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THE HELIOS EXPERIMENT 5 ANTENNA MECHANISM

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SUMMARY

This paper describes the Experiment 5 Antenna Deployment problem on board HELIOS A, the failure analysis, and changes in design, test, and operation which led to a successful deployment of both antennas during the early HELIOS B mission phase.

INTRODUCTION

The two Experiment 5 antennas are installed normal to the axis of rotation close to the equatorial plane. The antennas form a dipole which is used by the Plasma and Radio Wave Experiment. It was planned to deploy both antennas at once, about 3 hours after the launch of HELIOS A. However, the observed anomalies:

- Only one of the motors was switched off automatically by the end switch
- The spacecraft spin rate change due to the change in the spacecraft spin moments of inertia was from 52.966 rpm to 51.072 rpm instead of 49.36 rpm
- One antenna element was grounded to the spacecraft structure

indicated that only one antenna was deployed to the full length of 14.75 meters.

Description of the Antenna Mechanism

Figure 1 shows the simplified antenna drive system. Each antenna mechanism is powered by an AC motor and inverter which drives the antenna storage spool and the pinch drive rollers. The pinch drive rollers are geared to deploy the antenna material at a rate faster than it can be unwrapped from the driven spool. A slip clutch in the gear train makes this possible. The intent is to keep any slack material from developing between the spool and the pinch drive rollers by keeping tension in the antenna material. A one-way clutch permits the pinch rollers to free wheel during antenna retraction. A potentiometer with a range of five volts is driven by the rotating storage spool. Microswitches with arms riding against the antenna material shut the motor off automatically at full extension or retraction. This shut-off is accomplished by having a slot cut near each end of the antenna material. As the slot passes under the microswitch arm, the arm drops through the slot and opens the circuit to the motor. These switches are located outboard of the pinch drive rollers in an area where the antenna material is forming into a cylinder around a form; therefore, the antenna exhibits some stiffness in this area — it is not a flat ribbon. The antenna itself is a 0.0038 cm (0.0015 inch) thick Be Cu strip heat-treated to form a 0.673 cm (0.265 inch) diameter cylinder along the longitudinal axis of the strip. After forming into a cylinder, the edges of the strip overlap each other by approximately 90°; there is no interlocking feature. The outboard of the mechanism housing contains an ion guard approximately two meters long when fully deployed. This ion guard consists of a thin rubber sleeve expanded around a relatively long, weak coil spring, i.e., a glorified vacuum cleaner hose about 5.1 cm (2.0 inches) in diameter. During and prior to launch, the ion guard is compressed into a housing about 25.4 cm (10 inches) long and held in place by a fitting on the end of the retracted antenna. Upon deployment of the antenna, the free end of the ion guard follows the antenna out until the ion guard has extended to its full length. The inboard end of the ion guard remains fixed to the front end of the mechanism housing. The antenna then continues to deploy through the extended ion guard until the antenna is fully deployed. The mechanism is enclosed in thin sheet aluminum dust covers to provide an RF shield between the antenna and noise originating inside the spacecraft. The antenna itself is also isolated electrically from the remainder of the mechanism.

Failure Analysis

The commands to deploy both Experiment 5 antennas were properly received and executed by the spacecraft; however, due to a malfunction within unit S/N006, the antenna element of this unit was not properly deployed. The analysis performed was based on the following parameters:

- Telemetered antenna length readout
- Solar aspect angle information
- Science data of Experiment 5
- Spacecraft spin rate information

The telemetered antenna length readout of S/N006 shows some unsteady behaviour during the early deployment phase. But looking into all transmitted data, it is obvious that the motor and gear train of S/N006 started up and operated until the 10-turn potentiometer was driven against its mechanical stop, which indicated an 18 cm longer antenna element. The nonessential bus current monitor provides information on the total current drawn by all consumers fed by this bus. Besides the experiments, the E-5 antennas also are powered from this line. The current is sampled by the A/D converter for short time intervals only. This, together with the current chopping caused by the D3A 400 Hz inverter, provides a very unsteady current reading.

