Project Icarus

Efficient Solar Escape Trajectories for Interstellar Travel

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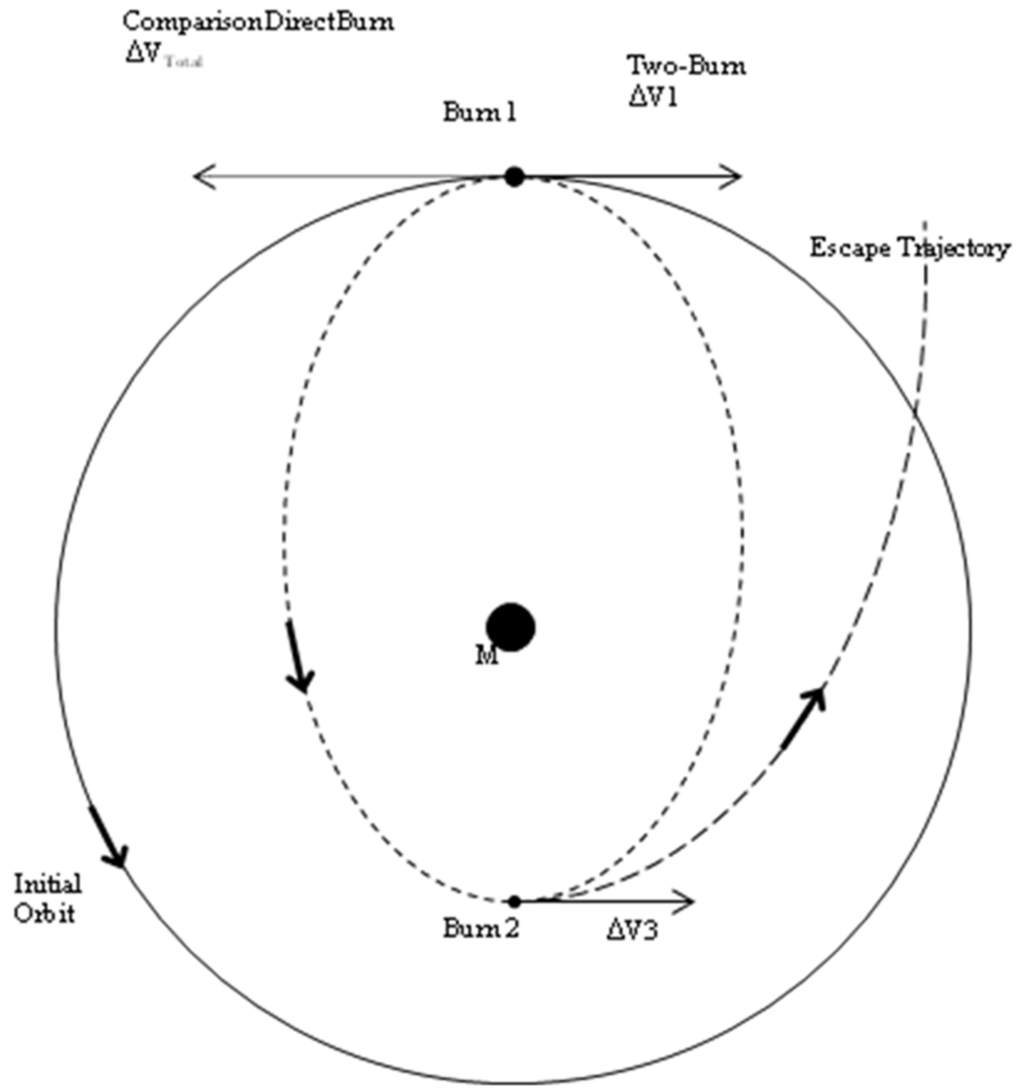
Two Burn Escape Maneuver

- Discussed in “Ways to Spaceflight”, Oberth, 1928
- First burn slows spacecraft, causing it to drop towards central body
- Second burn accelerates spacecraft.
- Loss from first burn overcome by additional energy extracted during second burn



Criteria for using Oberth Maneuver

- Derivation produces two roots
- Oberth did not give criteria for using maneuver
- Levin, others found first root in format similar to below

$$\Delta V_1 + \Delta V_3 = \sqrt{\frac{\mu}{r_0}}$$

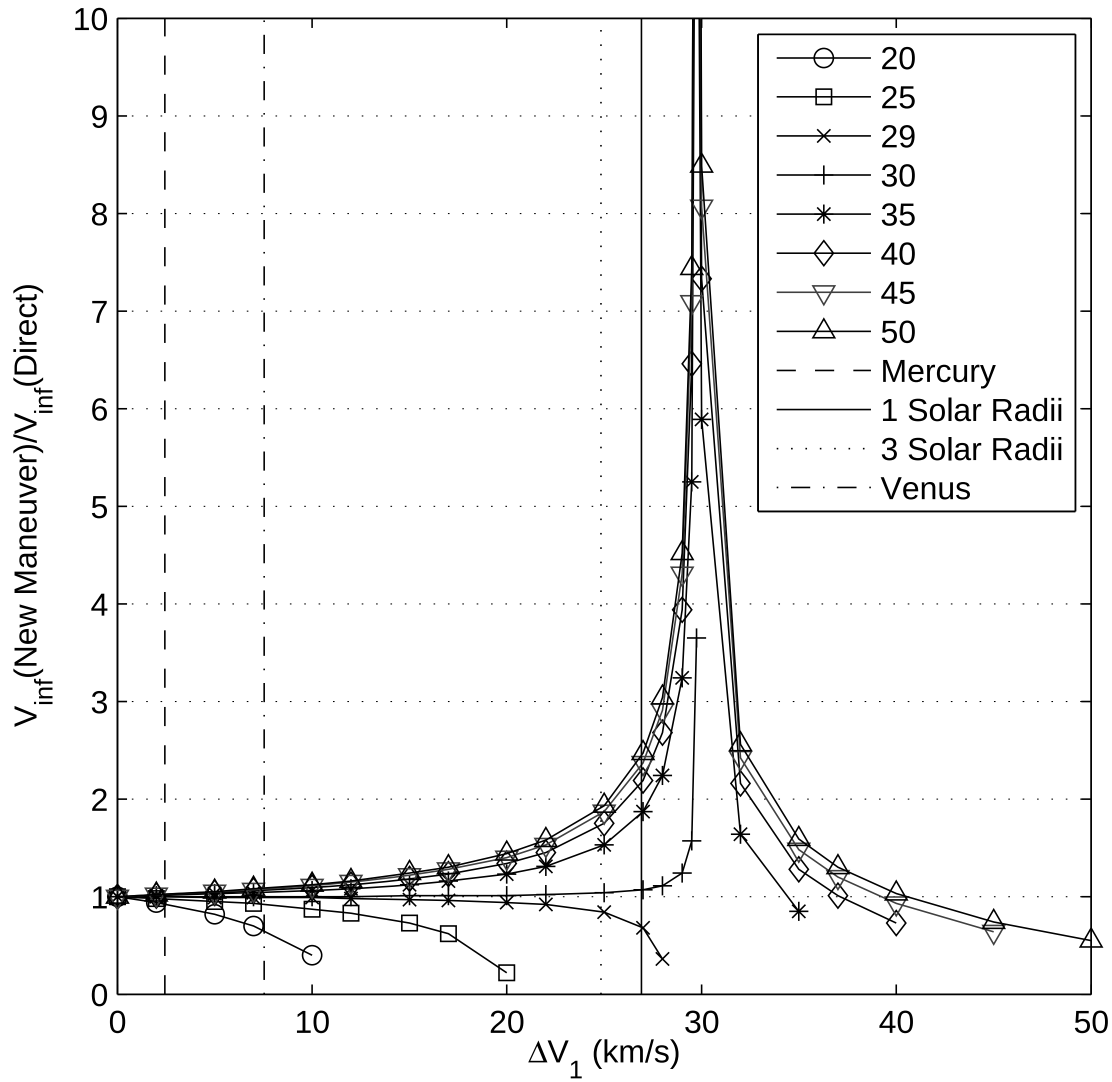
- Second real root indicates point at which Oberth maneuver is no longer more effective than direct option

