Some Applications of Entry Theory

- Taking an analytical look at recent* space events
- Crossrange and landing opportunities
- Ballistic aerobraking

*for suitable definitions of “recent”

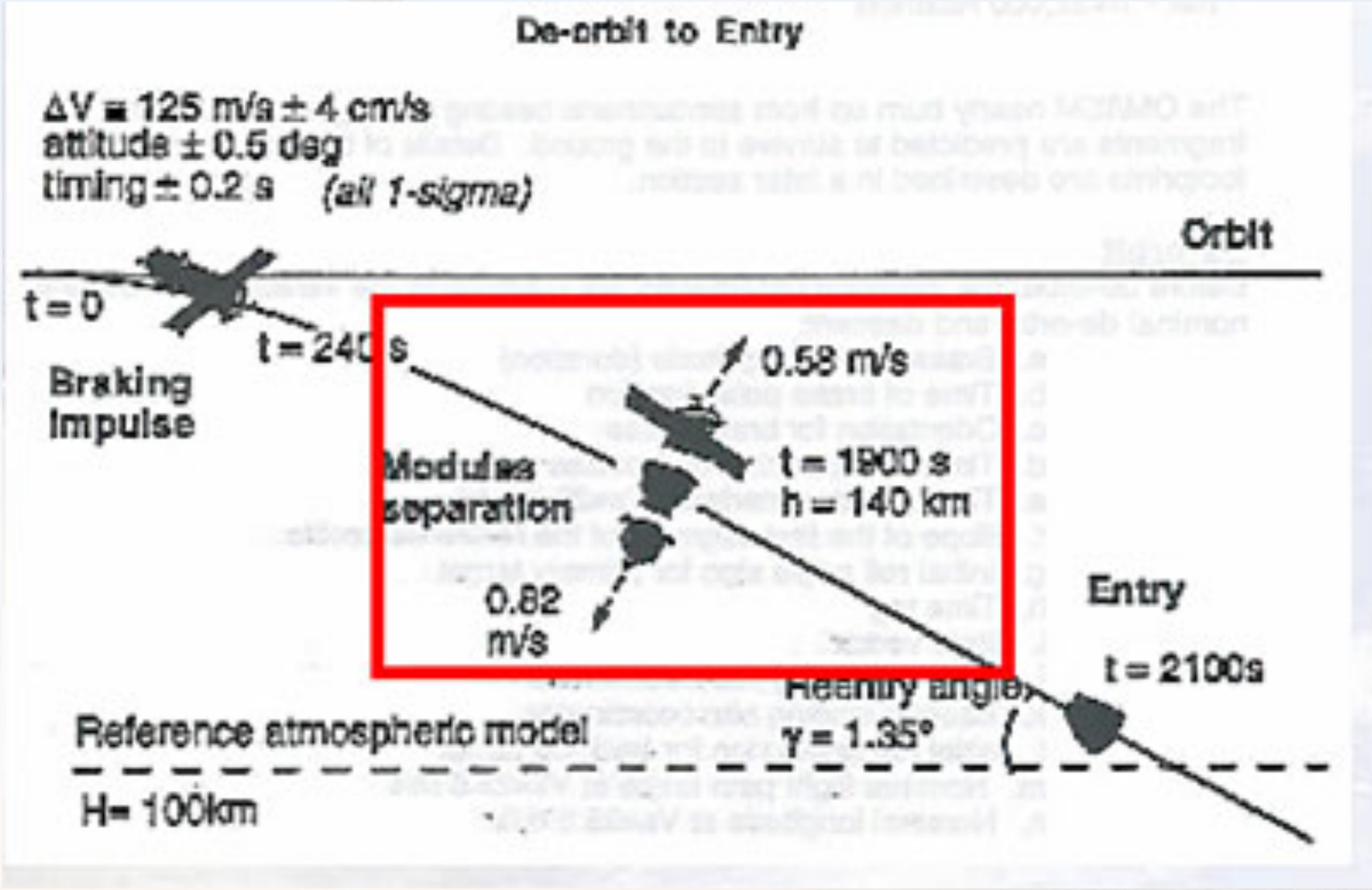
Washington Post - May 12, 2008

Perilous Landings by Soyuz Worry NASA

U.S. to Be Dependent on Russian Capsule

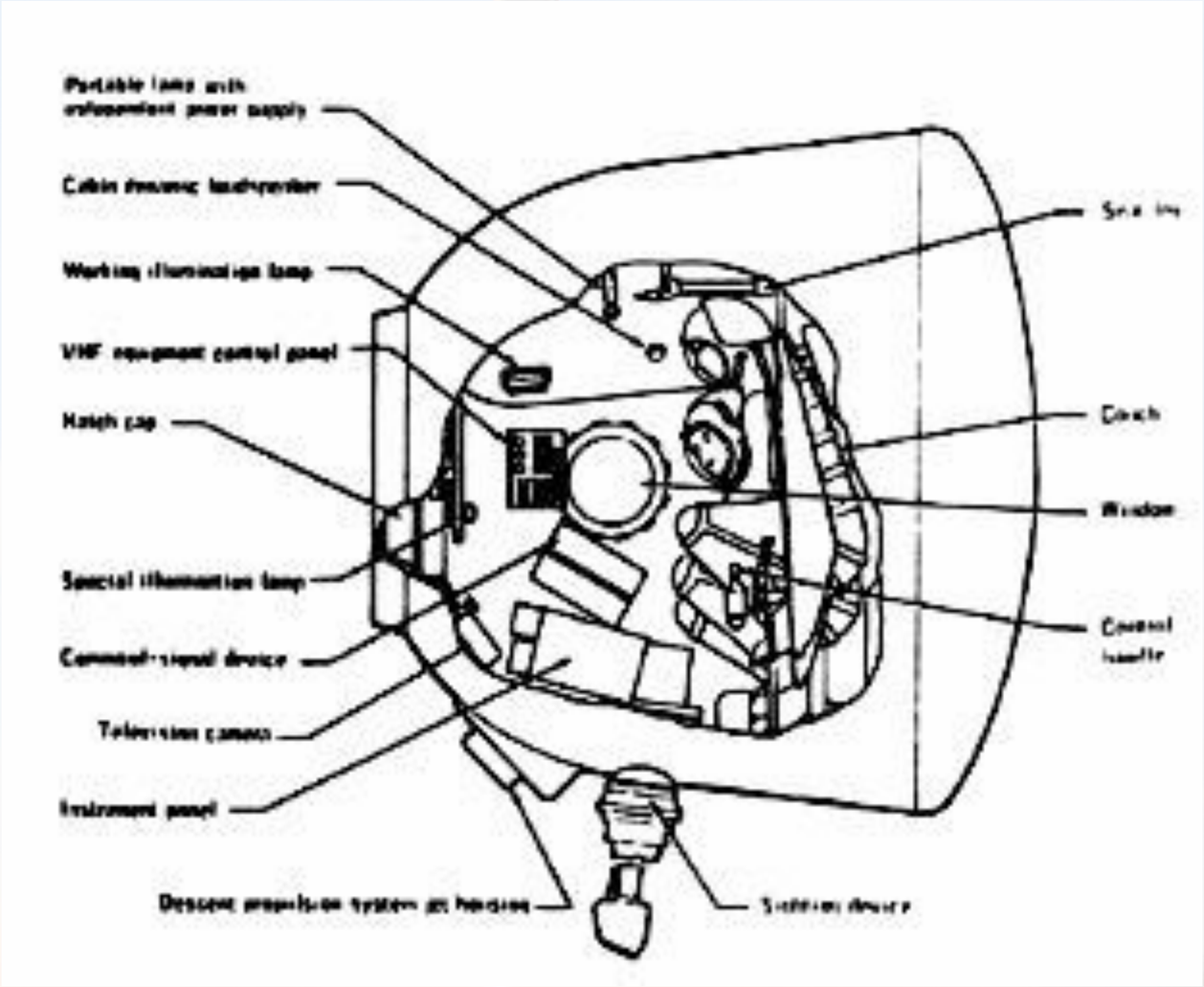
Members of the ground crew check the area around the Soyuz capsule. The three astronauts on board, including American Peggy A. Whitson, were uninjured. (By Shamil Zhumatov -- Associated Press)

