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Paper Session I-A - Advanced Liquid Feed Experiment (ALFE)

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ADVANCED LIQUID FEED EXPERIMENT (ALFE)

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INTRODUCTION

During the Advanced Spacecraft Feed System Study, conducted by the McDonnell Douglas Astronautics Company (MDAC) under contract to the Astronautics Laboratory - Air Force Systems Command (AL/AFSC), several key fluid system components were developed for potential application to a new generation of highly reliable, storable propellant spacecraft. These components demonstrated the capability to electronically control the pressurization schedule in the propellant feed tanks, to accurately gauge the available on board propellants, and to reliably track the propellant usage throughout the mission. In comparison with conventional mechanical regulators and capacitance type propellant gaging systems, they afford lower system cost and weight. When integrated with an attitude control system (ACS) tank designed for unlimited replenishment from main engine propellant tanks, overall system operability, on-orbit life, maintainability, and flexibility can be significantly enhanced.

To demonstrate the in-space performance of these components, the AL/AFSC initiated a joint program with Headquarters Space Systems Division-Upper Stages Program Office (HQ SSD/CLV), and the National Aeronautics and Space Administration - Marshall Space Flight Center (NASA/MSFC). The project was contracted to MDAC (since then has transferred the project to McDonnell Douglas Space Systems Company, MDSSC). The goal was to build a Get-Away-Special (GAS) type payload and to fly the payload aboard a space shuttle. Once flown, the experiment will provide the first space flight test of an electronic pressure regulator and ultrasonic gaging system. It will also be the first space flight demonstration of ACS propellant tank replenishment from main engine tanks.

This paper will discuss the technical approach and key issues encountered in designing, fabricating, assembling, and qualifying the hardware for flight aboard the space shuttle.

TECHNICAL APPROACH

Design approach for ALFE called for using commercially available components to build two hardware modules of approximately 140 lbs each to be contained by two Hitchhiker Get-Away-Special (GAS) canisters provided by NASA/GSFC. The first canister, called the Fluids Can, contains the fluid system and instrumentation. The second canister, called the Electronics Can, contains an

on-board computer and associated electronics systems which will serve as both the experiment conductor and data recorder. The two canisters are mounted on a Hitchhiker Mission Peculiar Experiment Support Structure (MPSS) to be loaded into the space shuttle cargo bay (Fig. 1). Power to ALFE is supplied by the space shuttle via MPSS electrical architecture. Communication between the two ALFE canisters is achieved with a specialized GAS electrical interface cable provided by NASA/Goddard Space Flight Center (NASA/GSFC).

The fluid system is built around a 5"X7" (1/4 scale) circumferentially vaned plexiglass tank and a plumbing system calibrated for flowrates between 0.1 to 1.0 gallons per minute (Fig. 2). The tank material was selected due to its excellent formability, strength, and fracture toughness while offering comparable transparency to glass. Freon 113 was selected as the test fluid with its density, surface tension, and wetting characteristics most closely matching those of Nitrogen Tetroxide, N_2O_4 . Scaling was done using the dimensionless Weber number.

$$We = \rho V^2 D / \sigma$$

where ρ = fluid density
 V = velocity
 D = tank diameter
 σ = surface tension

For the test tank with Freon-113, We ratio to the full scale ACS tank is 0.95.

The vane configuration was designed to hold the test fluid motionless under zero-g environment by allowing surface tension to pull the liquid onto the vanes toward the tank wall (Fig 3). This will provide the stable gas liquid interface required for the ultrasonic point sensors to function. Other fluid system components include a 7"X12" bulkhead supply tank, a 1000 psi nitrogen pressurization bottle, an (115V DC) magnetic gear electronic fluid transfer pump, and a calibrated turbine flowmeter. Figure 4 depicts the schematic of the overall fluid system.

The fluid system pressure is controlled by an advanced electronic pressure regulator built by Parker Hannifin of Irvine, CA. The regulator will provide smooth pressure ramp up during the experiment and clean shut down while the system is vented. The regulator is equipped with a flow limiting orifice to maintain the maximum flow within the capability of the relief valve system downstream in the event the regulator fails open.