$$\left(\Delta V_1 + \Delta V_3\right)\frac{\mu}{r_0} + \Delta V_1\left(\Delta V_3 - \Delta V_1\right)\sqrt{\frac{\mu}{r_0}} - \Delta V_1^{\,2}\Delta V_3 = 0$$

- Are DV's necessary for interstellar exploration inside the range where Oberth is most effective?

Oberth Two Burn vs. Direct Escape

- Oberth maneuver shows great improvement over direct option in achieving escape



Relevant Propulsion Concepts

Concept	I_{sp}	α	T/W_{eng}
	(sec)	(kW/kg)	(kN/kN)
Nuclear Pulse[1]	5,000	1250	5
Fusion – Inertial Confinement			
IEC[2]	50,000	1200	0.5
ICF[3]	13,000	10	0.02
Fusion – Magnetic Confinement			
Spherical Torus[3]	35,000	10	0.006
Gas Dynamic Mirror[3]	110,000	4	0.0007
Pulsed FRC[3]	100,000	15	0.003
Magnetized Target Fusion[3]	77000	100	0.04

[1]Bonometti, Joseph, personal communication.

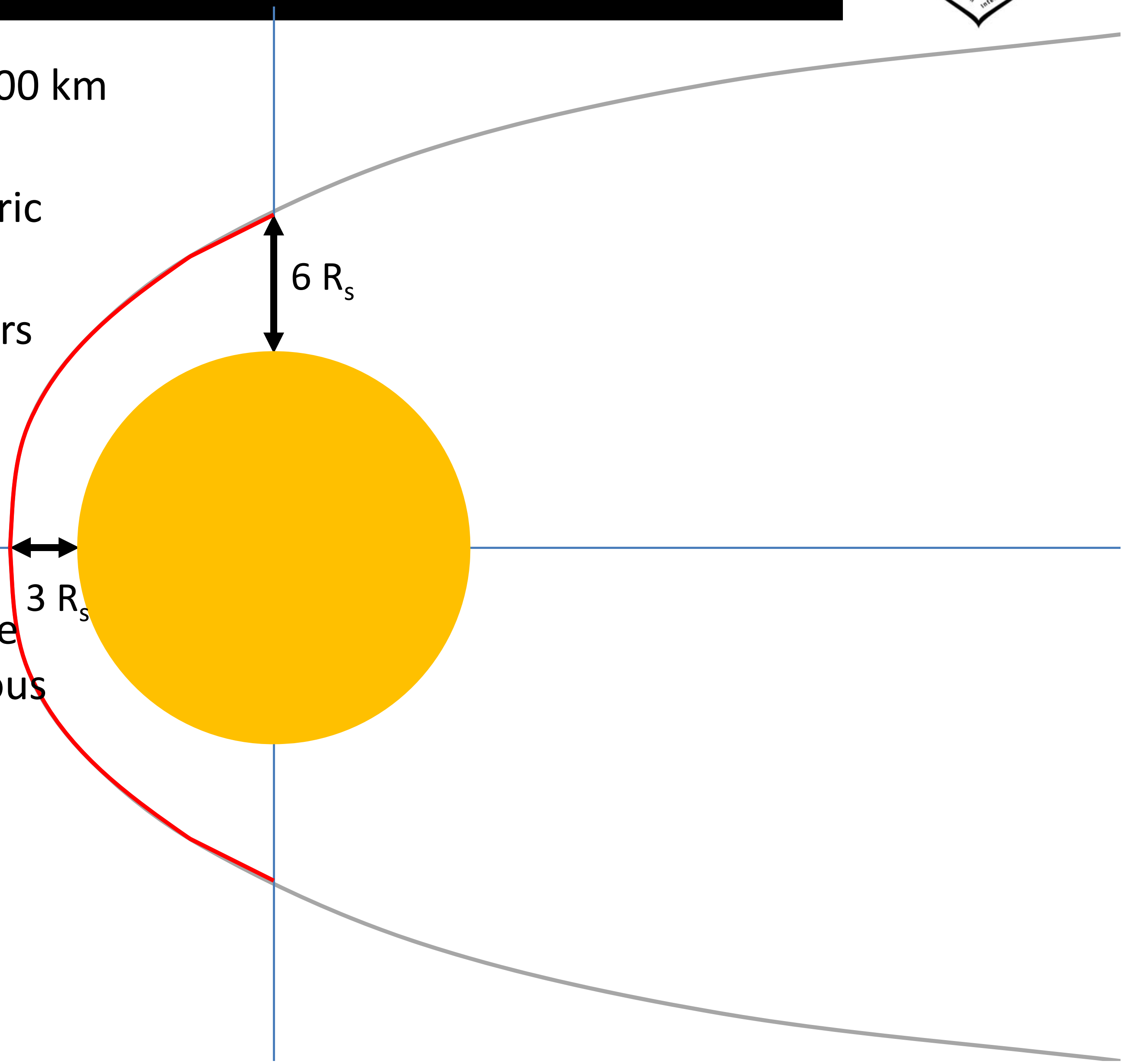
[2]Bussard, Robert W. and Jameson, Lorin, W., "From SSTO to Saturn's Moons: Superperformance Fusion Propulsion for Practical Spaceflight", in *Fusion Energy in Space Propulsion*, edited by Terry Kammash, AIAA, Washington DC, 1995.

[3]Polsgrove, Tara, and Adams, Robert B., "Trajectories for High Specific Impulse High Specific Power Deep Space Exploration", AIAA 2002-4433, 2002.