Soyuz Deorbit Milestones



Soyuz 5 Reentry

Soyuz Heat Shield Shape



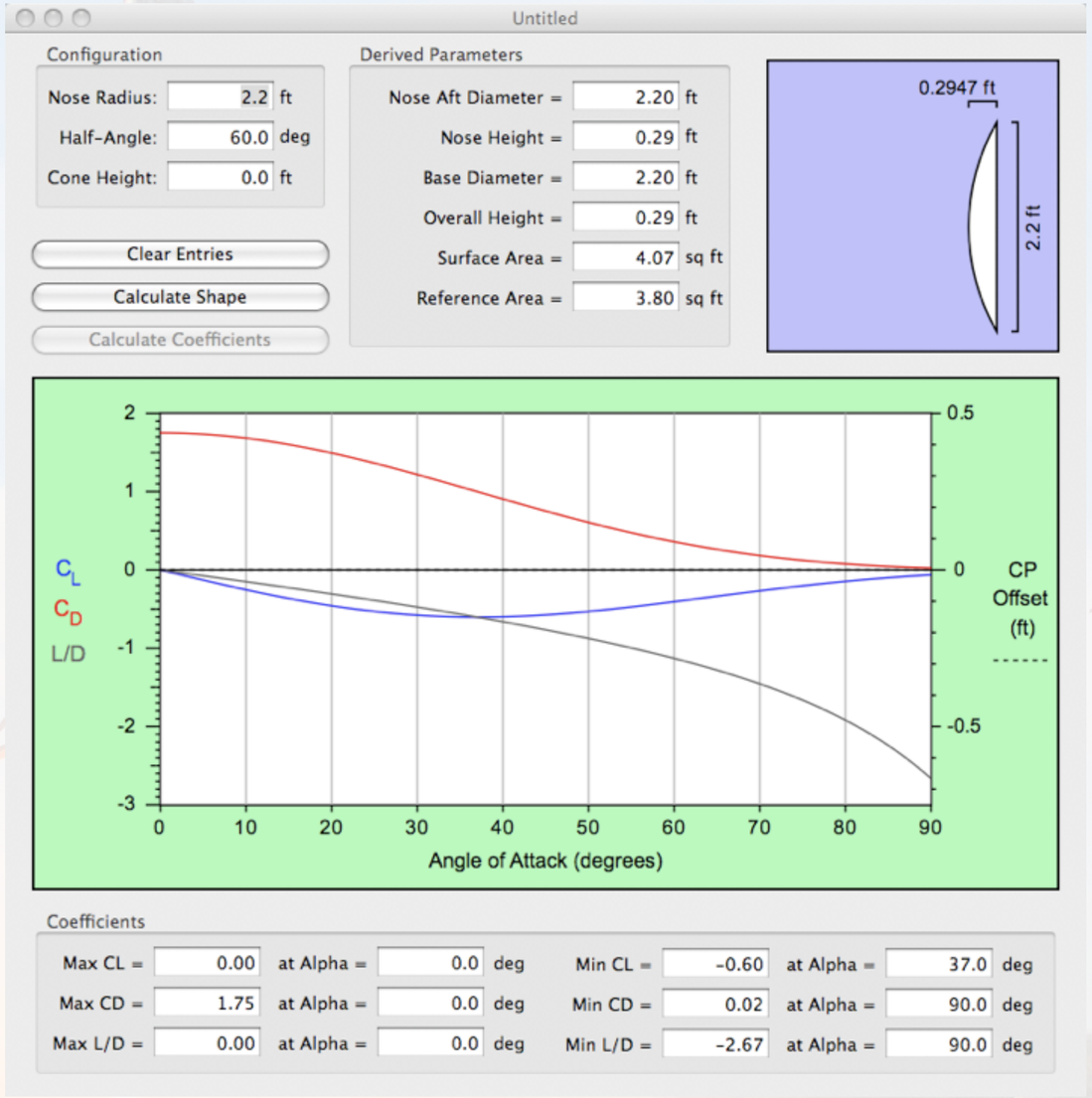
$$d = 2.2 \text{ m}$$

$$\text{depth} \sim 0.3 \text{ m}$$

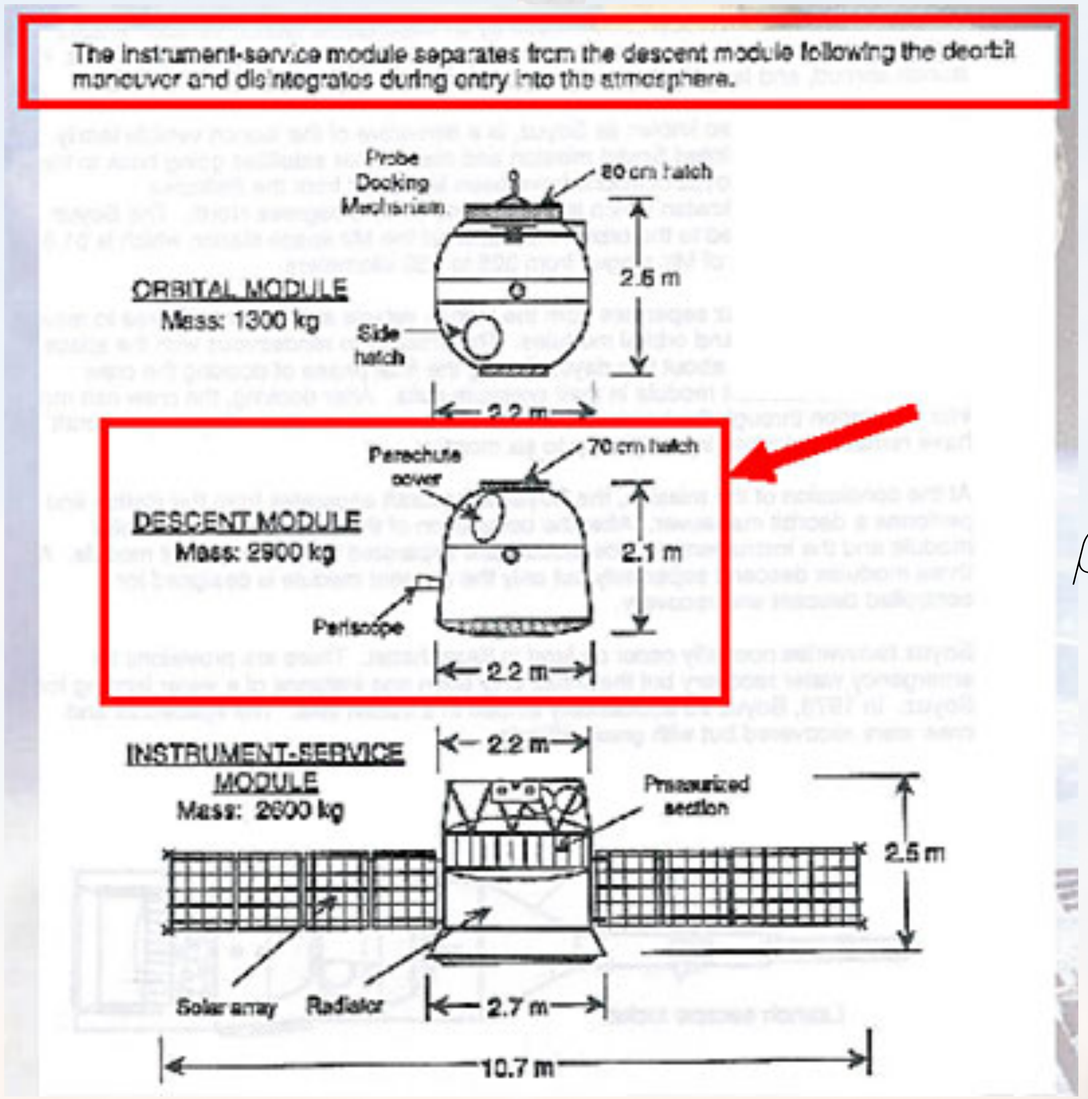
$$\text{half-angle} \sim 30 \text{ deg}$$

