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Low-Thrust Transfer to Interplanetary Trajectories from Lunar Trajectories with Rideshare

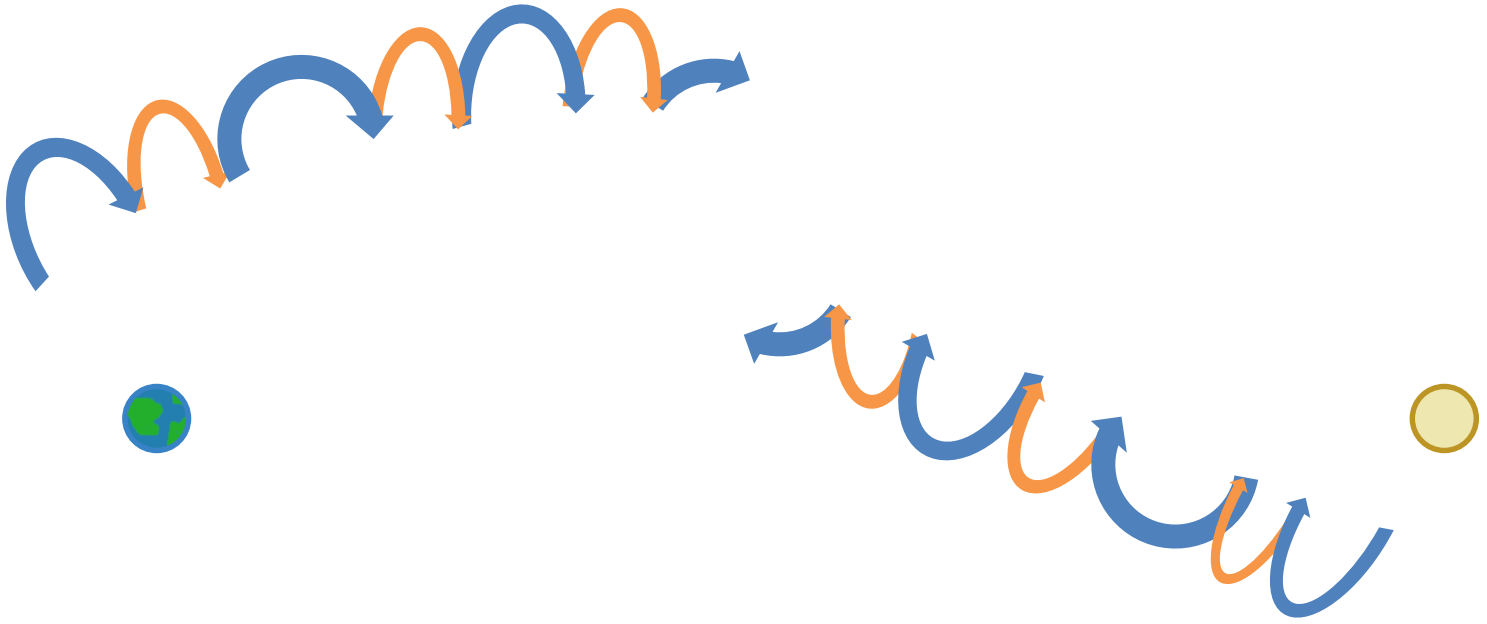
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AAS/AIAA Astrodynamics Specialist Conference
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Introduction

- Low-thrust interplanetary trajectory with no initial guess
- Sims-Flanagan and patched conic
- Starting from rideshare: not an escape trajectory

MGALT Model



Constraints

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Up-to-unit vector control

$$||\mathbf{u}_k|| = \sqrt{u_{x_k}^2 + u_{y_k}^2 + u_{z_k}^2} \leq 1$$

Time of flight

$$c_{\mathrm{TOF}} = \sum_{i=1}^{N_p} \Delta t_{p_i} \leq \Delta t_{\max}$$

Match point

$$\mathbf{c} = \mathbf{X}_B - \mathbf{X}_F = \begin{bmatrix} \mathbf{r}_B - \mathbf{r}_F \\ \mathbf{v}_B - \mathbf{v}_F \\ m_B - m_F \end{bmatrix} = \mathbf{0}$$

Gravity Assist

- Instantaneous change in velocity
- Patched conic
- Constraints:

