N93-13182

THE VTRE PROGRAM - AN OVERVIEW*

William J. Bailey and John P. Gille
Martin Marietta Corporation
Denver, Colorado

ABSTRACT

The Vented Tank Resupply Experiment (VTRE) Program is a NASA In-Space Technology Experiments Program (IN-STEP) that will develop and fly a small, low cost space experiment to investigate, develop, and acquire needed data to extend and advance the technology of capillary vane fluid management devices to applications requiring direct venting of gas from tanks in low-gravity. Gas venting may be required for control of pressure, or to allow low-g fill of a tank with liquid while holding a constant tank back pressure by gas venting. Future space applications requiring these fluid management capabilities include both cryogenic and Earth storable fluid systems. The experiment is planned as a Shuttle Hitchhiker payload, and will be developed around two transparent tanks equipped with capillary vane devices between which a test liquid can be transferred. Experiments will be conducted for vented transfer, direct venting, stability of liquid positioning to accelerations within and significantly above the design values, and fluid reorientation by capillary wicking of liquid into the vane device following intentional liquid upset.

INTRODUCTION

Strategies and hardware have been developed for space fluid management requirements for acquisition and delivery of liquid from part-filled tanks in the weightless, low-g space environment. Approaches used have included propulsive settling to establish a low-level artificial gravity; mechanical liquid-gas separation devices such as bladders, bellows and diaphragms; and "capillary" devices that exploit the small surface tension force of liquid-gas interfacial surfaces to collect liquid to a tank outlet port for delivery to using systems, such as propulsion and attitude control thrusters.

Capillary Fluid Management Techniques

Two types of capillary device are used. One relies on the characteristics of wetted fine-mesh woven screen, through which liquid flows in preference to gas. The screen devices are normally configured as a duct network (called channels or galleries) that connect various regions of the tank to the liquid outlet line. A part of the duct wall is made of very fine mesh screen. Gas entry into the duct is resisted by a significant "bubble pressure" required to force a bubble through the screen while liquid passes with little flow

---

* The Phase B Conceptual Design Study for VTRE was performed for NASA Lewis Research Center under Contract NAS3-25977. Mr. Don Bresnahan & Mr. Al Seigneur were NASA Project Managers.

PRECEDING PAGE BLANK NOT FILMED

resistance. In this way, liquid is collected and gas is prevented from entering the duct. The second type of capillary device consists of a number of surfaces configured to draw liquid into regions between closely spaced vanes by capillary wicking action. Capillary vane devices can be configured to collect and transfer liquid to a tank outlet under very low-g conditions.

Both capillary devices depend on liquid wetting the materials of which the device is constructed, an inherent characteristic of all liquids of interest in contact with most materials of construction. For this reason, there is no analogy for collecting gas using similar devices to support tank venting. However, gas can be positioned by default if all liquid is collected to a defined location. Propulsive settling is one approach; the capillary vane concept, designed for total liquid wicking is another. Capillary screen devices do not position liquid and can not implement gas venting.

Direct tank venting has been required infrequently to date. The Centaur vehicle requires a programmed reduction of propellant tank pressure that is accomplished by directly venting gas after firing thrusters to settle liquid propellants away from the vent port. The Saturn launch vehicle had a similar requirement. The Viking Orbiter (VO-75) propellant tanks were provided a capability for direct venting of pressurant for emergency overpressure relief, using a capillary vane type liquid acquisition system, depicted in Figure 1. This system primarily provided for liquid delivery to the propulsion system, but also positioned all liquid, thereby locating the ullage gas to the vent port in a very low g environment. However, venting was not attempted on either VO-75 mission.

Pressure reduction may result in formation of bubbles within the liquid bulk, by evolution of dissolved pressurant gas, as occurs when a carbonated beverage is opened, or when the boiling temperature is reached because of pressure reduction. To vent under these conditions, the vane device must be able to pump the bubbles toward the normal ullage region. This is accomplished by configuring the vanes so the size of a bubble that would not be constrained by the vanes increases toward the vent port. Bubbles of sufficient size to be squeezed by the vanes will be forced toward the more open region, and bubbles pushed together by this process will tend to coalesce into larger bubbles that will be further pumped toward the vent.

