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# SPACE TRANSPORTATION SYSTEM (STS) PROPELLANT SCAVENGING SYSTEM STUDY FINAL REPORT VOLUME II SUPPORTING RESEARCH AND TECHNOLOGY REPORT

JANUARY 1985

Contract NAS9-16994
DRL T-1811

Rockwell International
Space Transportation
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# 1. INTRODUCTION

This volume of the study report is presented to identify technology effort required for the development of a propellant scavenging system. For a cryogenic propellant system, the development tests identified are for a cryogenic capillary acquisition system for zero-g feedout capability and for definition of existing Space Transportation System (STS) performance capabilities. For a storable propellant system, the development tests identified are for three major components required in the system: a propellant pump, a helium compressor, and a zero leakage fluid disconnect.

# 2. CRYOGENIC PROPELLANT SCAVENGING SYSTEM COMPONENT TESTS

The major test/demonstration items needed to verify satisfactory scavenging system operation and performance are listed below:

- Verify receiver tank ground loading performance and procedures.
- Verify fluid acquisition from external tank (ET) and main propulsion subsystem (MPS) during post-MECO (main engine cutoff) spin.
- Verify post MECO fluid transfer and fill of receiver tank (in payload bay), preferably without venting.
- Verify zero-g fluid acquisition and transfer from the receiver tank in the payload bay to a receiver tank in the orbital maneuvering vehicle (OMV) or at the Space Station.

## 2.1 STATUS AND JUSTIFICATION

The testing proposed in this test plan is required for two basic reasons: (1) to gain knowledge of the capability of the existing STS, as applicable to the operational scenarios proposed by the study and (2) to develop performance capabilities of conceptual systems proposed by the study. The first applies to ground loading the scavenging tanks from the MPS and spinning the ET/orbiter for propellant acquisition and control. The second applies to the development of a capillary acquisition system and definition of system performance capability.

To meet the predesign confidence levels desired for the scavenging system, it is considered necessary to test at least a subscale prototype of the system in orbit using actual liquid hydrogen ($LH_2$) and liquid oxygen ($LO_2$) propellants. This is needed to verify acquisition and transfer of cryo fluids in zero-g, something never before accomplished. An end-to-end test of the entire scavenging/delivery sequence from ground prechill through post-MECO scavenging and off-loading under zero-g would be included. Before this overall test is performed, however, post-MECO acquisition of cryogenic propellants from the ET and MPS under a 2-deg/sec pitch rate can readily be demonstrated by tapping flow from a selected drain point in the MPS plumbing and dumping overboard.

Prior to the above orbital tests, many basic component- and system-level tests can be performed on the ground at g levels varying between +1 and -1, depending on hardware and orientation. These can help to verify both filling and draining operations, especially the effect of heat leakage and any bubble formation on screen channel performance.

This general approach is considered the most cost-effective strategy for developing and testing the cryogenic propellant scavenging system. Another option considered was using a small plexiglass subscale system model on the orbiter aft flight deck, utilizing water as a safe test fluid. Cryogenic boiling conditions could be simulated by operating at a low pressure (0.5 psia) and by using electric heaters as a heat source. The marked difference, however, in water properties (compared to $LH_2$ and $LO_2$), such as surface tension, vapor density, wicking, and wetting performance, would cast considerable doubt on the validity of test results, both good or bad. Secondly, the cost of modeling, scaling, designing, and qualifying such a portable system test package is not small. Also, a somewhat similar water transfer experiment was already scheduled for an STS flight in late 1984 and will provide some of the data obtainable by this method.

## 2.2 TECHNICAL PLAN

### 2.2.1 Component Ground Testing

A major question in the design of the scavenging/delivery system is whether the capillary acquisition screen channels can function satisfactorily under conditions of heat input, external boiling, and possible internal vapor generation. Figure 1 shows a proposed setup for testing a representative section of screen gallery in a transparent (glass) $LH_2$ Dewar to verify acquisition under conditions of high heat leakage through the tank wall. As shown, the channel is used to drain the Dewar against a negative-g head until the point of bubble breakthrough is reached (at the top of the wetted screen channel). The effect of helium versus hydrogen gas ullage on self-wicking and dry-out of the screen can be evaluated, as well as the effects of depressurization and repressurization on bubble behavior. It is believed any vapor bubbles left in the screen channel after filling can be condensed and collapsed by moderate pressurization. The above tests will be repeated with $LO_2$ (or liquid nitrogen [$LH_2$] as a substitute fluid if safety should be a problem).

