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List of Gimbal Test Support Equipment ........................................... Attachment 1

UARS Solar Stellar Pointing Platform Description Charts .................... Attachment 2
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 $\alpha/\beta$ 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 ($\alpha$) axis; the secondary ($\beta$) 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.
# Gimbal Test and Support Equipment

<table>
<thead>
<tr>
<th>Item No.</th>
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<th>Old IC</th>
<th>Description</th>
<th>Model</th>
<th>Cost</th>
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<th>Cost</th>
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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-OBJECT 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, gimbaled 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 accommodates 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

SSPP
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

SSPP SHOWN AT

\[ \alpha = 75^\circ \]
\[ \beta = 15^\circ \]

ANGLE FROM \( Z \times X \) PLANE PLUS TOWARD \( -Y_p \)

_POINTING DIRECTION = \( Z_s \)

ANGLE ABOUT \( Y_p \) FROM \( +Z_p \)

_RIGHT HAND RULE \(+Y_p\)
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<th>Parameter</th>
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Leap second indicator: No leap second

Extracted by Sandy Austin 12/1/91
SOLAR ULTRAVIOLET SPECTRAL IRRADIANCE MONITOR (SUSIM)

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

<table>
<thead>
<tr>
<th>ERROR SOURCES</th>
<th>PLACEMENT (arcsec (3σ))</th>
<th>KNOWLEDGE (arcsec (3σ))</th>
<th>IMPLEMENTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observatory Structure Dynamics</td>
<td>10</td>
<td>10</td>
<td>S/C structural design</td>
</tr>
<tr>
<td>Platform Sun Sensor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sun Sensor Accuracy</td>
<td>36</td>
<td>36</td>
<td>PSS calibration</td>
</tr>
<tr>
<td>Sun Sensor Boresight Position</td>
<td>NA</td>
<td>NA</td>
<td>On-orbit cal &amp; correction</td>
</tr>
<tr>
<td>Alignment (Sun Sensor to Instruments)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch Shift</td>
<td>25</td>
<td>25</td>
<td>SSPP structural design</td>
</tr>
<tr>
<td>1G Residuals</td>
<td>15</td>
<td>15</td>
<td>SSPP structural design</td>
</tr>
<tr>
<td>Instrument Positioning Accuracy</td>
<td>75</td>
<td>NA</td>
<td>Ground alignment and on-orbit cal</td>
</tr>
<tr>
<td>Ground Measurement Accuracy</td>
<td>20</td>
<td>20</td>
<td>Ground alignment</td>
</tr>
<tr>
<td>Instrument/SSPP Remate Accuracy</td>
<td>15</td>
<td>15</td>
<td>SSPP structural design</td>
</tr>
<tr>
<td>On-Orbit Thermal Effects (SSPP)</td>
<td>30</td>
<td>30</td>
<td>SSPP thermal design</td>
</tr>
<tr>
<td>Drive and Gimbal Control System</td>
<td>30</td>
<td>NA</td>
<td>SSPP control law</td>
</tr>
<tr>
<td>RSS at all instrument interfaces</td>
<td>101</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>Instrument allocation from UIAD</td>
<td>120</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

Total Root Sum Square (RSS)

- Requirement: 180
  - Budget: 157
  - Implementation: 86

sunbudget-CDR-3/88
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)**

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

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 gimbals axes shown in Figure 2 shall be as listed in Table III.
### Table II. SSPP Weight

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

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$^2$

<table>
<thead>
<tr>
<th>Ixx</th>
<th>37.3 ±0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iyy</td>
<td>44.6 ±0.8</td>
</tr>
<tr>
<td>Izz</td>
<td>38.5 ±0.8</td>
</tr>
<tr>
<td>Ixy</td>
<td>-5.2 ±0.2</td>
</tr>
<tr>
<td>Iyz</td>
<td>-2.0 ±0.2</td>
</tr>
<tr>
<td>Izx</td>
<td>-0.8 ±0.2</td>
</tr>
</tbody>
</table>

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 $\alpha$ (alpha). The second axis shall be perpendicular to the alpha axis, and designated as $\beta$ (beta), as shown in Figure 2.