Velocity relative to Moon

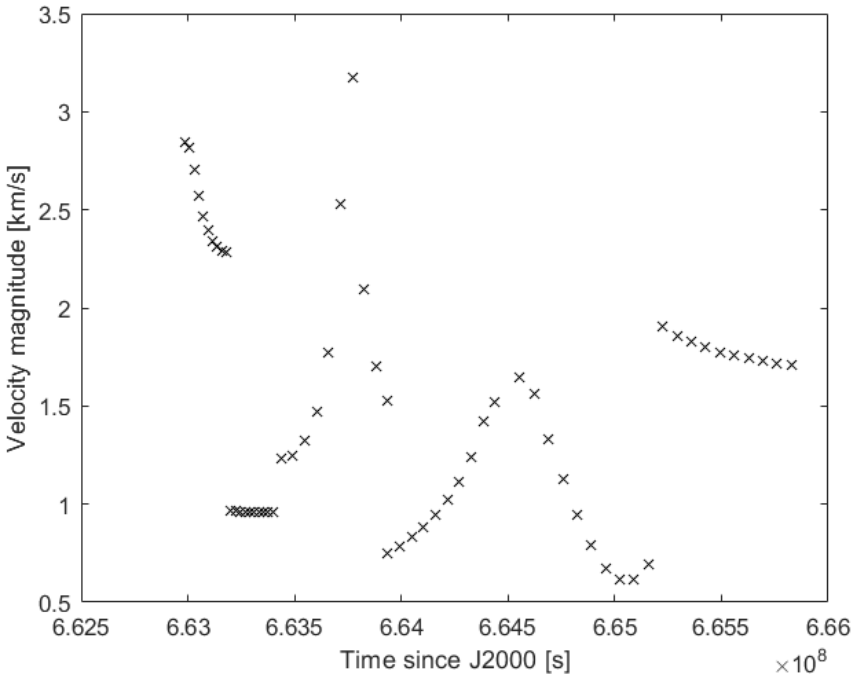
$$c_{v_\infty} = v_{\infty_f} - v_{\infty_i} = 0$$

Altitude constraint

$$c_{\text{altitude}} = r_{\text{periapse}} \geq r_{\text{body}} + h_{\text{safe}}$$

$$= \frac{\mu}{v_\infty^2}\left(\frac{1}{\sin\left(\frac{\delta}{2}\right)} - 1\right) - r_{\text{body}} - h_{\text{safe}} \geq 0$$

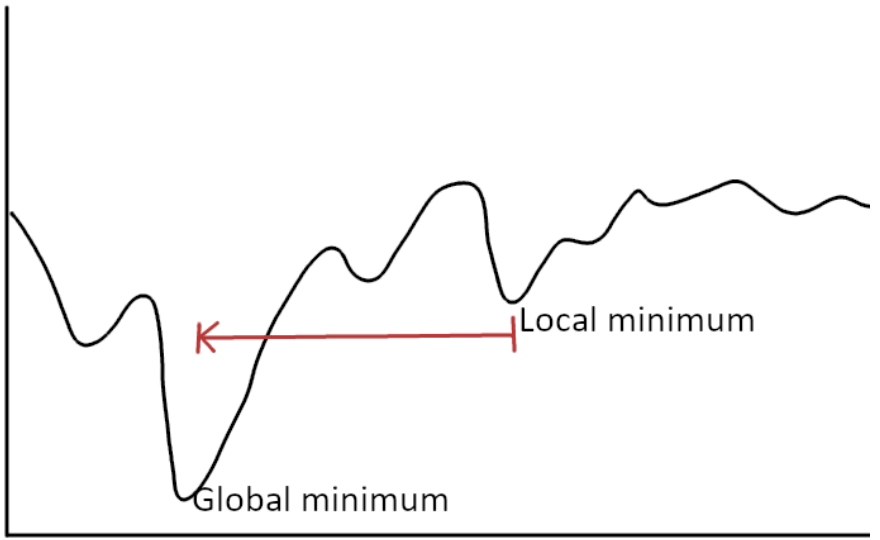
$$\delta = \arccos\left(\frac{\mathbf{v}_{\infty_i}\mathbf{v}_{\infty_f}}{v_{\infty_i}v_{\infty_f}}\right)$$