From this information, it can be deduced that both units drew approximately the predicted current (0.4 A each) and that one unit automatically switched off after a run time of 32.5 min. These data also show clearly that the second unit did not switch off automatically. Only when the power disable command for the antenna units was executed did the current reading drop to the value it had prior to antenna deployment. The solar aspect angle changed during the deployment by 0.2°, which also indicates a malfunction of one antenna element because both antennas are mounted about 10 cm above the center of gravity plane. During deployment of the E-5 antennas the experiment was collecting data. The noise spectrum obtained shows two distinct changes: 3.4 minutes after the deploy initiation command the noise went down, while at 7.1 minutes after initiation the noise went up to approximately its original level. The spacecraft spin rate data turned out to be the best tool for locating the failure. Figure 2 shows the relative spin rate variation as a function of the deployed antenna length. The upper dashed line shows the variation for a nominal simultaneous deployment of both antennas, the center line shows the variation in spin rate for deployment of one antenna only, and the lower line indicates the actual measured spin rate change as a function of the transmitted antenna length read out. As can be seen by looking at all observed anomalies, the failure must have occurred in the early deployment phase during the simultaneous deployment of the ion guards with the antenna elements. In subsequent meetings, the possible failure modes were discussed, and the following were seen as the most probable failure modes:

A) Failures based on the interaction of ion guard and antenna element:

- The turns necessary to fold the ion guard affected the boom element during the first phase of deployment when the ion guard rotated back.

- Ion guard jammed during element deployment; suddenly it came free, hit the antenna tip mass, and damaged the antenna element or tip mass.

B) Failed mechanism:

- Clutch on the drive roller failed, then antenna element bloomed up between spool and drive roller device.

- Element damage caused high friction between moving element and ploy; again blooming up of the boom either between spool and drive roller or between drive roller and ploy.

- Loss of load on the pinch roller caused element blooming up between spool and drive roller due to slippage between drive roller and antenna element.

- Loss of alignment due to a bearing failure or misalignment after relubrication at Kennedy Space Center (KSC).

- During lubrication at KSC, some lubricant (grease) was put on the drive roller, causing slippage between drive roller and antenna element.

- Wrong lubricant in the worm gears: silicon lubricants tend to creep. Suggestion was made to change to the Krytox 243 grease for lubricating the worm gears.

As the outcome of the discussions, a test sequence was set up to simulate the possible failure modes. It was decided to perform the tests with specimens S/N001 and 002. Units 003/004/005 were reserved as flight and spare units. The following tests were performed at Fairchild in early March 1975:

1. Test sequence for S/N 001/002

1.1	(S/N 002)	Deploy element to 1.2 mark. At his point, release ion guard instantaneously (element pointing down, motor in operation).
1.2	(S/N 002)	Store ion guard with "4-turn twist." During deployment, measure rotation of element tip and ion guard tip.
1.3	(S/N 001)	Twist element on stationary mechanism. Observe reaction of element on ploy and microswitch travel.
1.4	(S/N 001)	Stall element during extension. Observe buckling of element between drive roller and ploy.
1.5	(S/N 001)	Check pressure between drive and pinch roller.
1.6	(S/N 001)	Determine torque range of clutch for proper deployment, with no pull force acting on element. When clutch fails (at minimum torque setting), continue mechanism operation for 80 sec minimum and record status. Attempt "retract" of antenna element.
1.7	(S/N 002)	Determine clutch setting and roller pressure.
1.8	(S/N 002)	Run full extend/retract load cycles: 2 cycles, room temperature, min/max load 4 cycles, -20 °C, min/max load 4 cycles, +50 °C, min/max load Operation in air, load ±50% of nominal, retraction under nominal load.
1.9	(S/N 002)	Determine clutch setting and roller pressure.

2. Component tests and other matters

    2.1 Measure torque versus temperature performance for a clutch set at center of acceptable torque range. See test 1.6 (S/N 001) and callout on respective drawing.

    2.2 Regarding the intended deletion of the ion guards, it was clearly stated that antenna deployment will be achieved.

3. Test sequence for S/N 003/004/005 (spare unit)

3.1 If deployable ion guards are deleted, remove detent spring.

3.2 Check torque setting of drive roller clutch and check pressure between drive and pinch roller.

3.3 Perform full-length element extension at ambient pressure and -20 °C and +50 °C ambient temperature, respectively. (If wear-out was shown to be a problem by test 1.8, only the cold cycle deployment is to be performed.) Perform visual inspection of element when fully deployed.

