National Aeronautics and Space Administration

Analysis of Cislunar Transfers from a Near Rectilinear Halo Orbit with High Power Solar Electric Propulsion

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Summary

- **Purpose**
- **Reference Transfers**
  - NRHO to DRO
  - NRHO to NRHO
  - NRHO to L2 Halo
- **Power and Mass Sensitivity**
  - Methodology
  - Results
- **Conclusion**

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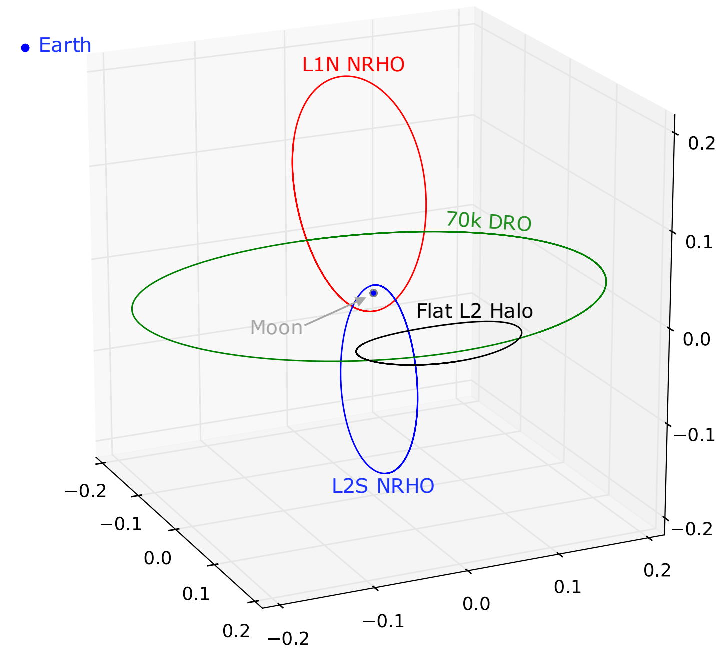
Purpose

For a massive low thrust solar electric propulsion spacecraft in a *9:2 Lunar Synodic Resonant L2 Southern NRHO (L2S NRHO)*:

- Design efficient reference transfers to:
  1. 70,000 km DRO
  2. L1 Northern NRHO (L1N)
  3. “Flat” EML2 Halo Orbit

- Understand the sensitivity to varying:
  1. SEP Power
  2. Spacecraft Mass
  3. Number of Thrusters



Earth-Moon Rotating Frame

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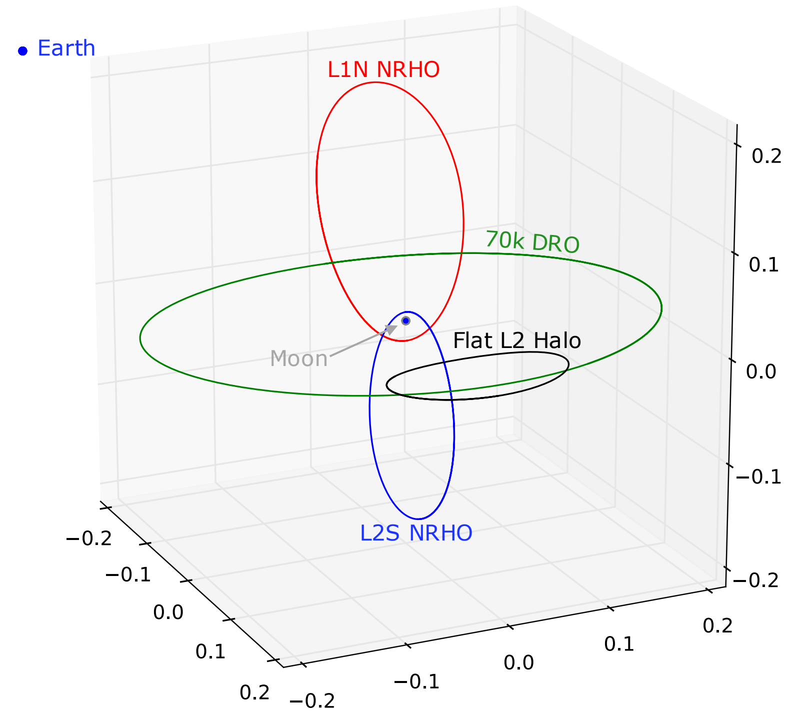
Reference Assumptions

- **Spacecraft Assumptions:**
  - Transfer Time: < 6 months
  - Initial Mass: 39 t
- **SEP Assumptions:**
  - SEP Power: 26.6 kW
  - Thrusters: 2 + 2 @ 13.3 kW each
  - Duty Cycle: 90%
- **Initial Orbit:** 9:2 Lunar Synodic Resonant L2 Southern NRHO
- **Destinations:**
  - 70,000 km DRO
  - L1 Northern NRHO
  - 3,500 km Flat L2 Halo Orbit



