Xenia Spacecraft Study

Spacecraft Design

March 2, 2009
Outline

• Study Overview
• Spacecraft Team Members
• Animation
• Overall Ground Rules and Assumptions (GR&A)
• Mission Analysis
• Configuration
• Mass Properties
• Guidance, Navigation, and Control (GN&C)
• Avionics
• Power
• Thermal
• Propulsion
• Structures
• Conclusions
Study Overview

• **Goal**
  – Perform a mission concept study for the proposed Xenia mission

• **Responsibilities**
  
  • **Spacecraft: ED04**
    – Avionics / GN&C
    – Communications
    – Electrical Power
    – Trajectory / Mission Analysis
    – Propulsion
    – Science Instruments Integration
    – Launch Stack Shroud Integration
    – Animation / Modeling
  
  • **Science: VP62**
    – Science Instruments Definition
    – Science Instruments Design
    – Mission requirements
<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chryssa Kouveliotou</td>
<td>Xenia PI</td>
<td>MSFC-VP62</td>
</tr>
<tr>
<td>Les Johnson</td>
<td>Study Manager and Lead</td>
<td>MSFC-ED04</td>
</tr>
<tr>
<td>Randy Hopkins</td>
<td>Technical Lead / Mission Analysis</td>
<td>MSFC-ED04</td>
</tr>
<tr>
<td>Mike Baysinger</td>
<td>Spacecraft Configuration</td>
<td>MSFC-ED04 / Qualis</td>
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<tr>
<td>P.J. Benfield</td>
<td>Propulsion</td>
<td>U. Of Alabama Huntsville</td>
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<td>Pete Capizzo</td>
<td>Avionics / GN&amp;C</td>
<td>MSFC-ED04 / Raytheon</td>
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<td>Tracie Crane</td>
<td>Mass Properties</td>
<td>MSFC-ED04 / Qualis</td>
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<td>Leo Fabisinski</td>
<td>Power</td>
<td>MSFC-ED04 / ISSI</td>
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<td>Linda Hornsby</td>
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<td>MSFC-ED04 / JTI</td>
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<td>David Jones</td>
<td>Structures</td>
<td>MSFC-ED04</td>
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<td>Dauphne Maples</td>
<td>Mass Properties / GR&amp;A</td>
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<td>Janie Miernik</td>
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<td>Tom Percy</td>
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<td>SAIC</td>
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<td>Kevin Thompson</td>
<td>Animation</td>
<td>MSFC-ED04 / Jacobs</td>
</tr>
<tr>
<td>Matt Turner</td>
<td>Propulsion</td>
<td>U. Of Alabama Huntsville</td>
</tr>
</tbody>
</table>
The Spacecraft Engineering team has created an animation that depicts the science mission of the Xenia spacecraft.

Link to the animation:
- http://sms.msfc.nasa.gov/xenia/
Additional GR&A are contained in each discipline section.

Preferred Launch Vehicle is the Falcon 9, launched from Omelek (Kwajalein).

Target orbit is 600km circular, 5-degree inclination (or less).

Target spacecraft lifetime = 5 years.

Target orbit lifetime = 10 years.

Science instruments designed by VP62.
  – Instrument parameters (power, mass, etc.) provided by VP62.
Mission Analysis
• **Launch Vehicle Performance**
  - Target orbit is 600km circular, inclination no greater than 5 degrees
    ▪ Avoid the South Atlantic Anomaly
  - Preferred launch vehicle is Falcon 9
    ▪ Launched from Omelek (Kwajalein)
    ▪ Payload adapter mass has been subtracted from the payload performance quotes

• **Orbital Lifetime**
  - Reentry interface defined as 400000ft altitude (122 km)
  - Initial Circular orbit altitude = 600 km
  - Target lifetime is 10 years
  - Start dates are July 1, 2012, and July 1, 2018, in order to capture the effect of the solar maximum
  - Use the orbital lifetime tool included in Satellite Toolkit (STK)
## Mission Analysis: Launch Vehicles

<table>
<thead>
<tr>
<th></th>
<th>Falcon 9</th>
<th>Vega</th>
<th>Atlas V 401</th>
<th>Delta II Heavy (7920H-10)*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Launch Site</strong></td>
<td>Omelek (Kwajalein)</td>
<td>CCAFS</td>
<td>Kourou</td>
<td>CCAFS</td>
</tr>
<tr>
<td><strong>600 km @ 5 deg</strong></td>
<td>7000</td>
<td>1700</td>
<td>2050</td>
<td>4395</td>
</tr>
<tr>
<td><strong>600 km @ 10 deg</strong></td>
<td>Not requested</td>
<td>TBD [3]</td>
<td>2040</td>
<td>5815</td>
</tr>
<tr>
<td><strong>600 km @ 15 deg</strong></td>
<td>Not requested</td>
<td>TBD [3]</td>
<td>Not requested</td>
<td>Not requested</td>
</tr>
<tr>
<td><strong>500 km @ 5 deg</strong></td>
<td>Not requested</td>
<td>Not requested</td>
<td>2120</td>
<td>4390</td>
</tr>
<tr>
<td><strong>500 km @ 10 deg</strong></td>
<td>Not requested</td>
<td>Not requested</td>
<td>2110</td>
<td>5820</td>
</tr>
</tbody>
</table>

* Also known as the 2920H-10 and 2925H-10.

[1] Interpolated results from performance plots. The mass of the 60kg type 937 payload adapter has been subtracted.

[2] The Falcon, Atlas, and Delta II guides do not include performance estimates for these low inclinations.

[3] Data is pending, but was not available at the time of this briefing.
Mission Analysis: Orbital Lifetime

Orbital Lifetime for two spacecraft masses, 2012 Launch Date

Altitude (km) vs. Date

- 2500 kg
- 2100 kg

10 years
Mission Analysis: Orbital Lifetime

Orbital Lifetime for two spacecraft masses, 2018 Launch Date

Altitude (km)

Date

2500 kg

2100 kg

10 years
Mission Analysis: De-orbit

- **Delta-V = 163 m/s** for a reentry flight path angle of -1.75 degrees
  - Impulsive Delta-V: 161.3 m/s
  - Gravity Loss: 1.7 m/s (assuming worst case T/W = 0.025)
  - Margin: 0 m/s (assumptions are already conservative)

- Perigee altitude = 34.6 km
  - Ranges from 65.7 km to 8.25 km for the acceptable range of reentry flight path angles

- **Gravity Loss** is insignificant for T/W > 0.025
Mission Analysis: Conclusions

• **Launch Vehicle**
  – Falcon 9 has large mass margin if launched from Omelek.
  – Atlas V 401 launched from CCAFS provides large mass margin.
  – Delta II Heavy has insufficient payload mass.
  – Vega has insufficient payload mass; envelope too small.

