# RECENT ACTIVITIES IN SOLAR SAIL TECHNOLOGY

**April 4, 2001**

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**Jet Propulsion Laboratory**

**California Institute of Technology**

**Thermal and Propulsion Engineering Section**

**Contributors:**

| | |
|---|---|
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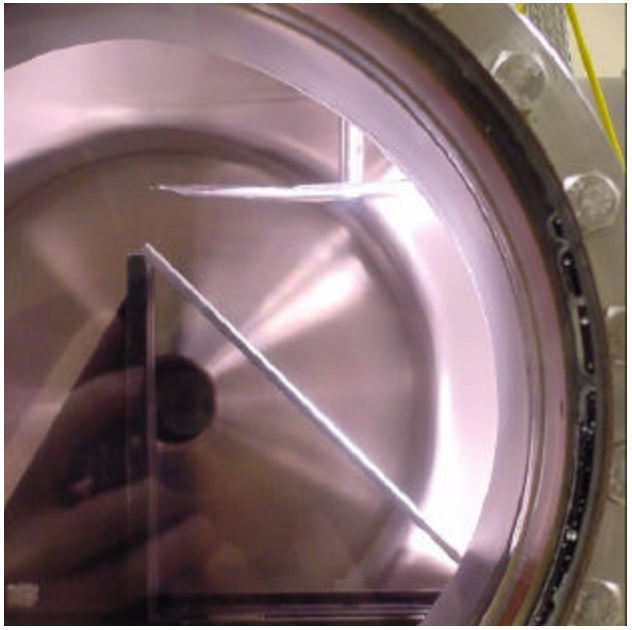
| **Humphrey Price** | **JPL** |
| **Moktar Salama** | **JPL** |
| **Paul Willis** | **JPL** |
| **Jim Rogan** | **Encounter 2001** |
| **Gordon Veal** | **L'Garde** |
| **Louis Friedman** | **Planetary Society** |
| **Keith Belvin** | **LaRC** |
| **Richard Blomquist** | **CMU** |
| **David Edwards** | **MSFC** |
| **Tim Knowles** | **ESLI** |

# Sail Activities at MSFC

Dave Edwards, MSFC

## Photon Momentum Measurements

- Determined momentum transfer on aluminum samples of photons from solar simulator
- Solar simulator produces up to 3 suns
- Experiments conducted in vacuum chamber at MSFC using microbalance
- Measured momentum within 10% of calculated value-now measure photon pressure on real sail materials!



## Space Environmental Effects Testing

- Al/Mylar samples on MISSE and ground test exps of simulated LEO exposures

## SBIR/STTR Programs

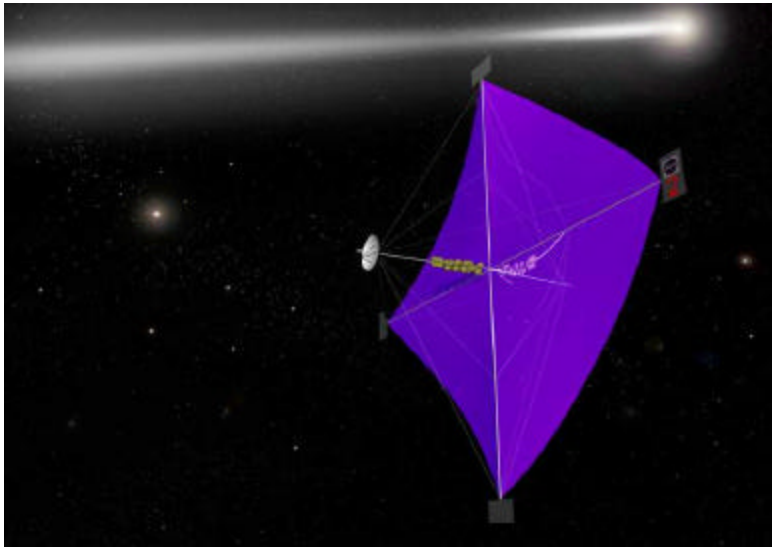
- Biomimetic Fabricated Solar Sail Technologies (Ph1) and Carbon µTruss (Ph2 at JPL)
- Carbon Sails for Gossamer Spacecraft Attitude Control (Ph1)