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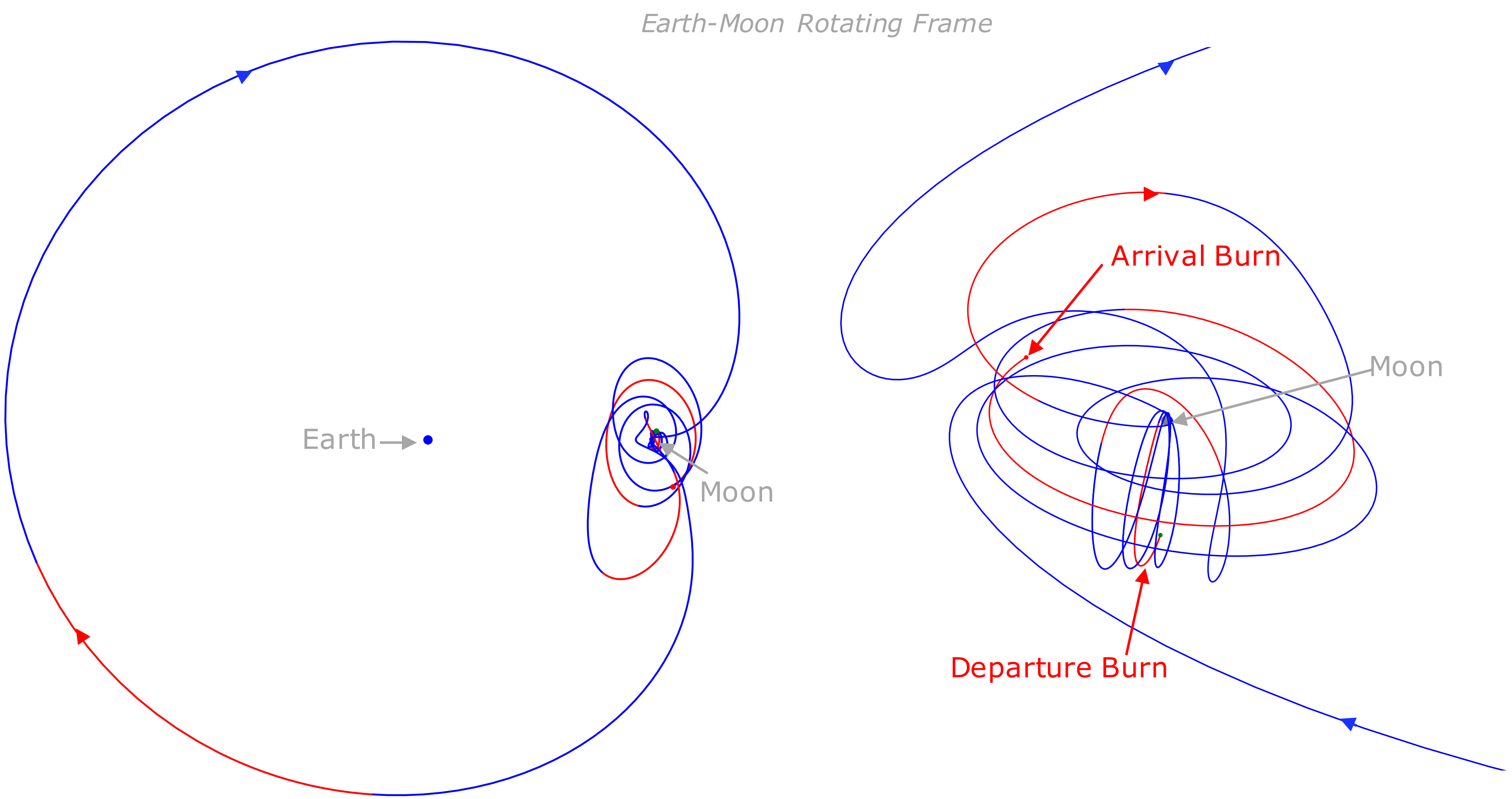
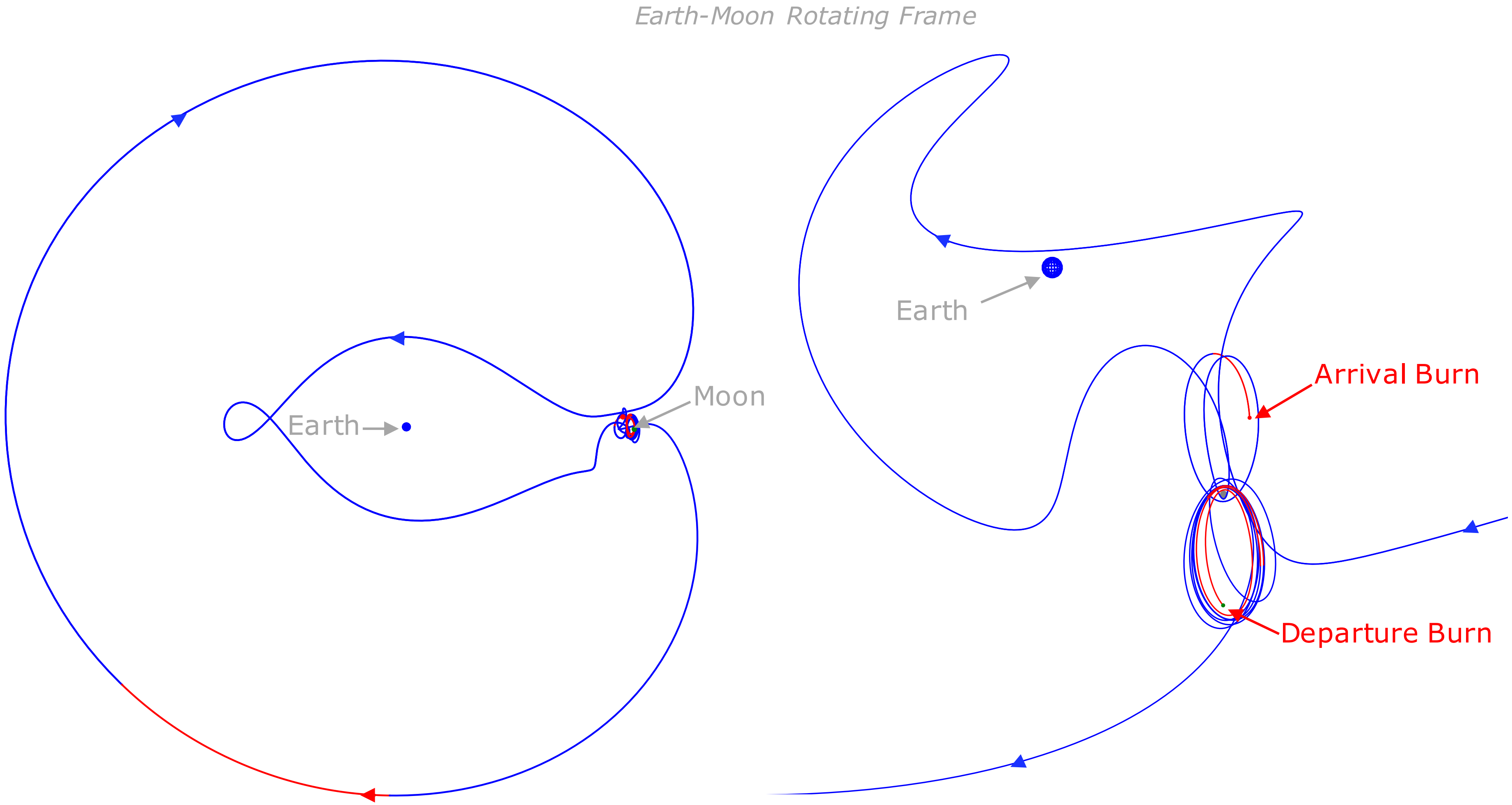
DRO Transfer



