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PERFORMANCE OF THE SERT II SPACECRAFT AFTER $4\frac{1}{2}$ YEARS IN SPACE

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ABSTRACT

The second Space Electric Rocket Test (SERT II) satellite, launched in February, 1970, has recently been reactivated after being dormant for a year. The satellite orientation was changed to spin stabilization in 1973 and the satellite is now coning such that the active side of the solar arrays move into and out of the sun every 23 days. There is sufficient power to operate the ion thrusters for seven days of this cycle. The #2 ion thruster system has been successfully operated; the electrical short in the accelerating grids had cleared during the year long dormant phase.

SUMMARY

The second Space Electric Rocket Test (SERT II) satellite, launched in February, 1970, has recently been reactivated after being dormant for a year. At the conclusion of the 1973 flight operations, the satellite was converted from gravity-gradient to spin stabilization. When the satellite was reactivated this August, it was found that there was a coning of the spin axis such that the active side of the solar arrays was moving into and out of the sunlight about every 23 days thus limiting the satellite operational periods.

The high voltage short between the accelerating grids of the #2 ion thruster system has cleared and this thruster has been operated at the design set points. The high voltage short in the #1 ion thruster still exists. Other spacecraft systems have been exercised and found to be operational.

INTRODUCTION

The second Space Electric Rocket Test (SERT II) satellite was launched from the Western Test Range into a 540 n.m. polar orbit on February 3, 1970. The satellite was gravity gradient stabilized with the ion thrusters pointing towards the Earth. The orbit plane was at the Earth's terminator and precessed to follow the Sun.

The main objective of the satellite was to provide a flight demonstration of the operation of the 15 centimeter ion thruster system for a period of six months or longer. The #1 ion thruster system was operated for approximately $5\frac{1}{2}$ months and the #2 thruster system was then operated for an additional three months. Both thrusters failed when an electric short developed between the accelerating grids of the thrusters preventing the application of the high voltages required for the thruster operation. The main discharge and neutralizer discharge could be initiated in both thrusters, but the ions could not be extracted and accelerated.

The satellite was operated continuously until February, 1972, when it was commanded off. The satellite was first reactivated in May, 1973 and for a three month period the main and neutralizer discharge in both thrusters were cycled to demonstrate the multiple restart capability of the ion thruster. By this time, the orbit plane, and spacecraft solar panels, had precessed to a 60^{o} sun angle. Therefore, the decision was made to spin the satellite with the spin axis perpendicular to the longitudinal axis of the satellite (normal to the solar arrays) and generally pointing towards the Sun. This would allow for a period of activation of the satellite on a yearly basis.

The satellite was commanded off again in August, 1973. The satellite system status by that time was as follows:

- Both ion thrusters - high voltage shorts prevented full operation but discharges could be initiated on command.
- Space probe - failed nine months after launch.
- Miniature electrostatic accelerometer - failed in first month after launch.
- #1 thruster system beam probe - stuck in full rotated position.
- Battery - failed during dormant period.
- Tape recorder #1 - failed prior to the 1972 shut down.
- Three spacecraft temperature sensors - failure of common signal conditioning regulator during first dormant period.
- All other systems functional.

The satellite was reactivated on August 15, 1974. It is the purpose of this paper to document the status of the satellite in this latest reactivation. The operating conditions of the satellite systems and the component operational times accumulated in the $4\frac{1}{2}$ year life of the satellite will be given.

DISCUSSION OF THE SPACECRAFT PERFORMANCE

SPACECRAFT ATTITUDE

The SERT II spacecraft was initially placed in a nearly sun synchronous orbit and stabilized, as shown in figures 1 and 2, by a semi-passive gravity-gradient, control moment gyro (CMG) system. During the first experiment period (1970) the orbit altitude was altered so that the orbit precession rate was changed to 341° per year. By September of 1973 the situation was as shown in figure 3. The sun incidence angle measured from the array normal was about 65°. Thus, part of each orbit was in shadow. Given the 341°/year orbit precession rate it was apparent that within the next year SERT II would lose power and experiment capability.

In an attempt to insure experiment capability the following year, the spacecraft pitch axis was misaligned from the orbit normal and the spacecraft then spin stabilized about that axis. The spacecraft spin rate has been determined to be 4°/second. The satellite cold gas back-up attitude control system (BACS) was used for this maneuver. In this configuration the spacecraft pitch axis (array normal) trajectory in space is a cone about the orbit normal. Figure 4 shows the present geometry. The X_o - Y_o plane is the orbit plane, and Z_o is the orbit normal. The pitch axis precession cone angle is about 75° and the precession rate is about 1.14°/orbit. The pitch axis precession period is about 23 days of which seven to ten days may be used for experiments. Maximum power is achieved when the pitch axis is most closely aligned with the sun. Figure 4 shows the

September 1974 misalignment to be only about 10°. Note that part of each orbit is still in the Earth's shadow. Therefore, the experiment operational time is limited to approximately 30 minutes of real-time data each orbit.

