Solar Sails and Strength of Materials

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The Issue

- Solar sails have to transfer the distributed light pressure from the Sun back to a concentrated mass – the "spacecraft" or "observatory"
- For solar sails to effect "significant" propulsive capability, they need to have a "lightness number" $\lambda \sim 1$, that is, the entire "sailcraft" (sails plus support plus observatory) must be sufficiently low-mass to be pushed efficiently by light pressure
- This means that the strength of the supports for transferring / concentrating the pressure force to the acceleration of the spacecraft provide a limit to what can be accomplished with solar sail propulsion
- The question is how to deal with calculating this constraint in a fashion that illuminates the necessary trades

A Gedanken Experiment Approach

- Consider an ideal sailcraft
  - Perfectly reflecting sails
  - “Point mass” observatory
  - Connected to the sail supports at the center of symmetry of the sail
  - Sail is taken as “flat” to first order
  - Sail segments are triangular
- Consider an ideal trajectory
  - Sail normal pointed radially toward the Sun
  - Angular momentum is conserved
- Consider an ideal configuration
  - Sails supported by simple hollow spars
  - Spars transfer the solar radiation pressure to the central observatory mass

Example of Stress Analysis

- Each spar individually experience a torque about the entral mass support
- Detailed analysis is a series of papers by Greschik and Mikulas (2002) and others

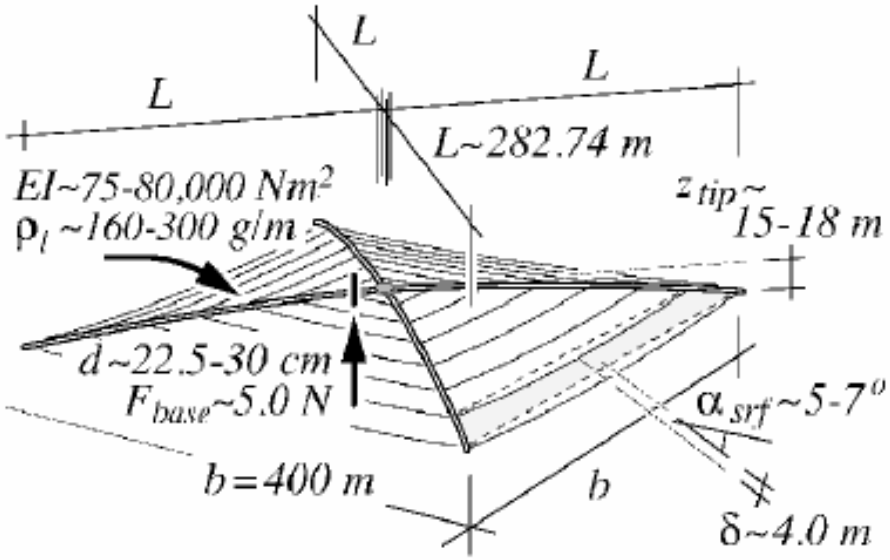

Fig. 3 Parameters for 400-m stripped sails at 1 AU: payload, m_{pl} = 320 kg; sail film, σ_{skin} = 6895 Pa = 1 psi; t = 2.5 μm; sailcraft, m_{tot} ~ 1200–1350 kg; $\bar{\rho}$ ~ 5.4–6.3 g/m^2; and performance, a_c ~ 0.9–1 mm/s^2.

4-spar example

Light pressure is “down” from “top”

Gravity is up – so concentrated mass of the observatory pulls center-point up

Provides a potential mechanical failure point where spars are cantelivered

Question Is What Materials Can Support

- As the observatory mass increases, the required sail size and spar lengths increase
- If the spars cannot support the radiation pressure, then they will fail like an umbrella in a strong wind