Solar Sails

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We tend to think of space as being big and empty...
Can we use the environments of space to our advantage?
Yes we can! With solar sails…

Solar sails use photon “pressure” or force on thin, lightweight, reflective sheets to produce thrust.
Solar Sails Experience **VERY Small Forces**

- Force on a 100 m x 100 m square sail:

  - Solar Force Equivalent at 1 AU

  - 10,000 m² (two football fields)
• Photons carry Momentum
  \[ \rho = \frac{hv}{c} \]
  - \( h \) = Planck’s, \( v \) = frequency, \( c \) = speed of light

• Force generated on Reflective Surface
  - Resultant force approximately perpendicular to surface
    - The bigger the surface, the more the force
  - Can “steer” sail by changing pitch angle \( \alpha \)

• Small, but potentially Constant Acceleration
  - Potentially unlimited “delta V”
  - Allows some otherwise impossible orbits
Solar Sail Trajectory Control

- Solar Radiation Pressure allows inward or outward Spiral
Potential Solar Sail Applications
(A Partial List!)

- NEA Reconnaissance & Small Body Science
- Earth Pole Sitting
- Rapid Outer Solar System Exploration and Escape
- Heliophysics & Out of the Ecliptic Science
- Data Relay
- Earth Observation
- Toward Higher Performance Beamed Energy Propulsion
Echo II 1964
Solar thrust effect 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, the 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.

- 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 m²

- Launched in 2005 from a Russian Volna Rocket from a Russian Delta III submarine in the Barents Sea.

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Rocket Failed.
NASA Ground Tested Solar Sails in the Mid-2000’s
NASA Space Technology Demo (2009)

- 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.
NanoSail-D Demonstration Solar Sail

Mission Description:
• 10 m² sail
• Made from tested ground demonstrator hardware
NanoSail-D1 Flight (2008)

Launch:

- Falcon-1, flight 3
- Kwajalein, Missile Range
- Primary payload: Air Force PnPSat
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NanoSail-D2 Mission Configuration (2010)

**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

- **Deployed CP-1 sail:** 10 m² Sail Area (3.16 m side length)
- **2.2 m Elgiloy Trac Booms**
- **UHF and S-Band communications**
Interplanetary Kite-craft Accelerated by Radiation of the Sun (IKAROS)

Liquid crystal device power was off.

Liquid crystal device power was on.
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 Launch 2015
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CANCELED
Lightsail-A
(The Planetary Society)

- 32 m²
- No active ‘sailing’
- 3U CubeSat

Flew successfully in 2015
Solar Sails **TODAY** – Many Missions Planned

- NASA’s *NEA Scout*
- The Planetary Society’s *LightSail-2*
- The University of Surrey’s *InflateSail*
- University of Illinois’ *CubeSail*
NASA’s 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)
• ~86 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
NEA Scout – Mission Overview
Near Earth Asteroid (NEA) Scout
NEA Scout Approximate Scale

Deployed Solar Sail

School Bus

Folded, spooled and packaged in here

6U Stowed Flight System
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
• The University of Illinois at Urbana-Champaign (UIUC), working with NASA MSFC, NSF, and CU Aerospace, built the flight hardware for a CubeSat-based 20 m² solar sail orbit raising demonstration mission

• Selected for flight under the NASA CubeSat Launch Initiative
Continuous Polar Observations

- Sailcraft over the polar regions of the Earth
- Sail tilted so the light pressure from the sunlight reflecting from it is exactly equal and opposite to the gravity pull of the Earth.
Deploy a large (>10,000 m$^2$) solar sail near the sun to enable travel 5X faster than Voyager.

Goal: Reach 250 Astronomical Units within 20 years of launch.
Ground to space laser illumination of a solar sail to impart measurable ΔV
My Real Motive…

- Solar Powered
- Laser Powered

= Areal Density (Sail Mass/Sail Area)
Solar Sails: A Step Toward the Stars

Honoring the late Dr. Robert Forward, the ‘father’ of laser beamed energy propulsion.