ION THRUSTER SYSTEM PERFORMANCE

System 1 - The power conditioner operated normally; thruster propellant tank pressures were normal. Restarting of the neutralizer and main discharge was successful. An attempt to establish high voltages was unsuccessful; thruster grids still remained shorted.

System 2 - The power conditioner operated normally; thruster propellant tank pressures were normal. Restarting of the neutralizer and main discharge was successful. An Attempt to establish high voltages was also successful; with thruster grids no longer shorted. This thruster had failed October 17, 1970 after 2,010 hours of operation. Presently beam currents as high as 200 MA have been recorded. Operation of the thruster at the 250 MA beam set points was not possible due to the present solar power limitations. The successful restart was the first attempt to establish high voltages on the thruster since the spacecraft orientation was changed from gravity-gradient to spin stabilization.

TELEMETRY AND POWER SYSTEM PERFORMANCE

The telemetry, command and power systems of the satellite continue to function properly. No new anomalies have been found in these systems.

The maximum total solar array power observed during this restart is 800 watts. This is probably close to the maximum power available at that time. The maximum thruster array current recorded is 14 amps, and the array voltage has varied from 72 volts open circuit to 54 volts under load.

Although the housekeeping loads are essentially constant at 50 watts, the solar array is configured in the emergency power mode to provide reserve housekeeping power. This ties (via diodes) the thruster array center tap to the housekeeping array. This also changes the grounding of the thruster array from the center tap to the negative terminal.

An estimate of the minimum sun angle, made using the maximum observed array loads, yields an angle of 20 degrees or less. Exact array degradation (estimated at 35 percent), array temperature variations, and telemetry sampling constraints all add uncertainty to the calculated sun angle.

During the period when the active side of the solar array was facing away from the sun, the satellite transmitter was left on. A signal was received which indicated that the solar arrays were receiving sufficient illumination to provide power to the transmitter. The pattern of transmitter on and off indicated that this illumination came from the earth albedo. The data handling system has been activated when the satellite is in this mode and the data verifies that the satellite is backwards to the sun.

THERMAL CONTROL SYSTEM PERFORMANCE

The passive thermal control system for the SERT II satellite was originally designed to satisfy the requirements of a gravity gradient stabilized spacecraft that had a fixed orientation relative to the sun and the earth. This spacecraft was also to be in a sun-synchronous orbit so that there would be no shadowing by the earth for the nominal mission life. The SERT II satellite is now spin stabilized and in an orbit such that it is shadowed for about 35 minutes of each orbit. Even so, the thermal control system is still functioning properly after the $4\frac{1}{2}$ years in space. The component temperatures are lower, corresponding to the lowered environmental heat input, but are still within reasonable limits.

Temperature data that has been collected since the reacquisition of the satellite has confirmed that the satellite is cycling relative to the sun. The data for selected sensors is shown in figure 5. The main solar array, reflector errosion experiment disc (REX DISC I) and high temperature solar cell contamination experiment (see figure 6) are essentially thermally isolated and have rapid response to the environmental heating. This data was obtained when the satellite was in the northern hemisphere (real time data from Winkfield, England), and it is believed that the sensors were responding primarily to solar heating. Therefore, these temperatures show that the satellite is moving relative to the sun and that the maximum solar incidence on the main solar arrays occurs every 23 days. Extrapolation from this data also shows that there should be sufficient solar illumination to operate the satellite for between 9 and 10 days centered around the peak solar incidence point.

The temperature cycles in any one orbit were also obtained from the on-board tape recorder data. The recorder was turned on as soon as the satellite was acquired on a given orbit and allowed to operate until it was shut off when the solar arrays were shadowed over the South Pole. The data obtained for selected sensors (see figure 6) in the orbit corresponding to the peak solar incidence in each of the two cycles observed to date is shown in figure 7. The thermally isolated sensor data indicates peaks in the orbital heating. This peak in the main solar array temperature occurs at the approximate time that the satellite is crossing the equator. This would indicate that the solar array is receiving additional heating from earth thermal and albedo at the back of the array. The orientation of the contamination experiment solar cell and the REX disc is such that the body of the satellite could shield the sensors from some of this heat input and thereby shift its temperature peaks. The spacecraft sunside panel is thermally coupled to the rest of the satellite and is typical of the temperatures in the spacecraft body. There is very little change in these temperatures over the orbit. The orbital temperature cycles were obtained for times other than the peak solar incidence. While the temperatures were lower, corresponding to the lower environmental heating, the trends were the same and the thermal cycles were not severe enough to cause concern.

