The Solar and Heliospheric Observatory (SOHO) Mission : An Overview of Flight Dynamics Support of the Early Mission Phase

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Abstract

The SOHO spacecraft was successfully launched by an Atlas IIAS from the Eastern Range on December 2, 1995. After a short time in a nearly circular parking orbit, the spacecraft was placed by the Centaur upper stage on a transfer trajectory to the L1 libration point where it was inserted into a class I Halo orbit. The nominal mission lifetime is two years which will be spent collecting data from the Sun using a complement of twelve instruments.

An overview of the early phases of FDF support of the mission will be given. Maneuvers required for the mission will be discussed and an evaluation of these maneuvers will be given with the attendent effects on the resultant orbit. Thruster performance will be presented as well as real time monitoring of thruster activity during maneuvers. Attitude areas that will be presented are star identification process and roll angle determination, momentum management, operating constraints on the star tracker, and guide star switching. A brief description of the two Heads Up Displays will be given.

I.   Introduction

On December 2, 1995, the Solar and Heliospheric Observatory (SOHO) spacecraft was launched by an Atlas IIAS with a Centaur upper stage into a near-circular parking orbit. After a brief coasting period in a parking orbit, the Centaur upper stage ignited at the Transfer Trajectory Insertion (TTI) point, placing SOHO on a direct transfer trajectory to the Sun-(Earth-Moon Barycenter) libration point L_1 and its Halo Orbit Insertion (HOI) point. The halo orbit is centered around the L_1 point, approximately 1.5×10^6 km toward the Sun along the earth-Sun line. The mission duration is two years with an extension of up to six years if spacecraft health and consumables allow. SOHO is a component of the International Solar and Terrestrial Physics (ISTP) program, which is an international effort reflecting the cooperation of the European Space Agency (ESA), the Institute of Space and Astronomical Science (ISAS - Japan), and the National Aeronautics and Space Administration (NASA). The objective of the ISTP program is to study the Sun and its interaction with the Earth. The objective of the SOHO mission is to investigate the outer layer of the Sun, to study the solar wind streams and associated wave phenomena at the L_1 point, and to probe the interior structure of the Sun. The Flight Dynamics Facility (FDF) at NASA's Goddard Space Flight Center provided, in addition to pre-mission support, early mission support for SOHO in the areas of maneuver planning and observation, orbit determination, attitude determination, and Attitude and Orbit Control System (AOCS) checkout.

II.   Mission Overview

a.   Baseline Trajectory

The baseline trajectory for SOHO is a direct transfer to a large-amplitude halo orbit around L_1. Figure 1 displays the baseline trajectory, including planned maneuver locations, and Figure 2 displays the baseline timeline. Three main maneuvers were baselined for SOHO. The first mid-course correction (MCC1) maneuver to correct for launch vehicle errors was planned for Launch (L) +24 hours. The second mid-course correction (MCC2), at L+24 days, would be performed if needed to correct for errors from MCC1. The baseline location for HOI was at the Rotating Libration Point (RLP) x-z plane crossing on the earth-side. Stationkeeping maneuvers were optimally planned at eight week intervals around the halo orbit.

Maneuver optimization during the transfer orbit was possible, but not investigated pre-mission due to a strict baseline definition. Also, studies indicate cheaper locations for the HOI maneuver (Reference 1) such as a sun-side insertion, but these were considered for contingency only.

Since the actual maneuver scenarios and locations differed somewhat from the baseline, Figure 3 is included to indicate these actual locations and times.

b.   Spacecraft Attitude

The spacecraft is three-axis stabilized, with the positive spacecraft x-body axis pointing to the Sun. The z-body axis is pointed toward the northern celestial sphere and the y-body axis completes the orthogonal right-handed-triad. The mission requirement is to maintain the attitude such that the solar spin axis is contained in the x-body -z-body plane as the spacecraft proceeds around the Sun. This results in the spacecraft rolling between approximately -7.25 and +7.25 degrees over the course of a year. Attitude is maintained through the use of three reaction wheels, with a fourth wheel being held in reserve. The wheels are unloaded through the use of thrusters at eight week intervals (a mission requirement), to be performed in conjunction with the station keeping maneuvers required to maintain the Halo Orbit (also a mission requirement).

III.   Spacecraft Description and Operation

a.   The Spacecraft

Figure 4 displays the spacecraft with its relevant subsystems labeled. The SOHO spacecraft mass at launch was 1863.7 kg wet mass, with a 251 kg fuel load. The spacecraft was manufactured through the European Space Agency by Matra Marconi Space, France. The propulsion system consists of 2 branches of eight hydrazine thrusters in pairs, providing around 4 Newton (1 pound) thrust each. These thrusters are labeled in Figure 4. All thrusters are used for orbit maneuvers, momentum management, and attitude control in certain modes.

b.   Thrusting and Maneuvers

The SOHO maneuvers are divided into two components: along the earth-sun line, and perpendicular to the earth-sun line components. These are referred to as x-axis and z-axis maneuvers, corresponding to the location of the thrusters on the spacecraft body axes. Thruster pairs 1 and 2, and 3 and 4, aligned with the x-body axis, are used for the maneuver components along the sun-line. Thruster pairs 1 and 2 are for negative x-axis thrust, and are canted 30° out in order to minimize plume impingement on the payload module. Pairs 3 and 4, on the bottom of the spacecraft, are for positive x-axis thrust. Thruster pairs 5 and 6 and 7 and 8 are aligned with the spacecraft z-axis and are for the perpendicular maneuver components. Although the spacecraft may be rolled by some amount around the x-axis and may have thrust components along the Rotating Libration Point (RLP) y and z axes, these maneuvers are still perpendicular to the sun-line and are thus still referred to as z-axis components. Total maneuver magnitude is determined by the sum of the x and z components instead of the root-mean-square.

FDF has several tools available to monitor the actual thruster firing. Although FDF has the capability to monitor spacecraft telemetry, both from telemetry packets and graphical data sent over from the SOHO Payload Operations Control Center (POCC), FDF developed a Head's Up Display (HUD) which reads certain telemetry items, processes them, and displays the results graphically. Section V discusses the HUD in more detail.

