Two starshade flight modes: station-keeping and Low thrust maneuvers through SEP or other.

Retargeting maneuvers can be achieved two ways:
1. Incorporate the higher fidelity fuel usage model in EXOSIMS and run end-to-end design reference mission simulations
2. Improve computation times associated with station-keeping requirements

Objectives:
The objective of this work was to create new capabilities in the simulation, analysis, and planning of starshade-based direct imaging exoplanet space missions. Our work seeks to maximize the science return of a starshade mission while accounting for realistic, dynamic mission constraints. We have created detailed orbital dynamics simulations for modeling fuel costs of the starshade in both of its two flight modes: (1) the formation flying mode with the telescope during an observation and (2) the slewing flight mode as the starshade re-aligns itself' simulations [1][2]. Fuel costs are combined with other optimization parameters, such as probability of detection and slew time [3][4]. The mission simulations provide the number of successful exoplanet detections and characterizations. The objectives of this work were to develop a higher fidelity model for fuel usage during impulsive station-keeping maneuvers and continuous thrust transfer slew, then integrate these models into EXOSIMS. Two major objectives for year 3 of this SURP were to:

Background:
A starshade is an external occulting spacecraft that flies in formation with a space telescope to enable high contrast imaging. The Habitable Exoplanet Observatory (HabEx) large mission concept is comprised of a 52 m starshade 76,000 km in front of a 4 m diameter telescope.

Approach and Results:
To the end of improving computation times of station-keeping metrics such as delta-v cost and frequency of maneuvers, we demonstrated that an analytical calculation of differential lateral acceleration between telescope and starshade effectively approximates all station-keeping metrics of interest. Figure 1 compares the delta-v cost calculated with a high fidelity simulation of station-keeping involving numerical integration and event detection against a simple analytical calculation based on differential lateral acceleration, demonstrating differences typically below 1% and on the order of 10% in some edge cases.

To improve understanding of trends in station-keeping as a function of telescope position and target star location, we analyzed differential lateral acceleration in the circular restricted three body problem. By projecting station-keeping costs as a function of eclipic coordinates onto the surface of a sphere in Figure 2, we explain the structure of heat maps from [1]. Minima of differential lateral acceleration lie approximately on a great circle and its two corresponding poles.

Given a telescope along a nominal Halo orbit, we plot the location of one pole in Figure 3. We approximate the location of the pole as an eigenvector of the Jacobian matrix of inertial acceleration at the telescope location, and present a closed form analytical expression for its eclipic coordinates as a function of telescope position. In this manner, all minima of differential lateral acceleration are known by analytical calculation for any telescope position. Future mission designs can leverage this analytical expression for telescope pointing vectors that require the lowest delta-v for station-keeping and fewest interruptions to observations.

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To understand the ability to use an analytical expression for telescope pointing vectors that require the lowest delta-v for station-keeping and fewest interruptions to observations, we present the location of one pole in Figure 3. We approximate the location of the pole as an eigenvector of the Jacobian matrix of inertial acceleration at the telescope location, and present a closed form analytical expression for its eclipic coordinates as a function of telescope position. In this manner, all minima of differential lateral acceleration are known by analytical calculation for any telescope position. Future mission designs can leverage this analytical expression for telescope pointing vectors that require the lowest delta-v for station-keeping and fewest interruptions to observations.

Publications:

Citations:

Benfides to NASA and JPL:
JPL is engaged in studies for exoplanet missions for the decadal survey, and in development of starshade technologies through the SS Technology project. This work advanced DRM simulation software for evaluating science yields for these exoplanet imaging missions under real fuel and mission time constraints, which was used in the JPL-led HabEx Concept study. The work positions JPL to serve as a leader in the design and analysis of future exoplanet missions.