Solar Sail Propulsion for Interplanetary Small Spacecraft

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### Payloads

#### NASA Centers

**BioSentinel**  
**ARC/JSC**
- **Strategic Knowledge Gaps Addressed**: Human health/performance in high-radiation space environments  
  - Fundamental effects on biological systems of ionizing radiation in space environments

**Lunar Flashlight**  
**JPL/MSFC**
- **Strategic Knowledge Gaps Addressed**: Lunar resource potential  
  - Quantity and distribution of water and other volatiles in lunar cold traps

**Near Earth Asteroid (NEA) Scout**  
**MSFC/JPL**
- **Strategic Knowledge Gaps Addressed**: Human NEA mission target identification  
  - NEA size, rotation state (rate/pole position)  
  - How to work on and interact with NEA surface  
  - NEA surface mechanical properties

**Mission Concept**
- **BioSentinel**: Study radiation-induced DNA damage of live organisms in cis-lunar space; correlate with measurements on ISS and Earth
- **Lunar Flashlight**: Locate ice deposits in the Moon’s permanently shadowed craters
- **Near Earth Asteroid (NEA) Scout**: Flyby/rendezvous and characterize one NEA that is candidate for a human mission

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HEOMD’s Advanced Exploration Systems (AES) selected 3 cubesats for flight on SLS EM1

**Primary selection criteria:**
- Relevance to Space Exploration Strategic Knowledge Gaps (SKGs)
- Life cycle cost
- Synergistic use of previously demonstrated technologies
- Optimal use of available civil servant workforce
Both Use Solar Sail Propulsion and 6U CubeSats
Solar sails use photon “pressure” or force on thin, lightweight reflective sheet to produce thrust.
ECHO II 1964
SOLAR THRUST AFFECT ON SPACECRAFT ORBIT

• 135-foot rigidized inflatable balloon satellite
• laminated Mylar plastic and aluminum
• placed in near-polar Orbit
• passive communications experiment by NASA on January 25, 1964

When folded, satellite was packed into the 41-inch diameter canister shown in the foreground.
Znamya (Space Mirror)

- Russian experiment that flew on Progress after undocking from Mir Space Station in 1993.
- Purpose was to reflect sunlight onto the ground from space.
- 20-m diameter sail successfully deployed
- 5-km spot illuminated Europe from France to Russia moving at 8 km/sec.
- Follow-on mission flew, but was damaged during deployment.
NASA GROUND TESTED SOLAR SAILS IN THE 2000’S

- Two solar sail technologies were designed, fabricated, and tested under thermal vacuum conditions in 2005:
  - 10 m system ground demonstrators (developed and tested in 2004/2005)
  - 20 m system ground demonstrators (designed, fabricated, and tested)

- Developed and tested high-fidelity computational models, tools, and diagnostics
- Multiple efforts completed: materials evaluation, optical properties, long-term environmental effects, charging issues, and assessment of smart adaptive structures
Planned to be a space flight demonstration of the solar sail developed and tested as part of the ground sail test program
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Canceled
THE PLANETARY SOCIETY’S COSMOS-1 (2005)

- 100 kg spacecraft
- 8 triangular sail blades deployed from a central hub after launch by the inflating of structural tubes.
  - Sail blades were each 15 m long
  - Total surface area of 600 square meters
- Launched in 2005 from a Russian Volna Rocket from a Russian Delta III submarine in the Barents Sea:
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Rocket Failed
Mision Description:
- 10 m² sail
- Made from tested ground demonstrator hardware
Launch

- Falcon-1, flight 3
- Kwajalein, Missile Range
- Primary payload: AFRL PnPSat
- Secondary P-POD payloads (2)
NANOSAIL-D1 FLIGHT (2008)

Launch

- Falcon-1, flight 3
- Kwajalein, Missile Range
- Primary payload: AFRL PnPSat
- Secondary P-POD payloads (2)

Rocket Failed
NANOSAIL-D2 MISSION CONFIGURATION (2010)

- HSV-1
- Ride Share Adapter (Space Access Technology)
- Air Force Research Laboratory (AFRL) Satellite (Trailblazer)
- NanoSat-D (MSFC)
- Presat (ARC)
- PPOD Deployer (Cal-Poly)
- Boom & Sail Spool (ManTech SRS)
- NanoSat-D (MSFC)
- Stowed Configuration
- AFRL Satellite (Trailblazer)
- Adapter

- 3U Cubesat: 10 cm x 10 cm x 34 cm
- Deployed CP-1 sail: 10 m² Sail Area (3.16 m side length)
- 2.2 m Elgiloy Trac Booms
- UHF and S-Band communications

Nanosail-D in Orbit: August 19, 2011 01h 19m 28s UT
Clay Center Observatory at Dexter and Southfield Schools
42.307404N, -71.137222W (WGS84)
www.claycenter.org  focal length: 12200mm,
Aperture = 46mm RitcheyChrétien
Contact Ron Dantowitz (roandantowitz@gmail.com)
Nanosail-D2 in Orbit  August 19 2011 01h 19m 28s UT
Clay Center Observatory  at Dexter and Southfield Schools
42.307404N, -71.13722W (WGS84)
www.claycenter.org  Focal length:12,200mm,
Aperture = 640mm Ritchey-Chretien
Contact: Ron Dantowitz  (rondantowitz@gmail.com)
Interplanetary Kite-craft Accelerated by Radiation of the Sun
(IKAROS 2010)
SUNJAMMER SOLAR SAIL DEMONSTRATION MISSION