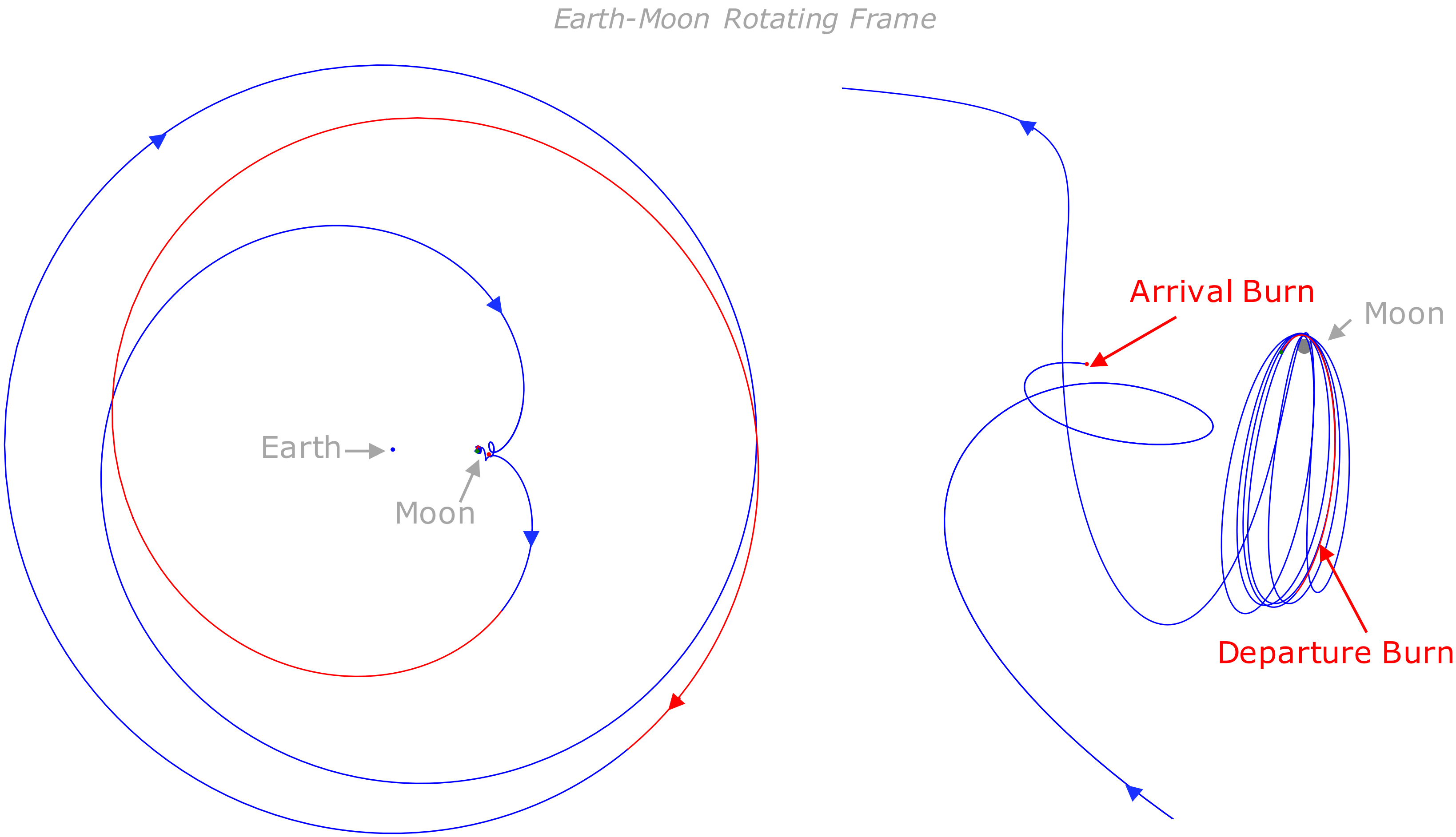
Xe Mass (kg)	TOF (days)	SEP ΔV (m/s)
135	156	85

