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Operation of the GE T64 on Emulsified Fuel

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ALL TOO FAMILIAR are the severe fires associated with accidents due to the large quantities of highly flammable fuel carried on today's military aircraft. Recent Army statistics amplify this and indicate that 72% of the fatalities in their helicopters destroyed by fire are due to the fire alone and not to the prior crash. This dramatic statistic has accelerated a major development program to develop a fuel which will burn only when we want it to.

From an engine point of view we are theoretically concerned not only with fuel that burns when we want it to, but with:

1. Good combustion characteristics.
2. No engine modification for its use.
3. No latent problems associated with extended operation.
4. Full environmental capability.

The U. S. Army Aviation Materiel Laboratories has been one of the strong forces sponsoring the development of these fuels that burn when we want them to or "safe fuel."

As part of the AVLABS' program to develop "safe" fuels for aircraft operation, a test program was defined using the General Electric T64 engine to evaluate the general effects of one of the safe, or emulsified, fuels on a typical modern turboshaft engine. The objectives of this test program were:

1. To determine whether or not the engine, without modification, could be started and operated on emulsified fuel.
2. To determine what deleterious effects, if any, emulsified fuel had on the engine system.

This paper will deal only with those test results and general problems and not with the relative merits of the various "safe fuels" or the chemistry of how they are made safe.

T64 ENGINE

The T64 engine is a versatile turboshaft/turboprop engine developed under a U. S. Navy contract. The outstanding features of the engine are its excellent specific fuel consumption and installation flexibility. It represents a modern design incorporating numerous advanced features. The fuel system consists of a hydromechanical main fuel control unit, 12 individual duplex fuel nozzles, and a single flow divider/filter combination.

The T64 engine is currently used in:

1. The Marine heavy assault helicopter, CH-53A, (Fig. 1) powered by two T64-6 engines rated at 2850 shp. This helicopter is now in production for the U. S. Marines and has been deployed to Vietnam for operational use. To date, the fuel system has given extremely satisfactory operation including a required 80 in. static lift from tanks located in sponsons.
2. The deHavilland (DHC-5) turboprop transport (CV-7A, C-8A, CC-115) powered by two T64 turboprops rated

ABSTRACT

Based upon initial testing, it was concluded that the T64 engine could operate on emulsified fuel (JD1) without any engine or control adjustment or modifications. This was accomplished without loss of performance or deterioration of engine components. However, the limited program indicated that water additives had severe effects on fuel system components which meet normal Military Specification corrosion resistance requirements. Extensive follow-on testing for fuels and long term engine endurance operation are required to evaluate these fuels fully from an engine life standpoint.

This paper summarizes engine operation, and decribes components following limited operation on a water emulsification of JP4.

at 2850 eshp for the CV-7A and 3060 eshp for the CC-115. This aircraft (Fig. 2) has a conventional fuel system with tanks located "overhead" in the wing structure with tank-mounted boost pump.

3. The Tri-Service tilt wing transport (Fig. 3), manufactured by Ling-Temco-Vought, Inc. and powered by four T64-1 engines rated at 3080 shp, uses a conventional fuel system.

DESIGN FEATURES - The T64 engine was designed as a lightweight, compact turboshaft/turboprop engine with exceptionally low fuel consumption (Fig. 4). The basic engine design consists of a 14-stage axial flow gas generator turbine and a free or independent 2-stage axial flow power turbine which transmits power through the forward end of the engine. On the turboprop configuration, a propeller speed decreaser gear (SDG) mounts on the forward end of the shaft housing forward of the power unit.