As part of the original thermal control system, heaters were adhesively bonded to the power conditioning radiator panels which are located on the nominally shaded portion of the satellite. These heaters were exercised during this reacquisition of the satellite and were found to be operational. The current requirement for these heaters was found to be the same as that required at launch $4\frac{1}{2}$ years ago. The temperatures of the power conditioning radiators indicates that the heaters are still bonded in place.

SELECTED COMPONENT OPERATING TIME

The operational hours on selected components are given in the table below. The total orbital life of SERT II satellite to date is approximately 40,000 hours.

OPERATIONAL TIME (HOURS)	COMPONENT
35,000	Command system, switching mode regulators, and command receivers.
25,000	Transmitter 1.
25,000	Battery charger, (turned off when battery failed).
23,000	Data system and instrumentation.
20,000	Main inverter and CMG's 3 and 4.
5,000	Standby inverter and CMG's 1 and 2.
4,000	Power conditioner 1.
3,000	Power conditioner 2.
1,500	Transmitter 2.

CONCLUDING REMARKS

The SERT II satellite has been successfully reactivated for the second time in the $4\frac{1}{2}$ years since launch. The satellite had been dormant for a year since the first reactivation. Spacecraft systems have been exercised and found to be operational.

Analysis of the spacecraft attitude and various power and temperature monitors has shown that the spacecraft is precessing at about 1.1 degrees per orbit or 15 degrees per day. As a result of this precession the solar array sun angle varies from about 10 degrees to 120 degrees (sun on backside of array) and returns to 10 degrees once every 23 days.

The electrical short in the accelerating grids of the #2 ion thruster has cleared and this thruster has been operated at the design set points within the limitations of available power. The #1 ion thruster electrical short still exists. Both power processors for the thrusters are still operational.

The housekeeping systems still operate as well as they did one year ago. Components in this system are exceeding 35,000 hours of operation in the $4\frac{1}{2}$ years in the space environment.

The passive thermal control system of the SERT II satellite is still functional, maintaining the spacecraft temperatures within operational limits even though the satellite orientation has changed from that used to establish the design. The temperature data has been used to confirm that the satellite is cycling relative to the sun with a period of about 23 days.

APPENDIX

Chronology of SERT II operations during the latest reactivation:

August 15, 1974	Located spacecraft; commanded on data system and placed housekeeping systems in operational status. All solar array temperatures were below 100 degrees F., but at least 400 watts of solar array power were available.
August 16, 1974	Operated horizon scanner to obtain information on spacecraft attitude. Spin rate was determined to be about .7 rpm. The calculated rate was .8 rpm. All solar array temperatures were below 100 degrees F.
August 17, 1974	Spacecraft temperatures increased with the solar array at 100 degrees F.
August 19, 1974	Established a discharge on both thruster neutralizers and main cathodes. Both power conditioners operated normally. Solar array temperatures averaged 120 degrees F., indicating improved sun angle.
August 20, 1974	Attempted to establish high voltages on thruster system No. 1; short still caused overload.
	Commanding high voltages on thruster system No. 2 revealed short had cleared; high voltages came up.
	Thruster operated at a 80 MA beam prior to being commanded off.

Solar array temperatures averaged 140 degrees F., indicating a further decrease in sun angle.

August 21, 1974 Two successful starts were completed on thruster 2. Highest observed power levels were 640 watts into the power conditioner and 50 watts into house-keeping systems.

Solar array temperatures averaged 115 degrees F., indicating increased sun angle.

August 22, 1974 Schedule was same as previous day's operation with thruster 2. Power conditioner trip outs occurred as a result of over loading the solar array.

Thruster shut down at end of pass.

Solar array temperatures averaged 110 degrees F., indicating further degradation of sun angle.

August 23, 1974 Thruster 2 was placed in propellant mode and left on for sunlit portion of orbit (about 55 minutes). Ran neutralizer bias experiment; swept beam probe 2 several times. Beam probe one filament failed to light. Horizon scanner was left on for orbit. Data was recorded on spacecraft recorder for play-back during pass on following orbit.

On a following pass the tape recorder was played back and placed back in record. The thruster was commanded into operating mode and left on for the sunlit portion of orbit. Data indicated the flooded thruster condition had been corrected. All solar array temperatures were below 100 degrees F., sun angle was still increasing.

On a third pass the playback of the spacecraft tape recorder indicated that the thruster operated in an abnormal manner during the orbit. Beam currents of five to ten MA were observed, and the discharge was not stable. A change in thruster set points may be required.

August 26, 1974	Negative Acquisition
August 27, 1974	Negative Acquisition
August 28, 1974	2 minute 21 second transmitter operation. Transmitter came on near end of Winkfield pass and operated to LOS.
August 29, 1974	8 minute 17 second transmitter operation in Winkfield pass to LOS. 13 minute 14 second transmitter operation in Rosman pass to LOS.
August 30, 1974	10 minute 31 second and 10 minute 33 second transmitter operation in two Winkfield passes to LOS.