L2S NRHO to L1N NRHO



Xe Mass (kg)	TOF (days)	SEP ΔV (m/s)
68	160	43

NRHO to Flat L2 Halo



Xe Mass (kg)	TOF (days)	ΔV (m/s)
118	170	74

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Methodology

- **Data Generation:**
  1. Generate optimal trajectories over a range of initial masses
  2. Fit a curve to total thrusting time as a function of initial spacecraft acceleration
  3. Propellant mass (M_{Xe}) can be estimated for any [power, mass, $N_{thrusters}$] combination:

$$a = \frac{thrust(P, N_{thrusters})}{mass}$$

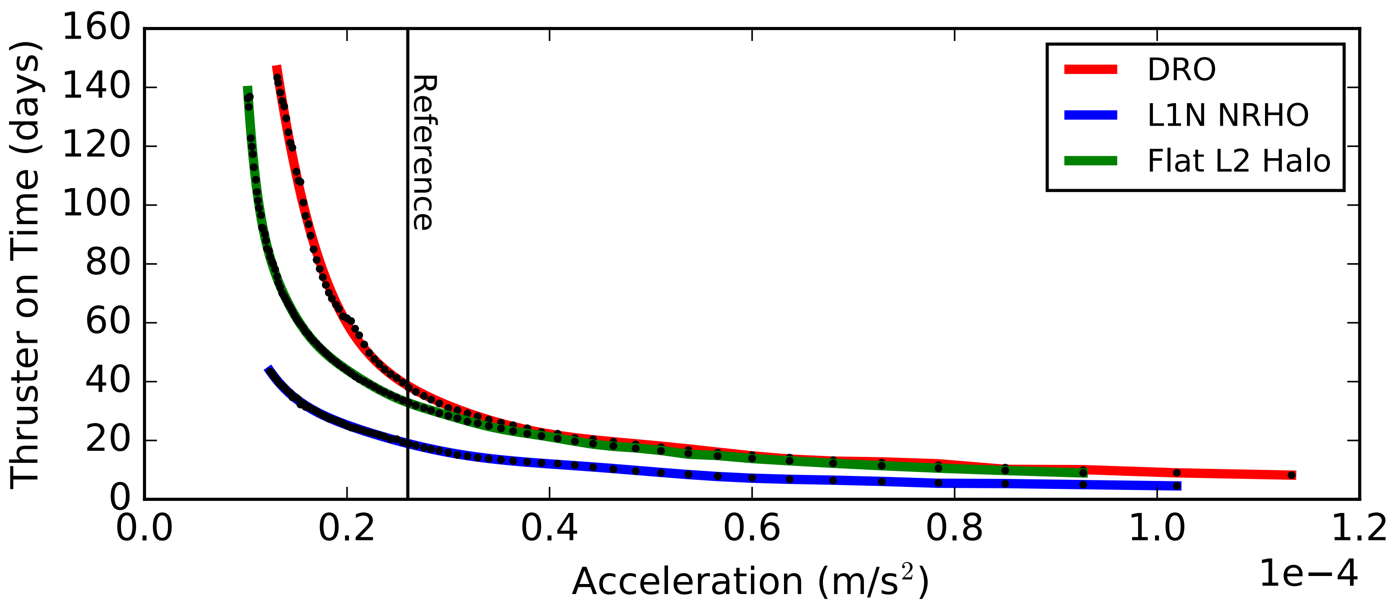
$$M_{Xe} = \dot{m}(P, N_{thrusters}) * \Delta t_{thrust}(a)$$

- **Caveats:**
  1. Neglect change in a during transfer because $M_{Xe} \ll M_{s/c}$
  2. Require well fit curve for $\Delta t_{thrust}(a)$
  3. Only valid for a specific transfer type

Acceleration Curve Fits

- **Thruster On Time vs. Acceleration shows the relative sensitivity of each transfer for a <u>fixed TOF and geometry</u>**

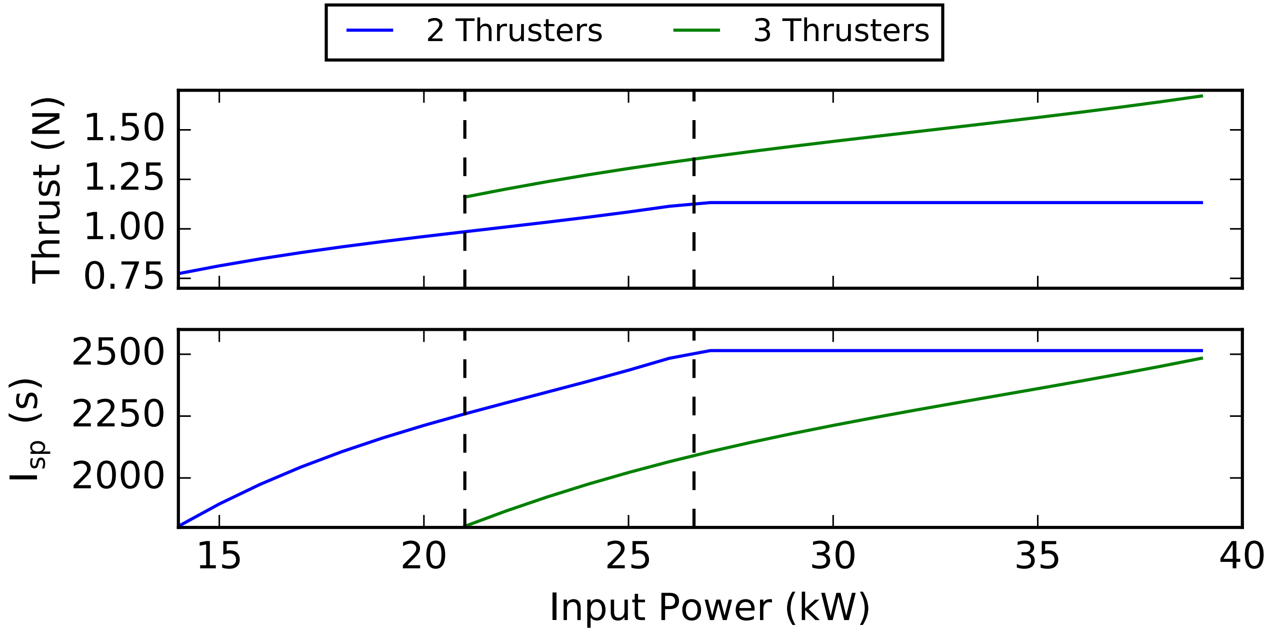
- **As acceleration decreases, total thrusting time increases**
  - DRO transfer is most sensitive to change in acceleration
  - L1N NRHO transfer is least sensitive to change in acceleration



