Beyond Einstein: From the Big Bang to Black Holes

LISA Propulsion Module Separation Study

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Stephen M. Merkowitz
NASA/GSFC

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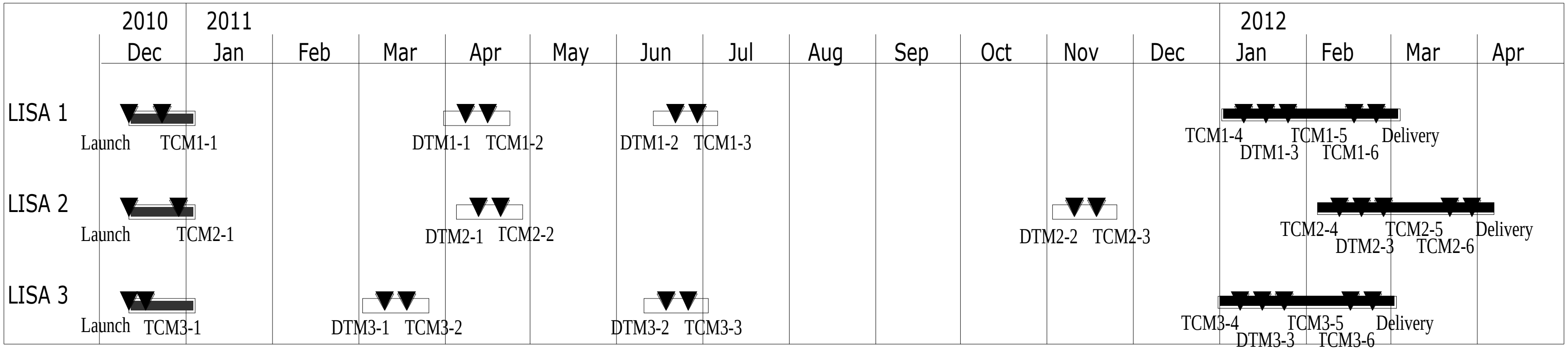
Contributions from:
A. Ahmad, E. H. Cardiff, and T. T. Hyde (NASA/GSFC)
T. Sweetser and J. Ziemer (NASA/JPL)
S. Conkey, W. Kelly III, C. Lashley, and B. Shirgur (Swales Aerospace)