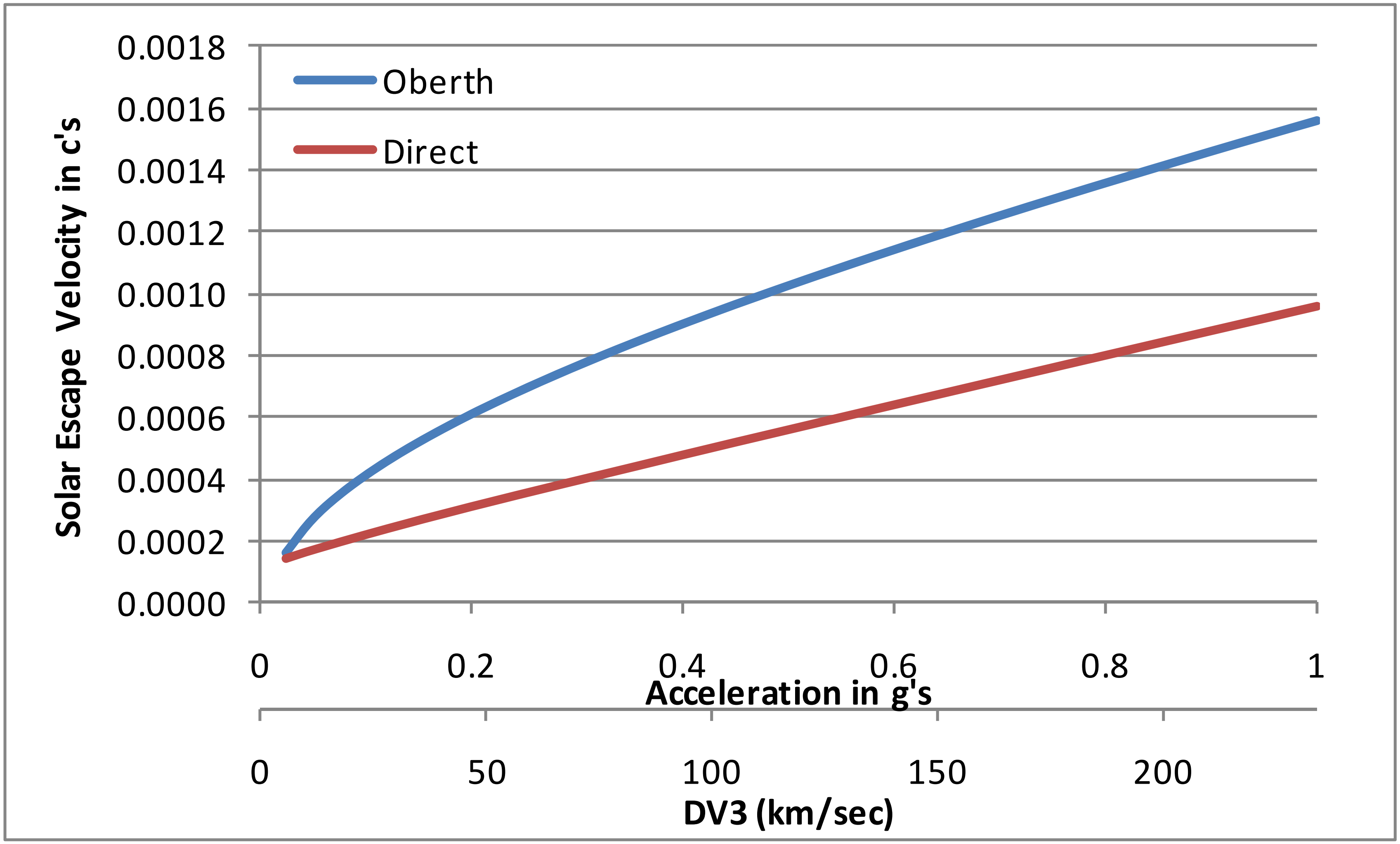
[4]Kammash, Terry, "Principles of Fusion Energy Utilization in Space Propulsion", in *Fusion Energy in Space Propulsion*, edited by Terry Kammash, AIAA, Washington DC, 1995.

Mission Profile

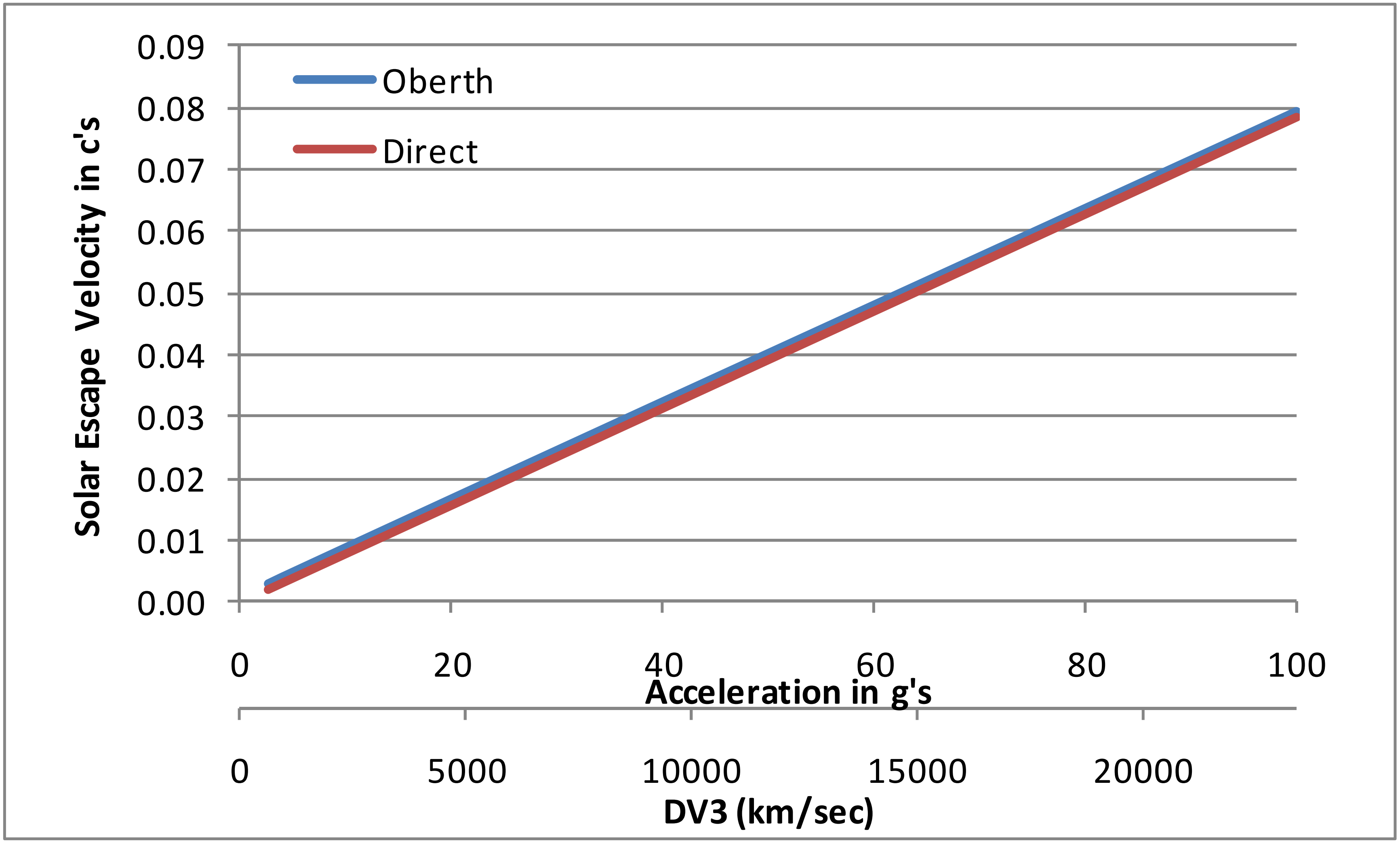
- Depart Earth from 400 km circular orbit
- Insert into heliocentric orbit
- Burn approx 6.5 hours around perihelion
- Use range of accel. and flight time to calculate ΔV
- Assume performance equal to instantaneous burn



