Lewis

NASA Contractor Report 4033

# Antimisting Kerosene JT3 Engine Fuel System Integration Study

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# Antimisting Kerosene JT3 Engine Fuel System Integration Study

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**Information Branch**

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# PREFACE

This report describes the work conducted by the Pratt & Whitney Engineering Division of United Technologies Corporation to assist NASA Ames-Dryden Flight Research Facility in their preparation for the Full-Scale Transport Controlled Impact Demonstration Test. This effort was sponsored by the National Aeronautics and Space Administration under Contracts NAS3-24217 and NAS3-24353 and funded by the FAA through Interagency Agreement No. DTFA03-81-A-00154.

The author wishes to acknowledge the guidance of Mr. L. Dean Webb of NASA Ames-Dryden Flight Research Facility whose keen interest and support were particularly instrumental in the successful completion of this support program.

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# SUMMARY

An analytical study and laboratory tests were conducted to assist NASA in determining the safety and mission suitability of the modified fuel system and flight tests for the Full-Scale Transport Controlled Impact Demostration (CID) Program. This 12 month study reviewed and analyzed both the use of antimisting kerosene (AMK) fuel and the incorporation of a "fuel degrader" on the operational and performance characteristics of the engines tested. Potential deficiencies and/or failures were identified and approaches to accommodate these deficiencies were recommended to NASA Ames-Dryden Flight Research Facility.

The results of flow characterization tests on degraded AMK fuel samples indicated levels of degradation satisfactory for the planned missions of the B-720 aircraft. The operability and performance with the AMK in a ground test engine and in the aircraft engines during the test flights were comparable to those with unmodified Jet A. For the final CID test, the JT3C-7 engines performed satisfactorily while operating on AMK right up to impact.

# INTRODUCTION

In a typical aircraft crash, fuel spilled from ruptured fuel tanks forms a fine mist which can be ignited by a number of sources at the crash site. If formation of this mist can be suppressed, fire hazards can be reduced and lives can be saved. FM-9, a high molecular-weight, long chain polymer, when blended with Jet-A fuel in concentrations in the range of 0.3 percent by weight, has demonstrated the ability to inhibit ignition and flame propagation of the released fuel in simulated crash tests.

This antimisting kerosene (AMK), when subjected to the shear levels expected in aircraft engine systems, can have undesirable flow characteristics such as poor fuel atomization and filterability. This precludes its direct use in a gas turbine engine because of possible clogging of filters, unacceptable spray quality of fuel nozzles/injectors and reduced heat transfer coefficients in fuel heat exchangers (Ref. 1). Therefore, the AMK fuel must be altered to restore its parent Jet-A properties for proper operation in the engine fuel system.

Fuel alteration can be accomplished by the application of sufficient molecular stress to rupture the polymeric additive contained in the AMK. This process or alteration of the AMK fuel is referred to as "degradation". The technical feasibility of devices designated "degraders" which utilize either mechanical or cavitation principles has been demonstrated (Refs. 1, 2, 3).

This report documents a twelve-month AMK Engine System Integration study that evaluated the use of antimisting kerosene and the incorporation of a "fuel degrader" on the performance, reliability and safety of the Pratt & Whitney JT3C-7 engines for short duration flights of a B-720 test airplane during the Full-Scale Transport Controlled Impact Demonstration (CID) Program held at the Dryden Flight Research Facility of the NASA Ames Research Center. This study was conducted under contracts NAS3-24217 and NAS3-24353 and focused on two major areas of activity: Task I- System Integration Study and Task II - Design Reviews and Flight Test Planning.

In Task I of the program, a review and analysis were made of the JT3C-7 AMK engine fuel system which included the degrader system, heat exchangers, engine fuel pump and filters, fuel controls and the resulting operational and performance characteristics of the engines. The B-720 instrumentation was reviewed and recommendations were made for additional degrader and engine instrumentation to identify problems that may occur.

As part of the Task I effort, laboratory fuel characterization tests were conducted to determine whether the AMK fuel was sufficiently processed or degraded before introduction to the engine fuel system. These fuel characterization tests consisted of filter ratio and transition velocity measurements which provided a correlation with the filters, fuel nozzles/injectors, combustor performance, etc., previously evaluated under NASA Contract NAS3-22045 (Ref. 1).

In Task II, Pratt & Whitney participated in design reviews and test planning. A major but necessary general effort was the assistance rendered to NASA Ames-Dryden Flight Research Facility in the planning and installation of both instrumentation and modifications to the engine fuel system for structural and operational considerations. This activity involved consultation with vendors, procurement of prints, schematics and parts, several visits to NASA Ames-Dryden Flight Research Facility and dialogue with NASA Ames-Dryden Flight Research Facility on almost a daily basis.

This report describes the baseline JT3C-7 engine and its modifications for the use of AMK. The levels of degradation adequate for operability in the test airplane are identified from fuel characterization tests. Finally, engine performance with AMK during these ground and flight tests is compared to the baseline sea level performance expected with Jet A.

## EQUIPMENT AND PROCEDURES

This section describes the JT3C-7 engine and its components which would be affected by the use of antimisting kerosene fuel. In addition, modifications to the bill-of-material engine fuel system and special test equipment used to analyze the antimisting kerosene will be discussed.

### ENGINE DESCRIPTION

Four Pratt and Whitney JT3C-7 engines powered the CID B-720-027(S/N 18066) test airplane. The JT3C-7 engine depicted schematically in Figure 1 and illustrated in detail in Appendix A represents first-generation commercial transport technology. This engine is a dual-spool, axial-flow turbojet, with a 16-stage compressor, a co-annular combustion section and a 3-stage turbine. In the Boeing 720 airframe installation, the engine is 11.4 ft long, 38.9 inches in diameter and weighs 3495 pounds. Key specifications for this engine are shown in Table I.

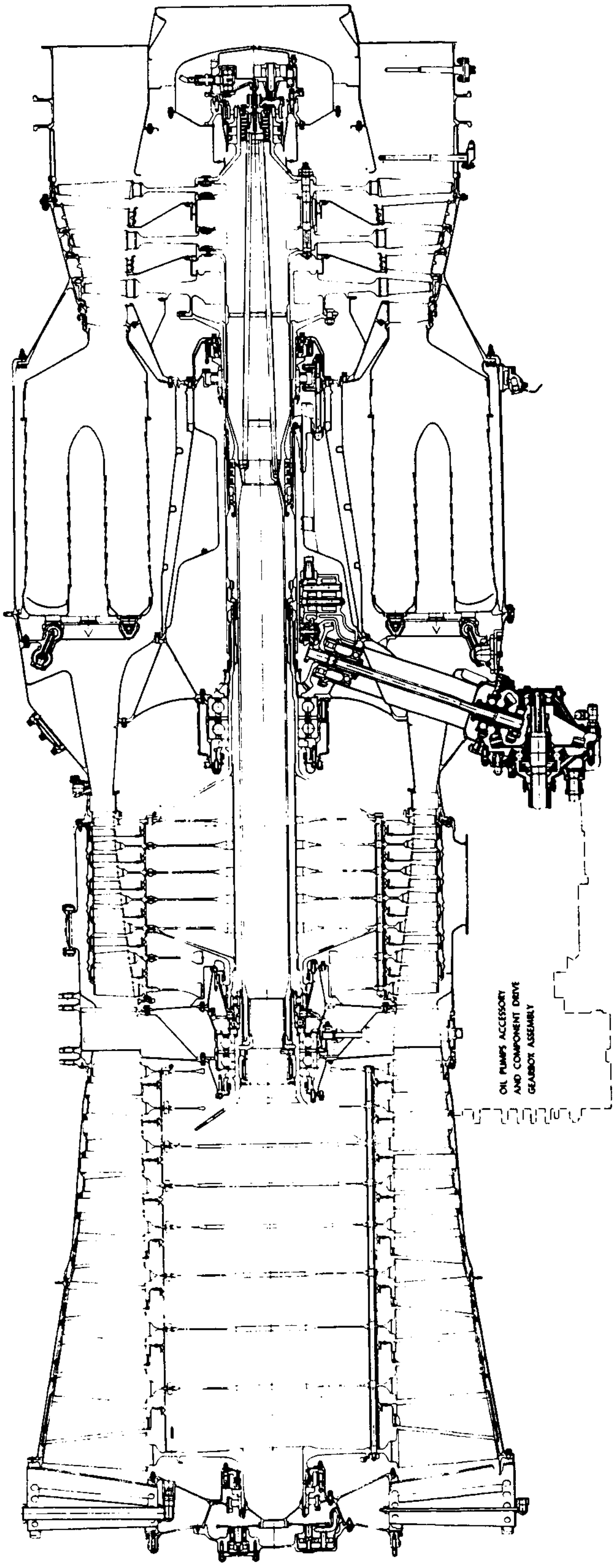

Figure 1 Cross-Sectional View of JT3C-7 Engine

## TABLE I
## SPECIFICATIONS OF THE JT3C-7 ENGINE

| | |
|---|---|
| Take-off Rating (at sea level) | 12,000 lb. thrust |
| Maximum Continuous Rating (at sea level) | 10,000 lb. thrust |
| Maximum Specific Fuel Consumption | .785 pph/lb. thrust |
| Total Air flow | 182 pps |
| Pressure Ratio | 13.0 |
| Dry Weight | 3495 lbs. |
| Engine Diameter | 38.9 inches |
| Engine Length | 11.4 ft |

### Engine Fuel System

The principal function of the aircraft fuel system is to supply clean liquid fuel, free from vapor, at the required pressures and rates of flow, to the engine under all operating conditions. Figure 2 shows the basic JT3C-7 fuel system for a commercial installation. Fuel is supplied from the aircraft tanks through the necessary filters and valves to the engine-driven fuel pump which is a two-stage, by-pass equipped unit that discharges fuel at predetermined pressures and quantities through a fuel de-icing system (customer optional) to the fuel control. The fuel de-icing filter assembly consists of a 40 micron paper filter element enclosed in a cylindrical housing. After pressurization, the fuel passes to the fuel control through a coarse mesh inlet filter. The fuel control is a hydromechanical fuel metering device designed to schedule the proper flow of fuel to maintain the engine speed selected. The metered fuel flows through the aircraft fuel-oil cooler to the pressurizing and dump valve which schedules flow to the fuel nozzle secondary manifold as a function of primary fuel nozzle pressure drop. This ensures the proper fuel spray quality and distribution for efficient combustion. The fuel manifold consists of eight circular clusters, each cluster having six dual orifice nozzles, located in the diffuser case annulus. The fuel is injected through each cluster into each of eight combustion chambers where it mixes with air and burns.

Fuel Pump - The main fuel pump (Figure 3) consists of two positive displacement gear-type pumping elements (boost stage and main stage) operating in series to supply fuel to the engine fuel control. Power to drive the pump is suppled directly by the main drive shaft. Under normal operating conditions, fuel flows through the pump from the fuel in port to the inlet fuel filter element containing a self-relieving valve to the boost stage. Between the boost and main stage is the interstage 40 micron pleated paper filter and optional de-icer system. The boost stage pressure regulating valve controls the pressure of the fuel delivered to the main stage inlet at between 45 and 65 psi above pump inlet pressure. The rated capacity of the pump is 41.6 gpm at 3260 rpm and a discharge pressure of 1000 psig.

Fuel Control - The Hamilton Standard JFC25-10 fuel control (Figure 4) is a hydromechanical high capacity fuel flow metering unit designed to permit selection of the desired engine thrust level throughout the flight envelope of