$$R \sim 2.2 \text{ m}$$

Soyuz Newtonian Aerodynamics



Estimation of Soyuz Entry Parameters



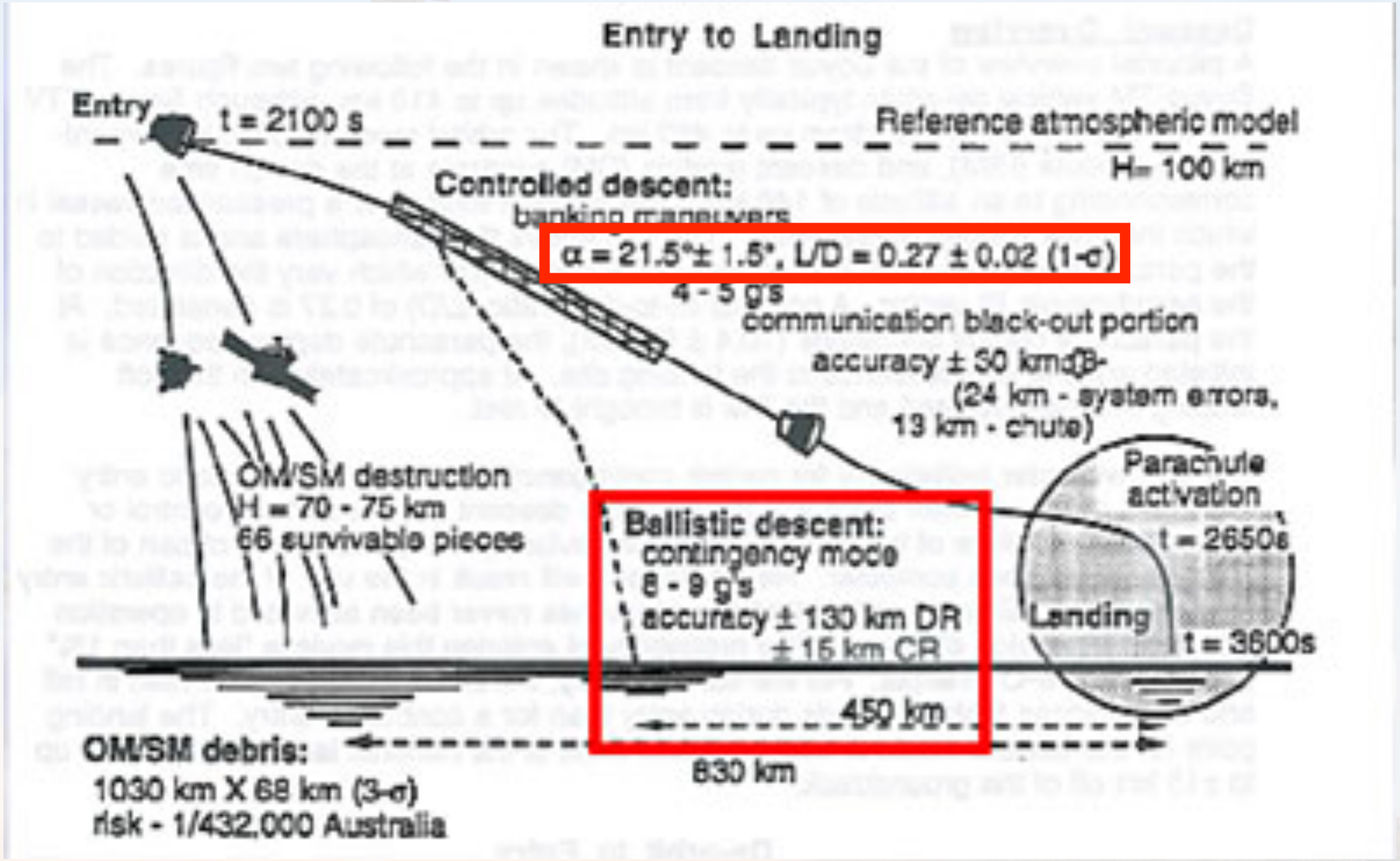
$$c_D \sim 1.75$$

$$A = \pi r^2 = \pi(1.1)^2 = 3.8 \text{ m}^2$$

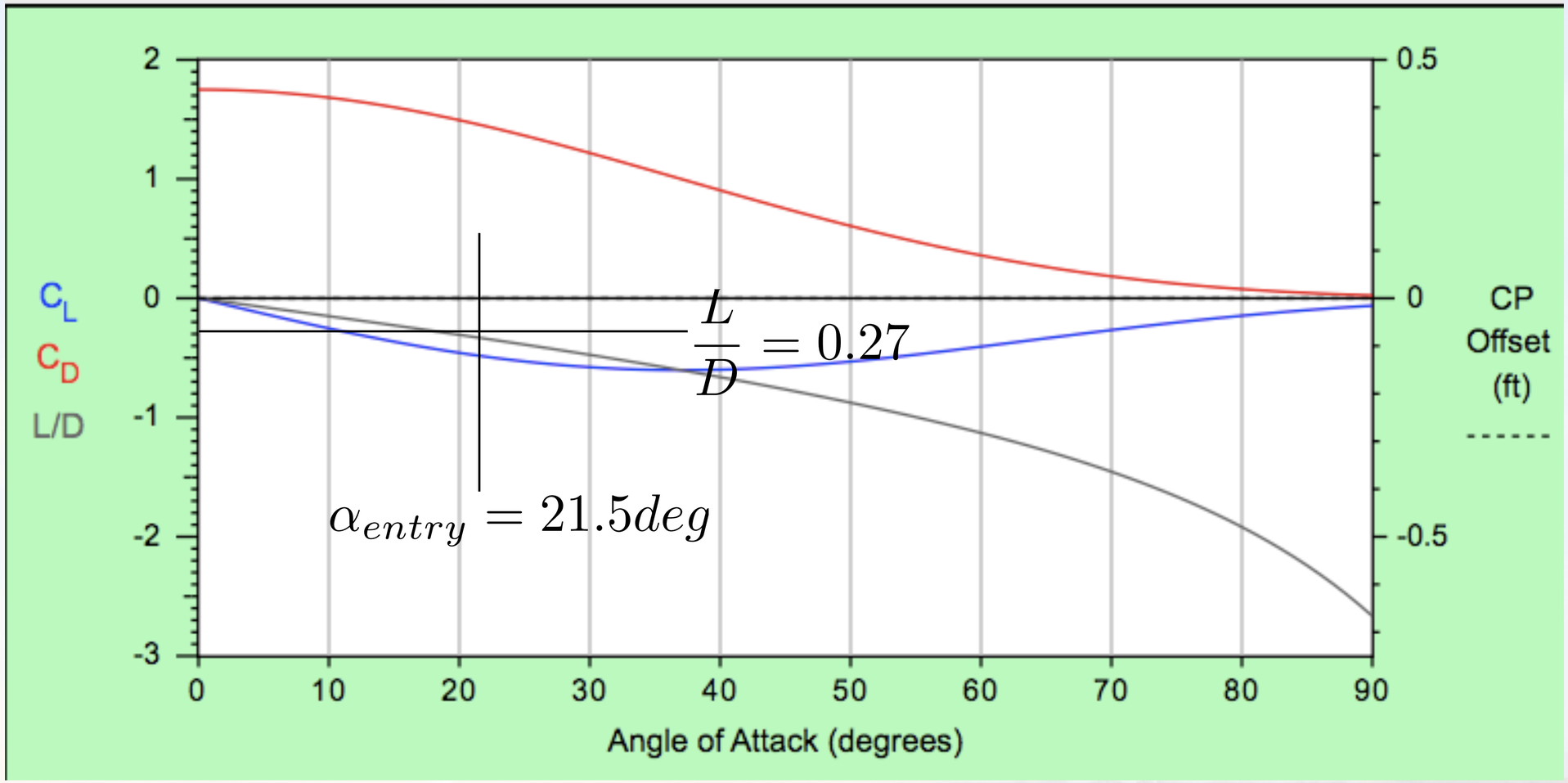
$$\beta = \frac{2900 \text{ kg}}{(1.75)(3.8 \text{ m}^2)} = 436 \frac{\text{kg}}{\text{m}^2}$$

$$\beta = 4270 \text{ Pa}$$

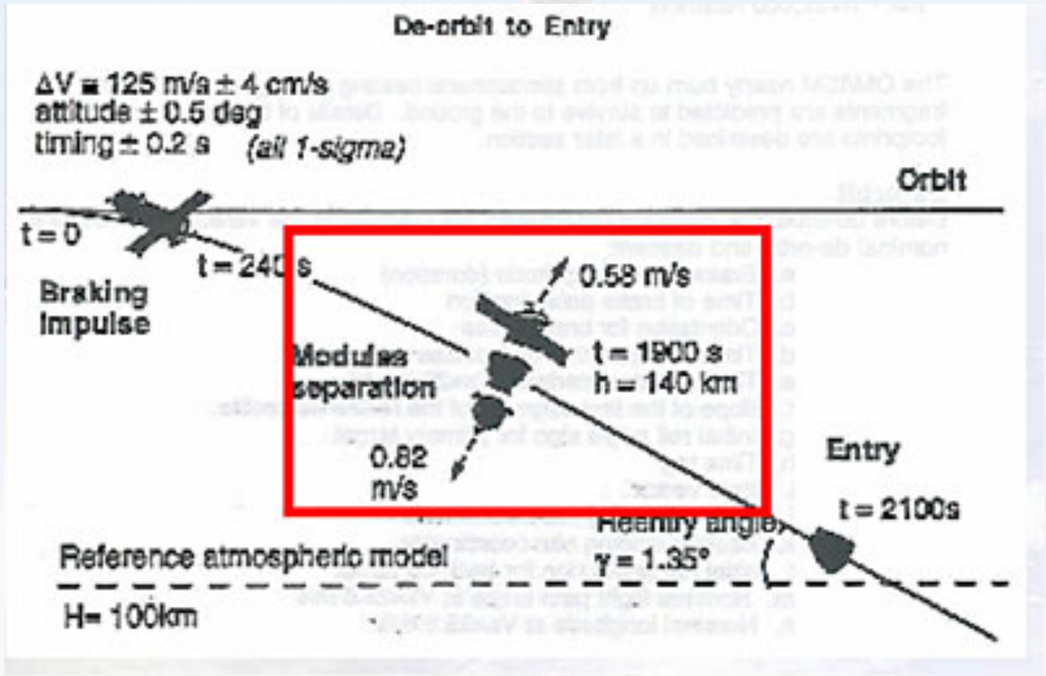
Published Flight Characteristics



Predicted and Published Soyuz Parameters



Soyuz Deorbit Reconstruction



International Space Station

$$r = 6720 \text{ km}$$

$$v = \sqrt{\frac{\mu}{r}} = 7702 \text{ m/sec}$$

$$v_{a,deorbit} = 7577 \text{ m/sec}$$

$$a_{deorbit} = \left[\frac{2}{r_a} - \frac{v^2}{\mu}\right]^{-1} = 6510 \text{ km}$$

$$r_p = 2a - r_a = 6300 \text{ km} \Rightarrow h_p = -78 \text{ km}$$

$$e = \frac{r_a}{a} - 1 = 0.03226$$

Velocity Components in Orbit (continued)

$$\vec{h} = \vec{r} \times \vec{v}$$

$$h = rv\cos\gamma = r\left(r\frac{d\theta}{dt}\right) = r^2\frac{d\theta}{dt}$$

$$v_r = \frac{r^2\frac{d\theta}{dt}e\sin\theta}{p} = \frac{he\sin\theta}{p} = \frac{\sqrt{p\mu}}{p}e\sin\theta$$

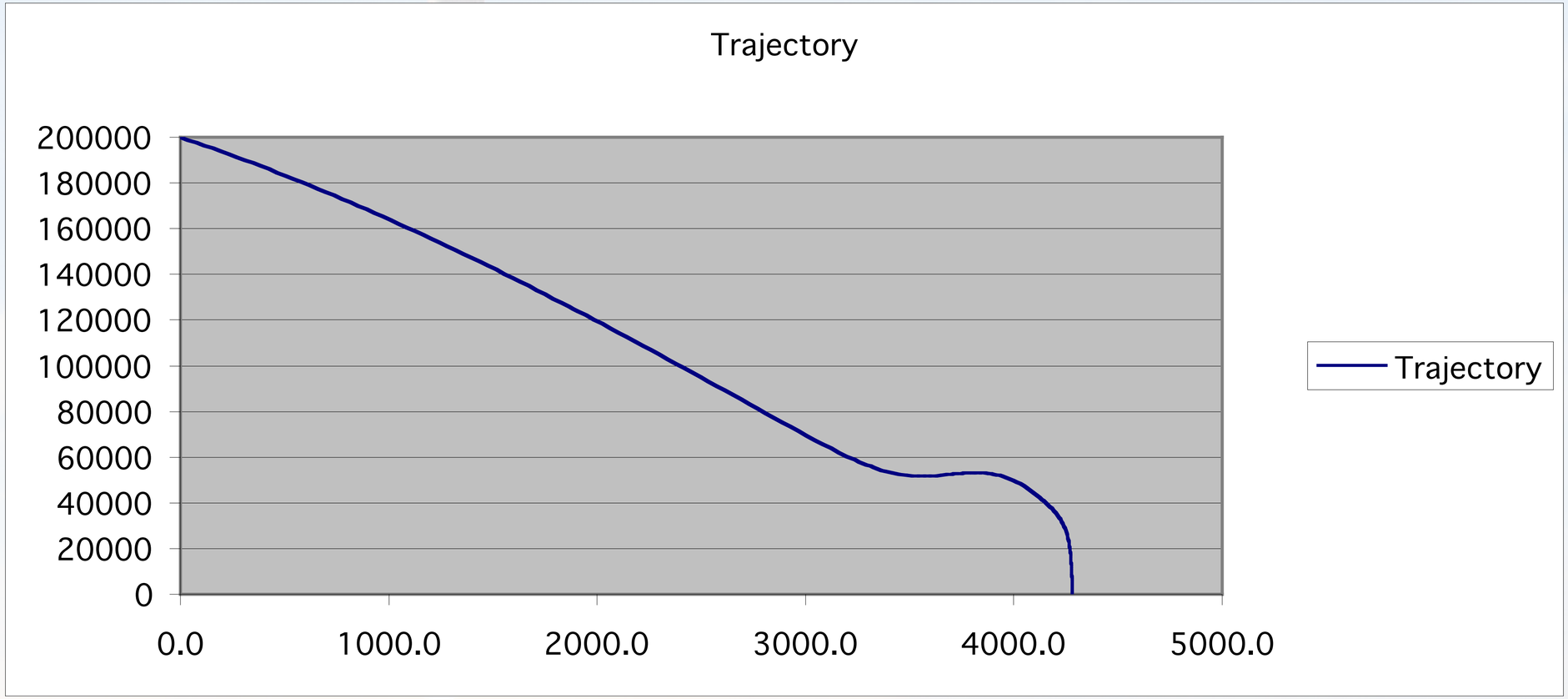
$$\boxed{v_r = \sqrt{\frac{\mu}{p}}e\sin\theta}$$

$$v_\theta = r\frac{d\theta}{dt} = r\frac{h}{r^2} = \frac{h}{r} = \frac{\sqrt{p\mu}}{r}$$