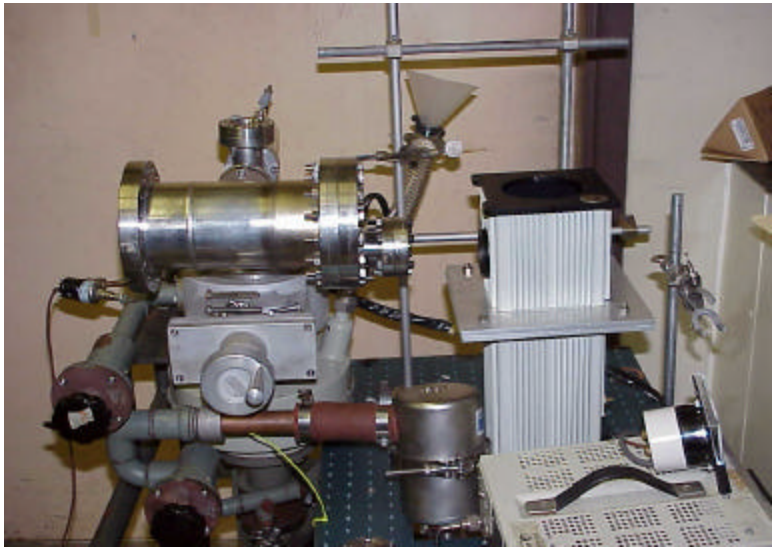
FY 02 Solar Sail Technology Working Group to fund technology developments

12th Annual Advanced Propulsion Workshop

# Solar Sail Fugitive Film Demonstration

Paul B. Willis, Jet Propulsion Laboratory, (818) 354-6998

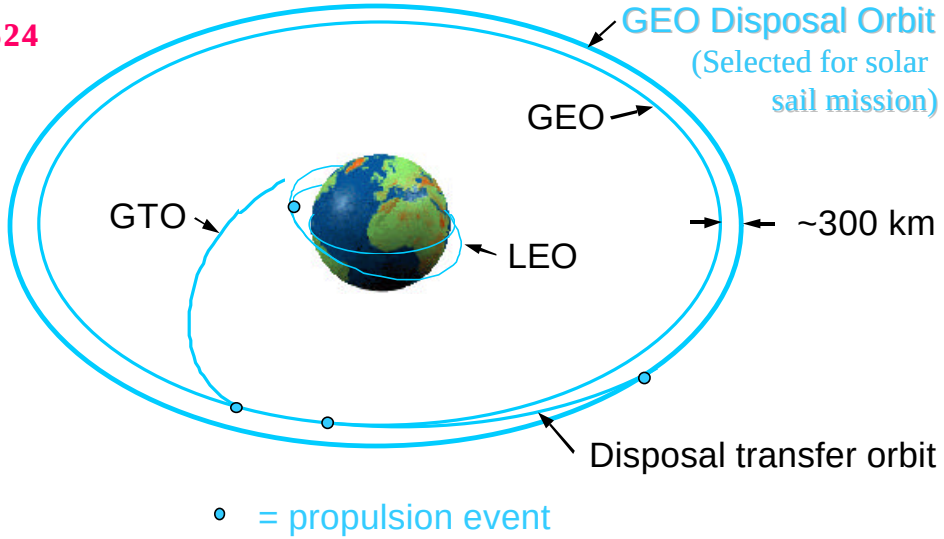




- Objective
  - Develop a coating that decomposes in light; lowers the mass and produces thrust
- Status-Success!
  - Apparatus complete,fully functional, excellent data
  - 7 candidate polymer films under test
  - Data indicates first-order kinetics, and provides decomposition rates
  - “Two for one”; films reduce mass and provide spacecraft thrust
- Plans
  - Attach mass spectrometer to identify fragments ; evaluate remaining polymer films, calculate thrust
- Multi-center effort
  - JPL is lead; collaborators include Adherent Technologies, Inc. and Howard University

# Proposed Solar Sail Flight Validation Mission

**H. Price, Jet Propulsion Laboratory, (818) 354-6524**

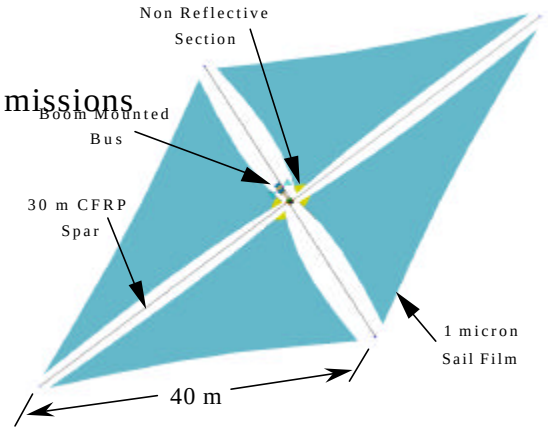



**Key Concept Parameters**

- Piggyback launch to GEO + 300 km
  - Other orbits (e.g. polar) are also an option
- Mission Duration:
  - Primary: 3 months
  - Extended: 12 months
- Representative Mass Breakdown
  - 10 kg instruments
  - 100 kg bus, 30 kg solar sail
  - 30% mass and power contingency
  - 200 kg at launch (incl. jettisoned components)
- ~0.4 Mbps Downlink

**Validation Mission Products and Results**

- Validated solar sail subsystem design that can be immediately applied to science missions
- Flight data and characterization of sail deployment
- Flight data and characterization of sail stability
- Flight data and characterization of sail performance and maneuverability
- Inspiring visual images and viewability by ground observers