Fig. 1 - CH-53 Marine assault helicopter

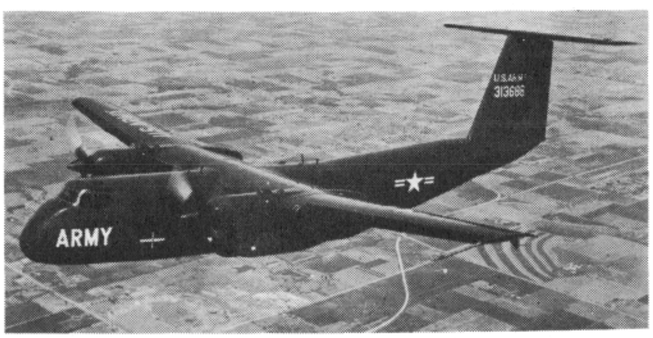

Fig. 2 - deHavilland DHC-5

Fuel System - The fuel system shown in Fig. 5 meets all normal civil and Military design requirements, including operation in corrosive environments and demonstrated contamination capability. Fuel is supplied from the airframe fuel system to the inlet of the purifier, is centrifuged, and passes to the high pressure gear pump then to the control -- a hydromechanical fuel metering system which permits utilization on either the turboshaft and turboprop versions. Here the fuel is filtered and metered. Excess fuel returns to the pump inlet; metered fuel passes through a flowmeter to a high pressure filter, flow divider, and into the fuel manifold which, in turn, supplies the 12 duplex fuel nozzles. Fuel is also supplied to the two variable geometry actuators to position the variable stator vane system.

Combustor-Annular Type for Simplicity - The combustion system is a full annular type, utilizing normal aircooled

Fig. 3 - XC-142A tilt wing transport

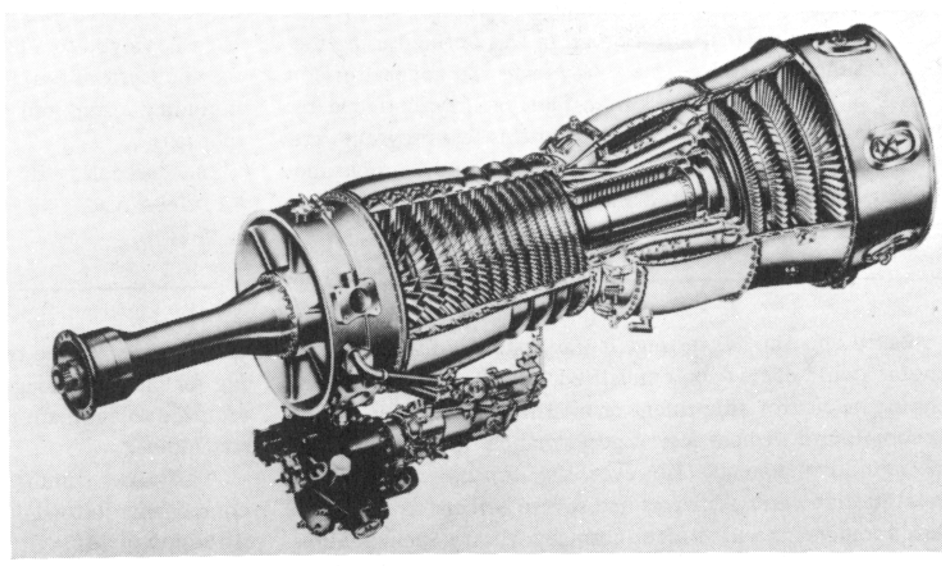

Fig. 4 - T64 engine

combustor design. Twelve easily removable duplex fuel nozzles are mounted to the engine externally, protruding into the liner grommets located at the combustor dome. This facilitates fuel nozzle inspection and replacement.

TEST PROGRAM

Our particular test program was conducted in two phases:

1. An engine fuel system bench test on JP-4 and on an emulsified JP-4 based mixture known as JD-1.

2. A series of full engine operational tests on JP-4 base emulsion.

The JD-1 consisted of an emulsifier, water, and approximately 97% JP-4. The engine used for this test program was a production T64 engine which had logged 505 hr of operational use on the CV-7A transport aircraft including 270 hr in Vietnam operation.

The basic characteristic of emulsified fuel is its rather thick consistency which is somewhat comparable to soft cold cream (Fig. 6). Being more of a solid than a liquid, solid impurities such as dirt, residue, etc., are kept in suspension and are not subject to "settling" as in normal liquid fuels.

