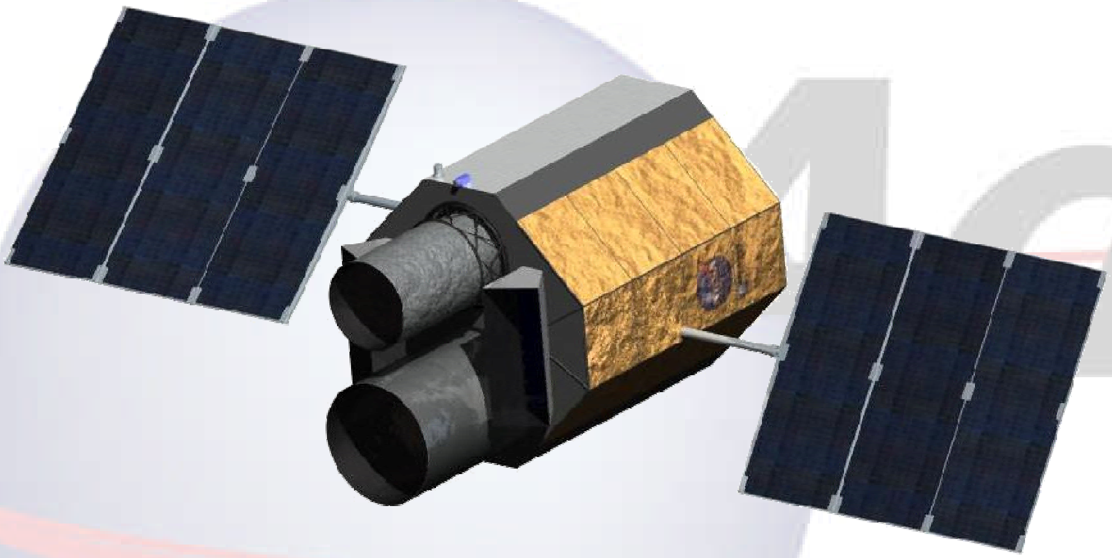
Xenia Spacecraft Study

Spacecraft Design

March 2, 2009

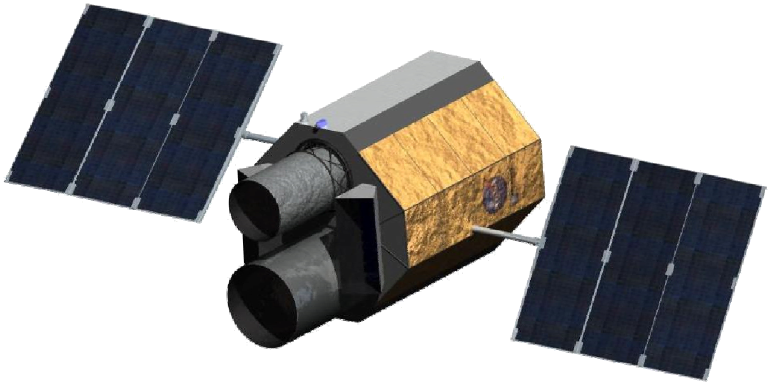


Outline

- 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



Spacecraft Team Members

Chryssa Kouveliotou	Xenia PI	MSFC-VP62
Les Johnson	Study Manager and Lead	MSFC-ED04
Randy Hopkins	Technical Lead / Mission Analysis	MSFC-ED04
Mike Baysinger	Spacecraft Configuration	MSFC-ED04 / Qualis
P.J. Benfield	Propulsion	U. Of Alabama Huntsville
Pete Capizzo	Avionics / GN&C	MSFC-ED04 / Raytheon
Tracie Crane	Mass Properties	MSFC-ED04 / Qualis
Leo Fabisinski	Power	MSFC-ED04 / ISSI
Linda Hornsby	Thermal	MSFC-ED04 / JTI
David Jones	Structures	MSFC-ED04
Dauphne Maples	Mass Properties / GR&A	MSFC-ED04 / Qualis
Janie Miernik	Structures	MSFC-ED04 / ERC
Tom Percy	Mission Analysis	SAIC
Kevin Thompson	Animation	MSFC-ED04 / Jacobs
Matt Turner	Propulsion	U. Of Alabama Huntsville

Animation

- **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/

Overall Ground Rules and Assumptions (GR&A)

- **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

Mission Analysis: GR&A

- **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

	Falcon 9		Vega	Atlas V 401	Delta II Heavy (7920H-10)*
Launch Site	Omelek (Kwajalein)	CCAFS	Kourou	CCAFS	CCAFS
Source:	NASA LSP [2]	NASA LSP [2]	Vega User's Manual [1]	NASA LSP [2]	NASA LSP [2]
600 km @ 5 deg	7000	1700	2050	4395	895
600 km @ 10 deg	Not requested	TBD [3]	2040	5815	1440
600 km @ 15 deg	Not requested	TBD [3]	Not requested	Not requested	Not requested
500 km @ 5 deg	Not requested	Not requested	2120	4390	885
500 km @ 10 deg	Not requested	Not requested	2110	5820	1435

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

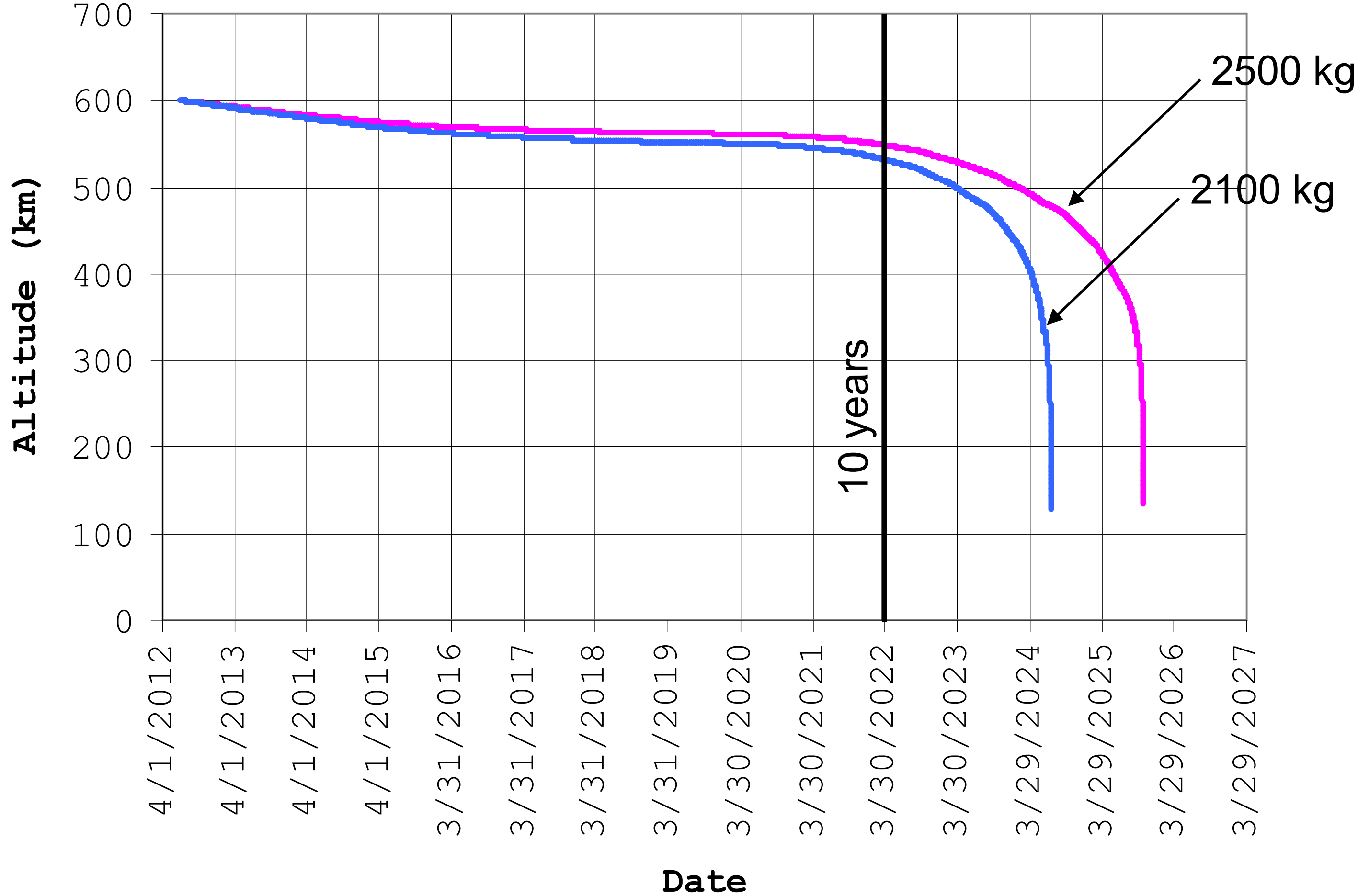
[1] Interpolated results from performance plots. The mass of the 60kg type 937 payload adapter has been subtracted.

[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.

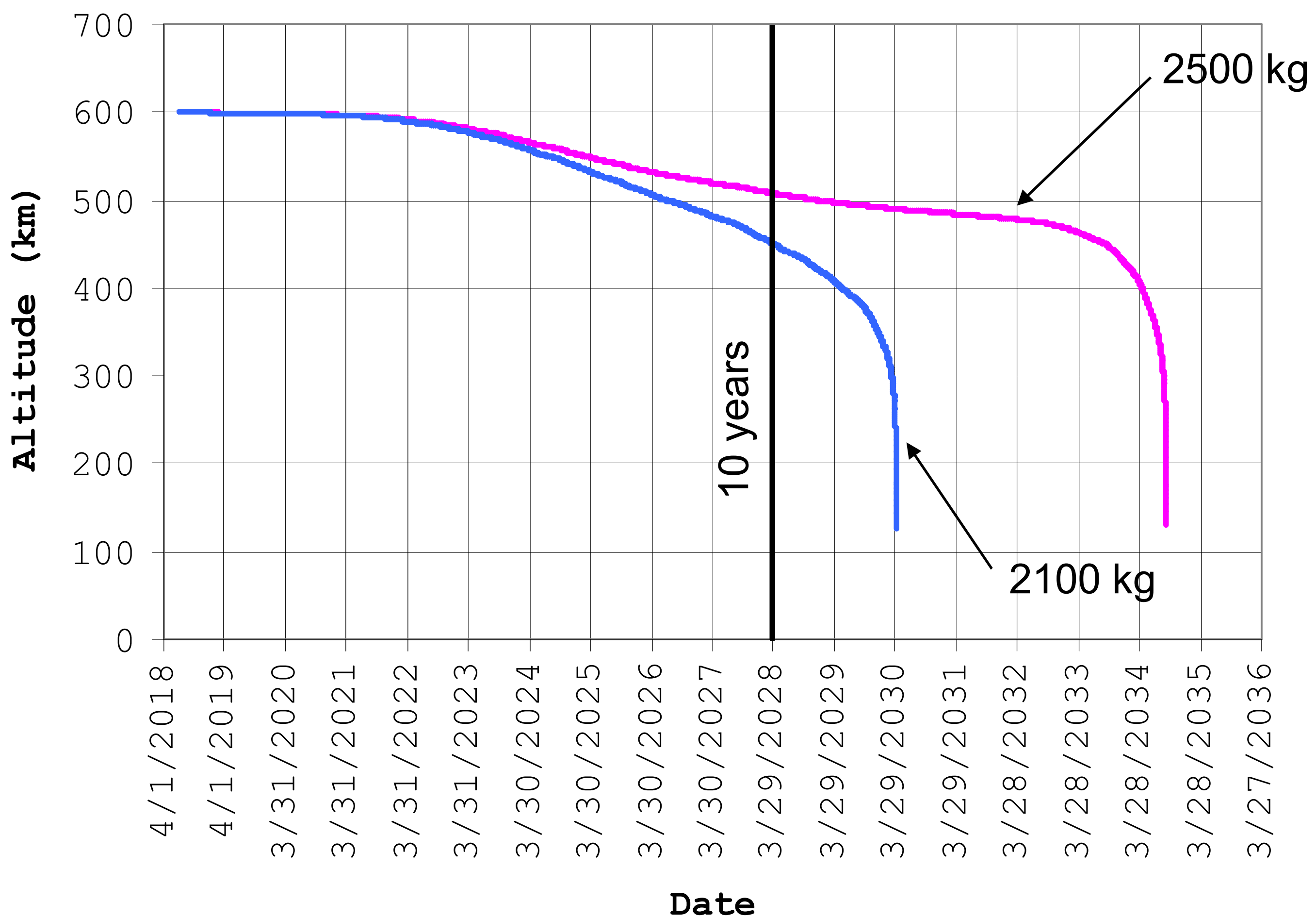
Mission Analysis: Orbital Lifetime

Orbital Lifetime for two spacecraft masses, 2012 Launch Date



Mission Analysis: Orbital Lifetime

Orbital Lifetime for two spacecraft masses, 2018 Launch Date



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.

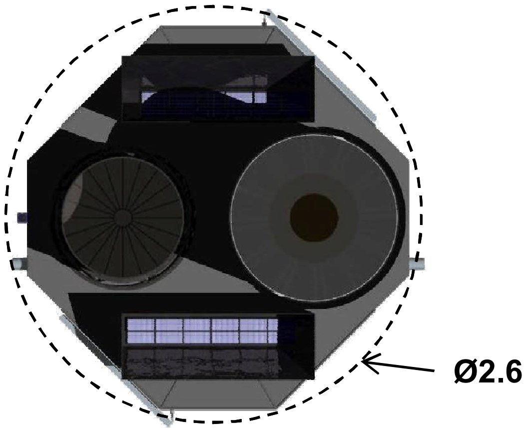
- **Orbital Lifetime**
  - Based on the calculations, no periodic orbit boost will be required.

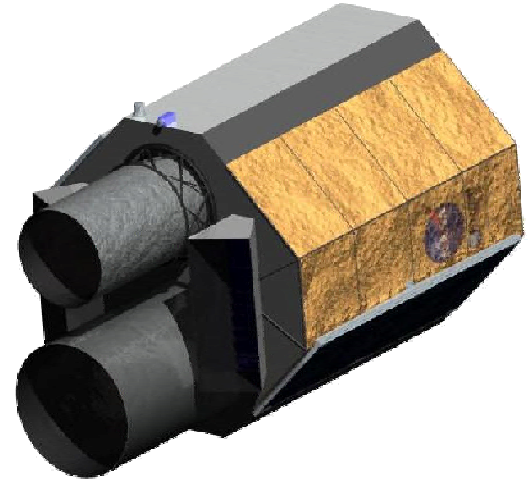
- **De-orbit**
  - Need a propulsion system which can supply a total delta-v of 163 m/s

