CR 115395

MCR-71-38

PASSIVE RETENTION/EXPULSION METHODS FOR SUBCRITICAL STORAGE OF CRYOGENS

TEST PLAN - SUBSCALE DUAL-SCREEN-LINER RETENTION/EXPULSION SYSTEM

July 1971

(NASA-CR-115395) PASSIVE RETENTION/EXPULSION METHODS FOR SUBCRITICAL STORAGE OF CRYOGENS: TEST PLAN, SUBSCALE DUAL-SCREEN-LINER R.E. Hise (Martin Marietta Corp.) Jul. 1971 24 p CSCL 21I G3/27

N72-18762

Unclas 17655

FACILITY (NASA CR OR TMX OR AD NUMBER)

Prepared for
National Aeronautics and Space Administration
Manned Spacecraft Center
Under Contract NAS9-10480

MARTIN MARIETTA
DENVER DIVISION

EP 5

MCR-71-38

Contract NAS9-10480

PASSIVE RETENTION/EXPULSION METHODS FOR SUBCRITICAL STORAGE OF CRYOGENS

TEST PLAN - SUBSCALE DUAL-SCREEN-LINER RETENTION/EXPULSION SYSTEM

July 1971

Prepared for

NASA Manned Spacecraft Center
Houston, Texas

by

Dr. Ralph E. Hise

Approved by

Howard L. Paynter
Program Manager

MARTIN MARIETTA CORPORATION
Denver, Colorado 80201

FOREWORD

This document is submitted in accordance with Exhibit C of Contract NAS9-10480, dated 19 February 1970. It is a test plan to verify the operational performance of the dual-screen liner concept. Normal 1-g, aircraft, and drop tower tests using nitrogen as the test liquid are discussed.

This work was performed by the Martin Marietta Corporation under the technical direction of Mr. Jerry Smithson, Power and Propulsion division, NASA Manned Spacecraft Center, Houston, Texas.

CONTENTS

I. INTRODUCTION

The objectives and guidelines for the test plan, along with the three basic modes for testing, are briefly outlined in this chapter.

A. OBJECTIVES AND GUIDELINES

The main test objective is to demonstrate liquid-free gas venting of a subcritically stored cryogen using a passive retention/expulsion system. The test plan presented here is aimed at verifying this capability for the dual-screen-liner (DSL) concept independent of gravity level ($\leq 1g$) and direction. A second objective is to verify that the concept will also provide gas-free liquid expulsion under the diabatic test conditions. The plan, therefore, is oriented toward verifying a concept rather than a particular tank system design.

The testing will also yield valuable data that will prove useful in documenting the operational characteristics of the DSL--in particular, tank filling, frequency and duration of venting, cryogen temperature and pressure histories, sensitivity of pressure relief control, and the ability of the passive device to provide communication between the vapor annulus and bulk regions. These data are needed to assess the practicability of the DSL for spacecraft applications.

Testing will be performed with liquid nitrogen in the subscale test article fabricated and delivered to NASA-MSC under this contract.

B. TEST MODES

The test plan covers three different test modes: (1) 1-g bench, (2) drop tower, and (3) KC-135 airplane. The bench tests are preferred since data tend to be more repeatable and tests can be monitored and controlled more easily. The frequency of tests is also much greater, in comparison. The drop tower and airplane afford relatively short test periods, 5 and 30 seconds, respectively. The availability of the airplane limits the frequency of tests while free-fall tests are limited to less than two per day. The latter is based on experience with our 2.1-second facility at Denver, Colorado. The airplane and drop tower tests also dictate the need for more sophisticated (remote) monitoring and control techniques. They do, however, provide a low gravity level ($< 10^{-5}g$) for testing, which supports their use in this program.

The subscale system was designed for use in all three test modes including use of one, or all, of the following drop towers: NASA-LeRC, NASA-MSFC, and the Martin Marietta Facility.

The recommended scheduling for the tests and associated cost estimates are not included in this report but are presented in Reference 1.

II. MARTIN MARIETTA DUAL-SCREEN-LINER CONCEPT

The DSL is an attractive passive retention/expulsion concept for subcritical storage of cryogens that permits gas-free liquid expulsion and liquid-free vapor venting in low gravity, based on the analysis and parametric study results for this program. It consists of two concentric screen liners separated by a small gap and placed close to the tank wall. The outer annulus between the tank wall and screen tends to fill with vapor (due to tank heat leak) and serves as a permanent source of vapor for venting overboard. The inner annulus between the two screen liners that is filled with liquid during tank loading remains full of liquid and provides a continuous liquid path from the bulk liquid to the tank outlet. It also supplies liquid to the outer screen so the heat leak is intercepted by vaporization at the screen. The outer annulus and bulk region are passively connected (through the liquid annulus) by a single communication screen for regulation of the pressure differential between the two regions. This pressure difference (greater in the vapor annulus) must support the hydrostatic head of the bulk liquid.

III. DESCRIPTION OF TEST ARTICLE

The subscale cryogenic storage system consists of a cylindrical DSL storage tank complete with a tank shell heater and multilayer insulation located within a spherical vacuum shroud as shown in Figure 1. System plumbing provides for LN_2 fill and drain, storage tank evacuation and pressurization, LN_2 outflow and GN_2 venting, plus instrumentation. Additional support systems are required for conducting the test program. The installation schematic for 1-g testing is shown in Figure 2. The test system is constructed of 300-series stainless steel.

