Attitude Determination & Control System

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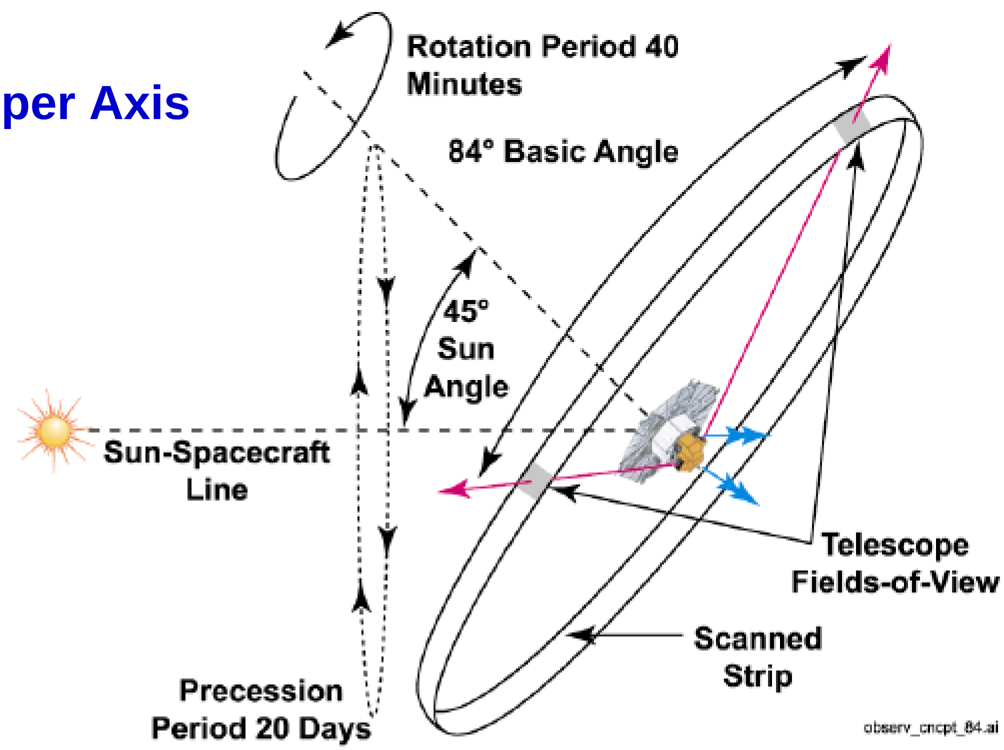
Top Level System Requirements (1 of 3)

- Spacecraft Observing Parameter Requirements
  - Spin Period: 40 +/- 2 Min (2.62 +/- 0.131 mrad/sec)
  - Precession Period: 20 +/- 2 Days
  - Sun Angle: 45 +/- 5 Deg
- Acquisition Mode Requirements
  - Attitude Knowledge: 50 mrad per Axis



Top Level System Requirements (2 of 3)

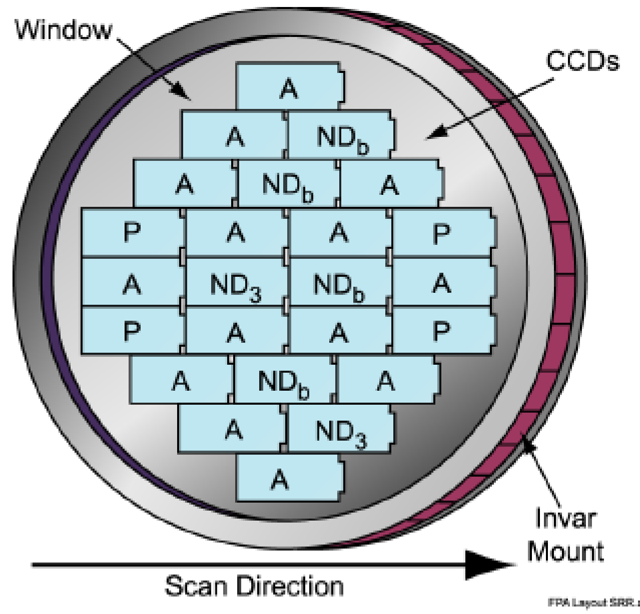
Science Collection Requirements

Astrometric Mission Along Scan Requirements

Modelable Spin Rate Variations: ± 0.262 mrad/sec in 300 sec

Unmodelable Variations (Jitter):

Frequency (Hz):	0.2	1.0	10	100
Amplitude (mrad):	0.01	0.001	0.003	0.01



Astrometric Mission Cross Scan Requirements

Nominal Solar Precession: 4.5 mrad in 1.56 sec

Other Modelable Disturbances: 5 mrad in 1.56 sec

Unmodelable Variations (Jitter):

Frequency (Hz):	0.2	1.0	10	100
Amplitude (mrad):	0.1	0.025	0.03	0.1

- **Astrometric Mission Requirement:**
  - **Alignment of FPA to Principle Spin Axis: 150 mrad**

Top Level System Requirements (3 of 3)

- Mission Support
  - Orbit Adjustment
    - AKM Burn for Transfer From GEO Transfer Orbit Into GEO Orbit
    - Orbit Correction Burn(s) to Get Into Final GEO Orbit
  - Instrument/Spacecraft Protection
  - De-orbit Capability at End of Mission

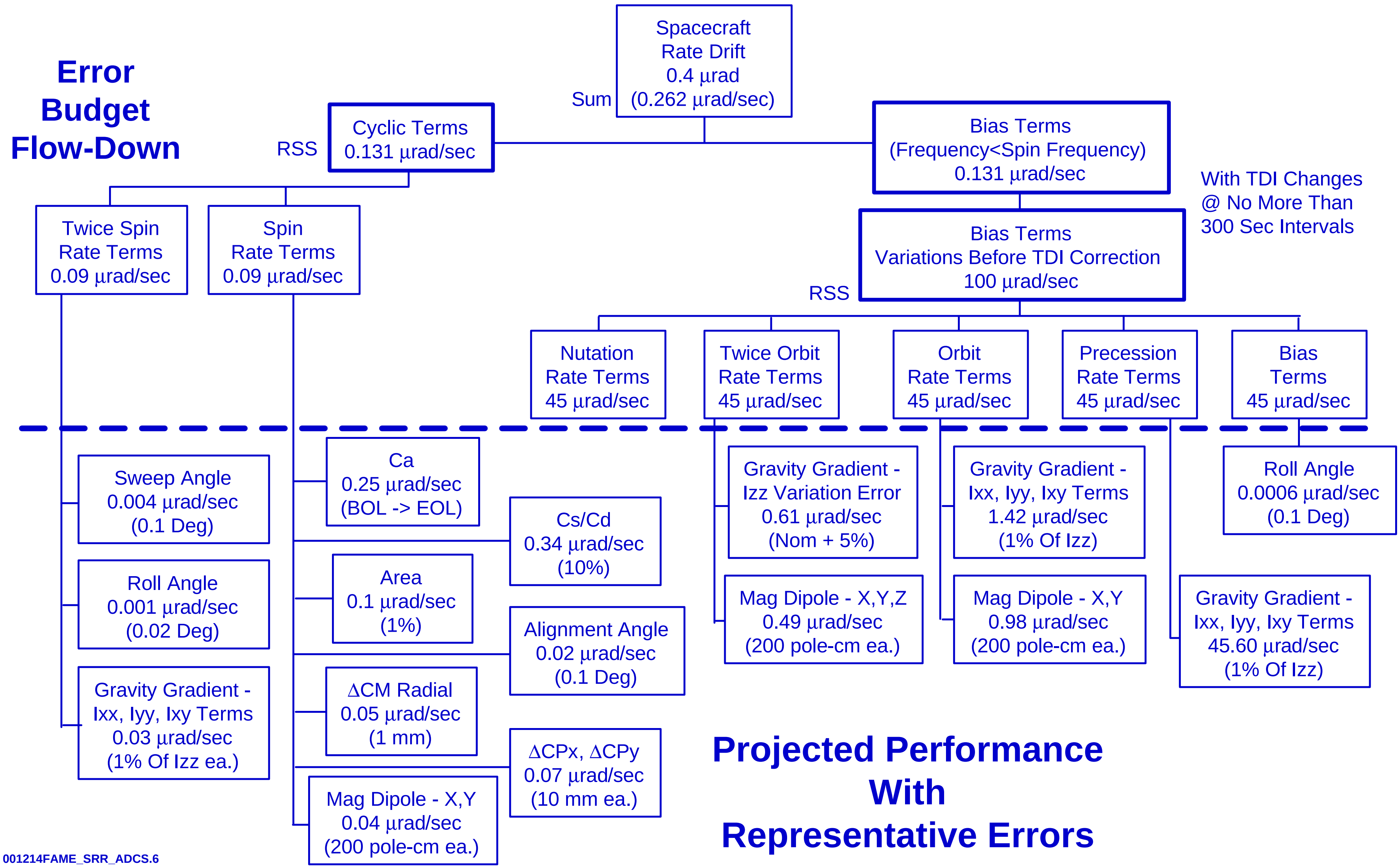
Requirement Flow-Down (1 of 5)