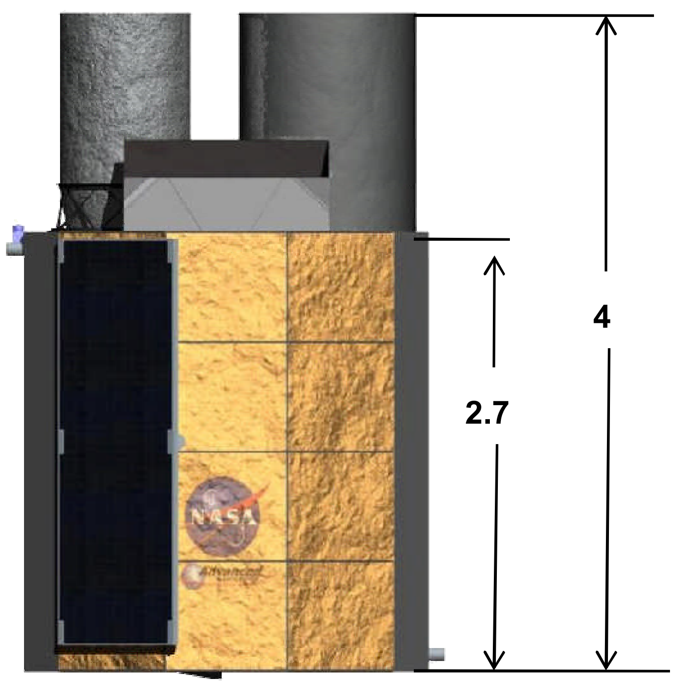
Spacecraft Configuration

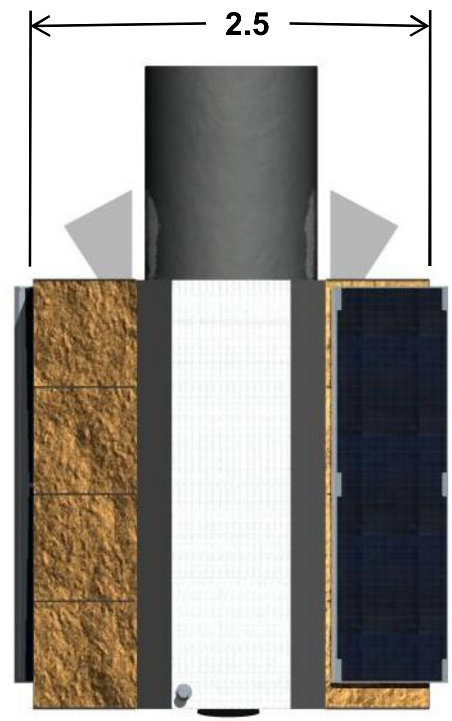
Configuration: Falcon Shroud

Configuration

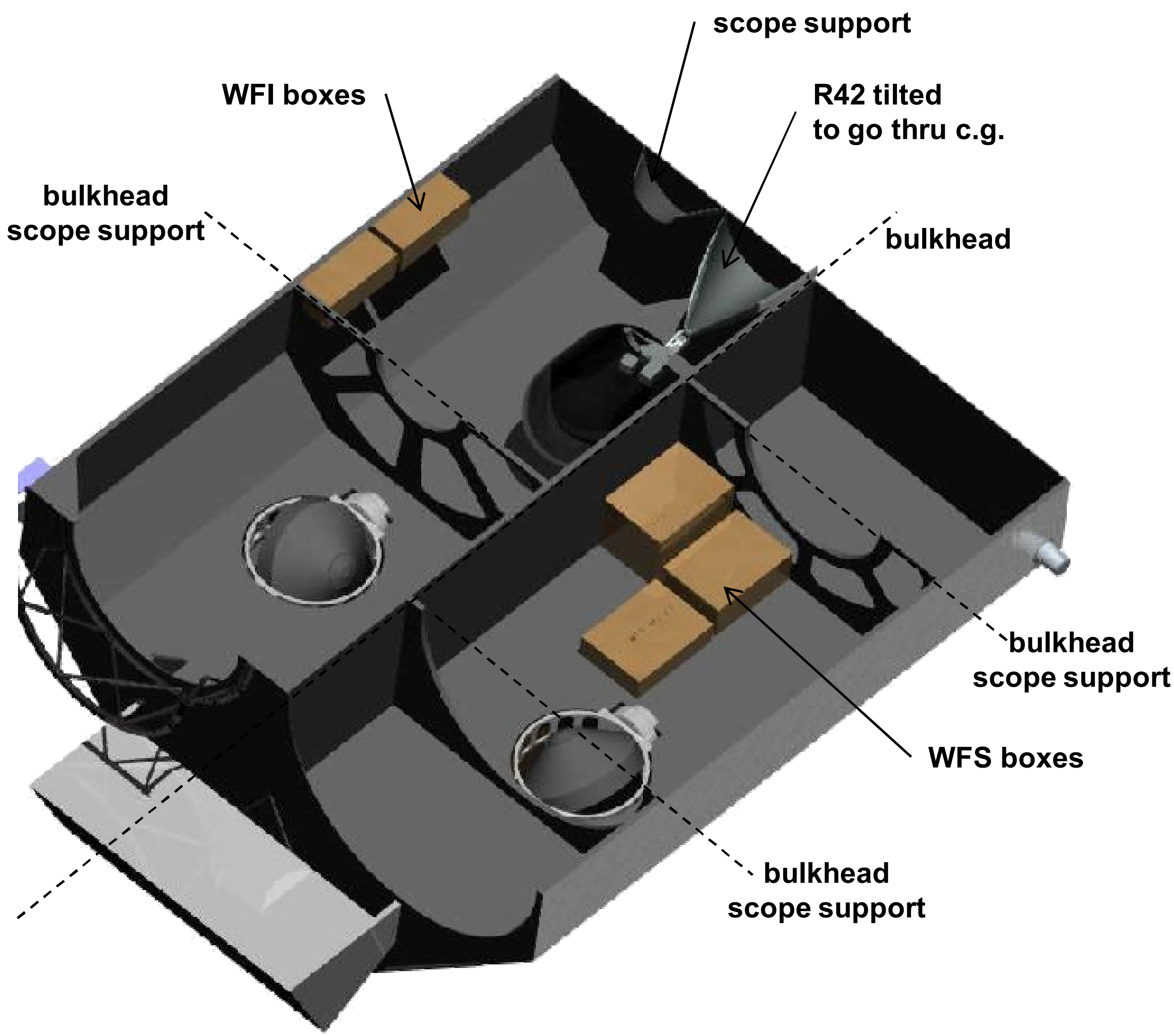








Configuration



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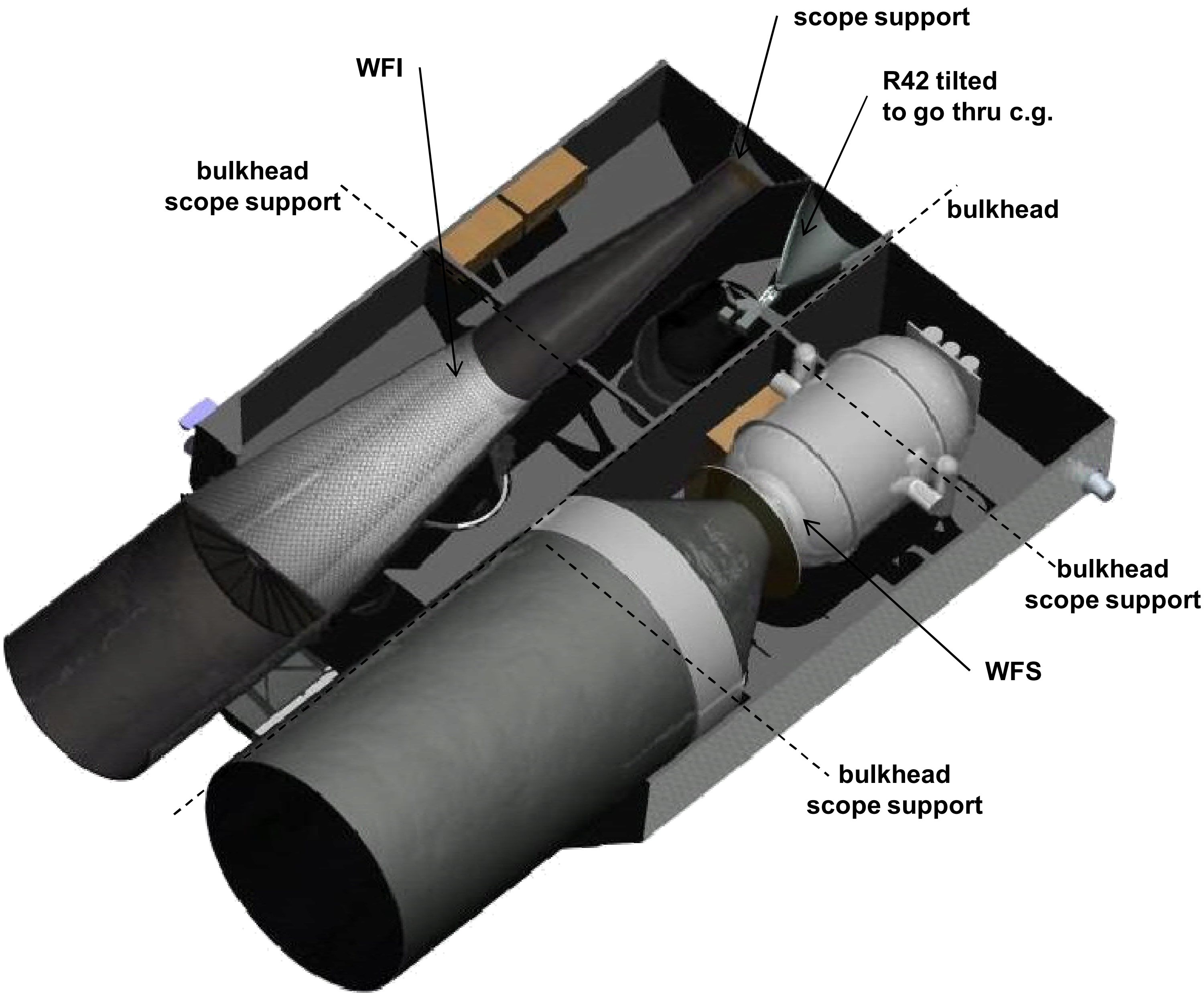
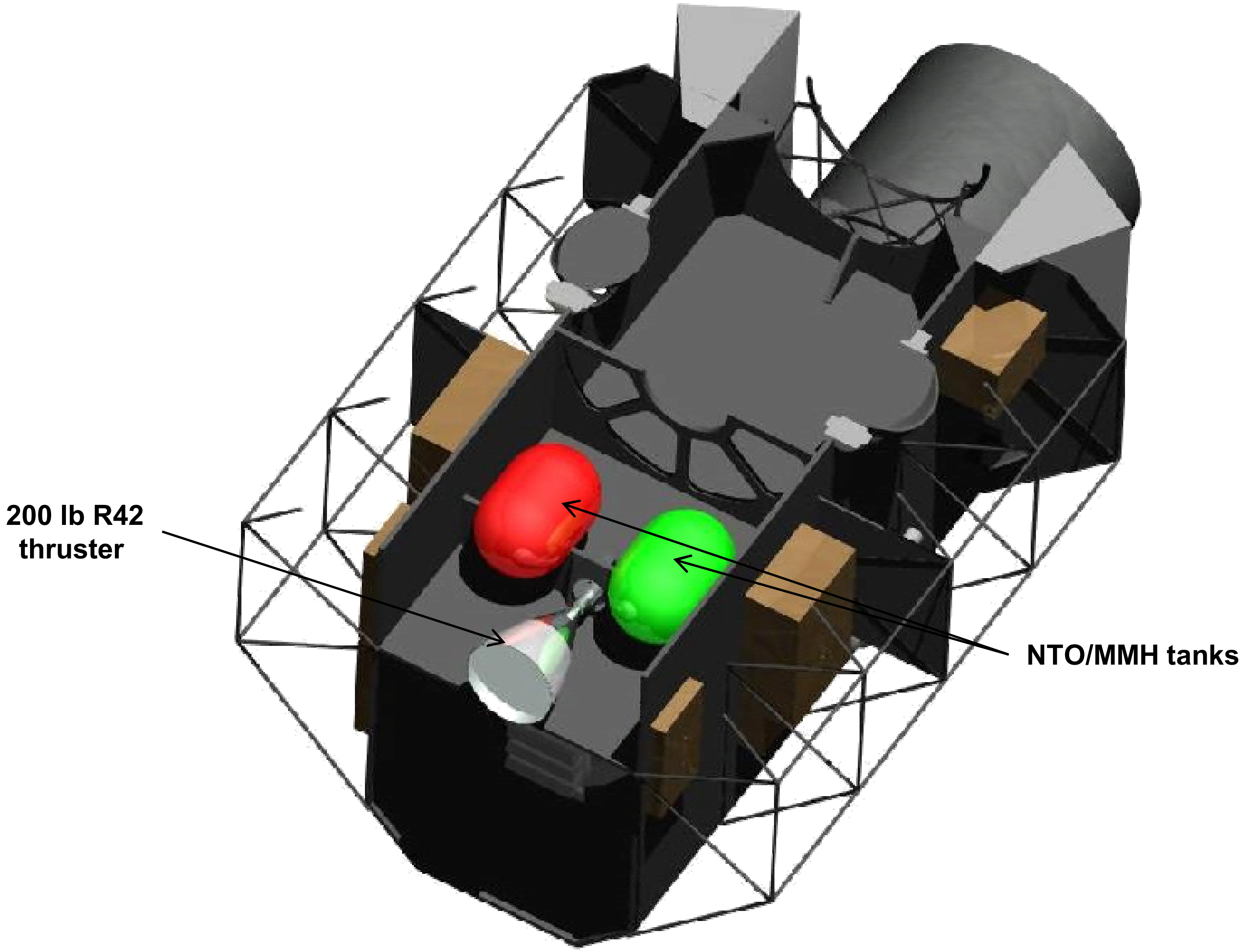
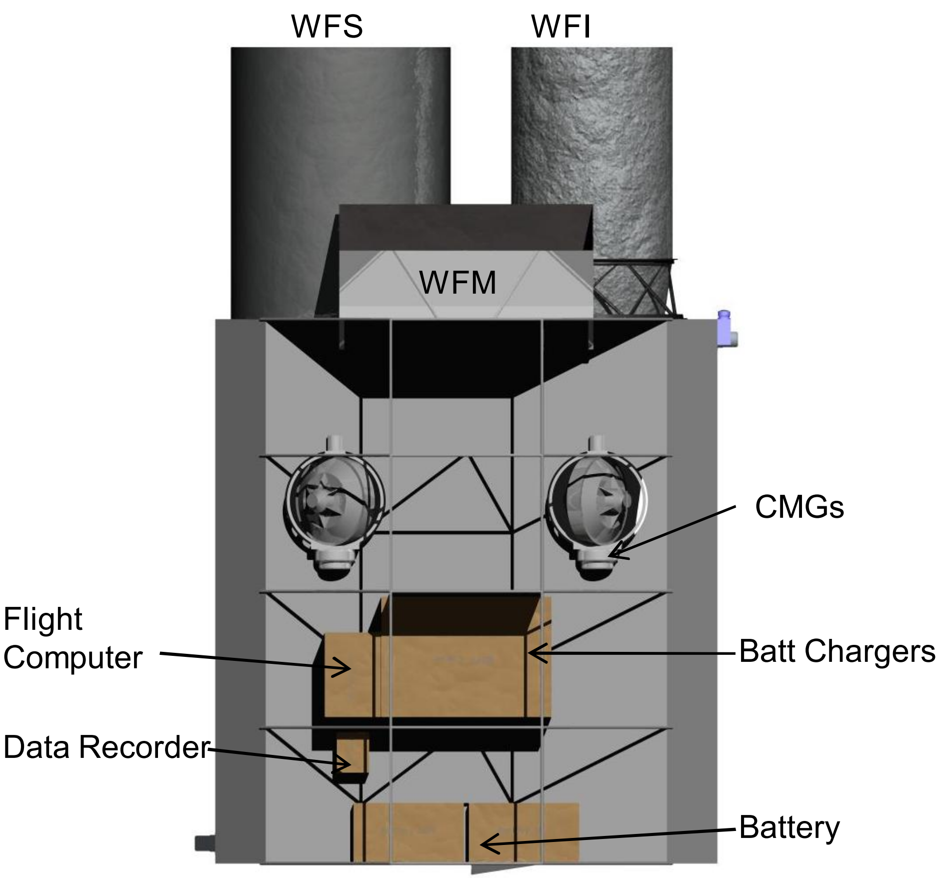
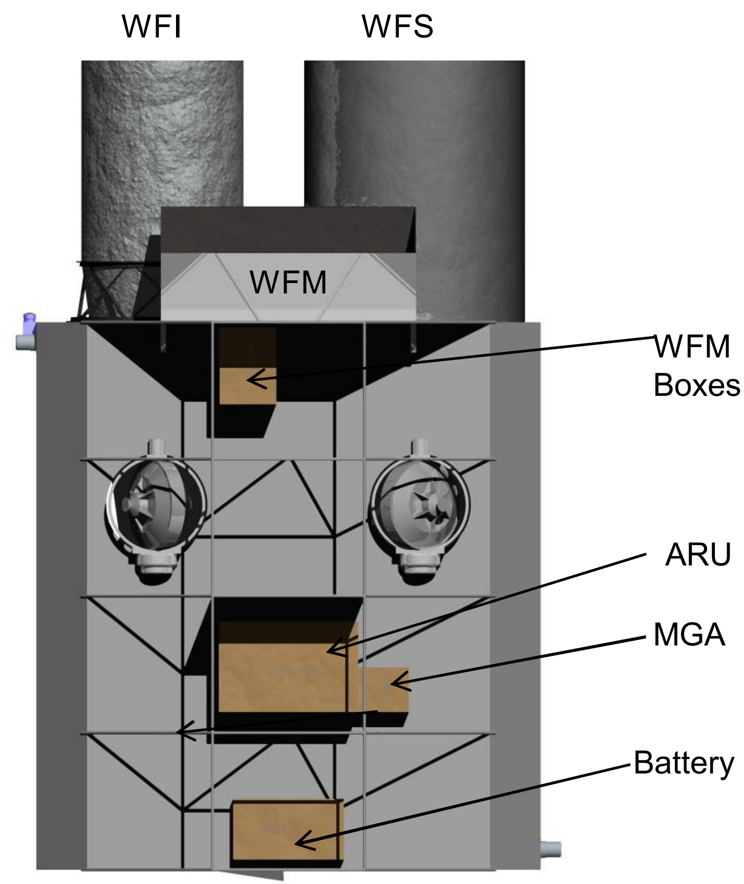