The data obtained from this type of basic component ground testing is expected to be valuable and cost-effective for later design of the prototype scavenging tanks and associated systems. Bubble detectors and mass flowmeters are long-lead items which can be included in ground component testing.

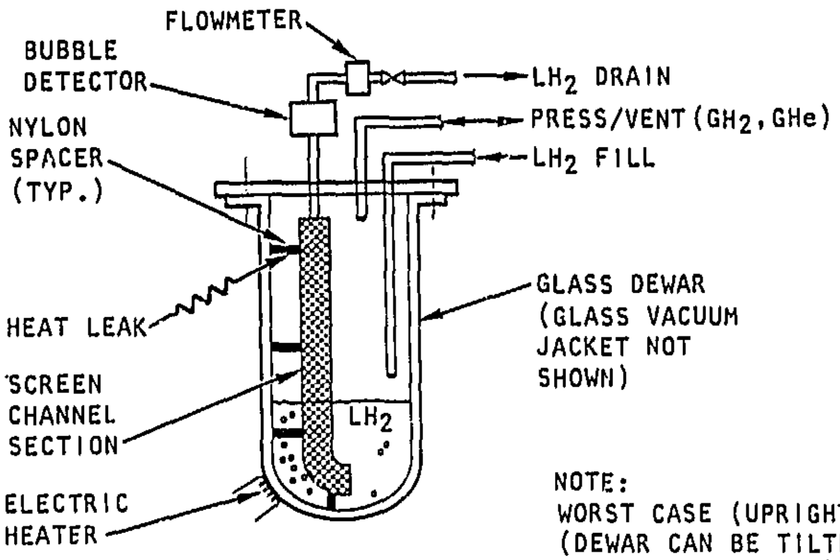



Figure 1. Screen Channel Component Test

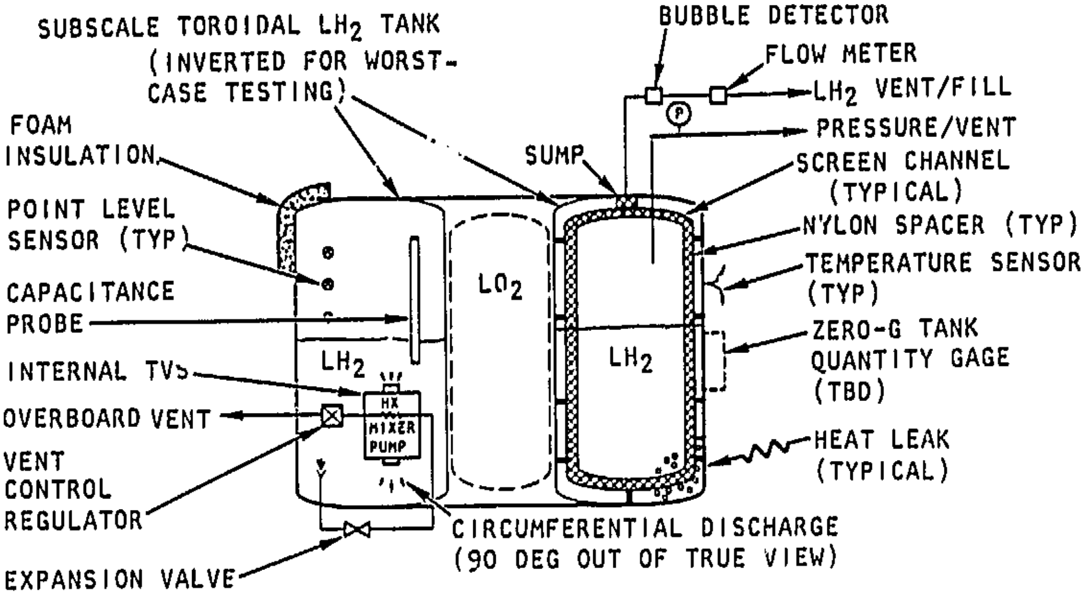
It is assumed automated cryogenic disconnects for final transfer of cryogenic propellants from the payload bay to the user vehicle will be developed under the orbital transfer vehicle (OTV) program prior to the need for handling scavenged propellants. Therefore, demonstration of such disconnects is not expected until final full-scale end-to-end scavenging operations are performed.