Many advanced missions will require space resupply of liquids, including Space Station Freedom, and the capability for resupply could be profitably used on current systems. An example is communications satellites whose life is normally limited by depletion of attitude control propellant, not by failure of the communications hardware. Only limited experience has been accumulated on liquid transfer in space, however. Soviet space programs have resupplied liquids using bellows type positive displacement tanks and NASA has demonstrated space servicing of a hydrazine tank equipped with a diaphragm type liquid management system (Orbital Resupply System - ORS). These capabilities are restricted to positive displacement fluid management devices which are limited in their applicability to relatively small tank size and ambient temperature fluids.

The Vented Tank Resupply Experiment (VTRE) addresses capillary vane fluid management technology in space applications of direct gas venting and vented resupply of liquids of all types, including cryogens & corrosive Earth storable oxidizers. The Viking Orbiter vane concept (Figure 1) represents a point of departure. This design was developed specifically for emergency vent of a relatively small tank in a very low drag environment with small and infrequent acceleration disturbances. Advanced systems must be designed for larger tanks, greater and more frequent disturbances (but still quite small), and venting to meet various mission needs. Vane systems must also be designed so capillary positioning strength exceeds the dynamic force of entering liquid during fill, positively controlling the liquid-gas orientation to assure only gas at the tank vent port. This capability will permit refill of tanks without loss of liquid with the approach normally used in the Earth environment, that is, maintain a constant receiver tank pressure by venting gas as required.

Background

There is significant research and development history relative to vent and resupply using capillary vane devices to support a flight investigation at this time. The most extensive effort was the development in the early '70s of the device for the VO-75 vehicles, which was provided by Martin Marietta Corp. Earlier (1969-72), NASA Lewis Research Center performed extensive drop tower testing of transfer of liquid into small cylindrical tanks free of internal hardware while venting, and established criteria for which stable fill could be achieved. Martin Marietta has continued low-g venting research (from 1976) under internal and contractual research and development programs. Venting and vented resupply tests have been conducted in KC-135 aircraft in spherical tanks of 10 and 32 cm (4 and 12.5 in.) diameter, and in 10 cm (4 in.) diameter spherical and cylindrical tanks in the Martin Marietta 2-second drop tower low-gravity facility, and vented fill tests are continuing at the present time under Independent Research & Development (IR&D) funding. Figure 2 illustrates the configuration of the current drop tower test articles including vane and tank inlet design. These tests have demonstrated the validity of the vane concept to control liquid location during fill, and dimensionless criteria for stable vs unstable fill have been bracketed.

VTRE Objectives

The mission of VTRE is to experimentally investigate capillary vane fluid management technology using the Shuttle Hitchhiker as the experiment carrier. VTRE experiments will specifically address direct tank venting and vented tank resupply. Secondary objectives are to determine positioning stability of the vane system under moderate acceleration disturbances, above the normal Shuttle background, and ability of the capillary vane system to reorient liquid following deliberate upset by adverse Shuttle thrusting. In addition, the VTRE transfer tests will inherently demonstrate the ability of the vane devices to deliver all liquid to the tank outlets under a nominal Shuttle acceleration environment at significant transfer rates. These experiments will obtain data that will define critical design parameters, verify scaling relationships, and provide a database and design approach for design of advanced capillary vane fluid management systems.

EXPERIMENT DESCRIPTION

Experiments to be conducted as primary objectives of VTRE are vented transfer and direct tank vent tests. Secondary tests investigate the ability of the capillary vanes to maintain liquid position during low-level acceleration disturbances, and the ability of the device to relocate liquid after it has been upset by an adverse acceleration.

Experiments will be performed using two transparent test tanks that are viewed with video camera-recorders. Tank A is a cylindrical tank 31.75 cm inside diameter by 40.6 cm inside length (12.5 x 16 in.) with hemispherical domes. Tank B is spherical with 35.5 cm (14 in.) inside diameter. The two tanks are of equal net volume. They are connected for liquid transfer through a series of parallel and series valves configured to provide seven discrete transfer flow rates. Each can be connected to the pressurization subsystem, and each can be connected to the vent system that either maintains a fixed backpressure or provides any of seven discrete flow impedances to the overboard vent. The test liquid selected is Refrigerant 113, a non-flammable, non-toxic liquid with characteristics suitable for simulation of most liquids of interest. Nitrogen was selected as the pressurant.