• **Orbital Lifetime**
  – Based on the calculations, no periodic orbit boost will be required.

• **De-orbit**
  – Need a propulsion system which can supply a total delta-v of 163 m/s
Spacecraft Configuration
Configuration

Ø2.6

2.5

4

2.7
Configuration

- WFI boxes
- R42 tilted to go thru c.g.
- Bulkhead scope support
- WFS boxes
- Bulkhead scope support
Configuration: De-orbit system

200 lb R42 thruster

NTO/MMH tanks
Configuration: Avionics Boxes

- WFS
- WFI
- Flight Computer
- Data Recorder
- Batt Chargers
- Battery
- CMGs
- WFM Boxes
- ARU
- MGA
- Battery
Configuration: CMG locations

CMGs 90 deg apart

$I_{xx} = 3092 \text{ kg m}^2$
$I_{yy} = 1900 \text{ kg m}^2$
$I_{zz} = 3317 \text{ kg m}^2$
Configuration: Array deployment
Mass Properties
• GR&A
  – Growth Allowance
    ▪ Spacecraft: 30%
    ▪ Science Instruments: Obtained through VP62 Science Team

• Results
  – **Mass Total 30% Margin**: 2753.83 kg
  – Mass Total 20% Margin: 2640.56 kg
  – Mass Total 0% Margin: 2414.03 kg

*Note*: Above margins do not apply to science instruments.
# Mass Properties: Results

## WBS Element - Descent Stage

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>Qty</th>
<th>Unit Mass (kg)</th>
<th>Total Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Structure</td>
<td>1.0</td>
<td>489.00</td>
<td>489.00</td>
</tr>
<tr>
<td>2.0 Propulsion</td>
<td>2.0</td>
<td>15.50</td>
<td>15.50</td>
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<tr>
<td>3.0 Power</td>
<td>3.0</td>
<td>169.52</td>
<td>169.52</td>
</tr>
<tr>
<td>4.0 Avionics/Control</td>
<td>4.0</td>
<td>425.94</td>
<td>425.94</td>
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<tr>
<td>5.0 Thermal Control</td>
<td>5.0</td>
<td>32.70</td>
<td>32.70</td>
</tr>
<tr>
<td>6.0 Growth</td>
<td>6.0</td>
<td>339.80</td>
<td>339.80</td>
</tr>
<tr>
<td>6.1 Structure</td>
<td>6.1</td>
<td>30%</td>
<td>146.70</td>
</tr>
<tr>
<td>6.2 Propulsion</td>
<td>6.2</td>
<td>30%</td>
<td>4.65</td>
</tr>
<tr>
<td>6.3 Power</td>
<td>6.3</td>
<td>30%</td>
<td>50.86</td>
</tr>
<tr>
<td>6.4 Avionics/Control</td>
<td>6.4</td>
<td>30%</td>
<td>127.78</td>
</tr>
<tr>
<td>6.5 Thermal</td>
<td>6.5</td>
<td>30%</td>
<td>9.81</td>
</tr>
</tbody>
</table>

## Dry Mass

- 7.0 Non-Cargo: 6.10
- 8.0 Cargo/Payload: 1138.00
  - 8.1 WFS: 1 575.00 575.00
  - 8.2 WFI: 1 384.00 384.00
  - 8.3 WFM: 1 144.00 144.00
  - 8.4 Instrument Cabling: 1 35.00 35.00

## Inert Mass
- 1144.10

## Total Less Propellant
- 2616.57

## Propellant
- 137.26

## Gross Mass
- 2753.83
• **Operational Pointing/viewing coverage**
  – 360deg (entire sky), with 45deg sun avoidance
  – no earth or moon avoidance required

• **Fast slew requirements**
  – autonomous slew of 60deg /60sec to detected target
  – At least once in a 24 hr period

• **Slow slew requirements**
  – Up to 5 slow slews per orbit, 100 deg per slew

• **Pointing accuracy:**
  – after fast slew - within 2 arcmin after 20sec maximum S/A damping time
  – after slow slew - within 1.25 arcmin, (assumed)
  – pointing knowledge of < 2” maintained throughout maneuvers
  – 30 minutes maximum observation time
GN&C: Strategy

• Build on previous work as much as possible: GLAST, EDGE

• Trade between Reaction Wheels and CMG
  – EDGE already did Reaction Wheel vs RCS
  – Trade using a CMG and RW combinations
    ▪ CMG used for the fast slew requirement
    ▪ RW used for everything else (slow slews, station keeping, dithers)
  – Trade using Ball Aerospace Worldview CMG alone

• Use 2 NFOV star trackers to achieve high accuracy pointing knowledge (2")

• Use 2 WFOV star trackers to maintain orientation during fast slews (1deg/s)
  – If the NFOV trackers get lost during fast slews, it will take a minute to re-establish attitude
  – Coupling the WFOV knowledge with the NFOV can keep the NFOV tracker from getting lost
Notes:
1) This diagram used to identify the physical parameters of the spacecraft.

2) Only need to identify one side of symmetric appendages.
(ex: only 1 of 2 opposite solar panels identified)

3) d1-y are y dimensions with torque about either the z or x axis depending on direction of attack. 
   d2-x are x dimensions with torque about either the z or y axis depending on direction of attack.  
   d3-z are z dimensions with torque about either the y or x axis depending on direction of attack.

Disturbance Equations:
1 Solar Torque
   \[ T_s = P_s A \cos(i) (1+q) L \]

2 Atmospheric Torque
   \[ T_a = \frac{1}{2} pV^2 C_d A L \]

3 Magnetic Torque
   \[ T_m = N I A (B_o R_o / R^3)(3\sin^2L + 1)^{1/2} \sin(q) \]

4 Gravity Gradient Torque
   \[ T_g = 3\mu / 2R^3 |I_z - I_{xy}| \sin 2q \]
GN&C: Results and Conclusions

• Suggest using Ball Aerospace Worldview Control Moment Gyro 4 wheel set
  – One set 4 CMG wheels to perform the fast slews, slow maneuvers, and station keeping
  – Wheels mounted in a pyramid configuration near the spacecraft center of mass
• Slightly better performance can be achieved using a CMG and Reaction Wheel combination set, but would be higher mass and power, and be significantly more complex
• A set of magnetic torquer rods used to perform the de-saturation of the wheels
  – Suggest using 1 Zarm/Microcosm MT400-2 rods, with .014Nm average torque capability per orbit
    ▪ De-saturation analysis has not been performed. De-saturation times may be significant, impacting science time
    ▪ Suggest using operational maneuvers to non-GRB event targets in round about paths to de-saturate wheels
• Suggest 2 sets of star trackers
  – One set of 2 NFOV perpendicular to each other, used for the high accuracy pointing knowledge (2"
    ▪ Goodrich has stated that the HD-1003 next generation star tracker can achieve 1” accuracy in x and y
    ▪ A second tracker is needed for the third axis high accuracy knowledge
  – Another set of 2 WFOV trackers is suggested for maintaining orientating knowledge during fast slews
    ▪ AeroAstro Mini-Star Tracker has a 10deg/sec rate capability advertised
• Suggest using Ball Aerospace M-95 CMG 4 wheel pyramid configuration for all slews, station keeping, and observations.