In addition to all these forms of telemetry monitoring, FDF uses tracking data observation to assess accuracy and completion of each maneuver segment. Reference 2 discusses the tracking data observation in detail. The basic procedure is to compare a file with modeled thrust, created before the maneuver segment, and against observed Doppler values collected during the maneuver segment. Plotting these comparisons provides a clear indication of anomalous thrust, as an early or late thruster cutoff would show up as a change in the slope of the plot. The ability to verify thruster cutoff at maneuver completion arose from a

requirement for FDF to provide independent verification of thruster cutoff separate from telemetry indications.

In addition to anomalous thrusting, these plots also provided a preliminary estimate of thruster performance. The preliminary estimates of maneuver performance referred to in subsequent maneuver sections were determined using Doppler analysis.

c.   Attitude Control

The Attitude and Orbit Control Subsystem (AOCS) has an attitude sensor complement of two Fine Pointing Sun Sensors (FPSS), three Rate-Integrating Gyros, all with the input axes on the spacecraft x-body axis, and two Charge Coupled Device (CCD) based Star Trackers comprising the Star Sensor Unit (SSU). The actuators are a set of four Reaction Wheels arranged symmetrically in a pyramidal orientation about the x-body axis and the redundant set of eight one pound thrusters.

IV.   Post-Launch

a.   Launch Window

The monthly launch window for SOHO was limited only by the position of the moon. Pre-mission analysis (Reference 3) determined that for certain days during each month the lunar perturbations had too great an affect on the trajectory. The November-December launch window extended from November 23 to December 15, inclusive. In addition to the monthly window, an optimum daily launch time was determined from the geometry of the transfer orbit, and the extent of the daily window was determined from a number of factors. For example, a requirement to have separation from the Centaur in view of a Deep Space Network (DSN) station limited the launch time due to the launch time's effect on the separation location. Daily launch window duration for the November-December block due to required DSN coverage of separation ranged from 55 to 91 minutes (Reference 4). The actual durations were slightly smaller due to additional launch vehicle constraints (including launch azimuth and range safety limitations).

b.   Launch and Very Early Orbit

On December 2 the launch window opened at 07:34:00 GMT and closed at 08:25:00 GMT. The AC-121/SOHO combination experienced a hold during the final launch countdown due to a Centaur problem, determined to be non-launch critical during the hold. Also during this hold one Advanced Range Instrumentation Aircraft (ARIA) went red, meaning one of the two aircraft used to cover the second stage burn was not able to support launch. This loss shortened the window by fifteen minutes, to 08:10:00 GMT. Due to the launch hold, the actual launch occurred just prior to window close, at 08:08:00.859 GMT (Reference 5).

The Atlas carrying SOHO ascended for approximately 10 minutes until it reached the near-circular low-earth parking orbit. Reference 5 contains actual times for each event in the launch sequence, as well as the pre-flight nominal expected values. The Centaur/SOHO combination coasted in the parking orbit for 74 minutes. The Centaur upper stage then ignited (Main Engine Start (MES) 2 - MES2) at the specified Transfer Trajectory Insertion (TTI) point and shut down (Main Engine Cut Off (MECO) 2 - MECO2) after approximately 118 seconds, placing SOHO on its transfer orbit. Due to the DSN separation viewing requirement, the Centaur remained attached to SOHO until 35 minutes after TTI. The separation vector received by FDF from the launch vehicle contractor contained an epoch of 10:10:27 GMT. The Madrid tracking station acquired SOHO just prior to separation.

After separation, initial orbit and attitude determination were critical. FDF received a preliminary indication of the launch vehicle performance, both the Atlas and the Centaur, from several Orbital Parameters Messages (OPM's) provided by the launch vehicle contractor, which were both faxed and teletyped to FDF. Initial indications from both the post-MECO2 and the post-separation vector indicated the launch vehicle performance was a little less than 1 sigma (1σ) hot, which translated into an extra 0.7 m/s of velocity. Later orbit determination confirmed that the launch vehicle performance was slightly hot, predominantly in the

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velocity direction with very small out-of-plane errors. The pre-mission analysis had indicated a 3σ velocity dispersion error of 2.15 m/s (Reference 3).

The spacecraft, after initiation of the AOCS, acquired the Sun and began a slow roll that continued until a star of magnitude 8, or brighter, was acquired. The roll rate was nulled, a mapping of the tracker field of view was performed and the data were sent to the ground for processing to identify the stars and determine the roll angle. Section VI provides more detail about the attitude determination.

c.   **Early Mission and First Mid-course correction**

Using the initial vector information, impulsive maneuver planning for SOHO indicated an MCC1 maneuver of 4.66 m/s using thrusters 1 and 2 for the x-axis components, and 0.34 m/s using thrusters 7 and 8 for the z-axis components. This maneuver sequence was planned for start time at TTI plus 24 hours. The x-axis burn was split into two segments separated by 90 minutes in order to provide an initial assessment of the thruster performance. Pre-mission analysis had determined the worst case MCC1 to be 30 m/s total performed at TTI + 24 hours (Reference 3). This magnitude increases the farther out from TTI the maneuver is performed. Delays in the maneuver start times subsequently increased the maneuver magnitudes.

Due to a desire by FDF to receive additional tracking data, MCC1 was re-scheduled for 16:00:00 GMT on December 3, approximately TTI+30 hours. Before this could occur, the spacecraft experienced a thermal anomaly. Since the spacecraft had to go through thermal reconfiguration, as well as accommodating a science instrument checkout request, the maneuver was rescheduled again to start at 23:30:00 GMT on December 3.

Finite maneuver planning determined that the two new x-segment maneuvers would be 3.04 m/s and 1.577 m/s, still using thrusters 1 and 2. One lone z-segment, determined to be 29 cm/s, was eliminated, since it was small and eliminating the maneuver did not significantly affect the HOI costs. The final maneuver replan changed the second x-segment slightly, to 1.578 m/s.