Twelve vented transfer tests are planned. Test parameters include the direction of transfer, into tank A (cylindrical) or tank B (spherical), the transfer flow rate, and the target fill level in percent. The first eleven tests will be conducted while maintaining a constant backpressure of approximately 117 kPa (17 psia) on the receiving tank. The twelfth will start with the receiver tank pressure initially near the triple point pressure of the test liquid, and the pressure will be allowed to rise until it reaches the preset backpressure level, allowing observation of the effects of partial vaporization of the liquid as it enters the tank. Acceleration is a parameter, with most tests conducted with normal Shuttle background acceleration environment, and also the maximum drag acceleration of 2×10^{-6} g. Initial and target fill levels are also test parameters.

Fourteen vent tests have been defined. Test parameters include the tank being vented, the vent rate as established by choice of the vent impedance selection valves, initial and final pressure, and quantity of liquid at the start. Except for one, these tests are run at normal Shuttle background acceleration; the one will be conducted at the maximum drag condition imposing an approximate 2×10^{-6} g laterally.

Tests for determining the stability of the capillary vane device, response to imposed acceleration disturbances, and reorientation of liquid by capillary wicking action are conducted simultaneously for both tanks. Each test run is accomplished by establishing the quantity of liquid required in each tank, actuating the lights and cameras, performing the Shuttle maneuver required to create the disturbance, and continuing the video record for sufficient time to permit the response to be completed. Test parameters are the accelerations imposed and the liquid fill level in each tank. For the stability tests, short accelerations on the order of $5x10^{-5}$ to $1x10^{-4}$ g are imposed. To assure large scale displacement of liquid from the vane device, an adverse (reverse relative to launch) acceleration of 4x10-4 or greater will be imposed for a period up to one minute depending on the Orbiter RCS firing configuration selected.

DESIGN

The VTRE system has been broken into various subsystems consisting of the following elements: Experiment Subsystem which is comprised of R-113 Test Tanks, GN2 Pressurization, Fluid Distribution and Experiment sensor elements; and Support Subsystem Elements that are comprised of an Avionics Subsystem (which is further broken down into Electrical Power Subsystem, Command and Data Handling (C&DH) Subsystem, Video & Lighting Subsystem, and Experiment Electronics), Structural Subsystem, Cabling and Harness Subsystem and Thermal Subsystem. A flight Software element completes the system flight element definition. In addition there are two ground support elements: the Mechanical Ground Support Equipment (MGSE) and Electrical Ground Support Equipment (EGSE), that will be utilized to provide ground test support, ground servicing, handling support, and maintenance functions.

The experiment tanks, one cylindrical (A) and one spherical (B) are made of crosslinked acrylic with high craze resistance. The tanks will be assembled from blown or vacuum formed domes, machined flanges and a barrel section, and details are shown in Figures 3 and 4. The capillary vane configuration has been developed on the basis of drop tower test results, and includes 12 inner and 12 outer alternating radial vanes. The vane device as it appears for the spherical tank is depicted in Figure 5. The same design concept is followed for the cylindrical tank, but the vanes are shaped to conform to the tank cross section. The combined inner plus outer vane concept provides a capillary wick structure that will maintain liquid position against normal Shuttle accelerations, and the capillary pressure will be sufficient to arrest the momentum of the entering liquid at a typical velocity of 4-6 cm/s (0.13-0.2 ft/s), and to redistribute the flow into the vane system, keeping liquid out of the designated ullage region surrounding the vent port.

The experiment is depicted schematically in Figure 6. For transfer tests, a gaseous nitrogen pressurization system provides a blanket pressure of approximately 172 kPa (25 psia) in the supply tank, and a back pressure regulator maintains the receiver tank pressure at 117 kPa (17 psia), providing a differential of 55 kPa (8 psid) to drive the transfer. Three solenoid valves in the transfer line between tanks select any combination of three pre-adjusted flow regulating valves to provide seven flow rates. The initial test will be performed at a flow rate expected to be near the critical point above which liquid would break free of the vanes and be expelled in the vent. A liquid-gas sensor will detect liquid in the vent, and if none is detected, a higher rate will be selected for the next test. If liquid is detected, experiment logic will select a lower rate instead, and subsequent tests will select from the seven available rates to bracket the critical flow below which the transfer will be successful. A Weber number relationship, a ratio of inertial flow forces to capillary restraining forces, is expected to characterize this stability criterion.

