Refueling Architectures for VLEO Missions

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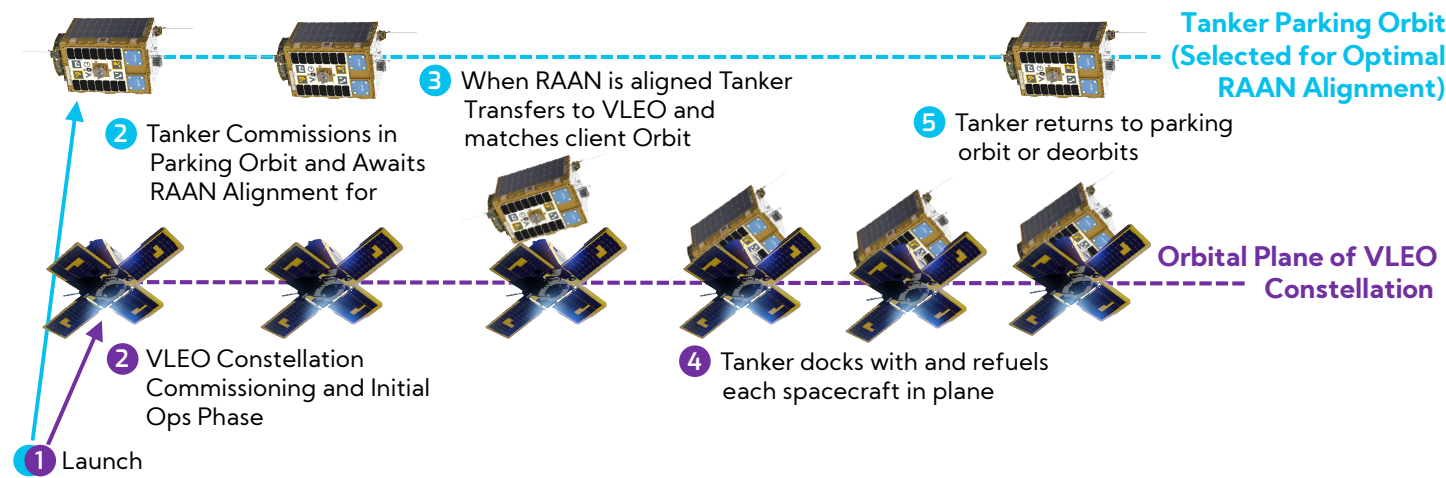
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Abstract

While VLEO missions offer the potential for incredible Earth imaging performance and other new applications, a major drawback is the high levels of drag that quickly degrade a satellite's orbit, requiring larger amounts of fuel or extremely frequent satellite replacements to maintain nominal operations. This paper explores architectures which overcome the challenge imposed by drag using Orbit Fab's in–orbit refueling technology. Architectures using refueling will significantly increase the economic viability of VLEO constellations. A regular supply of fuel will enable satellites in such a constellation to achieve significantly longer lifetimes than can be achieved with onboard propellant supplies alone. Additional propellant can also enhance operation flexibility to constellations, enabling repositioning of individual spacecraft or reconfiguration of the constellation as a whole. Orbit Fab specializes in providing these "Gas Stations in Space™" developed this paper to explore the magnitude of benefit provided by augmenting VLEO missions with refueling.

Reference Refueling Scenario

Orbit Fab's Universal Mission Planner for Investigating Refueling Effectiveness (UMPIRE) Provides a robust framework for analyzing refueling scenarios in various orbits including VLEO. UMPIRE modelling for VLEO is based on the following generic conops and includes relevant perturbation forces such as differential drag and J2. Particular attention must be paid to sizing the tanker orbits such that drift of their Right Ascension of Ascending Node (RAAN) drifts to match planes with the client spacecraft at the time of refueling. Tankers are sized to be able to successfully refuel all client spacecraft in 1–2 planes. Specific tanker constellation architectures and refueling conops are developed based on customer constellation architectures, spacecraft configurations, and mission requirements.