Along Scan Requirements

- Spacecraft Observing Nominal Scan Rate: 2620 mrad/sec
  - Maximum Variation Over Mission: +/- 131 mrad/sec (Available TDI Rates)
- Astrometric Along Scan Rate Variation
  - Modelable Variations Over 300 Sec: +/- 0.262 mrad/sec (Single TDI Rate)
  - Unmodelable Variations Over 1.56 Sec: See Jitter Requirements
- Disturbance Source Frequencies
  - Frequencies > 0.2 Hz: [See Jitter Requirements]
  - 0.2 Hz > Frequencies > 0.000417 Hz (Spin Frequency)
    - Treated As Bias/cyclic Over 1.56 Sec or 300 Sec Durations
    - Allowable Amplitude of Oscillations Over 300 Sec:
      - +/- 0.131 mrad/sec (= 0.2 mrad Error Over 1.56 Sec)
  - 0.000417 Hz > Frequencies
    - Treated As Bias Over 1.56 Sec or 300 Sec Durations
    - Allowable Amplitude Of Oscillations:
      - +/- 0.131 mrad/sec (= 0.2 mrad Error Over 1.56 Sec)
  - All Error Sources Assumed Independent for Budget Flow-Down

Requirement Flow-Down (2 of 5)

Along Scan Requirements (Cont.)



Requirement Flow-Down (3 of 5)

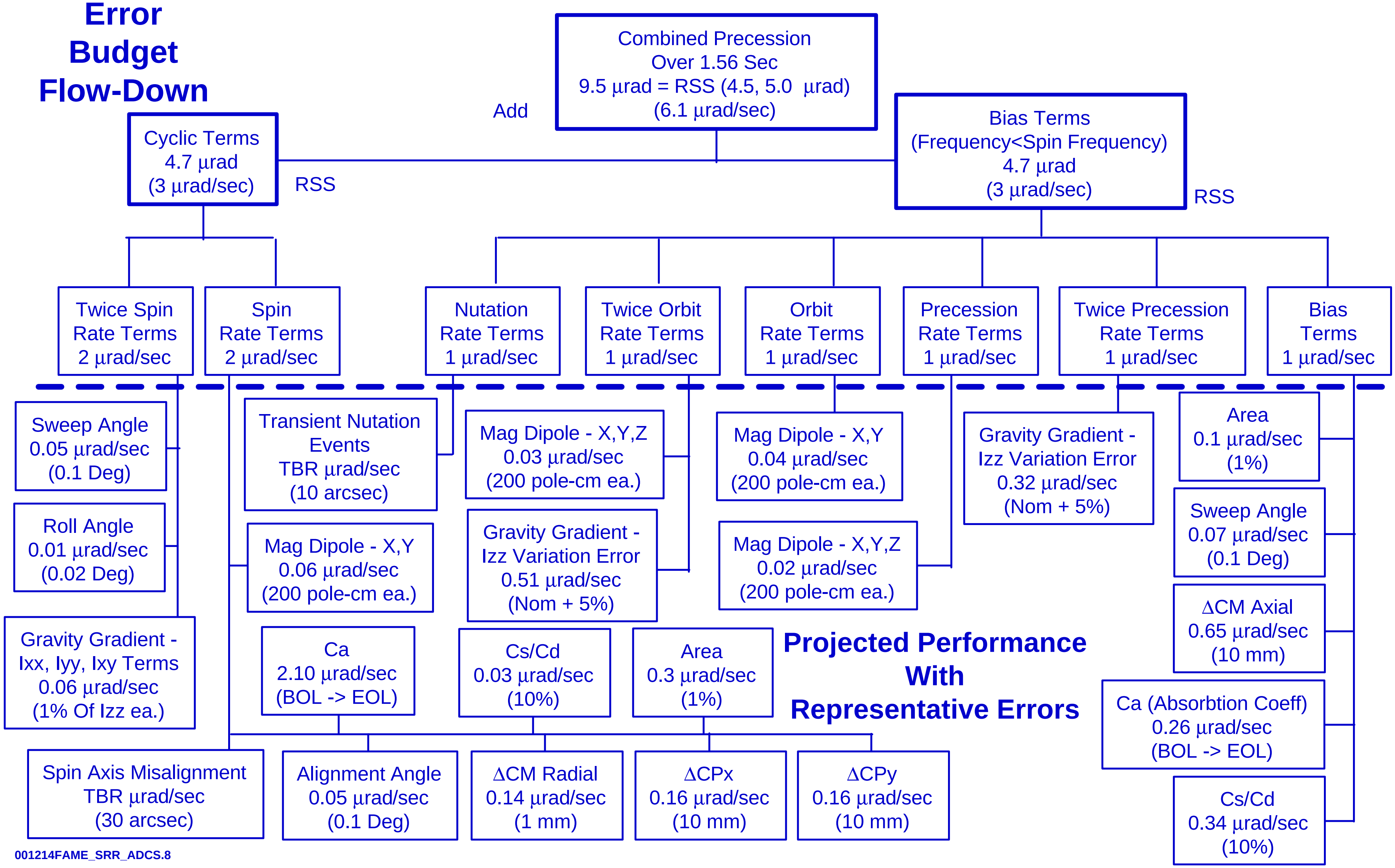
Cross Scan Requirements

- Astrometric Mission Cross Scan Requirements
  - Nominal Solar Precession: 4.5 mrad in 1.56 Sec
  - Other Modelable Disturbances: 5 mrad in 1.56 Sec
- Disturbance Source Frequencies
  - Frequencies > 0.2 Hz : [See Jitter Requirements]
  - 0.2 Hz > Frequencies > 0.000417 Hz (Spin Frequency)
    - Treated As Bias/Cyclic Error Source Over 1.56 Sec Duration
    - Allowable Amplitude of Oscillations Over 1.56 Sec:
      - +/- 3 mrad/sec (= 4.7 mrad Error Over 1.56 Sec)
  - 0.000417 Hz > Frequencies
    - Treated As Bias Error Sources Over 1.56 Sec Duration
    - Allowable Amplitude Of Oscillations:
      - +/- 3 mrad/sec (= 4.7 mrad Error Over 1.56 Sec)
  - All Error Sources Assumed Independent for Budget Flow-Down

Requirement Flow-Down (4 of 5)

Cross Scan Requirements (Cont.)