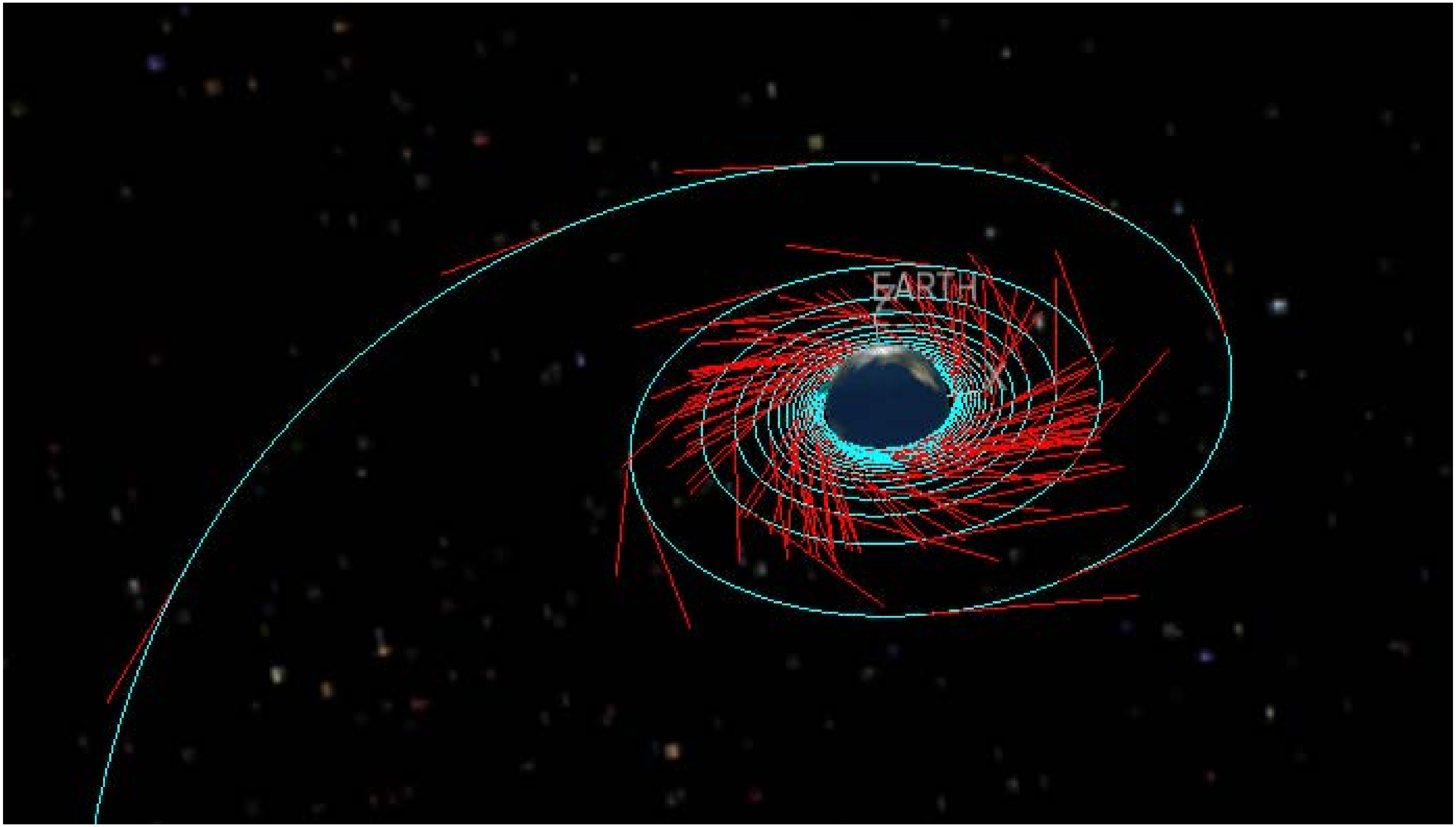
Achieved Escape Velocity (0.025-1 g acc.)