• Provides up to 6.1 Nm torque (~4.0 Nm required for Xenia)
## Performance Trade Table

<table>
<thead>
<tr>
<th>Number of Wheels</th>
<th>Source and Type</th>
<th>Nominal Wheel Condition</th>
<th>1 Wheel Failure Condition</th>
<th>Masses</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Slew Time (min)</td>
<td>Science Times (hr)</td>
<td>Slew Time (min)</td>
<td>Science Times (hr)</td>
</tr>
<tr>
<td>8</td>
<td>Ball Aerospace CMG-M95 and Teldix RSI 50-220/45</td>
<td>0.53</td>
<td>3.59</td>
<td>0.79</td>
<td>1.65</td>
</tr>
<tr>
<td>4</td>
<td>Ball Aerospace CMG-M95</td>
<td>0.90</td>
<td>3.22</td>
<td>1.4</td>
<td>0.98</td>
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<tr>
<td>6</td>
<td>Teldix MWI 30-400/37</td>
<td>3.00</td>
<td>1.34</td>
<td>5.00</td>
<td>0.79</td>
</tr>
<tr>
<td>4</td>
<td>Teldix MWI 30-400/37</td>
<td>5.00</td>
<td>0.98</td>
<td>15.00</td>
<td>0.69</td>
</tr>
</tbody>
</table>

*Total system mass includes isolation mounts and electronics
Xenia - CMG vs Reaction Wheel performance trade

Science Time vs Slew Time
(All Pyramid Configurations)

Shaded area meets requirement of 60 deg slew in less than 60 sec

4 Ball CMG-M95 and 4 Teldix-RSI50/220 Combo Set

4 Ball CMG-M95

6 Teldix-MWI30/400

4 Teldix-MWI30/400

Nominal Wheel Conditions
1 Wheel Failure Conditions
GN&C: Results

Number of slews possible per de-saturation cycle

Number of slews possible per de-saturation cycle given equal observation times

<table>
<thead>
<tr>
<th>Total Tob (min)</th>
<th>System Trades</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>17.00</td>
<td>13</td>
</tr>
<tr>
<td>12.00</td>
<td>18</td>
</tr>
<tr>
<td>10.00</td>
<td>22</td>
</tr>
<tr>
<td>8.00</td>
<td>27</td>
</tr>
<tr>
<td>5</td>
<td>43</td>
</tr>
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</table>
Avionics
• Communication transmission link via TDRSS

• Total science down-link communication data rate: 3.8 Mbps, orbital average

• Total telemetry up-link and down-link communication data rate: 4 kbps per transmission

• Total science on board memory required: 4 Gigabit
Avionics: Communication Strategy

**3 - Ground stations**

- WSGT White Sands NM
- GSFC Goddard MD

**Science data**
- 3.8 Mbps orbital average
- Ku-band

**GRB alerts, TOO**
- Engineering data
- 4 kbps, S-band

**TDRSS at GEO**
- Supports:
  - Ka-band 27.5-22.2 GHz
  - 25 Mbps up, 800 Mbps dw
  - Ku-band 15.0-13.7 GHz
  - 25 Mbps up, 300 Mbps dw
  - S-band 2.3-2.0 GHz
  - 300 kbps up, 6 Mbps dw

**Notes:**
This communication strategy is similar to FERMI (formerly GLAST), and suggested in EDGE.
## Avionics: Results

<table>
<thead>
<tr>
<th>Astronics</th>
<th>Mass (kg)</th>
<th>Power (W)</th>
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<tbody>
<tr>
<td>Attitude Control System</td>
<td>320</td>
<td>240</td>
</tr>
<tr>
<td>Command and Data System</td>
<td>22</td>
<td>107</td>
</tr>
<tr>
<td>Instrumentation and Monitoring</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Communications System</td>
<td>45</td>
<td>203</td>
</tr>
<tr>
<td>Avionics Cabling</td>
<td>34</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>426</strong></td>
<td><strong>557</strong></td>
</tr>
</tbody>
</table>
Avionics: Results

• An omni directional Ku band communication link was chosen for simplicity and mass savings
  – A pointing antenna may be blocked by S/C structures, restricting continues transmission capability
  – A 4Mbps omni link can be made to TDRSS with a 10w transmitter
    ▪ A link budget analysis was performed.

• A redundant 5w S-band system is used for command and telemetry links with TDRSS
  – It is planned to have no direct link to ground for normal operations, all links are through TDRSS

• The Saab Ericsson Spacecraft Computer has built in redundancy, extra memory and speed capacity, and all the I/O required for this application, along with good heritage
Power
Power: GR&A

• Long Mission: 5 Year Desired Life

• 600 km circular orbit: Max Dark Period 35.5 min, Min Light Period 61.2 min.

• Spacecraft must be independently oriented to view events of scientific interest

• Relatively high power levels (1-2 kW) required for science package

• Conditioned power, multiple voltages from common power bus @ 28V

• Required Power: 2027 W (including 30% margin)
Power: Design Highlights

- **Solar Array – 14.65 m^2**
  - GaAs 3j rated 348 W/m^2 (before Knockdowns)
  - 2.24 kg / m^2
  - Inherent Degradation 0.85
  - Degradation Rate 0.03/yr

- **Secondary Batteries – 8 Cells per Unit, 2 Units**
  - Based on Saft Li-Ion VES 180 Cells (50 Ah, 3.6V)
  - 1.29 Packing Factor
  - Cell Load Balancing Electronics
  - Max Depth of Discharge < 40%

- **Array Regulation – Direct Energy Transfer (0.95 Efficiency)**
## Power: Results

Sized to 2027W End of Life Power (1758W after 10 Years)

