Helios Mission Support

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This is the second in a series of articles relating to Project Helios which, when used in conjunction with the first article, will give the reader an overall view of the Project, its objectives and organization, and the support to be provided by the Deep Space Network (DSN). This article treats, in particular, the contemplated Helios trajectories. Both the near-earth phase and the deep space phase of the mission are discussed, with particular emphasis being placed upon the tracking and data acquisition aspects.

I. Introduction

The previous article (Ref. 1) provided the historical background of Project *Helios,* a cooperative U.S.–West German deep space effort to send a spacecraft closer to the sun than any currently planned, free-world space program to date. Two launches are planned: the first in mid-1974 and the second in late 1975. In addition, Ref. 1 described the physical configuration of the spin-stabilized *Helios* spacecraft and provided the reader with an overview of the spacecraft radio and antenna subsystems. This article will be devoted to the contemplated *Helios* trajectories and their associated tracking and data acquisition support requirements. For convenience, the discussion will be divided into two parts: the near-earth phase and the deep space phase of the mission.

II. *Helios* Near-Earth Phase Trajectory and Support

During the planning and early design stages of any new flight project, it is important to investigate a few typical spacecraft trajectories to ascertain whether or not the spacecraft design, the mission objectives, and the necessary tracking and data system support can be molded into a viable total concept. For *Helios,* an initial effort started in 1968 and was culminated by the publication of the "Mission Definition Group Report" in April 1969. This initial effort proved the feasibility of the basic *Helios* concept. Subsequently, the West German *Helios* Project Office has selected a spacecraft prime contractor – Messerschmitt-Boelkow-Blohm (MBB), Ottobrun (near Munich), West Germany – who has now made a preliminary design of the spool-shaped spacecraft (see Ref. 1). It was, therefore, appropriate to evaluate this preliminary spacecraft design with respect to not only the planned trajectory, but also to ascertain whether or not the post-launch mission sequences could be performed in an operationally efficient manner. Toward this end, a special *Helios* Near-Earth Phase Study Group was established during the Third *Helios* Joint Working Group Meeting in Bonn, October 5–9, 1970. In preparation for the Near-Earth Phase Study Group Meeting (which occurred the week following the Joint Working Group Meeting), the JPL/ETR organization developed a set of near-earth phase station coverage data for each of the tentative *Helios* trajectories developed by the NASA Lewis Research Center. These data, together with information provided by the *Helios* experimenters, provided a better knowledge of the spacecraft and launch vehicle performance characteristics, and a refined knowledge of the *Helios* Program mission objectives permitted the Near-Earth Phase Study Group to develop a tentative mission sequence following launch up through completion of the spacecraft's orientation maneuvers. In developing their recommendations for the near-earth sequence of mission events, the Near-Earth Phase Study Group considered both direct-ascent and parking-orbit trajectories. Typical "earth tracks" for these two classes of trajectories are shown in Figs. 1 and 2. The Near-Earth Phase Study Group concluded that the parking-orbit trajectory case provided only a moderate increase in launch window opportunities over that provided by the direct-ascent trajectory case, while at the same time presented a more difficult tracking and data acquisition problem due to the lack of sufficient tracking facilities in the South Atlantic and Indian Oceans. Therefore, the *Helios* Project Office accepted the Study Group's recommendation that for present planning purposes the nominal *Helios* mission design should be based upon a direct-ascent trajectory—but with the Project Office restriction that the spacecraft itself must be designed to be compatible with a parking-orbit trajectory in case the latter should become necessary sometime in the future.

Once the foregoing decision was made, the Lewis Research Center produced a formal set of *Helios* direct-ascent launch trajectories covering both the *Titan/Centaur* and *Atlas/Centaur* launch vehicle combinations (see Ref. 1). Subsequently, the JPL/ETR organization developed tracking and telemetry station coverage data for these upgraded trajectories. This material will be used during the second meeting of the Near-Earth Phase Study Group to be held in conjunction with the Fourth *Helios* Joint Working Group Meeting, Goddard Space Flight Center, April 28–May 5, 1971, to establish a formal mission sequence for the near-earth phase of the *Helios* mission. It is anticipated that this updated mission sequence will become the baseline design for the near-earth phase of the *Helios* mission, and that it will probably not undergo significant refinement until final spacecraft weights, etc., and launch vehicle performance data become available approximately a year prior to launch.