Configuration: De-orbit system

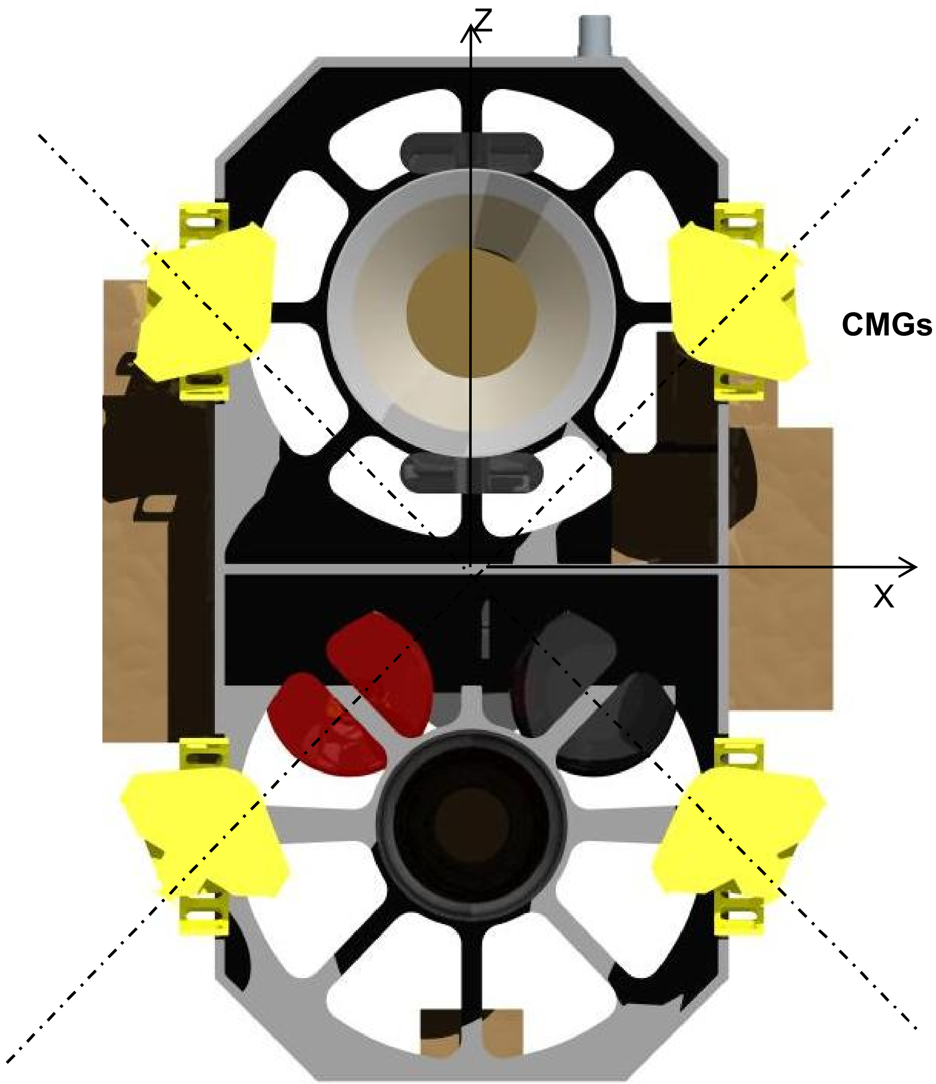


Configuration: Avionics Boxes





Configuration: CMG locations



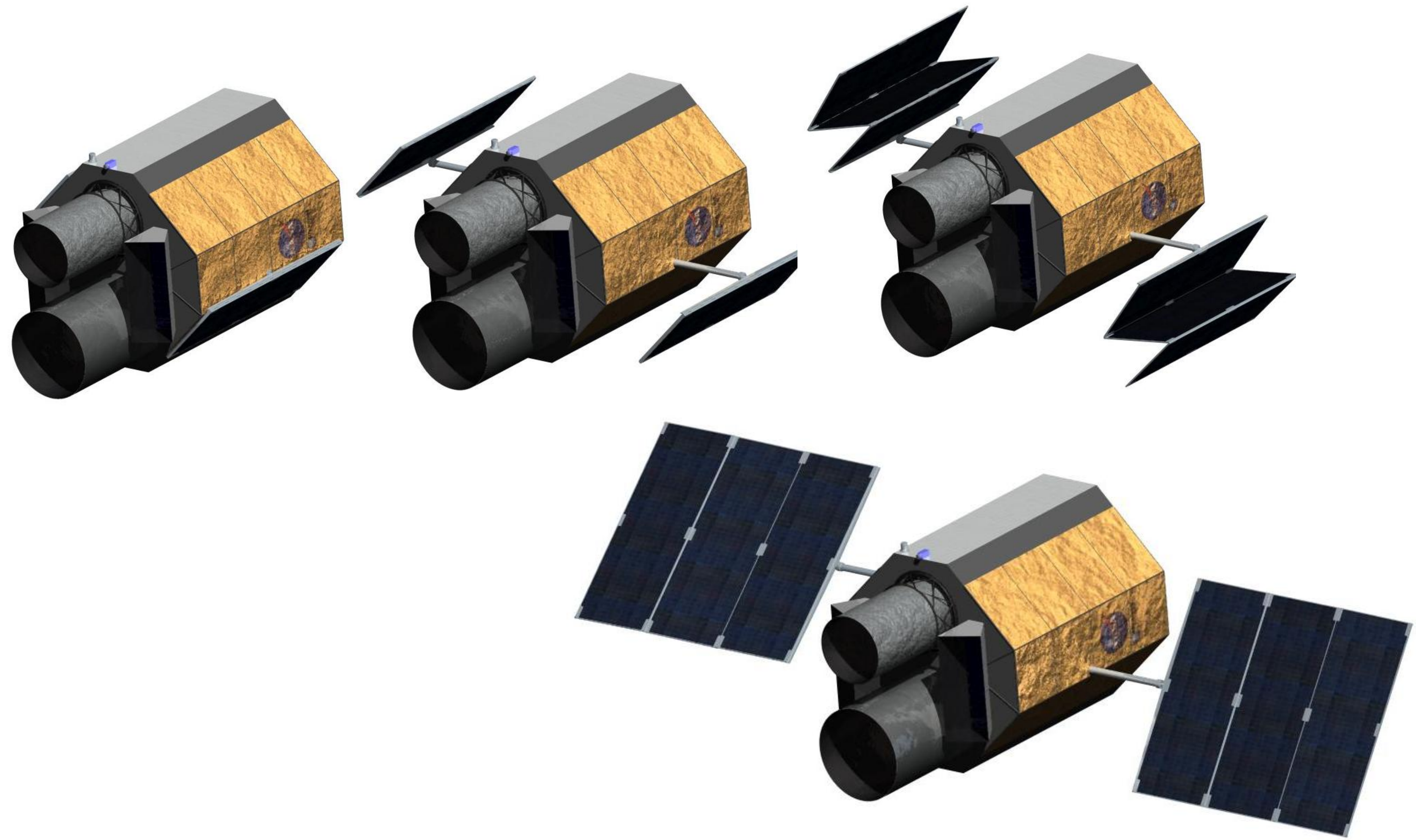
CMGs 90 deg apart

I_{xx}=3092 kg*m^2

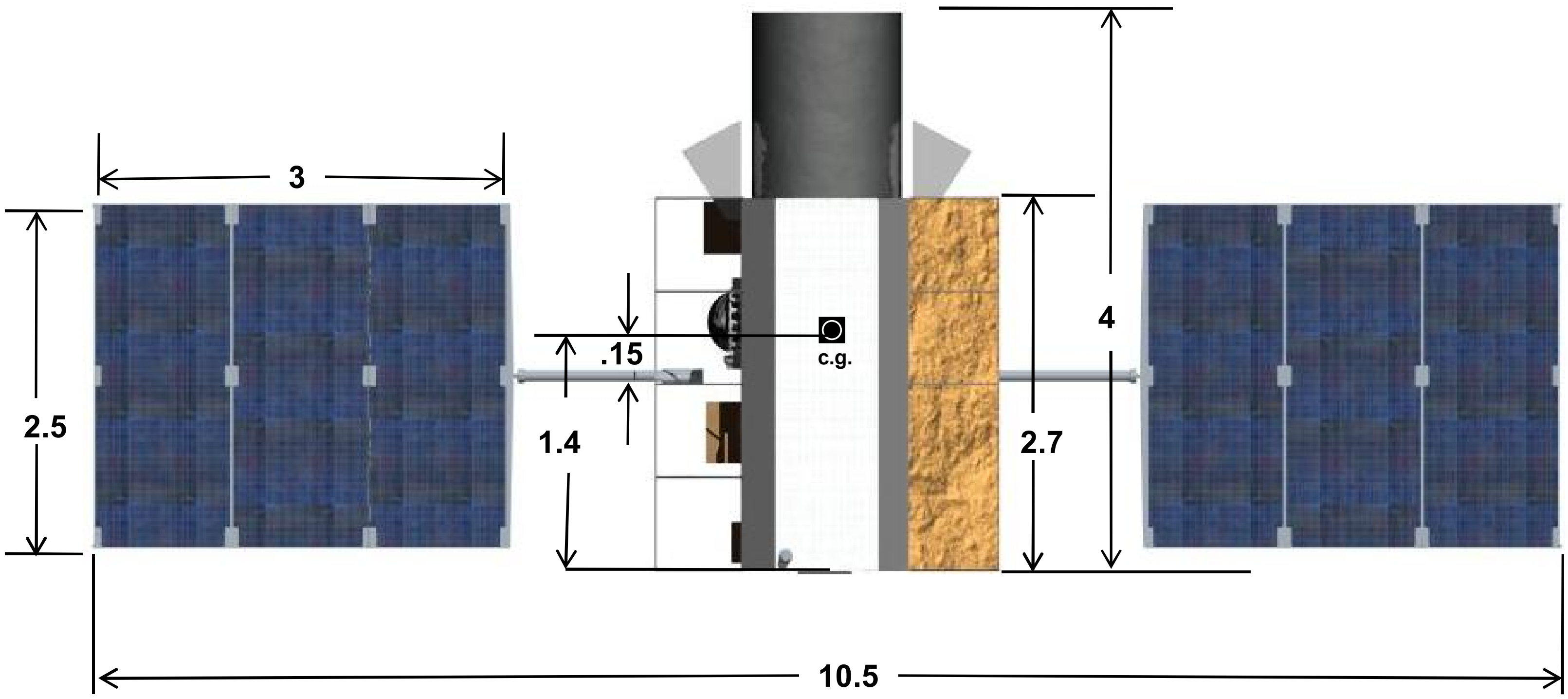
I_{yy}=1900 kg*m2

I_{zz}=3317 kg*m2

Configuration: Array deployment



Configuration



Mass Properties

Mass Properties: GR&A and Results

- **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			Qty	Unit Mass (kg)	Total Mass (kg)
1.0	Structure				489.00
2.0	Propulsion				15.50
3.0	Power				169.52
4.0	Avionics/Control				425.94
5.0	Thermal Control				32.70
6.0	Growth				339.80
	6.1	Structure	30%		146.70
	6.2	Propulsion	30%		4.65
	6.3	Power	30%		50.86
	6.4	Avionics/Control	30%		127.78
	6.5	Thermal	30%		9.81
Dry Mass					1472.47
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
9.0	Propellant				137.26
Gross Mass					2753.83

GN&C: GR&A

- **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 <u>after</u> 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**

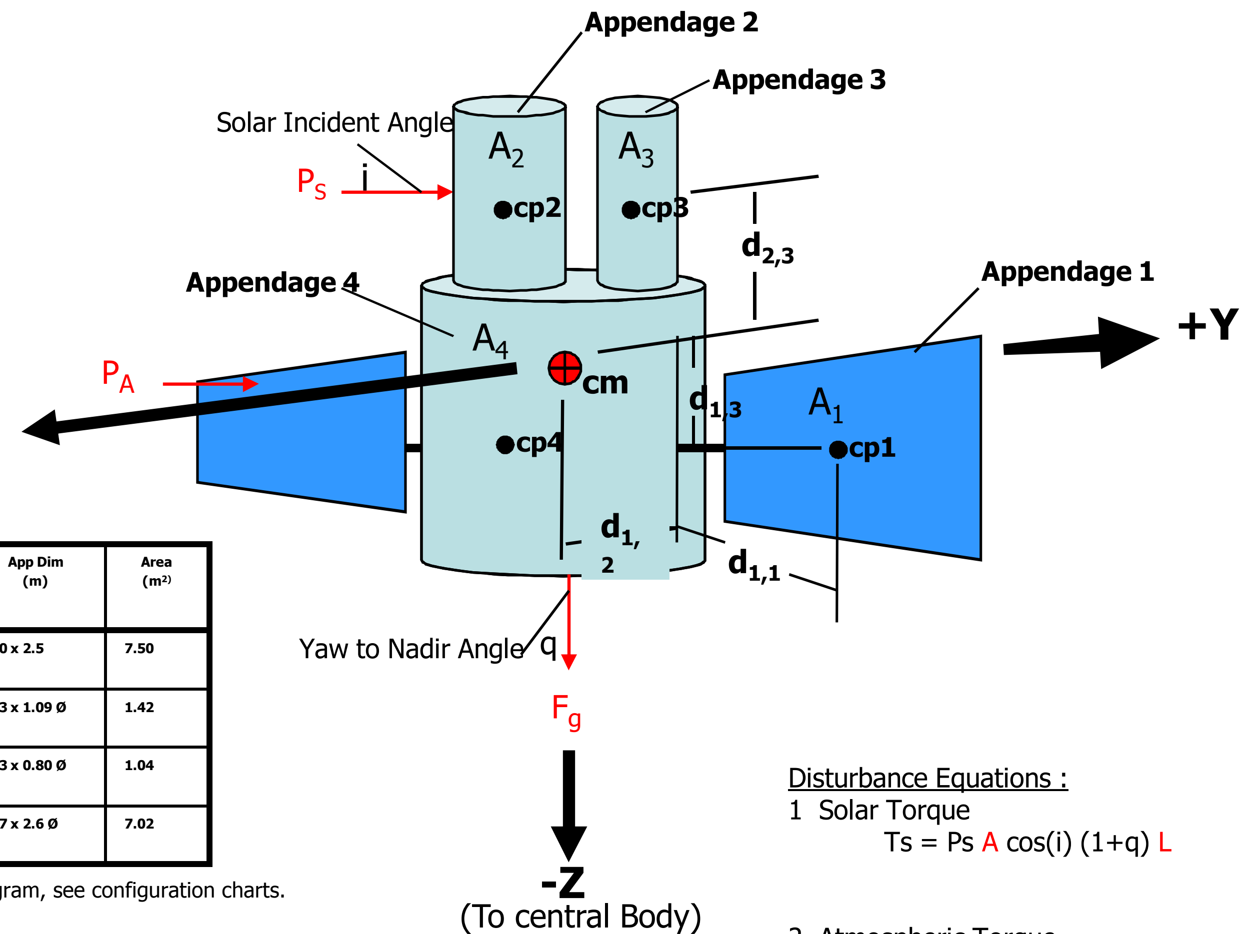
- **Trade between Reaction Wheels and CMG**
  - EDGE already did Reaction Wheel vs RCS
  - Trade using a CMG and RW combinations
    - CMG used for the fast slew requirement
    - RW used for every thing else (slow slews, station keeping, dithers)
  - Trade using Ball Aerospace Worldview CMG alone

- **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

GN&C: ACS Tool Inputs

I_{xx} = 3317 kgm^2
I_{yy} = 3092 kgm^2
I_{zz} = 1900 kgm^2



App(n)	dn1-y (m)	dn2-x (m)	dn3-z (m)	App Dim (m)	Area (m²)
	cp to cm				
1 - SA	3.50	0.0	-0.15	3.0 x 2.5	7.50
2 - WFS	-0.624	0.55	1.95	1.3 x 1.09 Ø	1.42
3 - WFI	0.620	0.40	1.95	1.3 x 0.80 Ø	1.04
4 - SC	0.0	1.30	-0.05	2.7 x 2.6 Ø	7.02

Dimensions are taken form configuration diagram, see configuration charts.