3.2.2.4.2 **Angles.** The angle of each gimbal axis shall be designated $\alpha$ (alpha) and $\beta$ (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**

<table>
<thead>
<tr>
<th>Axis</th>
<th>Angle</th>
<th>Degrees</th>
<th>Rates</th>
<th>Degrees/Sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>From</td>
<td>To</td>
<td>From</td>
<td>To</td>
</tr>
<tr>
<td>Alpha</td>
<td>-55</td>
<td>247</td>
<td>-0.200</td>
<td>+0.200</td>
</tr>
<tr>
<td>Beta</td>
<td>-2*</td>
<td>83.4</td>
<td>-0.155</td>
<td>+0.155</td>
</tr>
</tbody>
</table>

* 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.
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>
<thead>
<tr>
<th>Item</th>
<th>Orbit Average Watts (1)</th>
<th>Maximum Watts</th>
<th>Condition of Max. Power Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor-alpha</td>
<td>2.3</td>
<td>7.2</td>
<td>72 pps @ 28 V</td>
</tr>
<tr>
<td>Motor-beta</td>
<td>1.6</td>
<td>7.2</td>
<td>72 pps @ 28 V</td>
</tr>
<tr>
<td>Encoders (2)</td>
<td>5.2</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>Platform Sun Sensor</td>
<td>1.6</td>
<td>2.0</td>
<td>35 V</td>
</tr>
</tbody>
</table>

(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/protolflight 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
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

Major Sections of SSPP Structure

Upper Atmosphere Research Satellite

Sustin Support Panel

Acetylene Support Structure

Radiator Side Plates

Sun Sensor Support Brackets

Gimbal Drive/Solstice Support Panel

MCB Support Panel

Gimbal Installation Hatch

Retention System and Gimbal Lockout 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

<table>
<thead>
<tr>
<th>Subsystem or Component</th>
<th>Resonant Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stowed Solar Array Assembly</td>
<td>17 (See Note 1)</td>
</tr>
<tr>
<td>Stowed HGA Dish</td>
<td>35</td>
</tr>
<tr>
<td>Antenna Feed</td>
<td>50</td>
</tr>
<tr>
<td>Stowed ZEPS Boom</td>
<td>50</td>
</tr>
<tr>
<td>Stowed HGA</td>
<td>50</td>
</tr>
<tr>
<td>Large Components, Including SSPP (Locked)</td>
<td>35</td>
</tr>
<tr>
<td>Small Components and Panels (&lt;200 lbs.)</td>
<td>50</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Condition</th>
<th>STS Axes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$X_0$</td>
</tr>
<tr>
<td>Lift-Off$^1$</td>
<td>+5.6</td>
</tr>
<tr>
<td>Landing (6.0 ft/sec sink rate)</td>
<td>±3.0</td>
</tr>
<tr>
<td>Emergency Landing$^2$</td>
<td>+1.5</td>
</tr>
<tr>
<td></td>
<td>-4.5</td>
</tr>
</tbody>
</table>

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

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

FOR 1.0" SIDE PLATE, t = .06 TO .10, FOR A THROUGH CRACK,
\( \sigma_{\text{UN MAX}} = S_o \text{ MAX} = 20.5 \text{ ksi} \)
FOR CORNER CRACKS, t = .10 TO .25, USE CURVE BELOW
SSPP/ TAG THERMAL ANALYSIS

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 BASEPLATE TEMPERATURE
SSPP TWO-AXIS GIMBAL

1. LAYOUT
2. PERFORMANCE REQUIREMENTS
3. CABLE FEED-THROUGH CAPABILITY
4. THERMAL CONTROL
5. SUBASSEMBLIES
6. LIFE TESTING
Table X. Mechanical and Electrical Interfaces

<table>
<thead>
<tr>
<th></th>
<th>SSPP</th>
<th>HGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gimbal Assembly</td>
<td>47-292309</td>
<td>47-291625</td>
</tr>
<tr>
<td>Mechanical Interface with</td>
<td>47-281506</td>
<td>47-294771</td>
</tr>
<tr>
<td>Observatory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical Interface with</td>
<td>47-282825</td>
<td>47-294756</td>
</tr>
<tr>
<td>Item Pointed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical Interface</td>
<td>47-290022</td>
<td>47-292021</td>
</tr>
</tbody>
</table>

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 feet² for the HGA, and 43 slug feet² 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.
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

<table>
<thead>
<tr>
<th>In plane of both axes</th>
<th>$K_\alpha$</th>
<th>$K_\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load parallel to alpha axis</td>
<td>$1.5 \times 10^4$ lb/in</td>
<td>$1.5 \times 10^4$ lb/in</td>
</tr>
<tr>
<td>Load along beta axis</td>
<td>$2.2 \times 10^4$ lb/in</td>
<td>$3.1 \times 10^3$ lb/in</td>
</tr>
<tr>
<td>About alpha axis, beta axis</td>
<td>$4.5 \times 10^4$ in. lb/rad</td>
<td></td>
</tr>
</tbody>
</table>
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.