Tanker Parking Orbit (Selected for Optimal RAAN Alignment)

③ When RAAN is aligned Tanker Transfers to VLEO and matches client Orbit

② Tanker Commissions in Parking Orbit and Awaits RAAN Alignment for

⑤ Tanker returns to parking orbit or deorbits

Orbital Plane of VLEO Constellation

② VLEO Constellation Commissioning and Initial Ops Phase

④ Tanker docks with and refuels each spacecraft in plane

① Launch

Benefits of Refueling to VLEO Missions

• **Mission Life Extension** – Propellant availability is no longer the limiting factor for VLEO mission lifetime. Refueling allows VLEO missions with spacecraft lifetimes several times longer than can be achieved without refueling.

• **Propellant Type Flexibility** – The possibility of refueling enables VLEO missions using a wider variety of propellant types which may be simpler to procure and integrate than traditional electric propulsion systems.

• **Spacecraft Configuration Flexibility** – Refueling can allow for VLEO missions with smaller fuel tanks, enabling more efficient configurations.

Preliminary Results

Preliminary results of UMPIRE Modelling for VLEO mission scenarios indicate that it is feasible to develop a tanker constellation architecture that can serve the refueling needs of typical VLEO missions. For a typical VLEO mission with spacecraft expending their fuel supplies approximately every two years, it is possible to select from a range of tanker orbits that achieve RAAN alignment within time constraints while minimizing transfer delta V. One key observation is that alignment and delta V requirements are harshest for polar orbits. This should be considered when designing a VLEO constellation with refueling in mind.
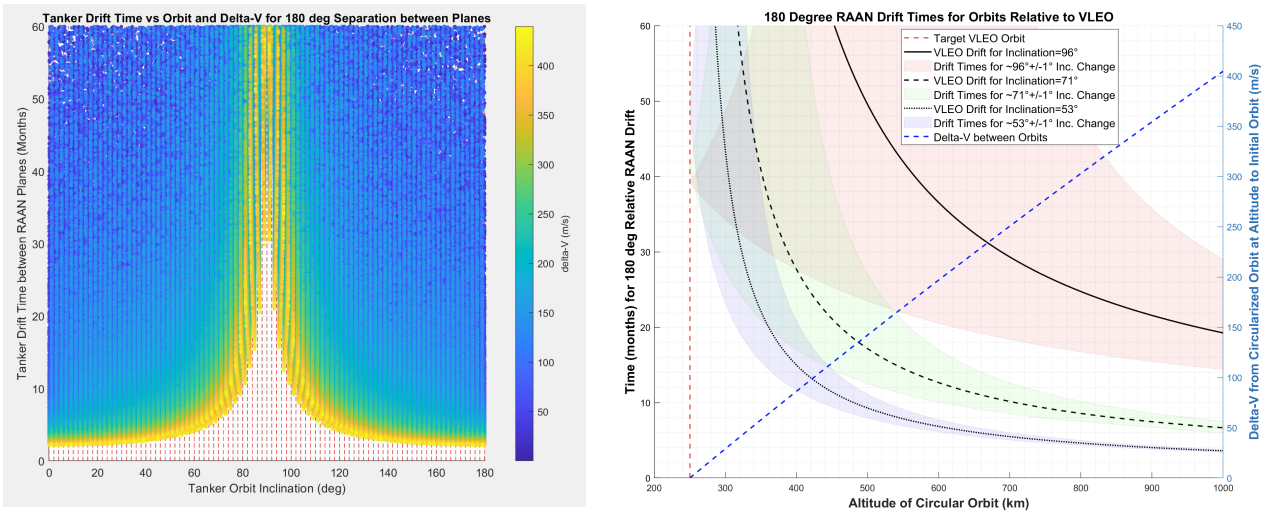
Example UMPIRE output plots showing the RAAN alignment drift times and transfer delta Vs for tankers refueling a particular VLEO constellation. These plots are used to select tanker orbits for VLEO refueling and ensure compatibility of refueling with a constellation's operational timeline constraints and requirements.