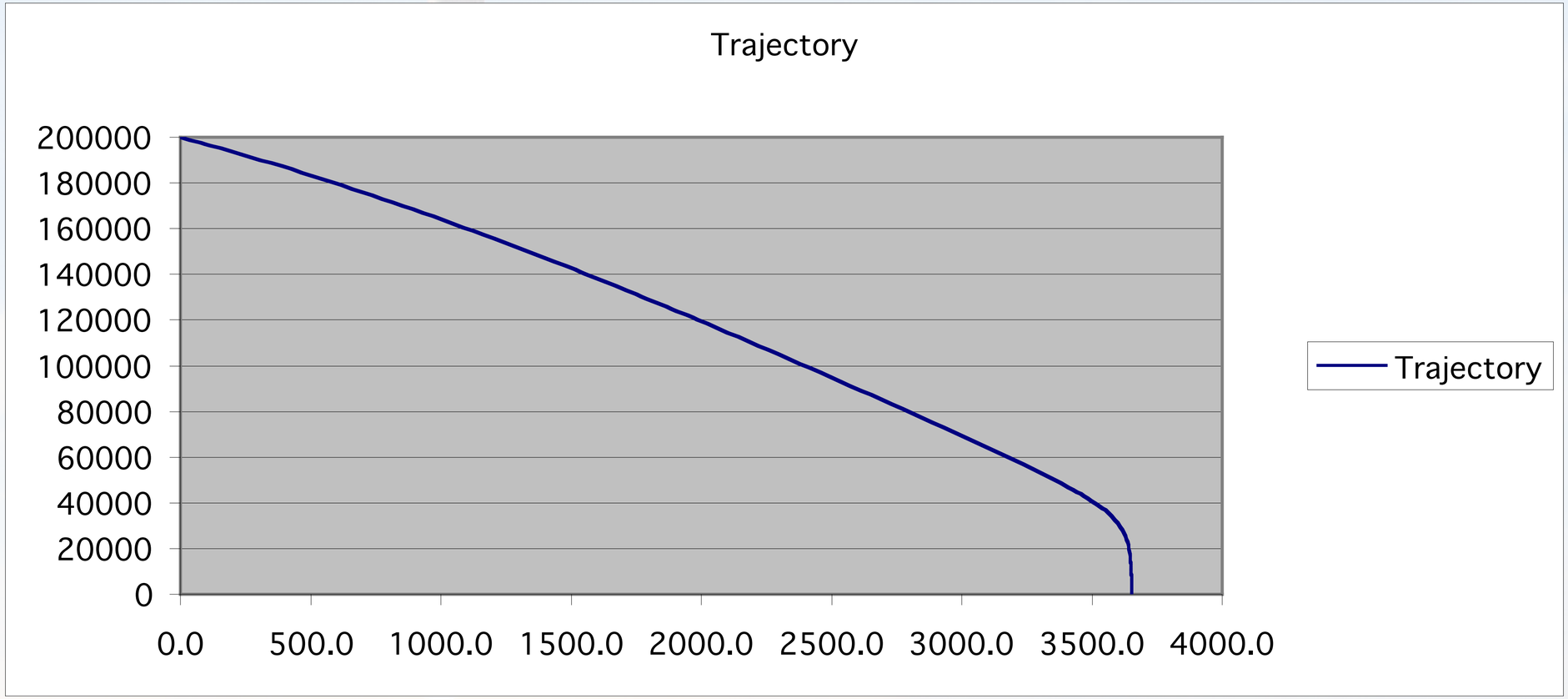
$$\boxed{v_\theta = \sqrt{\frac{\mu}{p}}(1 + e\cos\theta)}$$

$$\boxed{\tan\gamma = \frac{v_r}{v_\theta} = \frac{e\sin\theta}{1 + e\cos\theta}}$$

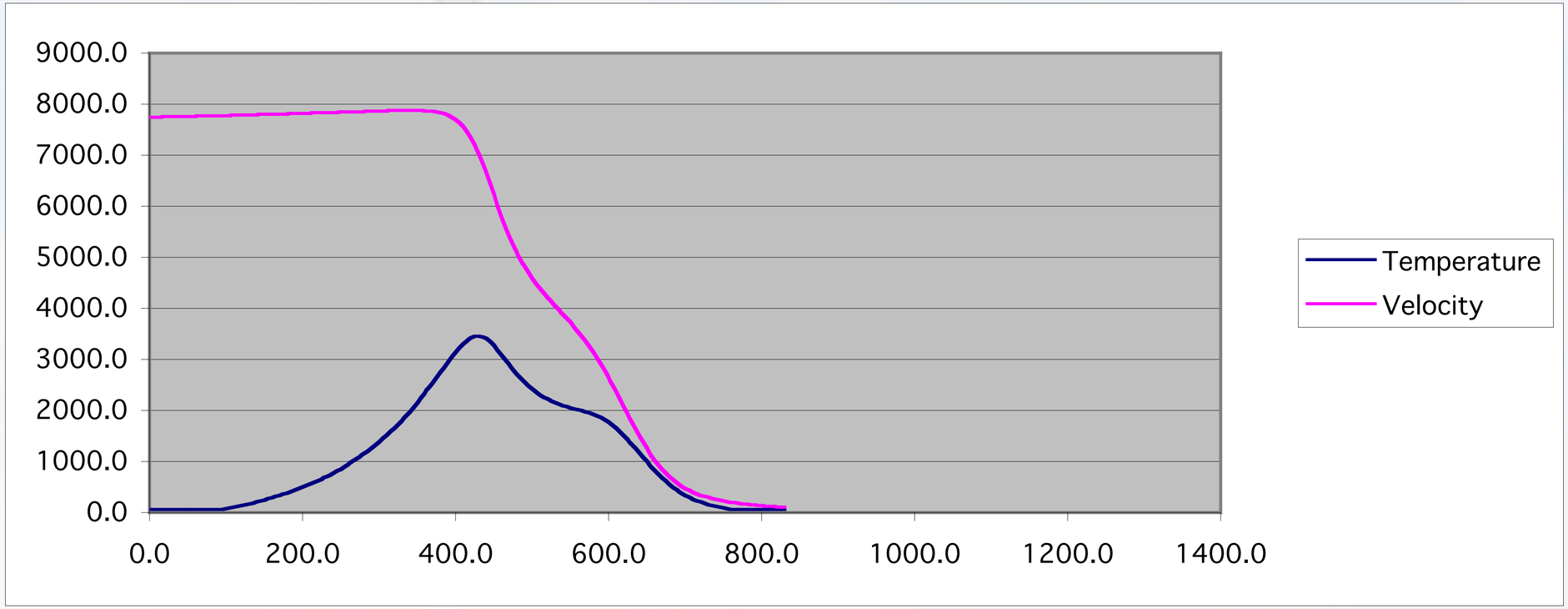
Nominal Soyuz Entry Trajectory



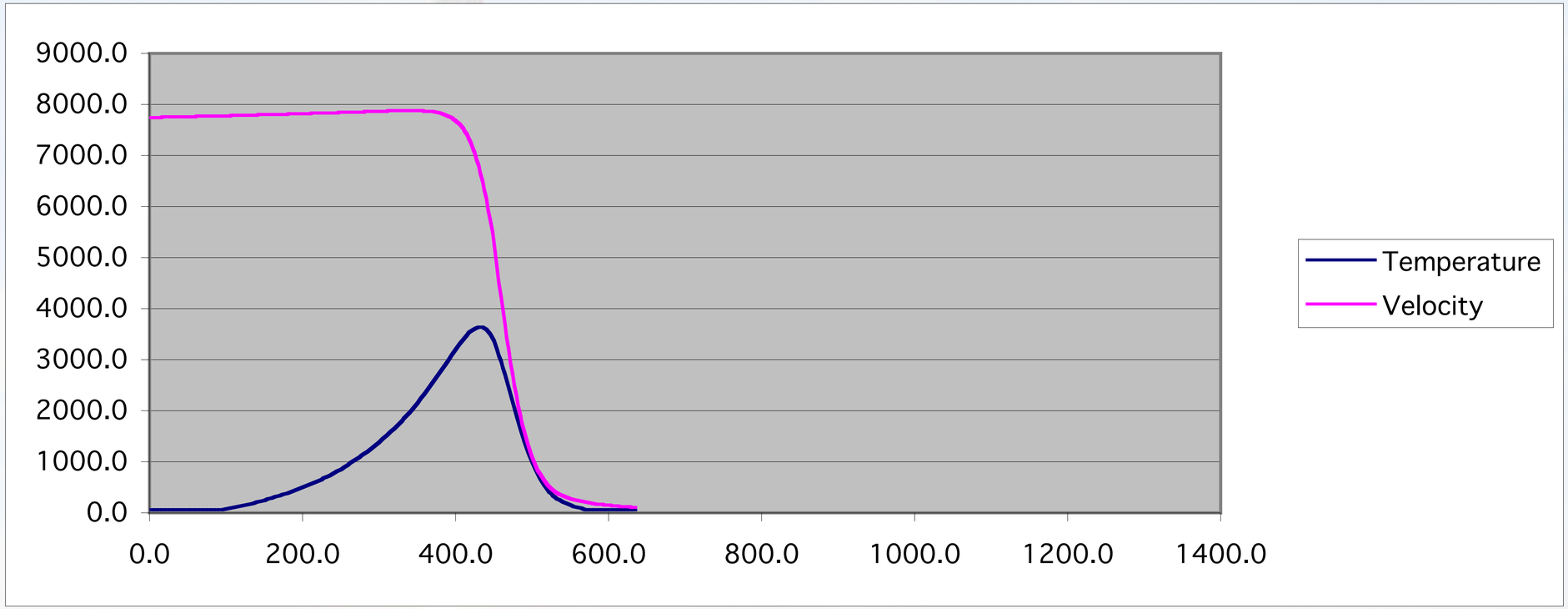
Soyuz Trajectory (Ballistic Entry)