<table>
<thead>
<tr>
<th>Power Masses</th>
<th>Qty</th>
<th>Weight (kg)</th>
<th>Total Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDU</td>
<td>1</td>
<td>12.48 kg</td>
<td>12.48 kg</td>
</tr>
<tr>
<td>5 m, redundant Cabling</td>
<td>1</td>
<td>5.59 kg</td>
<td>5.59 kg</td>
</tr>
<tr>
<td>ARU</td>
<td>1</td>
<td>31.35 kg</td>
<td>31.35 kg</td>
</tr>
<tr>
<td>Solar Array</td>
<td>1</td>
<td>32.82 kg</td>
<td>32.82 kg</td>
</tr>
<tr>
<td>2880 Wh</td>
<td>2</td>
<td>11.66 kg</td>
<td>23.32 kg</td>
</tr>
<tr>
<td>Secondary Battery</td>
<td>2</td>
<td>11.66 kg</td>
<td>23.32 kg</td>
</tr>
<tr>
<td>Battery Charger</td>
<td>1</td>
<td>63.97 kg</td>
<td>63.97 kg</td>
</tr>
</tbody>
</table>
Thermal
Thermal Control: GR&A

• Primary objective is to develop a passive thermal design concept for the Xenia spacecraft. Heat rejection of instrument and subsystems power is accomplished by spacecraft radiators, closeout MLI, heat pipes and silverized Teflon tape.
  – Circular orbit, altitude 600 km
  – $5^\circ$ inclination, $\beta_{\text{max}} = 33.5^\circ$, $\beta_{\text{min}} = 0^\circ$
  – 3-axis stabilized, $45^\circ$ sun avoidance angle

• Spacecraft bus outer structural panels double as radiators
  – Spacecraft Bus composed of Aluminum plate (thickness varies) for optimal thermal conductivity.
  – Radiator panels located on the sides and bottom of the spacecraft
The radiator panels on the ISS and Shuttle are covered with silver coated FEP tape. To insure a long life in the presence of atomic oxygen, the tapes were coated with silicon oxide which acts as an atomic oxygen absorber.

Side Panel Radiator/ 2 plcs
Silverized Teflon Tape
$\alpha/\varepsilon = .2/.7$ (Degraded)

Bottom Panel Radiator
$\alpha/\varepsilon = .2/.7$ (Degraded)

Interior surfaces
Bare Aluminum

Closeout Blankets, 2 layer
Aluminized Teflon
$\alpha/\varepsilon = .14/.62$
Thermal Control: Analysis

Heat Pipes used to isothermalize heat loads
# Thermal Control: Analysis

<table>
<thead>
<tr>
<th>Component</th>
<th>Total Power (w)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACS (Attitude Control System)</strong></td>
<td>140.00</td>
</tr>
<tr>
<td>Sun Sensor Electronics Unit</td>
<td>6.00</td>
</tr>
<tr>
<td>Star Tracker WFOV</td>
<td>4.00</td>
</tr>
<tr>
<td>Star Tracker NFOV</td>
<td>20.00</td>
</tr>
<tr>
<td>Magnetometers - 3 axis each</td>
<td>4.00</td>
</tr>
<tr>
<td>IMU Assy</td>
<td>20.00</td>
</tr>
<tr>
<td>CMG Controllers (4)</td>
<td>60.00</td>
</tr>
<tr>
<td>Control Moment Gyro</td>
<td>60.00</td>
</tr>
<tr>
<td>Magnetic torquers</td>
<td>10.5</td>
</tr>
<tr>
<td><strong>CDS (Command and Data System)</strong></td>
<td>82.00</td>
</tr>
<tr>
<td>Flight Computer</td>
<td>60.00</td>
</tr>
<tr>
<td>Data Acquisition Unit</td>
<td>22.00</td>
</tr>
<tr>
<td><strong>Communications</strong></td>
<td>156.00</td>
</tr>
<tr>
<td>MGA Transmitter/Amplifier</td>
<td>114.00</td>
</tr>
<tr>
<td>LGA Transceiver/Transponder</td>
<td>36.00</td>
</tr>
<tr>
<td>GPS units w/combiner</td>
<td>6.00</td>
</tr>
<tr>
<td><strong>Power and Thermal</strong></td>
<td>585.00</td>
</tr>
<tr>
<td>ARU</td>
<td>109.00</td>
</tr>
<tr>
<td>Secondary Battery (2)</td>
<td>104.00</td>
</tr>
<tr>
<td>Battery Charger</td>
<td>364.00</td>
</tr>
<tr>
<td>28 VDC PDU</td>
<td>8.00</td>
</tr>
<tr>
<td><strong>Thermal System (Heaters)</strong></td>
<td>15.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Total Power (w)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WFS</strong></td>
<td>909.00</td>
</tr>
<tr>
<td>Detector head</td>
<td>0.00</td>
</tr>
<tr>
<td>FEE</td>
<td>23.00</td>
</tr>
<tr>
<td>Filter wheel</td>
<td>10.00</td>
</tr>
<tr>
<td>Mirror and casing</td>
<td>150.00</td>
</tr>
<tr>
<td>Digital electronic box</td>
<td>135.00</td>
</tr>
<tr>
<td>Control/Power Electronic box</td>
<td>103.00</td>
</tr>
<tr>
<td>Cryosyatic cooler</td>
<td>0.00</td>
</tr>
<tr>
<td>2ST Drive Electronics box</td>
<td>213.00</td>
</tr>
<tr>
<td>2ST Drive Electronics box</td>
<td>399.00</td>
</tr>
<tr>
<td>ADR Analog Control box</td>
<td>59.00</td>
</tr>
<tr>
<td><strong>WFI</strong></td>
<td>60.00</td>
</tr>
<tr>
<td>Camera head and FEE</td>
<td>30.00</td>
</tr>
<tr>
<td>Filter wheel and shutter</td>
<td>20.00</td>
</tr>
<tr>
<td>TEC</td>
<td>35.00</td>
</tr>
<tr>
<td>Mirror and casing</td>
<td>40.00</td>
</tr>
<tr>
<td>Analog Electronic box</td>
<td>25.00</td>
</tr>
<tr>
<td>Control/Power Electronic box</td>
<td>35.00</td>
</tr>
<tr>
<td><strong>WFM</strong></td>
<td>92.00</td>
</tr>
<tr>
<td>Detector</td>
<td>48.00</td>
</tr>
<tr>
<td>ICU Electronic box</td>
<td>92.00</td>
</tr>
</tbody>
</table>

**Total Spacecraft Heat Dissipation considered in analysis = 1776W**
Thermal Control: Results

- Spacecraft temperatures are -10° to 34° C
- Heat dissipation = 1776W
- β=33.5°
- Sun Angle = 90°
- Orbital Average Temperatures (°C)
Thermal Control: Results

- Spacecraft temperatures are -9° to 35° C
- Heat dissipation = 1776W
- $\beta=0^\circ$
- Sun Angle = 90°
- Orbital Average Temperatures (°C)
## Thermal Control: Results

