Advantages of Small Satellite Carrier Concepts for LEO/GEO Inspection and Debris Disposal Missions

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The Small Satellite Carrier Concept

Overview

- A SmallSat Carrier concept consists of one or more SmallSats attached to a SmallSat Carrier
- SmallSat is deployed and transfers to an RSO of interest,
- Conducts an inspection or debris removal sortie, and
- Returns to the SmallSat Carrier to makes preparations for another sortie

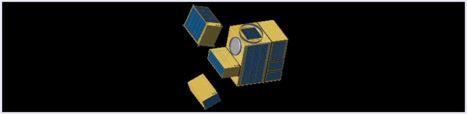
Potential SmallSat Carrier missions

- LEO/GEO satellite inspection missions
- LEO/GEO debris disposal missions
- Science missions with unique spatial and temporal requirements

Project Objectives

Assess launch mass advantages of SmallSat Carrier with SmallSat refueling capability

- Define requirements for LEO/GEO inspection and debris removal missions
- Conduct mission analysis to determine required delta-v/payload-to-orbit mass for a SmallSat/SmallSat Carrier
- Compare required launch mass to a Carrier-less concept
- Identify required SmallSat technologies



Project Assumptions

SmallSat Carrier

- 100-300 kg "capable" mass, propellant mass and 12% structure
- Full set of basic GN&C functions, direct comm link to ground
- Minimal propulsion capability
- Provides support for SmallSat docking, refueling, and short-range comm link with SmallSat

SmallSat

- 100 kg "capable" mass plus propellant mass and 12% structure
- Full set of basic GN&C functions, direct comm link to ground
- Hydrazine-based propulsion system - 220 sec Isp
- Optical or Lidar based relative navigation for inspection and debris capture with optional artificial illumination device

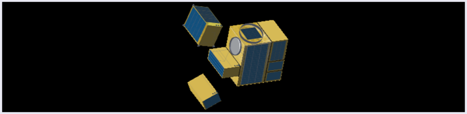
GEO Mission Requirements

Responsiveness requirements

- Inspect any GEO space object with an inclination < 0.1 deg within 90 days of notification
- Transport any GEO debris object ($<$5000 kg) with an inclination < 0.1 deg to a graveyard orbit within 90 days of notification

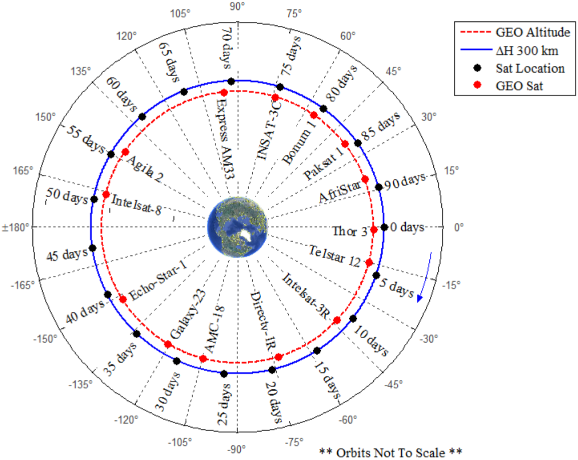
Communications requirements

- SmallSat/SmallSat Carrier direct comm link to the ground



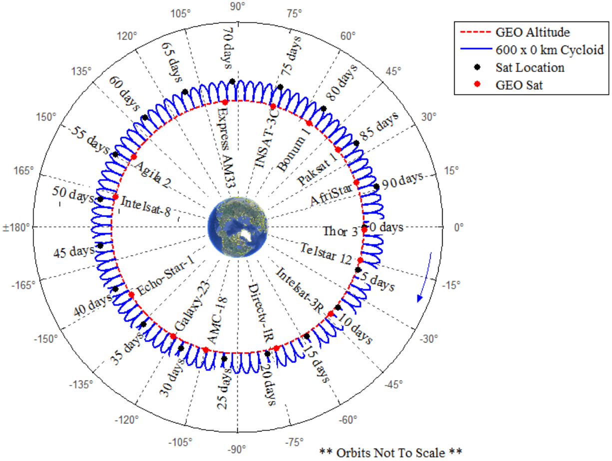
GEO SmallSat Carrier Orbit

300 km circular orbit above/below GEO - returns to the same geocentric longitude every 90 days



