Gravitational Assist

Deep-space missions sometimes use close swingbys of the planets to explore the vast reaches of the solar system. These planetary swingbys are referred to as gravity-assist swingbys and allow planetary spacecraft to gain or lose velocity so that they reach their final destination. While use of this technique has become more commonplace in recent years, the concept of gravity-assist was known much earlier in this century.

Two of the earliest pioneers were Yu. V. Kondratyuk and Fridrikh A. Tsander who documented their ideas on gravity-assist between 1918 and 1925. Kondratyuk proposed the "use of a satellite for flight in the solar system when it is required to gather velocity and the return from this flight when it is required to absorb energy." The gravity-assist concept was initially documented in western literature in the 1950s by V. A, Firshoff (1954), D. F. Lawden (1954) and G. A. Crocco (1956).

The gravity-assist concept is applied in interplanetary travel by controlling the spacecraft to swingby a planet at a specified altitude. The gravitational attraction of the planet causes the spacecraft trajectory to bend during its swingby. This results in a spacecraft velocity gain or loss with respect to the sun. Figure 1 illustrates a gravity-assist Earth swingby. The trajectory of the spacecraft with respect to Earth is a hyperbola; the spacecraft approaches and departs along the asymptotes of this hyperbola with a constant speed, called the V_∞. The spacecraft achieves its maximum velocity with respect to Earth at closest approach. The angle between the incoming and outgoing V_∞s is referred to as the bend angle of the flyby (ϕ). The velocity vector of the Earth with respect to the Sun at the time of the flyby is indicated by V_E. Adding the incoming and outgoing V_∞s to the velocity of the Earth yields the velocity vectors of the spacecraft with respect to the Sun before and after the flyby. The effect of the hyperbolic flyby in an Earth-centered reference frame is simply to rotate the V_∞ through an angle equal to the bend angle; there is no net energy change for the spacecraft trajectory with respect to Earth as a result of the flyby. However, the rotation of the Earth-centered V_∞ has the effect of increasing the magnitude of the velocity vector in a Sun-centered reference frame. The amount of bending and the magnitude of the spacecraft velocity change depends on the swingby closest approach altitude. The spacecraft velocity increases for spacecraft swingbys across the trailing hemisphere of the planet and decreases for swingbys across the leading hemisphere of the planet.

The change in spacecraft velocity is due to an exchange of energy between the spacecraft and planet. So if the spacecraft is speeded up from the gravity-assist, the planet is slowed. However, due to the relatively large mass of the planet, the change in planet velocity is infinitesimal while the change in spacecraft velocity is significant. The spacecraft velocity change achieved from the planetary swingby means that less propellant is required to be carried onboard to provide a velocity change.

Several planetary missions have used gravity-assist swingbys to reach their target destination. The first planetary mission to employ this concept was Mariner 10 which was launched in 1973. Mariner 10 used a Venus gravity-assist to reduce its velocity to enable a swingby of Mercury. The gravity-assist from the Mercury swingby was then used to adjust the spacecraft orbital period about the sun so that the spacecraft returned to Mercury for two additional swingbys.

The next usage of planetary gravity-assist was with the Pioneer 11 mission to Jupiter. This mission was initially intended to only be a Jupiter flyby mission. However, the close swingby was able to provide a near 180 deg gravity-assist turn that enable Pioneer 11 to flyby Saturn 5 years later on the opposite side of the solar system.

Both Voyagers 1 and 2, launched in 1977, used a gravity-assist swingby of Jupiter to reach Saturn. Voyager 2 continued on to Uranus and Neptune, using the gravity -assist of each planetary encounter to target the spacecraft to the next planet.

Gravity-assist planetary swingbys may also be used to change the plane of the spacecraft trajectory by flying over the poles of the planet. An example is the Ulysses mission where the spacecraft was initially launched to Jupiter. At Jupiter the spacecraft flew by the North Pole, kicking the spacecraft out of the ecliptic plane of the solar system. This enabled Ulysses to later fly over the poles of the Sun.

Several current and planned missions make extensive use of planetary swingbys to not only reach their target planet, but to also allow extensive trajectory modifications after the arrival at the destination planet. Galileo was launched in 1989 and performed gravity-assist swingbys at Venus and Earth (twice) to enable a Jupiter arrival in 1995. A close swingby of the satellite 10 will reduce the spacecraft velocity at Jupiter to assist in the capture of the spacecraft by the gravity field of Jupiter. Once in orbit at Jupiter there will be 10 close swingbys with the other Galilean satellites.