A set of six ultrasonic point sensors and a flowcell ultrasonic flowmeter, built by Panametrics of Waltham, MA, for evaluation, are externally mounted on the vaned tank and integrated into the fluid supply line, respectively. The point sensor (Model 5222) determines the wall-bound liquid depth by using the "pulse-echo" principle. A piezoelectric transducer, excited by an electrical pulse, generates ultrasonic waves through the tank wall into the test fluid. Reflected

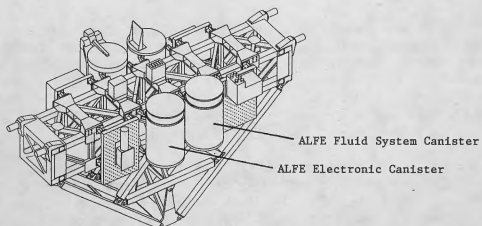


FIGURE 1. ALFE Integrated With MPSS

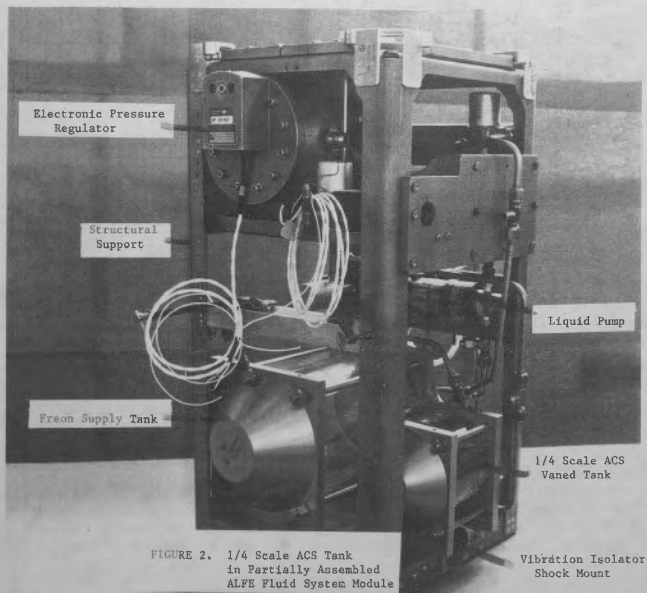


FIGURE 2. 1/4 Scale ACS Tank
in Partially Assembled
ALFE Fluid System Module

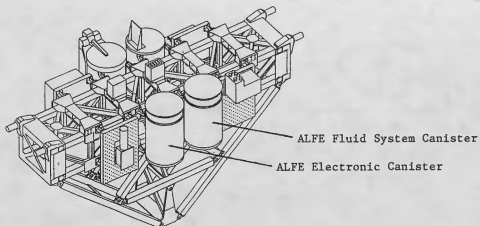


FIGURE 1. ALFE Integrated With MPSS

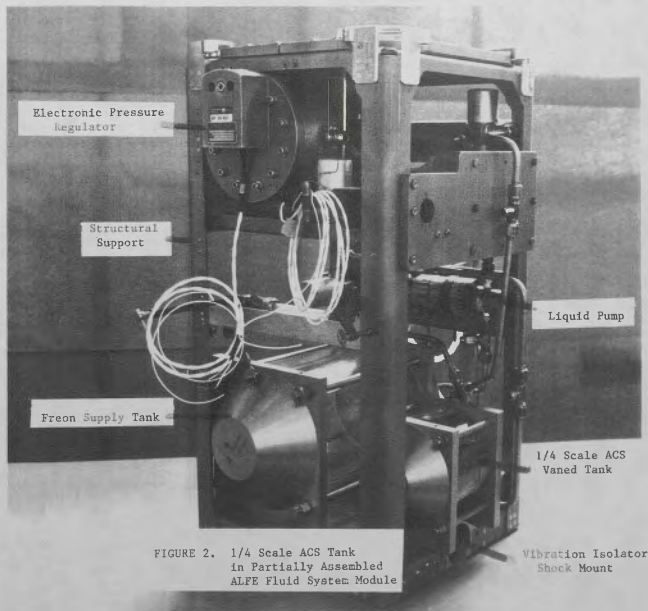


FIGURE 2. 1/4 Scale ACS Tank in Partially Assembled ALFE Fluid System Module

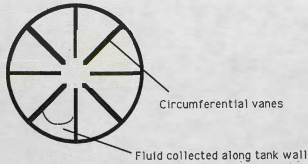


Figure 3. Surface Tension Action

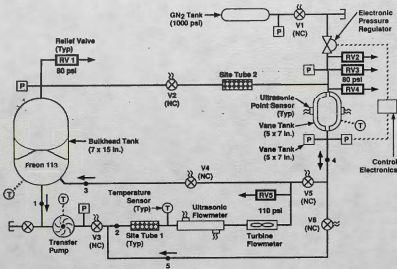


FIGURE 4. Fluid System Schematic

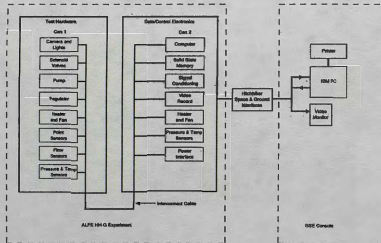


FIGURE 5. ALFE Electrical Command Configuration

echo from the gas-liquid interface is detected by the same transducer. The time delay of the echo is related to the liquid thickness by the relationship:

$$X = \frac{Vt}{2}$$

where X - thickness of the fluid
V - velocity of ultrasonic waves in the material
t - measured round trip time

The ultrasonic flowmeter (Model 6001), using an integrated measurement algorithm, provides flow measurements under various flow rates and back pressure settings. The flowmeter is an electroacoustic system consisting of electronics and two transducers mounted along selected fluid line. By sending ultrasonic pulses upstream and downstream, the difference in transit time is determined. A microprocessor relates the flow to the time difference and geometric parameters.

The onboard computer in the electronic can constitutes the brain of ALFE. It provides the command and control for signal conditioning, data recording and storage, thermal control, power management, and communication with ALFE ground command station. Component performance data is recorded into the solid state memory bank, and the fluid dynamic response into the VHS video recorder. Communication downlink will also allow the data to be simultaneously recorded on the ground. Figure 5 depicts the electrical schematic and control.

ALFE operation can also be controlled by a ground support equipment (GSE) console customized for ALFE support to be located at NASA/GSFC. The GSE console consists of an IBM PC with 8085 microprocessor. Commands are issued via a specially developed LOTUS 123 menu-driven program. ALFE GSE console commands are routed through Space Shuttle command and communication network to the shuttle via uplink HF communication channel. However, under limited communication situations, ALFE onboard computer will take over for autonomous operation.

