ENAE 483/788D LECTURE #05
(SPACE ENVIRONMENT) PROBLEMS – FALL, 2024

(1) Starship can be (crudely) approximated by a cylinder 9 m in diameter and 50 m long. At an orbital altitude of 200 km, what is the drag force on Starship if the long axis is perpendicular to the velocity vector?

The planform area perpendicular to the flow would be length × diameter, or $A = 9 \times 50 = 450\ m^2$. *From the notes (Lecture #05 pg. 20) the* c_D *for a cylinder in this orientation is 8/3. The orbital velocity is:*

$$v = \sqrt{\frac{\mu}{r}} = \sqrt{\frac{\mu}{r_{earth} + l_{altitude}}} = \sqrt{\frac{398,604(km^3/s^2)}{6,378(km) + 200(km)}} = 7.784\ km/sec$$

From page 13 of the lecture notes we can use the approximation formula:

$$\rho = 3.875 \times 10^{-9} e^{-\frac{h}{59.06}} = 3.875 \times 10^{-9} e^{-\frac{200}{59.06}} = 1.3109 \times 10^{-10}\ kg/m^3$$

$$D = \frac{1}{2}\rho v^2 (A) c_D = \frac{1}{2} 1.3109 \times 10^{-10} (7784)^2 450 \left(\frac{8}{3}\right) = \boxed{4.776\text{ N}}$$

Note: The velocity had to be converted to m/sec to make the units work out correctly for newtons

(2) In the same conditions, what is the drag force if Starship's cylindrical axis is aligned with the velocity vector?

From page 17, c_D *for a flat plate perpendicular to the flow is 4 since* $\alpha = 90°$

$$A = \frac{\pi}{4} d^2 = \frac{\pi}{4} 9^2 = 63.617\ m^2$$

$$D = \frac{1}{2}\rho v^2 A c_D = \frac{1}{2} 1.3109 \times 10^{-10} (7784)^2 63.617(4) = \boxed{1.011\text{ N}}$$

(3) After International Space Station is deorbited in 2030, it will be necessary to develop a replacement. People have suggested that a single Starship would have a greater pressurized volume than ISS and could be outfitted to serve as a long-term space station without requiring assembly. If it stayed in a 500 km orbit for 10 years, what is the largest MMOD particle would you have to design for (on average)?

$$A = 2 * A_{end} + A_{cylinder} = 2(\frac{\pi}{4}(d)^2) + \pi \ell d$$
$$= 2(\frac{\pi}{4}(9)^2) + \pi(50)9 = 127.235 + 1,413.717 = 1,540.95\ m^2$$

$$Flux = \frac{1\ hit}{(1,540.95\ m^2)(10\ yrs)} = 6.489 \times 10^{-5}\ hits/m^2 - yr$$

From the chart on page 34 of the lecture notes, find the flux on the vertical axis and read off the corresponding particle size on the horizontal axis. This gives the approximate size particle you would have to design to would be orbital debris of 0.55×10^{-1} *cm or* $\boxed{5.5\ mm}$. *You would also expect to be hit by micrometeoroid particles of approximate 3 mm, but the design case for the shielding would be the 5.5 mm orbital debris particle. See Figure 1*

