FY23 Strategic University Research Partnership (SURP)

Tool for the Study of InterStellar Object Rendezvous Missions with Hybrid Propulsion Systems

Principal Investigator: Damon Landau (312); **Co-Investigators:** Daniel Miller (MIT), Richard Linares (MIT)

Objectives: To develop an optimization package for the design of missions to known and expected interstellar object (ISO) populations and compare different mission architectures to determine the trade-offs between competing propulsion options. The optimization package features:

- A familiar MATLAB front end
- Ephemerides generated from the JPL HORIZONS database or from databases of synthetic target objects
- A wide variety of selectable propulsion systems and launch vehicles

Background: ISOs offer a unique scientific opportunity to answer fundamental questions about the origin of solar system volatiles, the composition of exo-solar systems, and the transfer rates of material between solar systems. Unfortunately, previous work has demonstrated that rendezvous trajectories to ISOs are difficult to achieve, particularly with realistic lead times and reasonable mission durations [1]. As a result, such a mission would greatly benefit from new propulsion technologies that solve these issues. One option is hybrid propulsion, which combines a solar sail with either chemical or electric propulsion [2] to either improve the total acceleration or reduce propellant consumption.

Approach and Results: Trajectories were generated from two databases of synthetic objects using direct forwards-backwards multiple shooting and optimized for arrival velocity. These target ISOs were sourced from two peer reviewed databases – Engelhardt et al. [3] and Hoover et al. [4] – and used to generate initial guesses by solving Lambert's Problem. Six spacecraft configurations, two launch vehicles, and a kick stage were considered in each case, and the results were compared both between configurations and between datasets.

On average, the hybrid XR-5 / Sail configuration was found to produce the lowest mean arrival velocity for the Engelhardt database (Fig. 1), while sail-only was found to be best for the Hoover database. Maximizing the performance of the launch vehicle and using a kick stage was found to be almost universally optimal across all configurations. Low-inclination target objects (Fig. 2) were found to be the most suitable and correlated with low arrival velocities (Fig. 3).