Error Budget Flow-Down



Requirement Flow-Down (5 of 5)

Illustration: Gravity Gradient Torque Error Contribution

Design Flow

Error Budget

Vehicle Attitude Motion Requirements
- **Precession rate variation**
- **Sun angle variation**
- **Spin rate variation**

Vehicle Dynamics Model

$$\Delta T_u \approx I_s w_s \Delta\dot{y}\ \sin q$$

$$\Delta T_v \approx -I_s w_s \Delta\dot{q}$$

$$\Delta T_w \approx I_s \Delta\dot{w}_s$$

Disturbance Torque Model
- **Gravity Gradient Torque**

$$\Delta T_u = f(orbit, inertia, attitude)$$

$$\Delta T_v = f(orbit, inertia, attitude)$$

$$\Delta T_w = f(orbit, inertia, attitude)$$

Subsystem Requirements
- **Mechanical: Inertia Property**

Attitude and rate variation	Amplitude and frequency
$\Delta\dot{y}$ (μrad/s)	$\pm$0.42 (cyclic @ 2ω_o), $\pm$0.22 (cyclic @ 2ω_p)
Δθ (deg)	$\pm$0.09 (cyclic @ 2ω_o), $\pm$1.20 (cyclic @ 2ω_p)
$\Delta\omega_s$ (μrad/s)	0

Torque (10^{-6} Nm)	Amplitude and frequency of oscillation
T_u	$\pm$0.31 (cyclic @ 2ω_o), $\pm$0.16 (cyclic @ 2ω_p)
T_v	$\pm$0.25 (cyclic @ 2ω_o), $\pm$0.16 (cyclic @ 2ω_p)
T_w	0

Baseline Model

Items	Values (kg-m^2)
Izz	400
Ixx	360
Iyy	360
|Ixx-Iyy|	0
Ixy	0

Attitude and rate variation	Amplitude and frequency
$\Delta\dot{y}$ (μrad/s)	$\pm$0.04 (cyclic @ 2ω_s)
Δθ (μrad)	$\pm$5.47 (cyclic @ 2ω_s)
$\Delta\omega_s$ (μrad/s)	$\pm$0.03 (cyclic @ 2ω_s), $\pm$1.03 (cyclic @ ω_o), $\pm$41.23 (cyclic @ ω_p)

Change in Torque (10^{-6} Nm)	Amplitude and frequency of oscillation
ΔT_u	$\pm$0.03 (cyclic @ 2ω_s)
ΔT_v	$\pm$0.03 (cyclic @ 2ω_s)
ΔT_w	$\pm$0.06 (cyclic @ 2ω_s), $\pm$0.03 (cyclic @ ω_o), $\pm$0.06 (cyclic @ ω_p)

Variations in Ixy

Items	Values (kg-m^2)
Izz	400
Ixx	360
Iyy	360
|Ixx-Iyy|	0
Ixy	4

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Other Variations (Izz, Ixx, Iyy, Ixx-Iyy)

Inertia (kg-m^2)	Requirements
Izz (spin axis)	380 <= Izz <= 430
Ixx	0.89 Izz <= Ixx <= 0.925 Izz
Iyy	0.89 Izz <= Iyy <= 0.925 Izz
|Ixx-Iyy|	<= 0.025 Izz, minimize
Ixy	|Ixy| < 4 kg-m^2 (0.01 Izz)

Derived Requirements Summary (1 of 2)

From Science Acquisition Requirements

- **Attitude Sensor Performance**
  - **ST, IMU, SS**
- **Actuator Sizing**
  - **Thrusters: Number, Size, Minimum Impulse Bit, Locations, Etc.**
- **Nutation Damping**
  - **Damper Mechanism, Requirements, Etc.**
  - **Allowable Residual Body Rates**

From Science Collection Requirements

- **Actuator Sizing**
  - **Trim Tabs: Number, Size, Location, Range Of Motion, Step Size, Degrees Of Freedom (DOF), Surface Properties, Flatness, Thermal Radiation**
  - **Trim Masses: Number, Size, Location, Range Of Motion, Step Size, DOF**

Derived Requirements Summary (2 of 2)

From Science Collection Requirements (Cont.)

- Disturbance Torque Sources
  - S/C Mass Property: CG Offset Tolerance, Cross-Products Of Inertia Tolerance (Or Spin Axis Misalignment)
  - Gravity Gradient Torque: Transverse Axis/Spin Axis Inertia Ratio
  - Magnetic Torque: Residual Magnetic Dipole
  - Thermal Radiation Torque: S/C Core Radiator, CCD Radiator, Sun Shield
  - Fuel Slosh
  - Earth Albedo and Thermal Radiation
  - Solar Irradiation Variation
  - Jitter
  - Thruster Leakage
- Sun Shield Property
  - Surface Optical Properties: Uniformity and Degradation
  - Orientation and Flatness of Solar Panel and Web
  - AKM Hole Coverage
- Payload Body Rate Knowledge Made Available for Refined Control of Trim Tabs and Trim Masses

Trade Studies

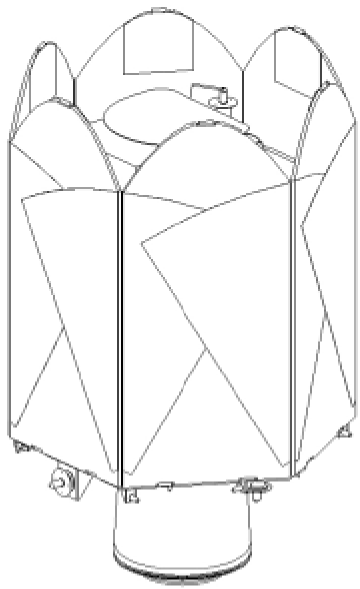
- Sensor (ST, IMU, SS) Selection
  - Performance Requirements, Vendors
  - Sensor Placement Vs Performance
- Passive vs. Active Nutation Damping
  - Active Nutation Damping Mechanism
    - Magnetic (Electromagnetic Torquers) vs. Solar (Trim Tabs)
  - Passive Nutation Damping Mechanism
    - Requirements, Build/Buy, Other Inherent Damping (Propellant or Structure)
    - Deployable/Retractable Nutation Damping Mechanism
- Backup Science Acquisition Concept
  - Mass Expulsion (Thrusters) vs. Magnetics (Electromagnetic Torquers) in Comparison to Baseline Concept (Solar Precession)
- Trim Tab vs. Thermal Radiation Patch

Issues / Challenges

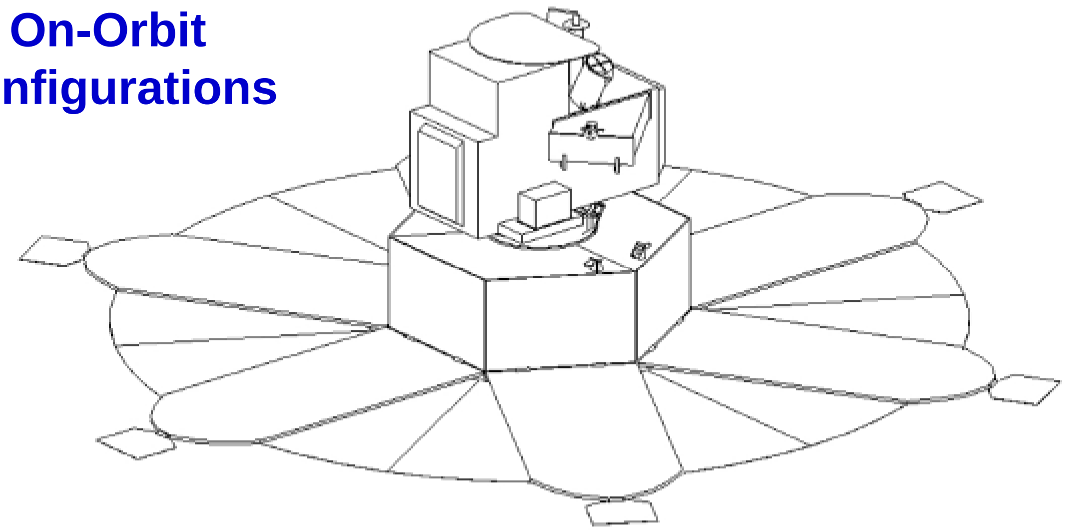
- Optical Properties Knowledge (BOL and EOL) and Balancing
- Mass Properties Control: CG Offset, Spin Axis Misalignment
- Thermal Radiation Disturbance Torque Knowledge and Control
- Trim Tab / Trim Mass Control Strategy
- Nutation Damping Mechanism Selection
- S/C Magnetic Dipole Measurement

Derived Requirements (1 of 14)

- **Derived Control Modes**



On-Orbit Configurations



GEO Transfer Orbit (GTO) Or Stowed Configuration

Safe Hold Mode

Standby Mode

Inertial Pointing Mode

Open Loop Burn Mode

Active Nutation Control Mode

Spin Axis Precession

Operational Or Deployed Configuration at GEO

Standby Mode (Stellar Mapping)

Inertial Pointing Mode

Safe Hold Mode (-Z @ Sun)

