Potential Orbital Capture Missions to Trans-Neptunian Objects
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BACKGROUND

To date, New Horizons has been the only interplanetary mission undertaken with the exploration of a trans-Neptunian object (TNO) as its primary objective (Ref. 1). This remote region of the Solar System contains a large number of minor planets, at least one of which (Eris) is larger even than Pluto. Our group has previously analyzed high thrust missions using a Jupiter gravity assist (JGA) to several TNOs (Ref. 2-4). In the current study, we extend our previous work by examining the potential for the orbital capture of a probe. We also evaluate the possible benefits of using a Jupiter - Saturn Gravity Assist (JSGA) instead of a JGA.

Critical mission performance parameters include transit time to the target, potential flyby mass or orbital capture mass for launch on a given bound, arrival energy slippage at the target (which determines target observation time for flyby missions), and spacecraft radiation dose during the Jupiter flyby. The reduction of these is important because of potential damage to electronics and the resulting shielding mass requirements.

OBJECTIVES

The main objectives of this project are:

• To design Jupiter Gravity Assist and Jupiter-Saturn Gravity Assist trajectories to several TNOs including Huya, Huamea, Ixion, Pluto, Quaoar, Varuna and Sedna.

• To identify the most favorable targets and opportunities for TNO orbital capture missions.

• To compare JGA and JSGA missions with regard to Jupiter passage distances (a simple surrogate for spacecraft radiation exposure), arrival planet hyperbolic excess velocity, potential orbital capture mass, etc.

• To compare our results with historical missions in terms of transit time to the target, payload capability, Jupiter flyby radiation exposure, etc.

METHODS

Interplanetary trajectory modeling was accomplished using Mission Analysis Environment (MAnE), a commercial software package developed by Space Flight Solutions (Ref. 5). Jupiter proximity trajectories were calculated using the Program to Optimize Simulated Trajectories (POST) (Ref. 6), and the Jupiter radiation environment was analyzed using the European Space Agency code SPENVIS (Ref. 7). The calculated radiation environment is expressed via depth curves, indicating the dose of radiation which would be experienced as a function of the equivalent thickness of aluminum shielding.

JGA trajectories are constructed by planning the second leg (Jupiter to the TNO) first, using a “pork-chop” plot which shows Jupiter departure and target arrival excess velocities, near Holmehof Transfer from Earth to Jupiter in then added. This yields departure opportunities to a given TNO approximately every twelve years, corresponding to Jupiter’s orbital period. Opportunities for JGA trajectories to a given TNO occur less frequently due to the synodic period of Jupiter’s and Saturn’s orbits, with the Jupiter encounter typically occurring before or near the time of those two planets’ conjunction. Two such conjunctions occur in 2040 and 2066.

As an initial guess for JSGA trajectories, we set the Jupiter to Saturn transit time to be 6.8 years (similar to that for Cassini) and use a Holmehoff Transfer from Earth to Jupiter in MAnE is then allowed to optimize the encounter dates and distances. Potential TNO targets are limited for JSGA trajectories to the first two large objects within the region where a satellite can travel in an efficient manner.

Launch is accomplished using either a Delta IV HLV or an Atlas V, 551 with a Star 48 upper stage (analysis was done for both vehicles, and the better option was chosen). The performance of the launch vehicles is shown in Figure 1, taken directly from Ref. 10. Orbital capture is simulated assuming an impulsive burn. The interplanetary trajectories typically yield arrival excess speeds of 6 to 10 km/s, necessitating a two stage propulsive capture. The first stage assumes a solid rocket motor with an ISP of ~2865 and a tankage fraction of 0.005 (based on an average of ATK solid engine specs). The second stage is a liquid-fueled HEP engine using mono-methyl hydrazine (MMH) and nitrogen tetroxide (N2O4). The engine is an ungraded version of the one used for Cassini orbital insertion and provides an ISP of 3223 and tankage fraction of 0.113.

RESULTS

Table 1 shows potential orbital capture masses and other critical parameters for JGA missions with a time of flight of approximately 25 years to various TNOs. It is apparent that Huya, Pluto and Ixion are the most promising targets in terms of potential capture mass. These results assume departure at the minimum slippage (however, that issue is addressed below). The table also shows the impact of using a JSGA trajectory to Huya rather than a JGA. For the cases considered here, the JSGA permits a much more distant Jupiter flyby maneuver, but increases the arrival excess speed at the target, thereby reducing the time available for observation for a target with orbital capture less feasible.

CONCLUSIONS

For selected TNOs, orbital capture of a small interplanetary probe appears feasible using a two-stage, traditional chemical propulsion system. The best targets identified to this point are Huya, Pluto and Ixion. Capture missions will typically require interplanetary transit times of approximately 20 years to have the low arrival excess speeds necessary to capture of a probe of reasonable mass. The interplanetary trajectory can incorporate either Jupiter Gravity Assist or a Jupiter-Saturn gravity assist. For a wide range of Huya missions using a JGA, radiation exposure of the spacecraft during the launch phase is less severe than that encountered during previous missions including Voyager 1 and Pioneer 11. Use of a JSGA would allow more distant flybys of Jupiter and less intense radiation environments.

REFERENCES


Figure 1. Launch Vehicle Performance Comparison for Interplanetary Missions (Ref. 10)

Figure 2. Jupiter flyby radiation environment for 2026 departure to Huya with Voyager flyby radiation comparison

Figure 3. Transit time vs capture mass and jovian flyby radiation for a mission to Huya departing in 2026

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