DOT/FAA/CT-86/6

FAA Technical Center
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George A. Coffinberry
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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-86/6		

4. Title and Subtitle	5. Report Date
Antimisting Fuel (AMK) Flight Degrader Development and Aircraft Fuel System Investigation	February 1987
	6. Performing Organization Code
7. Author(s) George A. Coffinberry and Thomas M. Tucker	8. Performing Organization Report No. R86AEB565
9. Performing Organization Name and Address General Electric Aircraft Engine Business Group Advanced Technology Operations One Neumann Way Cincinnati, Ohio 45215	10. Work Unit No.
	11. Contract or Grant No. DTFA03-83-C-00018
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08450	13. Type of Report and Period Covered Contract Final Report March 1983 - December 1985
	14. Sponsoring Agency Code

15. Supplementary Notes
General Electric Program Manager: George Coffinberry, Program Administrator: Thomas Tucker
FAA Technical Center Project Management Team: Bruce Fenton, Gary Frings, Francis Howard, Eugene Klueg

16. Abstract

This report summarizes results from a 20-month technical effort involving the design, fabrication and evaluation of an Antimisting Kerosene (AMK) degrader. The principal objective was to demonstrate the feasibility of employing a high-speed centrifugal pump to condition AMK fuel for use in an aircraft turbine engine. The effects of AMK fuel on the engine/airframe fuel system as well as any effect the flight environment might have had on the fire-preventive characteristics of the AMK were also investigated.

Five functionally identical degrader systems were produced. The first system was installed on the No. 3 engine of a CV880 aircraft with a dedicated AMK fuel tank. This system accumulated about 45 hours of engine operation on AMK, 30 of which were in-flight. The remaining four degrader systems were installed on a B720 aircraft that was used in the Full-Scale Transport Controlled Impact Demonstration (CID).

The degrader systems performed well and met the objectives of both the CV880 and the CID programs. In the early phases of the CV880 flight test program, gelling was observed on a number of the engine fuel filters. Three distinct types of gel subsequently were identified. The mechanisms involved in the formation of all the gels were not fully understood by the end of the program. Aside from the intermittent occurrence of gel, little difference in performance could be distinguished between the No. 3 engine, operating on AMK, and the No. 2 reference engine, operating on Jet A.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Antimisting Kerosene (AMK) AMK Degrader High-Speed Centrifugal Pump Aircraft Fire Safety	This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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EXECUTIVE SUMMARY

The primary focus of the program reported herein was in-flight demonstration and evaluation of an Antimisting Kerosene (AMK) degrader. The performance of AMK in the engine/airframe fuel system of a large, representative commercial transport and the effects of the flight environment on the quality of AMK were also evaluated.

The degrader concept evaluated in this program was based on a modified, high-speed, centrifugal pump. Five functionally identical AMK degrader systems were designed and fabricated. The first system was installed on the No. 3 engine of a CV880 aircraft with a dedicated AMK fuel tank and was employed in the first flight test evaluation of AMK fuel. The remaining four degrader systems were installed on a B720 aircraft and used to condition AMK fuel for engine use during the Full-Scale Transport Controlled-Impact Demonstration (CID) conducted at Edwards Air Force Base in December 1984.

CV880 testing accumulated approximately 45 hours of operation on AMK, 30 of which were in flight. During the tests, the degrader allowed the test engine to perform over the full operating envelope, including altitude windmill relights. The only area that wasn't investigated was the performance of the degrader system with very cold fuel temperatures. In the program, the coldest fuel temperature resulting in meaningful data was 4° F at the degrader inlet.

During initial on-wing testing of the degrader system, gelling was encountered on many of the filter screens in the engine fuel system. Subsequent investigation revealed that three distinct gelling mechanisms were active during the tests. By the end of the program, the formation of two of these gels was understood with reasonable confidence. The formation of these gels could be predicted and controlled. Very particular engine operating procedures and conditions had to be assumed before the occurrence of these gels would cause any significant concern. The cause and methods of eliminating the third type of gel were also investigated extensively within the constraints of the program. While much data was accumulated and many theories assessed, definitive conclusions could not be reached relating to the cause of this gel or methods to inhibit or preclude formation.

