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Small Experiments for the Maturation of Orbital Cryogenic Transfer Technologies

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SMALL EXPERIMENTS FOR THE MATURATION OF ORBITAL CRYOGENIC TRANSFER TECHNOLOGIES.

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Abstract

The no-vent fill method is a promising approach to handle the problems of low-g venting during propellant transfer. A receiver tank is first cooled to remove thermal energy from the tank wall and the resultant vapor vented overboard. Then nozzles mix the incoming liquid and residual vapor in the tank maintaining a thermodynamic state which allows the tank to fill with liquid without venting. Ground based testing at NASA Lewis Research Center (LeRC) has demonstrated the no-vent fill process and attempted to bound its low-gravity performance. But, low-gravity testing is required to validate the method. As an alternative to using a dedicated spacecraft for validation the authors have formulated several small scale experiments to study no-vent fill in low-g. Cost goals quickly limited the search to two possibilities: a secondary payload on the space shuttle, or a small scale sounding rocket experiment. This paper will discuss the key issues of small scale experimentation and present a conceptual design of a sounding rocket experiment with liquid hydrogen for studying the fill process.

Background

The filling of tanks in low gravity with cryogens is challenging. During a fill in a normal gravity environment, a top vent is kept open to maintain a low tank pressure by venting the vapor generated during the fill process. If the same approach is used in a low gravity environment, the vapor may not vent, since the position of the vent opening relative to the vapor cannot be predicted. Instead of vapor, large amounts of liquid may be vented. In addition to the unwanted loss of liquid, unbalanced torques produced by venting liquid have caused spacecraft to tumble out of control.

The LeRC has identified no-vent fill as the preferred technique for transferring cryogenic propellants in low-gravity environments based on the findings of reference 1. This and several previous paper studies and thermodynamic analyses of the process indicated the feasibility of the technique and established liquid hydrogen as the most difficult commonly used propellant to transfer by this method[1,2]. Early experiments demonstrated 1-G no-vent fills for fluorine and nitrogen[3]. In response to the need for in-space experimentation NASA's Lewis Research Center (LeRC) added transfer experiments to its already planned Cryogenic Fluid Management Experiment (CFME) studying storage and acquisition[4]. Two studies were carried to the preliminary design level[5,6] on this program, now called the Cryogenic Fluid Management Facility (CFMF). Both of these, constrained by the 22 cubic foot volume of the CFME, proposed using multiple flights with a small scale tank for transfer and a larger tank to study chilldown phenomena. One study was selected to be carried forward to the critical design stage, but was cancelled prior to reaching the critical design review (CDR). In an effort to obtain zero-g data LeRC defined the Cryogenic On-Orbit Liquid Depot Storage, and Transfer Satellite (COLD-SAT). The three parallel contracted efforts[7,8,9] that were conducted, detailed the design and analysis of hardware to conduct zero-gravity experiments on chilldown, no-vent fill, and low-g vented fill, as well as other technologies. These efforts were also canceled at a preliminary design level.

In parallel with the definition of these flight programs the Cryogenic Fluids Technology Office at Lewis Research Center conducted an extensive investigation of the no-vent fill process from 1987 to the present[10-17]. This investigation has focused on 1-G ground based testing and analytical model development. Results have been published for tests conducted at 2 facilities with 3 different receiver tank volumes (1.2, 5.0, and 175 cubic feet) and four different fluid injection techniques. The fluid injection techniques documented to date are a top mounted spray nozzle, a spray bar, a diffused submerged inlet, and a submerged jet directing the fluid toward the top of the tank. The other variables, in the testing performed to date, are the liquid inlet temperature, the liquid inlet mass flow rate, and the initial wall temperature. A model of the process for the top spray injection configuration

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has been developed and the results from this model compared with the test results for the different receiver tanks in references 13,16, and 17. Although references 13 and 16 show good agreement in the 1.2 ft^3 and 5 ft^3 tank tests, the results of reference 17 (for the 175 ft^3 tank) are not as satisfactory. However, a simple thermodynamic model of the process based on thermodynamic equilibrium has been shown by reference 17 to predict no-vent fill in the 175 ft^3 tank regardless of inlet geometry. Assuming the receiver tank and its contents are in thermodynamic equilibrium throughout the transfer process eliminates the configuration dependent process rate equations from the analysis. Additionally the thermodynamic equilibrium condition represents the theoretical best case performance, and can be used to calculate an efficiency for the real cases.

