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FINAL REPORT

52/402

GIMBAL SYSTEM EVALUATION

Volume 1

Lockheed Martin Missiles and Space
King of Prussia, Pa 19406

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Prepared For:
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Marshall Space Flight Center, Alabama 35812

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1.0 Gimbal Description and Support Equipment Assessment

The gimbal subsystem would include a two-axis gimbal housing redundant motors, harmonic drives, bearings and position encoders; as well as some or all of the following depending on system requirements:

1. Gimbal drive electronics (GDE) capable of issuing motor drive commands.
2. Encoder interface electronics capable of reading serial data from the encoder and routing it to the processor, most likely integrated into the GDE.
3. Flight processor hosting control software, most likely CFE in the form of a shared heritage flight processor.
4. Flight control software derived from the existing UARS SSPP software.
5. Mechanical platform for mounting scientific payloads, interfacing to gimbal.
6. Mechanical pedestal or similar adapter between gimbal and spacecraft.
7. Release and retention mechanisms similar to those used on UARS. If the payload is smaller, then only the gimbal-mounted retention may be required, reducing packaging and installation/test complexity.
8. Thermal control equipment for gimbal and (if necessary) electronics.
9. Sun sensor, most likely identical to the Platform Sun Sensor (PSS) purchased for UARS.

The residual test equipment from gimbal component- and subsystem-level development, which is identified in attachment 1 of this report, includes most of the electrical equipment (motor drive circuits, encoder serial read circuits, power supplies) necessary to interface with and control the gimbal elements as well as some of the associated electronics. This equipment will support the following activities with minimal adaptation:

1. Functional checkout and wiring of stepper motors.
2. Functional checkout and test of the independent gimbal (α/β) axes.
3. Functional and performance testing of the assembled two-axis gimbal, exclusive of torque margin testing.
4. Functional checkout of motor drive circuits for GDE.

The mechanical equipment includes strain gauges and load cells as well as some fixturing for the gimbal level assembly. With moderate mechanical adaptations, this equipment would allow torque margin testing of the gimbal in an ambient or temperature cycle environment, as well as stiffness testing of gimbal assembly.

Additional fixturing would be required for vibration, thermal vacuum or other environmental testing. In addition, assembly and test fixturing would be required for lower levels of assembly during which the bearings and drives are integrated onto the gimbal shafts, motor and encoder assemblies are built up, and runout and torque disturbance measurements are made.

For GDE testing (particularly the encoder interface), additional electrical equipment would be required, as would a box-level test fixture which would allow vibration and thermal testing. The subsystem-level testing would include the GDE, gimbal, sun sensor, platform and interface structures, as well as a breadboard model of the flight processor (most likely government furnished). Depending on the payload dimensions and mass properties, this testing would likely require dedicated mechanical fixturing.

In most cases, test cables would have to be designed and fabricated specifically to the test configurations.

2.0 Evaluation Results regarding Space Station Support Applications

2.1 General

Charts contained in attachment 2 of this report summarize the performance requirements, architecture, component designs, development process and on-orbit results for the UARS Solar Stellar Pointing Platform (SSPP), on which the new pointing system would be based. The SSPP was able to accommodate three solar- and stellar-viewing instruments with precise (180 arc-sec) pointing and tight (1 deg C) thermal requirements in a robust and reliable manner. The SSPP hardware functions in a low-Earth orbit having environmental conditions (altitude, inclination, solar angle) similar to those expected for the space station. The SSPP software allows either manual or autonomous control of the pointing and is adaptable to a variety of operational constraints. In addition, the processing and integration of the scientific payloads to the SSPP were performed by Lockheed Martin in parallel to spacecraft processing, with minimal serial impact to the bus. During this integration stringent process control was applied ensuring that the instruments remained damage- and contaminant-free.

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2.2 Resources

The pointing system would accommodate large payloads (up to 800 lb) and would itself weigh comparatively little (gimbal weight is 132 lb). Power requirements for the pointing system are modest (<40 W for all components exclusive of payload) based on the SSPP heritage. Data requirements are modest, with only limited serial command and telemetry, as well as an appropriate number of discrete commands and status telemetry, required for the gimbal and GDE. For control software operations, very little commanding is required as the system autonomously switches between the sun and available stars, and telemetry bandwidths are small due to the low sampling periods (1 sec) employed.

2.3 Interfaces

Electrically, the SSPP GDE was designed to interface to a NASA-supplied Remote Interface Unit (RIU) which had both serial and discrete data (command & telemetry) interfaces as well as passive and active analog telemetry interfaces. In addition, the GDE interfaced with a mission-unique avionics box (the Power Switching Unit) which provided power switching. Depending upon data bus architecture, it is likely that the RIU could be forgone in place of a direct data bus terminal in the GDE or space station standard remote terminal. For the power interface, the pointing system requires separate 28 V "quiet" and "noisy" lines; if these are not available then the transform and regulation functions would be integrated into the pointing system definition, most likely within the GDE.

Thermally, the gimbal is qualified for temperature gradients of up to 10 deg C between the spacecraft-fixed and payload-fixed ends. It is likely that thermal control equipment similar to those used for UARS (operational heaters and radiators) would be required to achieve this parameter. The platform instrument interface temperatures were controlled to within +/- 1 deg C using large radiator "winds" on the platform and operational heaters. In addition, compensation heaters were provided in the event an instrument failed.

Mechanically, the UARS spacecraft provided a stable, low-vibration platform to which the SSPP was affixed. Depending on the solar pointing stability requirements and the space station jitter environment, it is possible that mechanical isolation would be required, either through an isolated mount or by control system filtering, between the space station and the pointing system.

Geometrically, the gimbal's α/β axes would be readily adaptable for solar tracking as the space station orbit is very similar to the UARS orbit , although lower in altitude (375 vs 575 km) and slightly less inclined (51.6 vs 57 deg) . The similar inclination means that as on UARS the majority of tracking motion would be about the primary (α) axis; the secondary (β) axis would correct for solar "elevation" across the plane of the space station ground track. Of course, the platform would have to be located such as to provide clear fields-of-view (FOV's) for the platform instruments. If the sun sensor is employed, it's FOV (+/- 2 deg) and stray light avoidance will need to be accommodated in placement. On UARS, where the payloads were concerned about in-flight outgassing, the flight software was adapted to slew the platform away from the array should a ground operations error point them too close.

2.4 Safety & Reliability

Because the UARS hardware was built for a manned flight program, it is likely that many of the safety and quality assurance requirements applicable to the space station would be met by the existing designs; however, the details of any space-station specific requirements would need to be assessed as they became available.

The life-limited aspect of the subsystem would be the gimbal, which has been qualified for a three-year mission by engineering model test and analysis. The flight unit has been operating for over four years with no significant degradation. It is likely that the flight history along with additional analysis and engineering tests could extend the lifetime qualification as long as eight years at the current pointing requirements.

2.5 Environmental

The orbital environment would be similar to UARS with the exception of increased particulate and radiation hazards caused by the lower altitudes. Evaluation of these hazards would be required, especially with respect to radiation effects on the gimbal encoder LED's. Particulate build-up on the sun sensor optics may be a problem later in life; however, UARS demonstrated that on-orbit gimbal calibrations could be performed early in the mission while the sensors are "fresh", enabling tight pointing tolerances to be met later on in "open-loop" fashion without the sensor data.

2.6 Performance

The UARS SSPP was able to reliably "meet or beat" its pointing accuracy, knowledge and stability requirements for both solar and stellar targets. These were as follows:

1. Solar: 90 arc-sec knowledge, 180 arc-sec placement, 60 arc-sec stability
2. Stellar: 180 arc-sec knowledge, 360 arc-sec placement, 60 arc-sec stability.

In order to accomplish this, the gimbal mounting base attitude must be known precisely and made available to the pointing software via "actual" Euler parameters. If this is not known in real-time, then the software can generate "desired" Euler parameters generated using spacecraft ephemeris, although accuracy will be reduced.

Because of electrical harnesses routed through the gimbal to accommodate the payloads, the gimbal could not continuously rotate but instead "rewinds" to re-acquire targets. The UARS SSPP rewind rate was sufficient to provide 36 minutes of continuous solar tracking and 15 minutes of stellar tracking per orbit at most sun angles.

2.7 Payload Accommodations

The SSPP gimbal included a wire-wrap harness to provide numerous power and data interfaces to the three platform-mounted instrument RIU's. In addition, a similar gimbal constructed for the High Gain Antenna Subsystem (HGAS) included coaxial cables through which an RF or HF (high frequency) modulated data stream could be sent.

2.8 Conclusion

While a detailed evaluation cannot be performed without specific requirements and interface definitions, a first-order assessment indicates that the a pointing system based on the UARS SSPP could be accommodate a large (<800 lb) sun-pointed scientific payload for attached to the space station. The adaptation would likely be low-risk and cost-effective compared to a new design, and would give pointing performance adequate for spectral or radiometric measurements.

ATTACHMENT 1

GIMBAL TEST AND SUPPORT EQUIPMENT

Gimbal Test and Support Equipment

Item No.	New IC	Old IC	Description	Model	Cost
1	CH0BHN	UI0067	Stand High Boy, Optical	Brusson 232	$860
2	CH0BRC	G96893	Load Cell	SM 500	$200
3	CH0BRD	G96894	Load Cell	SM 500	$200
4	CH0029	G95400	Transducer	GSE 2106/5K	$2,795
5	CH01FX	G36040	Calibrator	HP 8477A	$450
6	CH01SB	G85342	Transducer	GSE 2106/5K	$2,795
7	CH011J	G34555	Strain Inductor	Budd P350	$6,660
8	CH016N	G85854	EMC Test Box	GE 47E2626	$1,500
9	CH0212	G85855	VIU	FC F10085	$50,000
10	CH03ZJ	G95387	Gimbal Drive Test Set	SK009/J	$15,000
11	CH04NT	G42998	Isolation Box Test Set	SKT JE81	$1,000
12	CH04N6	G86525	Load Junction	GE-SH GDG1	$350
13	CH04VQ	G85290	Power Supply	Magtrol 4637	$195
14	CH04VR	G85291	Dynamometer	Magtrol HD500	$2,265
15	CH04VS	G85289	Dynamometer Read Out	Magtrol 4618	$1,875
16	CH04VT	G86267	SADATA Test Set	GE 47-2810	$2,500
17	CH04VV	G85799	Motor Drive	New England 301H	$1,795
18	CH04ZW	G85343	Transducer Display	GSE 229D	$1,495
19	CH05FD		Torque Sensor	2105-500	$3,295
20	CH0782	VT0800	Tooling	C.B. Knapp	$8,580
21	CH0785	VT0804	Tooling	Spincraft 4727724	$6,975
22	CV00BJ	G43422	Data Rack	TRW DF71823	$210,000
23	CV00BK	G85768	Digital Programmer	GE 47-2809	$500
24	CV00BL	G85769	Digital Programmer	GE 47-2809	$500
25	CV02XG	G85765	Load Simulator	GE 47-2810	$15,000

Gimbal Test and Support Equipment

Item No.	New IC	Old IC	Description	Model	Cost
26	CV02XH	G85628	Power Controller	GE 47-2809	$4,500
27	CV02XM	G85624	Test Point Panel	GE 47-2809	$5,000
28	CV02XN	G85625	System Controller	GE 47-2810	$4,500
29	CV02XP	G85772	Power Controller	GE 47-2810	$6,000
30	CV02Y9	U10198	SCA Test Rack	GE 47E2100	$477
31	CV030B	G85790	Motor Drive Display Panel	GE 47-2811	$2,500
32	CV030L	G85339	Power Switch Rack	Elect. Encl. 5437	$2,059
33	CV030M	G85766	Test Point Panel	GE 47-2809	$8,000
34	CV030N	G85361	System Controller	GE 47-2810	$99
35	CV030P	G85767	Power Controller	GE 47-2809	$15,000
36	CV030R	G85362	Motor Simulator	GE 47-2810	$$99
37	CV0308	G85359	Motor Drive Rack	Elect. Encl. 5437	$201
38	CV0309	G85796	System Controller	GE 47-2811	$2,500
39	UARS EM 2 Axis Gimball DRW# 47-27741BGE1				$700,000

ATTACHMENT 2

UARS SOLAR STELLAR POINTING PLATFORM DESCRIPTION CHARTS

UARS SOLAR STELLAR POINTING PLATFORM REVIEW

1. OVERVIEW
2. SUBSYSTEM REQUIREMENTS
3. SUBSYSTEM ARCHITECTURE
4. PLATFORM AND STRUCTURE
5. TWO AXIS GIMBAL
6. GIMBAL DRIVE ELECTRONICS AND PLATFORM SUN SENSOR
7. CONTROL SYSTEM, FLIGHT SOFTWARE, AND VALIDATION
8. RETENTION AND RESTOW CAPABILITIES
9. OPERATIONAL ASPECTS
10. ON-ORBIT PERFORMANCE
11. PERFORMANCE ASSURANCE FEATURES

SSPP OVERVIEW

1. SUMMARY
2. LOCATION ON UARS OBSERVATORY
3. COORDINATE SYSTEM
4. ORBIT GEOMETRY
5. INSTRUMENTS

SSPP SUMMARY

1. THE SOLAR STELLAR POINTING PLATFORM IS A TWO AXIS, GIMBALLED POINTING SYSTEM WHICH SUPPORTS THE OBSERVATIONS OF THREE UARS INSTRUMENTS.

2. THE SSPP IS DESIGNED FOR HIGH PRECISION POINTING AT EITHER THE SUN OR UP TO TWENTY STARS.

3. SOLAR POINTING MAY BE PERFORMED IN EITHER OPEN OR CLOSED LOOP FASHION.

4. STELLAR POINTING MAY ONLY BE PERFORMED OPEN LOOP.

5. THE SSPP ACCOMODATES THE THERMAL, MOUNTING, POWER, AND ELECTRICAL INTERFACES OF THE THREE INSTRUMENTS.

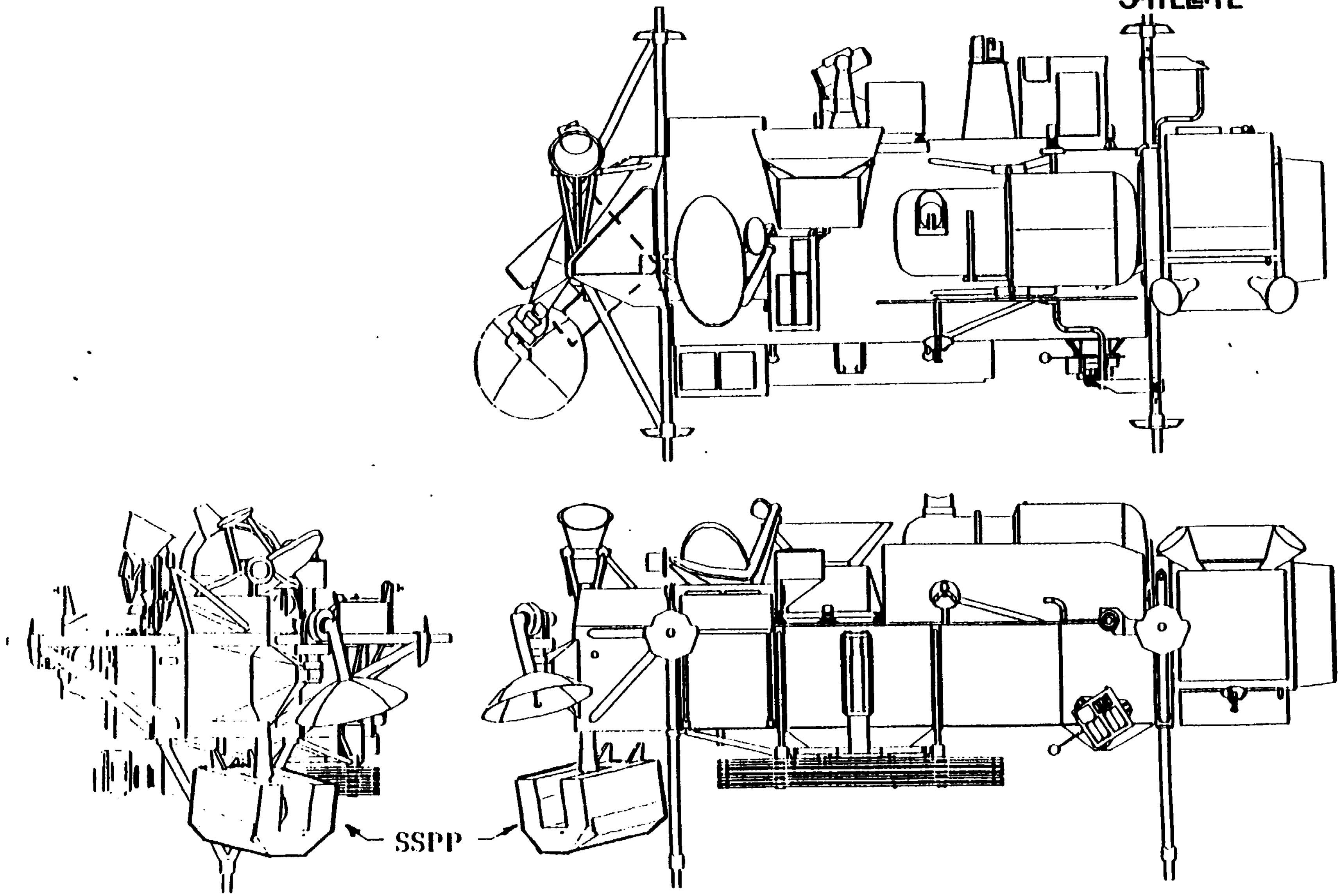
6. THE SSPP REQUIRES A SEPARATE ON-BOARD COMPUTER TO PERFORM CONTROL FUNCTIONS USING SSPP SOFTWARE (NOT PART OF SSPP).

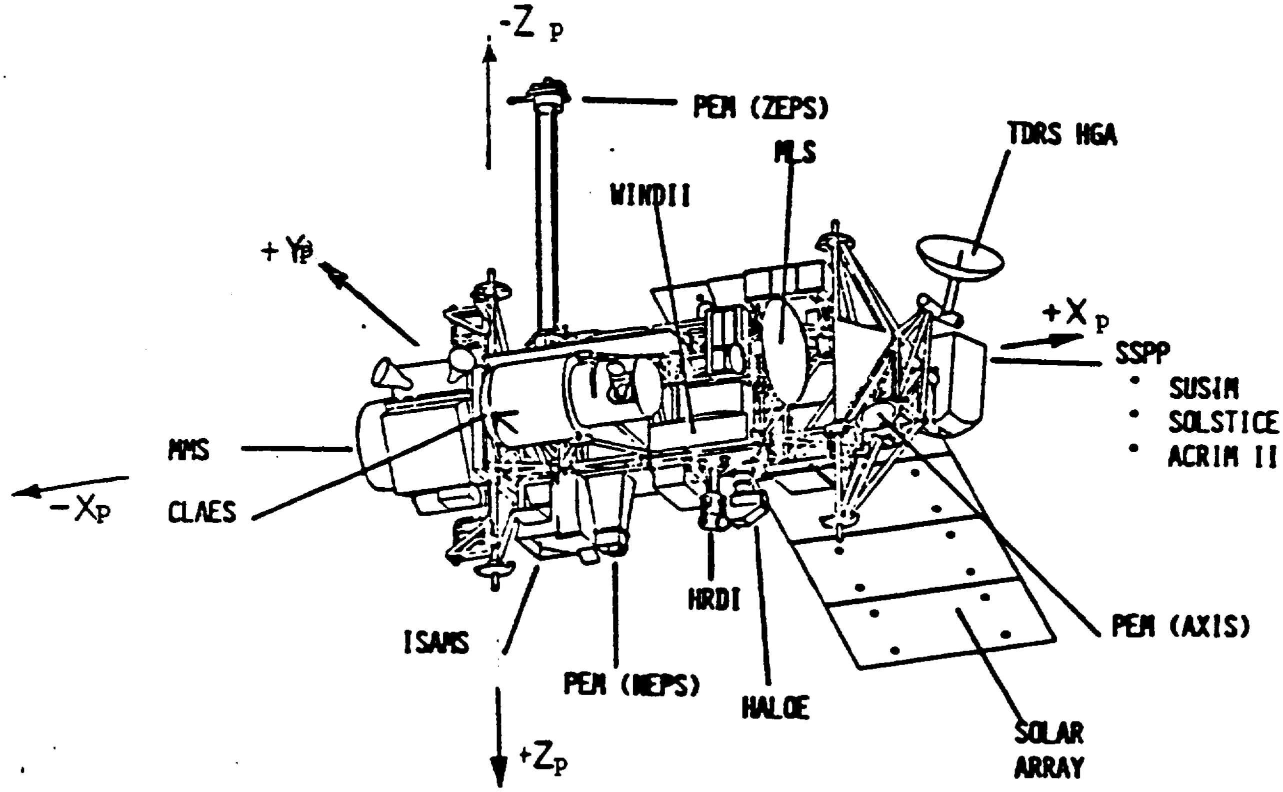
7. THE SSPP CAN OPERATE AUTONOMOUSLY FOR LONG PERIODS.

Solar Stellar Pointing Platform

LOCATION ON OBSERVATORY

UPPER ATMOSPHERE RESEARCH SATELLITE

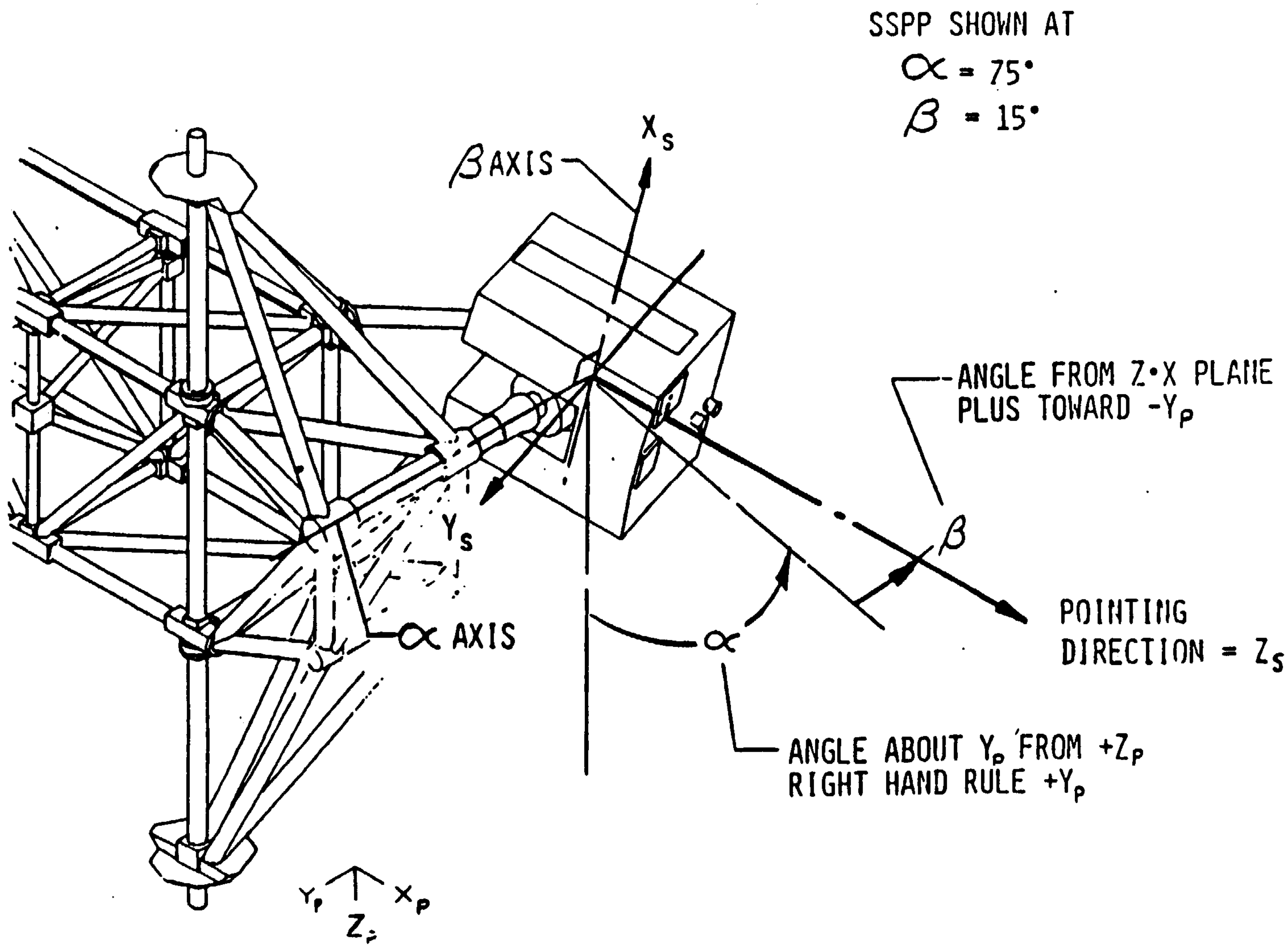




Note: The above configuration is exemplary of a configuration which could be used for UARS. This figure does not impose design requirements upon the UARS Observatory. It is provided for reference only.

Figure 1. UARS Configuration

SSPP AXES AND COORDINATE SYSTEMS



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UARS ELEMENTS

Start time (YYDDD msec):	91345 0
Epoch time (YYDDD msec):	91344 0
Semimajor axis (km):	6948.177889388511176
Eccentricity:	0.000470563476811
Inclination (rad):	0.994298371834426
Right ascension of ascending node (rad):	1.669824770590543
Argument of perigee (rad):	4.301000430373997
Mean anomaly (rad):	6.130081164293464
Anomalistic period (msec):	5763910.993547011166811
Perigee height (km at epoch):	566.768330643380068
Apogee height (km at epoch):	573.307448133641628
Mean motion (rad/sec):	813.748287286087546
Rate of change for argument of perigee (rad/sec):	0.270380493511154
Rate of change for right ascension of ascending node (rad/sec):	-0.606982099125426
Leap second indicator:	No leap second

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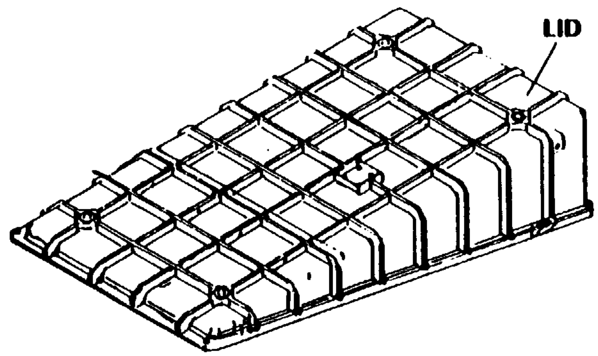
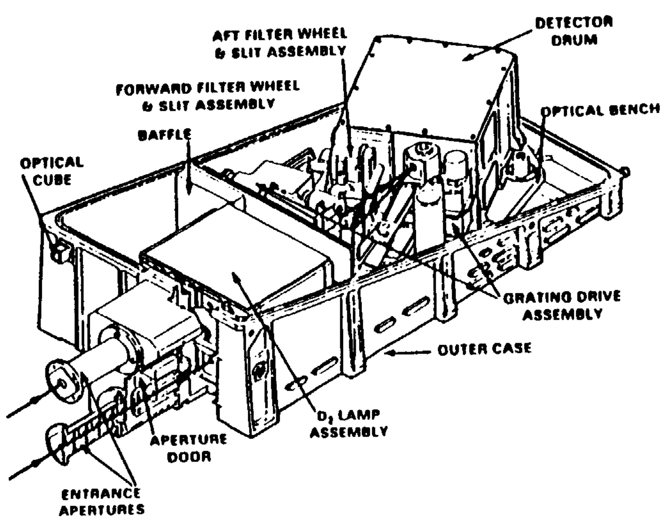
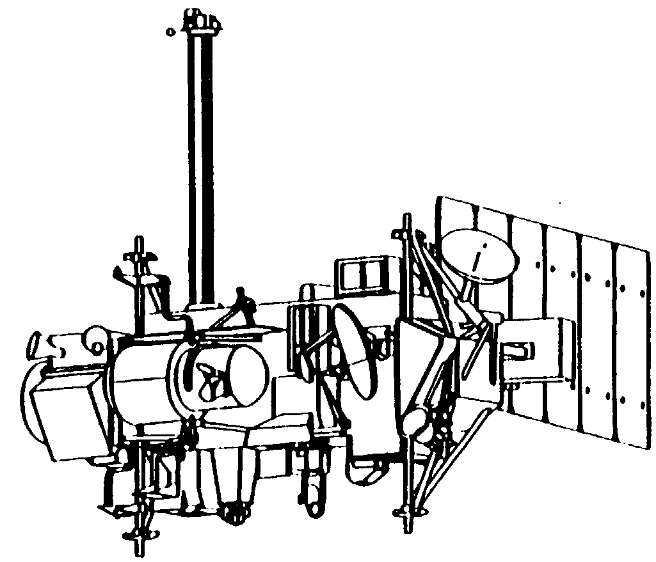
SOLAR ULTRAVIOLET SPECTRAL IRRADIANCE MONITOR (SUSIM)

UPPER ATMOSPHERE RESEARCH SATELLITE



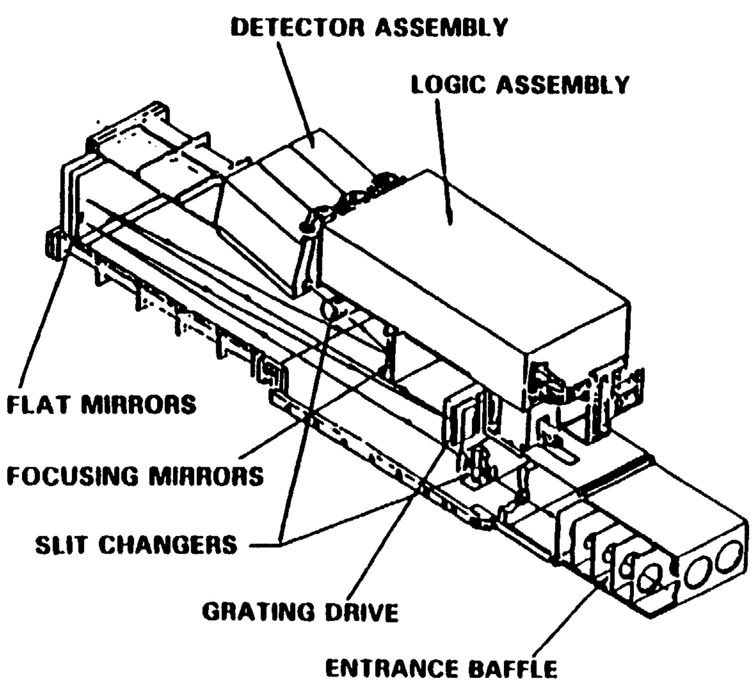


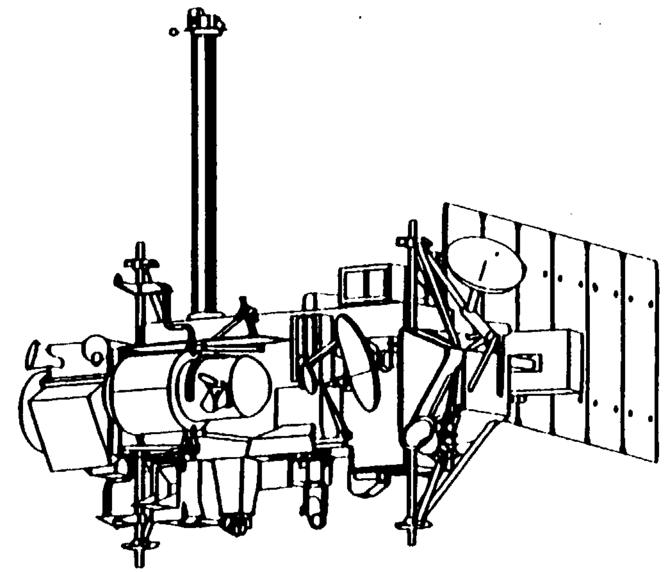


INSTRUMENT WT.:	**231 lb.**
AVERAGE POWER:	**21 WATTS.**
DATA RATE:	**2 kbps.**

SOLAR STELLAR IRRADIANCE COMPARISON EXPERIMENT (SOLSTICE)

UPPER ATMOSPHERE RESEARCH SATELLITE





INSTRUMENT WT.:	44 lb.
AVERAGE POWER:	6 WATTS
DATA RATE:	250 bps.

