Eternal Flight as the Solution for X

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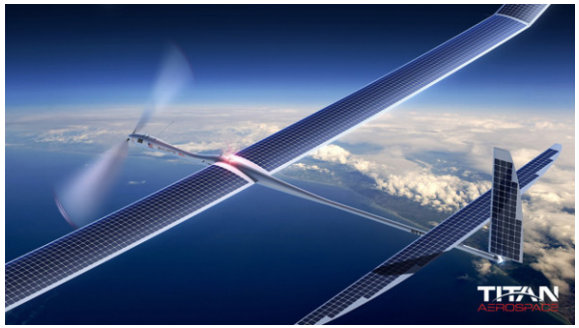
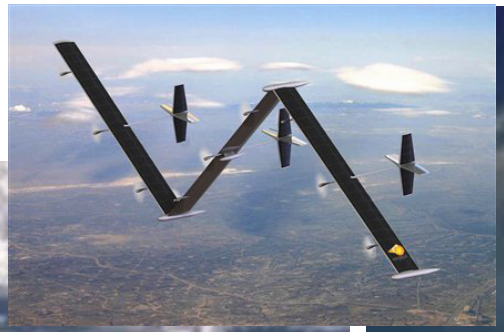
Current Atmospheric Satellite Approaches

Qinetiq
Zephyr
(3 week world record holder)

Google Project Loon



Titan
Aerospace



Lockheed, Aurora, and Boeing High Altitude Long Endurance Concepts

How will Atmospheric Satellites Compare to Orbital Satellites

Geosynchronous Earth Orbit (GEO) Satellite

Distance above Earth: 22,230 miles (i.e. XM-Ecostar)

Coverage Diameter: 7926 miles

Fleet Required: 1 for continuous coverage

Cost: $300M +$100M launch-insure cost

Signal Delay: >250 millisecond (ideal)

Low Earth Orbit (LEO) Satellite

Distance: 500 miles (i.e. Iridium)

Coverage Diameter: 2300 miles

Fleet Required: >50 satellites

Cost: $50M + $25M launch-insure/per

Signal Delay: >5 millisecond (40 typical)