Technological Objective

The objective of a transfer experiment will be to demonstrate the no-vent fill of a receiver tank in a low-gravity environment and compare the receiver tank transient pressure response to normal-gravity cryogenic test results. Existing analytical models will be used to predict the experiment behavior.

Justification

This experiment will provide the first low-gravity no-vent fill data for a tank of any size with a relevant working fluid. Ground based testing at LeRC has demonstrated the feasibility and the repeatability of the no-vent fill process (see Refs. 13, 14, 15, and 17) for both nitrogen and hydrogen. The tests conducted to date have attempted to bound the low gravity process by performing tests with spray systems which represent the best and worst fluid configurations found in low gravity. Testing with a top spray is expected to be the best because it promotes the condensation of the ullage vapor onto the spray droplets. Testing with a submerged diffused bottom inlet is expected to be the worst because it minimizes the mixing of the accumulating liquid and the agitation of the liquid vapor interface, hence, minimizing the heat and mass transfer at the liquid to vapor interface. The data obtained from the low-gravity test should fall between these two extremes when compared to the ground test data. Comparison to ground test will also quantify the utility of the bounding condition tests in predicting low gravity behavior.

Physical Process Description

The no-vent fill method for filling a receiver tank proceeds as follows. The receiver tank wall is chilled to reduce the wall's thermal energy to a point such that the incoming liquid can absorb the remaining wall energy without exceeding the tanks pressure limit (Note: for noncryogens this chilling is not usually required). Once the receiver tank has been chilled down, the tank pressure will be reduced to a low level by venting to space (on the ground this is simulated either by using a vacuum pump or air ejectors). At this point the vent valve is closed, and the fill process begins with the initiation of the liquid injection from the supply tank. The liquid is injected through spray nozzle(s) and or mixing jets. The initial liquid inflow will partially flash with the remaining mass striking the tank walls and vaporizing. The liquid striking the tank walls and vaporizing further cools the tank wall and raises the tank pressure. The continuous liquid inflow condenses the vapor in the receiver tank and at the same time reduces the volume occupied by the vapor. If the condensation rate is high enough the vapor is not compressed and the receiver tank pressure remains fairly constant. As the tank nears full, depending on the tank and liquid inlet configuration, the ullage volume will be compressed. As this occurs the tank pressure rises rapidly. The objective in investigating the no-vent fill process is to design the hardware and set the process parameters to postpone the compression phase until after high liquid fill volumes on the order of 95% liquid are achieved, while keeping transfer time to a minimum.

Analytical Model

The difficulties in developing an analytical model of the no-vent fill process lie in the deviations from thermodynamic equilibrium behavior inherent in the real process. If thermodynamic equilibrium conditions are assumed to exist in the receiver tank it can be shown that if the injected liquid is in a sufficiently subcooled state, the end state of the process will result in a tank full of fluid still in a subcooled state. Several conditions and processes cause the real process to deviate from the simple equilibrium analysis. Cooling down the tank wall from the initial condition to near the incoming liquid temperature, parasitic heat leaks to the tank and the fluid, and flashing of the incoming liquid during the initial phase of the transfer process all force the process away from equilibrium behavior.

Equilibrium Model

The no-vent fill process can be modelled as a process occurring with initial and end states for the receiver tank being at thermodynamic equilibrium. The receiver tank is initially evacuated and at some temperature, T_1. The incoming liquid, with enthalpy h_i flows into the tank until the desired mass has been transferred. With the process end state defined as thermodynamic equilibrium, the change in the internal energy of the tank wall must be equal to the change in internal energy of the fluid. This is represented mathematically as follows:

$$M(u_{w_1}-u_{w_2})=V\rho_2(u_{f_2}-h_i) \qquad (1)$$

where:

M = Mass of the receiver tank (lb_m)
V = Volume of the receiver tank (ft^3)
u_w = Tank wall internal energy (Btu/lb_m)
ρ = Fluid density (lb_m/ft^3)
u_f = fluid internal energy (Btu/lbm)
h_i = Inflow enthalpy (Btu/lbm)

The subscripts 1 and 2 indicate the beginning and current conditions of the process respectively. If the receiver tank is not evacuated initially, Equation 1 must be rewritten to account for the energy of the fluid in the receiver tank. In the case of a receiver tank filled with vapor at low pressure, the magnitude of this term is small. The NVEQU code of reference 17 uses a transient analysis of this equation to predict the no-vent fill process.