III. Deep Space Phase

A. DSN Initial Acquisition Phase

The exact definition of the completion of the near-earth phase and the beginning of the deep space phase of a particular mission is individually negotiated with each flight project; however, it is usually considered to be the point at which the spacecraft altitude is such that the Deep Space Network will have continuous (i.e., 24-hour/day) coverage of the spacecraft. For direct-ascent *Helios* trajectories, this would occur fairly soon after launch using one of the 0-degree longitude DSN stations, depending upon the launch azimuth. Figure 1 depicts two launch azimuth corridors for the *Helios* direct-ascent, *Titan/Centaur* launch vehicle. The upper corridor, between 50- and 60-degree launch azimuth, passes over the Madrid Deep Space Station while the lower corridor, 80- to 90-degree launch azimuth, passes over the Johannesburg, South Africa, DSN station. The gap between these two corridors represents an Eastern Test Range safety restriction to protect the island of Bermuda from possible launch vehicle impact. Of the two permissible *Helios* direct-ascent launch corridors, the one between 50- and 60-degree launch azimuth presents a slightly more difficult initial DSN acquisition problem due to high angular tracking rates, but at the same time affords the *Helios* Project the possibility of obtaining earlier communication with the spacecraft following separation. Figure 1 shows that for *Helios Titan/Centaur* direct-ascent trajectories, spacecraft injection occurs at approximately 15 degrees west longitude. Using the upper corridor, this would place spacecraft injection very close to spacecraft rise at the Madrid Deep Space Station. Since the spacecraft is still very close to the earth at that time, the angular tracking rates at Madrid can conceivably reach as high as 5 to 10 degrees per second immediately following injection. However, at the same time, the spacecraft is rapidly gaining altitude in its departure from the earth. This in turn causes the effective angular tracking rates to drop rather rapidly so that after 5 to 15 minutes following injection, the tracking rates should fall within the capabilities of the Deep Space Station. During this initial high-rate period, the DSN will probably request cross-support from the Manned Space Flight Network (MSFN) stations at Madrid or Canary Island because they have the capability of tracking at 3 degrees per second as opposed to the approximately 1-degree per second capability of the Madrid Deep Space Station. Handover from the MSFN station to the DSN station would then occur as soon as the angular tracking rates fall within the Deep Space Station capabilities. Once the latter is accomplished, the trajectory is such that the Deep Space Network would have continuous spacecraft coverage capability.

The situation with respect to the lower direct-ascent launch trajectory is not quite so acute from an angular tracking rate point of view, but increases the time delay to initial DSN acquisition. However, it is not necessary to wait until the spacecraft reaches the vicinity of Johannesburg, South Africa, to achieve initial DSN acquisition. This is because the spacecraft altitude is rising very rapidly following injection so that, depending upon the actual launch azimuth within the lower corridor, initial acquisition can occur at either or both the DSN Madrid and/or Johannesburg stations while the spacecraft is crossing the region of 0 to 10 degrees east longitude for the first time. Further, this initial acquisition can be enhanced by cross-support from the MSFN Canary Island and/or Ascension Island stations. Again, the *Helios* trajectory is such that once initial acquisition has occurred in the lower launch corridor of Fig. 1, the DSN would have continuous spacecraft visibility from then on to the end of the primary mission.