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
$Ts = Ps\ A \cos(i)\ (1+q)\ L$

2 Atmospheric Torque
$Ta = ½\ pV^2\ C_d\ A\ L$

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

4 Gravity Gradient Torque
$Tg = 3u\ /\ 2R^3\ |\ I_z - I_{x,y}\ |\ \sin 2q$

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 using1 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

GN&C: Results

Ball Aerospace Worldview CMG

- 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)

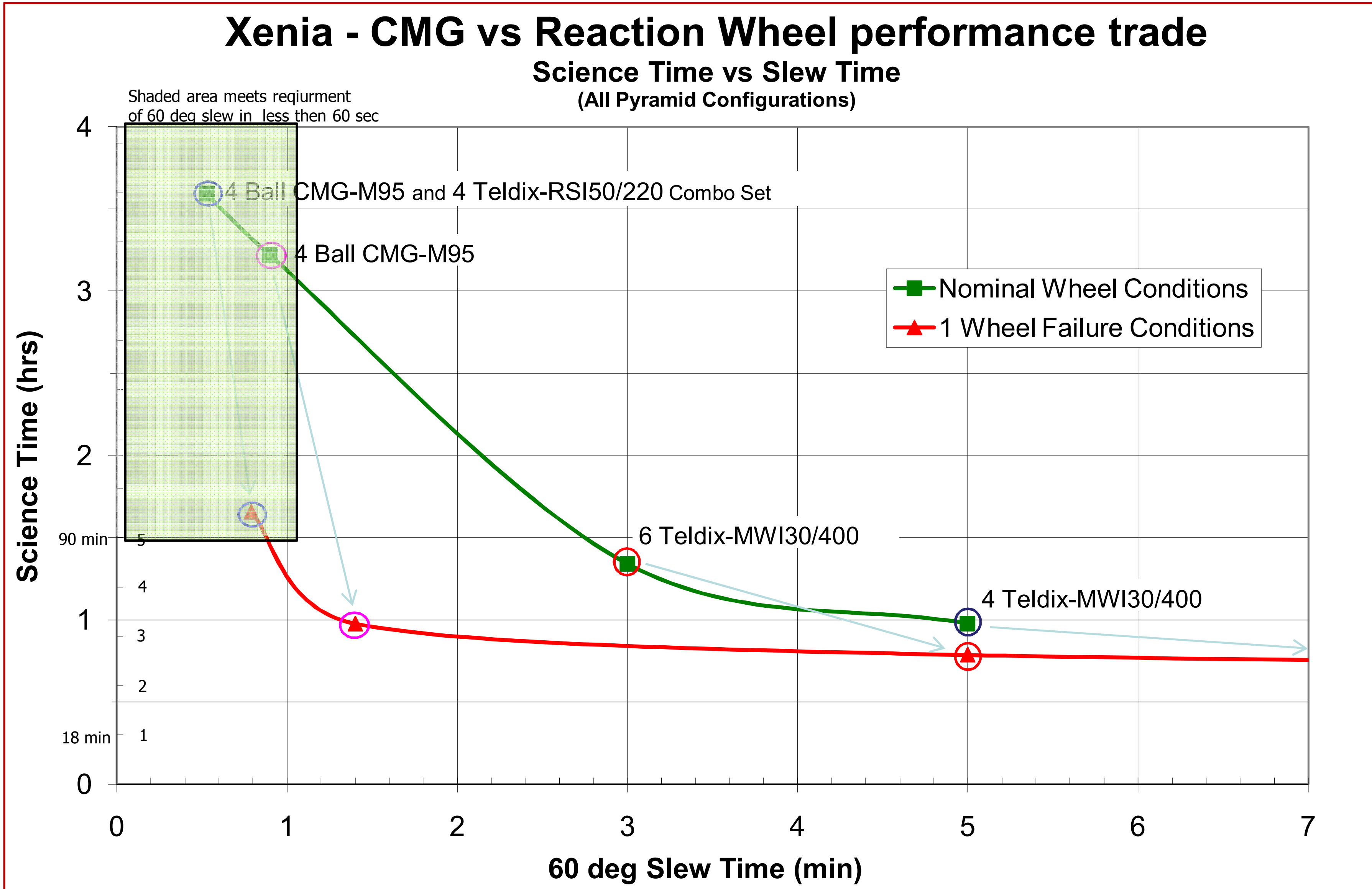
GN&C: Results

Performance Trade Table

Number of Wheels	**Source and Type** (All Pyramid Configurations)	Nominal Wheel Condition		1 Wheel Failure Condition		Masses		Power
		Slew Time (min)	Science Times (hr)	Slew Time (min)	Science Times (hr)	Total Wheel mass (kg)	Total System mass (kg)*	Total System Power (W)
8	Ball Aerospace CMG-M95 and Teldix RSI 50-220/45	0.53	3.59	0.79	1.65	167.2	334.4	820
4	Ball Aerospace CMG-M95	0.9	3.22	1.4	0.98	130.8	261.6	220
6	Teldix MWI 30-400/37	3	1.34	5	0.79	91.8	183.6	1800
4	Teldix MWI 30-400/37	5	0.98	15	0.69	61.2	122.4	1200

*Total system mass includes isolation mounts and electronics

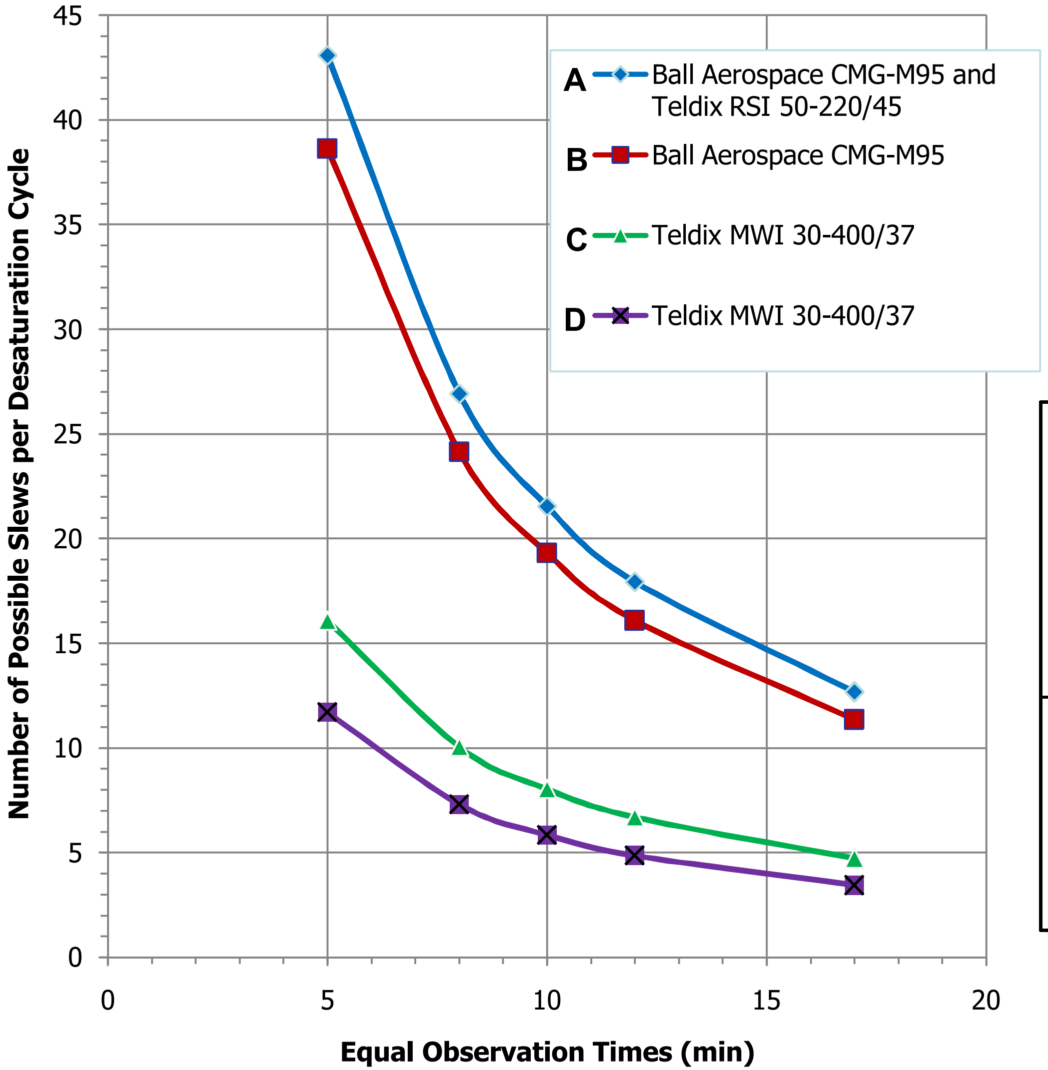
GN&C: Results



Xenia - CMG vs Reaction Wheel performance trade
Science Time vs Slew Time
(All Pyramid Configurations)
Shaded area meets reqiurment
of 60 deg slew in less then 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
Science Time (hrs)
90 min
18 min
60 deg Slew Time (min)
0
1
2
3
4
5
6
7

GN&C: Results

Number of slews possible per de-saturation cycle



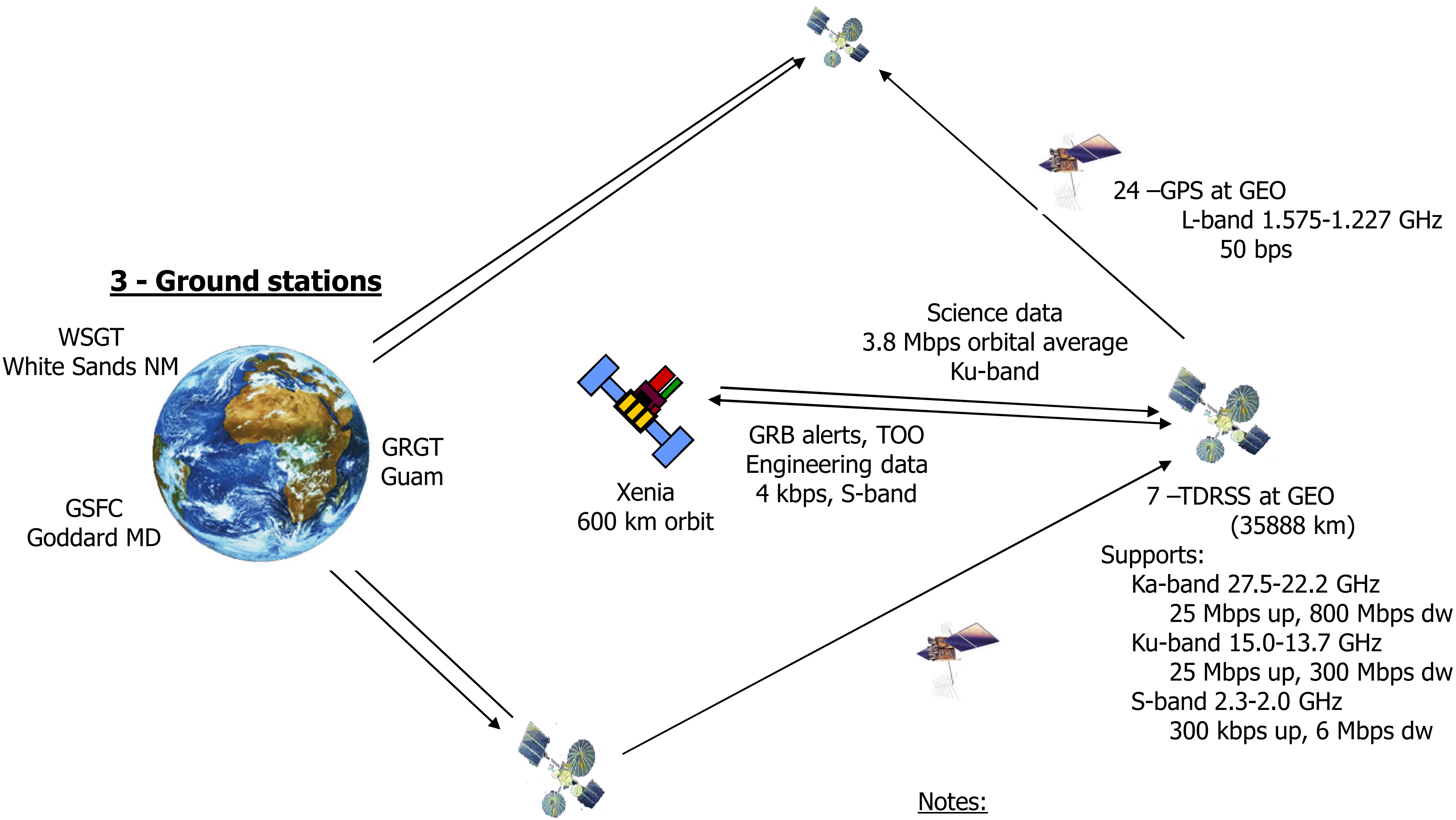
Total tob (min)	Number of slews possible per de-saturation cycle given equal observation times			
	System Trades			
	A	B	C	D
17.00	13	11	5	3
12.00	18	16	7	5
10.00	22	19	8	6
8.00	27	24	10	7
5	43	39	16	12

Avionics

Avionics: GR&A

- 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



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

Avionics: Results

Astrionics	Mass (kg)	Power (W)
Attitude Control System	320	240
Command and Data System	22	107
Instrumentation and Monitoring	5	7
Communications System	45	203
Avionics Cabling	34	N/A
Totals	**426**	**557**

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)

Power Masses		Qty		169.52 kg
	PDU	1	12.48 kg	12.48 kg
5 m, redundant	Cabling	1	5.59 kg	5.59 kg
	ARU	1	31.35 kg	31.35 kg
	Solar Array	1	32.82 kg	32.82 kg
2880 Wh	Secondary Battery	2	11.66 kg	23.32 kg
	Battery Charger	1	63.97 kg	63.97 kg

Thermal

Thermal Control: GR&A

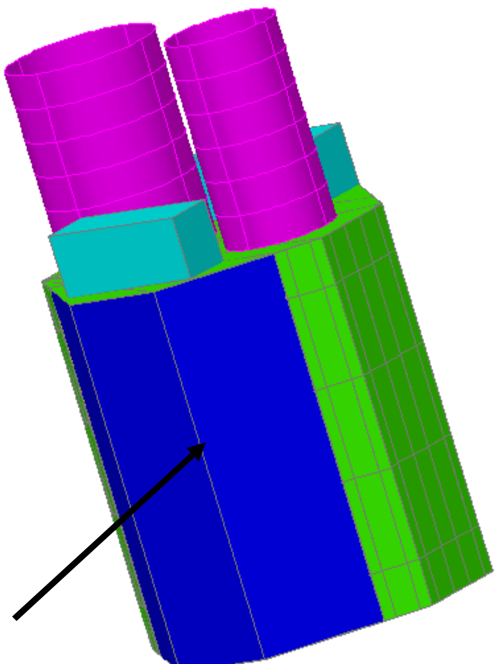
- **Primary objective is to develop a passive thermal design concept for the Xenia spacecraft. Heat rejection of instrument and subsystems power is accomplished by spacecraft radiators, closeout MLI, heat pipes and silverized Teflon tape.**
  - Circular orbit, altitude 600 km
  - 5° inclination, βmax = 33.5 °, βmin = 0 °
  - 3-axis stabilized, 45° sun avoidance angle