The successful use of the centrifugal pump/degrader to condition the AMK fuel in an actual flight environment was the single most significant result of the program. The degrader systems performed well, meeting the objectives of both the CV880 flight evaluation and the B720 CID. Installation of the degrader on the No. 3 engine of the CV880 demonstrated that a degrader system could be integrated effectively with the engine fuel system. The control, stability, and reliability of the system, from the standpoint of mechanical and thermo/fluid dynamic performance, left little concern about the feasibility of further developing the pump/degrader concept into an optimized engine fuel-system component. Aside from the formation of gel, no AMK-related differences were noted between the performance of the No. 3 (AMK) engine and the No. 2 (reference Jet A) engine.

The test results indicated that AMK fuel was suitable for engine use within approximately 30 minutes after blending. The use of AMK fuel in the aircraft fuel system resulted in a small decrease in boost-pump performance but did not present any critical operational problems during the experimental program. There was no evidence of fuel tank contamination due to the long-term storage of AMK fuel. The presence of a high-molecular-weight polymer in the AMK fuel resulted in enhanced fuel lubricity. Normal aircraft maneuvering and the extremes of temperature and pressure encountered in the program did not have a significant effect on the fire-preventive characteristics of the AMK fuel.

I. INTRODUCTION

ANTIMISTING KEROSENE AND CRASH SURVIVABILITY

Commercial transport Jet A is a kerosene-based fuel with relatively low vapor pressure characteristics. Vapor evolution, or boiling at room temperature, requires a pressure of less than 2 pounds per square inch absolute (psia). Consequently, rapid flame propagation of Jet A fuel in the vapor phase will normally not occur unless the fuel is heated to a relatively high temperature. A normal method of enhancing flame propagation is to increase the free-air surface area of the fuel. This typically is accomplished by either wetting a permeable surface, such as a cotton wick, or by producing a fine fuel mist. Fuel atomization is the initial mechanism in the burning of aviation kerosene in the combustor of a turbine engine.

In an aircraft crash scenario, when tanks rupture and spilled fuel is subjected to high-velocity wind shear, a very fine mist of fuel can be produced. This mist is prone to rapid and violent flame propagation; a "fireball" can develop when the fuel contacts any number of ignition sources. In crashes where impact is not severe enough to cause significant numbers of fatalities, Federal Aviation Administration (FAA) studies have shown that postcrash fire and related heat, smoke, and toxic fumes are responsible for a considerable number of fatalities. If the possibility of a mist-induced, explosive fireball could be minimized, the postcrash survivability of passengers and crew would be greatly enhanced.

Antimisting kerosene (AMK) fuel has been investigated by the FAA Technical Center since 1978 as a means of suppressing postcrash fire (Reference 1). AMK is less prone to form the fine fuel mist that is a characteristic occurrence in many aircraft crashes. AMK fuel is produced by adding 0.3 percent, by weight, of a high-molecular-weight polymer to Jet A along with a carrier fluid and stabilizer. The polymer causes large globules or droplets to form rather than a fine mist. The suppression of the fuel mist is the mechanism by which AMK prevents rapid flame propagation through airborne fuel.

THE NECESSITY OF A DEGRADER

The benefits of AMK to fire safety were evident. However, elimination of the misting properties of Jet A fuel had a profound effect on combustion in aircraft engines. Atomization in combustor fuel nozzles was so poor, ignition did not occur. The presence of the AMK polymer in Jet A under moderate fluid shear stress also had the potential to form a gel on fuel-system filters, clogging small orifices and tight-fitting pistons in the engine fuel control. If AMK were to be a viable technology, it was necessary to develop a method of reverting AMK to a state with properties very similar to untreated Jet A. The long-chain polymer had to be "degraded" to the extent it no longer produced antimisting, shear-thicking characteristics when exposed to the fluid-shear stresses of the engine fuel system. The term "degrader" has been applied to a mechanical device intended to revert AMK to Jet A characteristics.

Many different types of degraders have been developed; they range from high-speed, "soda fountain" blenders that chop the long-chain polymer to high-pressure, differential-needle-valve degraders that produce high fluid shear (References 2 and 3). To be practical, however, the device must degrade the AMK polymer effectively over the entire operating range of a jet engine, be compatible with aircraft fuel-system and engine controls, and not require an inordinate amount of power. Development of such a degrader was one of the critical enabling technologies which to be addressed before AMK technical feasibility could be demonstrated.

HIGH-SPEED CENTRIFUGAL PUMP DEGRADER

In 1981, General Electric demonstrated the feasibility of using a high-speed, centrifugal pump with a modified diffuser to degrade AMK (Reference 4). Tests were conducted in a laboratory over the fuel-flow range of General Electric's CF6-80A turbofan. Acceptable levels of degradation were achieved at fuel flows representative of idle and cruise power settings; results were slightly less encouraging at takeoff power. Confidence in the practicality of this degrader concept, as well as the possibility of refining impeller and diffuser designs to enhance the degradation characteristics, led General Electric to propose the high-speed centrifugal pump as the concept to be developed to assess the feasibility of aircraft operation on AMK fuel.