Velocity jumping with gravity assist

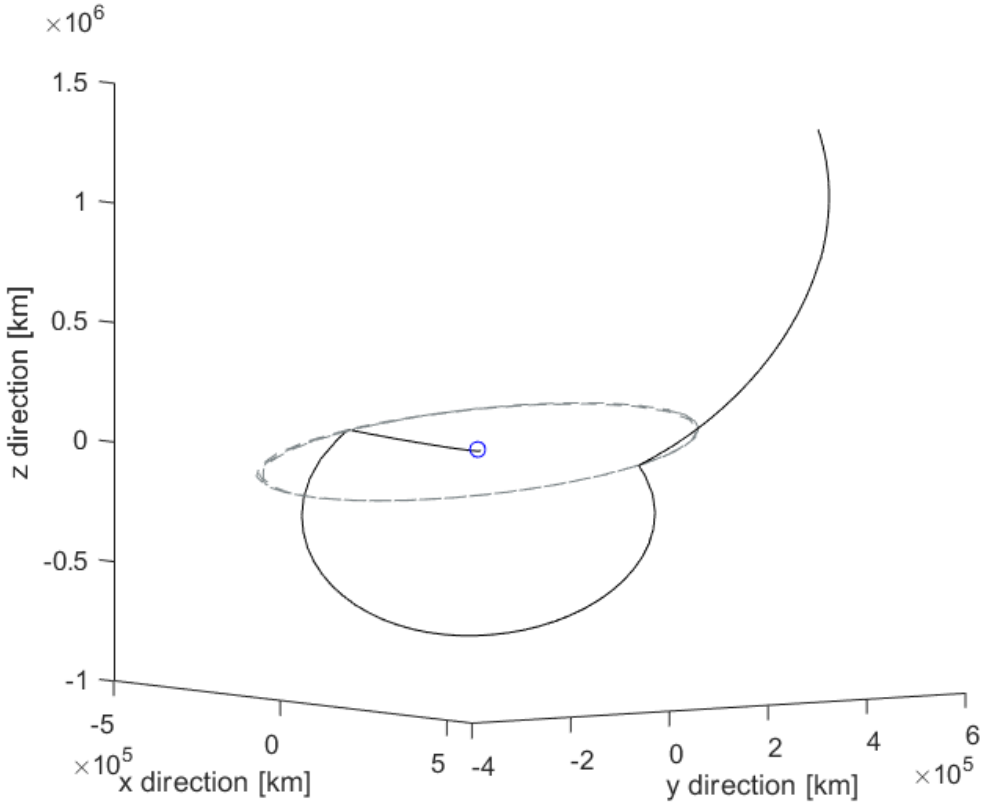
Optimisation with Monotonic Basin Hopping (MBH)

- Random initial guess
- NLP problem solved by fmincon
- Perturb optimised solution and resolve
- If this is minimises/maximises the objective better than the previous solution, update best solution
- When stop condition met, jump to entirely knew point in problem space and repeat



Sketch illustrating hopping from a local minima to a global minima

Earth-Moon Escape



The Earth-Moon escape trajectory

Initial mass: 10.5 kg

Launch C3 = -2 kg^2/s^2

Thrust arc to first lunar gravity assist, thrust arc between gravity assists, then coast to escape