Number of Thrusters

- **Power and Number of Thrusters Determines:**
  1. Thrust
  2. I_{sp} ($\propto 1/\dot{m}$)

- **For input power > 21 kW, can choose between 2 or 3 thrusters**



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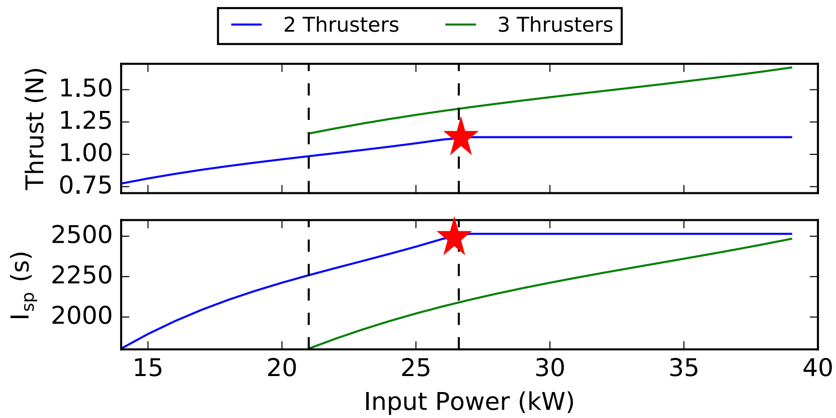
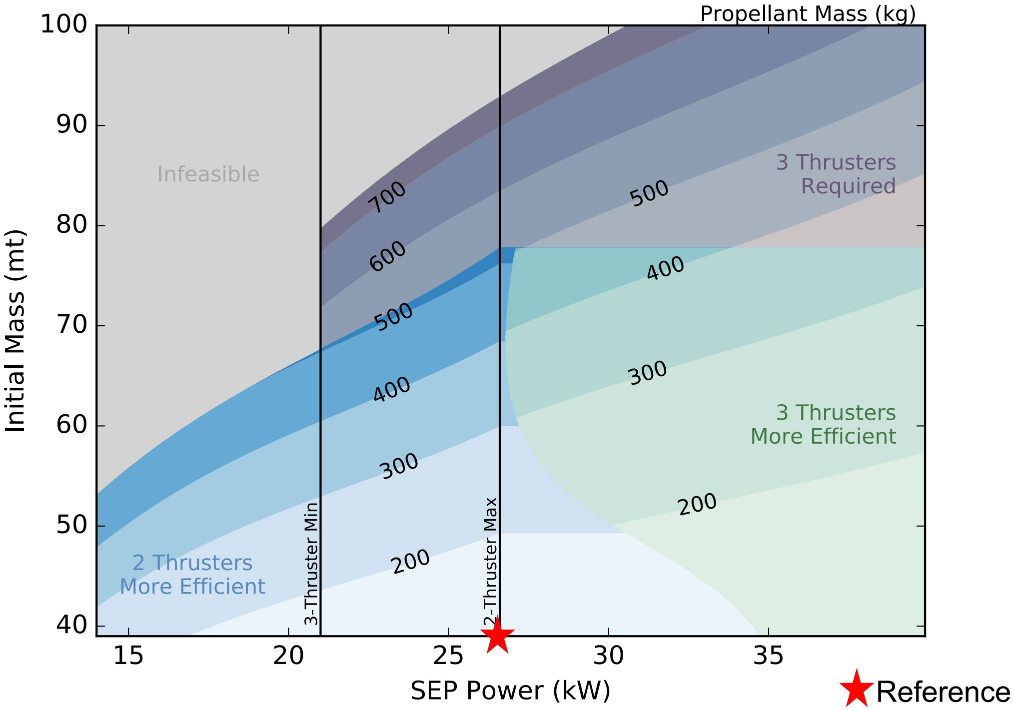
DRO Contours

Note: Margin Not Included

- Contours of Xe Mass as a function of Initial Mass and SEP Power
- Regions are colored by optimal or required number of thrusters





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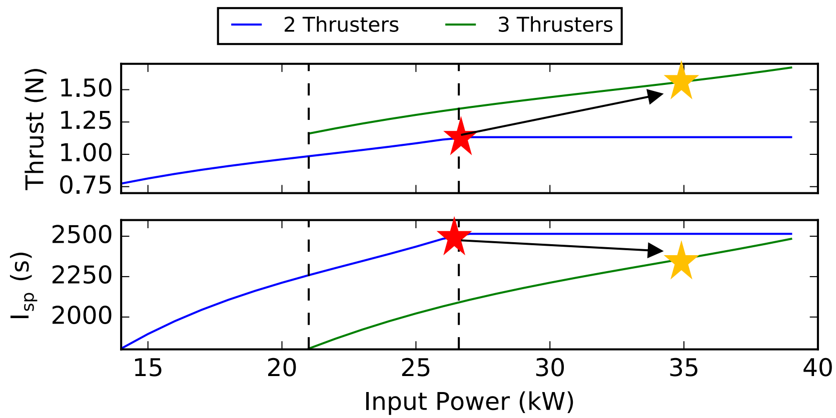