GSFC - JPL

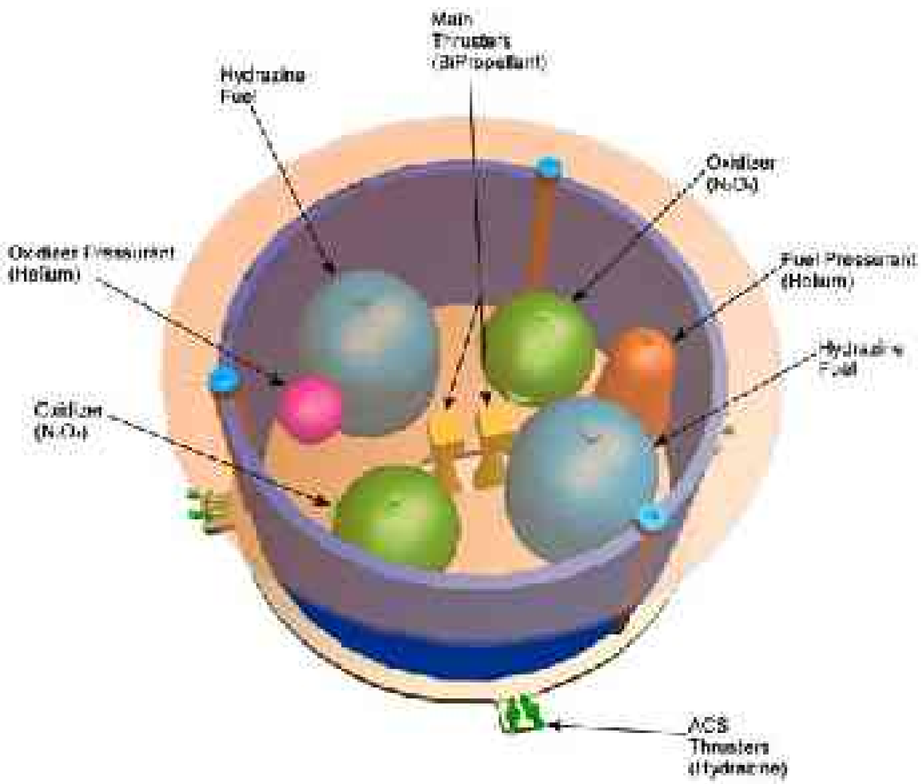
Delivery To Final Orbit

Beyond Einstein: From the Big Bang to Black Holes

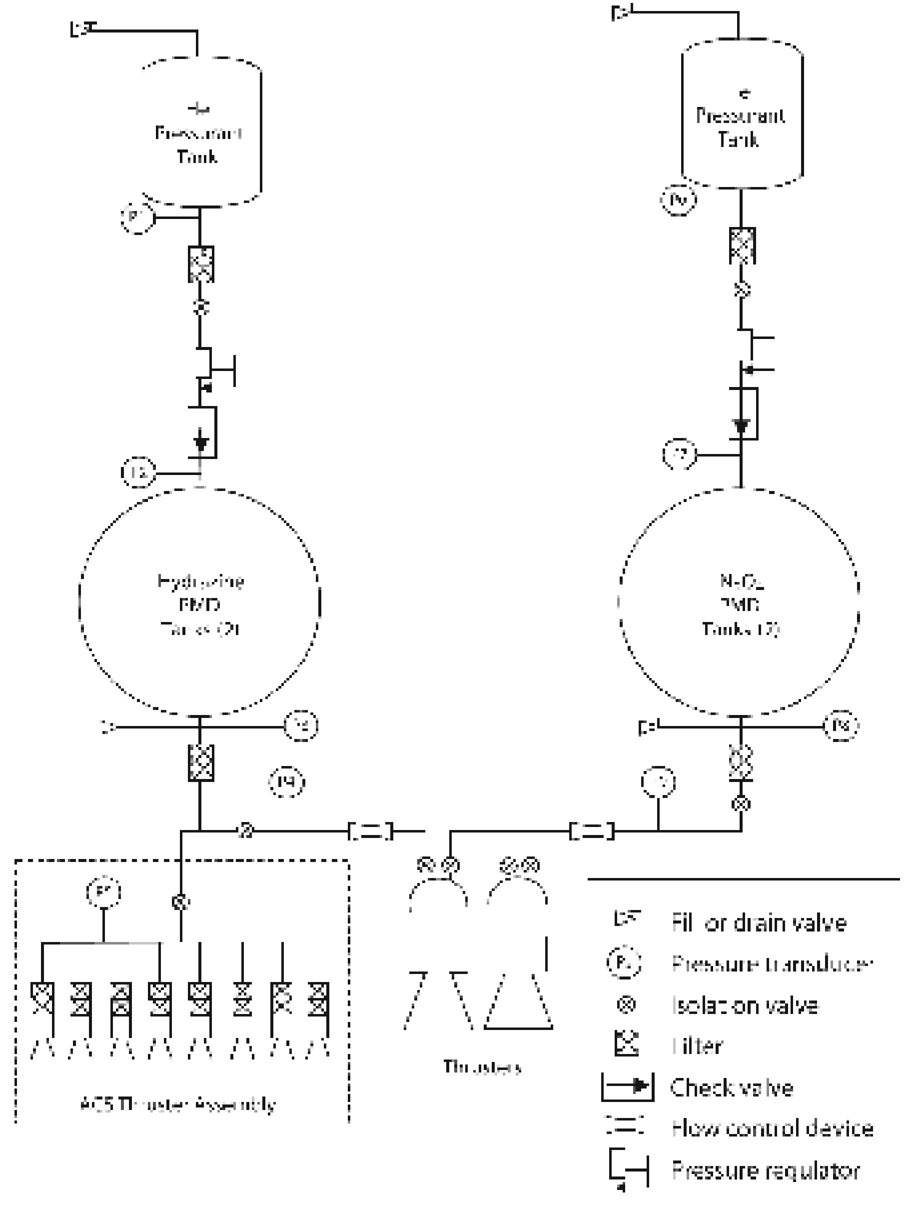
QuickTime™ and a
Cinepak decompressor
are needed to see this picture.



Propulsion Module



LISA Propulsion Module (Chemical Propulsion Version)