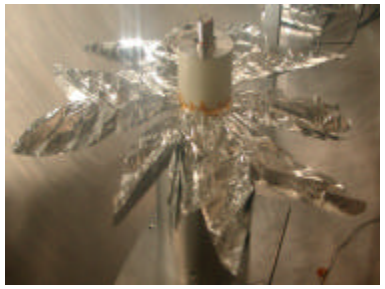
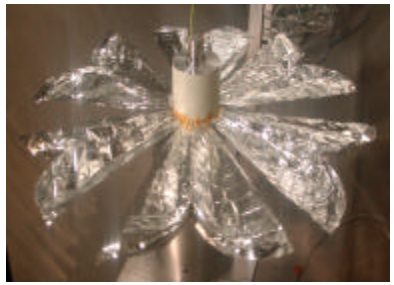
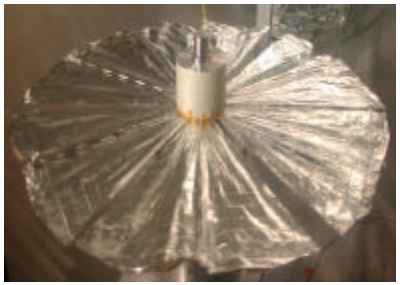



A representative concept for ST7

# Spinner Solar Sail Deployment Test

Moktar Salama, JPL

- **0.8 m scale model spinning sail deployed in vacuum chamber**
  - **Fabricated from 2.5 μm aluminized Mylar**
  - **Will help verify deployment models**
  - **Characterize some of the deployment challenges**
  - **Makes progress toward verifying design concept for spinners**

# Sail Activities at LaRC

Keith Belvin, LaRC

- Space Environmentally Durable Ultrathin Polymer Membranes

Goals:

- A0, UV Durable
- Low areal density- Electrospinning
- Low Solar Absorptivity
- Reflective Coatings -Self Metallizing
- Electrical Conductivity -Carbon Nano-Tubes
- Tear Resistance - Rip Stop and Microfiber Mat

*Under Development:*

**•Electrospun Sail Material 1mm CP-1**

Potential to Fabricate on-orbit
(0.125 g/m$^2$, Reflectivity = 76% (unmetallized),
Tg = 208° C), Potential to Make Conductive
Space Environmental Durability

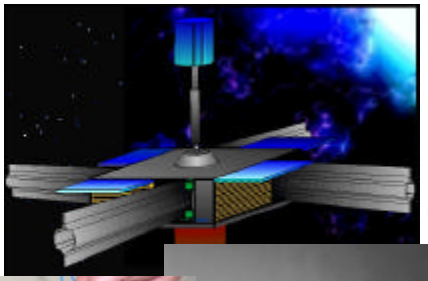
**•Rigid Porous Carbon Material**

Energy Sciences Lab, Inc.
JPL Ph II, ends 2/'02
(2 gm/m$^2$, Reflectivity 10%? (unmetallized),
Tg= 2500° C),High Temp Performance,
Space Environmental Durability

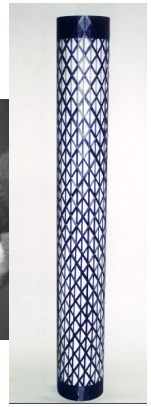
Electrospun
Sail Material

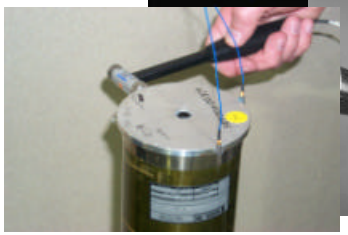
12th Annual Advanced Propulsion Workshop

