Space Handbook:

ASTRONAUTICS AND ITS APPLICATIONS

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stars with possibly two or three planetary systems, if the interpretation of the "wobbles" is correct. Kuiper estimates on the basis of the ratio of the masses of components of double stars that not more than 12 percent of all stars may have planetary systems.[13] When we realize that there are some 200 billion stars in our galaxy, this would give 1 to 10 billion with planetary systems. It seems reasonable to speculate that out of this vast number there surely must be some systems with earth-like planets, and that on some of these planets life similar to our own may have evolved.[14-17]

With our present state of knowledge, however, communication with such planetary systems is a matter of speculation only. When we recall that our galaxy is some 100,000 light-years in diameter, the Sun being an insignificant star some 30,000 light-years from the galactic center, circling in an orbit of its own every 200 million years as the galaxy rotates, we realize that even trying to visualize the tremendous scale of the universe beyond the solar system is difficult, let alone trying to attempt physical exploration and communication. Nor is the interstellar space of the galaxy the end, for beyond are the millions of other galaxies all apparently rushing from one another at fantastic speeds; and the limits of the telescopically observable universe extend at least 2 billion light-years from us in all directions.

Notes

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3.

Trajectories and Orbits

A. Fundamental Types of Trajectories and Orbits

The terms *trajectory* and *orbit* both refer to the path of a body in space. *Trajectory* is commonly used in connection with projectiles and is often associated with paths of limited extent, i.e., paths having clearly identified initial and end points. *Orbit* is commonly used in connection with natural bodies (planets, moons, etc.) and is often associated with paths that are more or less indefinitely extended or of a repetitive character, such as the *orbit* of the Moon around the Earth. In discussions of space flig..., both terms are used, with the choice usually dependent upon the nature of the flight path. Thus we speak of *trajectories* from the Earth to Moon, and of satellite *orbits* around the Earth.

The basic types of paths in space are determined by the gravitational-attraction properties of concentrated masses of material and the laws of motion discovered by Newton.

Virtually all major members of the solar system are approximately spherical in shape; and a spherical body will produce a force of attraction precisely like that of a single mass point located at the center of the body. Therefore, the fundamental problem is that of motion under the gravitational influence of a mass concentrated at a point.

Two general and several special types of paths are possible under the gravitational influence of a point mass. The two main types are illustrated in figure 1.

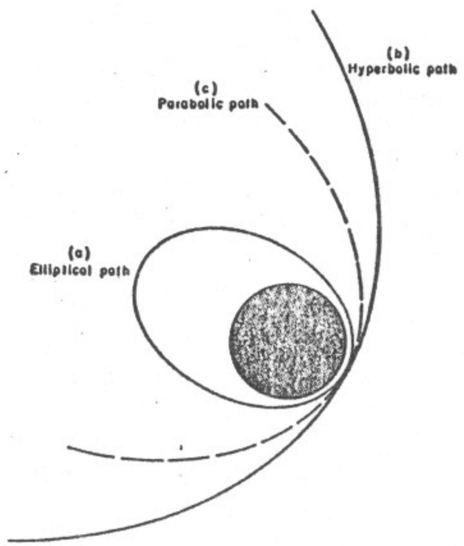

FIG. 1. Types of paths

Figure 1a is an *elliptical orbit*—the familiar artificial Earth satellite orbit. Figure 1b is a *hyperbolic orbit*—the kind that will characterize the start of an interplanetary flight. The elliptical orbit is closed on itself and would be traversed repetitively. The hyperbolic orbit is open, extending to infinity. Separating these two cases is a special one—the *parabolic orbit* —similar in general appearance to the hyperbolic. The parabolic orbit is the borderline case between open and closed orbits and therefore identifies the borderline condition between space vehicles that are tied to paths (elliptical) in the general vicinity of their parent planet and those that can take up paths (hyperbolic) extending to regions remote from their parent planet. For any of these orbits the vehicle's velocity will be greatest at the point of nearest approach to the parent body, and it will be progressively less at more remote points.

B. Escape Velocity

The type of path that will be taken up by an unpowered space vehicle starting at a given location will depend upon its velocity. It will take up an open-ended path if its velocity equals or exceeds *escape velocity;* escape velocity is, by definition, that velocity required at a given location to establish a parabolic orbit. Velocities greater than escape velocity result in hyperbolic orbits. Lower velocities result in closed elliptical orbits —the vehicle is tied to the neighborhood of the planet.

Since it essentially separates "local" from "long distance" flights, escape velocity is clearly a primary astronautical parameter. The exact value of this velocity is dependent upon two factors: (*a*) The mass of the parent planet, and (*b*) the distance from the center of the planet to the space vehicle. Escape velocity increases as the square root of the planet's mass, and decreases as the square root of the distance from the planet's center. The speeds required for escape directly from the surfaces of various bodies of interest are listed in table 1. These escape velocity requirements are a measure of the difficulty of departure from these bodies.