For venting tests, the pressurization system can be operated to establish an initial pressure in the tank, and the vent system will establish a vent flow to reduce the tank pressure. Three solenoid valves select three preadjusted control valves to select seven vent impedances, similar to the transfer flow selecting scheme. The liquid-gas sensor again provides the experiment software with information to determine whether the vent flow should be increased or decreased to bracket the critical vent flow.

FABRICATION AND TESTING

The VTRE has been classified as a Class D instrument payload, with relaxed reliability and product assurance requirements designed to permit development of low cost, single-flight, higher risk payloads, that must, however, meet all Shuttle safety requirements. VTRE is further classified as D-Modified, adding a rigorous test program to enhance confidence in the ability of the experiment to meet its performance objectives. To remain cost effective, the use of expensive flight qualified fluid mechanical and electrical/electronic/ microprocessor hardware cannot be considered except on a selective component-by-component basis and only when other commercial off-the-shelf options pose unacceptable program risk. For the most part, commercially available hardware has been found that has an acceptable risk to justify using for flight.

An engineering model (EM) will be fabricated as a tool that will aid in developing confidence that a multitude of commercial off-the-shelf hardware, including the command and data handling (C&DH) system will perform in the Shuttle launch and space environments. The EM will be a high fidelity duplication of the envisioned VTRE flight design. It will aid in the implementation of the protoflight hardware approach required by the Class D payload. The EM will provide for in-line testing during fabrication and assembly, followed with both functional and qualification tests which will provide early verification of design. A prime function of the EM is to provide a test bed to resolve any remaining engineering issues that might impact the cost and schedule during build and verification of the flight hardware. Another is to permit development and verification of flight software while operating with actual hardware and performing ground test of all flight operations.

The VTRE flight system, and therefore the engineering model, will be designed with adequate margin that will in many cases reduce testing requirements. Verification of hardware for flight will generally be provided by system level testing of the integrated VTRE hardware and by previous demonstration of capability provided by EM testing.

INTEGRATION & FLIGHT OPERATIONS

The VTRE has been developed to the conceptual design level as a Shuttle Hitchhiker payload. The experiment has been packaged into three interconnected Hitchhiker sealed canisters, and can be manifested on either the Hitchhiker -M or -G carriers. The M carrier is a bridge structure to which companion payloads are integrated at NASA Goddard Space Flight Center (GSFC), and the bridge is integrated as a unit into the Orbiter. The G approach requires that each canister be separately mounted to the Orbiter sidewall adaptor beams, and that inter-canister piping and electrical cabling then be installed. Figure 7 shows the layout of VTRE subsystems in the three canisters. The M carrier approach has been selected as the preferred approach, and VTRE is being considered as an OAST-3 experiment to fly in the 1995-1996 time frame. An artist's concept of VTRE on the Hitchhiker M beam is shown in Figure 8.

As a HH-M payload, primary integration activities will occur at Goddard Space Flight Center. The VTRE will be thoroughly inspected, all systems will be functionally tested and leak checked, and the liquid and pressurant tanks will be serviced with fluids. The three canister assemblies, that are shipped assembled to modified HH cover plates, will be installed into canisters, and the canisters mounted to the HH-M beam and electrically connected to the HH avionics unit that provides electrical power and uplink command signals. The interconnecting piping is leak checked, the integrated system is electrically verified with the VTRE ground support equipment (GSE), and multilayer insulation is installed over the external piping. At Kennedy Space Center, the VTRE GSE will perform functional checkout, before the HH-M beam is integrated to the Orbiter as a single payload.

The VTRE operates autonomously, and no data is downlinked or displayed on Orbiter systems. Experiments are, however, divided into seven groupings that will normally be run in sequence. In order to coordinate the experiments with Shuttle operations, and to work around unplanned changes in the Shuttle schedule, these sequences can be selected and initiated from the Payload Operations Center at GSFC. This capability, using the HH Bi-level uplink lines permits coordination of the stability and repositioning experiments with Shuttle maneuvers & thruster firings.

