Highlights 1978

Astrodynamics

By Richard H. Battin of Charles Stark Draper Laboratory, Chairman, AIAA Committee on Astrodynamics.

In the three centuries following Kepler and Newton, the world's greatest mathematicians brought celestial mechanics to such an elegant state of maturity that, for several decades preceding the USSR's Sputnik in 1957, it all but disappeared from the university curriculum. Of course, celestial mechanics to the classical astronomer was confined to the prediction of the paths followed by celestial bodies existing naturally in our solar system. Not until recently did the problem exist of designing orbits subject to elaborate constraints to accomplish sophisticated mission objectives at a target planet—except possibly in the fantasy of the boldest imaginations.

The feasibility of space flight by man-made vehicles became apparent in the early 1950s with the rapid development of rockets capable of intercontinental ranges, and gradually serious space-mission planning began. The term "Astrodynamics" (attributed to the late Professor Samuel Herrick) came into common usage at that time to categorize aspects of celestial mechanics relevant to a new breed—the aerospace engineer.

One class of imaginative proposals for space missions exploited the gravity field of the planets to achieve multiple planetary fly-bys. Apparently, the first such study was presented in 1956 at the 7th International Astronautical Congress in Rome by the Italian G. A. Crocco. His subject—a "One Year Exploration Trip Earth-Mars-Venus-Earth." Although his results were based on a solar system modelled by coplanar, concentric circular planetary orbits and pieced conic spacecraft trajectories, the germ of an important idea was born. Thus, it seems appropriate that one of the highlights in the field of astrodynamics should be the exotic mission planned for Project Galileo involving a dozen or more close encounter fly-bys.

Project Galileo, a combined orbiter and probe mission to the planet Jupiter, will be managed by JPL for NASA's Office of Space Science. Launch will take place in January of 1982 using the Space Shuttle—the first planetary mission to use the Space Transportation System. In April of 1982 the spacecraft will pass Mars at an altitude of 275 km for an important gravity assist on the way to Jupiter. This maneuver lowers the launch-energy requirements and increases payload.

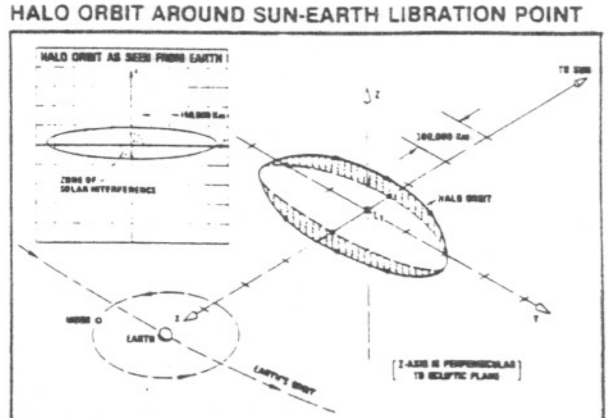
The spacecraft is scheduled to arrive in the vicinity of Jupiter on March 14, 1985, at which time the probe will separate from the orbiter. The probe will transmit data to the orbiter, which in turn will relay it back to Earth, during a 45-min atmospheric entry. Then the orbiter will reorient itself and execute a Jupiter-orbit-insertion burn.

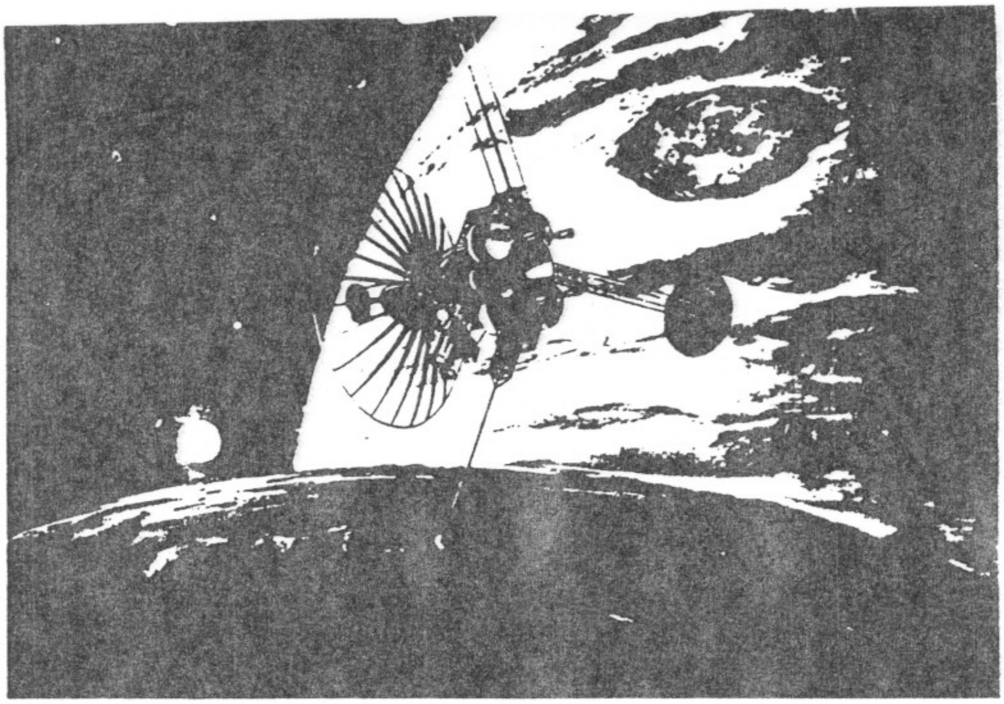
A second use of a gravity-assist maneuver, as currently contemplated, would give the orbiter a close fly-by of the satellite Io just before or some time after the Jupiter-orbit-insertion burn. (Io is the innermost of the four Galilean satellites, all of which are roughly the size of our Moon and move in approximately circular, equatorial orbits.) Then, once the spacecraft achieves orbit about Jupiter as many as eleven close encounters with Ganymede and Callisto will follow. The spacecraft will target for encounters with either Ganymede or Callisto and exploit the gravity assist—as much as 1 km/sec in effective velocity change—to achieve an encounter with another satellite on a subsequent orbit.