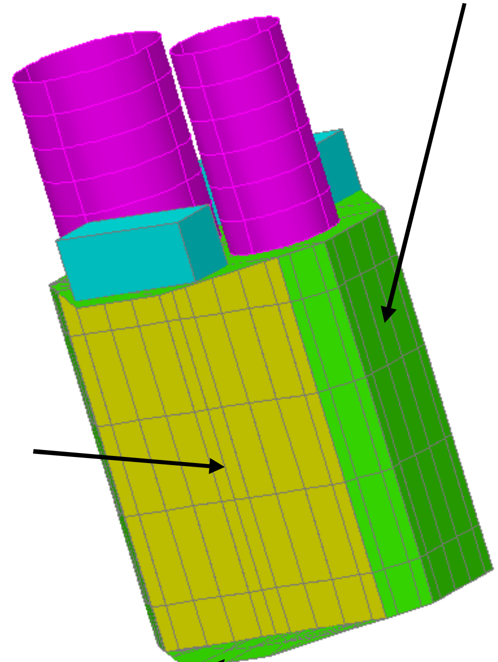
- **Spacecraft bus outer structural panels double as radiators**
  - Spacecraft Bus composed of Aluminum plate (thickness varies) for optimal thermal conductivity.
  - Radiator panels located on the sides and bottom of the spacecraft

Thermal Control: Design

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
α/ε=.2/.7 (Degraded)



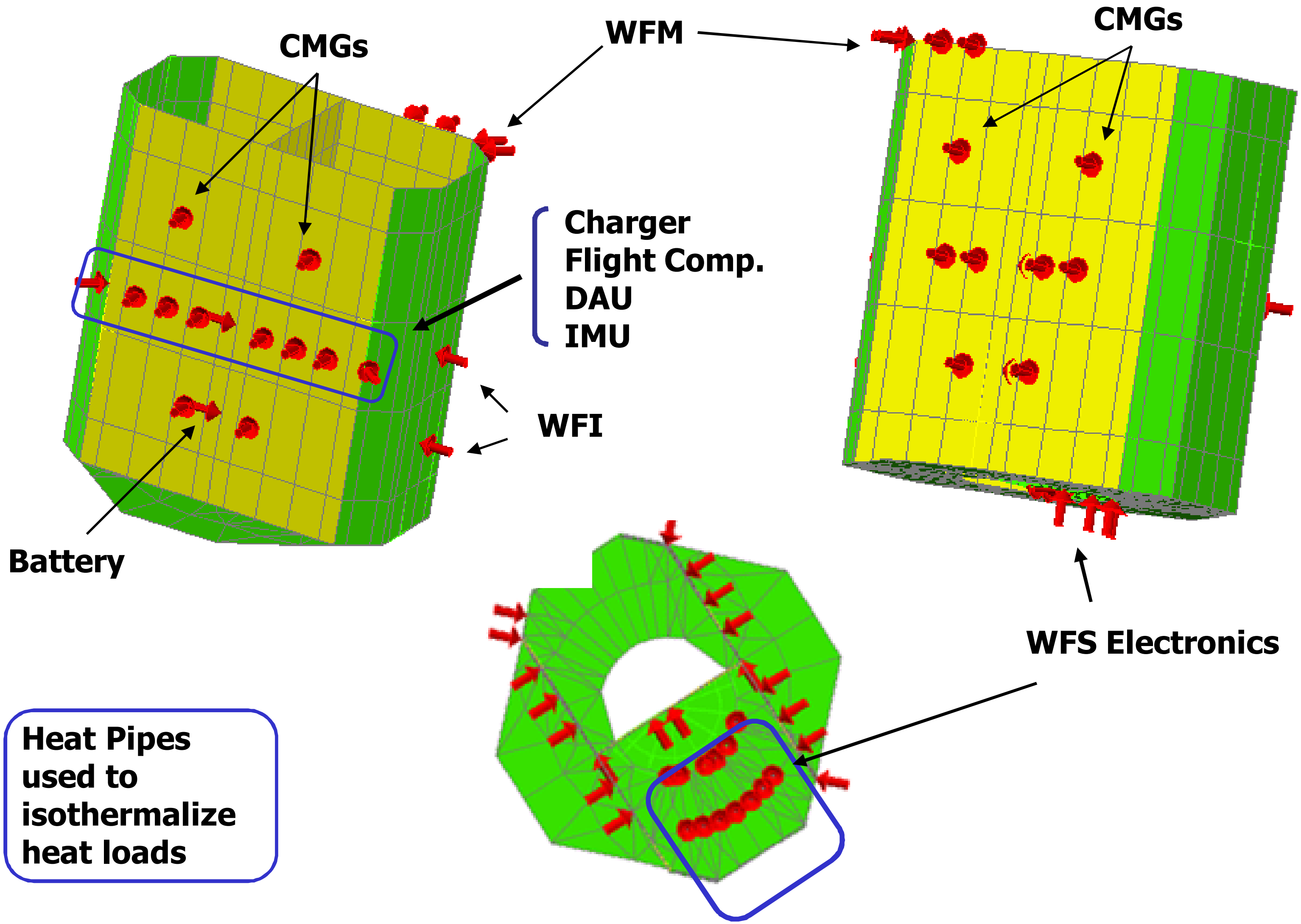


Interior surfaces
Bare Aluminum

Closeout
Blankets, 2 layer
Aluminized Teflon
α/ε=.14/.62

Bottom Panel Radiator
α/ε=.2/.7 (Degraded)

Thermal Control: Analysis



Heat Pipes used to isothermalize heat loads

Thermal Control: Analysis

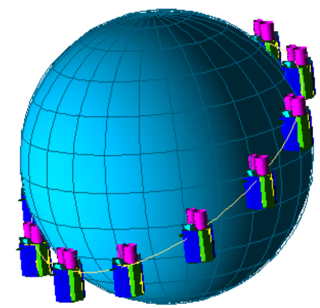
Component	Total Power(w)
ACS (Attitude Control Sytem)	**140.00**
Sun Sensor Electronics Unit	6.00
Star Tracker WFOV	4.00
Star Tracker NFOV	20.00
Magnetometers - 3 axis each	4.00
IMU Assy	**20.00**
CMG Controllers (4)	**60.00**
Control Moment Gyro	**60.00**
Magnetic torqueres	10.5
CDS (Command and Data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

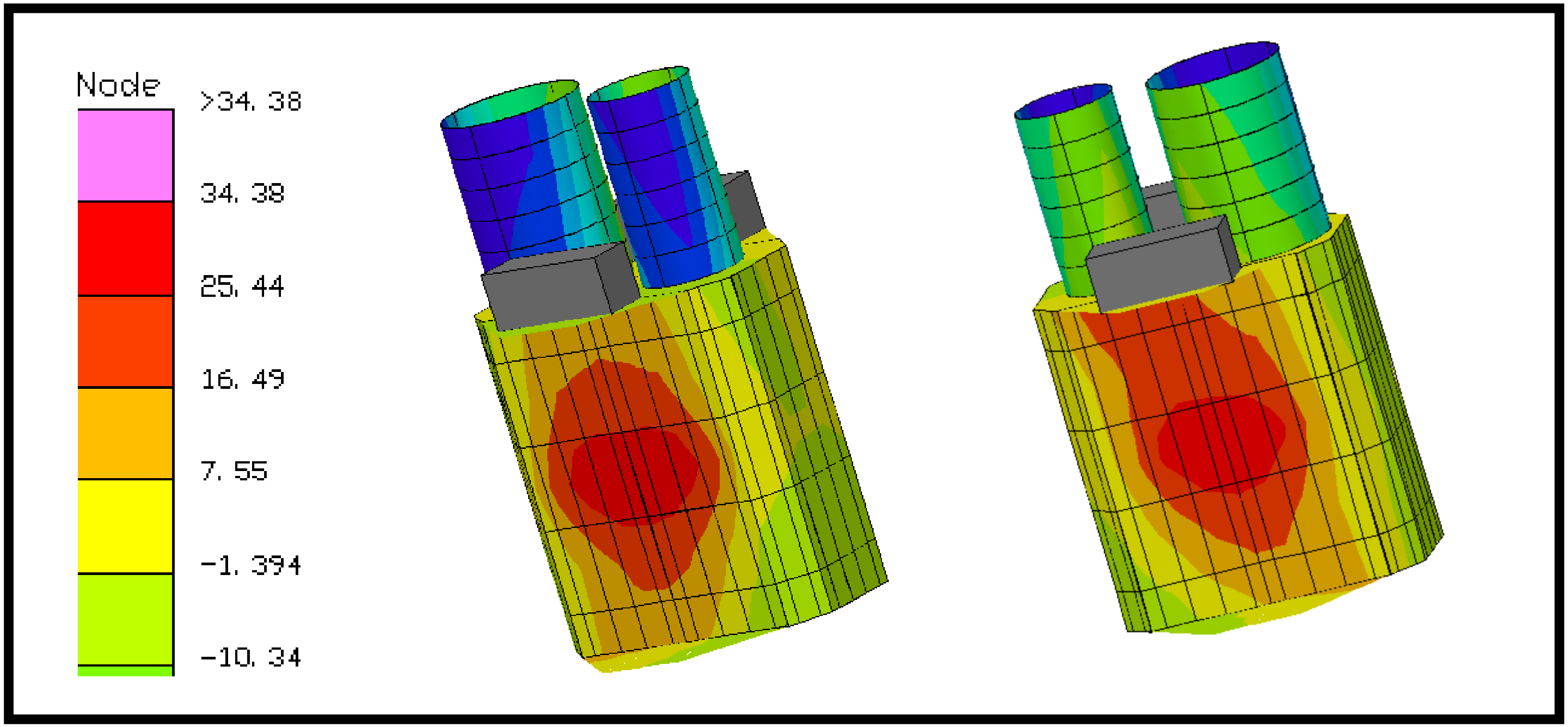
Component	Total Power(w)
Science Instruments	
WFS	**909.00**
Detector head	0.00
FEE	23.00
Filter wheel	10.00
Mirror and casing	150.00
Digital electronic box	**135.00**
Control/Power Electronic box	**103.00**
Crysyatic cooler	0.00
2ST Drive Electronics box	**213.00**
2ST Drive Electronics box	**399.00**
ADR Analog Control box	**59.00**
WFI	**60.00**
Camera head and FEE	30.00
Filter wheel and shutter	20.00
TEC	35.00
Mirror and casing	40.00
Analog Electronic box	**25.00**
Control/Power Electronic box	**35.00**
WFM	**92.00**
Detector	48.00
ICU Electronic box	**92.00**

Total Spacecraft Heat Dissipation considered in analysis = 1776W

Thermal Control: Results

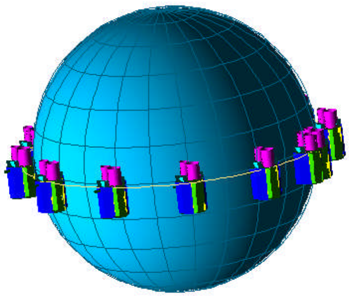
- Spacecraft temperatures are -10° to 34° C
- Heat dissipation = 1776W
- β=33.5°
- Sun Angle = 90°
- Orbital Average Temperatures (°C)

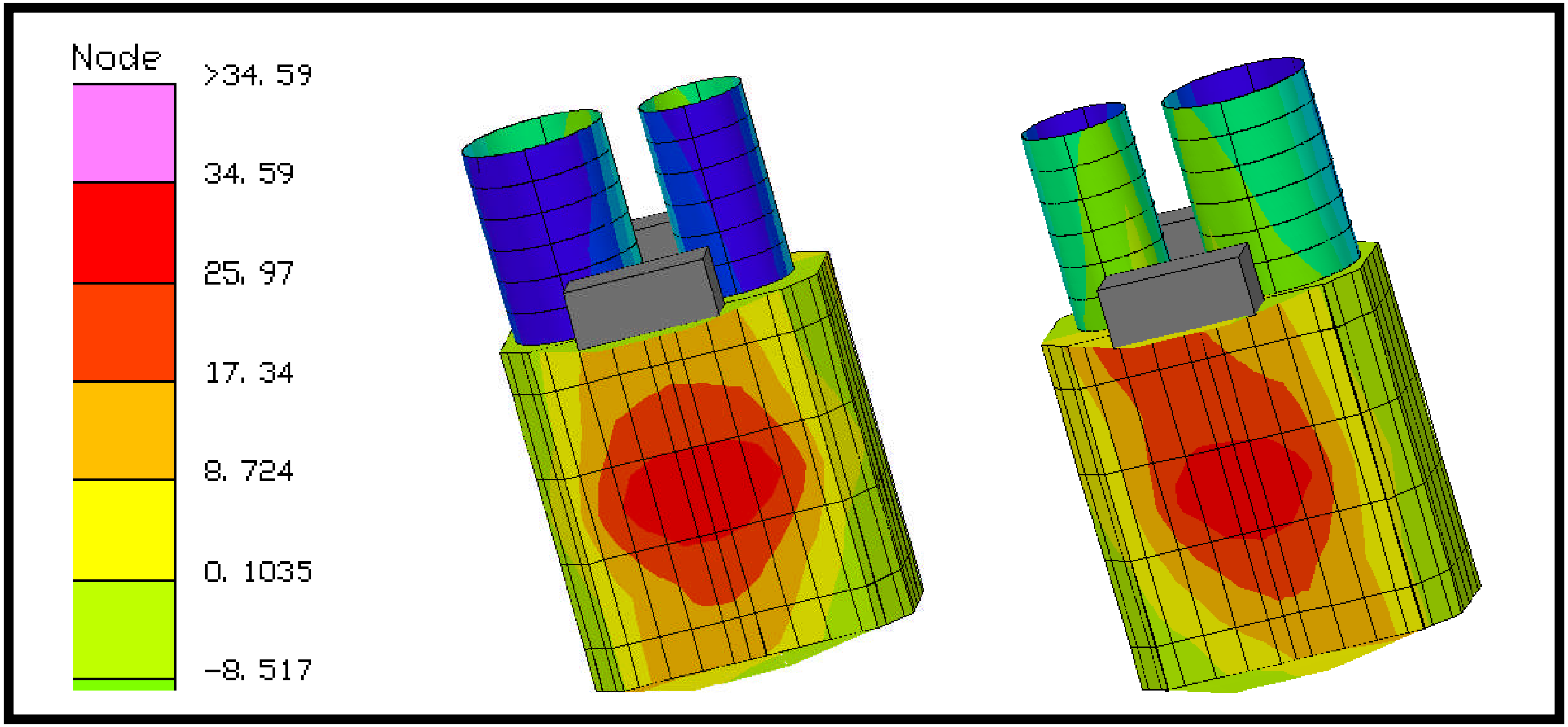




Thermal Control: Results

- Spacecraft temperatures are -9° to 35° C
- Heat dissipation = 1776W
- β=0°
- Sun Angle = 90°
- Orbital Average Temperatures (°C)





Thermal Control: Results

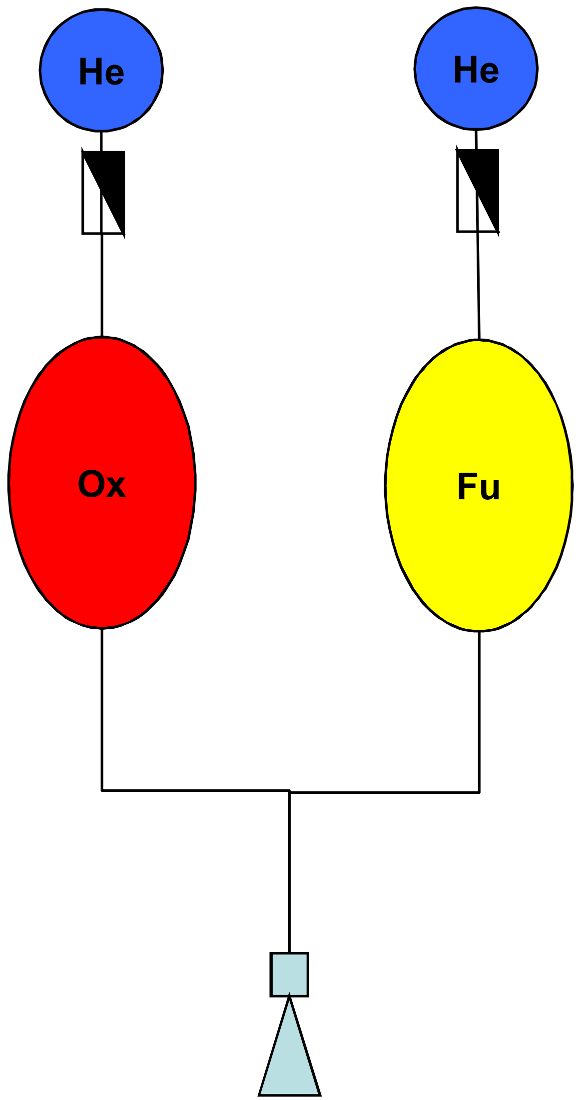
Component	Units	Mass (kg)
Instrument Light Shield & Baffle MLI	15 m^2	5.0
Closeout blankets	15 m^2	7.5
Heat Pipes	4 @ 1.3 kg each	5.2
Silverized Teflon Tape	25@ .6 kg/m^2	15.0
Total		32.7

