National Aeronautics and Space Administration

# FY24 Strategic Initiatives Research and Technology Development (SRTD)

# Agile Starshade Retargeting for Increased Exo-Earth Characterization Yield

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**Strategic Focus Area:** Starlight Suppression | **Strategic Initiative Leader:** David W Miller

## Objectives:

The most comprehensive analysis of Starshade, in the HabEx final report, showed much higher throughput for characterization but overall decreased yield due to the time it takes to slew the Starshade to make the observations. The goal of this task is to improve Starlight retargeting agility as one step in bringing Starshade back into the Habitable Worlds Observatory architecture. This is accomplished by exploring different methods for leveraging natural dynamics to reduce fuel costs on the Starshade spacecraft. There are three main objectives of the proposed work. The first objective is to increase habitable zone characterization yield of the Starshade from five to ten per year. The second objective is to improve on-board fuel efficiency (from 3500 to 1000 kg) and retargeting agility (double LOS slew rate). Finally, the third objective is to leverage natural dynamics at the Earth-Sun L2 to enable increased yield, reduced fuel consumption, and possibly enable different servicing mechanisms. By improving the main Starshade downside, the goal is to make Starshade a more viable architectural feature of the future Habitable Worlds Explorer mission.

## Background:

In the HabEx final report, the recommended scientific yield was spectral characterization of 25 exo-Earths over a five-year mission life. The resulting design required 3500 kg of Xenon propellant for the solar electric propulsion system to retarget the Starshade to occult, on average, five parent stars hosting exo-Earths per year. This gives a propellant-to-total-wet-mass-fraction of one-third, which is extremely inefficient, using much of the propellant to move the propellant itself. Several techniques have been researched to improve the efficiency of Starshade maneuvering over the baseline direct propulsive assumption. This research aims to understand the balance point between the scientific yield and the fuel utilization as a function of various parameters in order to make well informed decisions to refine Starshade architecture into a viable inclusion into HWO.

## Approach and Results:

The approach for Year 1 of this SRTD was to pick one new method, implement it in standalone simulation, assess to performance against the baseline model in ExoSims. The Year 1 method that was chosen was Lambert's maneuver for Starshade transfers, which solves the two body dynamics problem. The Lambert solution was chosen as it leverages the bulk of the gravity dynamics within the design of the maneuver. Figure 1 plots delta velocity, which translates directly to fuel usage, as a function of slew duration. Both methods show an exponential function that is highest at the minimum time transfer. The first result was that a time optimal solution can be tuned to a time-fuel optimal, to leverage savings with minimal loss.
Figure 2 shows the performance in ExoSims of changing alpha versus a baseline alpha of 1.16 (corresponding to almost min time where the thrust fraction of the slew is 85%). Values of alpha above ~2 reduce the fuel used, ~1000kg+ savings but do not affect science yield, using a standard set of Monte carlo seeds. The benefit of using the Lambert maneuver when the slew duration is ten days or less is negligible (the crossover point of the line with the lambert exponential in Figure 1). However, the slew maneuver longer the slew, the more fuel savings. The results can be compounded to leverage the dynamics for the long maneuvers, as well as take the time hit (with acceptable science yield metrics) and decrease fuel usage that way as well. Additional work was done with the Lambert maneuver to relax the line-of-sight velocity constraint (Figure 3), to see if that would help. Figure 4 shows the performance, where there is savings to be gleaned, though the stationkeeping fuel would increase.

