ADVANTAGES AND DISADVANTAGES OF A SPHERICAL PROOF MASS FOR LISA

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CONSIDERATIONS IN DESIGN OF INERTIAL SENSOR FOR LASER INTERFEROMETER SPACE ANTENNA (LISA)

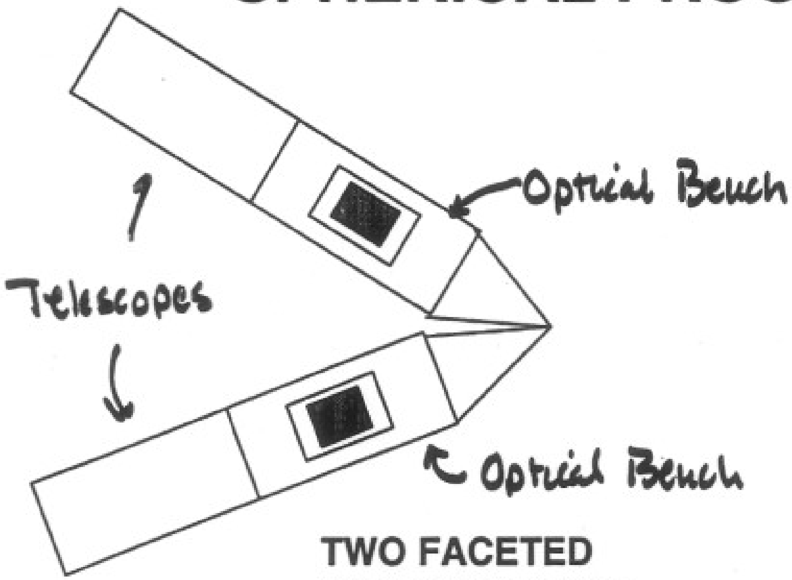
BASELINE DESIGN (FACETED PROOF MASS) OF INERTIAL SENSOR FOR LISA

- APPEARS TO BE ADEQUATE TO MEET REQUIRED SPECIFICATION,
- IS BASED ON SPACE-QUALIFIED ACCELEROMETERS THAT HAVE FLOWN ON SHUTTLE AND OTHER MISSIONS (ONERA),
- HAS RECEIVED CAREFUL THOUGHT IN DESIGN OVER THE LAST SEVERAL YEARS.

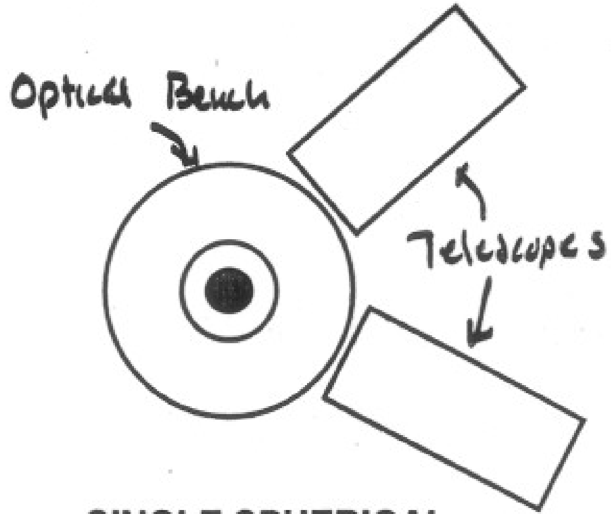
WHY CONSIDER ALTERNATE APPROACHES?

- CAN SOME OF THE DESIGN CONSTRAINTS BE RELAXED WITH ALTERNATE APPROACHES? COULD OVERALL DESIGN BE SIMPLIFIED?
- WHAT CAN WE LEARN ABOUT THE BASELINE DESIGN BY CONSIDERING ALTERNATE APPROACHES?
- WOULD A SPHERICAL PROOF MASS BE USEFUL FOR OTHER MISSIONS?

SPHERICAL PROOF MASS FOR LISA



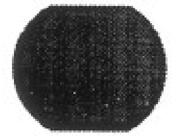
TWO FACETED PROOM MASSES



SINGLE SPHERICAL PROOF MASS

	Faceted Proof Mass	Spherical Proof Mass
Number of Proof Masses	2	1 Slowly Spinning
Controlled Degrees of Freedom	9 out of 12	0 out of 6
Gap Between Housing and Mass	~ 1 mm	~ 1 cm

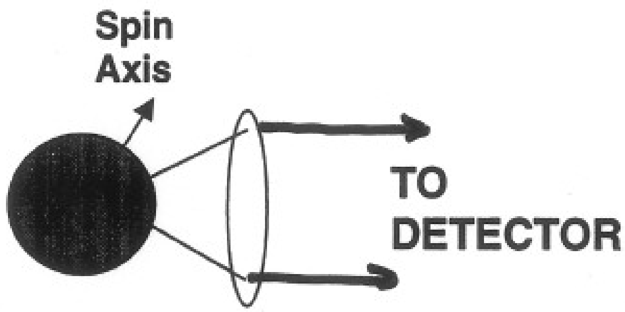
CAN A SPHERICAL PROOF MASS MAKE A GOOD MIRROR?



