

Performance of LIPS III Attitude Control System

Robert W. Conway
Bendix Field Engineering Corporation
Washington, D.C.

Robert L. Burdett
Naval Research Laboratory
Washington, D.C.

The LIPS III satellite is a spin stabilized sun tracking space platform whose primary mission is to test new space power sources. The attitude control system has two modes of operation, hydrazine gas jet for large attitude errors and an electromagnetic torque rod for nominal operations. The control law will be discussed and examples of inflight data will be given.

INTRODUCTION

The Living Plume Shield spacecraft, shown in figure 1, was designed, built and integrated in less than one year by the Naval Research Laboratory (NRL). As described in Reference(1), the satellite is a structurally stiffened plume shield, which is normally jettisoned as space junk after it has served its purpose. LIPS III was launched into a 600 nautical mile, nearly circular orbit at an inclination slightly over 60 degrees. The spacecraft at launch weighed just below the 138 pound flight restriction. It is donut shaped with an outer diameter of 74 inches, an inner diameter of 44 inches and is 4 inches thick.

The LIPS III primary mission is to provide an orbital test bed for new and innovative space power sources. A total of 141 individual experiments were included, 14 of which involve solar concentrators. These concentrators required that LIPS III be pointed at the sun to within 0.5 degrees and spin stabilized.

The purpose of this paper is to describe the overall attitude control system of LIPS III, emphasizing the attitude control law which forms the heart of the system. Flight attitude data will be presented to demonstrate the quality of system performance.

ATTITUDE CONTROL SYSTEM

The attitude control system has two modes of operation. The first mode employs a hydrazine thruster used to correct large attitude errors that need to be overcome quickly (2). In this mode a Digital Solar Aspect Sun Sensor (DSAS) sends sun crossing timing and spin axis direction information to a microprocessor where thruster pulse timing is determined.

The second mode was designed for correction of small errors and has, with one exception, operated continuously since shortly after launch. This system employs a Torque Rod (3), a solenoid with a ferromagnetic core, which produces a substantial magnetic dipole moment "pulse" when current flows through the solenoid coils. This dipole moment interacts with the ambient magnetic field to produce attitude control torques. The Torque Rod is mounted with its axis perpendicular to the satellite spin vector permitting control of both spin rate and spin axis direction. A three axis fluxgate magnetometer provides measurement of the ambient magnetic field while the Fine Angle Sun Sensor (FASS), of NRL design (4), continuously monitors the unit vector to the sun in spacecraft coordinates. This data is passed to the microprocessor where attitude error angle and vehicle spin rate are calculated from the FASS data. It is in this microprocessor that the control law is implemented. Using data indicating the presence or absence of sun, spin axis error angle and spin rate, and the relative components of the magnetic field, decisions are made to correct spin rate or spin axis direction by pulsing the Torque Rod at the appropriate time, or, alternatively, make no correction.

ATTITUDE CONTROL LAW

The control law is a systematic decision making process which chooses to correct spin rate, spin axis direction or neither at any given time. Referring to the numbered steps in figure 2, step 1 consists of passing the current attitude condition and magnetic field vector to the control law algorithm within the microprocessor. Tolerances of the control system are stored in the microprocessor and can be changed by ground command. Since the sun is the attitude reference, step 2 decrees that no correction is attempted when the satellite is in eclipse. The magnitude of the spin axis error relative to the sun is compared to its allowable tolerance in step 3. If spin axis direction is within tolerance, no action of any kind is taken. It would seem reasonable to investigate the need for spin rate correction under this condition, but this is not done. When the error angle is small, the signal from the FASS is small and signal to noise considerations make accurate measurement of the spin rate difficult.

The magnetic field "Z" component, along the spin axis, and the "X" component perpendicular to that axis are used in step 4 to determine whether a spin axis direction or spin rate correction is attempted. If the "Z" magnetic component (B_z) is large compared to the "X" or "Y" components then production of a large torque in the X-Y plane, suitable for changing the spin axis direction, is possible since

$$\text{Torque} = \text{Magnetic dipole} \times B \text{ ambient.}$$

Alternatively, if B_z is small and B_x or B_y are large, production of a large torque along the spin axis, affecting the spin rate, is

avored. The ratio of B_z to B_x is interrogated after multiplication by a bias to favor correction of error angle at the possible expense of spin rate control. The LIPS III mission requires accurate sun pointing of the spin axis, but precise control of spin rate is unneeded. When this control law was implemented in the microprocessor software, the "Y" magnetic component was totally ignored, and only the "X" component was considered. This was done for simplicity during the system design and has worked very effectively.