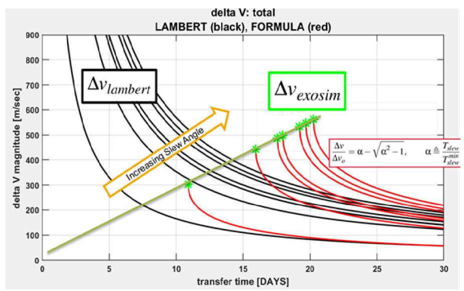


Figure 1: Benefit of impulsive Lambert solution over the non-impulsive minimum-time default in Exosims. Seven individual transfers plotted, with varying star angles. Black is using the lambert's method and varying slew duration. Red is using the Exosims relative straight-line method and varying slew duration. The green stars at individual slew durations taken from an Exosims run

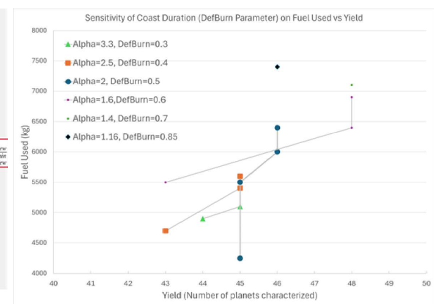


Figure 2: Sensitivity to Coast duration during default Exosims burns as a function of fuel used versus science yield, assuming no re-fueling. Baseline is the single point at fuel used of 7500kg. At alpha of 2 (coast fraction of 0.5), the science yield is still maintained but the fuel usage is under 6500kg.

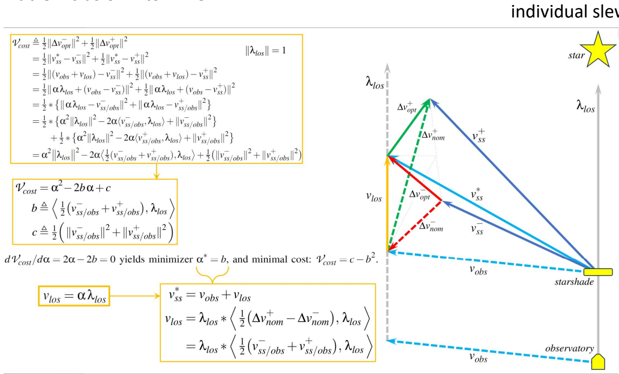


Figure 3: Derivation of Lambert maneuver with relaxation of end velocity along the line of sight. This shows how the projection of the line- of-sight of the Observatory to the star was used to relax just that component of the final arrival velocity. The line-of-sight direction has a wider box than the cross track so the objective was to understand if that could open up the feasibility space and help reduce fuel.

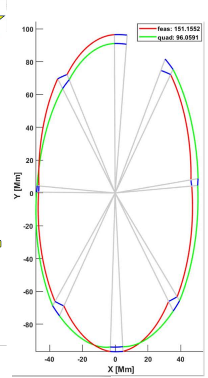


Figure 4: Performance of the trajectory with the relaxed line of sight (green) versus the constrained line of sight (red)

## Significance/Benefits to JPL and NASA:

Preliminary Year 1 work with the first level method showed a significant space in which the agility performance of the Starshade could be improved. The improvement in fuel consumption could be over 1000kg over a five-year mission. Given that the true observing cadence is not known due to uncertainty in the planet population, the performance of the Starshade can vary depending on the mission instantiation. Missions that are sparsely populated with characterizable earths are not affected strongly by increasing the slew time. For a densely packed population, a small reduction is still possible to decrease fuel consumption, but the amount of decrease is bounded by the science yield reduction. Increasing slew times slightly beyond the minimum-time default, can decrease fuel mass, making the spacecraft lighter, which increases the efficiency of the maneuver. This task found that given the sensitivity to the population density, and how many gravity methods can take significantly longer than a straight impulsive maneuver, the scheduling algorithm also needs to be evaluated to select the method based on the current assessment of the set of observable targets. Implementation of these could have significant improvement of Starshade, making it a viable option for HWO.

## Publications:

Jack Aldrich and Swati Mohan, "Simple Formulas For Reduced Fuel Consumptions in Agile Starshade Retargeting," submitting to AAS/AIAA Space Flight Mechanics Meeting, Lihue, HI, Jan 2025

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RPD-000 Clearance Number: CL#00-0000