Lecture 18
Solar Sails & Solar Panels

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Solar sails & solar panels

Consider solar photovoltaic process to convert solar energy to electrical energy

Solar → Photovoltaic cells → Electric rocket (versus Solar sails)

Average radius of the earth's orbit around sun

$$\frac{\dot{E}}{A} = 1366\left[\frac{W}{m^2}\right]\left(\frac{R}{r}\right)^2$$

Distance from the sun

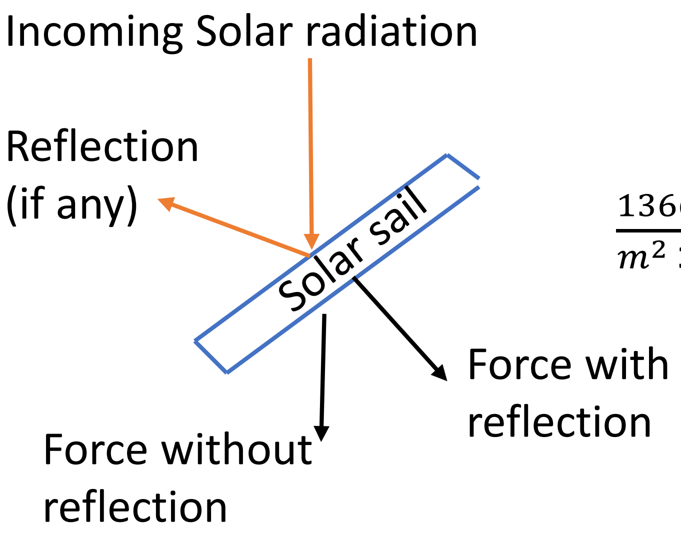
For ion rocket: beam power = kinetic energy flux

Suppose 1/10 of solar power is converted to beam energy

Consider a 1 m^2 panel: $P = 137\ watts = \frac{1}{2}\dot{m}UU = T\frac{U}{2} = \frac{TgI_{sp}}{2}$

$$\frac{T}{meter^2} = \frac{137\ joules/sec}{meter^2}\frac{1}{10\frac{m}{\sec^2}}\frac{2}{3000\ sec} = \frac{9.14\times 10^{-3}\ newton}{meter^2}$$

Solar sails & solar panels



Now, consider using pressure from photon momentum collision with sail surface.
The momentum flux per area of the photons is: $\frac{\dot{E}}{Ac} = \frac{F}{A} = P$

$$\frac{1366\ joules/sec}{m^2\ 3\times10^8 m/sec} = \frac{0.457\times10^{-5}}{m^2}\left[\frac{newton\ meter}{m}\right] = 0.457\times10^{-5} newton/m^2$$

Up to double if reflected!

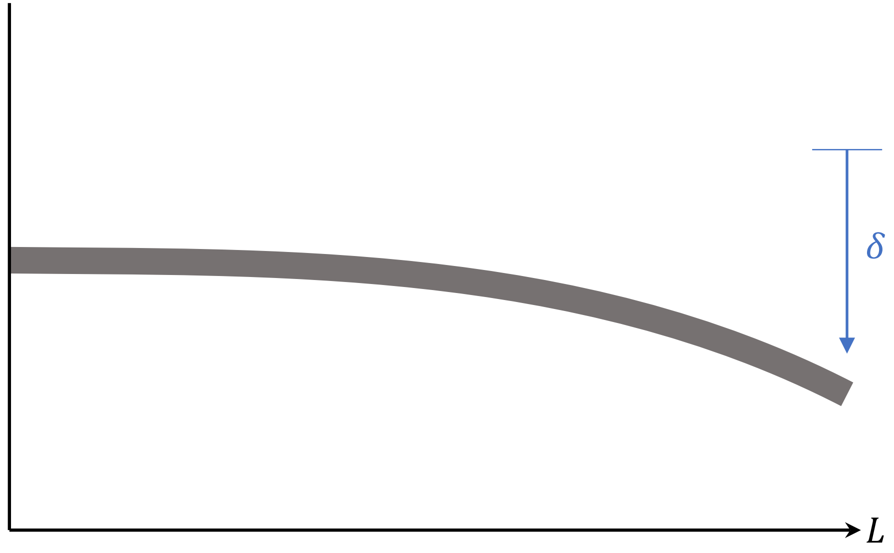
This is 1000 to 2000 times lower than the thrust with solar panel ! $\frac{9.14\times10^{-3}\ newton}{meter^2}$

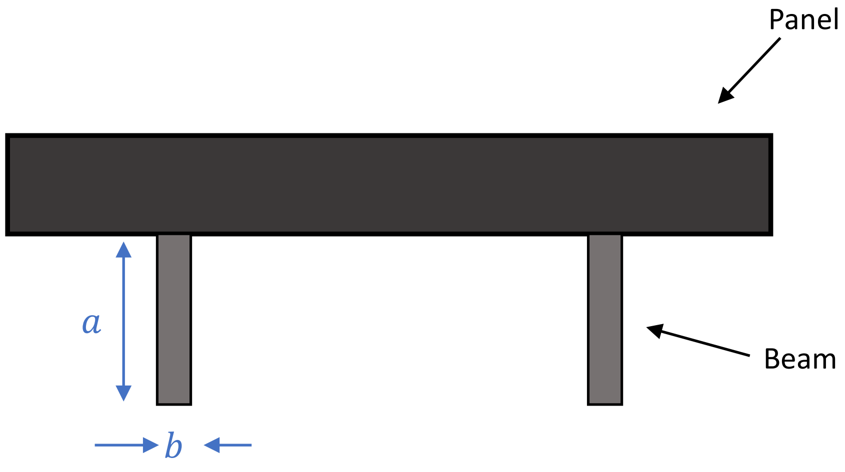
Solar pressure on span does affect trajectories on long flight and corrections to ballistic flights are made. Separation of center of pressure force and center of mass can be used for attitude controls!

Solar panels - structural issue

Solar power harnessed is proportional to panel area.

How does structural weight grow with area? Consider a cantilevered beam holding panels on the spacecraft.





(Cross-section of the structural beams and solar panel)

Solar panels --- structural issue

w: load per unit length including panel structure under acceleration neglecting solar momentum exchange
E: Young's modulus
I: moment of inertia
g : acceleration of structure

$$angle \approx \frac{\delta}{L} \sim \frac{wL^3}{EI}$$

$$I = \frac{1}{12} ba^3$$

$$w_{beam} = \rho_s gab$$

$$\frac{\delta}{L} \sim \frac{w_{beam}L^3}{Eba^3/12} \quad \Rightarrow \quad \frac{\delta}{L} \sim 12 \frac{\rho_s g}{E} \frac{L^3}{a^2}$$

To keep angle fixed: $a \sim L^{3/2}$

Shear force $\sim wL \quad \rightarrow \quad \dfrac{shear\ force}{area} \sim \dfrac{\rho_s gabL}{ab} \sim L$

Will exceed yield stress!

Mass of structure will grow at approximately $abL \sim L^{5/2}$, but power grows as L!

Eventually, nuclear power is superior!

Also, solar power is less useful as we fly further from the sun!