Once the decision is made that a spin vector correction is required, step 5 is then used to set the polarity of the Torque Rod pulse based on the polarity of B_z .

If alternatively, a spin rate correction is favored in step 4, spin rate error is compared to its tolerance in step 6 to determine if a correction to increase or decrease spin rate is necessary. If a spin rate correction is required, the decision to increase or decrease spin rate is made in step 7. In step 8, the torque direction required to produce the correction in spin rate found in step 7 is determined by the polarity of B_x as measured by the magnetometer.

If no torque is applied due to the satellite being in eclipse, or attitude errors being in tolerance, the attitude system enters a shut down mode until the next test phase begins. If a correction is deemed necessary, an appropriately timed current pulse is applied to the Torque Rod. After the correction is applied, the system begins a new test sequence at step 1 with a new set of conditions. Closing the loop in this manner permits autonomous system operation.

DISCUSSION OF FLIGHT DATA

LIPS III has completed more than 10,000 revolutions during the two years since launch, and with the exception of two short periods each year, the attitude control system has performed well. Initially the spacecraft was required to be pointed at the sun with errors less than 1.0 degrees. This tolerance was tightened to ± 0.5 degrees and subsequently to $\pm .25$ degrees by ground command early in the mission. Thus, attitude control is considerably better than originally planned.

One weakness of this control scheme is its reliance on the presence of certain components of the magnetic field to control spin rate and direction. Recall that the torque rod produces a magnetic dipole moment which interacts with the magnetic field component along the spin axis to produce an error angle correcting torque. If B_z (along the spin axis) remains small over some period, control of spin direction is jeopardized. Two periods of poor performance have been observed during each of the two years of operation, when control of spin direction is lost, with errors building to several degrees. These periods last for several days to several weeks, and appear to be correlated with low average

values of B_z . Flight attitude data is shown in the solid lines of Fig. 3 and 4. Fig. 3 shows normal spin axis direction control up to day 565 when control is lost permitting errors to build. Shown on the same axes is a quantity called "Maximum Correction Ability". This is calculated by taking the product of B_z , the torque rod effective dipole moment and the torque rod pulse length and dividing by the vehicle spin angular momentum. This is then integrated over all periods when the control law might call for torque rod pulses during the day of interest. This represents the largest correction of spin direction possible during any given day with the available magnetic field, and it measures the effectiveness of that available field in this control system. Note from the figure that control is held until a minimum value of Correction Ability is reached, after which control is altogether lost. When Correction Ability again increases to this threshold, control is reestablished and errors are monotonically reduced. The same discussion describes the data of Fig. 4, where spin rate is plotted with "Maximum Spin Rate Correction Ability", a calculated quantity describing the maximum spin rate correction obtainable for the prevailing magnetic condition.

A threshold effect, similar to that pointed out above in the Maximum Correction Ability for spin axis direction, might be expected in the spin rate data shown in Fig. 4. No such effect is apparent there, however. Recall that the control law was written to maintain accurate sun pointing, with spin rate control of much less importance. Spin rate error correction in step 3 of the control law is chosen only when the magnetic field direction is strongly favorable, thus many opportunities for correction are missed, and no discernible threshold can be seen.

Comparison of Figures 3 and 4 shows that the loss of spin axis control is not due to a change in daily average magnetic field strength but in direction of the averaged vector, for when the average Z component is small in Fig. 3, the X component is large in Fig. 4 and vice versa. Careful comparison of these figures shows another result of control law design. No effort was made in the control laws to minimize a perturbation of spin rate when a correction is made to spin axis direction. The converse is also true; when the spin rate is corrected perturbations in direction are likely. From day 575 through day 588 spin axis correction ability (related to average B_z) is small, spin rate correction ability (average B_x) is large, and spin direction error is certainly not within tolerance. These are ideal conditions for execution of spin rate correction, and spin rate is seen in Fig. 4 to be well controlled during this period. The short period oscillations seen in spin axis error from day 577 through 588 indicate occasional attempts by the system to correct the spin axis, but with many interruptions to control spin rate, with accompanying perturbations of spin axis direction. These two effects likely combined to produce the short period oscillations of the axis.