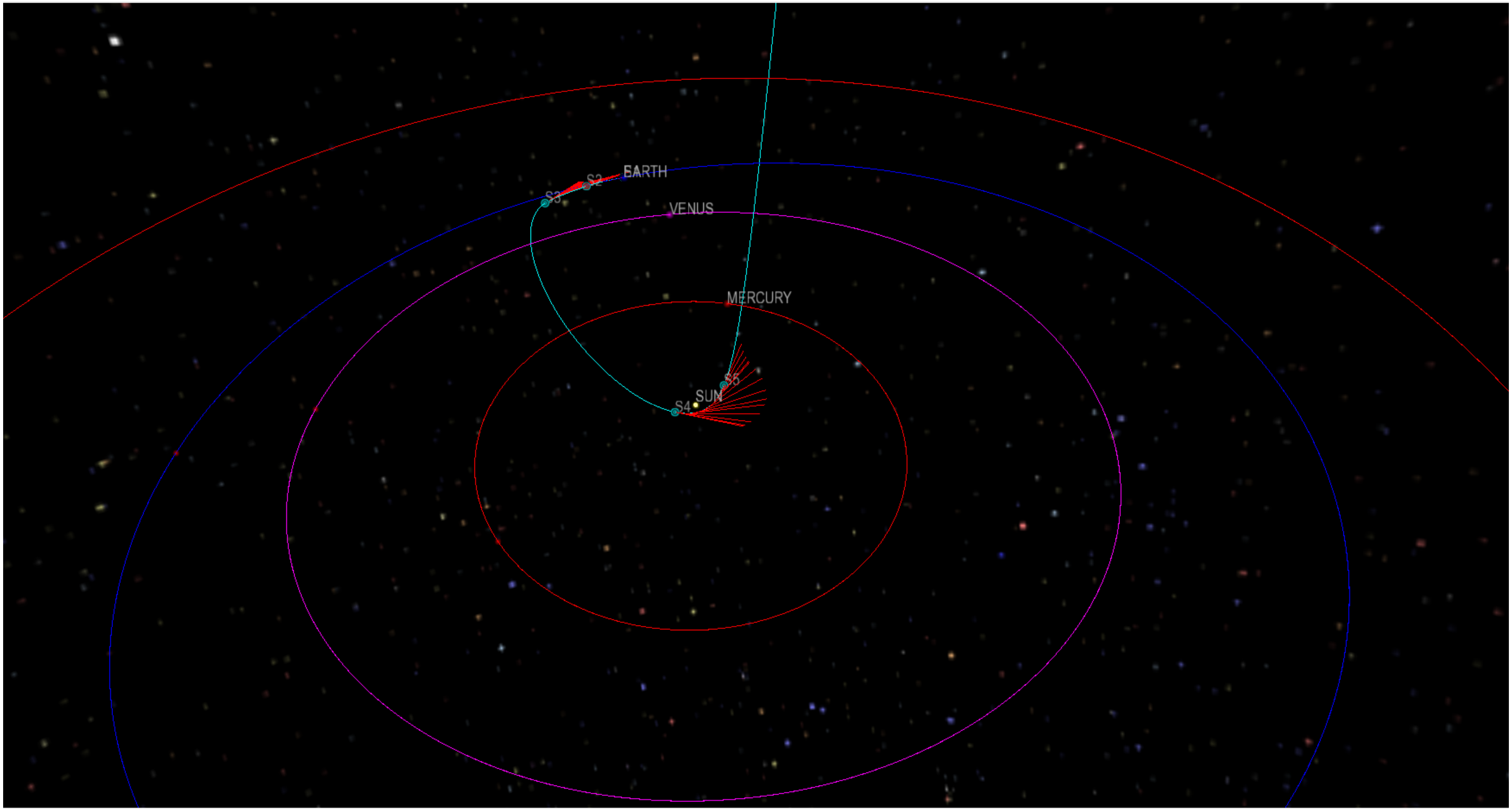
Achieved Escape Velocity (2.5-100 g acc.)



Earth Escape



Solar Escape



Specific Impulse and Specific Power

- Jet power defined as
- Thrust defined as
  - Pressure term is small contributor for a well designed nozzle
- Instantaneous specific impulse is
- Combining above yields
- Dividing by propulsion system mass yields
  - Defines specific power as function of Isp and thrust-to-weight