Nonequilibrium Model

The assumption of thermodynamic equilibrium in the receiver tank, while simplifying the problem, neglects the rates at which real processes occur. In order to see the effect of the inefficiencies associated with the real behavior of the fluid in the receiver tank, a model which treats the vapor and liquid phases of the fluid in the receiver tank separately was developed. This model does make several assumptions in analyzing the no-vent fill process including: liquid accumulation can begin prior to the wall being chilled to the temperature of the incoming liquid, the incoming liquid can flash depending on the conditions in the receiver tank, and no heat transfer occurs between the vapor and the tank walls. This last assumption is justified by the fact that typically the heat transfer between the wall and the vapor is an order of magnitude less than the heat transfer between the wall and the liquid. Additionally the wall energy content and parasitic heat leaks are only a minor contribution to the overall process energy balance due to the thin tank walls and high performance insulation typical of flight systems.

The model divides the fluid in the receiver tank into 2 nodes, the vapor and the liquid, with a third node representing the tank wall. Energy balances are performed on each node at every time step, while mass balances are calculated for the two fluid nodes. The whole model including the basic equations is described in reference 16. The NVFILL computer program incorporates this model in finite difference form, and solves the equations in an explicit time marching algorithm.

The critical processes for the no-vent fill transfer are the heat and mass transfer across the liquid to vapor interface(s). These two processes are related as shown in Equation 2.

$$hA_{inf}=\frac{\dot{m}_{cond}(h_{gas}-h_{liq})}{(T_{sat}-T_{liq})} \qquad (2)$$

where

h = heat transfer at the liquid to vapor interface (Btu/ft^2 hr-R)
A_{inf} = interface surface area (ft^2)
m_{cond}= vapor condensation rate (lb_m/hr)
h_{gas} = vapor enthalpy (Btu/lb_m)
h_{liq} = liquid enthalpy (Btu/lbm)
T_{sat} = liquid saturation temperature (R)
T_{liq} = bulk liquid temperature (R)

This heat and hence mass transfer at the liquid to vapor interface may be represented by summing several terms having the form of Equation 2 depending on the liquid injection system configuration. For example with a spray nozzle injecting an atomized liquid spray, the liquid to vapor interface would have two components, the surface of the spray droplets and the free surface of the accumulated bulk liquid in the tank. The heat and mass transfer at these two interfaces will be different due to the difference in areas and heat transfer coefficients and the temperature difference between the ullage vapor and droplet or liquid surface. In the NVFILL top spray model the heat and mass transfer at the free surface of the accumulated bulk liquid is neglected because the estimates of the magnitude of the transfer at this interface is less than 0.1% of the rate calculated for the droplet spray. The heat transfer coefficient, h, for the spray droplets is calculated from a correlation by Brown (as adapted by Chato[12]).

Scaling

Preliminary investigations have indicated it is possible to scale the results of no-vent fill testing with the same fluid for tanks of similar geometries, but different sizes via the tank mass to volume ratio and the fill rate[10,18]. The scaling for dissimilar fluids is a considerably more complex problem involving the introduction of two additional scale factors. The no-vent fill process is affected by the inlet subcooling of the incoming liquid, the initial temperature of the tank wall, the heat transfer between the wall and the liquid and vapor in the tank, the heat of vaporization of the fluid, and other fluid properties in a very complex interaction. Reference 18 discusses two time scales that occur in the no-vent fill process, the first being the fill time and the second being the condensation time scale. The analysis presented shows that it is usually only possible to match one of these scales for tests with different fluids. The scale factor for fill time S_{tfill} is shown in Equation 3.

$$S_{tfill}=\left(\frac{\rho_{l_1}}{\rho_{l_2}}\right)^{\frac{1}{3}} \qquad (3)$$

Where: ρ_{l1} = density of liquid 1
ρ_{l2} = density of liquid 2

The scale factor for the condensation time S_{tc}, as derived in Reference 18, is based on analogs to "well stirred reactors". The derived scaling relation is shown in Equation 4.

$$S_{tc}=\frac{S_{\rho_l}S_{h_{fg}}}{\left(\frac{S_{\rho_l}^{\ 2}}{S_{\mu_l}^{\ 3}}\right)^{.25}\left(\frac{S_{C_{pl}}S_{\mu_l}}{S_{k_l}}\right)^{.5}S_{k_l}} \qquad (4)$$

Where the scale factors, S_{xx}, are the ratios of the property identified in the subscripts for the two fluids.