Derived Requirements (2 of 14)

- **Derived Control Modes (Cont.)**

Mode	Objective	Measurement Capability	Control Method	ADCS Hardware
Standby	Monitor Sensor Data During Stellar Mapping Operations	Attitude & Body Rates	Passive Solar Precession & Nutation Control	Star Tracker (ST), Inertial Measurement Unit (IMU), Sun Sensor (SS), Nutation Damper (ND) [ST, IMU, SS: Not For Control Feedback]
Inertial Pointing	Hold Any Attitude	Attitude & Body Rates	Attitude & Body Rate Control	ST, IMU, SS, Thrusters
Safe Hold	Points Desired Vehicle Axis To Sun With Desired Body Rates	Sun Vector & Body Rates	Sun Vector & Body Rate Control	IMU, SS, Thrusters
Open Loop Burn	Spin Rate Changes, Orbit trim	Sun Vector & Body Rates	Open Loop Thruster Firings	IMU, SS, Thrusters [IMU & SS: Not For Control Feedback]
Active Nutation Control	Nutation Control At High Spin Rates	Body Rates	Active Nutation Angle Control	IMU, Thrusters
Spin Axis Precession	Precess Spin Axis	Spin Axis Pointing Direction & Roll Orientation	Closed Loop Precession Control	IMU, SS, Thrusters

Derived Requirements (3 of 14)

- **ACDS Mode Control & Knowledge Requirements**

Mode		Control requirement	Knowledge requirement	Remarks
Standby (Stellar Mapping)	Spin Rate Variation	±2.62 mrad/sec	±0.03 µrad/sec (TBR)	Derived requirement on instrument (ADCS capability: ± 1 µrad/sec)
	Precession Rate Variation	± 6.73 µrad/sec	±0.06 µrad/sec (TBR)	Derived requirement on instrument (ADCS capability: ± 1 µrad/sec)
	Sun Angle Variation	± 5 deg	± 0.5 deg	
	Nutation angle	< 10 as	TBD	
Inertial Pointing	Operational Configuration	± 0.1 deg	± 0.05 deg	
	GTO Configuration	± 1 deg	± 0. 5 deg	
Safe Hold		± 5.0 deg	± 2.0 deg	
Open Loop Burn		N/A	N/A	
Active Nutation Control		± 0.25 deg (half cone angle)	± 0.1 deg	
Spin Axis Precession		5 deg	1 deg	

Derived Requirements (4 of 14)

- **Thruster Minimum Impulse / Force Requirements**

Attitude Control Modes		Requirements	Rationale/Remarks
Science Acquisition and Collection	Spin Up/Down	Minimum Impulse Bit: 0.0125 N-s	40 min ± 5% spin period
Science Acquisition and Collection (Thruster Back-Up Only)	Precession Control (75-750 firings per 20 day precession period)	Minimum Impulse Bit: 0.015 to 0.0015 N-s	20 days ± 10% precession period, proposed back up for precession control, subject to trade studies
	Nutation Damping Augmentation	Minimum Impulse Bit: 1.2e-5 N-s	±10 as nutation angle, subject to trade studies, may require a second propulsion system
	Spin Rate Variation Control	Minimum Impulse Bit: 2.4e-5 N-s	50 mas/sec spin rate variation, subject to trade studies, may require a second propulsion system
Deployed Configuration at GEO	Spin Axis Precession	Thruster Force Range: 0.44 to 4.445 N	Support safe hold, inertial pointing, science acquisition
	Orbit Trimming	Thruster Force Range: 0.44 to 4.445 N	
GEO Transfer Orbit Stowed Configuration	Spin Up/Down	Thruster Force Range: 0.44 to 4.445 N	Spin rates up to 60 rpm (takes 4.7 to 47 min to reach 60 rpm)
	Spin Axis Precession Control	Thruster Force Range: 4.445 to 22.2 N	At spin rates up to 60 rpm
	Active Nutation Control	Thruster Force: 22.2 N	At spin rates up to 60 rpm
	ΔV Correction Burns	Thruster Force Range: 4.445 to 22.2 N	Non-Spinning
	Inertial Pointing	Thruster Force Range: 0.44 to 22.2 N	±0.5 deg pointing requirement

Derived Requirements (5 of 14)

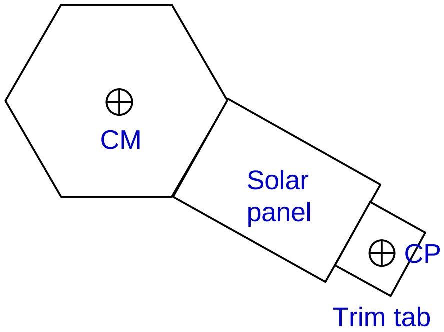
- **Nutation Damping Requirements**
  - **Stowed Configuration: Help Maintain DV Pointing During AKM Firing**
    - **See Active Nutation Control (ANC) Requirements**
  - **Deployed Configuration: Provide Sufficient Damping During Science Acquisition and Collection**
    - **Suppress Residual Body Rates**
    - **Dissipate Transient Motion Due to Eclipses, Occultations, Thermal Gradients, Etc.**

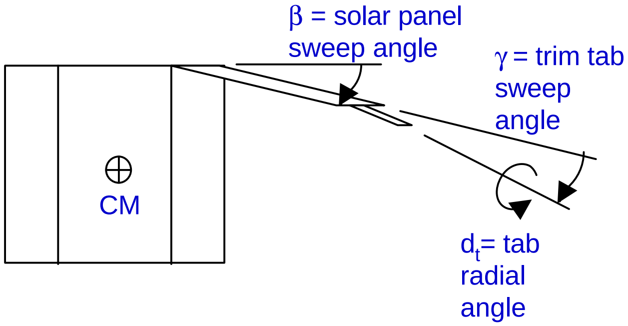
Derived Requirements (6 of 14)

Trim Tab System

- **Baseline Configuration & Requirements**

Items	Requirements	Rationale/Remarks
Quantity and location	Six (6), located symmetrically at the end of each solar panel	Accommodate difference among individual solar panels
Degrees of freedom	One (1), pitching up and down with respect to the solar panel (sweep angle)	May need a pair of trim tabs that have the roll DOF for spin rate control (TBR)
Deployment angle errors	Sweep angle error: $\pm$ 0.1 (TBR) deg Radial angle error: $\pm$ 0.02 (TBR) deg Clocking angle error: $\pm$ 0.1 (TBR) deg	Limited by solar precession, sun angle, and spin rate variation requirements
Flatness	1.25 mm / 0.5 m	Proportional to solar panel flatness of 5 mm / 2 meters
Maximum angular travel	$-(50-\beta) < \gamma < (50-\beta)$ (deg)	Sun angle of 45$\pm$5 deg limits the travel. Accommodate the sun shield sweep angle (β)
Angular resolution	$\leq$ 0.02 deg	Accommodate allowable ranges of spin axis inertia, spin rate, precession rate, and sun angle
Minimum surface area	0.2 m^2 (0.5 m by 0.4 m, shorter dimension attached to the panel)	Provide enough control authority for precession rate control
Optical properties	Ca < 0.15 (absorption), Cs (specular) < Cd (diffuse) (TBR)	Surface with higher Cd produces larger amount of torque.
Optical property variation	TBR	BOL to EOL
Thermal radiation	Sun and shade sides: ΔT (temperature differential) $\leq$ 1°C, $\Delta\varepsilon$ (emissivity) difference $\leq$ 1%	Minimize thermal radiation torque
Center of pressure	CP stays within 1 mm radius of the centroid	Control the length of moment arm