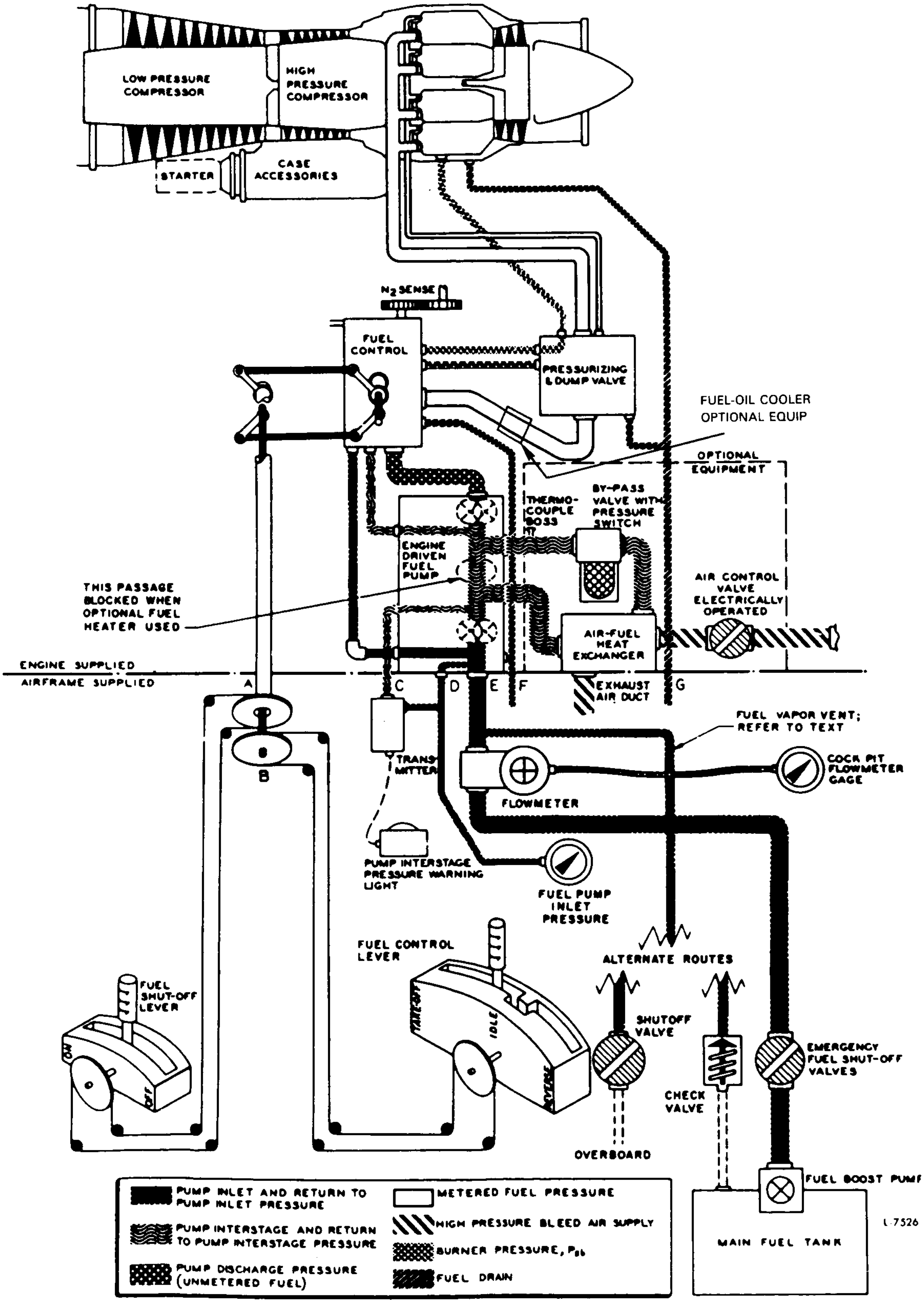

Figure 2 Basic JT3C-7 Fuel System

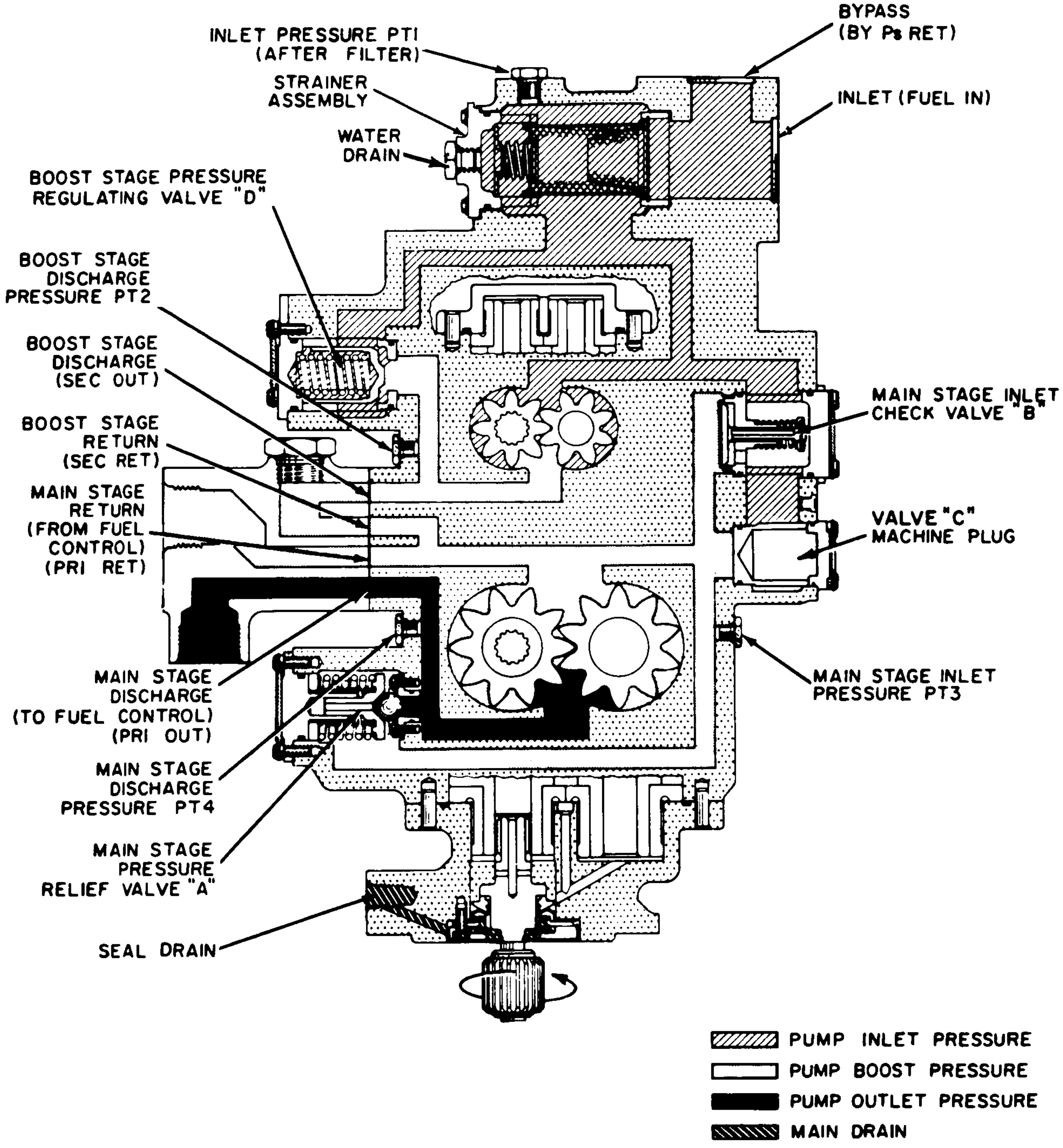

Figure 3 Two-Stage Main Fuel Pump

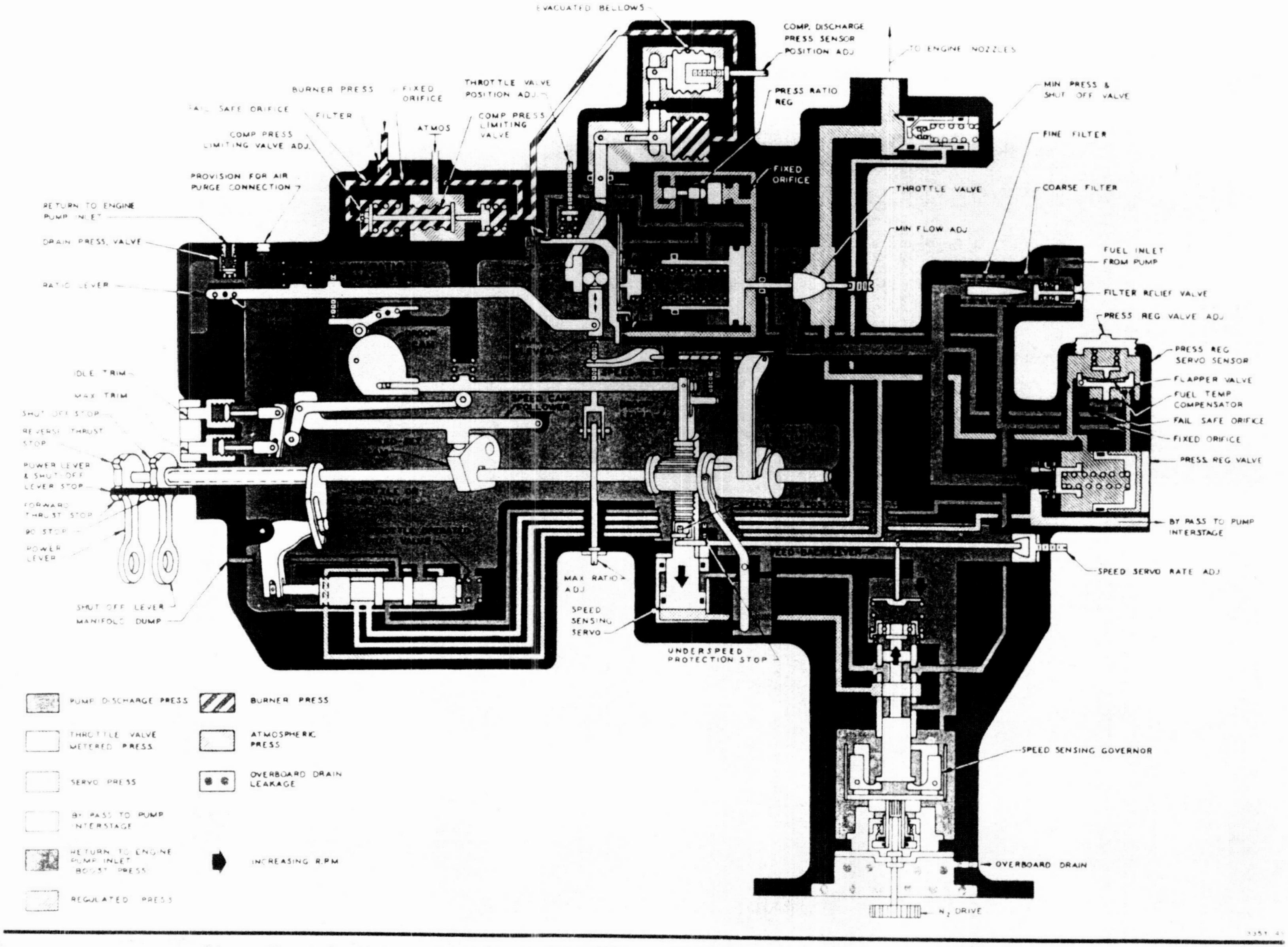

Figure 4 JFC 25-10 Fuel Control

the JT3C-7 engine equipped aircraft. Two manually operated levers are provided on each control: a power lever for regulating engine thrust in the range from full reverse through idle to takeoff; the other, a shutoff lever to regulate fuel for engine starting and shutdown. The variables sensed by the fuel control are power lever angle, burner pressure and engine $N_2$ rotor speed. By utilizing these variables, the fuel control accurately governs the engine steady state selected speed and limits fuel flow for acceleration and deceleration through a speed-governing system of the proportional or droop type.

The fuel control may be considered as consisting of a fuel-metering system and a computing system. The metering system regulates the fuel supplied to the fuel control by the engine driven fuel pump to provide the engine thrust output demanded by the pilot, but subject to engine operating limitations as sensed and scheduled by the fuel control computing system. The computing system senses and combines various operational parameters to govern the output of the metering system of the fuel control during all engine operating regimes. Figure 5 indicates the fuel control parameters and scheduling accuracy requirements for these parameters.

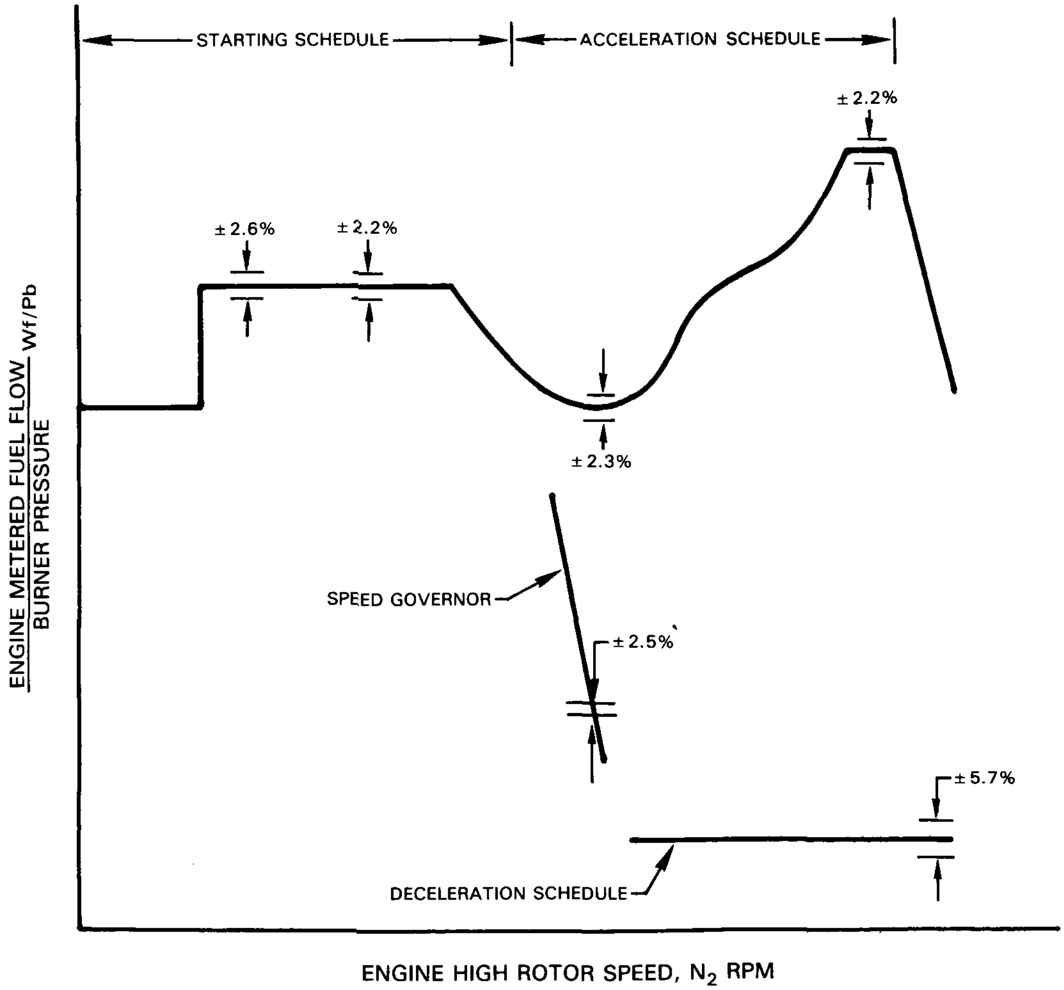

Figure 5 JT3C-7 Fuel Control Scheduling Accuracy Requirements

Fuel Filter Systems - The JT3C-7 engine fuel system incorporates several fuel filters differing in construction, filter area and filtration quality depending on the subsystem component protection requirements. Table II provides a fuel system filter tabulation for the JT3C-7 engine. It should be noted the interstage 40 micron pleated paper filter provides the primary protection for all subsystem components. It also acts as a collector of fuel borne ice crystals. An optional fuel deicing system can be added to the engine to increase fuel filter inlet temperatures, clearing the filter of collected ice.

TABLE II
JT3C-7 FUEL SYSTEM FILTER SURVEY

| Component | Location | Material | Pore Size | Area (in$^2$) |
|---|---|---|---|---|
| Fuel Pump | Inlet | Stainless Steel | 400 microns | 5.15 |
| *Fuel Deicing Filter | Pump Interstage | Paper | 40 microns | 625 |
| Fuel Control | Inlet | Stainless Steel | 200 microns | 18.8 |
| Fuel Control | Servo | Stainless Steel | 40 microns | 7.1 |
| Pressure and Dump Valve | Inlet | Stainless Steel | 74 microns | 8.5 |
| Fuel Nozzle | Primary | Stainless Steel | .007 - .009 Dia. opening | 0.39 |
| Fuel Nozzle | Secondary | Stainless Steel | .007 - .009 Dia. opening | 0.47 |

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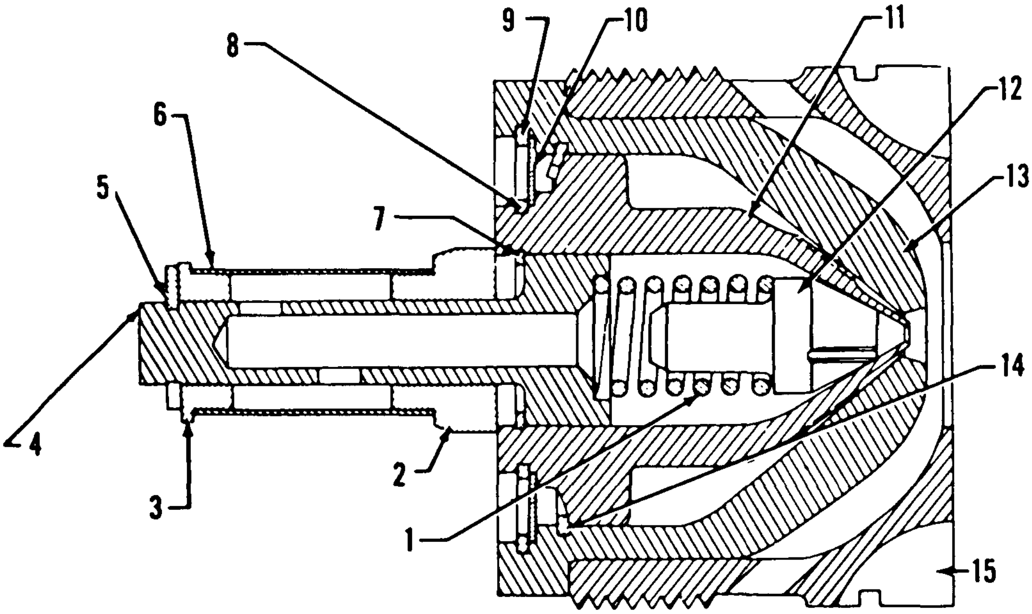
*Replaced for CID Test - See "Engine Modifications for AMK" Section

### Combustor Description

The JT3C-7 combustor section consists of eight separate tubular combustion chambers in a co-annular arrangement. The chambers, as viewed from the rear of the engine, are numbered clockwise starting with the uppermost chamber as No. 1. These chambers are interconnected by cross-over tubes for flame propagation during starting. Lighting or starting is initiated from spark igniters located in the No. 4 and No. 5 combustion chambers. Each combustion chamber comprises a series of formed sheet-metal, air cooled cylindrical liners.

The forty-eight fuel nozzle assemblies are supported in the fuel manifold and are arranged in eight clusters of six nozzles each. Each cluster projects into accommodating apertures in the upstream end or dome of each combustion chamber. The JT3C-7 combustor employs a dual-orifice pressure atomizing fuel nozzle (Figure 6) to obtain the required turndown ratio (ratio of maximum to minimum fuel flow). The nozzles are designed to discharge a predetermined amount of fuel when specified pressure drops are maintained across the primary and secondary stages, acting both as an atomizing and metering device. The relationship between fuel flow and nozzle pressure drop for a typical JT3C-7 engine is shown in Figure 7. The pressurizing and dump valve is used to channel flow to the primary or secondary system. When the secondary cracking or staging point is reached, the secondary valve opens and flow is admitted to the secondary system. Until then the system flow is to the primary only. This staging point is controlled by a spring loaded valve, which is sensitive to the difference between fuel pressure and combustor pressure.



1. SPRING
2. LOWER PRIMARY FERRULE
3. UPPER PRIMARY FERRULE
4. SPRING SEAT
5. PRIMARY STRAINER SNAPRING
6. PRIMARY STRAINER
7. SPRING SEAT SNAPRING
8. INNER SECONDARY STRAINER SNAPRING
9. OUTER SECONDARY STRAINER SNAPRING
10. SECONDARY STRAINER
11. NOZZLE BODY INSERT
12. PRIMARY PLUG
13. NOZZLE BODY
14. INSERT SNAPRING
15. RETAINING NUT

Figure 6 Fuel Nozzle

## ENGINE MODIFICATIONS FOR AMK

### B-720 Flight Test Engines

The approach followed by the FAA has been to blend Jet A and FM-9 additive in-line at the aircraft fueling point to produce an AMK fuel with acceptable fire supression properties in the aircraft's fuel tanks. This approach requires that the AMK be acceptable and useable within the aircraft's fuel and engine systems. Compatability studies (Refs. 1,4,5,6) evaluating the effects of using AMK on the performance of airframe fuel systems and engine components showed

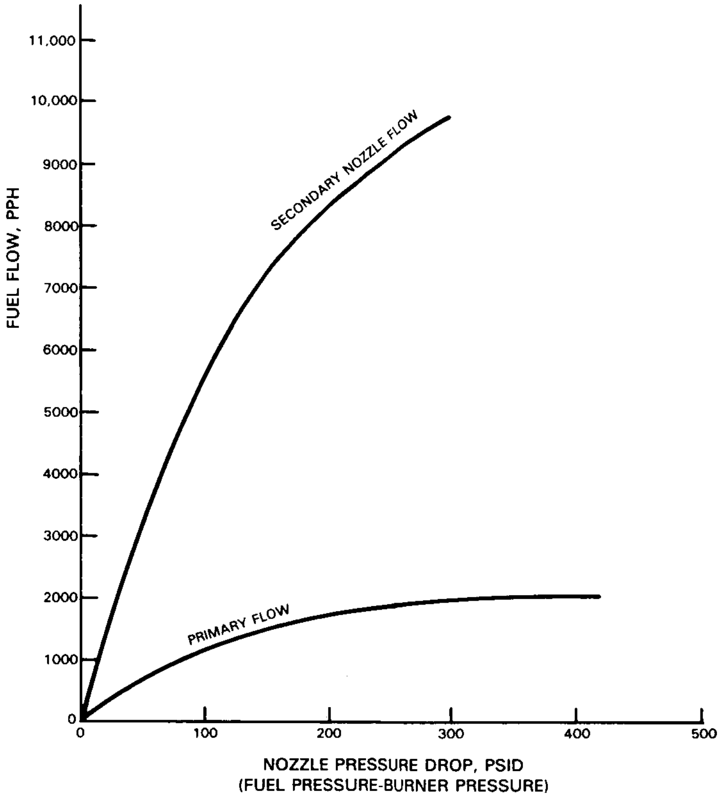


Figure 7 JT3C-7 Fuel Flow Schedule

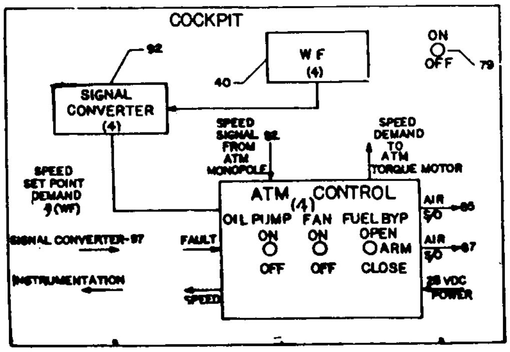
that the AMK needed to be processed or degraded to a fuel suitable to meet the requirements of the JT3C-7 engines for the B-720 aircraft for the planned Full-Scale Transport Controlled Impact Demonstration (CID) test. Specifically, these requirements involved engine operability (starting, acceleration/deceleration, relight) and performance (efficiencies, exit temperature distribution, filterability).