<table>
<thead>
<tr>
<th>Component</th>
<th>Units</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument Light Shield &amp; Baffle MLI</td>
<td>15 m²</td>
<td>5.0</td>
</tr>
<tr>
<td>Closeout blankets</td>
<td>15 m²</td>
<td>7.5</td>
</tr>
<tr>
<td>Heat Pipes</td>
<td>4 @ 1.3 kg each</td>
<td>5.2</td>
</tr>
<tr>
<td>Silverized Teflon Tape</td>
<td>25@ .6 kg/m²</td>
<td>15.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>32.7</strong></td>
</tr>
</tbody>
</table>
Propulsion
Propulsion: GR&A

• **Spacecraft initial mass** – 2760 kg
• **Deorbit ΔV 163 m/sec** (from mission analysis)
• **T/W > 0.025**

**Engine**
- 1 Aerojet R42 Engine
  - Oxidizer – NTO
  - Fuel – MMH
  - Isp = 303 seconds
  - 5% residual

**Tank configuration**
- 1 tank for each propellant
  - Metallic tanks
  - Pressure = 240 psia
- Separate pressurization system for each propellant
  - 2 helium bottles
  - Initial pressure at 4500 psia
GHe Tank (each)
V = 0.005 m$^3$ (326 in$^3$)
Geometry = 0.22 m sphere
MEOP = 4,500 psia

Prop Tanks (each)
V = 0.056 m$^3$ (3418 in$^3$)
Geometry = 0.62 m X 0.20 m dia.
MEOP = 240 psia
## Propulsion: Mass Statement

<table>
<thead>
<tr>
<th>WBS Element - Descent Stage</th>
<th>Qty</th>
<th>Unit Mass (kg)</th>
<th>Total Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2.0 Propulsion</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1 Main Engines</td>
<td>1</td>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>2.2 Fuel Tank</td>
<td>1</td>
<td>3.30</td>
<td>3.30</td>
</tr>
<tr>
<td>2.3 Main Oxidizer Tank</td>
<td>1</td>
<td>3.60</td>
<td>3.60</td>
</tr>
<tr>
<td>2.4 Pressurization Tank</td>
<td>2</td>
<td>1.30</td>
<td>2.60</td>
</tr>
<tr>
<td>2.5 Feed System</td>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>8.0 Growth</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.3 Propulsion</td>
<td></td>
<td></td>
<td>4.65</td>
</tr>
<tr>
<td></td>
<td>30%</td>
<td></td>
<td>4.65</td>
</tr>
<tr>
<td><strong>Dry Mass</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>9.0 Non-Cargo</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.1 Propellant Residuals</td>
<td>1</td>
<td></td>
<td>5.74</td>
</tr>
<tr>
<td>9.1.1 Fuel</td>
<td>1</td>
<td>2.17</td>
<td>2.17</td>
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<tr>
<td>9.1.2 Oxidizer</td>
<td>1</td>
<td>3.57</td>
<td>3.57</td>
</tr>
<tr>
<td>9.2 Pressurant</td>
<td></td>
<td></td>
<td>0.36</td>
</tr>
<tr>
<td>9.2.1 Fuel</td>
<td>1</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>9.2.2 Oxidizer</td>
<td>1</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>Inert Mass</strong></td>
<td></td>
<td></td>
<td>6.10</td>
</tr>
<tr>
<td><strong>Total Less Propellant</strong></td>
<td></td>
<td></td>
<td>26.25</td>
</tr>
<tr>
<td><strong>12.0 Propellant</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.1 Main Fuel</td>
<td>1</td>
<td>51.83</td>
<td>51.83</td>
</tr>
<tr>
<td>12.2 Main Oxidizer</td>
<td>1</td>
<td>85.43</td>
<td>85.43</td>
</tr>
<tr>
<td><strong>Gross Mass</strong></td>
<td></td>
<td></td>
<td>163.51</td>
</tr>
</tbody>
</table>
Structures
• **Spacecraft Bus**
  - Aluminum 2024-T351 plate for durability and optimal thermal conductivity
  - 7075-T651 Al used for struts and adapter ring
  - Two exterior structural panels and aft aluminum panel double as radiators
  - Half of the outer surface panel area is required for thermal management
  - The rest of the exterior is closed out with Multi-Layer Insulation (MLI)

• **Secondary Structure**
  - WFI and WFS payload mass is distributed along the axis of each instrument and supported with secondary structure
  - A folding boom and vibration damping mechanism to minimize oscillations after fast slew is similar to one used on the Hubble telescope, but proportionally less massive
• **Maximum Launch Loads for Falcon 9 payload**
  – 5.0 g along launch axis
  – 0.9 g lateral to launch axis

• **Load Set**
  – Axial plus lateral at 45 degree intervals around bus

• **Strength Criteria**
  – Factor of Safety (FOS) 1.4
  – Positive Margin of Safety (MOS) for static launch load analysis
  – No buckling or stiffness analysis performed

• **Optimization**
  – 3/5 of the structure could be composite
  – Structures mass is expected to decrease when analysis optimization is complete
Structures: Analysis

- **Finite Element Modeling and Post-processing (FEMAP)**
  - Images showing structural analysis results
<table>
<thead>
<tr>
<th>Structural Mass</th>
<th>Qty</th>
<th>Total</th>
<th>489* kg</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Secondary</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Panel Structure</td>
<td>2</td>
<td>30.5</td>
<td>61.0</td>
</tr>
<tr>
<td>Solar array dampers,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>actuators, and booms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Secondary</strong></td>
<td>1</td>
<td>15.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Propulsion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Secondary</strong></td>
<td>1</td>
<td>100.0*</td>
<td>100.0*</td>
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<tr>
<td>Science Instruments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Primary</strong></td>
<td>1</td>
<td>313.0*</td>
<td>313.0*</td>
</tr>
<tr>
<td>Spacecraft Bus</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Further optimization and analysis could decrease the structural mass of these components.
Conclusions
• **Observatory fits within the Falcon 9 mass and volume envelope**
  – Plenty of payload margin when launching from Omelek.

• **Pointing, slow slewing, and fast slewing requirements met**
  – The use of control moment gyros (CMGs) enables the observatory to meet these opposing requirements, even with one wheel failure.