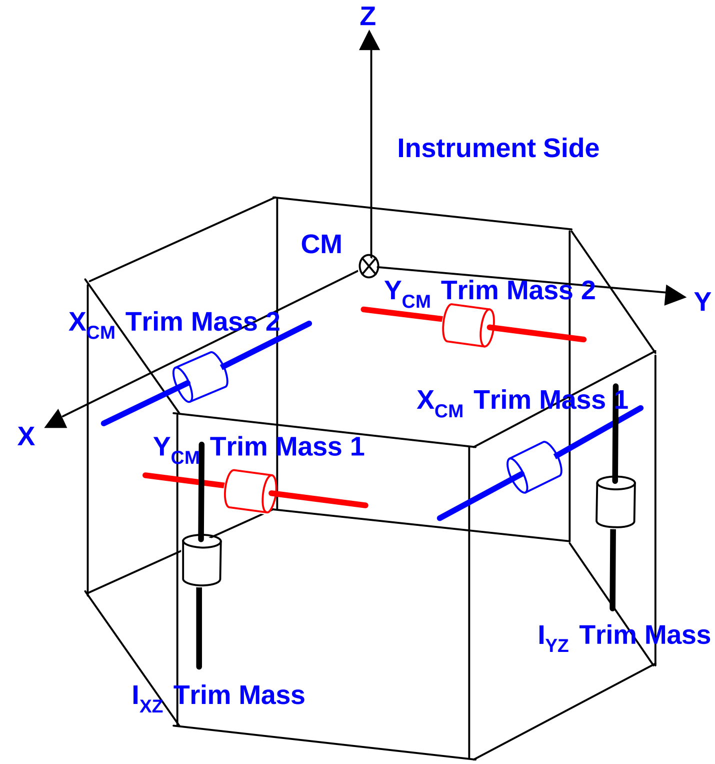
Derived Requirements (7 of 14)

Trim Mass System

- **Baseline Configuration & Requirements**

Trim mass ID	Mass (kg)	Stroke (m)	Null trim mass position from CM ([X,Y,Z], m)	Capability
X_{CM1}	6.0	+/- 0.5	[0,+Y,-Z_1]	Move X_{CM} +/- 0.01m
X_{CM2}	6.0	+/- 0.5	[0,-Y,- Z_1]	Move X_{CM} +/- 0.01m
Y_{CM1}	6.0	+/- 0.5	[+Y,0,- Z_1]	Move Y_{CM} +/- 0.01m
Y_{CM2}	6.0	+/- 0.5	[-Y,0,- Z_1]	Move Y_{CM} +/- 0.01m
I_{XZ}	3.3	+/- 0.35	[1,0,- Z_2]	Produce ΔI_{xz} of 1.1 kg-m^2
I_{YZ}	3.3	+/- 0.35	[0,1,- Z_2]	Produce ΔI_{yz} of 1.1 kg-m^2

Y=0.5 m, $Z_1 \leq$ 0.1 m, Z_2 = 0.2 m



Alignment & Placement Requirements

- **Nominal Position of Axial CM: ≤ 0.1m above X_{CM} & Y_{CM} Balance Masses**
- **Position Error: ± 0.01 in (± 0.254 mm)**
- **Alignment Angle Error: ≤ 0.1 deg**

Derived Requirements (8 of 14)

Mass Properties Requirements

- **Before Trim Mass Adjustment**

Assumed Vehicle Properties:

- Sun shield deployed
- AKM jettisoned
- Trim masses are in null positions
- Mission orbit with fuel load

Items	Requirements	Rationale
Izz (spin axis, centroidal MOI, kg-m^2)	380 <= Izz <= 420	Major axis, gyroscopic stiffness, required solar precession torque range
Ixx	0.89 Izz <= Ixx <= 0.91 Izz	Itmax <= 0.92Is for spin stability Itmin >= 0.88Is to limit gravity gradient torque in transverse axes (Itmax-Itmin)<0.025Is to limit gravity gradient torque in spin axis
Iyy	0.89 Izz <= Iyy <= 0.91 Izz	
|Ixx-Iyy|	<= 0.01 Izz, make Ixx and Iyy as close as possible to each other	
Ixy	|Ixy| < 4 kg-m^2 (0.01 Izz)	
Ixz	|Ixz| < 0.5 kg-m^2 (1.2e-3Izz), minimize	$\leq$1.5 deg spin axis misalignment Trim masses (3.3kg, single mass, +/- 0.35 m stroke, 2EA)
Iyz	|Iyz| < 0.5 kg-m^2 (1.2e-3Izz), minimize	
Xcm	|Xcm| < 10 mm	Control capability of trim masses (6 kg, single mass, +/- 1/2 m stroke, 2 pairs) for Xcm and Ycm
Ycm	|Ycm| < 10 mm	
Zcm	Range: 0.8 +/- 0.1 m (from the top of the electronics deck) Knowledge: |Zcm| < 20 mm	Sun shield sweep angle setting, trim tab and trim mass control authority

Derived Requirements (9 of 14)

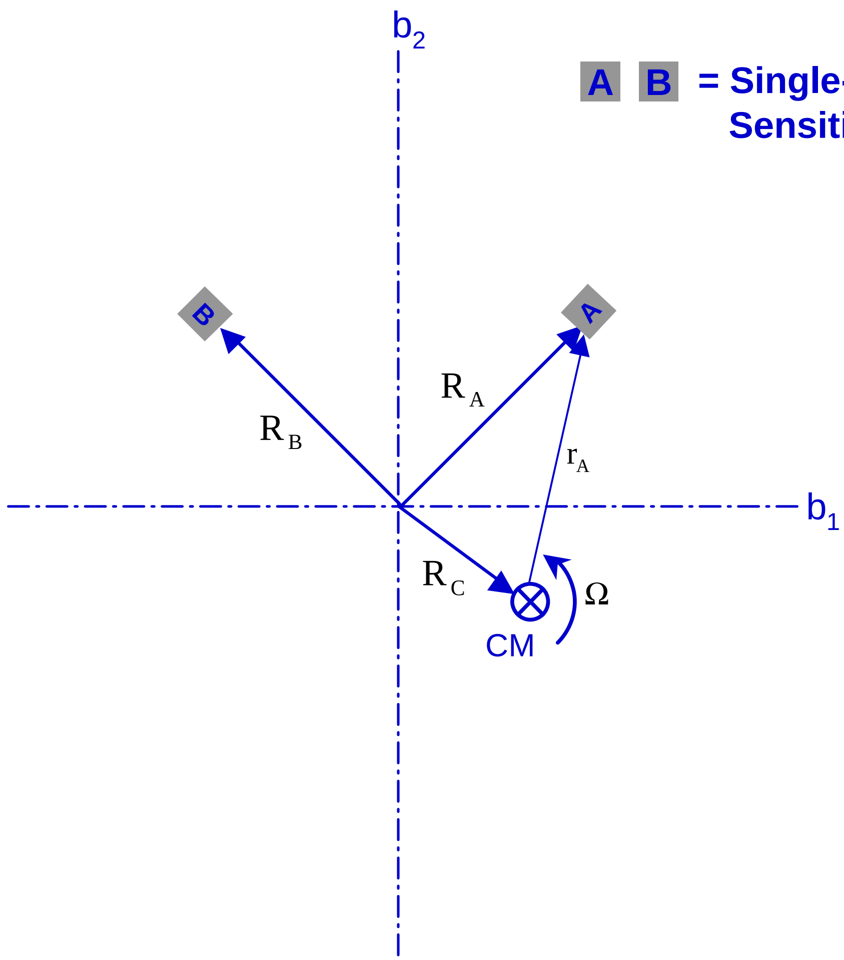
Mass Properties Requirements

- **After Trim Mass Adjustment**

Items	Requirements	Rationale
Izz (spin axis, kg-m^2)	380 <= Izz <= 430	Major axis, gyroscopic stiffness, required solar precession torque range; Allow room for increase due to CM control using trim masses
Ixx	0.89 Izz <= Ixx <= 0.925 Izz	Itmax <= 0.935Is for spin stability Itmin >= 0.88Is to limit gravity gradient torque in transverse axes; (Itmax-Itmin)<0.035Is to limit GG torque in spin axis; Allow room for changes in Ixx and Iyy due to CM control using trim masses
Iyy	0.89 Izz <= Iyy <= 0.925 Izz	
|Ixx-Iyy|	<= 0.025 Izz, make Ixx and Iyy as close as possible to each other	
Ixy	|Ixy| < 4 kg-m^2 (0.01 Izz)	
Ixz	|Ixz| <5e-6Izz, minimize	≤30 as spin axis misalignment Trim masses (3.3kg, single mass, +/- 0.35 m stroke, 2EA, 0.1 mm (TBR) stroke resolution)
Iyz	|Iyz| <5e-6Izz, minimize	
Xcm	|Xcm|<0.05 mm	Trim masses (6 kg, single mass, +/- 1/2 m stroke, 2 pairs, 1 mm (TBR) stroke resolution) to control CM location.
Ycm	|Ycm|<0.05 mm	
Zcm	|ΔZcm|<20 mm	Trim tab control capability for solar precession rate

