LEO CONSTELLATION DESIGN
USING THE LUNAR L1 POINT

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Notes on Extended Abstract

The following is an initial analysis of the use of the lunar L1 point for launching a global satellite constellation. This analysis is based on preliminary estimates and calculations, supplemented by discussions with subject experts at the NASA Jet Propulsion Laboratory. As this research progresses over the next few months, a more thorough analysis is being conducted, investigating such issues as spacecraft and carrier vehicle sizing, return Earth-bound L1 trajectories, radiation demands in MEO, ballute sizing for aerocapture, and the delta-V budget. The increased definition of these areas will influence the overall cost savings, rather than the feasibility of the concept.

INTRODUCTION

Over the last decade, there has been a growing interest in the development of low earth orbit (LEO) satellite constellations. Along with several commercial ventures (such as Iridium and Orbcomm), NASA and the Department of Defense have shown interest in using satellite constellations for continuous global coverage. However, a significant problem facing these developers is the high cost of these missions. In particular, since separate launch vehicles are generally required to reach different orbital planes, the cost of multiple launches may represent as much as 40% of the life-cycle cost. Thus, there is a need for new launch trajectories that would reduce the number of launch vehicles needed. This paper presents such a trajectory, which offers significant cost savings for several satellite constellations currently being considered.

CURRENT SATELLITE CONSTELLATION DESIGN

A critical factor in the design of a constellation is the number of orbital planes. Once a satellite has achieved a given plane, it is difficult to change planes, requiring significant fuel and propulsion capabilities. Thus, separate launch vehicles are generally required to reach different orbital planes, which significantly increases the mission cost.

For example, NASA has recently studied several micro-satellite constellation designs. Based on these studies, the following representative mission is considered for this paper:

- Science mission with continuous global coverage
- 90 satellites in 6 orbital planes
- 700 km polar orbits
- 75 kg spacecraft mass
- 6 Delta II launch vehicles (one per plane)

For this mission, the total estimated lifecycle cost has been estimated at $1 billion, of which $420 million is the launch cost for six Delta II launch vehicles.

PROPOSED CONSTELLATION DESIGN USING THE LUNAR L1 POINT

One possible method of reducing the cost of current constellation designs is to minimize the number of launch vehicles needed. However, it is prohibitively expensive (in terms of propellant) for the spacecraft to change orbital planes once deployed. The following design suggests an alternative method for distributing spacecraft to various orbital planes.
The design takes advantage of the complex dynamical behavior near the Lunar L1 Lagrange point (located between the Earth and the Moon). From a halo or Lissajous orbit about L1, it is possible, using minimal delta-V, to access various Earth return trajectories leading to different LEO planes. Thus, a single launch vehicle can carry an entire fleet of spacecraft to L1; from this location, they can be returned to multiple Earth orbital planes.

Aerocapture is employed to bring the spacecraft into LEO. Aerocapture involves a combination of atmospheric drag and small propulsive burns to slow the spacecraft and circularize its orbit.

**Overview of Proposed Mission Architecture**

Figure 1 gives an overview of the proposed architecture. Several carrier vehicles (each carrying a set of spacecraft to be deployed in a single orbital plane) are launched on a single launch vehicle to the Lunar L1 point, and inserted into a halo orbit. From this point, each carrier returns on a separate Earth-bound trajectory leading to different orbital planes. The carriers perform an Aerocapture maneuver and a circularizing burn to reach LEO. Following this insertion, the satellites are phased to evenly distribute them within the orbital plane.

![Figure 1: Overview of Trajectory](image-url)
Preliminary Analysis

In this section, a preliminary analysis looks at the feasibility of this trajectory for the proposed baseline mission of 90 micro-spacecraft in six orbital planes.

- **Spacecraft & Carrier Vehicle.** Assuming that the total weight of all 90 spacecraft is 6,750 kg, a reasonable total weight for the 6 vehicles is 2,250 kg (including sufficient fuel for halo orbit insertion and LEO circularization). The combined figure of 9,000 kg thus includes 90 spacecraft, along with 6 carrier vehicles and propellant.

- **Launch Vehicle.** A Lunar L1 point trajectory requires a C3 of $-0.6 \text{ km/s}^2$. Therefore, a Delta IV 4050H launch vehicle is selected, which provides a capability of 9,395 kg.

- **Halo Orbit Insertion at Lunar L1.** A delta-V burn of 600 m/s is required for halo orbit insertion, assuming a 7-10 day transfer time to L1. This burn requires approximately 1500 kg of fuel (for all 6 carriers).

- **Earth Return Trajectory.** Using minimal delta-V burns, the carrier vehicles return by separate Earth-bound trajectories leading to each of 6 different orbital planes.

- **Earth Orbit Insertion via Aerocapture.** To slow each carrier vehicle and yet minimize atmospheric heating during aerocapture, a ballute (or large, inflatable cushion) is deployed. The carrier velocity can then be reduced as necessary (without expending delta-V), depending on the ballute size and timing of its release. Finally, there is a delta-V burn of 120 m/s to raise the perigee for a circular orbit. In this fashion, each carrier vehicle achieves a circular orbit in the correct plane.

- **Satellite Deployment.** The individual satellites are deployed from the carrier spacecraft, and spread within the orbital plane using minimal delta-V maneuvers.

Estimated Savings for L1 Mission Architecture

The mission architecture presented in this paper can now be analyzed with respect to cost savings. Table 1 shows a comparison of launch costs for traditional LEO launches versus the Lunar L1 launch concept presented here.

<table>
<thead>
<tr>
<th>Number of Spacecraft</th>
<th>Orbital Planes</th>
<th>LEO Launch Vehicle</th>
<th>Number of Launch Vehicles</th>
<th>Launch Cost ($M)</th>
<th>Li Trajectory</th>
<th>Number of Launch Vehicles</th>
<th>Launch Cost ($M)</th>
<th>Savings ($M)</th>
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For each of the constellations, significant cost savings are realized. The baseline mission, for example has a launch cost of approximately $420 million. However, when launched using an L1 trajectory, the cost is $140 million, resulting in a savings of more than $280 million.
REFERENCES


ABSTRACT FOR CONFERENCE PROGRAM

Over the last decade, there has been a growing interest in the development of low earth orbit (LEO) satellite constellations. Along with several commercial ventures (such as Iridium and Orbcomm), NASA and the Department of Defense have shown interest in using satellite constellations for continuous global coverage. However, a significant problem facing these developers is the high cost of these missions. In particular, since separate launch vehicles are generally required to reach different orbital planes, the cost of multiple launches may represent as much as 40% of the life-cycle cost. Thus, there is a need for new launch trajectories that would reduce the number of launch vehicles needed. This paper presents such a trajectory, which offers significant cost savings for satellite constellations currently being considered. The new trajectory uses a lunar L1 point rendezvous and an Earth-return aerocapture to deliver satellites to multiple orbital planes via a single launch. This trajectory can reduce launch costs by more than 50% for certain types of micro-satellite constellations.