CONCLUSION

The LIPS III satellite has collected over two years of experiment data. During this time the attitude control system has met or exceeded mission specification except for two time periods per year. Because the mission of the LIPS III satellite is to monitor solar cell degradation for long term space exposure, these periods of lost control do not effect the quality of experimental results, since losing experiment data over relatively short time periods will still allow the the experimenters to gather quantitative results during a multiyear mission.

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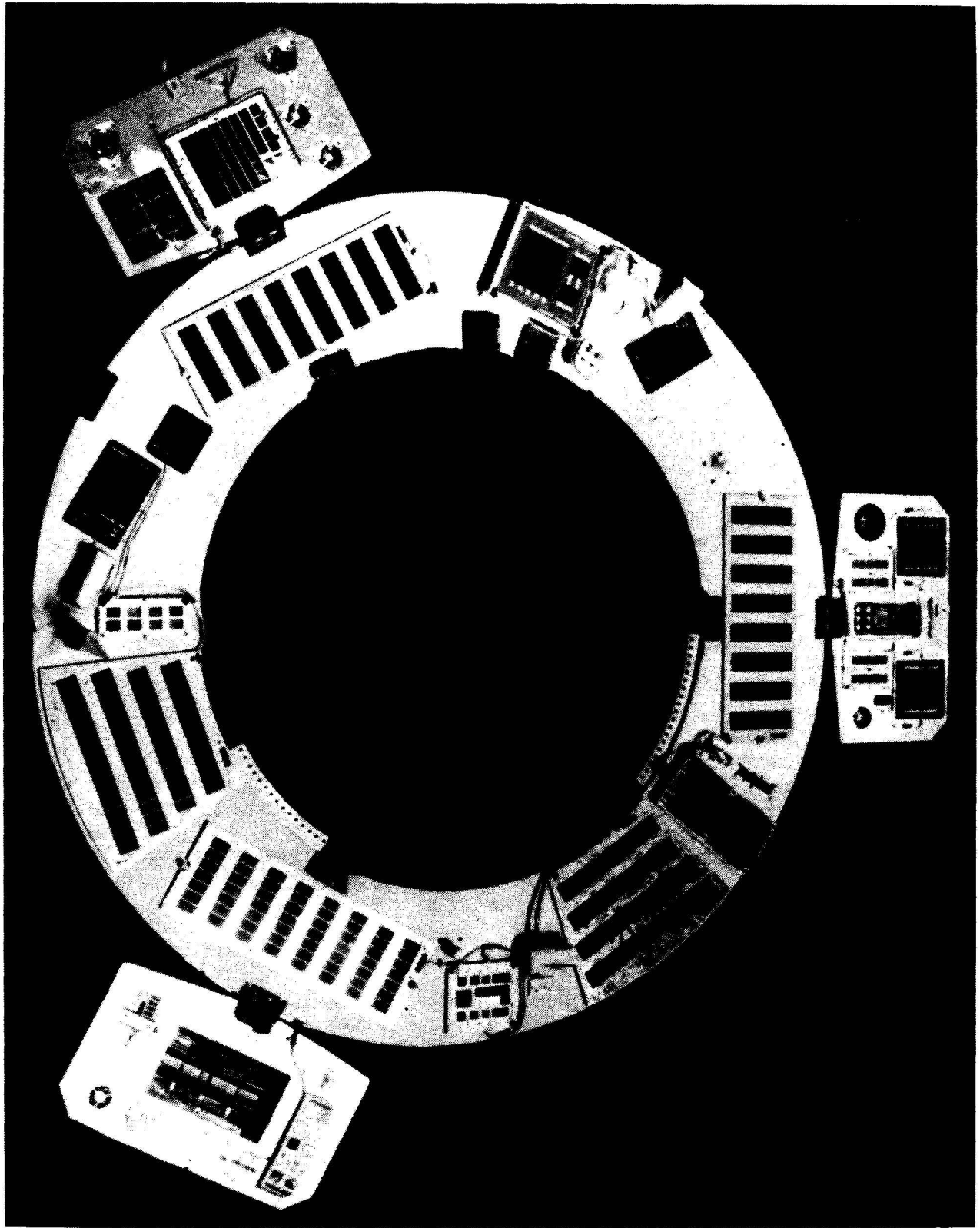
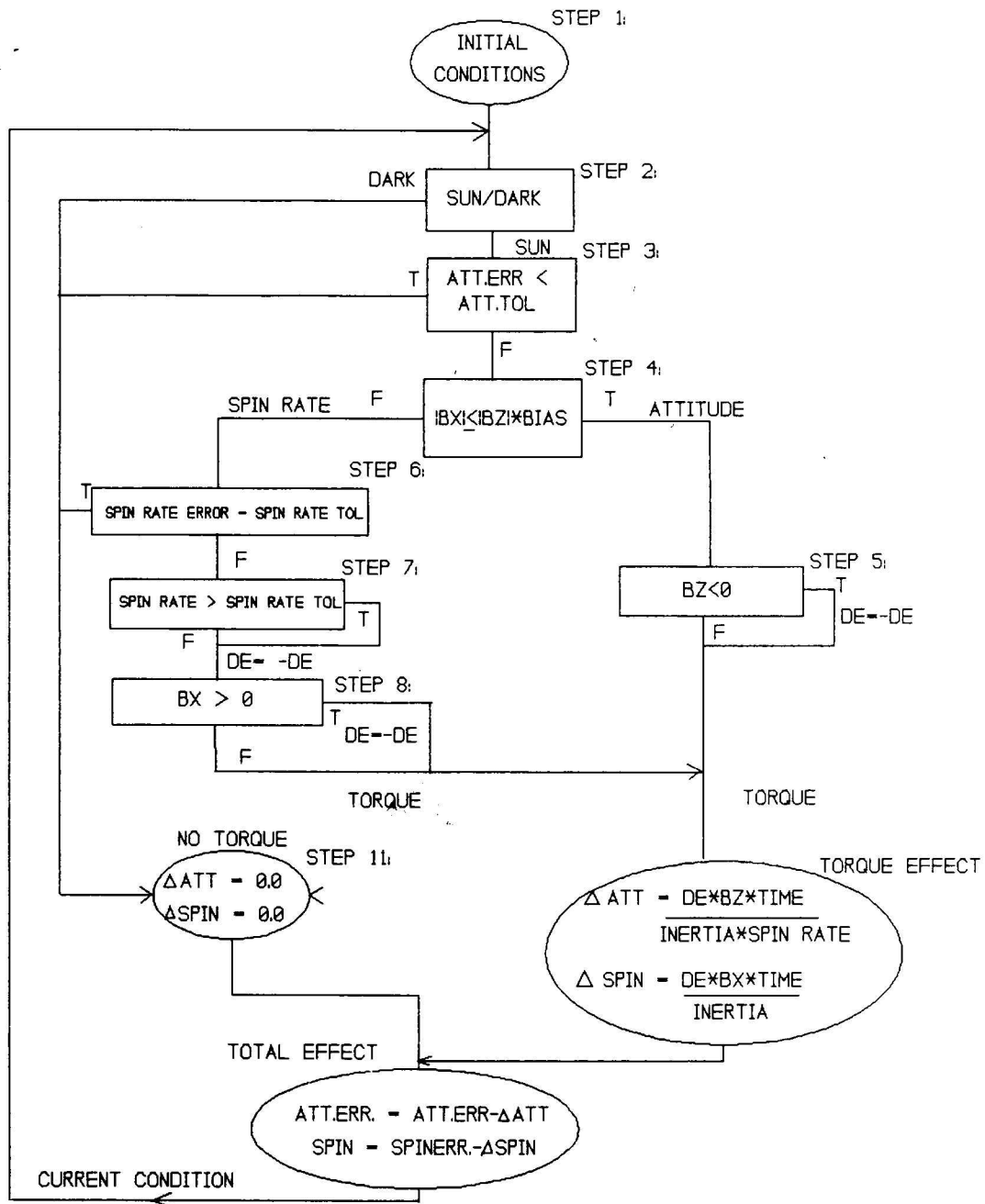