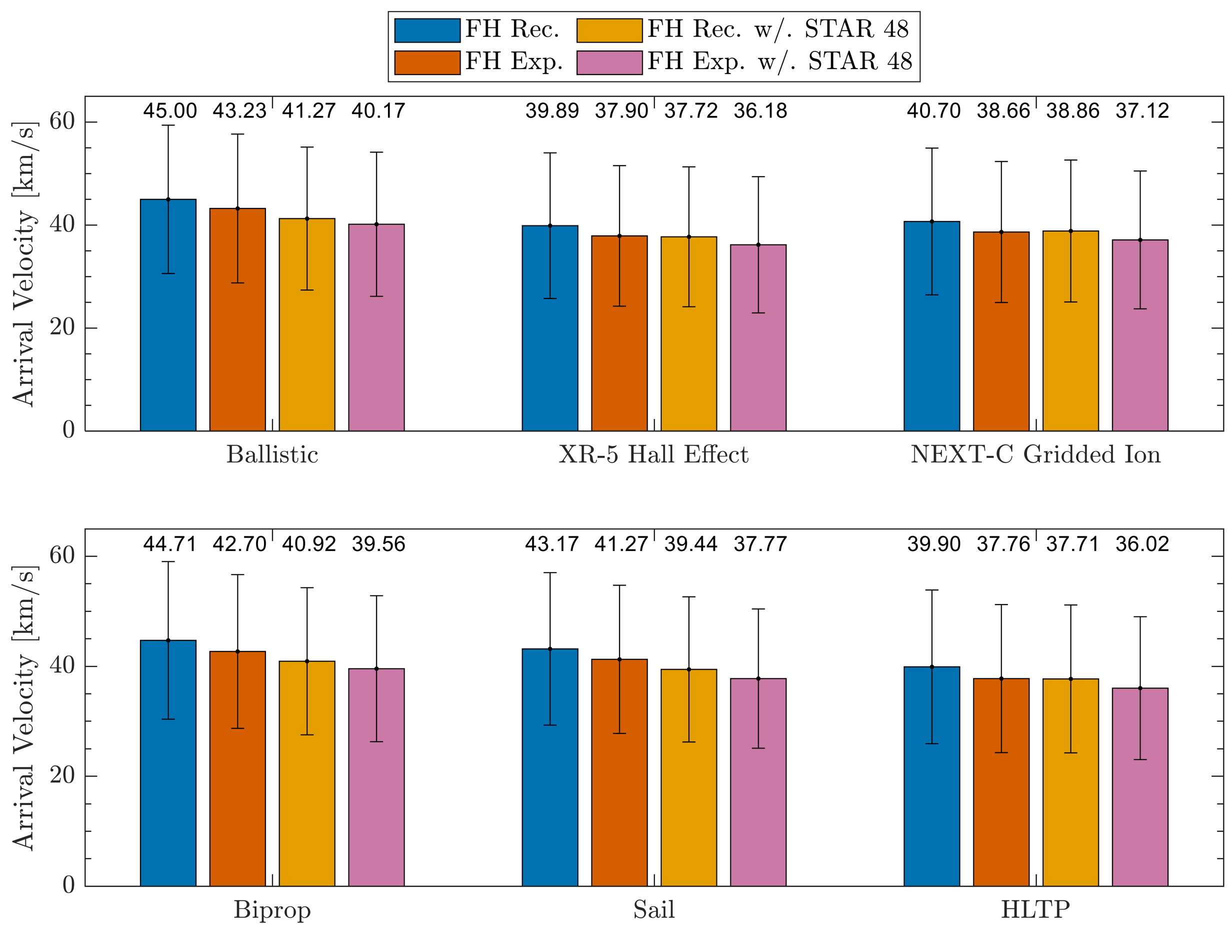

Fig. 1: Statistical results from the Engelhardt database of synthetic target ISOs.

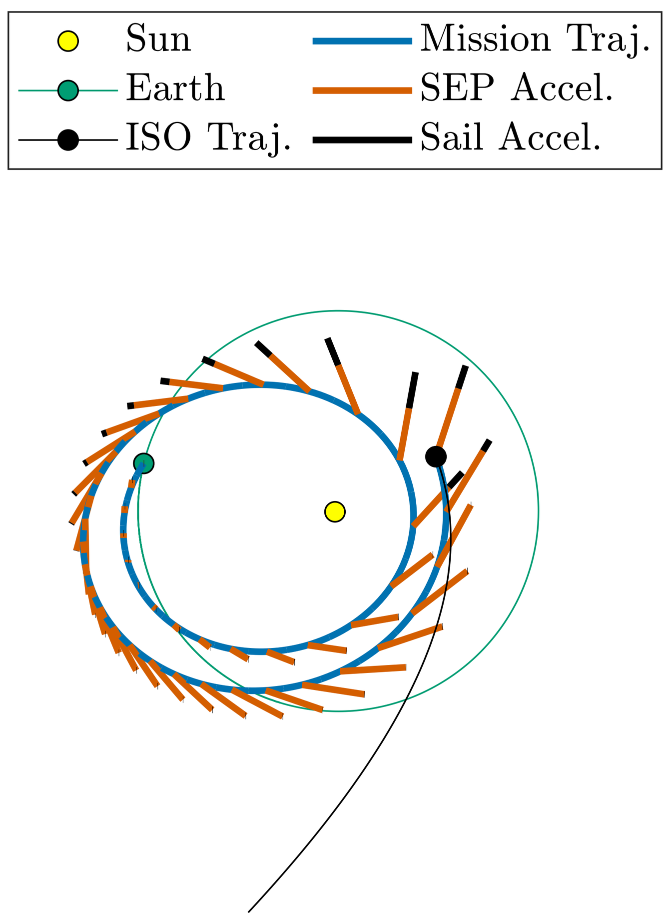

Fig. 2: Example of a trajectory to a low-inclination ISO.