• **Thermal requirements met**
  – Thermal analysis of the Xenia spacecraft with all instrument electronic units and subsystem heat loads considered, resulted in an internal temperature range of -10C to 35C. This temperature range is well within the operating temperature range of all instruments and subsystem components located within the spacecraft.
Backup
### Mission Analysis: Orbital Lifetime Inputs

<table>
<thead>
<tr>
<th>Model Parameters</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>NRL MSISE 2000</td>
</tr>
<tr>
<td>Solar flux sigma value</td>
<td>2</td>
</tr>
<tr>
<td>Rotating Atmosphere</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td>makes calculations more conservative</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Satellite Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Drag coefficient</td>
<td>2.2</td>
</tr>
<tr>
<td>Drag area</td>
<td>24</td>
</tr>
<tr>
<td>Area exposed to sun</td>
<td>30</td>
</tr>
<tr>
<td>reflection coefficient</td>
<td>1</td>
</tr>
<tr>
<td>Satellite mass</td>
<td>2100 – 2500</td>
</tr>
</tbody>
</table>
• Performance computations are based on the following main assumptions:

  – This performance does not include the effects of orbital debris compliance, which must be evaluated on a mission specific basis. This could result in a significant performance impact for missions in which launch vehicle hardware remains in Earth orbit

  – This performance is reflective of the Block 2 version of the Falcon 9

  – 3-sigma mission required margin, plus additional reserves determined by the LSP

  – A payload adapter has been assumed

• Source: NASA LSP performance quote.
Required Delta-V for Deorbiting Satellite from Circular Orbit for Various Interface Flight Path Angles

Initial Circular Altitude (km) vs. Delta-V (m/s)

-2  -1.8  -1.6  -1.4  -1.2  -1.0

interface defined as 400000ft altitude

flight path angle at interface (deg)
Mission Analysis: De-orbit

Perigee Altitude for Deorbiting Satellite from Circular Orbit for Various Interface Flight Path Angles

Initial Circular Altitude (km) vs. Perigee Altitude (km)

- Flight path angle at interface (deg)
- Interface defined as 400000ft altitude
Deorbit Gravity Loss vs. Thrust-to-Weight Ratio
for 600km Circ, Isp=250s
(Add this to the 161.3 m/s Impulsive Delta-V)
Xenia - Spacecraft Avionics Functional Diagram

Communications System (3)
- S-Band 4 kbps
- Ku-Band 4 Mbps
- Transponder
- Power Amp
- S-band Transceiver
- GPS
- Amplifier
- Ka Transceiver
- Transponder
- Power Amp
- S-band Transceiver
- Amplifier
- Ka Transceiver

Command and Data System (CDS) (1)
- Includes 2-16 Gbits Memory boards
- Data Acquisition Unit
- Digital Unit
- 2ST Drive
- ADR Analog
- STJT Drive
- Controller and Power Electronics Unit
- HUPS 1
- HUPS 2
- ICU Electronic Controller
- Analog Unit
- HUPS 1
- HUPS 2
- ICU Electronic Controller

GNC/Vetronics/Comm Flight Computer System
- with internal dual redundancy

Attitude Control System (ACS) (4)
- 2 – NFoV Star Tractor
- 2 – WFoV Star Tractor
- 2 - IMU Gyros
- 3 - Magnetometer
- 4 - Sun Sensors
- 3-Magnetic Torquer set
- De-orbit Engine Controller
- 4-CMG wheels

Power System (2)
- Magnetic Torque Rods
- Heaters
- Igniters
- Sensors
- Gimble Motors
- Torque Motors
- Deployment and Pointing Motors
- Solar Array #1
- Solar Array #2

Science Instrument Bus (1)(2)
- WFS
- WFI
- WFM
- HUPS 1
- HUPS 2
- ICU Electronic Controller
- WFM
- HUPS 1
- HUPS 2
- ICU Electronic Controller

2-23-09

H&M Instrumentation
- Pressure
- Temperature
- Strain

Solar Array #2
- Regulator Unit
- Charger
- Secondary Battery

Survival Heaters

TDRSS
Comm. To Ground

Analog Electronic Unit

Controller and Power Unit
Functional Diagram Notes

1. It is assumed that the individual science instrument packages include all the required data processing, filtering, and buffering required, along with thermal, health, and status control. All science data is to be transmitted to the spacecraft computer via a dual redundant spacecraft data bus for storage and downloading to ground. Instrument health and status telemetry will be collected by a second dual redundant spacecraft data bus, processed, and stored independently of the science data. All science and telemetry data should be ID and time stamp for later correlation and downloading to ground.

2. A dual redundant primary power feed will be supplied to an instrument controller for each of the 4 major instruments. Those controllers must distribute secondary power to the instrument and instrument's electronic boxes, perform all required operations (e.g. safe mode), control any mechanism required (e.g. shutters), and perform the thermal management of the dedicated systems. All cabling between the controllers and science boxes should be included in the science package mass estimates.

3. The communication system will be similar to GLAST/FERMI. The TDRSS communication satellite system will be used as the primary means of uploading commands and targets of opportunity (TOO), downloading science and telemetry data, along with broadcasting a detected event. Since the intent is to keep the comm system small and simple, direct ground link will be used only as backup at low data rates.

4. The final study plan is to perform fast slews with a 4 wheel Control Moment Gyro (CMG) set provided by Ball Aerospace. The slow target slews and regular station keeping operations will also be done using the same CMG set. De-saturation of the wheels will be accomplished using electromagnetic torque rods when needed. De-saturation down time may be significant unless de-saturation maneuvers are done.
ACS Tool Outputs and analysis

<table>
<thead>
<tr>
<th>Note:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desaturation period = 1 orbit (~90 min)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Units</th>
<th>( \text{Ixx} ) (roll)</th>
<th>( \text{Iyy} ) (pitch)</th>
<th>( \text{Izz} ) (yaw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{kgm}^2 )</td>
<td>( \text{kgm}^2 )</td>
<td>( \text{kgm}^2 )</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disturbance Torques</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Torques Nm</td>
<td>8.195E-06</td>
<td>1.245E-06</td>
<td>8.958E-07</td>
</tr>
<tr>
<td>Atmospheric Torques Nm</td>
<td>1.707E-03</td>
<td>1.153E-03</td>
<td>1.703E-04</td>
</tr>
<tr>
<td>Gravity Torques Nm</td>
<td>2.604E-03</td>
<td>2.190E-03</td>
<td>4.134E-04</td>
</tr>
</tbody>
</table>

| Total disturbance Torques Nm | 4.319E-03 | 3.345E-03 | 5.847E-04 |
| Disturbance times (.75' drift) sec | 12.94 | 14.20 | 26.63 |
| Disturbance times (1.25' drift) sec | 16.71 | 18.33 | 34.37 |