$$P_{jet} = \frac{1}{2}\dot{m}V_e^2$$

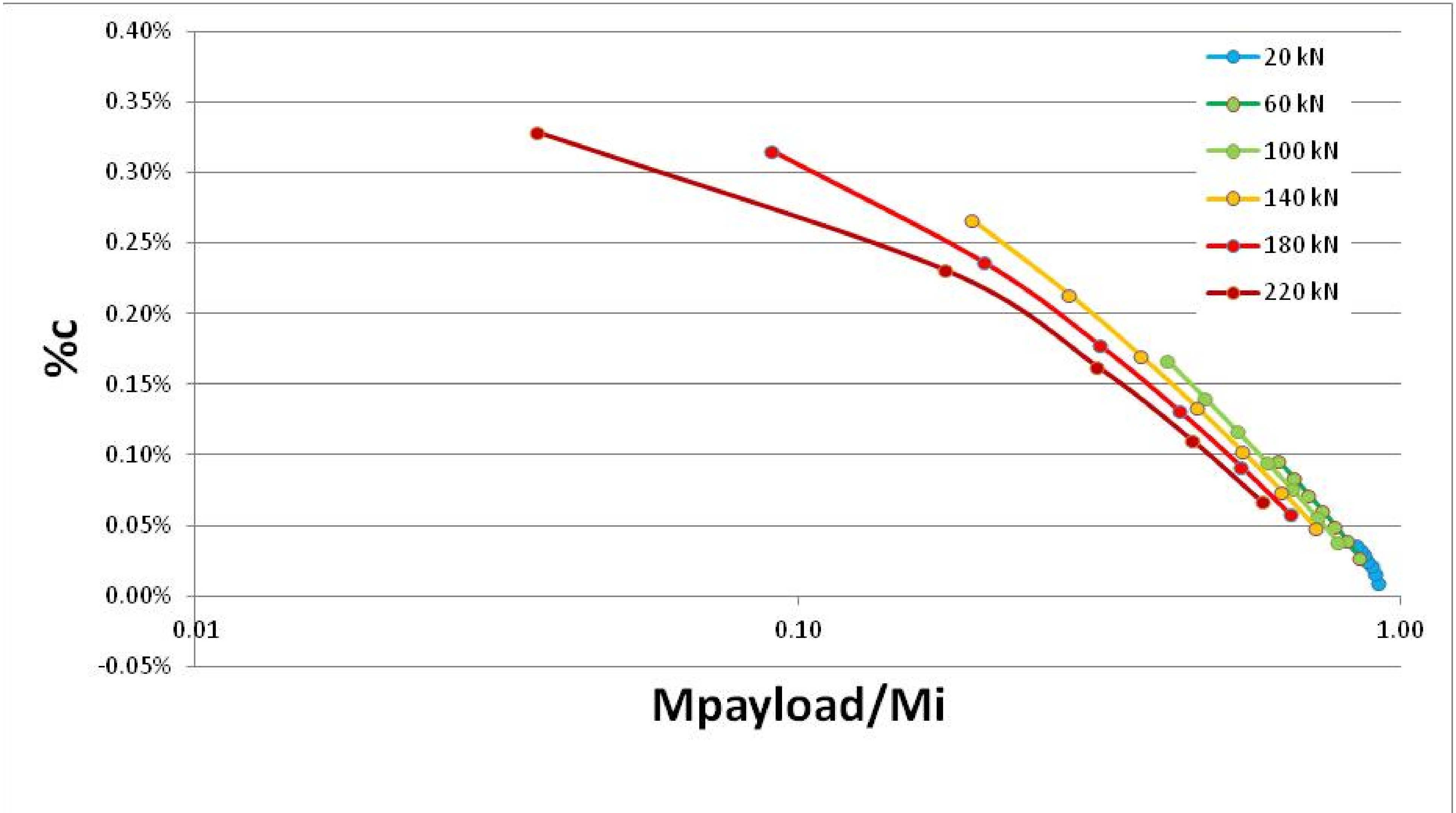
$$F = \dot{m}V_e + (p_e - p_a)A_e$$

$$I_{sp} = \frac{F}{\dot{m}g_0}$$

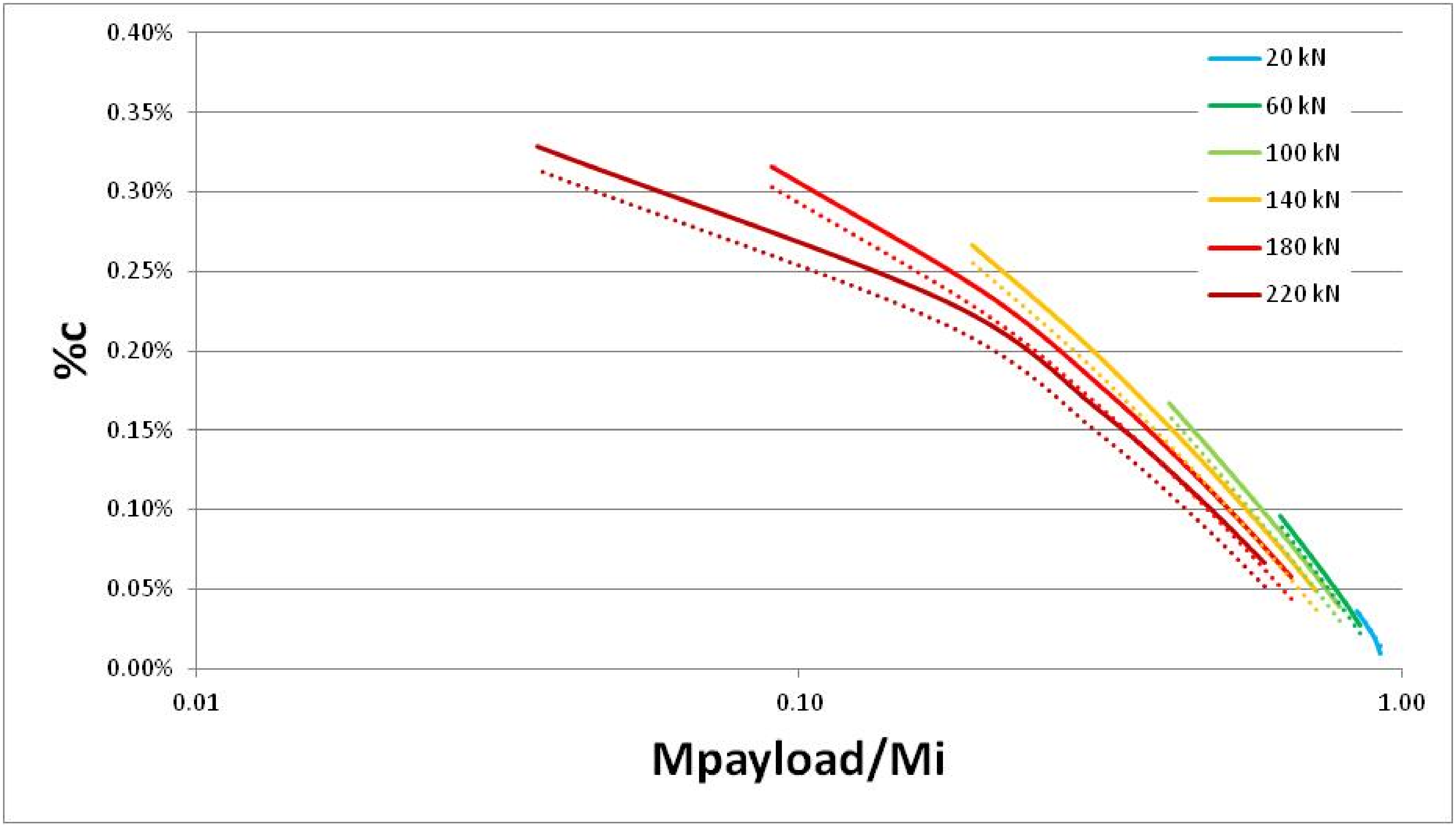
$$P_{jet} = \frac{1}{2}g_o I_{sp} F$$

$$\alpha = \frac{P_{jet}}{m_{eng}} = \frac{1}{2}g_o{}^2 I_{sp}\frac{F}{g_0 m_{eng}}$$