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

Propulsion: System Schematic



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 = 0.62m X 0.20 m dia.
MEOP = 240 psia

Propulsion: Mass Statement

WBS Element - Descent Stage				Qty	Unit Mass (kg)	Total Mass (kg)
2.0	**Propulsion**					**15.50**
	2.1	Main Engines		1	5.00	5.00
	2.2	Fuel Tank		1	3.30	3.30
	2.3	Main Oxidizer Tank		1	3.60	3.60
	2.4	Pressurization Tank		2	1.30	2.60
	2.5	Feed System		1	1.00	1.00
8.0	**Growth**					**4.65**
	8.3	Propulsion		30%		4.65
Dry Mass						**20.15**
9.0	**Non-Cargo**					**6.10**
	9.1	Propellant Residuals		1		5.74
		9.1.1	Fuel	1	2.17	2.17
		9.1.2	Oxidizer	1	3.57	3.57
	9.2	*Pressurant*				*0.36*
		9.2.1	Fuel	1	0.18	0.18
		9.2.2	Oxidizer	1	0.18	0.18
Inert Mass						**6.10**
Total Less Propellant						**26.25**
12.0	**Propellant**					**137.26**
	12.1	Main Fuel		1	51.83	51.83
	12.2	Main Oxidizer		1	85.43	85.43
Gross Mass						**163.51**

Structures

Structures: GR&A

- **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

Structures: Loads GR&A

- **Maximum Launch Loads for Falcon 9 payload**
  - 5.0 g along launch axis
  - 0.9 g lateral to launch axis

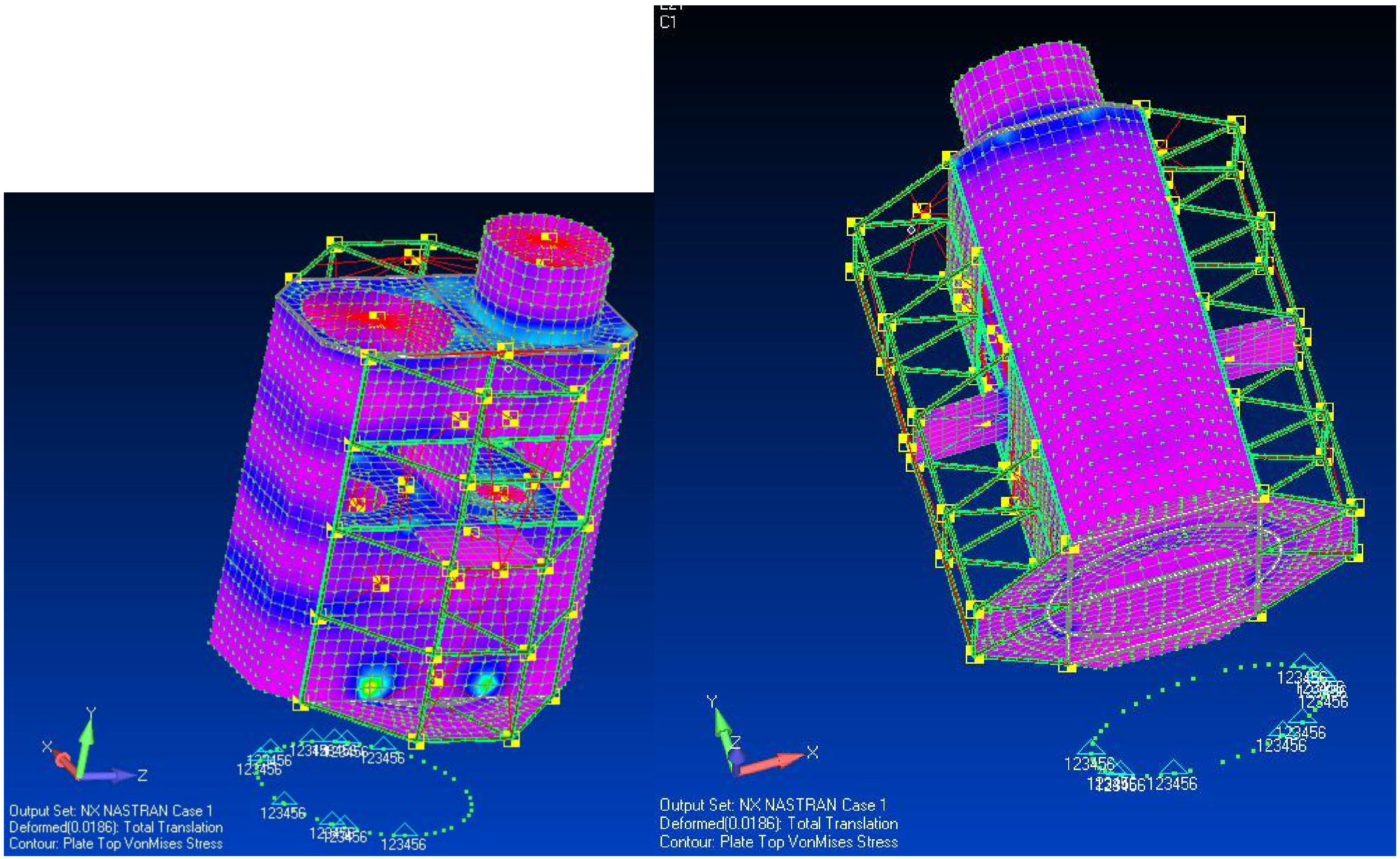
- **Load Set**
  - Axial plus lateral at 45 degree intervals around bus

- **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



Structures: Results

Structural Mass		Qty	Total	489* kg
Secondary	Solar Panel Structure Solar array dampers, actuators, and booms	2	30.5	61.0
Secondary	Propulsion	1	15 .0	15 .0
Secondary	Science Instruments	1	100.0*	100.0*
Primary	Spacecraft Bus	1	313.0*	313.0*

* Further optimization and analysis could decrease the structural mass of these components.

Conclusions

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

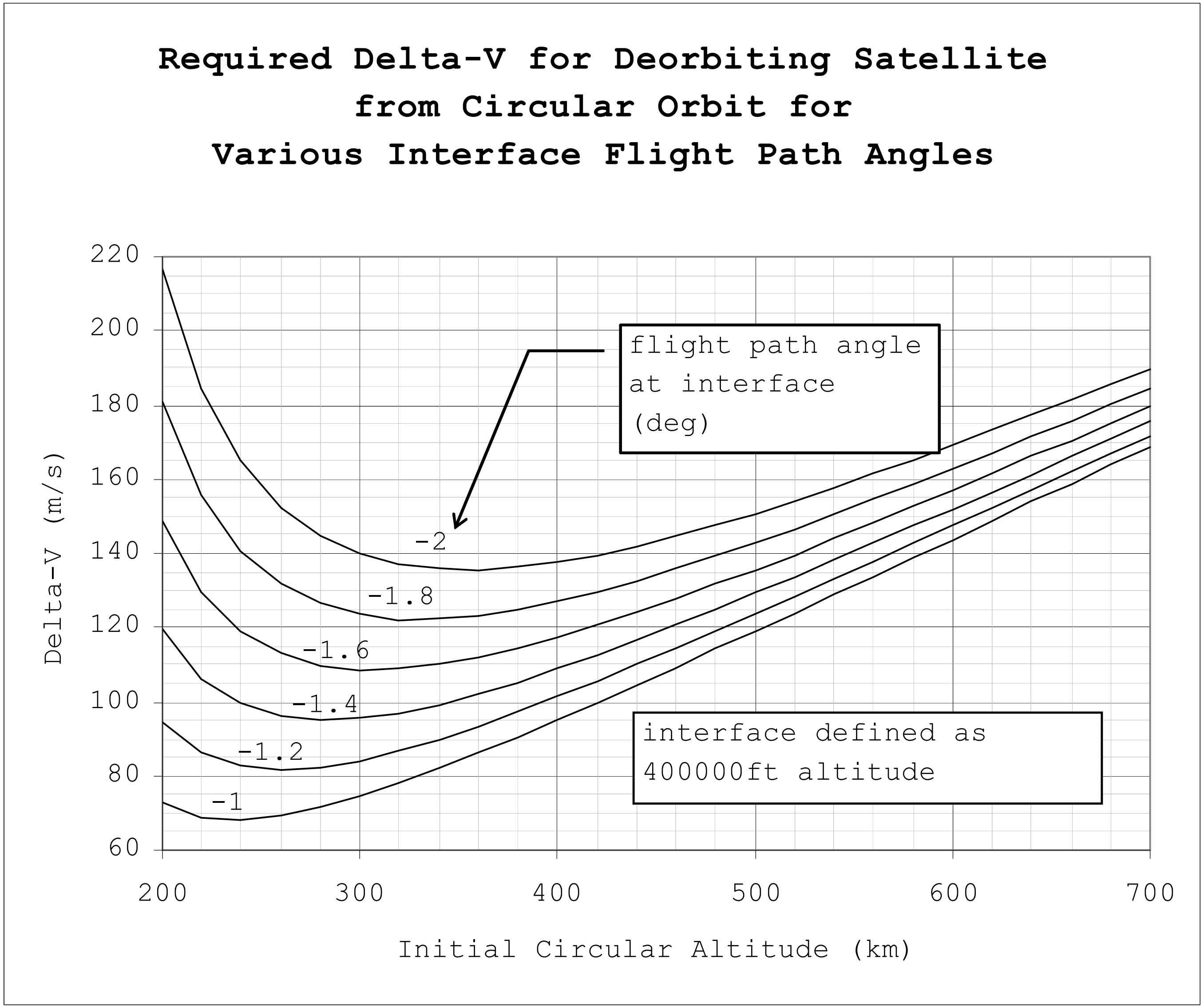
Mission Analysis: Orbital Lifetime Inputs

Model Parameters		
Atmosphere	NRL MSISE 2000	
Solar flux sigma value	2	
Rotating Atmosphere	no	makes calculations more conservative
Satellite Parameters		
Drag coefficient	2.2	
Drag area	24	m^2
Area exposed to sun	30	m^2
reflection coefficient	1	
Satellite mass	2100 – 2500	kg