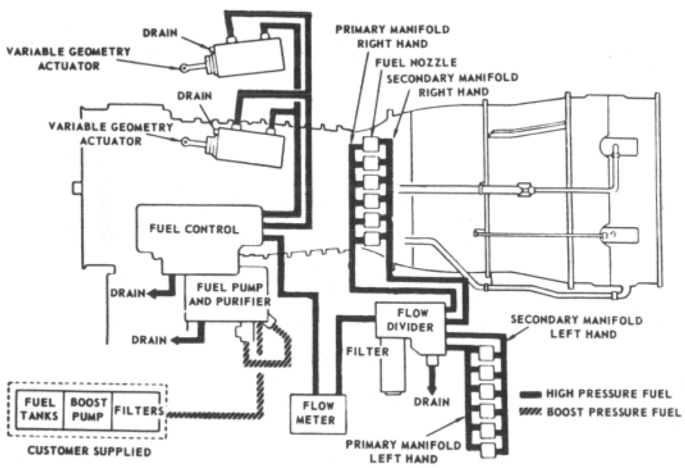

Fig. 5 - Schematic of T64 of fuel system

Fig. 6 - Emulsified fuel "flowing"

Consequently, initial tests conducted by various engine manufacturers included reports of severe fuel system contamination. This lead to the belief that detergent action of the emulsions cleaned out all settled residue of the fuel system causing severe solution contamination.

As a result of this prior experience, we carefully purged both test equipment and emulsion supply equipment to insure that clean fuel entered the test vehicle. Although our test engine had previously accumulated over 500 hr of operational time, no contamination problems were encountered.

BENCH TEST OF FUEL SYSTEM - The fuel system, consisting of fuel control, flow divider, V. G. actuator, manifolds, and nozzles was mounted on a bench test stand. A full bench testing of the system was conducted on JP-4 and JD-1.

Results of this test indicated no difference in fuel system operation between the two fuels. All fuel control schedules were well within limits with no adjustments required. All fuel spray patterns appeared normal and were judged

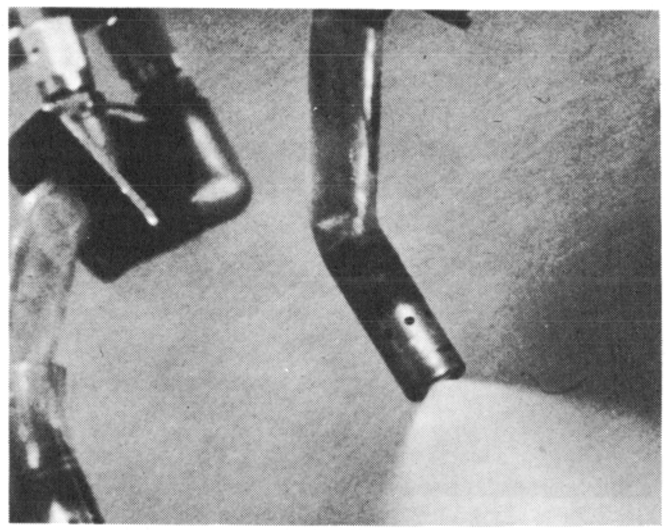

Fig. 7 - Typical JP-4 fuel nozzle spray pattern

Fig. 8 - Emulsified fuel spray pattern, showing "globbing" at tip

to be sufficiently good to support combustion (Fig. 7). Minor "globbing" of fuel nozzle tips was noted (Fig. 8). This condition could result in nozzles coking over extended periods of engine operation.

ENGINE TEST - The engine was installed on a test stand and operated as a turbojet engine by removing the power turbine or drive turbine. (The fuel and combustion systems were unchanged and did not recognize this engine modification.) Testing included:

1. Full calibration on JP-4.
2. Start on JP-4, switch to JD-1.
3. Calibration on JD-1.
4. Transients on both fuels.
5. Repetitive starts on JD-1 alone.
6. Final recalibration on JP-4.

ENGINE TEST OBSERVATIONS -

1. Engine operation normal on JD-1.
2. No change in operation noted on transition from JP-4 to JD-1.
3. Slightly longer transient times on JD-1 but within specifications.
4. Slightly longer starting time on JD-1 but within specifications.
5. No loss in performance (Fig. 9).

