PERMANENT CAPTURE OF MINIMOONS IN LIBRATION POINT ORBITS: A CASE STUDY ON CAPTURING ASTEROID 2006 RH_{120} AND 2020 CD_3. J. Shepard[1] and R. Fevig[2], [1]Independent Researcher, 5276 E Hamilton Avenue, Castle Rock, CO 80104. [2]Department of Space Studies, University of North Dakota, 4149 University Avenue Stop 9008, Grand Forks, ND 58202.

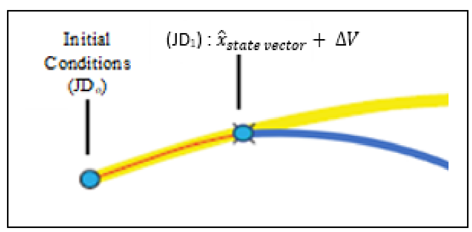
Scope: The purpose of this study is to understand the feasibility of altering temporarily captured asteroid trajectories and the amount of change in velocity (ΔV) required to follow a libration point orbit. The study will first consider the work of a previously conducted case study on 2006 RH_{120} [3] and develop a set of transfer points into a libration point orbit. The method of transfer will also be used for 2020 CD_3. A review of the colinear libration points within the Earth-Moon circular restricted three body problem (CRTBP) system is specifically considered for the use of the invariant manifolds to construct future rendezvous missions. Feasibility is determined for current or potential methods to initiate the required ΔV.

Introduction: The growing interest in minimoons, small temporarily captured asteroids, is often limited due to their short period nature and frequency. As Earth captures more minimoons, such as 2006 RH_{120} and 2020 CD_3, further studies can begin to explore questions involving their formation, composition, and other unique physical properties. To gain a detailed understanding of these minimoons, the idea of capturing these asteroids in closed orbits about Earth has gained popularity. Different methods have been proposed to capture such objects [5, 6, 7, 8, 9] and inspired a specific case study [3]. One purpose for placing asteroids into a long-term orbit is to enable the scientific community to gain an understanding of many questions through rendezvous missions with sample return and further data gathering. Rendezvous missions can even potentially provide future capabilities for resource utilization, further development of new technologies, and even bring about increased spaceflight.

One previous case study sought to understand what would be required to capture 2006 RH_{120} into an extended five-year Earth-Moon system trajectory. It was found that a ΔV of only 32 m/s [3] was needed to extend its dwell time in the Earth-Moon system. Understanding the nature of long duration capture is an important step toward understanding minimoons as their trajectories pass through the Earth-Moon system. With the idea of small alterations to their trajectory, studies that involve understanding the gravitational influence of the Earth-Moon system can potentially provide further leverage in constructing stable orbits [1, 2]. Stable periodic orbits would enable multiple missions to a minimoon, removing any time constraints. 2006 RH_{120} and 2020 CD_3 both have trajectories that are similar in nature and a general method for transfer could potentially be used for future minimoons. Given stable orbits about the libration point, the invariant manifolds can further provide a transit system to and from the target asteroid.

Data and Methods: The Earth-Moon CRTBP system as described by Grebow [2] and methods constructed from Grebow [2] and Kathleen [1] are used to simulate periodic orbits. The trajectories of 2006 RH_{120} and 2020 CD_3 are taken from HORIZONS Web-Interface [4] and mapped to the CRTBP Earth-Moon model. Given the data from both asteroids, the trajectories can be mapped and propagated. The initial state vector determined from the raw data [4] is given in the following table.