Derived Requirements (10 of 14)

Balancing Error Measurement Requirements



A B = Single-axis Accelerometers With Sensitive Axes in the Radial Direction

Strategy:

1. **Spin up S/C to an Acceptable Rate (~ 3 Rpm)**
2. **Collect a Few Minutes of Accelerometer Data**
3. **Spin up S/C to a New Rate (~ 5 Rpm)**
4. **Collect a Few Minutes of Accelerometer Data**
5. **Process Differenced Data and Average to Determine r_a and r_b**

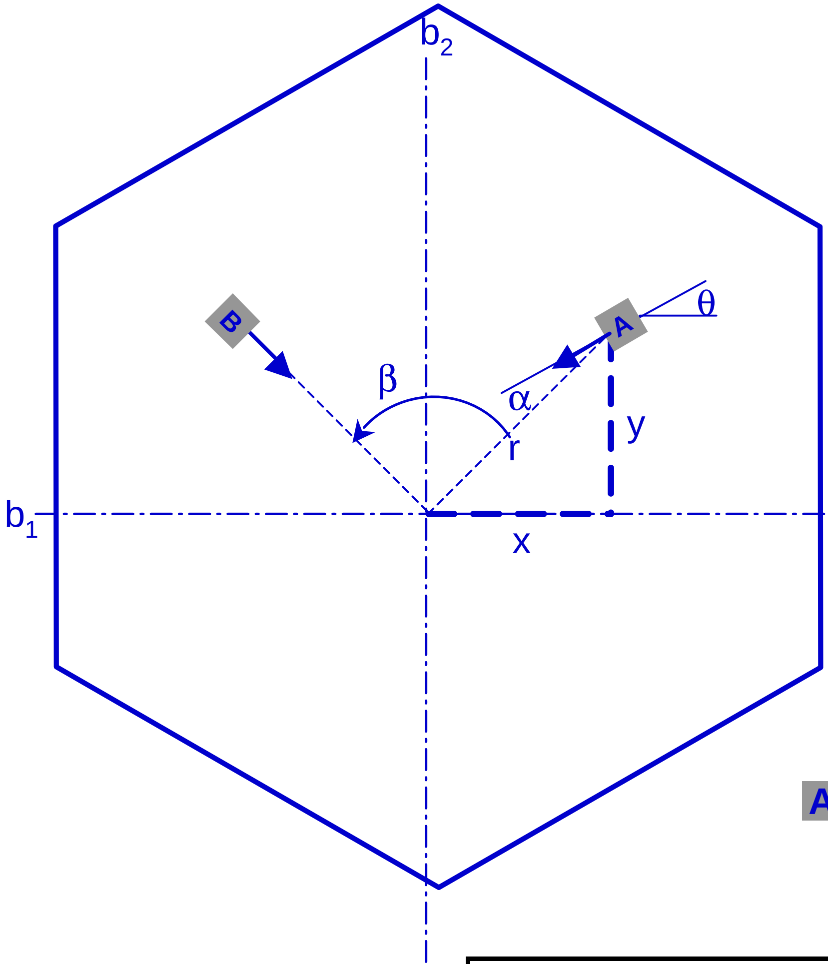
$$r_A \approx \frac{a_{A2} - a_{A1}}{\Omega_2^2 - \Omega_1^2} \qquad r_B \approx \frac{a_{B2} - a_{B1}}{\Omega_2^2 - \Omega_1^2}$$

(Differenced Data Removes Accelerometer Biases)

6. **Adjust CM Balance Masses to Drive $r_{a,b}$ to $R_{A,B}$**

Derived Requirements (11 of 14)

Balancing Error Measurement Requirements (Cont.)



Knowledge Requirements

Accelerometer Location (x,y) = 0.2 mm

Accelerometer Axis Orientation (q) = 0.1 Deg

Positioning Requirements

Radial Distance From Center to Accelerometer (R) > 40 cm

Angle Between Accelerometer Axes (b) = 90 +/- 10 Deg

Accelerometer Axis Orientation to Radial Line (a) < 5 Deg

A B = Single-Axis Accelerometers With Sensitive Axes in the Radial Direction

Accelerometer	Quantity	Resolution	Unit Size	Unit Mass	Unit Power
Honeywell QA-3000-030	2	1 μg	16 cm^3	0.071 kg	0.5 W
			Total	0.142 kg	1 W

Derived Requirements (12 of 14)

- **Solar Array Panel Requirements**

Items	Requirements	Rationale/Remarks
Quantity	Six (6)	Smooth solar precession torque generation
Deployment angle errors	Sweep angle error: $\pm$ 0.1 (TBR) deg Radial angle error: $\pm$ 0.02 (TBR) deg Clocking angle error: $\pm$ 0.1 (TBR) deg	Limited by solar precession, sun angle, and spin rate variation requirements
Deployment position error	$\pm$ 0.01 in ($\pm$ 0.25 mm)	Same in all three directions (x, y, and z)
Flatness	5 mm / 2 m	Accommodate manufacturing error, thermal deformation
Surface area	2.3 $\pm$ TBD m^2 (per panel)	Provide enough control torque for solar precession.
Optical properties	TBD < Ca (absorption) < TBD, TBD < Cs (specular) < TBD, TBD < Cd (diffuse) < TBD	Control the amount of solar radiation pressure torque. Ca +Cs+Cd=1
Optical property variation	TBR	BOL to EOL
Center of pressure	CP stays within a 10 mm (TBR) radius circle about the centroid	Control the length of the moment arm
Thermal radiation	Sun and shade sides: ΔT (temperature differential) $\leq$ 5°C (TBR), $\Delta\varepsilon$ (emissivity) difference $\leq$ 5% (TBR)	Control thermal radiation torque
Maximum jitter from thermal expansion	TBD	Each solar panel should not experience more than TBD°C temperature change per spin period
Solar cell location/operation	Maintain symmetry about the spin axis. Arrange solar cell strand to allow symmetry of operational/non-operational cells about the spin axis	Minimize unwanted imbalance torque. Accommodate optical property change for operational and non-operational cells

Derived Requirements (13 of 14)

- **Solar Array Web Requirements**

Items	Requirements	Rationale/Remarks
Quantity	Twelve (12)	Two (2) for each solar panel
Deployment angle errors	Sweep angle error: ± 0.1 (TBR) deg Radial angle error: ± 0.02 (TBR) deg Clocking angle error: ± 0.1 (TBR) deg	Limited by solar precession, sun angle, and spin rate variation requirements. Angle defined relative to the solar panel.
Deployment position error	± 0.01 in (± 0.25 mm)	Same in all three directions (x, y, and z)
Flatness	5 mm / 2 m	Accommodate manufacturing error, thermal deformation
Surface area	0.8 ± TBD m^2 (per web)	Provide enough control authority for precession rate control. Limited by solar panel size
Optical properties	TBD < Ca (absorption) < TBD, TBD < Cs (specular) < TBD, TBD < Cd (diffuse) < TBD	Control the amount of solar radiation pressure torque. Ca+Cs+Cd=1
Optical property variation	TBR	BOL to EOL
Center of pressure	CP stays within a 10 mm (TBR) radius circle about the centroid	Control the length of the moment arm
Thermal radiation	Sun and shade sides: ΔT (temperature differential) ≤ 5°C (TBR), Δε (emissivity) difference ≤ 5% (TBR)	Control thermal radiation torque
Maximum jitter from thermal expansion	TBD	Each web should not experience more than TBD°C temperature change per spin period