The actual maneuver start time was delayed by 51 minutes due to delays acquiring SOHO from the Canberra DSN tracking station. The first segment was executed successfully, and Doppler data provided a preliminary indication of a 2% cold maneuver. The second segment was replanned for 03:00:00 GMT, December 4, with a new predicted magnitude of 1.6354 m/s. Before this maneuver could be executed, the spacecraft experienced an Emergency Sun Reacquisition (ESR) at 02:05:00 GMT. {Discussed in section ?} The recovery from this ESR pushed the start time of the second segment to 18:00:00 GMT, with an expected magnitude of 1.878 m/s. The second segment was completed on time and preliminary indications were also for a 2% cold maneuver. Later maneuver calibration based on orbit determination indicated that MCC1 maneuver performance was 2.46% cold. (Reference 6)

d.   **Second Mid-Course Correction**

Preliminary analysis for MCC2 produced several options. The first option was to continue the maneuvers as baselined, with MCC2 sometime around 24 days after launch and HOI at the earth-side RLP x-z plane crossing. The second option involved not performing MCC2 and instead waiting until HOI. The third option, which turned out to be the best, was to optimize the MCC2 and HOI to find the best sum of the two. Initial analysis and the optimization of these two maneuvers is discussed in Reference 7.

For option 1, planning the maneuver for January 4 in order to avoid the holidays produced a total maneuver size of around 1 m/s. The corresponding HOI maneuvers, still planned as baselined for the x-z plane crossing, then totaled around 44 m/s. Option 2, canceling MCC2 due to its small size, produced HOI numbers of approximately 54 m/s total.

Option 3 proved to be the most viable. By changing MCC2 to an orbit shaping maneuver instead of a simple error correction maneuver and increasing its magnitude, the sum total of the two maneuvers was reduced. Preliminary planning indicated MCC2 could be performed in three segments, one x-segment of 6

m/s using thrusters 1 and 2, and two z-segments, one 15.7 m/s and one 10.0 m/s, again with thrusters 7 and 8. (The z-axis maneuver was split up since it was the first use of z-axis thrusters for an orbit maneuver) This reduced the HOI maneuver to one x-axis segment of approximately 14 m/s. The biggest advantage to Option 3 was a reduction in the number of maneuver segments required, from 6 (two segments at MCC2 and 4 at HOI) to 4 (three at MCC2 and 1 at HOI). Another advantage was elimination of a roll maneuver from the HOI scenario. This greatly simplified maneuver operations and reduced total maneuver operations duration.

After some debate option 3 was chosen, with the z-axis maneuvers performed first and then the single x-maneuver. Once again, the initial segment was delayed due to tracking station handover problems, so the second segment was slightly re-planned to account for the delay. The first z-segment occurred at 00:45 GMT on January 5. Doppler evaluation during the maneuver indicated it was 1.5% hot. The second z-segment was performed at 04:15 GMT, and the x-segment at 05:55 GMT. Preliminary indications were also for slightly hot maneuvers. Later maneuver calibration from orbit determination indicated the overall performance was 1.3 % hot.

e.   Halo Orbit Insertion

A preliminary HOI study produced a wide range of possible dates leading up to the baseline date. Reference 8 discusses HOI maneuver planning in detail. These maneuvers were all single x-axis segments again using 1 and 2, and ranged from February 16 (3.1 m/s) to March 15 (12.7 m/s). The baseline HOI location was at the earth-side RLP x-z plane crossing on March 14. This range of dates provided flexibility for scheduling of the DSN as well as spacecraft events. As analysis indicated, the earlier the maneuver was performed the lower the cost. Additional analysis provided several more dates on either side of the initial block. The actual maneuver date selected was February 14. In conjunction with HOI a trim maneuver was planned anywhere from 3 to 8 weeks past HOI in order to fine tune the halo orbit. This maneuver was executed on March 20.

During the maneuver on February 14, approximately 8 minutes into the maneuver, the primary tracking antenna went down, later determined to be a hardware problem. The backup antenna continued to track SOHO, however the switch in antennas corresponded to 7 minute loss of tracking data. For that reason the preliminary estimate of maneuver efficiency from Doppler data could not be performed accurately, but was estimated at 2% cold. A final resolution performed after collection of post-maneuver data indicated a 2.1% cold maneuver.

As stated above, an HOI trim maneuver was performed on March 20, with a magnitude of 89 cm/s using thrusters 1 and 2.

V.   Head's Up Display

SOHO was the first mission to use Heads-Up-Displays based on HP workstations. Two were developed, one for attitude and the other for maneuver support. Figure 5 and Figure 6 present representative samples of each. For attitude, displays of all sensors and actuators are presented, as well as on board computed attitude in both tabular and graphical form. Information on the current High Gain Antenna gimbal angles is also available, as well as the current telemetry type and AOCS control mode. The display is heavily used for attitude support to monitor sensor behavior, guide star status in the star tracker field of view, wheel speed progress, and telemetry type and control mode switching.

The maneuver display is an integral part of the support of all maneuvers. Thruster on time, for all thrusters separately as well as total on-time is displayed by sliding bars as well as numerically. The same is true for tank temperature and pressure. These thruster on-times are monitored closely, as is the polar plot displaying the progress of each burn. This plot is a representation of the projection of the current velocity vector, both instantaneous and cumulative, onto a plane normal to the desired velocity vector at the center of the plot. Consequently, a path is projected that is expected to show a convergence to the center of the plot. If the thrust vector deviates significantly from the center, then an anomaly is known to have occurred and immediate corrective actions can be initiated. There is also a graphical representation of each of the active thrusters and whether the "A" or "B" side set of thrusters is in current use.

Both displays were very useful to the support of the SOHO mission. A detailed description of both HUDs is to be found in Reference 9.

