4. ORBIT.

IUE was successfully launched on January 26, 1978 at 17:36 UT on a Delta launch vehicle.

The spacecraft was introduced into geosynchronous orbit through one stage of spin-stabilized flight and two stages of three axis-controlled flight. Prior to the Delta third stage burn for injection into the transfer orbit, the spacecraft and third stage assembly were spun-up to 60 rpm by the Delta spin table. After injection from the parking orbit into the transfer orbit and separation from the Delta's third stage, an automatic nutation control (ANC) system on the spacecraft was initiated because the moment of inertia ratio with respect to the spin vector was unfavourable. This spin mode lasted about 21 hours. Along the transfer orbit, range and range rate (R & RR) measurements were made to accurately predict the orbit and time of apogee motor firing. Additionally precession of the spin vector was determined to align the apogee motor in the proper direction for boost into the synchronous orbit. At apogee, the motor was commanded to ignite by ground command.

When the desired station was obtained, the spacecraft was despun in two phases to gain three-axis gyro rate control. In the first phase, the IUE was spun up to 2 to 5 degrees per second, and the solar arrays were deployed. In the second phase, the IUE was rate damped to 0.25 degrees per second. The early orbit phase was concluded after the spacecraft was aligned with the sunline normal to the primary plane of the solar arrays.

The orbital elements measured on January 27, after the geosynchronous orbit was reached, were exceptionally good.

	Predicted	Actual
Semi-Major axis (a):	42164 km	42156 km
Eccentricity (e):	0.250	0.239
Inclination (I):	28.7 degr.	28.63 degr.
Argument of perigee (ω):	257 degr.	257.04 degr.
Period (P):	23.93 hrs	23.927 hrs
Perigee height (Pe):	25230 km	25669 km
Apogee height (Ap):	46340 km	45887 km

The mission requirements specified GSFC visibility time had to be 24 hours per day and VILSPA visibility time had to be at least 10 hours per day, these were satisfied with these orbital elements. To maintain these requisites, station keeping maneuvers (Delta-V) had to be performed periodically throughout the mission. In this way, the science operations were conducted 16 hours per day from GSFC and 8 hours per day from VILSPA until September 30, 1995. On this date, the spacecraft operation changed, VILSPA conducted science operations 16 hours per day and GSFC maintained the spacecraft health and safety the remaining 8 hours. This new distribution, which was called Hybrid Operations, needed different visibility conditions which were achieved with extra Delta-Vs.

Like all other satellites, the IUE orbit is described by Kepler's law. To describe the motion of an object in a Keplerian orbit, a standard set of 6 orbital elements is used. Five elements are needed to describe the shape, size and orientation of the orbit, and one is needed to pinpoint the satellite along its orbital path. In addition to these laws, there are certain physical forces acting on an orbiting object that will cause changes in all orbital parameters. These perturbations may be generated by several sources, including gravitional effects (from the Earth, Moon or Sun), atmospheric drag, or solar pressure.

Following is a list of the 6 major orbital elements along with a brief explanation of each term. Also shown for each element is a graph illustrating how it evolved over the life of the spacecraft.

- **Semi-Major Axis (a).** The semi-major axis is defined as the average of the apogee and perigee radii of an orbit. It is measured in km and specifies the size of an orbit (figure 4-1).