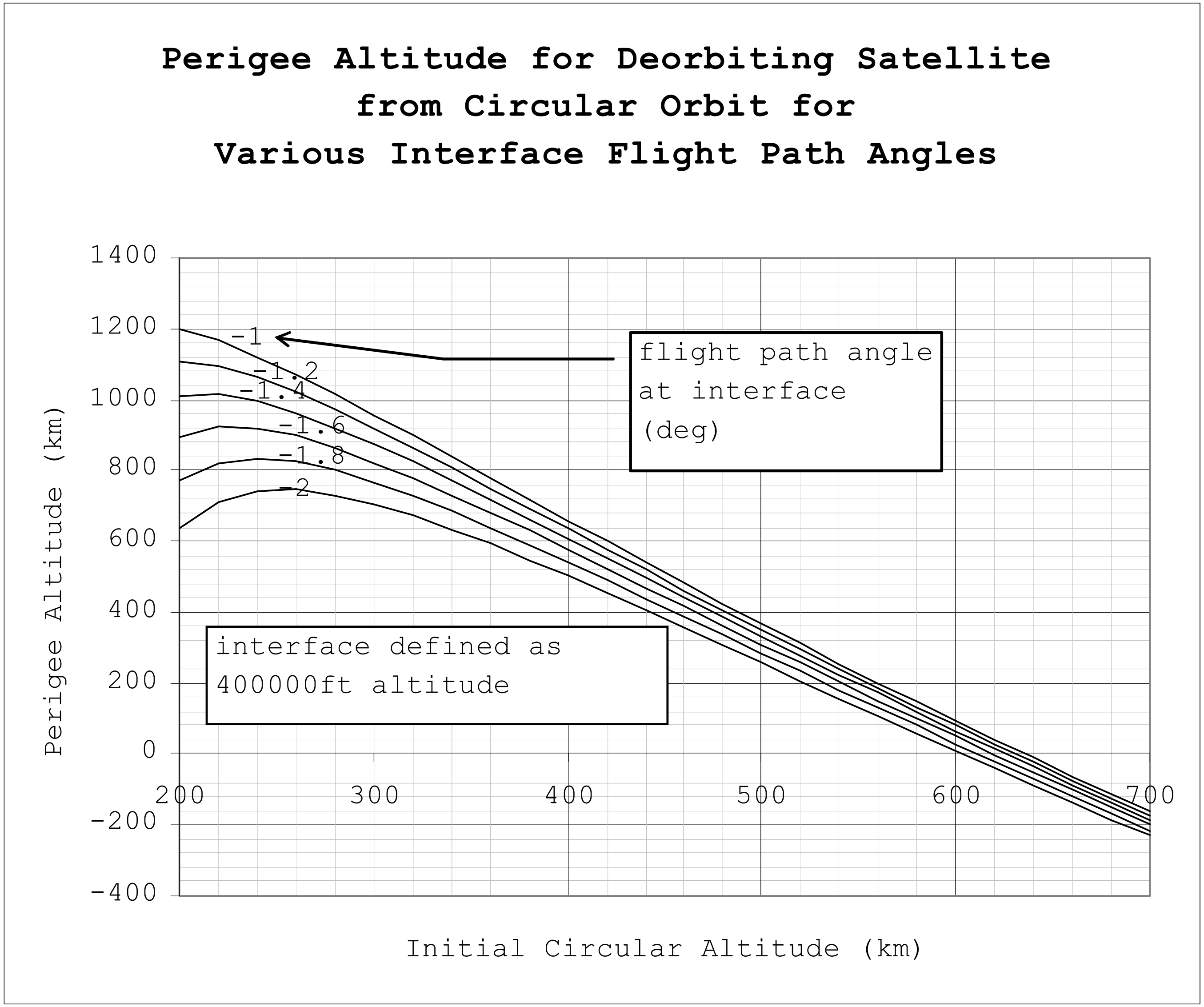
Mission Analysis: GR&A for Falcon9

- 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.*

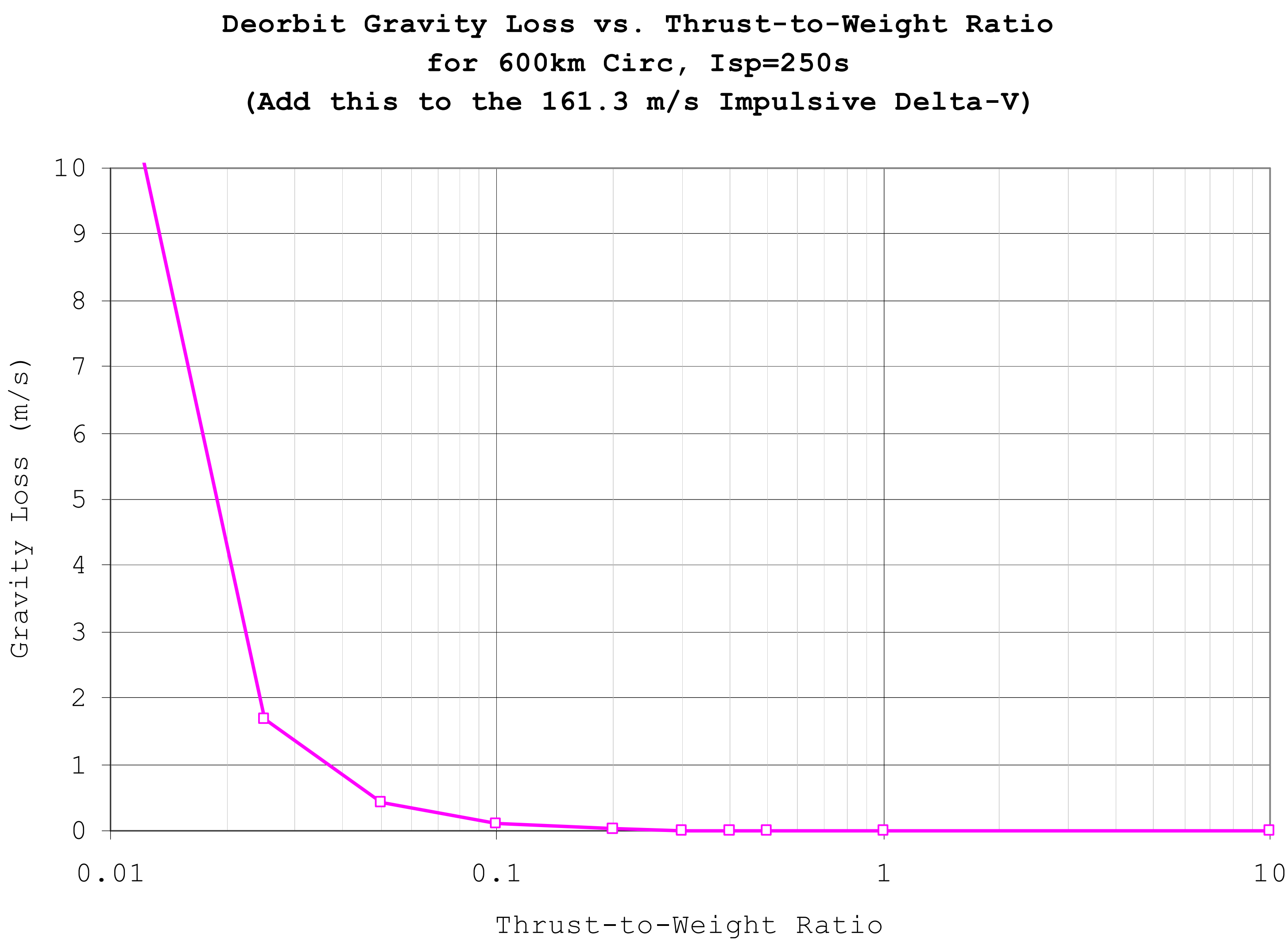
Mission Analysis: De-orbit



Mission Analysis: De-orbit

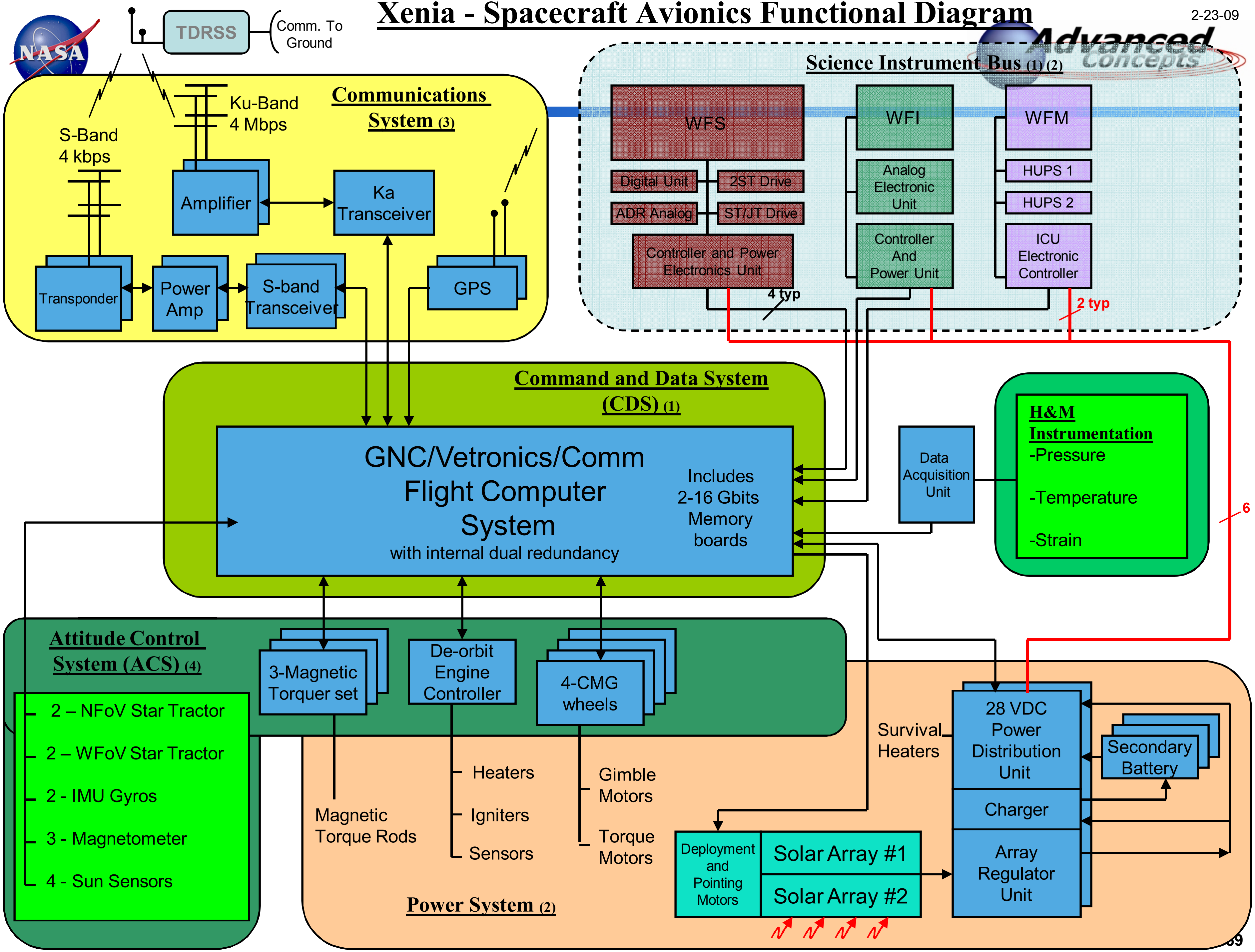


Mission Analysis: De-orbit



Xenia - Spacecraft Avionics Functional Diagram

2-23-09



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

Note: (~90 min) Desaturation period = 1 orbit	Units	3.317 Ixx kgm^2 (roll)	3.092 Iyy kgm^2 (pitch)	1.900 Izz kgm^2 (yall)
Disturbance Torques				
Solar Torques	Nm	8.195E-06	1.245E-06	8.958E-07
Atmospheric Torques	Nm	1.707E-03	1.153E-03	1.703E-04
Gravity Torques	Nm	2.604E-03	2.190E-03	4.134E-04
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**
Attitude Corrections				
Correction Torque (.75' drift)	Nm	0.0417	0.0389	0.0239
Correction Torque in (1.25' drift)	Nm	**0.0250**	**0.0233**	**0.0143**
Correction time (.75' drift)	sec	8.333	8.333	8.333
Correction time (1.25' drift)	sec	**13.88**	**13.88**	**13.88**
Correction Momentum (both drifts)	Nms	0.174	0.162	0.099
Correction Cycles per desat period (.75' drift)	#	254	240	155
Correction Cycles per desat period (1.25' drift)	#	**177**	**168**	**112**
Momentum per desat period (.75' drift)	Nms	44.11	38.86	15.42
Momentum per desat period (1.25' drift)	Nms	**30.74**	**27.20**	**11.14**
Maneuvers per desaturation Period				
1 - Fast Slew Torque (60deg/45sec)	Nm	6.861	6.396	3.930
1 - Fast Slew Torque (60deg/60sec)	Nm	3.860	3.598	2.211
1 - Fast Slew Torque (60deg/90sec)	Nm	1.715	1.599	0.983
1 - Slow Slew Torque (100deg/100sec)	Nm	2.316	2.159	1.326
1 - Fast Slew Momentum (60deg/45sec)	Nms	154.38	143.91	88.43
1 - Fast Slew Momentum (60deg/60sec)	Nms	115.79	107.93	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

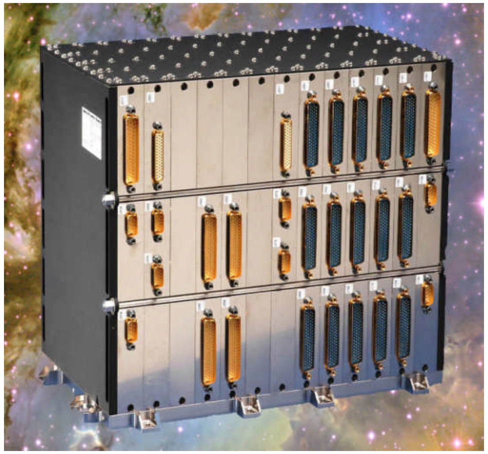
Recommended design parameters

Ball Aerospace M95 CMG - 129 Nms each wheel x 2.31 for a 4 wheel pyramid = 298 Nms.

Collective torque capability = 6.1 Nm

Avionics – Flight Computer

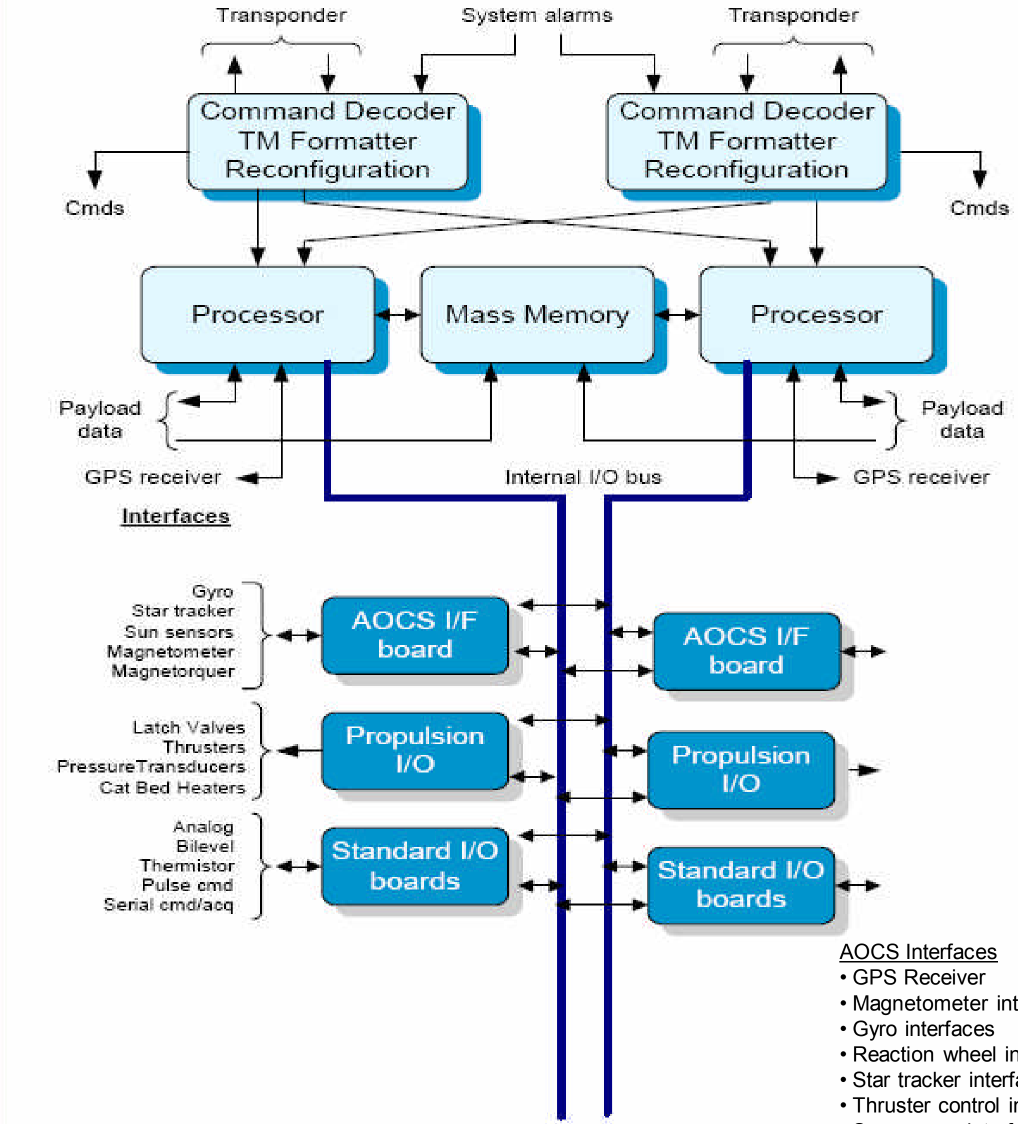
Saab Ericsson Space (Sweden) – Spacecraft Management Computer



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

Avionics - Communications

T-720 Transmitter

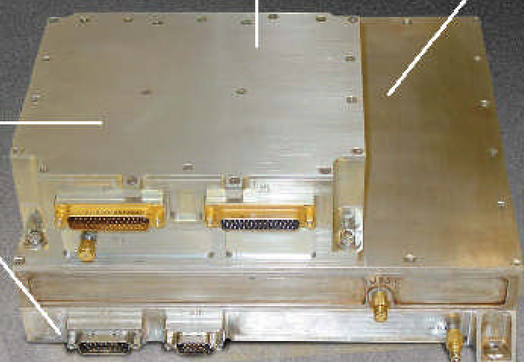
Ku-Band TDRSS Transmitter

Interface – The interface accepts separate I&Q data and clock inputs via a high-speed Low Voltage Differential Signaling (LVDS) interface. A redundant set of I&Q data and clock inputs are also provided to facilitate satellite data source cross-strapping. NRZ-L to NRZ-M data conversion is performed and the data is processed in parallel encoders designed for rate 1/2, k=7 convolutional coding in compliance with the 530 Space Network User's Guide (SNUG). The unit also includes a pseudorandom test pattern mode, which allows for bit error rate testing of the transmitter through the TDRSS return link.

PDRO - Dual phase locked dielectric resonator oscillators are utilized to generate the necessary LO references to up-convert the modulated spectrum to Ku-Band. The LO's are phase locked to highly stable, low phase noise, temperature compensated crystal oscillators (TCXO).

Modulator/Upconverter – Data is Offset Quadrature Phase Shift Keyed (OQPSK) directly onto a carrier with a phase and amplitude imbalance of less than 4° and ±0.375 dB, respectively.

SSPA - Modularized high efficiency Ku-Band gain stages implemented with GaAs FET technology are cascaded to provide a minimum output power of +40 dBm over a temperature range of -25°C to +65°C.



L3 communications
Cincinnati Electronics

A New Generation of Performance

The L-3 Communications Cincinnati Electronics (L-3 CE) Ku-Band Transmitter is a Tracking and Data Relay Satellite System (TDRSS) Compatible Transmitter, designed to utilize the TDRSS Ku-Band Single Access (KuSA) Return Service. The transmitter combines state-of-the-art design techniques with proven reliability utilizing heritage circuitry and algorithms.

Specifications T-720

INPUT CHARACTERISTICS

Data A (I&Q)	LVDS
Clock A	LVDS
Data B (I&Q)	LVDS
Clock B LVDS	
Primary/Redundant Cmd	28V Pulsed CMD
FEC On/Off	RS-422
PN Test Pattern On/Off	RS-422

POWER REQUIREMENTS

Input Voltage	+28 Vdc
Input Power	< 114 Watts (max.)
Peak Inrush	15A max < 50 mS

OPERATING MODES

OQPSK	I Channel (up to 75 Mbps w/ FEC)
	Q Channel (up to 75 Mbps w/ FEC)
	FEC (R=1/2, k=7)
	NRZ-L to NRZ-M

Internally Generated Pseudorandom Test Pattern
Data Source A or Data Source B

CONNECTORS

RF- Female SMA according to MIL-C-39012
15 pin Filtered D-Sub for Power
22 pin High Density D-Sub for Telemetry
44 pin High Density D-Sub for Primary Input Signals
44 pin High Density D-Sub for Redundant Input Signals

OUTPUT CHARACTERISTICS

RF Pout	10 Watts min (EOL)
RF Frequency	Ku-Band, 14.8-15.2 GHz selectable; factory preset)
RF Phase Noise	< 2° RMS
Frequency Source	Low Phase Noise TCXO
Spectral Emissions	NTIA Compliant
RF Power TLM	0-5V Analog
Secondary V TLM	0-5V Analog
Temperature TLM	Thermistor
CMD Status TLM	RS-422

RADIATION

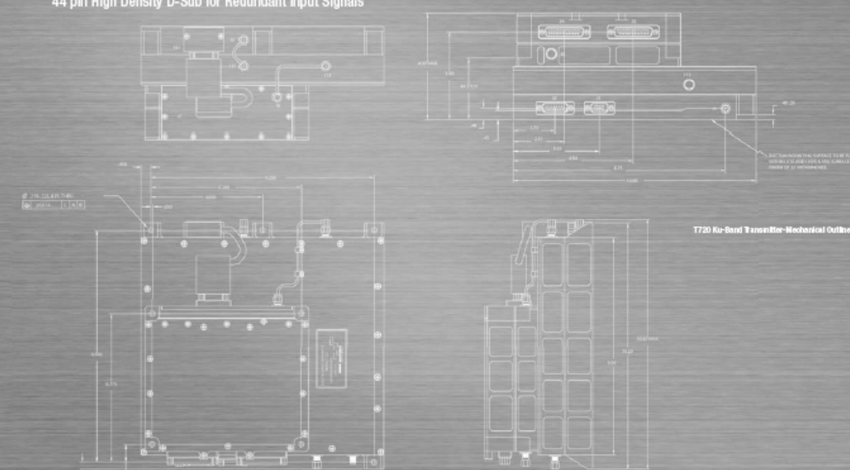
Total Dose	60 krad
Latch-up	Immune

ENVIRONMENTAL SPECIFICATIONS

Temperature	-40°C to +85°C (non-operating)
	-25°C to +65°C (operating)
Vibration	Random; 14.1 grms, 3-axis
Pyro Shock	2800 g's

PHYSICAL

Footprint	10.00" (W) x 9.0" (D) x 4.75" (H)
Weight	<12 lbs. (max)



Space Electronics ~ 7500 Innovation Way ~ Mason, Ohio 45040-9699 U.S.A.
Tel: 1-800-852-5105 ~ Fax: 513-573-6767 ~ Visit our web site at www.L-3Com.com/CE ~ e-mail: Larry.Dobbs@L-3Com.com

Cleared by DoD/OSR for public release under 07-S-1089 on May24, 2007

AEROASTRO

Modular S-Band Radio

Receiver - can be used stand-alone

Interface/Power Controller

Transmitter

The AeroAstro Modular S-Band Radio System is a miniature software/FPGA based radio providing full NASA/DSN, 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.