ISSUES ENCOUNTERED

DESIGN:

Freon - Plexiglass compatibility: Significant crazing (surface hairline cracks) of both of the plexiglass tanks by Freon 113 was observed soon after ALFE was filled with the test fluid for ground check. Concerns were raised regarding potential degradation of the structural strength of the tanks and the quality of the video data on fluid settling characteristics. A burst test was done on a similar plexiglass tank which was heavily crazed by Freon 113 over a three year period showed no significant strength degradation. Addition of blue dye to the test fluid resolved the visual white out problem of the test

tank due to crazing. Movement of the fluid can be easily monitored but with the loss of through-tank sight.

Safety Requirements: In the post Challenger accident era, Shuttle Safety Review Board has become very stringent in reviewing potential safety hazards. To qualify ALFE for a space shuttle mission, various key NASA safety documents and MIL-STDs were used in the design, test, and qualification process. Hitchhiker-G Customer Accommodations and Requirements Specification (NASA HHG-730-1503-03, Dec 1986) controls the structural design approach and provides the specifications for fluid and electrical interface with the space shuttle. MIL-STD 1522A specifies the design margins and verification process for structural and pressurized components. In addition, metal structures have to pass stress corrosion requirements per MSFC 522A. NASA Handbook (NHB) 1700.7A (being updated with NHB 1700.7B version) provides requirements on the identification and resolution of potential in-flight hazards. For ground safety requirements, Kennedy Space Center Handbook (KHB)1700.7 provides methods for identifying potential hazards to ground personnel, plan for developing hazard controls, and criteria for accepting safety verification methods. All organic components (plastic parts and epoxy) were required to be evaluated by NASA/GSFC Materials Laboratory for outgassing and toxicity. Finally, MIL-STD-461 was used to define the electromagnetic compatibility requirements specific to ALFE.

Thermal Control: Thermal analysis showed that ALFE may experience a temperature drop to below -20 F during the shuttle cold soak in the earth's shadow. To maintain the internal temperature inside each canister above 32F, electrical heaters (130W each) are mounted inside both cans. The heaters are under continuous control by the on board computer and are programmed to fail open if the internal bulk temperature exceeds 116F. Dry nitrogen gas (pressurized to 1atm) provides the medium for thermal transport inside each can. The gas is circulated by electrical fans to prevent local hot spots due to the lack of natural convection under zero-g environment.