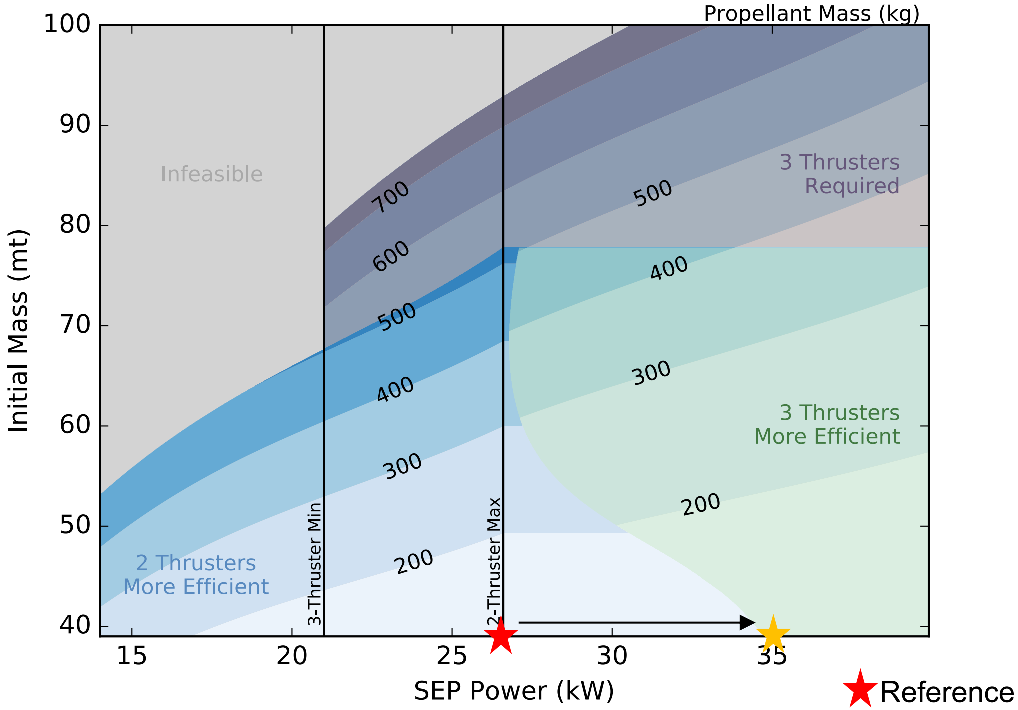

L1N NRHO Contours

Note: Margin Not Included

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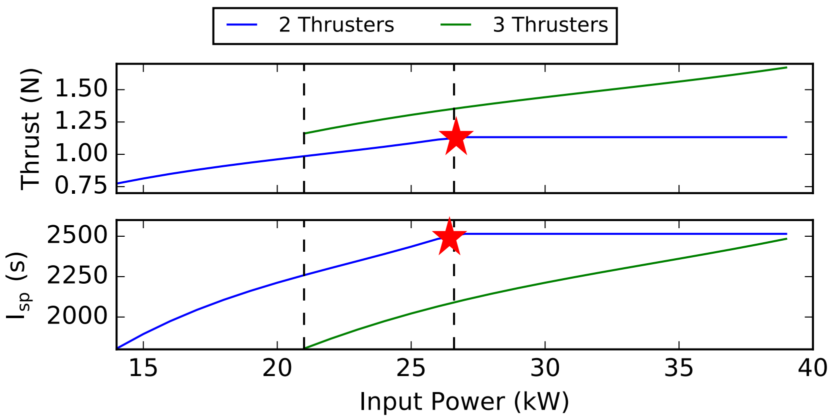