### 2.2.2 System-Level Ground Tests

Ground testing of subscale tankage and associated plumbing can simulate much of the launch pad and flight operations and provide valuable data for use in full-scale system design. Figure 2 shows a schematic of the recommended test setup using a subscale toroidal $LH_2$ tank, with associated plumbing and an internal mixer pump thermodynamic vent system (TVS) installed. The central $LO_2$ tank system is not shown for reasons of clarity but should be tested simultaneously with the $LH_2$ tank to simulate thermal conditions. $LH_2$ may be substituted for $LO_2$ if dictated by safety considerations.

The scope of ground system testing will include:

- Childown, ground fill, and replenish control, as performed on the launch pad
- Fluid acquisition and drain of $LH_2$ and $LO_2$ against negative gravity to the limit of screen gallery bubble breakthrough. This will be tested under conditions of ullage pressure, ullage gas composition (helium and hydrogen), ambient heat leakage, liquid drain rate, and operation of the mixer pump TVS unit. Bubble-free draining at the tank sump




NOTE: WORST-CASE POSITION SHOWN (TANK CAN BE TILTED TO LESSEN NEGATIVE G EFFECT)

Figure 2. Subscale $LH_2$ Receiver Tank Ground Test

against a foot or more of negative-g liquid head would be a strong predictive indicator of successful draining in zero g to the desired expulsion efficiency.

- Simulation of emergency dumping from STS

- Effectiveness of the mixer pump TVS in controlling tank temperature and pressure and reducing boiling inside the tank. This type of device has been developed by General Dynamics under the Centaur program, and separate component testing prior to installation into the system test setup is not anticipated.

- Propellant gaging. It is doubtful the capacitance probe shown in Figure 2 will perform satisfactorily in the low-g environment of post-MECO pitch rotation and later zero-g conditions. If accurate monitoring of the receiver tank quantity during orbital fluid transfer operations is desired, it will be necessary to provide a true zero-g gaging system, such as a radioactive or infrasonics type. To gain operating experience with such a system, it would be useful to install it in the ground system and check it against output of the point sensors and capacitance probe. Final verification would be accomplished during flight testing.

An alternative to a zero-g gaging system would be to closely monitor receiver tank pressure during unvented zero-g fill operations. If a reasonable mixing flow is maintained in the tank, a sharp increase in tank pressure will occur as a full condition is approached (for example, 97 percent), at which time transfer can be slowed and terminated. A rough indication of tank quantity at lower levels could be obtained from flo... 'er data. A choice between this method and a true zero-g gaging system should be made during follow-on design studies of the scavenging system.

### 2.2.3 STS Spinup and Fluid Acquisition Test

It is recommended that testing of the ET and MPS fluid acquisition method be performed early in the demonstration program to obtain long lead time on any unforeseen problems that might develop. This can be accomplished by simply pitching the orbiter and attached ET (after MECO) at the planned rate of 2 deg/sec and venting fluid overboard from the MPS fill and drain valve through the existing relief port. Bypass plumbing around the MPS relief valves would be required. Figure 3 shows a schematic of the proposed configuration.

Flow rates would be measured and integrated to obtain the total quantity of propellants acquired and dumped. Quality meters or bubble detectors should be provided in the relief line to determine the time of vapor ingestion and when the transfer process should be terminated.

### 2.2.4 End-to-End Flight Demonstration

The purpose of this test is to demonstrate end-to-end scavenging operation of the selected system: from partial filling of the receiver tanks at the launch pad to transfer, filling, and draining of the user tank on the OMV, OTV, or Space Station. Two identical subscale cryogenic receiver tanks could be installed side by side in the payload bay, with plumbing systems equivalent to that shown on the detailed schematics (Figures 4 and 5). Testing procedures would include:

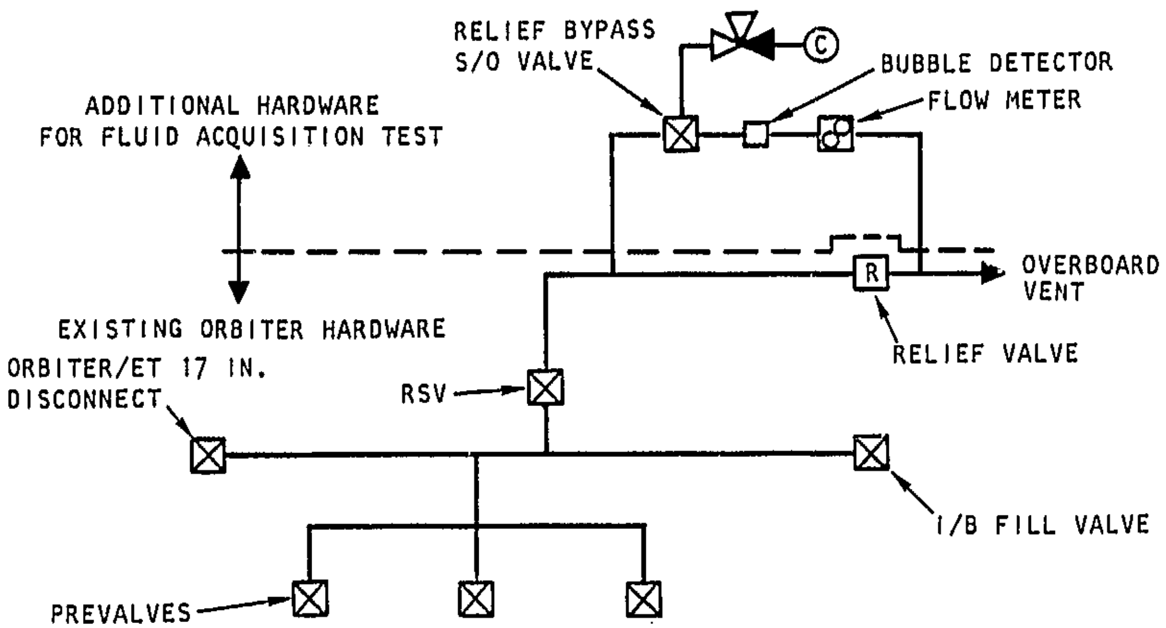



Figure 3. ET/Orbiter Spinup and Fluid Acquisition Test--$LO_2$ and $LH_2$ Systems