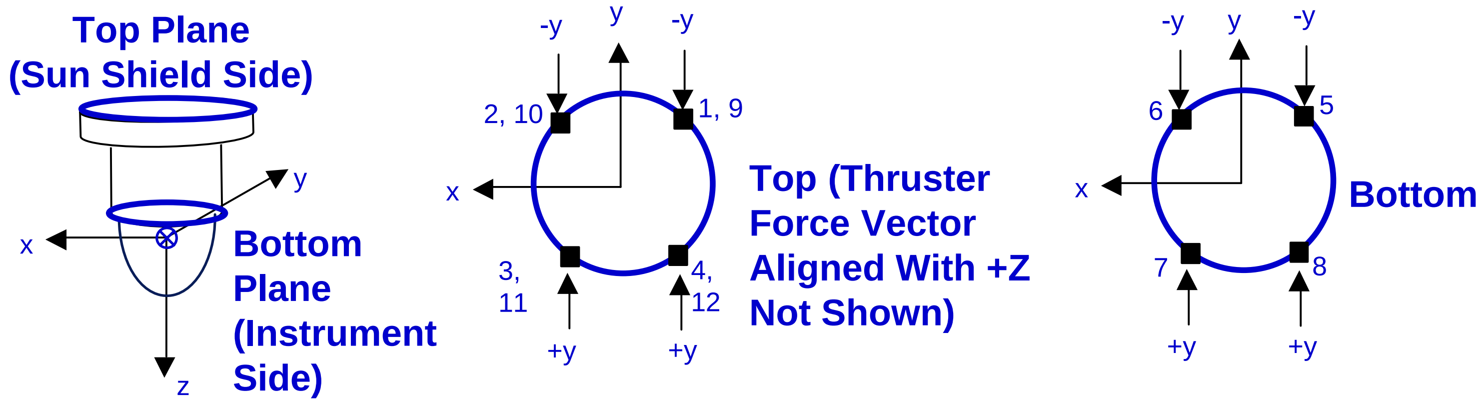
Derived Requirements (14 of 14)

- **Electronics Deck Panel Requirements**

Items	Requirements	Rationale/Remarks
Quantity	Three (3)	
Deployment angle errors	Sweep angle error: $\pm$ 0.1 (TBR) deg Radial angle error: $\pm$ 0.02 (TBR) deg Clocking angle error: $\pm$ 0.1 (TBR) deg	Limited by solar precession, sun angle, and spin rate variation requirements.
Deployment position error	$\pm$ 0.01 in ($\pm$ 0.25 mm)	Same in all three directions (x, y, and z)
Flatness	5 mm / 2 m	Accommodate manufacturing error, thermal deformation
Surface area	1.0 $\pm$ TBD m^2	Provide enough control authority for precession rate control. Limited by solar panel size
Optical properties	TBD < Ca (absorption) < TBD, TBD < Cs (specular) < TBD, TBD < Cd (diffuse) < TBD	Control the amount of solar radiation pressure torque. Ca+Cs+Cd=1
Optical property variation	TBR	BOL to EOL
Center of pressure	CP stays within a 10 mm (TBR) radius circle about the centroid	Control the length of the moment arm
Thermal radiation	Sun side: temperature gradient $\leq$ 5°C (TBR), $\Delta\varepsilon$ (emissivity) variation $\leq$ 5% (TBR)	Control thermal radiation torque
Maximum jitter from thermal expansion	TBD	Each panel should not experience more than TBD°C temperature change per spin period

Backup (1 of 7)

- **Baseline Thruster Arrangement**



Thruster ID	Force Vector			Position Vector			Torque Vector			Remarks
	x	y	z	x	y	z	x	y	z	
1	0	0	+1	-1	+1	-1	+1	+1	0	ΔV
2	0	0	+1	+1	+1	-1	+1	-1	0	ΔV
3	0	0	+1	+1	-1	-1	-1	-1	0	ΔV
4	0	0	+1	-1	-1	-1	-1	+1	0	ΔV
5	0	-1	0	-1	+1	-0.1	-0.1	0	+1	For stowed configuration only
6	0	-1	0	+1	+1	-0.1	-0.1	0	-1	
7	0	+1	0	+1	-1	-0.1	+0.1	0	+1	
8	0	+1	0	-1	-1	-0.1	+0.1	0	-1	
9	0	-1	0	-1	+1	-1	-1	0	+1	For deployed configuration only
10	0	-1	0	+1	+1	-1	-1	0	-1	
11	0	+1	0	+1	-1	-1	+1	0	+1	
12	0	+1	0	-1	-1	-1	+1	0	-1	

Maneuver	Thruster Combination	Remarks
ΔV (+Fz)	1+2+3+4	Zero net torque
Spin up (+Tz)	9+11 (deployed) 5+7 (stowed)	Tx=Ty=0, zero net force
Spin down (-Tz)	10+12 (deployed) 6+8 (stowed)	Tx=Ty=0, zero net force
Precession (+Tx)	7+8 (deployed) 11+12 (stowed)	Ty=Tz=0, Fy≠0
Precession (-Tx)	5+6 (deployed) 9+10 (stowed)	Ty=Tz=0, Fy≠0
Precession (+Tx)	3+4	Ty=Tz=0, Fz≠0
Precession (-Tx)	1+2	Ty=Tz=0, Fz≠0
Precession (+Ty)	1+4	Tx=Tz=0, Fz≠0
Precession (-Ty)	2+3	Tx=Tz=0, Fz≠0

• Gravity Gradient Torque As Function Of Inertia Variation

- Geosynchronous orbit
- 45 deg half cone angle (precession)
- Effect of Ixz and Iyz is treated in spin axis misalignment.

Variations	Solar radiation torque (10^{-6} N-m)			Parameter values (kg-m^2)			
	ΔT_u	ΔT_v	ΔT_w	Izz (spin axis MOI)	Ixx	Iyy	Ixy
Baseline	**Tu: ±0.31 (cyclic @ twice orbital rate), ±0.16 (cyclic @ twice precession rate)**	**Tv: ±0.25 (cyclic @ twice orbital rate), ±0.16 (cyclic @ twice precession rate)**	**Tw: 0**	**400**	**360 (0.90 Izz)**	**360 (0.90 Izz)**	**0**
Izz	±0.14 (cyclic @ twice orbital rate), ±0.08 (cyclic @ twice precession rate)	±0.13 (cyclic @ twice orbital rate), ±0.08 (cyclic @ twice precession rate)	0	420 (+5%)	360	360	0
Ixy	±0.03 (cyclic @ twice spin rate)	±0.03 (cyclic @ twice spin rate)	±0.06 (cyclic @ twice spin rate), ±0.03 (cyclic @ orbital rate), ±0.06 (cyclic @ precession rate)	400	360	360	4
Ixx	±0.02 (cyclic @ twice spin rate)	±0.02 (cyclic @ twice spin rate)	±0.03 (cyclic @ twice spin rate), ±0.02 (cyclic @ orbital rate), ±0.03 (cyclic @ precession rate	400	356 (0.89Izz)	360	0
Iyy	±0.02 (cyclic @ twice spin rate)	±0.02 (cyclic @ twice spin rate)	±0.03 (cyclic @ twice spin rate), ±0.02 (cyclic @ orbital rate), ±0.03 (cyclic @ precession rate	400	360	356 (0.89Izz)	0

Backup (3 of 7)

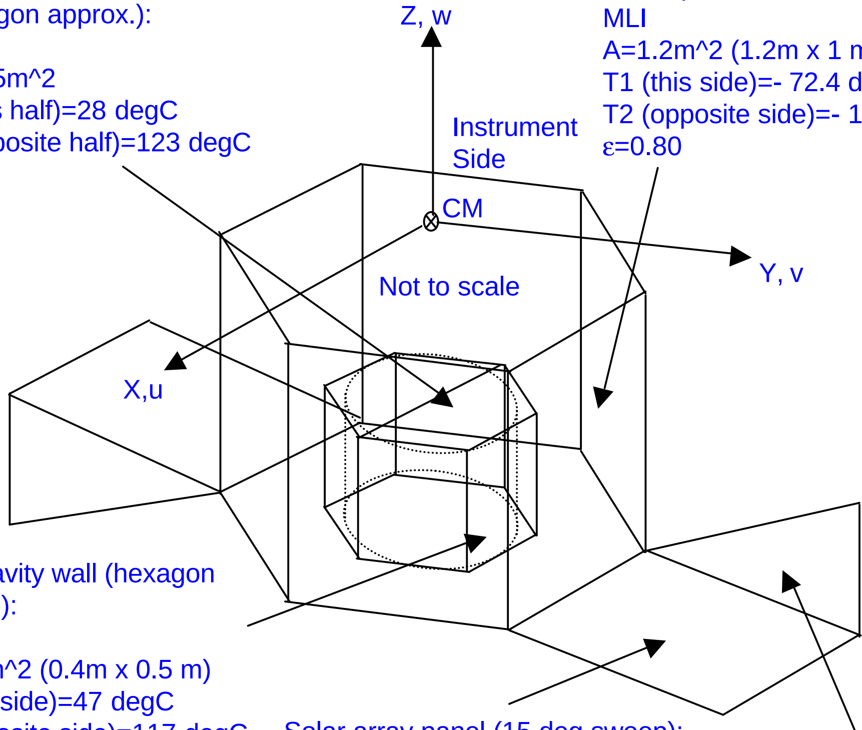
- **Magnetic Torque Due to Residual Spacecraft Dipole Moment**
  - Geosynchronous orbit
  - 45 deg half cone angle (precession)
  - Dx, Dy, and Dz are S/C magnetic dipole vector components in x, y, z.