September 3, 1974 — Data handling turned on, but power was too low for normal operations.

September 4, 1974 — Monitored transmitter operation. Had LOS 13 minutes early at Ascension.

September 5, 1974 — Monitored transmitter operation. LOS 3 minutes early at Winkfield. Negative acquisition at Ascension.

September 6, 1974 — Monitored transmitter operation. Had a complete pass with Winkfield. Five minutes after the start of the Ascension pass, the transmitter went off. After this until LOS at the predicted time, the transmitter cycled on and off with a period of approximately 90 seconds. If this is shadowing of the solar array due to the spin of the spacecraft, it would indicate a spin rate of .67 rpm which correlates well with the measured rate of .7 rpm.

September 9, 1974 — Monitored transmitter operation. First pass AGC data indicated probable good power level available, so data handling and S/C instrumentation were turned on during the second pass. Adequate power was verified, and the MESA experiment was turned on during the third pass. MESA data was off scale possibly due to the acceleration due to spinning.

September 10, 1974 Two successful operations of thruster 2 were obtained. The thruster was started and put into the operate mode and left for the full sunlit part if the orbit. Data for the orbit was recorded on tape recorder 2, and played back in subsequent orbits. The thruster operated with a stable beam current controlled at 85 MA.

September 11, 1974 Thruster 2 was operated with stable beam currents of 85 and 200 MA. When commanded to 250 MA beam current, the solar array was overloaded and the power conditioner tripped out. The RFI experiment was commanded on but was inoperative. Tape recorder 2 did not play back when commands were sent in the first pass. It was then turned off. Operated properly in the subsequent pass. Beam probe 2 was swept with neutralizer 2 biased at 0, -25, and -50 volts.

September 12, 1974 All attempts to operate thruster 2 were unsuccessful due to power conditioner trip-out because of excessive beam current. Tape recorder 2 did not play back on first attempt and was turned off. On subsequent pass it operated normally. Thruster 1 neutralizer was lit and beam probe 2 was swept.

September 13, 1974 Attempts to operate thruster 2 repeat previous days results. Thruster 2 neutralizer was lit and beam probe 2 was swept with neutralizer 2 biased at 0,

-25, and -50 volts. Turned spacecraft instrumentation and data handling off in preparation for loss of solar power.

September 16, 1974 Spacecraft tape recorder played back (previous days data) command off data system in preparation for loss of solar power.

September 17-20, 1974
No Commands.

September 23-25, 1974
Command data handling on twice each day to obtain data with sun on rear of solar panels. Spacecraft operated off of earth albedo with 40 to 50 watts of housekeeping loads.

September 26-29, 1974
No Commands.