GEO SmallSat Carrier Orbit

"Cycloid orbit" (600 km x 0 km) - returns to the same geocentric longitude every 90 days

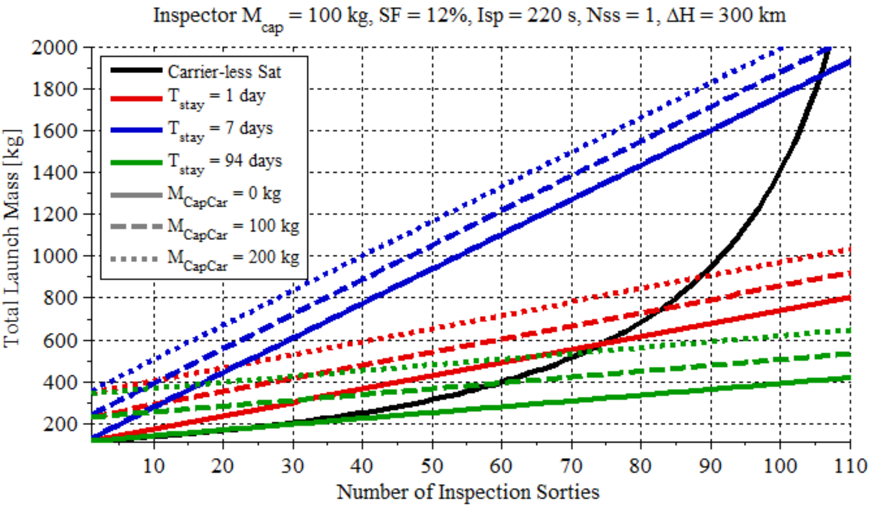


GEO SmallSat Sortie

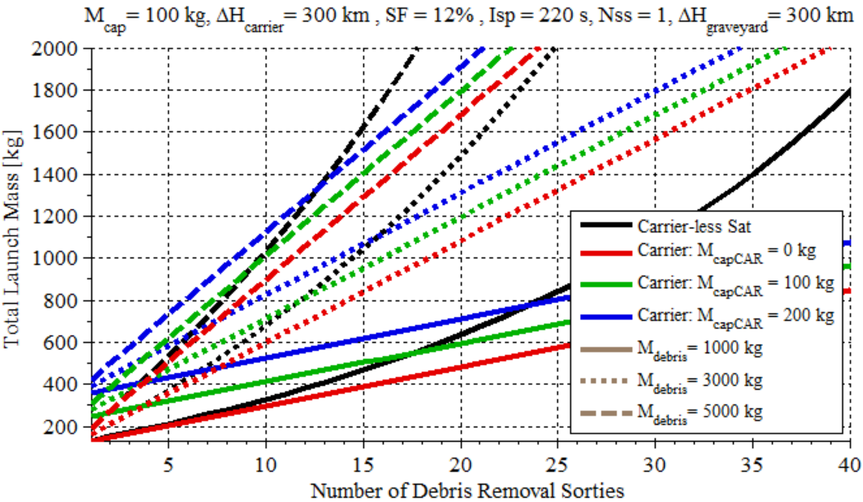
Nominal Orbital Maneuvers

- Inclination change at RSO node
- Two-maneuver in-plane orbital transfer (non-Hohmann transfer)
- *Optional debris removal maneuvers*
- Inclination change at RSO node
- Two-maneuver in-plane orbital transfer (non-Hohmann transfer)
- Additional delta-v for midcourse corrections and proximity operations - %10 of total nominal delta-v