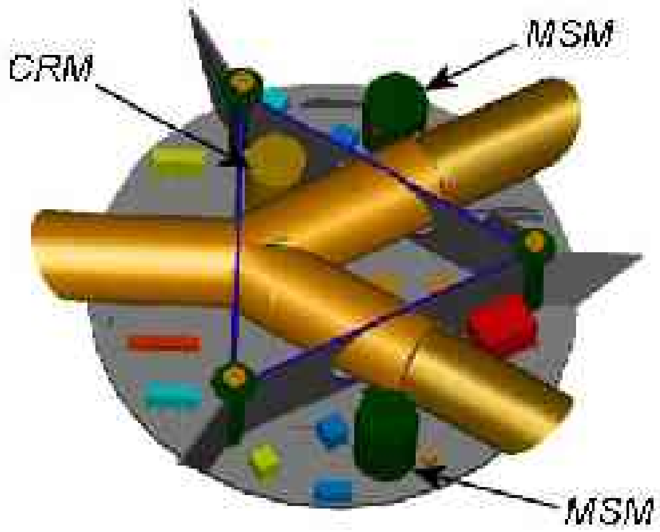


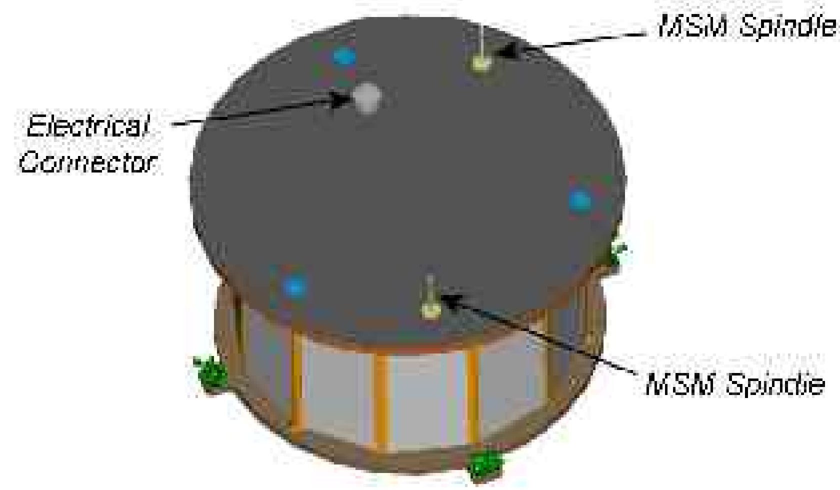
Baseline Propulsion Module Separation

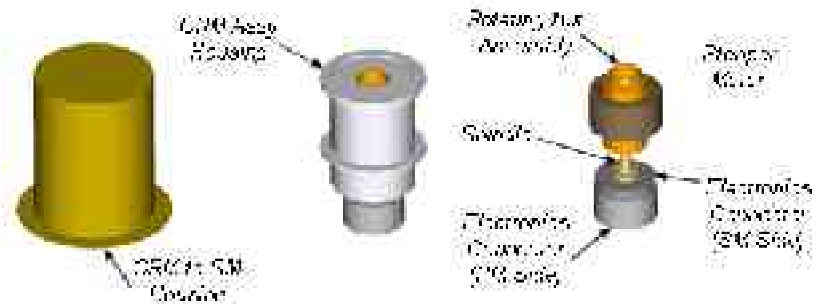
- Immediately after injection into transfer orbit, separation of load carrying parts via Pyronut.
- P/M delivers S/C to operational orbit.
- Perform slew maneuver to leave it in proper attitude.
- Two stage separation:
  - Separation nuts for mechanical separation (4 mechanism with central non-load bearing one actuated last),
  - Spindle drives and a connector release mechanism for electrical separation.
- Direction fixed by P/M AOCS.
- Spindles define separation velocity (3 cm/s, rotation rate of s/c < 1 mrad/s).
- Solar radiation pressure ensures steady increase in separation.

QuickTimeª and a
Video decompressor
are needed to see this picture.

Separation Mechanisms





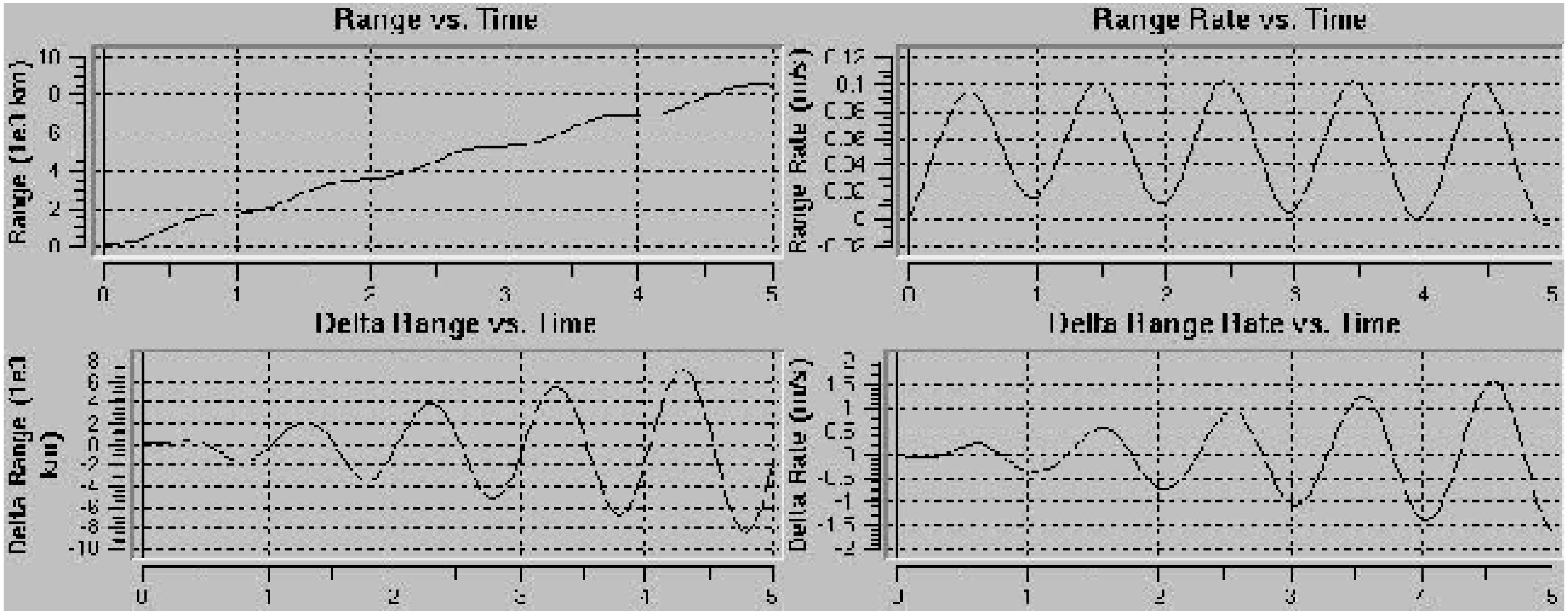


Goals of study

- Define maximum allowable change in velocity during separation constrained by orbit sensitivity.
- Redefine tip-off requirements (previous definition was to constraining, < 1 mrad/s, due to omission of a battery).
- Define maximum thrust requirements for micronewton thrusters.
- Define power requirements throughout separation.
- Identify propulsion module separation mechanism options.

Effects of Final Delivery Error

- Period errors dominate long-term stability of constellation.
  - Lead to a linear secular change in position.
  - Order of magnitude more effect after five years than other component errors.
- A 100 km radius error has the same effect as a 2 cm/s speed error over five years:
  - Differences in range to other spacecraft grows to almost 10000 km,
  - Differences in range rate to other spacecraft grows to almost 2 m/s.