Results of the Failure Investigation Tests

The most probable failure mode which could have caused the problem on HELIOS A was found in tests No. 1.2 and 1.3 when the effect of the ion guard on the antenna element was determined. When the ion guard and the antenna system are assembled for S/C integration, the ion guard is compressed to about 30 cm for storage. During storage, it is additionally twisted axially through two to four turns due to the normal rotation of the helical spring inside the ion guard. When the ion guard deploys (simultaneously with the antenna element), it imparts a torque to the antenna element transmitted by the friction between ion guard end flange and antenna tip mass. When the direction of the ion guard torque is such that the antenna cross section tends to open, the antenna element is caused to bind at the end of the ploy. As a result, a blooming or buckle occurs between the drive roller and the ploy. When this effect was detected at Fairchild, approximately 5 seconds had elapsed between stall of element and power switch-off. The 5-second delay was enough to damage the antenna element. A possible explanation was that one antenna worked properly and that it was impossible to overcome the failure on board HELIOS A by retracting and deploying maneuvers of the S/N 006 unit. Figure 3 shows a close-up view of the failed mechanism after test step 1.2.

Modifications

A) Design Modifications

Based on S/C noise data obtained by Experiment 5a on board HELIOS A, the experimenter requested the elimination of the foldable ion guard. It should be replaced by a rigid electrically conducting tube of 10-cm diameter and 0.8-m length to provide electrostatic shielding of the antenna base from noise originated by the spacecraft solar array. This modification completely eliminated the interaction between ion guard and antenna element. Together with the elimination of the foldable ion guard, the detent spring inside the mechanism could be removed. This spring was necessary to hold the antenna element in its stored position during vibration loads, because of the pulling force of the ion guard on the antenna element.

B) Test Modifications

Two full extension/retraction tests were added on a system level: one prior to the spacecraft vibration test and one after all mechanical system tests, prior to encapsulation at Cape Kennedy.

C) Operational Modifications

A new operational procedure was worked out that makes it possible to stop the deployment if any anomaly occurs. It was planned to deploy both antennas on board HELIOS A at once. The new procedure was the following.

Before starting antenna deployment, operations E5 and E4 shall be turned on and S/C telemetry shall be in science data mode to monitor S/C spin rate for possible antenna short to ground and indication of motor current flow. It shall be monitored continuously, displaying nonessential bus current, antenna potentiometer reading, antenna motor switch status, S/C spin rate, E5b scientific data, and E4 scientific data. One operator shall continuously plot the above parameters on a chart which has the predicted values plotted on it. Deviations from predicted values will be cause to stop antenna deployment operations. A pre-arranged command shall be at the instant ready, stowed in the command queue, to turn off the antenna motor current.

Sequence of E5 Antenna Deployment

Step 1

Deploy the +Y antenna element to a length of 1 m, where it is possible to detect a change in the S/C spin rate and monitor all parameters.

Step 2

Deploy the -Y antenna element analogously to step 1.

Step 3

Deploy the +Y antenna element from 1 m to 2.5 m.

Step 4

Deploy the -Y antenna element from 1 m to 2.5 m.
Time for bow shock measurements.

Step 5

Deploy the +Y antenna element from 2.5 m to 14.4 m.

Step 6

Deploy the -Y antenna element from 2.5 m to 14.4 m.

Step 7

Deploy the +Y antenna element to the full length in steps of 50 to 60 mm, which correspond to a running time of 10 to 12 seconds. Monitor all parameters and perform an impedance measurement after each step. Deployment commands shall be terminated after a step increase of the impedance measurement or closure of the end switch.

Step 8

Deploy the -Y antenna element analogously to step 7.

The Inflight Deployment of the HELIOS B Experiment 5 Antennas

Steps 1 to 6 of the deployment were performed successfully on the first day of the HELIOS B mission. All above-mentioned parameters were monitored and plotted and did not deviate from the predicted values. Figure 4 shows the plot of the spacecraft spin rate and solar deviation angle as function of deployed antenna length. Steps 7 and 8 were performed successfully during the third Goldstone pass on the third day of the mission.

Acknowledgement

The author thanks Gordon Smith and Richard Kramer of Fairchild Industries and Dr. Wunderer of Messerschmitt-Bölkow-Blohm for the excellent cooperation which made it possible to locate the problem and introduce, in a short time, changes to prevent a similar failure on board HELIOS B.