Atmospheric Satellite

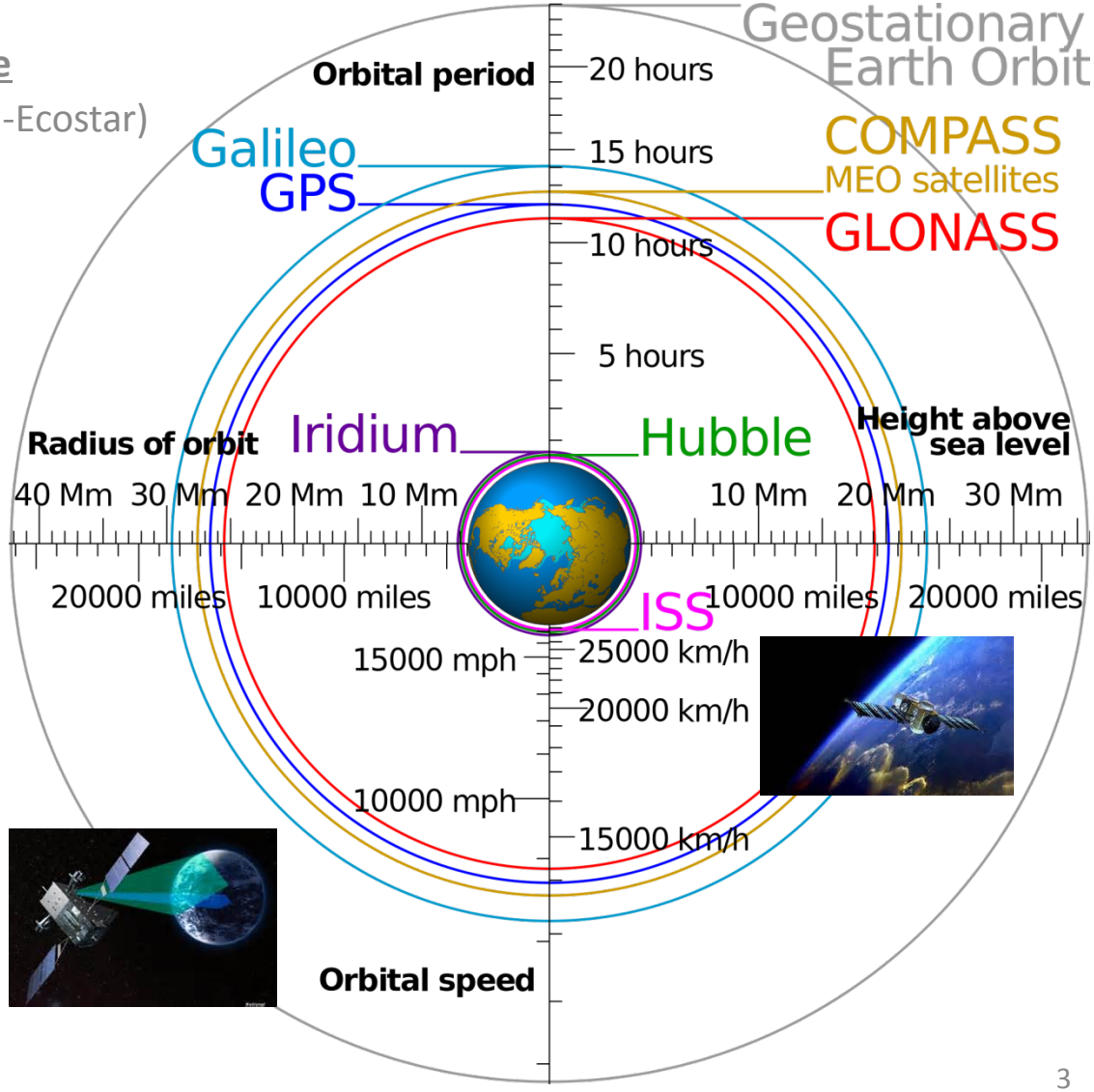
Distance: 10 miles

Coverage Diameter: 362 miles

Fleet Required: 1 for continuous coverage

Signal Delay: ~.1 millisecond

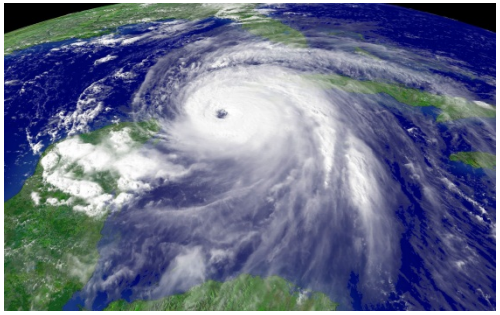
Proximity: 50 to 2000 times closer

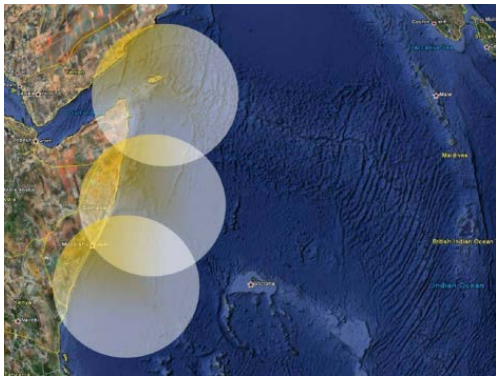


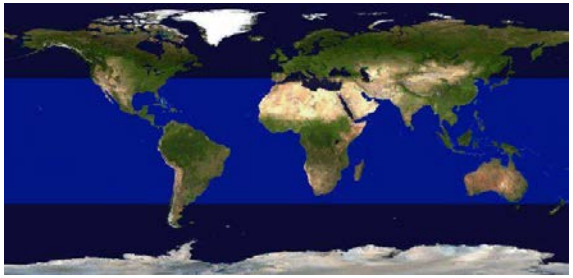
Why Pursue this Capability?

High Altitude (60,000 ft+)

Earth Science Missions
Extreme Weather Observation
Hurricane Genesis and Evolution
Tornado Monitoring
Cloud and Aerosol Measurements
Stratospheric Ozone Chemistry
Tropospheric Pollution/Air Quality
Water Pollution Monitoring
Water Vapor Measurements
O2 and CO2 Flux Measurements
Vegetation Composition
Aerosol and Precipitation Distribution
Glacier and Ice Sheet Dynamics
Antarctic Exploration Surveyor
Imaging Spectroscopy
Topographic LIDAR Mapping
Magnetic Fields Measurement
Oceanographic research
Volcano Monitoring
Surface Deformation Interferometry







Government Services
Active Plume Assessments
Forest Fire Damage Assessment
Forest Fire Communications
Wildlife Census / Animal Tracking
Land Resource Management
Crop Disease Tracking
Invasive Plant Assessment
Pirate / Coastal Patrol
Emergency On-Demand Comms
Disaster Assessment
Border Patrol
Search and Rescue
Mapping

Civil Missions
Omnipresent Wireless Broadband
Sat-Cell Phone Service
High Resolution Imagery
Agriculture Yield Maximizing