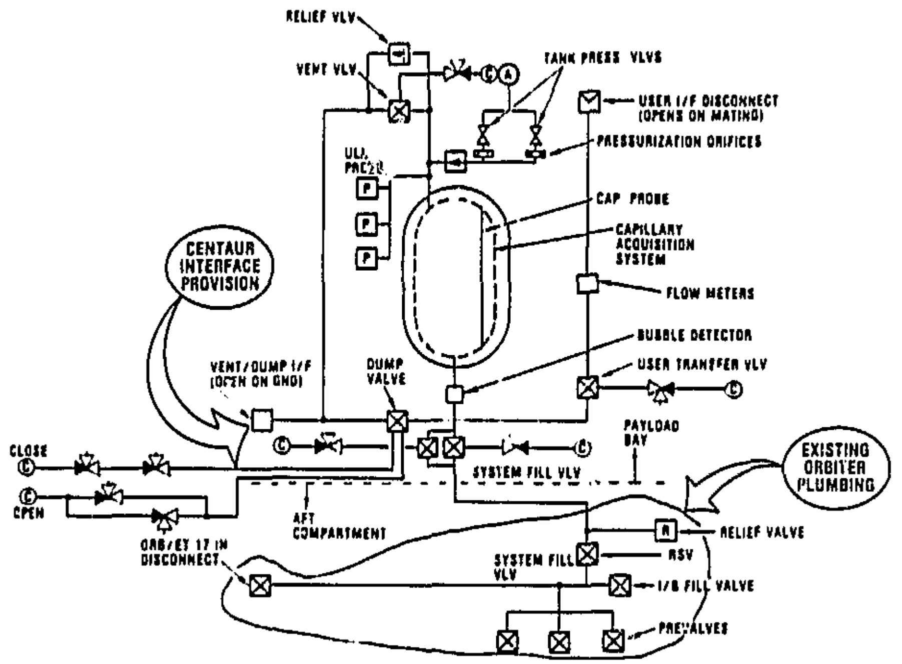



Figure 4. Cryogenic Scavenging System--$LO_2$ System Schematic

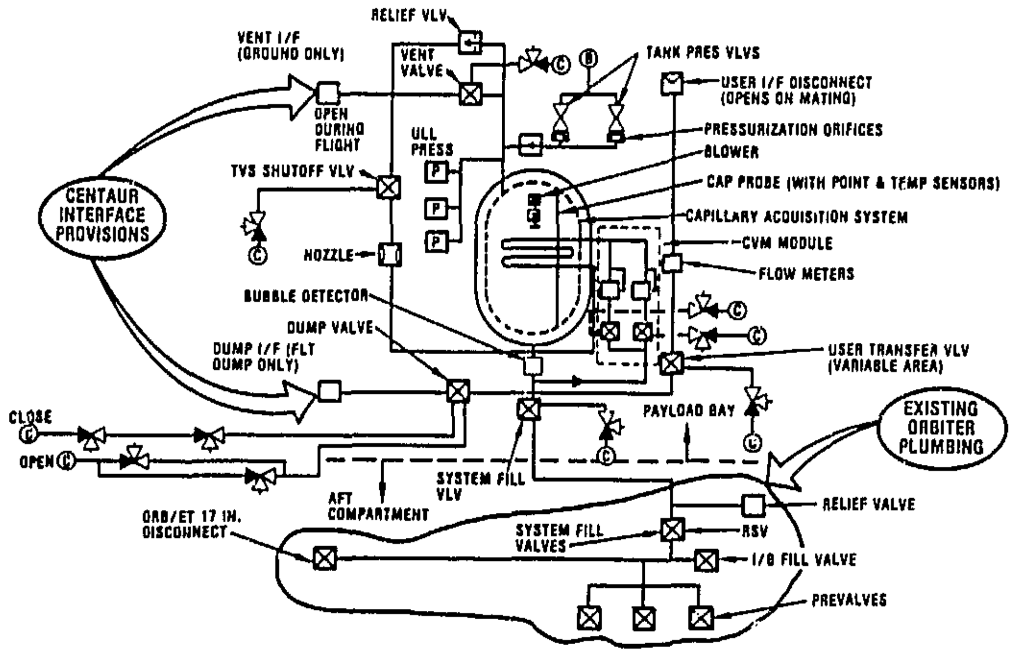



Figure 5. Cryogenic Scavenging System--$LH_2$ System Schematic

- Fill the No. 1 receiver tank on the launch pad and drain to 25-percent prior to lift-off.

- Spin up the mated ET/orbiter to 2-deg/sec pitch rate after MECO.

- Scavenge $LH_2$ and $LO_2$ from the ET and MPS to fill the No. 1 receiver tank (without venting the receiver, if possible).

- Despin the orbiter to zero-g condition.

- Chill down and fill the No. 2 receiver (from No. 1) at zero g to simulate transfer to OMV or Space Station.

- Drain the No. 2 tank and vent fluids overboard through flowmeters to determine filling efficiency and expulsion efficiency with quick zero-g chilldown.

An option that should be evaluated is the use of two full-scale receiver tanks (of different operational sizes) instead of two subscale tanks. This would demonstrate full-scale scavenging, provide tanks for later operational use, and save the cost of subscale tanks. One-g system ground testing might also be convenient with the smaller of the two sizes.

If satisfactory zero-g cryogenic propellant transfer data should become available from another test program, it may be possible to eliminate the No. 2 receiver tank and vent directly overboard from Tank 1. In any case, it is still recommended that the flight test of Tank 1 be retained due to the special conditions of low transfer pressure, STS pitch rate, ET/orbiter heating, and the possibility of two-phase transfer flow, all unique to the scavenging process.

## 2.3 RESOURCE REQUIREMENTS FOR TEST/DEMONSTRATION

Based on the planned scope of testing, the following resource requirements have been identified:

<u>Facilities</u>

- Cryogenic fluids lab with test cell
- Machine shop
- Prototype shop
- Engineering office space
- Modification and checkout areas at the Kennedy Space Center (KSC)

<u>Man-hours</u>

- Cryofluids analysis/design engineer 3,000
- Cryofluids test engineer 3,000

| | |
|---|---|
| • Cryofluids test technician | 3,000 |
| • STS project engineer | 3,000 |
| • STS safety engineer | 1,000 |
| • STS fluid system technicians | 3,000 |
| • STS fluid systems engineer | 2,000 |
| • Machinist | 500 |
| • STS software programmer | 1,000 |
| • STS payload technician | 250 |
| • Flight mission specialist | 500 |
| • Ground mission support | 200 |
| • STS payload designer | 1,000 |
| • STS console design engineer | 1,000 |
| Total | 22,450 |