A. STORAGE TANK

The 6.4-in. ID by 7.4-in. inside length LN_2 storage tank (see Fig. 3) contains the DSL retention/expulsion system. A vapor annulus with a 0.48-in. gap is provided between the outer screen and tank wall with a 0.31 in. gap liquid annulus between the two concentric screens. The LN_2 bulk storage region is located within the inner screen. Both screen liners are 325 x 2300 Dutch twill (stainless steel) with a minimum bubble point of 23-in. of water (measured in methanol). The 1/2-in.-diameter screen connecting the vapor annulus and the bulk storage region is provided to limit the pressure differential between the two regions. The maximum bubble point of the communication screen is 21-in. of water (measured in methanol), which is sufficient to hold liquid out of the vapor annulus in 1-g.* The communication screen bubble point must be less than that for the screen liners so the vapor enters the bulk region rather than the liquid annulus. The maximum allowable bubble point of the communication screen is 2-in. below the bubble point for the screen liners. Support for the screen is provided by perforated plate (the screen is sandwiched between two plates).

---

*Based on a stability factor of 2.0.

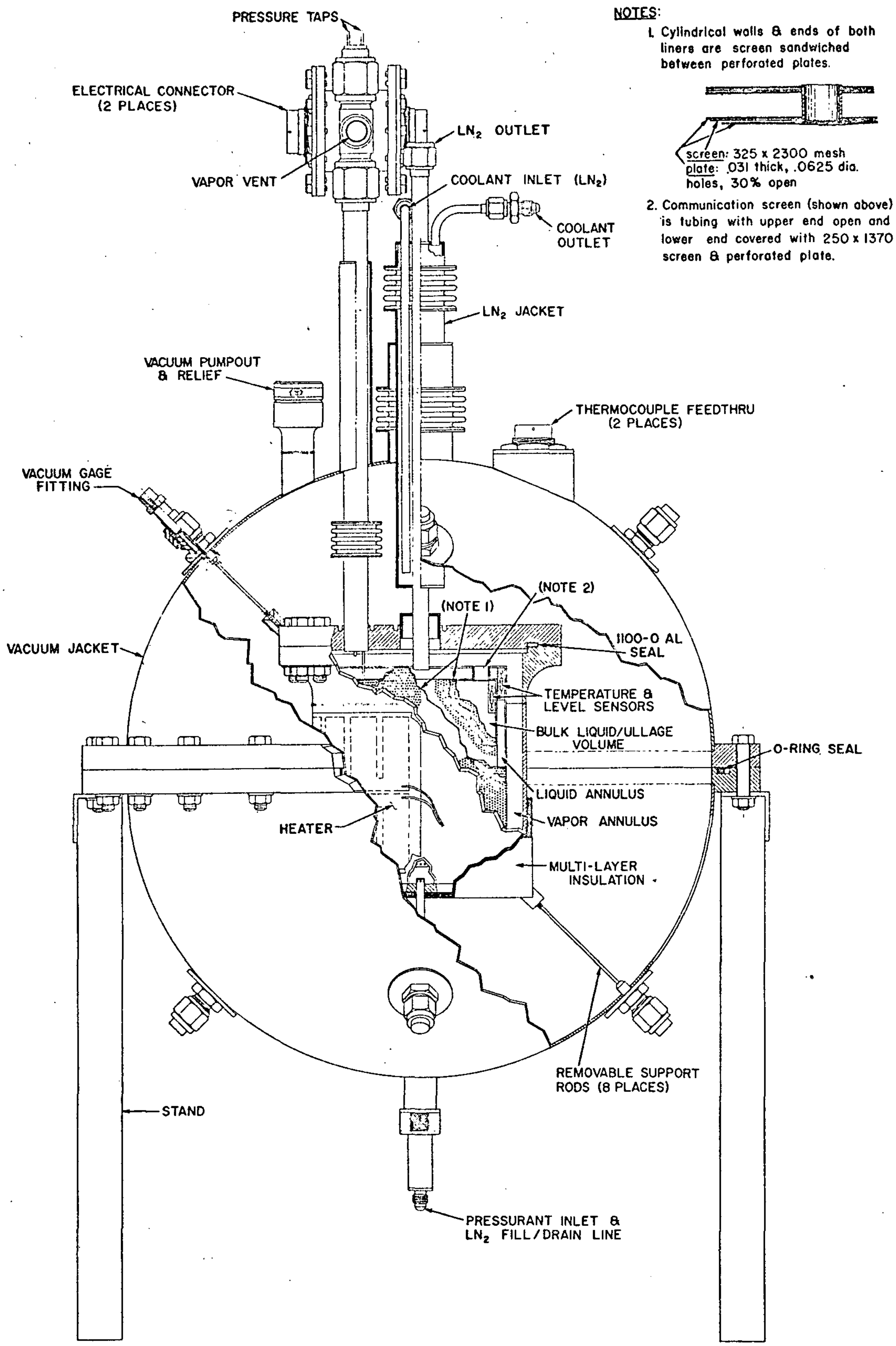

Figure 1 Cutaway View of Subscale DSL Passive Retention/Expulsion System

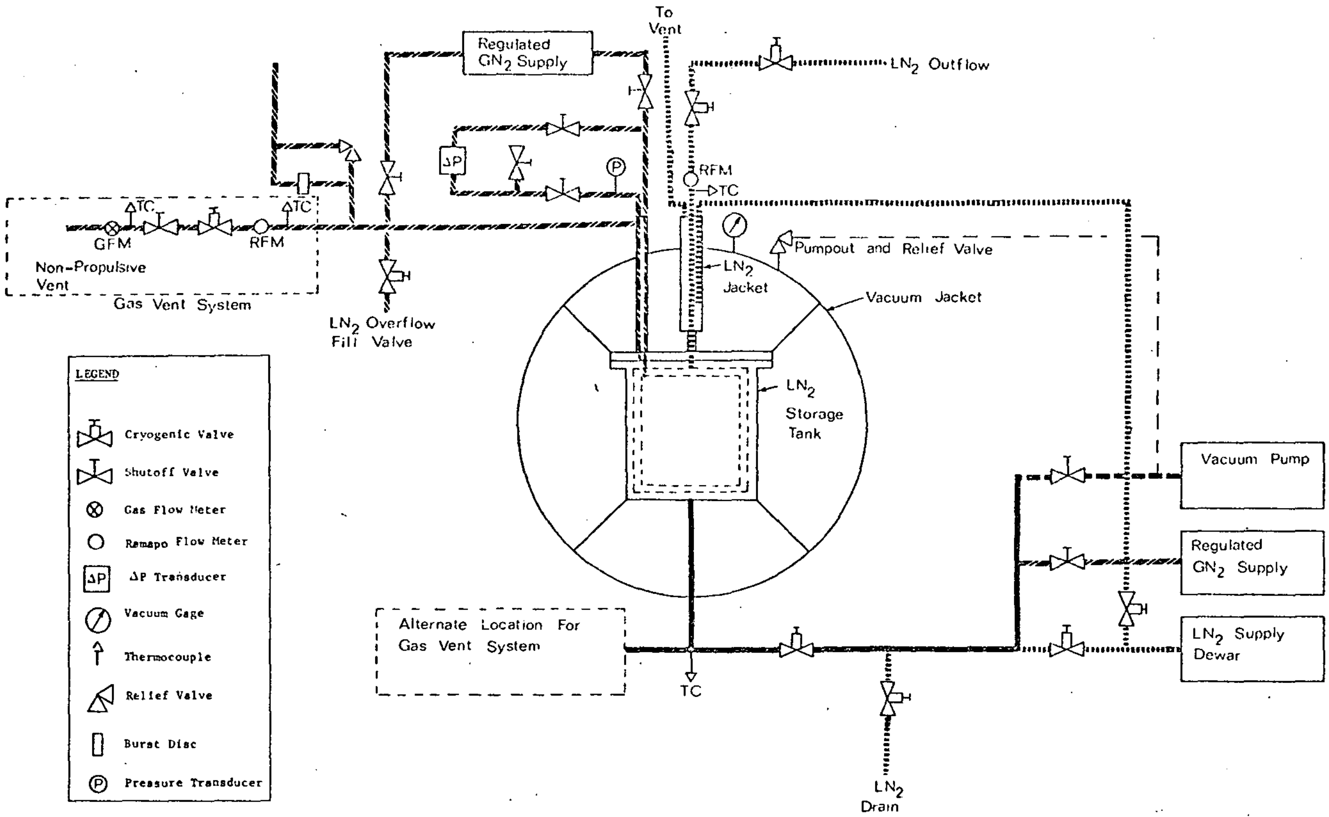

Figure 2 Bench Test Setup (One-g Test)