	SPHERE	NEAR SPHERE
Material	AuPt	AuPt
Radius	2.3 cm.	2.3 cm.
Density Inhomogeneity	10^{-4}	10^{-4}
Asphericity	50 nm	100 nm
Mass Unbalance (center of mass – center of spherical surface)	2.3 μm	1 μm radial 3 μm axial
Fractional Difference in Moments of Inertia	1.4×10^{-5}	0.04
Spin Frequency	10 Hz	10 Hz
Polhode Frequency	1.4×10^{-4} Hz	0.4 Hz

Polhode: Path followed by Spin Axis in Body-Fixed Reference Frame
- Determined by Euler's Equation of Motion

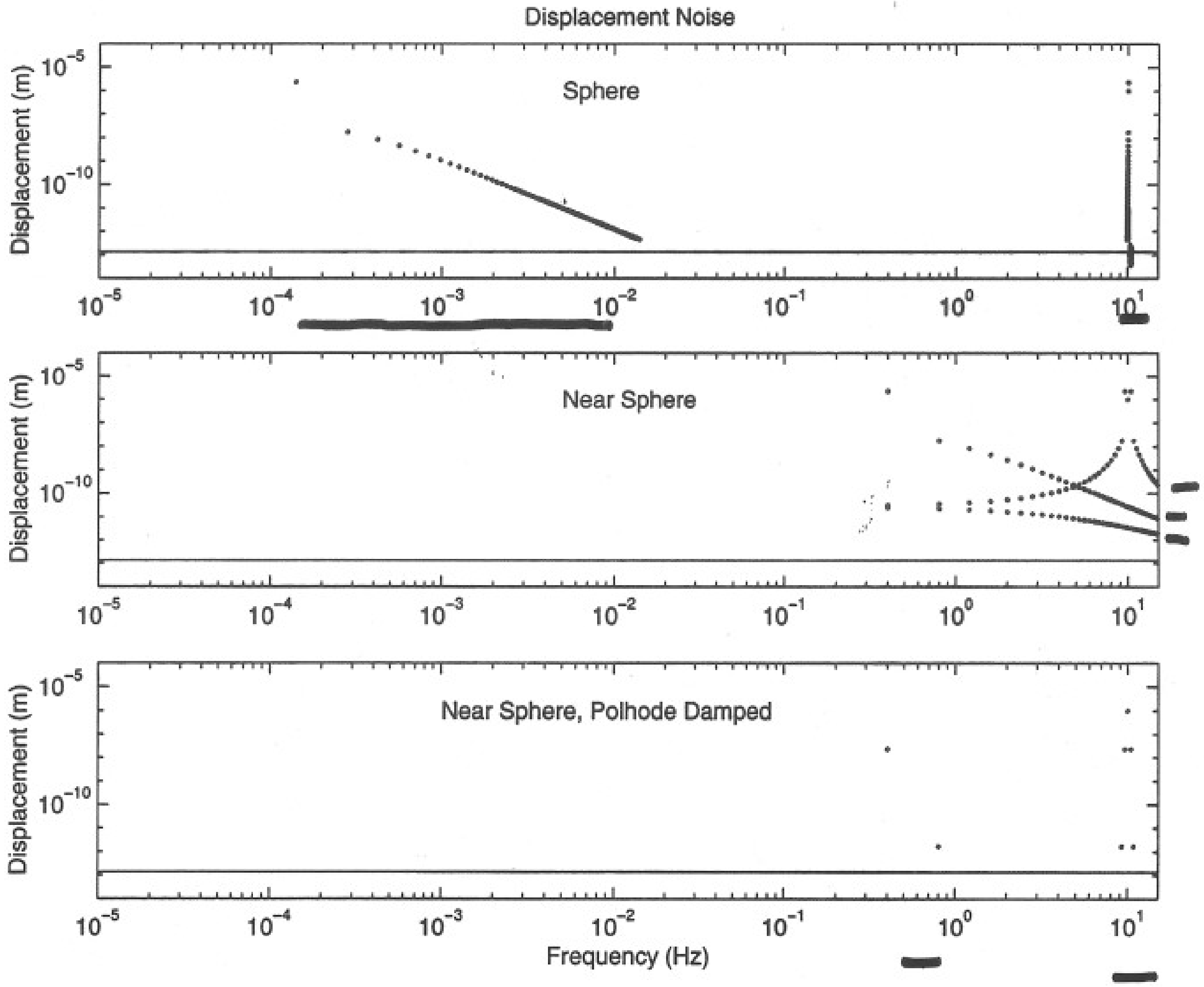
Optical Reflections From an Imperfect Spinning Spherical Surface