The Basic Problem

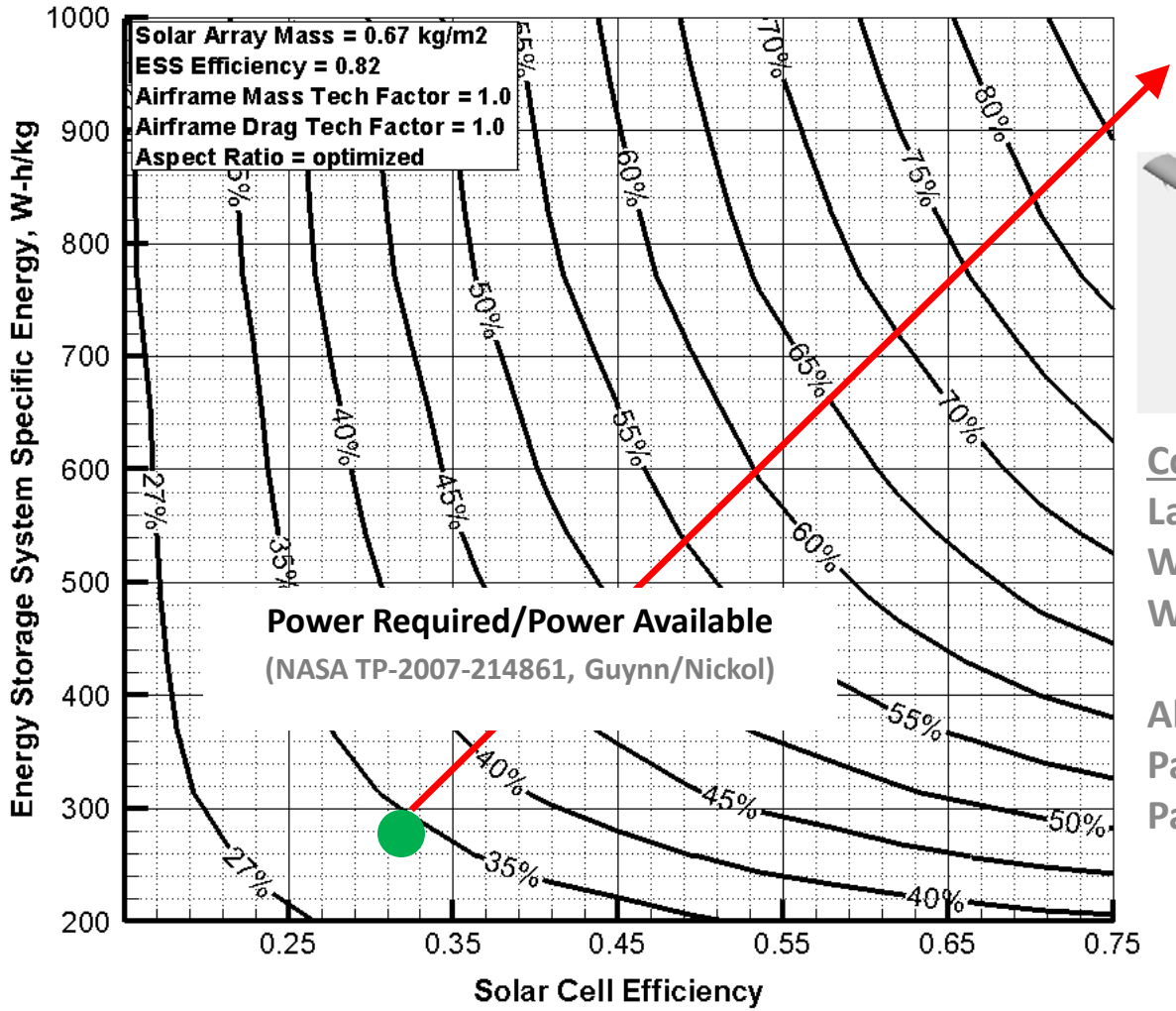
Power Required = Drag * Velocity

Low Cruise Speeds
High Cruise Altitudes (<10% Sea Level Density)
High Aerodynamic Efficiency (Lift/Drag Ratio)
High Structural Efficiency (Light Weight Structure)
High Efficiency Solar Cells, Energy Storage, Motors, Controllers, Propellers

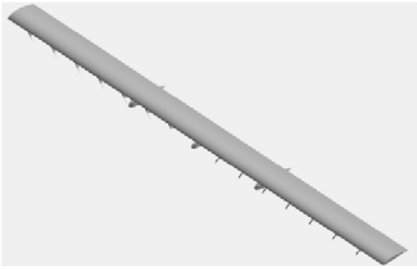
Energy collected during the day ≥ Energy sent to storage for the night + Energy used during the day

Most Difficult in Winter at Higher Latitudes
Able to Deal with Solar Cell Incidence Angle
Ability to Handle Winds Aloft
Very High Reliability Sub-Systems with Few Moving Parts

How Close Are Atmospheric Satellites?



Feasibility



<u>Comm Relay Mission</u>

Latitude of 47 deg N
Worst case winter day
Winds aloft for 99% of days (~120 mph)
Altitude of ~60k ft
Payload mass of ~5%
Payload/Avionics power of 1.3 kW

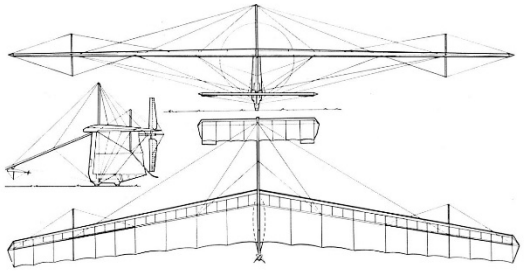
If we stick with conventional high span aircraft configuration approaches,
Then we'll need to wait until solar cells and electrical energy storage are ready

Audacious Challenges
Can Force Intriguing New Solutions

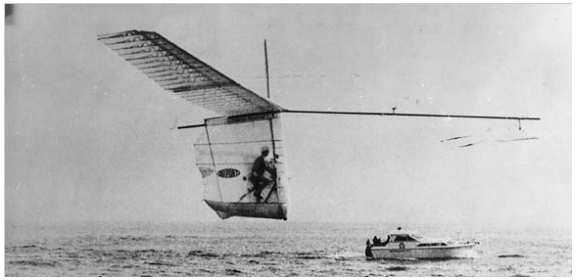
AeroVelo Atlas, Sikorsky Prize Winner 2013

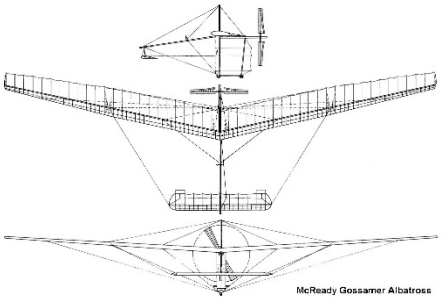
What if… a robust vehicle could be developed capable of carrying 150 lb payload with 1 hp?

Human Powered Aircraft
The Ultimate in Low Power



Gossamer Condor, Kremer Prize Winner 1977 (1/2 mile Figure Eight)

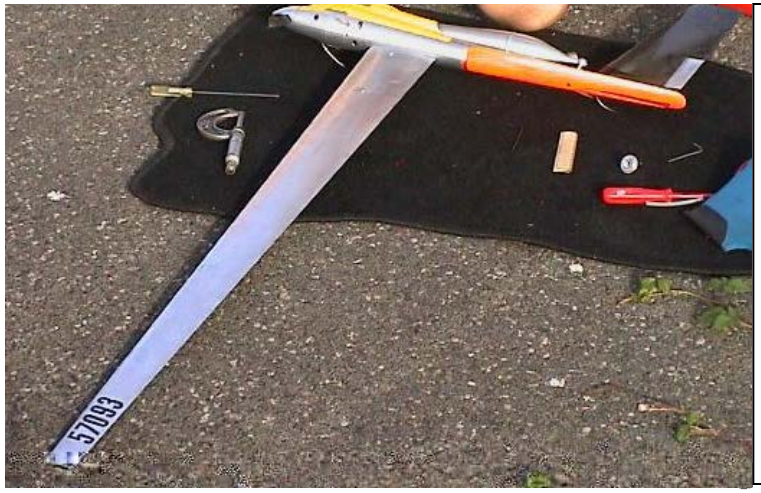




Gossamer Albatross, Kremer Prize Winner 1979 (Across English Channel)

AeroVironment Helios, 2003

CSR Advanced Concept
(Centrifugally Stiffened Rotor-wing) Technology
(Continuous Surveillance Reconnaissance) Capability