The DSN initial acquisition situation with respect to the *Helios* parking-orbit trajectories is quite different. Though not part of the present *Helios* mission nominal design, the parking-orbit trajectory must be considered in case it is necessary to return to the *Atlas/Centaur* launch vehicle combination. In this event, the trajectory would be as shown in Fig. 2. The spacecraft is inserted into a nominal 160-km (100-mile) parking orbit at launch vehicle main engine cutoff (MECO). It remains in the 160-km (100-mile) parking orbit until third-stage burnout east of Johannesburg, South Africa, at which time it is injected into its heliocentric orbit. During the parking-orbit arc, only relatively short (3 to 8 minutes) tracking periods are possible from the Ascension Island station and/or any ships that might be deployed in the South Atlantic. Due to the high angular rates when a spacecraft is in earth orbit, it will probably not be possible to track the spacecraft from the Johannesburg Deep Space Station during its initial overhead pass, but rather await the time that the spacecraft has gained sufficient altitude following injection for it to re-rise over the station's eastern horizon. Depending upon the particular trajectory flown, the initial DSN acquisition could occur at either or both the Johannesburg and/or Canberra Deep Space Stations. However, this would occur a considerable number of minutes following injection and separation. Due to the criticality of these latter two events, the Project Office would probably request the TDS to deploy a ship into the Indian Ocean to cover this sequence. In such an event, the tracking ship would be considered part of the near-earth phase network, mentioned in *Section II*.

B. Spacecraft Orientation Maneuvers and Near-Earth Science Phase

As mentioned briefly in Ref. 1, the first of two spacecraft orientation maneuvers occurs shortly after spacecraft injection. The first maneuver, which normally occurs automatically, orients the spacecraft's solar panels until they are fully illuminated by the sun in order to relieve the load on the spacecraft's batteries. During this maneuver, the spacecraft's spin axis remains basically in the plane of the ecliptic with the result that the DSN's communication with the spacecraft is via the latter's omni-directional antenna system. Since the latter has not yet been completely designed, it is possible that there may be some antenna pattern nulls which could cause momentary communications dropouts following the initial DSN acquisition. However, the frequency of such dropouts should diminish as the spacecraft assumes a stable position and departs the vicinity of the earth. Once the spacecraft has completed its first (Step I) orientation maneuver, selected onboard science experiments are activated to measure the various shock fronts that surround the earth. This initiates the near-earth science phase of the mission which continues until the spacecraft has reached a distance equivalent to lunar range from earth. Due to the spacecraft's high-departure velocity from earth, it reaches lunar distance in approximately nine hours following injection (direct-ascent case). During this time, the spacecraft is still over the Madrid/Johannesburg Deep Space Stations (Fig. 1). The spacecraft's initial Goldstone rise occurs approximately 7 hours after injection—at which time the vehicle sub-earth point is slightly west of Ascension Island in Fig. 1. Following handover to the Goldstone Deep Space Station, the spacecraft is commanded to turn off the science instruments and then to execute the second (Step II) of the two planned maneuvers. Using the procedures described in Ref. 1, Step II maneuver orients the spacecraft's spin axis to the pole of the ecliptic. This in turn permits the first use of the spacecraft's medium- and high-gain antenna systems. Following completion of the Step II maneuver and the orientation of the spacecraft's high-gain antenna, the onboard science instruments are reactivated to initiate the Cruise-Science Phase of the mission, which continues to the end of the primary mission.

The foregoing description depicted the case for the direct-ascent trajectory. The situation for the parking-orbit trajectory would be roughly similar except that the initial DSN acquisition and subsequent handover to Goldstone would be delayed in time over the direct-ascent trajectory case. This would mean that the spacecraft would be automatically performing its Step I maneuver during the time the DSN was attempting its initial acquisition. This might accentuate the problem associated with nulls in the spacecraft omni-directional antenna pattern, but at the same time, the acquiring Deep Space Station (either Johannesburg or Canberra) would be experiencing much lower angular tracking rates (and smaller general changes in azimuth pointing direction) than experienced in the direct-ascent case over Madrid. The degree to which these two factors might offset each other has not yet been determined. The parking-orbit trajectory does offer a slight advantage for early orbit determination purposes in that it is possible to get a two-station, different longitude orbit determination solution slightly sooner than in the direct-ascent case. However, since *Helios* spacecraft does not have a midcourse correction capability, there is no primary requirement for early orbit determination. These factors, combined with the somewhat delayed first acquisition at Goldstone, make the parking-orbit trajectories slightly less attractive than the direct-ascent trajectories using the *Titan/Centaur* launch vehicle. However, studies to date have indicated that a meaningful *Helios* mission can be flown using the *Atlas/Centaur* launch vehicle using the parking-orbit trajectory approach.