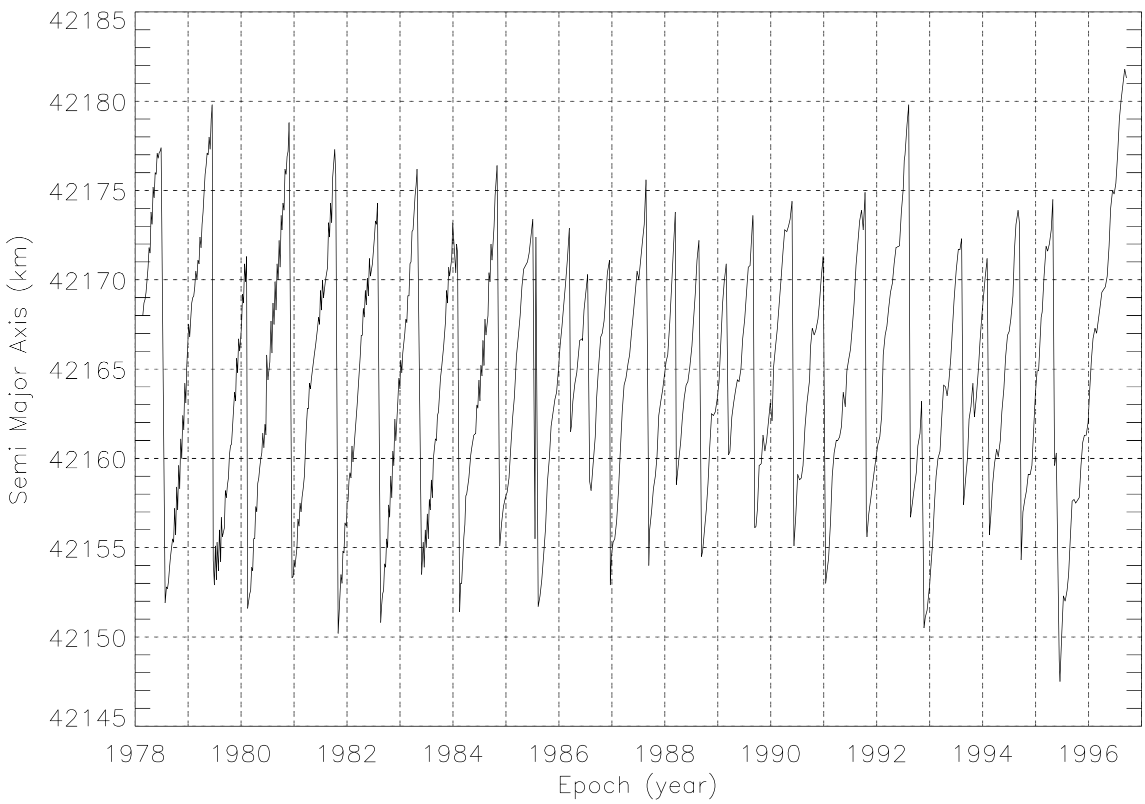

Figure 4-1. History of semi-major axis.

- **Eccentricity (e).** The eccentricity is defined as the difference between the apogee and perigee radii divided by their sum. This parameter specifies the shape of the orbital ellipse and is dimensionless (figure 4-2).

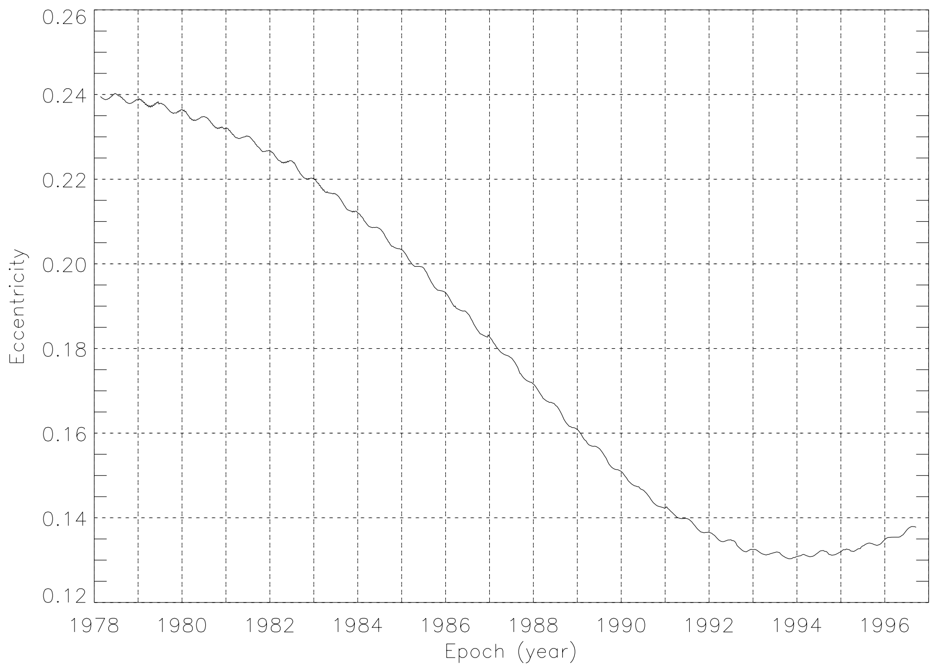

Figure 4-2. History of eccentricity.

- **Inclination (I).** The inclination of an orbit is the angle between its angular momentum vector and the Earth's North pole. It is also known as the angle between the orbital plane and the Earth's equatorial plane. This magnitude is measured in degrees (figure 4-3).

