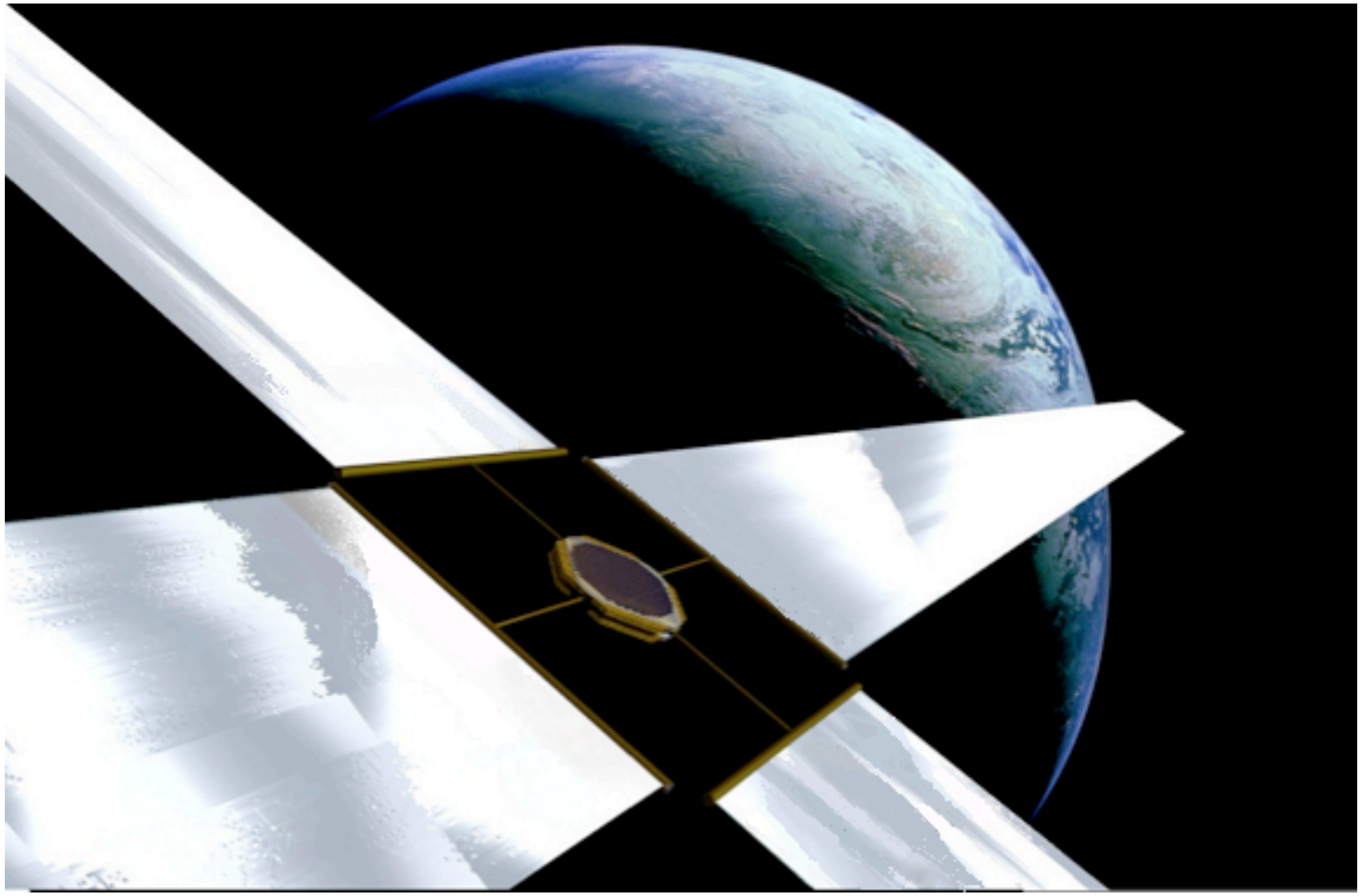
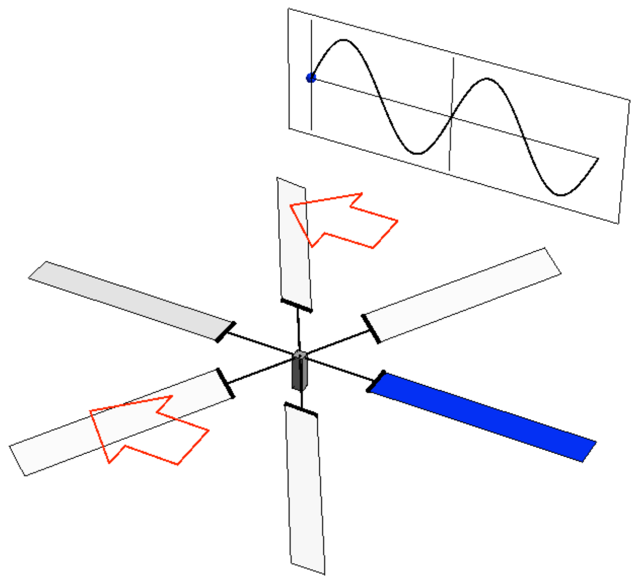
Solar Cube Heliogyro Cubesat



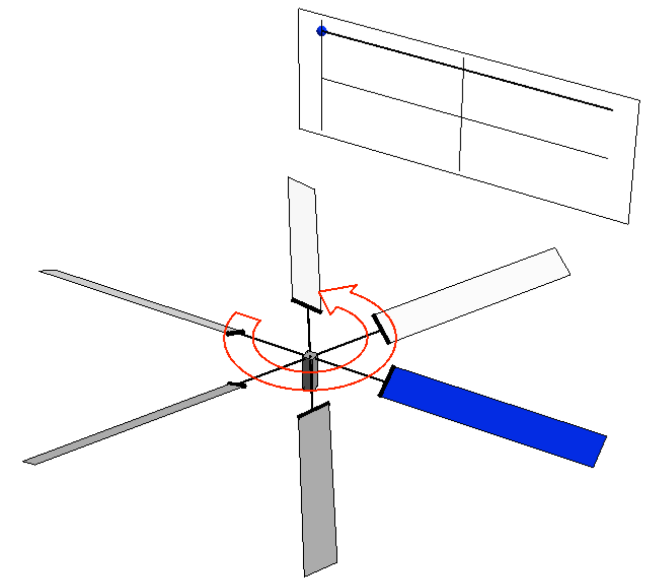
Opening Solar System Exploration to the Masses

Richard S. Blomquist, PhD

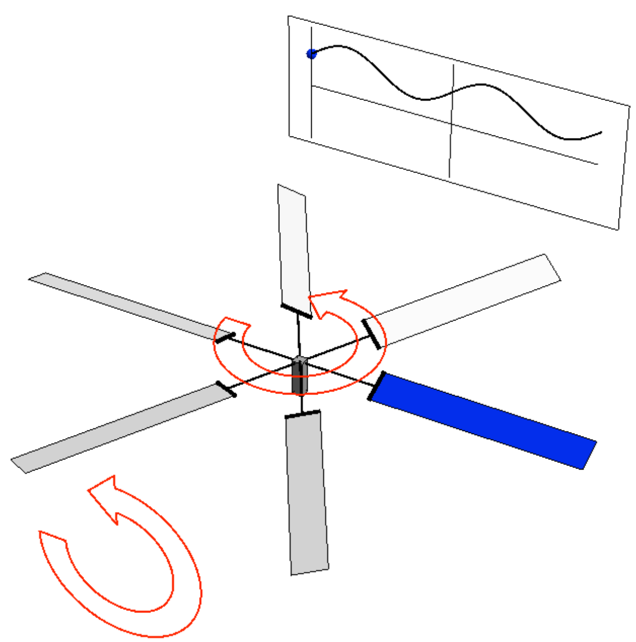
Pitch Maneuvers



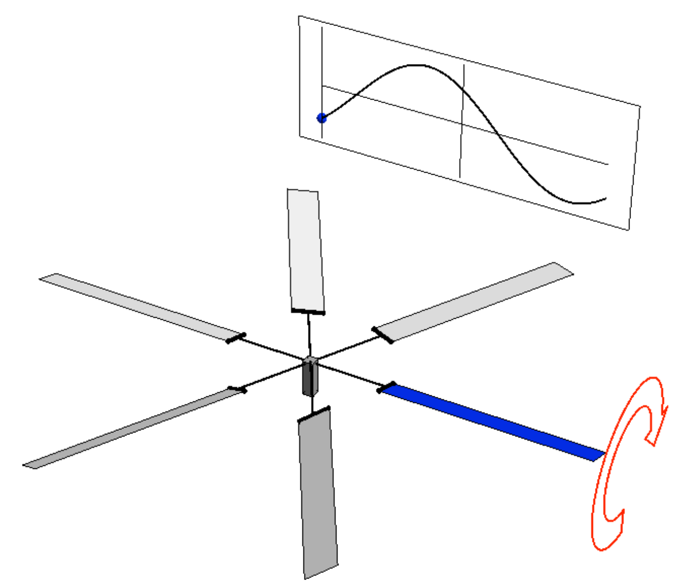
Cyclic



Collective

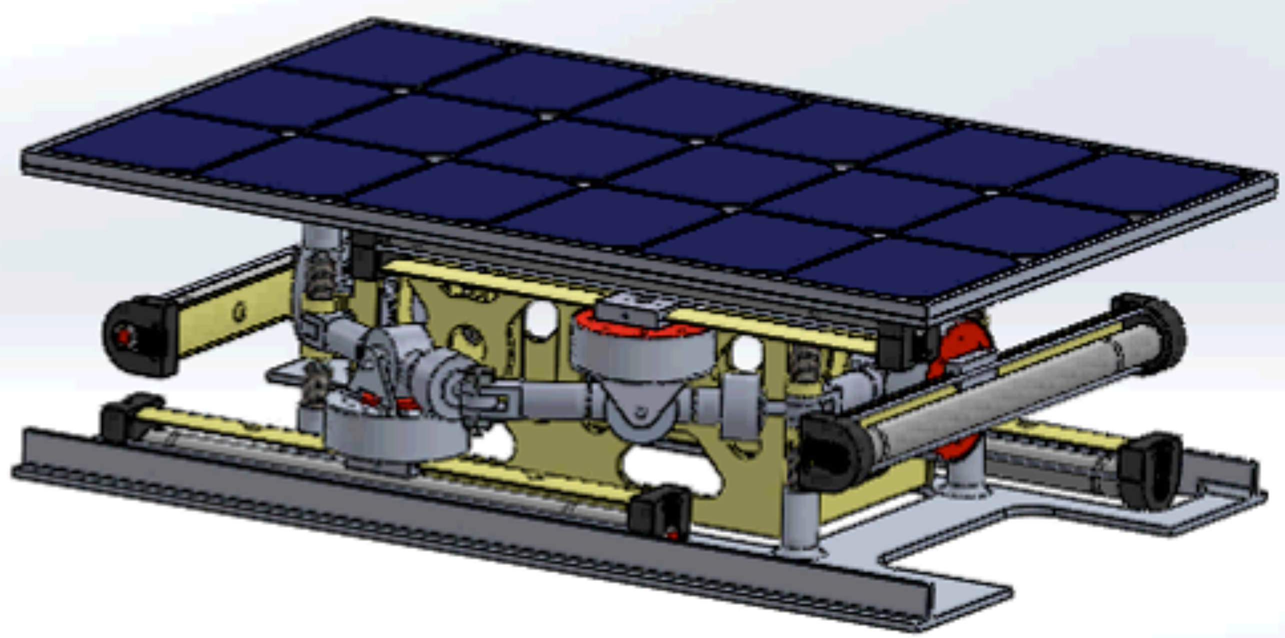


Collective-cyclic



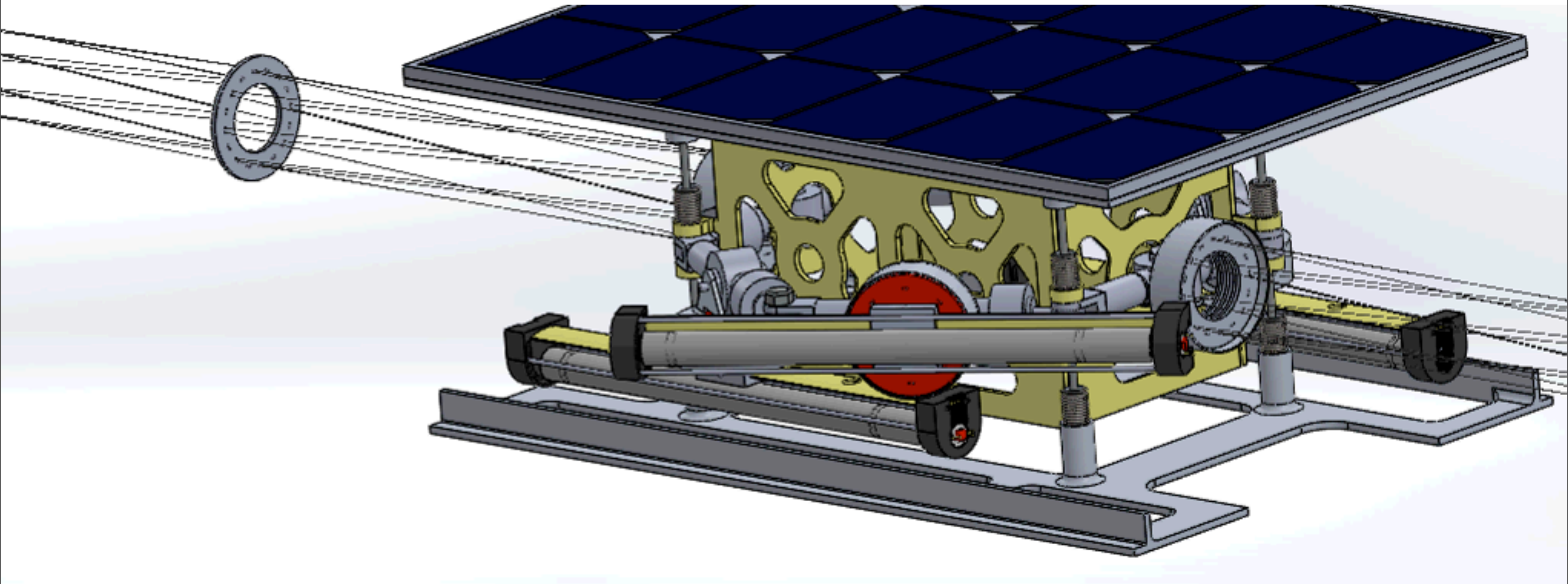
Half-P

Solar Cube



- 6U Form Factor
- 6 Blades, 0.2m x 3µ x 200 m
- Charact. Accel = 0.22 mm/s^2
- Expanding Chassis
- Articulating Booms
- 2U Avionics/Payload
- Total Weight < 10 kg.