Material

| | |
|---|---|
| • Raw stock (tubing, sheet, wire) | $10,000 |
| • Valves and miscellaneous plumbing components | $200,000 |
| • Miscellaneous instrumentation and controls | $200,000 |
| • Mixer pump TVS | $200,000 |
| • Zero-g tank gaging system (based on nucleonic type) | $500,000 |
| Total | $1,110,000 |

Auto Comp 5 hours

## 2.4 TEST SCHEDULE

The preliminary schedule shown in Figure 6 is considered to have the minimum time span consistent with cost-effectiveness (assuming a go-ahead at the start of FY 1986). A reasonable allowance is included for unforeseen technical problems. The schedule can be accelerated, if desired, but at a corresponding total cost increase.

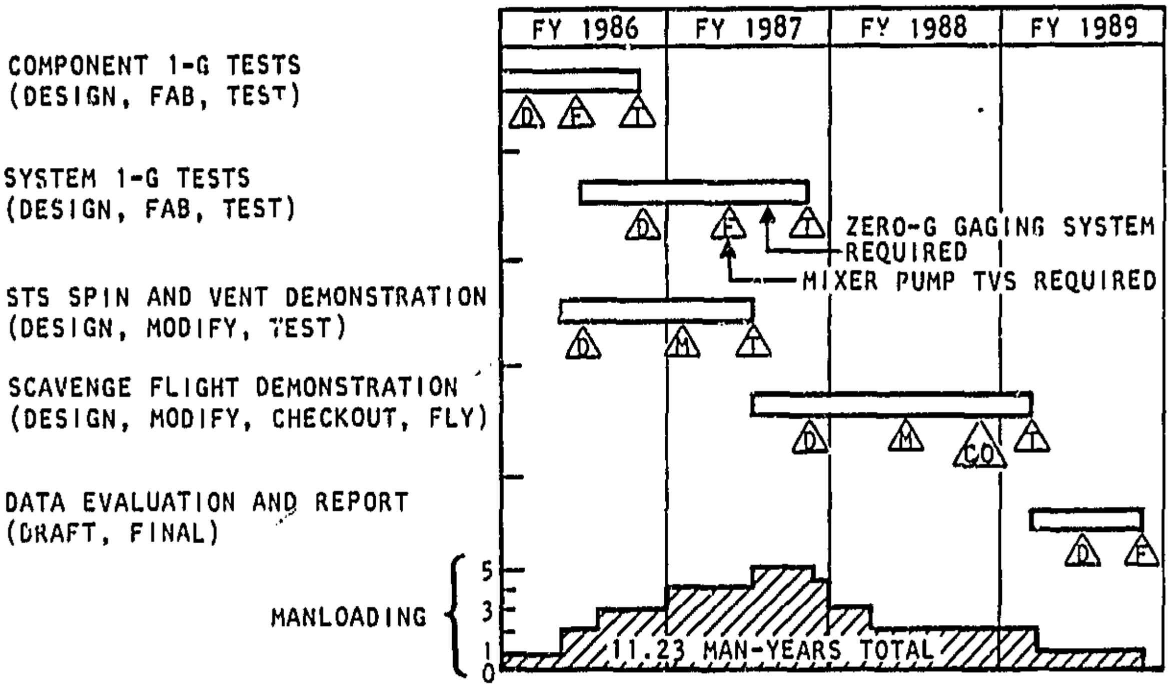



Figure 6. Preliminary Cryo Test Schedule

The test sequence is based on starting system ground test design shortly after critical component verification (i.e., screen channel performance under boiling conditions). STS spinup and vent testing is scheduled for completion prior to the start of final flight system test design.

## 3. HYPERGOLIC PROPELLANT SCAVENGING TESTS

Three major components of this system require special developmental testing to prove concept feasibility: the propellant pump, helium compressor and fluid disconnect. Since the development approach is essentially the same for all three components, all are covered in this section. The resource requirements and test schedules, however, are identified for each component.

Except for the helium compressor, component qualification for space usage will consist primarily of application of an existing concept to the rigors of space requirements (i.e., zero g, reliability, light weight, redundancy, contamination, maintainability, material compatibility, etc.). In the case of the helium compressor, some developmental effort on more than one concept may be required before determining which is to be certified.