References

1 MBB Procurement Specification Extensible Antenna, HELIOS Spacecraft.

2 Dr. Wunderer (MBB), Failure Analysis D3A S/N 006.

3 E. Angulo/W. Sours (GSFC), Memorandum, "Summary of the HELIOS Experiment 5 Antenna Problems."

4 E. Müller (GfW), E5 Antenna Problem Investigations.

5 Fairchild/MBB, Test procedure for failure investigation tests with S/N 001/002.

6 E. Müller, Test report of failure investigation tests.

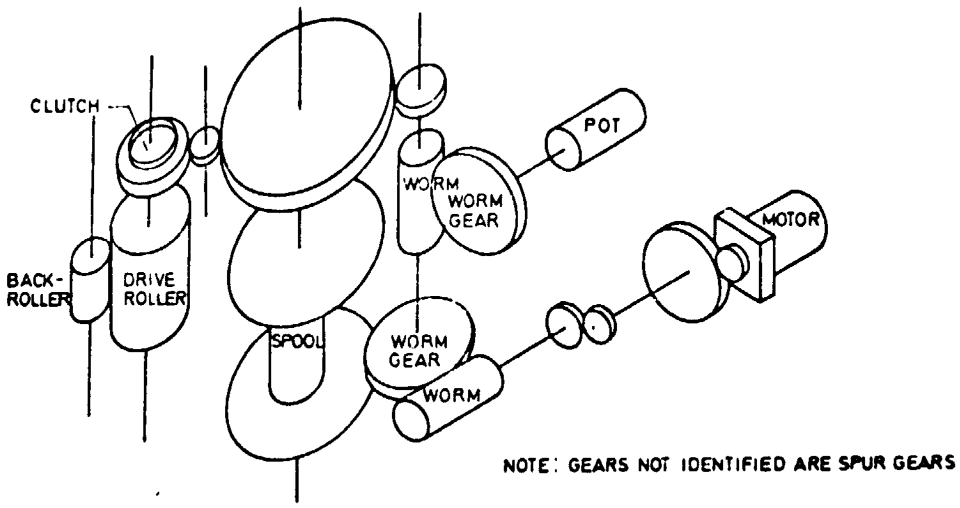

Fig. 1 Antenna drive system

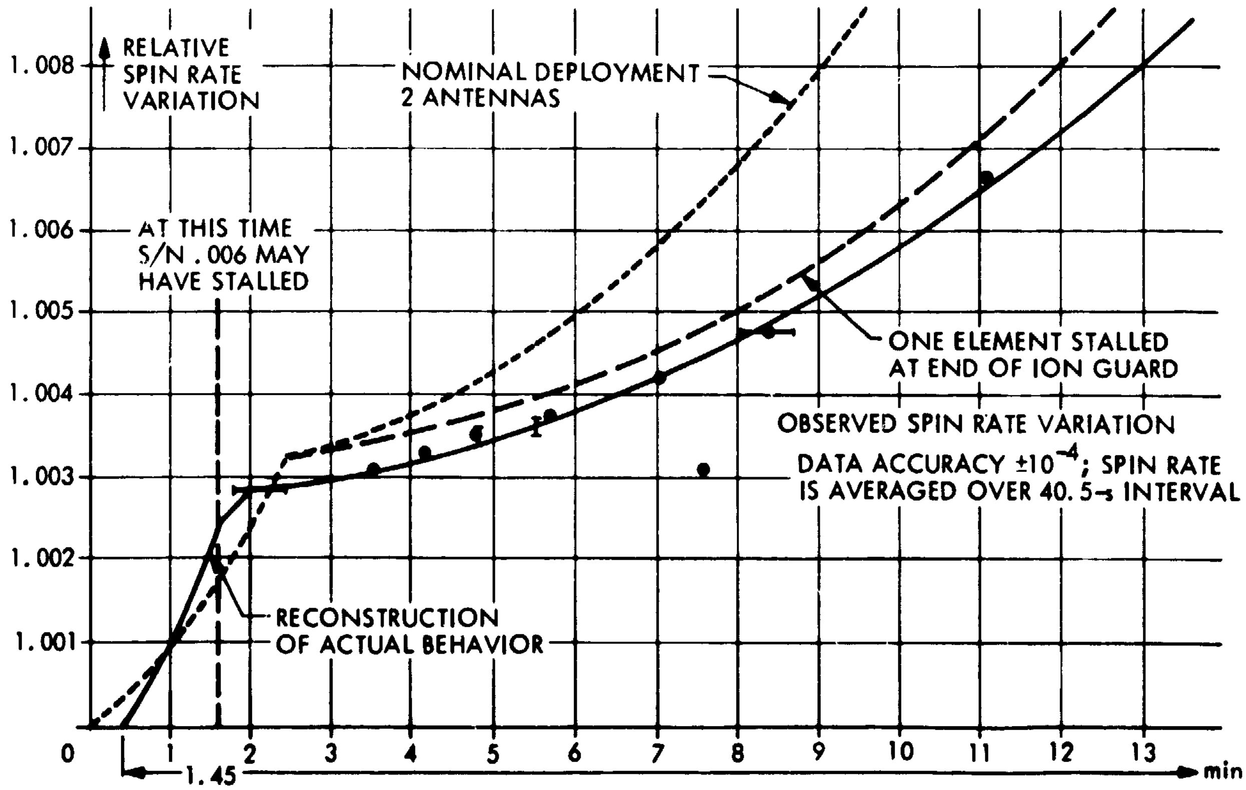