Solar Cube Deployment



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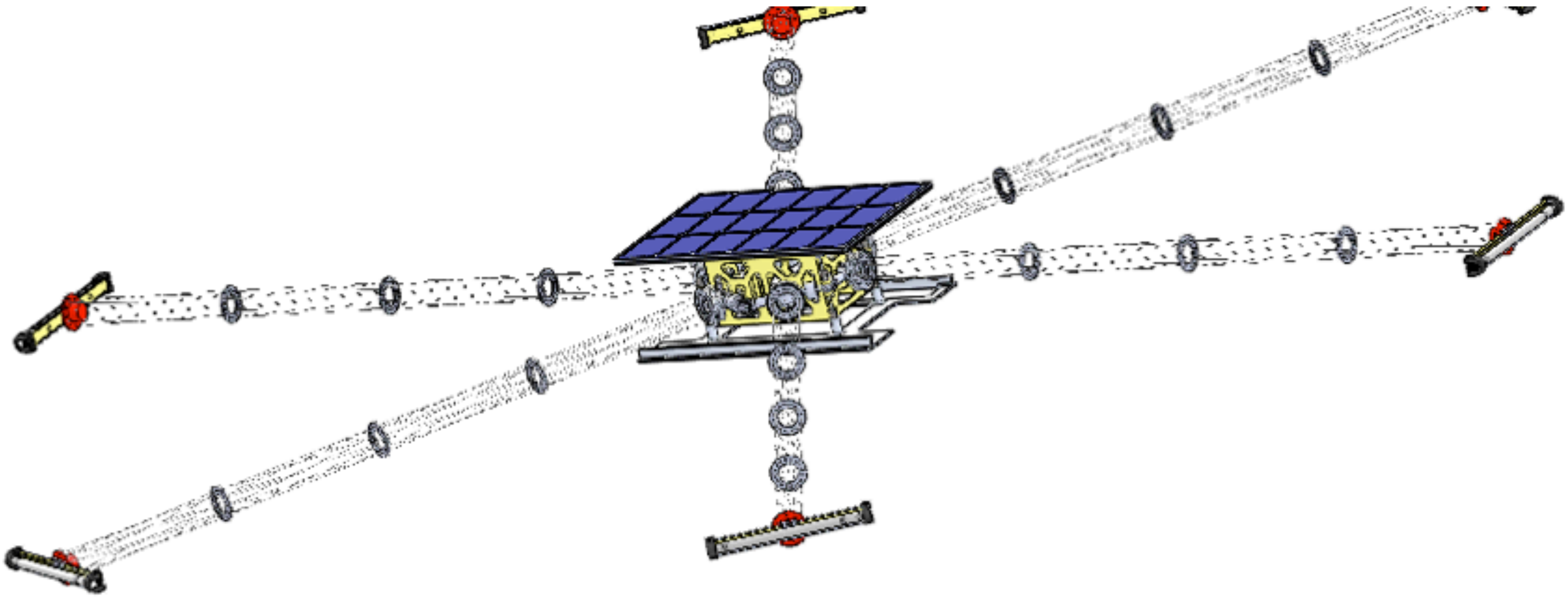

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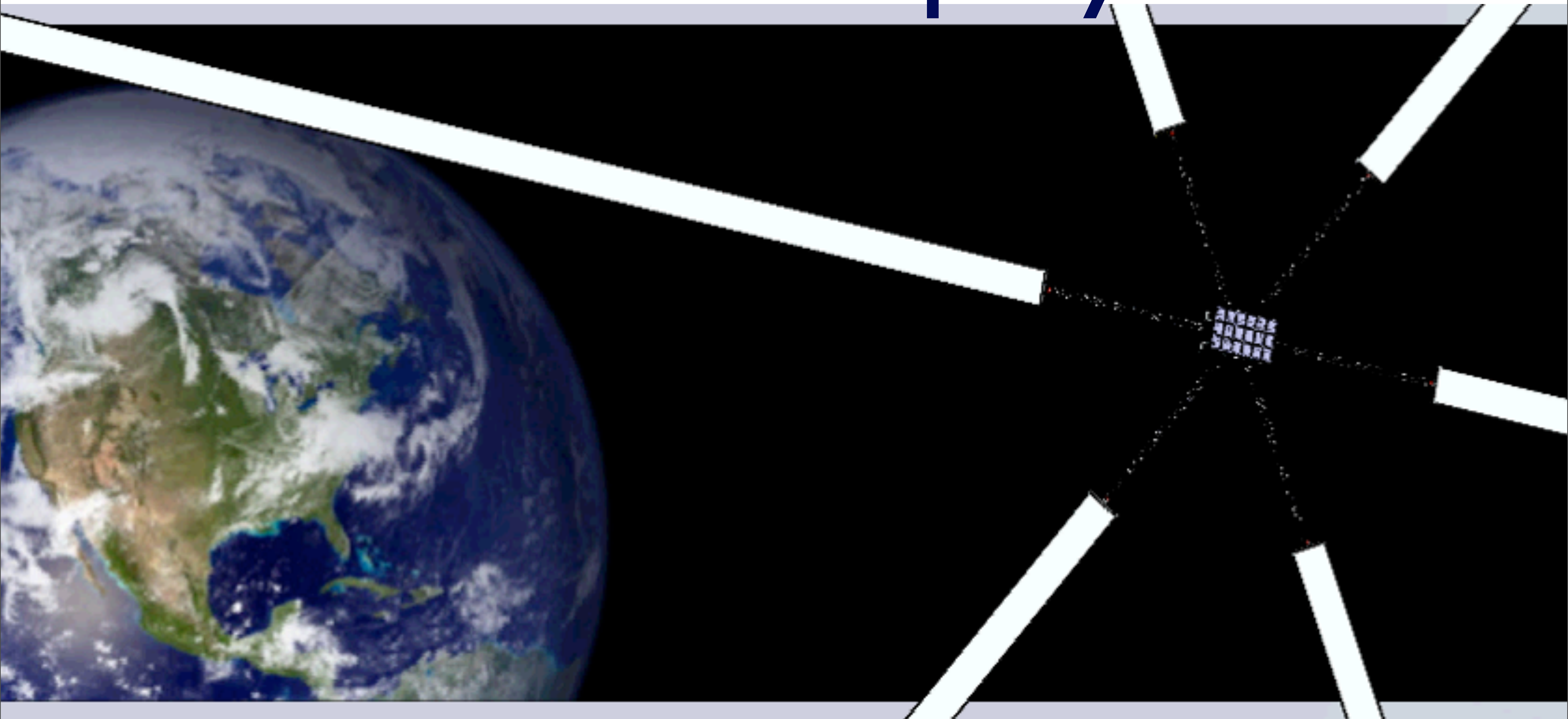

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- 2U Avionics/Payload
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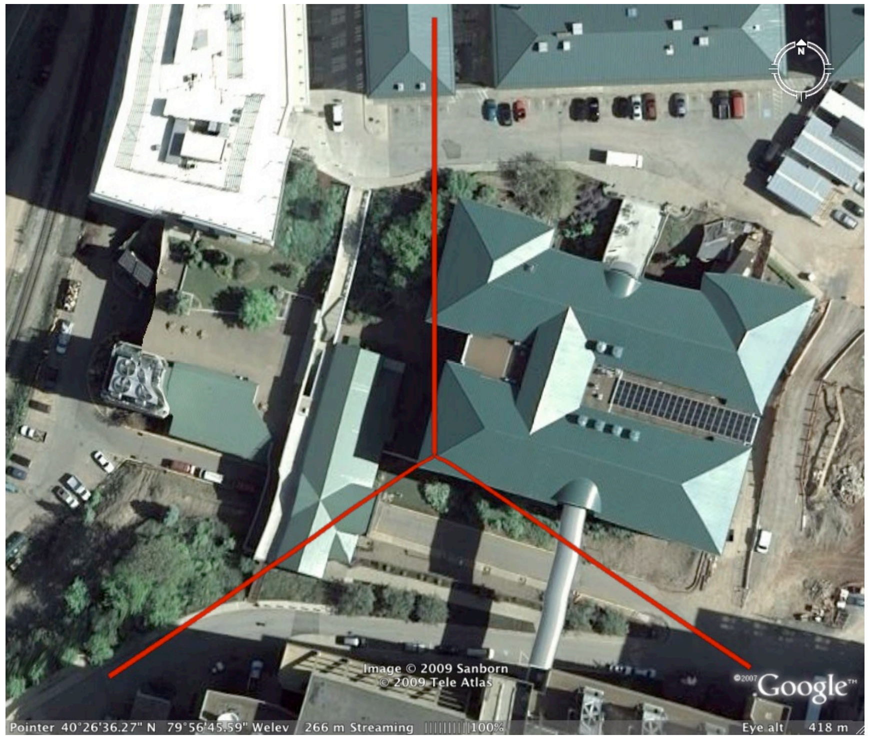
What Does a 1000:1 Aspect Ratio Look Like?

Assume a 1 meter wide blade

10:1



100:1

1000:1

Why can a 1000:1 ratio blade be controlled?