VI.   Attitude

a.   Star Identification and Roll Angle Determination

After acquisition of the Sun and transition to the Fine Pointing Sun Sensor the spacecraft began a slow roll about the x-body axis with the star tracker active. When the star tracker acquired a star of visual magnitude of 8.0, or brighter, this star was used as a guide star by the control system to null out the roll rate. A mapping of the field of view was initiated and all stars obtained were transmitted to the ground for processing. The stars were processed using a multi-star-identification algorithm described in Reference 10. The results are presented in Figure 7. The outer rectangle shows the total field of view and the inner rectangle shows the reduced field of view that is used for routine operations. The spacecraft roll-labeled axis is the spacecraft x-body, and science instrument, axis. The "+" symbols represent the stars from the catalog; the "o" symbols represent the observed stars. Eight stars were identified. The orientation of the spacecraft z-body axis was determined and the identified stars were used with the Sun sensor data to determine the spacecraft attitude. The goodness of fit is represented by the root-sum-square of the angular separation between the observed and the catalog stars which is seen to be 0.04 degrees. The attitude was determined to be a roll of 96.33, a pitch of 0.1 and a yaw of 0.0 degrees.

As stated above, before the second segment of the MCC1 maneuver could be executed, an ESR was triggered at 02:05:00 GMT on December 4, and transition to the "B" side of the AOCS was performed. A dump of the flight software was taken for detailed analysis on the ground by the supporting staff of Matra Marconi Space, and technical staff of ESA, to determine the specific chain of events that led to the ESR. After analysis of the data, it was found that there was an improper response to a ground command to reset the AOCS. A large roll rate developed, causing the Failure Detection Electronics to trigger an ESR. The process of recovering from this mode of operation took approximately eight hours. At the end of this interval with the spacecraft in the Roll Maneuver with Wheels (RMW) mode another star mapping was done. The resulting data was again processed and eight stars were identified. The results are presented in Figure 8. The goodness of fit is 0.09 degrees. The attitude was subsequently found to be a roll angle of 141.4 degrees. Shortly thereafter the Flight Operations Team (FOT) switched to the "A" side of the AOCS, and another star mapping performed. Figure 9 shows that nine stars were identified with a goodness of fit of 0.05 degrees. The attitude was found to be 141.0 degrees. It was determined that the performance of star tracker B was not as good as that of star tracker A. This can be seen by comparison of Figure 8 with Figure 9. The goodness of fit of tracker B is almost twice as large as that of tracker A, reflecting the larger random scatter between the observed and the catalog stars. This observation led FDF to recommend that tracker "A" be used for the continued normal operation of the spacecraft.

Whenever the spacecraft was reoriented to a new roll orientation, either to the normal mission orientation or to a different one to support a station-keeping maneuver, the performance of the star identification algorithm produced results similar to those shown in Figure 9.

b.   Star Tracker Operational Constraints

The star trackers were required to produce star data in the visual magnitude range of from 2.0 to 8.0. Therefore, pre-mission analysis to determine star availability indicated that there should be no difficulty in having an adequate number of stars to be tracked during the mission lifetime. FDF had indicated that it would be beneficial to track three stars, the current guide star and two others. It was also recommended that the magnitude threshold of the star tracker be set at the limit for the dimmest stars, viz., 8.0, to allow the largest number of stars to be available when mappings would occur. Both recommendations were accepted. However, early into the mission the star tracker began to send Single Event Upsets (SEUs) to the AOCS. An SEU is determined to occur in the tracker if the location of the star shifts by one pixel, or the magnitude shifts across a gain threshold gap. There are four gain values depending on the magnitude of the star and each applies to a range of magnitudes, ranging from 2.0 to 8.0 for gains 1 to 4. The magnitude ranges are not contiguous, but rather have gaps of 0.05 between these ranges. Furthermore, there is a tolerance on the

limits of less than 0.025. There can arise, therefore, many situations where due to the electronic noise in the tracker, especially for dimmer stars where the noise is the largest, and for stars with magnitudes near a range boundary, the magnitude may vary from measurement to measurement across a gain boundary and back. If more than a preset number of SEUs occur within a prescribed time interval, then an SEU is sent to the AOCS. This was found to be happening early in the mission after the ESR had occurred. Because of this the Matra-ESA engineers modified the mode of operation of the star trackers. The magnitude threshold was to be set at 7.0 for future star mappings and the guide star designated by the FDF had to be 6.0, or brighter.

c.   Guide Star Switching

Because of the limitation on the magnitude of the star selected to be used as the guide star certain operational constraints ensued. The star tracker, when performing a mapping, starts from the center of the field of view and spirals outward in a stepwise fashion until the entire field of view has been covered. When a roll maneuver has occurred and a mapping automatically is obtained, the first star encountered could be brighter than 7.0 in magnitude but not necessarily brighter than 6.0. It therefore became necessary to switch stars. There were two possible ways in which this could be done; one more conservative, and consequently more time-consuming, and the other more direct and quicker to accomplish. The former required the continuous tracking of the original star while the FOT was directed to command the tracker to an empty area of the field of view and then to command the tracker to the area containing the new guide star. This was a more tedious approach for FDF as both areas were required to contain a minimal number of pixels and FDF personnel had to scrutinize the whole field of view and do this quickly as the timeliness of the information was important. The latter required only the search area of the new star to be obtained. It was also more daring inasmuch as the original guide star was dropped at the start of the switch before the new guide star was established. After the first few guide star switches it was decided by the FOT in consultation with FDF and SOHO Project personnel to use only the more direct method. However, because of the problems associated with the star trackers and the resultant constraints arising therefrom, more previously unscheduled support was required from the FDF and more commanding of the spacecraft by the FOT was necessary.

d.   Momentum Management

At the L_1 point, on mission orbit, effectively the only external environmental torque that acts upon the spacecraft is that due to the solar radiation. As the resultant torque on the spacecraft is compensated for by commanding the reaction wheels, over time the wheels need to be "unloaded". The mission requires that momentum management be performed no sooner than eight (8) weeks, in conjunction with the station keeping maneuvers required to maintain the halo orbit. This, coupled with the requirement that the solar spin axis be contained within the x-body-z-body plane, ensures a relatively long period of continuous observation of the sun's surface as it rotates across the scientific instruments fields of view.