Space Shuttle Experiments

These scale factors were used in an attempt to identify hydrogen simulants for use in a space shuttle experiment. Stringent safety requirements limit those experiments within the crew cabin to using room temperature water as a simulant. Reference 19 has demonstrated no-vent fills with water. However, water's low saturation pressure at room temperature (0.36 psia versus 15-17 psia for a typical hydrogen transfer system) makes extrapolation of this result to liquid hydrogen difficult. Payload bay based experiments offer a broader range of possible simulants. But the desire for a low cost experiment combined with still fairly strict safety requirements eliminated those simulants which were flammable or highly toxic. The payload bay temperature average is near room temperature, but the instantaneous temperature is highly variable. This variability enables the operating temperature of the experiment to be designed to be anywhere within a broad range. A review of two of the commonly used references[20,21] for thermodynamic properties to identify substances with normal boiling points ±50 F of room temperature which met the safety criteria, found four possible candidates. Table I summarizes these scale factors for these substances. Although the fill time scale is only about 3 times that of liquid hydrogen, the condensation time scales for these simulants is much longer. Refrigerant C-318 is the best at 10 times the condensation scale. Although something useful about the fluid dynamics of transfer operations may be learned by matching the fill scales the difference in rate between the condensation and fill process will make comparing pressure histories to hydrogen ground test difficult. Pending a more sophisticated analysis of simulant properties effects, conducting a test with the fluid of interest (liquid hydrogen) seems preferable. The use of hydrogen as the test fluid precludes the flying of this experiment on the space shuttle due to the high cost of assuring crew and shuttle safety, so alternate means of obtaining a low gravity environment were considered.

Sounding Rocket Experiment Concept

The uncertainties of the process and the available models and the difficulties of scaling data between dissimilar fluids make it desirable to obtain data for the fluid(s) of interest. The flight test data obtained using hydrogen can be directly compared to test data from the ground based testing of the small receiver tank in the Cryogenic Components Laboratory Site 7 (CCL-7) by designing test tanks of similar size. The utility of the results of using hydrogen more than compensate for the design and operational complexities that result.

Testing at CCL-7 has established that no-vent fills can be accomplished in the order of 2 minutes (transfers this rapid where not believed possible prior to CCL-7 tests). While this time still makes the use of either aircraft flying a parabolic path or drop towers unsuitable, it is within the range of low-gravity time available on a sounding rocket. Sounding rockets were selected as an alternative to shuttle based testing for a low-cost, small scale experiment (estimated costs are about 3 million dollars, about the same as a shuttle Get Away Special (GAS) experiment).

Sounding Rocket Experiment Requirements

Objective

The general goals of the experiment are to demonstrate a no-vent fill of a receiver tank in a low gravity environment and thereby obtain data on the transient pressure behavior of the receiver tank to be compared with the results from the ground test program and from the NVFILL and NVEQU computer programs. Achieving these goals will require the following information: 1) known temperature and pressure for the receiver tank throughout the transfer process (initial conditions, transient measurements during the transfer, and final conditions), 2) known state of the incoming liquid, and 3) the liquid inlet mass flow rate.

Description of Experiment

The hydrogen transfer experiment will transfer liquid hydrogen from a supply tank to a receiver tank in a low gravity environment. The receiver tank will be preconditioned to a low temperature and pressure prior to performing the experiment. The transfer process will be pressure driven, with the supply tank being pressurized with helium from a high pressure storage tank. The experiment will be performed once during a given flight.

Hardware concept

A conceptual design of the experiment is shown in figure 1. Figure 2 shows the flow schematic. This concept is designed for launch on a Black Brant sounding rocket and hence has an outer diameter of 15 inches. Both tanks are enclosed in a common vacuum jacket which allows them to be insulated with high performance multilayer insulation. All systems are protected against overpressure by burst disks.