Design Heritage:
- Cold Rigidization Boom Technology
- Distributed Load Design
- Aluminized Sun Side
- High Emissivity Eclipse Surface
- Beam Tip Vane Control
- Spreader System Design

Design Features:
- High density packagability
- Controlled linear deployment
- Structural scalability
- Propellantless operation
- Meets current needs

83 m² ISP L’Garde Solar Sail 2004
318 m² ISP L’Garde Solar Sail 2005
1200 m² L’Garde Sunjammer
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CANCELED
SOLAR SAILS TODAY – MANY MISSIONS PLANNED

- NASA’s *NEA Scout* and *Lunar Flashlight*
- The Planetary Society’s *LightSail-A* and *LightSail-B*
- The University of Surrey’s *CubeSail*, *DeorbitSail*, and *InflateSail*
LIGHTSAIL-A AND -B (THE PLANETARY SOCIETY)

- 3U Cubesat design
- Sail Material: aluminized 4.5 micron Mylar film
- 32 square meters solar sail area fully deployed
**InflateSail** is an **inflatable**, **rigidizable** sail for flight in Low Earth Orbit:

- 3U CubeSat with deployed sail area of 10 m²
- Sail supported by bistable booms
- Inflation is driven by Cool Gas Generators (CGG): low system mass, long lifespan
Near Earth Asteroid Scout

The Near Earth Asteroid Scout Will

- Image/characterize a NEA during a slow flyby
- Demonstrate a low cost asteroid reconnaissance capability

Key Spacecraft & Mission Parameters

- 6U cubesat (20 cm X 10 cm X 30 cm)
- ~85 m² solar sail propulsion system
- Manifested for launch on the Space Launch System (EM-1/2017)
- Up to 2.5 year mission duration
- 1 AU maximum distance from Earth

Solar Sail Propulsion System Characteristics

- ~ 7.3 m Trac booms
- 2.5μ aluminized CP-1 substrate
- > 90% reflectivity
### Mission Concept
- Characterize a Near Earth Asteroid with an optical instrument during a close, slow flyby

### Payload
- Malin Space Science Systems ECAM-M50 imager w/NFOV optics
- Static color filters (400-900 nm)

### Mechanical & Structure
- “6U” CubeSat form factor (~10x20x30 cm)
- <12 kg total launch system mass
- Modular flight system concept

### Propulsion
- ~85 m² aluminized CP-1 solar sail (based on NanoSail-D2)

### Avionics
- Radiation tolerant LEON3-FT architecture

### Electrical Power System
- Simple deployable solar arrays with UTJ GaAs cells (~35 W at 1 AU solar distance)
- 6.8 Ah Battery (3s2p 18650 Lithium Cells)
- 10.5-12.3 V unregulated, 5 V/3.5 V regulated

### Telecom
- JPL Iris 2.0 X-Band Transponder; 2 W RF SSPAs; supports doppler, ranging, and D-DOR
- 2 pairs of INSPIRE-heritage LGAs (RX/TX)
- 8x8 element microstrip array HGA (TX)
- ~500 bps to 34m DSN at 0.8 AU

### Attitude Control System
- 15 mNm-s (x3) & 100 mNm-s RWAs
- Zero-momentum slow spin during cruise
- VACCO R134a (refrigerant gas) RCS system
- Nano StarTracker, Coarse Sun Sensors & MEMS IMU for attitude determination
NEA Scout Approximate Scale

Deployed Solar Sail

School Bus

Folded, spooled and packaged in here

6U Stowed Flight System
Solar Sail Mechanical Description

- 4 quadrant sail
- 85 m² reflective area
- 2.5 micron CP1 substrate
- Z folded and spooled for storage
  - 2 separate spools with 2 sail quadrants folded onto each
- 4 7-meter stainless steel TRAC booms coiled on a mechanical deployer
  - 2 separate deployers and each deployer releases 2 TRAC booms
- Motorized boom deployment
Fabricated 2 flight size 10m sails from existing 20m CP1 sail.
Z-folded and spooled 2 sail quadrants onto the hub.
Calculated new packing efficiency to be **27.5 %**

Higher percentage results in tighter packaging and thus more volume margin for design space.
Lunar Flashlight Requires Surface Illumination:

- Determine the capabilities of the solar sail in regard to the amount of light that the sail can reflect into the desired 3 degree cone onto a surface.
SKG Addressed: Understand the quantity and distribution of water and other volatiles in lunar cold traps

Look for surface ice deposits and identify favorable locations for in-situ utilization

Recent robotic mission data (Mini RF, LCROSS) strongly suggest the presence of ice deposits in permanently shadowed craters.
What Next?

Out of the ecliptic and over-the-Earth’s pole science

Solar storm warning

Comet rendezvous

Multiple NEA reconnaissance