C. Primary Mission Phase

The primary phase of the *Helios* mission encompasses that time period from launch through first perihelion and up to the first solar occultation of the *Helios* spacecraft. (This encompasses Phase I and Phase II described in Ref. 1, i.e., Phase I covering the first several weeks where Mission Operations are conducted from the SFOF, and Phase II where Mission Operations are conducted from the remote terminal at Oberpfaffenhofen, West Germany.) The Deep Space trajectory for the *Helios* 0.25 AU perihelion case (*Titan/Centaur* launch vehicle) is shown in Fig. 3, and for the 0.3 AU case (*Atlas/Centaur* launch vehicle) is shown in Fig. 4. By current definition, the primary mission phase of *Helios* ends at first solar occultation—which in the case of the 0.25 AU mission occurs at approximately 110 days after launch, and in the case of the 0.3 AU mission occurs at approximately 120 days after launch. The region of greatest scientific interest occurs around perihelion (90 and 100 days, respectively, in Figs. 3 and 4), since this will be the previously unexplored region of our solar system. Therefore, continuous DSN coverage during this time period is a primary requirement. As mentioned in Ref. 1, the telecommunications link is being designed to provide useful scientific data rates back to the DSN 26-meter network during this time period, with the possibility of enhanced mission data return through supplemental use of the DSN 64-meter subnet and/or the West German 100-meter Effelsberg antenna station. While the perihelion phase has the greatest scientific interest, other important scientific objectives have created a requirement for the DSN to provide continuous (i.e., 24-hour/day) coverage to the *Helios* spacecraft from initial acquisition through first solar occultation. In the region from earth to first perihelion, the primary responsibility for providing continuous coverage will be placed upon the DSN 26-meter subnet, while in the region from perihelion to first solar occultation, the primary responsibility for *Helios* support will probably fall upon selected DSN 64-meter antenna stations in order to obtain planetary ranging data in support of the celestial mechanics experiment. During this same time period, the West German 100-meter Effelsberg station will be supporting the onboard scientific experiments at telemetry data rates in excess of those possible into the DSN 64-meter antennas. Since the Effelsberg antenna is a receive-only station, it will not be able to obtain planetary ranging data for the celestial mechanics experiment. However, the combination of the 100-meter Effelsberg station and selected DSN 64-meter stations will provide extremely valuable scientific data to the project in the region from perihelion to first solar occultation. This will be the first time that these large aperture antennas will be combined in the support of a flight project, and as such is an example of one of the benefits derived from this international cooperative project between the U.S. and the Federal Republic of West Germany.

D. Extended Mission Phase

Officially, there are no project requirements for DSN support to the extended phase of the *Helios* mission. In fact, it would be very premature for the project to place such requirements on the DSN at the present time. Nonetheless, the contemplated *Helios* trajectories (Figs. 3 and 4) suggest some very interesting scientific rationale for continued tracking support to the *Helios* spacecraft during the extended mission portion of the trajectory. For one, the retrograde loop behind the sun offers the opportunity for three solar occultations rather than just one; and, for another, the spacecraft will experience a second perihelion pass prior to returning to the vicinity of the earth. The trajectory, therefore, offers multiple opportunities to obtain the same type of data as obtained during the primary mission but at later points in time—provided, of course, that the spacecraft is still functioning properly. It is, therefore, plausible to expect that at some future time, requirements could develop for DSN support to the extended mission phase of the *Helios* Project.

