In-Orbit Fuel Supply: Enabling Smallsats with Extreme Delta-V

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Current spacecraft operations require launching spacecraft with all the fuel they will ever need. Fuel mass ratios of 2:1 to 4:1 can enable a spacecraft to depart from a LEO parking orbits to reach GEO or Mars. After arrival at an operating orbit, typical fuel mass ratios of 0.1:1 provide for lifetime operations. This paradigm defines what is seen as "normal", however it is interesting to contextualize how extraordinary this is in comparison with other transportation technologies in common usage. For example, cars massing about 1 ton consume around 40kg of fuel per week, or 20 tons over a 10-year lifetime for a fuel ratio of 20:1. Vehicles optimized for distance performance will have significantly higher lifetime fuel mass ratios. This comparison provides a glimpse of the future that can be enabled by an on-orbit supply of fuel.

Two technologies enable this new paradigm: on-orbit fuel tankers and expandable fuel tanks called FlexTanks™. These tanks allow spacecraft to be launched without both fuel mass and tank volume and provide a very high expansion ratio. In an example implementation, a spherical FlexTank™ with a stowed volume of 2L can expand to 60cm diameter and 100L fuel capacity (a 50:1 expansion ratio).

An example point design could be considered for a 6U CubeSat launched with tanks empty. If we assume a 10kg CubeSat mass and the above FlexTank™ configuration with 100L fuel, the fuel mass ratio will be around 10:1. Assuming a thruster with 2000s isp (we note that Hall Effect thrusters with power levels around 100W using low pressure, storable fuels are currently being tested and are expected to be flight-ready in 2019), a delta-V of 50 km/s is achieved. For a LEO departure at low thrust, approximately 8 km/s is required to reach Earth escape and an equal amount to return with a sample from Earth escape to LEO, leaving 34 km/s for maneuvers within the solar system. Missions enabled by such a high delta-V include sample return missions for as far away as the Main Asteroid Belt or Mercury.

The presentation will go into more detail on the in-orbit fueling architecture and the example mission concept.