Final excess velocity: 0.4048 km/s

Final mass: 10.349 kg

Time of flight: 64.9 days

Earth-Moon Escape

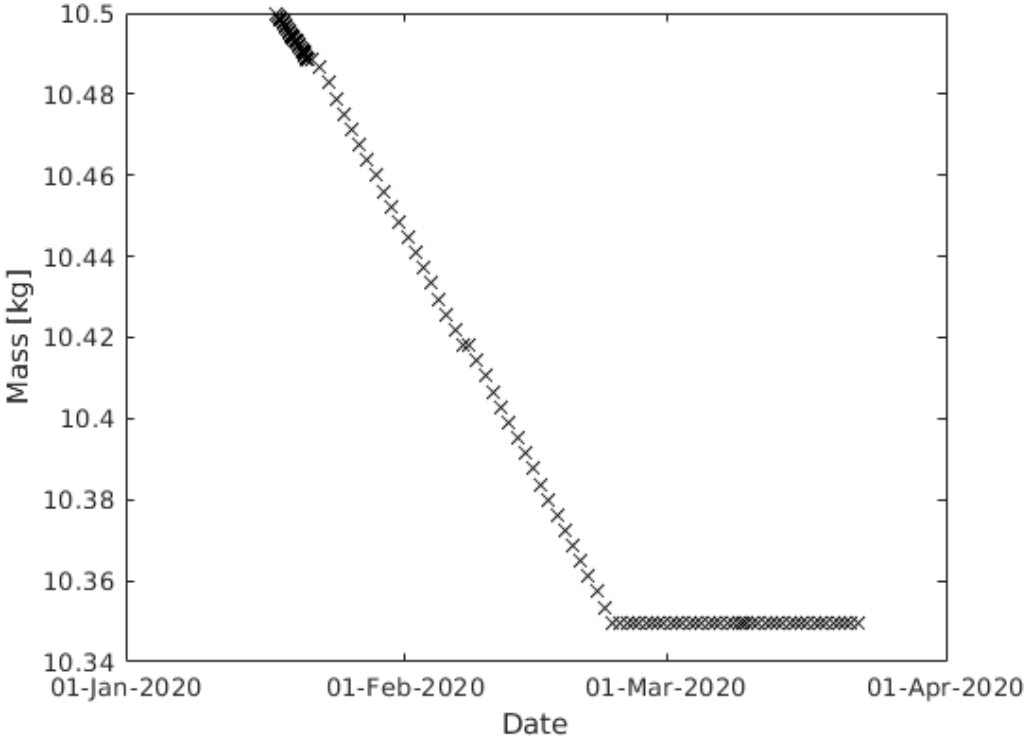


Figure showing the mass