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CERTIFICATION TESTING OF A SUCTION LIFT  
AND MOTIVE FLOW FUEL SUPPLY SYSTEM

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1.0 ABSTRACT

Fuel systems for turbine-powered helicopters have become more complex in the process of striving for performance and reliability. Traditionally, these requirements have been satisfied by adding redundant components to the engine and airframe which usually results in an increase in cost, weight and maintenance tasks. Using an actual aircraft application as an example, this paper describes the certification process of an integrated suction lift and motive flow fuel system that can operate continuously under sub-atmospheric conditions. The objective of the certification test was to demonstrate functional compatibility between the powerplant and airframe and to satisfy qualification requirements of the Federal Aviation Agency and the U.S. Coast Guard. To expedite this process, a realistic airframe mission profile test was simulated in lieu of conducting actual flight tests. Operationally, this system improves overall reliability, lowers weight and cost penalties, simplifies maintenance tasks and reduces aircraft vulnerability to fire hazards.

## 2.0 INTRODUCTION

Historically, fuel systems of light rotorcraft have become increasingly more complex in the never-ending search for maximum safety and reliability. Usually this goal is accomplished by employing redundant hardware which results in a corresponding increase in cost, weight and maintenance tasks. From a safety and crashworthiness viewpoint, in the event of structural damage and subsequent rupturing of airframe fuel lines, conventional aircraft supply systems can pump pressurized liquid fuel into the engine compartment, thus increasing the potential of post-crash fires.

After considering all factors, an obvious solution for simplifying the delivery of fuel is to transfer the responsibility of a fluid supply system from the airframe to the powerplant that will require the engine-driven fuel pump to lift or suck fuel from the aircraft's reservoir. Once the system has been primed and the engine is running at idle speed, a signal-actuated motive flow valve will extract high pressure flow from the main pump to operate integral, tank-mounted jet pumps for automatic fuel management. This approach simplifies fuel handling equipment and eliminates dependence on aircraft subsystems. In addition, it will also improve system reliability, remove weight and cost penalties, reduce aircraft vulnerability to fire hazards and minimize maintenance requirements.

## 3.0 FUEL SYSTEM REQUIREMENTS

Within the last few years, trade-off studies conducted by both the military and civil aviation industry have revealed that suction fuel supply systems can be very cost effective while providing specific operational advantages. It was concluded that an effective system could be designed and certified if a realistic compromise was obtained by integrating the strict requirements found in current military specifications with commercial experience. A similar application using this approach is described in Reference 1.

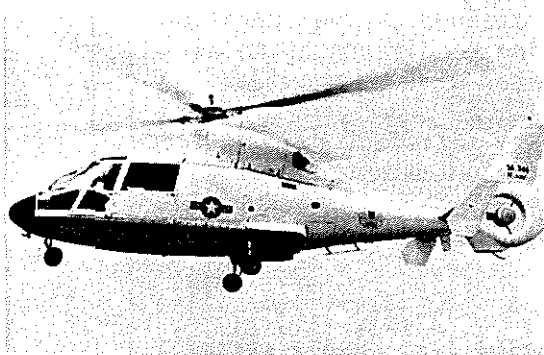


FIGURE 1  
AEROSPATIALE HH-65A HELICOPTER

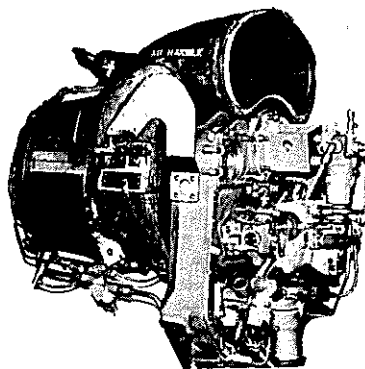


FIGURE 2  
LYCOMING LTS-101-750-A1 ENGINE

After preliminary technical discussions had been completed, it was mutually decided to incorporate a combination suction lift and motive flow system in the Aerospatiale HH-65A light twin rotorcraft. This aircraft, shown in Figure 1, is an adaptation of the 10 passenger Model SA 366 helicopter, which has been modified for U.S. Coast Guard search and rescue missions. It is powered by two Lycoming LTS-101-750A-1 gas turbine engines which is shown in Figure 2. Specific suction lift and motive flow requirements were formulated with the assistance of the aircraft manufacturer and the results are summarized in Table 1.