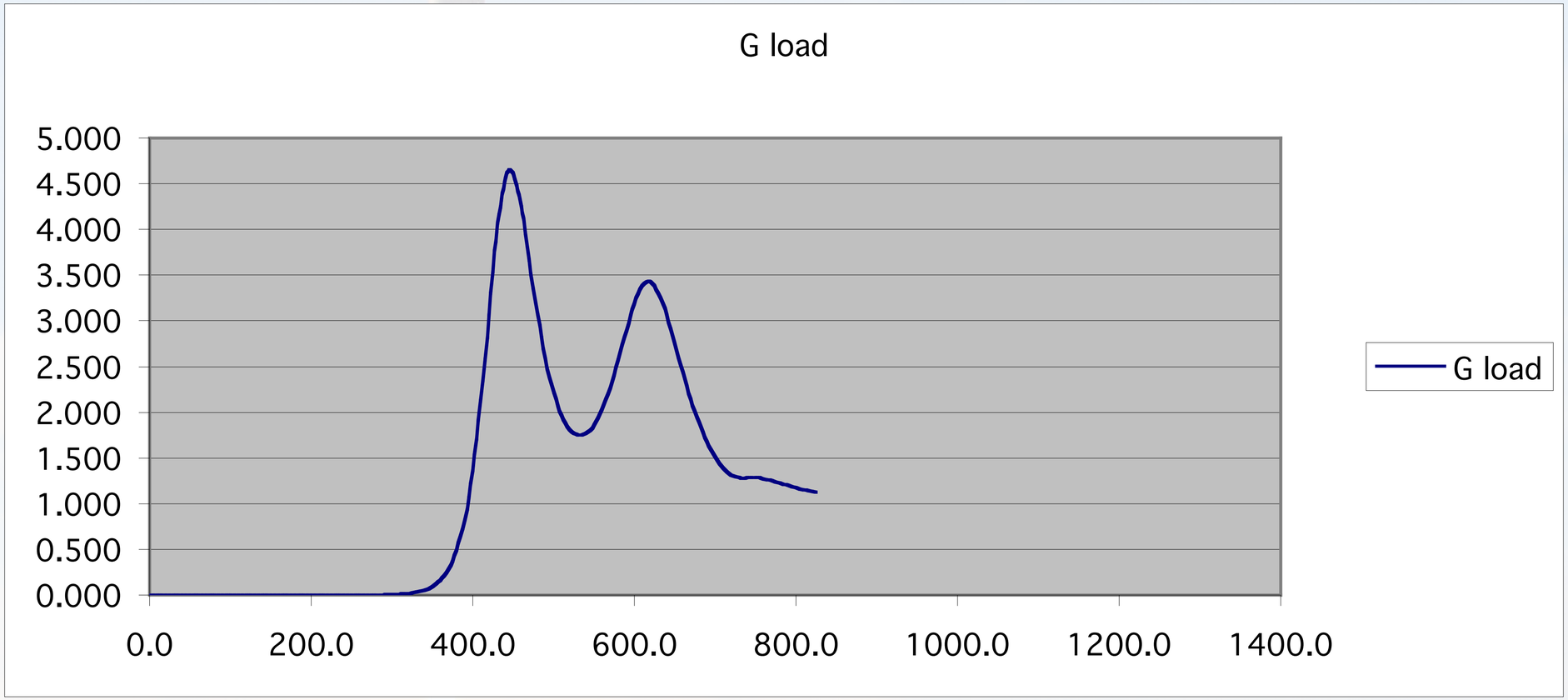
Nominal Entry Heating and Velocity



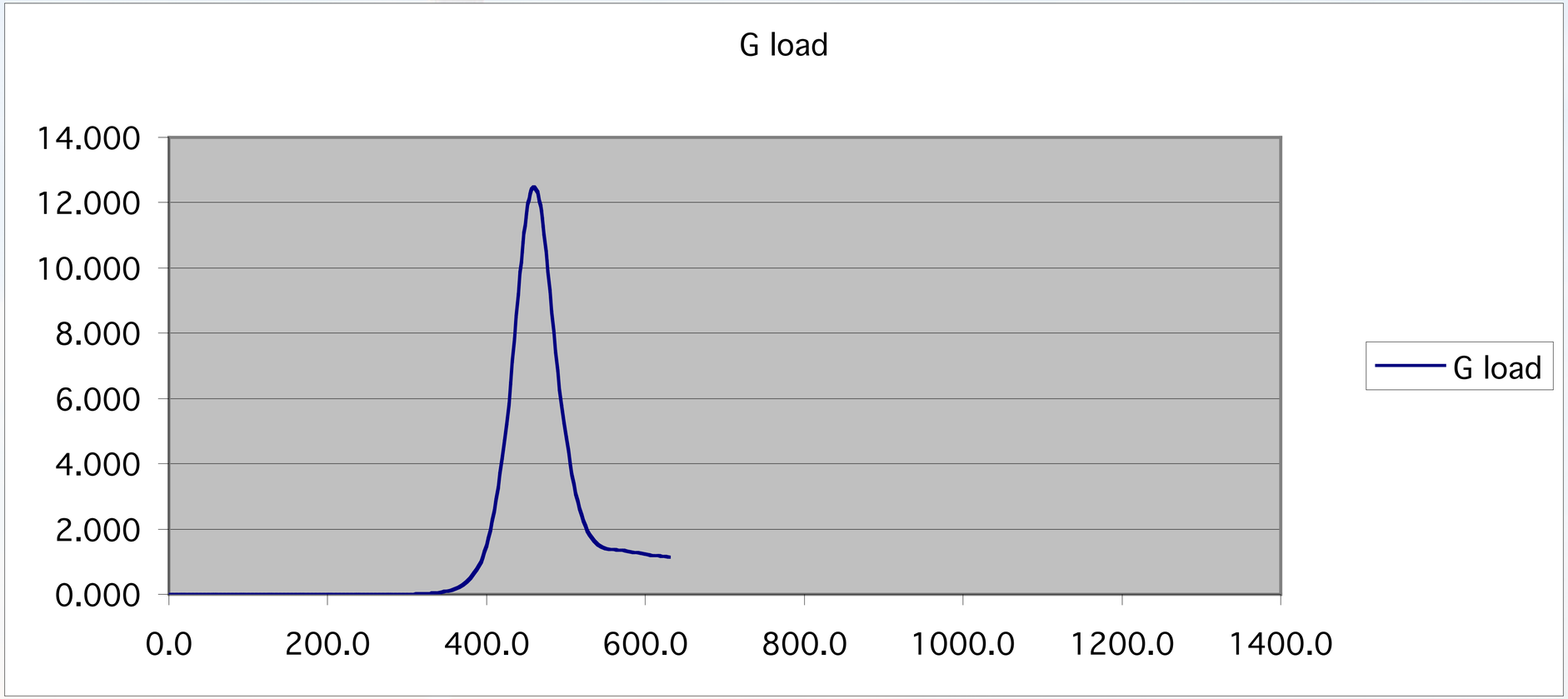
Ballistic Entry Heating and Velocity



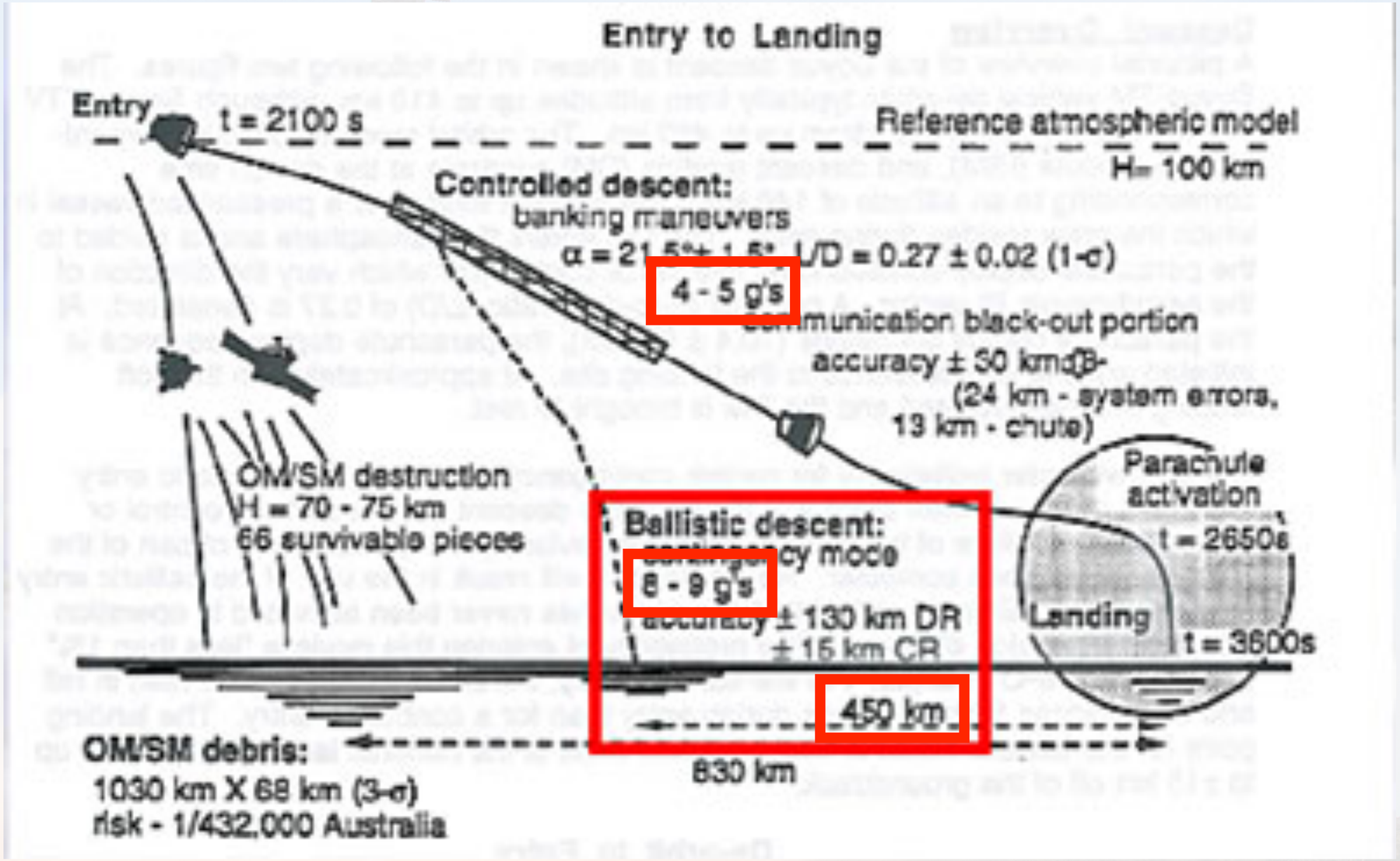
G Loading (nominal entry)