PROGRAM OBJECTIVES AND OVERVIEW

The objectives of the Antimisting Fuel Flight Degrader Development and Aircraft Fuel System Investigation were as follows:

- To design a degrader system capable of on-line conditioning or degrading AMK in a flight environment.
- To fabricate, bench test, and deliver five prototype degraders, each capable of a minimum of 50 hours of flight testing.
- To determine the effects of AMK on airframe/engine fuel-system performance, incorporating the degrader, in a limited flight test evaluation.
- To determine the effects of aircraft fuel system and flight environment on the quality of AMK fuel during the flight test evaluation.

The Program objectives were quite challenging in view of the complexity of the required tasks and the time available to complete them. Schedule constraints did not permit a methodical and deliberate approach to improving the degrader. Figure 1 shows the schedule and work flow of the major tasks of the program. The major tasks and responsible organizations involved in meeting the overall program objectives are described below.

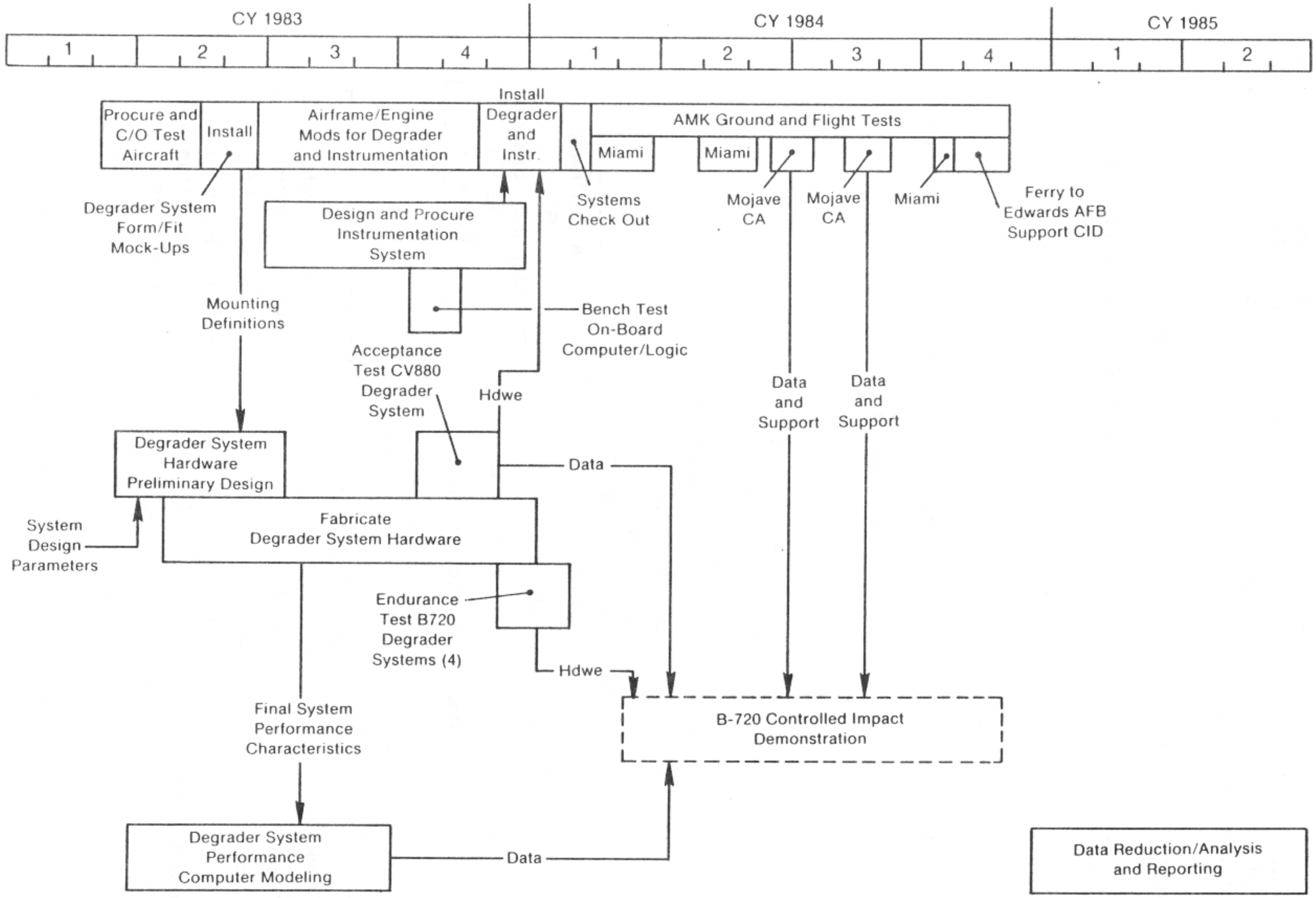

FIGURE 1. PROGRAM SCHEDULE AND FLOWCHART