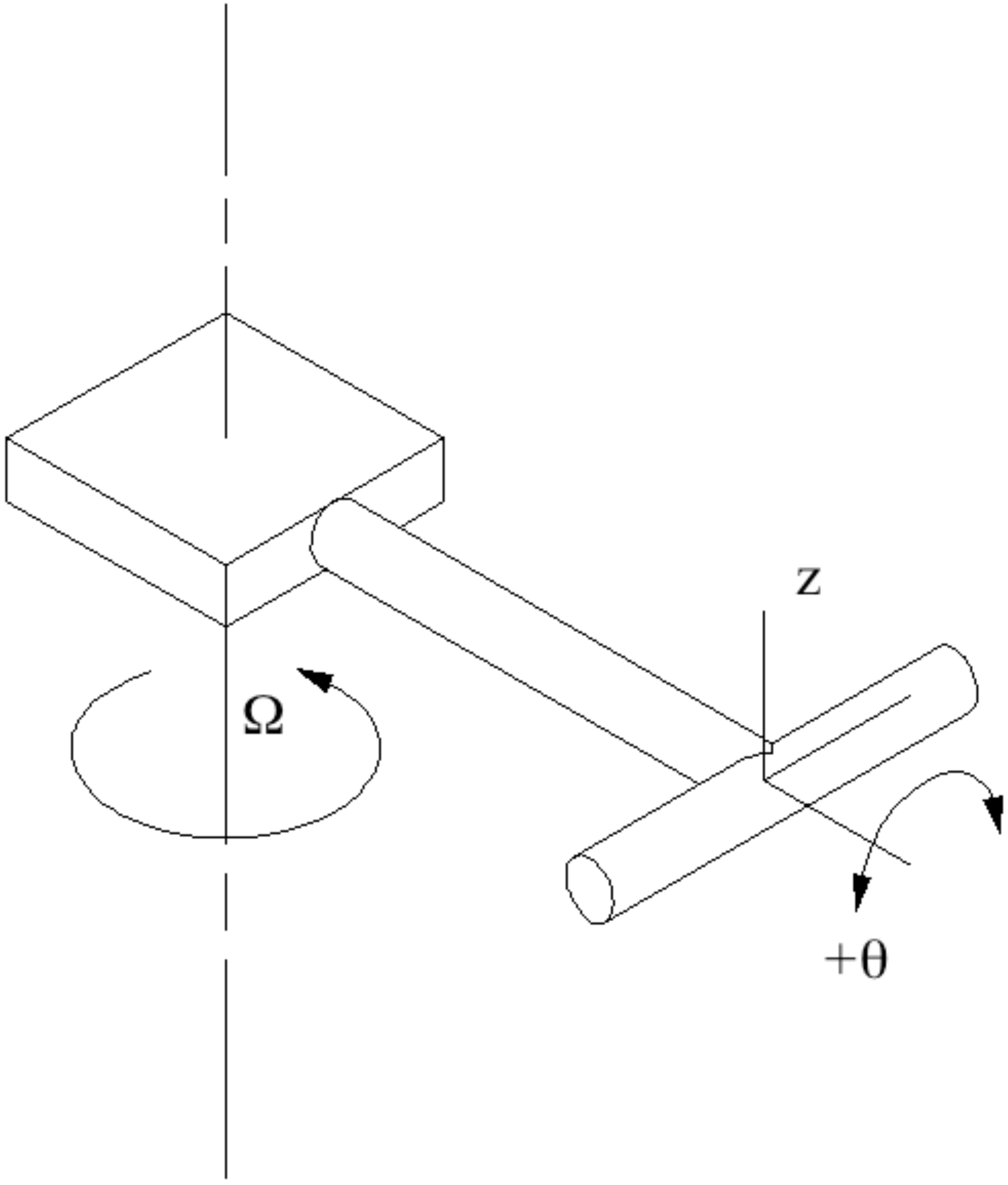
Fundamental Principle

Bar, hinged at its center,
rotating about a vertical axis

Governing Equation

$$\ddot{\theta} + \frac{1}{2} c \sin 2\theta = 0$$

$$c = \frac{(I_z - I_y)}{I_x} \Omega^2.$$



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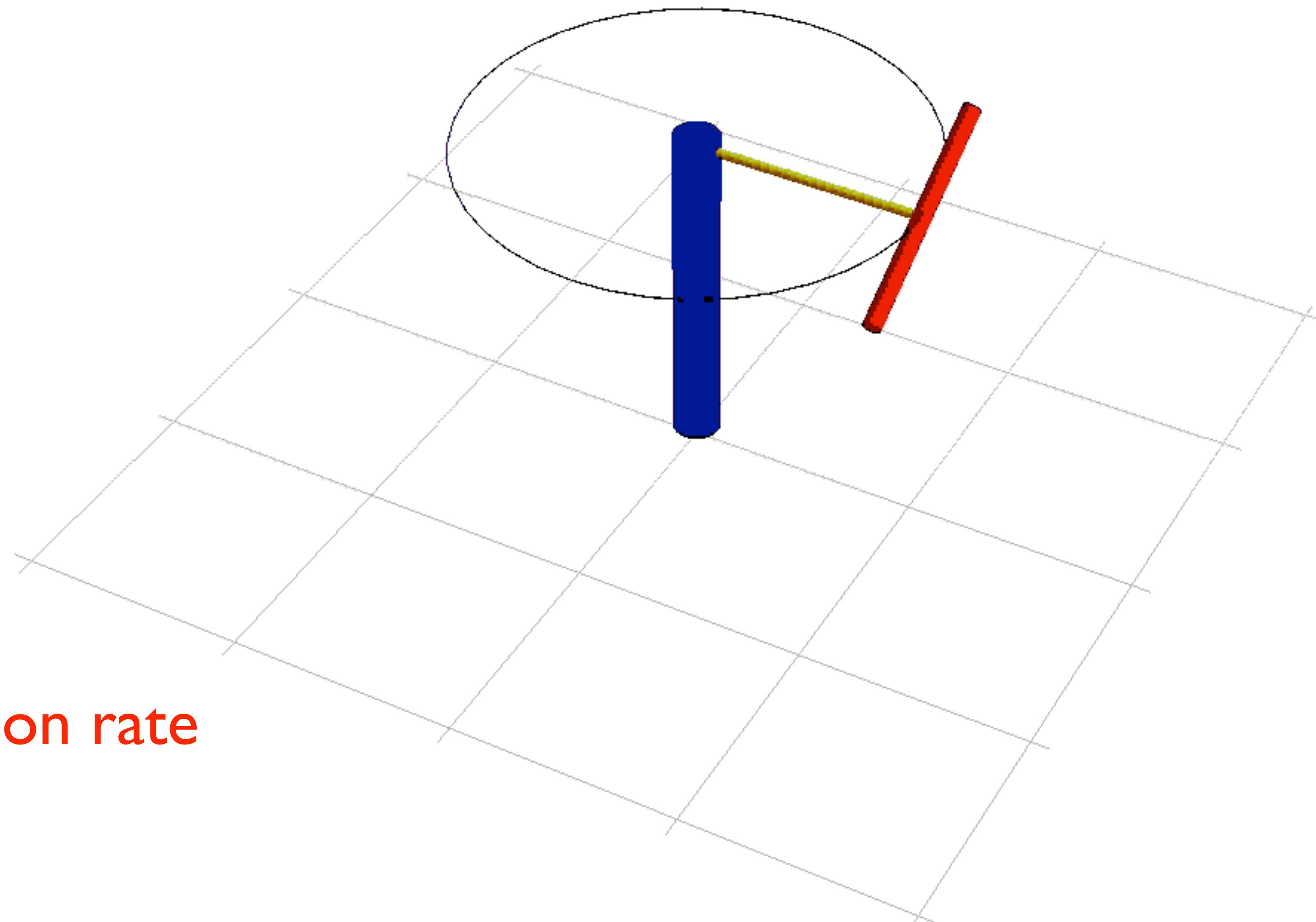


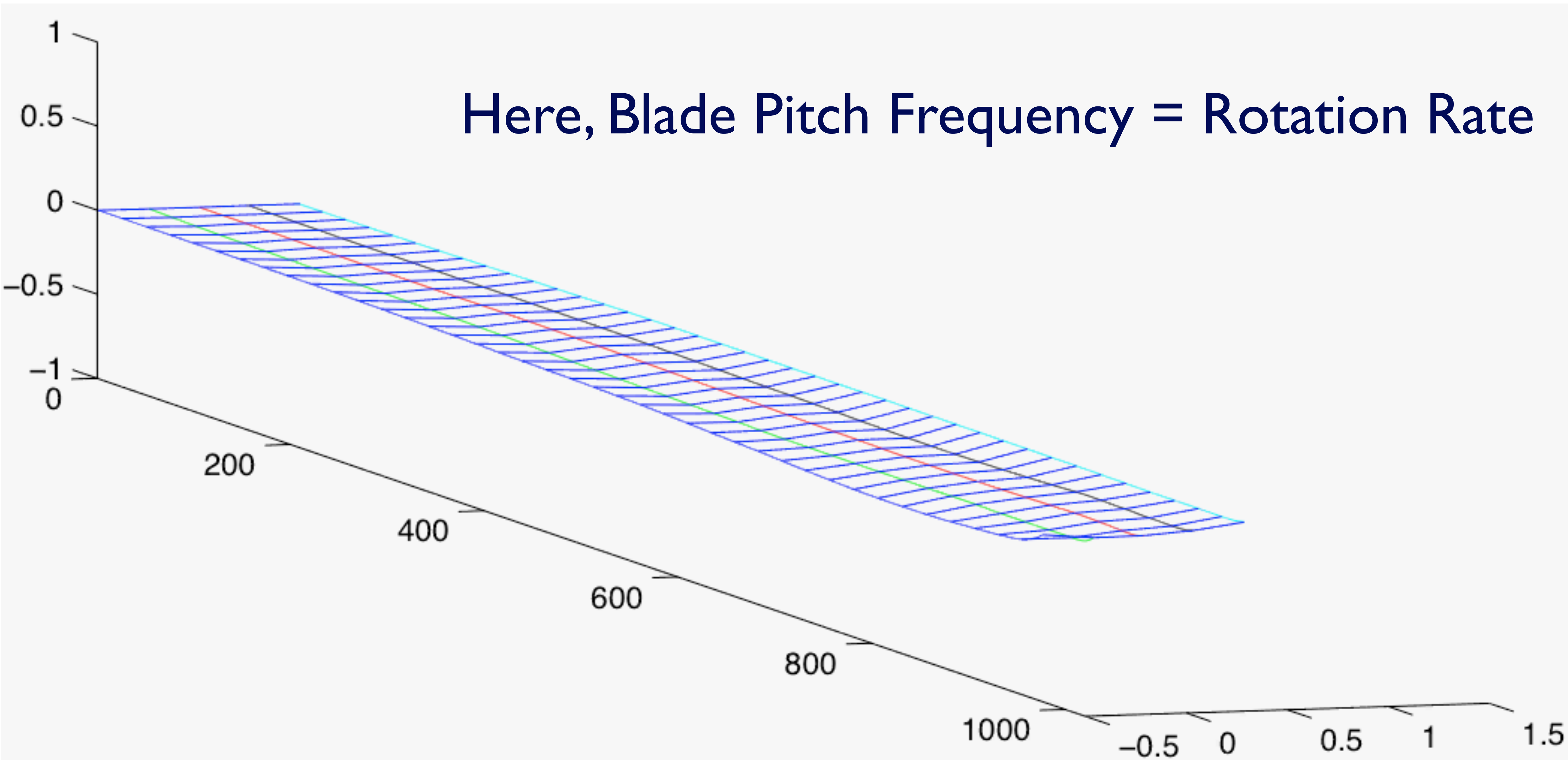
Governing Equation

$$\ddot{\theta} + \frac{1}{2} c \sin 2\theta = 0$$

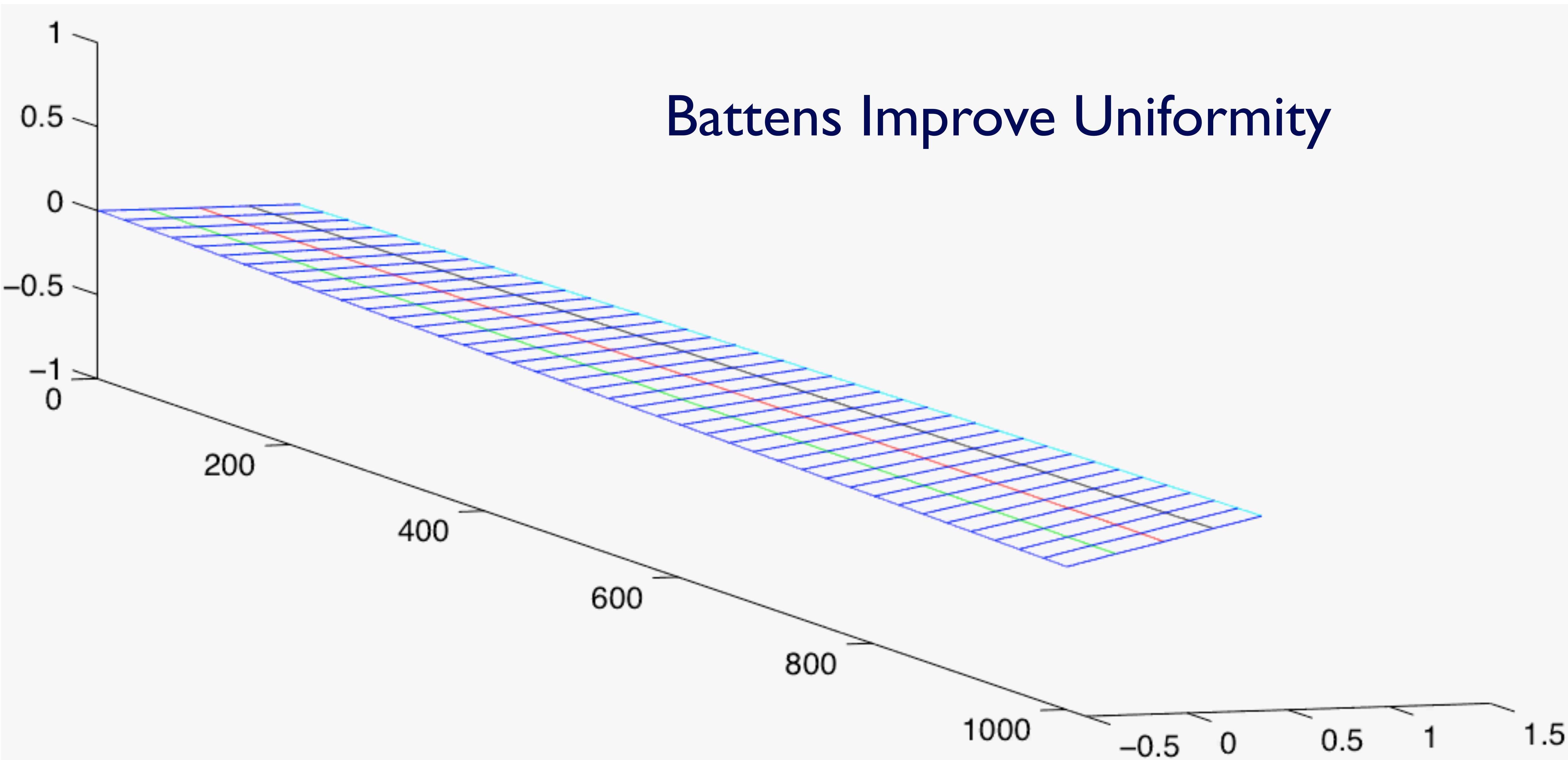
$$c = \frac{(I_z - I_y)}{I_x} \Omega^2.$$