Momentum management consists of monitoring the wheel speeds, predicting their future secular variation and, therefore, when the next wheel dumping need be performed, and determining the new speeds for each wheel. Actual wheel speeds are also compared with the predicted speeds to detect any unanticipated activities that might have happened on the spacecraft. Wheel speeds are also selected to perform roll maneuvers to achieve the orientation to support station keeping maneuvers. Description of the algorithm is contained in Reference 11.

Figure 11 presents the predicted wheel speeds for the reorientation of the spacecraft from its roll of 141 degrees, which it attained after recovery from ESR, to the normal mission roll of -7 degrees. This is typical of the wheel variations resulting from any such roll maneuvers. The actual wheel speed variations, if presented on the same plot, would not be discernible. This was found to be the true in almost all cases.

Figure 12 presents a sample of actual versus predicted wheel speeds for a period of several days starting on the third day. There is good agreement between the two and it was determined that the solar torques acting on the spacecraft over this span were of the order of 10^{-5} Newton-meters, two orders of magnitude larger than pre-mission expectations.

As an example of unanticipated activities affecting the spacecraft, Figure 13 presents the actual versus predicted wheel speeds for the period of twenty days following the span of time from the previous figure, viz., from December 15, 1995 into January 1996. It is clear from the figure that on about December 21, 1995 something occurred that caused a change in the resultant torque acting on the spacecraft. Consultation with the FOT and SOHO project personnel provided no explanation as far as any known spacecraft activity. This was found to occur again during the transfer trajectory. The departure between the actual and predicted wheel speeds was just as pronounced but less dramatic. The graphical representation of the second case is not given herein.

Figure 13 presents the same information as the previous two figures for a span of approximately 12 days starting on February 16, 1996, two days after Halo Orbit Insertion. The agreement between the actual and predicted wheel speeds is even better than before and the solar radiation torques were found to be of the order of 10^{-7} Newton-meters, as expected from pre-mission analysis.

VII. Summary

As the SOHO mission proceeded, scheduled activities were postponed, the sequence of events was changed, and it became necessary to respond quickly to previously unexpected requests for analysis support to help explain spacecraft responses to command sequences. For example, the initial star mapping and the subsequent analysis to determine the spacecraft attitude was delayed several hours because of a spacecraft thermal problem. The spacecraft was triggered into a safehold mode with unexpected behavior of the star tracker as a contributing factor, causing the second segment of MCC1 to be postponed and to be completely replanned several different times. The use of the star tracker was changed, causing additional support activity to be provided by the FDF. However, despite these and other problems that occurred, FDF support personnel continually provided the highest level of support in an apparently routine manner. Generally, the flight support systems, both the institutional and those systems and utilities developed specifically for this mission, performed quite well. The system support staff, with insightful observations and suggestions from operational personnel, responded quickly to correct the few resident quirks as they were discovered. The support provided by the FDF for the SOHO mission was highly successful.
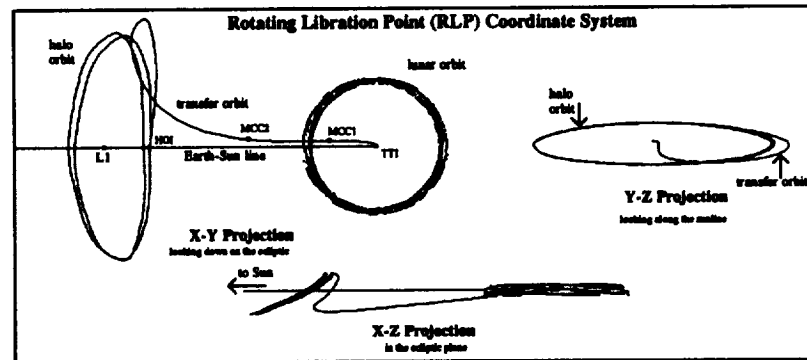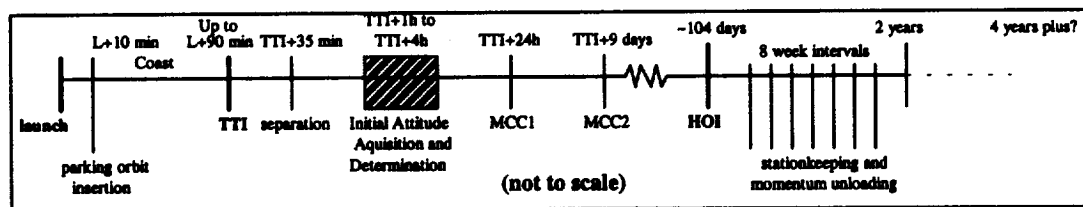