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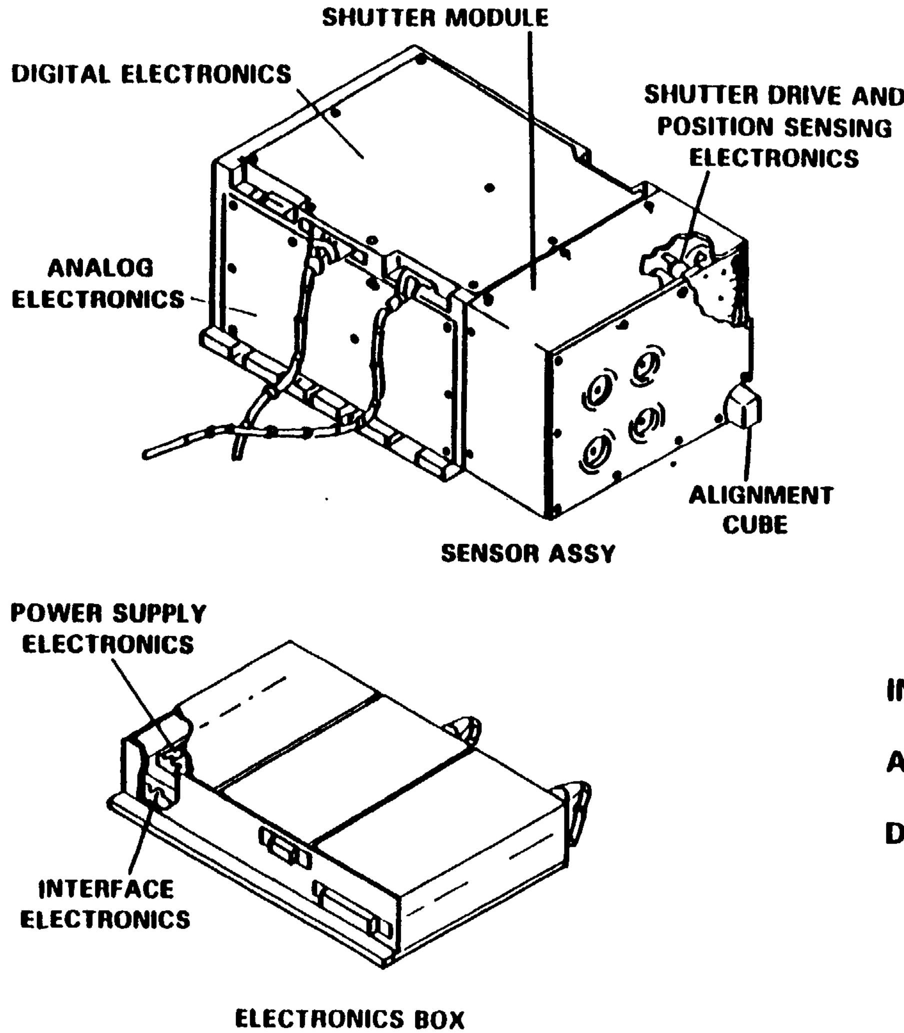
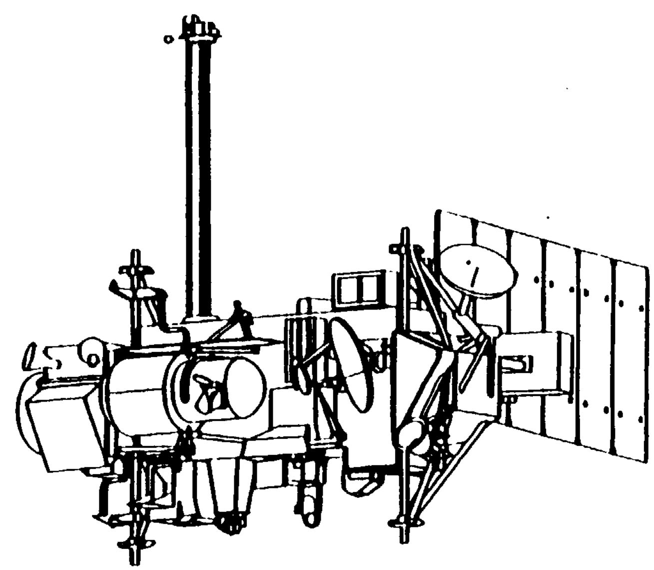
ACTIVE CAVITY RADIOMETER IRRADIANCE MONITOR (ACRIM II)

UPPER ATMOSPHERE RESEARCH SATELLITE





INSTRUMENT WT.:	51 lb.
AVERAGE POWER:	5.2 WATTS.
DATA RATE:	500 bps.

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SSPP REQUIREMENTS

1. SOLAR VIEWING
2. SOLAR POINTING
3. STELLAR VIEWING
4. STELLAR POINTING
5. FUNCTIONAL REQUIREMENTS
6. OFFSET POINTING
7. MASS PROPERTIES
8. RANGES AND RATES
9. POWER CONSUMPTION
10. THERMAL CONTROL

PURPOSE - SSPP REQUIREMENTS

1. POINTING ACCURACY (SOLAR) — 180 SEC OF ARC
2. POINTING KNOWLEDGE (SOLAR) — 90 SEC OF ARC
3. POINTING ACCURACY (STELLAR) — 360 SEC OF ARC
4. POINTING KNOWLEDGE (STELLAR) — 180 SEC OF ARC
5. MECHANICAL I/F — MOUNTING & ALIGNMENT
6. THERMAL I/F — TCS
7. ELECTRICAL I/F — DATA, POWER, PYRO

SUPPORT ACRIM, SOLSTICE, SUSIM OBSERVATIONS

SSPP Design Requirements

Functional Requirements

- **Solar Viewing**
  - Time

	Requirement	Design Goal	Performance
Minimum:	25 min	30 min	**36 min**
Continuous:	16 min	30 min	**36 min**

Settling time less than 1 minute (2 min, during offset maneuvers).

  - Pointing Accuracy
    * Requirements:

Placement:	±180 arcsec	3σ	
Knowledge:	±90 arcsec	3σ	
Stability:	±60 arcsec	3σ	per 1000 sec
Jitter:	±60 arcsec	3σ	per 1 sec

    * Implementation: Specially developed gimbal drive control law.
    * Performance: Accuracy requirements met in closed-loop mode.
  - Offset Maneuvers

NO CHANGES SINCE OBSERVATORY PDR

SSPP Design Requirements

Error Source Allocation Budgets

- **Solar Pointing Accuracy Budgets (Closed-Loop Tracking)**

ERROR SOURCES	PLACEMENT (arcsec (3σ))	KNOWLEDGE (arcsec (3σ))	IMPLEMENTATION
Observatory Structure Dynamics	10	10	S/C structural design
Platform Sun Sensor			
Sun Sensor Accuracy	36	36	PSS calibration
Sun Sensor Boresight Position	NA was 60 sec	NA	On-orbit cal & correction
Alignment (Sun Sensor to Instruments)			
Launch Shift	25	25	SSPP structural design
1G Residuals	15	15	SSPP structural design
Instrument Positioning Accuracy	75	NA	Ground alignment and on-orbit cal
Ground Measurement Accuracy	20	20	Ground alignment
Instrument/SSPP Remate Accuracy	15	15	SSPP structural design
On-Orbit Thermal Effects (SSPP)	30	30	SSPP thermal design
Drive and Gimbal Control System	30	NA	SSPP control law
RSS at all instrument interfaces	101	61	
Instrument allocation from UIAD	120	60	
Total Root Sum Square (RSS)	157	86	
Requirement	180	90	

SSPP Design Requirements
Functional Requirements

- **Stellar Viewing**
  - Time
    - Requirement: 10 viewing periods per day, 15 continuous minutes per viewing period, mission average.
    - Performance:

Conservative:	11.7 15-min viewing periods per day
With Doubling:	**19.6** 15-min viewing periods per day

  - Pointing Accuracy
    - Requirements:

Placement:	±360 arcsec	3σ	
Knowledge:	±180 arcsec	3σ	
Stability:	±60 arcsec	3σ	per 1000 sec
Jitter:	±60 arcsec	3σ	per 1 sec

    - Implementation: Specially developed gimbal drive control law.
    - Performance: Accuracy requirements met in open-loop mode.

NO CHANGES SINCE OBSERVATORY PDR

SSPP Design Requirements

Error Source Allocation Budgets

- **Stellar** Pointing Accuracy Budgets (Open-Loop Tracking)

ERROR SOURCES	PLACEMENT (arcsec (3σ))	KNOWLEDGE (arcsec (3σ))	IMPLEMENTATION
Observatory Structure Dynamics	10	10	S/C structural design
Observatory Attitude Uncertainty	30	30	Attitude error correction
Platform Sun Sensor Accuracy	36	36	PSS calibration
On-Orbit Boresight Alignment Accuracy (SOLSTICE Relative to Sun Sensor)	30	30	On-orbit cal & correction
On-Orbit Thermal Effects (Observatory)	135	35	S/C thermal design
On-Orbit Thermal Effects (SSPP)	30	30	SSPP thermal design
Drive and Gimbal Control System	60	20	SSPP control law
RSS at SOLSTICE interface	161	76	
Requirement	360	180	

SSPP Design Requirements
Functional Requirements

- **Restow**
  - Requirement: Provide capability to restow platform to launch configuration.
  - Implementation: Gimbal Drive Electronics designed to reorient platform to stow position upon command receipt + relatch capability.
  - Remote relatch capability no longer required. — because deploy post STS.
- **Pointing Verification/Calibration**
  - Requirement: Provide capability to verify/calibrate platform pointing accuracy on orbit.
  - Implementation: Ground processing of platform sun sensor, position encoder, and ACS flight data characterizes pointing performance.

3.2.1.4.4 Jitter. The short-term stability of the SSPP shall be such that the change in pointing error due to all disturbance sources does not exceed 60 arc-seconds (3σ) during any one second period. Error sources affecting SSPP short term stability include: spacecraft structure dynamics, motor step size, motor drive/sensor error, harmonic drive and gear train accuracy, cable wrap and bearing friction.

3.2.1.5 Offset pointing

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INS

3.2.1.5.1 Incremental. The SSPP shall provide for offsetting the pointing direction in increments of not greater than 3 arc minutes over a range of ±60 arc-minutes along each of two orthogonal axes, one axis at a time. Each offset position shall be capable of being held for six minutes minimum. The settling time between offset changes shall not exceed two minutes.

3.2.1.5.2 Scanning. The SSPP shall provide for offsetting the pointing direction at ±nominal alpha tracking rate relative to the tracking rate, for ±one degree from the tracking position, along each of two orthogonal axes, one axis at a time.

3.2.2 Physical characteristics

3.2.2.1 Mass properties

3.2.2.1.1 Weight. The total weight of the SSPP subsystem shall be 655 ±7 pounds. The weight of the Platform Assembly with instruments, as mounted on the Observatory forward structure, shall not exceed 980 pounds. Allocations are listed in Table II with notation of those items whose weight is included in other subsystems.

3.2.2.1.2 Moments of inertia. The moments of inertia of the SSPP moving mass corresponding to weights of Table II about axes fixed to the SSPP and passing through the intersection of the gimbal axes shown in Figure 2 shall be as listed in Table III.

MASS PROPS

Table II. SSPP Weight

Item	SSPP Subsystems Pounds	Other Subsystems Pounds
Platform Assembly		
Structure	348	
Gimbal	134	
Electrical Harnesses	11	
Thermal Cover, Heaters	20	
Retention	79	
Sun Sensors (2)	8	
ACRIM II		56
SOLSTICE		48
SUSIM		255
RIU's (3)		14.2
Pyro Repeater Mod.		0.8
Subtotal	600	374
Mounted elsewhere		
GDE	12	
Retention Supt. Structure	43	
Total, by subsystem	655	

3.2.2.2 Mechanical natural frequency. The minimum mounting natural frequency design goal for the SSPP stowed in the launch position shall be as specified in SVP-11111. In the tracking configuration, frequencies less than 1.3 Hertz (Hz) shall be avoided.

3.2.2.3 Launch configuration. The SSPP shall be retained at alpha equals 310.2 degrees and beta equals -10 degrees.

3.2.2.3.1 Retention function. The retention system shall be capable of releasing and securing the SSPP upon ground command.

3.2.2.3.2 Retention motor. The retention system shall be operated by motors as specified in SVS-11075.

Table III. SSPP Moments of Inertia
Units = Slug Feet^2

I_{xx}	37.3 $\pm$0.8
I_{yy}	44.6 $\pm$0.8
I_{zz}	38.5 $\pm$0.8
I_{xy}	-5.2 $\pm$0.2
I_{yz}	-2.0 $\pm$0.2
I_{zx}	-0.8 $\pm$0.2

3.2.2.4 Gimbal. The gimbal shall be as specified in SVS-11065.

3.2.2.4.1 Axes. One gimbal axis shall be fixed to the Observatory parallel to the Y axis, and designated as α(alpha). The second axis shall be perpendicular to the alpha axis, and designated as β (beta), as shown in Figure 2.

3.2.2.4.2 Angles. The angle of each gimbal axis shall be designated α (alpha) and β (beta), as shown in Figure 2. The SSPP shall be able to be positioned at any angle between the limits, which include zero degrees, listed in Table IV.

Table IV. Gimbal Operating Angular Displacements

Axis	Angle Degrees		Rates Degrees/Sec.	
	From	To	From	To
Alpha	-55	247	-0.200	+0.200
Beta	-2*	83.4	-0.155	+0.155

* Does not include stowed position

3.2.2.4.3 Rates. The SSPP shall be able to rotate about gimbal axes as listed in Table IV.

RANGE / RATES

POWER CONSUMPTION

3.2.2.7 Power. The maximum electrical power required by the SSPP, exclusive of the instruments, and thermal control shall be 11.2 watts from the pulse bus, and 27.5 watts from the quiet bus. Table V lists the orbit average and maximum power required by components of the SSPP Subsystem on the platform.

Table V. SSPP Electrical Power

Item	Orbit Average Watts (1)	Maximum Watts	Condition of Max. Power Ref.
Motor-alpha	2.3	7.2	72 pps @ 28 V
Motor-beta	1.6	7.2	72 pps @ 28 V
Encoders (2)	5.2	8.0	
Platform Sun Sensor	1.6	2.0	35 V

(1) Orbit average is defined as tracking for 76 percent, and slewing for 24 percent of orbit at 28 V.

3.2.2.8 Thermal control. The SSPP shall provide thermal control to maintain the temperature requirements of the instruments as specified in applicable thermal ICD's (Table I) in accordance with SVS-11095.

3.2.3 Reliability. The reliability design sufficiency of the SSPP shall be such that it can support a useful orbital design life of not less than 36 months assuming continuous operation after 36 months in storage and 2000 hours of testing. The expenditure of design life at the SSPP (accumulated cycles) during assembly testing, acceptance/protoflight testing, integration, storage checkout, and on-orbit life shall be not more than 40,000 cycles. One cycle is defined as travel of a gimbal axis between extremes in both directions.

The design of the SSPP shall be such that the specified performance will be maintained considering all identifiable wearout factors and expendable depletions. Electrical and mechanical redundancy shall be applied to

SSPP THERMAL CONTROL REQUIREMENTS

1. RANGE: 20 +/- 5 deg C
2. VARIANCE: +/- 1 deg C about SET POINT
3. APPLIES WHILE MEETING PRESCRIBED SOLAR/STELLAR VIEW TIMES

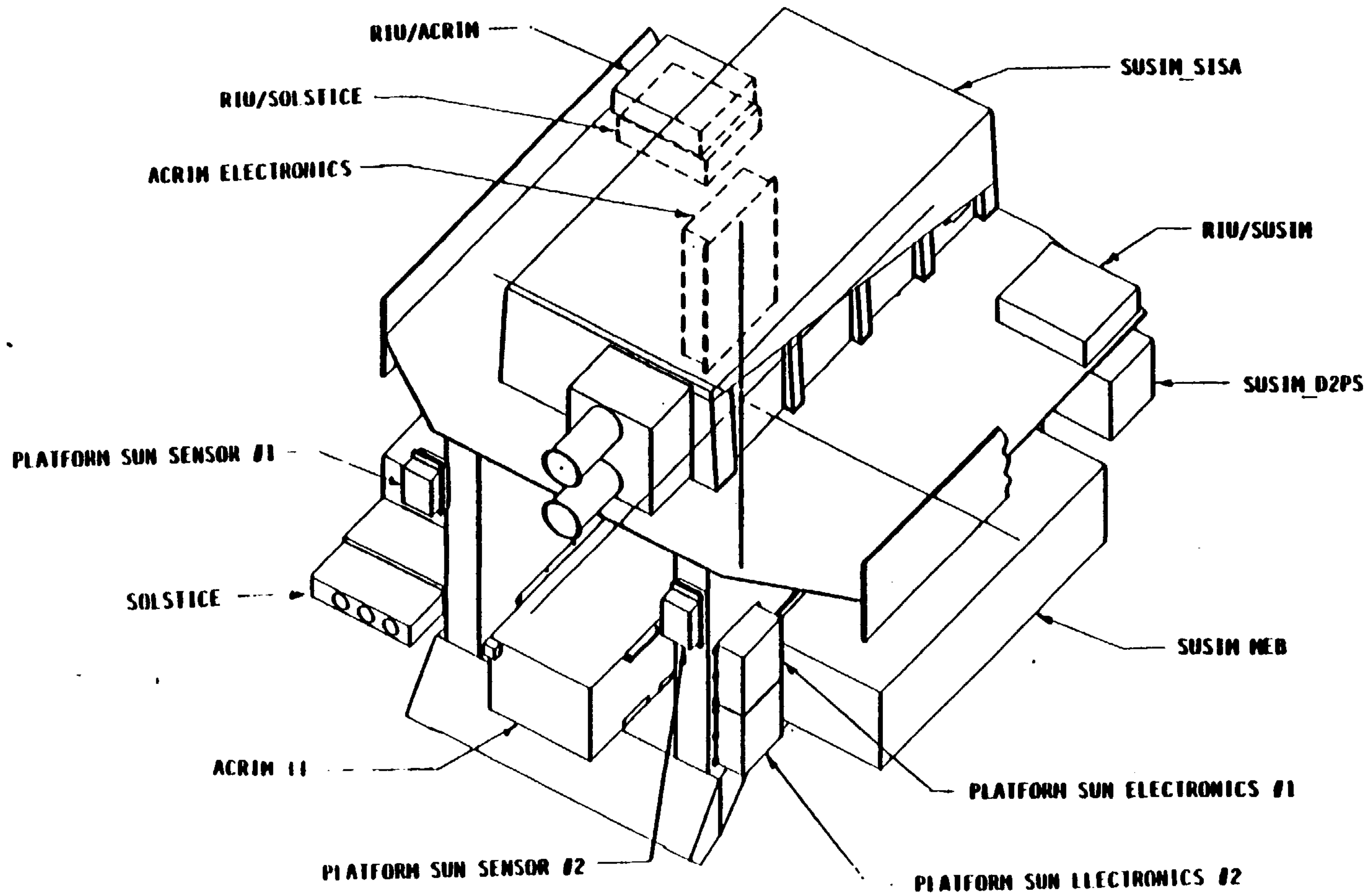
SSPP SUBSYSTEM ARCHITECTURE

1. MECHANICAL LAYOUT
2. BLOCK DIAGRAM

SOLAR STELLAR POINTING PLATFORM

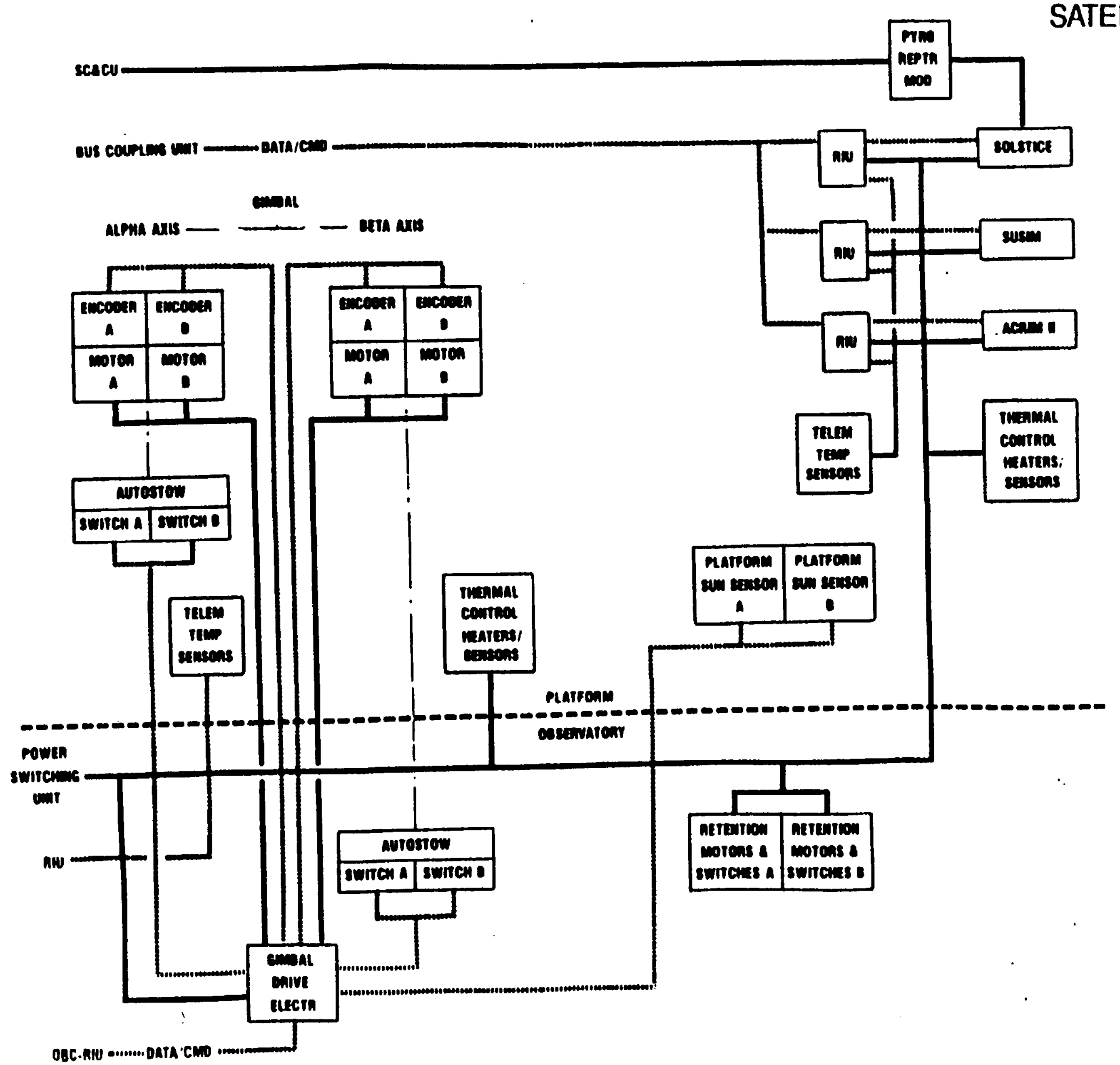
SSPP ASSEMBLY

UPPER ATMOSPHERE RESEARCH SATELLITE



SSPP BLOCK DIAGRAM

UPPER ATMOSPHERE RESEARCH SATELLITE



SSPP PLATFORM & STRUCTURE

1. SYSTEM VIEW
2. MASS LOCATIONS
3. EXPLODED VIEW
4. STOWED FREQUENCY REQUIREMENTS
5. LOADS & STRESS ANALYSIS
6. THERMAL DESIGN

