Electric Sail Propulsion for Deep Space Missions

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The relative velocity of the Solar Wind through the decades

The solar wind ions traveling at 400-500 km/sec are the naturally occurring (free) energy source that propels an E-Sail
Electrostatic Sail (E-Sail): Operational Principles

- The E-sail consists of 1 to 20 conducting, positively charged, bare wires, each 1–20 km in length.
- Wires are deployed from the main spacecraft bus and the spacecraft rotates to keep wires taut.
- The wires are positively biased to a 6 kV-20 kV potential.
- The electric field surrounding each wire extends ~66 m into the surrounding plasma at 1 AU.
- Positive ions in the solar wind are repulsed by the field created surrounding each wire and thrust is generated.
Electrostatic Sail (E-Sail): Operational Principles

• As the E-sail moves away from the sun and the plasma density decreases (as \(1/r^2\)), the electric field around the wires gradually expands (to 180 m at 5 AU), partially compensating for the lower plasma density by increasing the relative size of the ‘virtual’ sail.
  - The thrust therefore drops only as \(\sim 1/r\), instead of \(1/r^2\)

• An electron gun is used to keep the spacecraft and wires in a high positive potential (~kV).

• Wire length and voltages are mission specific and determine the total \(\Delta V\) available
Velocity vs. Radial Distance
Comparison for Equal Mass Spacecraft

![Graph showing velocity vs. radial distance for Solar Sail and Electric Sail.]
Electrostatic Sail (E-Sail): Operational Principles

Characteristic accelerations of $1 - 2 \text{ mm/sec}^2$

Spacecraft velocities of 10 – 15 AU/year possible (3X -4X faster than Voyager)
Electric Sail Performance

E-Sail propulsion can significantly reduce travel time to 100 AU compared to more conventional propulsion systems.
Plasma Testing was Key to Advancing Knowledge of Space Plasma Physics

• The Phase II experimental testing enabled a ‘knowledge bridge’ to be constructed from the testing performed > 30 years ago on negative biased objects operating in a space environment to recent testing on positive biased objects operating in a similar space environment.

• Phase II experimental results were a combination of:
  - Extensive plasma chamber testing, and
  - Rigorous analysis of data collected on positive biased objects for an appropriate set of dimensionless space plasma parameters under the condition of Debye length $\lambda d < \text{tether diameter}$
    - Normalized Potential ($\Phi_b$)
    - Mach Number ($S$)
E-Sail Plasma Physics Testing at MSFC
Electric Sail TRL Assessment and Advancement Reports (E-STAAR)

- MSFC Engineering Directorate conducted a TRL assessment of E-Sail systems and components.
- Most components are at relatively high TRL (with flight heritage for other applications – hence lower TRL for this application).

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* Updated to reflect advancements made resulting from NIAC and MSFC internal funding.
Questions?