Table 1. Engine Fuel System Requirements

|                         |   |
|-------------------------|---|
| Static Head Pressure    | Capability to generate an inlet pressure to lift 74.5 inches of JP-4 fuel at 125 deg. F.  |
| Dynamic Pressure Loss   | Must overcome inlet line pressure loss when flowing JP-4 fuel through a 0.4 inch line at -25 deg. F.  |
| Motive Fuel Flow        | Must provide up to 400 PPH of JP-4 motive flow to tank ejectors at 125 deg. F under One Engine Inoperative (OEI) conditions.  |
| Pump Inlet Pressure     | Minimum of 10 PSI must be generated by boost stage and supplied to main pump stage under OEI conditions.  |
| Air Re-Start Ceiling    | Capability to start the engine up to 15,000 feet with a service ceiling of 20,000 feet.   |
| Priming Time            | Time to self prime should not exceed 30 seconds from sea level up to 15,000 feet.   |
| Cavitation Endurance    | Must operate continuously with two-phase fuel supply up to 69% liquid volume and 31% separated vapor volume (V/L = 0.45). A V/L of 0.6 may be present for 10 seconds during a transient maneuver. |
| Fuel Icing              | Must insure sustained engine operation under fuel icing conditions as no aircraft fuel heater will be provided.   |
| Contamination Endurance | Must demonstrate satisfactory compliance when exposed to contaminated fuel according to MIL-E-8593 (1954).  |

#### 4.0 FUEL SYSTEM DESCRIPTION

The LTS 101/HH-65A suction lift and motive flow supply system is the result of innovatively combining engine fuel delivery and aircraft fuel management requirements into a single-integrated configuration. Typical airframe motive flow and related tank components, schematically shown in Figure 3, and suction lift and motive flow hardware, illustrated in Figure 4, are described in the following text.

##### Aircraft Fuel Supply System

##### Fuel Tank Configuration

Taking into consideration established requirement criteria, the Model HH-65A helicopter fuel reservoir was configured to eliminate unnecessary hardware while maintaining a certain level of commonality with production aircraft. The fuel system arrangement consists of a front tank, rear tank, and two center tanks. Each right-hand and left-

hand center tank contains a cannister-type feed tank that provides independent, leak proof supply lines to each LTS 101-750A-1 engine.

Foot, or check valves in each feed tank maintains the column of fuel in the supply line during periods of inactivity and provides pressure relief in the event of thermal expansion. A coarse mesh icing screen surrounds the foot valve to remove ice formations when using water-saturated fuel during cold weather operation. All line dimensions have been optimized to reduce flow velocity and the number of fittings and bends have been minimized to decrease pressure losses. A noncontinuous electric fuel transfer pump allows the operator to select the weight distribution and control the fluid level between the two center tanks.

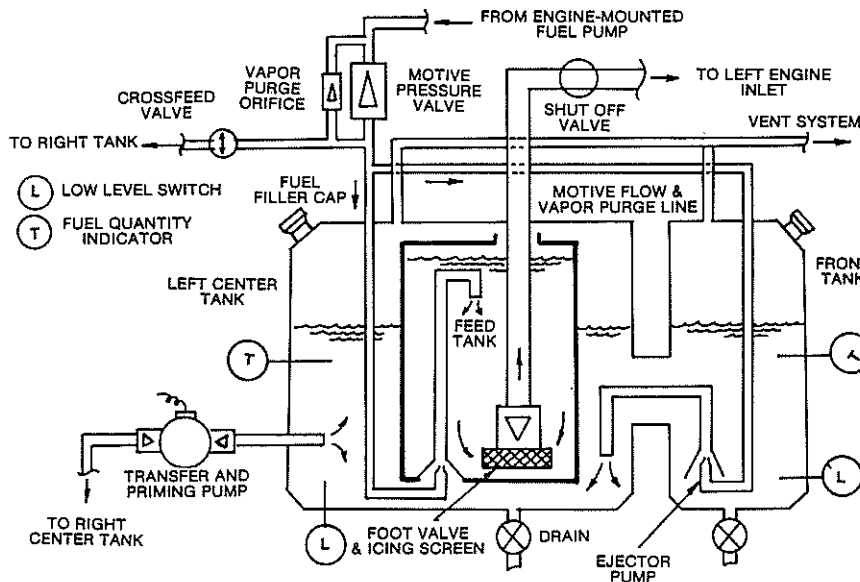


FIGURE 3 HH-65A AIRCRAFT FUEL SYSTEM

### Tank Ejector Pumps

Each fuel tank section contains a jet-induced ejector pump to provide automatic fuel management within the entire system. The ejectors are arranged to transfer fuel from the front and rear tanks to the center tanks and then into each feed tank.

