Optimization of Earth-to-Mars Transfer Trajectories

Using Porkchop Plots and Numerical Methods

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Outline

Introduction

- Focus: Design Earth-to-Mars trajectories that minimize total ΔV
- Uses patched-conic approximations and ephemeris data
- Techniques: Lambert's Problem, Porkchop Plots, SLSQP Optimization

Trajectory Phases

1. Earth Departure (from 300 km LEO)
2. Interplanetary Transfer (Heliocentric Lambert arc)
3. Mars Arrival (Mars orbit capture)

ΔV Calculations: Earth Departure

- Initial orbit: 300 km Low Earth Orbit (LEO)
- Radius: $r_{\text{LEO}} = R_{\oplus} + 300\,\text{km}$
- Orbital velocity:

$$v_{\text{LEO}} = \sqrt{\frac{\mu_{\oplus}}{r_{\text{LEO}}}}$$

- Hyperbolic excess speed:

$$v_{\text{hyp}} = \sqrt{v_{\infty}^2 + \frac{2\mu_{\oplus}}{r_{\text{LEO}}}}$$

- Burn required to escape Earth:

$$\Delta V_{\text{LEO}} = v_{\text{hyp}} - v_{\text{LEO}}$$

ΔV Calculations: Mars Arrival

- Circular Mars orbit insertion radius:

$$r_{\text{Mars}} = R_{\text{Mars}} + 300\,\text{km}$$

- Circular velocity at Mars:

$$v_{\text{Mars}} = \sqrt{\frac{\mu_{\text{Mars}}}{r_{\text{Mars}}}}$$

- Hyperbolic arrival speed:

$$v_{\text{arr}} = \sqrt{v_\infty^2 + \frac{2\mu_{\text{Mars}}}{r_{\text{Mars}}}}$$

- Required burn to enter Mars orbit:

$$\Delta V_{\text{Mars}} = v_{\text{arr}} - v_{\text{Mars}}$$

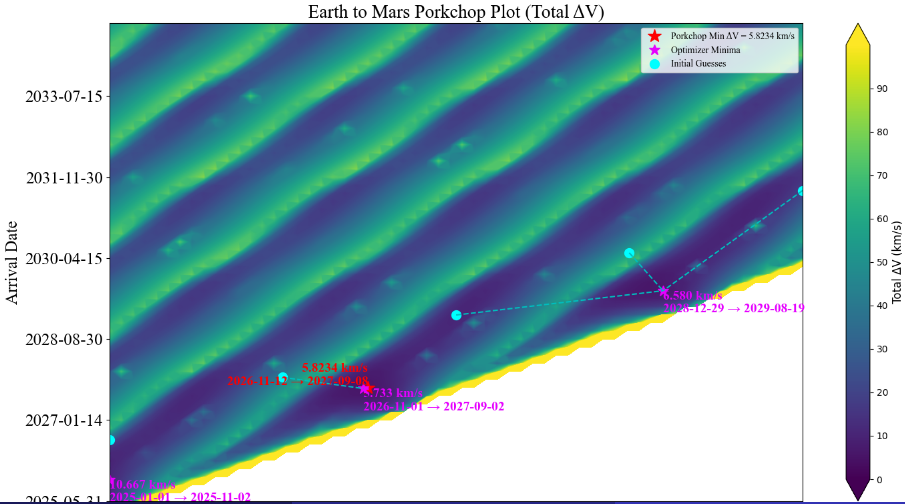
ΔV_{Total} Summary

- Total mission delta-V is the sum of Earth departure and Mars arrival:

$$\Delta V_{\text{total}} = \Delta V_{\text{LEO}} + \Delta V_{\text{Mars}}$$

Porkchop Plot Method

- Grid sweep from 2025–2035 for launch/arrival dates
- Solve Lambert's problem, compute ΔV for each pair
- Visualize with contour plot to find minimum ΔV



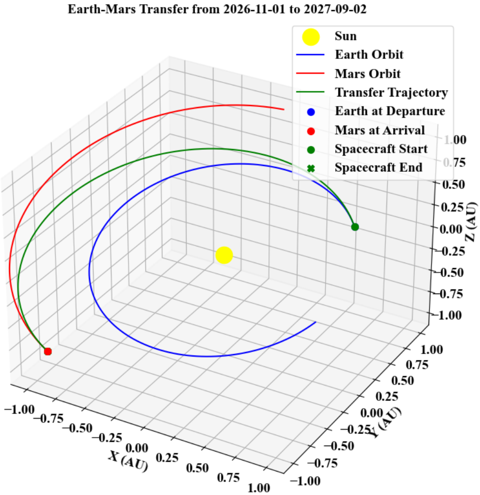
Numerical Optimization (SLSQP)

- Uses continuous variables: t_{start} and t_{end}
- Objective: Minimize ΔV_{total}
- Constraints: time of flight, date bounds

Results Summary

- Porkchop plot minimum $\Delta V = 5.82$ km/s
- Optimizer minimum $\Delta V = 5.73$ km/s
- Best: Depart Nov 1, 2026 $\rightarrow$ Arrive Sep 2, 2027

Transfer Trajectory Visualization



3D Rendered Trajectory (Blender)

Discussion

- Porkchop plot offers global view, good for initial planning
- Optimization refines to precise ΔV minimum
- Combined use provides both overview and accuracy

Conclusion

- Earth-Mars transfer optimized using both methods
- Found efficient and realistic trajectory
- Valuable tools for future Mars mission planning