Postflight operations will include offloading data that is stored in computer memory and in 8 mm video cassettes, deservicing fluids, removing interconnecting piping and cabling, and removing the canisters from the beam and the experiment elements from the canisters. Inspection of the hardware will determine if any anomalies developed, and viability of the experiment for reflight. Analysis of the flight data will reconstruct all experiments and reduce all numeric and video data. Critical parameters that must be met to achieve successful venting and transfer will be determined. Test results will be compared with pre-flight analyses and modeling, and these analytical tools will be updated. Results will be extrapolated to full size systems of interest, and a final report, as well as a summary video presentation, will be prepared.

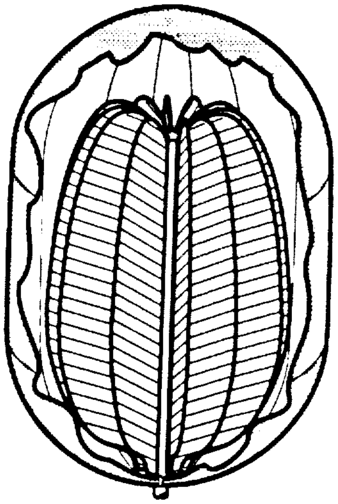

Figure 1 Capillary Fluid Management Concept Used In Viking Orbiter

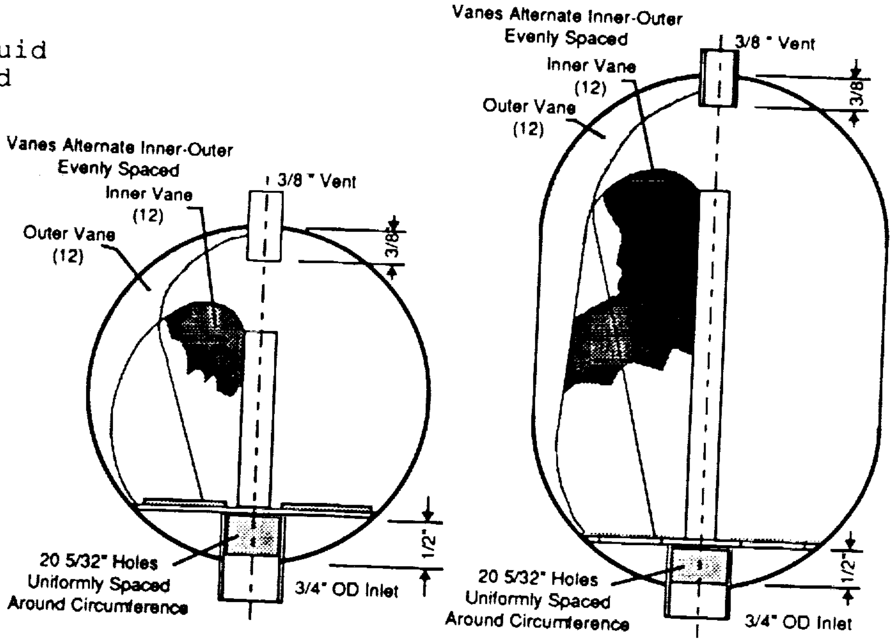

Figure 2 Capillary Vane Test Articles for Recent Vented Fill Drop Tower Test Program