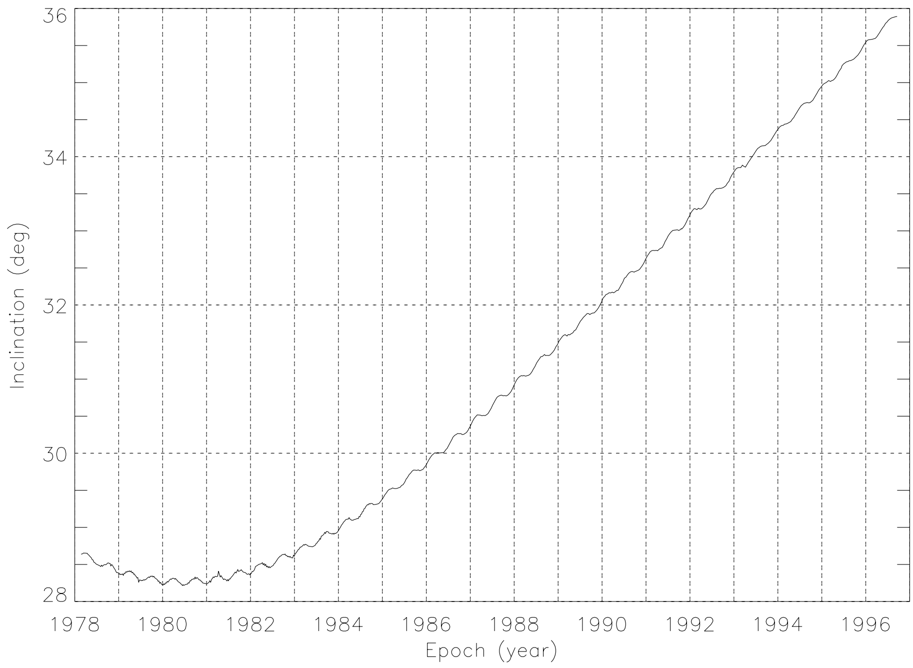

Figure 4-3. History of inclination.

- **Right Ascension of the Ascending Node (Ω).** The RA of the Ascending node is a measurement (in degrees) from the Vernal Equinox (Right Ascension = 0°) to where the orbital plane and the Earth's equatorial plane intersect. The measurement is made counterclockwise from RA=0° to where the orbital plane makes its south to north crossing of the equatorial plane (figure 4-4).

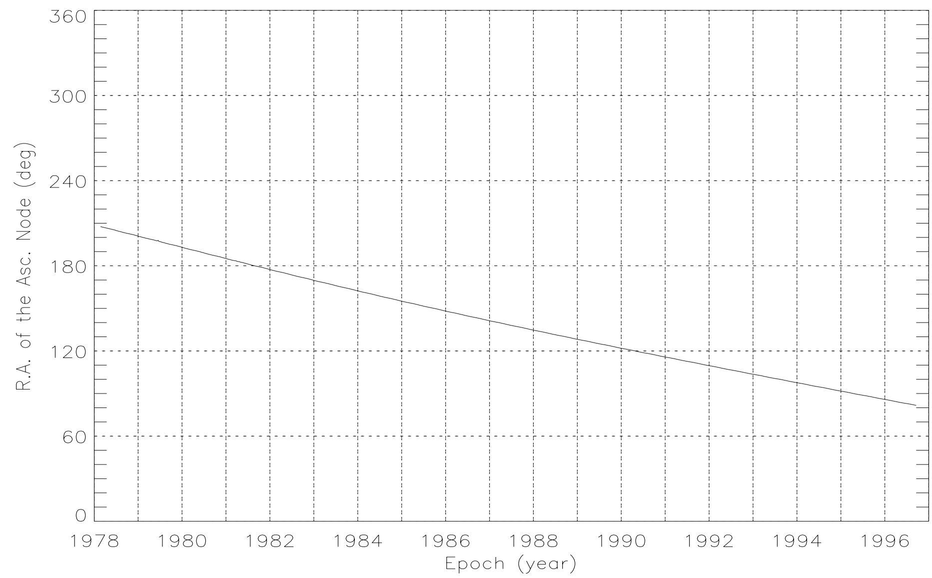

Figure 4-4. History of right ascension of the ascending node.

- **Argument of Perigee (ω).** The argument of perigee is the angle between the Ascending node of the orbit and orbit perigee. It is measured in the direction of travel of the spacecraft and in the plane of the orbit in degrees (figure 4-5).

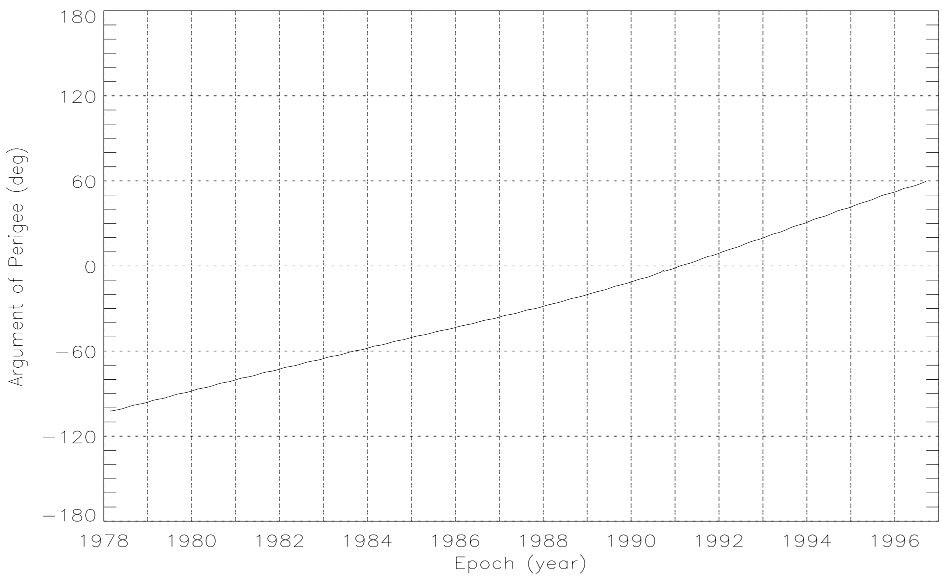

Figure 4-5. History of argument of perigee.