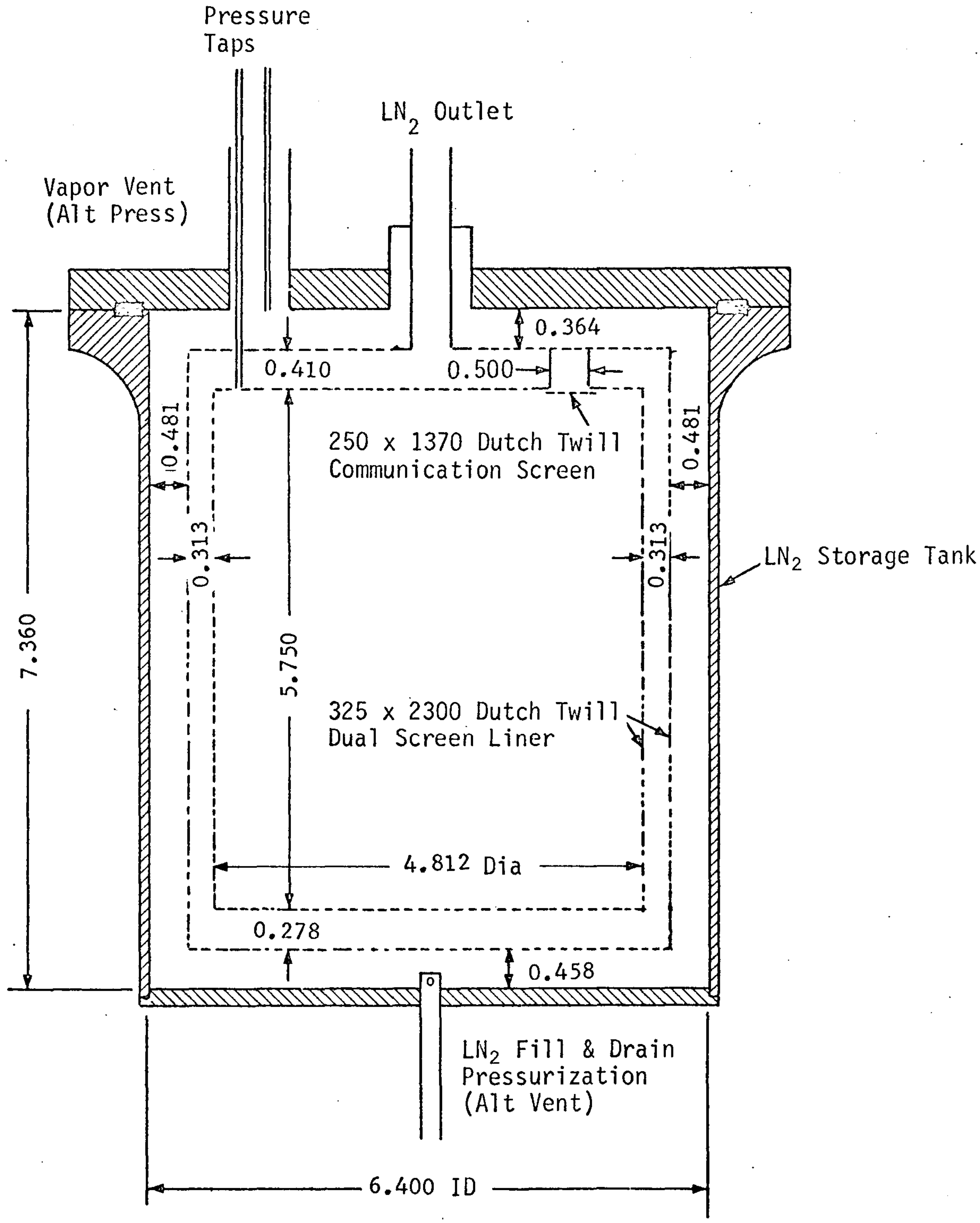

Figure 3 Subscale DSL Dimensions

The storage tank is insulated with multilayer insulation (MLI) composed of 20 layers of Mylar aluminized on both sides with each layer separated by nylon netting. Two 124-ohm electrical heater blankets are located beneath the MLI adjacent to the storage tank wall barrel section to provide a heating capability up to 200 watts with a 110-volt power supply. Each separately controlled heater encompasses one-half of the tank barrel section. Eight minimum-heat-conducting supports attach and position the storage tank to the 18-in.-diameter spherical vacuum jacket. A combined vacuum pumpout/pressure relief valve is incorporated in the vacuum jacket.

B. SYSTEM PLUMBING

A 1/4-in. line from the bottom of the LN_2 storage tank connects the vapor annulus with a vacuum, pressurization, and LN_2 fill and drain manifold. This line terminates in a pressurant diffuser inside the vapor annulus. The LN_2 outflow line and the vent line for the vapor are connected to the top of the LN_2 storage tank. The 1/2-in. LN_2 outflow line is connected to the liquid annulus and has a LN_2 jacket starting just above the top of the storage tank and extending through the vacuum jacket to the inlet of the liquid flowmeter. The 3/4-in. vent line duct connects to the vapor annulus at the storage tank top and also extends through the vacuum jacket. This duct contains electrical leads to sensors located within the storage tank, 1/16-in. pressure-tap lines to the vapor annulus and the bulk liquid region, and allows gas venting (a 1/4-in. gas vent line leads from the duct after it passes through the vacuum jacket). A safety relief valve and burst disc package located external to the vacuum jacket is connected to the gas side of the storage tank. A 47-psig burst disc and a 42-psig relief valve setting are employed and system operating pressure is limited to 37 psig. These values arose from the 65-psia maximum line pressure capability of the differential pressure transducer. The design operating pressure for the LN_2 storage tank was 100 psia.

Manually operated valves are included in the various lines for system operation.

C. INSTRUMENTATION

Instrumentation for the system includes platinum resistance sensors for measuring temperature and liquid level in the bulk liquid/ullage region, in the liquid annulus, and in the vapor annulus. Platinum sensors are used to verify liquid-free vapor in the gas vent and vapor-free liquid in the LN_2 outflow line. Strain gage-type flowmeters are also located in these lines, outside the vacuum jacket, to measure flow rates and to aid in verifying a single-phase flow. In addition, a rotameter will be used in the gas vent line to measure low flow rates and a liquid displacement technique will be added for ultralow venting rates. A load cell measuring changes in system weight may aid in verifying liquid level prior to and after liquid outflow.

Chromel-Constantan thermocouples are employed to measure storage tank wall temperature, external insulation temperature, temperatures at each end of the storage tank penetrations and supports, fill and drain line temperature, and fluid temperatures immediately ahead of each flowmeter.

System pressure is measured by a 0 to 100-psia absolute pressure transducer connected to the vapor annulus. A $\pm$1-psi differential pressure transducer is used to measure the small ($<$0.3 psi) pressure differential across the dual screen liner (between the vapor annulus and the bulk liquid/ullage region).

D. SUPPORT SYSTEMS

A LN_2 supply dewar, a pressurant supply, and a vacuum pump are required for system operation. Connecting lines and valving are also needed. No provisions are included for trapping either the LN_2 outflowed or the vapor vented from the storage tank; these are simply plumbed overboard to a suitable outlet area. Equipment is also required for measuring and recording the output from the various instrumentation sensors.

E. MODIFICATIONS FOR DROP TOWER AND AIRCRAFT TESTING

No structural additions are required to meet the higher g-level requirements outlined in Reference 2. The valving, however, must be modified to provide remote actuation. Also a new approach incorporating automatic sensing of vapor flow rate is required. In addition, vapor and liquid catch tanks would be needed for drop tower testing. This could necessitate additional valving and instrumentation. Catch tanks are probably not required for airplane tests since an overboard vent is available (Ref 2). Modifications in the data recording techniques may also be required.