The projection speed required to escape directly from the Earth's surface is about 36,700 feet per second. If a vehicle takes up unpowered flight (end of rocket propulsion) at an altitude of, say, 300 miles, it requires the somewhat lesser speed of 35,400 feet per second to escape into interplanetary space. This reduction in required velocity has, of course, been obtained at the expense of the energy expended in lifting the vehicle to an altitude of 300 miles.

TABLE 1.—*Surface escape velocity*

	Feet per second		*Feet per second*
Mercury	13,600	Mars	16,700
Venus	33,600	Asteroid Eros	~50
Earth	36,700	Jupiter	197,000
Moon	7,800		

C. Satellite Orbits

The elliptical orbits generated by velocities below escape velocity are the type followed by artificial satellites, as well as by all the planets and moons of the solar system.

The period of the satellite—the time required to make one full circuit—is dependent upon the mass of the parent body and the distance across the orbit at its greatest width (the length of the *major axis*). The period is less if the parent body is more massive—the Earth's Moon moves more slowly than similarly placed moons of Jupiter. The period gets longer as the length of the major axis increases—the period of the Moon, with a major axis of about 500,000 miles, is much longer than those of the first artificial satellites, with major axes of about 9,000 miles.

The velocity required to establish a satellite at an altitude of a few hundred miles above the Earth is about 25,000 feet per second. This required *orbital velocity* is less at greater altitudes. At the distance of the Moon it is only about 3,300 feet per second.

D. Lunar Flight

The gravitational attraction of the Moon affords some assistance to a vehicle on an Earth-Moon flight. However, the Moon is so far removed that this assistance is only enough to

reduce the required launching velocity slightly below escape velocity.

E. Interplanetary Flight

To execute a flight to one of the other planets, a vehicle must first escape from the Earth. Achieving escape velocity, however, is only part of the problem; other factors must be considered, particularly the Sun's gravitational field and the motion of the Earth about the Sun.

Before launching, the vehicle is at the Earth's distance from the Sun, moving with the Earth's speed around the Sun—about 100,000 feet per second. Launching at greater than Earth escape velocity results in the vehicle's taking up an independent orbit around the Sun at a velocity somewhat different from that of the Earth. If it is fired in the same direction as the Earth's orbital motion, it will have an independent velocity around the Sun greater than that of the Earth. It will then take up an orbit such as A, figure 2, which moves farther from the Sun than the Earth's orbit; the vehicle could, if properly launched, reach the outer planets Mars, Jupiter, and so forth. The minimum launch velocities required to reach these planets are given in table 2.

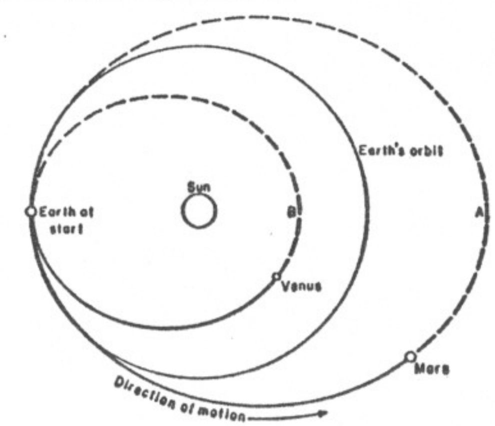

FIG. 2. Interplanetary trajectories

If the vehicle is launched "backward," or against the Earth's velocity, it will assume an independent velocity less than that of the Earth and move on an orbit like B, figure 2, so that it could reach the inner planets Venus and Mercury.[1]

To reach the more distant portions of the solar system requires that the vehicle take up a velocity, relative to the Sun, that is considerably *greater* than that of the Earth. A large launch velocity is required to produce this excess (after a good deal of it has been absorbed by the Earth's gravitational field). On the other hand, to travel in close to the Sun requires that the vehicle take up a velocity, relative to the Sun, that is considerably *less* than that of the Earth. A large launch velocity is this time required to cancel out the component of vehicle velocity due to the Earth's motion, and again much of the launch velocity is absorbed by the Earth's gravitational field. Thus, as seen from table 2, it is almost as hard to propel a vehicle in to Mercury as it is to propel it out to Jupiter.

TABLE 2.—*Minimum launch velocities, with transit times, to reach all planets*

Planet	Minimum launching velocity (feet per second)	Transit time
Mercury	44,000	110 days
Venus	38,000	150 days
Mars	38,000	260 days
Jupiter	46,000	2.7 years
Saturn	49,000	6 years
Uranus	51,000	16 years
Neptune	52,000	31 years
Pluto	53,000	46 years

The velocities in table 2 are minimum requirements, and lead to the transit times shown. Higher velocities will reduce transit times.