Several studies in the United States and United Kingdom indicated that the FM-9 polymer can be highly degraded and the AMK restored to near Jet A properties (Refs. 1,2,3). A prototype AMK fuel degrader for the CID aircraft was developed by the General Electric Company based on a high speed, air driven centrifugal pump. Four degraders of this type, necessary for the B720, were to be engine nacelle mounted and capable of running on Jet A and/or degraded AMK for the required ground and flight test missions. NASA Ames-Dryden Flight Research Facility was responsible for the installation of the four degrader systems on the B720 aircraft as well as necessary modifications to the aircraft.

Figure 8 is a schematic of the AMK degrader system installed on each of the four engines of the B-720 CID aircraft. The primary degrader components consisted of the F101 engine augmentor centrifugal pump, the C5A aircraft auxiliary power air turbine motor, and fuel pressure throttling valve. The air

B720 AMK INSTALLATION PARTS LIST

| ITEM | DESCRIPTION | QTY/ ENGINE | SUPPLIED BY |
|---|---|---|---|
| 40 | DEGRADER SPEED CONTROL FUEL FLOW SENSOR | 1 | NASA |
| 41 | DEGRADER ASSEMBLY, PUMP AND AIR TURBINE MOTOR (ATM) | 1 | NASA |
| 42 | DEGRADER MOUNTING BRACKET | 1 | NASA |
| 43 | FUEL LINE ADAPTER (INCLUDES TWO -4 NIPPLES) | 2 | NASA |
| 44 | FUEL HOSE, 3000 PSI OPERATING (0.75-INCH NOM) | 1 | GE |
| 45 | FUEL TUBE, 1000 PSI OPERATING (0.75-INCH NOM) | 1 | GE |
| 50 | FLOW ORIFICE (0.75 - 0.50 INCH MS REDUCER) | 1 | NASA |
| 51 | FUEL RECIRCULATION HOSE, 1000 PSI OPERATING (0.75-INCH NOM) | 1 | GE |
| 52 | FUEL/AIR HEAT EXCHANGER | 1 | NASA |
| 53 | HEAT EXCHANGER MOUNTING BRACKET | 1 | GE |
| 54 | HEAT EXCHANGER AIR FLANGE CLAMPS | 2 | NASA |
| 55 | HEAT EXCHANGER AIR DUCT | 1 | GE |
| 57 | BELLMOUTH AIR SCOOP | 1 | GE |
| 58 | FAN AND RELAY (115 VAC, 3 PH, 400 HZ, 11 A, INRUSH 90 A/PH FOR 1 SEC) | 1 | NASA |
| 59 | FAN MOUNTING BRACKET | 1 | GE |
| 62 | FAN WIRING AND CIRCUIT BREAKER | 1 | GE |
| 63 | ATM OIL COOLER | 1 | NASA |
| 64 | ATM OIL COOLER MOUNTING BRACKET | 1 | GE |
| 65 | ATM OIL HOSE, 1000 PSI OPERATING (0.50-INCH NOM) | 1 | GE |
| 66 | ATM OIL FILTER | 1 | NASA |
| 67 | ATM OIL FILTER MOUNTING BRACKET | 1 | GE |
| 68 | ATM OIL PUMP (28 VDC, 22 A, INRUSH 135 A FOR 0.5 SEC) | 1 | NASA |
| 69 | ATM OIL PUMP BYPASS FLOW ORIFICE (0.50-INCH NOM) | 1 | NASA |
| 70 | ATM OIL PUMP MOUNTING BRACKET WIRING AND RELAY | 1 | GE |
| 71 | ATM OIL PRESSURIZATION HOSE (0.25-INCH NOM) | 1 | GE |
| 72 | ATM SEAL DRAIN HOSE (0.375-INCH NOM) | 1 | GE |
| 73 | FUEL THROTTLING VALVE | 1 | NASA |
| 74 | FUEL THROTTLING VALVE MOUNTING BRACKET | 1 | GE |
| 75 | CDP AIR BLEED REG CHK AND S/O VALVE WITH CLAMPS (CV880) | 1 | GE |
| 76 | ENGINE FUEL SUPPLY HOSE, 1000 PSI OPERATING (1.5-INCH NOM) | 1 | GE |
| 77 | FUEL BYPASS VALVE (1.5-INCH, 14/28 VDC, 1 A) | 1 | GE |
| 78 | FUEL BYPASS VALVE MOUNTING BRACKET | 1 | GE |
| 79 | CDP AIR BLEED VALVE SWITCH (COCKPIT) | 1 | NASA |
| 82 | ATM SPEED SIGNAL CABLE AND CONNECTORS | 1 | NASA |
| 83 | ATM AIR SUPPLY DUCT (3.5-INCH NOM, 0.040 WALL STAINLESS STEEL) | 1 | GE |
| 84 | ATM AIR REGULATOR AND SHUTOFF VALVE CLAMPS | 2 | NASA |
| 85 | ATM AIR REGULATOR AND SHUTOFF VALVE (28 VDC, 1 A) | 1 | NASA |
| 86 | ATM AIR SHUTOFF VALVE AND ATM AIR INLET CLAMPS | 3 | NASA |
| 87 | ATM AIR SHUTOFF VALVE (28 VDC, 1 A) | 1 | NASA |
| 88 | ATM AIR EXHAUST DUCT CLAMP | 1 | NASA |
| 89 | ATM AIR EXHAUST DUCT (4.0-INCH NOM, 0.020 WALL STAINLESS STEEL) | 1 | GE |
| 90 | FUEL THROTTLING VALVE SERVO PRESS. TUBE, 3000 PSI OPERATING (0.25-IN.) | 1 | GE |
| 91 | FUEL HEATER JUMPER TUBE | 1 | GE |
| 92 | SIGNAL CONVERTER (FUEL SENSOR SIGNAL TO VDC) | 1 | GE |
| 93 | ATM OIL PRESSURE (0-200 PSIG) | 1 | GE |
| 94 | DEGRADER FUEL DISCHARGE PRESSURE (0-2000 PSIG) | 1 | GE |
| 95 | DEGRADER FUEL DISCHARGE TEMPERATURE (0°-250°F) | 1 | GE |
| 96 | THROTTLING VALVE INTERSTAGE PRESSURE (0-250 PSIG) | 1 | GE |
| 97 | FAULT CONVERTER (SENSOR SIGNAL TO VDC) | 6 | GE |
| 98 | ENGINE FUEL PUMP INLET PRESSURE (0-150 PSIG) | 1 | GE |
| 99 | PRIMARY FUEL NOZZLE PRESSURE (0-1000 PSIG) | 1 | GE |
| 100 | SECONDARY FUEL NOZZLE PRESSURE (0-1000 PSIG) | 1 | GE |
| 101 | ENGINE FUEL FILTER DIFFERENTIAL PRESSURE (0-50 PSID) | 1 | GE |
| 102 | DEGRADER FUEL INLET TEMPERATURE (0°-175°F) | 1 | GE |
| 103 | DEGRADER FUEL INLET PRESSURE (0-50 PSIG) | 1 | GE |
| 104 | ENGINE FUEL PUMP INLET TEMPERATURE (0°-200°F) | 1 | GE |
| 105 | ENGINE SCAVENGE OIL TEMPERATURE (0°-350°F) | 1 | GE |
| 106 | ATM OIL TEMPERATURE (0°-300°F) | 1 | GE |
| 107 | FUEL CONTROL WASH SCREEN DIFFERENTIAL PRESSURE (0-50 PSID) | 1 | GE |
| 108 | THROTTLING VALVE LEAKAGE CHECK VALVE | 1 | NASA |
| 109 | THROTTLING VALVE LEAKAGE HOSE, 1000 PSI OPERATING (0.50-INCH) | 1 | GE |
| 110 | CHECK VALVE | 1 | GE |
| 111 | PRESSURE TRANSDUCER, 50 PSID MFP INLET-MFP INLET SCREEN ENG 2 & 3 | | |
| 112 | DIFFERENTIAL PRESSURE TRANSDUCER | | |
| 113 | RESTRAINED BELLOWS | | |
| 114 | ATM AIR SUPPLY DUCT (3.5 NOM, 0.040 WALL SS WITH 2-, 3-INCH BELLOWS) | | |



(A) DEGRADER PARTS

Figure 8 B720 Anti-Misting Kerosene Degrader Installation Schematic

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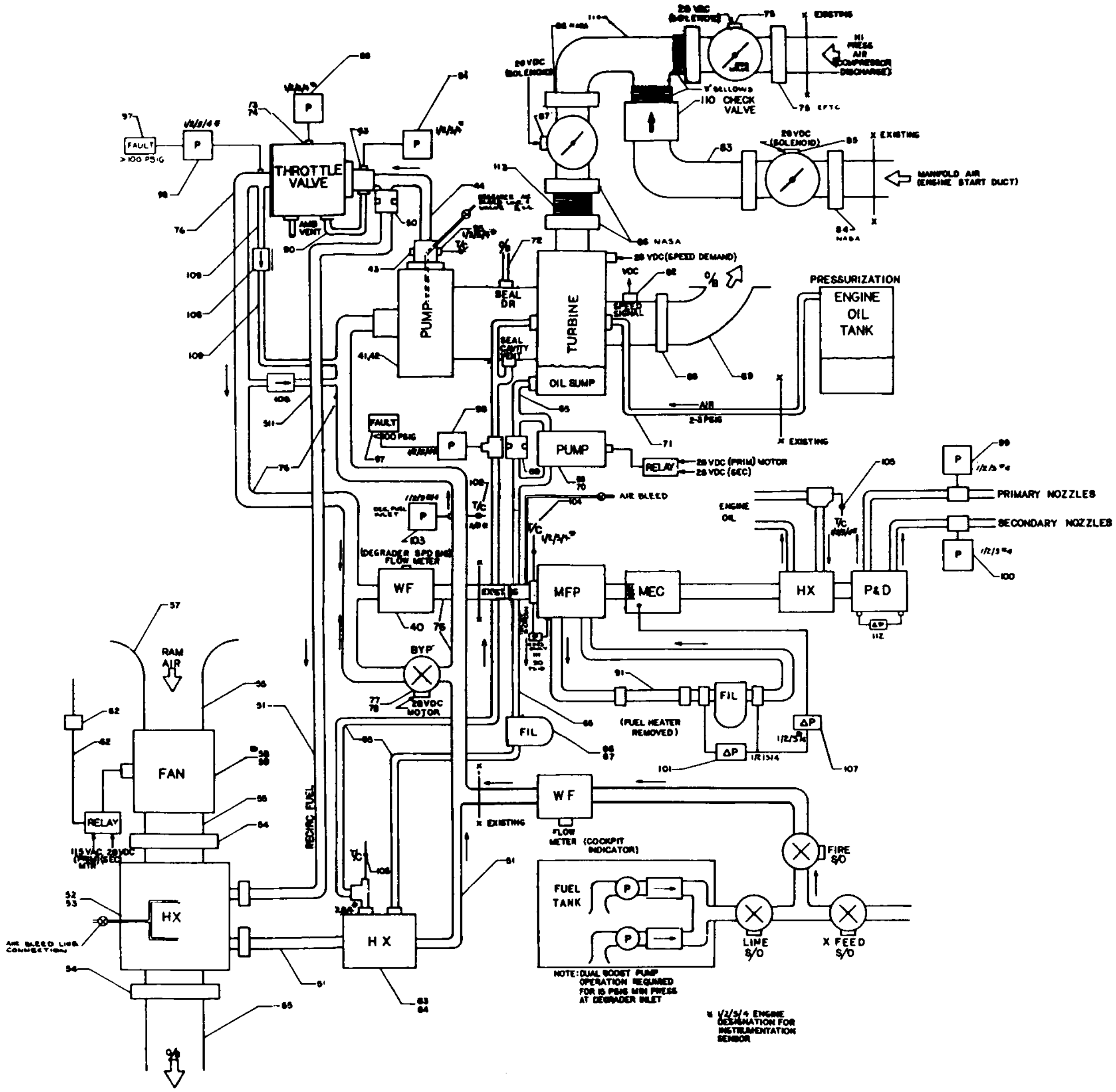

(B) DEGRADER SCHEMATIC

Figure 8 B720 Anti-Misting Kerosene Degrader Installation Schematic (Cont'd)

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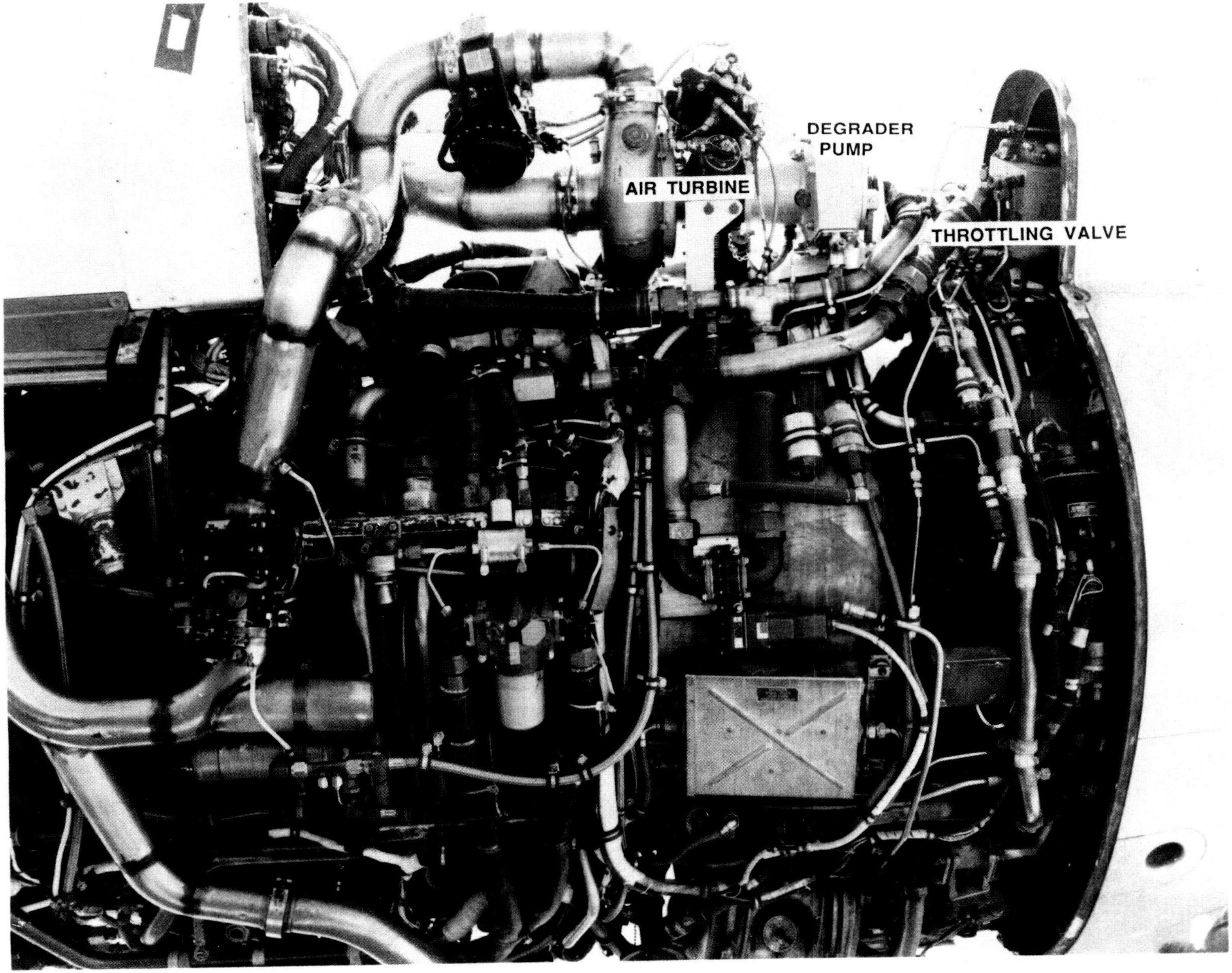

Figure 9 B-720/JT3C-7 Fuel Degrader Installation (Right Side)