# Support Structure Characterization and Analysis



Isogrid Boom





Inflatable Boom

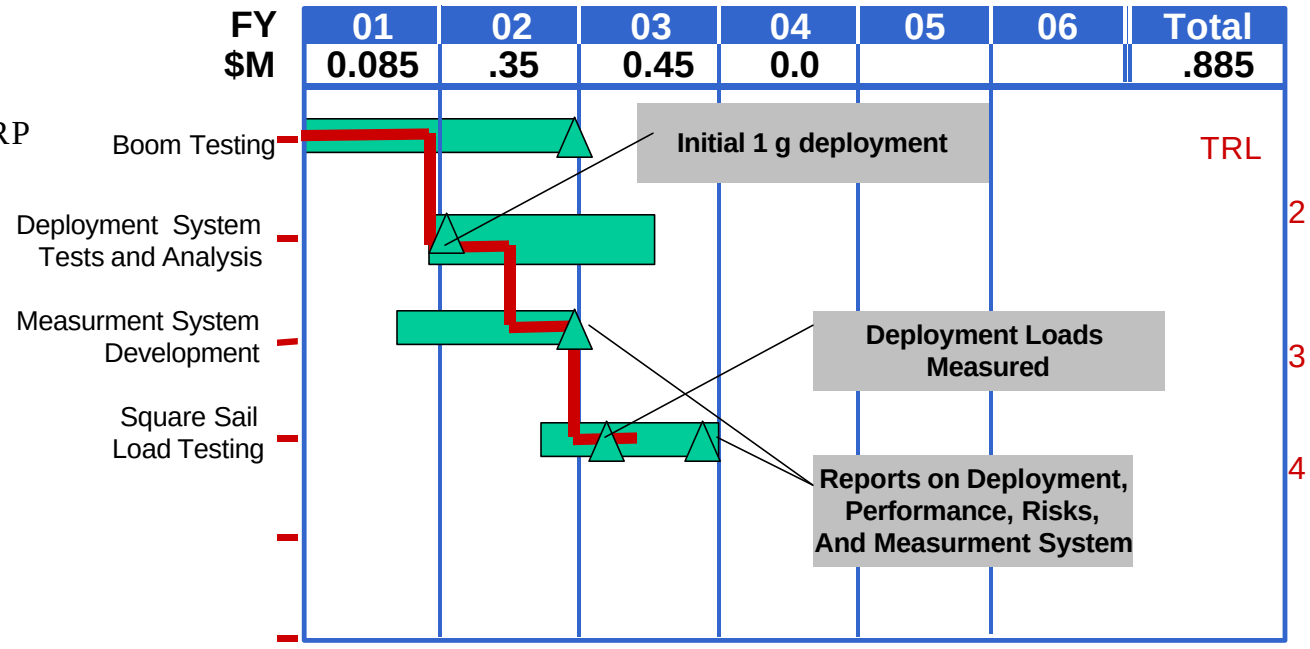
Stem Boom

## Milestones / Activities

- FY'01 Milestones
  - Static and Dynamic Isogrid Tests
  - In-Situ Measurement Concept
- FY'02 Milestones
  - Multiple Boom Type Deployment Tests/Analysis
- Prioritized list of Activities:
  - Structural Property Characterization
  - Component Assembly
  - Deployment Tests in Vacuum

## Implementation / Metrics

- Current State of the Art
  - Various Low TRL Industry CFRP Rigidizable Booms
- Performance Metrics
  - Goal <50 g/m$^2$
  - Repeatable Deployment
- Risks
  - Deployment Reliability
  - Shell Buckling
- Participants/University
  - NASA- LaRC, JPL
  - Industry -CTD, ILC, L'Garde,...
  - Univ. of Colorado



# Sail Deployment Model Development and Ground Tests

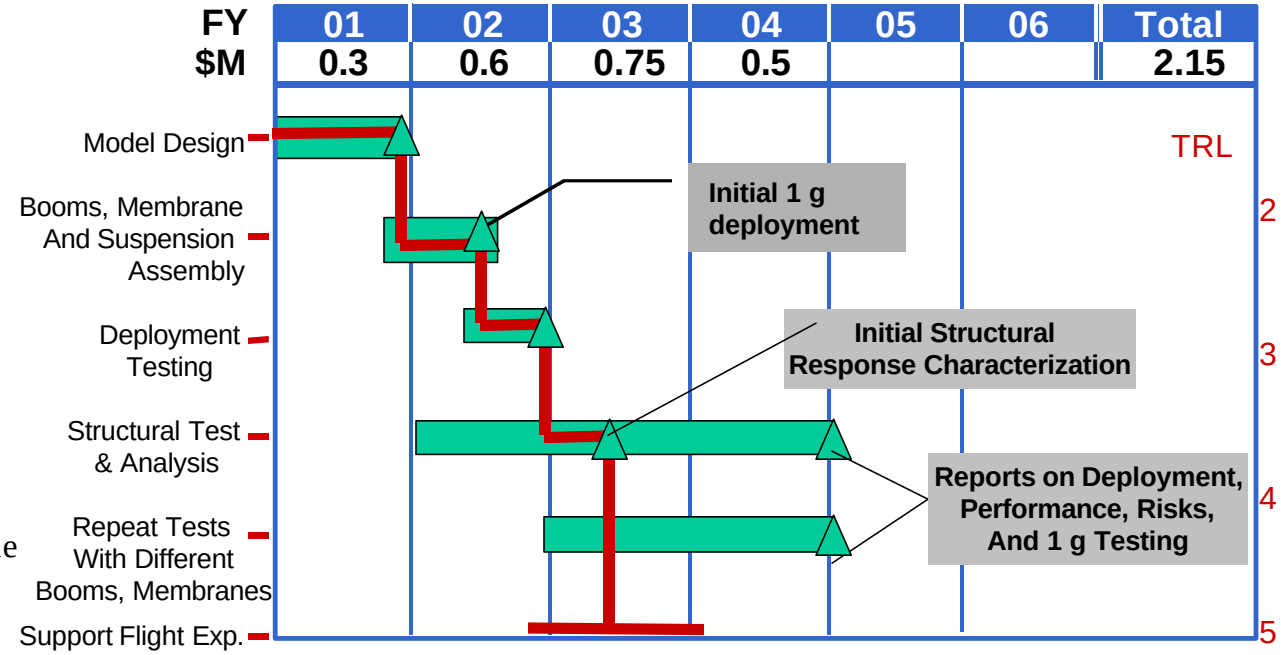
DLR ODISSEE
20 m Sail

## Milestones / Activities

- FY'01 Milestones
  - Design of 10 m solar sail deployment model
- FY'02 Milestones
  - Support Structure and Membrane Acquisition, Model Fabrication, and Initial Deployment Tests
- Prioritized list of Activities:
  - 1 G model design (analysis)
  - Component Assembly
  - Deployment Tests in Vacuum with Analysis Correlation
  - Grants with U of Colorado, Connecticut, and Duke