Sensitivity to Errors

Error Source	Magnitude	Range Rate Oscillation Amplitude
Radial position	100 km	Increasing to about 1.9 m/s after 5 years
Tangential position	100 km	0.06 m/s
Vertical (out of ecliptic) position	100 km	Initially 0.02 m/s; 0.04 m/s after 5 years
Radial Velocity	0.02 m/s	0.08 m/s
Tangential Velocity	0.02 m/s	Increasing to about 1.9 m/s after 5 years
Vertical velocity	0.02 m/s	Initially 0.02 m/s; 0.04 m/s after 5 years

Contributors to Final Delivery Error

- Delivery control pre-separation
  - The final clean-up TCM (Trajectory Correction Maneuver) for each spacecraft will be less than 10 cm/s with an expected execution error of <1 mm/s.
- Delivery knowledge pre-separation
  - Absolute position within a kilometer and absolute velocity within a fraction of a mm/s possible.
- Separation velocity error
  - ~20 mm/s (mostly radial)
- Delay in drag-free operation
  - Solar radiation pressure is equivalent to change in $GM_{\odot}$.
  - 3 weeks of pressure produces an outward displacement of 122 km and a backward displacement of 30 km.
  - If drag free operations starts after 3 weeks, period difference from original orbit is ~1 millisecond.

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Tip-off Simulation

- Determine the time to recover and resulting battery sizing as a function of initial (tip-off) angular velocity
- Single axis model only
- 30 μN thrusters in hex configuration
- Power system:
  - Continuous load of 220 W
  - Solar array max power of 466 W
  - Battery sized so that worst case depth of discharge is 60%
- Bang-bang control

QuickTimeª and a
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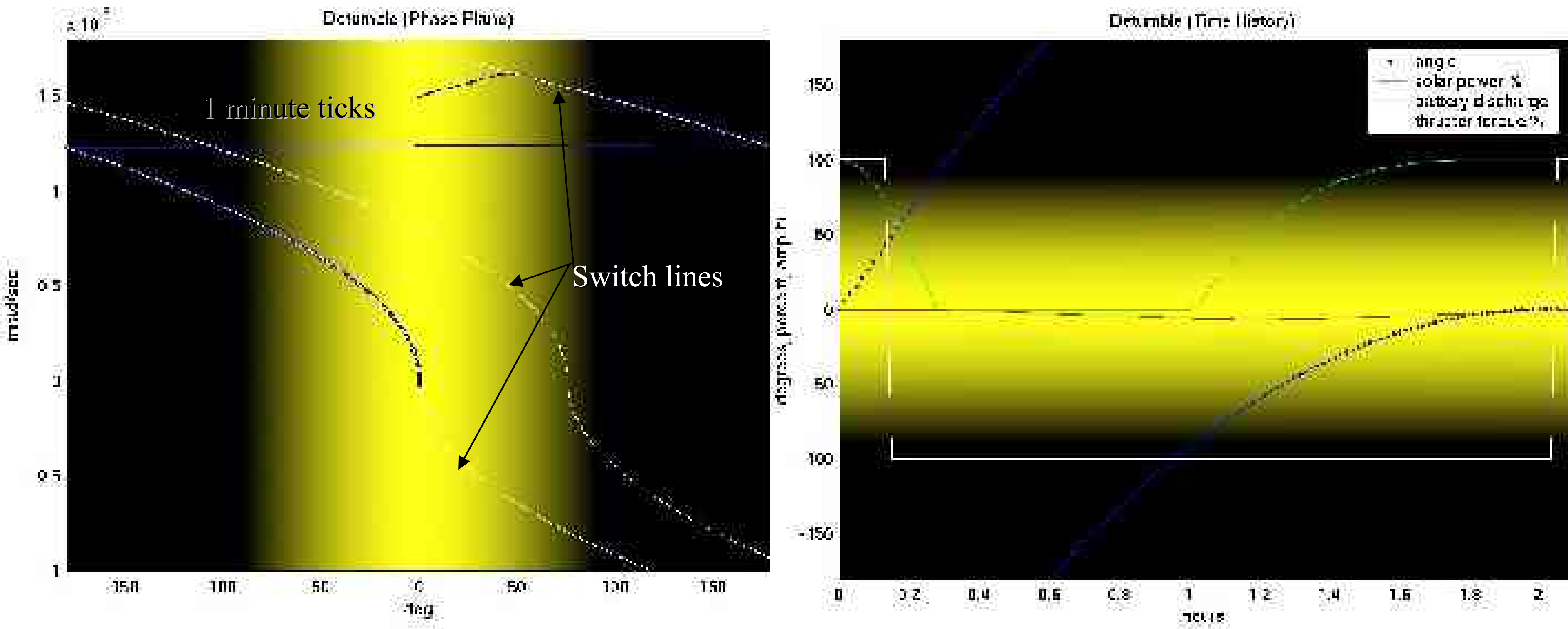
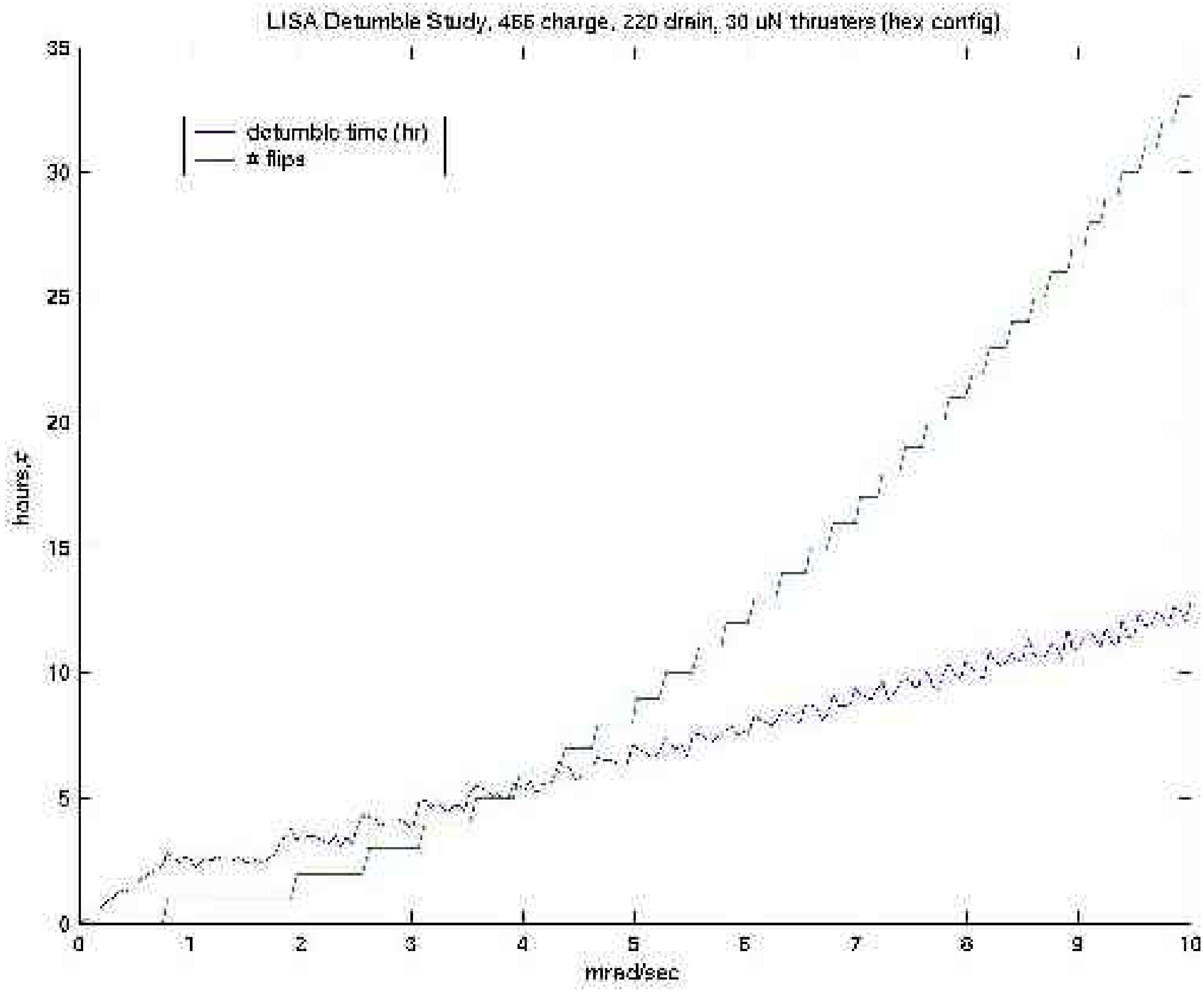
Phase Plane Controller