Motive supply pressure to each pair of jet pumps is supplied by excess capacity from the engine-driven main fuel pump and is regulated by a combination vapor purge and motive flow valve. An electrical cross-feed valve between the left-hand and right-hand side of the aircraft permits emergency operation of the entire motive flow system by a single engine under OEI conditions.

### Engine Suction Lift and Motive Flow System

#### MFP-261 Main Fuel Pump

A high performance ejector, or jet inducer, was designed to provide a low cost, contaminant resistant supercharging stage which is hydraulically driven with bypass fuel from the main control. The ejector has no moving parts and will boost the inlet pressure to the

main gear stage by at least 10 PSI over the complete operating range, including OEI conditions. With inlet pressure losses held to reasonable values, this feature will permit continuous operation when exposed to a two-phase JP-4 fuel mixture at vapor-to-liquid (V/L) ratios up to 0.45 with fuel temperatures as high as 125 deg. F. Emergency operation up to 0.6 V/L can also be achieved for short time intervals.

A self-relieving, low pressure fuel strainer is located after the ejector stage to remove any unusually large contamination particles that might damage the main gear stage. The strainer element contains a cleanable, woven metal screen with a nominal rating of 74 microns (0.003 inches) particle size opening. Bypass or relief pressure is very low to minimize system pressure losses, and the typical pressure loss with a noncontaminated element is approximately 1.5 PSI.

A pressure-loaded, positive displacement main gear stage is mechanically driven by the accessory gearbox and provides a gas producer speed intelligence signal to the fuel control. The gear set exhibits excellent self-priming and static head lifting capability in order to operate with sub-atmospheric inlet supply pressures during engine starting and flight conditions. Excess pumping capacity allows extraction up to 400 PPH to operate the tank-mounted jet pumps while providing the necessary engine fuel flow from starting to OEI power.

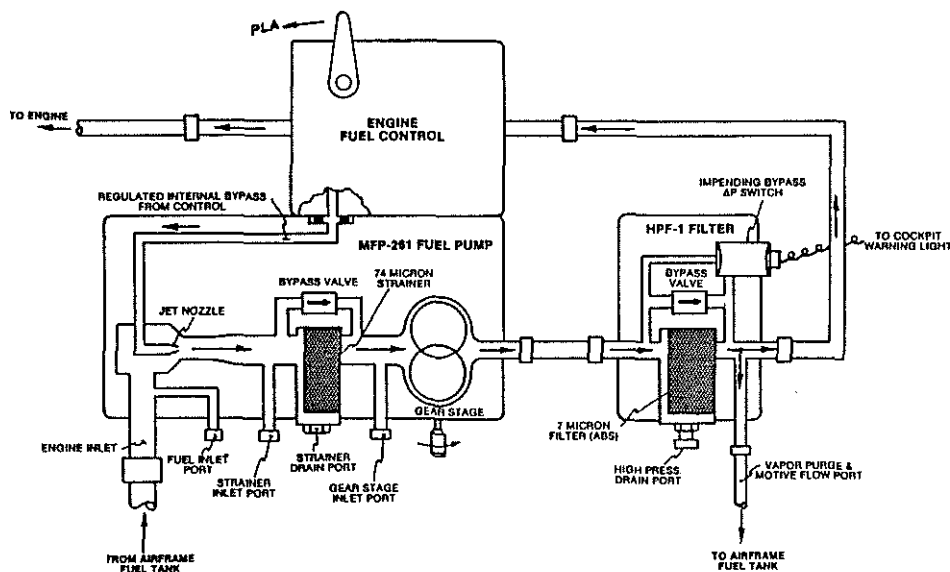


FIGURE 4 SUCTION LIFT FUEL SYSTEM

#### HPF-1 High Pressure Filter

A separate, self-relieving high pressure filter is located downstream of the main fuel pump to remove any fine contamination particles that might cause damage to the fuel control, flow divider or fuel nozzles. The filter element is a replaceable unit with a nominal 7 micron rating (0.00027 inches particle size opening). It is sized to provide nearly 20 hours of engine operation when exposed to fuel contamination as per MIL-E-8593 (1954) in conjunction with naphthenic acid and salt water. The filter assembly also provides an impending bypass electrical signal to the cockpit that warns the operator the element is becoming clogged and will go into complete bypass within a certain time interval. A combination vapor purge and motive flow extraction port, located after the filter element, returns trapped air or vapor back to the fuel tank and directs high pressure fuel to the motive flow valve.