Of the three possible *Helios* trajectories under current discussion (0.3 AU, 0.25 AU, and 0.2 AU), the 0.25 AU trajectory has the additional characteristic that it is harmonically synchronous with the earth's orbit. Theoretically, the trajectory could be retraced several times if the spacecraft's orbital parameters were not perturbed by the earth's gravity when it returned after each year's traverse. However, such an ideal case would be difficult to achieve, so in practice it is expected that the *Helios* orbit will become skewed with each return pass near earth so that the retrograde loop in the trajectory would cease to occur behind the sun. Earth's gravity would also influence the next perihelion distance—it could be closer to or farther from the sun depending upon whether the spacecraft passed behind or in front of the earth on its return trajectory.

Considering the above, it is understandable why there are no official requirements for extended mission support at the present time. However, it is just as important to recognize that many scientific possibilities exist for such an extended mission should it materialize sometime in the future.

IV. Concurrent DSN Flight Project Support

During the *Helios* time period, the DSN will also be providing support to other flight projects as depicted in Fig. 5. By plotting the various spacecraft viewperiods with respect to "station local meridian time," it is possible to make Fig. 5 apply to any station in the world—if one ignores the effects of station latitude or local terrain. 1200 hours is "local station noon-time," i.e., the time the sun crosses the station's local meridian. Similarly, 0000 hours is station local midnight. For approximation purposes, one can consider sunrise to occur at 0600 hours and sunset to occur at 1800 hours local meridian time.

Inspecting *Helios-A* in Fig. 5, one notes that it is launched near sunset in mid-CY 1974. This is in agreement with Fig. 3, which shows the spacecraft departing the vicinity of the earth in a direction retrograde to earth's orbit around the sun. However, as time progresses from launch, the spacecraft viewperiods approach closer and closer to the sun with the first hump in the curve denoting the first perihelion pass shown in Fig. 3. Past perihelion, the spacecraft viewperiod returns closer to the sun as it goes through the several occultations noted in Fig. 3. For obvious reasons, this type of presentation has been nicknamed a "worm chart." The fat part of the *Helios* "worm" denotes the primary mission phase while the dotted worm portion represents a possible extended mission support for the *Helios* celestial mechanics experiment. The subsequent large excursions of the *Helios* viewperiod curve denote that portion of the trajectory when the spacecraft returns to the vicinity of the earth and then possibly repeats the cycle.

With the foregoing explanation in mind, it is now possible to compare the *Helios* viewperiods with those of other spacecraft that will be operational and requiring support during the *Helios* time period. The "fat worm" portions of the other spacecraft trajectories denote the time span associated with their respective planetary encounters. It is seen that, if one considers only the primary mission objectives of all of these space flight projects, there is a very minimum viewperiod conflict between them and that, if the DSN stations were operated on a 24-hour/day basis, it should be able to support all of the noted flight projects without conflict—especially when one remembers that the DSN has both 26- and 64-meter subnetworks at its disposal during this time period. However, conflicts can occur if any of these flight projects develop tracking requirements into their extended mission time periods or if their planetary encounter dates shift significantly. Since neither of the latter can be accurately predicted at the present time, the DSN is only making firm commitments for the primary phase of these respective missions. This does not preclude possible extended mission coverage for any of the flight projects, but the exact amount of additional coverage possible will probably not be known until these spacecraft have been launched and their trajectories accurately determined.

V. Conclusion

This article and Ref. 1 complete the general description of the *Helios* Program—its international management, its mission objectives, its spacecraft and launch vehicle configuration, the spacecraft radio system, and the support requirements it places upon the Tracking and Data System. The treatment has been intentionally general in nature in order to provide the reader with a composite overview which he can use as a basis for understanding the more detailed radio subsystem discussions that will appear in future articles.

Reference

1. Goodwin, P. S., "*Helios* Mission Support," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. II, pp. 18–27. Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1971.