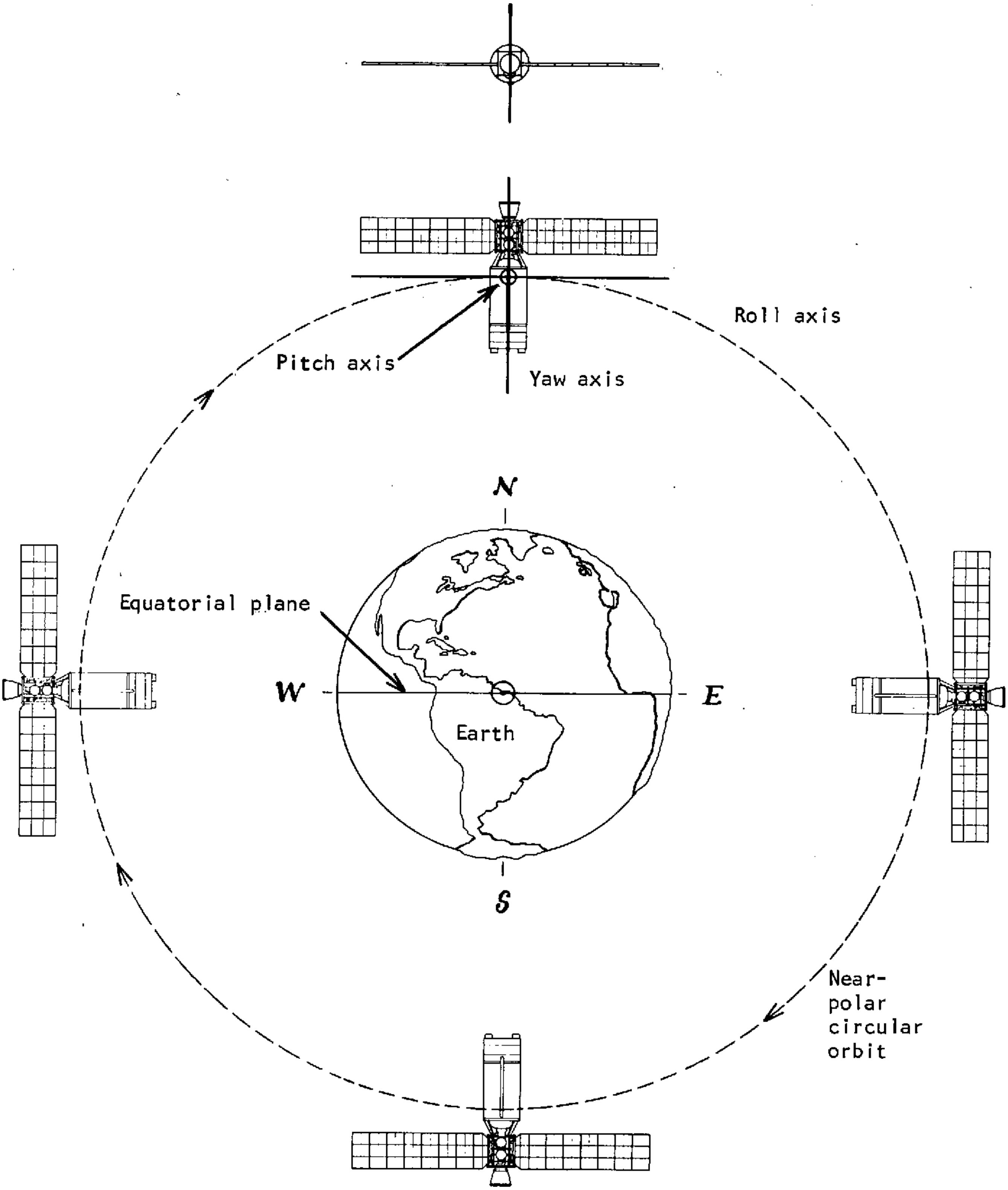

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Figure 1. - SERT II spacecraft-vehicle coordinate system in orbit viewed from Sun for spring launch and sunrise orbit injection.