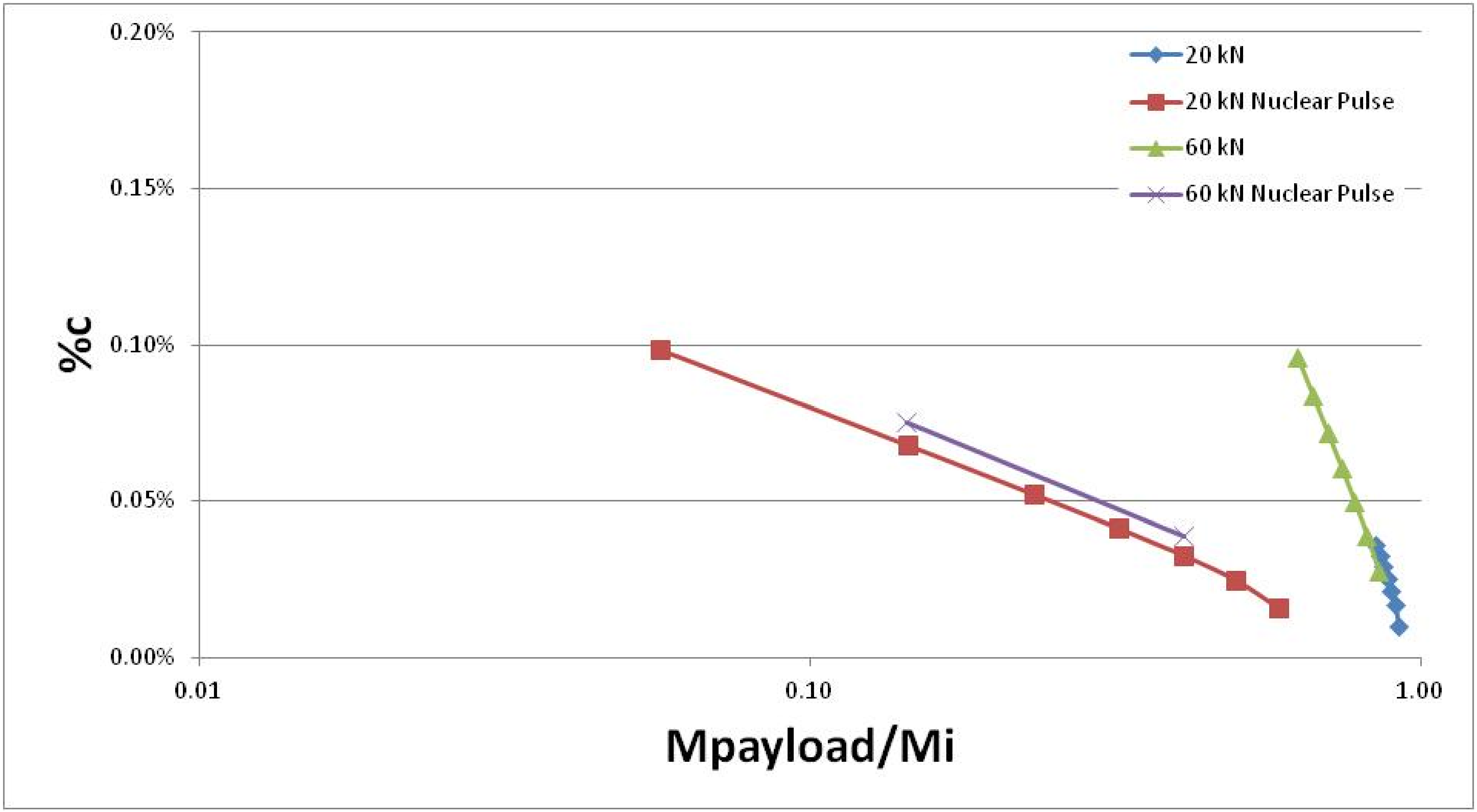
PJMIF Performance



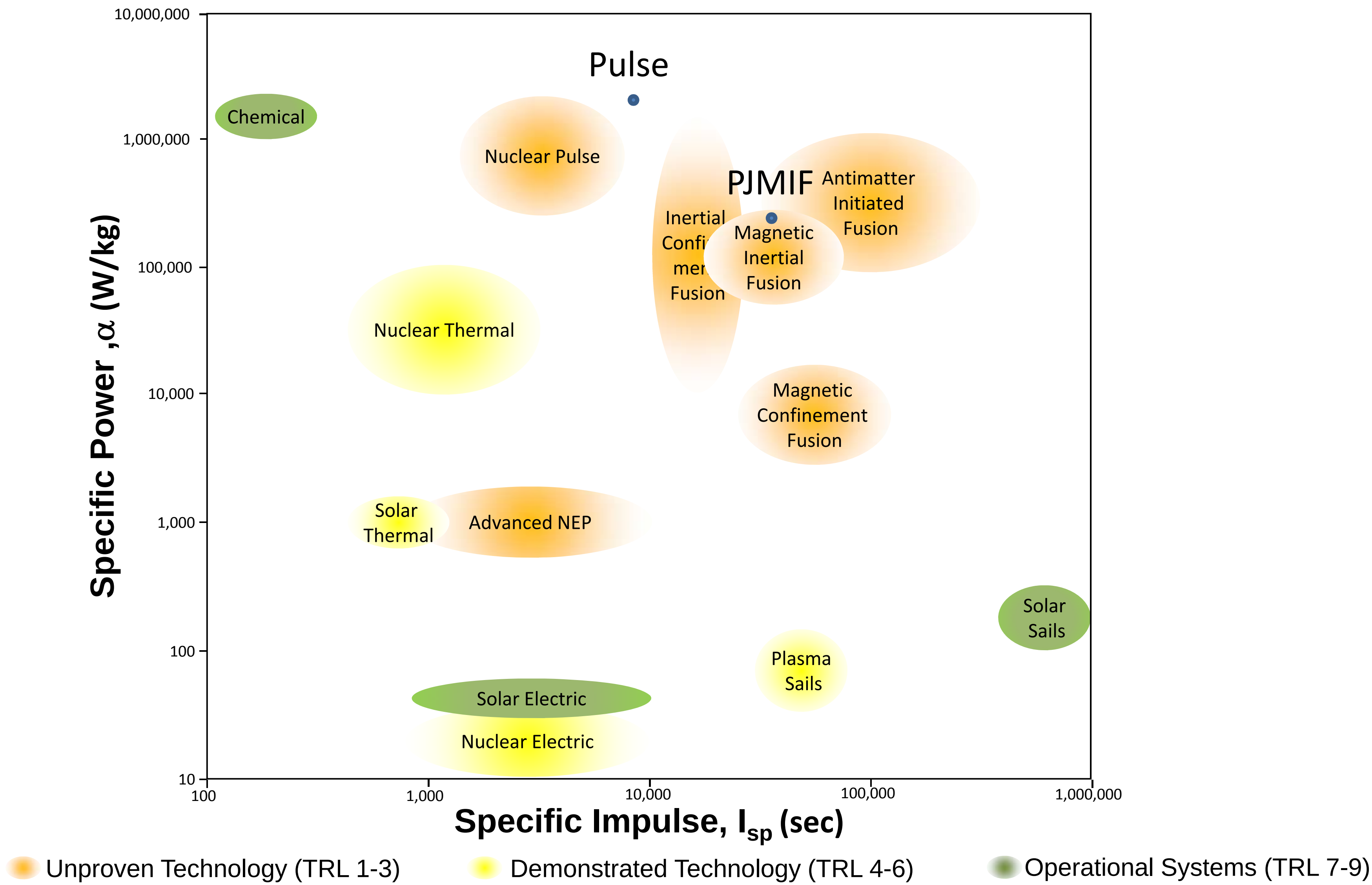
PJMIF Performance vs. Ideal



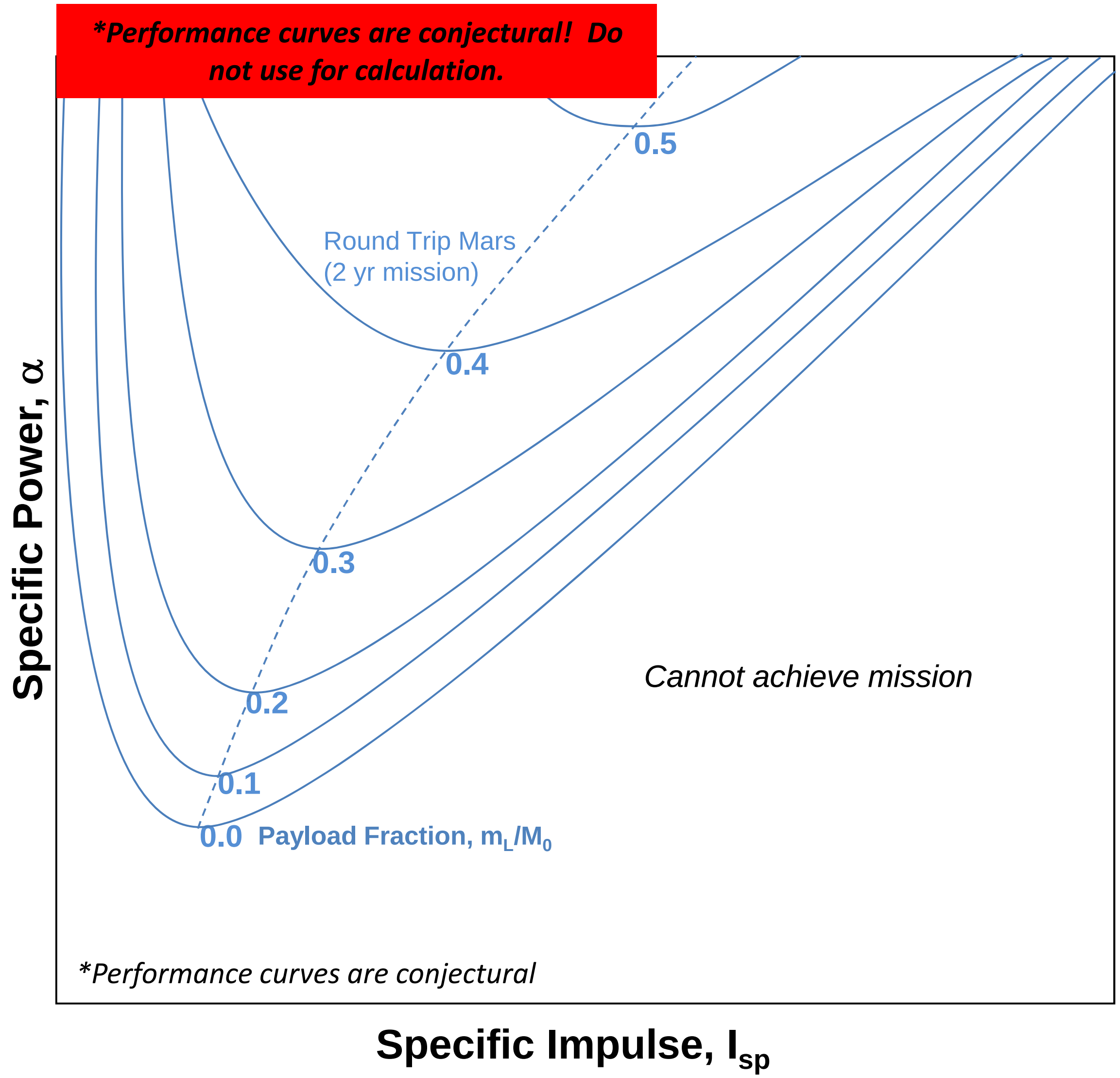
PJMIF Performance vs. Nuclear Pulse



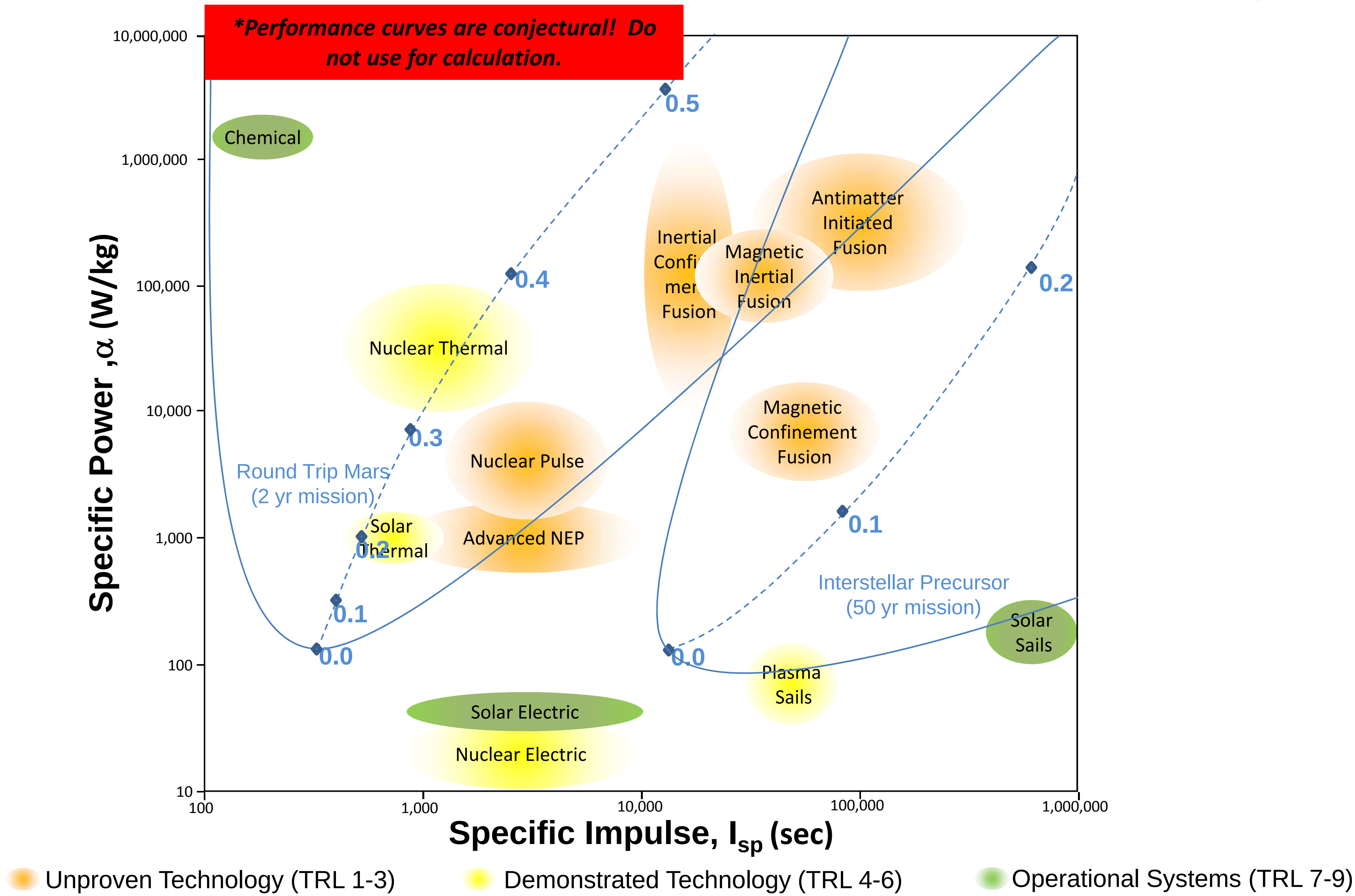
Propulsion Technologies



Parametric Trajectory Analysis

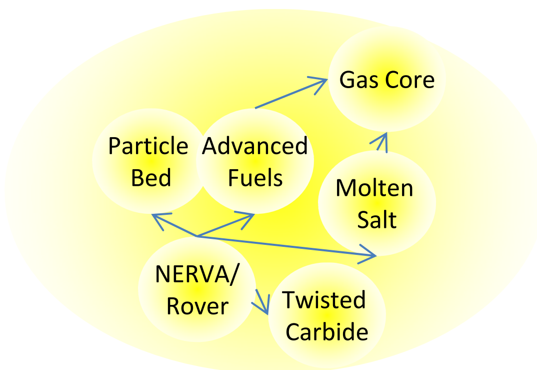


Missions vs. Propulsion Technologies



Propulsion Research Effort

- Each propulsion category can be expanded into individual propulsion concepts
- Nuclear Thermal is expanded here
- Individual concepts are mapped inside bubble with dependancies shown by arrow



Conclusions

- Oberth two-burn maneuver is little known but worthwhile for solar escape applications
- Producing total DV using Oberth maneuver is infeasible
- Accelerations achievable by planned propulsion systems will benefit from Oberth maneuver

Acknowledgements

- NASA – MSFC for supporting my efforts with Project Icarus
- G. Richardson for co-authoring previous work in exploring the Oberth maneuver