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ZERO BOIL OFF STORAGE OF LIQUID HYDROGEN APPLIED TO THE MARS TRANSFER VEHICLE

Abstract

Current methods for storing large quantities of liquid hydrogen in space involve the venting of vaporized hydrogen (boil-off) to space with the consequence that significant amounts of hydrogen are wasted. Accordingly, additional hydrogen is stored resulting in a significant mass penalty. Improved storage methods to reduce or eliminate boil-off are vital to the success of future space missions. Zero boil-off (ZBO) can greatly reduce vehicle mass thereby extending mission range and lowering trip times and costs. While it has been determined that ZBO is readily achievable during periods in which a significant portion of the spacecraft has an isolated view of deep space, it is unknown whether this can be accomplished when orbiting celestial bodies such as Earth and Mars. An analytical model was developed using the Mars Transfer Vehicle and NASA's design reference architecture as benchmarks. A thermal analysis of the MTV's propellant tanks was performed for its three mission phases: Cis-Lunar orbit, Mars/Earth transfer, and Mars orbit. The propellant tanks were discretized into isothermal nodes to compute the temperature profile and heat flux of the system. With this information, the insulation R-values required to achieve ZBO were calculated for each phase. A thermal control method (TCM) was selected by comparing the ZBO R-values to the R-values of existing TCMs. This research establishes a method for defining an effective R-value for passive TCMs, active TCMs, and combinations of passive and active TCMs. Furthermore, a correlation between R-value and system mass/power consumption/cost is established to support the selection of TCMs based on mission requirements. The TCM's required to accomplish zero-boiloff incur their own mass penalties, thus further mass savings can be gained by carefully selecting the appropriate TCM. It is the objective of this research to show that the MTV's hydrogen can be stored with ZBO using only passive TCMs throughout all phases of its mission. This will yield the largest mass savings in the design of the MTV, significantly reducing mission costs and trip times to Mars. Alternatively, by maintaining the same propellant mass, eliminating boil-off extends the range capability of the MTV allowing missions beyond Mars. Additionally, the methods herein developed are applicable to any space mission that requires the storage of cryogenic liquids.