F. Escape from the Solar System

If a vehicle reaches escape velocity with respect to the Sun it will leave the solar system entirely and take up a trajectory

in interstellar space. Starting from the surface of the Earth, a launch velocity of about 54,000 feet per second will lead to escape from the solar system. The course of the vehicle will be a parabola, with the Sun at its focus, until eons later it is deflected by some star or other body.

The flight capabilities that become available as the total velocity potential of a ballistic rocket vehicle increases are illustrated in summary form in figure 3.

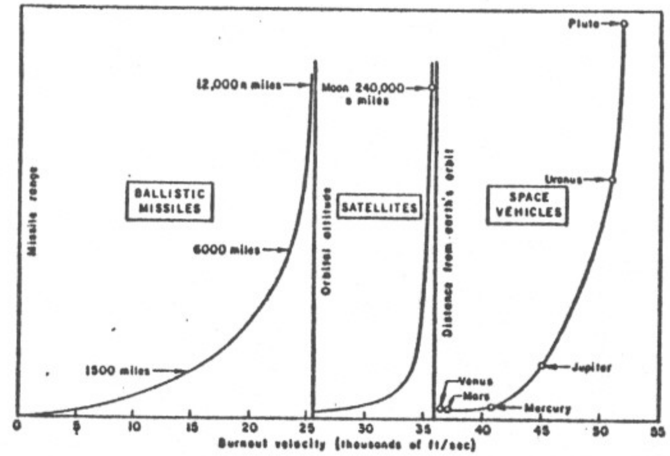

FIG. 3. Velocity requirements for ballistic missile and space flight

G. Powered Trajectories in Space

Once a vehicle is in space, moving at high velocity, say in a satellite orbit, it requires no further propulsion to stay aloft. Its flight path can, however, be very appreciably influenced and great increases in velocity imparted by very small forces acting over long periods of time. The fact that useful results can be derived from small thrusts in space—thrusts that would be entirely insignificant on the Earth—leads to interest in unique propulsion systems based on electrical accelerator principles. One kind of application of particular interest involves the use of heavy conventional propulsion systems to develop orbital velocity (say, 25,000 feet per second) and then to build up the remaining 12,000 feet per second to reach escape velocity by a low-thrust electrical system.[2, 3]

H. Velocities Near That of Light

As the velocity of a space vehicle nears that of light (not likely to be achieved in the foreseeable future), the effects of relativity theory enter into the situation. Of particular interest is the so-called "time dilatation" effect predicted by this theory —and supported by experimental evidence in the physics of high-speed particles.

Briefly, the predicted effect is as follows: Consider two men, A and B, of identical age, say, 20 years old. A will remain at home on the Earth, and B will undertake a voyage in space at a speed very near that of light and eventually return to Earth. The total duration of the voyage will be different, as measured by the two men, the exact amount of the difference depending upon how close B's vehicle approached the speed of light.

As an example, suppose B took a round trip to the vicinity of a nearby star at a speed very near that of light (about 186,000 miles per second). It would appear to A that the trip took, say, 45 years—he would be 65 years old when his friend returned. To B, however, the trip might appear to take about 10 years, including a year or so for acceleration to flight speed and deceleration for the return landing—he would be 30 when he returned.

Different values of vehicle speed will lead to widely different time disparities. By approaching ever closer to the speed of light, B could take more extended trips that would last millions of years in earthtime, but still appear to him to take only a few years.

Achievement of near-light velocities would require stupendous amounts of propulsion energy—nothing less than complete conversion of matter into usable energy will do.[4-6]

In addition to the fact that no presently foreseeable propulsion scheme will deliver the required quantities of energy, there are also problems of a very severe and uncertain nature concerning environment. The traveler at speeds approaching that of light will find himself immersed in a grossly altered

natural environment and will also face the problems of carrying with him a source of extremely intense radiation—in whatever form his propulsion system may take.

Notes

[1] The time of day of launching is also different for flights to regions closer or farther from the Sun than the Earth. For areas farther away, seeking to use the Earth's orbital and rotational speeds to best advantage, the launching must be from the dark side of the Earth. On the other hand, a point that is in daylight will be moving with a speed opposite to the Earth's orbital motion and such a point would be chosen for missions nearer the Sun. Hence, to Mars by night and to Venus by day.

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4

Rocket Vehicles

A. General Description of Rocket Vehicles

The principal elements of any rocket-powered flight vehicle are the *rocket engine,* to provide the propulsive force; the *propellants* consumed in the rocket engine; the *airframe,* to contain the propellants and to carry the structural loads; and