The Fluid and Energy Transfer Systems Unit of General Electric's Aircraft Engine Business Group, Advanced Technology Operation, was responsible for the program management and technical integration of this effort. Figure 2 shows the flow of program-management responsibility. Technical integration was quite broad and involved the following:

- Conceptual design of the overall degrader system
- Preliminary and detailed designs of the high-speed centrifugal pump degrader
- Specifications of system components
- System computer modeling and performance predictions
- Design and integration of degrader-system aircraft installation
- Planning and direction of the AMK testing

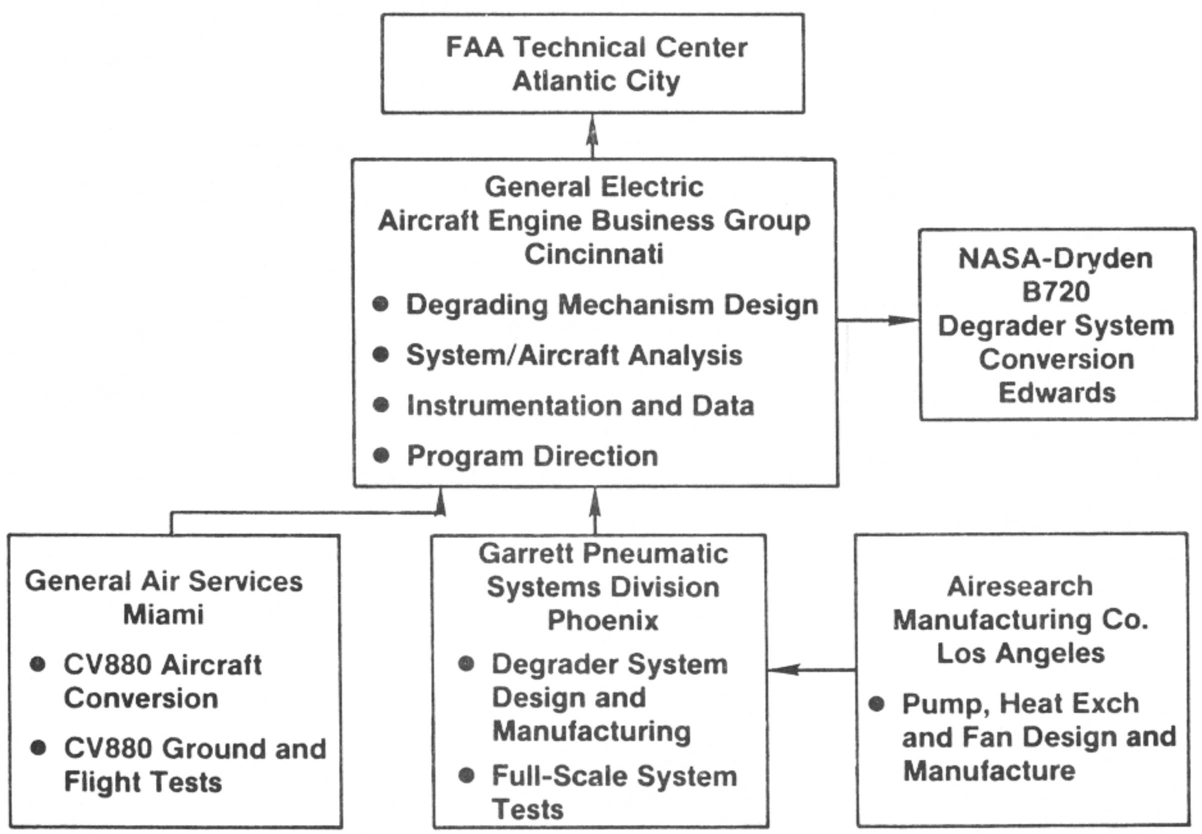

FIGURE 2. FUNCTIONAL RELATIONSHIP OF PROGRAM CONTRIBUTORS

Design of the degrader was complicated considerably by the fact that a single system had to be developed with enough flexibility to allow it to serve two related but distinct functions. First, a useful experimental tool was needed for investigation of AMK degradation - a laboratory-type implement. Second, the same system would have to serve as a flight component compatible with aircraft/engine fuel systems and enable an aircraft to operate on AMK fuel.