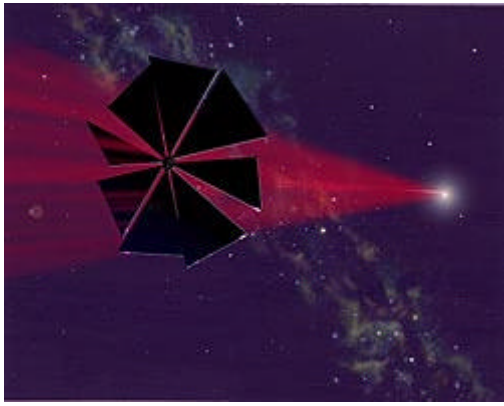
## Implementation / Metrics

- Current State of the Art
  - DLR ODISSEE (20 m Model)
- Performance Metrics
  - Goal 10-20 g/m$^2$
  - < 25 % Membrane Wrinkles
- Risks
  - Deployment in 1G
  - Membrane Management, Tearing
- Participants/University
  - NASA- LaRC, MSFC, JPL
  - Industry -SRS, CTD, ILC, L'Garde
  - U. Colorado, Connecticut, Duke,




**Sponsored by Cosmos Studios**

- Deployment Demo scheduled for April 17-24, 2001
  - Sub-orbital flight launched from Barents Sea on converted ICBM
  - 2-bladed sail using 5 µm Russian Mylar and inflatable booms
  - 15-m sail blades will be Z-folded for deployment
  - Purpose of test is to validate deployment



- Full-up Sail Demonstration Flight late 2001
  - 30-m -dia sail with 8 triangular blades built at Babakin Space Center
  - 40 kg spacecraft launched on Volna rocket to 850 km circular near-polar orbit
  - Telemetry will be received in Russia and the United States

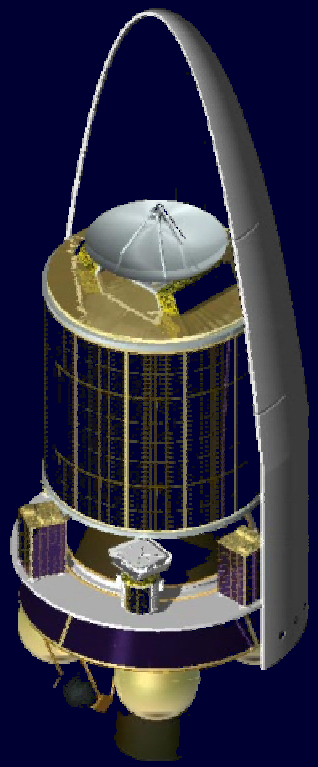
# Self-Deploying Hoop Sail

- Hollow stainless tubes welded to adjoining hoops
- Weld forms a low-mass hinge for deployment
- 6 µm Kapton film is stretched across the hoops to form the sail
- Total areal density is 14.5 g/m2 (>9 g/m2 is film)