<table>
<thead>
<tr>
<th>Attitude Corrections</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Correction Torque (.75' drift) Nm</td>
<td>0.0417</td>
<td>0.0389</td>
<td>0.0239</td>
</tr>
<tr>
<td>Correction Torque in (1.25' drift) Nm</td>
<td>0.0250</td>
<td>0.0233</td>
<td>0.0143</td>
</tr>
<tr>
<td>Correction time (.75' drift) sec</td>
<td>8.333</td>
<td>8.333</td>
<td>8.333</td>
</tr>
<tr>
<td>Correction time (1.25' drift) sec</td>
<td>13.88</td>
<td>13.88</td>
<td>13.88</td>
</tr>
<tr>
<td>Correction Momentum (both drifts) Nms</td>
<td>0.174</td>
<td>0.162</td>
<td>0.099</td>
</tr>
<tr>
<td>Correction Cycles per desat period (.75' drift)</td>
<td>254</td>
<td>240</td>
<td>155</td>
</tr>
<tr>
<td>Correction Cycles per desat period (1.25' drift)</td>
<td>177</td>
<td>168</td>
<td>112</td>
</tr>
</tbody>
</table>

| Momentum per desat period (.75' drift) Nms | 46.51 | 39.98 | 31.43 |
| Momentum per desat period (1.25' drift) Nms | 30.74 | 27.20 | 11.14 |

<table>
<thead>
<tr>
<th>Maneuvers per desaturation Period</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Fast Slew Torque (60deg/45sec) Nm</td>
<td>6.861</td>
<td>6.396</td>
<td>3.930</td>
</tr>
<tr>
<td>1 - Fast Slew Torque (60deg/60sec) Nm</td>
<td>3.860</td>
<td>3.598</td>
<td>2.211</td>
</tr>
<tr>
<td>1 - Fast Slew Torque (60deg/90sec) Nm</td>
<td>1.715</td>
<td>1.599</td>
<td>0.983</td>
</tr>
<tr>
<td>1 - Slow Slew Torque (100deg/100sec) Nm</td>
<td>2.316</td>
<td>2.159</td>
<td>1.326</td>
</tr>
</tbody>
</table>

| 1 - Fast Slew Momentum (60deg/45sec) Nms | 154.38 | 143.91 | 88.43 |
| 1 - Fast Slew Momentum (60deg/60sec) Nms | 115.79 | 107.95 | 66.32 |
| 1 - Fast Slew Momentum (60deg/180sec) Nms | 77.19 | 71.95 | 44.22 |
| 1 - Slow Slew Momentum (100deg/75sec) Nms | 154.38 | 143.91 | 88.43 |
| 1 - Slow Slew Momentum (100deg/100sec) Nms | 115.79 | 107.93 | 66.32 |
| 1 - Slow Slew Momentum (100deg/150sec) Nms | 77.19 | 71.95 | 44.22 |

| Sum of greatest Momentums Nms | 198.49 | 182.76 | 103.85 |
| Sum of mid-level Momentums Nms | 159.90 | 146.79 | 81.74 |
| Sum of least Momentums Nms | 121.30 | 110.81 | 59.64 |

Critical design parameters

Recommended design parameters

Ball Aerospace M95 CMG - 129 Nms each wheel x 2.31 for a 4 wheel pyramid = 298 Nms.
 Collective torque capability = 6.1 Nm
ESA planned and heritage missions:
- Herschel - 3.5 m IR telescope at L2
- Planck - cosmic microwave background
- Pleiades - Earth observation satellite
- Aeolus - Atmospheric wind sensor (same as MSFC canceled Sparkle)

Properties and Interfaces
- Power consumption: <40 W average, < 60 W peak
- Mass: 18 kg
- Dimensions: 420 (L) x 270 (H) x 276 (D) mm
- Reliability:
  >0.99 over a 3-year mission using class B components
  >0.95 over a 15-year mission using class S Components
- Heaters: 50 W per line, > 500 W total
- secondary power distribution
- Solar Array Drive Motor
- 32/64 Gbit mass memory boards
- 1553 Data buses
- 40 Mbps payload wire links
- 20 Mbps RS-422 Synchronous serial links
- 1.5 Mbaud UART links RS-422 or RS-485
- RS-422 Synch pulses fixed and programmable

AOCS Interfaces
- GPS Receiver
- Magnetometer interfaces
- Gyro interfaces
- Reaction wheel interfaces
- Star tracker interfaces
- Thruster control interfaces
- Sun sensor interfaces
Modular S-Band Radio

The AeroAstro Modular S-Band Radio System is a miniature software/FPGA based radio providing full NASA/DOD, ESA and AFSCN interoperability, enabling a new low-cost generation of space missions.

Three 3.5” x 2.0” x 1.1” modules combine to create a powerful 5W RF transceiver and/or coherent transponder. The modular approach supports distributed placement in the small recesses of a spacecraft or UAV. With a total mass of less than 1 Kg and a volume of just over 23 in³, the AeroAstro Modular S-Band radio provides the designer more useful payload while reducing costs.

The radio modules interconnect via an EIA-485 network which can also interface with other future radio products to add flexibility and capability.

- SGSL, STDH and CCSDS variants
- Interface to MCU-110 crypto unit
- RS-422, EIA-485 & custom I/F
- PRN ranging / coherency supported
- Telemetry uplink at 1, 2 or 10kbps
- Downlink rates to 25 kbps
- Receiver available for stand-alone use

Specifications

- Input Voltage: 15 – 50Vdc continuous operation
- Reverse Voltage Protection: Up to -50V continuous
- Output Protection: No damage, open or short circuit
- Thermal Monitoring: Individual sensors and reporting from each of the three modules.

- RF Input Dynamic Range: -130dBm to -40dBm
- RX Carrier Tracking range: ±105kHz
- RX Carrier Acquisition Threshold: -119dBm
- RX Noise Figure: 4dB
- RX Carrier Acquisition Time: <0.5sec
- TX Frequency Stability: ±20ppm over temperature

- Output Power: Adjustable in 0.5W steps from 0.5W to 5W RF under software control.
- Ranging: B/W: 100Hz to 1MHz (-3dB) \n  Turnaround UMI: 1:1 (±10%)
- Uplink Modulation Index: 0.3Rad peak (nom.)

- Interface: RS-422/EIA-485 software command I/F

- Operating Temperature: -20°C to -60°C
- Vibration: 14.1grms (proto qualification level)

- Radiation Tolerance: 10krads(Si) - box level
  (higher levels available with shielding)
- Latch-up: Detection and Mitigation
  (2usec response, 200msec reset)

- Dimensions: three modules – each 3.5” x 2.0” x 1.1”
  (8.9 cm x 5.1 cm x 2.6 cm)
- Mass: < 900g (total for 3 modules)
**Miniature Star Tracker**

AeroAstro's Miniature Star Tracker (MST) design is a small, low power (< 2 Watt) star tracker, with an accuracy of better than ±70 arc-seconds in all three axes (3σ). It achieves reasonable star tracking accuracy with low mass and power consumption at less than half the cost of other star trackers.