Solar Stellar Pointing Platform

SSPP FEM

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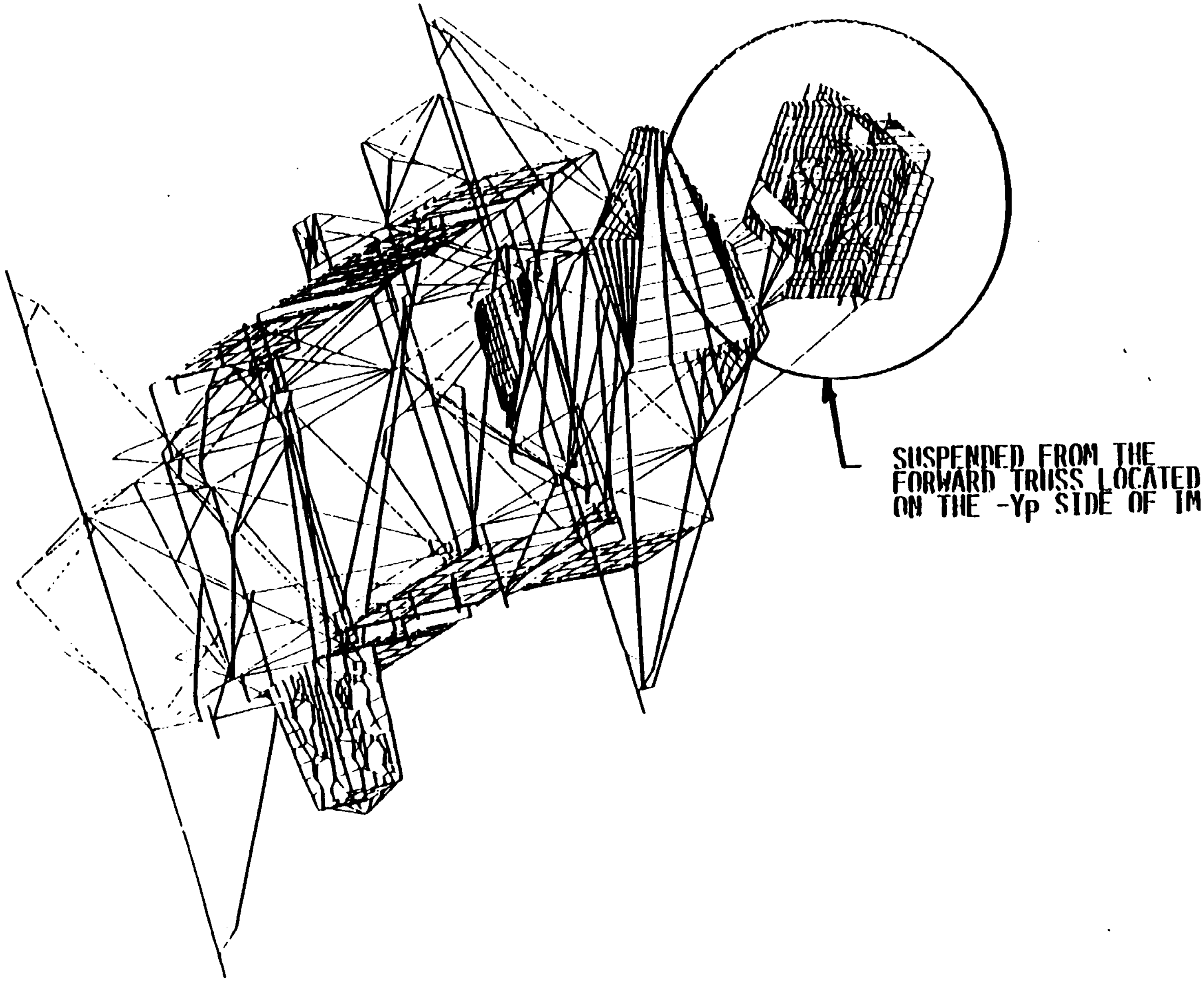
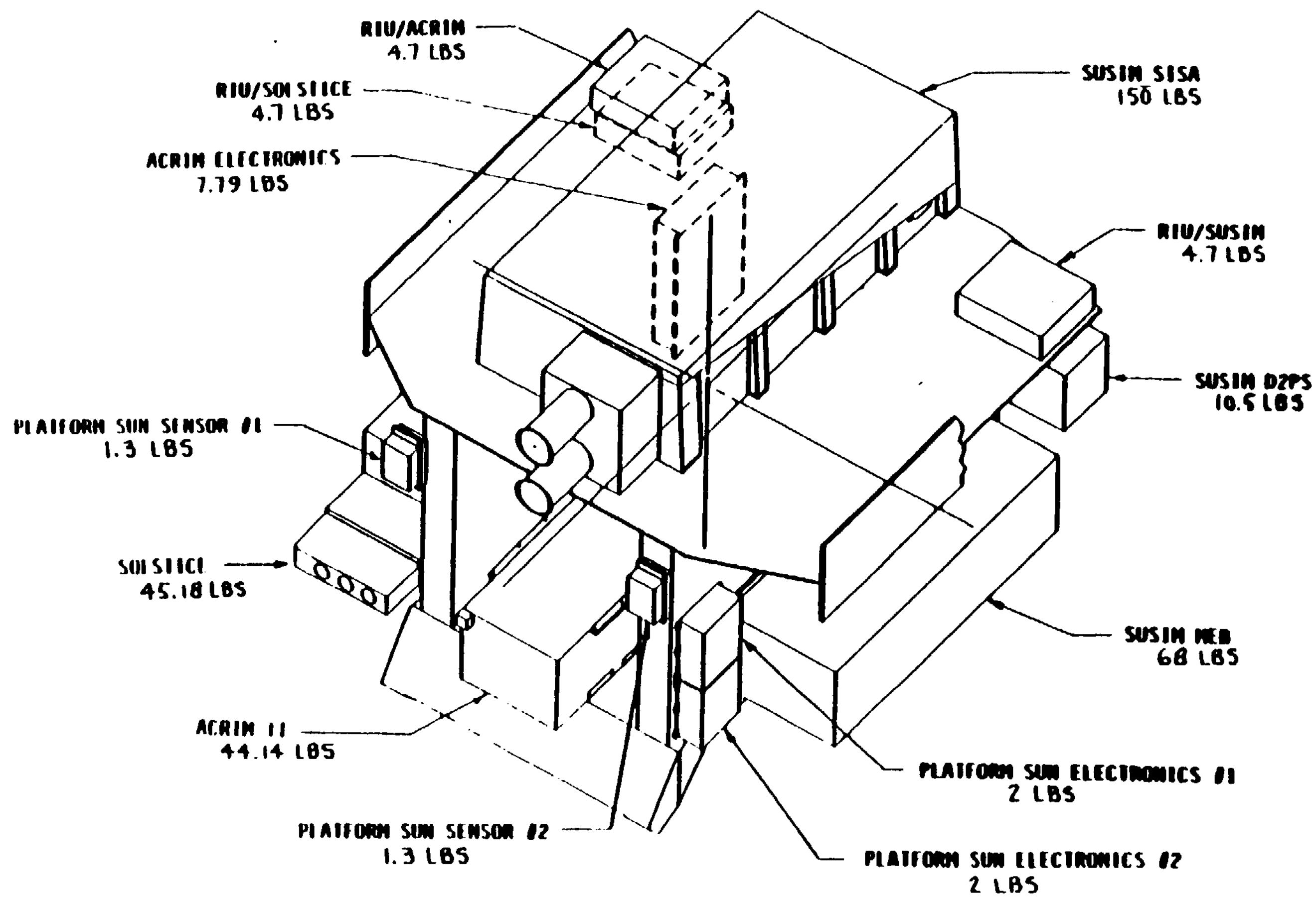
RESEARCH
SATELLITE



UARS SSPP STRUCTURE

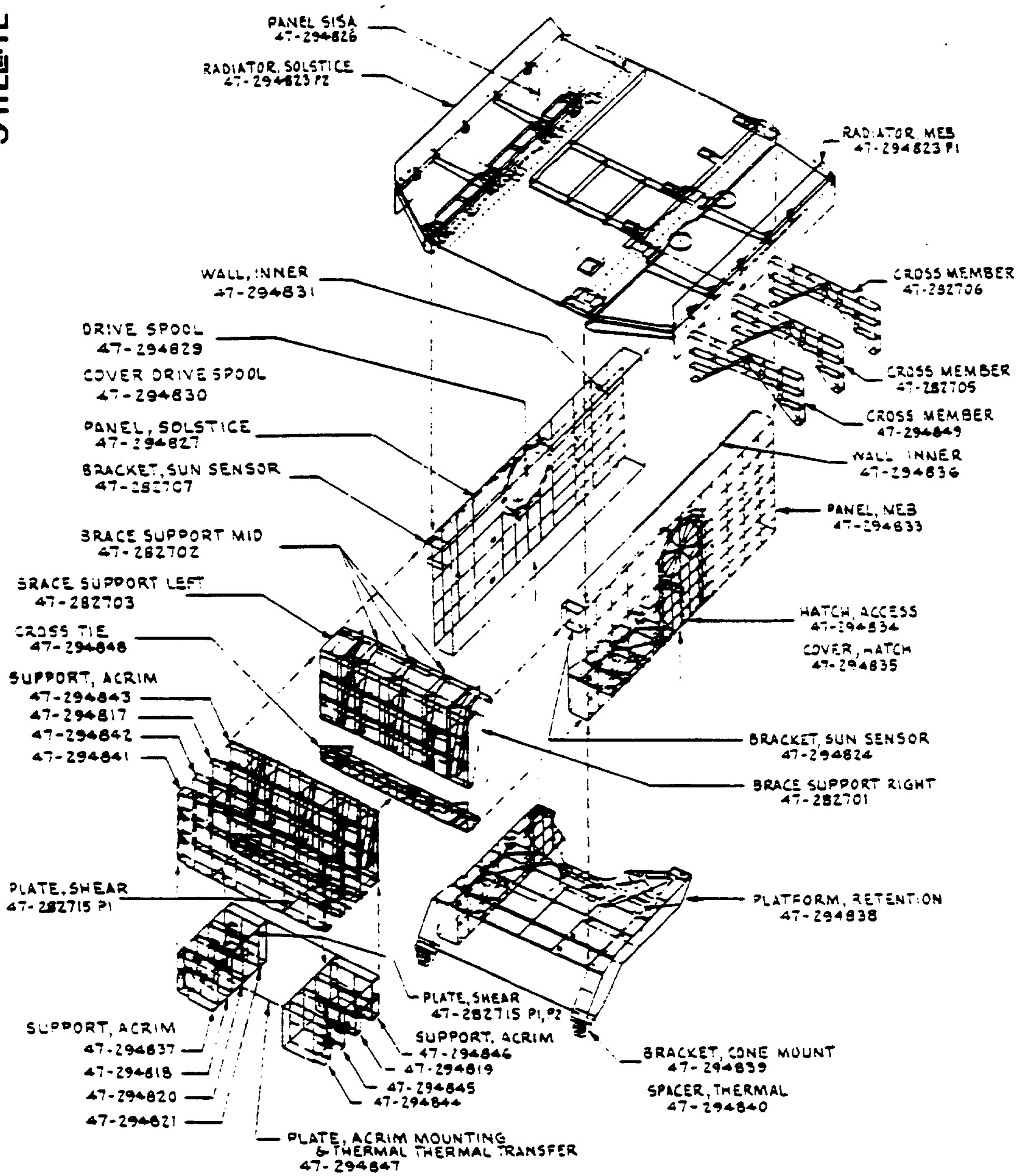
UPPER ATMOSPHERE RESEARCH SATELLITE

COMPONENT-STRUCTURE ARRANGEMENT



UPPER ATMOSPHERE RESEARCH SATELLITE

SOLAR STELLAR POINTING PLATFORM STRUCTURE



UPPER
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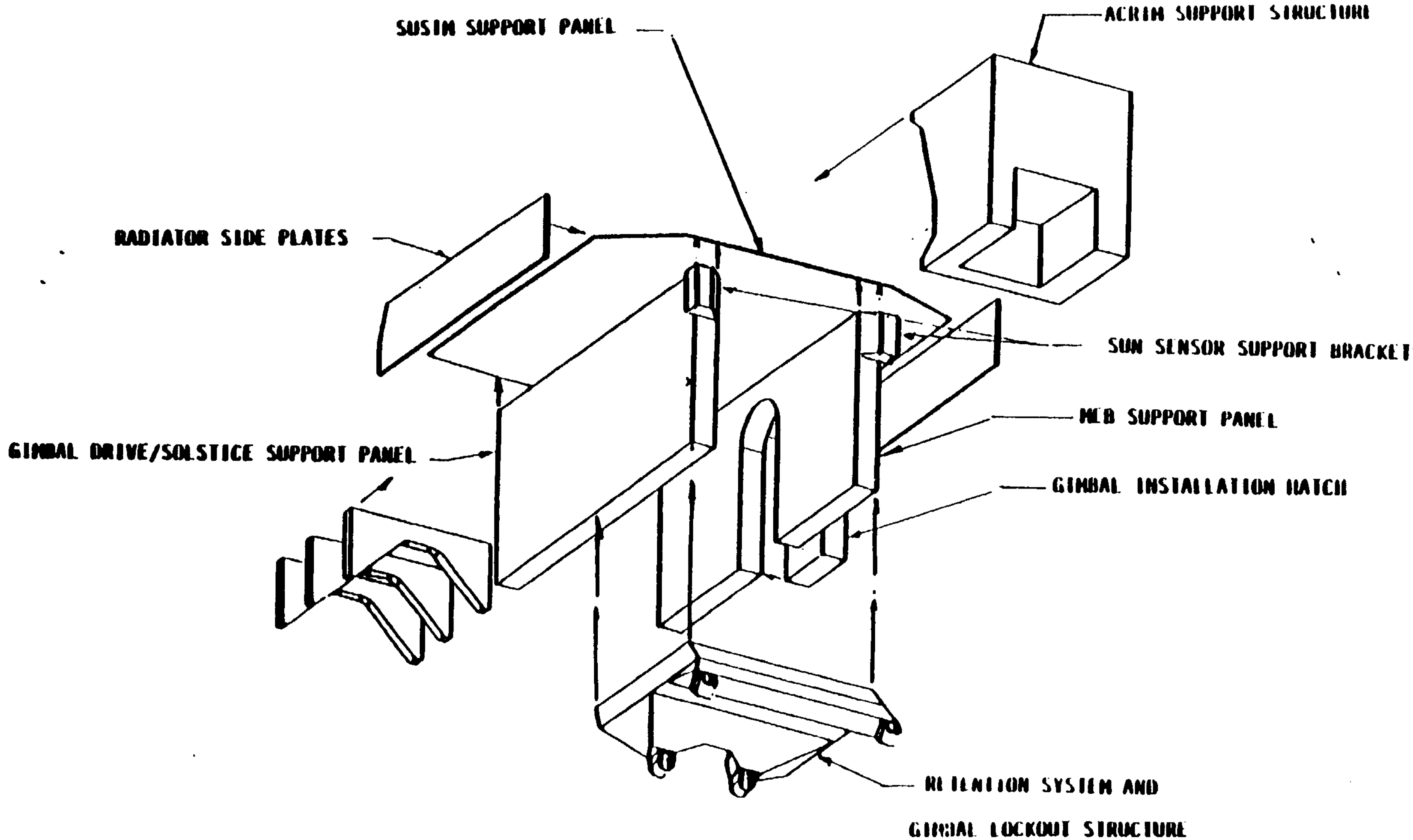
RESEARCH
SATELLITE

Solar Stellar Pointing Platform

MAJOR SECTIONS OF SSPP STRUCTURE



UARS SSPP STRUCTURE

UPPER
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RESEARCH
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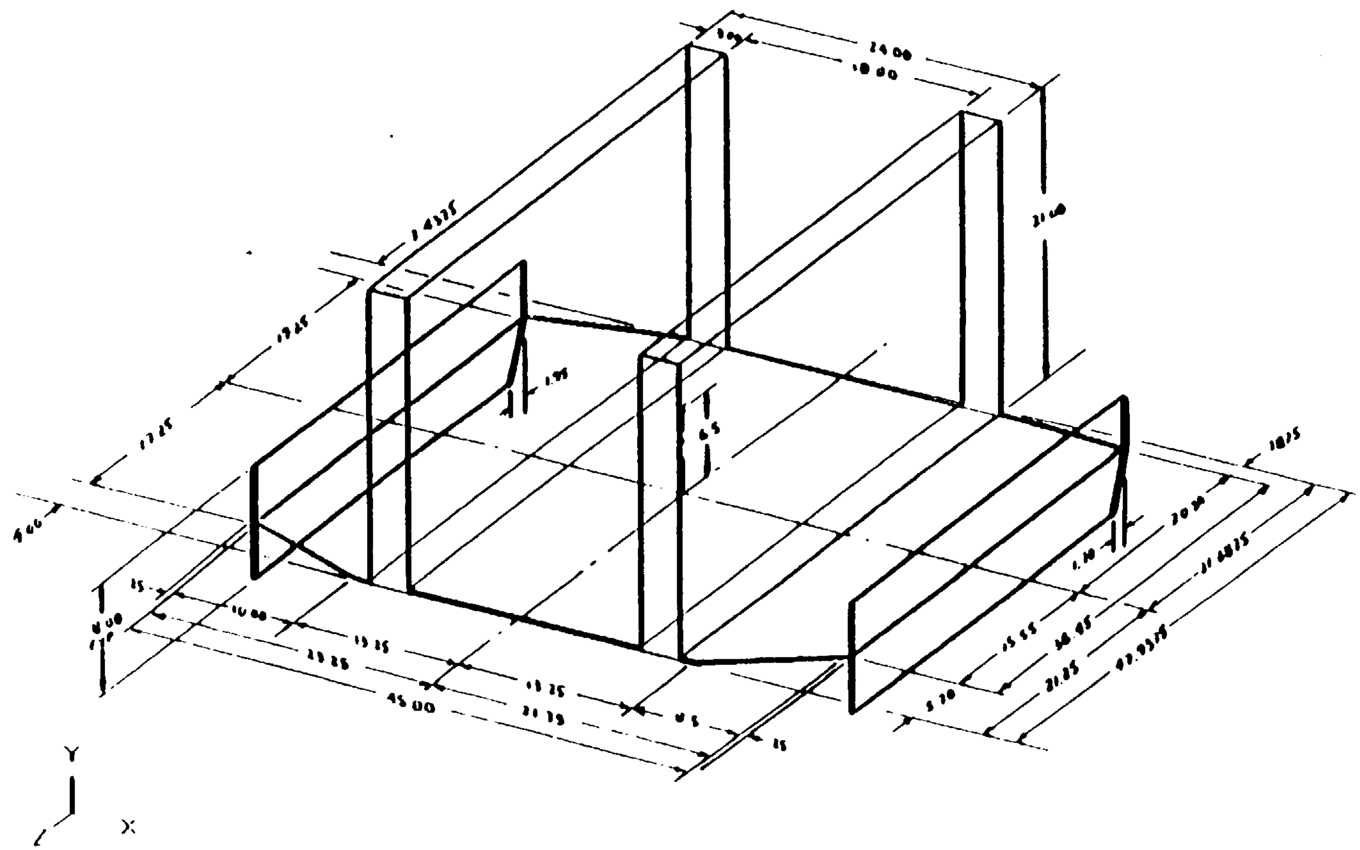
DIMENSION OF BASIC STRUCTURE



subsystem minimum mounting resonant frequencies of 50 Hz or less are specified in Table VIII. Adherence to these minimum frequencies is strongly recommended but not required.

Table VIII. Design Goals for Minimum Resonant Frequencies of Subsystem/Component Mounting

Subsystem or Component	Resonant Frequency (Hz)
Stowed Solar Array Assembly	17 (See Note 1)
Stowed HGA Dish	35
Antenna Feed	50
Stowed ZEPS Boom	50
Stowed HGA	50
Large Components, including SSPP (Locked)	35
Small Components and Panels (<200 lbs.)	50

Note: 1. Seventeen (17) Hertz or 1.4 times Observatory fundamental pitch frequency

3.4.3 Shock. The shock environment due to activation of separation devices and of on-board Observatory separation/deployment devices shall be analyzed. The maximum expected shock environment is specified in Figure 5 and 10.2.

3.4.4 Acceleration. Maximum acceleration loads shall be determined from the worst case vibroacoustic effects of quasi-steady acceleration and transient response of the Observatory and Orbiter due to launch, recovery and wind gusts. Where resonant frequencies of flight hardware mounting may couple with launch or recovery transients (viz., < 50 Hz), the maximum expected acceleration level shall account for possible dynamic amplification. Preliminary design quasi-steady limit loads for lift-off and landing shall be as specified in Table IX. General loads requirements for preliminary design

LOADS

Table IX. Observatory Quasi-Steady Limit Loads (g)

Condition	STS Axes (See SVS-11100 for Transformation)		
	X_0	Y_0	Z_0
Lift-Off[1]	+5.6	±3.2	±4.8
Landing (6.0 ft/sec sink rate)	±3.0	±2.25	-6.3
Emergency Landing[2]	+1.5 -4.5	+1.5 -1.5	+2.0 -4.5

Note: 1. Lift-off loads contain the vibroacoustic contribution.

2. Emergency landing loads are ultimate loads and are applied separately.

of secondary structure are a function of component design weight, as specified in Figure 1. For each component, loads are applied in each axis simultaneously or the vector sum is applied in the most critical direction, if known.

The maximum acceleration environment for the design of flight hardware is specified in 5.2.6.3 as the qualification/protoflight test levels. Verification shall be by detailed analysis or test if analysis or other considerations so dictate.

3.4.5 Acoustic field. The acoustic environment resulting from the launch vehicle's engines and aerodynamic pressure fluctuations shall be analyzed. The maximum expected acoustic environment is specified in Table XX as the acceptance test requirements.

Solar Stellar Pointing Platform

STRESS ANALYSIS PROCEDURES

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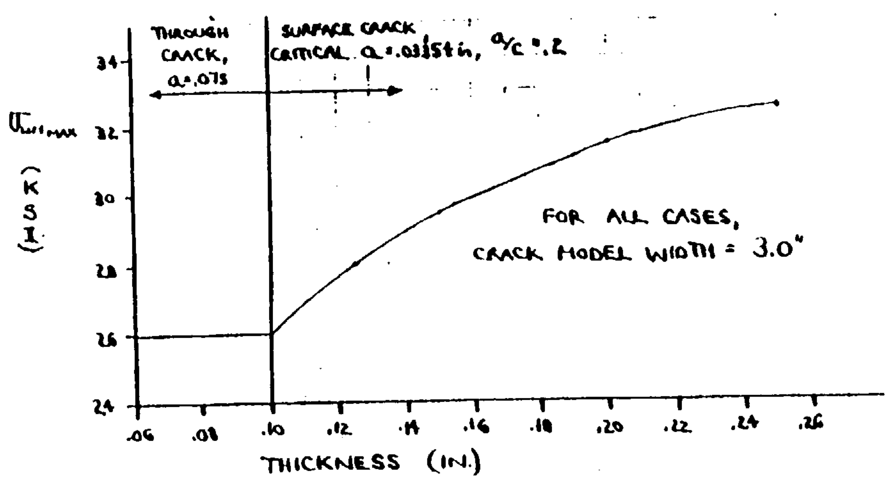
- Analysis Based on Detailed FEM's of Platform Components
- Quasi-Static Load Factors Provided by Dynamics Group
  - Updates to the Structural Design Criteria Based on Load Cycle Results
- NASTRAN Analysis Provides Design Loads
  - Use Maximum Loads From Either:
    * SSPP FEM Supported by Flexible Massless UARS IM
    * SSPP Subsystem With Boundary Conditions at the IM Interface
- Factors of Safety per Structural Design Criteria
- Material Allowables per MIL-HDBK-5
- Calculate Critical Margins of Safety
- Fracture Analysis per Rev C of UARS Fracture Control Plan
  - Safe-Life Analysis per NASA/FLAGRO

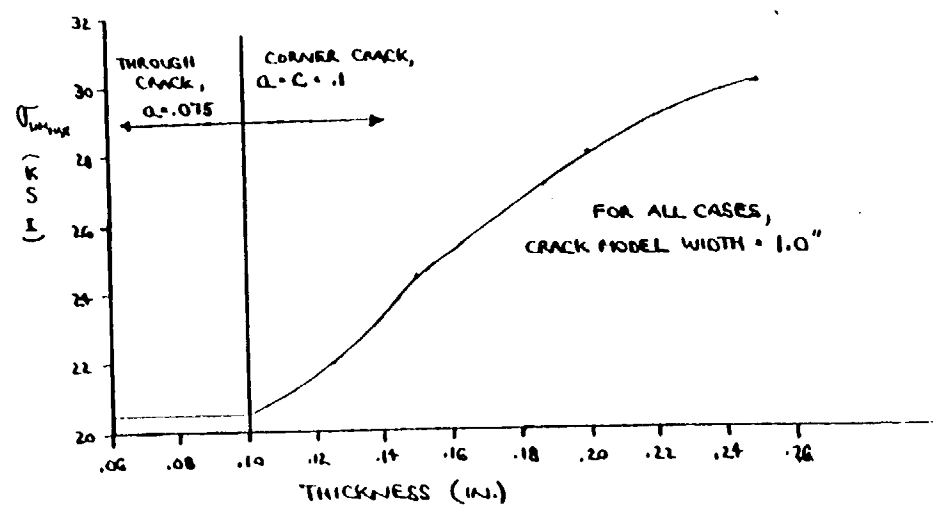
UPPER ATMOSPHERE RESEARCH SATELLITE

SOLAR STELLAR POINTING PLATFORM
FRACTURE CONTROL ANALYSIS

FOR 3.0" WIDE PLATE, t = 0.6 TO .10, FOR A THROUGH CRACK,
$\sigma_{UM\ MAX} = S_o\ MAX = 26.0$ ksi
FOR SURFACE CRACKS, t = .10 TO .25, USE CURVE BELOW



FOR 1.0" SIDE PLATE, t - .06 TO .10, FOR A THROUGH CRACK,
$\sigma_{UM\ MAX} = S_o\ MAX = 20.5$ ksi
FOR CORNER CRACKS, t = .10 TO .25, USE CURVE BELOW



UPPER
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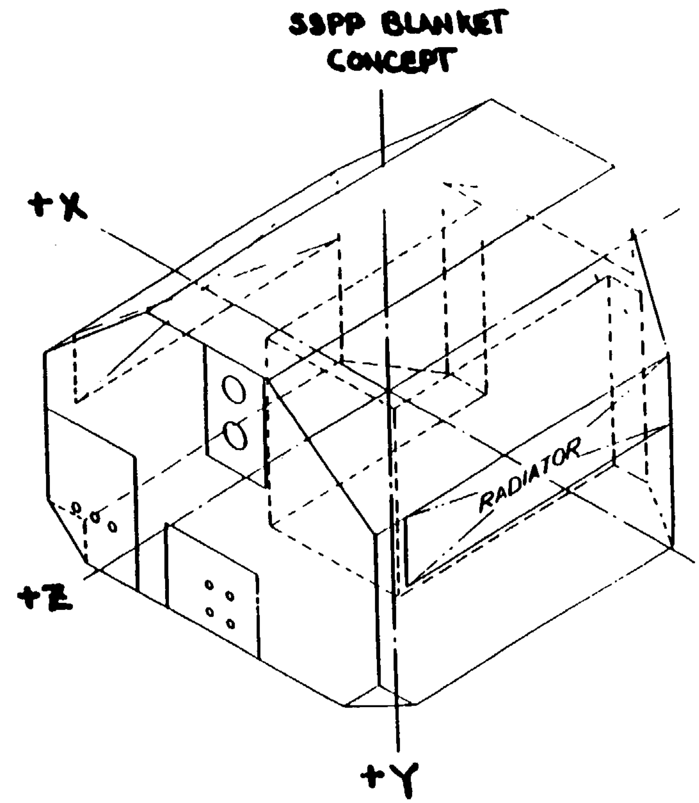
SSPP THERMAL DESIGN

- TWO 2 SQ. FT. DIAMETRICALLY-OPPOSED RADIATORS
- 0.25 INCH THICK ALUMINUM BASEPLATE
- THERMAL BLANKET ENCLOSURE EXCEPT RADIATORS AND APERTURES
- TWO REDUNDANT THERMOSTATICALLY-CONTROLLED HEATER CIRCUITS
- TWO COMPENSATION HEATER CIRCUITS
- FIVE THERMISTORS TO MONITOR BASE-PLATE TEMPERATURE

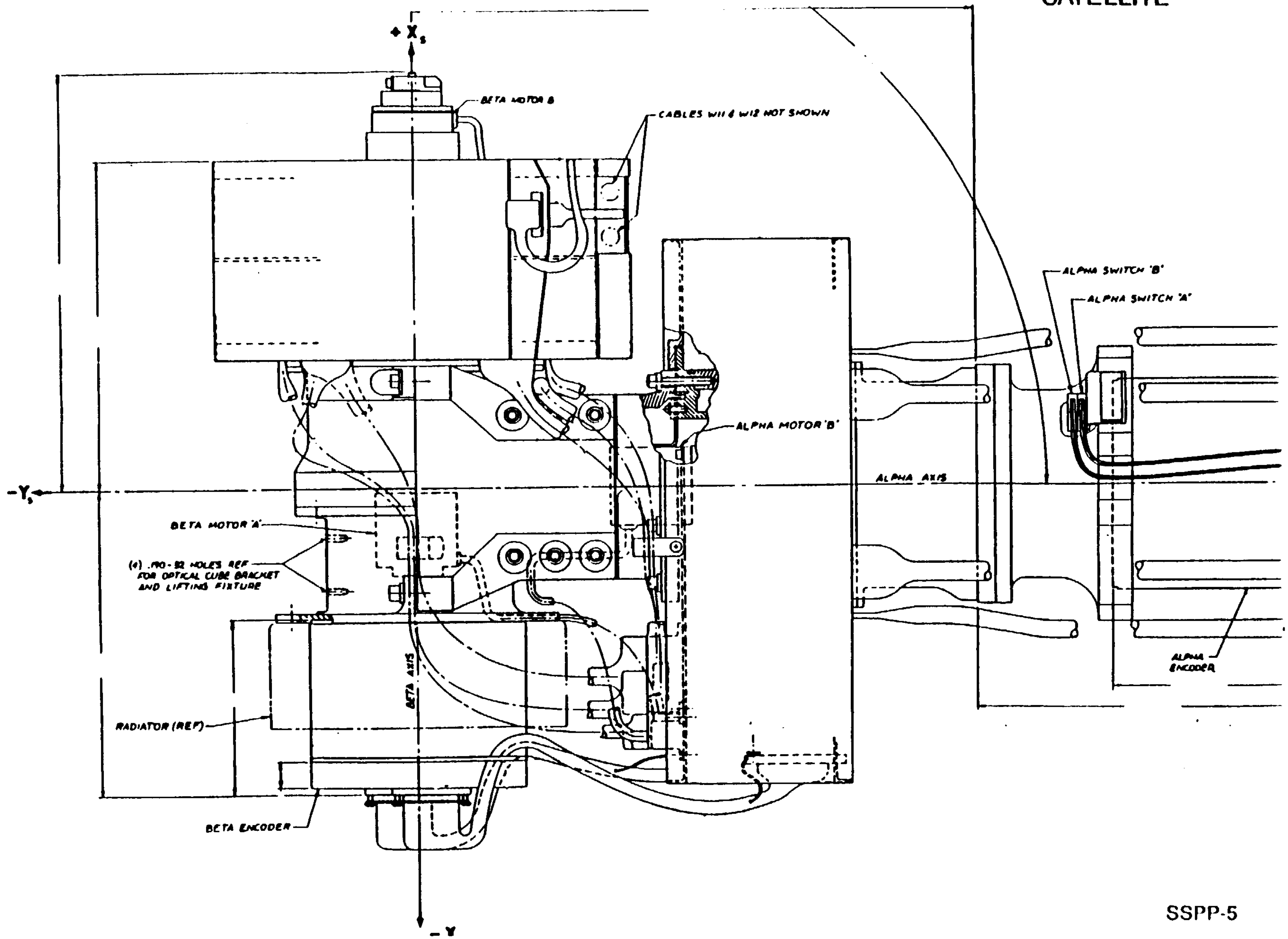


SSPP TWO-AXIS GIMBAL

1. LAYOUT
2. PERFORMANCE REQUIREMENTS
3. CABLE FEED-THROUGH CAPABILITY
4. THERMAL CONTROL
5. SUBASSEMBLIES
6. LIFE TESTING