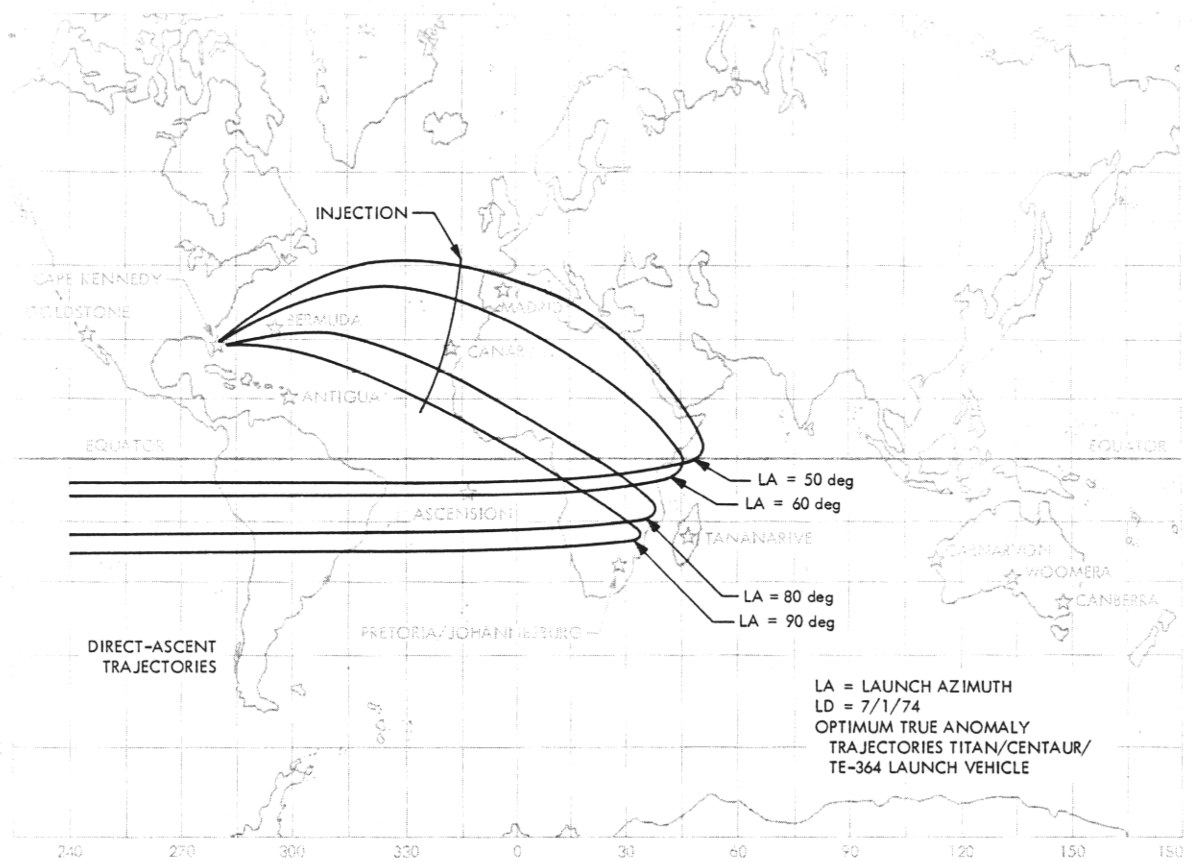

Fig. 1. ***Helios*** **direct-ascent trajectories using a** ***Titan/Centaur*****/TE-364 launch vehicle**