- SGLS, STDN 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 Mbps
- Receiver available for stand-alone use

Making Space For Everyone™

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) \
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 (2µsec 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)

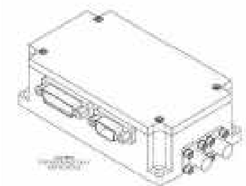
Flight Heritage of AeroAstro Radios

ALEXIS

HETE

MOST

NASA NM/ST-5



Receiver showing connectors

AEROASTRO
20145 Ashbrook Place
Ashburn, VA 20147
info@aeroastro.com
www.aeroastro.com

p: 703.723.9800
f: 703.723.9850

GN&G – Attitude Sensors

AeroAstro

Miniature Star Tracker

MST - Horizontal View

MST - Vertical View

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 4^{th} 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.

Making Space For Everyone™

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

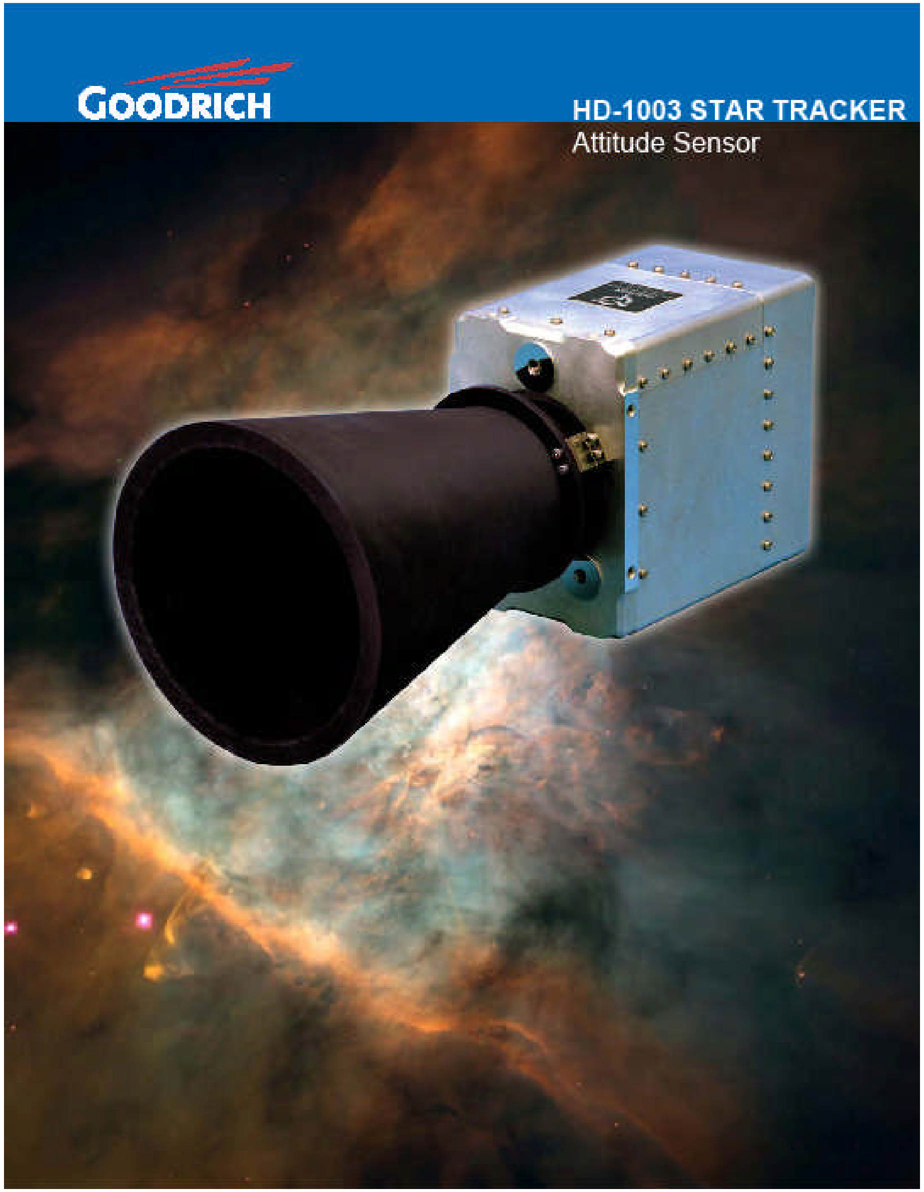
Radiation Tolerance: Up to 30 krad(Si), more with shielding

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

GN&G – Attitude Sensors



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.

Performance Category	*Narrow FOV*	*Wide FOV*
Field of View Magnitude Sensitivity Power (avg. at +45°C)	8° x 8° +6.5 10W	20° circular +5.1 10W
Weight (with lightshade) Update Rate Stars Simultaneously Tracked	8.5 lb 6 Hz 6	7.5 lb 2 Hz 6
Overall Accuracy -Pitch/Yaw, rms -Roll, rms	 2 arc sec 40 arc sec	 5 arc sec 40 arc sec

ADVANCED DESIGN FEATURES

- Automatic Proton and Debris Noise Rejection
- Six-Star Tracking Capability
- Robust Acquisition/Tracking
- 1553B Communication Interface
- Modular Construction
- Quaternion Output Option (Wide FOV Only)

HIGH RELIABILITY

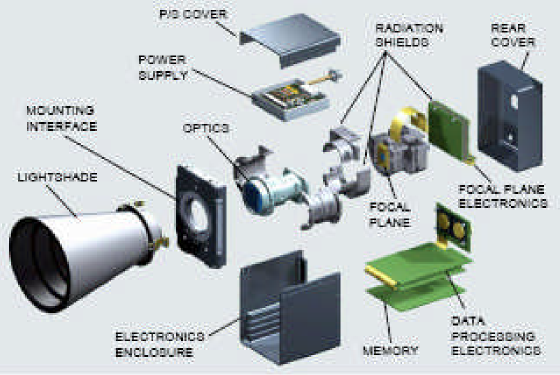
- Class-s Equivalent Parts
- MTBF of One Million Hours

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

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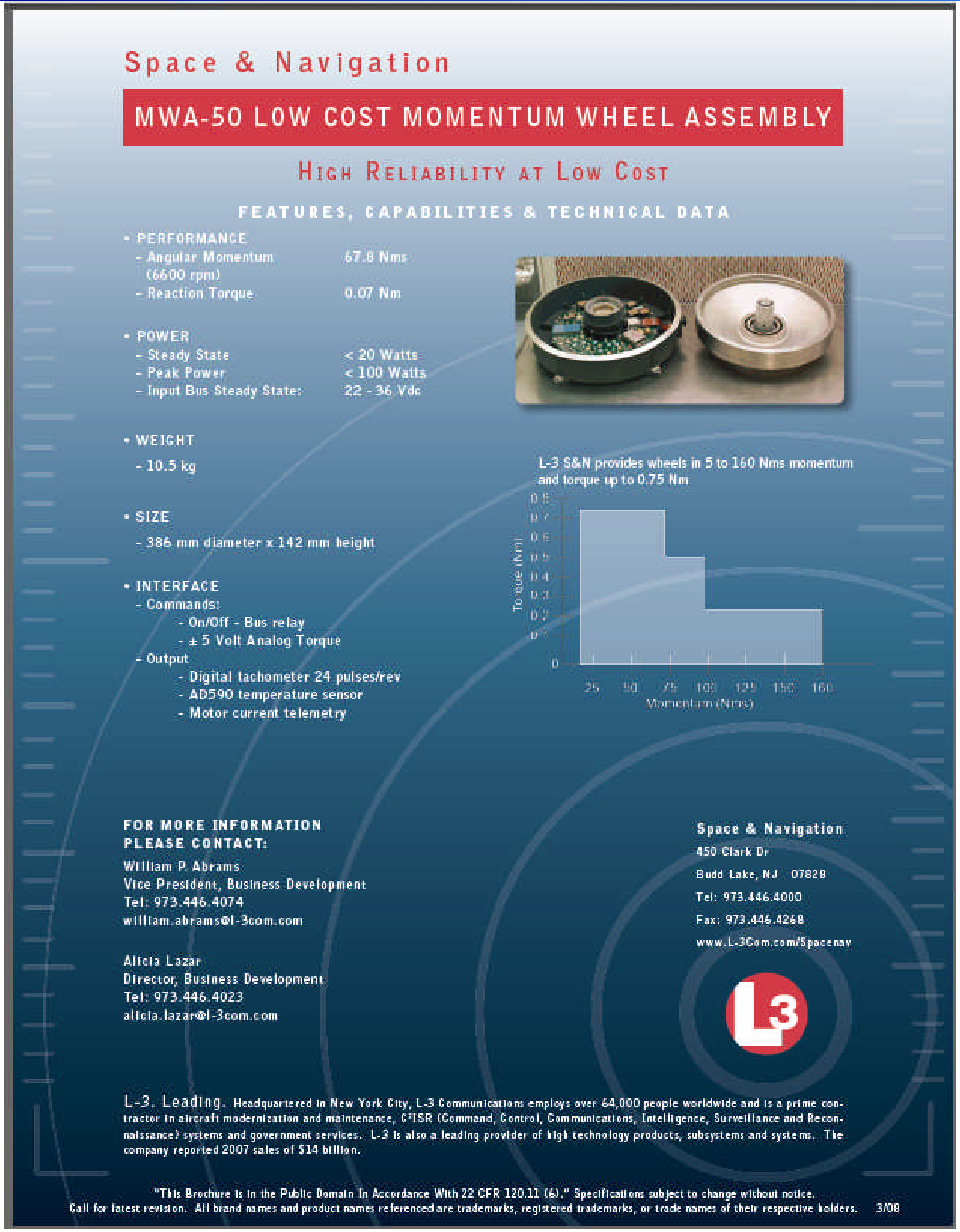
Ball Aerospace Worldview CMG

- 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)

GN&C – Reaction Wheel example


Space & Navigation

MWA-50 LOW COST MOMENTUM WHEEL ASSEMBLY

HIGH RELIABILITY AT LOW COST

FEATURES, CAPABILITIES & TECHNICAL DATA

- PERFORMANCE
  - Angular Momentum (6600 rpm) 67.8 Nms
  - Reaction Torque 0.07 Nm
- POWER
  - Steady State < 20 Watts
  - Peak Power < 100 Watts
  - Input Bus Steady State: 22 - 36 Vdc
- WEIGHT
  - 10.5 kg
- SIZE
  - 386 mm diameter x 142 mm height
- INTERFACE
  - Commands:
    - On/Off - Bus relay
    - ± 5 Volt Analog Torque
  - Output
    - Digital tachometer 24 pulses/rev
    - AD590 temperature sensor
    - Motor current telemetry

L-3 S&N provides wheels in 5 to 160 Nms momentum and torque up to 0.75 Nm

FOR MORE INFORMATION PLEASE CONTACT:

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L-3. Leading. Headquartered in New York City, L-3 Communications employs over 64,000 people worldwide and is a prime contractor in aircraft modernization and maintenance, C³ISR (Command, Control, Communications, Intelligence, Surveillance and Reconnaissance) systems and government services. L-3 is also a leading provider of high technology products, subsystems and systems. The company reported 2007 sales of $14 billion.

- 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

Power: Photo-Voltaic Arrays

- 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 %

Power: Battery Charge/Discharge Units (BCDU)

- Linear Regulation
- Charge / Discharge Efficiency 81%
- Ripple < 0.5 %

Thermal: Heat Pipe Info

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

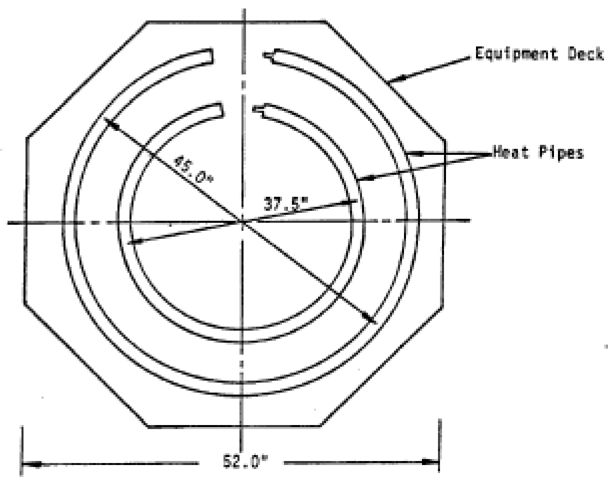


Fig. 9-7. I.U.E. Heat Pipes on lower deck of the spacecraft

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.

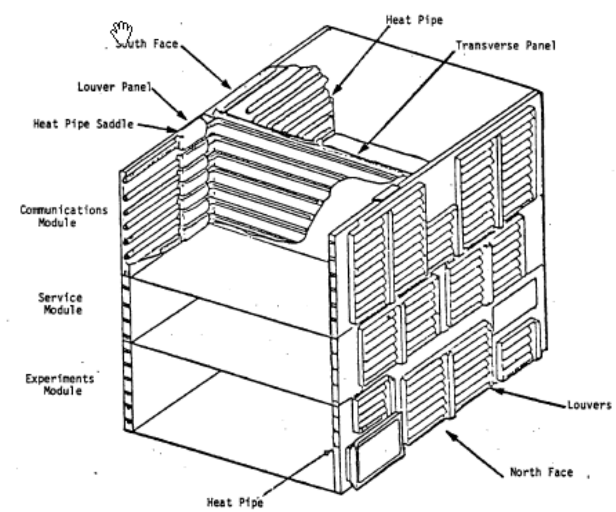
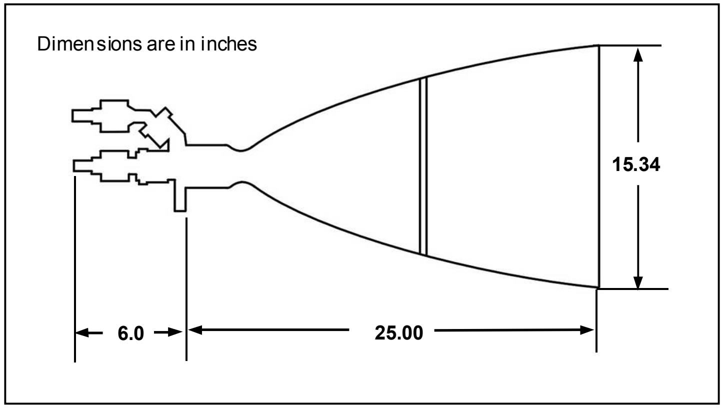


Fig. 9-5 Primary thermal control system schematic

Propulsion: R-42 Engine Data Sheet

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

Rev. Date: 5/17/06

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