Pitch frequency ~ rotation rate

1000:1 BLADE BEHAVIOR: NO BATTENS



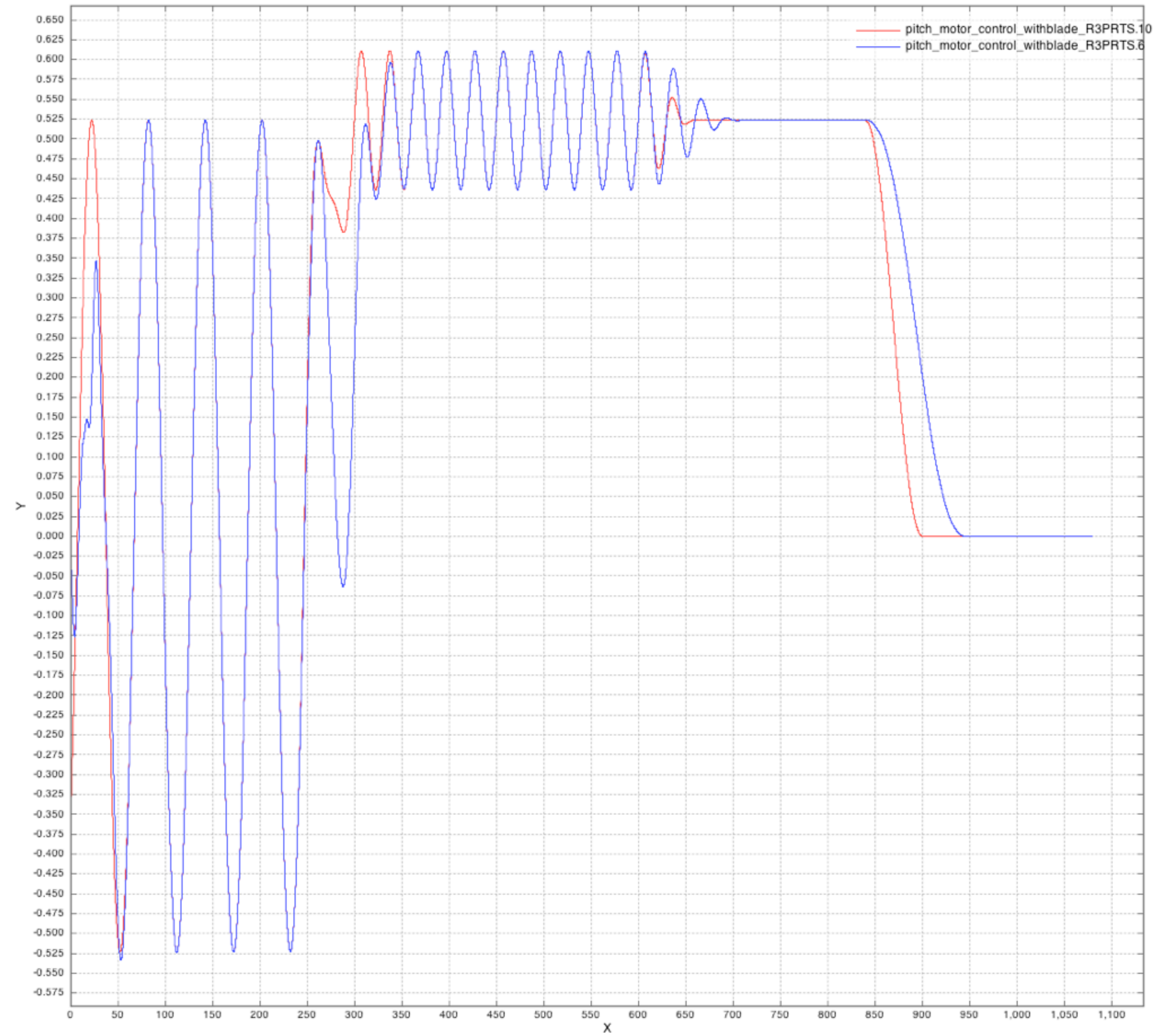
1000:1 BLADE BEHAVIOR: BATTENS



Pitch Actuation Control

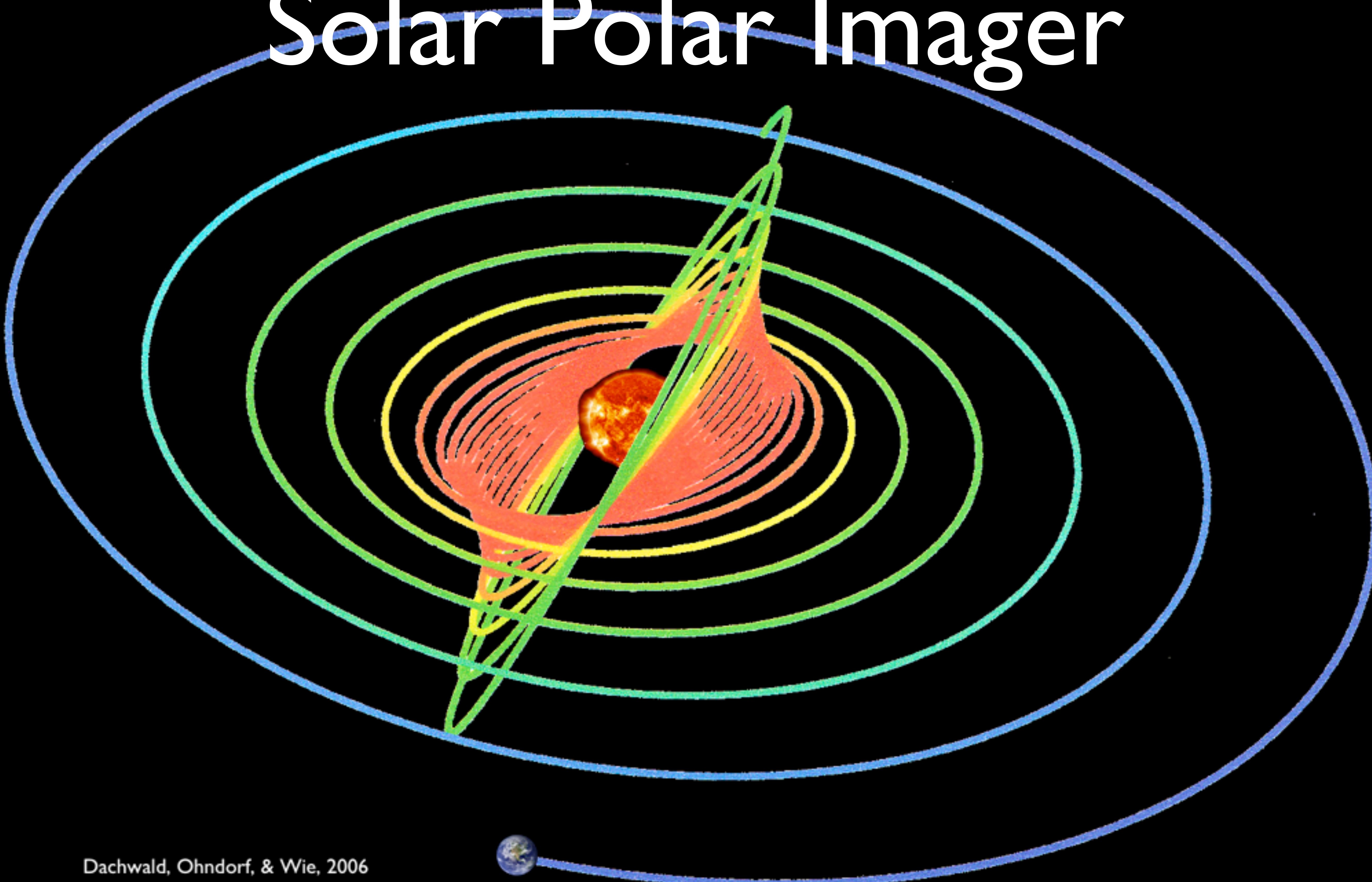
Pitch control of highly flexible blade is possible

Pitch vs. Time



Red is reference signal
Blue is blade root pitch

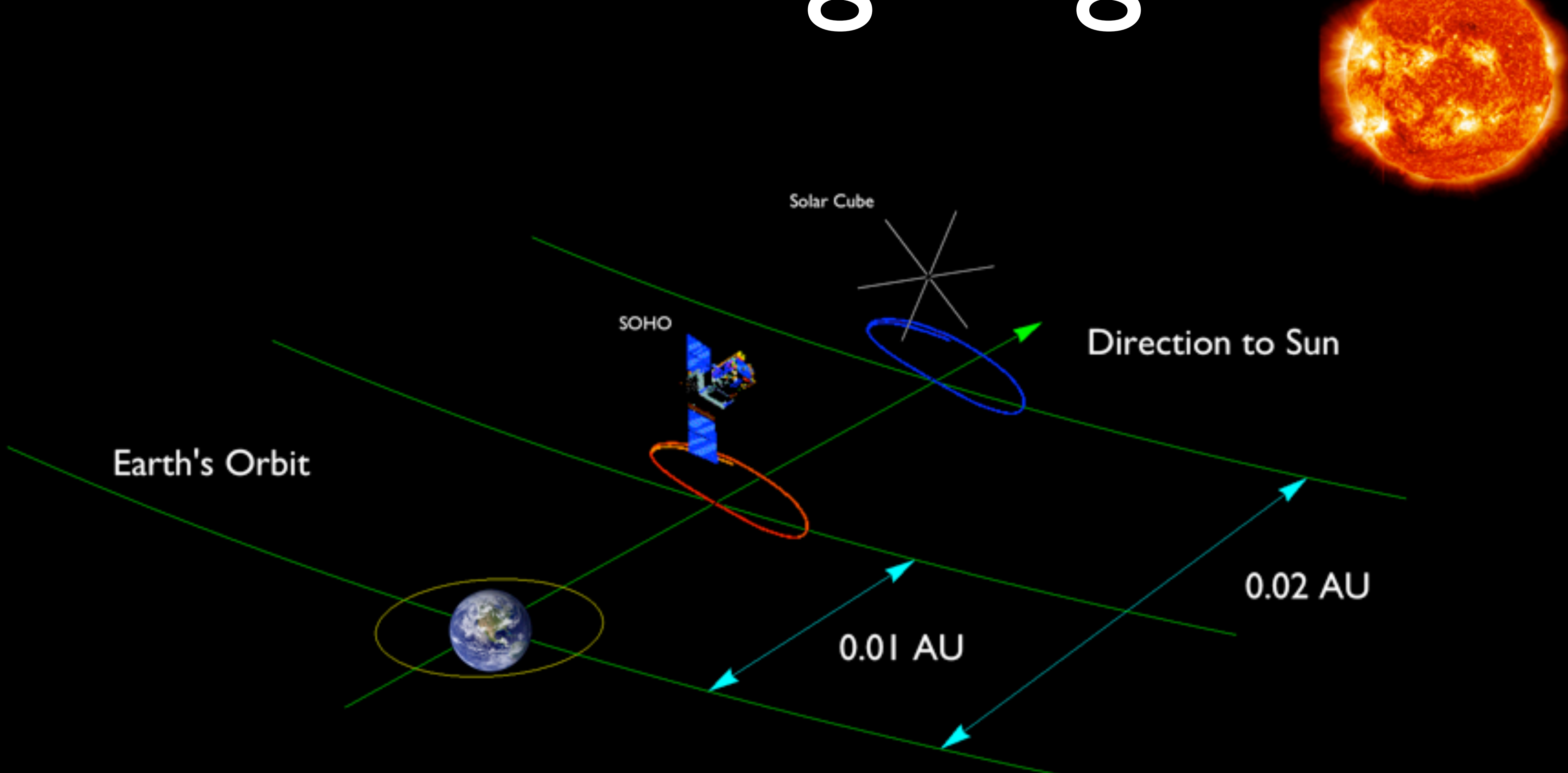
Solar Polar Imager



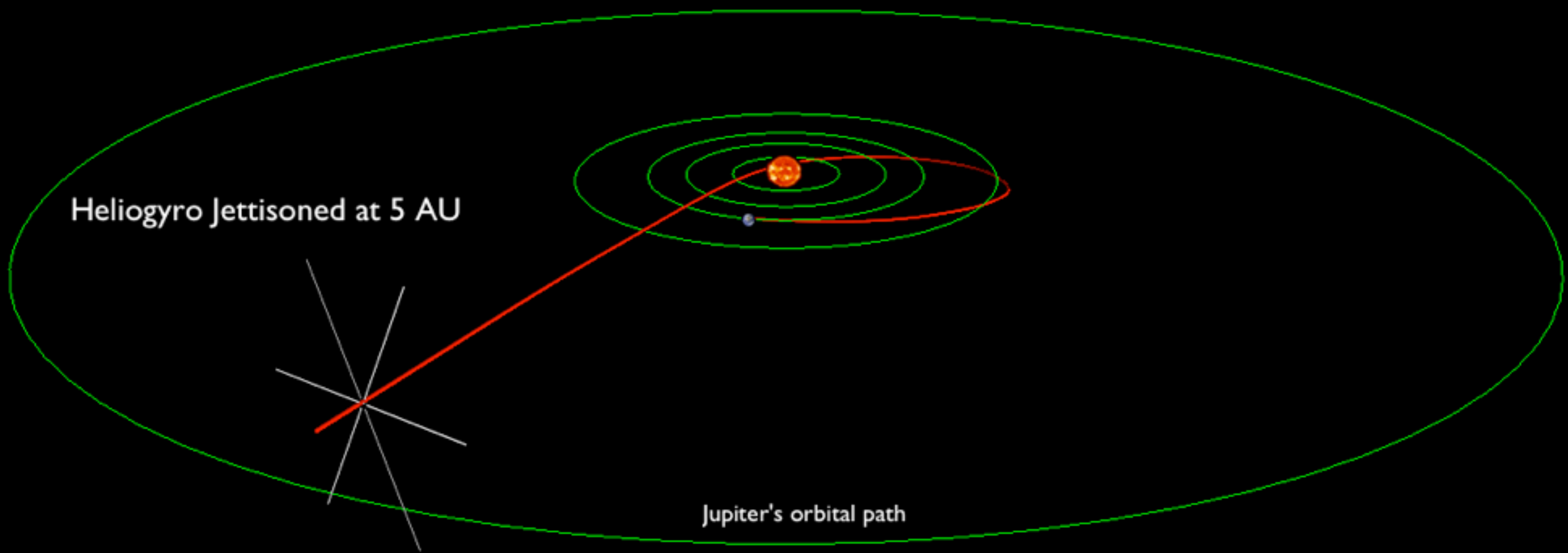
Dachwald, Ohndorf, & Wie, 2006

AIAA/AAS Astrodynamics Specialist Conference, 21-24 August 2006

Sub-L1 Lagrange Point



Dash to Heliopause



Based on Sauer'99

http://trs-new.jpl.nasa.gov/dspace/handle/2014/16979

Heliogyro Configurations for Big 3

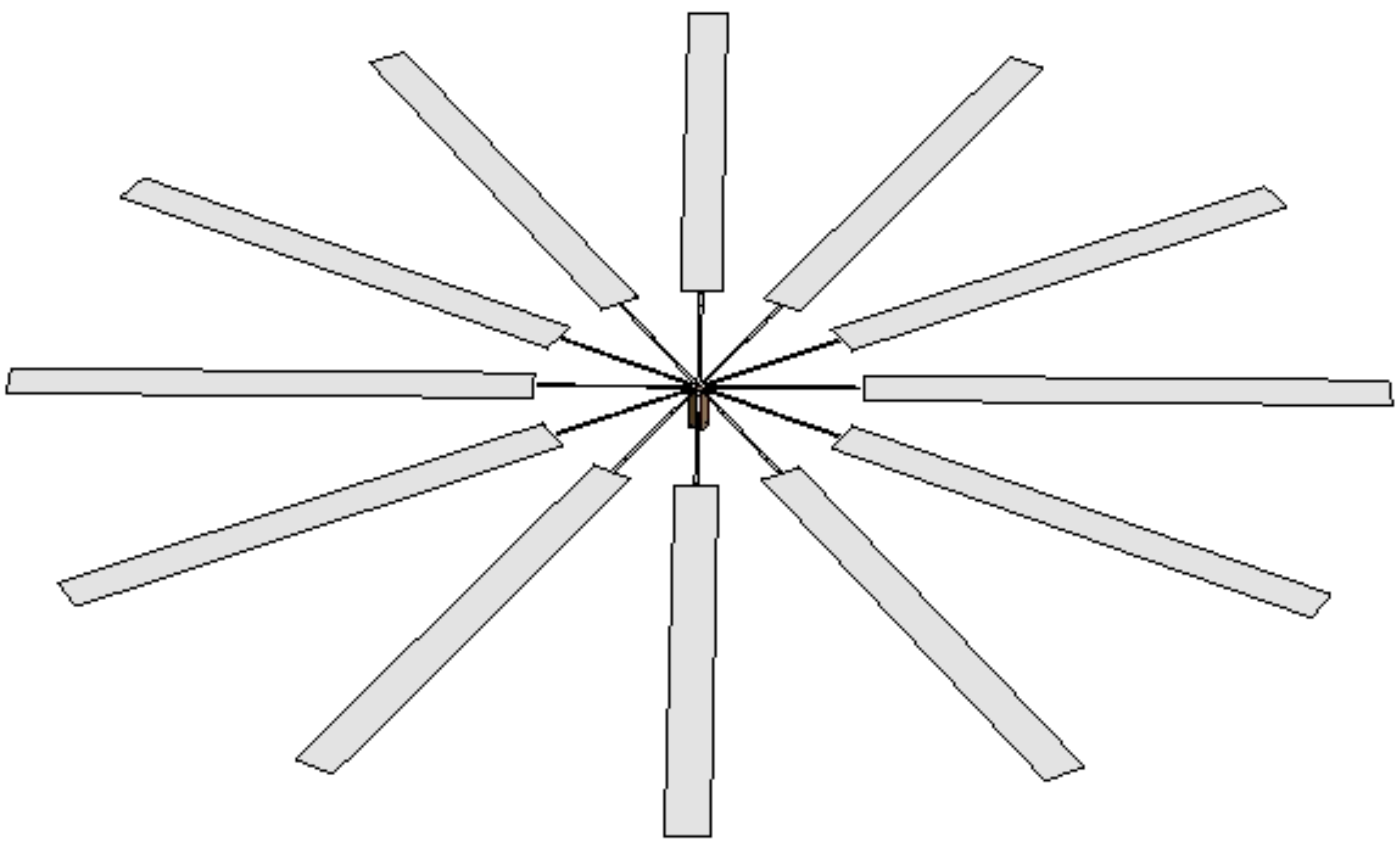
	Sun-Earth L1	Solar Polar	Interstellar Heliosphere
Blades	12	12	24
Chord, m	2	2	2
Blade Length, m	415	960	2,000
Aspect Ratio	208	480	1,000
Blade Thickness, μm	3.00	3.00	0.67
Rotational Period, s	30	480	120
Sail S/S Mass, kg	45	101	96
Non-sail Mass, kg	251	300	150
Total S/C mass, kg	296	401	246
Areal Density, g/m^2	4.5	4.38	1.00
Charact. Accel, mm/s^2	0.246	0.419	2.85
Precess rate, °/day	15.3	105.5	56.7

Applications for Nanosat Community

- A gravitational offset of the sun, a planet, or a moon to allow a persistent presence;
- Decreased transit time for very long trajectories (larger delta V);
- A substitute for a booster to the moon and beyond;
- Increased flexibility of launch opportunities -- orbital insertion needn't be where the final orbit is, due to the ability to accomplish orbital altitude, phase, and plane changes;
- Rapid spacecraft deorbiting;
- Repeated repositioning capability.

