In-Space Cryogenic Propellant Transfer: Modeling and Validation of Two-Phase Flow Dynamics in Low-Gravity

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A cryogenic propellant transfer test was conducted last year aboard SpaceX's Starship vehicle. The test involved transferring multiple metric tons of cryogenic liquid oxygen between tanks under low-gravity conditions, addressing challenges such as managing the liquid location in the supply tank and preventing vapor pull-through during the transfer process. To ensure proper liquid settling, the propellant was settled using a controlled milli-g level acceleration. Additional complexities arose from managing the two-phase cryogenic flow across the transfer line, driven by variations in the propellant's thermodynamic properties during the transfer process.

This paper presents an overview of the predictive tools and methodologies employed to ensure mission success, including high fidelity computational fluid dynamics (CFD) models and lower fidelity thermal-fluid simulations. These tools captured the intricate two-phase flow dynamics within the transfer system, which enabled accurate predictions and effective risk mitigation. Comparisons between simulation results and measured flight test data will be discussed to provide insights into the performance and validation of these predictive models.