FIGURE 1. LIPS III SATELLITE

LIPS III ATTITUDE CONTROL FLOW CHART



BZ - "Z" COMPONENT OF AMBIENT FIELD ALONG THE SPIN AXIS
 BX - "X" COMPONENT OF AMBIENT FIELD PERPENDICULAR TO THE SPIN AXIS
 DE - EFFECTIVE MAGNETIC DIPOLE MOMENT

FIGURE 2. ATTITUDE CONTROL FLOW CHART

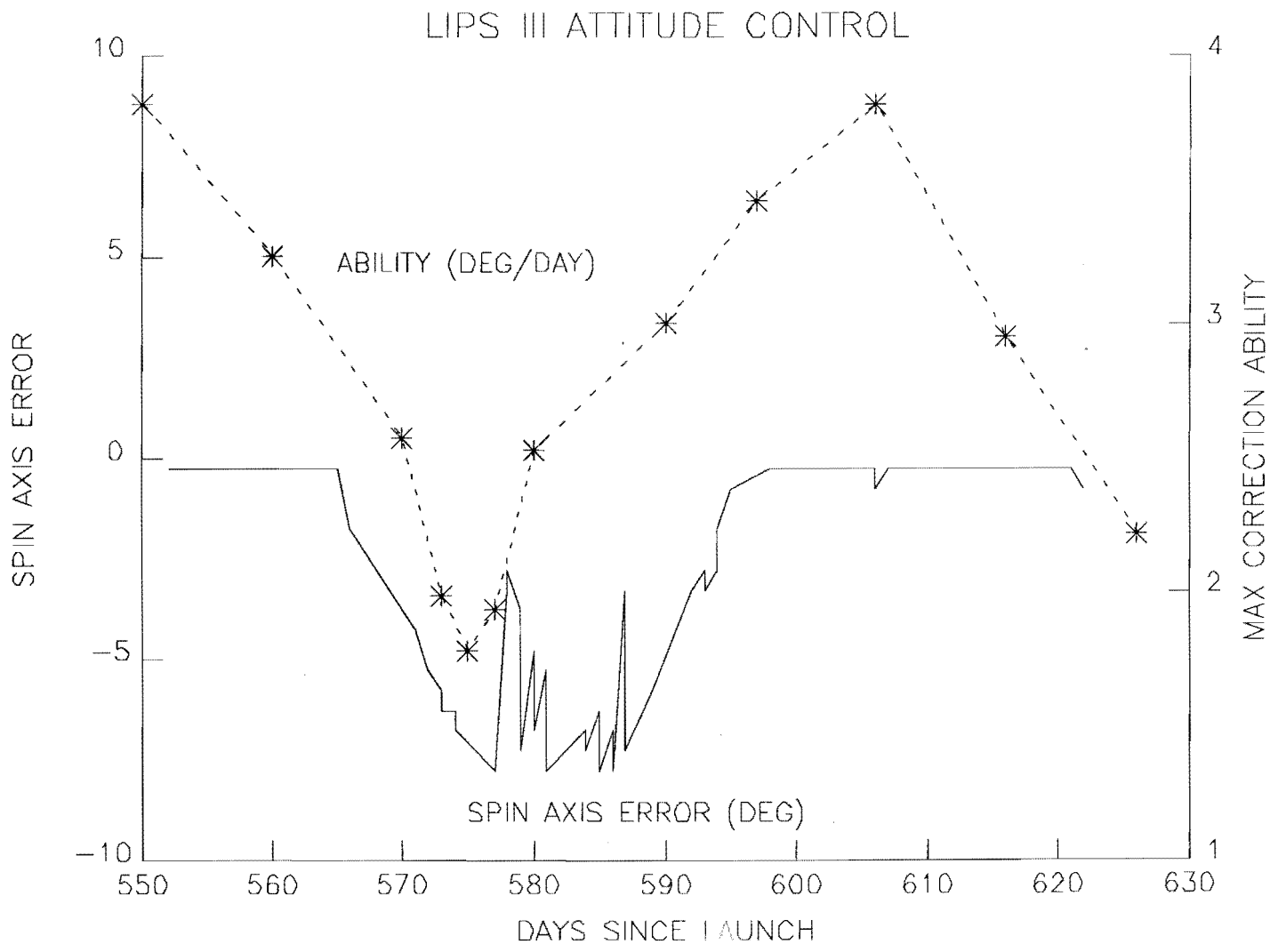


FIGURE 3. SPIN AXIS ERROR AND MAXIMUM CORRECTION ABILITY

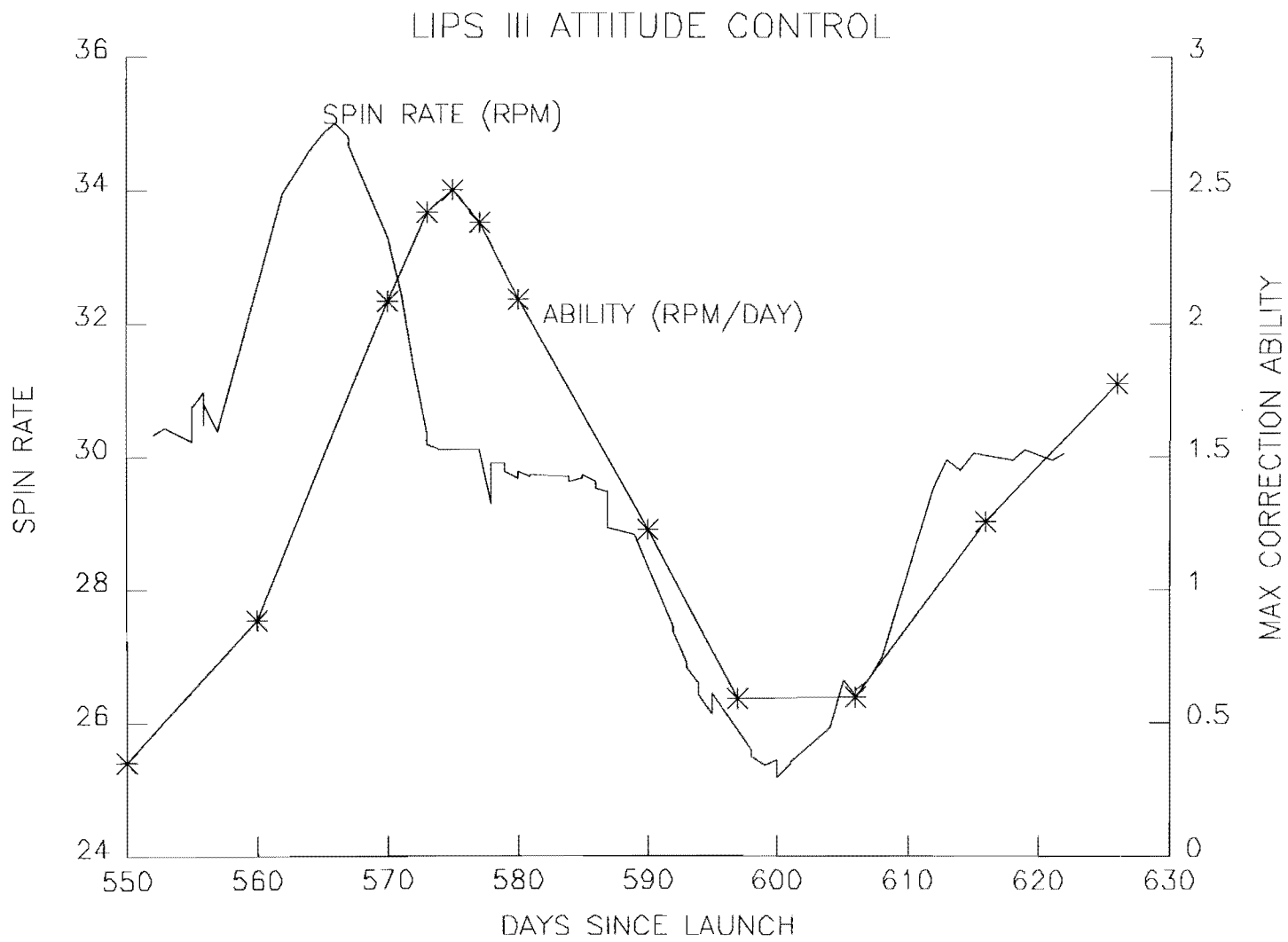


FIGURE 4. SPIN RATE AND MAXIMUM CORRECTION ABILITY