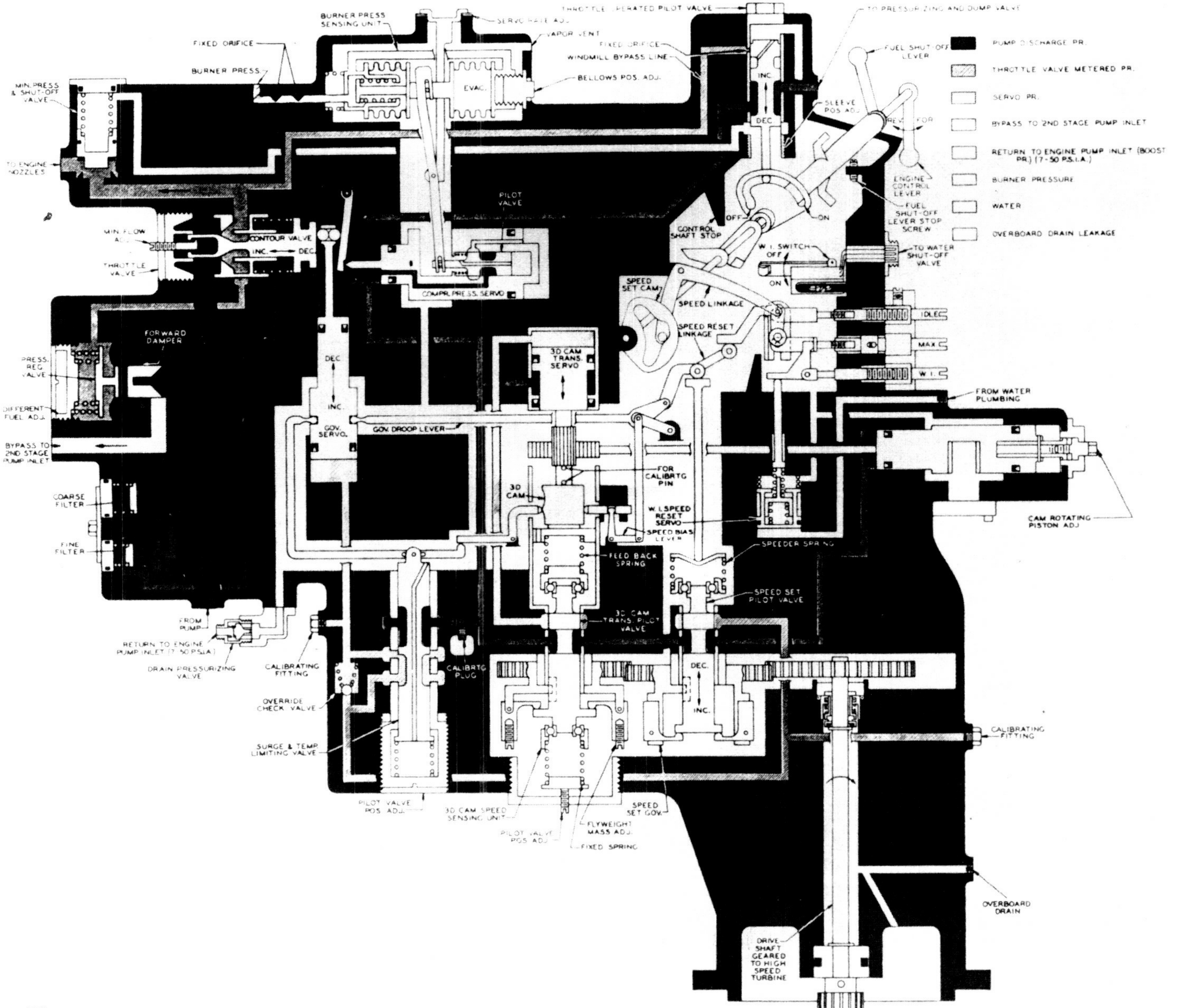

Figure 10  JT3C-6 Engine Fuel Control

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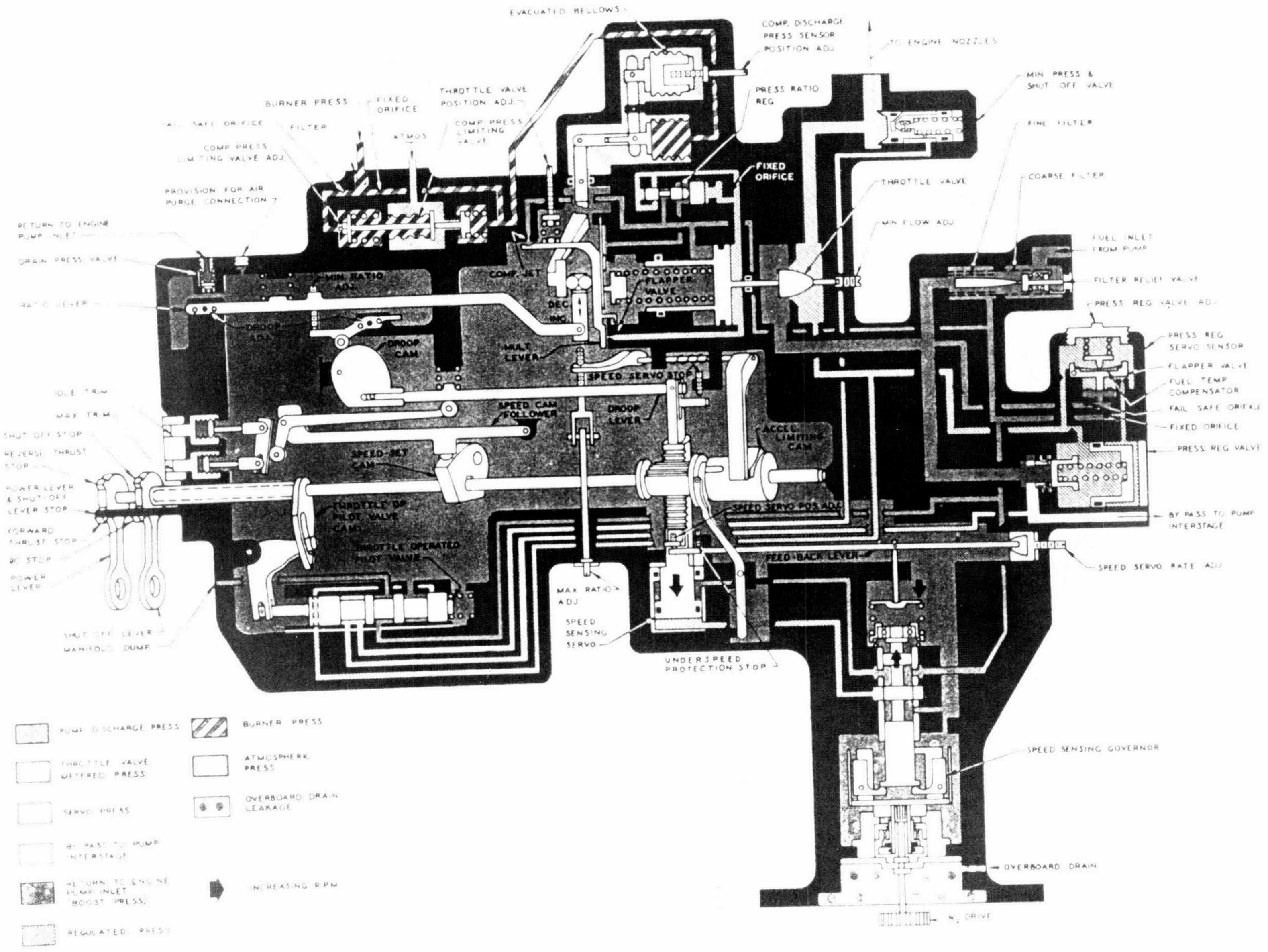


Figure 11 JT3C-7 Engine Fuel Control

turbine was driven by compressor bleed air during engine operation and was capable of providing degraded AMK for engine start through the use of high pressure air from ground carts or engine cross bleed. The F101 engine pump utilized by G.E. as the degrader had a design flow capacity much higher than that required by the JT3C-7 engine. Therefore, it was necessary to include a recirculation loop through an air-fuel heat exchanger, mounted in an external wing mounted pod, to dissipate excess heat generated by the degrader to the fuel. A throttling valve located at the degrader exit reduces the fuel pressure before the main fuel engine pump to acceptable levels (<55 psig) during engine operation. In case of a degrader shutdown, the modified fuel system provided for an automatic quick acting bypass loop allowing AMK fuel to flow directly to the engine fuel pump. The B-720 aircraft was modified and instrumented to operate all four engines on AMK with provisions for switching from Jet A to AMK fuel. Figure 9 is a photograph showing the right side view of the B-720 degrader-engine nacelle installation.

An extensive amount of instrumentation was added to the engine fuel system to monitor important engine/fuel system parameters for the CID program. This instrumentation measured and determined the effect of AMK fuel on aircraft, engine and fuel system performance and conversely, the effect of the aircraft flight environment and fuel system on AMK fuel characteristics. Critical fuel system components were monitored for signs of clogging tendency while flowing AMK fuel. In particular, engine filters/screens were instrumented and monitored for pressure differential throughout the course of the program.

Besides the additional instrumentation, the only other modification made to the B-720 engine fuel system was the removal of the fuel pump interstage heater/filter (de-icer), downstream of the degrader, to make room for degrader components. In place of the standard JT3C-7 fuel filter, a G.E. J-79 metal filter of smaller filter area (200 in$^2$ versus 625 in$^2$) was installed.

### FAA Technical Center Ground Test Engine

As part of the overall evaluation of AMK and in support of the CID program, the FAA Technical Center utilized an available JT3C-6 ground test engine instead of a JT3C-7 engine to evaluate the effects of degraded/undegraded AMK on engine performance and control. The primary differences between the two engine models are that the JT3C-7 engine is a lighter engine without water ingestion capability (for takeoff thrust augmentation) and contains a significantly different fuel control. As a result of the planned AMK ground testing, an evaluation was made of the differences between the Hamilton Standard JFC12-11 and JFC25-10 controls used on the JT3C-6 and JT3C-7 engines, respectively. The JFC25-10 fuel control contains a servo filter (44 microns) with no provision for bypass, whereas the JFC12-11 fuel control utilizes the same filter but is bypassed when the pressure differential exceeds 25 psi. In addition, the mesh size of the fuel control inlet filter is 200 microns on the JFC12-11 versus 74 microns on the JFC25-10. While both models exercise control in a similar manner, their mechanical designs differ as can be seen in Figures 10 and 11. The JFC12 series is the first generation controls for the JT3 turbojets while the JFC25 series is the second generation controls for the JT3 and JT4 models.

In preparation for one series of tests conducted at the FAA Technical Center, the JT3C-6 fuel control was modified by blocking shut the servo filter bypass and replacing the 74 micron inlet filter screen with a newly fabricated 200 micron size filter. At the request of NASA/FAA, another series of tests were scheduled to evaluate the operability of the JT3C-7 control of the B-720 test airplane when operating on AMK fuel. Pratt & Whitney assisted in the preparation and installation of a JT3C-7 fuel control on the JT3C-6 engine. The JT3C-7 fuel control was inspected, repaired and modified with a down change acceleration cam in order to make the control compatible with the JT3C-6 test engine. Installation of the cam and checkout was accomplished by Hamilton Standard. A mockup of the JT3C-7 control and several special fittings were provided to assist in plumbing the modified JT3C-7 fuel control to the JT3C-6 engine. The resulting schedule is shown in Figure 12 with the Bill-of-Material JT3C-6 and JT3C-7 schedules.

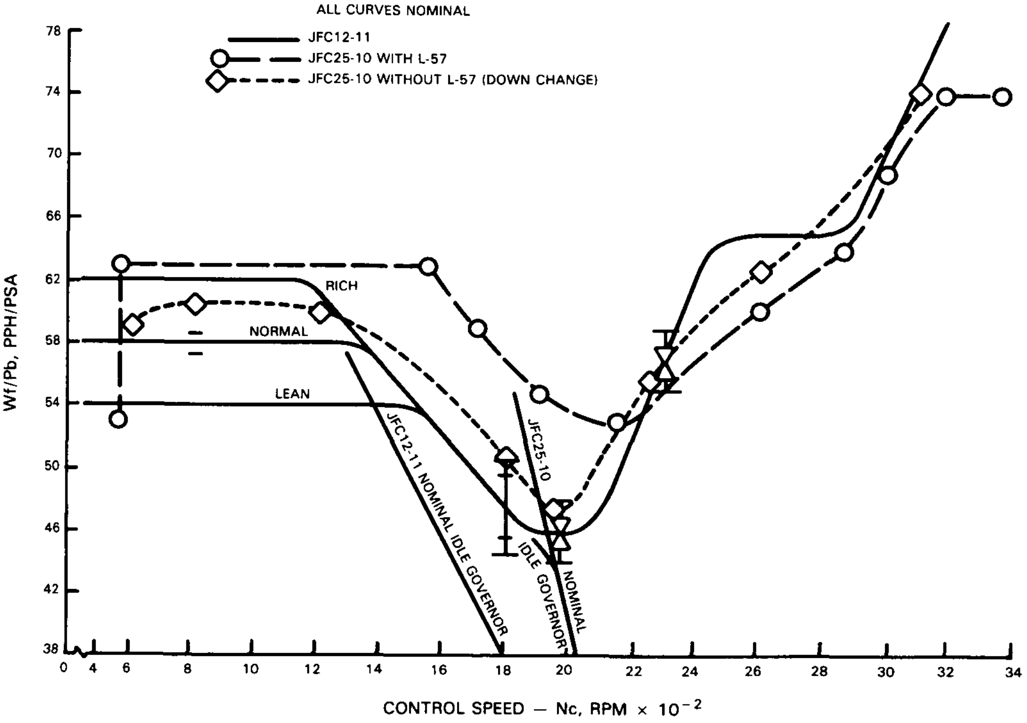


Figure 12 Fuel Control Acceleration Schedules

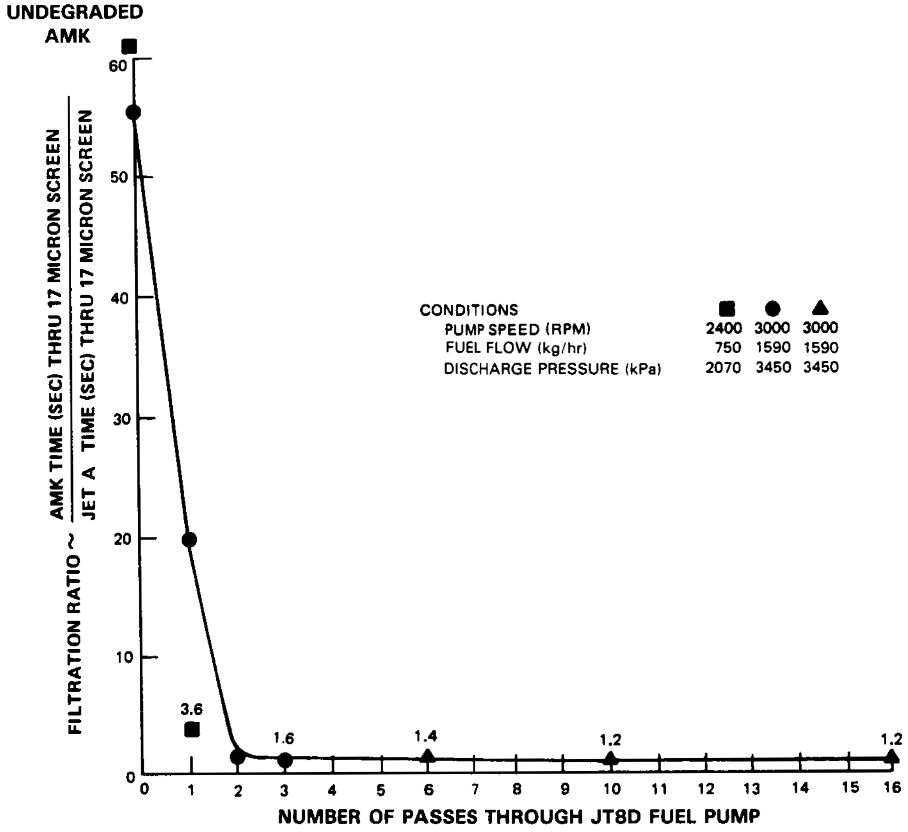


Figure 13 Filter Ratio Sensitivity

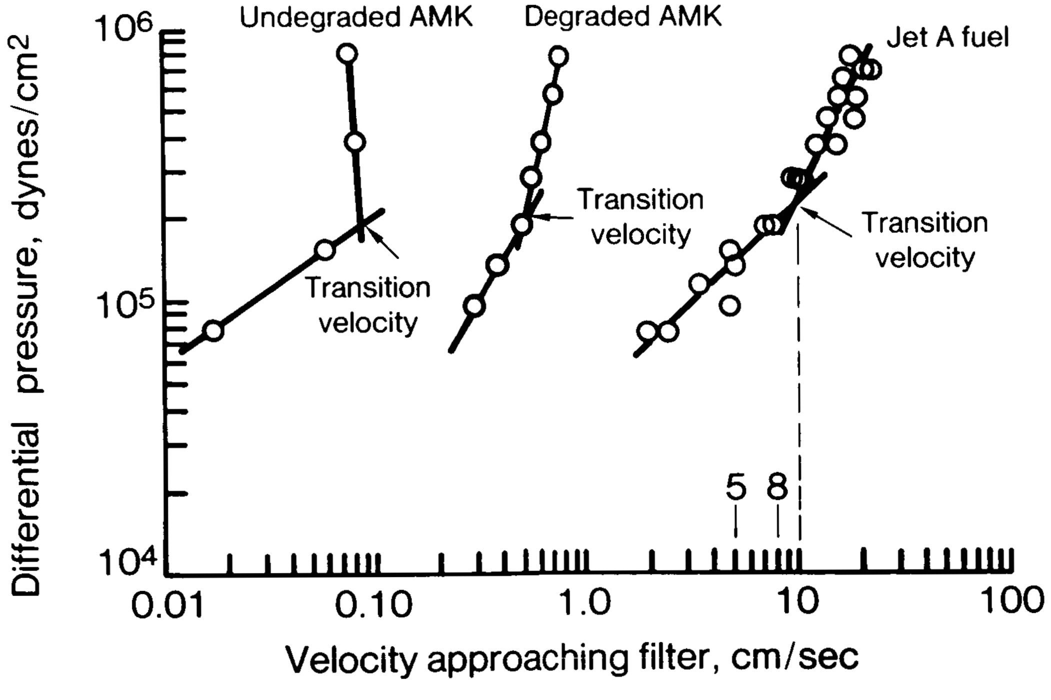


Figure 14 Transition Velocity

## LABORATORY FLOW CHARACTERIZATION EQUIPMENT

Under NASA/FAA sponsorship, Pratt & Whitney investigated the extent of AMK pre-shearing or degradation required to enable satisfactory operation of the engine components at various fuel temperatures. Fuel characterization tests, developed by Pratt & Whitney and other investigators, were used to determine a correlation with the performance required of the filters, fuel nozzles and combustor of the JT3C-7 engine for the CID mission. Because the antimisting additive increases the effective viscosity of the blended AMK fuel, techniques that measured viscosity and filterability were used to quantify the extent to which AMK was degraded from its initial origin or unsheared state. For low levels of polymer degradation, the degradation level was evaluated by a filter ratio obtained from a single flow filtration test. This test is a ratio of the times required for a known quantity of test fuel and the same quantity of Jet A fuel to flow through a specified filter (17 micron screen) (see Appendix B-1 for a detailed procedure).