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.
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 EMISSANCE
- 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 $G_T/G_{T_0}$ as a function of absolute temperature. $G_T$ is the evaporation rate at absolute temperature $T$, and $G_{T_0}$ is the evaporation rate at an assumed average (constant) absolute temperature $T_0$. For this plot, $T_0$ is assumed to be $27.67^\circ C = 300.82^\circ K$ which is the predicted effective average temperature for the SSPP during orbit life. The plot covers the range 300-370$^\circ K$ (26.85-96.85$^\circ C$).
Figure 14: Plot of test time in days as a function of effective average SSSP temperature during test. The calculation assumes an effective average temperature during the mission of 300.82K = 27.6°C.
SSPP GIMBAL DRIVE ELEX & PLATFORM SUN SENSOR

1. GIMBAL DRIVE ELECTRONICS

2. PLATFORM SUN SENSOR
GIIMBAL DRIVE ELECTRONICS

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

<table>
<thead>
<tr>
<th></th>
<th>ALPHA AXIS</th>
<th>BETA AXIS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 1</td>
<td>7 8 9 10</td>
</tr>
<tr>
<td>D I R</td>
<td></td>
<td>DRIVER RATE</td>
</tr>
<tr>
<td>(data LSB in bit #8)</td>
<td></td>
<td>DRIVER RATE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(data LSB in bit #15)</td>
</tr>
</tbody>
</table>

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 Alpha Axis = 0 - 127 pulses per 1.024 sec (SSPP) Beta Axis = 0 - 63 pulses per 1.024 sec (Command Resolution = 1 pulse)
4) Drive Rate Alpha Axis = 0 - 254 pulses per 1.024 sec (HGAS) Beta Axis = 0 - 126 pulses per 1.024 sec (Command Resolution = 2 pulses)
Table II. GDE Telemetry Outputs

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

NOTE: (A) or (B) indicates that telemetry is from "A" side or "B" side of GDE, respectively.
Table III. Telemetry Data Word Configuration

<table>
<thead>
<tr>
<th>Telemetry Buffer</th>
<th>Format</th>
<th>Update Rate</th>
<th>Cycle Reset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science TLM</td>
<td>Science</td>
<td>1/SMIF</td>
<td>SMAF</td>
</tr>
<tr>
<td>Engineering TLM</td>
<td>Engineering</td>
<td>1/EMIF</td>
<td>EMAF</td>
</tr>
<tr>
<td>OBC Data</td>
<td>Science/Engineering</td>
<td>1/SMIF</td>
<td>SMAF</td>
</tr>
</tbody>
</table>

Serial Telemetry Data Word Format

Science Telemetry Word

<table>
<thead>
<tr>
<th>Byte No</th>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>MSB</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>LSB</td>
<td>MSB</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>4</td>
<td>MSB</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>LSB</td>
<td>MSB</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>7</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Engineering Telemetry Word

<table>
<thead>
<tr>
<th>Byte No</th>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>MSB</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>MSB</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table III. Telemetry Data Word Configuration (Cont'd)

OBC Data Word

<table>
<thead>
<tr>
<th>Contents</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSPP Configuration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HGAS Configuration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Byte No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>MSB--------------------(Alpha Axis Position)-----------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>---------------------------</td>
<td>LSB</td>
<td>SPR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>MSB--------------------(Beta Axis Position)-----------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>---------------------------</td>
<td>LSB</td>
<td>FLG</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 coincident 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
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

SOFTWARE | HARDWARE
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:

\[
U_k = A_k(G_9) \quad (2)
\]

\[
Y_{k+1} = G_8U_k + (1 + G_1)D_{1,k+1} + (2 - G_8)D_{2,k+1} + (1 - G_7)D_{3,k+1} \quad (3)
\]

where,

\[
\begin{pmatrix}
D_{1,k+1} \\
D_{2,k+1} \\
D_{3,k+1}
\end{pmatrix} =
\begin{pmatrix}
1 & 0 & 0 \\
1 + G_1 & -G_6 & -G_7 \\
0 & 1 & 0
\end{pmatrix}
\begin{pmatrix}
D_{1k} \\
D_{2k} \\
D_{3k}
\end{pmatrix} +
\begin{pmatrix}
G_8 \\
G_8 \\
0
\end{pmatrix}U_k \quad (4)
\]