Variations	Solar radiation torque (10^{-6} N-m)			Parameter values (pole-cm)		
	ΔT_u	ΔT_v	ΔT_w	Dx	Dy	Dz
Baseline	**0**	**0**	**0**	**0**	**0**	**0**
Dx	±0.03 (cylcic @ spin rate), ±0.01 (cyclic @ twice orbital rate), ±0.02 (cyclic @ orbital rate, ±0.01 (cyclic @ precession rate)	±0.03 (cylcic @ spin rate), ±0.01 (cyclic @ twice orbital rate), ±0.02 (cyclic @ orbital rate, ±0.01 (cyclic @ precession rate)	±0.03 (cylcic @ spin rate), ±0.02 (cyclic @ twice orbital rate), ±0.02 (cyclic @ orbital rate	200	0	0
Dy	±0.03 (cylcic @ spin rate), ±0.01 (cyclic @ twice orbital rate), ±0.02 (cyclic @ orbital rate, ±0.01 (cyclic @ precession rate)	±0.03 (cylcic @ spin rate), ±0.01 (cyclic @ twice orbital rate), ±0.02 (cyclic @ orbital rate, ±0.01 (cyclic @ precession rate)	±0.03 (cylcic @ spin rate), ±0.02 (cyclic @ twice orbital rate), ±0.02 (cyclic @ orbital rate	0	200	0
Dz	±0.02 (cyclic @ twice orbital rate), ±0.01 (cyclic @ precession rate)	±0.02 (cyclic @ twice orbital rate), ±0.01 (cyclic @ precession rate)	0	0	0	200

- **Thermal Radiation Torque**

AKM cavity bottom
(hexagon approx.):
MLI
A=0.25m^2
T1(this half)=28 degC
T2(opposite half)=123 degC
ε=0.80

Shear panel:
MLI
A=1.2m^2 (1.2m x 1 m)
T1 (this side)=- 72.4 degC
T2 (opposite side)=- 102.5 degC
ε=0.80



AKM cavity wall (hexagon
approx.):
MLI
A=0.2m^2 (0.4m x 0.5 m)
T1(this side)=47 degC
T2(opposite side)=117 degC
ε=0.80

Solar array panel (15 deg sweep):
Silver Teflon & solar cells:
A=2.3m^2 (1.2m x 1.9 m)
T1 (top surface)=-12 degC
T2 (bottom surface)=-12.7 degC
T3 (top surface, opposite side)=-27.4 degC
T4 (bottom surface, opposite side)=-27.9 degC
ε(top)=0.78
ε(bottom)=0.75

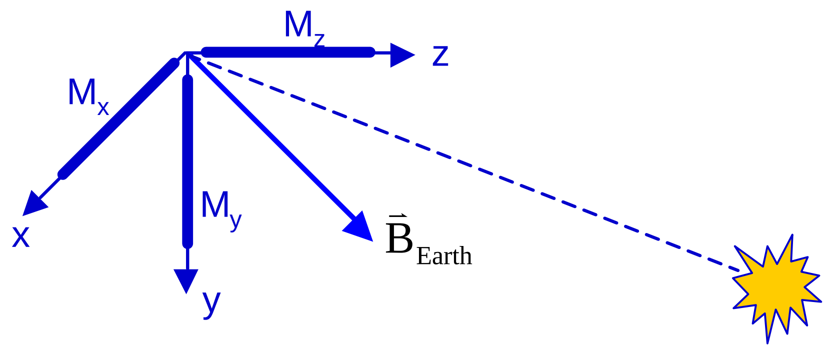
Sources	Thermal radiation torque (10^{-6} N-m)		
	T_u	T_v	T_w
Solar array panels	±0.04 (cyclic @ spin rate)	±0.04 (cyclic @ spin rate)	0
Solar array web	0	0	0
Shear panel	±0.04 (cyclic @ spin rate)	±0.04 (cyclic @ spin rate)	0
AKM cavity wall	±0.16 (cyclic @ spin rate)	±0.16 (cyclic @ spin rate)	0
AKM cavity bottom	±0.08 (cyclic @ spin rate)	±0.08 (cyclic @ spin rate)	0
RSS total	±0.19 (cyclic @ spin rate)	±0.19 (cyclic @ spin rate)	0
Electronics deck	TBD	TBD	TBD
Instrument	TBD	TBD	TBD

Solar array web (15 deg sweep):
Beta cloth:
A=1.7m^2
T1 (top surface)=4.2 degC
T2 (bottom surface)=4.2 degC
T3 (top surface, opposite side)=-39.5 degC
T4 (bottom surface, opposite side)=-39.5 degC
ε=0.8

Backup (5 of 7)

Magnetic Control Concept

Torque Coil Configuration



- ➡ M_x And/or M_y Used for Active Spin Control
- ➡ M_z Used for Active Nutation Control
- ➡ Solar Pressure Used for Passive Precession Control

Feedback Control Laws

$$u_x = k_N I_x(\Omega_{Tx} - w_x)$$
$$u_y = k_N I_y(\Omega_{Ty} - w_y)$$

Nutation Control

$$u_z = k_S I_z(\Omega_S - w_z)$$

Spin Control

Dipole Logic $(\vec{u} = \vec{M} \times \vec{B})$

$$M_x = \frac{u_z B_y}{B_x^2 + B_y^2}$$
$$M_y = -\frac{u_z B_x}{B_x^2 + B_y^2}$$

Spin Control

$$M_z = \frac{u_y B_x - u_x B_y}{B_x^2 + B_y^2}$$

Nutation Control

Backup (6 of 7)

Magnetic Control Hardware

Item	Quantity	Capability	Unit Size	Unit Mass	Unit Power
Torque Coil (Ithaco TR10CFR)	3	(+/-) 15 amp-m^2	38 x 5 x 4 cm	0.454 kg	1.6 W
3-Axis Magnetometer (Ithaco IM-103)	1	(+/-) 120 mG with a resolution of 60 μG[(1)]	16 x 4 x 4 cm	0.227 kg	1 W
			Total	1.6 kg	5.8 W

Note (1): Resolution obtained using a 12-bit A/D converter over a +/- 1 volt range

Backup (7 of 7)

Magnetic Control Simulation Results

***Simulation Includes*:**

- **Geosynchronous Orbit Dynamics and Low-Spin Attitude Dynamics**
- **High-Order Magnetic Field Model**
- **Ideal Sun Precession Control**
- **Gravity Gradient Disturbances**
- **Bias S/C Dipole, Mbias = 0.5 Amp-m2**
- **Magnetometer Random Noise and Bias Errors**
- **High-Pass Magnetometer Filter to Remove Magnetometer Bias**
- **Torque Coil Shut-Off During Magnetometer Sensing**
- **Simple On/off Dipole Logic Using Small Coils (Mx = My = Mz = +/- 15 Amp-m2)**
- **Non-Ideal Inertia Matrix, IS/C =** $\begin{bmatrix} 360 & 3 & 0 \\ 3 & 370 & 0 \\ 0 & 0 & 400 \end{bmatrix}$ **kg-m^2**