change. Note mass only changes in the second phase as this is the only place thrusters are firing.

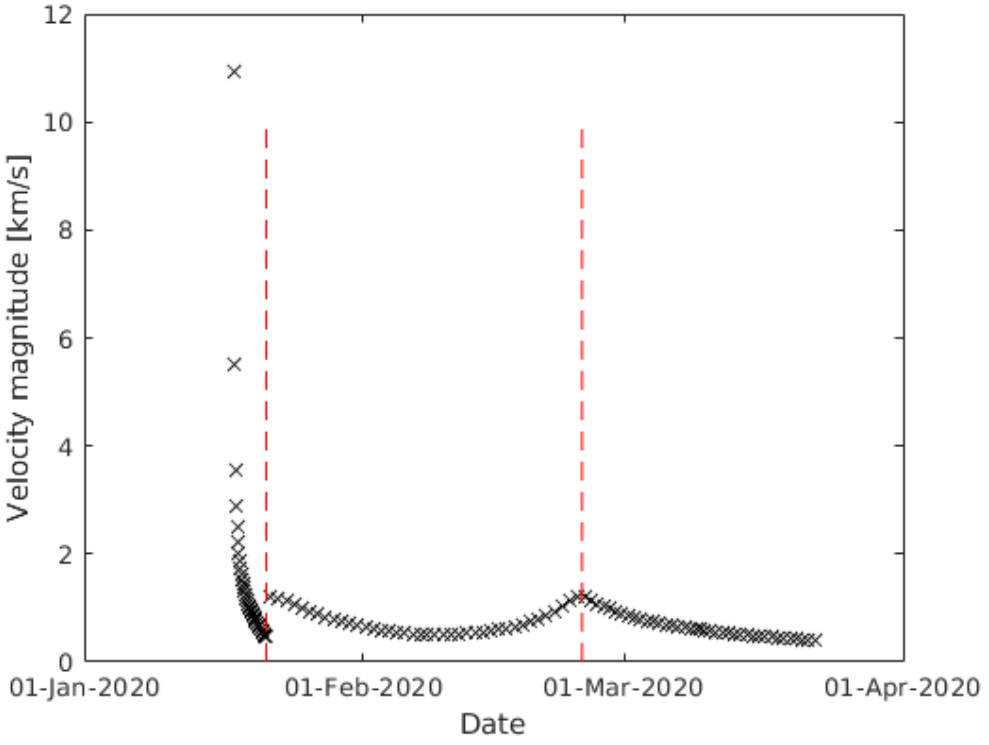
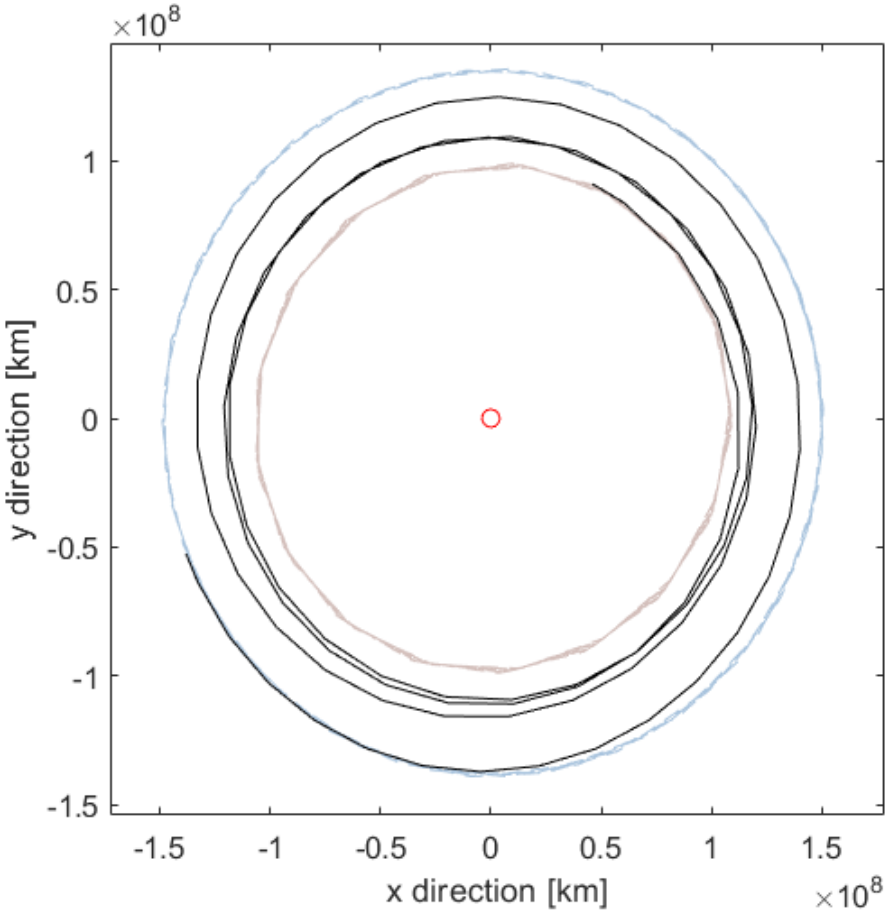


