seeding it with a small amount of an easily ionisable substance such as sodium or potassium. If an electric field can be applied across the hot seeded air, an electric current will flow. If a magnetic field be also applied the combination of current and magnetic field will give rise to a force (in analogy to an electric motor) which, however, can be directed so as to accelerate the air flow. This would provide a unique method of accelerating gases to extremely high speeds, as for example in the nozzle of a rocket. The speeds thus attainable by the magneto-aerodynamic rocket are theoretically unlimited. The ultimate of all propulsion schemes is of course the utilisation of photons which however still awaits even a laboratory basis.

The methods so far discussed are all concerned with one of the means of achieving high performance, viz., increasing the exhaust velocity. A second method is to work with a high mass-ratio. The most effective method of increasing the mass-ratio is the step principle, exemplified in the V-2-carried Wac-Corporal. A multi-stage rocket consists of several rocket stages, the firing of each stage beginning after the burn-out of the previous one. Each stage preceding the last one is jettisoned after its fuel is burnt out. In such a multistage rocket the final velocity corresponds to the product of the individual mass-ratios of the several stages. It is therefore possible to obtain a high final mass-ratio while that for each individual stage need not be large. A theoretical analysis shows that for the same gross weight, performance and payload, the velocity gain over a single stage is 33 per cent for 2 stages, 45 per cent for 3 stages and so on. Because of the greater complexity of additional stages, it is desirable to limit the number of stages to 3 or 4. The character of each stage, its size and complexity and whether it should employ liquid or solid propellants are influenced by the basic decision regarding the extent to which active guidance would be employed. The basic energy requirements determine the payload weight of the satellite for a given booster vehicle and the size of the stages or the requisite specific impulse of fuel if an assigned take-off weight is not to be exceeded. The loss in velocity incurred during powered ascent of the vehicle (*e.g.*, gravitational loss) as well as the burning time of each individual stage are determined by the deflection programme, the initial thrust to weight ratio, the specific impulse and the loading factor which is defined as the ratio of propellant weight to gross weight of the particular stage (inclusive of the upper stages, if any). Given the values of the specific impulse and the loading factors for the first two stages of a 3-stage rocket, the loading factor of the third stage can be expressed in terms of the specific impulse of the third stage and the over-all cut-off velocity of the vehicle. This can be used to calculate the satellite pay-load as function of the flight-performance for given take-off weight and to obtain an idea of the range of payload weights which can be expected.

We have already seen that an accurate control system to aim the third stage velocity vector accurately is essential. Guidance and control equipment is also required for attitude control during the first-stage and second-stage flights so that the launching vehicle may keep to the prescribed flight plan and also for carrying through the schedule for employment of the various power plants.

The gimballed motor for obtaining pitching and yawing correction moments is a useful device. For a variety of reasons, such as structural imperfections, varying winds etc., the launching rocket rolls, pitches and yaws. These motions may become large, causing the rocket to tumble. Departures from the programmed trajectory are sensed by a system of gyros which transmit the information in the form of changes in voltage (or inductance) to servomotors which initiate the necessary corrective action.

Tracking and Data Transmission

Tracking is the basic prerequisite for any successful satellite operation. Continuous or intermittent tracking of the satellite is necessary for receiving information from it and for transmitting control signals to it. Tracking is also a means of research when the motion of the satellite is affected by forces of unknown magnitude. The tracking can be done by radio, optical or radar techniques. In radio tracking a micro-wave beacon is carried in the rocket and two ground receivers, widely separated, lock on to the signal and provide a continuous record of the relative azimuths and elevations of the satellite. The trajectory is then calculated by computers. In optical tracking the satellite is photographed in flight by high-speed tracking cameras. Radio Doppler or radar techniques can also be employed. Optical and radar techniques are more precise than radio tracking. The radar method has considerable potentialities, as for example in providing a means of determining the reflecting area of the satellite.

Data transmission is an essential component of a satellite's operational capability. The satellite has to make continuous transmission of telemetered scientific data or tape recorded information. This raises problems of adequate supply of auxiliary power for transmission so that the operational power consumption is determined by the size and purpose of the satellite. The transmission power requirements generally increase with distance, with receiver band-width, and with required signal-to-noise ratio in the receiver. Batteries as auxiliary power sources are acceptable only for not too long operational lifetimes and low power drainage. Solar and nuclear batteries must be looked upon as the most promising sources for systems of long operational life. Both Vanguard I and Sputnik III are equipped with solar batteries. Solar mirror systems, energizing a Mercury turbine and a generator, have also been proposed.

However, it is one thing to get a satellite to orbit in the sky and quite another to get back a full yield of information from the satellite. It is said that the Americans have succeeded in winning back only 3% of the information being continuously radioed by Explorer I. This seems a poor return for the huge investment involved. The main reason for the small yield is that there are not yet enough stations competent and equipped to pick up all the signals.

Satellite Data and Nomenclature

The following scheme of nomenclature for the satellites already launched and to be launched in future has been adopted. Each satellite is designated by the year in which it was launched followed by a Greek letter. Thus the two satellites Sputnik I and II launched in 1957 are designated as 1957 α and 1957 β respectively; the American Explorer I, which was the first to be launched in

1958 is designated as 1958 α and so on. Where more than one object corresponding to the same satellite is in orbit, they are distinguished by a numerical subscript to the designation; for example, the instrumented sphere of Vanguard I is 1958 β_2 while its rocket case which is also in orbit is 1958 β_1. Some data regarding the satellites launched into orbit so far are given in Table II.