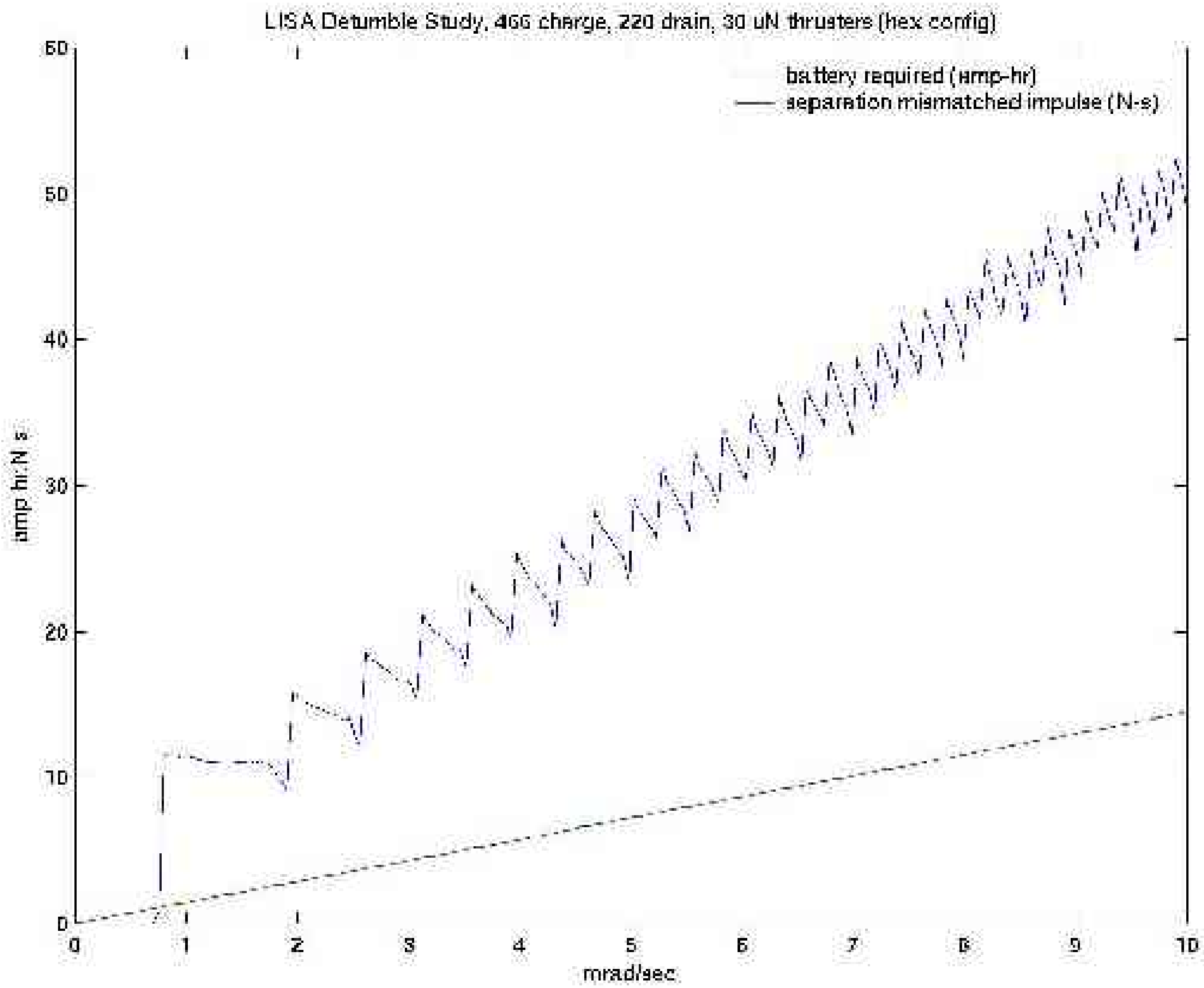


- Switch logic
  - Traditional time optimal phase plane logic (parabolic switch line)
  - Wrapped to shoot for nearest “0” (sun-facing position)
  - Two extra switch lines to bump for “once more over” during penultimate pass

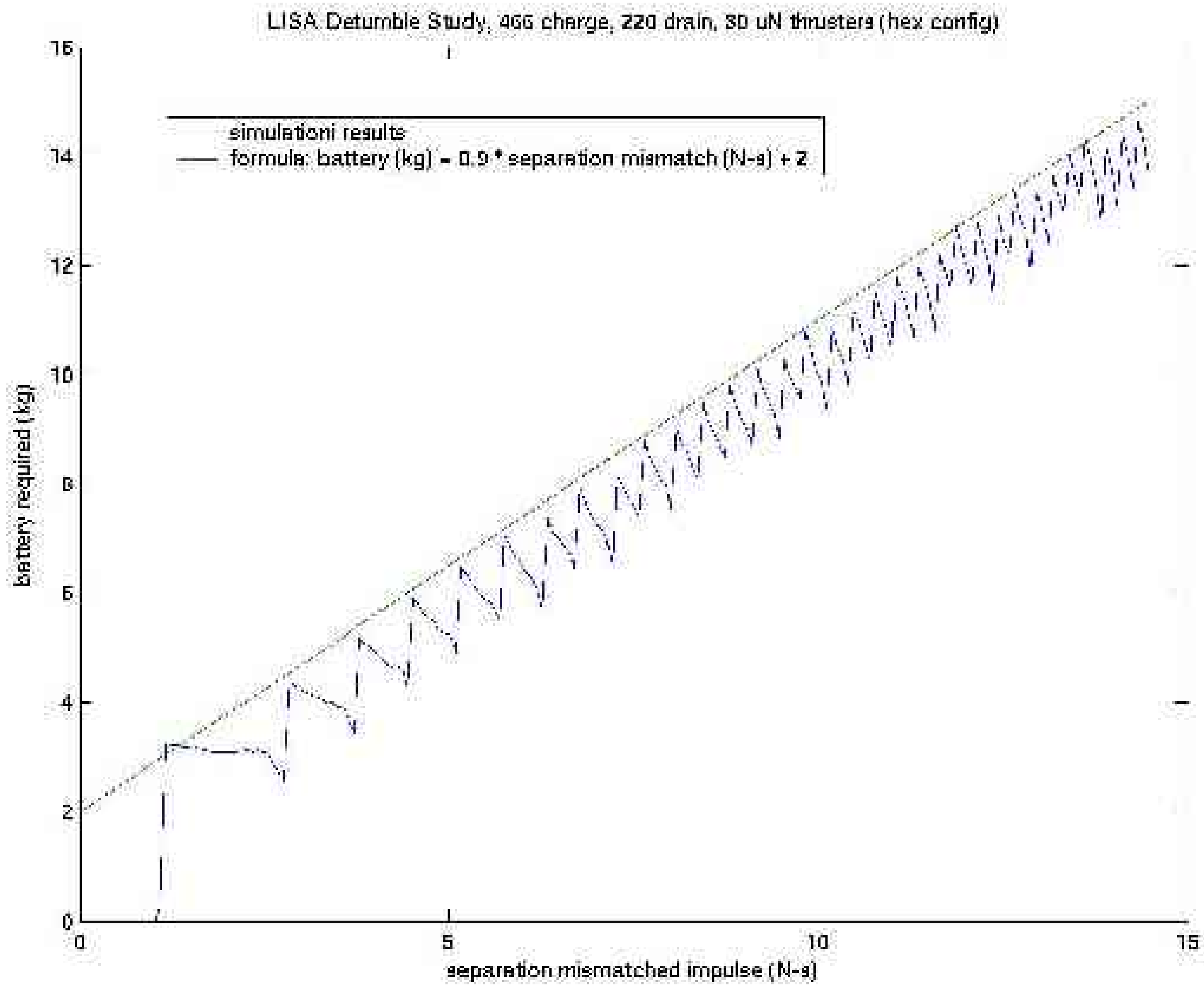
Time & Flips


LISA Detumble Study, 466 charge, 220 drain, 30 uN thrusters (hex config)
detumble time (hr)
flips
hours,#
mrad/sec
0
5
10
15
20
25
30
35
0
1
2
3
4
5
6
7
8
9
10