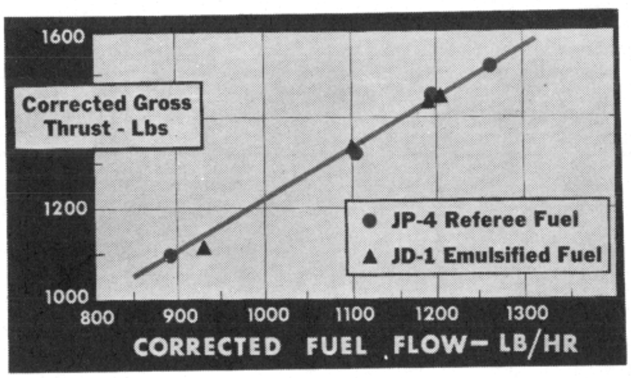

Fig. 9 - Calibration comparison JD-1 versus JP-4

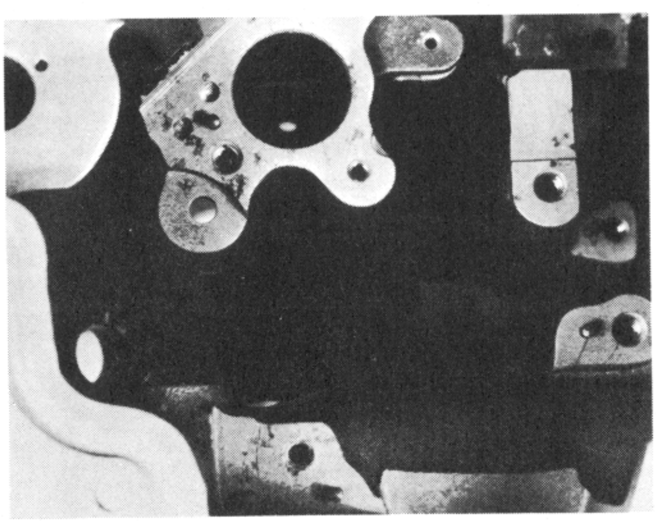

Fig. 10 - Typical aluminum corrosion resulting from JD-1

The JD-1 emulsion contains approximately 3% water, so we feel the specific fuel consumption should have increased, although we did not detect this in our measurements. Fuel flow measurement is, therefore, suspect.

From a test viewpoint, we had all been skeptics about attaining normal engine operation. All engine test results were excellent, however, with essentially no difference between JD-1 and JP-4 operation. The engine test phase indicated no problem areas.

ENGINE TEARDOWN RESULTS -

Hot Parts - No abnormal effects were noted in the hot parts. In fact, there were no signs that the engine had operated in any other manner than on JP-4.

Fuel Control - Following the engine test, the fuel control was fully bench tested on JP-4. Results indicated that all control schedules were within limits and showed no change from prior test results.

Following this test, the fuel control was fully disassembled. This occurred two months after the emulsified fuel testing. The control disassembly revealed:

1. Large globs of JD-1 still present that had not been flushed by several hours of bench testing. Further, these were still present after 2 months.
2. Extensive corrosion to all aluminum and stainless components far beyond that seen earlier and far more than expected for a control that meets full Military and civil corrosion requirements. (See Fig. 10-12.)

TEST PROGRAM CONCLUSIONS

The results of our test program, although involving only limited engine operating experience, proved that engines can be run without modification on "safe" fuels. Now the job becomes even more challenging. Fuels and engines must be compatible.

Ideally, the fuel's combustion and chemical properties should be identical to JP-4/JP-5 but burn only when we want it to. Unfortunately, we must deal with additives or agents to make this fuel safe. Herein lies a major development program. From our limited testing it is evident that several problems must be overcome:

1. Cold corrosion. The extensive control corrosion seen on the T64 after use with JD-1 is unacceptable. Fuels must

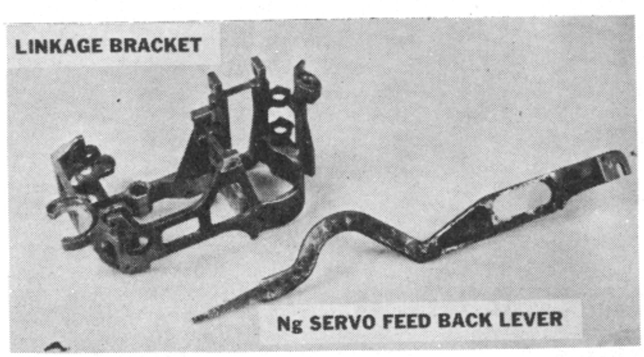

Fig. 11 - Typical control component, corrosion resulting from operation with JD-1