\(^1\)See reference 11
3 SPECIFIC REQUIREMENTS

\[ Y_{k+1} \quad \text{next sample of compensator rate output} \quad \text{(deg/sec)} \]
\[ A_k \quad \text{current sample of uncompensated gimbal angle error} \quad \text{(degrees)} \]
\[ U_k \quad \text{current sample of modified gimbal angle error} \quad \text{(degrees)} \]
\[
\begin{pmatrix}
D_{1k} \\
D_{2k} \\
D_{3k}
\end{pmatrix}
\quad \text{kth sample of discrete state variables}
\]

\( G_i \quad \text{coefficients (see Table 1)(i=1,9)} \)

\( k \quad \text{sampling period} \)

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.
   \[
   D_1(old) = D_1(new) \\
   D_2(old) = D_2(new) \\
   D_3(old) = D_3(new)
   \]

4. Calculate the new controller states.
   \[
   D_1(new) = D_1(old) + G_8(U_k) \\
   D_2(new) = D_1(old)(1 + G_1) + G_8(U_k) - D_2(old)G_6 - D_3(old)G_7 \\
   D_3(new) = D_2(old)
   \]

5. Limit the variable \( D_1 \) (See section 3.6)

6. Calculate the compensator output.
   \[ Y_{k+1} = U_k(G_8) + D_1(new)(1 + G_1) + D_2(new)(2 - G_6) + D_3(new)(1 - G_7) \]
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.

Begin
Mode 1 Switching Logic

- If selected, initialize Mode 1.

- Is target within acceptable range in alpha?

Select target as goal.

- Was goal acquisition orientation, last cycle?
  - T
  - F

  - Is target the sun?
    - T
    - F

  - Is open - closed switch selected?
    - T
    - F

  - Does PSS indicate sun presence?
    - T
    - F

  - Have tracking errors settled within thresholds?
    - T
    - F

  - Switch mode to closed loop mode.

Select acquisition orientation as goal.

- Select mode initialization.

Determine next mode.

End
Mode 1 Switching Logic
SSPP Flight Software Simulation Results

UARS SSPP SOFTWARE ANALYSIS

OPEN AND CLOSED LOOP TRACK SOLAR TRACKING

TEST_CASE:   TEST C NO PSS MISALIGNMENT

DATA TIMES:  0274:13:10:00.000 TO 0274:15:09:59.104 DATE PLOTTED: 18-JUN-97 09:34:24

ALPHA CORRECTION LIMITS: POS = 9.99E-03 STATE = 1.67E-06

INPUT_FILE: USERSAN:CHENDEL.SM.PLAT.SIN.RUN3TESTCPLT1 / E-JUN-1997 17:30:30

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)

ERROR (ARC-SEC)

-100
-50
0
50
100

100 150 200 250 300 350 400

TIME (SECONDS)

60 ARC-SEC REQUIREMENT

BEGIN TRACKING SESSION

END TRACKING SESSION
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

UPPER ATMOSPHERE RESEARCH SATELLITE

SSPP-9B
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
SSPP Sun Sensor A & B

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

June 4, 1990
<table>
<thead>
<tr>
<th>Beta RANGE (degrees)</th>
<th>C/L SUN</th>
<th>O/L SUN</th>
<th>O/L STAR</th>
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<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
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<tr>
<td></td>
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<td>950 -&gt; 950</td>
<td>950 -&gt; 950</td>
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</table>

(B) = Earth Mask of Beta Angle

TABLE I. SSPP Operational Mask
SSPP OPERATIONAL SCHEDULING FUNCTION
OVERVIEW

STEP 01
MPG Prepares Daily Science Plans (DSPs)

STEP 02
FOT Prepares SSPP Daily Sun Plan (SDSPs)

STEP 03
SOLSTICE Prepares SSPP Edited Daily Sun Plan (SEDSPs)

STEP 04
FOT Prepares SSPP Daily Operational Scenario (SDOSs)

STEP 05
FOT Revises SSPP Daily Operational Scenario

STEP 06
FOT Prepares Precision SSPP Operational Scenario

STEP 07
CMS Generates Daily Commands Loads & Reports

ACTIVITY PLAN EXPANSION

LOAD GENERATION

MERGED ACTIVITY LIST
MERGED COMMAND LIST
INTEGRATED PRINT
DAILY OPS PLAN (PASS PLAN)