TWO-AXIS GIMBAL

UPPER
ATMOSPHERE
RESEARCH
SATELLITE



Solar Stellar Pointing Platform

UPPER ATMOSPHERE RESEARCH SATELLITE

TWO AXIS GIMBAL

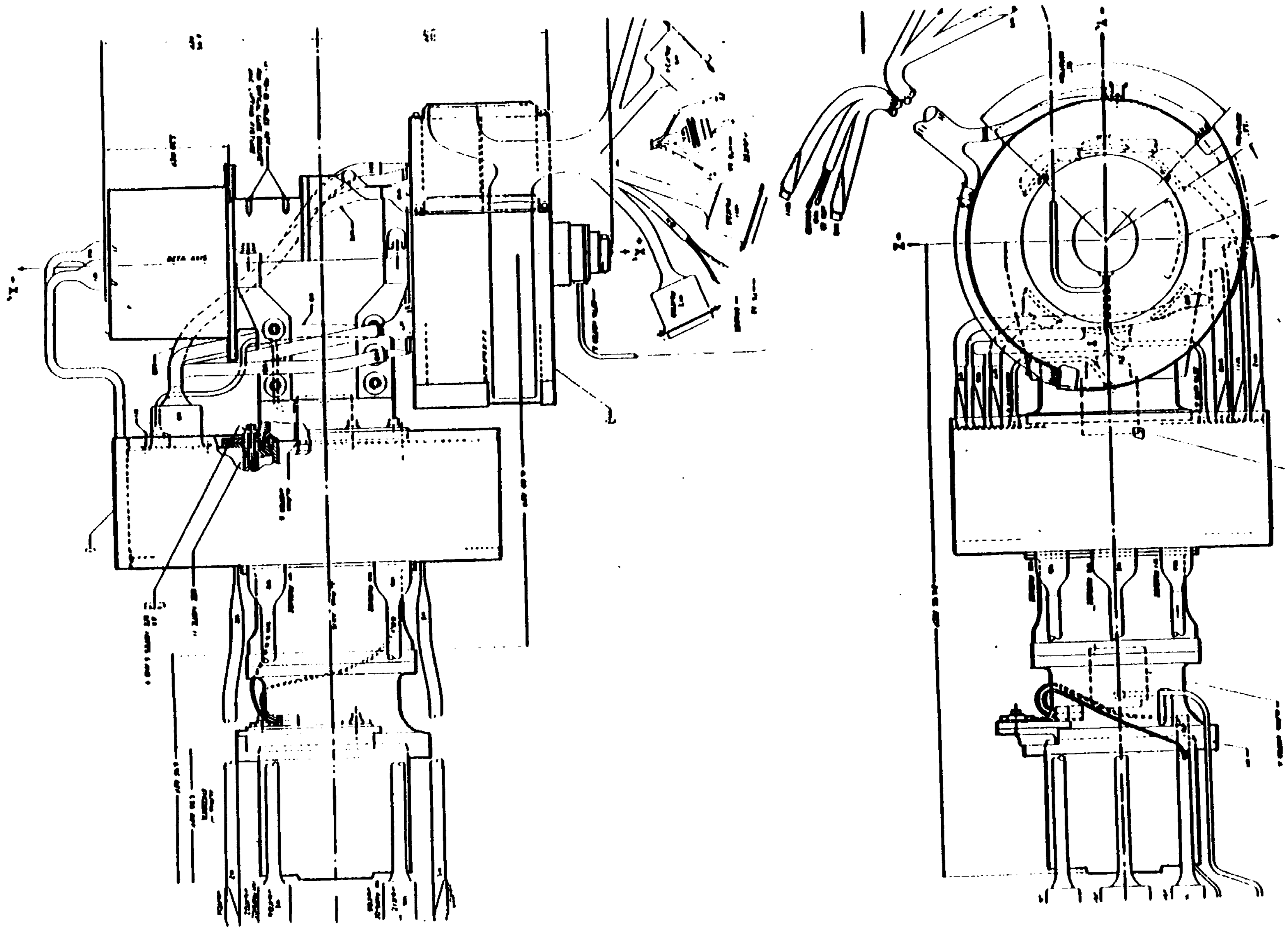


Table X. Mechanical and Electrical Interfaces

	SSPP	HGA
Gimbal Assembly	47-292309	47-291625
Mechanical Interface with Observatory	47-281506	47-294771
Mechanical Interface with Item Pointed	47-282825	47-294756
Electrical Interface	47-290022	47-292021

3.2.1.1 Output step size. Each pulse to a motor shall move the output shaft of each gimbal axis 9.9977 arc seconds nominal.

3.2.1.2 Load inertia. The TAG shall drive a load in either direction with a maximum value of inertia of 3.0 slug feet^2 for the HGA, and 43 slug feet^2 for the SSPP, in each axis.

3.2.1.3 Stepping rates. Each axis shall drive the loads in either direction at any rate up to 150 pulses per second. Functional rates are listed in Table 1.

3.2.1.4 Rotational acceleration. Each axis shall accelerate the loads for the specified application between any rates as specified in Table I, in not more than four pulses applied to the motor. When the direction is reversed, the hysteresis shall not exceed 40 motor steps.

3.2.1.5 Error signature. The maximum input-output error for both axes shall not exceed 50 arc-seconds during any 22 pulse (one second tracking) period.

TORQUE MARGIN:

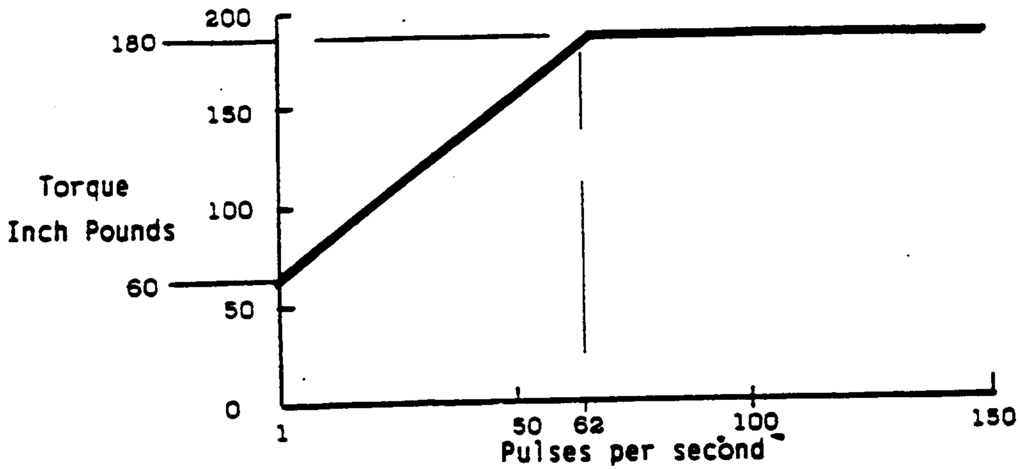


Figure 2. Starting Torque

3.2.2.10 Lubrication. Bearings and gear tooth elements shall be lubricated with perfluorinated polyether oil (based) lubricants sufficient to last the design lifetime. Bearings and faying surfaces operating occasionally shall be lubricated in accordance with 171A4566.

3.2.2.11 Seals. The drive train shall be closed to external contaminants except for parts having relative motion in the functional operation, which shall have labyrinth seals.

3.2.2.12 Stiffness. The stiffness of the output shaft relative to the outer gimbal mounting shall be as shown in Table III and Figure 3.

Table III. Gimbal Stiffness

In plane of both axes	K_α	K_β
Load parallel to alpha axis	1.5×10^4 lb/in	1.5×10^4 lb/in
Load along beta axis	2.2×10^4 lb/in	3.1×10^3 lb/in
About alpha axis, beta axis	4.5×10^4 in. lb/rad	

STIFFNESS

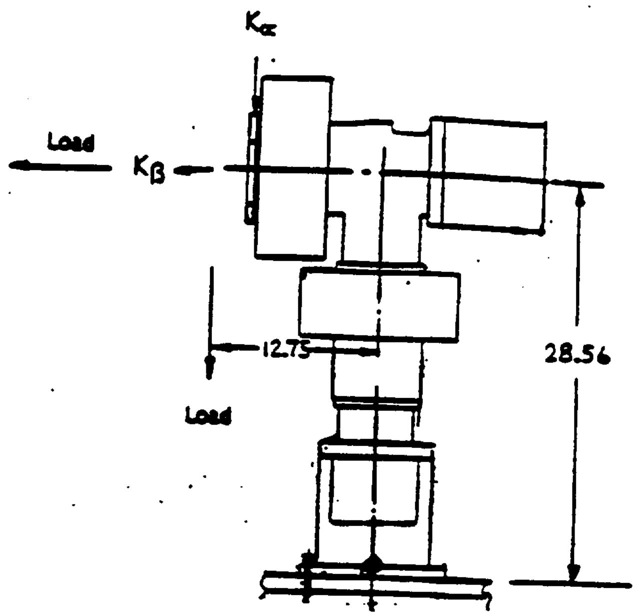


Figure 3. Gimbal Stiffness

3.2.2.13 Encoder. Each axis shall measure the shaft angular position with the 17 bit absolute Shaft Encoder in accordance with SVS-11067.

3.2.2.14 Cable wrap. Electrical power, command, data, and Radio Frequency (RF) shall be transferred across the gimbal rotating joints via wire wraps.

3.2.2.15 Coaxial cable. The coaxial cables shall be one segment through the TAG. The cable shall have a Voltage Standing Wave Ratio (VSWR) not exceeding 1.35:1, and the insertion loss shall not exceed 1.40 decibels at frequencies between 2100 MegaHertz (MHz) and 2300 MHz.

Table IV. Wire Wrap - Common

Deleted

Table V. Wire Wrap - SSPP Unique

Deleted

SSPP TWO AXIS GIMBAL MAJOR SUBASSEMBLIES

1. MOTOR
   - 23 pps STEPPER MOTOR
   - RAPIDSYN
   - REDUNDANT

2. BEARING/SHAFT ASSEMBLY
   - REDUNDANT DUPLEX PAIR
   - ITI
   - BEARING GRADIENT DESIGN GOAL: 5 deg C

3. POSITION ENCODER
   - 17-bit (10 arc-sec) ABSOLUTE POSITION
   - BEI
   - INTERNALLY REDUNDANT ELECTRONICS

4. HARMONIC DRIVE
   - COUPLES MOTOR TO SHAFT
   - 200:1 RATIO + ADDITIONAL 6.83:1 GEARBOX
   - HARMONIC DRIVE DIVISION
   - 30-45 ARC-SEC ERROR SIGNATURE DRIVES SYSTEM ACCURACY

cause that failure. Potential failure modes that could be caused by a single element and that cannot be eliminated from the design shall be identified in a Critical Items list. Justification for the retention of Critical Items elements shall be provided in the Critical Item list.

3.2.4 Maintainability. The item shall be designed so that no regular maintenance will be required. Removable dust covers or other protective devices shall be provided over electrical connectors.

3.2.5 Environmental conditions. The TAG shall suffer no damage or any degradation of performance below the level of the requirements specified herein while exposed to, or after exposure to, the applicable environments as specified in SVS-11111.

TMP MSTS

3.2.5.1 Temperature limits. Non-operating (survival) temperature limits shall be -40 Degrees Centigrade (°C) to +85°C. Predicted orbital mission operating temperature limits shall be -10°C to +50°C.

3.2.5.2 Vibration. The random vibration environment shall be as specified in SVS-11111. Sine vibration for structural verification shall be as specified in SVS-11098.

3.2.5.3 Shock. The shock environment shall be as specified in SVS-11111.

3.2.5.4 Pressure. The pressure environment shall be as specified in SVS-11111.

3.2.5.5 Acoustic noise. The acoustic noise environment shall be as specified in SVS-11111.

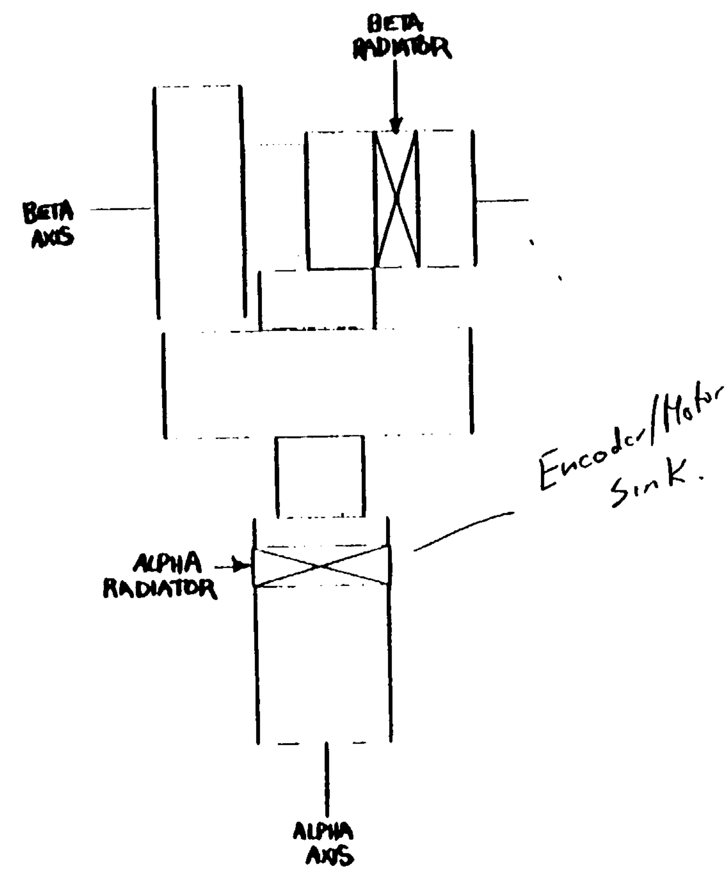
3.2.6 Transportability. The completely assembled TAG configured with the observatory, shall be transportable by air and road with adequate provisions for protection of the observatory from the transportation and handling environments defined in SVS-11111.

GRADIENT GOAL : $\Delta T_{BEARING} \leq 5°C$

SSPP/TAG THERMAL ANALYSIS

TAG THERMAL DESIGN

- TWO CIRCUMFERENTIAL RADIATORS
  - ALPHA RADIATOR : 43 SQ. IN.
  - BETA RADIATOR : 62 SQ. IN.
- INTERNAL COPPER SHUNTS AT DRIVE MOTOR LOCATIONS
- INTERNAL SURFACES HIGH EMITTANCE
- TITANIUM AT I/F OF IM AND SSPP
- THERMAL BLANKETS COVERING ALL GIMBAL SURFACES EXCEPT RADIATORS
- ONE REDUNDANT THERMOSTATICALLY-CONTROLLED HEATER CIRCUIT
- TWO THERMISTORS TO MONITOR GIMBAL TEMPERATURES



SSPP TWO AXIS GIMBAL TESTING

1. PERFORMANCE TESTING:

   - ACCURACY, STIFFNESS, TORQUE MARGIN, LIMIT SWITCH OPERATION, HARD-STOP RANGE, ACCELERATION, DETENT TORQUE

2. ENVIRONMENTAL TESTING:

   - RANDOM VIBRATION, THERMAL CYCLE, STATIC LOAD, THERMAL VACUUM (ENG UNIT)

3. LIFE TESTING:

   - THERMAL PART (THERMAL EFFECTS ACCELERATED BY TEMPERATURE)
   - AMBIENT PART (FULL 40 SLUG-FT^2 LOAD, ACCELERATED PULSE RATE)
   - QUALIFIED TO THREE YEAR LIFE (80,000 CYCLES)
   - NO SIGNIFICANT LUBE LOSS (BRAYCOTE 815Z)

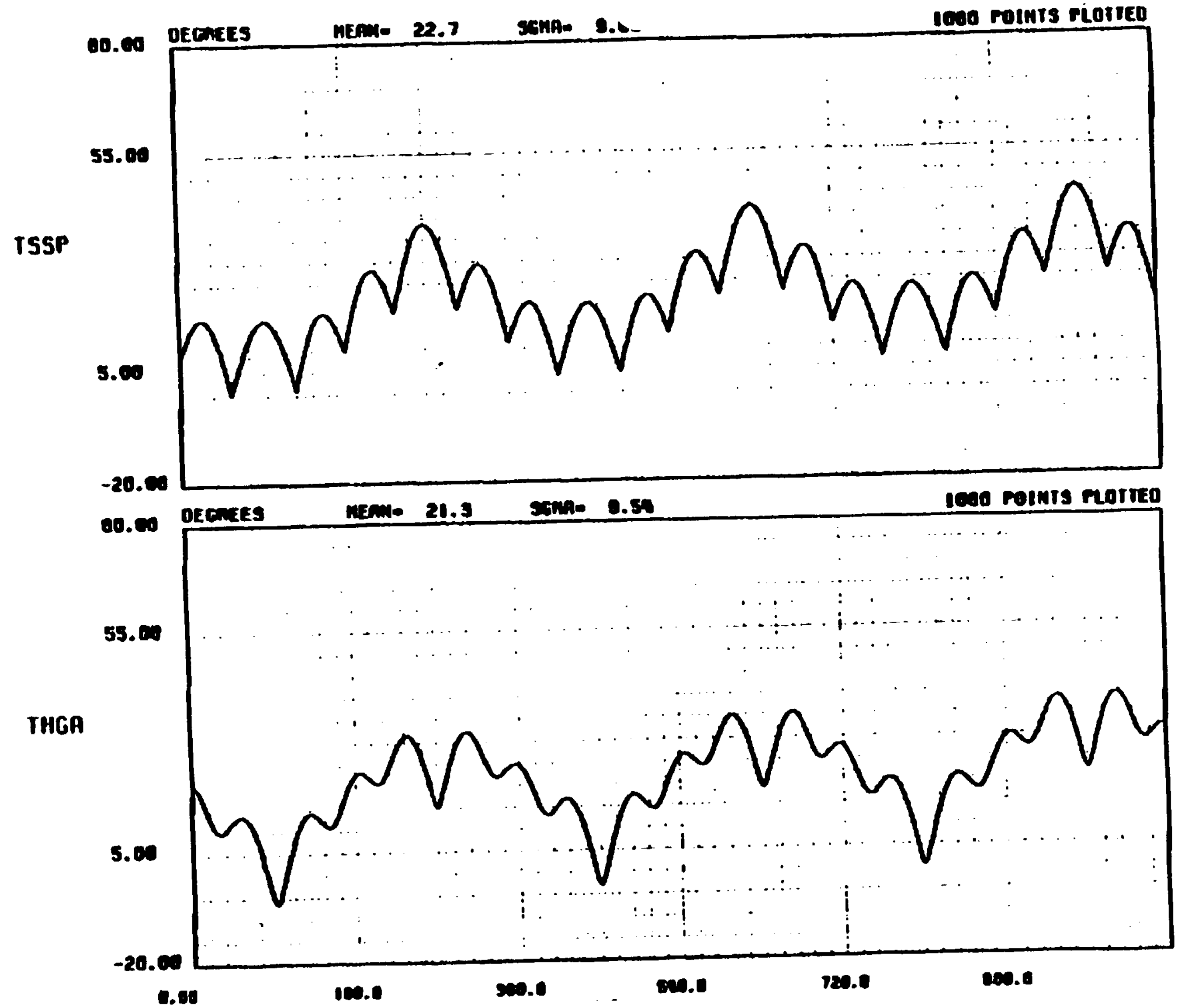


Figure 10: Predicted on-orbit time/temperature profiles for the SSPP (upper plot) and HGA gimbals.

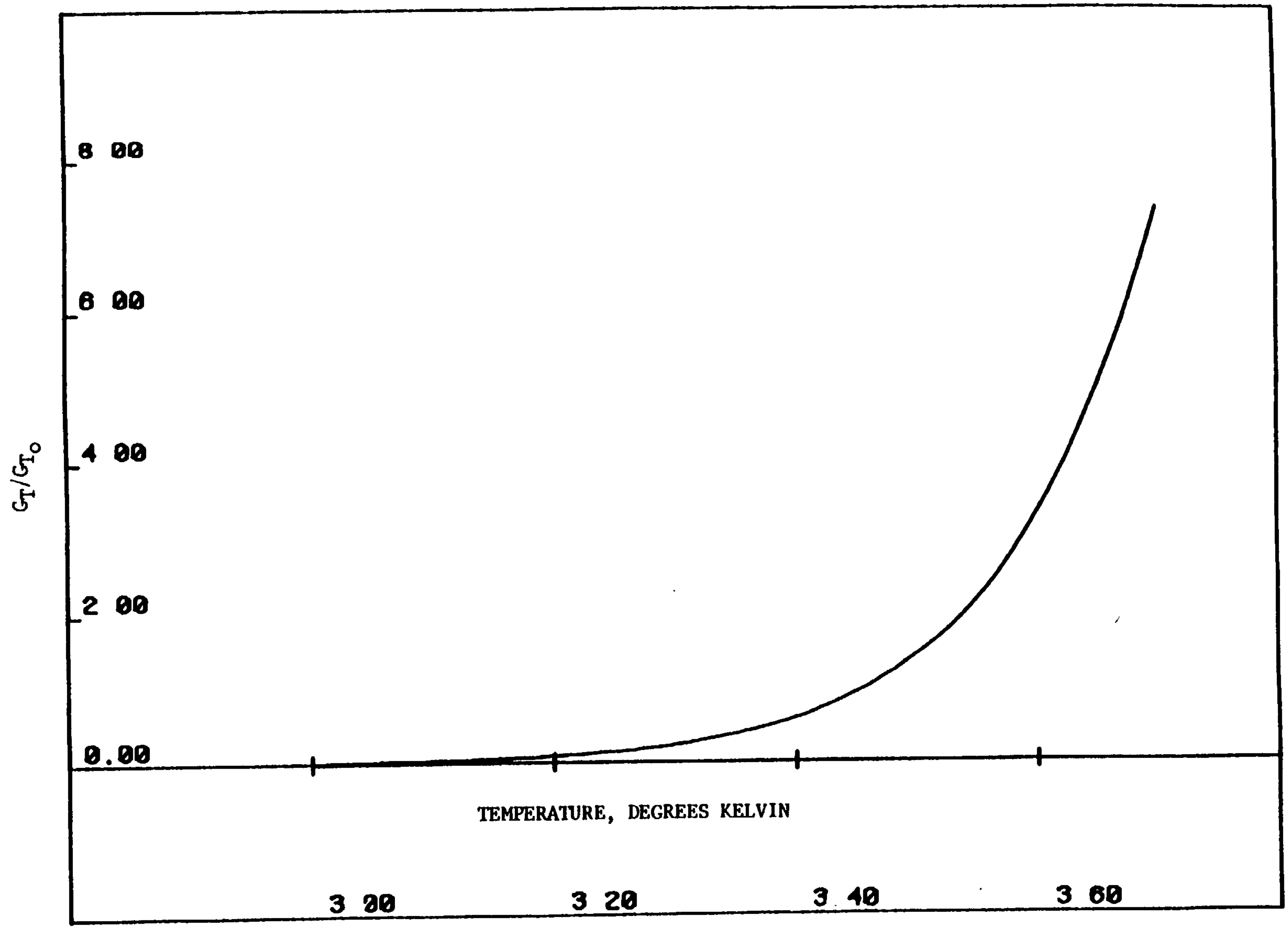


Figure 13: Plot according to Eq. (10) of the acceleration factor G_T/G_{T_o} as a function of absolute temperature. G_T is the evaporation rate at absolute temperature, T. and G_{T_o} is the evaporation rate at an assumed average (constant) absolute temperature T_o. For this plot, T_o is assumed to be 27.67°C = 300.82°K which is the predicted effective average temperature for the SSPP during orbit life. The plot covers the range 300-370°K (26 85-96.85°C).

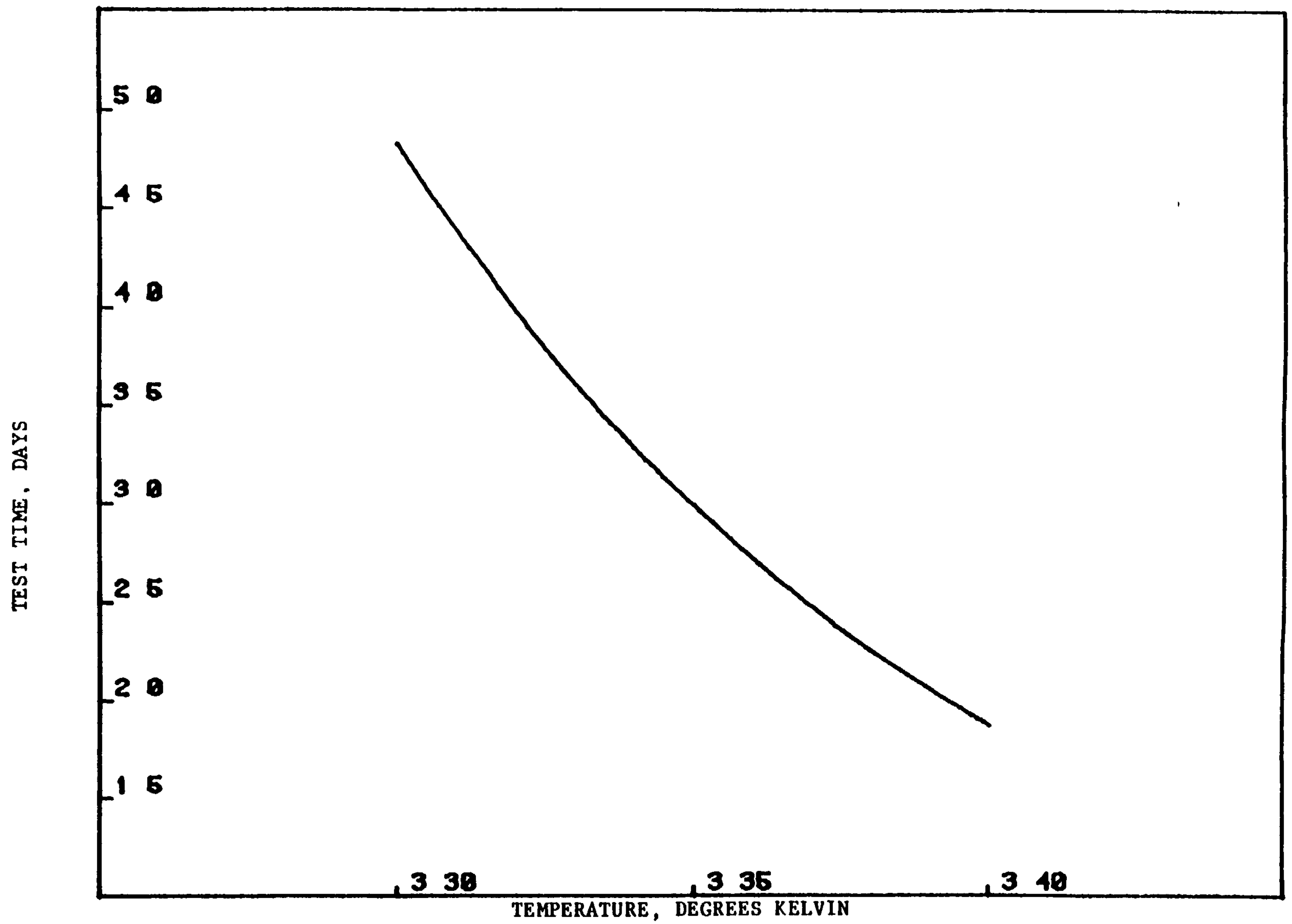


Figure 14: Plot of test time in days as a function of effective average SSPP temperature during test. The calculation assumes an effective average temperature during the mission of 300.82°K = 27.67°C.