**Zero-G deployment test of 52-hoop array is scheduled for April 16, 2001 on NASA's "Vomit Comet"**


# MISSION CONFIGURATION

# MISSION PLAN

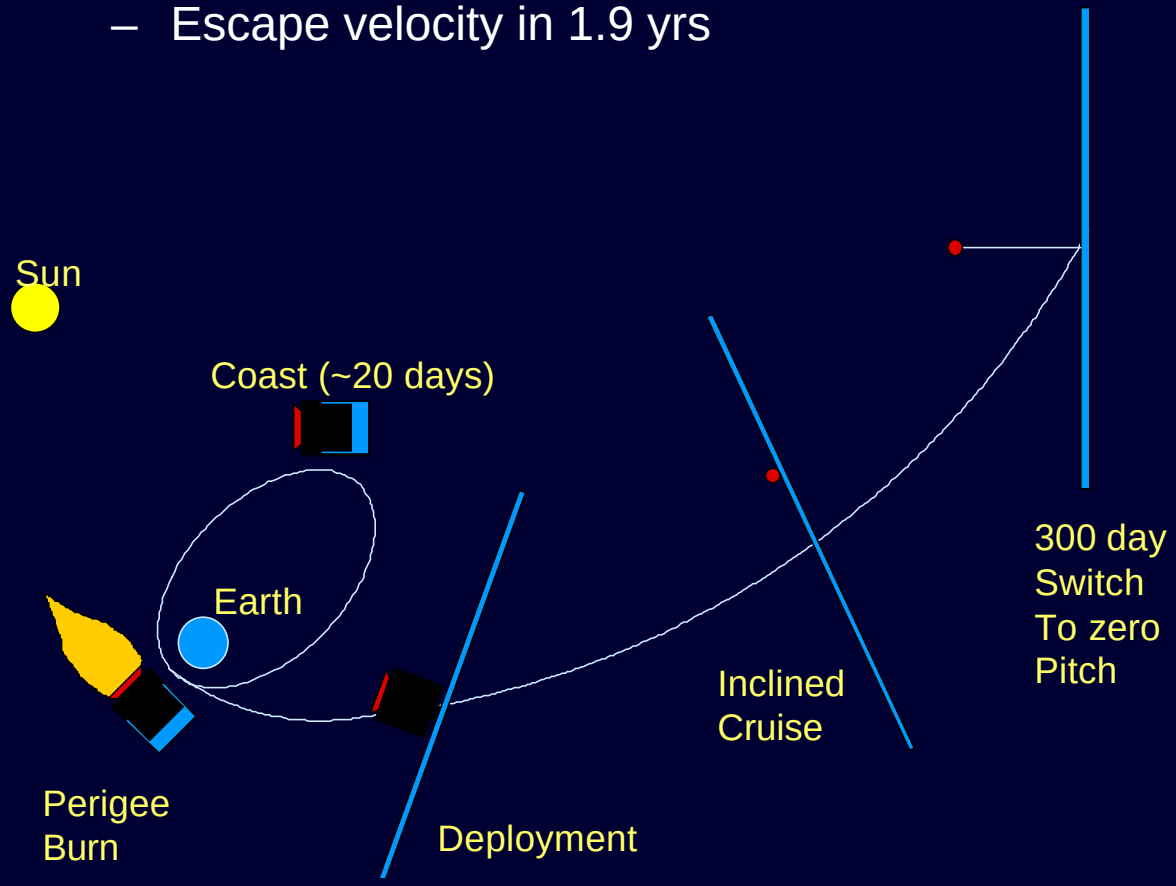


Team Encounter spacecraft attached to the ARIANE V ASAP ring

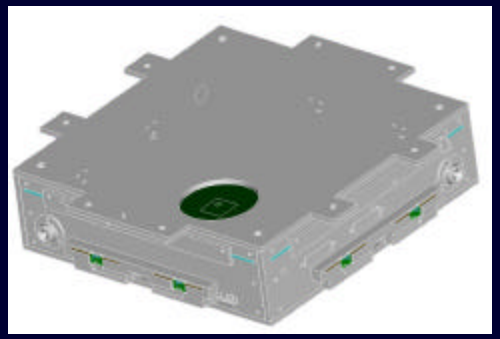
- **Spacecraft launch as secondary payload on Ariane 5 (ASAP ring)**
- **Spacecraft has two parts:**
  - Carrier
    - Gets sail to release point
    - Transmits video of sail to earth
  - Sailcraft
    - Carries 3 kg payload to solar escape

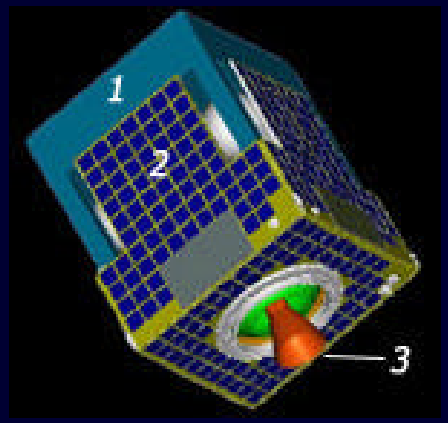
# MISSION PHASES

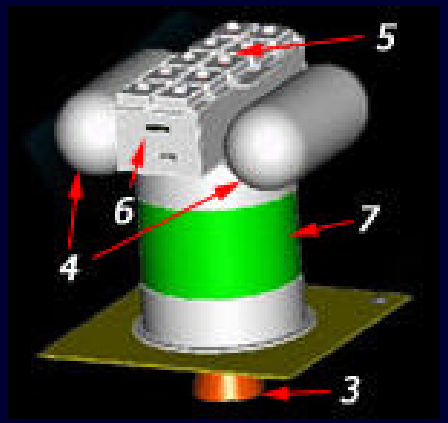
- **Solar sailing**
  - First 300 days, “jibbing” away from the sun
  - Reorient
  - Escape velocity in 1.9 yrs