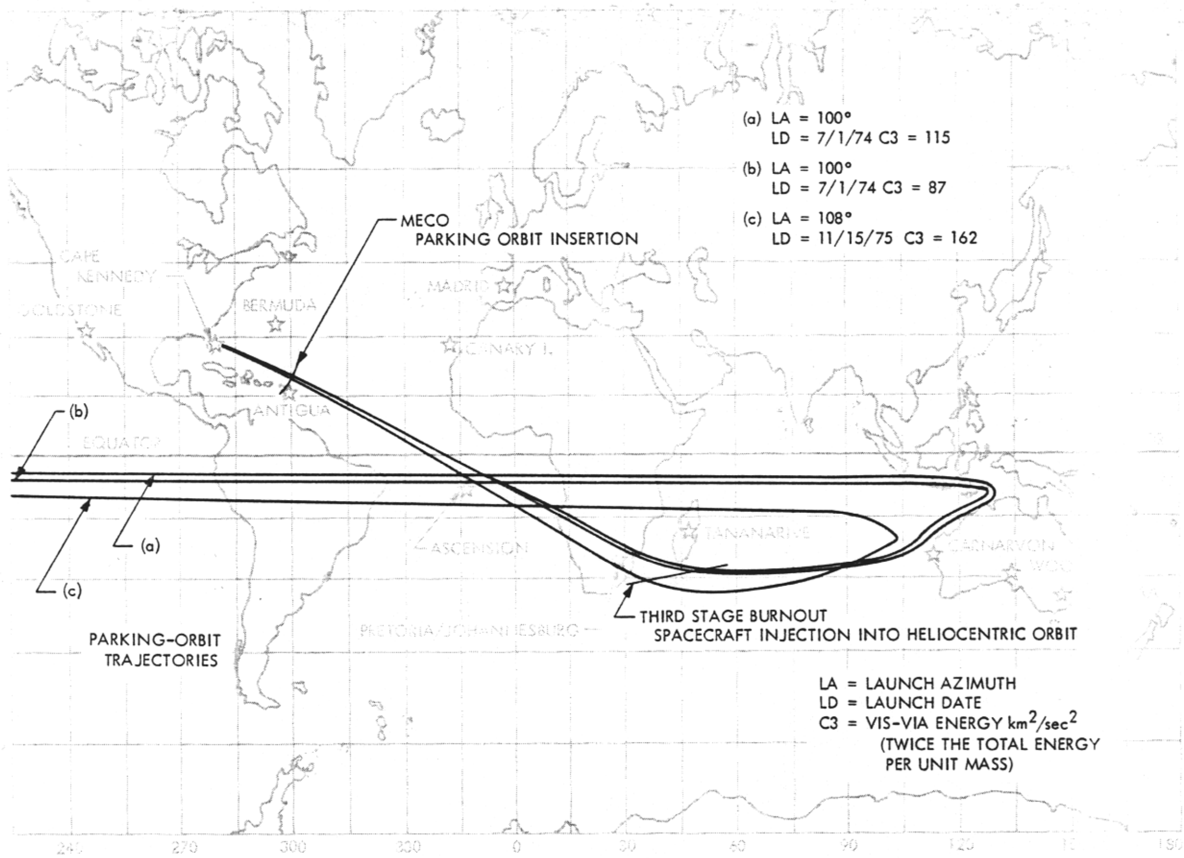

Fig. 2. *Helios* parking-orbit trajectories using an *Atlas/Centaur*/TE-364 launch vehicle