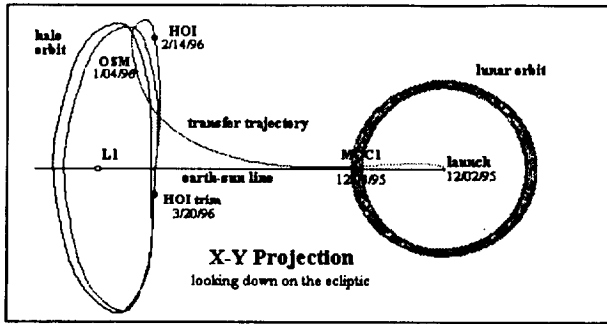**Figure 1. Baseline SOHO Trajectory**

Figure 2. Mission Timeline

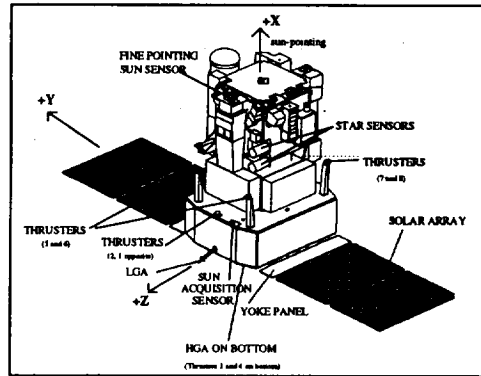**Figure 3. Actual SOHO Trajectory with Maneuver Locations**
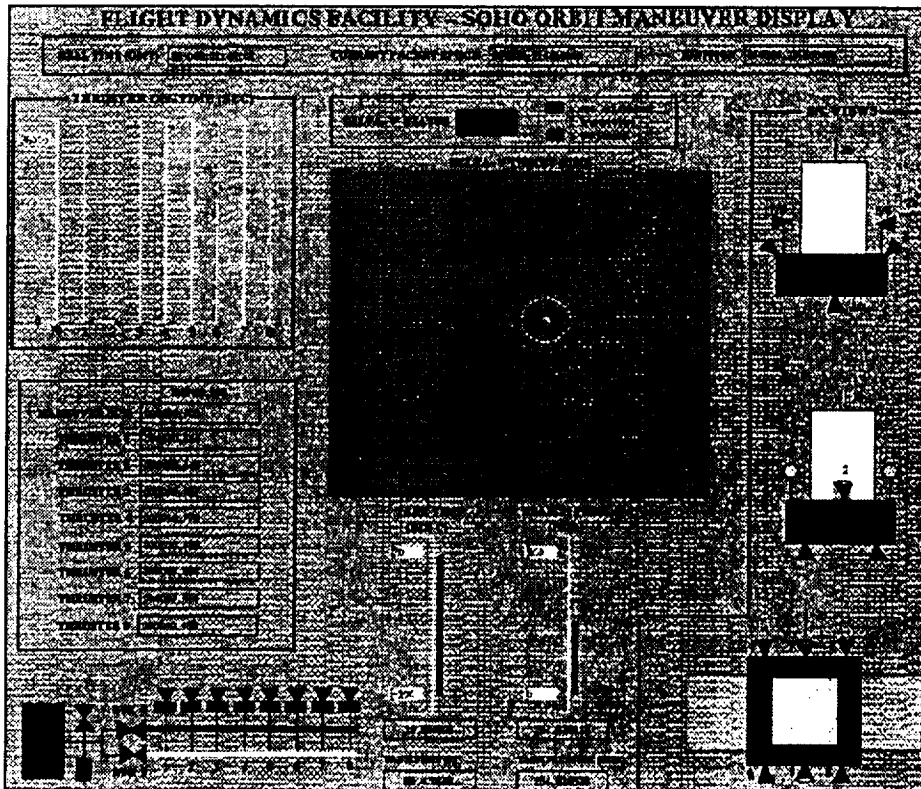

