Contribution ID: **951** Type: **Poster Presentation**

C1Po1B-10 [06]: A Model Based Systems Engineering Approach to Achieve Zero Boil-off on A Nuclear Thermal Propulsion Spacecraft

Monday, July 22, 2019 9:00 AM (2 hours)

Aerojet Rocketdyne's 2033 Fast Conjunction Vehicle Concept to get to Mars is split into five segments: Deep Space Habitat, Inline Stages 1-3 and Core Stage. The three Inline Stages are propellant tanks carrying 19,205kg of liquid hydrogen (LH2). The Core Stage contains a smaller propellant tank of 14,084kg of LH2, a radiation attenuator and three nuclear thermal rocket engines. Each individual segment requires its own SLS rocket launch and will be launched every 180 days. Each segment will orbit around the moon—Near Rectilinear Halo Orbit (NRHO). NASA chose NRHO based on its low orbital stationkeeping and low thermal influence. The Inline Stage 1 is the first LH2-containing segment to reach NRHO with a loiter period of 905 days. Heat loads are of critical importance when storing LH2 due to its low boiling point. Venting the boiled LH2 is not an option for a mission of this length, which is why cryogenic fluid management (CFM) systems of passive and active cooling techniques need to work together to ensure zero boil-off. Several CFM systems will be simulated with one particular configuration involving lightweight, highly effective sun shades. Sun shades are deployable, radiation reflective shields that intercept incoming thermal radiation. Multiple sun shades can be stacked together and angled to allow thermal radiation between shields to reflect outward to space. A 2016 study showed that a two-stage cryocooler requires less mass and energy than a single-stage for large tanks due to the increase in heat load. By implementing one to many sun shades in-between the spacecraft and the sun, perhaps a single stage cryocooler configuration would be more advantageous—shown in the same 2016 study when looking at small tanks. Software tools such as Systems Modeling Language, MATLAB, Systems Tool Kit, and Model Center collaborate together to resolve this hypothesis.

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Session Classification: C1Po1B - Aerospace Applications