- **Mean Anomaly (M).** The mean anomaly represents the position of the spacecraft relative to its ascending node at a given time. It is measured, like the Argument of Perigee, in the direction of travel of the s/c and in the plane of the orbit in degrees (figure 4-6).

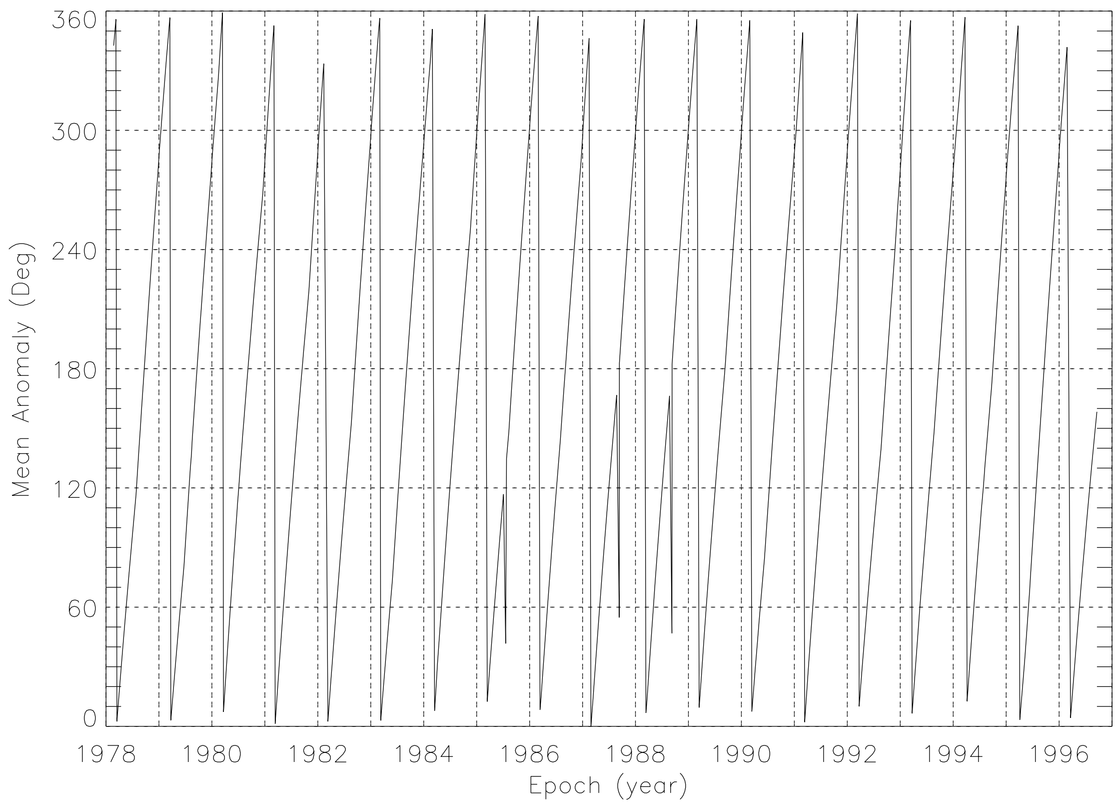

Figure 4-6. History of mean anomaly.

Orbit Perturbations.

Below is a brief explanation of some of the forces acting on an orbiting object and their impact on IUE.

- **Atmospheric Drag.** For IUE the Earth's atmosphere is not a factor as its perigee is approximately 30,200 km. The atmospheric drag has a significant effect for satellites below 1000 km.

- **Earth Gravitational Forces.** The deviation of the Earth from a perfect sphere is mainly responsible for the changes seen in the Right Ascension of the Ascending Node, Argument of Perigee, Mean Anomaly, and for the westward drift of IUE's ground trace. This perturbation produces the changes in visibility which are corrected with Delta-Vs.

- **Lunisolar Gravitational Forces.** The lunisolar gravitational forces takes into account the effects on an orbit produced by the gravitational pull of the Moon and Sun. These forces contribute to the long-term changes in the Right Ascension of the Ascending Node and the Argument of Perigee, and also produce long-term changes in inclination and eccentricity. The figures 4-7 and 4-8 show the predicted changes and the measured ones.