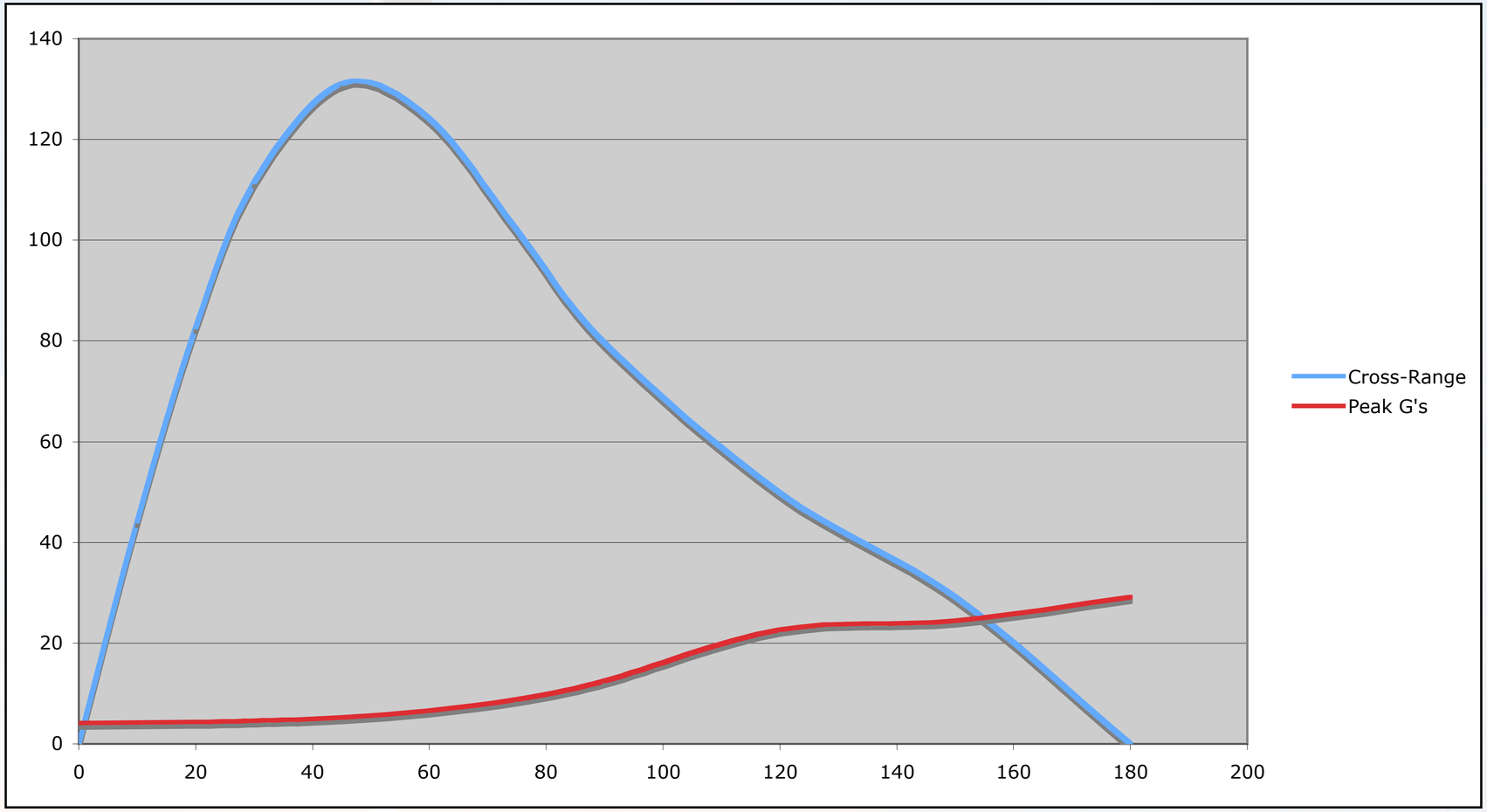
G Loading (Ballistic Entry)