Supply Tank

The supply tank volume is based on having sufficient liquid available to fill the receiver tank to 95% by volume after accounting for losses due to boiloff during prelaunch and ascent and residual hydrogen in the supply tank at the end of the transfer. The receiver will be chilled during the supply tank fill process so extra liquid for chilldown during flight is not required. For the design concept shown in figure 1 the supply tank is sized at 10 % greater volume than the receiver tank. The supply tank is insulated to maintain the tank pressure below 30 psia (assuming the tank is filled with hydrogen at 20 psia to start) during the ascent phase of the flight. The supply tank is designed for maximum operating pressures of 50 psia and equipped with a liquid acquisition device for supplying single phase liquid to the transfer line between the supply and the receiver tank. The supply tank is instrumented with a single pressure sensor. It is desirable, but not required, that the supply tank be instrumented with temperature sensors similar to the receiver tank as described in the following section

Receiver Tank

The receiver tank volume requirement is a minimum of 0.9 cubic feet and a maximum of 1.5 cubic feet (75% to 125% of CCL-7 Small Receiver Tank volume). Figure 1 shows a layout with a 0.9 cubic foot receiver tank The receiver tank wall will be cooled to an average temperature of less than or equal to 150 R prior to performing the transfer. Ground testing shows that at this level wall energy does not dominate the fill process. Six temperature sensors are allocated to measure the tank wall temperature. One sensor would be mounted on each of the bottom and top domes of the tank with the remaining 4 sensors spaced evenly longitudinally along the cylindrical barrel section of the tank. A pressure sensor will also be incorporated into the receiver tank for measuring the pressure in the tank. The tank is designed for maximum operating pressures of 50 psia. It is desirable that the tank have a mass to volume ratio on the order of 5:1 or less. It is desired that the overall heat leak to the tank be less than or equal to 1.0 Btu/(ft^2 hr) to prevent nucleate boiling of the hydrogen. Both these desires appear conceptually attainable.

Liquid Transfer Line

The transfer line is insulated to minimize the heat leak to the liquid hydrogen during the transfer process. The transfer line contains a temperature sensor, a flow meter and two pressure sensors (one absolute measurement and one side of the differential measurement across the spray nozzle) within 6 inches, closer if practically attainable, to the inlet to the spray nozzle. Flow in the transfer line is initiated by an isolation valve to be located downstream of the flowmeter as close as practical to the spray nozzle. This will enable the majority of the transfer line to be filled with liquid hydrogen prior to launch. Due to the problems of measuring two phase flow the transfer line must be designed to maintain single phase flow throughout the test. The mass flow rate through the line will be 3.0 to 3.5 lb$_m$/min. The line should be sized so that the pressure drop across the transfer line (including the flowmeter, valve, and spray nozzle) shall be less than 10 psid with a flow rate of 3.5 lb_m/min. The liquid mass flow rate of 3.0 to 3.5 lbm/min was selected based on the testing conducted with the small receiver tank at CCL-7. The tests conducted at these flow rates succeeded in filling the receiver tank 95% full by volume 80% of the time and were 100% successful in filling the receiver tank 90% full by volume.

Spray Nozzle

The spray nozzle will have a full cone spray pattern. The spray nozzle flow rates will be correlated to the pressure drop across the nozzle in ground tests, prior to integrating the nozzle into the experiment. This calibration will be used to check the liquid inlet flow rate reading of the flow meter and to analyze the transient behavior of the experiment. The spray nozzle shall be located at either end of the receiver tank, on the tank axis (or as close as practically attainable).

Measurements

The following parameters are required to be measured on the hydrogen transfer experiment:

1. the receiver tank pressure.
2. the receiver tank wall temperature.
3. the supply tank pressure.
4. the liquid transfer line pressure (at a point near the inlet to the receiver tank).
5. the liquid transfer line temperature (at the same position as the pressure measurement).
6. the local acceleration level.
7. the transfer line flow rate
8. differential pressure drop across the spray nozzle.

All measurements will be taken at a minimum frequency of once every 2 seconds. This data rate corresponds to the experiment setup at CCL-7. Table II summarizes the requirements for the different sensors. The accuracy requirements for the liquid temperature and the transfer line pressure sensors are driven by the need to characterize the thermodynamic condition of the fluid entering the receiver tank. The wall temperature measurements are required to calculate the wall energy content at the beginning and end of the transfer. The accuracy of the pressure transducers in conjunction with that of the temperature sensors will allow assessment of the deviation of the real system behavior from the ideal case of thermodynamic equilibrium. The transfer line flow meter will measure the volumetric inflow rate and provide the principle evidence that liquid hydrogen is moving from the supply to the receiver tank. An integration of the volume flow rate combined with the temperature and pressure measurements will be used to determine the final fill level. Because of the importance of the flow rate measurement, it will also be determined by a differential pressure measurement across the spray nozzle which will have been previously calibrated for the flow rate as a function of differential pressure in ground based tests.