SSPP GIMBAL DRIVE ELEX & PLATFORM SUN SENSOR

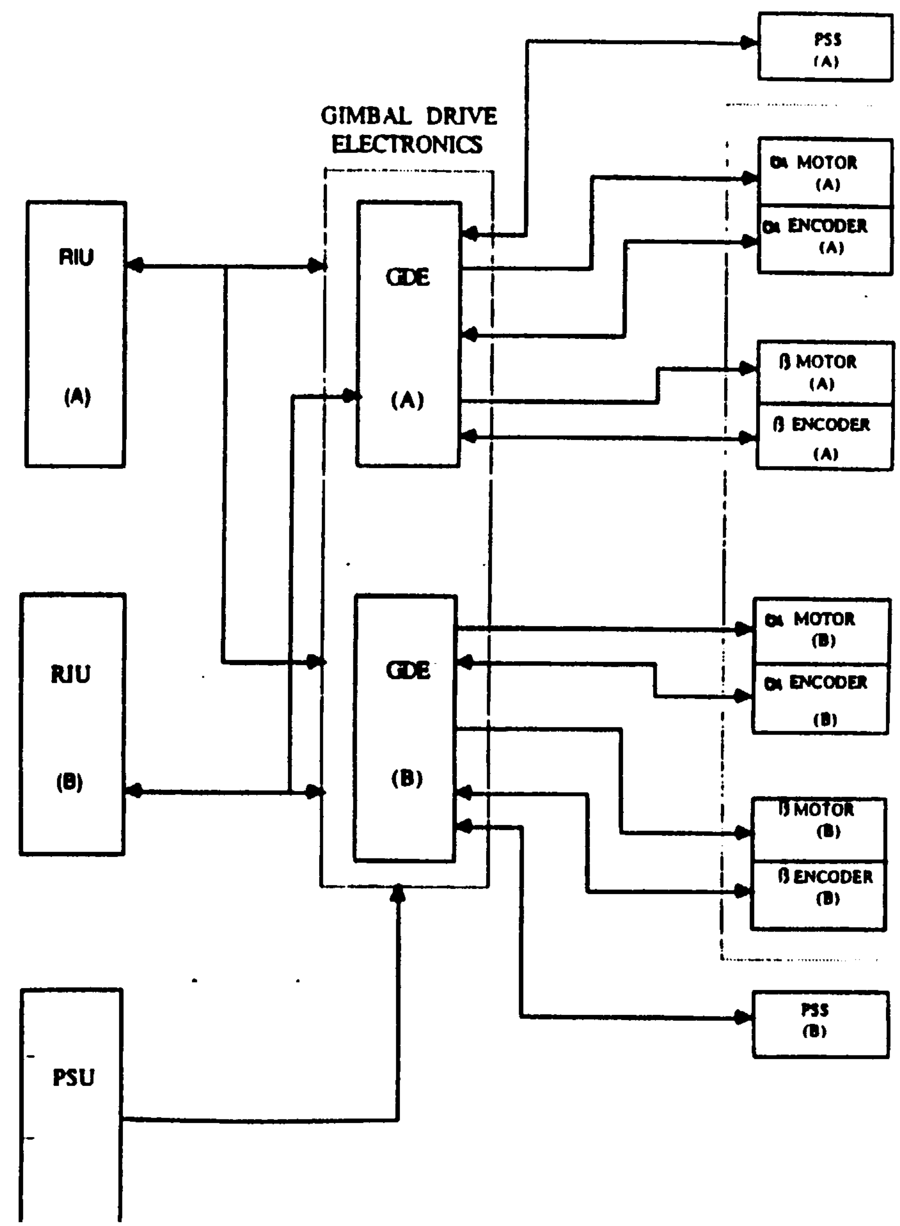
1. GIMBAL DRIVE ELECTRONICS
2. PLATFORM SUN SENSOR

GIMBAL DRIVE ELECTRONICS

1. BLOCK DIAGRAMS
2. FUNCTIONS
2. COMMANDS
3. TELEMETRY

SSPP GIMBAL DRIVE ELECTRONICS

UPPER ATMOSPHERE RESEARCH SATELLITE



GDE FUNCTIONS

1. POWERS GIMBAL ENCODER AND PLATFORM SUN SENSOR
2. PROVIDES 4-PHASE STEPPER MOTOR PULSES TO GIMBAL
3. ACCEPTS RATE COMMAND FROM OBC
4. READS ENCODER AND PSS SERIAL TLM & PROVIDES TO OBC
5. PROVIDES DISCRETE TLM TO DATA BUS CU
6. PROVIDES SERIAL TLM TO DATA BUS CU
7. CONTROLS AUTO-RESTOW FUNCTION

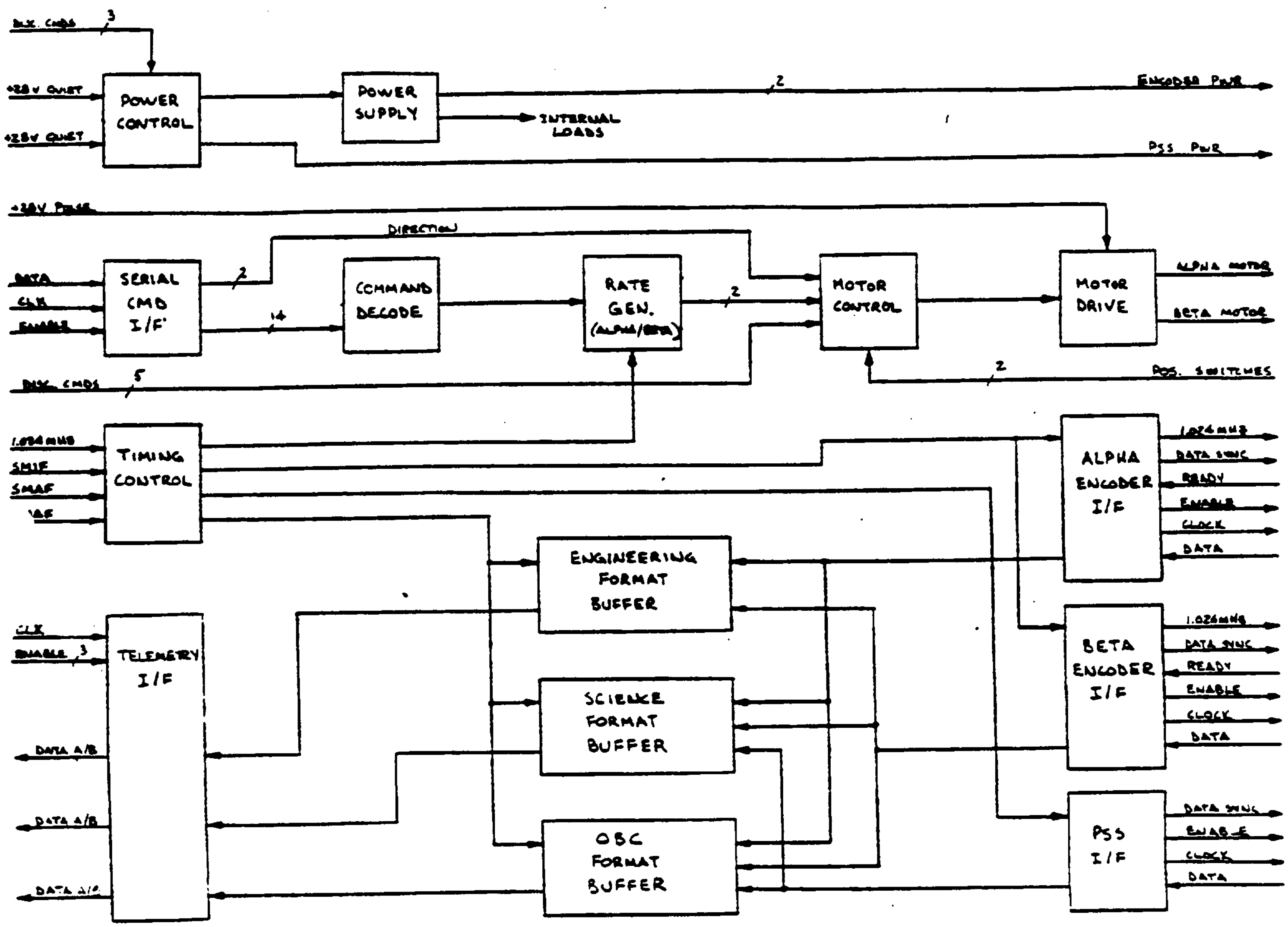


Figure 2. Signal Flow Diagram

Table I. RIU Commands

SERIAL COMMANDS

- NUMBER OF PULSES ALPHA/BETA AXIS

DISCRETE COMMANDS

- GDE A ON/GDE B OFF
- GDE B ON/GDE A OFF
- BOTH A AND B OFF
- STOW ENABLE
- STOW EXECUTE
- EXTERNAL CONTROL
- FULL DUTY CYCLE ENABLE
- FULL DUTY CYCLE DISABLE

3.2.1.1.1.1 Serial commands. Serial commands shall be received from the RIU every 1.024/2.048 seconds depending on the GDE configuration (SSPP/HGAS respectively), as shown in Figure 12. The serial command identifies the rate to be executed during the next 1.024/2.048 second time frame. In order for the command to be executed during the next period, the command must be received a minimum of 270 microseconds prior to the start of that period.

Serial Command Format

	ALPHA AXIS			BETA AXIS
0	1 ... 7	8	9	10 ... 15
DIR	DRIVE RATE (data LSB in bit #8)	DIR	PAR	DRIVE RATE (data LSB in bit #15)

Notes:

1) A data "1" in the direction (DIR) bit (bit 0) indicates the positive direction of rotation.

2) PAR = parity bit (odd parity)

3) Drive Rate (SSPP) Alpha Axis = 0 - 127 pulses per 1.024 sec
Beta Axis = 0 - 63 pulses per 1.024 sec
(Command Resolution = 1 pulse)

4) Drive Rate - (HGAS) Alpha Axis = 0 - 254 pulses per 1.024 sec
Beta Axis = 0 - 126 pulses per 1.024 sec
(Command Resolution = 2 pulses)

Table II. GDE Telemetry Outputs

Description	Type
Science Telemetry Data (A)	Serial
Engineering Telemetry Data (A)	Serial
OBC Data (A)	Serial
Science Telemetry Data (B)	Serial
Engineering Telemetry Data (B)	Serial
OBC Data (B)	Serial
Temperature 1	Passive Analog
Temperature 2	Passive Analog
Temperature 3	Passive Analog
Temperature 4	Passive Analog
Temperature 5	Passive Analog
Temperature 6	Passive Analog
Power Supply A Voltage	Analog
Power Supply B voltage	Analog
PSS Sun Presence (A)	Bilevel
PSS Power On (A)	Bilevel
RIU A/B Selected (A)	Bilevel
Stow Enable/Disabled (A)	Bilevel
Stow Active/Disabled (A)	Bilevel
Alpha Axis Stowed (A)	Bilevel
Beta Axis Stowed (A)	Bilevel
Gimbal Stowed (A)	Bilevel
Full Duty Cycle Enabled/Disabled (A)	Bilevel
Valid Command Received (A)	Bilevel
Multiple Commands Received (A)	Bilevel
Parity Error (A)	Bilevel
PSS Sun Presence (B)	Bilevel
PSS Power On (B)	Bilevel
RIU A/B Selected (B)	Bilevel
Stow Enabled/Disabled (B)	Bilevel
Stow Active/Disabled (B)	Bilevel
Alpha Axis Stowed (B)	Bilevel
Beta Axis Stowed (B)	Bilevel
Gimbal Stowed (B)	Bilevel
Full Duty Cycle Enabled/Disabled (B)	Bilevel
Valid Command Received (B)	Bilevel
Multiple Commands Received (B)	Bilevel
Parity Error (B)	Bilevel

NOTE: (A) or (B) indicates that telemetry is from "A" side or "B" side of GDE, respectively.

Table III. Telemetry Data Word Configuration

Telemetry Buffer	Format	Update Rate	Cycle Reset
Science TLM	Science	1/SMIF	SMAF
Engineering TLM	Engineering	1/EMIF	EMAF
OBC Data	Science/Engineering	1/SMIF	SMAF

Serial Telemetry Data Word Format

Science Telemetry Word

```
Byte No        0     1     2     3     4     5     6     7
   0        MSB ------------(Alpha Axis Position)----------------
   1        -----------------------------------------------------
   2        LSB   | MSB ---(Alpha Axis PSS Error)-----------------
   3        -------------------------LSB  | PRT  | SUN  | CMD
   4        MSB ------------(Beta Axis Position)-----------------
   5        -----------------------------------------------------
   6        LSB   | MSB ---(Beta Axis PSS Error)------------------
   7        -------------------------LSB  | FLG  | PWR  | TMR
```

Engineering Telemetry Word

```
Byte No        0     1     2     3     4     5     6     7
   0        MSB ------------(Alpha Axis Position)----------------
   1        ---------------------------------- LSB | PRT | CMD
   2        MSB ------------(Beta Axis Position)-----------------
   3        ---------------------------------- LSB | TMR | FLG
```

Table III. Telemetry Data Word Configuration (Cont'd)

OBC Data Word	Contents							
SSPP Configuration	(Same as Science TLM)							
HGAS Configuration	(As Follows)							
Byte No	0	1	2	3	4	5	6	7
0	MSB ------------(Alpha Axis Position)----------------							
1	--------------------------------------- LSB | SPR							
2	MSB ------------(Beta Axis Position)-----------------							
3	--------------------------------------- LSB | FLG							

Notes: 1) Where the telemetry format contains less than the full component data word, the telemetry data shall be the most significant bits.

2) SUN = PSS Sun Presence Signal
PWR = PSS Power On
CMD = OBC Rate CMD Not Received
PRT = Parity Error
FLG = Encoder READY Timeout
TMR = Multiple Rate Commands Received
SPR = Spare

formats. However, the OBC buffer shall contain either the science format or a modified engineering format. The format provided is based on the GDE configuration (SSPP/HGAS respectively). In the case of the Engineering telemetry buffer, data word update attempts shall only occur on SMIF pulses coincedent with the Engineering Minor Frame sync pulses, every 1.024 seconds.

In each case no data buffer updating shall be allowed from the start of the data word transfer to the RIU to its completion, or until the cycle has been reset by that format's associated major frame sync pulse. In this way, the circuit is operated independently of the telemetry rate. The telemetry buffers shall contain the most recent data, and will remain intact until they have been fully read. The telemetry update rates are summarized in Table III.

PLATFORM SUN SENSOR

1. COORDINATE SYSTEM
2. ENVELOPE DRAWINGS
3. TELEMETRY

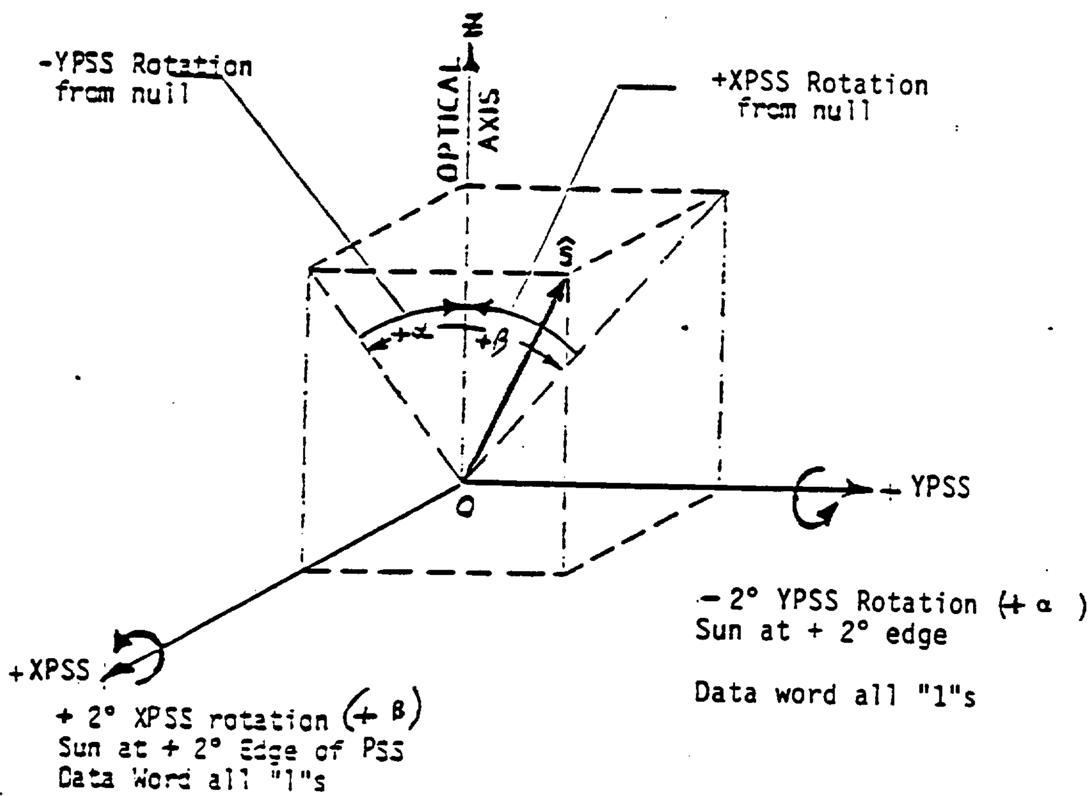


Figure 6. Sensor Coordinate System

Shift Direction →

31 32	30	29	28 — 17	14 15 16	13	12 — 1	bit #
SPARES	PWR STATUS	PWR STATUS	β sun angle (About PSS X axis) data word with MSB in bit #17	SPARES	SUN PRES	α sun angle (About PSS Y axis) data word with MSB in bit #1	data out →

PSS Data Word

The Sun Presence bit is bit 13. When the Sun Presence bit is a one (1) the angle data shall be valid. Power "ON" is indicated by a zero (0) bit in bit Position 29 and a one (1) bit in bit Position 30. All spares shall be set to zero (0). Power "OFF" is indicated by the same logic value in both bits 29 and 30. (A (1) in bit 29 and a (0) in bit 30 is an undefined combination resulting from a logic failure.)

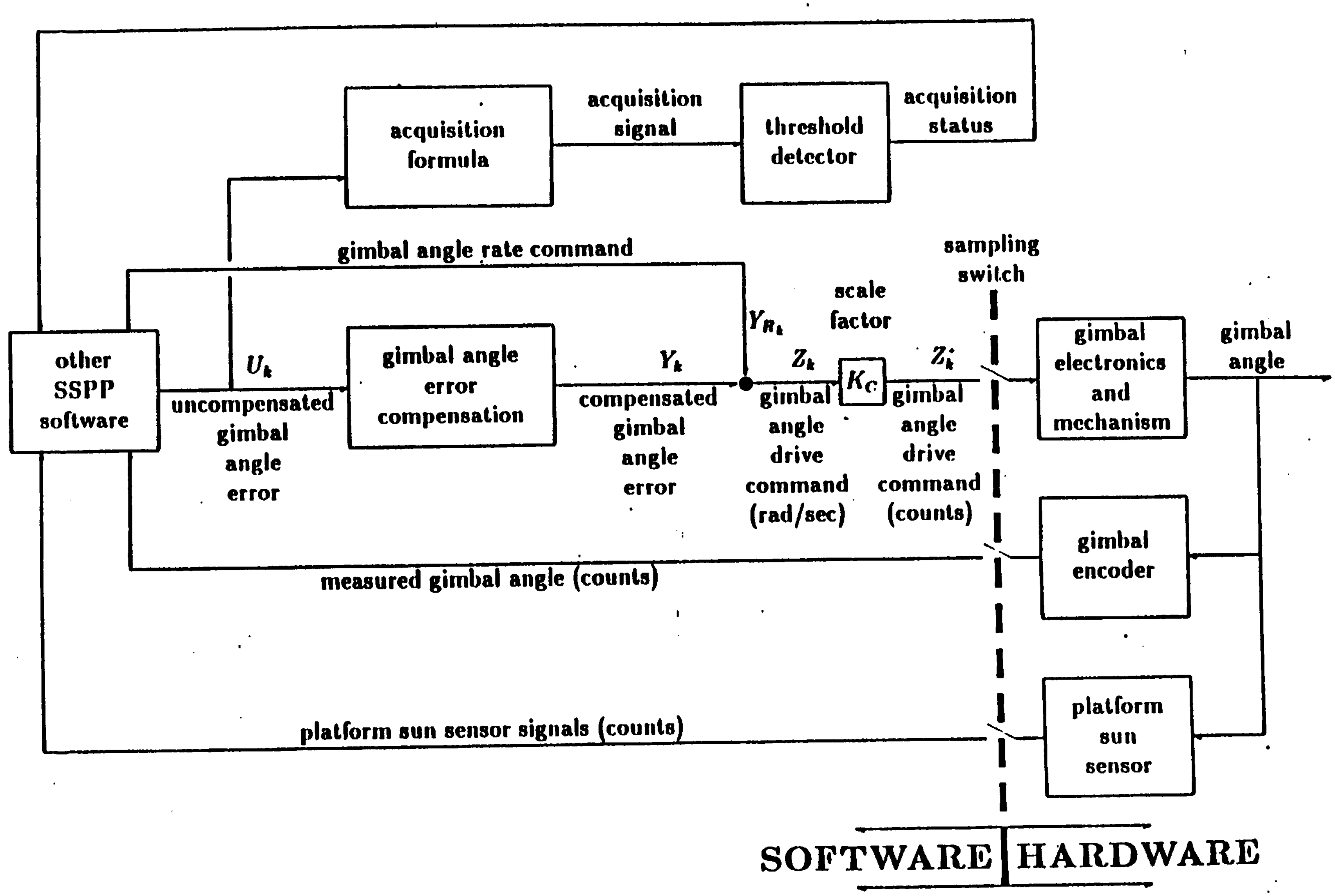
3.1.2.1.2 PSS data sampling rate. The time interval between complete PSS data word readouts by the GDE will be 32 milliseconds (msec) ±1%.

3.1.2.1.3 PSS data word update timing. PSS data word update shall be synchronized by the data sync pulse. The time interval between data sync pulses will be 32 msec ±1%. The α angle data shall be determined within 3.0 msec prior to the data sync pulse. The β angle data shall be determined within 8.3 msec prior to the data sync pulse.

SSPP CONTROL SYSTEM

1. BLOCK DIAGRAM
2. CONTROL COMPENSATION ALGORITHM

Figure 1
TOP LEVEL BLOCK DIAGRAM OF SSPP HARDWARE AND SOFTWARE



periods, both errors for each axis are within the limits required for operation of an experiment, then the platform is considered to have acquired precision tracking; that is, the drive transients have settled to steady state values.

The *loss* logic is to be exercised at regular intervals following acquisition. If the acquisition threshold is violated for one or more consecutive sampling periods, then some as yet unspecified action is to be executed. The action taken is expected to vary from mode to mode and may be limited to simply sending a message to an experiment or ground station.

The switch from open to closed loop tracking will be made after specific conditions are satisfied. The algorithm used to determine whether or not the switch from open to closed loop can be made is similar to the acquisition algorithm.

3 SPECIFIC REQUIREMENTS

3.1 Gimbal Angle Error Compensation

The equalization network for the SSPP gimbal controller has been previously defined by P. Matheson[1]. The software required to implement the digital filter is presented separately for the alpha and beta axes. The form of the compensation is shown in the following equations.

A new compensator output, Y_{k+1}, is to be computed from the preceding samples of the algorithm state variables and the present sample of the uncompensated gimbal angle error, A_k, as follows:

$$U_k = A_k(G_9) \tag{2}$$

$$Y_{k+1} = G_8U_k + (1 + G_1)D_{1,k+1} + (2 - G_6)D_{2,k+1} + (1 - G_7)D_{3,k+1} \tag{3}$$

where,

$$\begin{pmatrix} D_{1,k+1} \\ D_{2,k+1} \\ D_{3,k+1} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 1 + G_1 & -G_6 & -G_7 \\ 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} D_{1k} \\ D_{2k} \\ D_{3k} \end{pmatrix} + \begin{pmatrix} G_8 \\ G_8 \\ 0 \end{pmatrix} U_k \tag{4}$$

[1]See reference 11

Y_{k+1}	next sample of compensator rate output	(deg/sec)
A_k	current sample of uncompensated gimbal angle error	(degrees)
U_k	current sample of modified gimbal angle error	(degrees)
$\begin{pmatrix} D_{1k} \\ D_{2k} \\ D_{3k} \end{pmatrix}$	kth sample of discrete state variables	
G_i	coefficients(see Table 1)(i=1,9)	
k	sampling period	

The order in which the compensator equations are calculated is as follows:

1. The uncompensated position error is modified.

$$U_k = A_k(G_9)$$

2. Limit U_k (See section 3.5)

3. Save the previous controller states.

$$\begin{aligned} D_1(old) &= D_1(new) \\ D_2(old) &= D_2(new) \\ D_3(old) &= D_3(new) \end{aligned}$$

4. Calculate the new controller states.

$$\begin{aligned} D_1(new) &= D_1(old) + G8(U_k) \\ D_2(new) &= D_1(old)(1 + G1) + G8(U_k) - D_2(old)G6 - D_3(old)G7 \\ D_3(new) &= D_2(old) \end{aligned}$$

5. Limit the variable D_1 (See section 3.6)

6. Calculate the compensator output.

$$Y_{k+1} = U_k(G8) + D_1(new)(1 + G1) + D_2(new)(2 - G6) + D_3(new)(1 - G7)$$

SSPP FLIGHT SOFTWARE

1. DERIVED REQUIREMENTS
2. PROCESS CONTROL
3. TARGET COMPUTATION
4. SAMPLE PROCESS - OPEN LOOP TRACKING
5. SIMULATION RESULTS

SSPP Design Requirements

Derived Software Requirements

- Operational Modes
  1. Open-Loop Target Tracking Mode
  2. Closed-Loop Solar Tracking Mode
  3. Slew Mode
  4. Wait Mode
  5. Position Command Mode
- Automatic or Manual Control
- Gimbal Rate Limiting
- Software Gimbal Stops
- *Misalignment Correction*
- Failure Detection and Correction
- Telemetry Contributions
- 1.024-second Control Cycle
- Tracking Status Commands to SSPP Instruments

Figure 1: Top-Level Control Flow Diagram.

Start SSPP

↓

If selected,
initialize SSPP module.

↓

Update control parameters.

↓

Convert position encoder data.

↓

Convert PSS data.

↓

Compute target gimbal angles.

↓

If enabled,
implement FDC logic.

↓

Implement appropriate
mode switching logic.

↓

Implement appropriate
mode processing.

↓

Generate gimbal drive commands.

↓

Format gimbal commands.

↓

Generate instrument commands.

↓

Save data for next cycle.

↓

If requested,
format telemetry data.

↓

End SSPP

Figure 4: Geometry of Spacecraft and Sun Vectors.