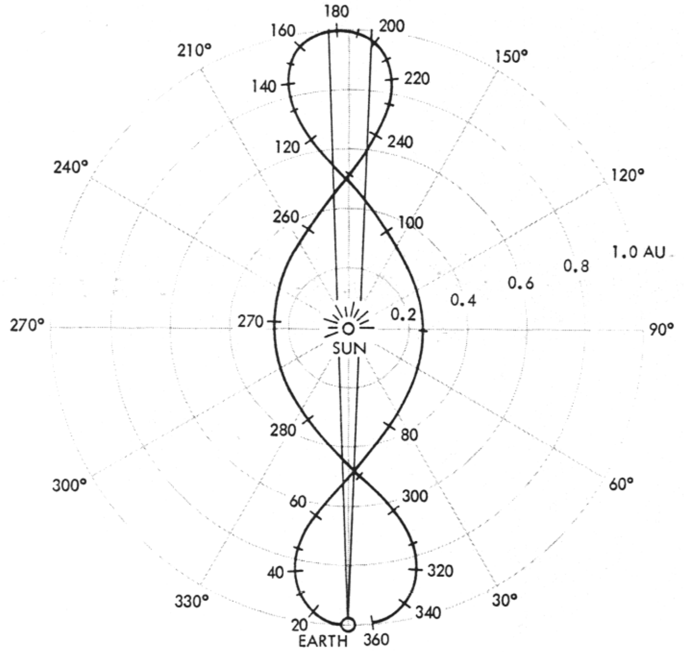

Fig. 3. Typical *Helios* trajectory at 0.25 AU

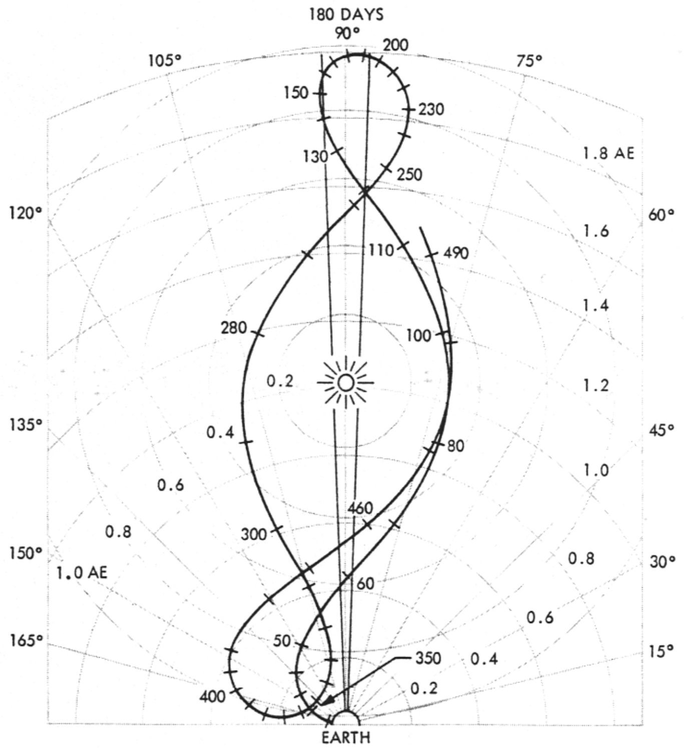

Fig. 4. Typical *Helios* trajectory at 0.3 AU

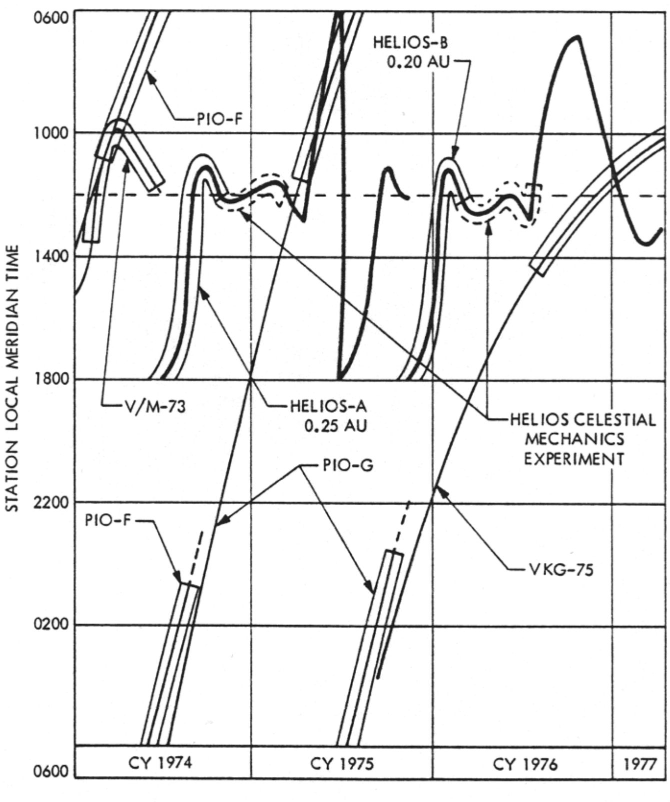

Fig. 5. Spacecraft viewperiods for 1974–1977 era