Figure showing magnitude of velocity and the velocity jumping with gravity assist. Red lines indicate when gravity assist occurs.

Earth-Venus Trajectory



Earth (blue orbit) to Venus (brown orbit) trajectory

Initial mass: 10.349 kg

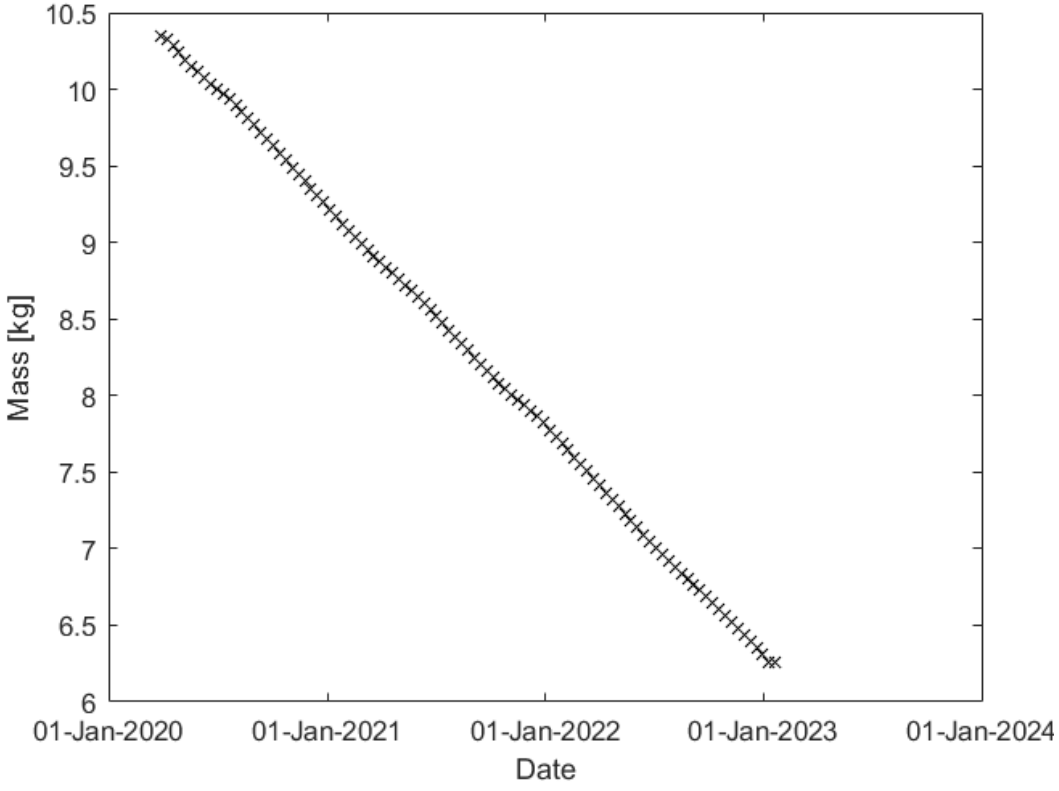
Single thruster always firing

Excess velocity on arrival at Venus: 1.3890 km/s

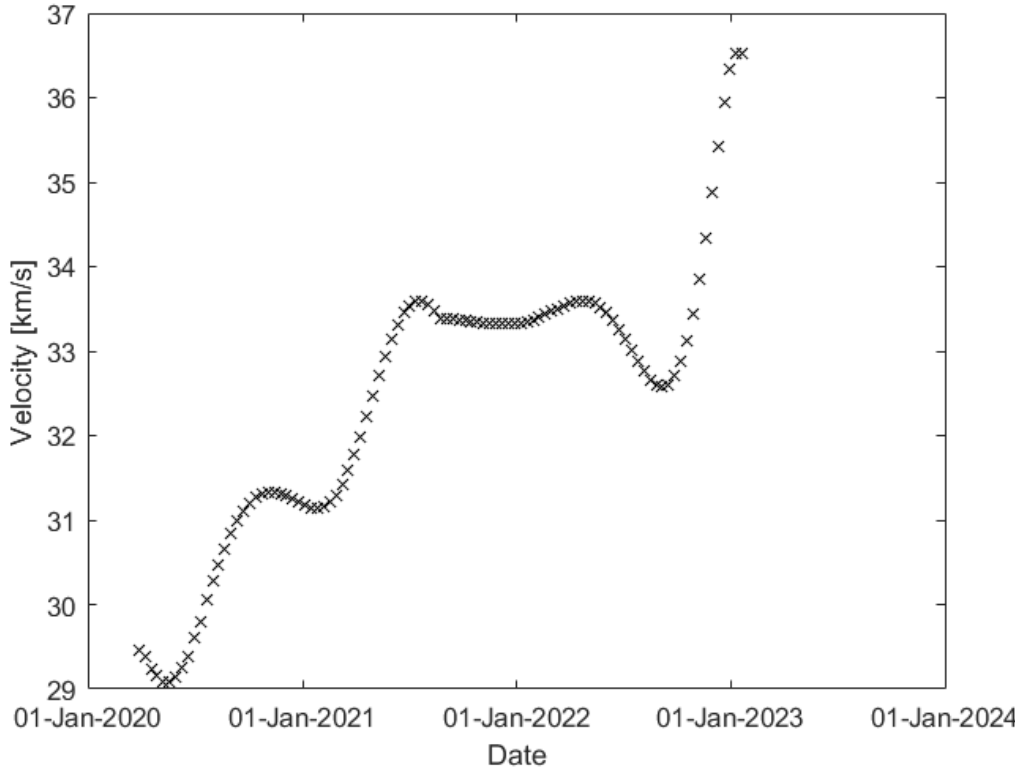
Final mass: 6.2624 kg

Time of flight: 1050 days

Earth-Venus Trajectory



Mass changing over time



Velocity magnitude change during trajectory

Future Work

- SNOPT to take advantage of sparsity pattern
- Venus capture/better flyby model
- Model flybys as not patched conic
- Allow Earth-Venus trajectory to change Earth escape trajectory

Conclusions

- Plan a trajectory from launch from Earth to Venus without any initial guess
- Saves time and computing hours
- Link Earth escape endpoint to start point of Venus trajectory
- Useful for rideshare missions where dedicated launch not possible

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Thank you