The major hardware components of the degrader system were fabricated by the Garrett Pneumatic Systems Division (GPSD). A total of five complete degrader systems were assembled and tested at Garrett. The first degrader system was installed on the No. 3 engine of a CV880 aircraft, the test-bed to investigate in-flight performance of the degrader and compatibility of AMK fuel with the engine and aircraft fuel systems. The remaining four degraders were shipped to NASA-Dryden for installation on all four engines of the B720 Full-Scale Transport Controlled Impact Demonstration (CID) Program test vehicle.

In order to meet the program schedule, all of the mechanical components of the degrader system were standard, "off-the-shelf" items modified for use in this program. However, it was necessary for Garrett to design a special electronic controller specifically for the flight degrader program.

The initial laboratory acceptance and endurance tests of the degrader system were also conducted at GPSD under the direction of GE and the FAA.

General Air Services (GAS) Inc. of Miami, Florida was responsible for the operation of the CV880 AMK test-bed during the program. GAS performed all the necessary airframe modifications and installed the degrader system. After the initial AMK tests, GAS mechanics and technicians also assisted in the blending and characterization of the AMK fuel and in the operation of the computerized, on-board, data-acquisition system.

The instrumentation system used on the CV880 was designed by General Electric, Edwards Flight Test Center. The on-board computer stored data on a nine-track magnetic tape recorder in a format compatible with the mainframe computer at General Electric's Evendale Plant. Visual data monitoring as well as hard copy was available on board the test aircraft. GE personnel from the Edwards Flight Test Center directed the installation of instrumentation sensors by GAS, conducted the original system checkout, and monitored data acquisition during the early test sequences. GAS personnel monitored the data acquisition during later testing.

THE FULL-SCALE TRANSPORT CONTROLLED IMPACT DEMONSTRATION

The CID was a joint FAA/NASA program involving the intentional crash-landing of a highly instrumented B720 commercial aircraft. General Electric provided four degrader systems to the CID (functional replicas of the CV880 system) and provided consultation to NASA-Dryden on the installation and operation of the systems. Much of the data generated in the CV880 degrader evaluation program directly supported the B720 CID program. Detailed results of the CID program are reported in References 1 and 5.

Discussion of the B720 installation in this report emphasizes the differences between the single degrader installed on the CV880 and the complete set of four degraders installed on the B720 CID test vehicle.

DEVELOPMENT OF THE FINAL REPORT

This final report is a compilation and summary of pertinent information and data, chosen by the authors, from General Electric Technical Memoranda. All four reports are available from the FAA Technical Center Library.

Antimisting Fuel (AMK) Flight Degrader Development and Aircraft Fuel System Investigation:

Volume I	Program Work Breakdown Structure and Technical Guide (Reference 6)
Volume II	Degrader Systems Acceptance and Endurance Tests (Reference 7)
Volume III	Degrader System Aircraft Testing - Phase I (Reference 8)
Volume IV	Degrader System Aircraft Testing - Phase II (Reference 9)

Volume I was the technical and administrative planning document used by GE during the course of the program to coordinate the efforts of the major sub-contractors. The report was updated regularly during the design phase of the program and includes data and analyses considered too lengthy for inclusion in this final report.

Volume II addresses the degrader hardware configuration and the endurance and acceptance testing of the degrader systems. The report was compiled by Garrett Pneumatic Systems Division and covers their effort prior to acceptance of the hardware by General Electric and the FAA.

Volume III covers the the initial series of degrader testing with the system installed on an aircraft. A significant number of these tests involved ground testing of the degrader system only, without engine operation (systems test), as well as ground operation of the degrader and the engine. Four flight tests were also conducted during the period covered in Volume III.

Volume IV contains test results from Phase II of the degrader system aircraft tests. The predominance of the tests performed during this Phase were actual flight tests of the degrader. Much of the flight testing in Phase II was conducted at Mojave, California to permit direct support of the B720 CID program.