Unique Characteristics

Structural Efficiency

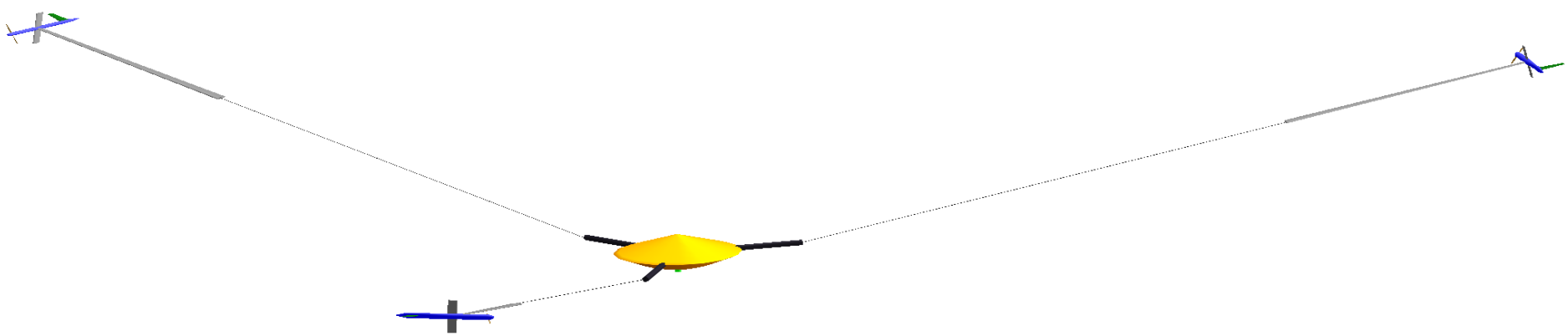
Tethered Rotors = Low Bending Moment

High Rotor-Tip Mass Loading = Centrifugal Stiffening

Aerodynamic Efficiency

High Aspect Ratio, Thin Rotors, Tip-Driven = Low Drag and Power

Stationary Payload Module = Volume Independent of Speed



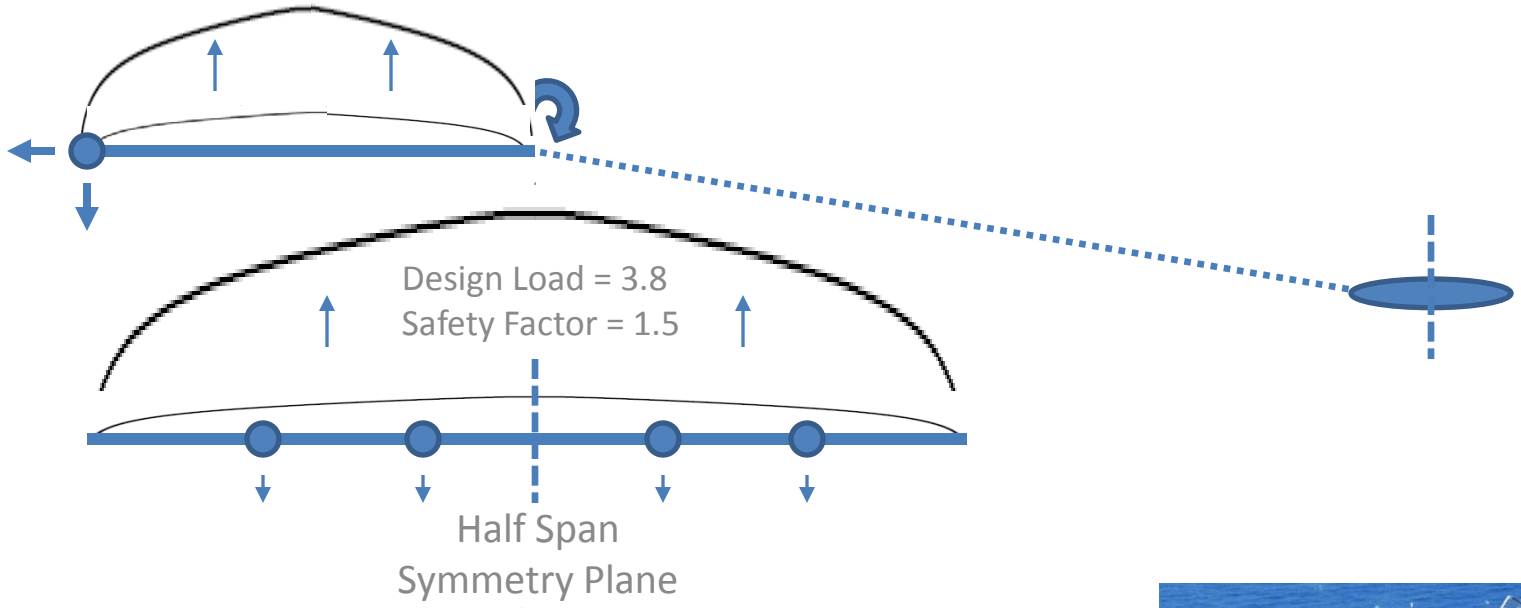
Extendable Spectra Tethered Rotor-Wings with Stationary Center Payload

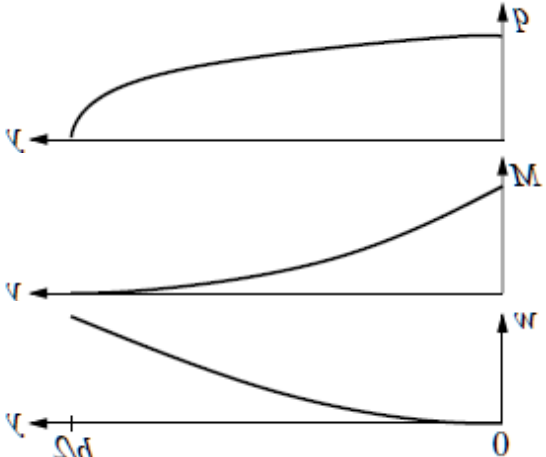
CSR Concept Structural Efficiency

CSR rotor-wing is free to rotate at tether joint instead of imparting large bending moments, with centrifugal restoring forces to achieve an efficient tensegrity structure

