RAPID MISSION DESIGN TO ENABLE ASTEROID MINING. D. Lantukh[1] and C. Helms[2], [1]Mission Operations Engineer, AstroForge (15261 Connector Ln, Huntington Beach, CA 92649. Demyan@astroforge.io), [2]Principal Engineer, AstroForge (15261 Connector Ln, Huntington Beach, CA 92649. Colin@astroforge.io).

Introduction: AstroForge is a space resources company: we mine asteroids to deliver valuable goods to Earth and, once the market matures, to wherever they are needed in the solar system. A realistic near-term realization of this vision leads us to target high-value platinum group metals (PGM) first. Achieving this vision also requires valuing speed and flexibility over any specific asteroid target or any specific technology.

Traditionally, mission planning begins with science requirements that set payload and the target celestial body early in the process, limiting mission options considered from that point forward. AstroForge turns this process around to focus on rapid iteration.

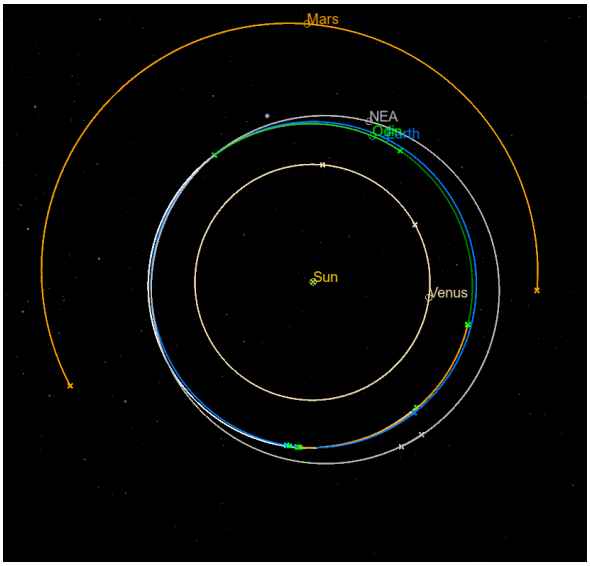
AstroForge is pioneering a space mission design approach that embodies speed and flexibility. This approach enables the commercial mining mission by dealing with some of the key uncertainties and risks, such as launch delays, rideshare constraints, and a rapidly growing list of potential asteroid targets. AstroForge's novel mission design approach is centered on two requirements:

1. We value iterating quickly, so our missions will be short - one to two years maximum.
2. We need to launch toward a selected asteroid within a few months of selecting it.

Points 1 and 2 mean we think about missions fundamentally differently from NASA or other space agencies, and lead to the innovative mission design pipeline AstroForge is building.

Speed in Flight: Setting an upper limit on mission duration severely limits the asteroids we can reach and the mass we can deliver there, since longer flight times often enable ΔV savings. However, limiting flight time ensures we maintain speed of iteration and can continue learning for the next mission rather than trying to execute the perfect mission. Limiting flight time also reduces the inherently combinatorial nature of path planning computation: by making each trajectory simpler, we can allocate our time and computational resources to generate more trajectory options.

A key difference in AstroForge's philosophy is to pick from targets that meet the timeline, rather than getting a better target. This strategy is feasible because of the plethora of asteroids and because we have some flexibility with target characteristics. Implementing this flexibility in target selection requires a system that embodies speed in planning.



Focusing initially on short transfers helps iterate on mission execution and enables AstroForge to build the planning pipeline with simpler trajectories first.

Speed in Planning: AstroForge is building a mission design data pipeline to quickly select or change the mission target. This speed in the planning cycle enables AstroForge to leverage cislunar rideshare opportunities, where we do not control launch dates or departure direction. We describe it as a data pipeline because preliminary design is not sufficient - the process must generate data products and risk analysis at flight fidelity within a few months. The AstroForge implementation is also a data pipeline in our focus on retaining and reusing data (mission designs) once calculated, which makes it possible to compare many different options and to trend designs over time. To achieve this comparison capability, the pipeline operates in three stages of increasing fidelity, where each successive stage also decreases the number of targets considered.

A shared database implementing a common data ontology and translation layer unifies these stages of mission design into a cohesive pipeline.

L - 1-3 years - Target Prioritization & Feasibility

- Preliminary design with low-fidelity models across thousands of asteroids with thousands of launch and arrival dates
- Handle chemical and electric propulsion.
- Quickly parse and filter the data for different mission types and requirements (e.g., one-way vs two-way missions, ΔV available, target absolute magnitude)
- Generate requests to astronomical observatories to gather data on the most promising asteroids

L - 6 months - Launch Window Computation

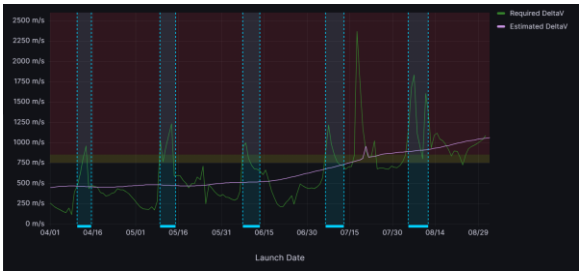
- Detailed design at flight fidelity over a couple of months of potential launch dates
- Use launch estimates or models.
- Mix of analyst-produced trajectory point-designs and automated designs based on continuation.
- Monte Carlo and sensitivity analysis at multiple design points in launch window
- Generate operations products for tests and rehearsals.
- Multiple target asteroids in consideration

L - 1 month - Target Selection & Flight Products

- Use launch window analysis and any data from ground-based observations to down-select specific target.
- Detailed design at flight fidelity using design reference mission (DRM) from launch provider.
- Generate operations products and apply before flight (ABF) settings

Using a database to filter thousands of potential target asteroids in seconds enables fast mission design iteration. In this example, five asteroids meet a particular set of mission constraints for launches sometime in 2025.

Net Effect – Flexibility: This mission design pipeline focused on speed brings additional benefits. For example, target selection can leverage new scientific data up to a month before launch and astrometric observations of a given target feed into mission planning even after launch. Because we use data such as ephemeris uncertainty, light curve, and albedo for prioritizing between potential targets, engaging with astronomical observatories is a key part of AstroForge target selection strategy.



5-month launch window for cislunar rideshare to one target. Example shows a mix of interplanetary effects (trend in the estimated ΔV, spike on July 16) and lunar phasing effects (monthly spikes inside vertical bars)

The mission design pipeline also separates data generation from decision-making based on that data, further accelerating the entire process. Data generation is physics-based and is traditionally done after key decisions such as target and vehicle propellant load are made. However, a framework that can leverage large quantities of data encourages the creation of many candidate designs early: this data is not wasted when requirements change but contributes to the body of understanding for how to fly the class of mission. As a result, filtering and sorting for decision-making have a wealth of data to work from. This filtering and sorting also uses inherently parallelized and optimized database queries to parse the large datasets, accelerating the pace of understanding and acting on the data.

Fundamentally, this flexibility in design guards against flying a mission that is obsolete before it leaves Earth, maximizing the return we get on each prospecting or extraction mission.