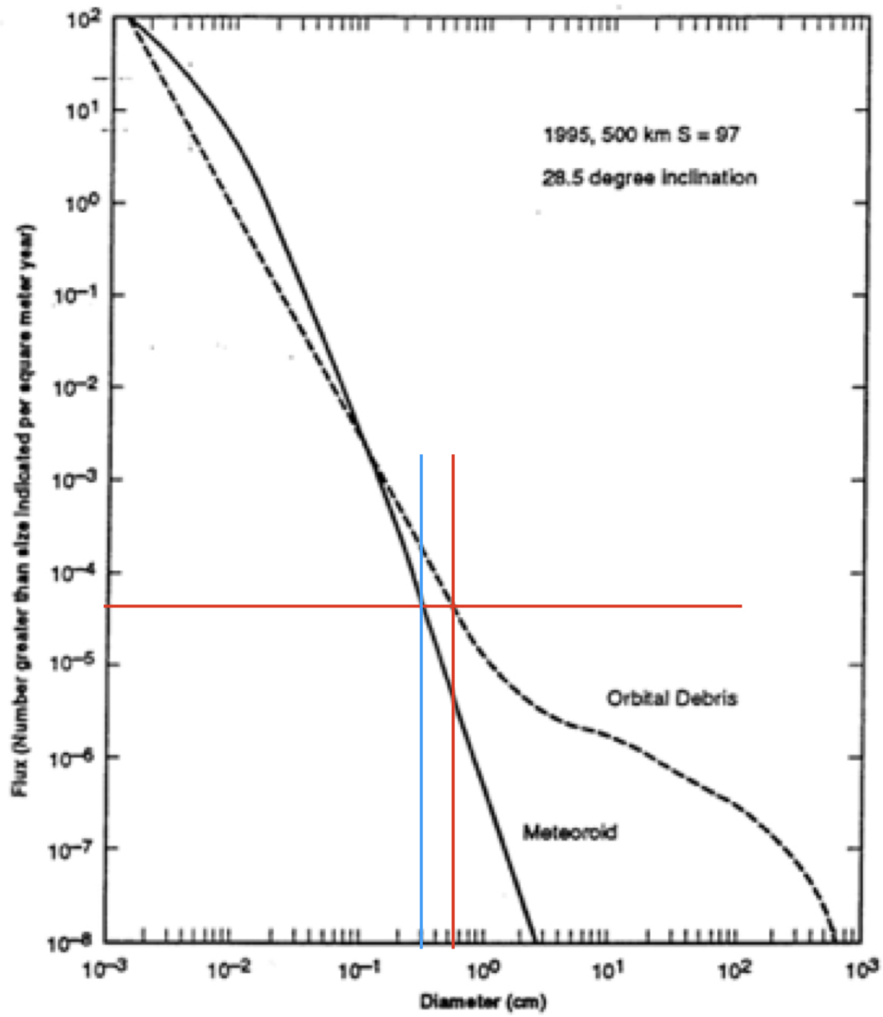

FIGURE 1. MMOD Flux with plotted results

(4) Over that same time, how many hits would you expect to have from particles with a diameter of 0.2 mm?

From the same chart, a particle size of 0.2 mm corresponds to a micrometeoroid flux of 1 hit/m^2-yr. It also would correspond to an orbital debris flux of 0.15 hit/m^2-yr, for a total flux of 1.15 hit/m^2-yr. For the spacecraft area and lifetime in low Earth orbit, this would be 1.15(1540.95)(10)= $\boxed{17,721 \textit{ hits}}$ *by all particles of this size over the lifetime of the vehicle. Again these are approximate and will be graded as such. See Figure 2*

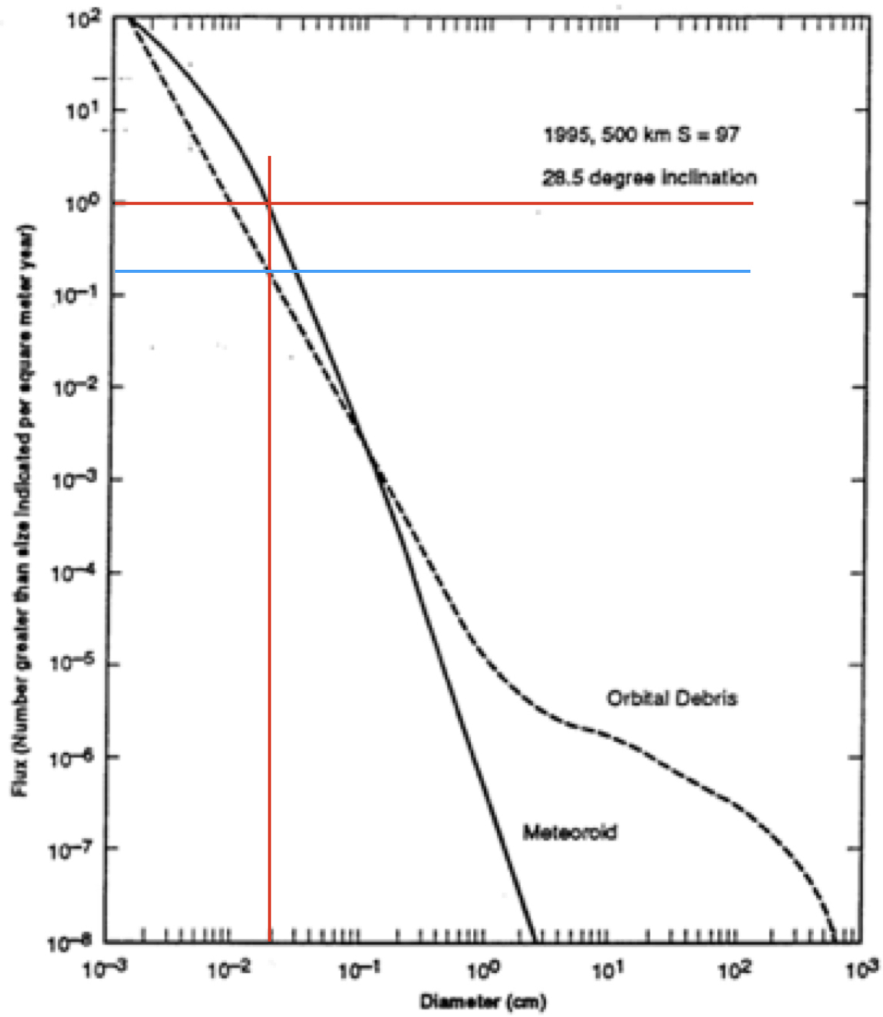

FIGURE 2. Particle Size to MMOD Flux