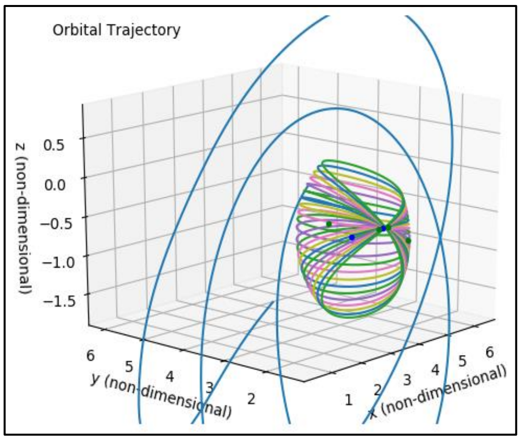
au/day	*2006 RH_{120}*	*2020 CD_3*
x	2.709168583726760E-02	1.846892311214098E-02
y	2.417971679468609E-02	1.314547067961380E-02
z	-8.122310395410729E-03	-2.700217236131744E-04
$\dot{x}$	-8.687670626207110E-04	-1.334969618410757E-03
$\dot{y}$	-2.666582277112110E-04	-6.841998409928946E-04
$\dot{z}$	-9.505734770686391E-05	8.402969645991618E-06



Analysis is conducted on the amount of ΔV needed to alter the trajectory to a desired orbit which is notionally represented in the previous figure. The yellow curve represents the initial trajectory the blue curve represents the altered trajectory. Analysis is further augmented with a review of the case study to extend the capture of 2006 RH_{120} [3]. Analysis methods of 2006 RH_{120} are further used for the data gathered on 2020 CD_3. Construction of the maneuvers are intended to be designed such that the method can be extended to capture future minimoons as they are discovered.

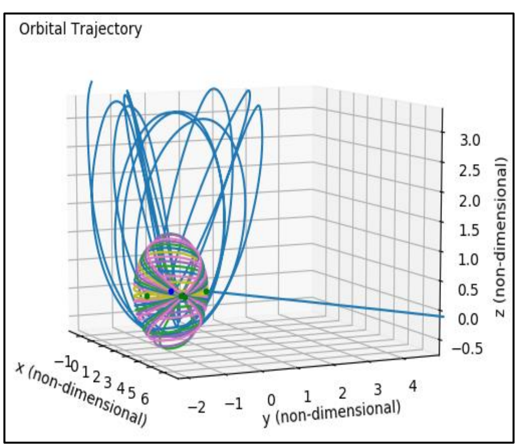
Preliminary Comparisons: Inside the Hill's sphere the different perturbations that can impact the system primarily include the gravitational pull of the Sun, Earth, and Moon, Earth J_2 effects, and any thrust that is initiated. Within this study, the closer the asteroid is to the Earth and Moon, the better the approximation the CRTBP of the Earth-Moon system provides for trajectory propagation. Given the hyperbolic nature of the trajectories for 2006 RH_{120}, a vertical Lyapunov orbit is used to determine an initial amount of ΔV for a stable periodic orbit about L2.

The trajectory for the given 2006 RH_{120} state vector is converted to unitless values. The state vector is then transferred into the rotational reference frame and compared to a family vertical Lyapunov orbits to determine an intersection point, as indicated in the figure below. The difference in velocity between the two state vectors is calculated as an initial ΔV cost.



The resultant ΔV requirement for the initial test run for the method is considered a non-efficient transfer directly into the stable periodic orbit. The ΔV required for the direct transfer is 2.505 km/s.

Similarly, a mapping was also constructed for 2020 CD_3 for a range of Jacobi values to determine an initial point to start a analogues maneuver, as shown in the figure below.



Preliminary results would indicate that such a transfer is also non-efficient for 2020 CD_3. However, with slight alterations at different points along the trajectory there is a potential to greatly reduce both ΔV requirements. The calculated ΔV provides an upper limit to total cost.

Continuing Work: As the study continues, the goal is to significantly decrease the ΔV requirement to capture a minimoon. An impulsive maneuver of about 32 m/s at a target Jacobi constant range for 2006 RH_{120} demonstrates an extended time duration in the Hill's sphere [3]. Analysis of the preliminary data from this study provides an upper bound for ΔV cost. To further expand the idea of changing the trajectory to a stable periodic orbit, this study will seek a set of trajectory correction points at which small changes in ΔV optimize the desired transfer. In the development of these sets of low-cost maneuvering points, the same methodology is to be used for 2020 CD_3. The constructed method could then offer the potential for future use as more minimoons pass through the Earth-Moon system. As more minimoons are discovered, the method created in this study with the construction of a trajectory using the stable and unstable boundaries would enable an efficient, optimized transfer for future rendezvous missions.

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