What Performance Can a Cubesat Heliogyro Provide?

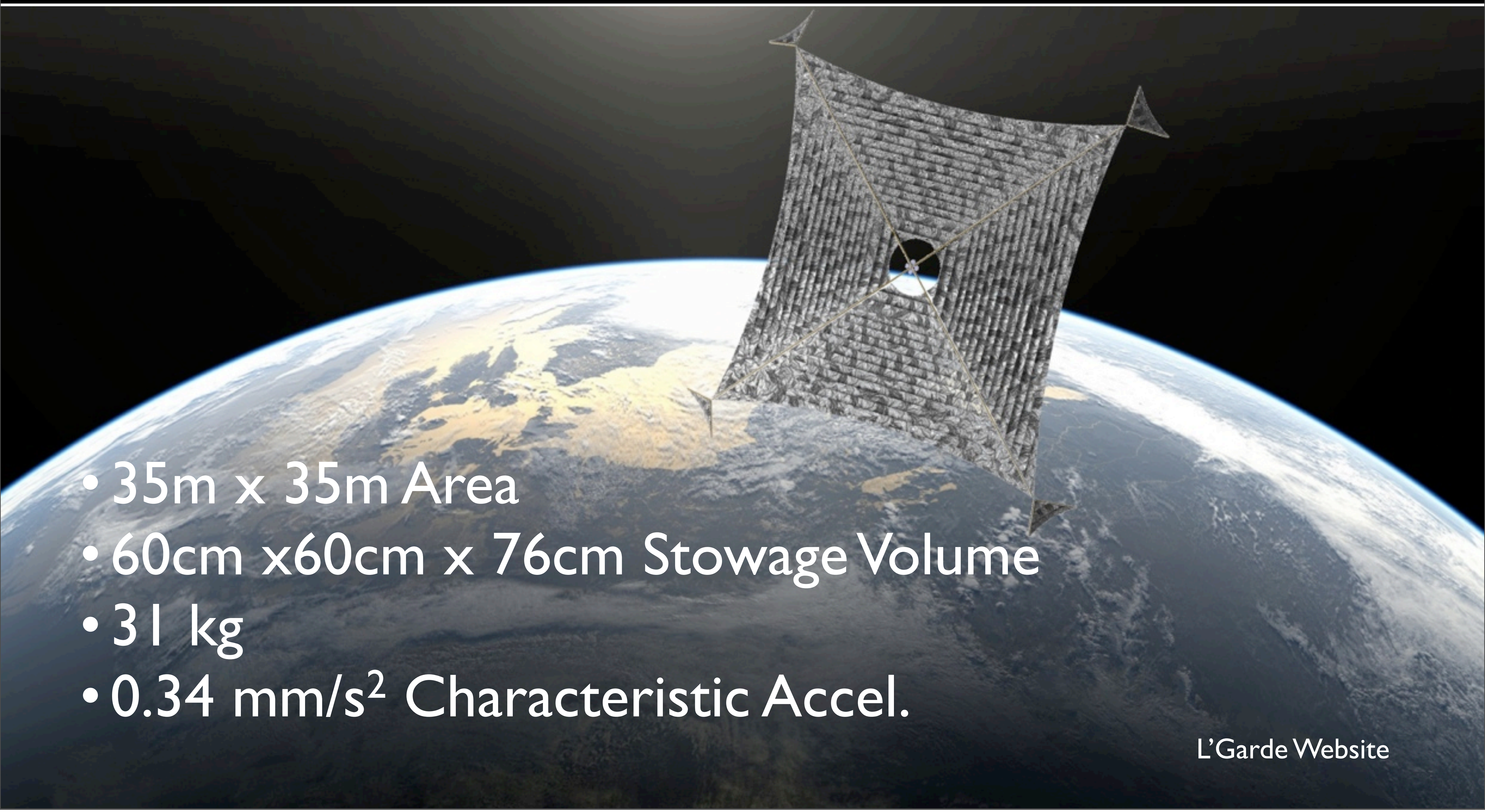
- Assume a 12U form factor
- Scale up to 12 blades
- Each blade 0.32m x 320m x 3µ
- 2.5U Avionics/payload envelope
- 16 kg
- 0.7 mm/s^2 Characteristic Accel.
  - Sub-L1 0.246 mm/s2
  - → Solar Polar 0.419 mm/s2
  - Heliopause 2.85 mm/s^2



If blades were 1µ thick,
Characteristic Accel = 1 mm/s^2

How does this compare with Sunjammer?

Compare to Sunjammer



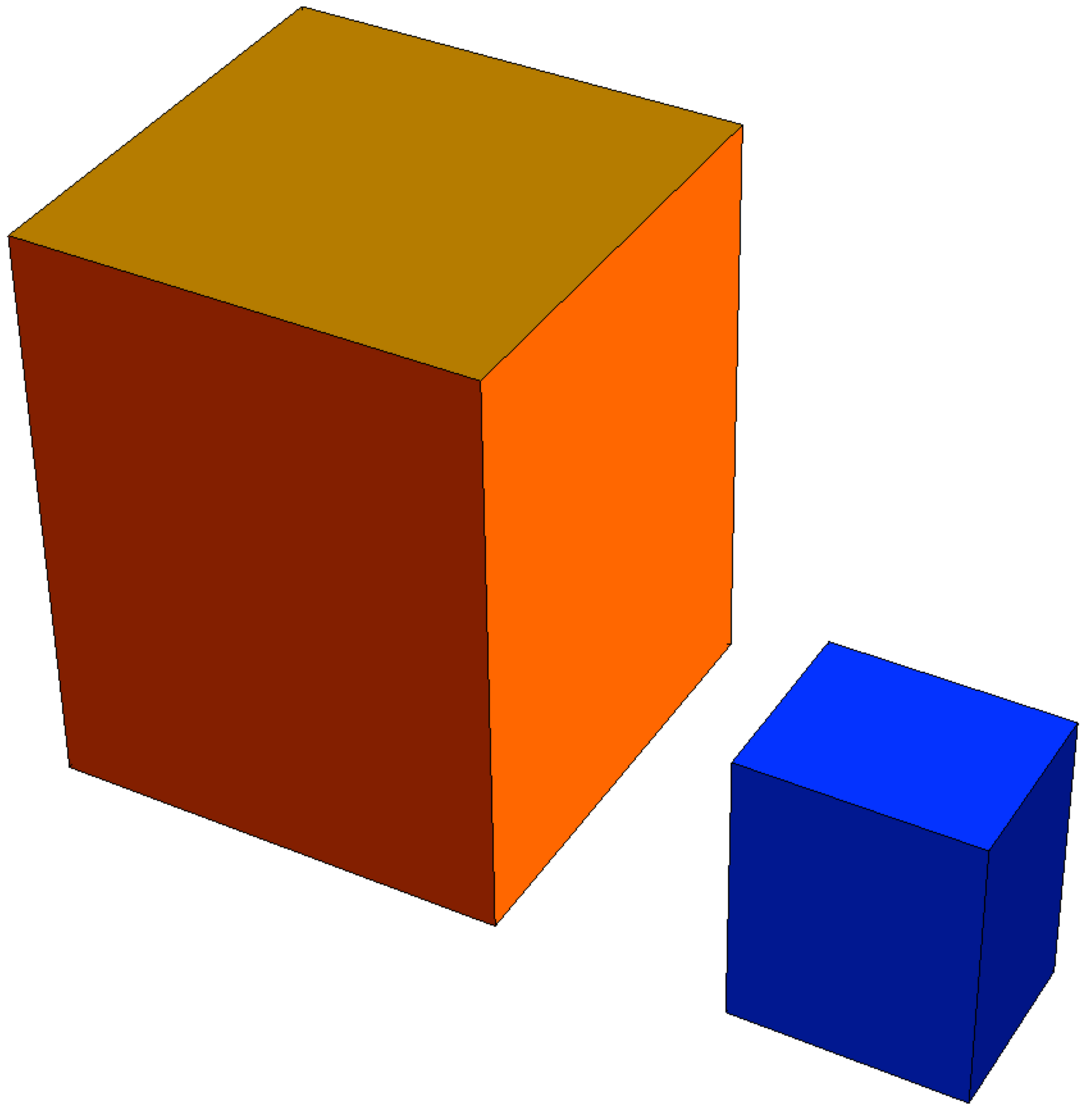
- 35m x 35m Area
- 60cm x60cm x 76cm Stowage Volume
- 31 kg
- 0.34 mm/s^2 Characteristic Accel.

L'Garde Website

Comparison
Sunjammer vs. Solar Cube 12 Blade

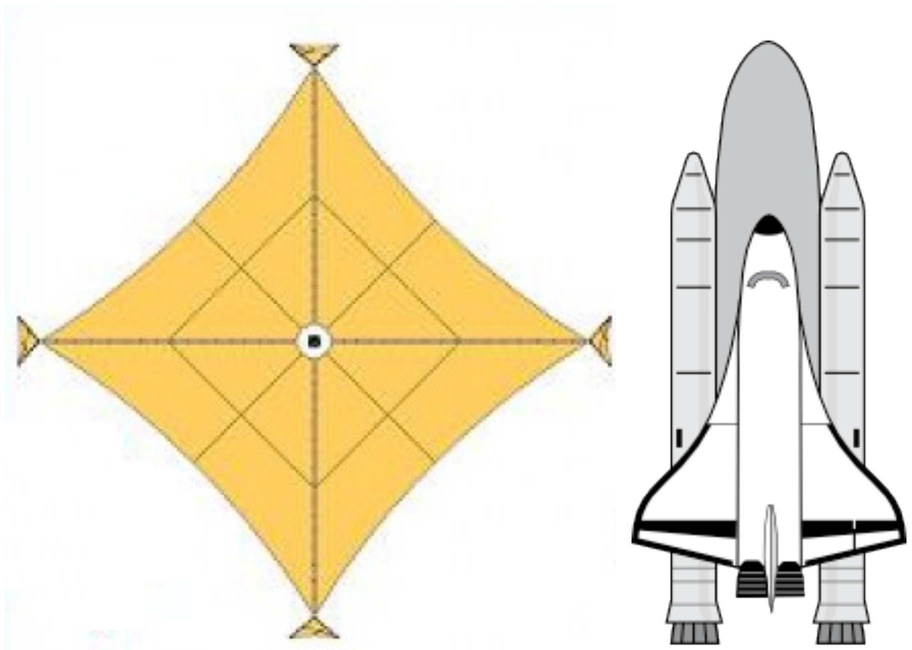
Sunjammer Stowed
60cm x 60cm x 76cm
31 kg

Solar Cube 12 Blade Stowed
22cm x 24cm x 37cm
16 kg

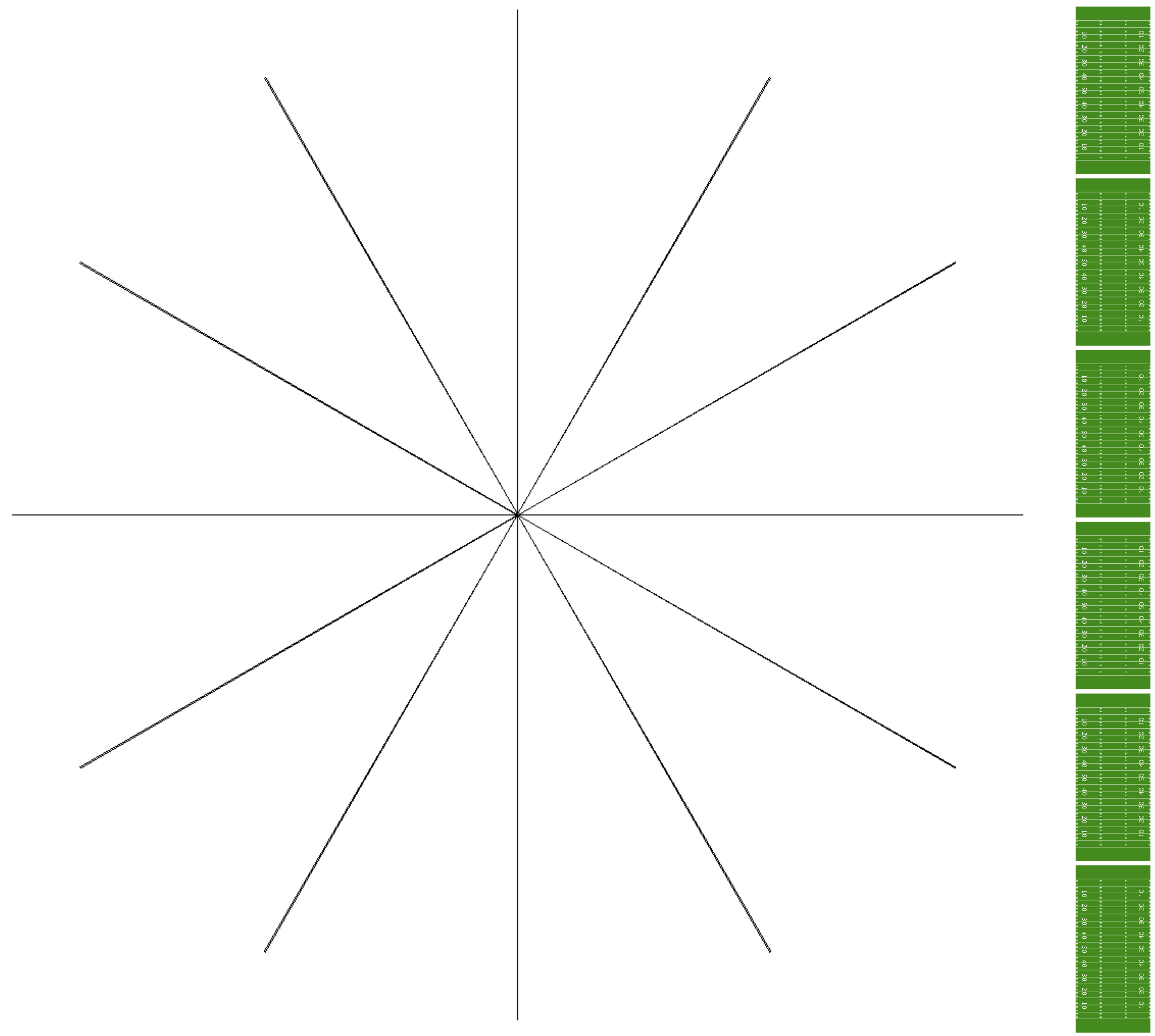


Sunjammer Char. Accel: 0.34 mm/s2
Solar Cube 12 Blade Char. Accel: 0.7 mm/s2

Comparison
Sunjammer vs. Solar Cube 12



Sunjammer Deployed
35m x 35m



Solar Cube 12 Blade Deployed
640m across

MacNeal's Spinning Room Test

Blade Properties

Thickness: .001'' (Kapton)