Procedures

A detailed test procedure will be developed as the design progresses. However, in general terms the procedure for performing the hydrogen transfer experiment will be as follows:

1. The receiver tank will be prechilled to a predetermined temperature prior to launch. This temperature will be low enough to ensure the wall temperature is less than 150 R at the start of the transfer.
2. The supply tank will be filled to approximately 95% with liquid hydrogen at atmospheric pressure.
3. The receiver tank pressure will be reduced to below 2 psia by venting to space prior to initiating the transfer.
4. Upon reaching altitude and the experiment package separated from the booster and despun, the supply tank will be pressurized to a predicted pressure sufficient to provide the subcooling of the liquid hydrogen in the supply tank to required to complete the test (this is currently estimated at 15 psi over atmospheric).
5. The valve on the transfer line will be opened.
6. Transient measurements of the transfer line pressure, the transfer line liquid temperature, the receiver tank pressure, the local acceleration level, the differential pressure across the spray nozzle, the supply tank pressure, the supply tank wall temperatures (if available), and the receiver tank wall temperatures.
7. Data will be taken until the experiment reenters the atmosphere.

Test Matrix

A single test will be performed per flight. Ground tests will be performed both pre- and postflight (if the experiment package is recovered or a duplicate set of hardware is built) to characterize the experiment performance in normal gravity and to duplicate, to the extent possible, the flight test conditions to provide a direct comparison between the low gravity and the normal gravity experiments. The ground test program will also characterize the system heat leaks for the tanks and transfer line by filling the system with liquid hydrogen and measuring boiloff rates.

Data Analysis

The data obtained from the hydrogen transfer experiment flight will be analyzed to determine the instantaneous and the time integrated mass flow into the receiver tank, based on the calibration curves developed for the transfer line flowmeter and spray nozzle during the experiment development. The receiver wall temperature data will be used to estimate the wall energy content during transfer. The NVFILL and NVEQU computer programs developed at LeRC will be used to make preflight predictions. Additionally, after the actual in-flight initial conditions are known, these programs will be run at the flight conditions and the results compared to the test data. The comparison parameter will be the receiver tank's transient pressure response. The flight test results will also be compared to the results obtained in the ground test program. If necessary additional ground testing will be performed, in order to obtain data directly comparable to the flight test in terms of initial conditions and inlet mass flow rate. Again the comparison parameter will be the receiver tank's transient pressure response.

Concluding Remarks

It was the objective of this paper to identify small experiments for maturing no-vent fill transfer technology. To fulfill this objective the authors have formulated a conceptual design of a sounding rocket experiment and explored concepts for shuttle based experiments. All the room temperature liquids examined as simulants in this paper show a significant difference between fill and condensation rate scale factor for correlation to hydrogen. The conceptualization of a shuttle based experiment must await either identification of suitable simulant, or an analysis capable of addressing the more complex problem of scaling for dissimilar fluids. The use of hydrogen as the test fluid precludes the flying of a inexpensive experiment on the space shuttle due to the high cost of assuring crew and shuttle safety. Hydrogen will be used in the sounding rocket experiment. One final caveat, the small scale of these experiments and limited number of test conditions may force conservative designs of flight systems, and proof of concept demonstration flights. Large scale tests to verify low-gravity performance are still desirable, although small scale testing will allow the large experiments to be conducted with reduced risk and complexity.