IV. DESCRIPTION OF ANALYTICAL MODEL

The computer program developed under Task II, NAS9-10480, models the thermodynamics of the dual-screen liner in 1-g. The contents of the tank are divided into five thermal nodes corresponding to the following volumes:

1) Outer annulus vapor volume;

2) Bulk vapor volume;

3) Bulk liquid volume;

4) Inner annulus liquid volume facing bulk ullage;

5) Inner annulus liquid volume facing bulk liquid.

Heat and mass transfer occur between nodal interfaces:

$A \rightleftarrows D$, $A \rightleftarrows E$, $B \rightleftarrows C$, $B \rightleftarrows D$, $C \rightleftarrows E$, $D \rightleftarrows E$.

Mass transfer occurs through the communication tube and screen connecting the outer annulus and bulk vapor region, $A \rightleftarrows B$.

A uniform heat flux is input to the outer annulus vapor. A communication screen bubble point is input as a criterion for flow between the outer annulus and the bulk ullage. A maximum tank pressure is set as a criterion to initiate vent flow (at an input rate). The venting is stopped when the pressure difference between the outer annulus and bulk region lowers to some input value. Liquid expulsion may be programmed at an input flow rate commencing and terminating at input times.

Computer-plotted pressure and temperature histories are outputs of the program. The program can be used for numerical experiments to establish detailed test procedures and operating conditions and parameters. Comparison of the computer and actual test results is recommended to verify the model and to evaluate the performance of the DSL operation.

V. ONE-G TEST PROGRAM

A. FACILITY DEFINITION

1. Test Fixture

The test fixture consists of the spherical vacuum tank containing the DSL tank, which is mounted on a portable platform. Plumbing includes pressurization, vent, drain, and outflow lines. All lines permit liquid outflow. All valves mounted on the fixture are manually operated.

2. Electrical and LN_2 Servicing

A receptacle is provided for 110-volt ac or 28-volt dc electric power for tank heaters. The liquid nitrogen supply, typically a portable, pressurized 25-liter dewar, connects to the drain line for bottom filling.

3. Test Data Recording Equipment

Two 37-pin connectors mounted on the fixture supply data on 8 internal temperatures and 18 external temperatures. Additional connectors come from the vent flowmeter, liquid expulsion flowmeter, tank pressure transducer, external thermocouples, differential pressure transducer, and from load cells. Scanning visual readout is required on all data during the tests to provide operational information to the test conductor.

Permanent data storage may be taken by digitized recording on magnetic tape. Conversion factors and data plots are then available directly from the computer.

4. Test Controls

All test operations are controlled manually. Test operator access to test conditions is maintained by open communication between the operator and personnel monitoring test data in the data collection center.

B. TEST PROCEDURE - GENERAL

The multilayer insulation thermal properties require the vacuum tank pressure to be taken down to about 10^{-5} torr. A fitting on the 18-in.-diameter tank attaches to a diffusion pump and a roughing pump. The initial evacuation may require several hours pumping to remove gases trapped in the insulation. Periodic repumping between tests is required since the insulation will continue to slowly outgas over the span of the test program.

C. TEST OUTLINE

1. Tank Childown and Fill with LN_2

It is significant to show that the DSL tank can be readily and easily filled, avoiding the trapping of unwanted gas pockets, particularly within the liquid annulus. The performance of simultaneous childown and fill, including the time to reach thermally steady-state conditions, is desired to show system feasibility.

2. Outer Annulus Vapor Fill

A unique characteristic of the DSL concept is that a complete vapor blanket is maintained in the annulus between the tank wall and the outer screen between liquid outflow demands during coast periods in a mission profile. This vapor region is designed as a continuous source for direct vapor venting to hold tank pressure.

An objective of this test program is to show that the outer annulus can be filled with vapor either by evaporation due to external heat leak or electrical heating, or by pressurized outflow of liquid from the outer annulus. Surface tension forces must hold liquid out of the annulus in the 1-g adverse environment. If this can be accomplished in 1-g, then it can be reasonably expected that a vapor annulus can be maintained in the spacecraft environment.

3. Communication Screen (Pressure Retention)

The bulk region inside the screen liners will normally contain an ullage. As the heat leak raises the outer annulus pressure, the bulk region and outer annulus pressure difference can increase and cause vapor breakthrough into the liquid annulus. The pressure difference between the two regions must be kept above a minimum value to prevent liquid spilling into the outer annulus, yet not so high as to cause gas ingestion into the liquid annulus.

A screen passageway (tube) is placed through the liquid annulus to directly connect the two regions, alleviating the problem. A screen of a coarser mesh than the screen liners is placed across the tube. This communication screen wicks by liquid flow from the liquid annulus, providing a barrier to direct gas flow between the bulk region and outer annulus. The wetted communication screen permits a pressure difference to exist up to bubble point of the screen. If the difference rises to exceed the bubble point, then vapor bubbles through the wetted screen, passing from the outer annulus to the bulk region until the difference is reduced below the screen bubble point.

It is desirable to the DSL concept that the communication screen and vent valve regulate the bulk region and outer annulus pressure difference between a lower limit that prevents liquid spilling into the outer annulus, and an upper limit that prevents gas ingestion into the liquid annulus. The specific objective of this test is to verify functional operation.