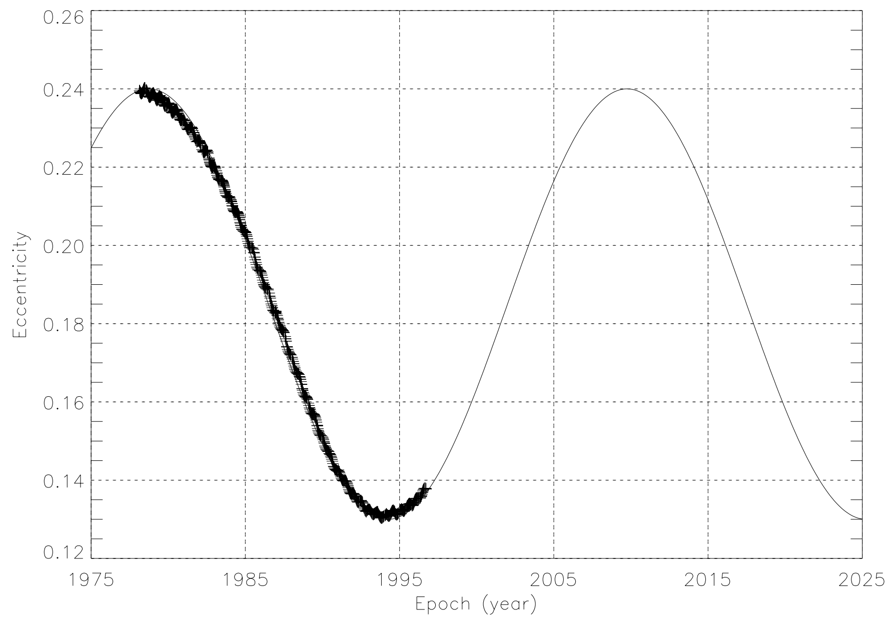

Figure 4-7. Predicted Long-Term Changes in IUE Orbital Eccentricity.

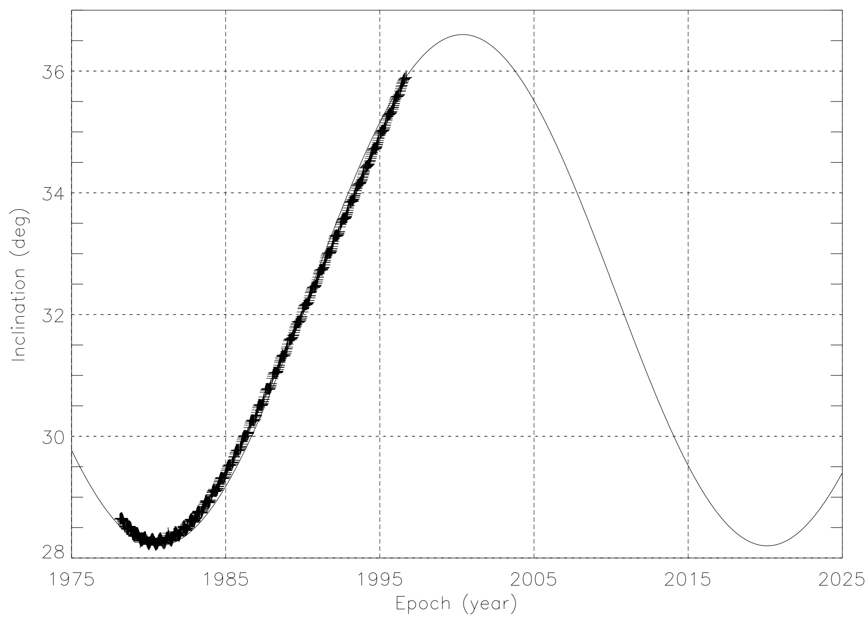

Figure 4-8. Predicted Long-Term Changes in IUE Orbital Inclination.

- **Solar Radiation Pressure.** The sun is constantly emitting radiation pressure, which induce perturbations on the orbit. The radiation pressure from the Sun imparts a continual force on the spacecraft which has the effect of performing a small Delta-V. Six months later the change in the Sun and the IUE geometry will produce similar forces in the opposite direction. The eccentricity and inclination undergo periodical changes during the year as shown the figures 4-9 and 4-10.

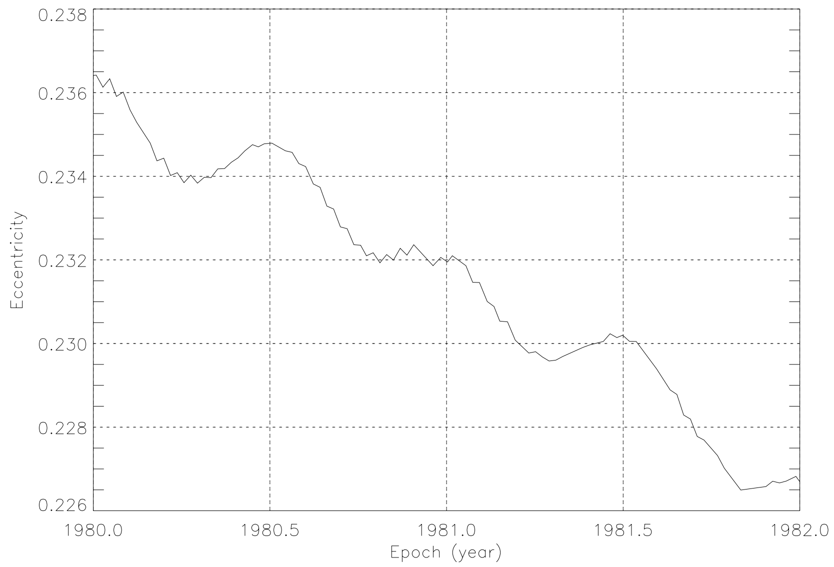

Figure 4-9. Periodical changes in eccentricity.