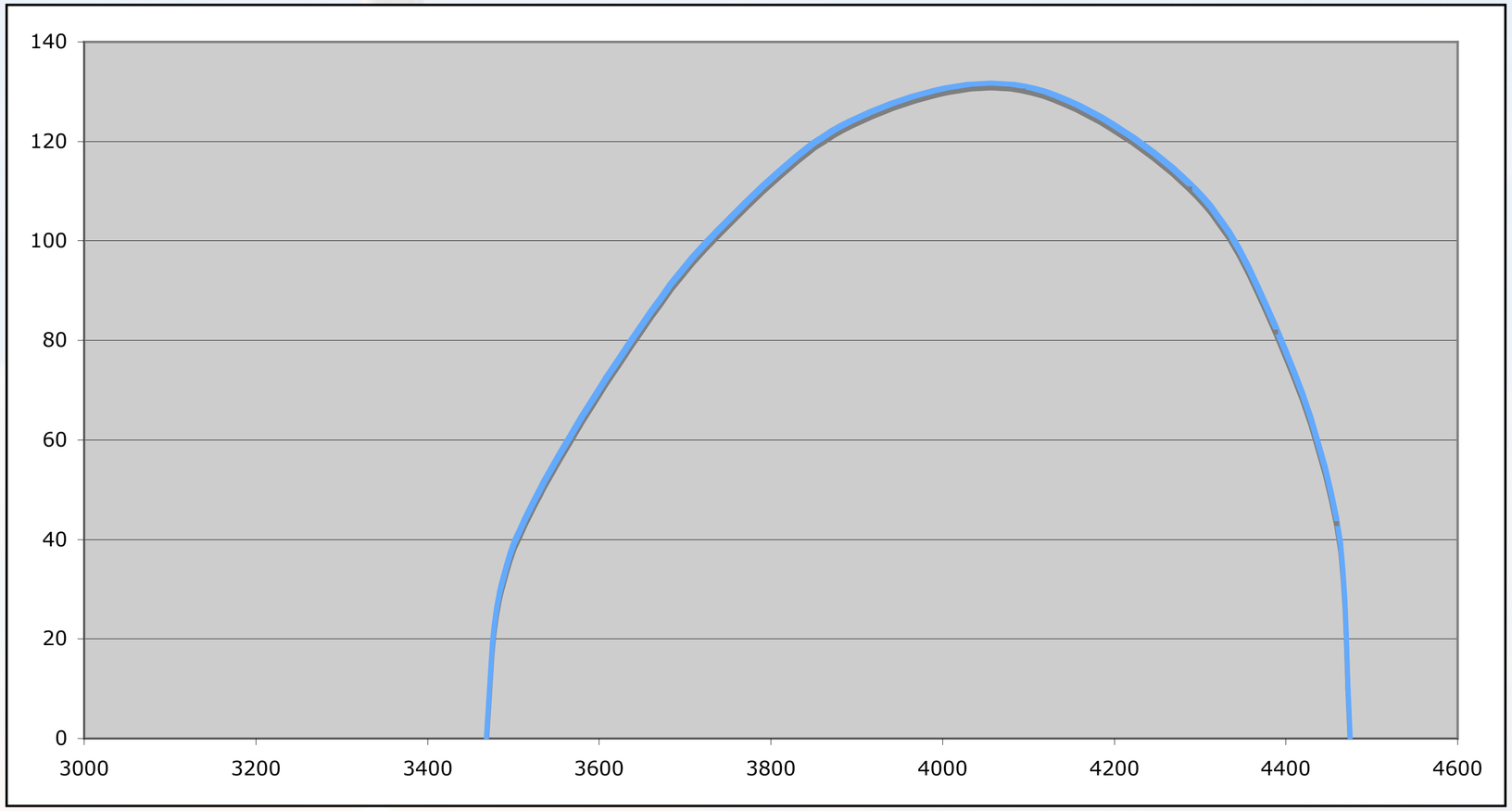
Published Flight Characteristics



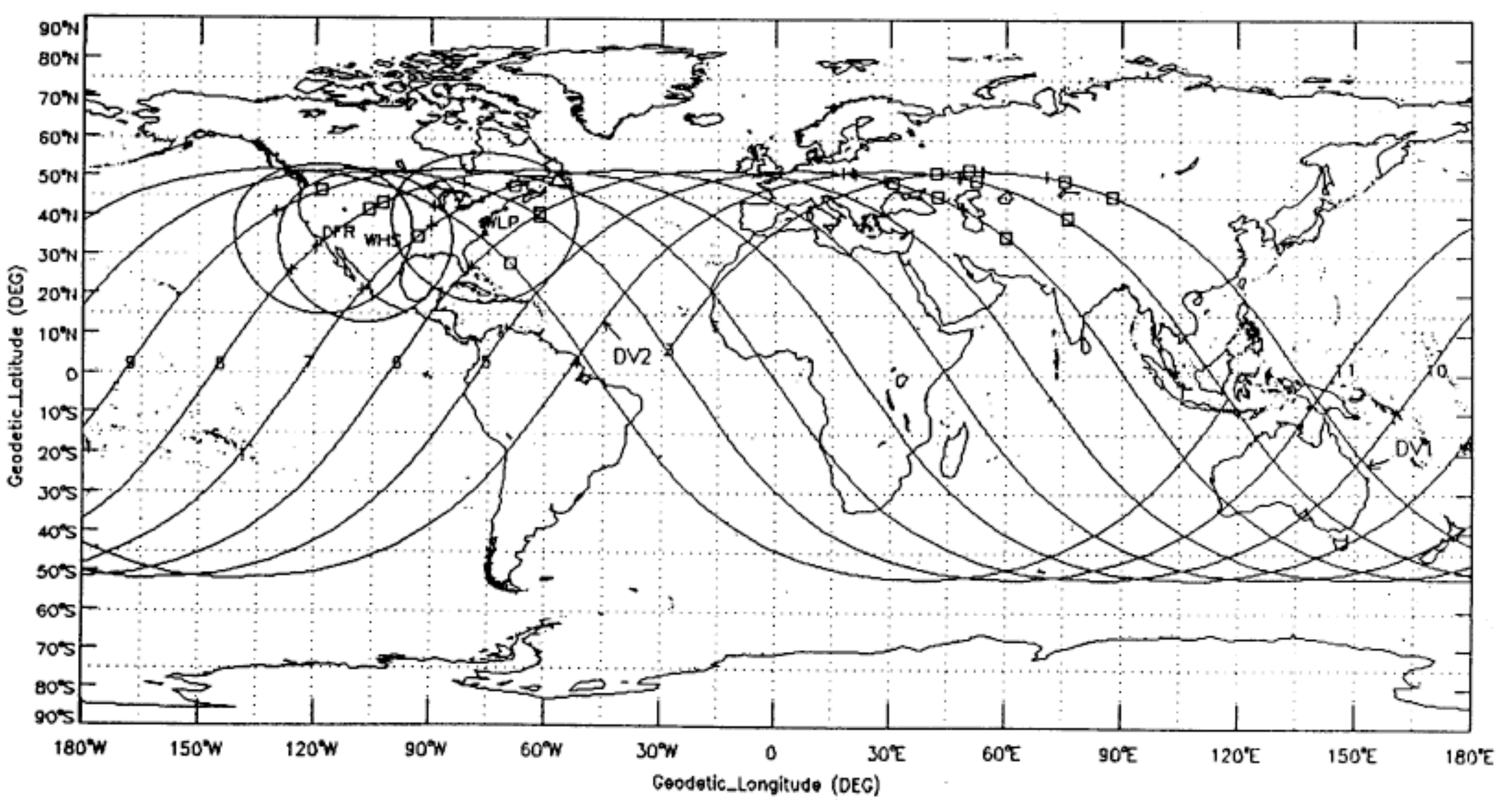
Cross-Range and G's vs. Roll Angle



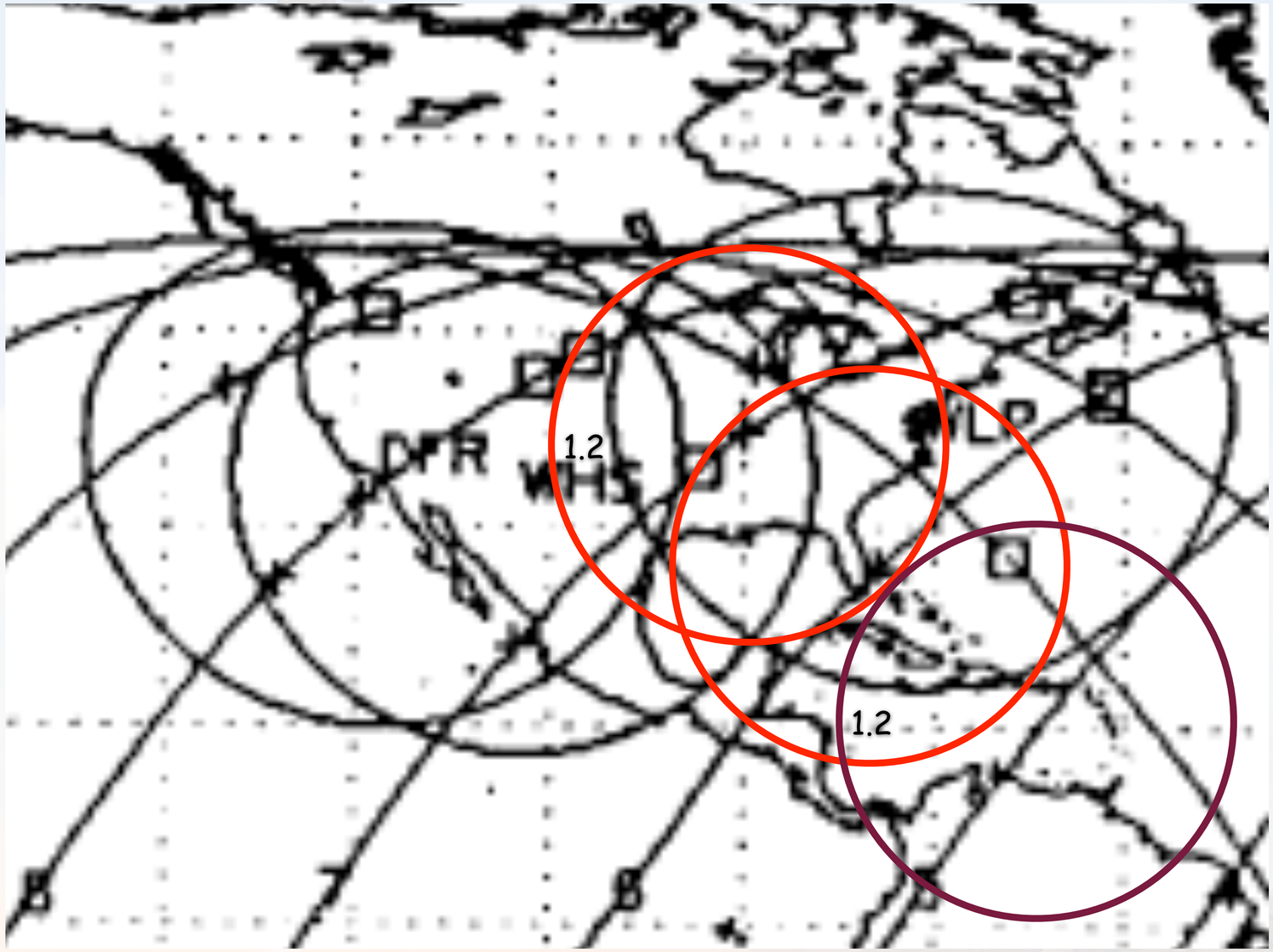
Soyuz Landing Ellipse



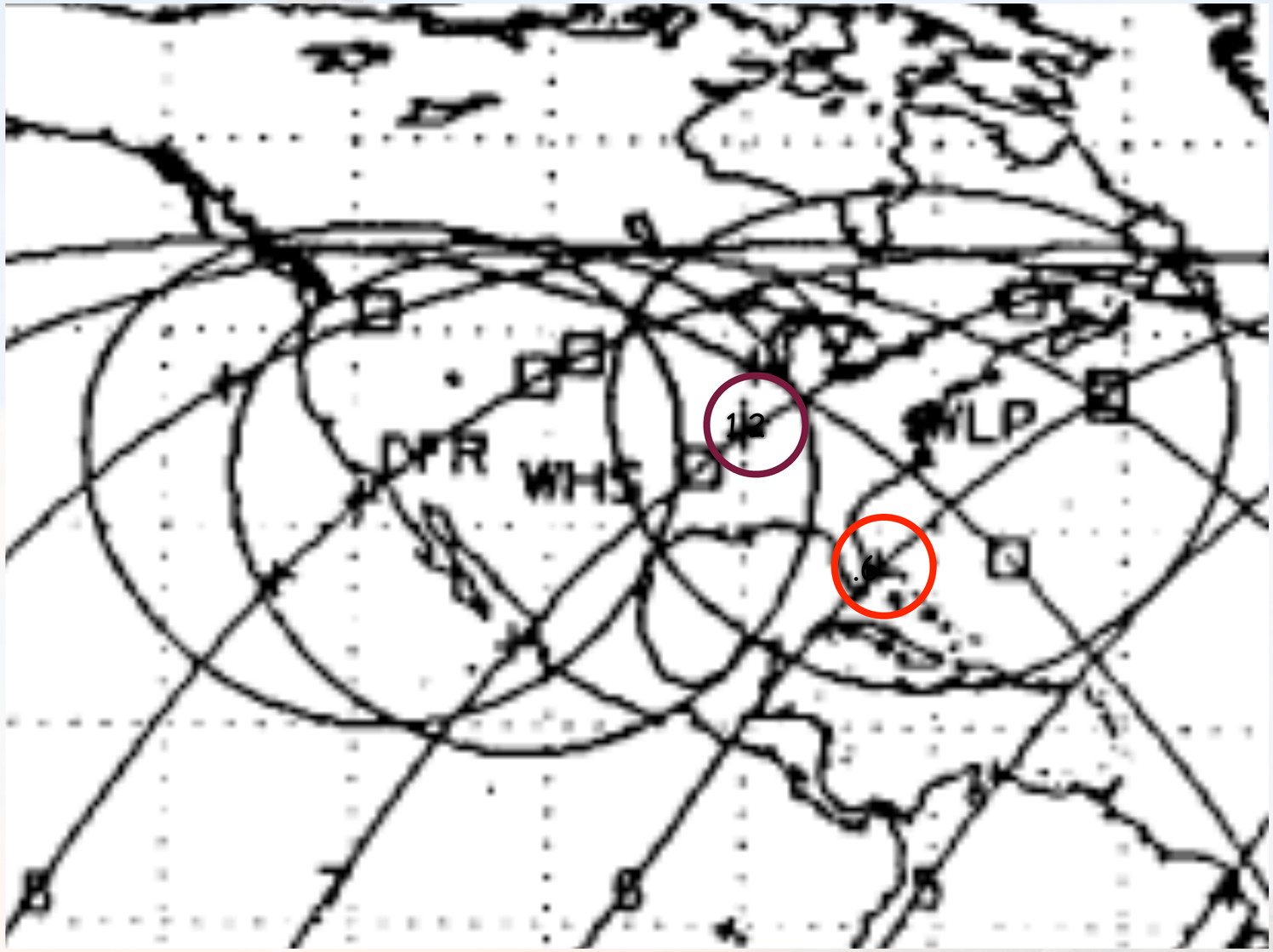
Typical Orbit Groundtrack



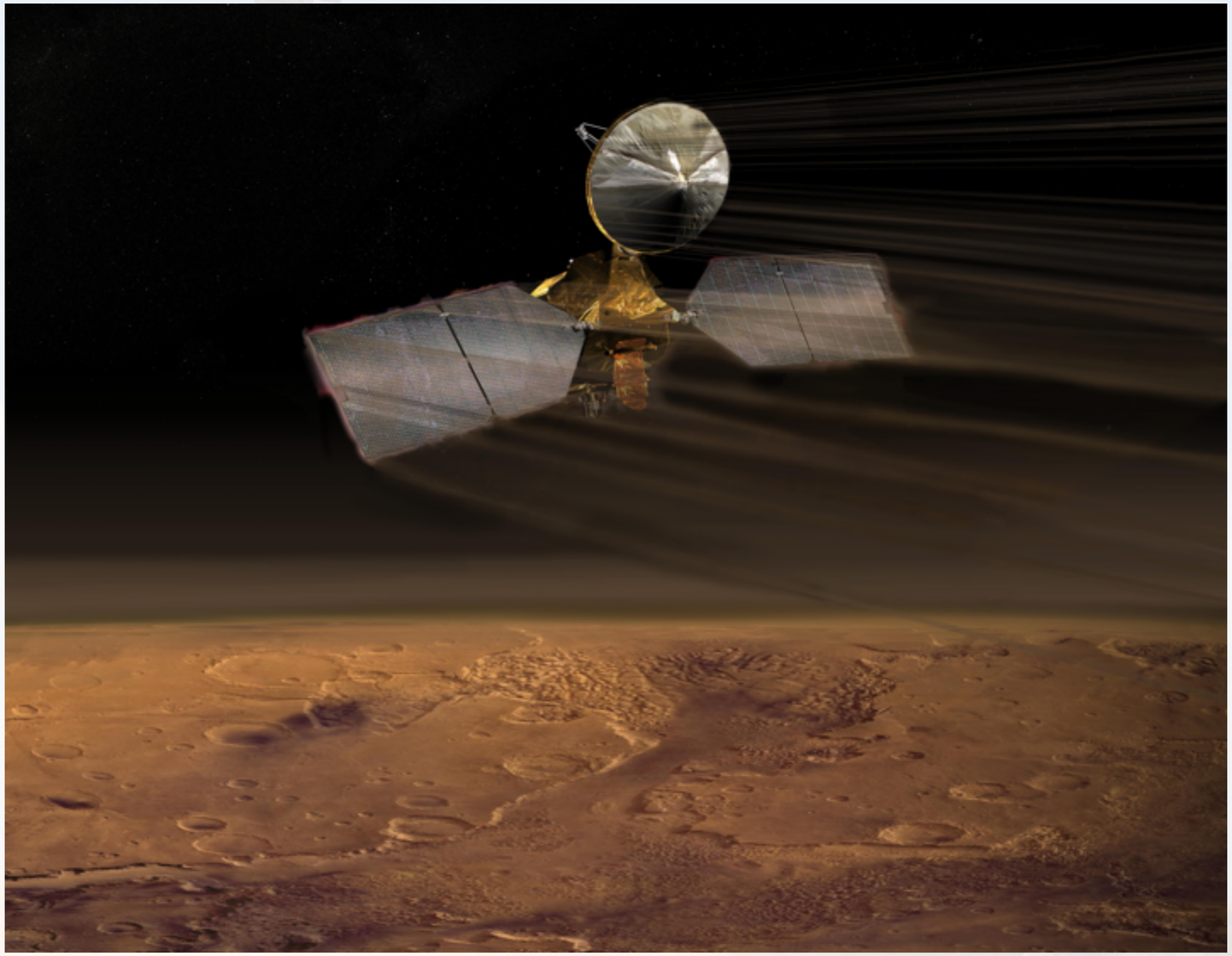