4. Liquid Expulsion

Demonstration of single-phase liquid expulsion following thermal venting operations is necessary to show that the screen retention capability has not broken down with gas ingestion into the liquid annulus. It is also desirable to show whether the pressurant flow from the outer annulus to the bulk region will dry out the communication screen, allowing liquid to spill into the outer annulus during expulsion. (This would not invalidate the DSL concept, of course, since any liquid in the outer annulus would be transferred back into the bulk region before venting would become necessary.)

5. Vapor Venting for Tank Pressure Regulation

Over long time periods between liquid outflows, the tank heat leak may raise the tank pressure to the point of requiring relief. A unique advantage of the DSL concept is that in any gravity condition between ±1g (including low-g) the outer annulus is filled with vapor. The specific test objective is to demonstrate tank pressure regulation by single-phase vapor venting.

6. Thermal Performance Assessment

The thermal performance increase provided by the passive DSL retention/expulsion system is demonstrated through testing its ability to control tank pressure over an extended time by periodic vapor venting. The objective of this test is to show the feasibility of rejecting a sufficient portion of the tank heat leak by cyclic vapor venting from the outer annulus to bound tank pressure.

D. TEST RESULTS

1. Tank Childown and Fill

The time required for LN_2 overflow to remove most system heat and the time required at passive hold for thermal stabilization are desired results to be indicated by temperature decays. A second result is to determine whether the inner screen liner will support complete liquid expulsion from the bulk region. This is checked by pressurizing the bulk region and outflowing liquid.

2. Vapor Annulus Fill

Specific results include determining the rates at which the outer annulus can be emptied of liquid by pressurization, natural heat leak, or by electrical heating elements with either a full or partial liquid load. Demonstrating that the screen design can support the head necessary for a full vapor annulus is a desired result.

Comparison of computer calculations and experimental data yields checks on model validity and lends interpretation to collected data.

3. Communication Screen Pressure Regulation

Adequacy of the screen cross sectional area and screen rewicking are key results to determine the feasibility of the passive self-regulation technique.

4. Liquid Expulsion

Single-phase liquid expulsion demonstrates that the thermal control operations of the dual-screen liner do not impair the screen design capability for liquid expulsion in an adverse 1-g field.

5. Vapor Venting/Tank Pressure Regulation

The primary result of the test is to show that the vapor annulus can be vented on a steady cyclic basis. Maintenance of thermal stability and control is the second desired result.

Comparison of experimental and computational results further verify the analytical model.

6. Thermal Performance

The specific results of the tests will be a measurement of the natural heat flux to the liquid and vapor in the DSL tank and the percentage heat influx being vented over a vent cycle. The tank pressure control through vapor venting over an extended test time of several days is the desired result that most clearly shows the thermal performance increase capable through the use of the dual-screen-liner.

E. TEST PROCEDURE - SPECIFIC

1. Tank Childown and Fill

a. The tank is stored at ambient temperature under a gaseous (dry) nitrogen blanket pressure of 3- to 5-psig.

b. Connect LN_2 dewar to pressurant/drain line and begin to slowly fill the tank.

c. Open liquid outflow line and overflow valve on gas vent line.

d. Maintain 1- to 3-psig so that atmospheric gases do not back-diffuse into the tank.

e. Keep LN_2 flowing into tank until continuous single-phase liquid overflows the ports.

f. Stop LN_2 inflow.

g. Maintain slight flow with venting until temperature measurements show the tank approaching a near-steady thermal condition.

h. Seal ports.

i. Prepressurize tank to collapse any condensible gas pockets.

j. Weigh tank to measure fill efficiency.

k. Outflow LN_2 against 1-g (pressurizing bulk region) to demonstrate single-screen-liner expulsion, noting any gas bubbles expelled, screen breakdown, and expulsion efficiency.

l. Allow N_2 gas blanket to warm inside tank to prechilldown and fill conditions.

Instrumented data to be monitored and recorded during the test include:

1) Tank pressure;

2) Tank temperatures;

3) LN_2 outflow rate;

4) Weight of loaded LN_2;

5) Time.

2. Outer-Annulus Vapor Fill

a. Chill and fill tank with LN_2.

b. Prepressurize tank.

c. Displace outer annulus liquid with vapor or pressurant:

1) Using natural heat leak; or

2) Using wall heat; or

3) Draining liquid while pressurizing through the outer annulus vent line.

d. When the pressure differential between the bulk region and outer annulus indicates that the liquid level has reached the bottom of the screen, drain last liquid from annulus while pressurizing through outer annulus vent line.

e. Terminate draining when liquid no longer comes out of the drain line.

f. Equalize the bulk region and outer annulus pressures by opening a connection between the two vent lines, allowing liquid to spill back into the outer annulus.

g. Close the connecting line and allow the heat flux to raise the pressure in the outer annulus forcing the liquid in the outer annulus to flow back into the bulk region.

h. Repeat steps d, e, f, and g until the bulk region liquid is depleted.

Instrumented data to be monitored and recorded during the test include:

1) Heater power;

2) Tank pressure;

3) Bulk region/outer annulus pressure differential;

4) Tank temperatures;

5) LN_2 weight (liquid fill level);

6) Time.

3. <u>Communication Screen Pressure Regulation</u>

a. Chill and fill tank with LN_2.

b. Fill outer annulus with vapor/pressurant.

c. Allow outer annulus pressure to rise toward the vent pressure limit either by natural heat leak or by heater power.

d. Monitor pressure difference between bulk region and outer annulus while vapor is being passed across the communication screen.

e. Monitor outer annulus temperatures for liquid spillage.