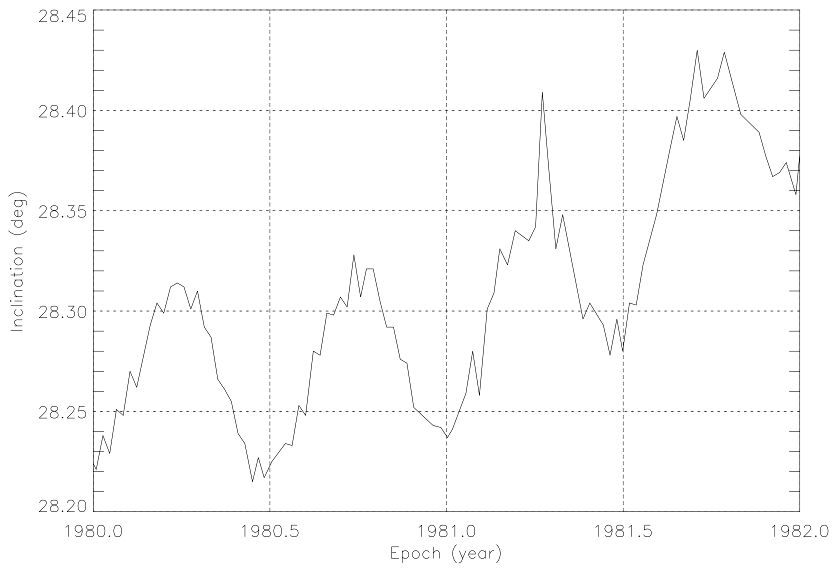

Figure 4-10. Periodical changes in inclination.

The ground trace continually changed from launch until the end of the IUE. The next figures are examples of the IUE ground trace on twelve different dates. In the figures, there is also a line which represented the VILSPA visibility region for a 3° antenna elevation.

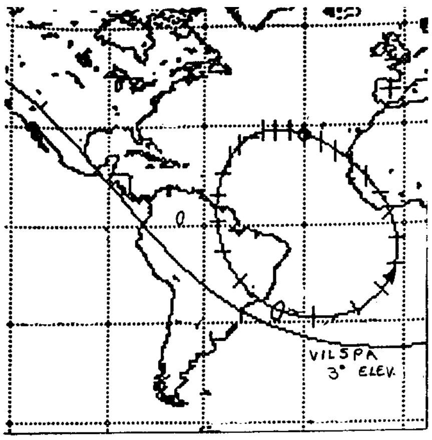

Figure 4-11. Ground trace at 01/30/1978.

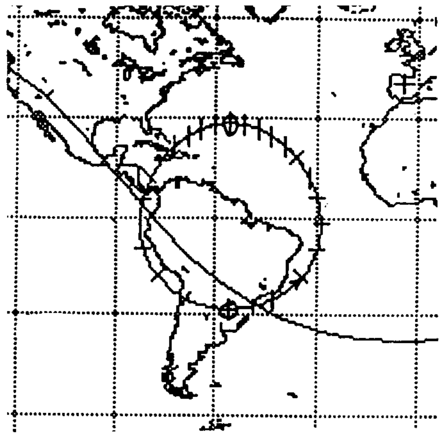

Figure 4-12. Ground trace at 01/01/1980.

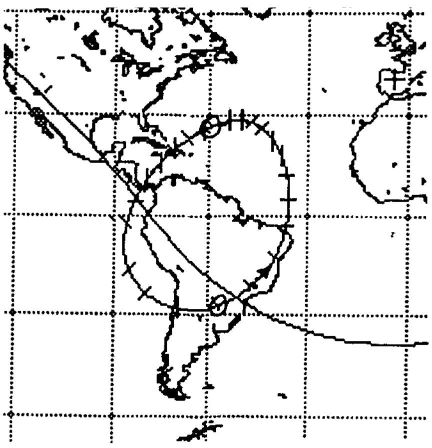

Figure 4-13. Ground trace at 01/01/1982.

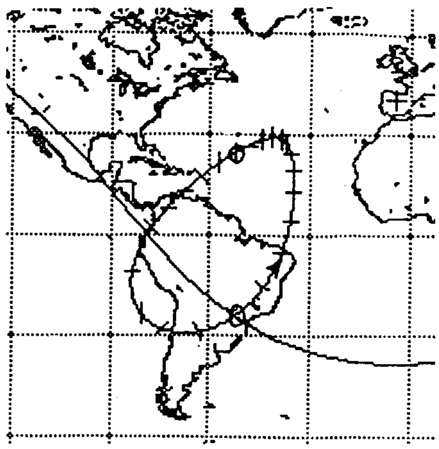

Figure 4-14. Ground trace at 01/01/1984.