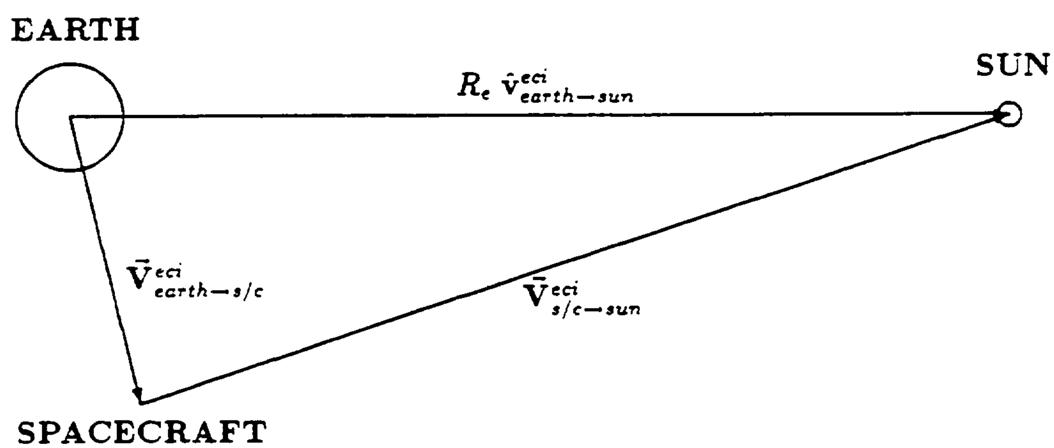
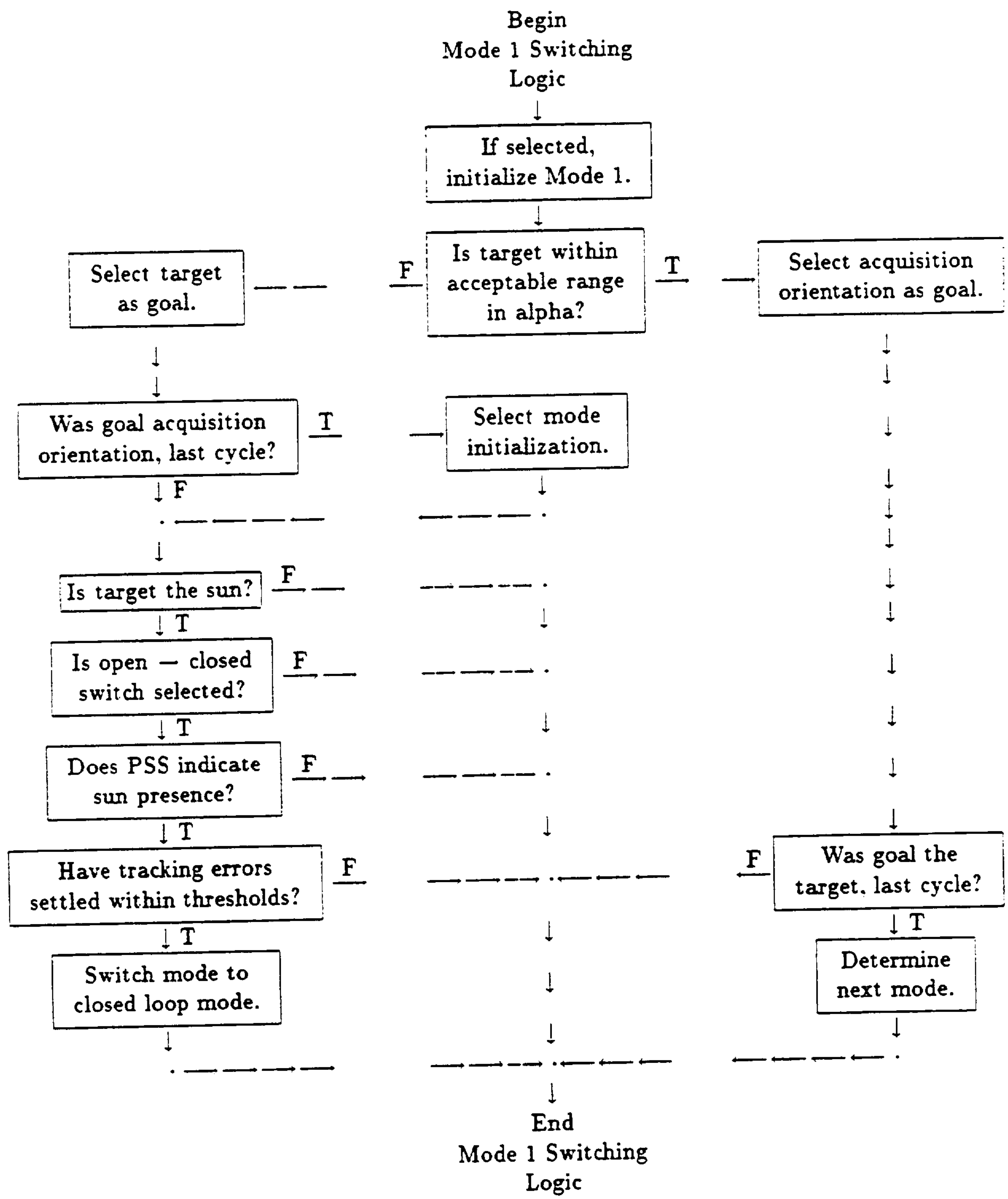


Figure 6: Open Loop Target Tracking Mode Switching Flow Diagram.



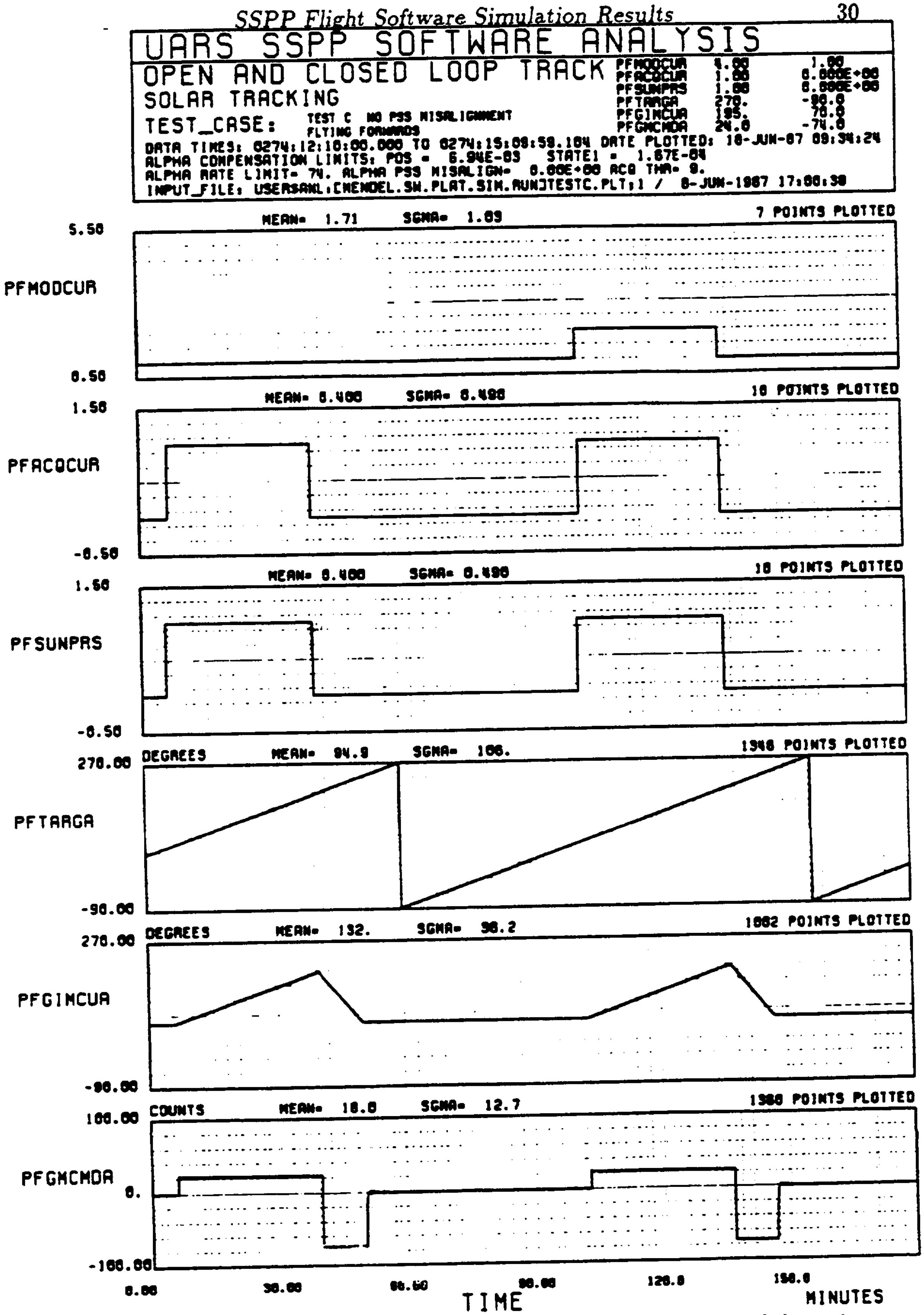


Figure 4: Test C: Open and Closed Loop Solar Tracking: Alpha axis.

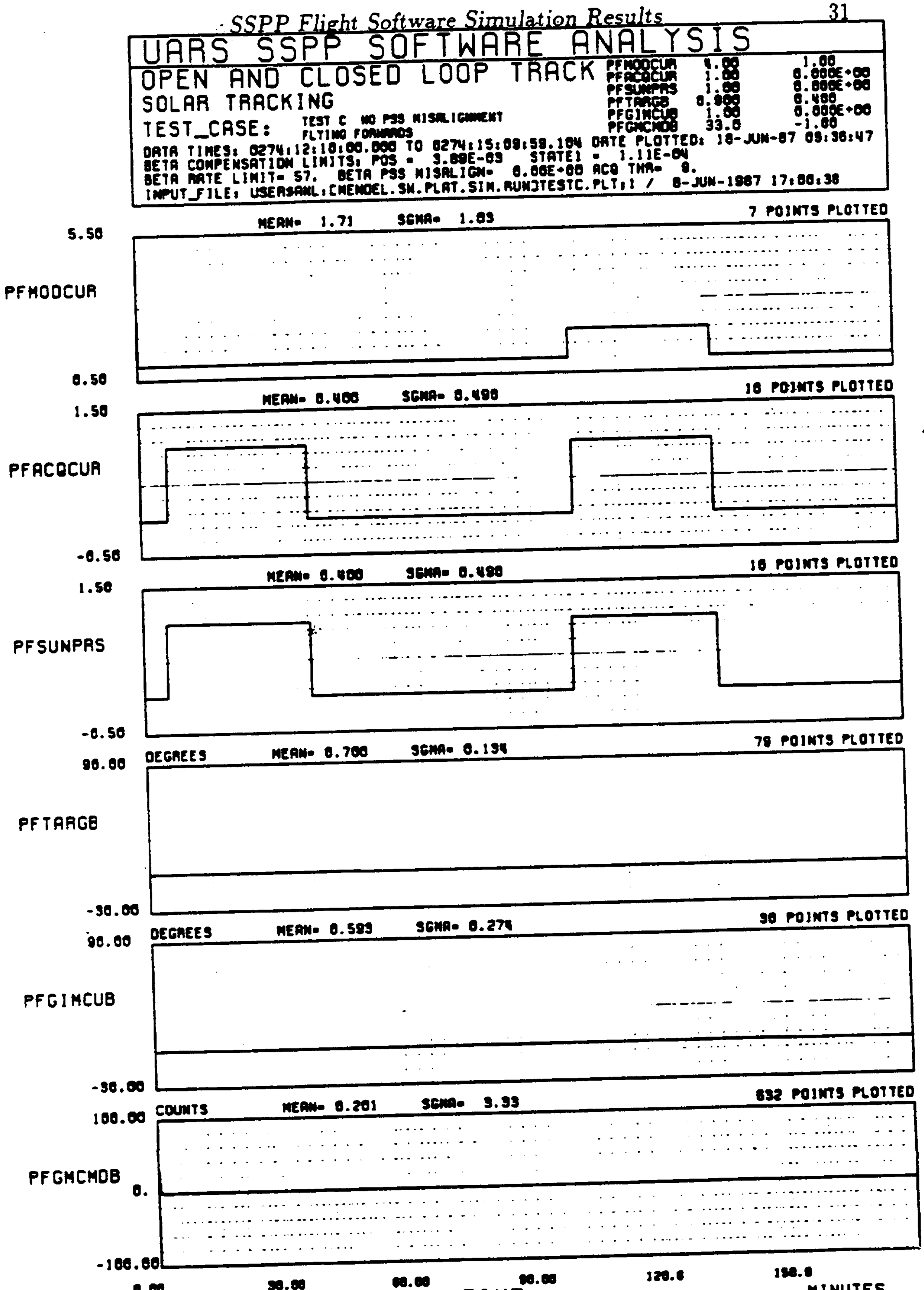


Figure 5: Test C: Open and Closed Loop Solar Tracking: Beta axis.

SSPP SUBSYSTEM & CONTROL LOOP VALIDATION

1. ATTITUDE SIMULATIONS - FORTRAN-BASED, ALGORITHMIC
2. FSW SIMULATIONS - FORTRAN CODE-EMULATION
3. FSW TESTING - ENG'G OBC H/W & ASSEMBLY CODE
4. FULL FUNCTIONAL TEST - ENG'G OBC/CODE, GDE, GIMBAL, PLATFORM,
   - GRAVITY COMPENSATION (WEIGHT & MOMENT)
5. S/C LEVEL TEST - FLIGHT H/W & S/W ON S/C
   - GRAVITY COMPENSATION (MOMENT ONLY)
   - PERFORMED IN EMC, T/V, RF ENVIRONMENTS]

Figure 6: Subsystem Configuration for Full Functional Testing and Partial Functional Testing.

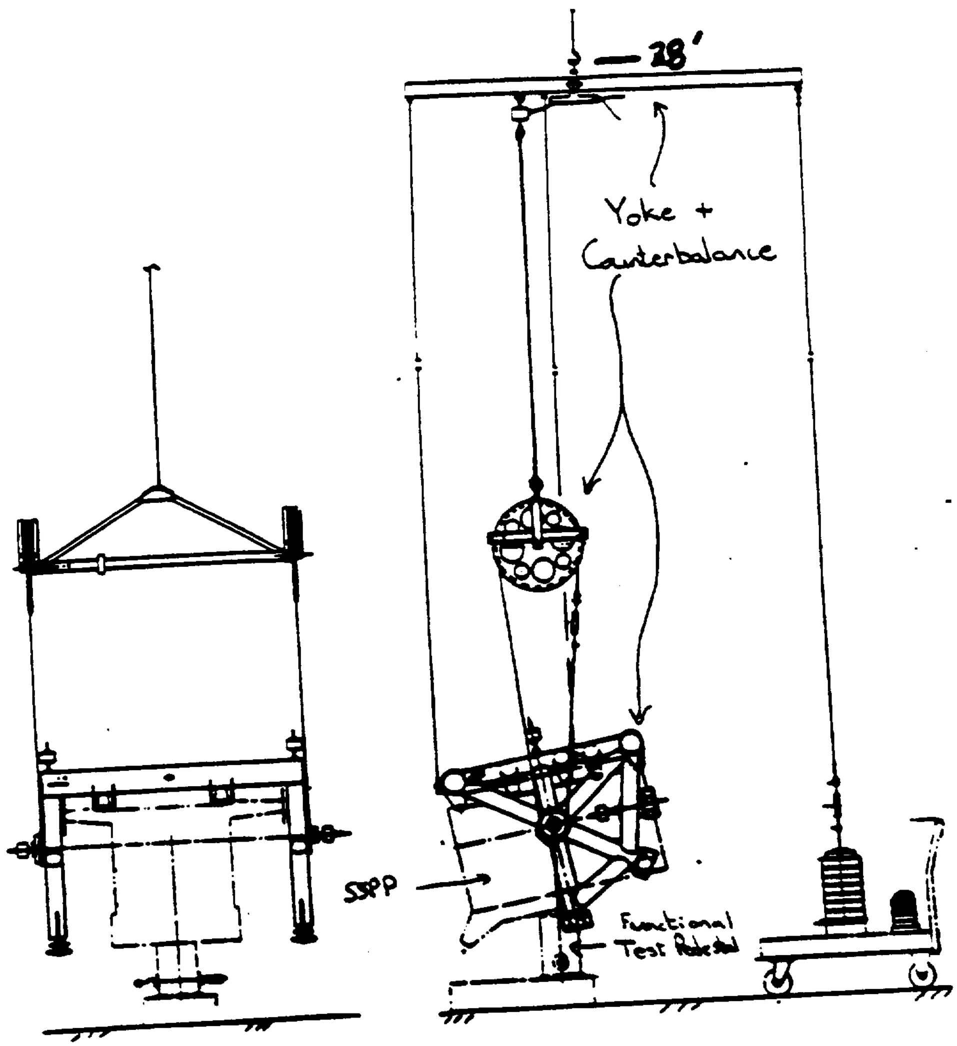


Figure 7: SSPP Subsystem Block Diagram for Full Functional Testing. Note: Flight hardware shown with cross-hatching, simulated hardware with shading, and test hardware unshaded.

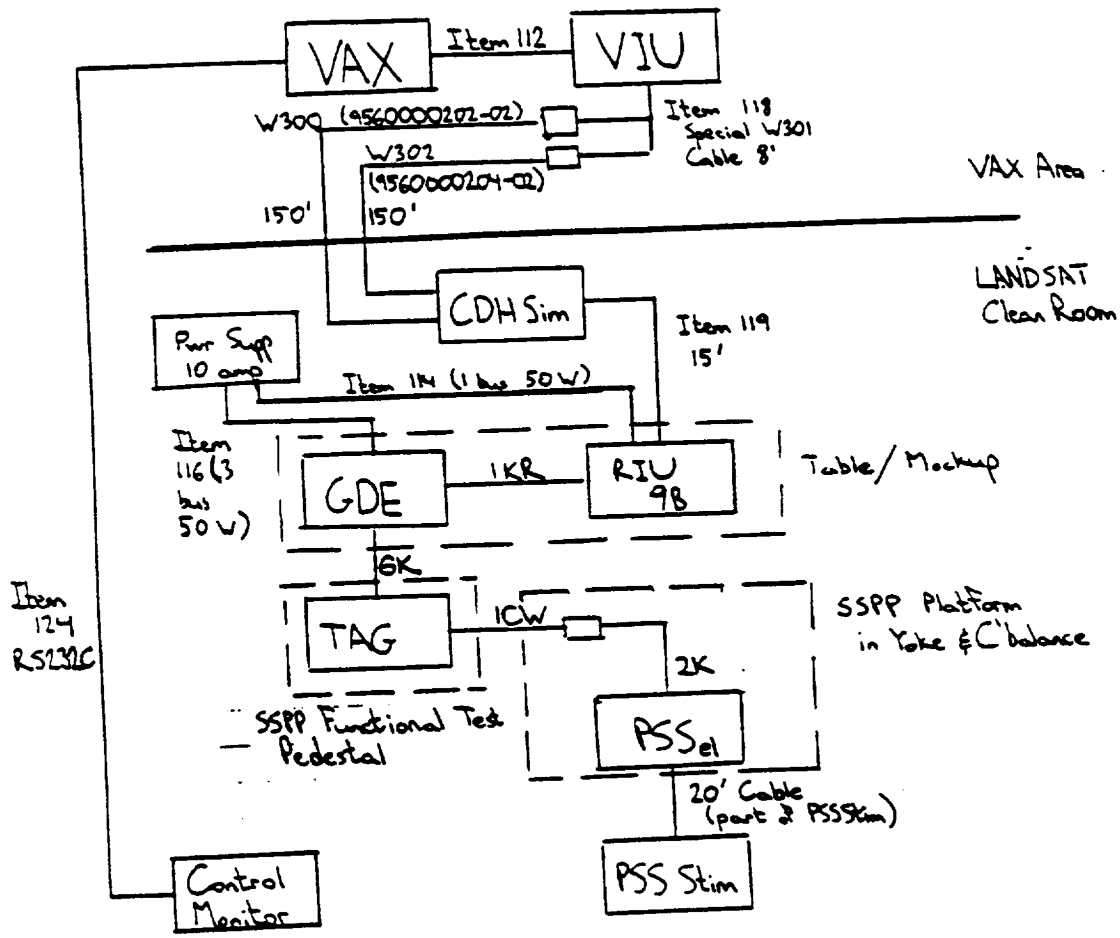
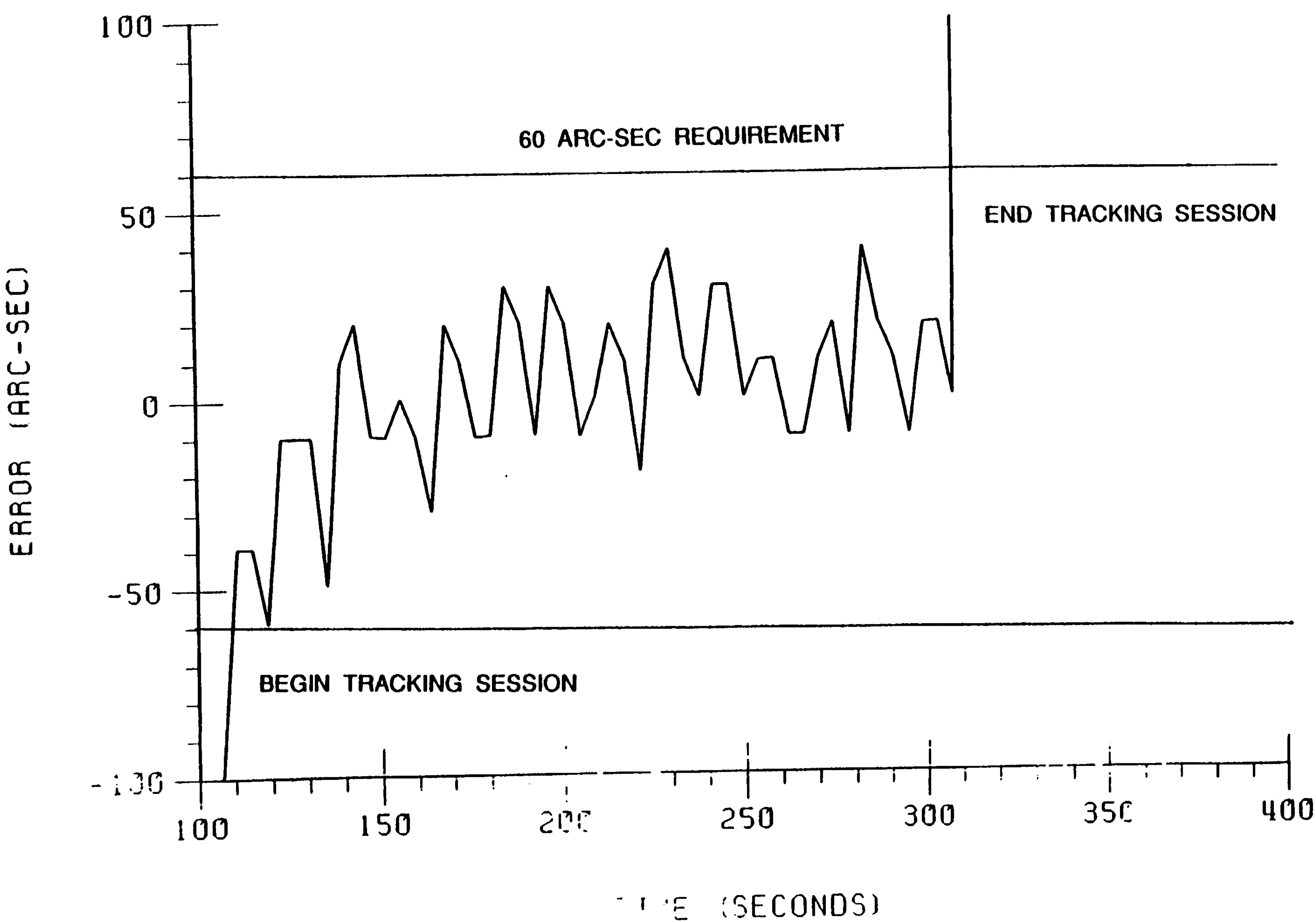


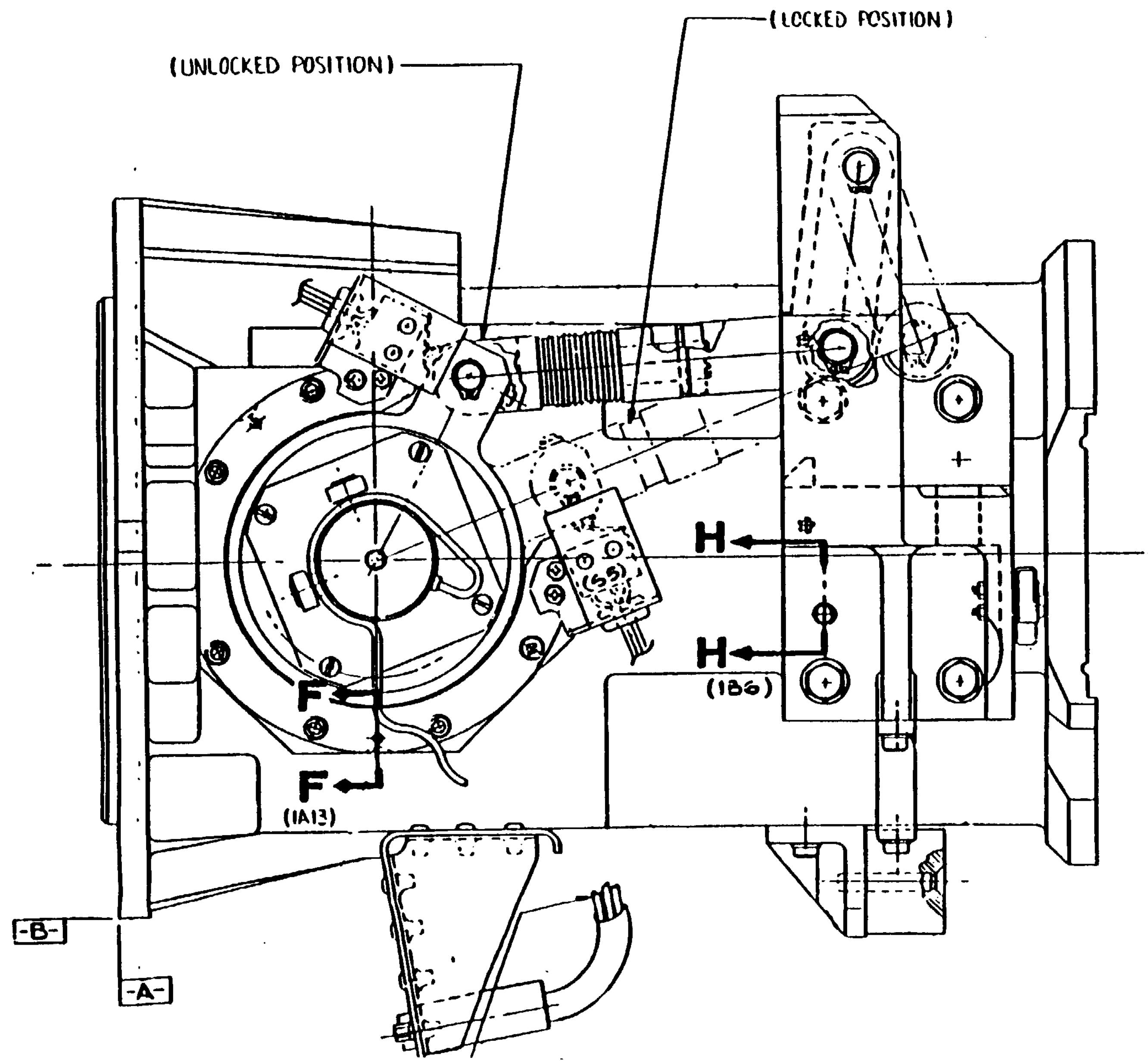
FIGURE 3: ALPHA AXIS OPEN LOOP TRACKING ERROR
(DATA FROM OL3_A)



SSPP RETENTION AND RESTOW/RELATCH

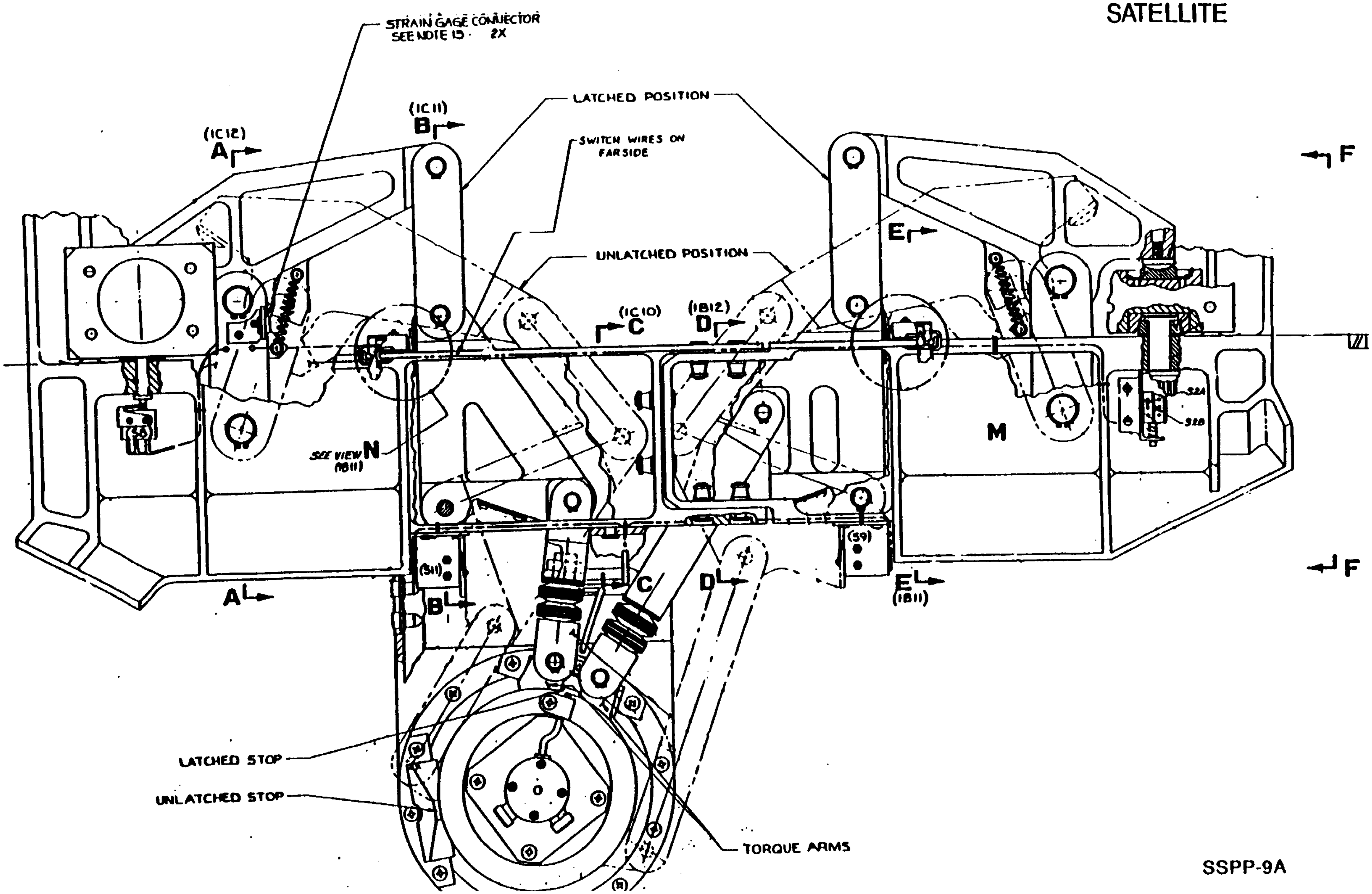
1. NOMINAL SCENARIO - SSPP IS POSITIONED INTO STOW USING OBC POSITION AND RATE COMMAND MODES
2. CONTINGENCY SCENARIO - SSPP IS POSITIONED INTO STOW USING GDE AUTO-STOW FUNCTION, BASED ON LIMIT SWITCHES
3. GIMBAL RETENTION LOCKED FIRST
4. PLATFORM RETENTION LOCKED SECOND
5. REDUNDANT MOTOR/LIMIT SWITCH CONFIGURATION
6. LIMIT SWITCHES GIVE UNAMBIGUOUS "STOWED" AND "LATCH/UNLATCH" INDICATIONS