The Cassini mission to Saturn will launch in 1997. Its interplanetary trajectory will include swingbys of Venus (twice), Earth and Jupiter to provide a Saturn arrival in 2004. once in orbit, the Cassini spacecraft will use over 30 swingbys of the moon, Titan to modify its trajectory and allow a though exploration of the Saturnian system.

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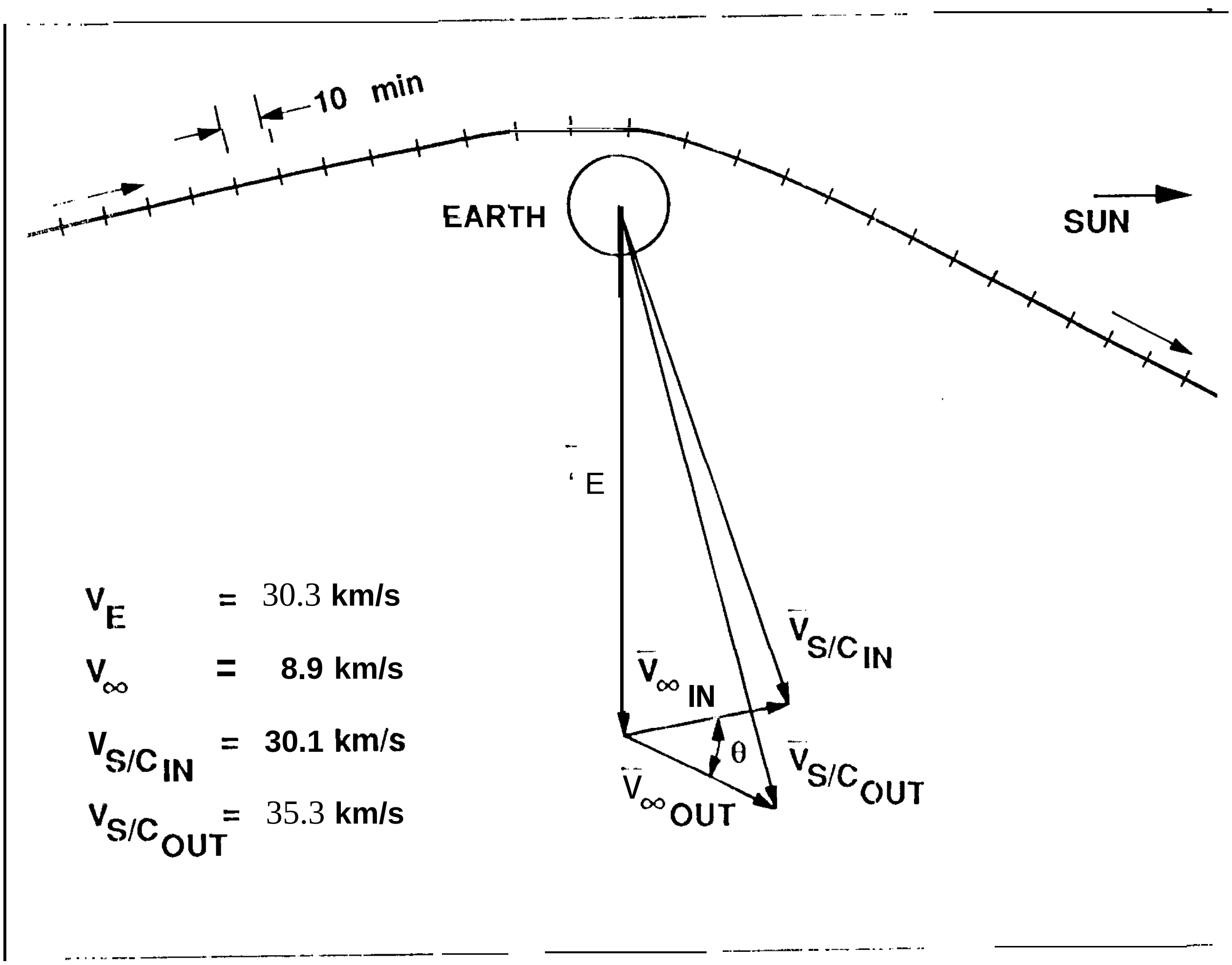

Figure 1. Gravity-assisted swingby illustration