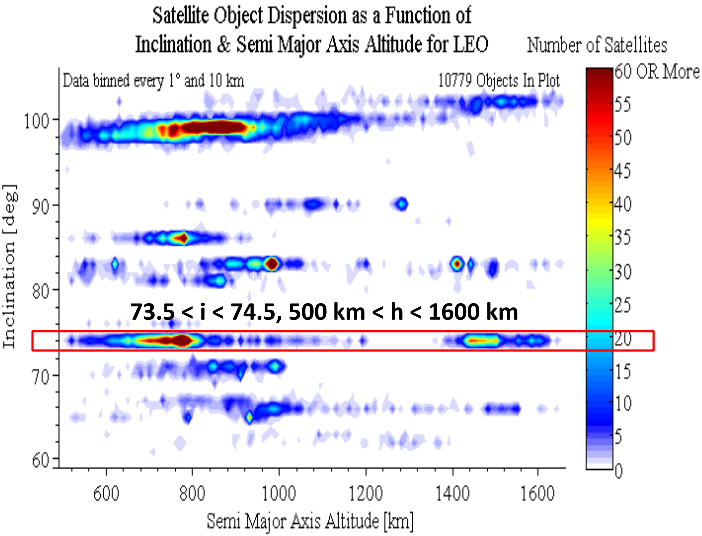
Required Mass-to-Orbit - GEO Inspection Missions



Required Mass-to-Orbit - GEO Debris Removal



LEO Mission Requirements



LEO Mission Requirements

Responsiveness requirements

- Inspect any LEO space object with an inclination between 73.5 deg and 74.5 deg, and an altitude between 500 km and 1600 km, within a 5 year period
- Transport any LEO debris object with an inclination between 73.5 deg and 74.5 deg, and an altitude between 500 km and 1600 km, to a debris disposal orbit, within a 5 year period

Orbit lifetime requirement

- Debris disposal orbit - $<$ 3 year lifetime

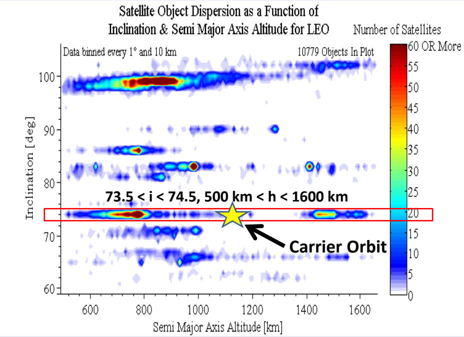
Communications requirements

- SmallSat/SmallSat Carrier direct comm link to the ground

LEO Carrier Orbit

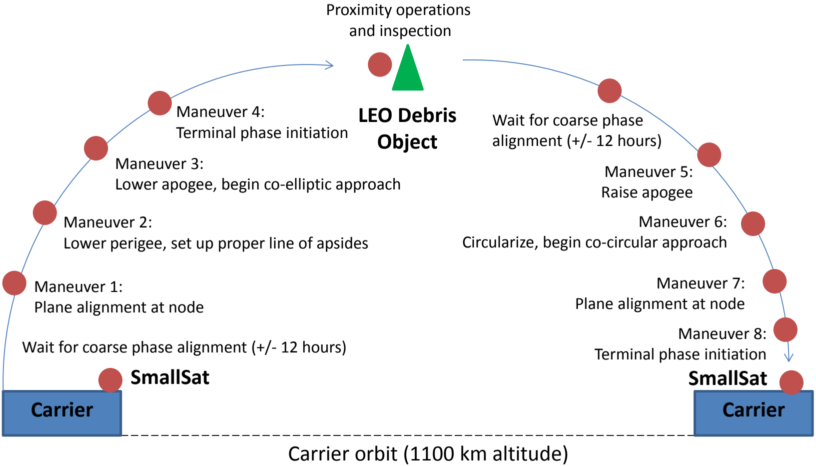
74 deg inclination, 1100 km altitude, circular orbit

- Differential precession of ascending node provides access to all objects in this inclination band that are more than 300 km above/below Carrier orbit over a 5 year period.