# CARRIER LAYOUT





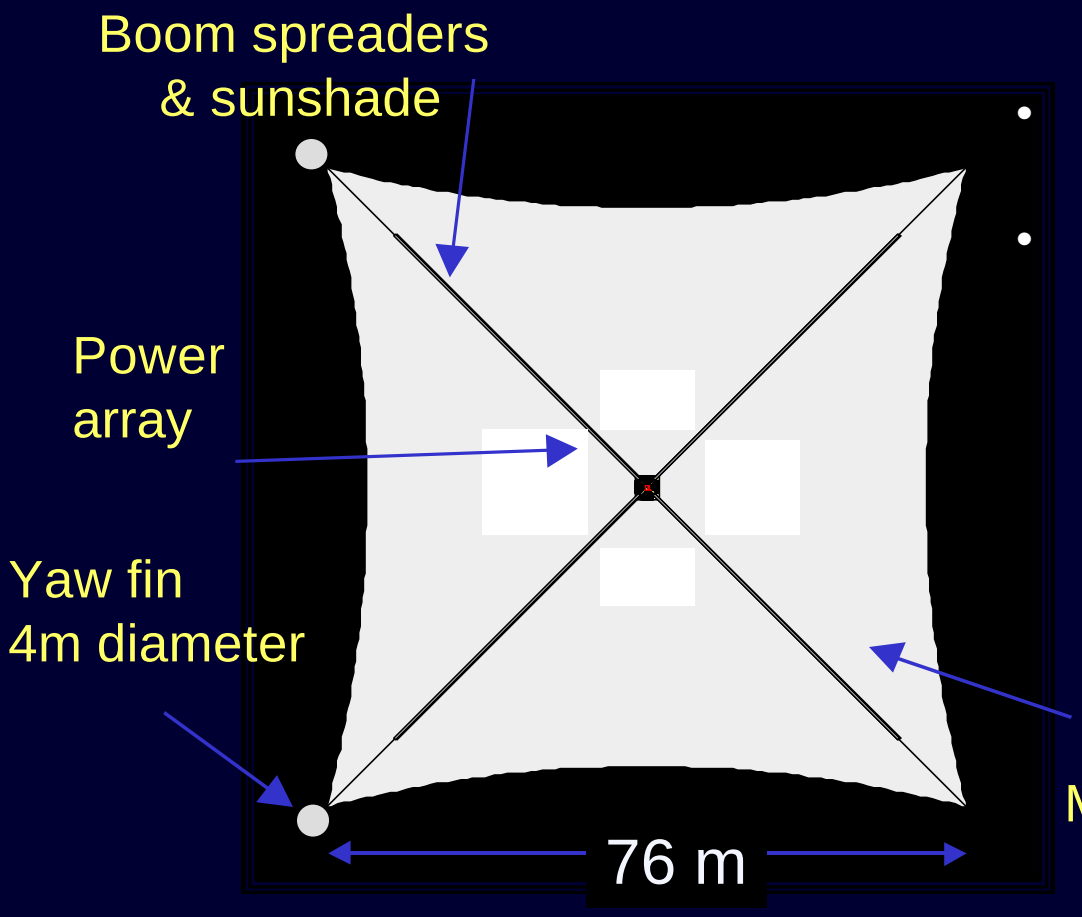




- **Built around "Bitsy-SX" spacecraft kernel**
  - No onboard autonomy
  - Command and data handling
  - Power supply and regulation
- **Overall dimensions**:
  70 cm x 58 cm (2.3 ft. x 1.9 ft)

- **Additional hardware**
  - Propulsion
  - Attitude Control and Determination
  - Communications
  - Imaging cameras
- **ASAP 5 allowed dimensions:**
  60 cm x 60 cm x 71 cm (above separation plane)

1. Stowed Solar Sail ; 2. Side Solar Panels; 3. Thruster ;4. Cold Gas Tanks; 5. Imaging Cameras (10X) ; 6. BITSY™ -SX ; 7. STAR 12G Solid Motor