Instrumented data to be monitored and recorded during the test include:

1) Tank pressure;

2) Bulk region/outer annulus pressure differential;

3) Heater power;

4) Tank temperatures;

5) Time.

4. <u>Liquid Expulsion</u>

a. Chill and fill tank with LN_2.

b. Fill outer annulus with vapor/pressurant.

c. Expel a percentage of the bulk liquid while pressurizing outer annulus.

d. Observe outer annulus temperatures for liquid spillage.

e. Monitor communication screen pressure differential for screen dryout.

f. Continue expelling liquid to the point of screen breakdown.

g. Measure expulsion efficiency.

h. Allow N_2 gas blanket inside tank to warm to prechilldown and fill conditions.

5. Vapor Ve[illegible]

a. Chill and fill tank with LN_2.

b. Fill outer annulus with vapor/pressurant.

c. Allow outer annulus pressure to rise either by natural heat leak or by heater power.

d. Establish cyclic pattern of pressure buildup and annulus venting.

e. Monitor annulus pressure cycles.

f. Monitor annulus temperatures for liquid spillage into outer annulus.

g. Monitor communication screen pressure differential for proper regulation of the pressure difference between the bulk region and outer annulus.

h. Run vent cycles for a spectrum of vent flow rates, upper pressure limits to open vent valve, and lower pressure limits to close the vent valve.

i. Partially expel liquid and run vent cycles at a second liquid fill level.

6. Thermal Performance

a. Chill and fill tank with LN_2.

b. Fill outer annulus with vapor/pressurant.

c. Establish a steady venting cycle.

d. Measure the vented mass and the temperature rise in the bulk liquid over 5 cycles; calculate the heat leak into the tank as the heat content of the vented vapor plus the enthalpy rise in the bulk liquid.

e. Record temperatures on both ends of the penetrations into the tank; estimate the distribution of the total tank heat flux between each of these sources.

f. Continue vent cycle sufficiently long (2 days) to demonstrate that a thermal performance increase can be provided by the dual-screen-liner method in limiting tank pressure rise.

VI. DROP TOWER TEST PROGRAM

A. FACILITY DEFINITION AND TEST PROCEDURE (GENERAL)

Two drop tower conditions have a major impact on the facility design. First, the test article is isolated from the operator before, during, and after the drop, necessitating remote control of the heat conditions and catch tanks to receive vented and expelled fluids; second, the deceleration of the drop capsule at the end of drop exposes the test article to 32-g for up to 1 second. The support structure holding the test tank inside the vacuum tank is designed to hold the load.

Liquid nitrogen servicing -- tank chilldown and fill -- must be accomplished while there is complete access to the test article. After the drop capsule is poised for the drop, the test conductor must remotely establish the DSL operational conditions he wishes to observe in the low-gravity environment of the drop test by remote manipulations. The control console must display instrumental data brought by landlines from the capsules and contain switches to actuate valves and the heater. Any changes in the DSL operation during a drop must be programmed to occur automatically. High-speed strip chart recorders are required to preserve data generated during the short drop test times.

Additional safety precautions will have to be taken with the use of cryogenic nitrogen in the drop tower facility.

B. TEST OUTLINE

The short test duration (less than 5 s) is the primary limitation to significant drop tower tests. Mission time for the test article is typically on the order of hours. A vent cycle requires about 1 minute with a 5 Btu/ft^{2}hr heat leak, according to computer calculations. However, small segments of the DSL operation can be demonstrated in low gravity as described in the following three experiments. The results from these experiments will not be significantly improved by moving from the industrial capability of two seconds to the NASA Lewis 5 to 10-second drop tower.

1. Vapor Venting

Having established complete vapor fill of the outer annulus prior to drop, vapor venting can be observed for 2 seconds under zero-g conditions. The test will determine whether liquid is drawn into the outer annulus at the vent port.

2. Communication Screen Operation

Having established a vapor annulus and the thermodynamic condition causing ullage to flow from the outer annulus to the bulk region, the 2.1-second drop test will be initiated. Pressure monitoring will indicate any changes in the DSL operation in zero-g.

3. Liquid Expulsion

Liquid outflow with pressurization in the outer annulus will demonstrate that ullage flow through the communication screen forcing liquid out of the bulk region is feasible.

C. TEST RESULTS

The three series of tests will ascertain how the critical DSL operations are affected by the introduction of a zero-gravity environment. However, the large amplitude fluid motions caused by the step change in gravity are not characteristic of spacecraft conditions. That, coupled with the short test time, limits the significance of the results.

1. Vapor Venting

The vent flow rate will indicate the presence of any liquid expelled from the outer annulus. An imposed low-gravity condition will position any liquid brought into the annulus over the vent port. It is anticipated that the liquid reorientation in the bulk region will cause a faster pressure decay than experienced in the 1-g tests.

2. Communication Screen Operation

The primary effects to be seen are the drop in bulk region pressure due to destratification caused by liquid reorientation and the liquid covering the bulk region side of the communication screen. Since the vapor bubble passing through the screen is superheated relative to the liquid, heat transfer will tend to collapse the passed bubble.

It is anticipated that the data may show that the vapor flow across the communication screen is not sufficient to maintain the pressure differential at the communication screen bubble point.

3. Liquid Expulsion

The desired test result is to show whether sufficient pressurant can flow across the communication screen to counter the pressure decay due to liquid reorientation and to expel the bulk liquid.