CSR 150' Span Rotor Wing

Baseline 300' Span Flying Wing





Lift Loading

Bending Moment

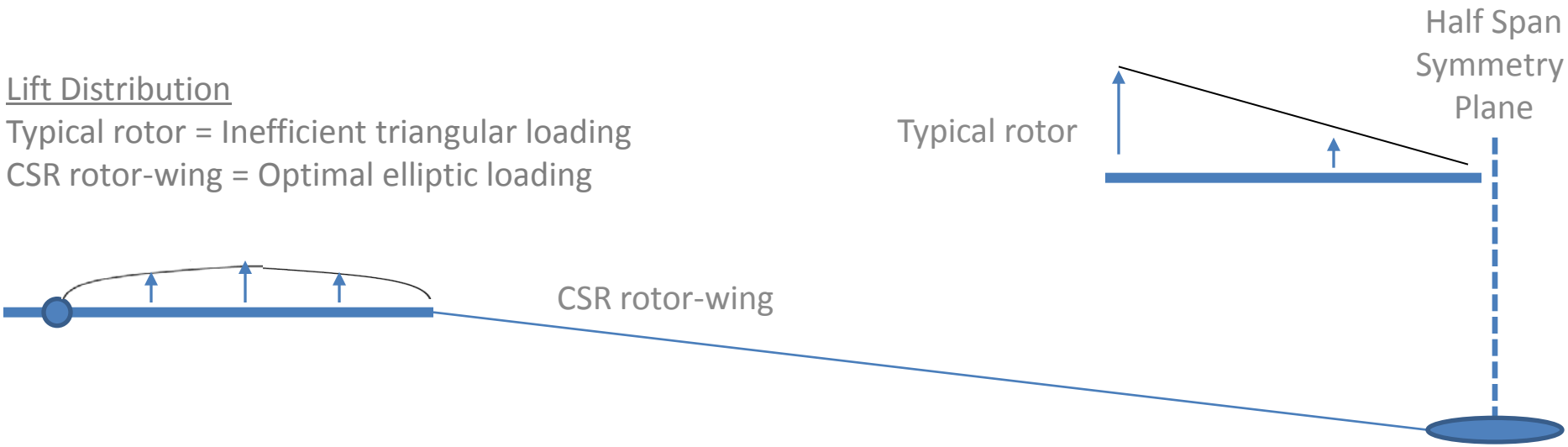
Deflection

CSR Concept Aerodynamic Efficiency

Lift Distribution

Typical rotor = Inefficient triangular loading

CSR rotor-wing = Optimal elliptic loading



Outoard Horizontal Stabilizer (OHS) Layout

Provides upwash to pitch trim tail to provide thrust

Original Blohm & Voss Concept

Scaled Composites Spaceship One

Why is the CSR concept more aerodynamically efficient?

High span with ideal loading, without weight penalty

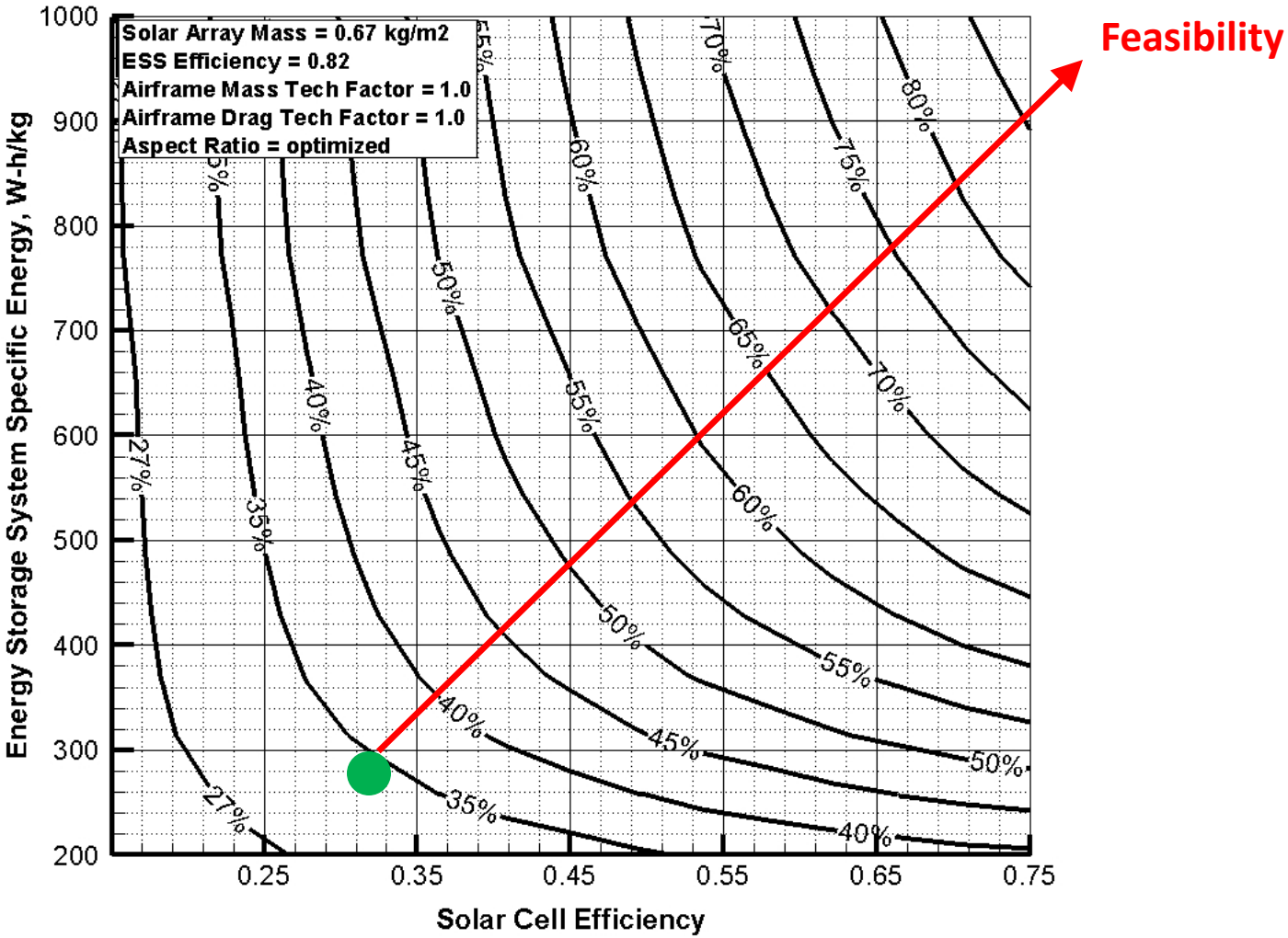
OHS configuration layout, without weight penalty