Figure 4. The SOHO Spacecraft

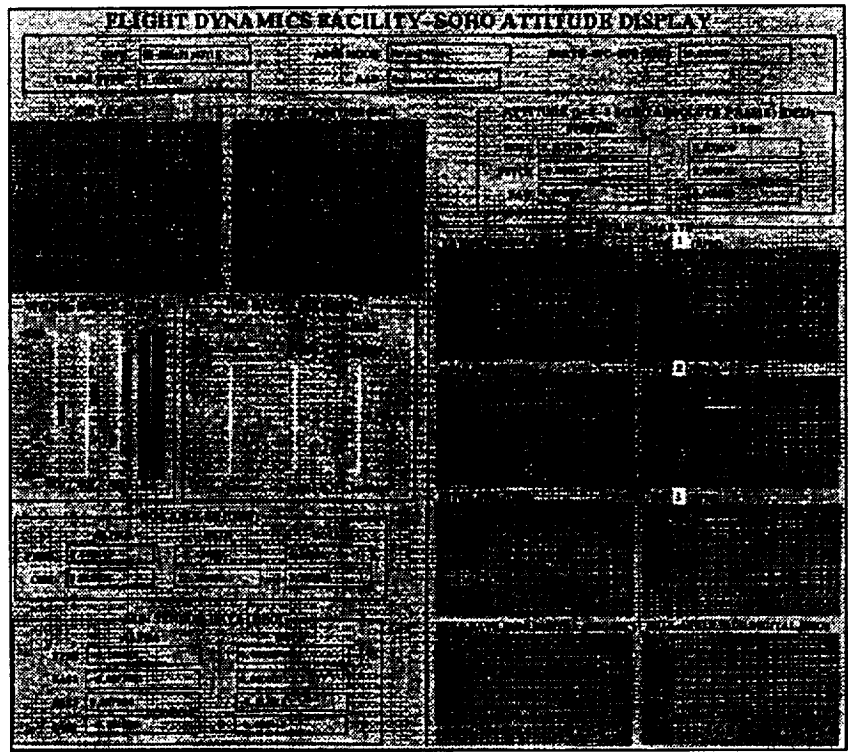**Figure 5. Maneuver HUD Display**

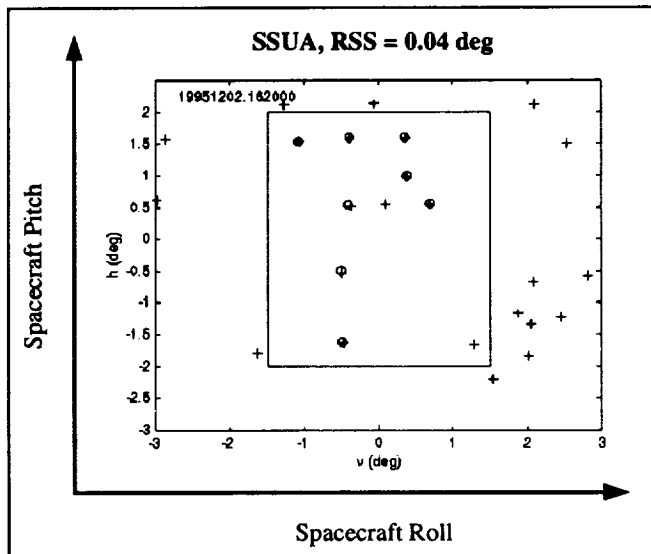**Figure 6. Attitude HUD Display**

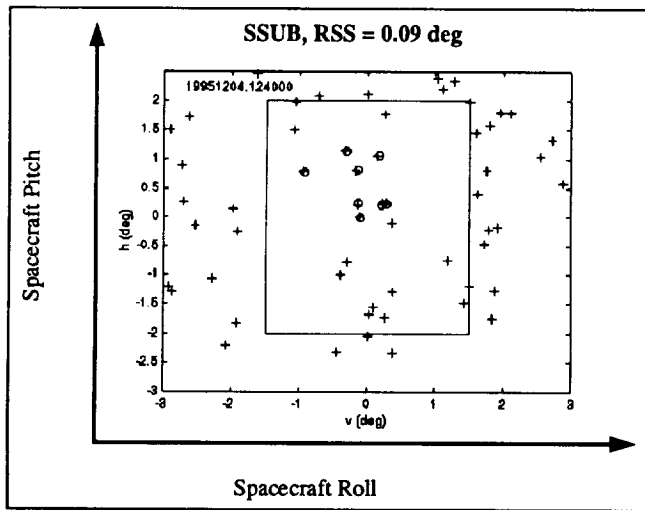**Figure 7. Initial Star Mapping and Identification Results**

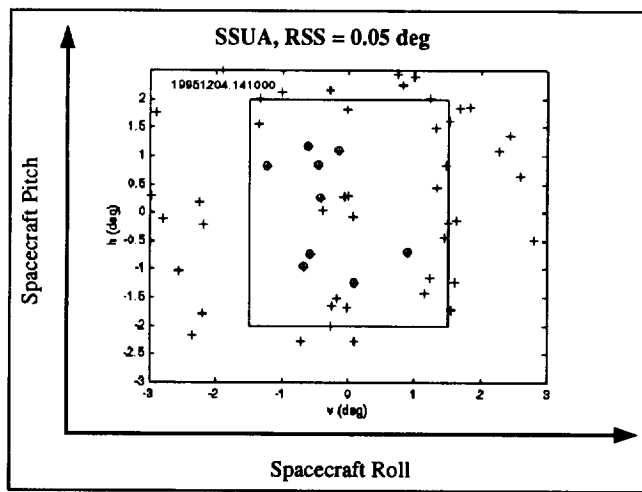**Figure 8. Star Mapping and Identification During Recovery ESR - Star Tracker B**