The MST is available in a low-cost commercial-off-the-shelf (COTS) version tolerant up to 30 krad and can be modified for higher radiation tolerance. The MST also provides a lost-in-space capability and is currently being enhanced to achieve fast angular rate sensing.

The star tracker features a user-definable star catalog and powerful hybrid processor. With a 1 Mpixel CMOS array, the star tracker is sensitive up to 4th magnitude stars.

Images can be downloaded for ground processing and custom code can be incorporated. Built-in test includes the ability to upload images and verify star tracker performance.

**Specifications**

- **Accuracy:** Better than ±70 arc seconds, 3-axes (3σ)
- **CMOS Imager:** ~ 1024 x 1280 pixel array each pixel ~ 7 μm square
- **Sensitivity:** Up to 4th magnitude stars
- **Maximum Pitch/Yaw Rate:** 10°/sec (goal)
- **Update Rate:** ~ 1 Hz
- **Output:** Quaternion, Centroids, and custom
- **Stars Tracked:** Up to 9 simultaneously
- **Star Catalog:** 600 and can employ user-defined catalogs
- **Image Rate:** 0 to 24 fps
- **Power:** < 2 Watts
- **Radiation Tolerance:** Up to 30 krad(Si), more with shielding
- **Dimensions:** 2”x 2”x 3”(5.4 cm x 5.4 cm x 7.6 cm)
- **Mass:** 425 g (not including baffle)
- **Self Test:** Images can be up and down loaded for verification
HD-1003 STAR TRACKER

STELLAR PERFORMANCE
This small, low cost, lightweight, advanced Star Tracker is space qualified and in production for all major spacecraft manufacturers in the U.S. today. The HD-1003 is the world's most reliable and survivable high accuracy star tracker, backed by the world's most experienced CCD Star Tracker production team.

LIGHT YEARS AHEAD IN DESIGN
The HD-1003 has more than 30 years of Star Tracker experience built in, and is manufactured by the company that was first in space with CCD Star Trackers. Our design's versatility accommodates most military, commercial and scientific mission scenarios in any orbit.

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>Narrow FOV</th>
<th>Wide FOV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of View Magnitude Sensitivity</td>
<td>9° x 9°</td>
<td>10° x 10°</td>
</tr>
<tr>
<td>Power (avg at +45°C)</td>
<td>+0.5 W</td>
<td>+5.1 W</td>
</tr>
<tr>
<td>Weight (with lightshades)</td>
<td>8.5 lbs</td>
<td>7.5 lbs</td>
</tr>
<tr>
<td>Update Rate</td>
<td>6 Hz</td>
<td>2 Hz</td>
</tr>
<tr>
<td>Overall Accuracy Pitch/Yaw, rms</td>
<td>2 arc sec</td>
<td>5 arc sec</td>
</tr>
<tr>
<td>Roll, rms</td>
<td>40 arc sec</td>
<td>40 arc sec</td>
</tr>
</tbody>
</table>

ADVANCED DESIGN FEATURES
- Automatic Proton and Debris Noise Rejection
- Six-Star Tracking Capability
- Robust Acquisition/Tracking
- 1534B Communication Interface
- Modular Construction
- Quaternions Output Option (Wide FOV Only)

HIGH RELIABILITY
- Class-E Equivalent Parts
- MTBF of One Million Hours

MISSION VERSATILITY
- On-orbit Upload Capability
- Modular Radiation Shielding
- Modular Lightshades

SURVIVABILITY
- Radiation Hardened Electronics (100K rads minimum)
- Radiation Tolerant CCD Detector
- EMC per MIL-STD-461C
- Survival Temperature Range of -30°C to -65°C

Goodrich
Optical and Space Systems Division
Electro-Optical Systems
100 Woonsocket Heights Road
Danbury, CT 06810-7899
USA
Phone: (203) 797-5210
FAX: (203) 797-5668
Email: EOS@goodrich.com
www.goodrich.com
• Suggest using Ball Aerospace M-95 CMG 4 wheel pyramid configuration for all slews, station keeping, and observations.

• Provides up to 6.1 Nm torque (4.8 Nm required for Xenia)
• Option using MWA-50 wheels for slow slew station keeping, and dither maneuvers.

• Provides 68Nms momentum storage and .07Nm torque
  93 to 58 Nms required for mid-level performance
  .05Nm torque required for dither roll

• 4 wheels at 10.5kg each gives a total mass of 42kg
• Ga-As 3j
• 258 W / m^2 (End of Life, with knockdowns for cell mismatch, interconnect failures, margin)
• 2.24 kg / m^2
Power: Array Regulation Unit

- Sequential Shunt Regulator
- 60 Strings
- PWM Freq 50kHZ
- Ripple < 1.65 %
- Linear Regulation
- Charge / Discharge Efficiency 81%
- Ripple < 0.5 %
Axially grooved aluminum extrusions with ammonia working fluid are used to isothermalize the equipment platform of the International Ultraviolet Explorer as shown in the figure below.

Ambient temperature heat pipes have been used successfully in numerous spacecraft applications. They are accepted as a reliable aerospace component based on extensive flight data. One of the most extensive application in the use of heat pipes aboard an operational spacecraft has been on the Applications Technology Satellite (STS-6). A total of 55 heat pipes were placed in equipment panels to carry solar and internal power loads to radiator surfaces. Ammonia was used with aluminum axially grooved tubing. Data taken over a 24 hour orbital period shows a maximum gradient of 3 deg. C existed from one side of the spacecraft to the other. No degradation in thermal design was seen.
R-42 890N (200 lbf) BIPROPELLANT ROCKET ENGINE

Design Characteristics

- Propellant: MMH/NTO(MON-3)
- Thrust/Steady State: 890N (200 lbf)
- Inlet Pressure Range: 29.3-6.9 bar (425-100 psia)
- Chamber Pressure*: 7.1 bar (103 psia)
- Expansion Ratio: 160:1
- Flowrate*: 300 g/sec (0.66 lbm/sec)
- Valve: Aerojet Solenoid, Single Coil, Single Seat
- Valve Power: 46 Watts @ 28 Vdc
- Mass: 4.53 kg (10.0 lbm)

*At rated thrust

Performance

- Specific Impulse*: 303 sec (lbf-sec/lbm)
- Total Impulse: 24,271,000 N-sec (5,456,700 lbf-sec)
- Total Pulses: 134
- Minimum Impulse Bit: 44.48 N-sec (10.0 lbf-sec)
- Steady State Firing Cumulative: 27,000 sec
- Steady State Firing (Single Firing): 3,940 sec

Reference

- AIAA - 1990 - 2055

Dimensions are in inches