Performing such a mission obviously requires precise navigation. The Galileo navigation system resembles the current Voyager's with two notable differences—it has a charged-couple-device (CCD) imaging system and a differential very-long-baseline interferometry (ΔVLBI) system as a new Earth-based radio receiver. Although a science instrument, the CCD imaging device is well suited as a precision optical measurement instrument for navigation. The CCD imaging system will photograph the Jovian satellites against the known star background while the ΔVLBI simultaneously interferometrically tracks a spacecraft and an angularly nearby extragalactic radio source.

The second highlight in astrodynamics to be cited here had its origins in 1772 when Lagrange submitted his prize memoir "Essai sur le Probleme des Trois Corps" to the Paris academy. In it he described particular solutions to the problem of three bodies today known as the Lagrangian libration points. Lagrange showed that if two bodies of finite mass circularly orbit their common

HALO ORBIT AROUND SUN-EARTH LIBRATION POINT





Project Galileo, recently in Congress's eye, would arrive near Jupiter in 1985.

center of mass, then there will be two points in space forming equilateral triangles with the two masses plus three points on the straight line connecting the two masses where placing a third mass will conserve the configuration with respect to a rotating frame of reference.

The equilateral points are known to be stable. As if in tribute to Lagrange's monumental work, early in the Twentieth Century the so-called "Trojan asteroids" were discovered in the vicinity of the Jupiter-Sun equilateral libration points. The colinear points, on the other hand, are unstable points of equilibrium, as was demonstrated by the mathematician Liouville in 1845.

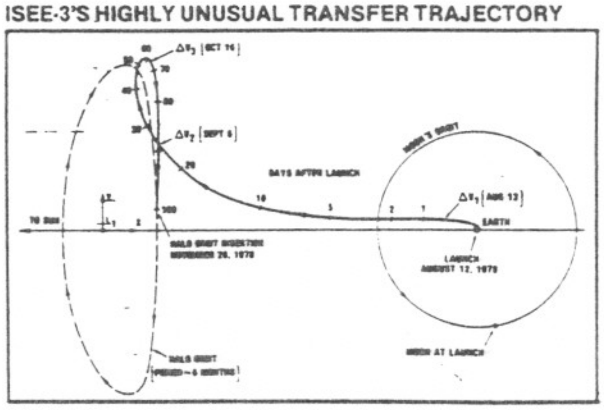
The Earth-Moon equilateral points have been a subject of much popular interest recently as potential sites for space colonies. Meanwhile, one of the Sun-Earth colinear points is being exploited at this very moment by a spacecraft known as the International Sun-Earth Explorer-3 (ISEE-3).

As of this writing, ISEE-3 is en route to the vicinity of the L_1 libration point (i.e., the colinear point between the Sun and the Earth) to be inserted in a so-called "halo orbit" about L_1. As shown in the chart here, the halo orbit has been designed to pass slightly above and below the ecliptic plane to avoid a zone of excessive solar RF interference.

From its halo orbit, the ISEE-3 spacecraft can monitor the characteristics of the solar wind and other solar-induced phenomena (e.g., solar flares) about an hour before they disturb the space environment near the Earth. The many scientific instruments aboard this spacecraft can measure conditions far enough upstream from the Earth to be free from the influence of the Earth's bow shock, but close enough to provide correlative data for measurements made within the magnetosphere by Earth-orbiting spacecraft.

The ISEE-3, built by NASA Goddard Space Flight Center, was launched towards the L_1 libration point by a Delta-2914 rocket on August 12, 1978. The second chart illustrates its highly unusual transfer trajectory. During the transfer phase, several maneuvers minimize trajectory dispersions as well as decrease the magnitude of the halo-orbit insertion maneuver. Following orbit insertion on November 20th, small station-keeping maneuvers will be required at irregular intervals to maintain the delicate equilibrium in the halo orbit. The criticality of these maneuvers arises from the inherently unstable nature of the halo orbit. At present, the spacecraft is carrying enough hydrazine propellant to guarantee an orbital lifetime of at least ten years.

ISEE-3'S HIGHLY UNUSUAL TRANSFER TRAJECTORY



Libration-point orbits, we expect, will play an increasingly important role in space flight. In addition to scientific applications, these orbits are advantageous for lunar-farside communications, staging sites for lunar and interplanetary transportation systems, and locales for possible space colonizations.