In an earlier program (Ref. 1), AMK was degraded by increasing number of passes through a JT8D fuel pump. The sensitivity of filter ratio to the number of passes through the pump is shown in Figure 13. This plot and subsequent tests showed that although filter ratio is an adequate measurement technique for degradation levels equivalent to filter ratios down to approximately two, it did not provide sufficient resolution to describe levels below that point. Filterability, fuel spray quality, and combustion tests recorded in Ref. 1 indicated that there were significant differences in the way AMK degraded between the 3 and 16 passes performed although filter ratios showed almost no distinction. In filtration experiments, when AMK volumetric flow rate per unit area or velocity is plotted against increasing differential pressure across a very fine filter, there is a noticeable increase in flow resistance at a particular velocity as shown in Figure 14. The shift point is a function of fuel type or level of AMK degradation and has been labeled transition velocity ($V_t$). It has been hypothesized that these shifts or transition velocities are analogous to transition from laminar to turbulent flow within the filter. Pratt & Whitney has found this measurement technique to be a valuable and reproducible means of categorizing highly degraded AMK fuels. A detailed laboratory procedure for measuring transition velocity is included in Appendix B-2.

The levels of AMK degradation recommended by Pratt & Whitney to satisfy the filterability and combustor performance required for the CID program will be assessed in the next section of this report.

# RESULTS AND DISCUSSION

## FUEL SYSTEM AND ENGINE OPERABILITY

Pratt & Whitney assisted NASA in determining the safety and mission suitability of the modified fuel system for the proposed engine tests and subsequent flights. This study reviewed and analyzed information and test data received from NASA/FAA regarding the degrader system, heat exchangers, engine fuel system and subsequent effects to engine oil and fuel as they pertained to operability. Recommended limits for fuel degradation and engine condition (s) were determined and presented to NASA/FAA.

The filterability characteristics of all the fuel system components were surveyed to assess clogging for subsequent engine tests. A summary of the JT3C-7 bill-of-material fuel system filters and screens is tabulated in Table II. These filters were included in the assessment except for the fuel pump interstage which was replaced by a GE J-79 metal filter of smaller area but slightly coarser mesh size (44 microns). Based on known filter characteristics (area, mesh size, fuel flow requirements) and the filterability experiments performed under NASA contract NAS3-22045 and documented in Ref. 1, the pressure and dump (P&D), and fuel control servo filters were judged to be most susceptible to clogging. The clogging phenomena due to gel formation was found to be a function of increased fuel flow or velocity, decreased fuel temperature and cumulative time (Ref. 1). Therefore, it was projected that for short durations, low altitude flights and environmental conditions for the CID program, AMK degraded to filter ratios of approximately 1.2 or transition velocities at least 2-3 cm/sec., would preclude clogging in the engine fuel system. Based on fuel nozzle spray quality and subsequent combustion tests (Ref. 1), this level of degradation was judged to be acceptable for engine combustor requirements as well. In addition, the engine two stage gear pump could provide further degradation margin to the AMK fuel delivered from the degrader system. In the event that significant clogging of the servo filter takes place, the fuel control could begin to react sluggishly, especially at low power. Complete blocking of the servo filter would cause loss of servo pressure with subsequent fuel flow reduction to a minimum setting. The minimum flow level for the JT3C-7 engine is 640 pph which is below idle. Removal of the servo filter was not practical because contaminants could affect the various servos resulting in unpredictable metering and governing effects. For reasons of safety, it was strongly recommended that filters/screens without provisions for automatic bypass, (fuel control servo and fuel nozzles) be monitored on all four engines for pressure rise. It was also recommended that appropriate fuel samples be analyzed for degradation level by filter ratio and transition velocity tests.

Information was submitted to NASA Ames-Dryden Flight Research Facility in the areas of engine and component operability and durability, air bleed, plumbing, instrumentation, etc. This section summarizes only the more critical areas that required significant study or analysis. One of the first areas of investigation concerned the availability and effects of engine bleed air required to drive the air turbine motor drive for the degrader. Air bleed flows and pressure levels predicted for degrader operation (G.E. computer model) were compared to those available from the JT3C-7 engine. Table III shows the results of this comparison which indicates that the air bleed requirements were only slightly higher than those available from a typical in-service JT3C-7 engine.

In regard to the possibility of locking engine bleed open or closed, it was conveyed that this could be detrimental to engine transient operation. In particular, the JT3C-7 engine thrust loss when the automatic surge bleeds are opened on a low power approach condition at 3000 feet and 150 knots true air speed was estimated to be approximately 327 pounds or 10%.

TABLE III
AVAILABLE JT3C-7 BLEED FLOWS, PRESSURES
AND TEMPERATURES VS. PREDICTED QUANTITIES

| | | PREDICTED - G.E. MODEL | | | |
|---|---|---|---|---|---|
| | | CASE (1)<br>(idle) | | CASE (2)<br>(max) | |
| PCN$_2$ | | 63% | | 98% | |
| $T_o$ | ((T$_{amb}$ (°R)) | 550 | 565 | 565 | 550 |
| $P_{TX}$ | (Bleed Pressure psia) | 44.9 | 44.9 | 174.9 | 174.9 |
| $T_{TX}$ | ((Bleed Temp (°R)) | 725 | 725 | 1181 | 1181 |
| $W_B$ | (Bleed Flow (pps) ) | 1.0 | 1.0 | 1.9 | 1.9 |
| $W_R$ | (Bleed Ratio) | 0.027 | 0.027 | 0.012* | 0.012* |

Available HPC Bleed Pressures and Temperatures (from JT3C-7 engine at the above bleed flows)

| | | | | | |
|---|---|---|---|---|---|
| $P_{TX}$ | (Bleed Pressure at Bleed Port (psia) ) | 30.5 | 30.5 | 168.3 | 171.9 |
| $T_{TX}$ | (Bleed Temp. at Bleed Port (°R)) | 737 | 737 | 1243 | 1228 |

---

* = Slightly exceeds JT3C-7 specification limit of 0.012 for HPC bleed air for maximum continuous to takeoff power

Several recommendations were made by Pratt & Whitney relating to fuel pressure, fuel temperature and oil temperature limits for the JT3C-7 engine. During engine operations, fuel pressure at the engine fuel pump inlet should be maintained at not less than 7.5 psi above the true vapor pressure of the fuel to prevent vapor lock and/or pump cavitation from occurring at elevated fuel temperatures. Fuel pressure should be kept below 55 psig during engine operation and should not be allowed to exceed 85 psig after shutdown when the fuel pressure may increase due to thermal expansion of the fuel. The engine fuel system can tolerate short duration (milliseconds) pressure excursions or spikes of 100 psi above the pump inlet pressure. The limiting area is a section of the fuel control which sees pump inlet pressure and is capable of sustained operation only up to 115 psia.

Fuel temperature limits were established with the assumption that long descents from high altitudes were beyond the slope of the flight tests planned so that extremely high temperature rises through the fuel pumps could be avoided. It was recommended that pump inlet temperature be limited to 160°F with overshoots to 170°F for short periods of time only. This limit was set because of the unknown condition of the low temperature elastomer seals that were present in the engine fuel pumps and fuel control. Pratt & Whitney recommends maintaining engine oil inlet temperatures between 176 and 212°F for extended service life. However, oil temperatures were permissible to 270°F with overshoots to 290°F for 10 minutes for both ground and in-flight operations.

## FUEL CHARACTERIZATION TESTS AND ANALYSES

The purpose of the laboratory fuel characterization tests was to verify AMK fuel blended for the CID program reacted in the same manner as the previously evaluated AMK (Ref. 1) for filterability and combustor performance, and to assess the degradation level achieved by the degrader system for subsequent engine tests. Two sets of filter ratio and transition velocity measuring equipment were fabricated by Pratt & Whitney for NASA Ames-Dryden Flight Research Facility and the FAA Technical Center. A list of the equipment comprising each of the flow measuring devices is provided in Table C-1 of Appendix C.

Degraded AMK was obtained from the FAA for use in calibrating the newly fabricated equipment against equipment used in earlier programs at Pratt & Whitney. The fuel was further degraded using a Gaulin Disperser or homogenizer for one pass at 8000 psi (NASA CR -168081) before comparative experiments were conducted. Results of the calibrations indicated good agreement between the equipment for the highly degraded AMK tested. Table IV is a tabulation of the data recorded and subsequent calibrated filter ratios. The transition velocities for the three units obtained from the plots shown in Figures 15, 16 and 17 are shown in Table V.

Table IV
FILTER RATIOS

| Unit | Jet A Time | AMK Time | Filter Ratio |
|---|---|---|---|
| #1 (Pratt & Whitney) | 5.33 sec | 5.86 | 1.1 |
| #2 (NASA Ames-Dryden) | 5.41 sec | 5.93 | 1.1 |
| #3 (FAA Tech Center) | 5.13 sec | 5.68 | 1.1 |

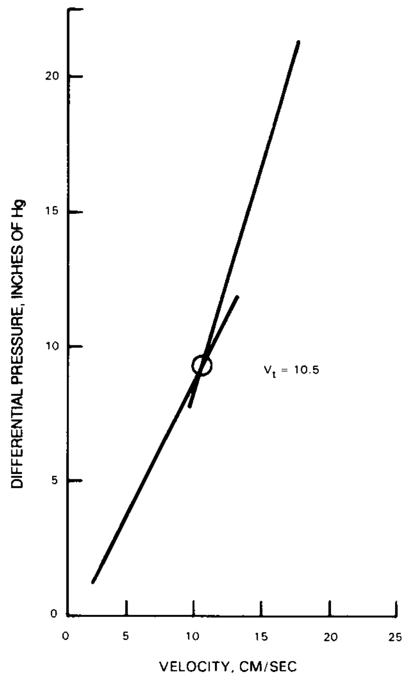


Figure 15 Determination of Transition Velocity. Unit #1

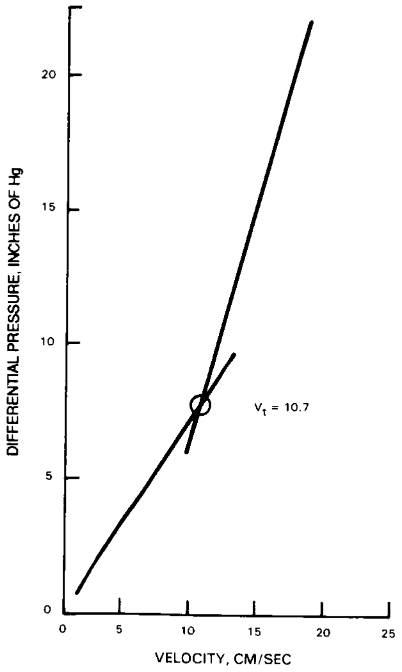


Figure 16 Determination of Transition Velocity. Unit #2

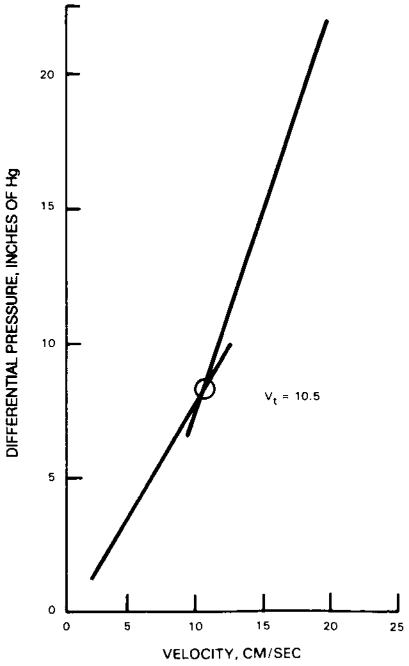


Figure 17 Determination of Transition Velocity. Unit #3

## TABLE V
## TRANSITION VELOCITY

| Unit | Transition Velocity |
|---|---|
| #1 (Pratt & Whitney) | 10.5 cm/sec |
| #2 (NASA Ames-Dryden) | 10.7 cm/sec |
| #3 (FAA Tech Center) | 10.5 cm/sec |

The filter ratio and transition velocity measurement equipment were delivered, set up and demonstrated for both NASA Ames-Dryden Flight Research Facility and FAA Technical Center personnel for their subsequent use on-site.

A sample of AMK fuel, typical of that used in the CID test, was tested to establish the flow characteristics and filtration properties as a function of degradation level and to compare the filterability characteristics of the recently blended fuel with fuel tested during earlier NASA/P&W programs. Two batches of fuel were tested as a result of abnormally high filter ratios found in the first batch of AMK fuel. Initial testing of the fuel to determine its filter ratio showed unusually high levels of filter ratio (over 500). A portion of this fuel was degraded to a transition velocity of 4.5 and then subjected to filterability testing. Immediate filter clogging occurred, even at the lowest flow rates. The unusually high filter ratios obtained prior to the filterability testing was ascribed to contamination from a sample being drawn from the bottom of a storage tank. Evaluation of the initial batch of AMK fuel was discontinued and a new fuel sample was requested to continue the evaluation of the AMK fuel. The remainder of the contaminated fuel was sent to Imperial Chemical Industries (ICI) for analysis.

A second batch of AMK fuel sample recorded filter ratios of 57 which is considered to be a normal level for unsheared or virgin AMK. The sample was divided into two portions which were degraded to transition velocity ($V_T$) levels of 2.0 and 2.7 cm/sec. Filterability tests were conducted to measure the pressure drop across a 16 micron stainless steel screen as a function of AMK fuel flow at ambient temperature (Ref. 1). The filter test is described in NASA CR-168081. Table VI presents the results of the filterability testing conducted on the AMK fuel during this program. Table VII presents the data recorded under contract NAS3-22045. In the tables, filter clogging is indicated for those velocity entries where the pressure drop is shown as a range, rather than as a single value.

Results of the filterability testing conducted on the second batch of AMK fuel indicated that the clogging characteristics of the on-line blended AMK made for the CID program are very similar to the batch blended fuel under NASA contract NAS3-22045. This testing established the criteria for filterability and combustor requirements during the CID program. Fuel samples taken downstream of a degrader, while the engine operated at idle, resulted in transition velocity levels of 2.9 and 3.2 cm/sec which was considered satisfactory for the planned missions of the B-720 aircraft.

## TABLE VI
## FILTERABILITY TEST (16 μm ABSOLUTE SCREEN) 1984

| | ΔP psi | Flow Rate cc/sec/ | Superficial (1) Velocity, cm/sec | True Velocity (2) cm/sec. |
|---|---|---|---|---|
| $V_T = 2.0$ | 0.20 | 1.0 | 3.1 | 141 |
| | 0.40 | 2.0 | 6.3 | 210 |
| | 0.60 | 2.7 | 8.4 | 247 |
| | 0.80 | 3.6 | 11.3 | 290 |
| | 0.90 | 4.1 | 12.8 | 312 |
| clogging | 1.30-1.40 | 5.4 | 16.9 | 367 |
| | 1.60-1.80 | 6.0 | 18.8 | 392 |
| | 2.10-2.30 | 6.5 | 20.3 | 406 |
| | 3.00-3.40 | 8.0 | 25.0 | 463 |
| | 4.00-4.40 | 8.8 | 27.5 | 491 |
| | 5.80-9.40 | 10.4 | 32.5 | 551 |
| $V_T = 2.7$ | 0.10 | 1.0 | 3.5 | 141 |
| | 0.30 | 2.0 | 6.3 | 210 |
| | 0.50 | 2.8 | 8.8 | 251 |
| | 0.80 | 4.0 | 12.5 | 313 |
| | 1.10 | 5.6 | 17.5 | 380 |
| clogging | 1.20-1.30 | 6.1 | 19.1 | 398 |
| | 1.50-1.60 | 7.7 | 24.1 | 455 |
| | 1.90-1.20 | 9.0 | 28.1 | 502 |
| | 2.10-2.60 | 10.0 | 31.3 | 331 |
| | 3.60-4.60 | 13.4 | 41.9 | 665 |

---

(1) Superficial velocity is based on pipe cross-sectional area in which the filter is placed.

(2) True velocity is based on flow coefficient corrected flow area from a Jet A calibration for the filter being tested.

## TABLE VII
## 1981 FILTERABILITY TEST (16 μm ABSOLUTE SCREEN) 1981

TEST #45

| | ΔP psi | Flow Rate cc/sec/ | Superficial (1) Velocity, cm/sec | True Velocity (2) cm/sec |
|---|---|---|---|---|
| $V_T = 1.9$ | 0.30 | 1.6 | 5.0 | 179 |
| | 0.52 | 2.7 | 8.4 | 290 |
| | 0.69 | 3.0 | 9.4 | 303 |
| clogging | 0.94-1.10 | 3.8 | 11.9 | 350 |
| | 1.21-1.49 | 4.1 | 12.8 | 366 |
| | 2.43-3.80 | 5.8 | 18.1 | 441 |
| | | | Test #34 | |
| $V_T = 2.5$ | 0.65 | 3.5 | 10.9 | 321 |
| | 1.03 | 5.3 | 16.6 | 415 |
| clogging | 1.28-1.61 | 4.2 | 19.4 | 451 |
| | 1.62-2.48 | 8.2 | 25.6 | 533 |
| | 2.9-3.7 | 9.4 | 29.4 | 576 |
| | 4.2-5.5 | 11.1 | 34.7 | 643 |
| | 6.9-9.9 | 13.6 | 42.5 | 720 |
| | 12.2-15.6 | 16.4 | 51.3 | 802 |
| | 15.6-18.2 | 18.0 | 56.3 | 853 |

---

(1) Superficial velocity is based on pipe cross-sectional area in which the filter is placed.