Battery Size



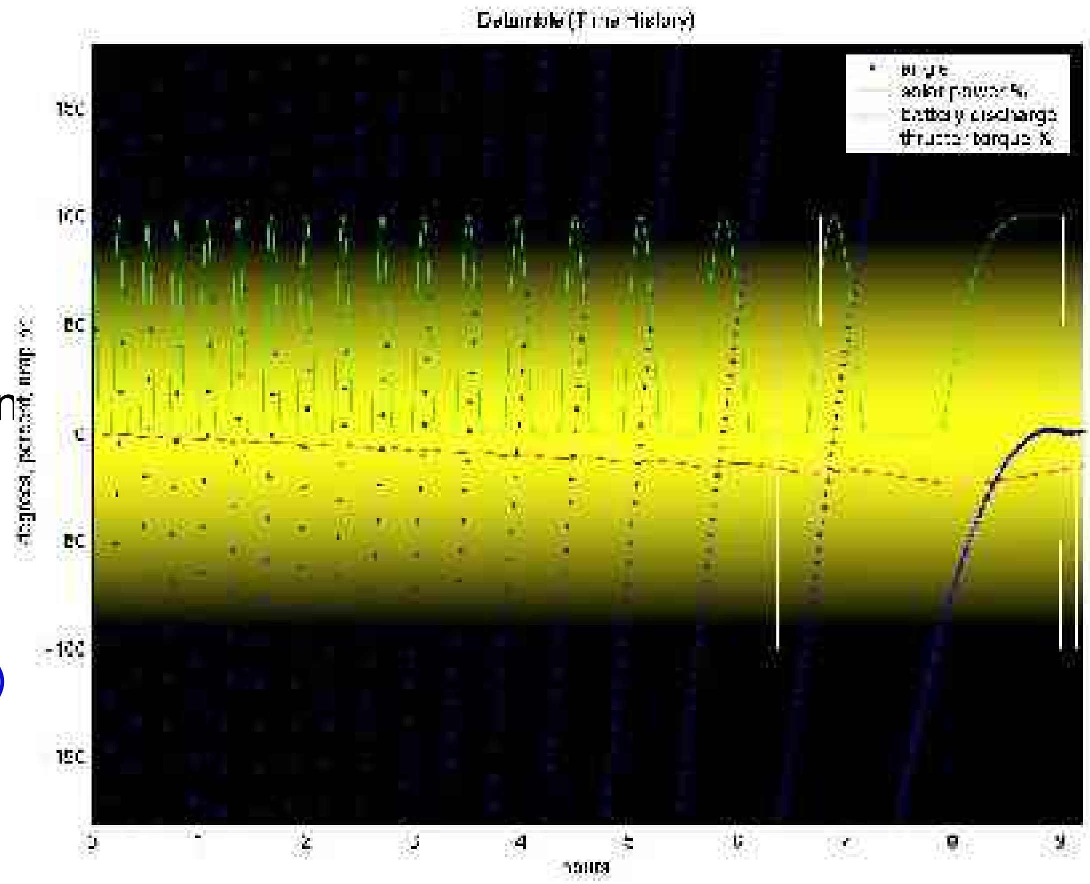
Battery Size vs. Mismatch



- Battery mass (kg) = 0.9 * Sep Imp Mismatch (N-s) + 2

Reasonable Case

- Initial angular velocity = 7 mrad/s (0.401 deg/sec)
- Time to finish = 9.2 hours
- Battery size = 40 amp-hour, mass = ~11 kg
- Number of flips = 17
- 7 mrad/sec converts to separation impulse mismatch of 10.1 N-s
  - If all three uncertain to this amount, then the $\Delta v = 0.019$ m/s
  - This means 70.9 hours (~3 days) of solar pressure (30 uN) is required to null.



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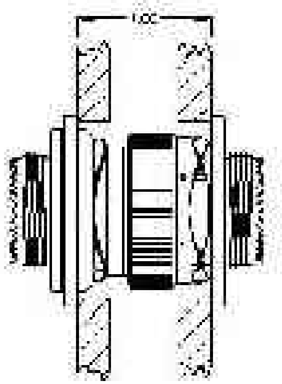
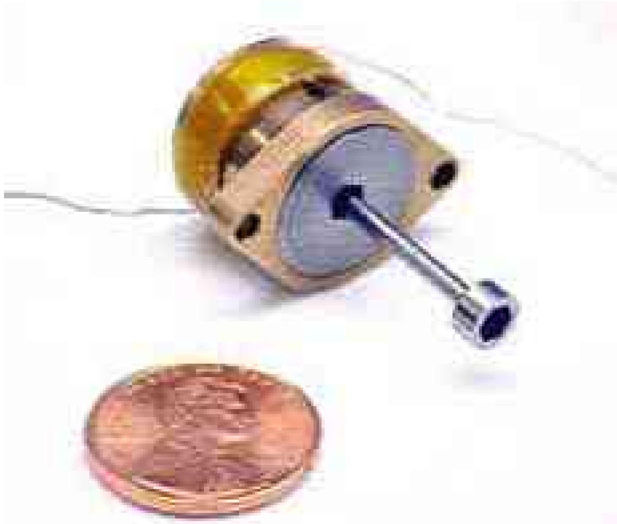
Separation System

- With relaxed tip-off requirements a number of standard separation systems are available.
- A number of release devices are available.
  - Non-explosive device is desirable
  - Final selection can be made based on reliability, mass,…
- Zero force connector can be used for electrical connection.