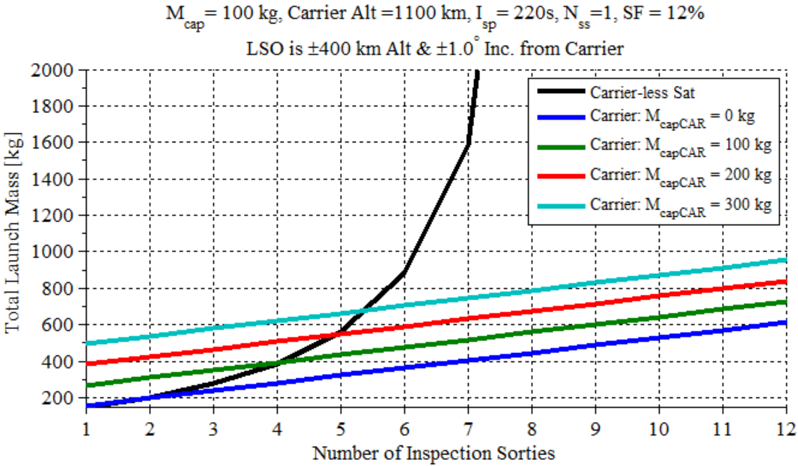


LEO SmallSat Sortie

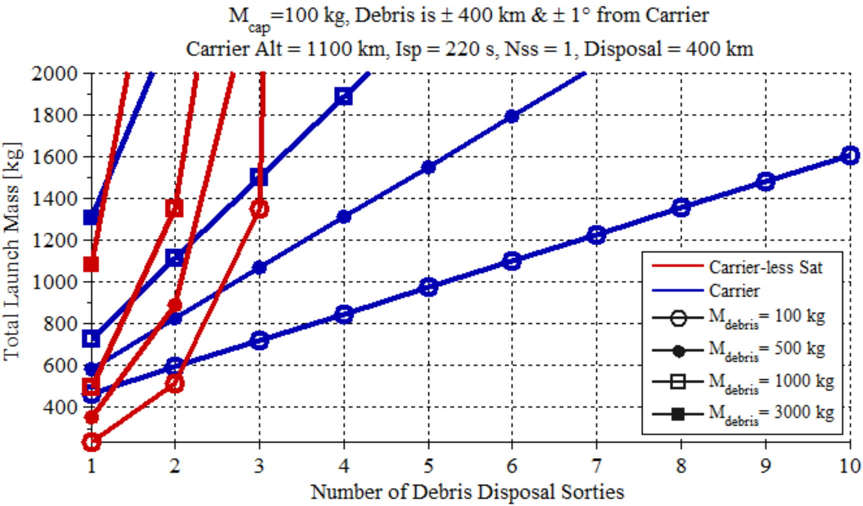
Orbital maneuvers (avg. $\Delta i = \pm 0.25$ deg, avg. $\Delta h = \pm 400$ km)



Required Mass-to-Orbit - LEO Inspection Missions



Required Mass-to-Orbit - LEO Debris Removal

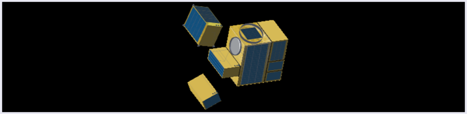


Conclusions

- The Small Carrier concept requires significantly lower mass-to-orbit for LEO inspection and debris disposal sorties...as compared to a Carrier-less system.
- For GEO missions, the advantages are less clear.
- If GEO inspection and debris disposal delta-v requirements become large, e.g. due to a faster response requirement, the Carrier concept will outperform the Carrier-less system
- While there is theoretical mass advantage to in-space refueling, the optimal solution will depend upon
  - Actual/real mission requirements
  - Thruster Isp
  - Carrier capable mass
  - # of SmallSats in system

SmallSat Carrier will Require New SmallSat Technologies

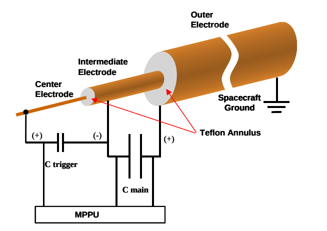
1. Optical-based or Lidar-based relative navigation ($<$ 100 m) with an uncooperative object
2. Artificial illumination for proximity operations ($<$ 100 m)
3. On-orbit cooperative docking devices
4. Deployable towing boom with electro-adhesive pads for removing orbital debris
5. Dynamics and control of multi-body space systems
6. *On-orbit propellant storage and transfer devices*



Carrier with CubeSats and Micro-PPT Thrusters

CubeSats with Micro-PPT for orbital maneuvering

- High Isp ($>$ 700 sec)
- Solid inert Teflon propellant - no propellant storage issues
- Micro-PPT thruster cartridges can be *replaced* - *eliminates the need for propellant transfer*
- Perhaps a CubeSat Carrier study is warranted...



Questions?