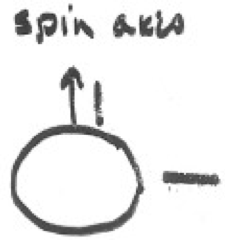


Analysis Method:

- In a rotor-fixed coordinate system aligned with principal axes, expand rotor shape in spherical harmonics
- Use rotation matrices to transform
  - to rotor-fixed reference frame with z-axis aligned with instantaneous spin axis (polhode motion)
  - to inertially-fixed reference frame where spin axis is aligned with z-axis (spin)
  - to direction of incoming light
- Find average displacement weighted over reflected light beam

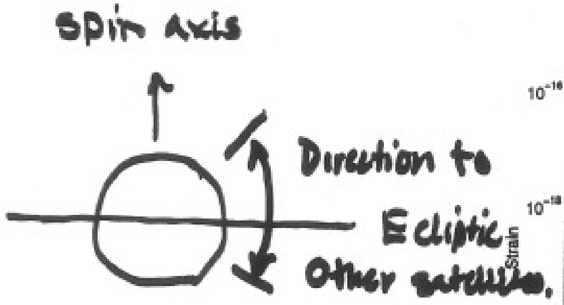
FREQUENCY DISTRIBUTION OF MEASURED DISPLACEMENT

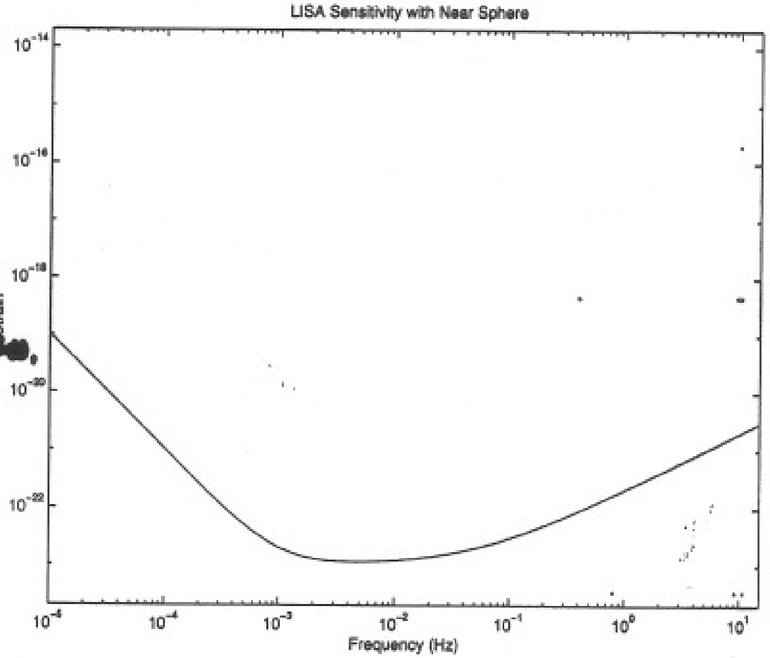




EFFECT OF ROTOR SURFACE ON INTERFEROMETER SENSITIVITY

NEAR SPHERE, POLHODE DAMPED

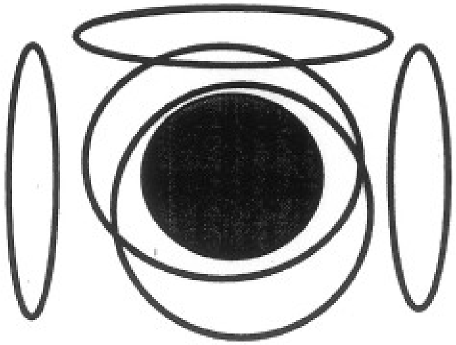




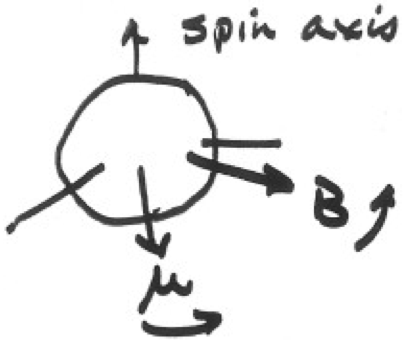
OTHER CONSIDERATIONS:

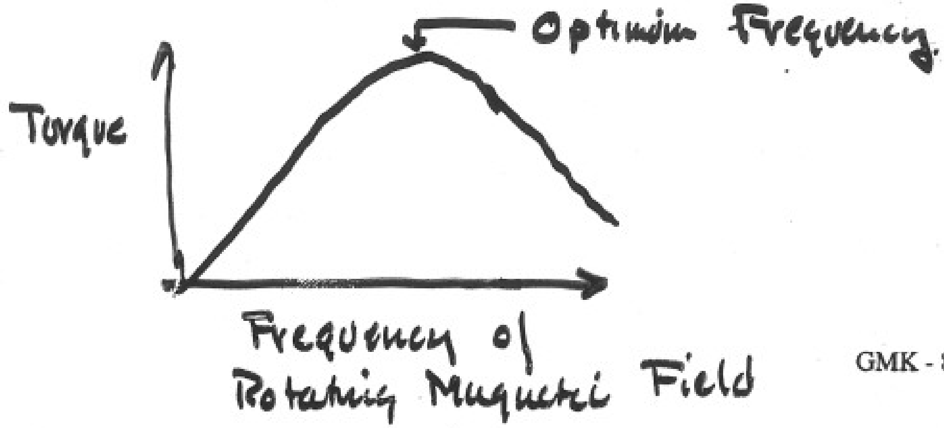
- Sphere is common reference for two arms of interferometer. Some part of the displacement will be incoherent
- Sensitivity Changes as plane of interferometer changes
- Effects of Even Harmonics (l=even) may be decreased by measuring opposite sides of sphere

DESIGN CONSIDERATIONS
Spin Up, Polhode Damping,
Position Sensing



	Methods	Design Parameters
Spin Up	Eddy Current	Spin up rate 1.5×10^{-4} Hz/sec for 1 g field at 67
Polhode Damping	Passive Magnetic Active Magnetic	Time constant 10hr. for 50 g field
Forcing	Eddy Current	Specific force 10^{-6} g with 1 gauss field and 1 gauss/10 cm. field gradient
Caging	Mechanical	
Charge Control	Ultraviolet	
Optical Position Readout	Confocal Microscope Light from interferometer	





COMPARISON OF REQUIREMENTS TO MAINTAIN ACCELERATION NOISE < 10^{-15} m/sec^2 $\sqrt{Hz}$

	Two Faceted Proof Masses	One Spherical Proof Mass
1. Coupling of S/C motion to Proof Mass		
a.) Coupling, K/m	10^{-6}/sec^2	<10^{-7} sec^2
- Position Sensing		
- Inhomogeneous Contact Potentials		
- Forcing		
- Charge Measurement		
- Gravitational		
- Charge		
b.) Position of S/C relative to Proof Mass	10^{-9} m/$\sqrt{Hz}$	>10^{-8} m/$\sqrt{Hz}$
- Position Readout		
- Thruster Noise		

Note: Effect of laser phase noise also affected by position of S/C relative to Proof Mass

2. Acceleration due to charged rotor		
a.) Lorentz Force on Charge Rotor	No change	
b.) Electrostatic Force Noise		reduced
c.) Interaction with Noisy Voltage		reduced
3. Variation in Gravitational Acceleration		symmetry
- Thermal Design		

COMPARISON OF REQUIREMENTS TO MAINTAIN ACCELERATION NOISE $< 10^{-15}$ m/sec^2 $\sqrt{Hz}$

	Two Faceted Proof Masses	One Spherical Proof Mass.
4. Radiation Effects		
a.) Differential Radiation Pressure		No change radiation pressure on p.m.
b.) Radiometer Effect		{ spin averaged ⊥ / no change ∥
5. Thermal Noise		
a.) Brownian Motion due to Residual Gas		No change
b.) Dielectric Loss		Reduced
6. Cross-Coupling to Other Degrees of Freedom		Reduced

7. Magnetic Disturbance

a.) Magnetic Susceptibility of Material $\chi \sim 10^{-6}$ $\quad B\frac{dB}{dx} \lesssim 10^{-10} \frac{T^2}{m\sqrt{Hz}}$, same

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Sphere Only

b.) Barnett Moment $\quad \frac{dB}{dx} < 3\times10^{-2} \frac{T}{m\sqrt{Hz}}$.

c.) Eddy Current Dipole Moment $\quad B\frac{dB}{dx} \ll 10^{-14} \frac{T^2}{m\sqrt{Hz}}$!

- Sphere Is More sensitive to Magnetic Disturbances
- Magnetic Shielding

ADDITIONAL QUESTIONS

- Spherical Proof Mass Could Lead to Smaller Spacecraft (One Optical Bench)

  BUT Overall Configuration with 3 spacecraft Not Fault Tolerant.

- Overall Control System Simplified with Spherical Proof Mass
  - No need to control additional degrees of freedom

  BUT Need Optical Position Sensor
  Eddy Current Spin Up and Forcing

- Open Issues:
  - Manufacturing Issues High Density Sphere
  - Caging
  - Optical Position Sensor
  - Telescope Articulation