## Sequence of Operation

### Starting Cycle

With the aircraft fuel supply line empty ("worst case"), the engine is cranked to approximately 12% rotational speed with the fuel control shut off valve in the closed position. As the main pump drive starts to rotate, the gear stage generates a suction pressure to initially lift a 15 to 20 cubic inch column of vapor and air. A vapor return line after the filter assembly vents the trapped air back to the aircraft fuel tank within 10 to 15 seconds. At this point, the fuel control shutoff valve is opened and liquid fuel is permitted to enter the engine combustor.

During a typical sea level engine start, the main gear stage of the suction lift pump will prime and lift a 74.5 inch static head of JP-4 fuel at 125 deg. F within 15 to 20 seconds. The time to prime is determined by the volume of air in the fuel line and the associated pressure losses in the aircraft supply system.

### Idle Conditions

Once the engine has been started and is running at 52% speed, the super-charging or ejector stage becomes operational and provides a positive boost pressure of approximately 8 PSI to the inlet of the main pump. The ejector is driven by pump bypass flow whose motive pressure is determined by the jet nozzle geometry. During this interval, a pre-determined pressure signal, that corresponds to idle speed, opens a flow valve which simultaneously directs motive flow to the tank ejectors.

### Flight Conditions

After the helicopter is airborne and the engine is operating at maximum continuous speed, the ejector produces a pressure rise of over 22 PSI to the gear stage inlet. Under emergency or OEI conditions, the inlet boost pressure decreases to approximately 15 PSI, but it is more than adequate to permit continuous engine operation up to 20,000 feet altitude with air-entrained, hot JP-4 fuel at V/L ratios up to 0.45. Hydraulic motion of transferred fuel, caused by the ejector pumps, also has an added benefit of providing sufficient agitation to keep entrained air homogeneously distributed throughout the liquid which prevents stratified flow.

## 5.0 CERTIFICATION TEST PROGRAM

### Certification Requirements

In lieu of a full scale flight test program, it was decided that engine mounted fuel system components would be integrated with a detailed simulation of the airframe fuel system, and the certification test would be conducted at the pump vendor's facility. In addition to traditional test procedures, a unique flight test sequence was conceived that would simulate a typical mission profile of the HH-65A helicopter and is shown in Figure 5.

Because this application was slated for civil aviation, it was also necessary to comply with requirements of current Federal Aviation Regulations. Therefore, a certification test specification was jointly conceived by Lycoming, Aerospatiale, and Chandler Evans under the cognizance of the regional office of the Federal Aviation Administration and the U.S. Coast Guard. Individual test segments were constructed to represent realistic conditions that could be expected in actual service and the details are described in Reference 2.