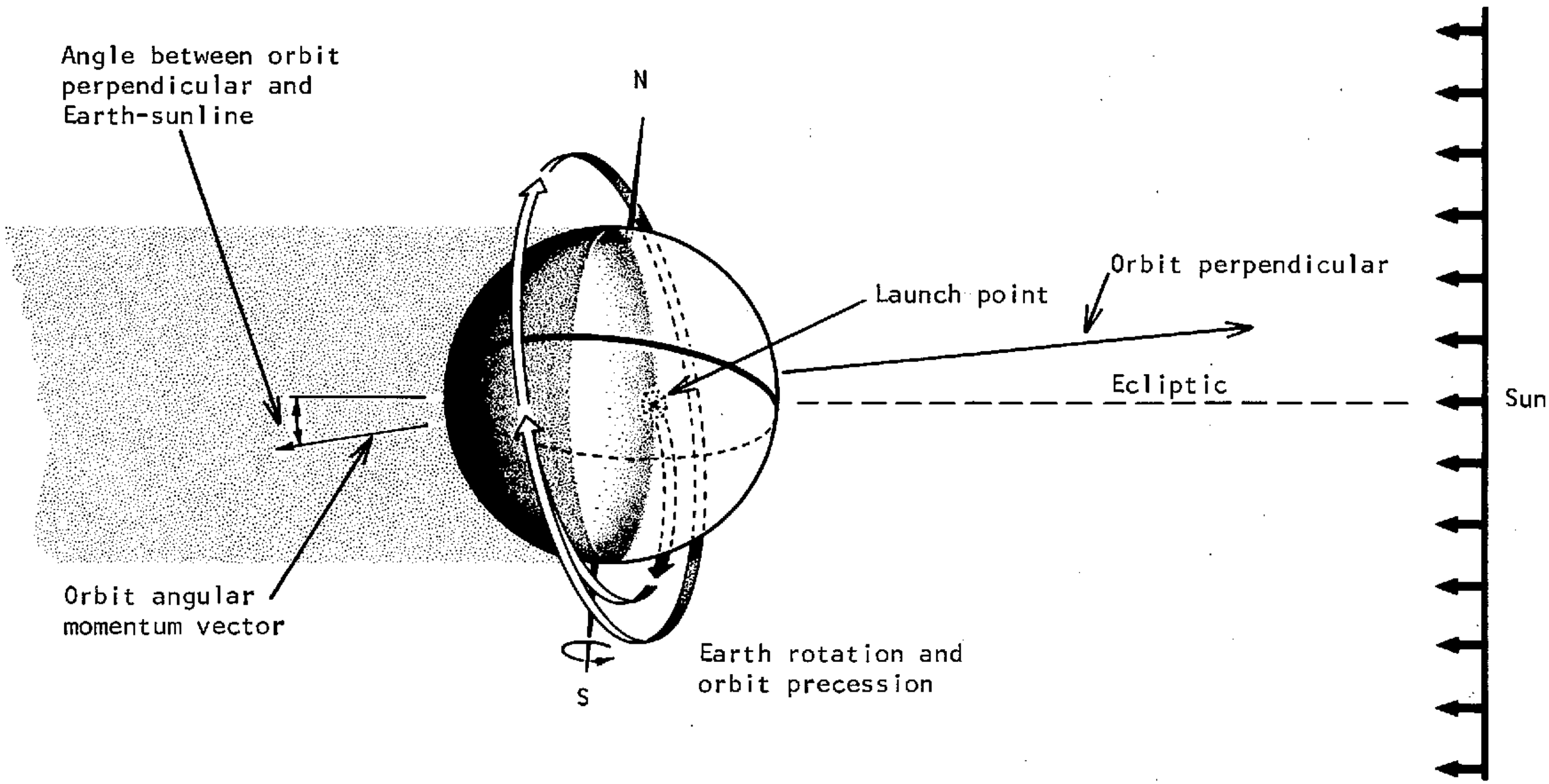

Figure 2. - Orbit-plane - Sun geometry for spring-sunset launch.

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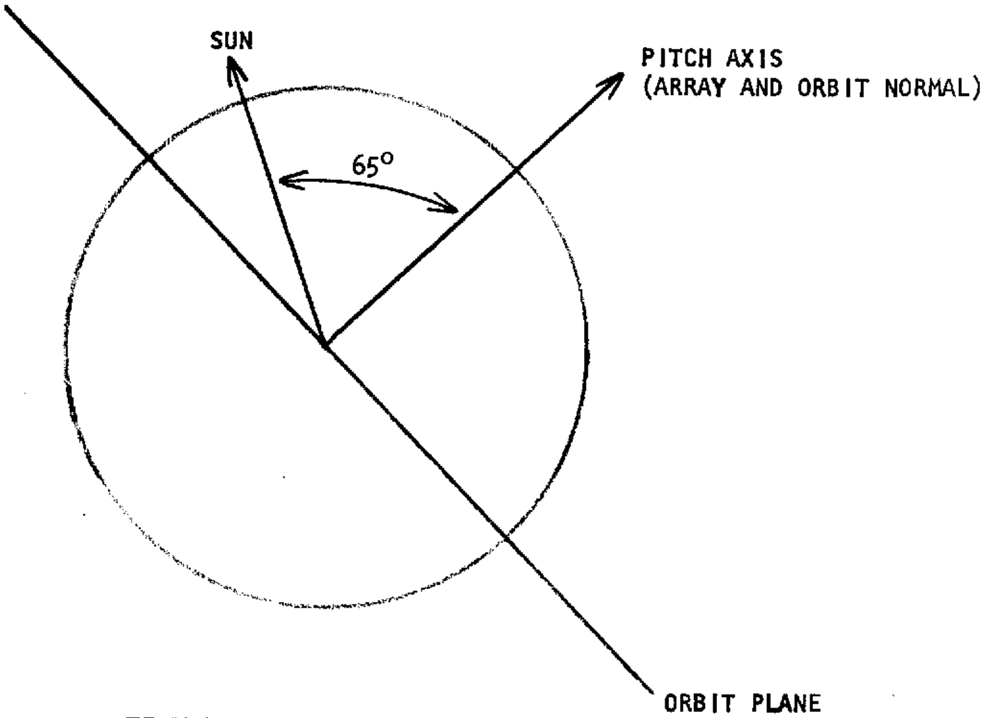

FIGURE 3 SEPTEMBER 1973 GEOMETRY.