D. TEST PROCEDURE (SPECIFIC)

1. Vapor Venting

a. Fill and chill down the tank while the test conductor has direct access to the test article. Dump overflow and vented N_2 overboard. Seal system and switch vent to an onboard evacuated catch tank.

b. Move drop capsule to drop position. Remotely drain liquid from outer annulus into a second catch tank.

c. Turn on heater to 20 watts. Record pressure and temperature rises inside the tank.

d. When the pressure reaches a prescribed vent level, open vent valve remotely. After a few seconds pause, release the drop capsule to "zero-g."

e. Continue the vent through the drop period, recording pressures and temperatures inside the tank as well as the vent flow rate.

f. At capsule bottoming turn off heater. The intense turbulent mixing will destratify the system, cooling the walls and ullage. The overall effect will be to drop the tank pressure and stabilize the pressure rise to a low natural heat leak effect.

g. Open capsule as soon as reasonable and drain liquid overboard.

h. Repeat test with heater power of 40 watts and 60 watts with correspondingly higher vent rates.

i. Repeat tests following expulsion of 50% of liquid load prior to drop.

j. Repeat tests with a drop condition of -0.01 g.

2. Communication Screen Operation

a. Fill and chill down tank.

b. Move drop capsule to drop position. Remotely drain liquid from outer annulus.

c. Turn on heater to 20 watts. Record pressure and temperature inside the tank.

d. When the communication screen pressure differential reaches the bubble point, pause for about 15 seconds and release the drop capsule to "zero-g."

e. Record total tank pressure, the communication screen pressure differential, and tank liquid and vapor temperatures through the drop.

f. At capsule bottoming turn off heater and open vent valve.

g. Open capsule as soon as reasonable and drain liquid overboard.

h. Repeat test with heater power of 40 watts and 60 watts.

i. Repeat tests following expulsion of 50% of liquid load prior to drop.

j. Repeat tests with a drop condition of -0.01 g.

3. Liquid Expulsion

a. Fill and chill down tank.

b. Move drop capsule to drop position. Remotely drain outer annulus.

c. Prepressurize and begin liquid expulsion to catch tank at 0.05 gal/min.

d. Immediately release drop capsule to "zero-g," recording outflow rate, tank pressure, communication screen pressure differential, and liquid and vapor temperatures.

e. At capsule bottoming, stop liquid expulsion and open vents.

f. Open capsule as soon as reasonable and drain liquid overboard.

g. Repeat test releasing drop capsule after 50% of liquid is expelled.

h. Repeat tests at 0.1 gal/min and 0.4 gal/min.

i. Repeat tests with a drop condition of -0.01 g.

VII. KC-135 AIRPLANE TEST PROGRAM

A. FACILITY DEFINITION AND GENERAL TEST PROCEDURES

The test fixture must be mounted on a tiedown pallet with an aluminum tubing framework to protect the package. Structural demands include design to 16-g forward, 8-g down, 4-g up and laterally, and 1.5-g aft. The structure holding the test tank within the vacuum tank is adequate to withstand these accelerations. A free-floating pallet adds an unwarranted complexity to the test program. In actuality, the airplane loads imparted to a tiedown pallet more realistically model the spacecraft environment.

Modification for remote operation from a control console with adequate data display and recording capability is required. The aircraft 28-volt power supply will be used. A LN_2 supply must be provided.

The liquid nitrogen fill and tank chilldown are to be done in the 1-g steady environment of the plane. Prior to pulling the 2.5-g maneuver to establish the Keplerian trajectory, approximately 50% of the liquid load must be expelled. Immediately on entering the zero-g environment, the liquid remaining in the outer annulus is pressure-fed into the bulk region. At this point the specific tests may begin. The annulus emptying time is estimated to be about 2 seconds.

B. SPECIFIC TESTS

The longer airplane test time available, as compared to the drop tower facility, is not sufficient to broaden the scope of the testing. (Several hours, or more, are required to model spacecraft initial conditions.) Rather, the longer airplane test time permits a more indicative measure of the effects of low gravity on critical parts of the DSL operation--vapor venting, communication screen pressure regulation, and liquid expulsion.

Therefore, the three test series described under Chapter VI, Drop Tower Test Program, will be repeated in KC-135 airplane testing with the exception of the initially full-liquid-load tests. The mechanism for draining the outer annulus must necessarily change since the screen cannot support a full vapor annulus at 2.5 g.

C. TEST RESULTS

The results of these tests will be compared with the drop tower test results to verify that the observed low-g performance is independent of the change in test environment and the longer test time (sufficient for most liquid sloshing to dampen down). However, realization of the DSL operation in a conduction-dominated heat transfer environment still is not possible with the KC-135 test times available.

VIII. REFERENCES

1. R. E. Hise: Recommended Schedules and Estimated Costs for Conducting One-g and Low-g Tests Using the Passive Retention/Expulsion Prototype. Memo No. 10480-30, Martin Marietta Corporation, Denver, Colorado, 26 February 1971.

2. K. C. Lunden: Evaluation of Test Modes of Contract NAS9-10480. Memo No. 10480-24, Martin Marietta Corporation, Denver, Colorado, 3 November 1970.

DISTRIBUTION

Copies	Recipient	Designee
1	NASA Manned Spacecraft Center R&D Procurement Branch Houston, Texas 77058 J. H. Goldstein/BG721	(X)
2-5	NASA Manned Spacecraft Center Power and Propulsion Division Houston, Texas 77058 J. Smithson, Mail Code EP5	(X)
6-14	Internal Distribution H. Paynter, Mail Code 1660	(X)