Chord, C = 1.938''

Weight/unit area = 1.08×10^{-4} lb/in^2 (Kapton plus paint)

Modulus of elasticity, E = 500,000 psi

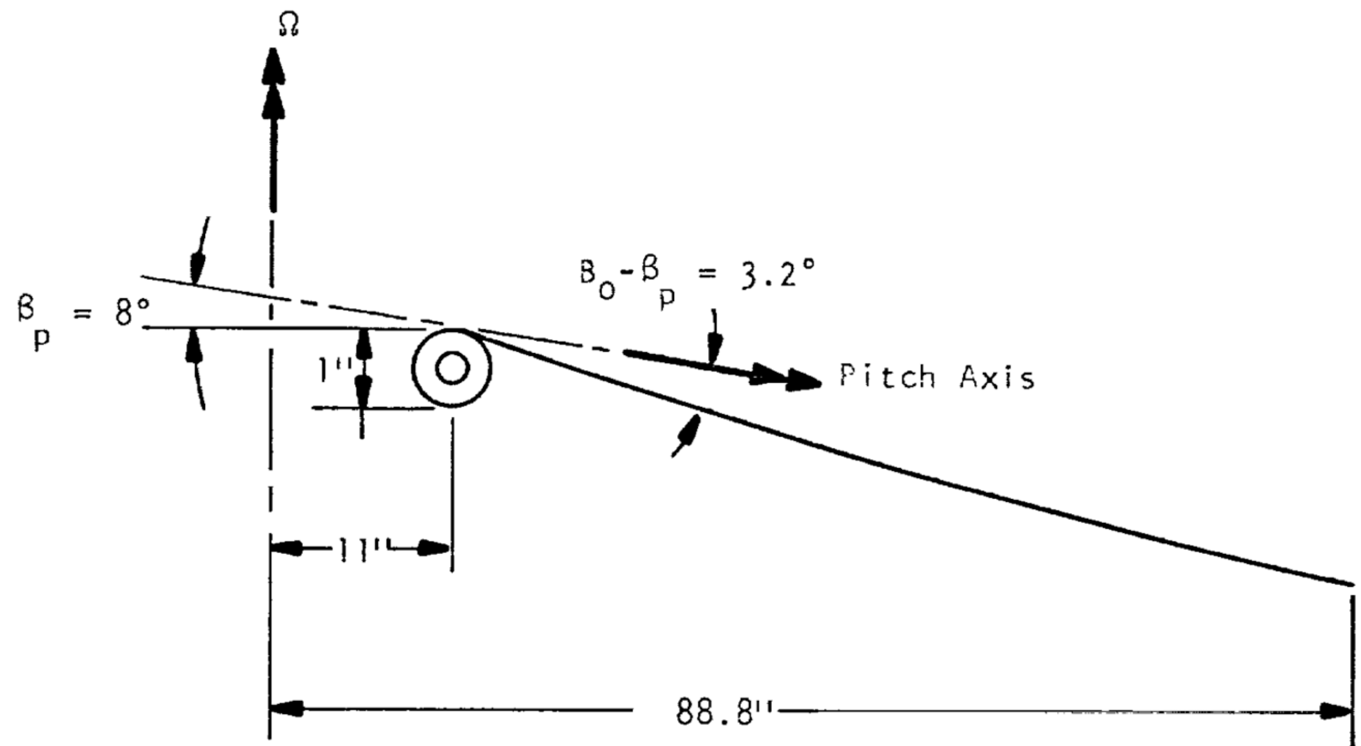
Operating Parameters

Spin rate, $\Omega = 2\pi$ rad/sec

Stress at Centerline, σ_o = 43.6 psi

Coning angle at tip, $\beta_t = 6.33°$

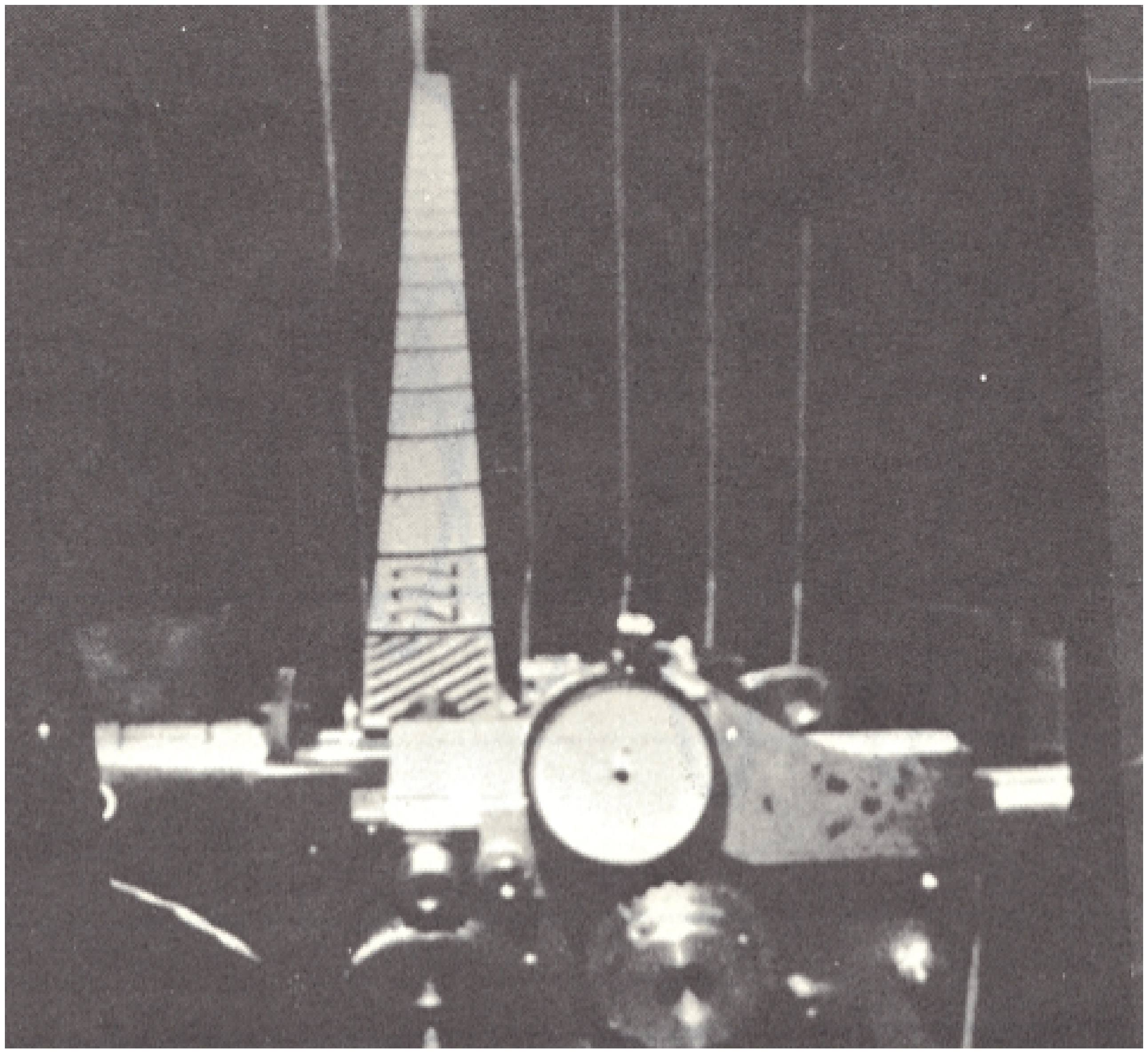
Inplane Stiffness Parameter, $K = \frac{1}{12}\left(\frac{E}{\sigma_o}\right)\left(\frac{c}{R}\right)^2 = .454$



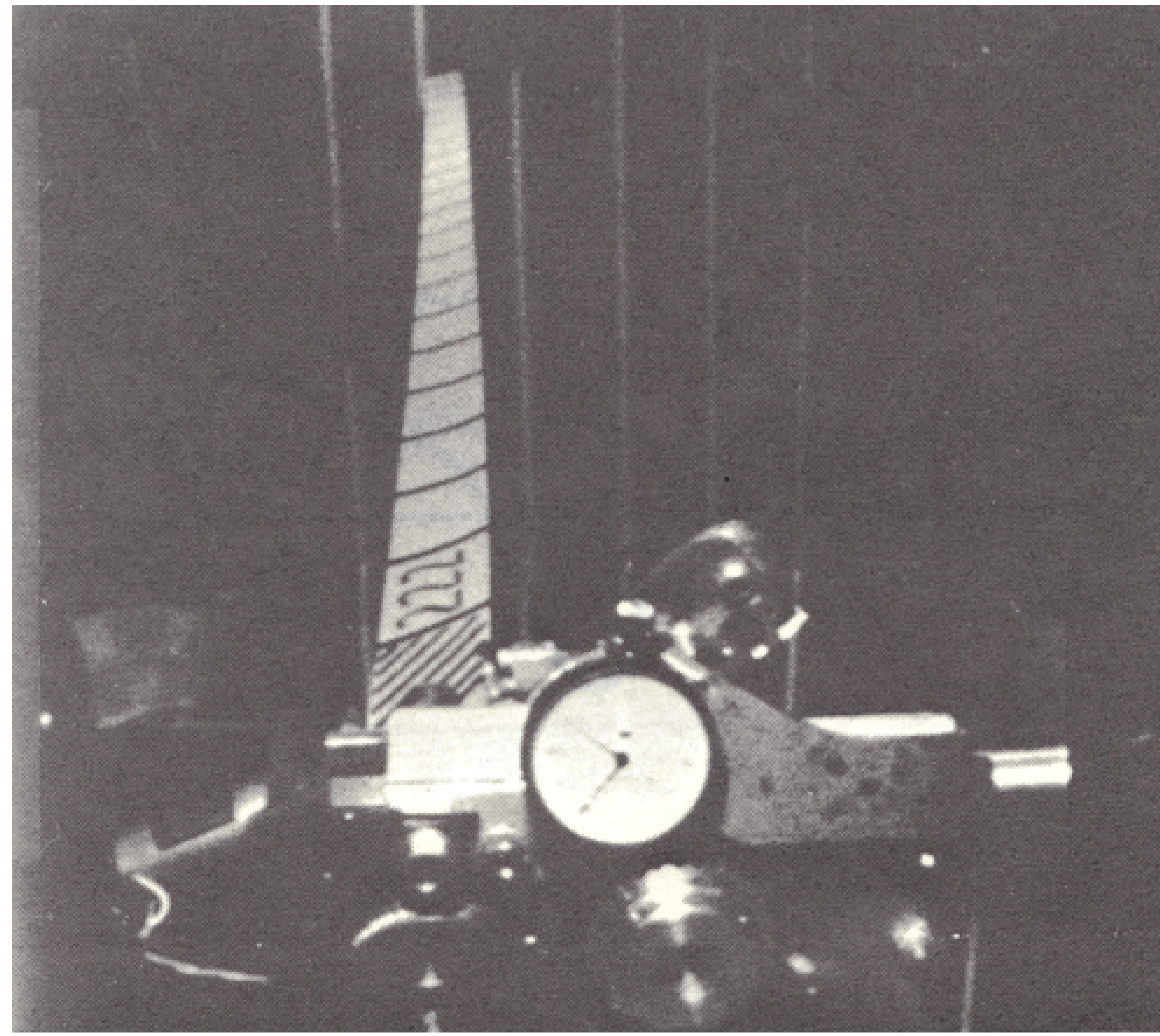
MacNeal, R. H., "Structural Dynamics of the Heliogyro", NASA-CR-1745A, 1971.