(2) True velocity is based on flow coefficient corrected flow area from a Jet A calibration for the filter being tested.

## ENGINE PERFORMANCE

The B-720/JT3C-7 simulation for the CID flight plan supplied by NASA Ames-Dryden Flight Research Facility was reviewed and assessed to be satisfactory from an engine operability standpoint. Engine simulated part power and takeoff power parameters were compared with similar power condition data from in-house and FAA Tech Center generated ground test data and the agreement was good. It was noted that there was some engine operation in the compressor "bleeds open" power region during aircraft approach.

Figure 18 shows typical JT3C-7 engine performance data used as a baseline reference taken for standard day at sea level static conditions. In Figure 18, $N_1$ represents the low rotor speed, and $N_2$ the high rotor speed, in RPM, corrected to sea level static standard day conditions as a function of engine pressure ratio, $P_{T7}/P_{T2}$. Figure 18 presents the engine exhaust gas temperature in degrees Rankine, and $W_F$ represents engine fuel flow, in lbs/hr, with both parameters corrected to sea level static standard day conditions.

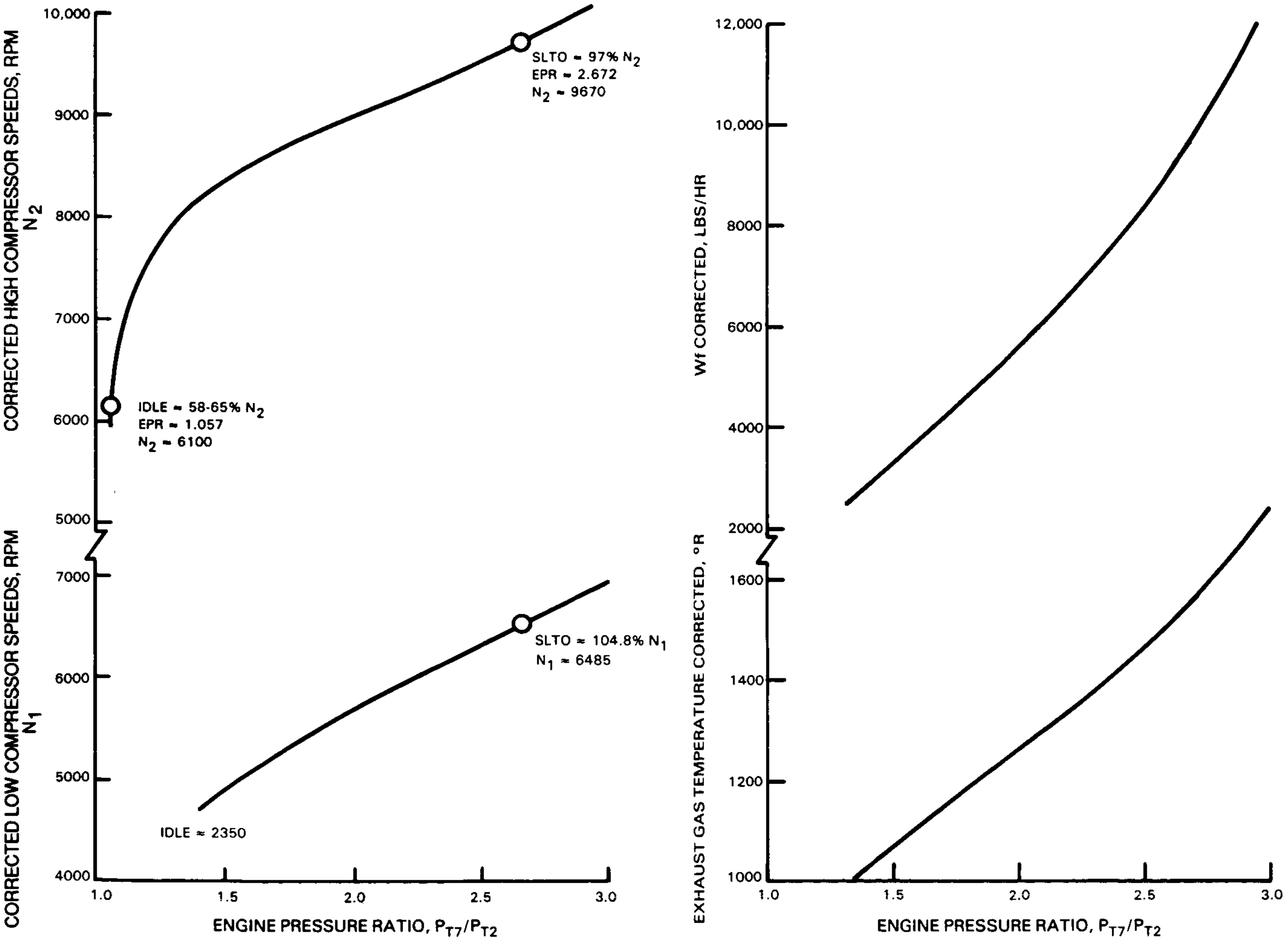


Figure 18 Typical JT3C-7 Engine Performance (Standard Day Sea Level Static)

The significance of the engine fuel flow, exhaust gas temperature, and the rotor speeds is that these parameters define the performance characteristics of the engine and are thus an indication of engine "health". For example, if the fuel flow and exhaust gas temperatures are higher than normal at a given engine pressure ratio, it indicates a loss in engine efficiency. The behavior of the low and high pressure compressor rotor speeds, $N_1$ and $N_2$, provides an indication whether the loss of efficiency is in the low or in the high spool.

The expected range of values above and below the average of each of the four performance parameters for a new production JT3C-7 engine has been estimated to be as follows at a given engine pressure ratio:

| | |
|---|---|
| Low Rotor Speed, $N_1$ | ± 1.2% |
| High Rotor Speed, $N_2$ | ± 1.2% |
| Exhaust Gas Temperature | ± 30°R |
| Fuel Flow, $W_F$ | ± 2.5% |

It should be noted that the above variations relative to an average production engine are for an uninstalled engine and do not reflect airframe installation effects, power extraction, engine system air bleed, and engine deterioration.

The following discussion covers three groups of performance results: observations for ground engine tests at the FAA Technical Center, flight test made on September 18, 1984 with both Jet A and AMK, and CID of December 1, 1984 with AMK only.

### FAA Technical Center Tests

In order to evaluate the engine performance that could occur if the fuel degrader shut down during flight, a JT3C-6 engine test was conducted with Jet A and undegraded AMK fuels at the FAA Technical Center. During the test, fuel was supplied from a tank using standard B-707 boost pumps. As previously described, the JT3C-6 fuel control was modified to incorporate filtration features more in line with the JFC25-10 C-7 control used in the JT3C-7 engines in the CID aircraft. The engine appeared to perform surprisingly well on AMK that was only slightly degraded (F.R. $\approx$ 30) by the B-707 boost pumps. Steady state performance at EPRS of 1.5 to 2.5 and transient response calibrations, while burning AMK, indicated no significant differences from baseline tests conducted with Jet A fuel. The only operational abnormality noted was the immediate pressure rise increase across the instrumented fuel filter/screens up to a steady, limited value (s) as the fuel was switched from Jet A to undegraded AMK.

A second test was performed with the JT3C-6 engine using a JT3C-7 fuel control similar to that used on the CID aircraft to evaluate the operability of the JT3C-7 controls on the the B-720 test airplane when operating on undegraded AMK fuel. NASA Ames-Dryden Flight Research Facility reported the engine operated satisfactorily for 41 minutes on undegraded AMK fuel. Post test inspection of the fuel control servo filter revealed significant amounts of soft gel on the downstream side of the screen. Filter ratio measurements of the fuel indicated levels of 40 from the fuel tank and 11 from locations downstream of the boost pumps.

## Flight Tests

Flight test data was analyzed from the B-720 aircraft operating alternatively with Jet A and AMK during flight 9 on September 18,1984. Figure 19 shows Jet A and degraded AMK test points plotted with a typical baseline JT3C-7 engine performance curve for a standard day at sea level static conditions. The performance of the four flight test points in terms of $N_2$ speed, fuel flow ($W_F$), and exhaust gas temperature (E.G.T.) is higher then the typical JT3C-7 sea level static (S.L.S.) performance. This difference was expected because: 1) the flight test data are at approximately 0.3 Mn rather than at S.L.S., 2) the flight engines had undoubtedly deteriorated due to age and high-engine times and 3) the flight engines could differ due to installed effects (air bleed, power extraction etc.). However, the slope of the flight test data agrees closely with the typical engine slope and there is essentially no difference in performance between AMK and Jet A fuel.

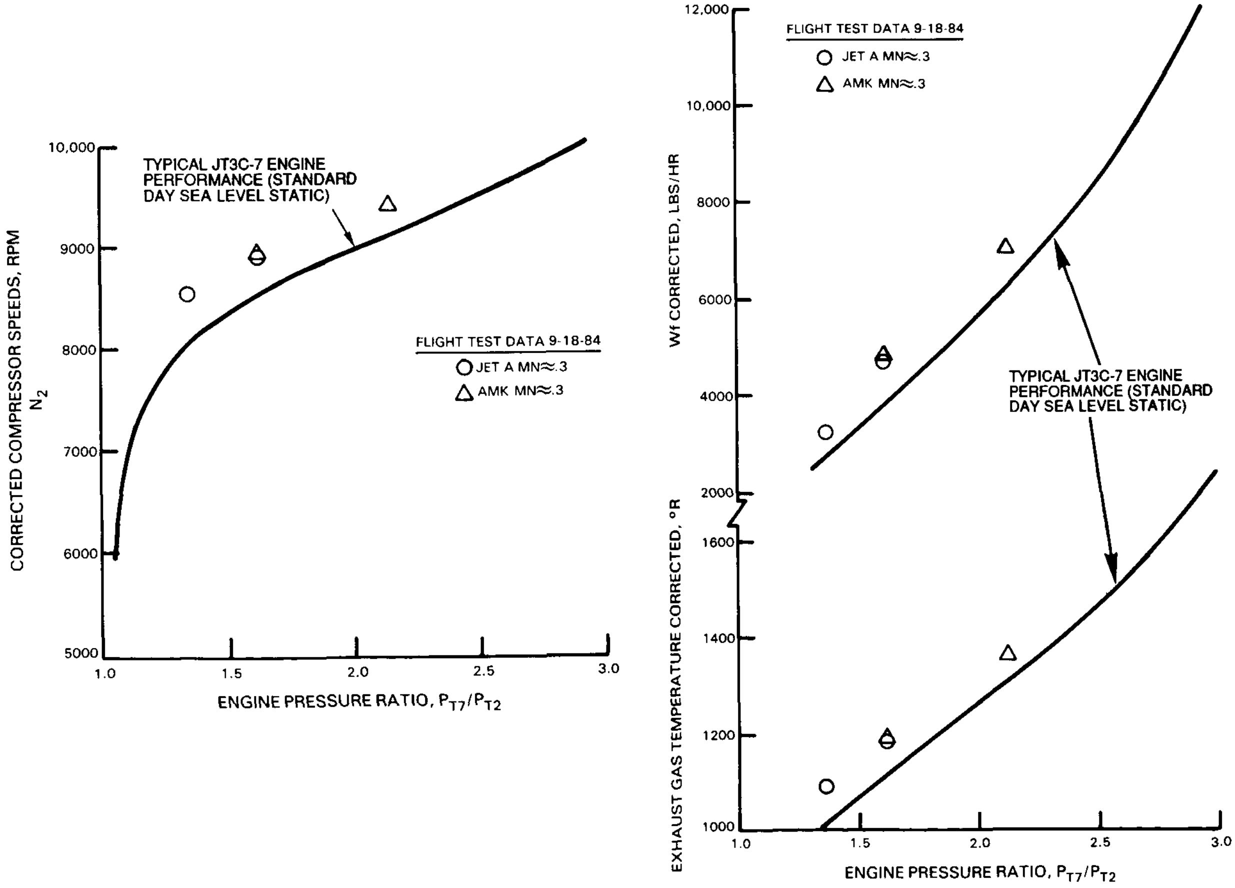


Figure 19 Flight Test Data Compared to Baseline Performance

## CID Test

Data taken from the B-720 test aircraft operating with AMK during flight 15 of the CID test on December 1, 1984 were analyzed to evaluate engine performance before ground impact. Three data points representing three power levels were selected for each of the four engines. The points ranged from Mn 0.15 to 0.25 at altitudes of 2000 to 4500 feet. The lowest power point selected was recorded three seconds before ground impact. The results are plotted in Figure 20 and were compared to the data taken during flight 9 and to a typical uninstalled baseline for a JT3C-7 engine. This comparison showed no significant difference in engine performance for CID flights 9 and 15. The four flight engines used during the CID performed as expected.