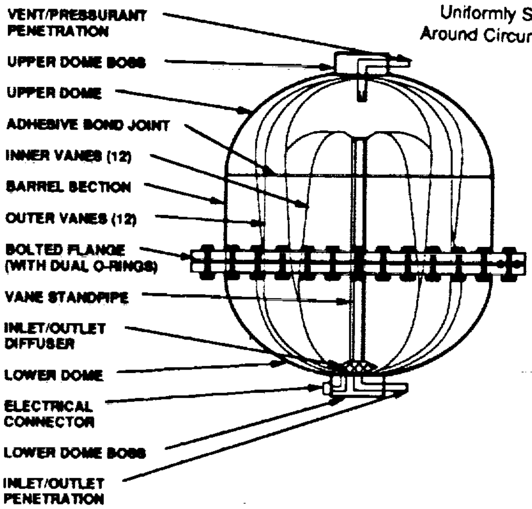

Figure 3 VTRE Cylindrical Tank

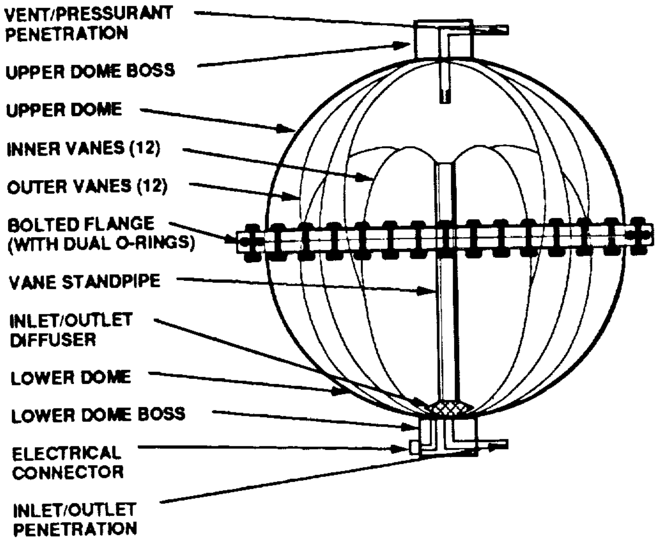

Figure 4 VTRE Spherical Tank

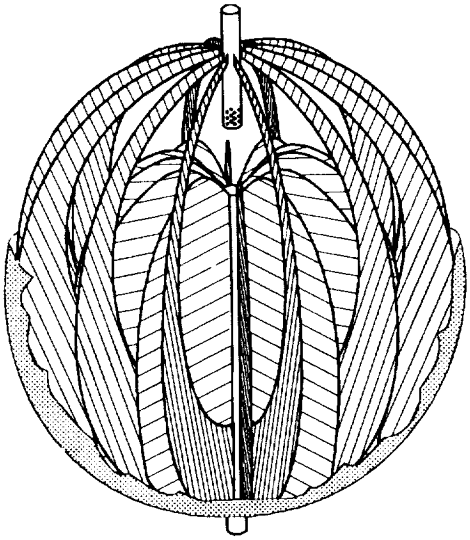