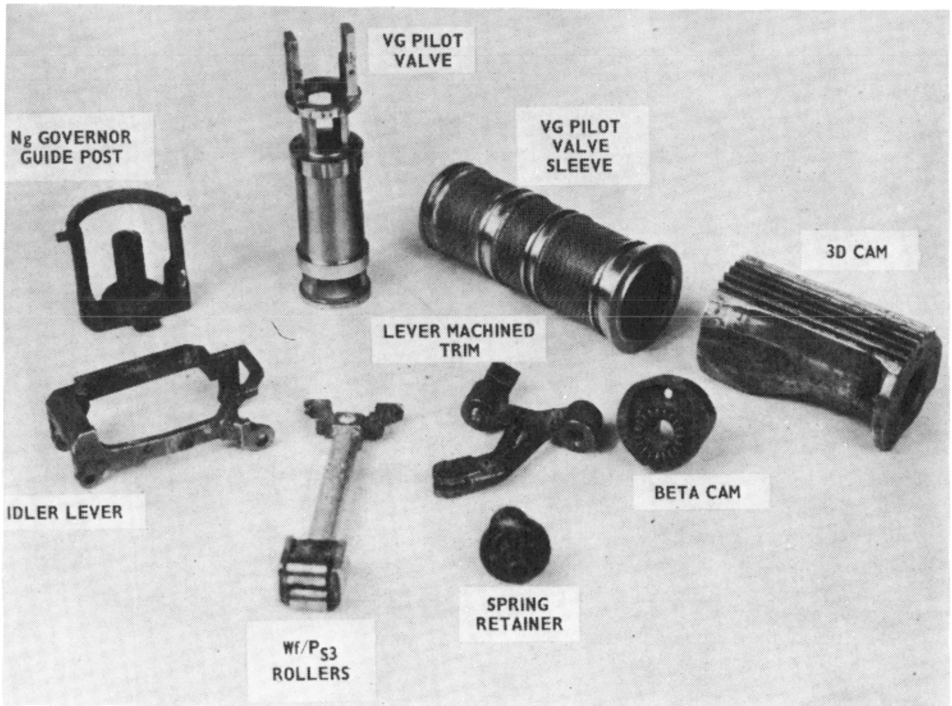

Fig. 12 - Typical control components, corrosion from operation with JD-1

be usable on existing engines and components to be satisfactory. From a practical standpoint, the fuel industry has tried for years to prevent water in fuel because of corrosion and freezing problems -- unless positive corrosion inhibition is afforded to even low grade alloys -- water additives should not be used.

2. Instrumentation. Fuel flow measurement systems need to be verified on the new fuels.

3. Long-term storage/trapped fuels. The safe fuel must be completely usable/storable or easily reconverted to JP-4/JP-5. However, if it must be reconverted to avoid a contamination or corrosion problem (that is, fuel control), an operational problem is created.

4. Engine component life testing. All fuel system components must be verified for long-time endurance (pumps, seals, controls, etc.).

5. Hot corrosion and oxidation. There is a trend in the industry to wider use of improved high temperature metals. These new materials need our help, and must be kept from the corrosive elements such as sulfur, sodium, and other materials. Any new fuels must be compatible with the newest alloys under all temperature conditions including severe engine over-temperature.

6. Smoke/solids. The smoke and residue from jet engines is not just a nuisance, it is contributing to the growing air pollution problem. These new fuels should be developed with the aim of reducing smoke.

Certainly the carbon/erosion should not be higher than the current fuels.

7. Environmental characteristics. Our testing has been limited to "sheltered" sea level. Any new fuel needs the full range of environmental testing (hot, cold, wet, dry, high altitude, etc.) including engine operation, restart, etc. at these conditions.

SUMMARY

Although this list of problems and work areas tends to be somewhat overwhelming, we believe the potential advantages of "safe fuel" more than warrant the effort required to solve these problems.

We hope the Army will "press on" with its pioneering role in this field.

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