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EXPERIMENTAL INVESTIGATION OF STRATIFICATION WITH LIQUID NITROGEN IN A LARGE SCALE CRYOGENIC TANK DEMONSTRATOR

Abstract

Increasingly complex modern space missions demand for flexible launchers particular considering future cryogenic upper stages. Mission lengthening with reignition phases lead to further extension of cryogenic storage times. Meanwhile heat fluxes and propellant movements (e.g. sloshing, settling) induce both challenging thermal stratification and destratification scenarios. In consequence temperature distribution and evaporation masses of the tank liquid phase become severely predictable quantities which result in uncertain thermal propellant residua. The need for profound knowledge of thermal stratification mechanisms is evident.

The relevant characteristic numbers of natural-convection-dominated thermal stratification are strongly dependent on geometric tank scales. Accurate experimental data with a well determined test tank provide the base for precisely predicting large scale tank stratification regimes. Thus, in order to analyze the behavior of cryogenic liquids in tanks during filling and accelerated mission phases, three test campaigns with liquid nitrogen in the frame of an ESA FLPP3 project were performed. Stratification within a chilled tank structure was examined in the second test campaign using autogenous pressurization with nitrogen. The tank pressure and liquid fill level are altered during stratification experiments. As test vessel the polyurethane insulated cryogenic tank demonstrator (CTD) with a volume of 717 l is equipped with wall temperature sensors, fill level sensor, pressure sensor, a camera system and mass flow meters. Moreover the CTD applies two movable sensor rods with silicon diodes in order to gauge temperature evolution in the liquid as well as in the vapor phase.

Mass and energy budgets for both liquid and ullage phases are provided for each stratification test case. In addition, continuous temperature profiles are derived in the stratified liquid for discrete points of time. Extensive calibration procedures of both wall and sensor rod temperature sensors enable precise evaluation of the unsteady natural convection regime. The sidewall heat flux into the liquid is intensively changing with vertical tank position due to double-walled or flange dominated tank wall sections. A subcooled tank wall section in the lower bulkhead is identified to cause two separated convection cells with corresponding s-shaped temperature profiles in the stratified liquid. As a result the modified Rayleigh number decreases with distinct effects on both thermal residua and evaporation rate. The temperature and fill level sensor offer further information on the radial distribution of phase change masses with progressive evaporation at the tank wall and slight condensation in the inner region of the liquid free surface.