Use thinner airfoils to maximize low Reynolds number laminar flow, without weigh penalty

Payload volume independent of cruise speed

Tether drag is only <10% of total drag

How Close Are Atmospheric Satellites?

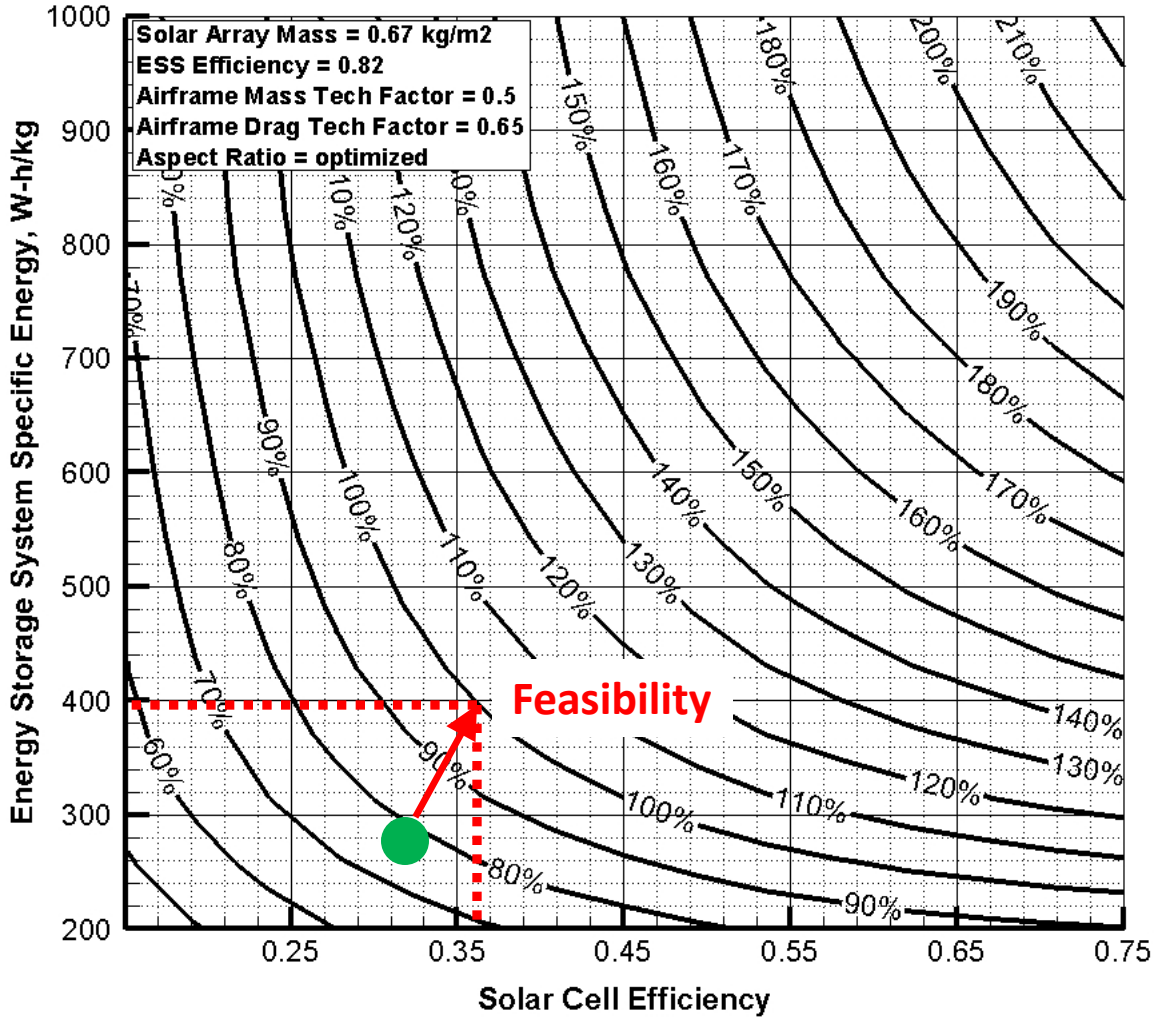


CSR Concept Goals

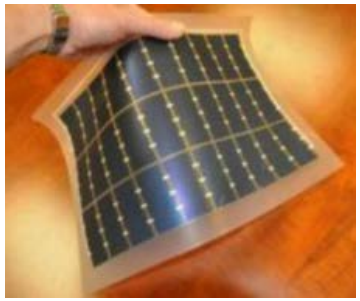
50% reduction in structural mass

33% reduction in drag

How Close Are Atmospheric Satellites?



Envia
400 Watt hr/kg
Argonne Lab testing



MicroLink Devices
Triple Junction Thinfilm
Solar Cell >30% eff

If our new technology/configuration approach can improve the Lift/Drag ratio from 30 to 45 and decrease the Airframe Weight by 50% Then we can do the mission with near-term solar cells and batteries

CSR Concept Feasibility

Flexible Multi-Body Tether Dynamics Control Problem

Objectives:

- Create a model for the concept vehicle dynamics
- Simulate the vehicle dynamics
- Perform a controls analysis on the full scale vehicle
- Validate the simulation through scale model testing

Significant modeling effort using SimMechanics with a focus on the stability, controllability, robustness, and disturbance rejection.