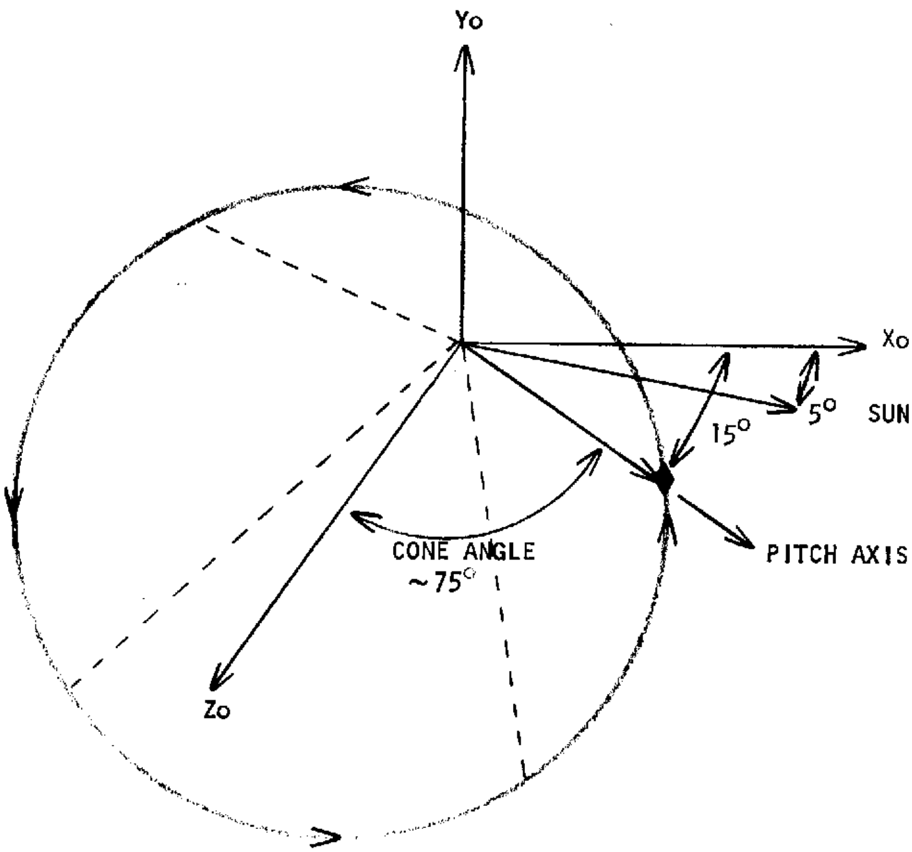

FIGURE 4 SEPTEMBER 1974 GEOMETRY

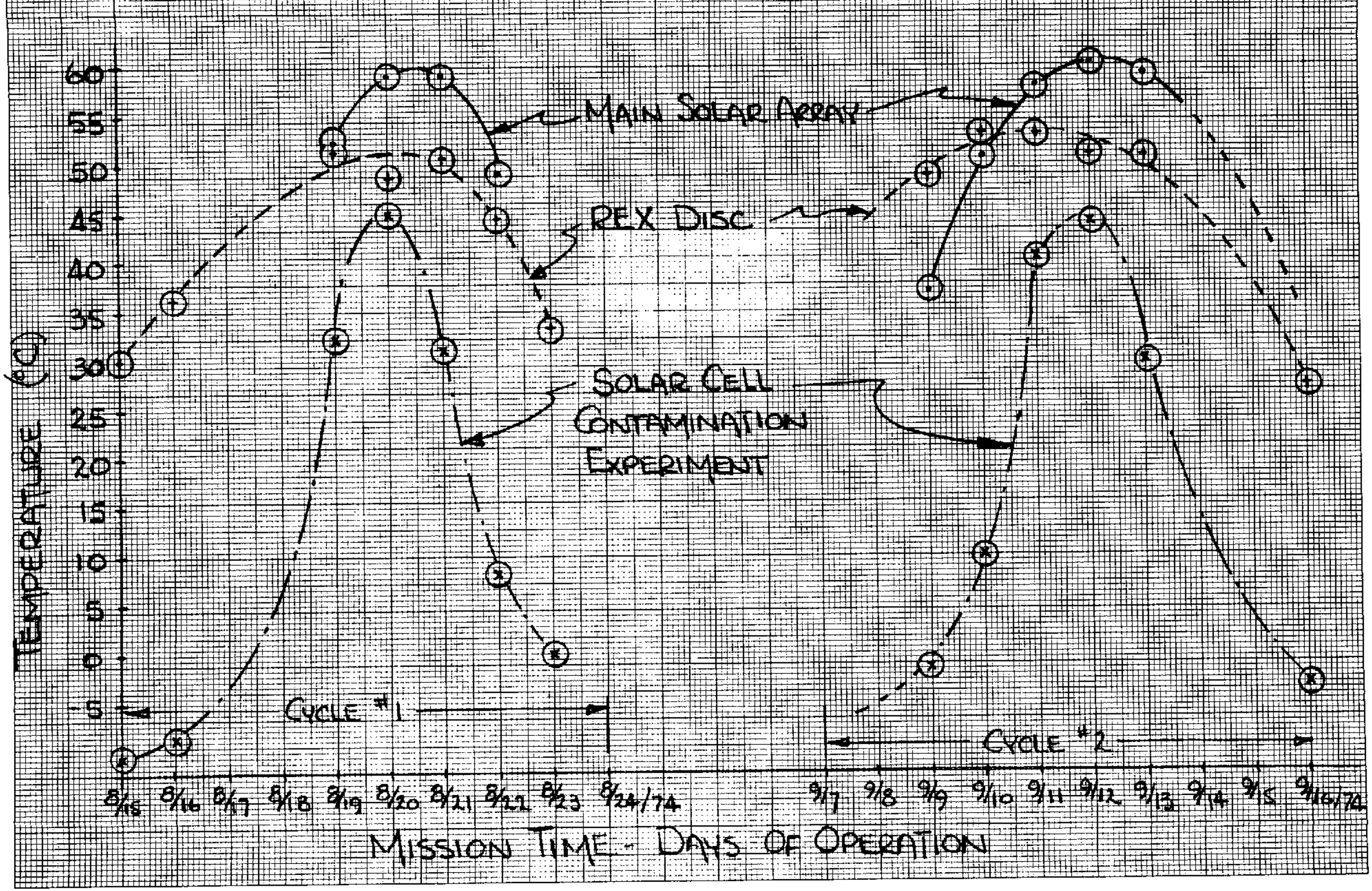

FIGURE 5

SERT II FLIGHT TEMPERATURE DATA

