LOW POWER OPERATIONS AT THE OUTER PLANETS: TROJAN ASTEROID MISSION ENABLED THROUGH RADIOISOTOPE-THERMAL PHOTOVOLTAIC POWER SUPPLIES

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Introduction:

The work presented herein was developed with the funding and support of the summer fellowship program at the Center for Space Nuclear Research (CSNR) under Director Dr. Steven Howe. The purpose of this work was to integrate a radioisotope thermal photovoltaic (RTPV) power source being developed at the CSNR into a micro-sat structure with the express purpose of enabling cheap and effective ways to sustain long duration missions to the outer planets. Exploration to the outer planets is an ongoing endeavor but in the current economical environment, cost reduction is at the forefront of all concern. The success of small satellites such as CubeSats launched to Near-Earth Orbit has lead to examine their potential use to achieve *cheaper science* for deep space applications. However, to achieve lower cost missions; hardware, launch and operations costs must be minimized. Additionally, as we push towards smaller exploration beds with relative limited power sources, allowing for adequate communication back to Earth is imperative.

This project's primary scientific goals were developed in order to be in-line with the Vision and Voyages for Planetary Science in the Decade 2013-2022 published by the National Academy of Science. An initial trade study narrowed down the feasible mission concepts from those proposed by the Decadal Survey, and lead to a new CubeSat and Carrier craft architecture for a Trojan Asteroid Mission.

The reserach focused in addressing the feasibility of mission architecture, operations, trajectory analysis, science objectives and instrumentation, communication architecture, mass budget, power management and distribution, data budget, cost model and risk analysis.

Concept: The general architecture developed and described here are generally feasible for use at any number of target bodies in the outer solar system. A carrier craft (or 'Mothership') provides the primary propulsion and communication for the mission; while a number of released daughter satellites (CubeSats) perform the science at the target body. The inclusion of a small, 5W RTPV power source had implications for the design of a CubeSat-class satellite. The requirements for additional radiation shielding, and the new thermal balance resultant from having an always-active heat source on board were discussed. Further, developing a battery-free power budget dependent on 5W of energy allowed a new paradigm for CubeSat mission design, enabling more fluid communication, and improved science instrument time utilization.

In order to optmize communication operations, the mission was designed to have a three tier bend pipe communication architecture, consisting of a mothership carrying multiple units of 6U CubeSats, which will be deployed around the selected Trojan asteroids. The main objective of the mothership is to be the link between the DSN and the orbiter. The data from the lander is uplinked to the orbiter and the orbiter transfers this data along with uplinking it's own science data to the mothership, which in turn transmits it to the DSN. The research's primary focus was on the operation of this bend pipe communication architecture in conjunction with the ground operations of the DSN.

Approach: A science traceability matrix was evaluated to narrow down the most feasible mission type from the decadal survey and Trojan Asteroid mission was selected. Various current CubeSat scale science instruments that could address the science objectives for this mission were studied and compared. Operational conditions, environmental conditions, priming requirements and power requirements were considered in engineering various science instrumentation and sensors for the mission architecture. A concept of operations was then drawn out for this specific mission.

The trajectory optimization (coupled with communication operations feasibility) was performed and tested using Evolutionary Mission Trajectory Generator (EMTG), a new trajectory software implemented by NASA Goddard Space Flight Center. In addition, a trade analysis of launch vehicles to reduce operations cost and mass was performed. The trajectory analysis also involves the operation of using impulsive burns on a duty cycle at optimal points. A sample trajectory, created using EMTG, to one of the Trojan Asteroid - *Nestor* is shown in the figure 1 below.

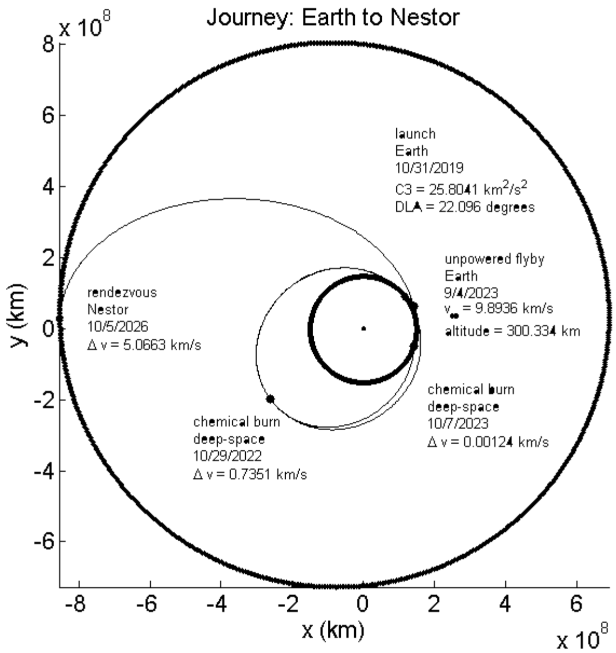

Figure 1: Trajectory generated from Earth to Nestor using EMTG. (*The bold circular black line in the figure represent the trajectory of the Earth and Nestor*)

In addition to the small, 5W RTPVs, this technology can scale near-linearly for larger applications. A 50W RTPV system can be used to power a Carrier craft, capable of transporting the CubeSats out to almost any body in the solar system. With an appropriately sized battery (found to be about 4 kW-hrs) coupled with the 50W RTPV, a high-voltage burst-mode communication scheme was demonstrated to be capable of transmitting megabits of information back to Earth from as far as Jupiter Orbit, albeit for only eight minutes every few days. Further, the RTPV assists in keeping the larger craft warm, where most outer planet satellites might require active heaters to maintain their thermal balance. Finally, the implications of this 50W RTPV power source with respect to propulsion were analyzed, and it was determined that traditional chemical propellant is still required for a system running on so little power.

The high power pulse discharge system is required for deep space communication to transmit large amount of data. To address concerns regarding a sufficient power supply, the Radioisotope Thermophotovoltaic (RTPV), coupled with batteries and super capacitors will be used to implement the acyclic high power bursts. The secondary focus of the paper, apart from the system architecture, was the intelligent strategic operation of this system for both propulsion and communication.

Conclusion: Using RTPV-powered CubeSats, riding on the previously described Mothership, a scientific mission to the Jupiter Trojan asteroids can be seen as not only scientifically interesting, but also highly cost effective due to the inclusion of the RTPV power source. A CAD model of a sample daughter Cubesat is shown in figure 2 below:

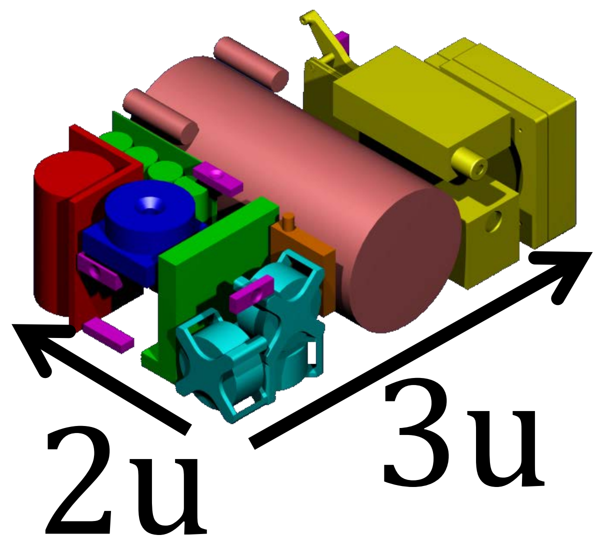

Figure 2: CAD model of a sample daughter CubeSat.

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