CMS
DAILY COMMAND LOAD
## SSPP PROJECTED SUN PLAN

**Tracking Definition File Name:** UARSDPS2:UARSPK.UG.UARS.SSHG\INDF328.DDB\1  
**SSPP Projected Sun Plan Name:** UARSDPS2:UARSPK.UG.UARS.SSHG\SUNPLAN328.ART\1

**SSPP Start Time:** 1991:328:00:00:00  
**SSPP Stop Time:** 1991:328:23:59:59

**Legend:**
- a/m: arc-minutes

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<tr>
<th>SOLAR CHANGE</th>
<th>EVENT TIME</th>
<th>TARGET</th>
<th>EVENT</th>
<th>ALPHA/INITIATION</th>
<th>BETTA/TERMINATION</th>
<th>MODE</th>
<th>AUT</th>
<th>LVL</th>
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<td>195.26</td>
<td>33.33</td>
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<td>F</td>
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<td>195.25</td>
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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 PARAMETER

POINTING PLATFORM

TEST_CASE: ALPHA AX1S

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

INPUT_FILE: DISK11:CFOT.DAT1A00082.GMNEW_PlT12 / 3-DEC-91 21:54:26

250.00 DEG
MEAN = 110.  SGMA = 54.6
3050 POINTS PLOTTED

JOBSFPFCMEAL

175.00

25.00

-50.00

250.00  DEG
MEAN = 115.  SGMA = 36.4
4547 POINTS PLOTTED

175.00

25.00

-50.00

DEC 5'91 17:50 FROM UARS CONTROL-GSFC-MD TO UF

0336:00:00:36 TIME  6.00  12.00  18.00  24.00
0.00  6.00  12.00  18.00  24.00 HOURS
UARS FLIGHT DATA
SSPP ALIGNMENT
PSS ALPHA, BETA ERROR VS. GIMBAL

TEST_CASE: SUN SENSOR ERRORS VS BETA

DATA TIMES: 0336:00:11:42.660 TO 0336:23:11:47.490 DATE PLOTTED: 4-DEC-91 13:12:06


662 POINTS PLOTTED

0.05 DEG
MEAN=-1.86E-02 SGRA= 8.60E-02

0.05 DEG
MEAN=-2.20E-04 SGRA= 3.697E-03

0.05 DEG
MEAN= -1.03 SGRA= -1.57E-02
UARS FLIGHT DATA

SSPP Status Flags

Sun, Target, Goal, FOC, Acq

TEST_CASE: Reconstructed 1.0% second Tel

DATA TIMES: 0336:00:00; 33.066 TO 0336:06:02; 33.097 DATE PLOTTED: 4-DEC-91 19:12:12


1.50

OBSPFSUNST1

0.50

Mean = 0.444

Sigma = 0.497

18 POINTS PLOTTED

-0.50

1.50

Y/N

Mean = 0.000E+00

Sigma = -1.00

2 POINTS PLOTTED

OBSPFTRGST1

-0.50

1.50

Mean = 0.471

Sigma = 0.488

94 POINTS PLOTTED

OBSPFGOLST1

-0.50

1.50

Mean = 1.00

Sigma = -1.00

2 POINTS PLOTTED

OBSPFFOCST1

-0.50

1.50

Mean = 0.471

Sigma = 0.488

94 POINTS PLOTTED

OBSPFRCOST1
SSPP Performance

SSPP Daily Average
Sun Sensor Errors

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

Note rate units not scale
## PSS FOV Calibration Validation

<table>
<thead>
<tr>
<th>Validation Parameter</th>
<th>Value (arcseconds)</th>
<th>Pre-calibration</th>
<th>Post-calibration</th>
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<tbody>
<tr>
<td>Attitude Residuals for Normal Pass Measure of total pointing accuracy near center of FOV.</td>
<td>12.20</td>
<td>8.81</td>
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<tr>
<td>Attitude Residuals for Offset Maneuver Measure of total pointing accuracy throughout the FOV.</td>
<td>15.01</td>
<td>12.17</td>
<td></td>
</tr>
</tbody>
</table>
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
# Gimbal System Evaluation

**Author(s):** Michael Payonk, Keith Baranoff

**Performing Organization Name(s) and Address(es):**
Lockheed Martin Missiles and Space, King of Prussia, PA 19406

**Sponsoring/Monitoring Agency Name(s) and Address(es):**
National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Marshall Space Flight Center, Alabama 35812

**Supplementary Notes:** None

**Distribution/Availability Statement:**
Distribution Authorized to US Government agencies and their contractors.

**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.