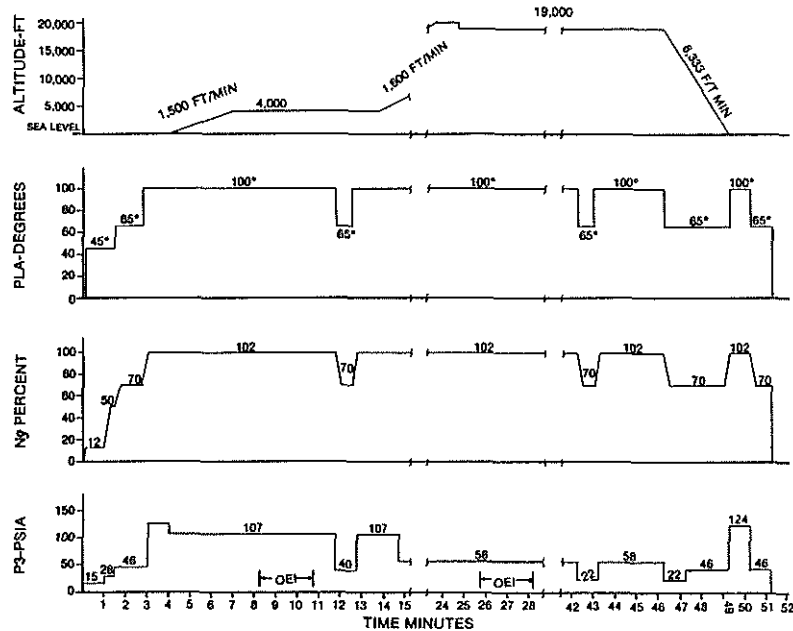


FIGURE 5 MISSION PROFILE TEST SEQUENCE

### Certification Test Facility

The pressure vessel used to simulate the Model HH-65A helicopter main center tank is capable of depressing internal pressures comparable to altitudes in excess of 20,000 feet, and the tank is equipped with a sight glass to facilitate maintenance of the surface level of the fuel to produce a 74.5 inch lift to the pump inlet port. A circulator is used to direct the fuel through a heat exchanger to provide a constant tank fuel temperature between 125 deg. F and -25 deg. F. The helicopter feed tank, suction supply and motive flow line lengths and bends were duplicated exactly by using actual air-frame hardware. In order to monitor transient performance of pump inlet conditions during all hot fuel tests an IKOR 545 meter was used to take continuous measurement of the two-phase fluid. A schematic of the certification hardware is depicted in Figure 6.

In order to simulate the correct values of engine flow and pressure, an LTS 101-750A-1 engine fuel control, flowing into a calibrated restrictor orifice to represent combustor fuel nozzles, was installed on the MFP-261 suction lift pump. In this manner, metered flow, bypass flow, motive flow, and pump discharge pressure were automatically maintained at the level corresponding to the particular engine power condition being evaluated. The entire assembly was mounted on an elevated test stand that could be regulated to any height above the feed tank to simulate installation in the aircraft and all system parameters were documented on a time history recorder. The actual certification test facility is pictorially shown in Figure 7.