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Table I
Scale Factors for Hydrogen Substitutes

Scale Factor	Refrigerant 11	Refrigerant 113	Refrigerant 114	Refrigerant C-318
S_{ufal}	2.74	2.79	2.73	2.75
S_{tc}	13.5	15.08	10.49	9.56

Table II
Sensor Requirements for Sounding Rocket Experiment

Property	Location	Range	Accuracy	Quantity
Liquid Temperature	Transfer Line	20-50 R	0.2 R	1
Wall Temperature	Receiver Tank	20-200 R	0.2 R	6
Pressure	Supply Tank	0-50 psia	0.5 psia	1
Pressure	Receiver Tank	0-50 psia	0.5 psia	1
Pressure	Transfer Line	0-50 psia	0.5 psia	1
Flow Rate	Transfer Line	0-1.2 ft^3/min	0.5% full scale	1
Differential Pressure	Spray Nozzle	0-50 psid	0.5 psid	1
Acceleration		10-1000 μg	15%	1

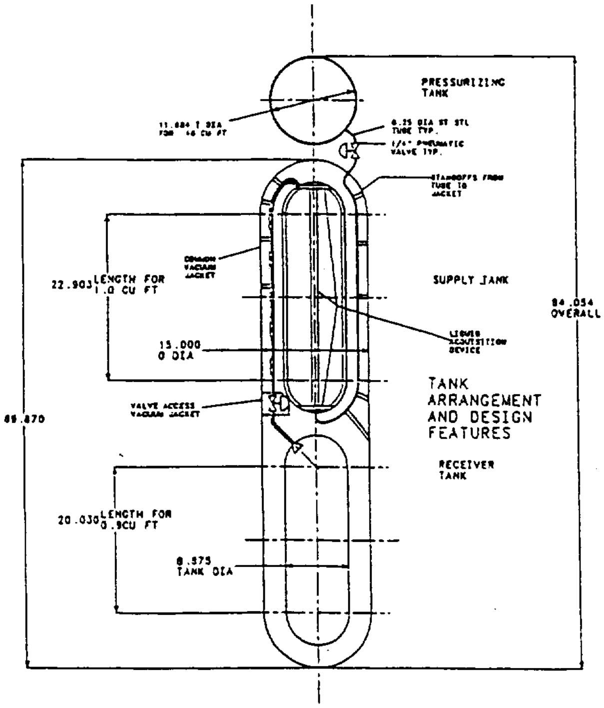

Figure 1 Conceptual Hardware Layout for Small Scale Liquid Hydrogen Transfer Experiment on Black Brant Sounding Rocket

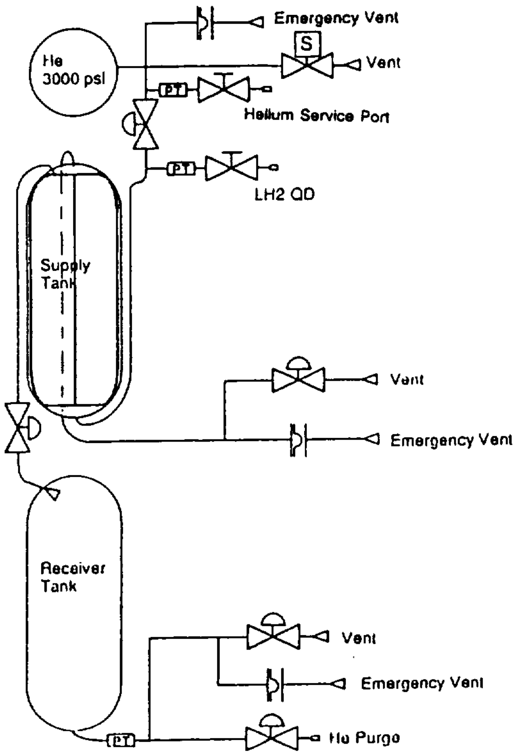

Figure 2 Flow Schematic for Small Scale Liquid Hydrogen Transfer Experiment on Black Brant Sounding Rocket

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13. ABSTRACT ***(Maximum 200 words)***

The no-vent fill method is a promising approach to handle the problems of low-g venting during propellant transfer. A receiver tank is first cooled to remove thermal energy from the tank wall and the resultant vapor vented overboard. Then nozzles mix the incoming liquid and residual vapor in the tank maintaining a thermodynamic state which allows the tank to fill with liquid without venting. Ground based testing at NASA Lewis Research Center (LeRC) has demonstrated the no-vent fill process and attempted to bound its low-gravity performance. But, low-gravity testing is required to validate the method. As an alternative to using a dedicated spacecraft for validation the authors have formulated several small scale experiments to study no-vent fill in low-g. Cost goals quickly limited the search to two possibilities: a secondary payload on the space shuttle, or a small scale sounding rocket experiment. This paper will discuss the key issues of small scale experimentation and present a conceptual design of a sounding rocket experiment with liquid hydrogen for studying the fill process.

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