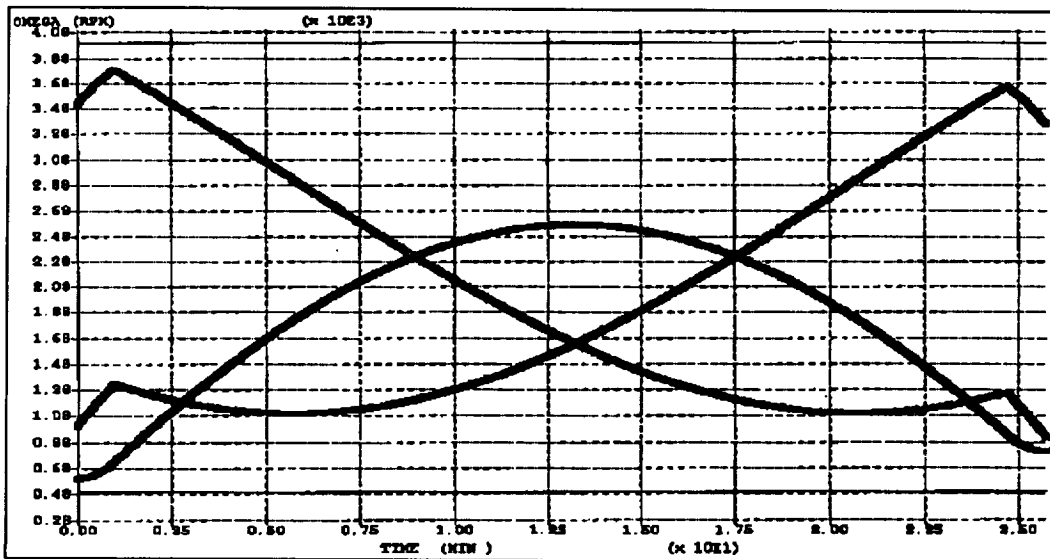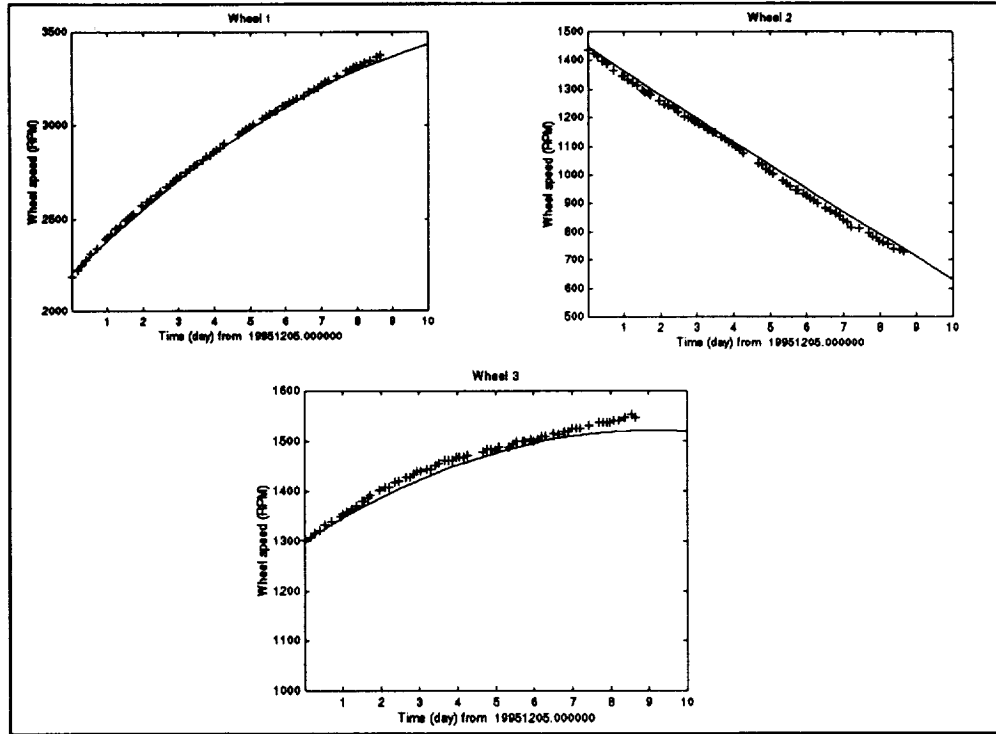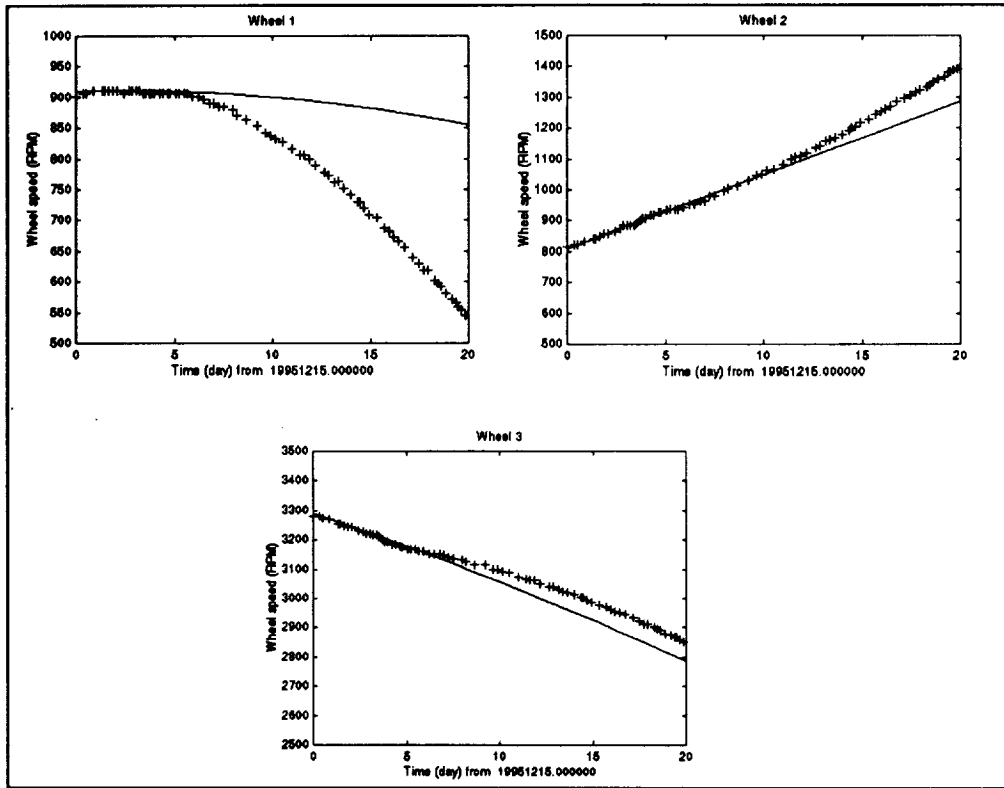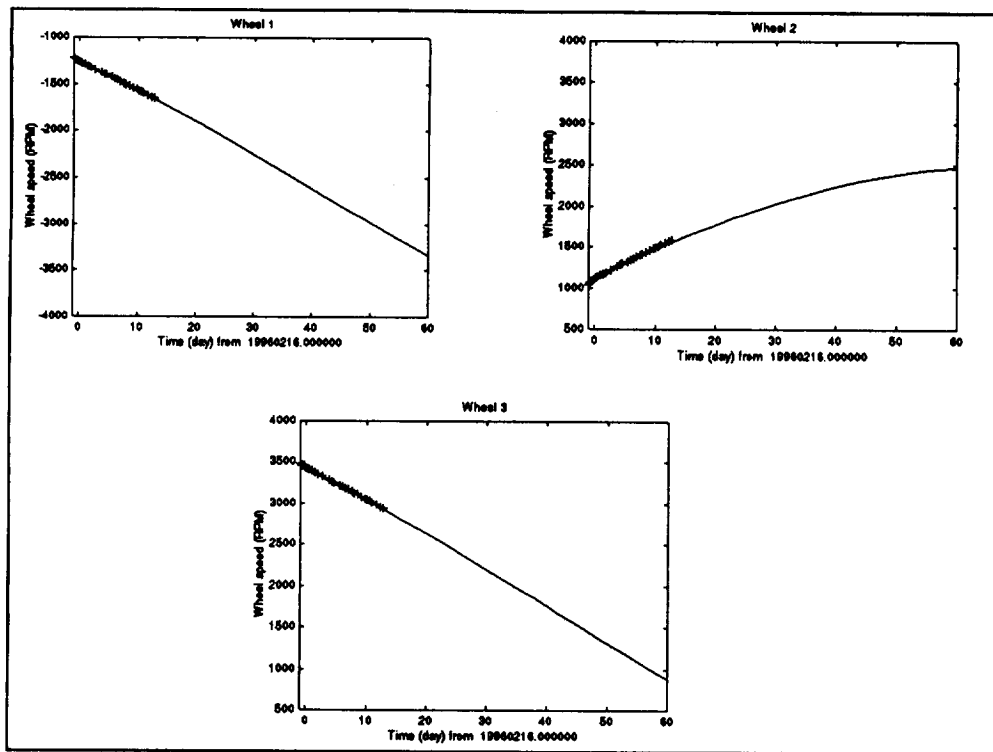**Figure 9. Star Mapping and Identification After Recovery From ESR - Star Tracker A**

Figure 10. Predicted Wheel Speeds for First Wheel Unloading

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Figure 11. Early Mission Predicted/Observed Wheel Speed Comparison

Figure 12. Predicted/Observed Wheel Speed Comparison Showing Sudden Change in Torque

Figure 13. Predicted/Observed Wheel Speed Comparison During Normal Operations

Direct References:

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