Landing Opportunities - 1200 mi Xrange



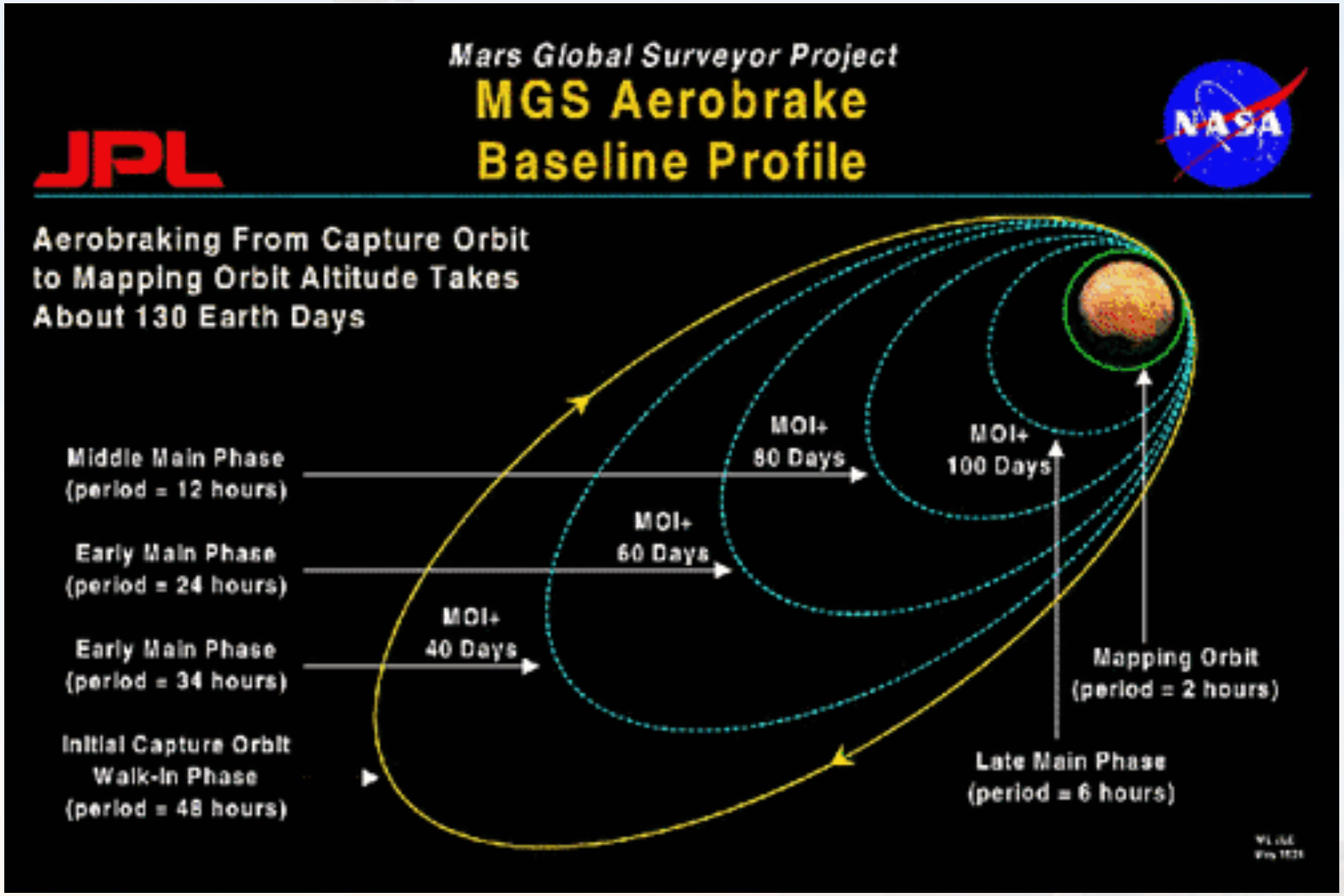
Landing Opportunities - 300 mi Xrange



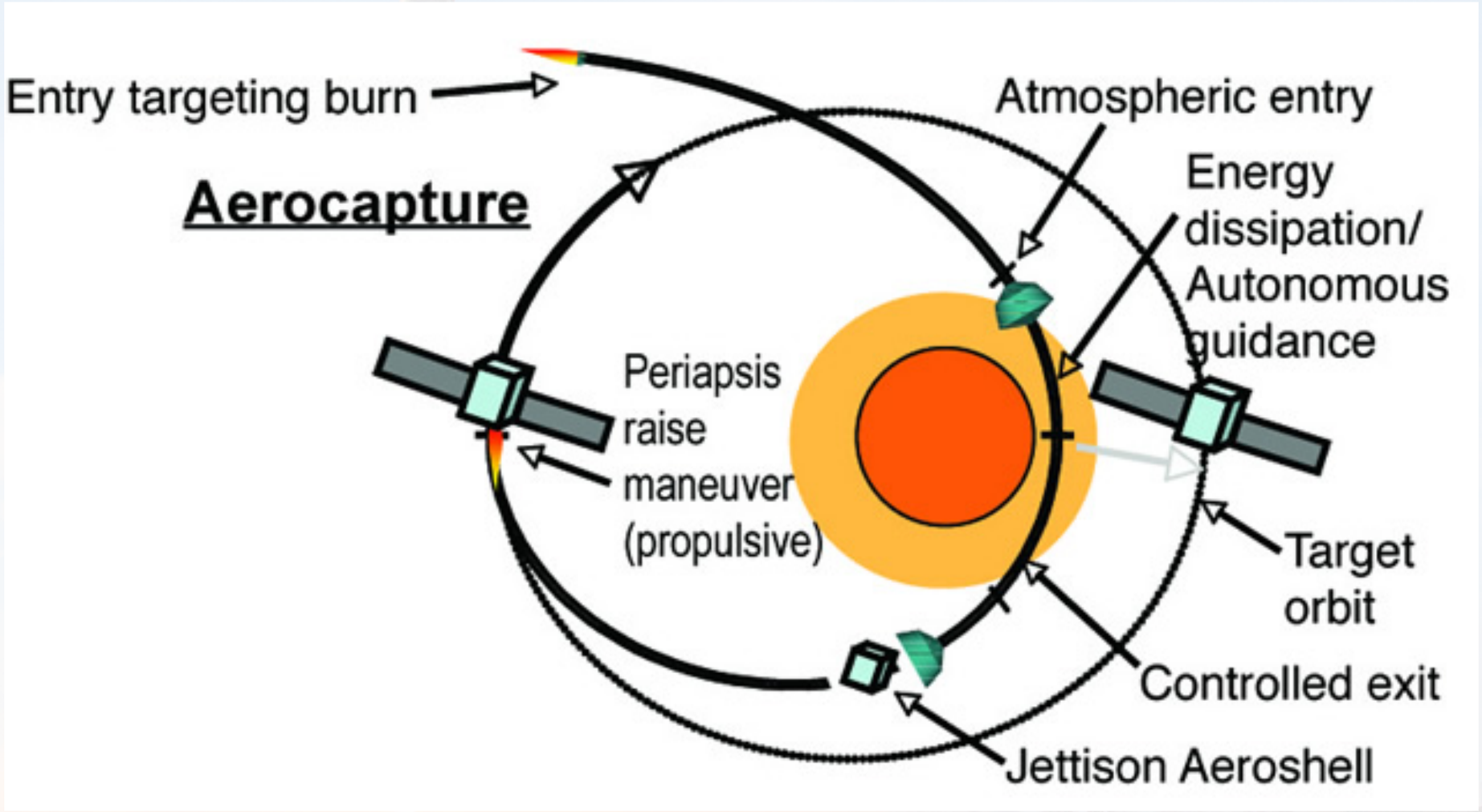
Mars Global Surveyor Aerobraking



MGS Multipass Aerobraking



(Single-Pass) Aerocapture Maneuver



Ballistic Aerocapture Trajectories