Deploy and pitch a blade in an 18 foot diameter spinning room

MacNeal's Spinning Room Test



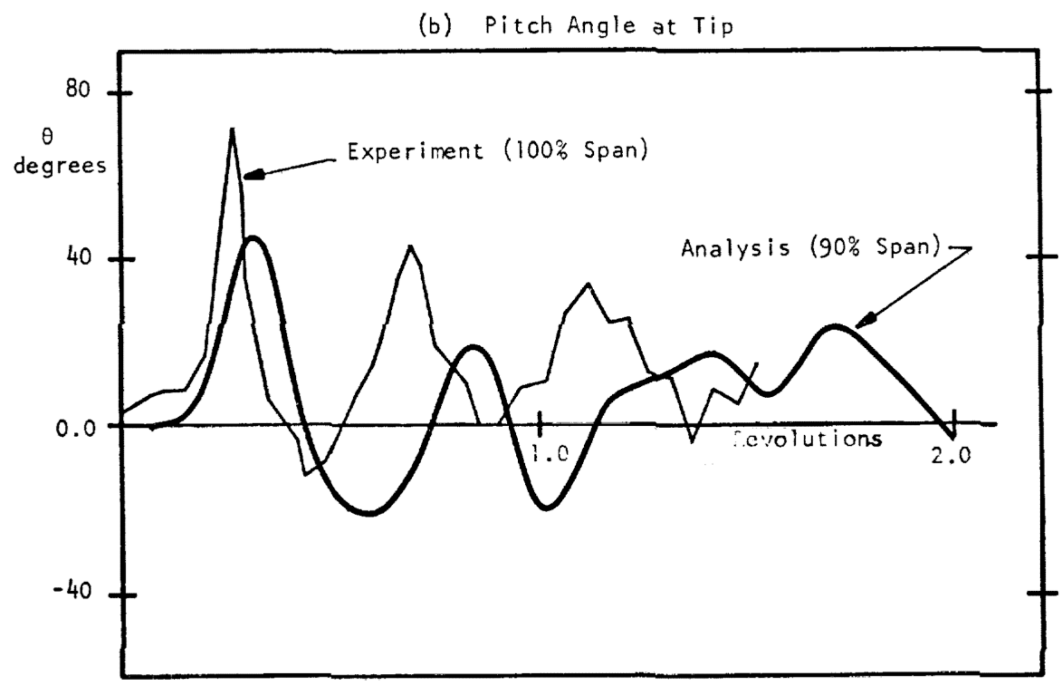
0 Degree Pitch

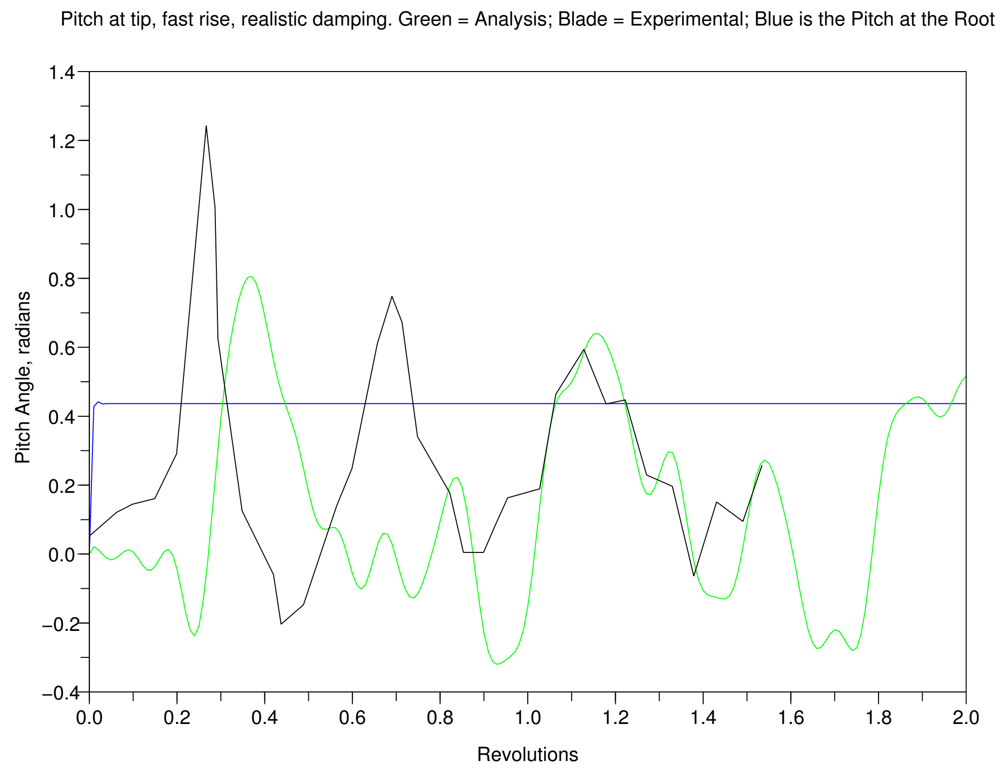


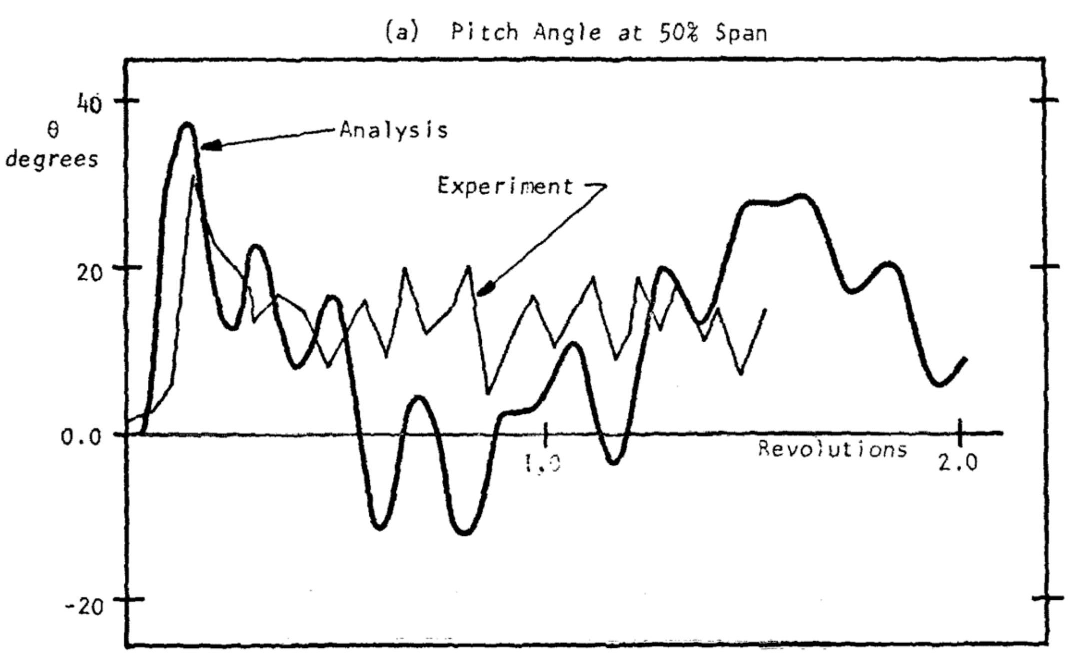
25 Degree Collective Pitch

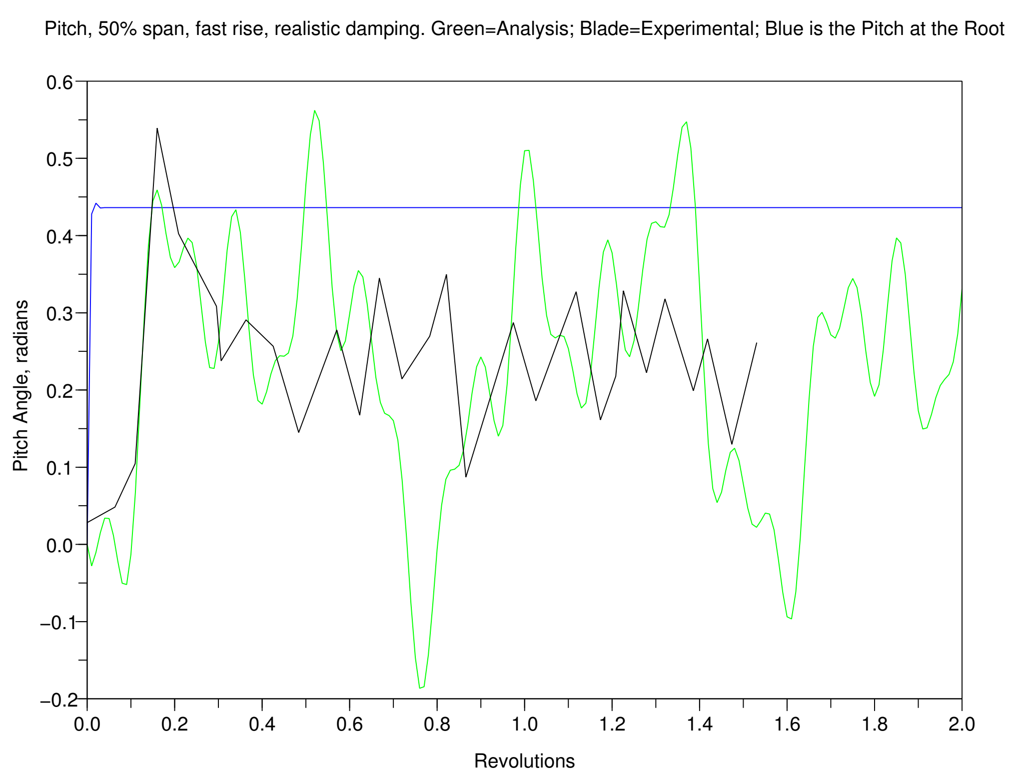
MacNeal's Spinning Room Test

Step Increase in Collective Pitch, 0° to 25°, Calculated Damping



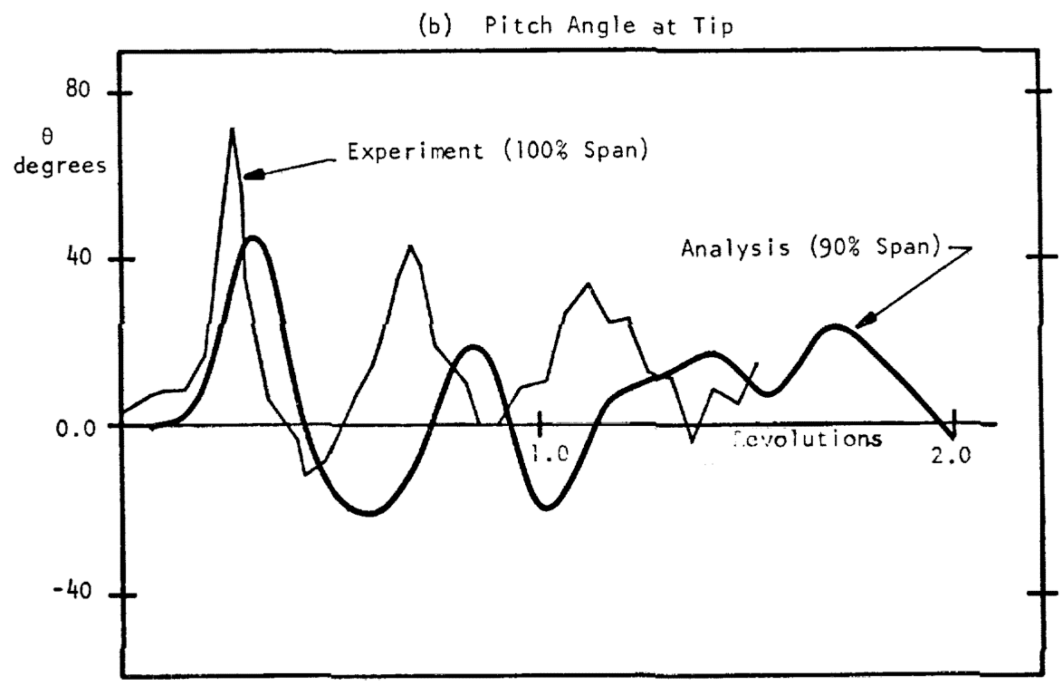


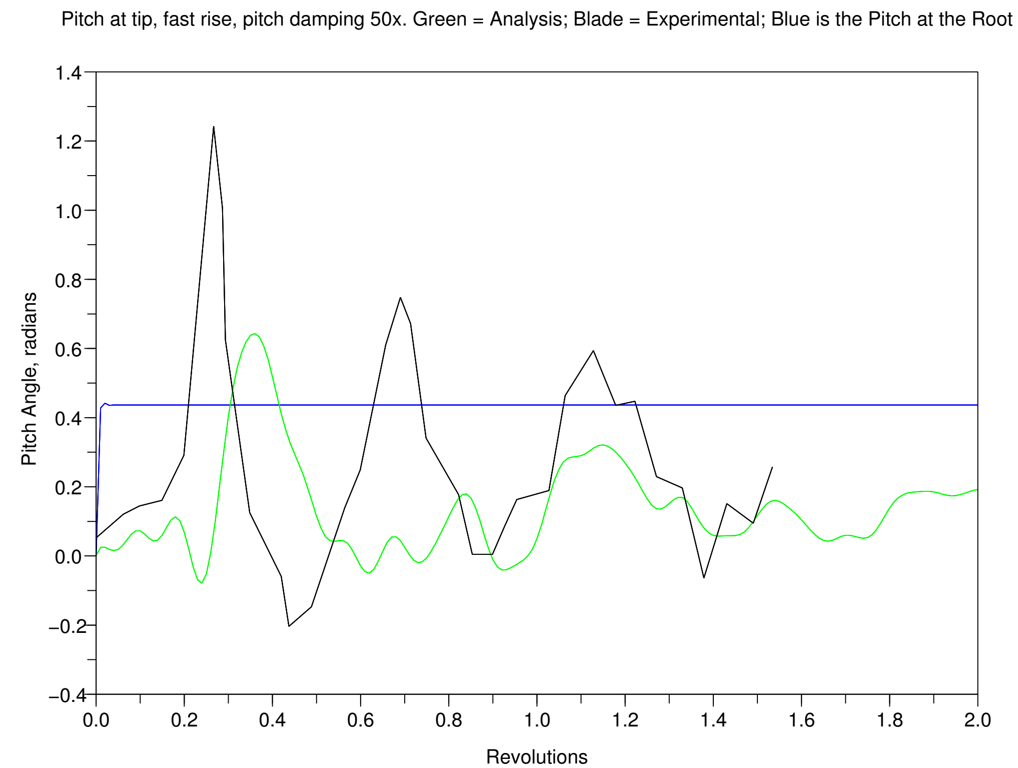


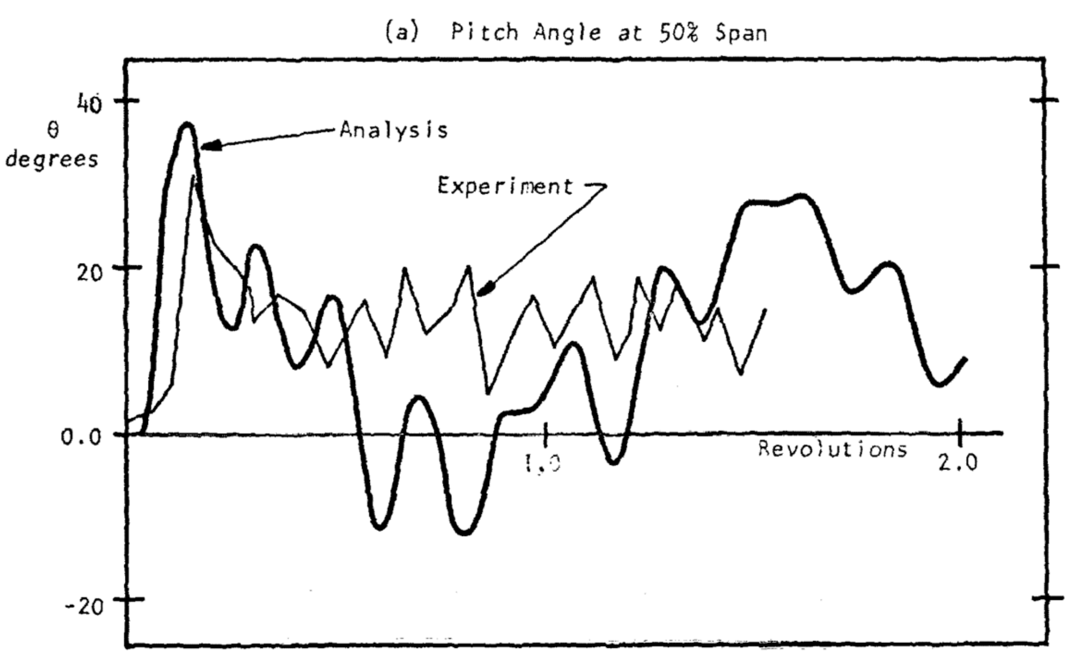


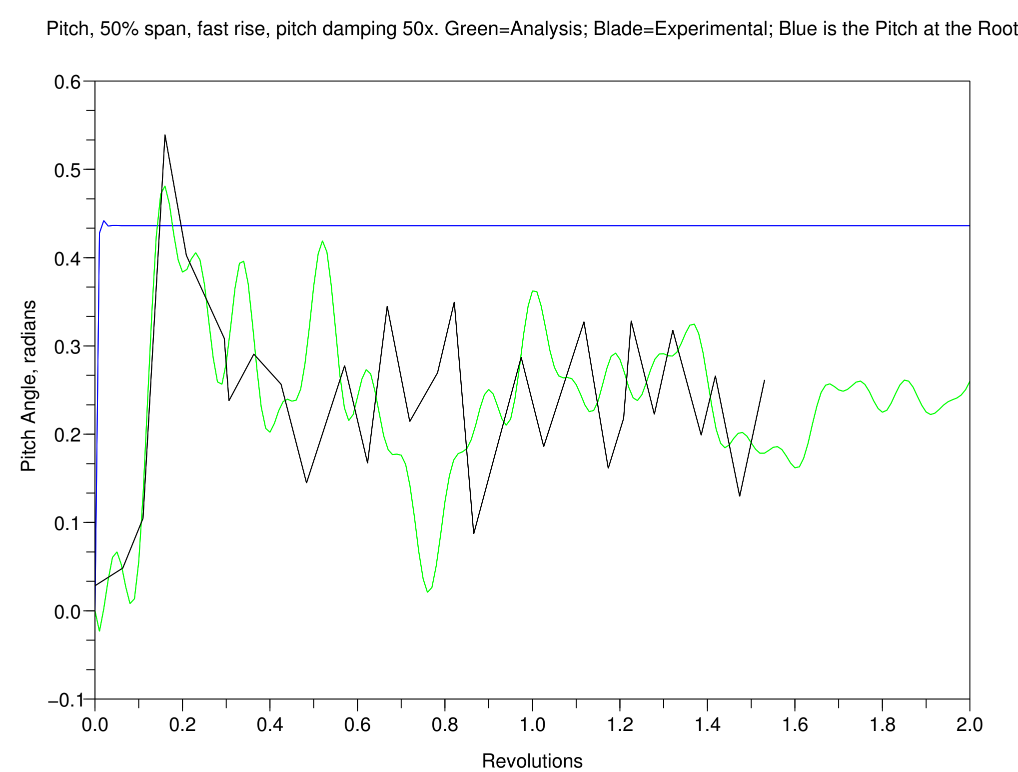
MacNeal's Spinning Room Test

Step Increase in Collective Pitch, 0° to 25°, Increased Damping









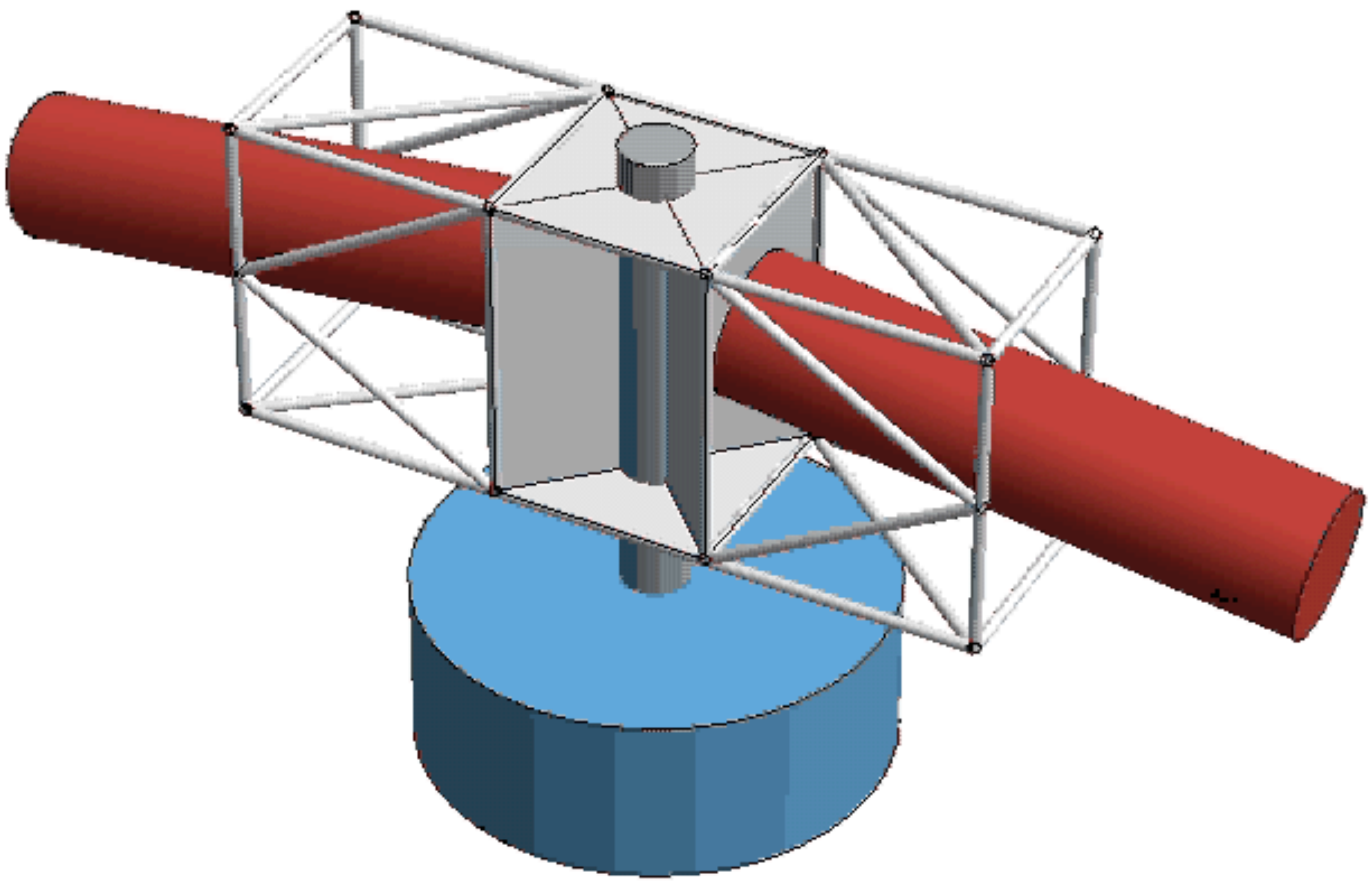
MacNeal's Spinning Room Test

Step Increase in Collective Pitch, 0° to 25° -- CONCLUSIONS