FIGURE 6
COMPONENT & TEMPERATURE LOCATIONS
SERT II SATELLITE

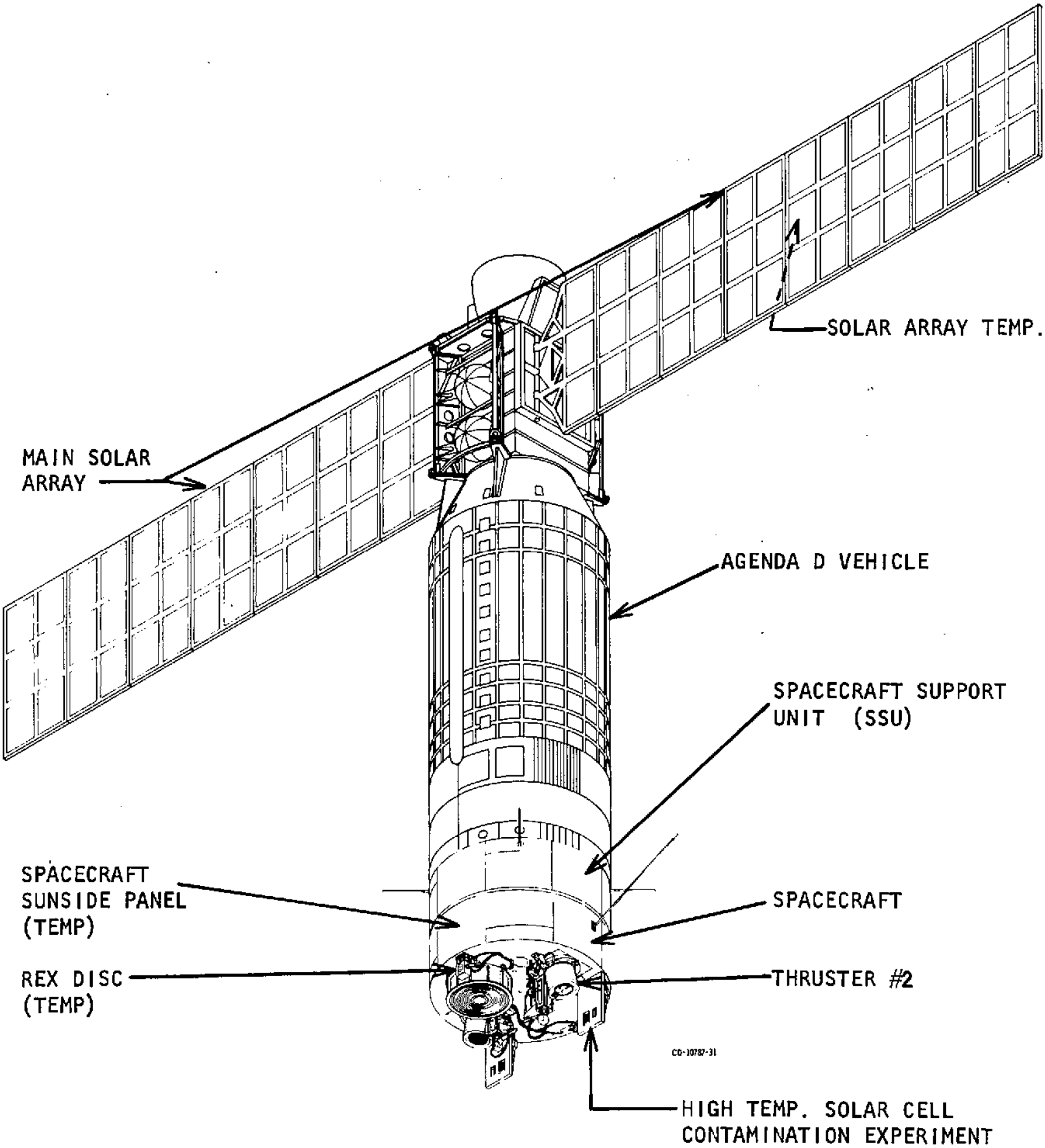

Figure 7

SERT II Flight Temperature Data Variation Over Orbit