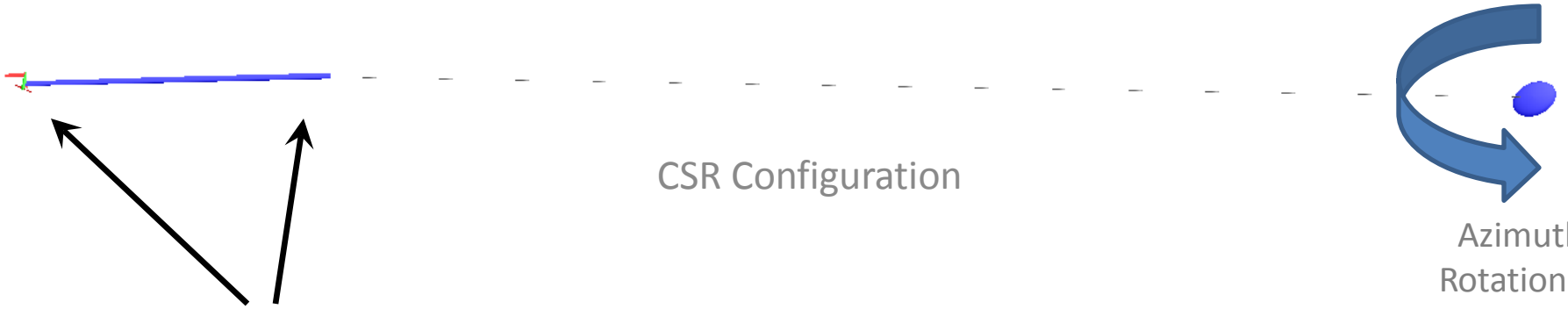
Also, the ability to accommodate 99% winds aloft is a critical factor, that is fundamentally different than other HALE aircraft.

Unique CSR Missions: High Altitude

Distributed Aperture Atmospheric Satellite Observatory

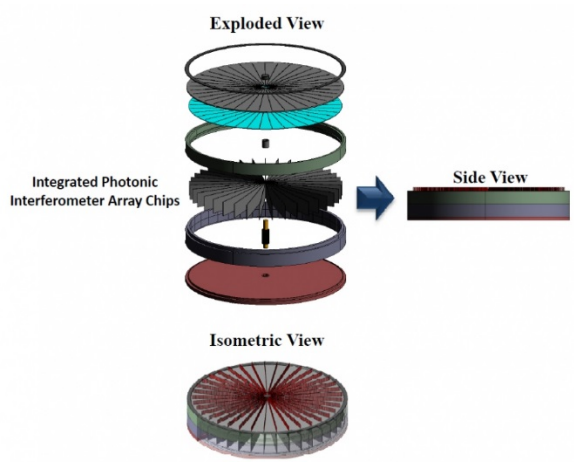
High resolution linked sensors rotate around azimuth, at 450 and 600 ft radius locations

Low resolution sensor in center payload section provides filling



CSR Configuration

Azimuth Rotational Axis



Low-Mass Planar Photonic Imaging Sensor

Very Large Array (VLA) Radio Telescopes

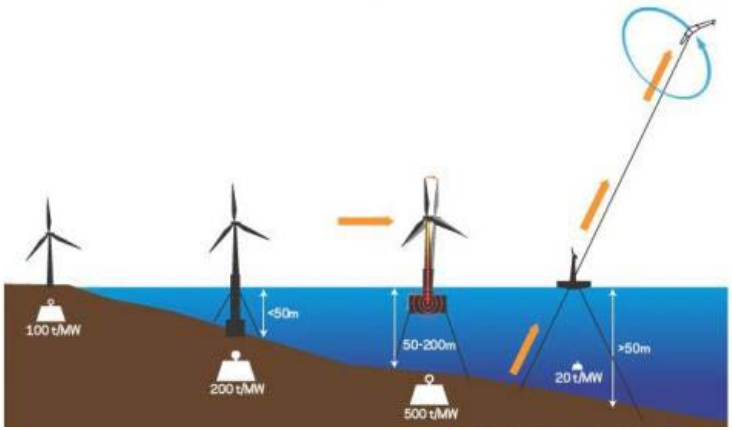
Unique CSR Missions: Low Altitude

Dual-Use Airborne Wind Energy Platform and Coastal Ocean Observation

Ground conductive tethered wind energy extraction (CNT tether key enabler)

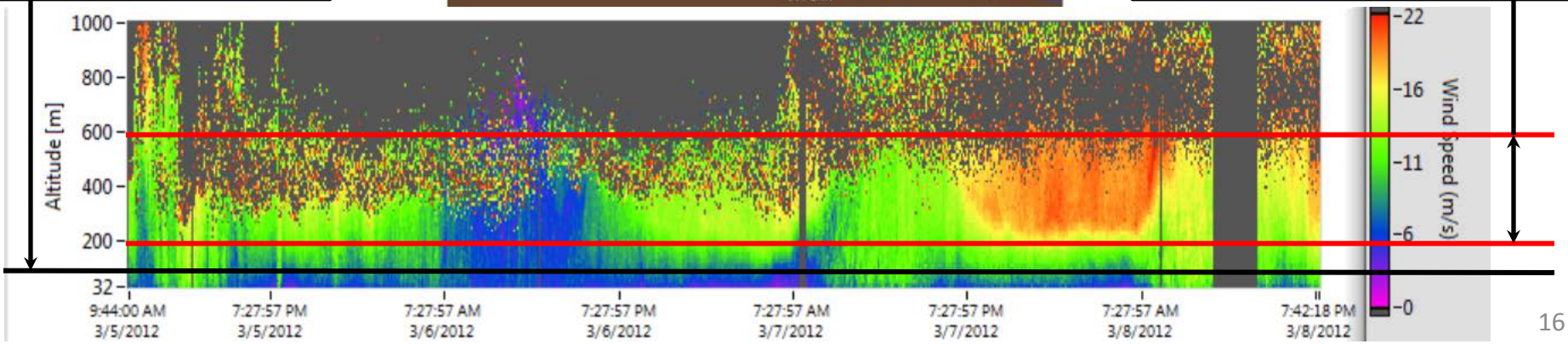
Rotor-wing tip propellers act as turbines