## 3.1 STATUS

The present development statuses of the identified components are discussed below.

### 3.1.1 Bipropellant Pumps

Pumps that can handle monomethyl hydrazine (MMH) and nitrogen tetroxide (NTO) and have been developed and preprototypes tested by contractors. The specific use for these pumps is in the supply of bipropellant thrusters that have operational requirements of short duration. The type of operation required for scavenging will be of a relatively long duration. Significant development will be required to validate bipropellant pumps to scavenging operating times and environments.

### 3.1.2 Compressors

Compressors meeting scavenging operational requirements are presently available for ground use. However, flight-weight, low-power compressors do not exist and prototypes are not available. Several designs are potentially adequate for helium repressurization, including diaphragm or piston-type compressors. Each have unique features associated with contamination and through-port capabilities. Significant development is required in this area.

### 3.1.3 Fluid Disconnects

Disconnects with the capability to be remotely actuated and yet maintain zero leakage will be required as a part of the scavenging technology demonstration. The NASA Johnson Space Center (JSC) is funding a disconnect development program, the results of which should be directly applicable to the development effort identified herein.

## 3.2 JUSTIFICATION

Moderate risks are anticipated during the development of the fuel and oxidizer propellant transfer pumps, the helium gas pressurant compressor, and the hypergolic propellant transfer disconnects. The propellant transfer pumps and disconnects need improved seals and sealing methods able to withstand prolonged exposure to the hypergolic propellants. The oxidizer, NTO, is especially difficult to contain using elastomer or mechanical seals on rotating or sliding surfaces. Known elastomers compatible with NTO are marginal in sealing capabilities and long-term exposure.

Teflon seals are permeated by NTO, causing swelling of the seal (approximately 3 percent), resulting in seal cold-flow and wear. When the seal is dried (NTO removed) for system checkout, seal leakage is evident and may cause component replacement. In most cases, upon rewetting the seal with NTO, leakage of NTO is evident for up to 24 hours as the seal swells to its former shape. Fabrication of rotating and sliding surfaces presents a potential problem for the propellant transfer pumps, the pressurant transfer compressor, and the propellant transfer disconnects since both MMH and NTO tend to strip lube from the exposed surfaces. Special attention must be provided to the pressurant compressor design to avoid problems due to inadequate heat rejection capabilities.

The fluid disconnects required for the scavenging program will probably utilize the results of the current NASA JSC disconnect program. Therefore, they will not be required for inclusion in the basic technology demonstration program. The program estimates for resources and schedule have been included in this report, however, because the NASA development program is only in a conceptual phase.

## 3.3 TECHNICAL PLAN

### 3.3.1 Objectives

The major test/demonstration items required to verify satisfactory component operation and performance are listed below:

- Evaluate component design concept feasibility with a workhorse-type test unit.
- Verify operation and performance of a flight-weight prototype test unit to flight application requirements.
- Verify operation and performance of a flight-type qualification test unit to flight application requirements.

Testing under zero-g conditions in the Shuttle payload bay using the prototype or qualification test units in an abbreviated or simulated scavenging system would be highly desirable in order to assess component performance, especially in the propellant pump and helium compressor development effort.

### 3.3.2 Test Plan

The scope of the test program will encompass the following:

- Breadboard-type tests using referee fluids and a development (workhorse) component test unit will provide the basic data base for component functional design evaluation.
- Development tests using referee fluids, propellants, and prototype flight-weight test components will provide the basis for verification of the component design feasibility. These tests will assess operation and performance capabilities when subjected to flight launch environments, ground servicing, and fluid transfer usage. In addition, component life will also be demonstrated.
- Finally, certification tests using a flight-qualifiable test component shall demonstrate its flight worthiness. Based on preliminary assessment it is believed the components can be certified for flight application based upon ground test results; however, it is still recommended that zero-g testing to assess system application effects be

considered for implementation early in the component development program. Zero-g testing effort is not included in this test plan.

### 3.3.3 Resource Requirements for Scavenging Tests

Based on the test program planned, the resource requirements listed in Table 1 have been identified.