- MacNeal's Analysis used uncoupled pitch, in-plane, out-of-plane modes.
- Blomquist uses coupled modes
- MacNeal knew the details of the test
- Blomquist is guessing what the test conditions were.
- Getting damping right is essential.
- THEREFORE, A RETEST TO VERIFY CURRENT MODELS, AS WELL AS ACTUATION AND MODAL DAMPING STRATEGIES, IS NEEDED

Centrifuge for spinning blade tests

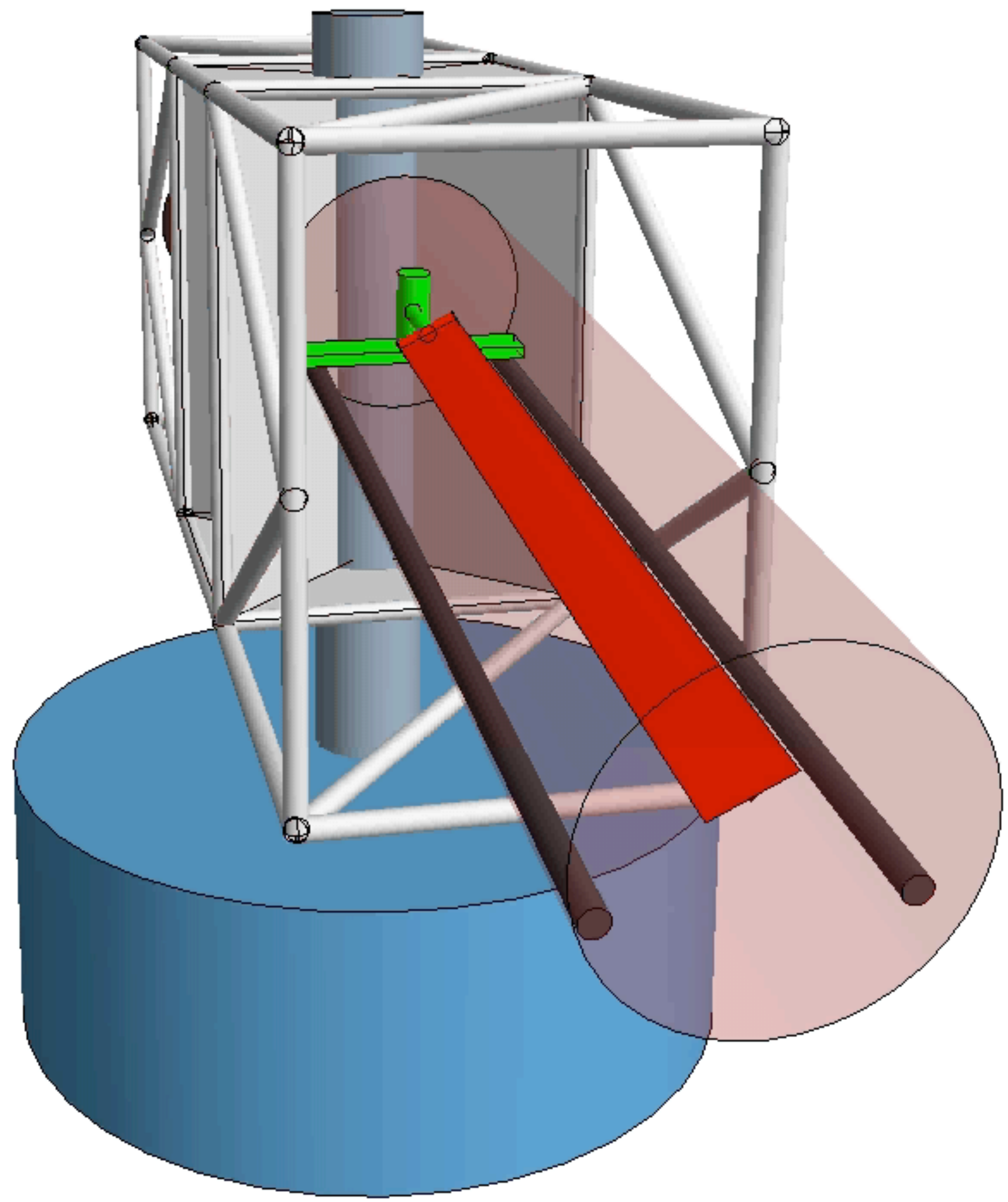
- 2.5 meter tubes
- Spinning at 60 rpm
- Tubes inclined downward 7°
- Cameras inside

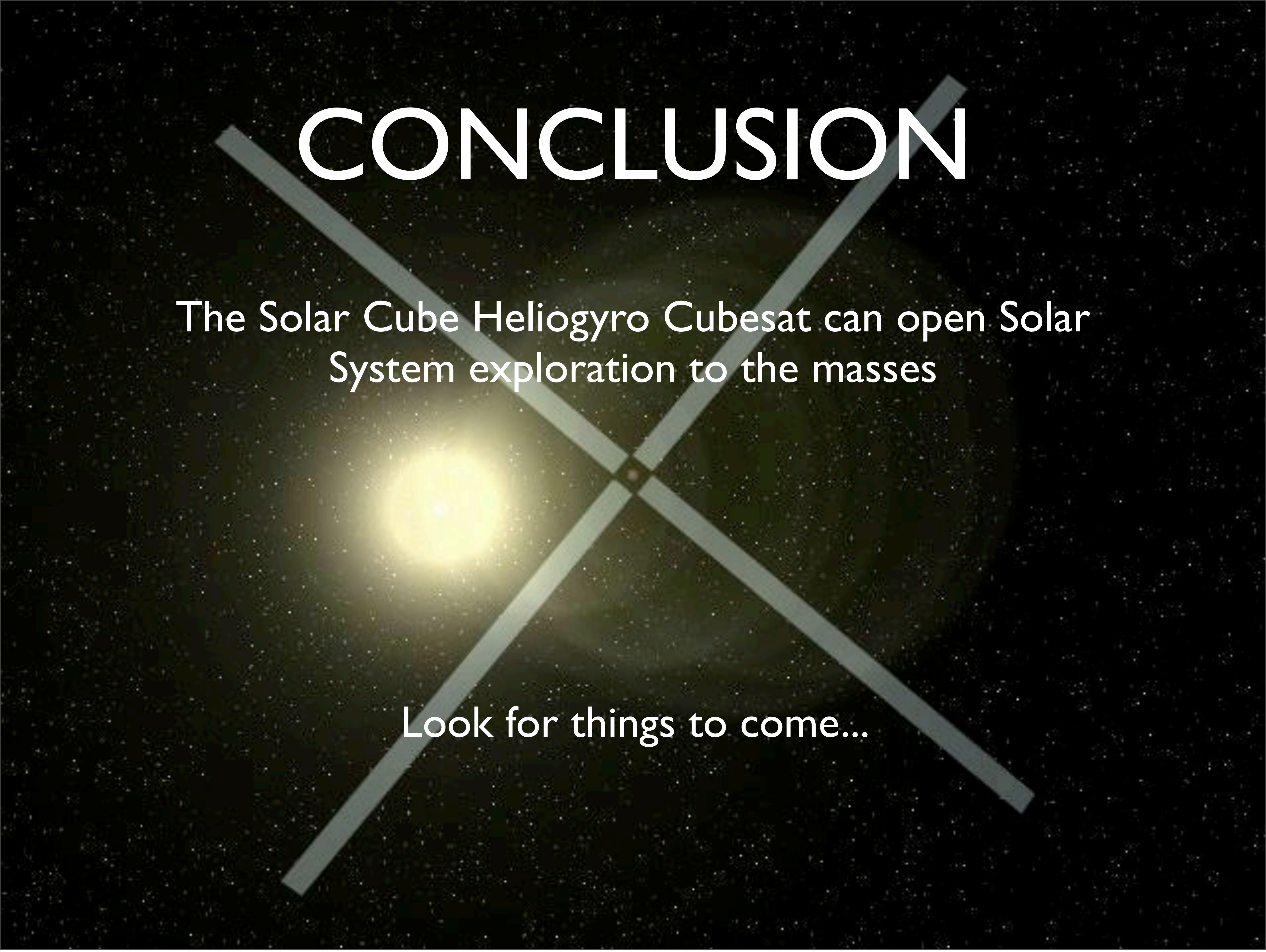


Centrifuge for spinning blade tests

- Blades unfurl as pitch device moves radially inward

- Blades pitch as in MacNeal's test




CONCLUSION
The Solar Cube Heliogyro Cubesat can open Solar System exploration to the masses
Look for things to come...