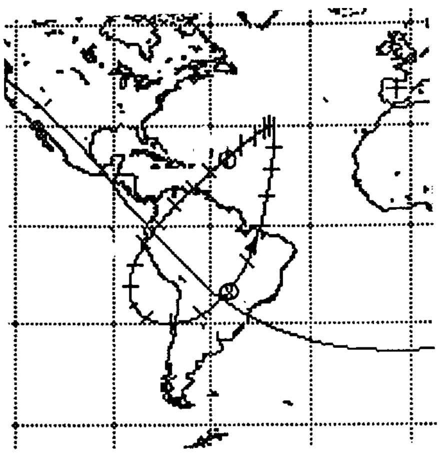

Figure 4-15. Ground trace at 01/01/1986.

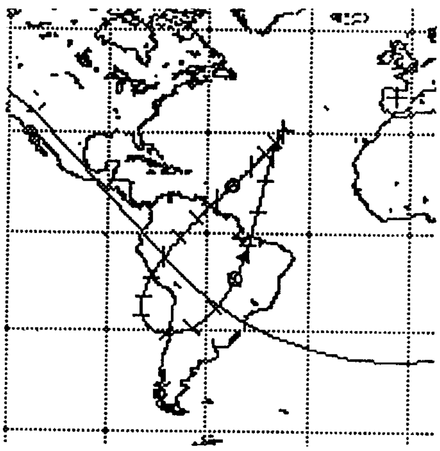

Figure 4-16. Ground trace at 01/01/1988.

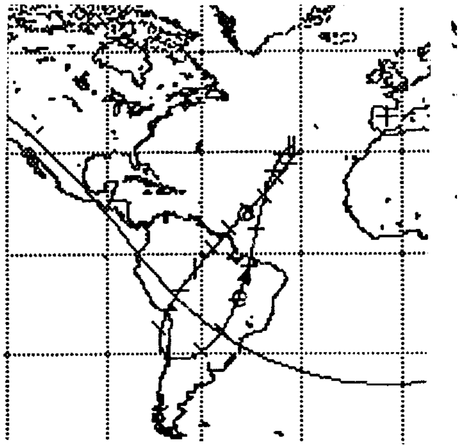

Figure 4-17. Ground trace at 01/08/89.

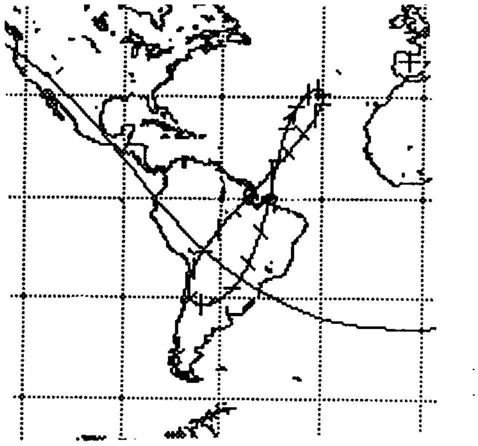

Figure 4-18. Ground trace at 01/09/1990.

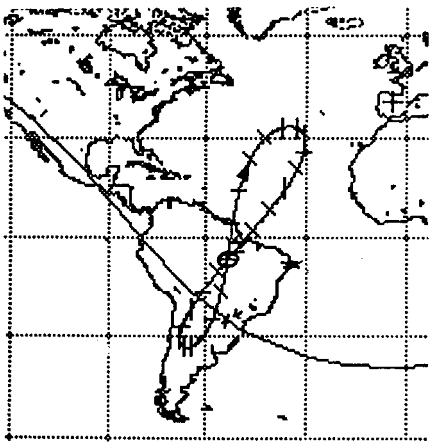

Figure 4-19. Ground trace at 01/08/1992.

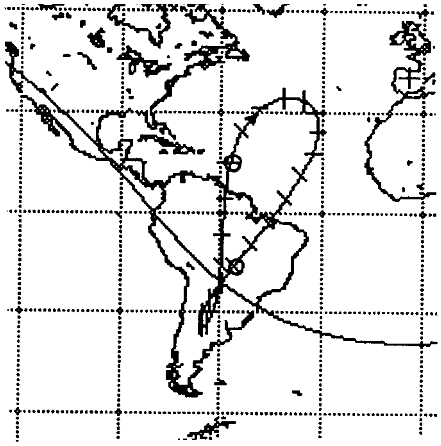

Figure 4-20. Ground trace at 01/08/1994.

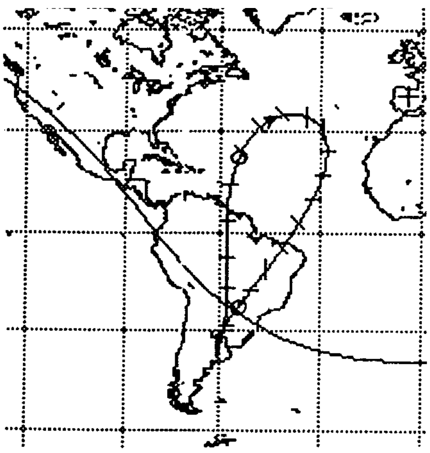

Figure 4-21. Ground trace at 01/10/1995.

