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Numerical Modeling of Thermofluid Transients During Chilldown of Cryogenic Transfer Lines

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ABSTRACT

The chilldown of fluid transfer lines is an important part of using cryogenic systems such as those found in both ground and space based applications. The chilldown process is a complex combination of both thermal and fluid transient phenomena. A cryogenic liquid flows through a transfer line that is initially at a much higher temperature than the cryogen. Transient heat transfer processes between the liquid and transfer line cause vaporization of the liquid, and this phase change can cause transient pressure and flow surges in the liquid. As the transfer line is cooled, these effects diminish until the liquid reaches a steady flow condition in the chilled transfer line. If these transient phenomena are not properly accounted for in the design process of a cryogenic system, it can lead to damage or failure of system components during operation. For such cases, analytical modeling is desirable for ensuring that a cryogenic system transfer line design is adequate for handling the effects of a chilldown process.

Since 1960, several analytical investigations [1-3] to model chill down of cryogenic transfer lines were reported in literature. Burke et al [1] developed a single control volume model to predict chill down time of a long stainless steel tube by flowing liquid nitrogen. Chi [2] developed an analytical model of the chill down under the assumptions of constant flow rate, constant heat transfer coefficient and constant fluid properties. Steward et al [3] modeled chill down numerically using a finite difference formulation of the one-dimensional, unsteady mass, momentum and energy equation. Heat transfer coefficients were determined using superposition of single-phase forced convection correlations and pool boiling correlations for both nucleate and film boiling. In recent years, a task has been undertaken at Marshall Space Flight Center to develop the Generalized Fluid System Simulation Program (GFSSP). GFSSP is a robust general fluid system analyzer, based on the finite volume method, with the capability to handle phase change, heat transfer, chemical reaction, rotational effects and fluid transients in conjunction with subsystem flow models for pumps, valves and various pipe fittings [4]. GFSSP has been extensively verified and validated by comparing its predictions with test

data and other numerical methods for various applications such as internal flow of turbo-pumps [5], propellant tank pressurization [6,7], and squeeze film damper rotordynamics [8]. GFSSP has also been used to predict the chilldown of a cryogenic transfer line, based on transient heat transfer effects and neglecting fluid transient effects [9]. Recently, GFSSP's capability has been extended to include fluid transient effects [10].

The purpose of this paper is to present the results of a numerical model developed using GFSSP's new fluid transient capability in combination with its previously developed thermal transient capability to predict pressure and flow surge in cryogenic transfer lines during a chilldown process. An experiment performed by the National Bureau of Standards (NBS) in 1966 has been chosen as the baseline comparison case for this work [11]. NBS's experimental set-up consisted of a 10.59 ft^3 supply dewar, an inlet valve, and a 200 ft long, _ in Outside Diameter (OD) vacuum jacketed copper transfer line that exhausted to atmosphere. Three different inlet valves, a _ in port ball valve, a 1 in port globe valve and a 1 in port gate valve, were used in NBS's experiments. Experiments were performed using both liquid hydrogen and liquid nitrogen as the fluids. The proposed paper will include detailed comparisons of GFSSP's predictions with NBS's experimental results.

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