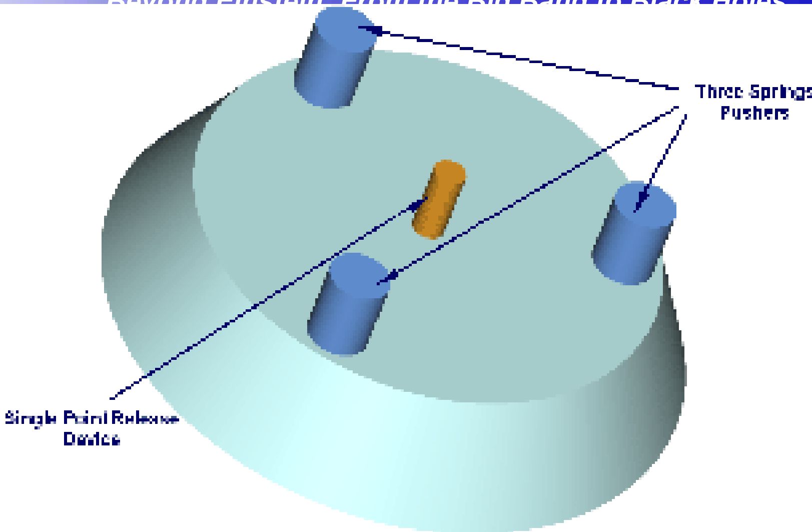
Zero Force Connector

Starsys FASSN Separation Nut

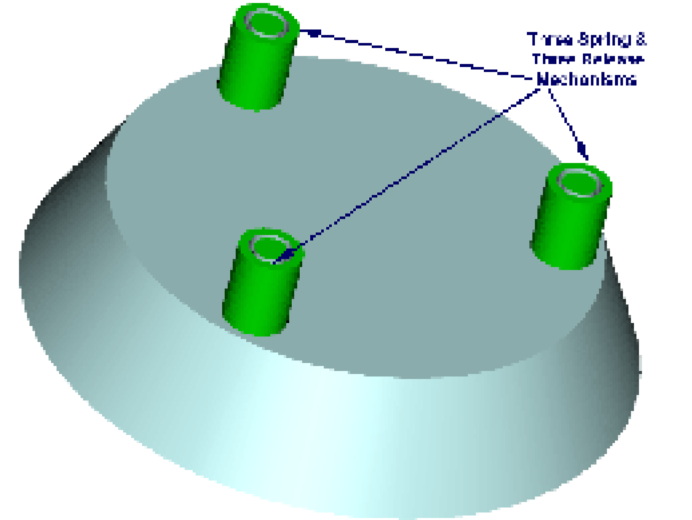


Starsys Mini Qwknut

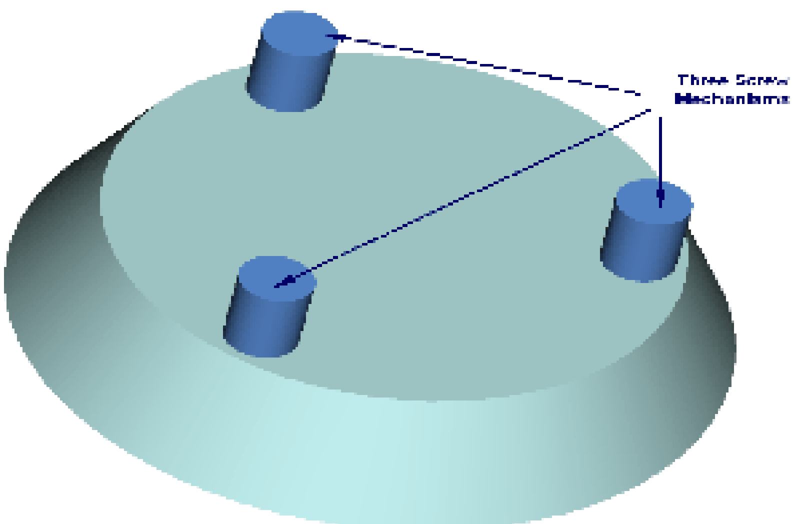
Separation Configuration Options



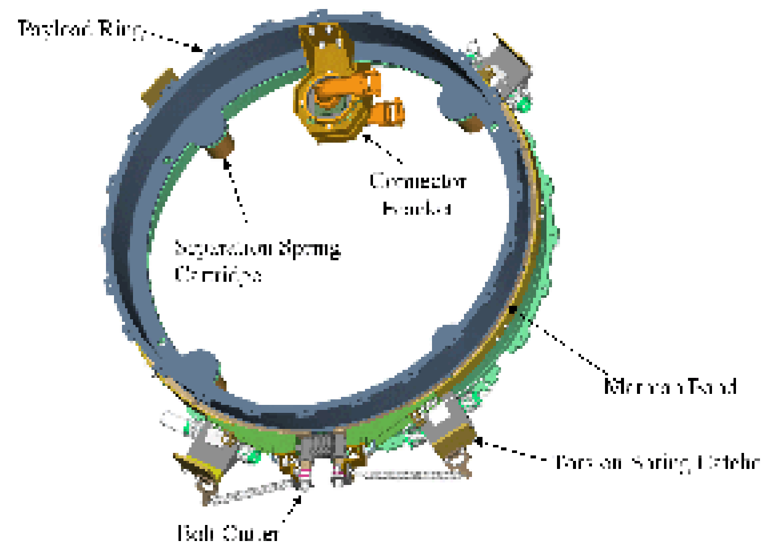
Single point release w/ 3 springs



Three spring release



Three screw release



Marman band

Summary

- Orbits not sensitive to reasonable delivery and separation errors.
- Orbits not sensitive to a delay of drag-free operation.
- Tip-off requirement can be relaxed to ~7 mrad/s.
- Maximum thrust requirement of 30 μN sufficient:
  - No major technology change from LISA Pathfinder!
- Several separation system options available:
  - No new technology development required!