Fig. 2 Spin rate variation on board HELIOS A as function of time

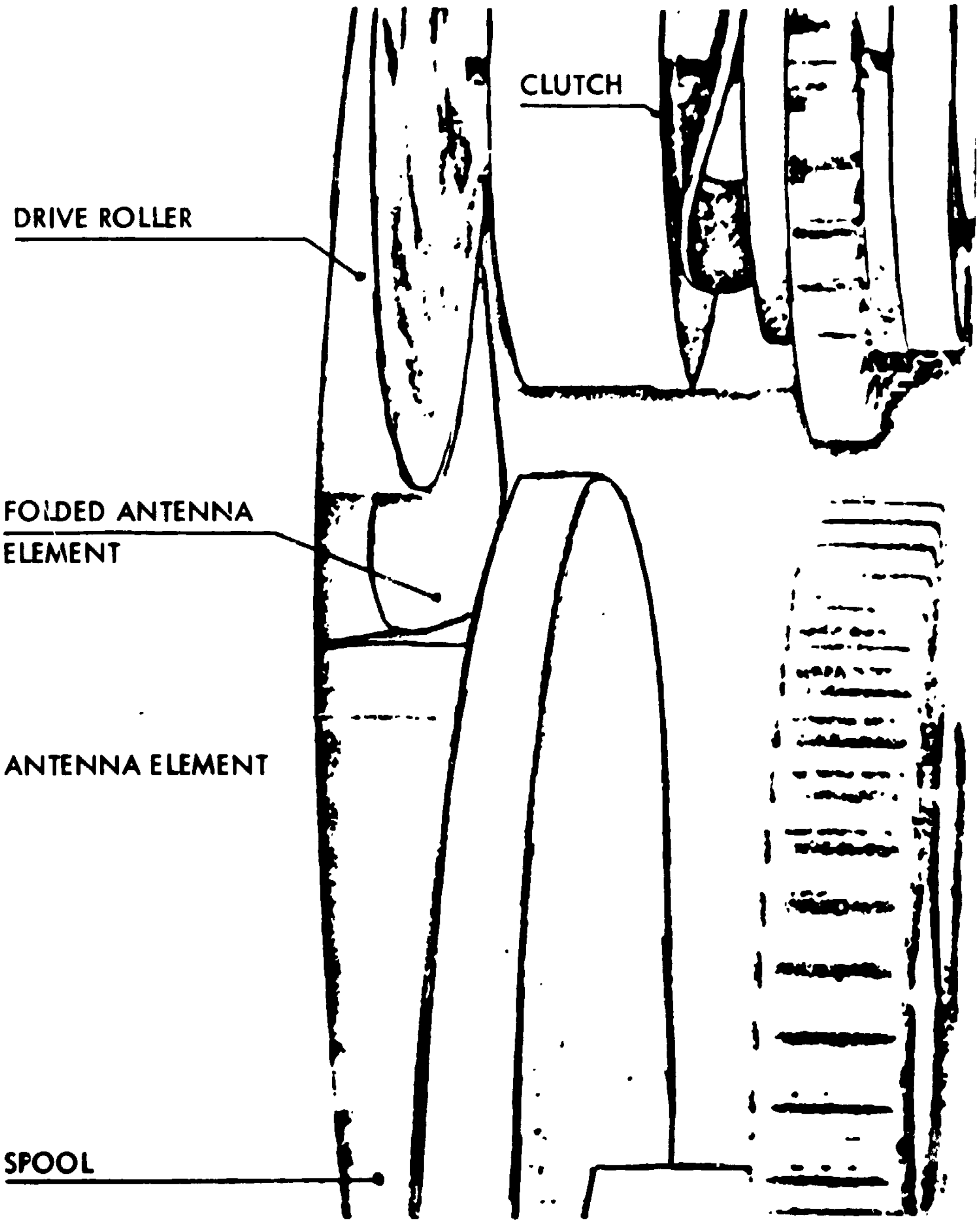

Fig. 3 Close-up view of the failed mechanism after test step 1.2

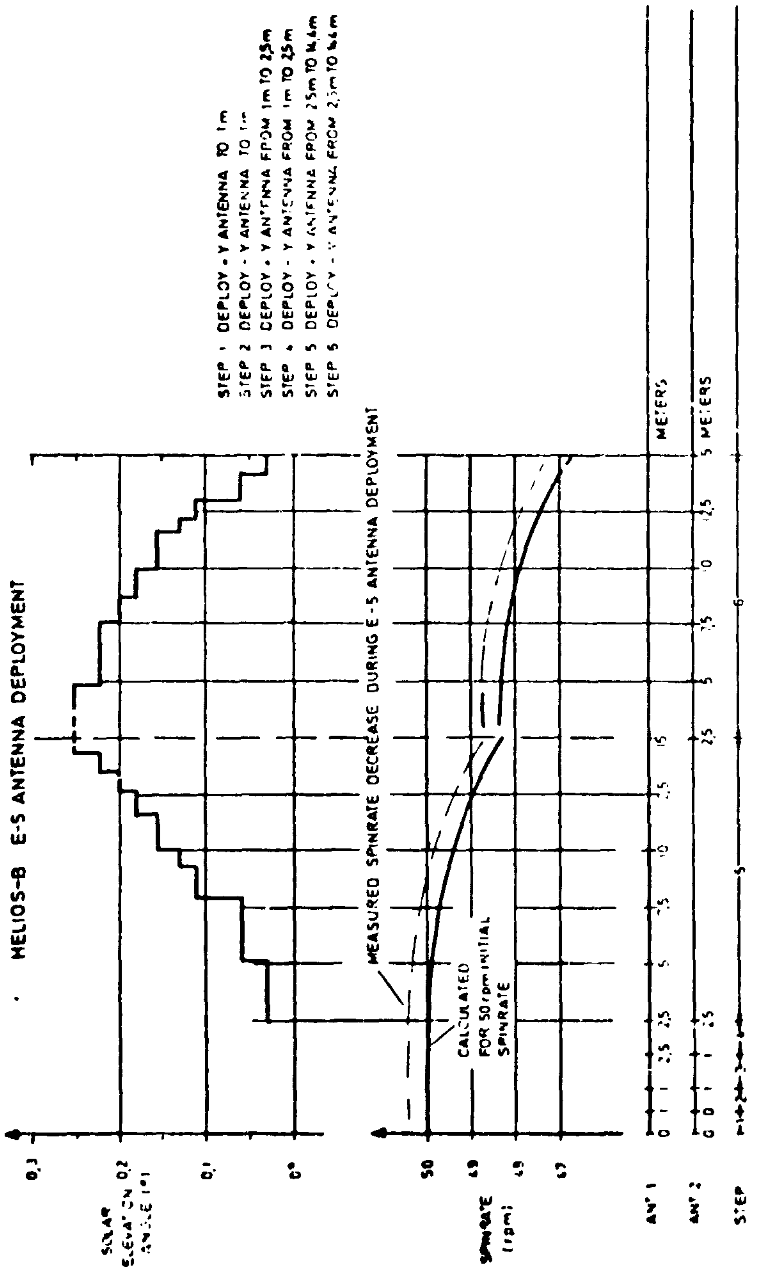

Fig. 4 HELIOS B Experiment 5 antenna deployment steps 1 to 6