Scientific uses of Satellites

It has been explained above how observations of the satellite orbit can lead to important data regarding the size and shape of the earth as well as the structure of the atmosphere. A number of exciting and important research programmes could be carried out with an artificial satellite. They include: geodetic studies, ionospheric research, measurement of the sun's radiation in the ultra-violet and X-ray wavelengths, cosmic ray investigations. Further an artificial satellite provides the only means for certain types of biological experimentation such as study of the effects of prolonged exposure to primary cosmic radiation and of peculiar environmental characteristics like weightlessness, high vacuum, extremes of temperature etc.

Future Developments

The next step forward will probably be a rocket to the moon or a manned satellite. The Americans have already made some attempts at firing a rocket to the moon, but so far, without success. Further attempts are planned. As regards the manned satellite, many problems have to be solved before this can be achieved. One of the main barriers to manned flights outside the earth's atmosphere is the problem of re-entry. The Soviet scientists claim that they have gone a long way towards solving this problem. Experiments have been conducted during the last few years with dogs rocketed into space. The Russians announced recently the successful return to earth of two dogs which had been shot up in a rocket to a height of 280 miles. There is also the problem of providing a livable environment including protection from harmful radiation. Moreover equipment reliability is still too low. This "reliability barrier" may well hold up long range manned space flight for a considerable time. An inescapable requirement for all projects to reach farther into space is of course the development of more powerful propulsion techniques. Some of the possibilities in this direction have been discussed earlier.

Broadly speaking the lines of future progress seem to be: new propulsion techniques, orbits of higher energy, payloads of greater weight and complexity, including advanced auxiliary power supply systems for long operational life time, and recovery of satellites. These developments may well be expected to make space travel a reality.

TABLE II—

Name	IGY Designation	Launching date	Shape & size	Angle of orbit to equator	Initial	
					Period (min.)	P'gee height (mls)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sputnik I (instrumented sphere)	1957 α_2	Oct 4, 1957	Sphere 22·8″ dia	65°	96·2	122
Sputnik II	1957 β	Nov 3, 1957	Conetipped tube (Final stage attd) 15 to 20 ft. long	65°	103·7	122
Explorer I (rocket case with instrumented nose cone)	1958α	Jan 31, 1958	Conetipped tube (Final stage attached) 80″ ×6″	33·5°	114·8	199
Vanguard I (instrumented sphere)	1958β_2	March 17, 1958	Sphere 6·4″ dia	34·1°	134	353
Vanguard I (rocket case)	1958β_1	March 17, 1958	Tube 48″×20″	34·1	134	353
Explorer III	1958γ	March 26, 1958	Cone tipped tube 80″×6″	33·3°	115·7	101
Sputnik III (Instrumented nose cone)	1958δ	May 15, 1958	Cone 12·3' × 5·6 ft.	64·9°	106	122
Sputnik III (rocket case)	1958δ_1	May 15, 1958	Tube 30 ft. long	64·9°	106	122
Explorer IV (rocket case with instrumented nose-cone)	1958ϵ	July 26, 1958	Tube 80×6 in	51° (launched in northerly direction)	110·2	163

*Estimated

Since the above was written, three more successful launchings have been achieved :— (*i*) The U. S. December, 1958. (Perigee height 115 miles, apogee height 920 miles; Period 101 min.) The pay load in station on command. (*ii*) On January 2, 1959 the Russians launched *Lunik* which has become the tenth It passed within 5,000 miles of the lunar surface. (*iii*) On March 3, 1959 the U. S. fixed yet another planet,

SATELLITE DATA

orbit								
A'gee height mls)	Eccen-tricity	Orbital lifetime	Total wt. placed in orbit (lbs.)	Pay load (lbs.)	Trans. freque-ncy	Launch. vehicle	Remarks
(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
512	·052	92 days	330*	184	40·002 (Mc/s 20·005 Mc/s	Modified ICBM(?) 3 stages	Disintegrated Jan 4, 1958.
902	·0987	162 days	2000*	1118	Do.	Do.	Disintegrated April 14, 1958.
1371	0·139	4 yrs	30·8	18·13	108 Mc/s 108·03 Mc/s	Modified Jupiter-C 4 stages.	..
2140	0·191	200 yrs	3·25	3·25	108 Mc/s 108·03 Mc/s	Vanguard 3 stages	..
2140	0·191	5 years or more	50	..	..	..	..
1511	0·166	94 days	31	12	..	Modified Jupiter-C 4 stages	Disintegrated June 27, 1958.
1013	0·111	2 years	2926	2134	20·005 Mc/s	..	Besides satellite & rocket, three other pieces in orbit viz two halves of nosecone sheath and a nose-cone probe .
1013	0·111	7 months	600	..	..	..	..
1373·3	0·1373	4 to 5 years	38·5	25·76	108 Mc/s 108·03 Mc/s	Modified Jupiter-C 4 stages	..

Value.

Atlas, weighing about 8,700 lbs. (pay load 150 lbs) was launched into orbit round the earth on 18th
cluded a novel Communication System which can receive messages from the earth and return them to ground
planet of the solar system, weight of final stage of carrier rocket is about 3,240 lbs, and pay load 796·5 lbs.
of the solar system—*Pioneer* IV, (pay load 13·4 lbs).