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ASSESSMENT OF ON-ORBIT CRYOGENIC REFUELING: OPTIMAL DEPORT ORBITS, LAUNCH VEHICLE MASS SAVINGS, AND DEEP SPACE MISSION OPPORTUNITIES

Abstract

Cryogenic fuels offer higher energy densities than their storable counterparts, increasing the performances of spacecraft propulsion systems and reducing system masses. In fact, many of the high- performance launch vehicles today utilize cryogenic fuels for that reason. However, as increasingly ambitious missions are planned, required payload masses must increase, inevitably increasing launch vehicle size, cost, and complexity as well. The exponential relationship of payload mass and launch vehicle size dictates that a method be developed that limits the size of launch vehicles, while also keeping payload masses high. One potential solution lies with on-orbit cryogenic refueling depots, where a spacecraft can be launched with a smaller launch vehicle, refueled in orbit, and allowed to continue its mission. Ultimately, such architectures could maximize payload masses, simplify staging requirements, and reduce launch vehicle masses overall, while promoting a sustainable, infrastructure-based expansion into the solar-system.

The idea of cryogenic fuel depots is not new, and researchers have been developing the required technologies for decades. Recently, however, renewed efforts at NASA and other organizations to overcome remaining technological challenges have made great progress, potentially enabling the use of on-orbit cryogenic fuel depots within the next ten years. Therefore, it is worth taking a renewed look at how this technology might be implemented into today's space environment and assessing what benefits this technology might offer for the modern space age.

In this paper, the ESA's PyKEP orbital mechanics library is utilized with Python to determine where cryogenic fuel depots might be best positioned around the Earth and Moon for aiding human missions to deep space. The outputs of this program include porkchop plots, estimates of optimal orbits for depots around the Earth and the Moon, and trajectories detailing how to place the depots into such orbits. Next, required fuel masses for getting a spacecraft from a depot to a destination, such as Mars, and back are computed. From this point, resulting launch vehicle masses are calculated to compute possible mass savings as compared with traditional launch vehicles and architectures. Specifically, the Orion Spacecraft with the European Service Module is used as the baseline spacecraft for human missions into deep space, with an accompanying upper stage varying in size and capability depending on the desired mission. Finally, the idea of sustainable on-orbit cryogenic refueling infrastructures is discussed as a whole, with long-term effects on the human exploration of the solar system theorized and presented.