Deployment Technology of a Heliogyro Solar Sail for Long Duration Propulsion

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Solar Sail Missions

Heliogyro Solar Sail Mission: 2-bladed 6U Form Factor Deployment Technology

Current Focus

Benefits

Summary

Square-Shaped Solar Sailing ➔ Heliogyro Solar Sail

1969

1993
Znamya [1]

1993

2010

2015

Future Mission

NEA Scout
LUNAR Flashlight
Heliogyro Solar Sail
2-Bladed Heliogyro Orbital Platform in Space (HOPS^2B)

Image Credit: NASA/JPL
IKAROS: Image Credit: JAXA [3]

1969

1993
Znamya [1]

2010

2015

 NanoSail-D
Image Credit: NASA

2-Bladed Heliogyro Orbital Platform in Space Mission (HOPS$^2$B)

- **Anti-Jamming Technology**
- **Re-Usable Locking/Release Mechanism**
- **Solar Sail: 2 μm thick Polyethylene Naphthalate (PEN)**
- **Large Solar Sail Area (~ 720 m$^2$)**

**Heliogyro-Configured: 6U Form Factor**

- No fuel
- Mass ~ 8 kg
- Retractable Solar Sail System: Control CM/CP*, avoid thermal heat flux

CM = center of mass, CP = center of pressure

HOPS$^2$B Mission

Interplanetary Travel

Validate and Demonstrate Heliogyro Solar Sail Deployment/Retraction
Attitude Control
Station-Keeping
Acceleration

HOPS$^2$B – Deployment Technology & Concept

Right Angle Gearhead Deployment Motor

Solar Sail Roll

Solar Sail Spindle

Bearing

Solar Sail Roll

Control Unit:
Communication, Data Handing, ADCS, EPS, Instrument Package

Camera & Uncooled Microbolometer

Photodiode Linear Speed Sensor

Tip Rod Lock Mechanism

Camera & Uncooled Microbolometer

Guiding Gap

Solar Sail Tip Rod

Background Image Credit: NASA
HOPS\textsuperscript{2B} – Deployment Technology & Concept

**Solar Sail**  
Image Credit: NASA

**Rolling of Solar Sail**  
Image Credit: NASA

**Motor**  
Image Credit: NASA

**Tip Rod**  
Image Credit: NASA

**To scale model**  
Image Credit: NASA

Background Image Credit: NASA  
HOPS$^2$B – Hardware + Expected Performance

### Hardware

<table>
<thead>
<tr>
<th>Components</th>
<th>Vendor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Angle Gearhead Deployment Motors</td>
<td>CDA Intercorp, USA</td>
</tr>
<tr>
<td>Spacecraft Door Release Mechanism</td>
<td>Avior Control Technologies, Inc, USA</td>
</tr>
<tr>
<td>Photodiode Linear Speed Sensor</td>
<td>Aeroflex, USA</td>
</tr>
<tr>
<td>Coated Solar Sail 2 μm thick</td>
<td>Astral, USA</td>
</tr>
<tr>
<td>Uncooled Microbolometer</td>
<td>Sofradir EC, Inc., USA</td>
</tr>
<tr>
<td>Hybrid-Ceramic Bearings</td>
<td>CEROBEAR GmbH, Germany</td>
</tr>
<tr>
<td>Batteries</td>
<td>Clyde Space, UK</td>
</tr>
<tr>
<td>Solar Panels</td>
<td>Vanguard Space Technologies, USA</td>
</tr>
</tbody>
</table>

### Expected Performance

<table>
<thead>
<tr>
<th>Solar Sail Mission</th>
<th>IKAROS$^1$</th>
<th>NanoSail-D$^2$</th>
<th>LightSail-1$^3$</th>
<th>CubeSail$^4$</th>
<th>HOPS$^2$B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>Custom</td>
<td>3U</td>
<td>3U</td>
<td>3U</td>
<td>3U</td>
</tr>
<tr>
<td>Total sail area [m$^2$]</td>
<td>200</td>
<td>10</td>
<td>32</td>
<td>25</td>
<td>717</td>
</tr>
<tr>
<td>Total mass [kg]</td>
<td>310</td>
<td>3.99</td>
<td>5</td>
<td>3</td>
<td>~8</td>
</tr>
<tr>
<td>Characteristic Acceleration* [mm/s$^2$]</td>
<td>0.0053</td>
<td>0.02</td>
<td>0.05</td>
<td>0.068</td>
<td>0.74</td>
</tr>
</tbody>
</table>

*Calculated at 1 AU

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HOPS\textsuperscript{2B} – Current Focus

- **Navigation Control** – attitude determination and control, navigation of the spacecraft
- **Deployment and Spin Control** – deployment of solar sails, spin rate of the spacecraft
- **Location and Speed** – location of the spacecraft and its speed
- **Communication** – communication between the spacecraft and the Earth
- **Dynamics** – dynamics of the solar sail and spacecraft

Benefits

• Future spacecraft can have a heliogyro-configured solar sail installed on board for fuel-less in-Space navigation and propulsion.

• Orbiting CubeSat heliogyro(s) can be sent to assist spacecraft that require additional power to achieve a different orbit.

• Missions: long mission period such as interplanetary travel, multi-missions, station keeping, asteroid field mapping, and interception of micrometeoroids can be performed.

• Perform a precision de-orbit by imposing solar/aerodynamic drag. This has been proven by analysis to be a more cost effective approach to de-orbiting than carrying extra fuel to achieve the same goal.\textsuperscript{1,2}

\begin{itemize}
\item \textsuperscript{1} Vaios Lappas et al., CubeSail: A low cost CubeSat based solar sail demonstration mission, Advances in Space Research 48 (2011) 1890–1901
\item \textsuperscript{2} Walker et al., Update of the ESA Space Debris Mitigation Handbook, ESA, 14471/00/D/HK
\end{itemize}

Background Image Credit: NASA \url{http://www.nasa.gov/mission_pages/hubble/multimedia/index.html?id=355696}
2-Bladed Heliogyro Orbital Platform in Space Missions (HOPS²B)

Summary

• Deployment Demonstration: Polar Orbit beyond 35,000 km
  - Validate and Demonstrate Heliogyro Solar Sail Deployment/Retraction
  - Attitude Control
  - Station-Keeping
  - Acceleration
  - Interplanetary Travel

• Heliogyro-Configuration
  - 6U CubeSat Form Factor, ~ 8 kg
  - Solar Sail Fully Deployed Area ~ 720 m²
  - Calculated Characteristic Acceleration ~ 0.74 mm/s²
  - Re-Usable Locking/Release Mechanism
  - Solar Sail Anti-Jamming