SSPP RETENTION SYSTEM



SSPP RETENTION SYSTEM

UPPER
ATMOSPHERE
RESEARCH
SATELLITE



SSPP-9A

SSPP OPERATIONS

1. GENERAL
2. MASKING
3. SCHEDULING TOOL (UARS)

SSPP OPERATIONS - GENERAL INFO

1. CURRENT ARCHITECTURE REQUIRES S/C EPHEMERIS AND SOLAR EPHEMERIS FOR ACQUISITION & O/L SOLAR POINTING

2. REQUIRES STAR UNIT VECTORS (ECI) FOR ALL STELLAR POINTING

3. REQUIRES S/C ATTITUDE SOLUTION *TAKEN AT MOUNTING INTERFACE* OR KNOWLEDGE OF TRANSFORMATION FROM NAVIGATION BASE TO MOUNTING I/F FOR ACQUISITION & O/L POINTING

4. FOR LESS PRECISE APPLICATIONS, IDEAL S/C ATTITUDE CAN BE ASSUMED AND USE INSTEAD OF ACTUALS (IE EARTH-POINTED S/C)

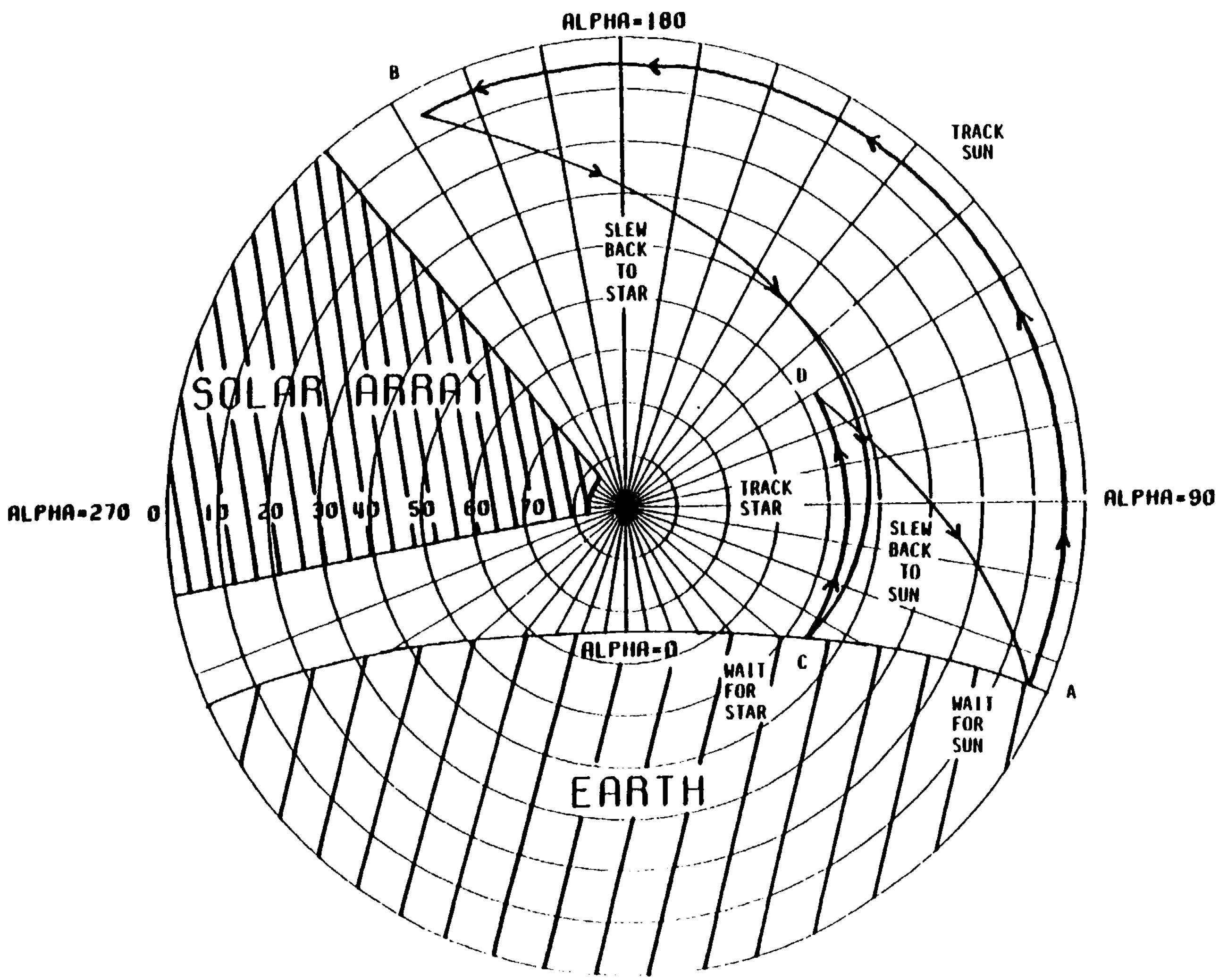
5. ON-BOARD HARDWARE AND SOFTWARE LIMITS AVAILABLE TO PROVIDE SSPP W/ WORST-CASE MASK & PREVENT HARDWARE COLLISIONS, USING CONSTANT ALPHA/BETA LIMITS

6. MORE COMPLEX MASK GEOMETRY REQUIRES GROUND SCHEDULING OR FSW UPGRADE (NOT DIFFICULT)

7. CURRENT CONFIGURATION CAN ACT *COMPLETELY AUTONOMOUSLY* FOR SOLAR-ONLY, SIMPLE MASK CONFIGURATION ASSUMING S/C POSITION IN ECI COORDS IS AVAILABLE AND APPLICATION IS NOT PRECISION

SSPP Design Requirements

Operational Overview



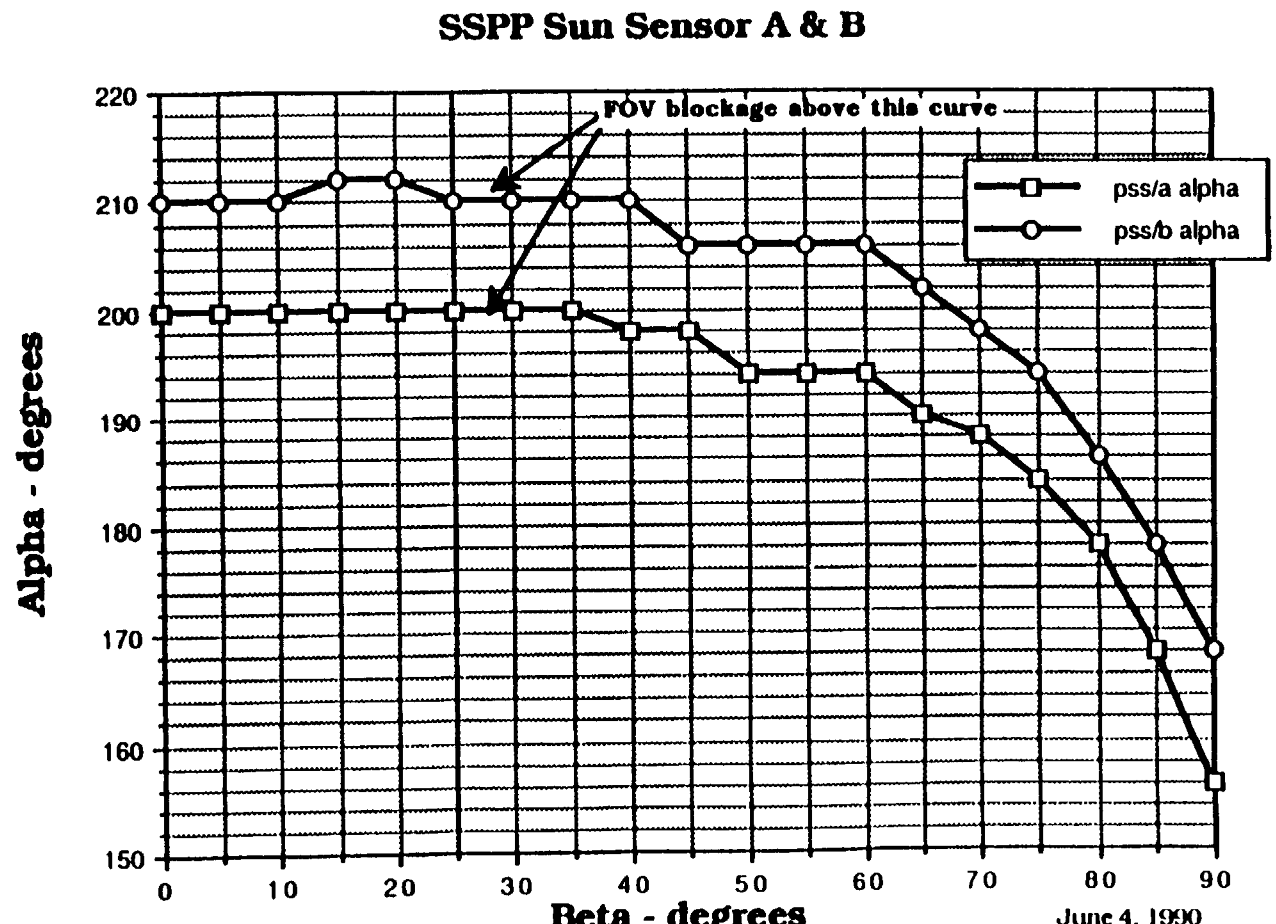


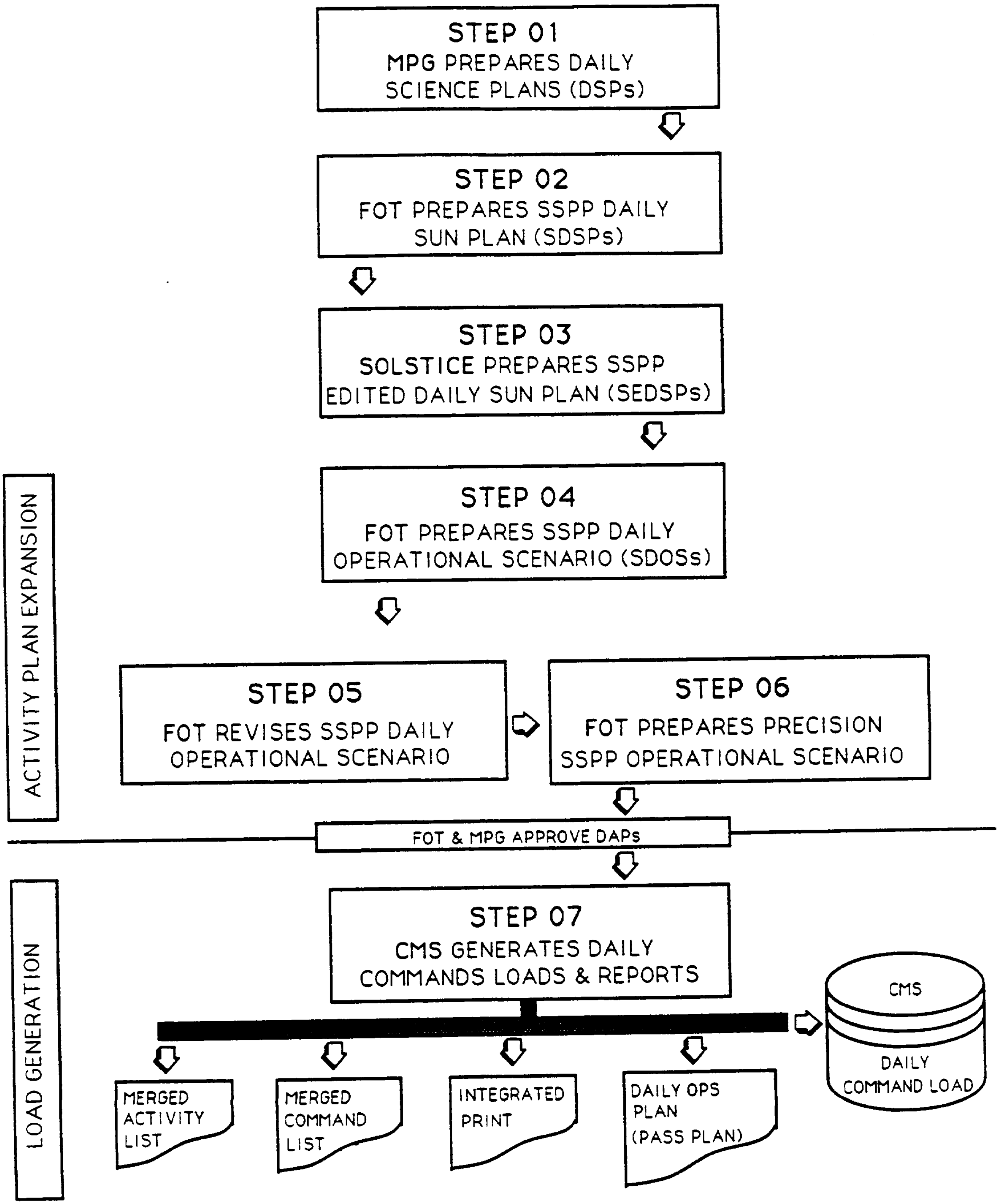
Figure 1. FOV 30 Deg Included Cone Angle, Closed Loop Tracking.
(Solar Target)

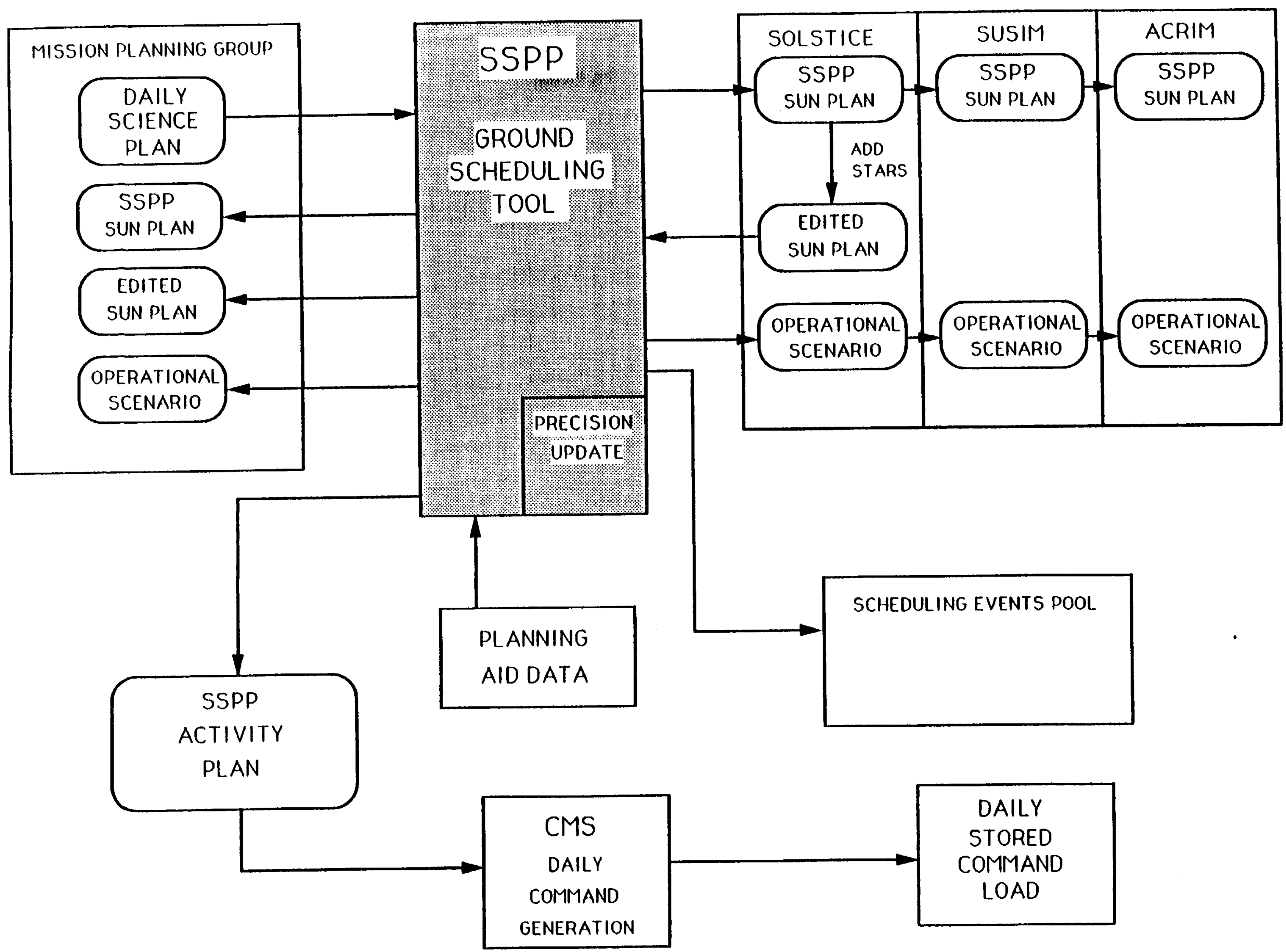
	Alpha RANGE (degrees)					
Beta RANGE	C/L SUN		O/L SUN		O/L STAR	
(degrees)	Min	Max	Min	Max	Min	Max
-2.0 -> 5.0 (fwd)	95.0 -> 95.0	199.0 -> 199.0	95.0 -> 95.0	203.0 -> 202.0	95.0 -> 95.0	199.0-> 197.0
-2.0 -> 5.0 (bck)	f(B)	199.0 -> 199.0	f(B)	203.0 -> 202.0	f(B)	199.0-> 197.0
5.0 -> 10.0	"	199.0 -> 199.0	"	202.0 -> 202.0	"	197.0-> 195.0
10.0 -> 25.0	"	199.0 -> 199.0	"	202.0 -> 202.0	"	195.0-> 198.0
25.0 -> 30.0	"	199.0 -> 199.0	"	202.0 -> 201.0	"	198.0-> 199.0
30.0 -> 35.0	"	199.0 -> 199.0	"	201.0 -> 202.0	"	199.0-> 200.0
35.0 -> 50.0	"	199.0 -> 193.0	"	202.0 -> 201.0	"	200.0-> 201.0
50.0 -> 55.0	"	193.0 -> 193.0	"	201.0 -> 198.0	"	201.0-> 202.0
55.0 -> 66.3	"	193.0 -> 188.0	"	198.0 -> 197.0	"	202.0-> 185.0
66.3 -> 75.0	-38.3 -> -28.0	188.0 -> 183.0	-57.0 -> -57.0	197.0 -> 195.0	-54.6 -> -44.0	185.0-> 167.0
75.0 -> 82.4	-28.0 -> -14.0	183.0 -> 172.0	-57.0 -> -57.0	195.0 -> 188.0	-44.0 -> -35.6	167.0-> 135.0

f(B) = Earth Mask of ***Beta*** Angle

TABLE 1. SSPP Operational Mask

SSPP OPERATIONAL SCHEDULING FUNCTION OVERVIEW





MISSION PLANNING GROUP
DAILY SCIENCE PLAN
SSPP SUN PLAN
EDITED SUN PLAN
OPERATIONAL SCENARIO
SSPP
GROUND SCHEDULING TOOL
PRECISION UPDATE
SOLSTICE
SUSIM
ACRIM
SSPP SUN PLAN
ADD STARS
EDITED SUN PLAN
OPERATIONAL SCENARIO
SCHEDULING EVENTS POOL
PLANNING AID DATA
SSPP ACTIVITY PLAN
CMS DAILY COMMAND GENERATION
DAILY STORED COMMAND LOAD

S S P P   P R O J E C T E D   S U N   P L A N

TRACKING DEFINITION FILE NAME: UARSOPS2:[UARSFOT.IG.UARS.SSHG]TRKDEF328.ODB;1
SSPP PROJECTED SUN PLAN NAME : UARSOPS2:[UARSFOT.IG.UARS.SSHG]SUNPLAN328A.RPT;1

SSPP START TIME: 1991:328:00:00:00
SSPP STOP TIME : 1991:328:23:59:59

SOLSTICE REVISION TIME :
SOLSTICE REVISION LETTER:
SOLAR CHANGES (Y/N) :

LEGEND:
a/m : arc-minutes

SOLAR CHANGE	EVENT TIME	TARGET	EVENT	ALPHA/ INITIATION	BETA/ TERMINATION	MODE	AUT LVL	DIR
	1991:328:00:20:17		SS_SUNMASK	195.26	33.33			
	1991:328:00:34:20		SC_ASCNODE					
	1991:328:01:20:48		SS_SUNRISE	61.06	33.29			
	1991:328:01:20:48	SUN	TRACK START	61.06	33.29	OPEN		F
	1991:328:01:56:52		SS_SUNMASK	195.21	33.21			
	1991:328:01:56:52	SUN	TRACK STOP	195.21	33.29	OPEN		F
	1991:328:02:02:43	18360206	TRACK START	124.81	41.83	OPEN		F
	1991:328:02:10:51		SC_ASCNODE					
	1991:328:02:21:41	18360206	TRACK STOP	195.54	41.83	OPEN		F
	1991:328:02:57:26		SS_SUNRISE	61.12	33.17			
	1991:328:02:57:26	SUN	TRACK START	61.12	33.17	OPEN		F
	1991:328:03:33:30		SS_SUNMASK	195.25	33.09			
	1991:328:03:33:30	SUN	TRACK STOP	195.25	33.17	OPEN		F
	1991:328:03:39:20	18360206	TRACK START	125.12	41.63	OPEN		F
	1991:328:03:47:22		SC_ASCNODE					

SSPP ON-ORBIT RESULTS

1. NOMINAL DEPLOYMENT, ACTIVATION, AND CALIBRATION
2. DAILY ACTIVITY PLOTS
3. MONTHLY AVERAGE ERRORS
4. ATTITUDE KNOWLEDGE RESIDUALS

UARS FLIGHT DATA

GIMBAL SUBSYSTEM PARAME

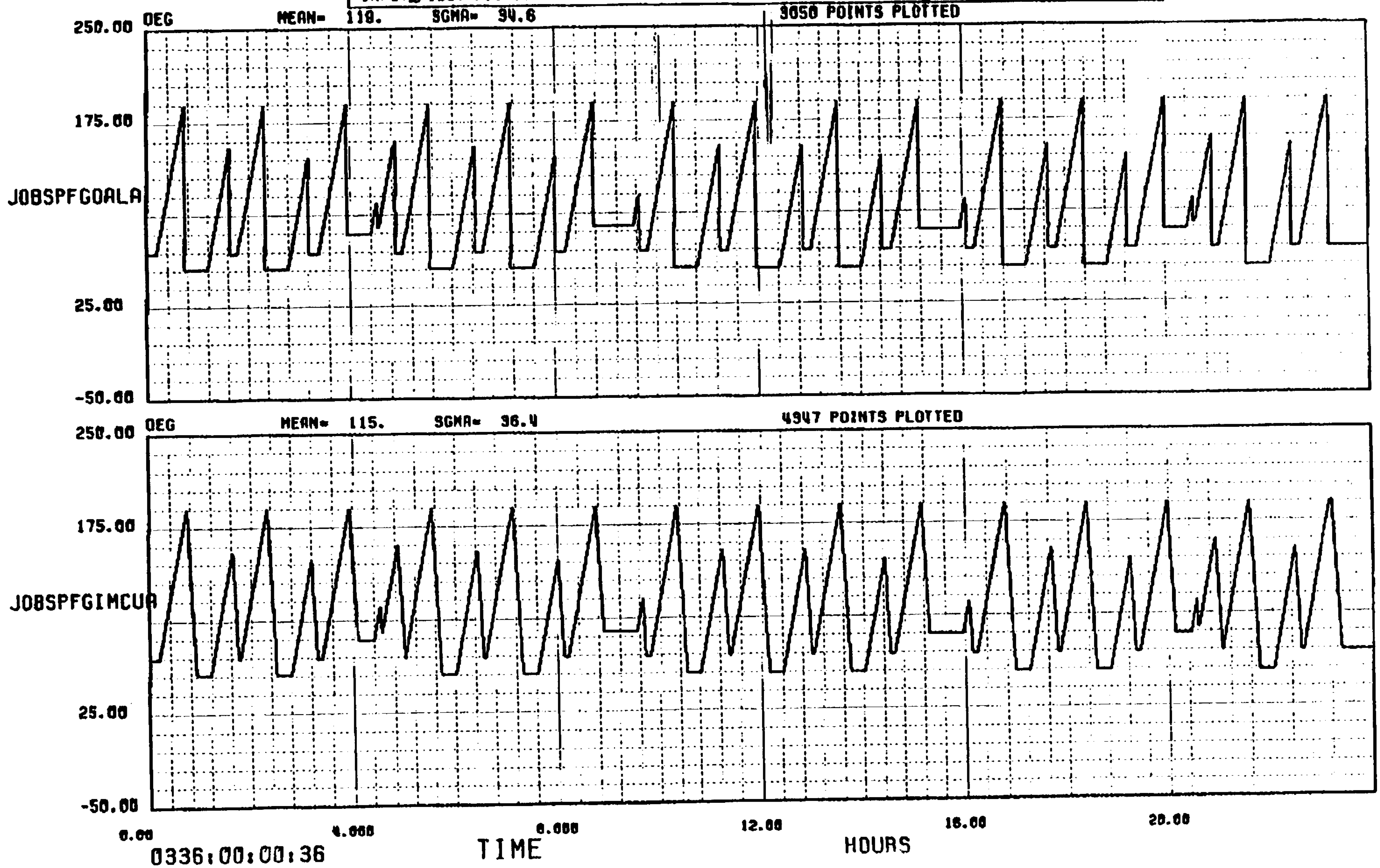
JOBSPFGOALA	190.	53.9
JOBSPFGIMCUR	190.	53.7

POINTING PLATFORM

TEST_CASE: ALPHA AXIS

DATA TIMES: 0336:00:00:49.204 TO 0337:00:00:09.905 DATE PLOTTED: 4-DEC-91 13:11:32

INPUT_FILE: DISK11:[FOT.DATA]00082_GM_NEW.PLT;2 / 3-DEC-1991 21:34:26



UARS FLIGHT DATA

GIMBAL SUBSYSTEM PARAME

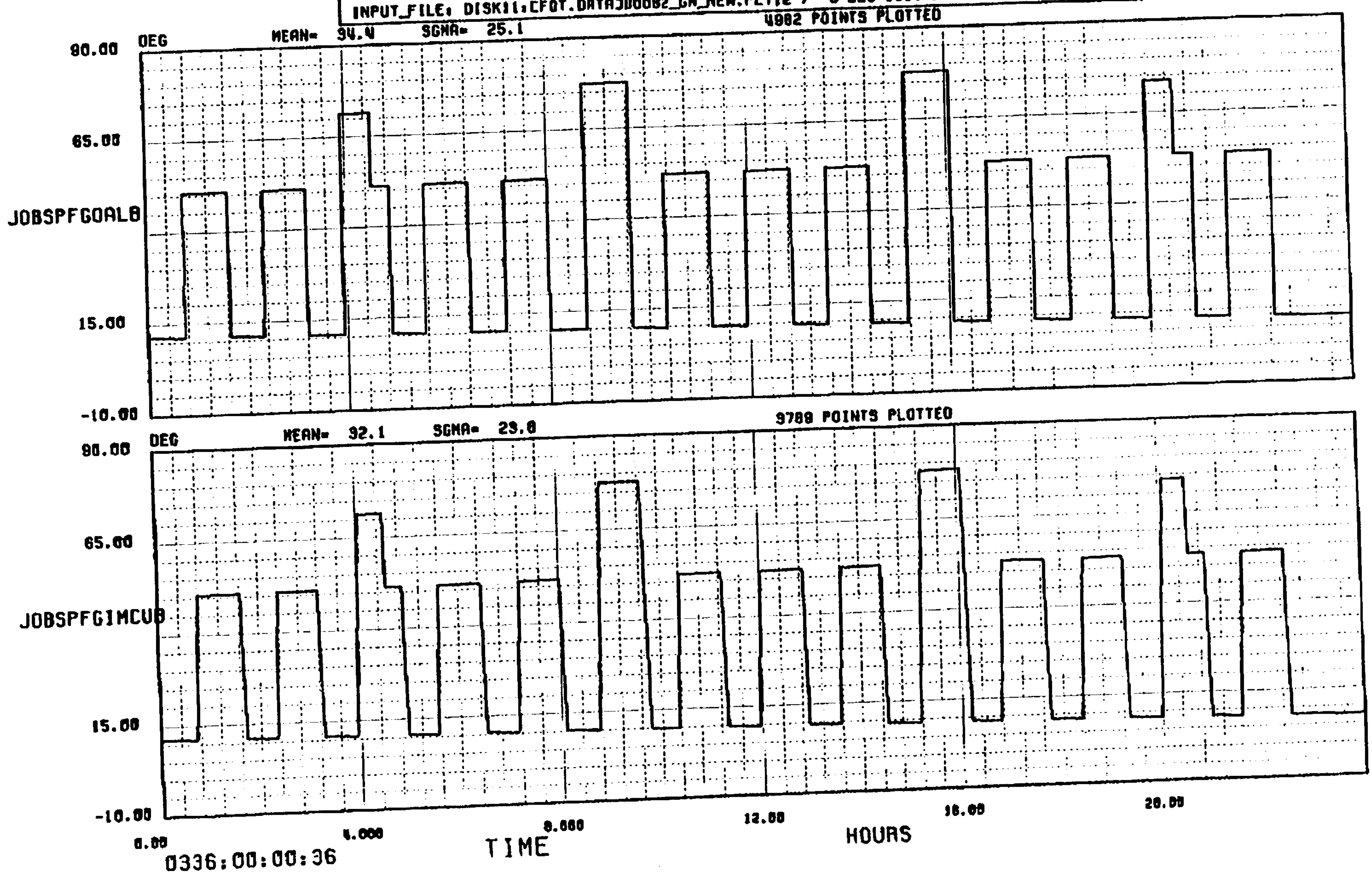
JOBSPFGOALB	78.0	7.65
JOBSPFGIMCUB	78.0	7.68