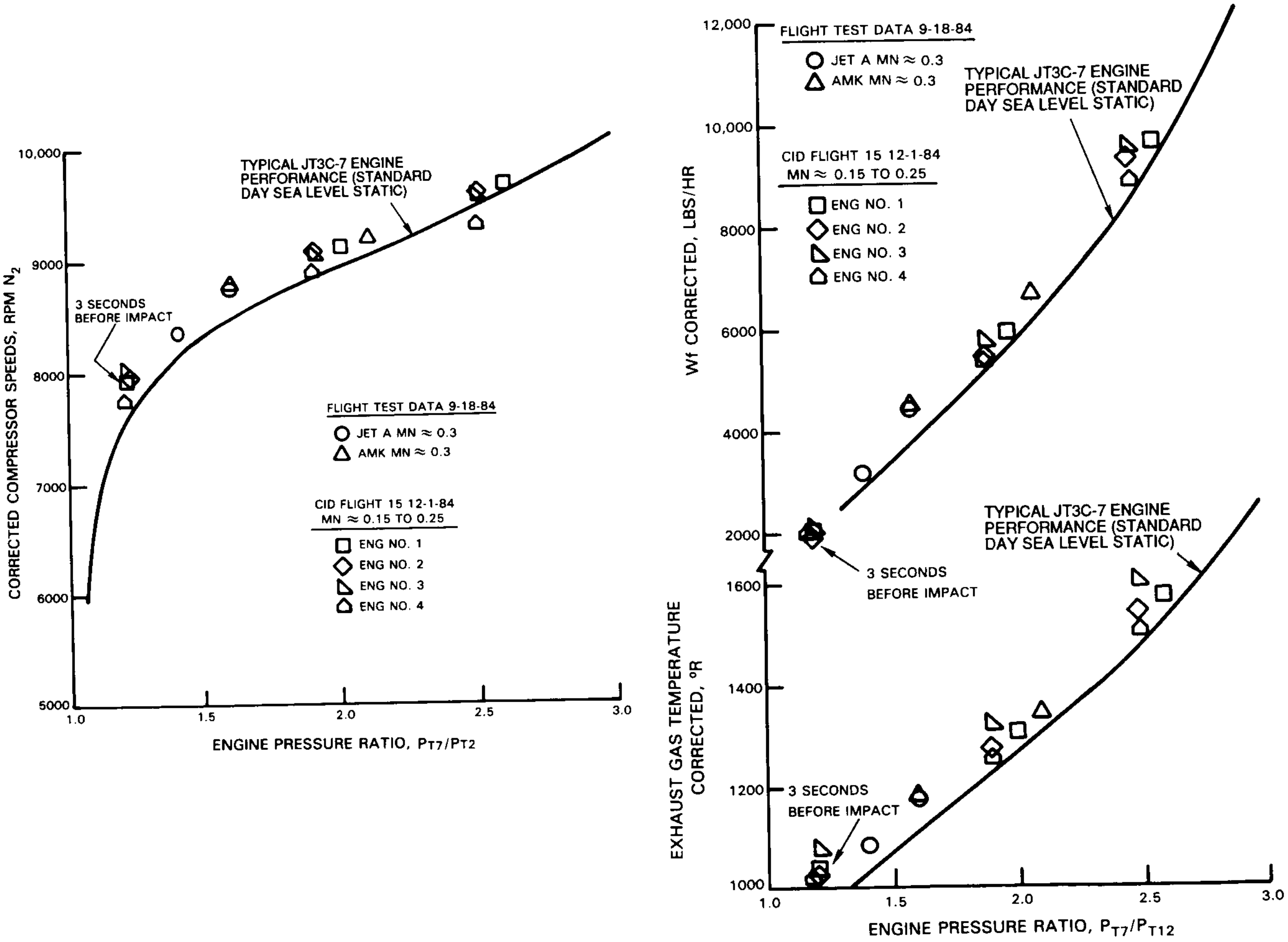


Figure 20 Flight and CID Test Data Compared to Baseline Performance

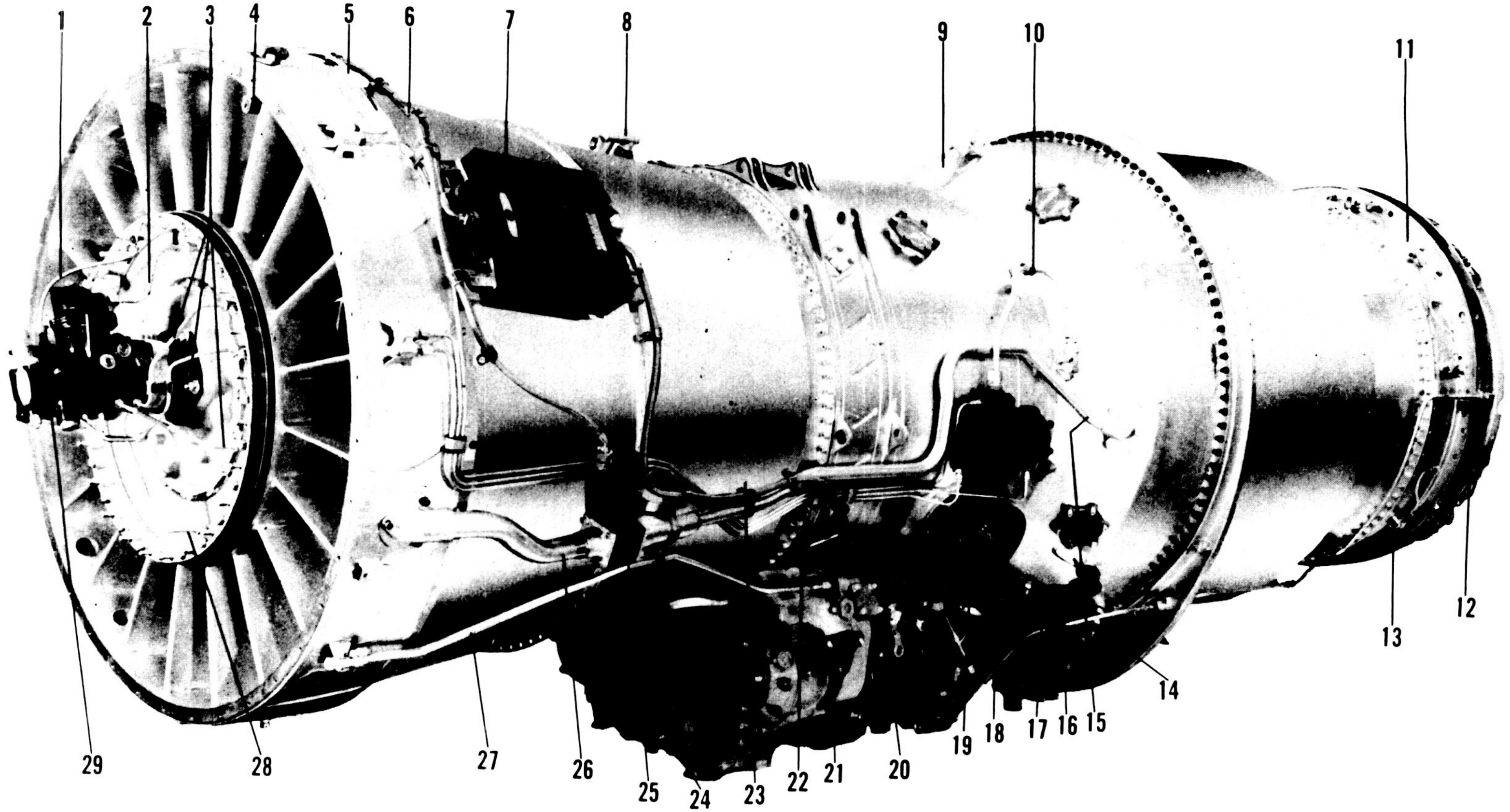
## CONCLUDING REMARKS

Fuel characterizations and a review of JT3C-7 engine performance are documented for a B-720 test airplane operated on an antimisting kerosene (AMK) fuel. The four engines were modified by adding a fuel degrading system to improve the flow qualities of the fuel in the engine. These evaluations were made for a ground test engine and for the flight engines, culminating in the Controlled Impact Demonstration (CID) December 1, 1984. The following results were obtained:

- Flow characterization tests on degraded AMK fuel samples indicated levels of degradation satisfactory for the planned sea level engine tests and short flight time, low altitude missions of the B-720 aircraft.
- The operability and performance of the JT3C-7 engines operating on degraded AMK were comparable to results with Jet A for the flight conditions assessed during this program.
- The performance of the four flight engines during flight and to ground impact was satisfactory for the CID mission.

# APPENDIX A

# JT3C-7 ENGINE



1. CAPILLARY TUBE
2. CONTROL AIR SUPPLY TUBE
3. AIR TRANSFER TUBES
4. INLET PRESSURE PROBE
5. INLET PRESSURE TUBE
6. MAIN ELECTRICAL HARNESS
7. IGNITION EXCITER
8. ANTI-SIPHON OIL TUBES
9. REAR BREATHER TUBE
10. BLEED VALVE ACTUATOR AIR PRESSURE TUBE
11. EXHAUST PRESSURE PROBE MANIFOLD
12. NO. 6 BEARING REAR OIL SUCTION TUBE
13. EXHAUST PRESSURE PROBE
14. SPARKIGNITER
15. REAR ANTI-ICING TUBE
16. FUEL SUPPLY TUBE
17. HIGH VOLTAGE LEAD
18. BLEED VALVE ACTUATOR
19. BLEED VALVE
20. FUEL CONTROL
21. MAIN OIL STRAINER
22. COMPRESSOR BLEED VALVE CONTROL TUBES
23. FRONT COMPRESSOR CASE
24. OIL PUMPS, ACCESSORY AND COMPONENT DRIVES GEARBOX
25. ANTI-ICING VALVE
26. FRONT ANTI-ICING TUBE
27. NO. 1 BEARING OIL SUCTION TUBE
28. BLEED GOVERNOR OIL DRAIN TUBE
29. COMPRESSOR BLEED CONTROL

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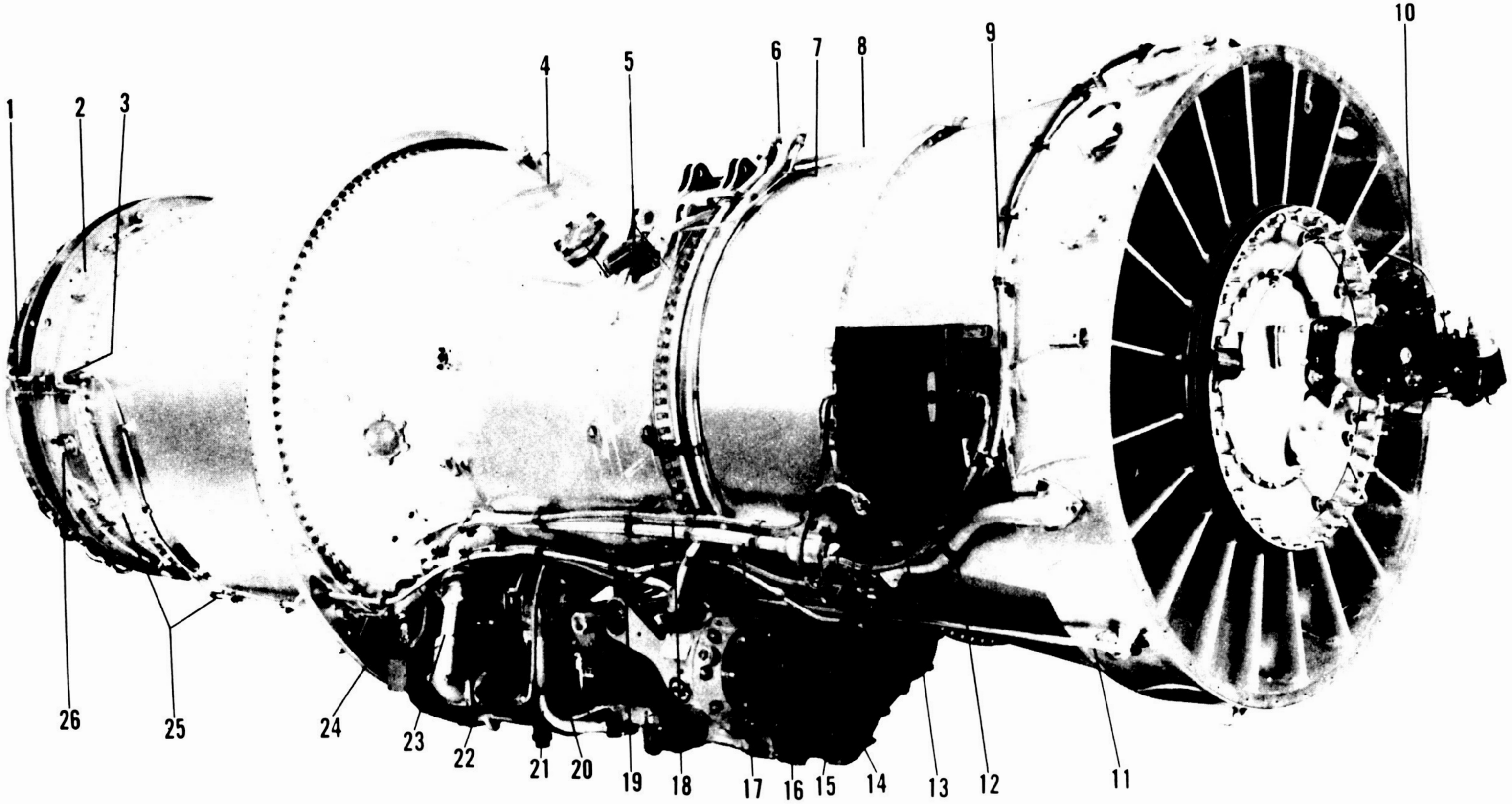
Figure A-1 Three Quarter Left Front View of the JT3C-7 Engine



1. THERMOCOUPLE HARNESS
2. EXHAUST PRESSURE PROBE MANIFOLD
3. THERMOCOUPLE LEAD CONNECTOR
4. REAR BREATHER TUBE
5. BREATHER TUBE TEE
6. ANTI-SIPHON OIL TUBES
7. ANTI-SIPHON BREATHER TUBE
8. FRONT BREATHER TUBE
9. MAIN ELECTRICAL HARNESS
10. COMPRESSOR BLEED CONTROL
11. NO. 1 BEARING OIL PRESSURE TUBE
12. FRONT ANTI-ICING TUBE
13. IGNITION EXCITER
14. STARTER DRIVE
15. ANTI-ICING VALVE
16. OIL PUMPS, ACCESSORY AND COMPONENT DRIVES GEARBOX
17. REAR ANTI-ICING TUBE
18. HIGH VOLTAGE LEAD
19. THERMOCOUPLE LEAD
20. FUEL DE-ICING AIR SHUT-OFF VALVE LEAD
21. FUEL DE-ICING FILTER-TO-PUMP TUBE
22. FUEL DE-ICING AIR SHUT-OFF VALVE
23. FUEL HEATER AIR SUPPLY TUBE
24. SPARKIGNITER
25. NO. 6 BEARING OIL PRESSURE TUBE
26. EXHAUST PRESSURE PROBE

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Figure A-2 Three Quarter Right Front View of the JT3C-7 Engine

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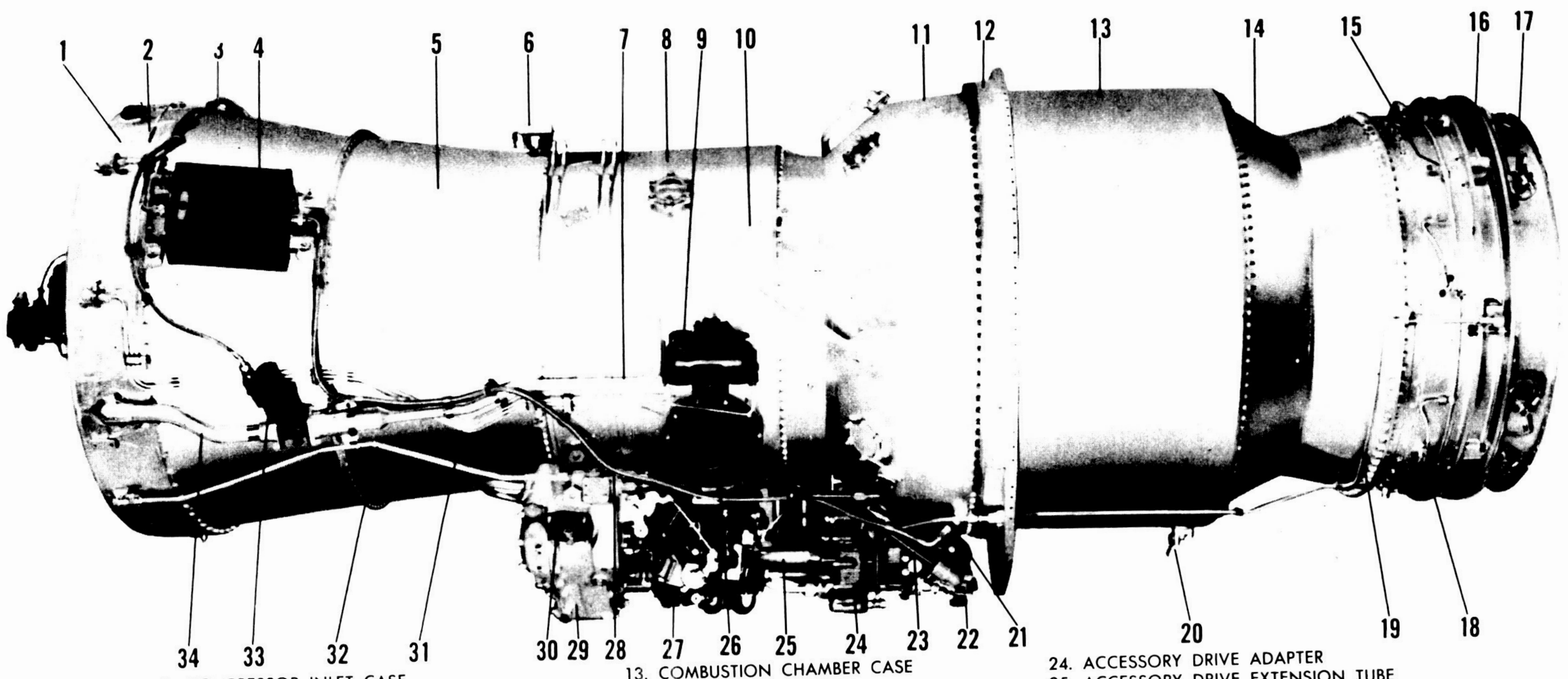

1. COMPRESSOR INLET CASE
2. INLET PRESSURE TUBE
3. MAIN ELECTRICAL HARNESS
4. IGNITION EXCITER
5. FRONT COMPRESSOR CASE
6. ANTI-SIPHON OIL TUBES
7. REAR ANTI-ICING TUBE
8. INTERMEDIATE CASE
9. BLEED VALVE ACTUATOR
10. BLEED VALVE ACTUATOR AIR PRESSURE TUBE
11. DIFFUSER CASE
12. FIRESEAL
13. COMBUSTION CHAMBER CASE
14. TURBINE NOZZLE CASE
15. EXHAUST PRESSURE PROBE MANIFOLD
16. TURBINE EXHAUST CASE
17. TURBINE EXHAUST THERMOCOUPLE
18. EXHAUST PRESSURE PROBE
19. NO. 6 BEARING OIL SUCTION TUBE
20. FUEL DRAIN CAN BRACKET
21. SPARKIGNITER
22. FUEL PRESSURIZING AND DUMP VALVE
23. FUEL SUPPLY TUBE
24. ACCESSORY DRIVE ADAPTER
25. ACCESSORY DRIVE EXTENSION TUBE
26. COMPRESSOR BLEED VALVE
27. FUEL CONTROL
28. HIGH VOLTAGE LEAD
29. OIL PUMPS, ACCESSORY AND COMPONENT DRIVES GEARBOX
30. MAIN OIL STRAINER
31. COMPRESSOR BLEED VALVE CONTROL TUBES
32. NO. 1 BEARING OIL SUCTION TUBE
33. ANTI-ICING VALVE
34. FRONT ANTI-ICING TUBE

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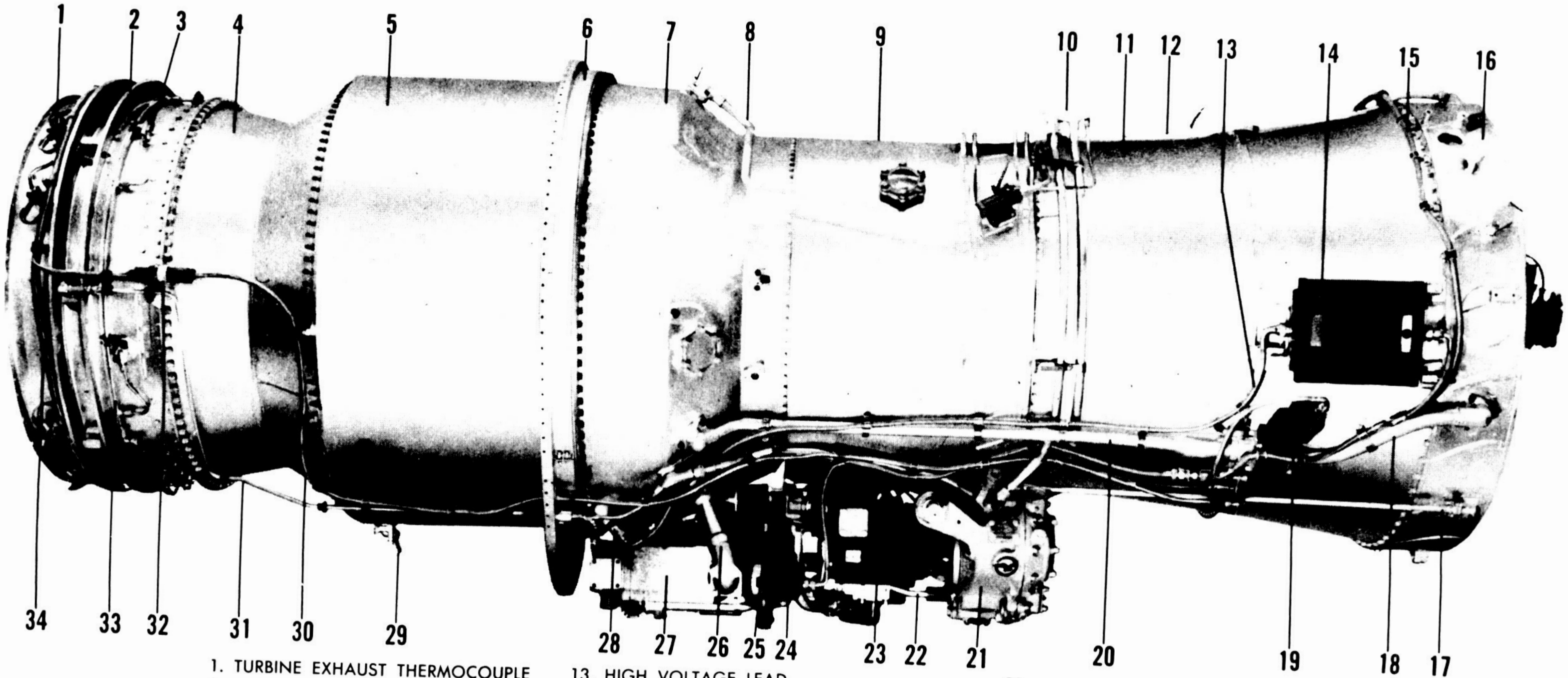
Figure A-3 Left Side View of the JT3C-7 Engine