Cross-wind flight velocity scales with vehicle L/D

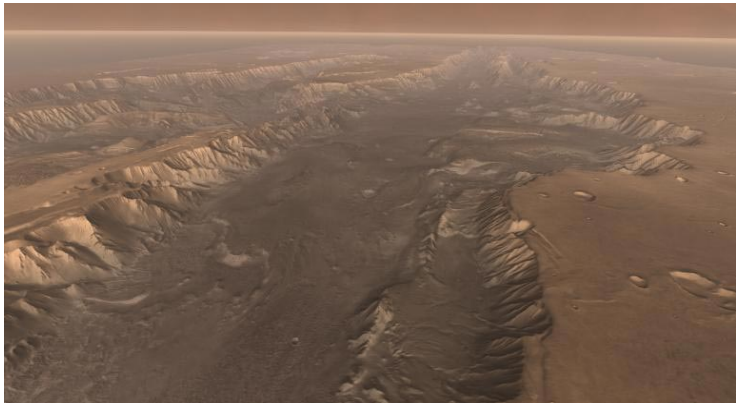


Conventional HAWT
80m

Airborne Wind Energy
200-600m



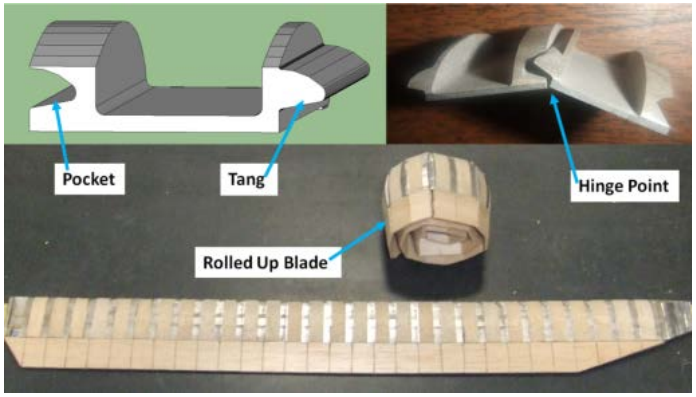
Extra-Planetary Missions



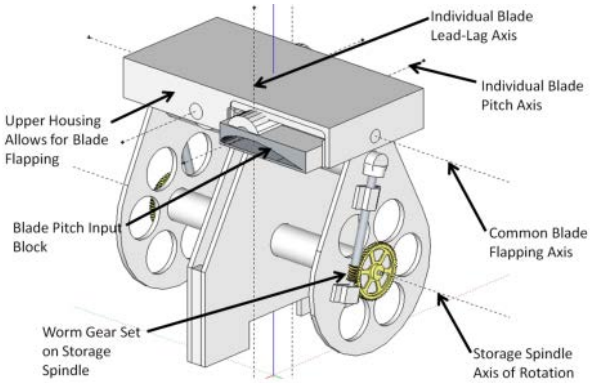
Ultra Low Power, Compact VTOL Mars Explorer for Low Density Atmospheres

Fully retracting version of the CSR rotor-wing to fit within transit aeroshell

Operation from a recharging station (with potential to use wind energy capture)



NASA Langley Rapid Prototyped Centrifugally Stiffened Rotor



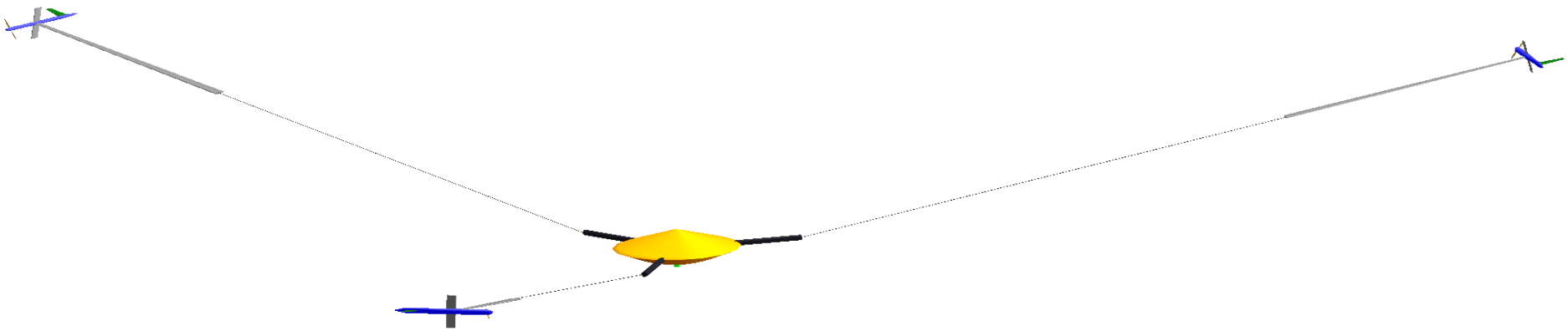
Rotor-wing Retraction Mechanism CAD Design

Conclusions

The CSR concept offers a unique configuration approach that could lead to fundamentally new degrees of freedom that open up new missions and design space.

Research has focused on tool development for this unique tethered multi-body dynamics control problem with 3 graduate students.

Analysis is focusing on modeling of a 300 lb payload size to compare to a well understood conventional all wing configuration,
as well as modeling and development of a 55 lb gross weight UAV that can showcase scaling issues and provide an initial validation experiment.

If the structural and aerodynamic efficiency goals can be met,
as well as complex control while accommodating 99% of winds aloft
Then AtmosSats feasibility is achievable with near-term solar cell and batteries.

Questions?