POINTING PLATFORM

TEST_CASE: BETA AXIS

DATA TIMES: 0336:00:00:49.204 TO 0337:00:00:03.305 DATE PLOTTED: 4-DEC-91 13:11:39

INPUT_FILE: DISK11:[FOT.DATA]D0082_GM_NEW.PLT;2 / 9-DEC-1991 21:34:28



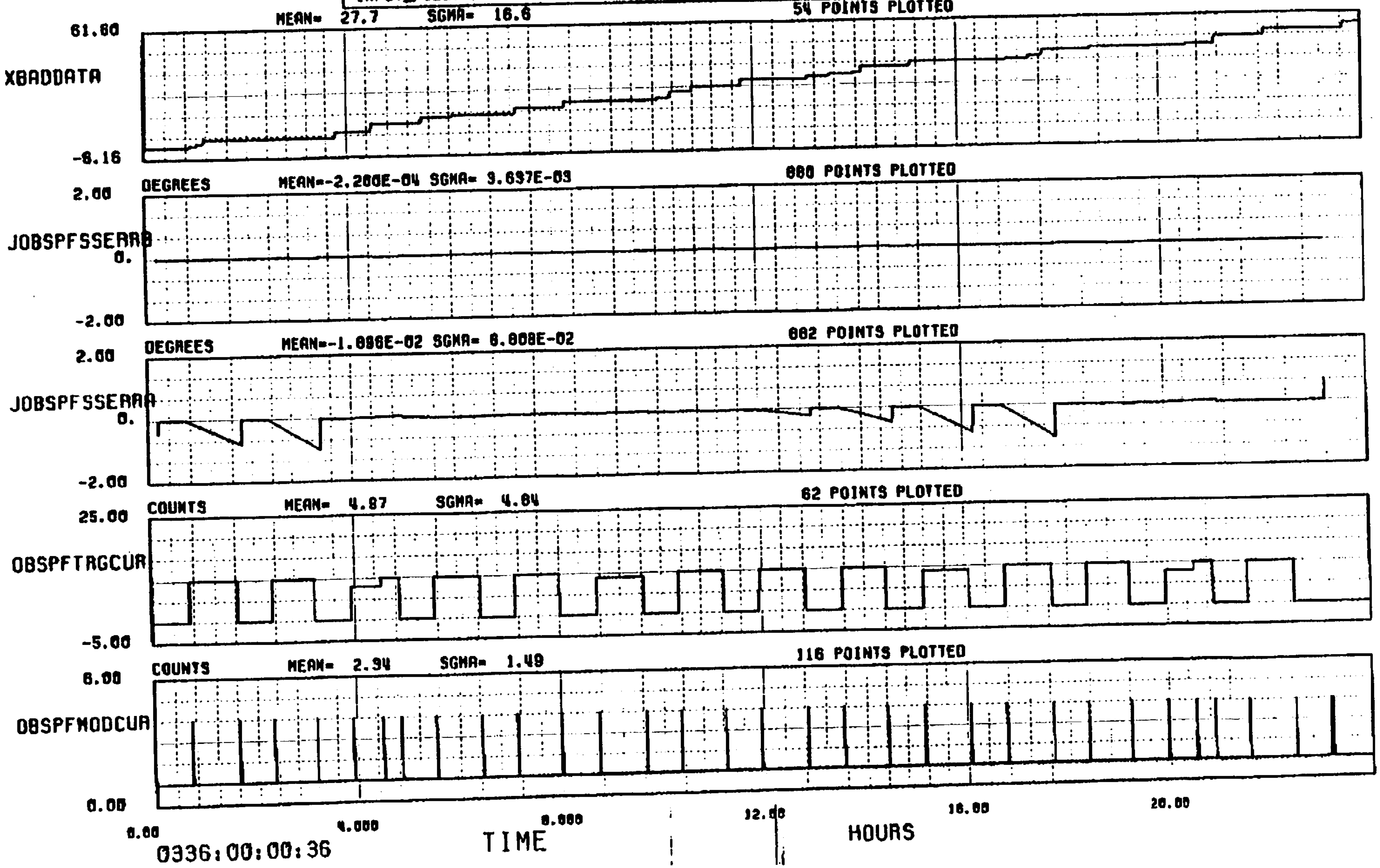
UARS FLIGHT DATA

GIMBAL SUBSYSTEM PARAME
POINTING PLATFORM
TEST_CASE: MODE: 1=OL,2=CL,3=SL,4=HA,5=PO

XBADDATA	56.0	0.000E+00
JOBSPFSSERRB	2.498E-02	-1.579E-02
JOBSPFSSERRA	0.650	-1.09
OBSPFTRGCUR	10.0	0.000E+00
OBSPFMODCUR	4.00	1.00

DATA TIMES: 0336:00:00:37.080 TO 0337:00:00:09.445 DATE PLOTTED: 4-DEC-91 13:11:45

INPUT_FILE: DISK11:[FOT.DATA]D0002_GM_NEW.PLT;2 / 9-DEC-1991 21:34:26



UARS FLIGHT DATA

SSPP ALIGNMENT

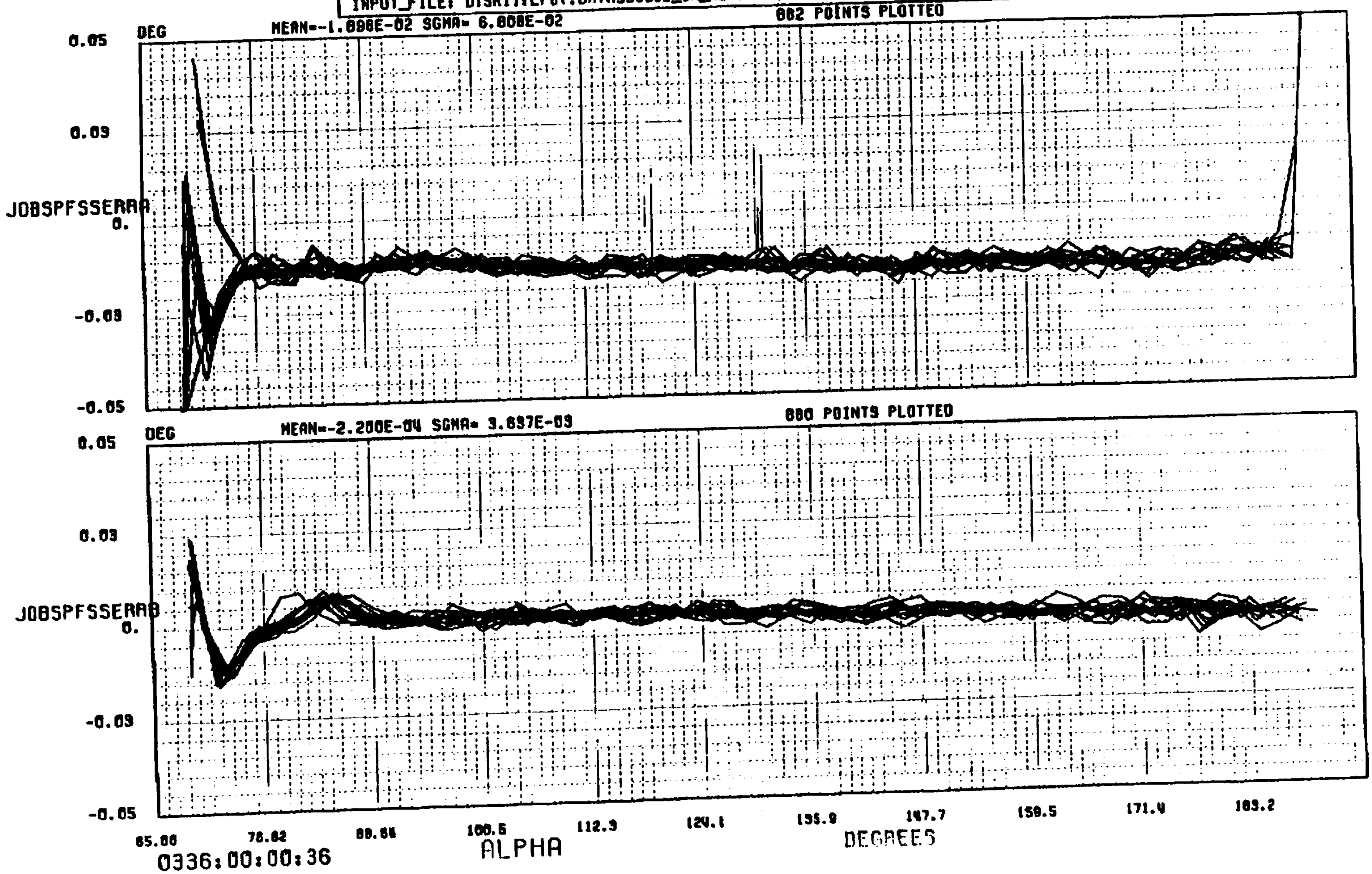
JOBSWFSSERRA	0.850	-1.03
JOBSPFSSERRB	2.438E-02	-1.578E-02

PSS ALPHA, BETA ERROR VS. GIMBAL

TEST_CASE: SUN SENSOR ERRORS VS ALPHA

DATA TIMES: 0336:00:11:42.660 TO 0336:23:11:47.490 DATE PLOTTED: 4-DEC-91 19:11:58

INPUT_FILE: DISK11:[FOT.DATA]D0002_GM_NEW.PLT;2 / 9-DEC-1991 21:34:28



UARS FLIGHT DATA

SSPP ALIGNMENT

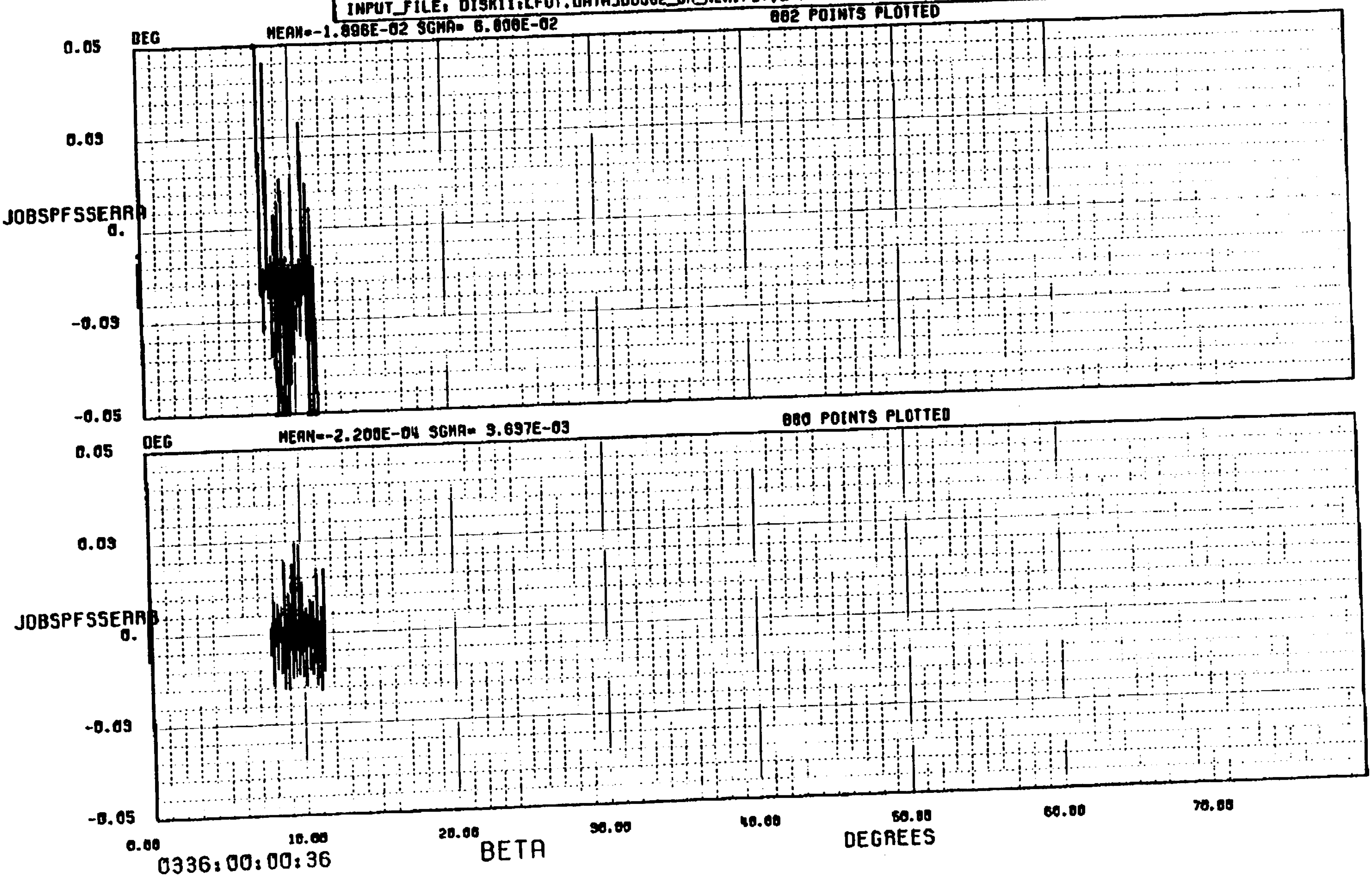
PSS ALPHA, BETA ERROR VS. GIMBAL

TEST_CASE: SUN SENSOR ERRORS VS BETA

JOBSMESSERRA	0.650	-1.03
JOBSMESSERRB	2.498E-02	-1.579E-02

DATA TIMES: 0336:00:11:42.860 TO 0336:23:11:47.490 DATE PLOTTED: 4-DEC-91 13:12:08

INPUT_FILE: DISK11:[FOT.DATA]D0082_GM_NEW.PLT;2 / 3-DEC-1991 21:34:26



UARS FLIGHT DATA

SSPP Status Flags

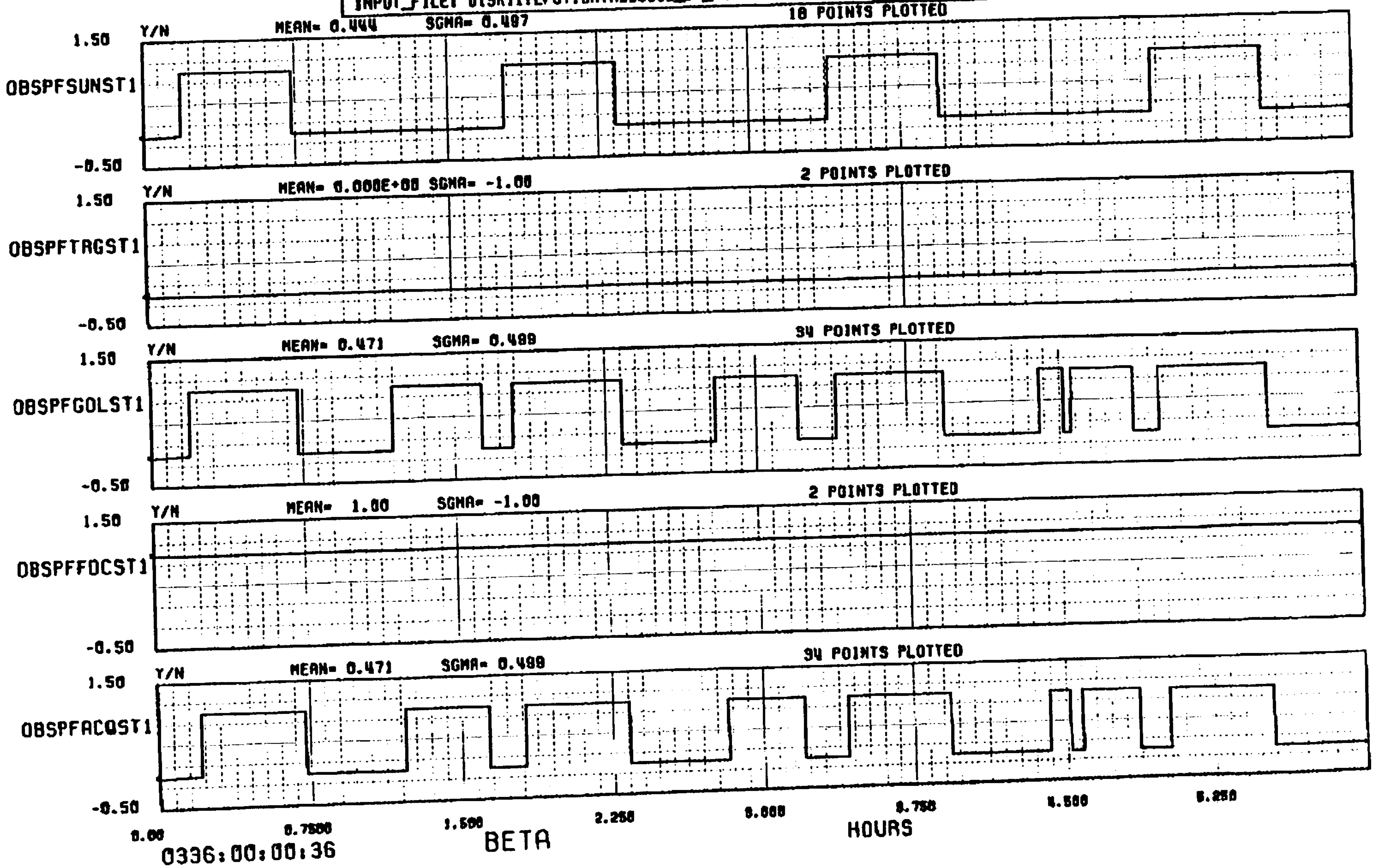
Sun, Target, Goal, FDC, Acq

TEST_CASE: Reconstructed 1.024 second Tele

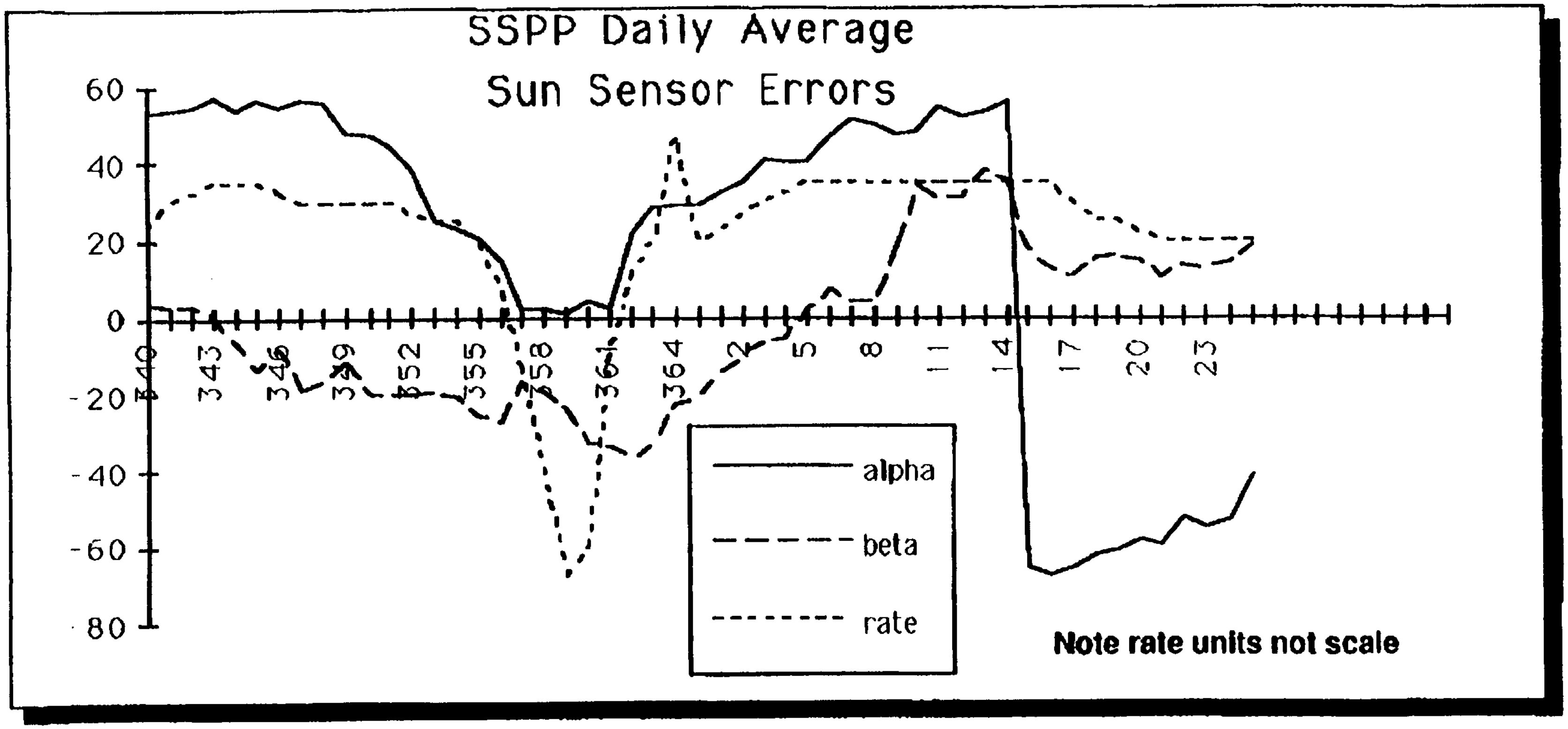
OBSPFSUNST1	1.00	0.000E+00
OBSPFTRGST1	0.000E+00	0.000E+00
OBSPFGOLST1	1.00	0.000E+00
OBSPFFDCST1	1.00	1.00
OBSPFACQST1	1.00	0.000E+00

DATA TIMES: 0336:00:00:33.000 TO 0336:06:02:33.037 DATE PLOTTED: 4-DEC-91 19:12:12

INPUT_FILE: DISK11:[FOT.DATA]00002_GM_NEW.PLT;2 / 9-DEC-1991 21:34:28



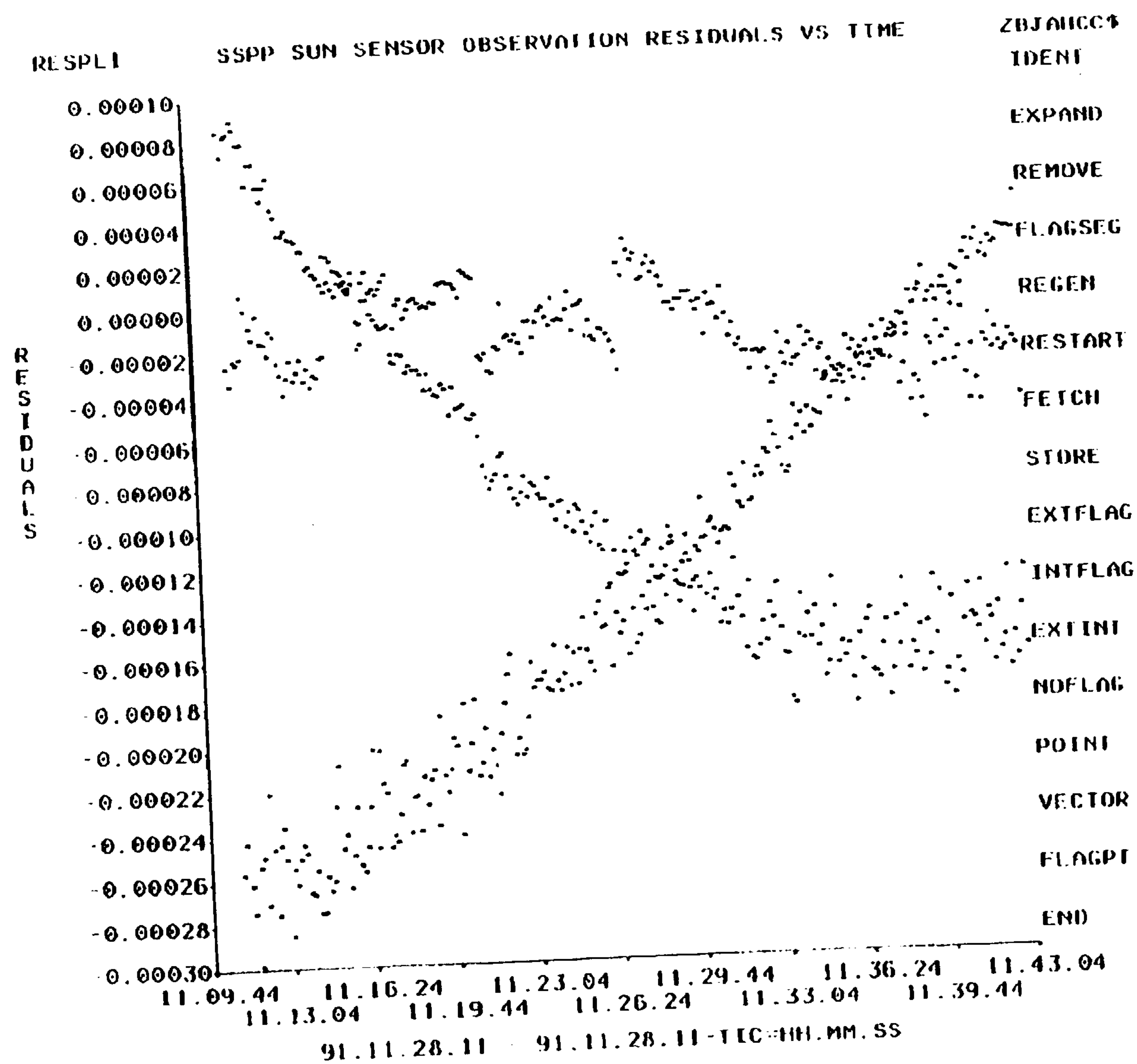
SSPP Performance



- Errors in arc-seconds as seen by PSS averaged over one day
- Alpha error proportional to in-plane rate vs. feed forward rate

PSS FOV Calibration Validation		
Validation Parameter	Value (arcseconds)	
	Pre-calibration	Post-calibration
Attitude Residuals for Normal Pass Measure of total pointing accuracy near center of FOV.	12.20	8.81
Attitude Residuals for Offset Maneuver. Measure of total pointing accuracy throughout the FOV.	15.01	12.17

Figure 1. Attitude Residuals For PSS Before Calibration for a Normal Orbit



SSPP/UARS PERFORMANCE ASSURANCE FEATURES

1. UARS WAS A SHUTTLE-LAUNCHED, MANNED-FLIGHT PROGRAM WITH RETRIEVAL CAPABILITY
2. FRACTURE CONTROL
3. STRESS CORROSION CONTROL PER MSFC-SPEC-522A
4. SAFETY IMPLEMENTATION PLAN MET JSC PIP REQUIREMENTS
5. FLAMMABILITY CONTROL: NHB 1700.7
6. PARTS CONTROL: GSFC PPL-16 & PPL-17, MIL-STD-975
PAPL 430-1704-002
7. RELIABILITY ANALYSES INCLUDED FMECA AND TREND ANALYSIS

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13. ABSTRACT *(Maximum 200 words)*

Suitability of support and test equipment from the UARS Spacecraft Solar Stellar Pointing Platform (SSPS) for the application to a space station pointing platform.

14. SUBJECT TERMS

UARS Solar Stellar Pointing Platform, Space Station Pointing Platform, UARS Test and Support Equipment

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