1. TURBINE EXHAUST THERMOCOUPLE
2. TURBINE EXHAUST CASE
3. EXHAUST PRESSURE PROBE
4. TURBINE NOZZLE CASE
5. COMBUSTION CHAMBER CASE
6. FIRESEAL
7. DIFFUSER CASE
8. REAR BREATHER TUBE
9. INTERMEDIATE CASE
10. ANTI-SIPHON OIL TUBES
11. FRONT COMPRESSOR CASE
12. FRONT BREATHER TUBE
13. HIGH VOLTAGE LEAD
14. IGNITION EXCITER
15. MAIN ELECTRICAL HARNESS
16. COMPRESSOR INLET CASE
17. NO. 1 BEARING OIL PRESSURE TUBE
18. FRONT ANTI-ICING TUBE
19. ANTI-ICING VALVE
20. REAR ANTI-ICING TUBE
21. OIL PUMPS, ACCESSORY AND COMPONENT DRIVES GEARBOX
22. ACCESSORY DRIVE ADAPTER OIL SUCTION TUBE
23. FUEL PUMP
24. DE-ICING AIR SHUT-OFF VALVE
25. FUEL DE-ICING FILTER
26. FUEL HEATER AIR INLET ELBOW
27. FUEL DE-ICING HEATER
28. SPARKIGNITER
29. FUEL DRAIN CAN BRACKET
30. THERMOCOUPLE LEAD
31. NO. 6 BEARING OIL PRESSURE TUBE
32. THERMOCOUPLE CONNECTION
33. EXHAUST PRESSURE PROBE MANIFOLD
34. THERMOCOUPLE HARNESS

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Figure A-4 Right Side View of the JT3C-7 Engine

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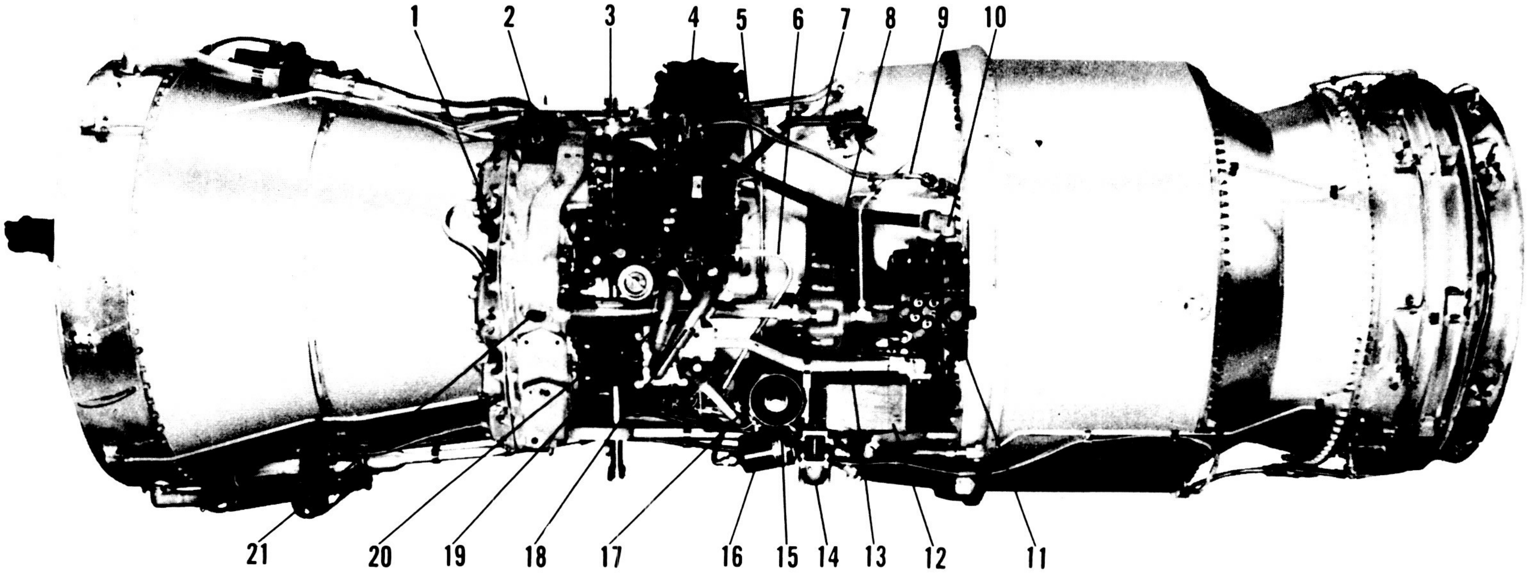

1. OIL PUMPS, ACCESSORY AND COMPONENT DRIVES GEARBOX
2. MAIN OIL STRAINER
3. POWER LEVER CROSS SHAFT
4. FUEL CONTROL
5. FUEL CONTROL-TO-DUMP VALVE SIGNAL TUBES
6. FUEL CONTROL-TO-FUEL PUMP BY-PASS TUBE
7. DIFFUSER-TO-SCAVENGE PUMP TUBE
8. ACCESSORY DRIVE ADAPTER
9. HIGH VOLTAGE LEAD
10. FUEL SUPPLY TUBE
11. FUEL PRESSURIZING AND DUMP VALVE
12. FUEL DE-ICING HEATER
13. PUMP-TO-HEATER FUEL PRESSURE TUBE
14. FUEL HEATER AIR INLET ELBOW
15. FUEL DE-ICING FILTER
16. FUEL DE-ICING AIR SHUT-OFF VALVE
17. FUEL FILTER-TO-FUEL PUMP TUBE
18. FUEL CONTROL DISCHARGE TUBE
19. FUEL CONTROL SUPPLY TUBE
20. FUEL PUMP
21. OIL SUCTION PUMP STRAINER

P99357

Figure A-5 Bottom View of the JT3C-7 Engine

# APPENDIX B-1

## PROCEDURE FOR DETERMINING FILTER RATIO

The filter screen device shown in Figure B-1 (standardized by United States/ United Kingdom AMK Technical Committee) was utilized to measure effective viscosity. This filter ratio procedure measured the time required for a predetermined volume of fuel to flow through a 17 micron size screen at 20°C. Effective viscosity was measured by filling the tube of the filter device with the reference fuel to the uppermost reference mark, then allowing the fuel to drain out of the tube. The time required for the meniscus of the fuel to pass between the two reference marks on the tube was recorded. This procedure was repeated with the antimisting kerosene test fuel. The ratio of the time required for the antimisting kerosene and the reference fuel to flow between marks is defined as the filter ratio (FR).

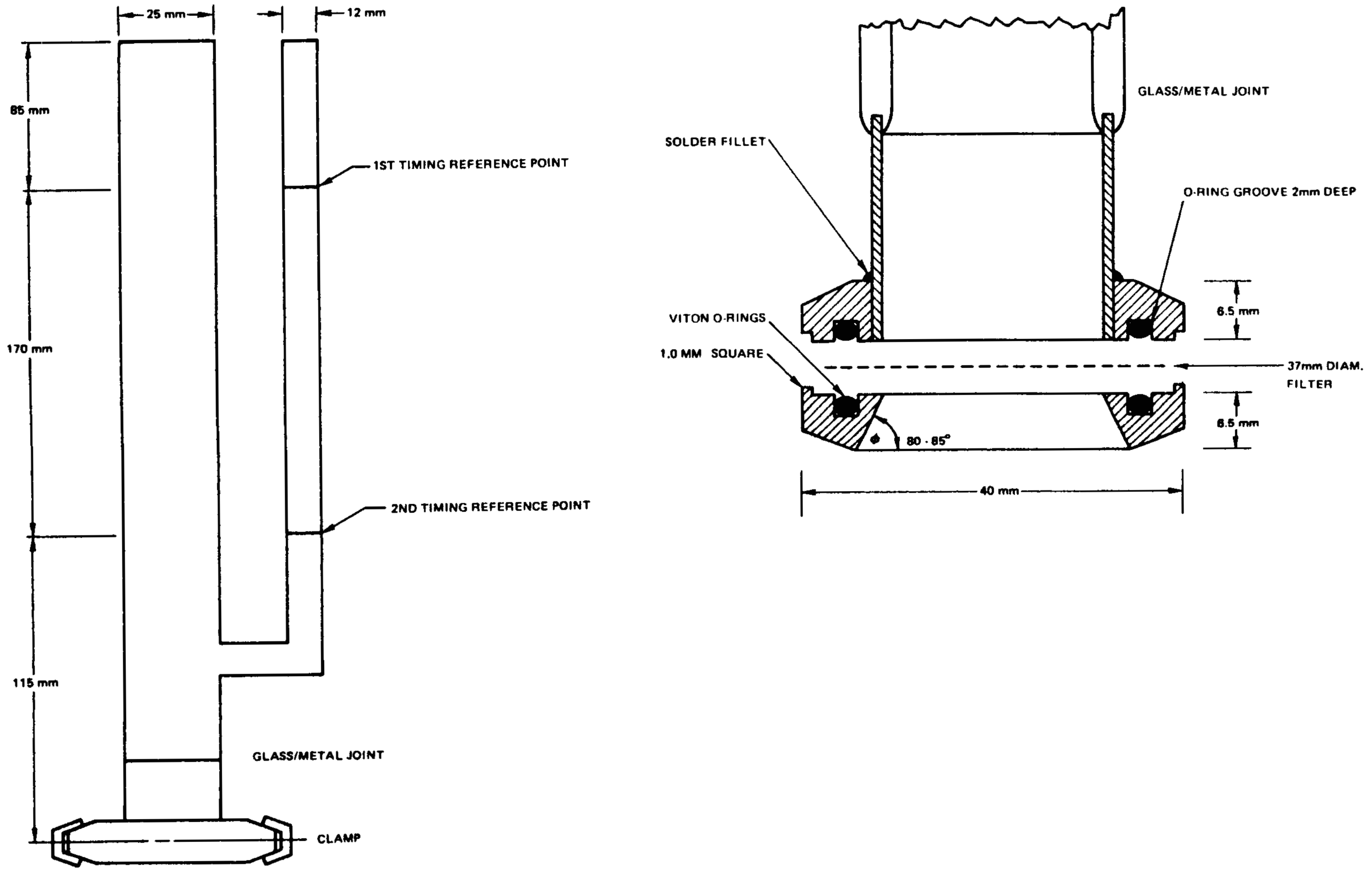

Figure B-1 Filter Screen Device

## APPENDIX B-2

## PROCEDURE FOR DETERMINING THE TRANSITION VELOCITY (A Measure of AMK Degradation Level)*

1. Assemble the apparatus shown in Figure B-2. The device is basically a millipore filtration apparatus with a ball valve added between the vacuum flask and the filter support. In addition, the fine wire mesh filter support is replaced with a 16 mesh wire screen.

2. Place a 47 mm diameter, 8 micron pore size Nuclepore filter (1) on the support and close the valve to the flask.

3. Add 300 ml of the test fuel to the reservoir. Turn the vacuum pump on and adjust the vacuum level to 2 inches mercury with the valve closed.

4. Simultaneously open the valve and start the timer. Rapidly make any fine adjustment necessary to keep the vacuum at the desired level. Record the time to the nearest tenth of a second for all the fuel to pass through the filter.

5. Using the same filter, repeat steps 3 and 4 at vacuum levels of approximately 4, 10, 17.5, and 20 in Hg vacuum.

6. Prepare a plot of flow rate in cc/sec-cm$^2$ versus vacuum level. Plot a straight line through the first three points and another straight line through the tip three points(2). The flow rate where the two lines intersect should be reported as the transition velocity in cc/sec-cm$^2$.

7. Replace the filter for each additional fuel tested.

Notes:

(*) This test is not suitable for fuels with filter ratios greater than two. For those fuels, the filter ratio is an adequate measure of degradation. Solid debris in the fuel will give a biased result.

(1) Nuclepore polycarbonate membrane filters manufactured by Nuclepore Corporation, 7035 Commerce Circle, Pleasanton, Ca. 94566, are available from most scientific supply sources.

(2) The transition point should occur at a vacuum level of 5 ± 2 in. Hg. Jet A fuel should give a transition velocity of 9 ± 2 cc/sec-cm$^2$.

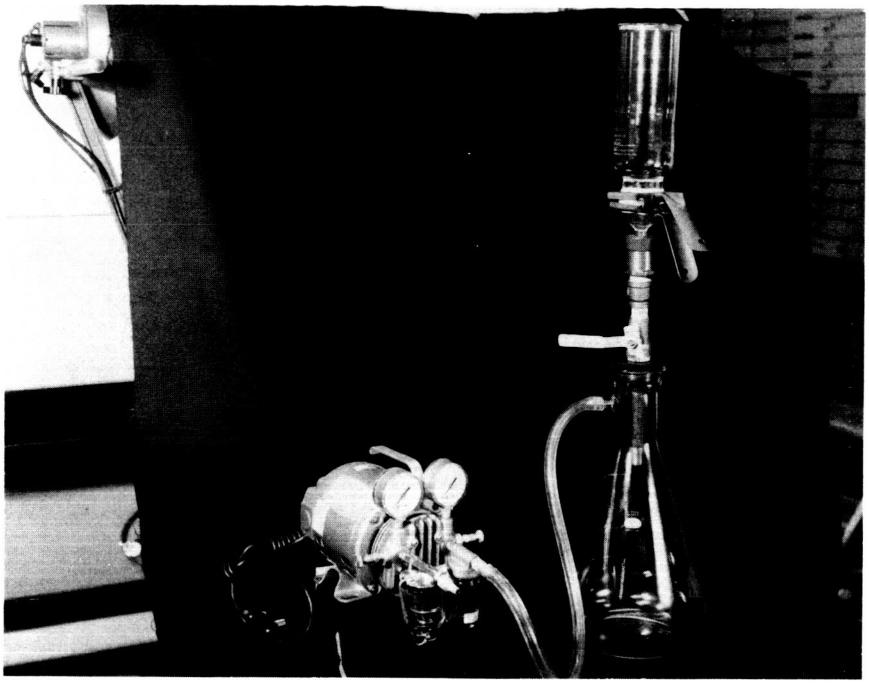

Figure B-2  Transition Velocity Apparatus

## TABLE C-I
## TRANSITION VELOCITY AND FILTER RATIO APPARATUS

1) Screen Filter: Custom produced at Pratt & Whitney
   Millipore screen filter was machined out and a circular section of U.S.A No. 18 screen secured in place.

   U.S.A Standard Sieve ASTM E-11
   U.S.A No. 18 - Tyler equivalent 16 mesh
   Van Waters and Rogers
   Catalog #57322-186

2) 2-Liter Vacuum Flask

3) Gast Vacuum/Pressure Pump

   Gast Mfg. Corp., Benton Harbor, Michigan
   Motor: 1/6 hp 1750 rpm
   Pump: Eccentric rotor type
   115V, 60 hz AC

   Macalaster Bicknell Co., Catalog #35230-000

4) Vacuum Pump Oil: Gast P/N AD220 SAE 10

5) Nuclepore Polycarbonate Filter Membrane

   47mm 8.0 micron Stock #111114 Lot #51B8B35
   Nuclepore Corp.
   7035 Commerce Circle
   Pleaston, CA 94566

6) Millipore Filtration Apparatus
   Top filter holder, Part #4
   Bottom filter holder, part #2
   Pyrex brand glass
   Millipore Corporation
   Bedford, Mass. 01730

7) Ball Valve/Pipe Assembly
   A 1/2" ball valve with 1/2" heavy walled pipe is coupled to a copper coupling which accepts a #10 cork with the millipore filtration apparatus.
   Filter Ratio Apparatus: Custom produced at Pratt & Whitney
   a) Glassware - Custom produced at Pratt & Whitney
   b) Cork
   c) Screen
      304 L stainless steel wire cloth
      165 x 1400 / 0.0028 x 0.0016
      Tetko, Inc.
      525 Monterey Pass Road
      Monterey Park, CA 91754

   d) O-Rings
      Width 0.070"
      Approx Dia. 1 3/8"

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15. Supplementary Notes

NASA Technical Monitors: Robert J. Freedman, Lewis Research Center, Cleveland, Ohio 44135, and Lannie D. Webb, Ames Research Center, Dryden Flight Research Facility, Edwards, California 93523-5000

16. Abstract

An analytical study and laboratory tests were conducted to assist NASA in determining the safety and mission suitability of the modified fuel system and flight tests for the Full-Scale Transport Controlled Impact Demonstration (CID) Program. This 12 month study reviewed and analyzed both the use of antimisting kerosene (AMK) fuel and the incorporation of a "fuel degrader" on the operational and performance characteristics of the engines tested. Potential deficiencies and/or failures were identified and approaches to accommodate these deficiencies were recommended to NASA Ames-Dryden Flight Research Facility.

The result of flow characterization tests on degraded AMK fuel samples, indicated levels of degradation satisfactory for the planned missions of the B-720 aircraft. The operability and performance with the AMK in a ground test engine and in the aircraft engines during the test flights were comparable to those with unmodified Jet A. For the final CID test, the JT3C-7 engines performed satisfactorily while operating on AMK right up to impact.

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