Communication Interface: Communication between the two canisters, ALFE to shuttle, and ground link network presented special challenges. A special canister interface electrical cable had to be designed for connecting the two canisters without causing electromagnetic interference (EMI) with the space shuttle. During the preliminary EMI tests conducted for the interface cable at NASA/MSFC excessive emission around the cable to GAS canister bottom plates were found. This required changes in the routing of the electrical power, signal levels, and EMI filters. The cable passed formal acceptance tests completed by NASA/GSFC.

Command Relay Architecture: ALFE electrical interface was designed to meet STP-1 MPRESS electrical architecture. Special switching controls provided by MPRESS provide power and route command and control signals for ALFE through the space shuttle communication system. A series of space and ground relays hand off these signals to the GSE console. Figure 6

illustrates the network of the communication traffic. With the large number of players in the network, the Space Shuttle Operation office requires all commands to be submitted to NASA/GSFC for screening and lockout of potentially hazardous commands.

Fracture Control: Concerns of the potential failure of the plexiglass tanks causing fragments to penetrate the fluid system GAS canister and damage the space shuttle required in-depth analysis of all potential failure modes, fragment dynamics, and penetration mechanics. While only one highly improbable failure of the tanks due to impacts by loose components was identified, a fracture control plan was required. The ALFE fluid system design was changed to include protective metal and Lexan plates to protect the two tanks from damage while in flight.

System Structural Integrity: Potential failure of components or structural supports in each of the canisters, due to worst case landing loads or pressure lockup, required large margins in design. Both of the plexiglass tanks were designed for an operating pressure of up to 50 psia (14.7 psi external) with demonstrated burst pressure of over 420 psid. Triple redundant relief systems were incorporated upstream of the 1/4 scale ACS tank and downstream of the turbine flowmeter with relief valves set at 60 psid. The N₂ pressurization bottle was made of 304 stainless steel to be charged to a maximum service pressure of 1090 psi (7200 psid rated burst pressure). All other components were designed with minimum safety margin of 2.0.

FABRICATION:

Computer Software Programming: ALFE was programmed to conduct the experiment in independent sequences or in whole. The software was written in BASIC. While trying to compile the whole program, the on-board computer often failed to properly store the information. The problem was traced to the compiler software provided by the manufacturer. An updated compiler with larger memory allocation solved the problem.

Structural Fabrication: Safety requirements called for modification of ALFE structure design to include vibration isolation mounts to prevent excessive vibration and flight loads. Lack of communication caused the information to not be transferred to the fabrication personnel correctly. This resulted in a payload structure longer than the GAS canisters. A waiver had to be secured from NASA/GSFC to design and fabricate an extension ring for the GAS canister.

TEST AND QUALIFICATION:

Thermal Load Test: ALFE was taken down to -20F during thermal cycling tests at NASA/MSFC. The facility operating procedures required that only conditioned and heated air be used for thermal cycling to prevent an

asphyxiation hazard. Water condensation was to be alleviated by using heated dried air and slow warm up cycle. During the warming up cycle from the freezing temperature, water condensation sweated on various structural and electrical components. This caused the on-board computer to malfunction during subsequent tests resulting in several days of delay in the test program. The problem was attributed to inadequate calibration of humidity level and too rapid warming up of the hardware.

CONCLUSION:

Designing, building, and qualifying an experiment for flight aboard the space shuttle is an intensive process. Prospective investigators should be familiar with the many design and safety requirements associated with flying a payload aboard the space shuttle. In addition, thorough knowledge of the qualification and reviewing process for space payloads will reduce the likelihood of costly design changes and hardware modifications. By designing the experiment to be able to fly as a GAS experiment, yet integrated into a multiple space experiments test program such as STP-1, one can have both the flexibility of GAS payload and the visibility of a secondary payload in the mission queue. An experimenter should plan for 3 to 4 years from the start to the flight date. Valuable government test and evaluation resources, NASA/GSFC, NASA/MSFC, NASA/WSTF, are available to support the experimenter and should be considered in the planning process. Finally, one should not assume that a system is safe by design. A plan must be provided for all possible anomalies however remote they may be.

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