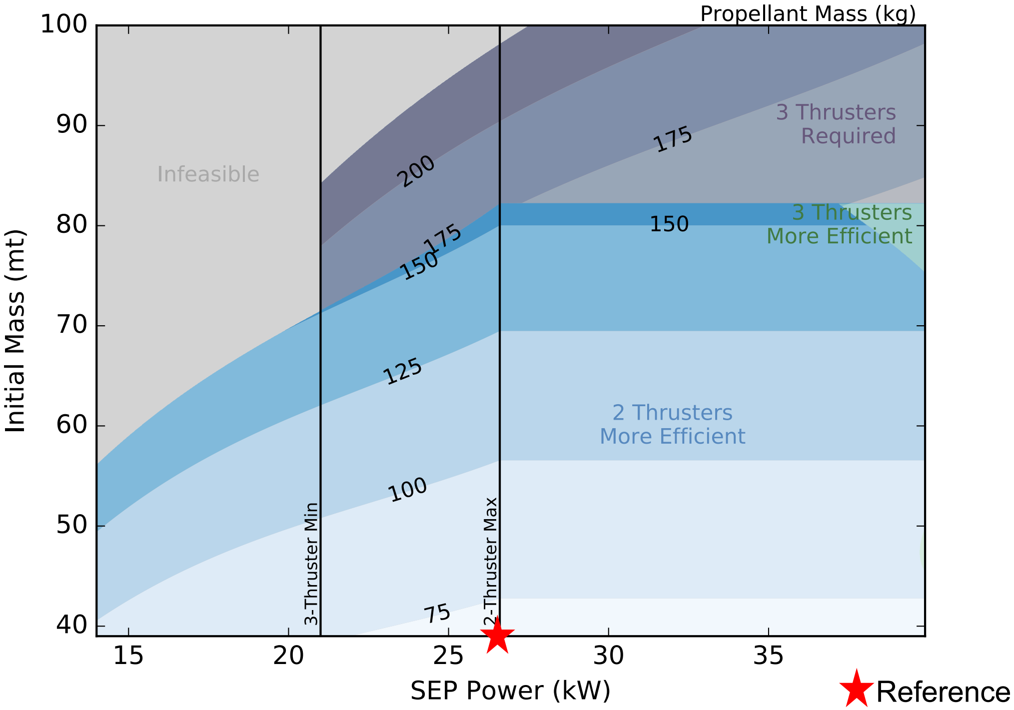

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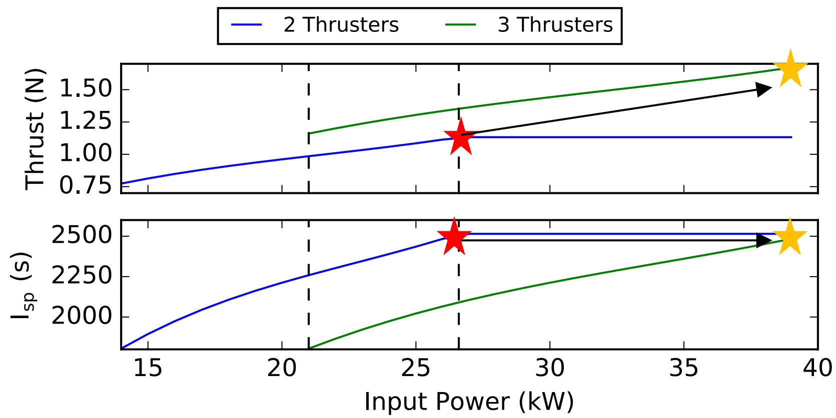

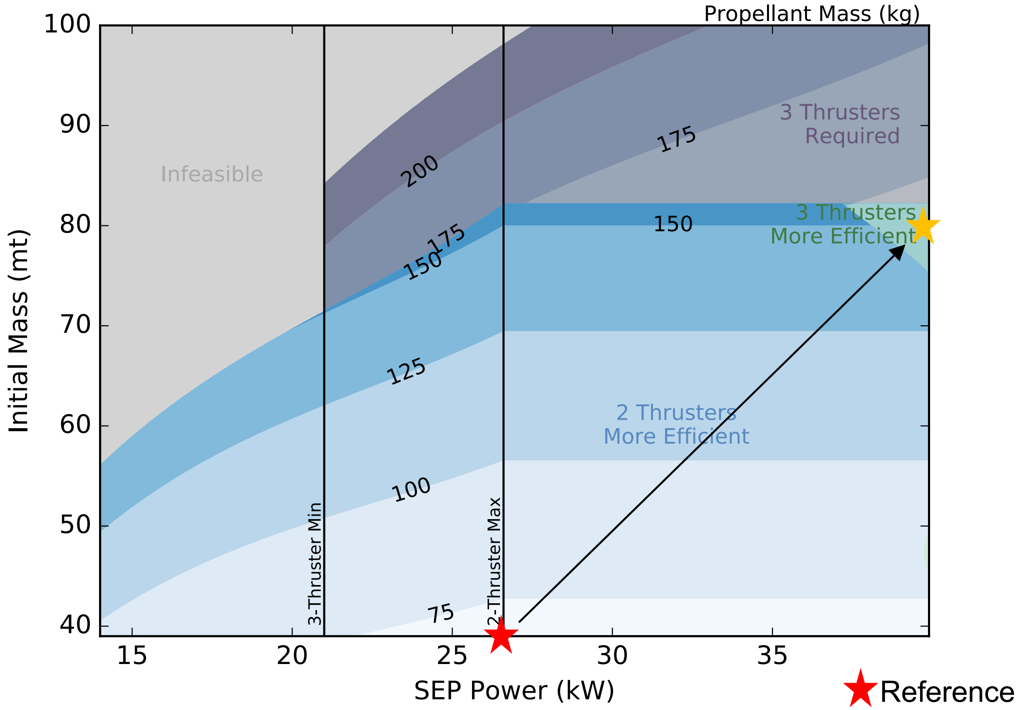

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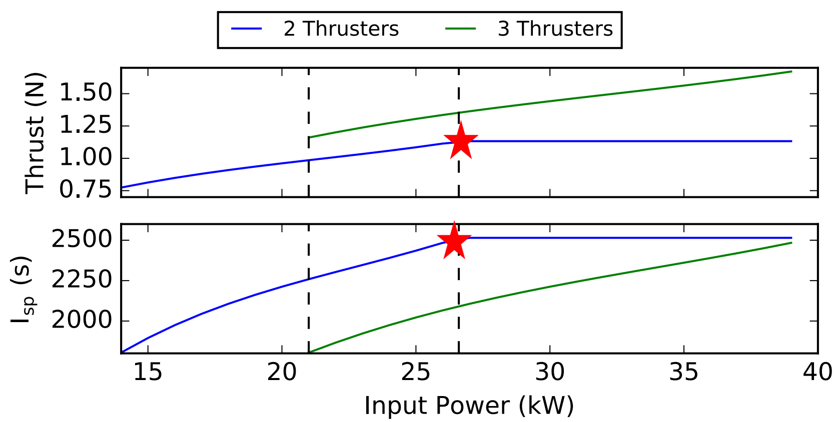