Table 1. Resource Requirements for Scavenging Tests

| Resource | Compressor | Disconnect | Pump |
|---|---|---|---|
| **Facilities** | | | |
| • Hypergolic lab and test cell | | X | X |
| • Machine shop | X | X | X |
| • Referee fluids lab | | X | X |
| • High-pressure gas test area | X | | |
| • Vacuum test cell | X | | X |
| • Engineering office space | X | X | X |
| **Man-hours** | | | |
| • Analysis engineer | 3,000 | 1,000 | 1,500 |
| • Support engineering | 1,500 | 1,500 | 1,500 |
| • Test engineer | 3,000 | 1,500 | 1,500 |
| • Technician | 1,500 | 1,500 | 1,500 |
| • Machinist | 300 | 300 | 300 |
| • Data engineer | 1,500 | 300 | 1,500 |
| • Test cell crew | 1,500 | 1,500 | 1,500 |
| • Computer support | 300 | | |
| • Design engineering | 8,000 | 5,000 | 5,000 |
| | 20,600 | 12,600 | 14,300 |
| **Material (dollars)** | | | |
| • Raw stock (tubing, sheet, wire) | 3,000 | 5,000 | 3,000 |
| • Valves and miscellaneous plumbing components | 20,000 | 30,000 | 20,000 |
| • Miscellaneous instrumentation and controls | 30,000 | 10,000 | 20,000 |
| • Tankage for transfer tests | 20,000 | 2,000 | 10,000 |
| • Component test units (two for breadboard tests, two for development tests, three for qualification tests)* | 380,000 | 380,000 | 380,000 |
| Auto comp (hr) | 3 | 2 | 2 |
| *To be provided by outside component supplier. | | | |

### 3.4 TEST SCHEDULE

The preliminary schedule for the propellant scavenging system tests is presented in Figure 7 (assumes go-ahead at the start of FY 1986).

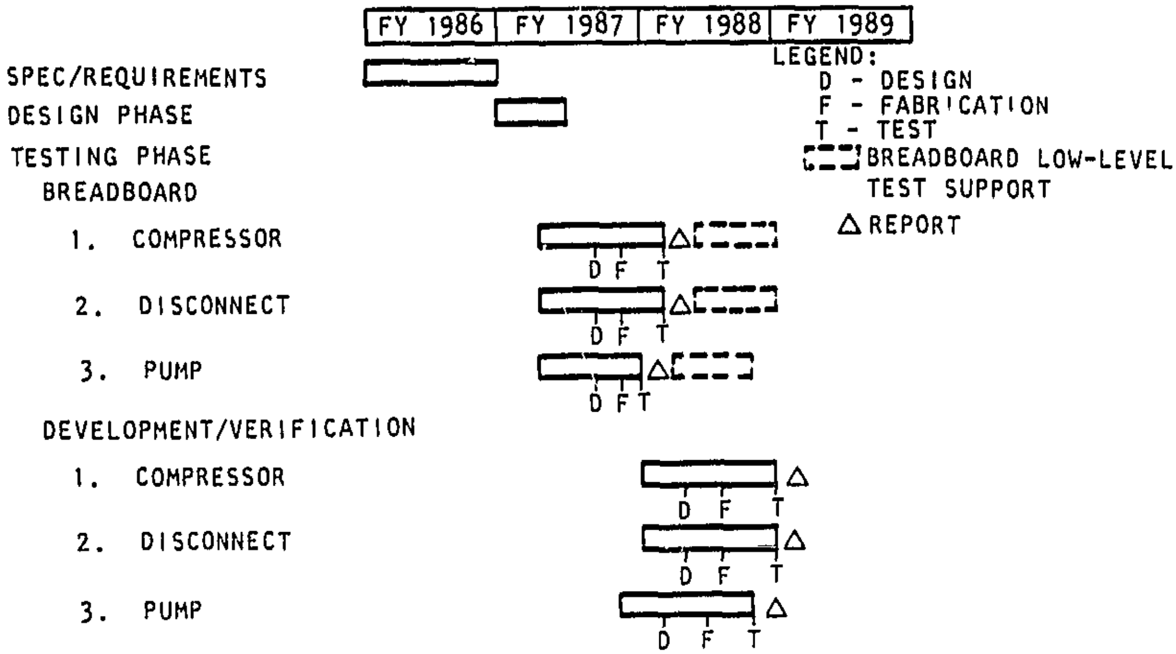



Figure 7. Preliminary Hypergolic Propellant Scavenging Test Schedule