# SAIL CONFIGURATION

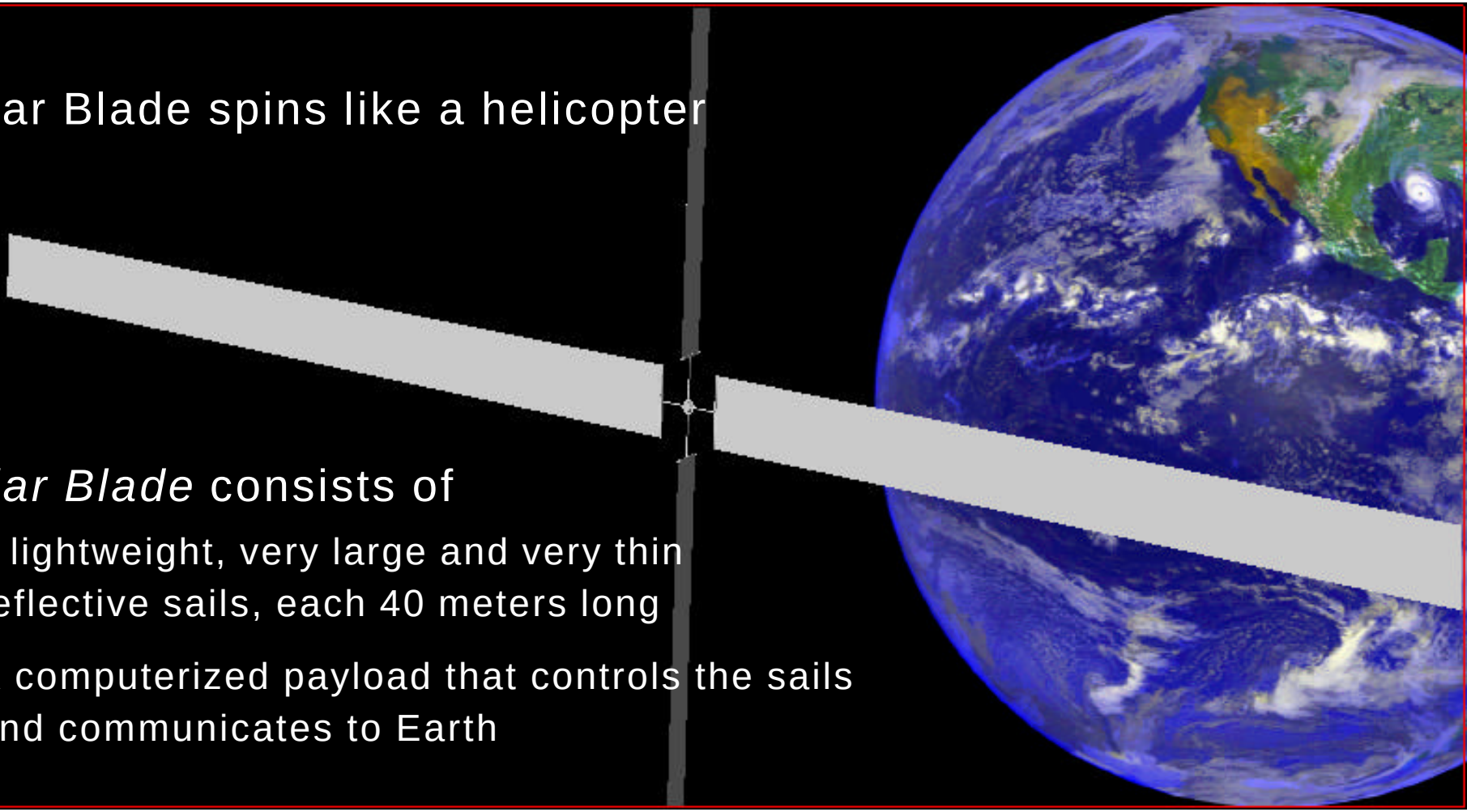



- **Sail material:**
  - mylar: 0.9 mm (~0.000035 in.)
  - Front: aluminum metalization
  - Back: chromium metalization
- **Overall sail dimensions**:
  76.4 m x 76.4 m (250 ft. x 250 ft.)
- **Life expectancy:** exceed 10 yrs.

# SPACECRAFT SPECIFICATIONS

- **Mass:**
  - Sailcraft: 19.0 kg (41.9lbs)
  - Carrier 84.9 kg (187.2 lbs)
  - Total: 103.9 kg (229 lbs)
- **Power (Max):**
  - Sailcraft: 24 watts
  - Carrier: 93.2 watts
  - Total: 117.2 watts
- **Overall spacecraft dimensions: 70 x 58 cm (2.3 ft. x 1.9 ft)**
- **Overall sail dimensions: 76.4 x 76.4 m (250 x 250 ft.)**
- **Sail Area: 70 m x 70 m (230 x 230 ft.)**
- **Boom Length: 54 m (177 ft.)**
- **Sail material: mylar: 0.9 mm (~0.000035 in.)**
- **Power source: solar cells**
- **Communications link: S-Band (located on carrier)**
- **Velocities:**
  - At perigee in GTO: 9.9 km/s (6.2 miles/s) prior to motor burn
  - Earth Orbital Velocity:7 km/s (4.4 miles/s)
  - Earth Escape Velocity: 10.7 km/s (6.7 miles/s)
  - Solar Escape Velocity (relative to the sun):
    - 42.1 km/s at sail release (26.3 mile/s) 17 km/s at 1.9 years (10.6 miles/s)
    - 12.5 km/s (7.8 miles/s) final velocity

Solar Blade spins like a helicopter



*Solar Blade* consists of

- 4 lightweight, very large and very thin reflective sails, each 40 meters long
- A computerized payload that controls the sails and communicates to Earth

# Solar Blade Heliogyro

- Accomplishments
  - **Spacecraft & Mission Design**
  - **Technical Baseline Document of Complete Mission -** Reviewed and endorsed by the Aerospace Corporation
    - Includes all aspects of a PDR. Avionics is at the conceptual design level
  - **Complete Mechanical Prototype Built**
- Current and Near-term Work
  - **Avionics Breadboard**
  - **Propulsion Prototype for Sail Deployment**
  - **Mechanical Hardware Design & Analysis for Flight**
  - **DDR**