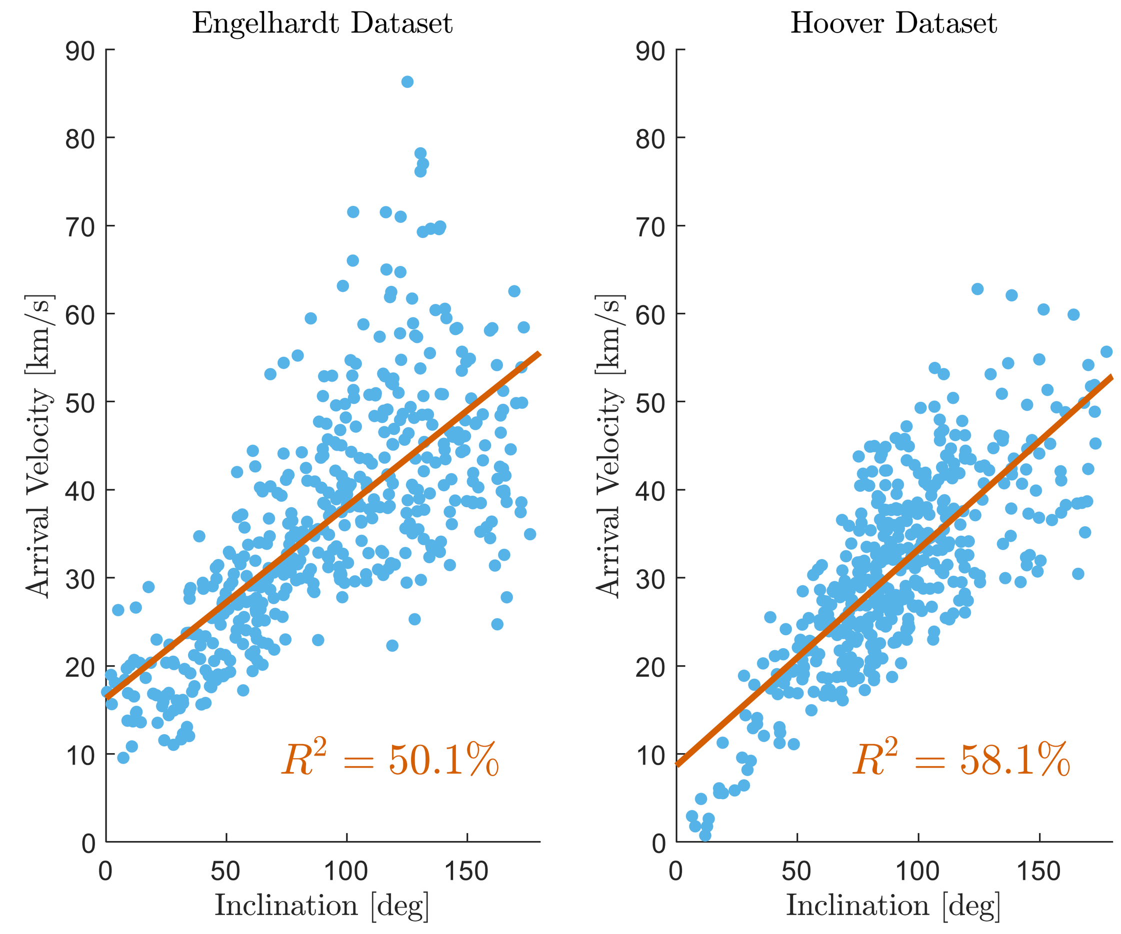

Fig. 3: Correlation between inclination and arrival velocity of both the Engelhardt and Hoover datasets (XR-5 thruster with Falcon Heavy Expendable and STAR 48 configuration).

Significance/Benefits to JPL and NASA: While trajectory design tools already exist both inside and outside of JPL, they are not designed for the study of missions that utilize hybrid propulsion systems where multiple, disparate control profiles are optimized simultaneously. The optimization package developed by this partnership provides the capability to examine this concept while advancing the prospect of missions to interstellar asteroids and comets. With many new ISOs expected to be discovered by the Vera C. Rubin Observatory in the coming years, the benefits of this resource will only grow.

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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References:

[1] Damon Landau, Benjamin Donitz, and Reza Karimi, "Near-Term Strategies to Rendezvous with an Interstellar Object," *Acta Astronautica*, May 2023.

[2] Daniel Miller, Jacob Englander, and Richard Linares, "Hybrid Solar Sailing and Electric Propulsion: A Mission Concept to Comet 45P," *AAS/AIAA Astrodynamics Specialist Conference*, Aug. 2021

[3] Toni Engelhardt et al., "An Observational Upper Limit on the Interstellar Number Density of Asteroids and Comets," *The Astronomical Journal*, Feb. 2017

[4] Devin. Hoover, Darryl Seligman, and Matthew Payne, "The Population of Interstellar Objects Detectable with the LSST and Accessible for *In Situ* Rendezvous with Various Mission Designs," *The Planetary Science Journal*, Mar 2022

PI/Task Mgr. Contact Information: damon.landau@jpl.nasa.gov