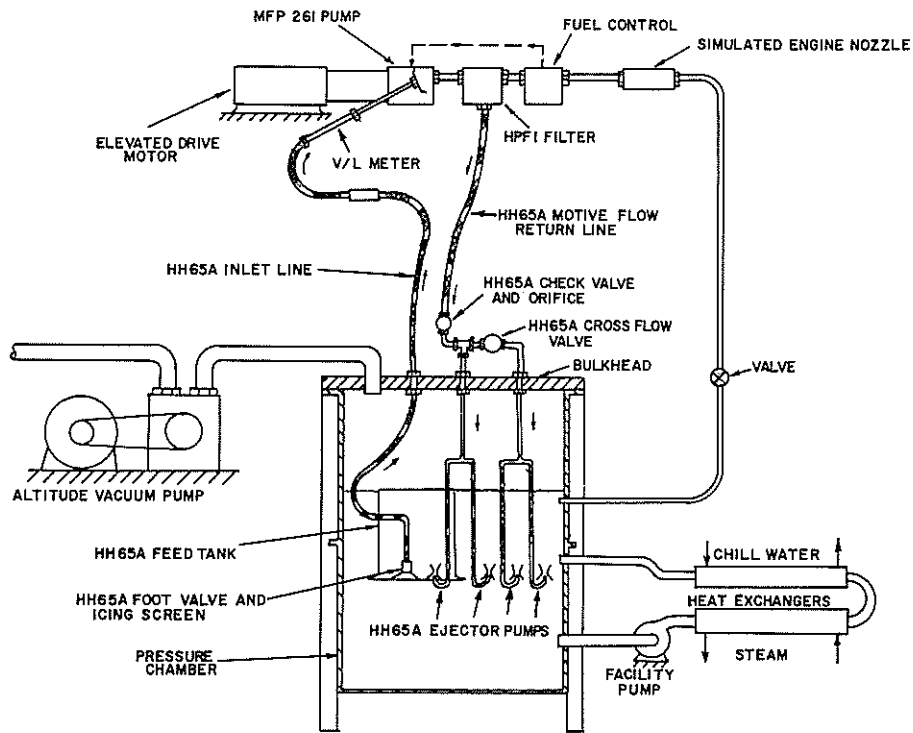


FIGURE 6 CERIFICATION TEST SCHEMATIC

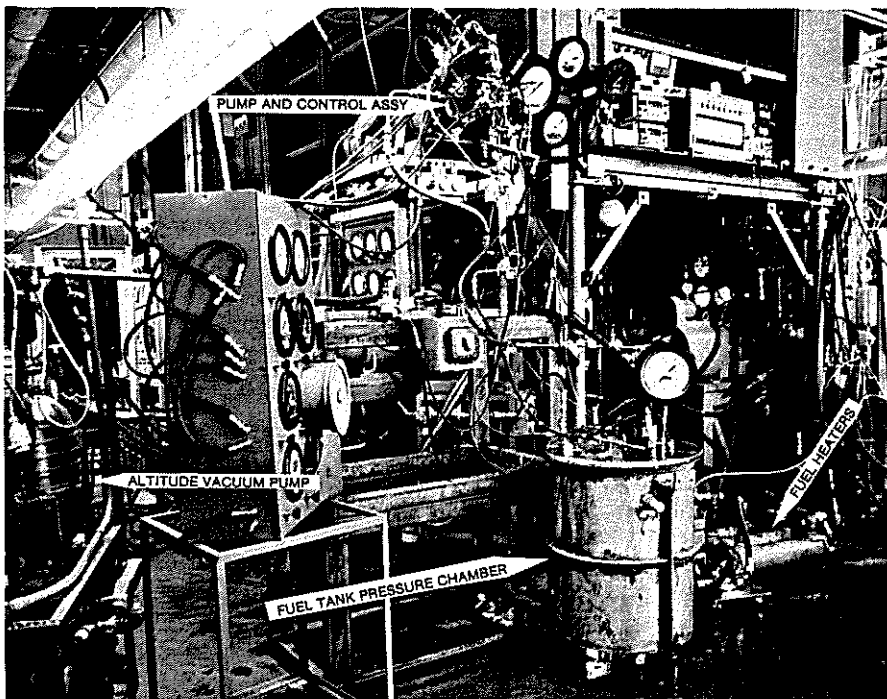


FIGURE 7 CERTIFICATION TEST FACILITY

## 6.0 CERTIFICATION TEST RESULTS

### Mission Profile Test - Phase I

After fabricating the HH-65A/LTS 101-750A-1 fuel system hardware simulation, initial dry lift and main fuel pump priming operation proved to be unsuccessful. Evaluation of test data indicated that aircraft plumbing pressure losses were greater than anticipated, and the ejector flow demand was considerably more than the main pump could provide.

A step-by-step evaluation process was used to isolate the problem cause wherein; each component in the simulation was examined, individually evaluated, modified if necessary, and reinstalled to be tested as part of the overall system. A series of test iterations conducted over a 6 day period revealed many problems. Convolute metal suction lines produced unusually high pressure losses and were replaced with smooth stainless steel, braided hoses. The transfer ejector pumps exhibited motive flow leakage paths and were repaired. Contamination from plumbing and fuel tanks migrated into engine components and had to be continually flushed. Auxiliary and main transfer ejectors were interchanged with each other because of unbalanced aspiration characteristics.

It is believed that if the aircraft and engine hardware simulation was not designed to be representative of the actual application, fault isolation and problem resolution could never have been accomplished in such a short period of time. It has been estimated that incorporating the same number of changes during an aircraft flight test program would take 10 to 15 times longer and cost 100 times more. In any event, all the modifications were successful and the official test could now commence.

### Mission Profile Test - Phase II

#### Room Temperature Fuel Test

A baseline test with JP-4 fuel at 75 deg. F was performed according to the mission cycle sequence described in Figure 5. The pump dry lifted 74.5 inches, primed and reached stable output flow in 10 seconds at 12% cranking speed. The complete flight mission, including a climb and stabilized operation at 20,000 feet, along with two OEI demonstrations, was conducted successfully.

#### Hot Fuel Test

The system dry lifted and reached stable output flow in 13 seconds at 12% cranking speed. Fuel temperature was 122 deg. F during the sea level starting cycle and was eventually reduced to 90 deg. F at 20,000 feet altitude. The pump maintained its prime throughout the test, and the inlet V/L ratio did not exceed 0.30 at any time. The complete flight mission cycle, including a climb to altitude, stabilized operation at 20,000 feet and two OEI demonstrations were successfully completed.