Figure 5 Capillary Vane Concept - Spherical Tank

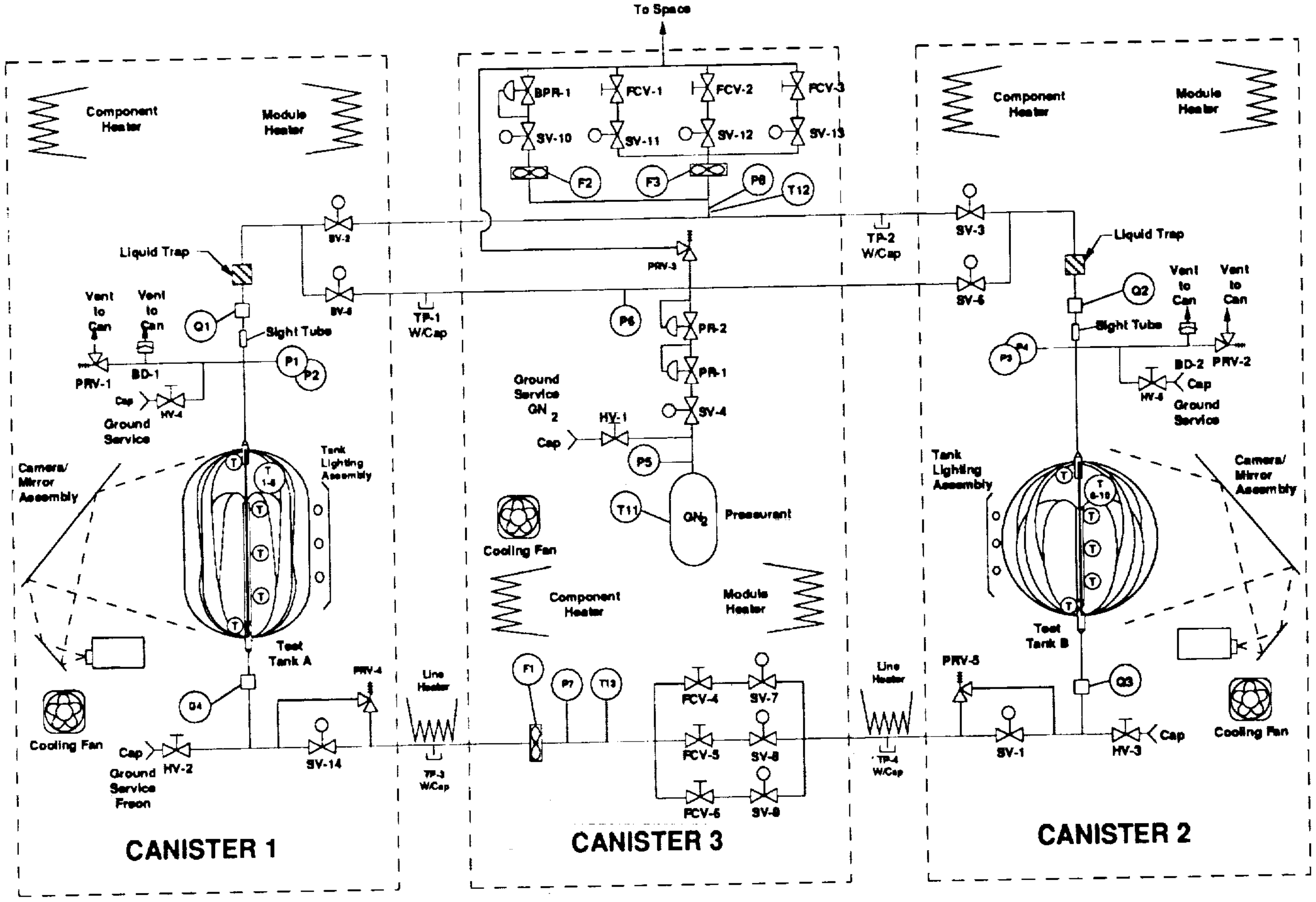

Figure 6 VTRE Schematic

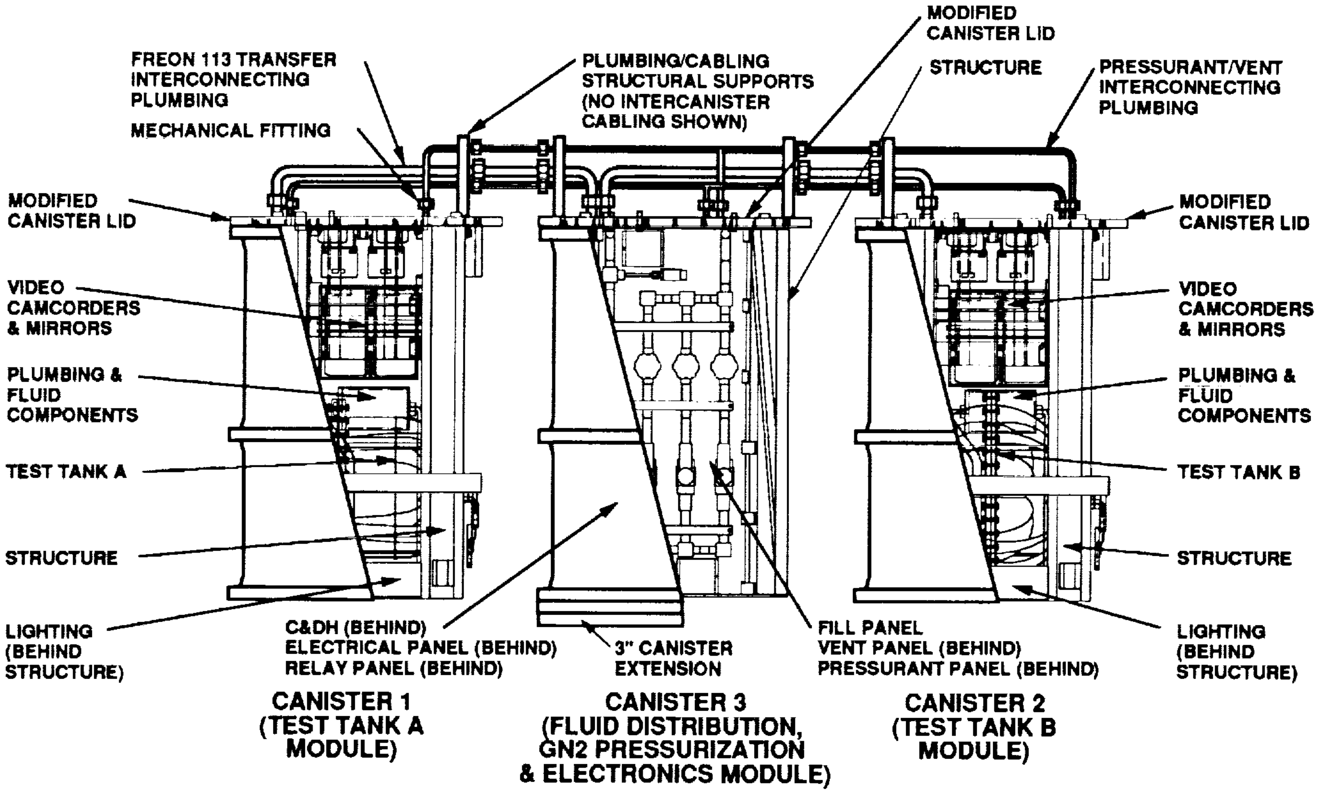