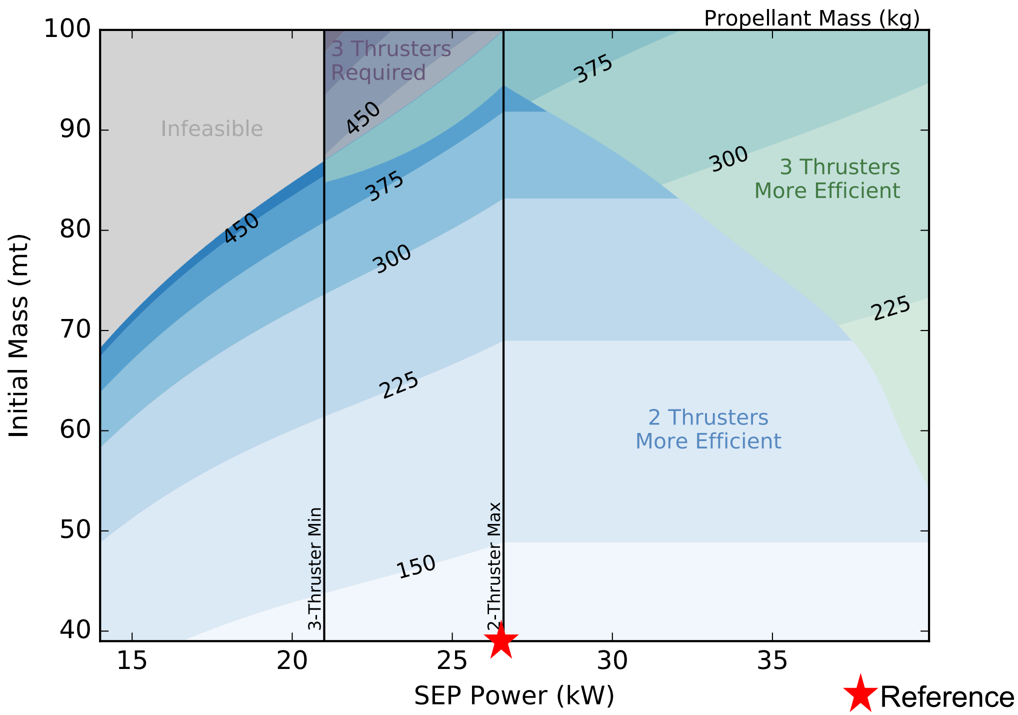

Flat L2 Halo Orbit Contours

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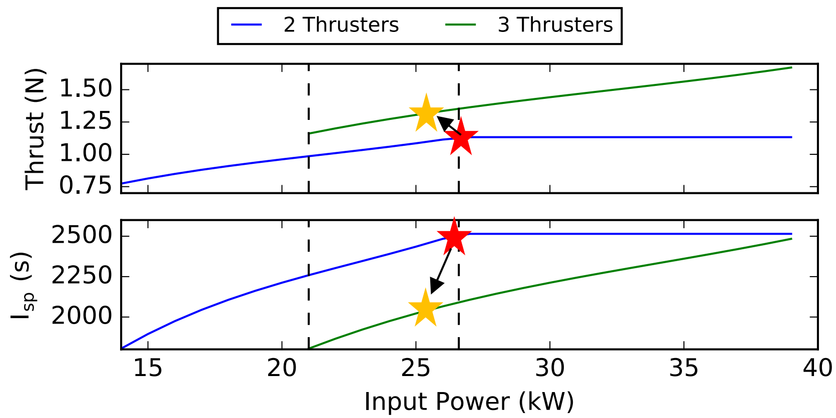
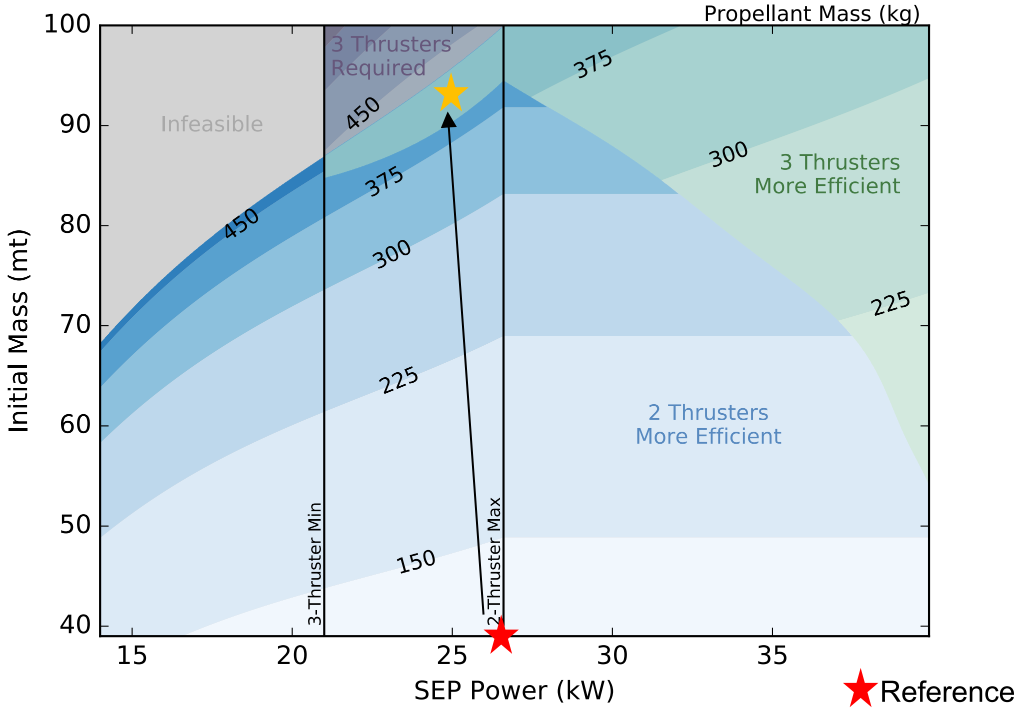
- Regions are colored by optimal or required number of thrusters





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Conclusion

1. Designed efficient low thrust transfers of a 39 t spacecraft:

Transfer	Propellant (kg)	Delta V (m/s)	TOF (days)
DRO	135	85	156
L1N NRHO	68	43	160
Flat L2 Halo	118	74	170

2. Characterizing transfer by acceleration and thrusting time is useful for understanding sensitivities
   - Propellant requirements are sensitive to spacecraft acceleration
   - Additional power is not always useful
   - Sometimes more thrusters and lower power (each) is preferable

Thank You.