### High Altitude Airport Test

A special test was performed to demonstrate dry lift and system prime capability with hot fuel at a typical airport with an 8,000 feet elevation. The test conditions were simulated by controlling fuel tank pressure and temperature. The unit primed within 13 seconds at 12% cranking speed with 125 deg. F JP-4 fuel, and the V/L ratio did not exceed 0.15 throughout the test. A 4 minute maximum power run was successfully completed at a fuel temperature of 121 deg. F.

### Hot Fuel Altitude Climb Test

At the request of the Aerospatiale engineering representative, a special maximum climb test to 20,000 feet altitude was conducted. A number of calibration points were run every 4000 feet using the same elevated drive/airframe hardware configuration while maintaining JP-4 fuel temperature constant at 118 deg. F. Although these tests were conducted as a courtesy to Aerospatiale and are not part of the certification program, the suction fuel system performed flawlessly. The V/L ratio never exceeded 0.45 even during OEI operation.

### Contamination Fuel Test

The pump and filter were mounted on the calibration test stand and run using JP-4 fuel contaminated according to requirements of Reference 2. The solid contaminant was added to the supply tank at a ratio of 8 grams/1000 gallons. Liquid contaminant consisted of 0.03% by volume of naphthalenic acid and 0.01% by volume of entrained salt water. No cleanup filters were used nor was the fuel recirculated. The pump was operated at 100% speed, and the total flow (metered plus motive) was set at 840 PPH. The test was run until a minimum of 7000 lbs of contaminated flow passed through the pump. Post-test calibration of the pump was excellent with no signs of performance degradation.

No change in pressure drop was noted across the 74 micron self-relieving strainer assembly. The pressure drop across the 7 micron high pressure filter increased gradually by 5 PSI throughout the 8 hour test, however, the impending bypass indicator light was not actuated at any point. Using this contamination add rate, approximately 17 hours of maximum power operation can be achieved before the filter goes into complete bypass.

### Fuel Icing Test

To accurately simulate the actual aircraft installation, all icing tests were performed on the elevated drive stand. The test was conducted in two phases and utilized airframe components such as lines, motive flow hardware and feeder tanks.

1200 gallons of JP-4 fuel were saturated with water which was established by laboratory procedure and analysis. According to FAR 33.67a, Amendment 33-5, the additional 0.75 cc of free water per gallon was added to super-saturate the mixture. The fuel temperature to the pump inlet was reduced to the pre-established critical value of -20 to -30 deg. F. The pump was then operated at 100% speed, and a total inlet flow (metered plus motive) of 840 PPH. The test was continued until 1000 gallons of fuel had been consumed.

During the certification test phase for the Aerospatiale feeder tank, it was determined that a significant amount of water, in the form of ice, came out of solution and adhered to the icing screen. Although this demonstrated the effectiveness of the tank anti-icing feature, it was decided to replace airframe fuel inlet hardware with a single length of clear, plastic hose. This was done to assure that there would be no interaction between the airframe fuel inlet hardware and the engine fuel system, relative to trapping or restricting ice particles before entering the fuel pump. In this manner, the fuel pumping system could be exposed to all the water-entrained fuel used during the second phase of the icing test.

The suction lift fuel system demonstrated excellent performance throughout the test. The pressure drop across the 74 micron fuel inlet strainer increased gradually for one hour until the strainer began to bypass fuel. From that point on, the pressure drop remained relatively constant in the range of 5-7 PSID at a fuel tank temperature of -20 deg. F. The high pressure, 7 micron fuel filter clogged with ice very quickly. After 8 minutes of operation at a fuel temperature of -4 deg. F, the filter bypass valve opened and remained open throughout the test and the impending bypass warning light was illuminated. However, there was no indication of unstable fuel control or fuel pump operation at any point during the 8 hour test.

#### Pump Cavitation Test

The recommended practice for evaluating the performance of an aircraft fuel pump with nonhomogeneous, two-phase flow is the measurement of cavitation or vapor-to-liquid ratio (V/L) at the pump inlet. In order to provide instantaneous recording of these values, an IKOR 545 V/L meter was employed to record continuous measurement of the average dielectric constant of the two-phase flow. The capacitance network of this meter is specifically designed to provide an accuracy of  $\pm 1.5\%$  with a response time of less than 5 milliseconds.