Figure 7 VTRE Flight System Elements Mounted Into Hitchhiker Canisters

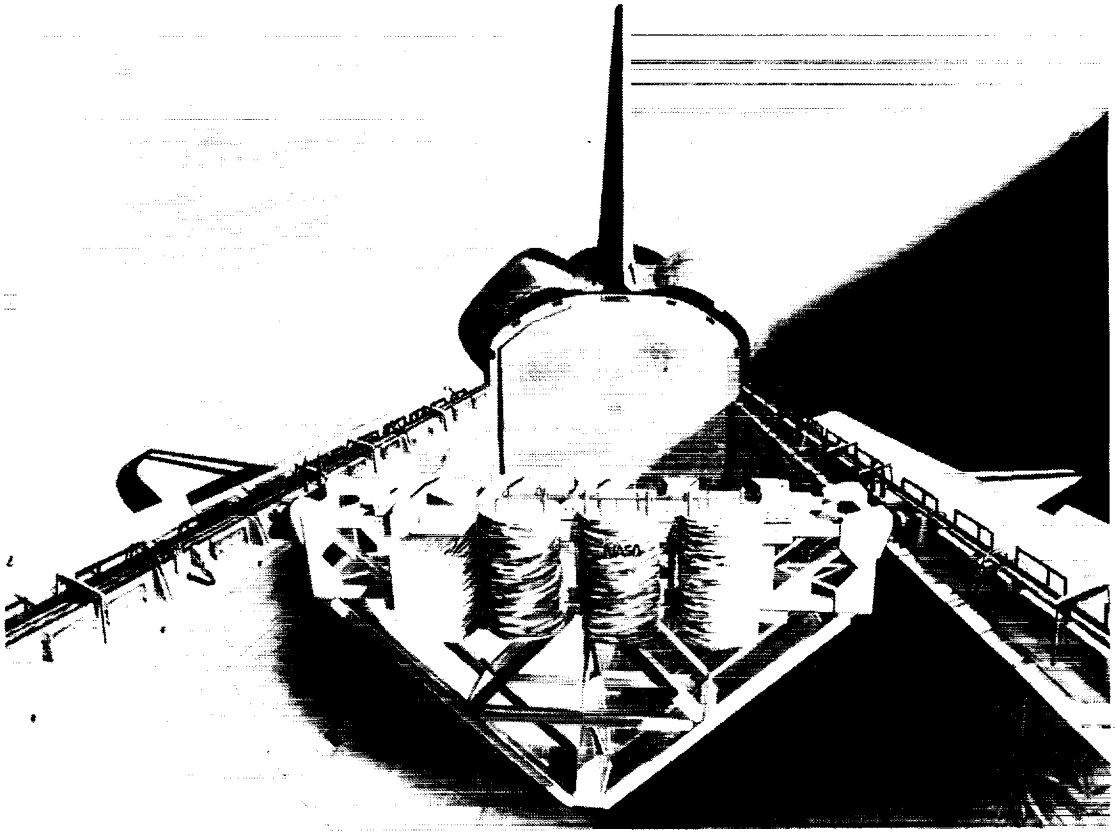

Figure 8 VTRE Flight Installation on Hitchhiker M Carrier