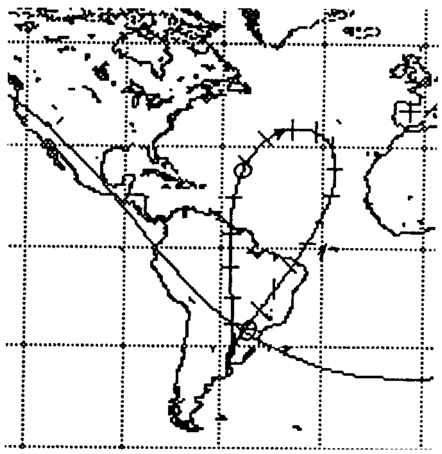

Figure 4-22. Ground trace at 07/09/1995.

4.1. Orbital corrections (Delta-V).

The major in-plane perturbation is caused by the ellipticity of the Earth's shape, which causes large in-plane angle oscillations of the spacecraft around the closest minor axis of the equatorial section. The Earth's minor axis (which contains a stable point at either end) is located at 255.3 degrees east longitude and 75.3 degrees east longitude. As the IUE was located around 300 degrees east longitude, the spacecraft was drawn to 255.3 degrees east longitude, which is to the west of its position. This constant westward drift had to be countered periodically to maintain the station operations by performing Delta-V maneuvers. In this way, the ground trace of IUE could be normally kept between longitudes of 270 and 330 degrees west until September 30, 1995, as shown the figure 4-23. After that, the longitude position was further altered, to around 340 degrees, to increase the VILSPA visibility as the hybrid operations mode required.

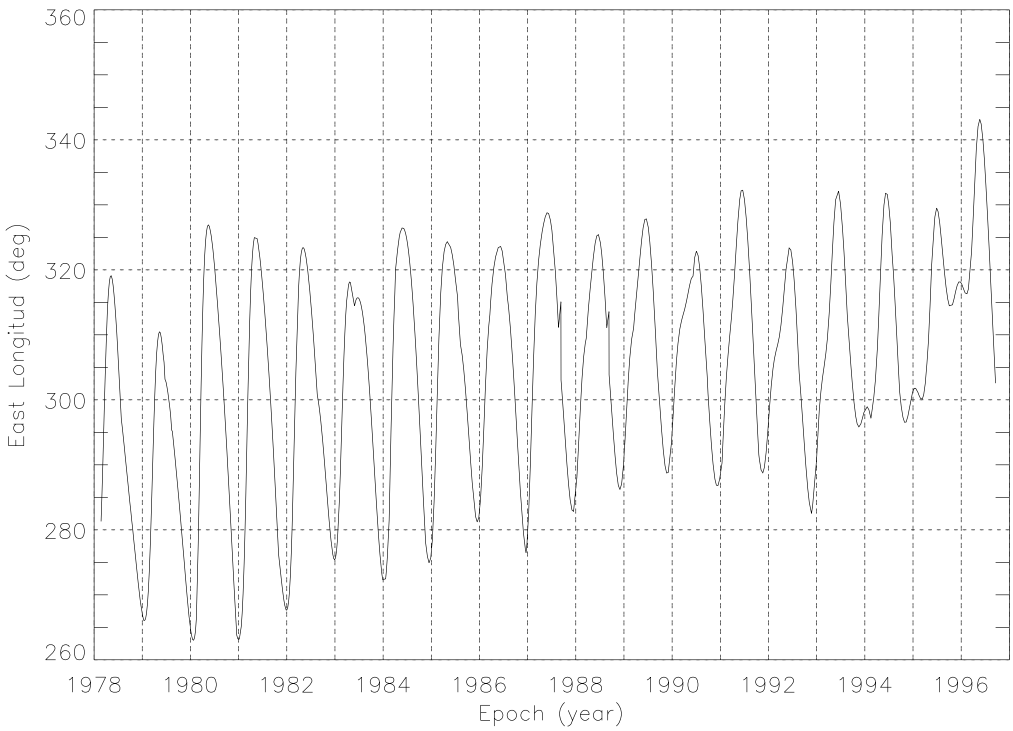

Figure 4-23. History of east longitude.

Along the spacecraft life, thirty Delta-V maneuvers were successfully performed (see Appendix B) and only two had to be aborted during their execution due to an OBC software malfunction.

A normal Delta-V was carried out by firing two 5 pounds thrusters, jets 2 and 8 (see section 5.5.9. and section 5.6.), during a time less than 15 seconds, to minimize the stress of the thrusters. An OBC program (worker 19) performed both the burn and the attitude control. This program also used the low thrust jets to maintain the attitude control during the burn.