The pump inlet conditions were established according to the requirements described in ARP-492A (1963) which is accepted by both the military and the aerospace industry. The pump inlet cavitation condition was set by throttling the upstream restriction to maintain a V/L reading of 0.45 (minimum) on the IKOR meter. The pump and filter were run for five and one-half hours under the prescribed conditions. After the completion of the test, examination of the data sheets revealed that the V/L ratio was below 0.45 during a considerable portion of the test due to problems with test stand hardware. An extensive effort was undertaken to eliminate unnecessary throttling devices in the inlet line, as well as sealing air leaks throughout the system.

After resolving facility problems, a second cavitation test was conducted by re-establishing initial conditions. During this test phase, the V/L ratio was maintained at a minimum of 0.47 for nearly 6 hours. In order to demonstrate an acceptable level of cavitation margin for emergency OEI operation, the pump was run for an additional 30 minutes at a V/L ratio of 0.60. Post-test calibration of the pump revealed no performance degradation or unusual operating conditions. Figure 8 graphically describes the operational range of V/L ratios as a function of fuel temperature, altitude pressure and total fuel flow.

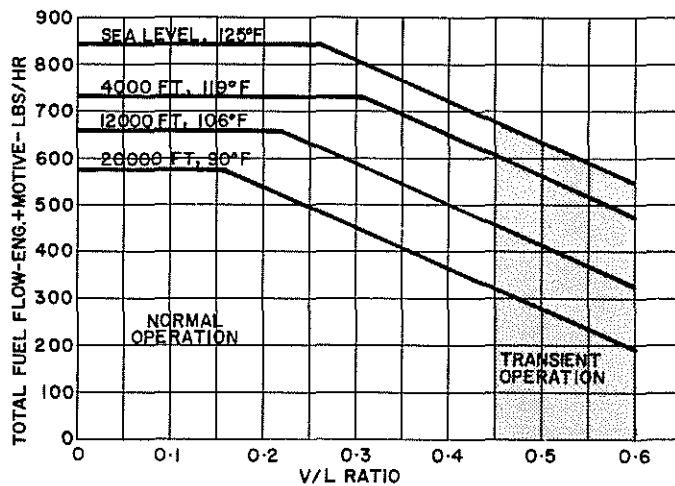


FIGURE 8 VAPOR/LIQUID RATIO OPERATIONAL LIMITS

## 7.0 CONCLUSIONS

Fabrication of a simulated suction lift and motive flow fuel supply system, by utilizing actual engine and aircraft hardware and conducting certification tests by using a realistic flight mission profile is an extremely cost-effective and time-saving development procedure. Consequently, as this program successfully integrated engine and aircraft fuel system requirements, the test results were approved by the certifying agency as satisfactory compliance to Federal Aviation Regulations.

Because a realistic simulation was utilized, as each operational limitation was encountered during initial phases of the certification test program, instantaneous changes to the hardware configuration were easily implemented. This level of flexibility ensured that basic problems were resolved and all system design criteria were satisfied at the completion of the test prior to initiating flight testing.

Utilizing engine motive flow pressure to actuate tank-mounted ejectors provides an additional benefit when using high vapor pressure fuel under sub-atmospheric conditions. Fuel pump cavitation and subsequent loss of prime at altitude is generally the result of stratified or "slug" vapor/liquid combinations. By introducing a flow source into the fuel tank, the resulting agitation or stirring motion tends to keep entrained air, gas or vapor homogenously distributed throughout the liquid, which is the only type of polyphase flow acceptable for continuous engine operation.

Lastly, incorporation of a suction lift and motive flow fuel supply system will eliminate dependence on aircraft sub-systems and offers a real promise of improving overall performance and reliability, lowering life cycle costs, decreasing maintainability tasks and increasing safety of operation.

## 8.0 REFERENCES

1. Petro, David, "Suction Fuel Systems For Turbine Powered Aircraft", Paper 81-37 presented at the 37th Annual Forum of the American Helicopter Society, New Orleans, Louisiana, May, 1981.
2. Bernard J. Bisson, "Verification Test Procedure for the Suction Lift and Motive Fuel Flow System", Chandler Evans Engineering Report No. R-1106, September 25, 1981.