The only major section of this Final Report not addressed in any of the above four documents is Section II, Development of the High-Speed Centrifugal Pump

Degrader. Section II describes earlier work at General Electric in which the concept of the centrifugal pump/degrader was developed and demonstrated. The design considerations that had to be addressed in the degrader flight test program are discussed as well as the fluid/thermodynamic computer model used to analyze the degrader system.

Section III of this final report, Degrader System Components and Aircraft Installation, discusses the components of the degrader system and describes the installation in the CV880 test vehicle.

Section IV, Instrumentation System Design and Configuration, describes the on-board data system used in the CV880 Program. The computerized data plots presented frequently in this report are also discussed in this section.

Section V, Degrader System Testing, is the core of the final report. The data acquired during the bench tests and the on-wing testing of the degrader system are discussed and analyzed in this section.

Section VI, Support of the Controlled Impact Demonstration, addresses the B720 degrader installation and the preparatory tests of the degraders prior to the actual impact flight demonstration on December 1, 1984.

Section VII presents the general conclusions developed by General Electric during the course of the program.

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II. DEVELOPMENT OF THE HIGH-SPEED CENTRIFUGAL PUMP DEGRADER

INTRODUCTION

Development of the degrader system for the flight test program evolved through the following three phases:

- Proof of Concept Tests
- Modification of Aircraft/Engine Computer Model
- Design of the Degrader System for the Flight Test Program

In 1981, the FAA sponsored a laboratory experiment, at the General Electric Evendale Plant, to assess the effectiveness of a centrifugal pump in degrading AMK fuel and to develop a data base relating to the characteristics of the modified pump as a degrader. The scope and depth of this experiment were modest, only two test sequences were performed; nevertheless, enough data were gained to allow GE to propose the modified centrifugal pump/degrader for use in the degrader flight test program.

A computer model of the DC10/CF6-80 aircraft/engine system was modified to represent a pump/degrader installed on a CV880/CJ805 aircraft/engine system. The model was quite useful in evaluating the design of the degrader system for the flight test program.

Requirements of the degrader flight test program were assessed and balanced against fiscal and schedule constraints and program technical risk. The goal was development of a system capable of performing the program tasks. The degrading characteristics of the centrifugal pump had to be integrated for use in the flight test vehicle. The chosen design was conservative, leaving as much latitude as possible for design improvements during the program.

RATIONALE FOR A CENTRIFUGAL PUMP/DEGRADER

From the onset, General Electric's development of a degrader focused on two basic considerations. The machine had to be an effective degrader of AMK; equally important, the device should be practical for use in an aircraft. The latter consideration is not a trivial point because, in General Electric's opinion, some of the laboratory devices that have been developed as degraders could not be readily integrated into an aircraft. By choosing an aircraft engine component as the starting point for the degrader, many of the problems involved with taking the device from proof-of-concept to flight-operational feasibility were dispensed with early in the development of the degrader.

The issue of practicality is far-reaching. Practicality ultimately rests on the possibility of integrating an optimized degrader system into a commercial aircraft. The pump/degrader offers a reasonable facility for optimization and integration. The broad context of practicality did not have to be achieved for successful completion of the degrader flight test program. Compromises were necessary and permitted. Nevertheless, the more practical the design, the better the chance of success in demonstrating the feasibility of the degrader in the flight test program. The following is a brief discussion of some of the considerations affecting the practicality of the pump/degrader.

ADAPTABILITY. In an optimized, fully developed configuration, a pump/degrader could be adapted as either a retrofit component to be used in conjunction with a conventional gear-type fuel pump or, in the long term, totally integrated into the engine as a replacement for the conventional fuel pump.

SIZE AND WEIGHT. The F101 augmentor fuel pump, which had been the basis for all of General Electric's degrader investigations, weighs approximately 19 pounds and is 6 inches long. This pump, acting as a degrader, is capable of degrading AMK at flow rates typical of the operation range of the largest current commercial turbofans. For example, a CF6-80A engine, rated at over 50,000 pounds takeoff thrust, requires 15,600 pounds per hour (pph) of fuel at takeoff and 1,200 pph at idle. The fuel pump for the CF6-80A weighs about 39 pounds and is approximately 11 inches long. The pump/degrader is only slightly more than half the weight of this standard, gear-type, fuel pump.

COMPLEXITY AND RELIABILITY. In an optimized pump/degrader, the degrading mechanism would be inherent within the device. Degradation need not be the result of power-consuming, complex components. Consequently, with the concept of the pump/degrader, the issues of size/weight, cost, and reliability lie in one component and not necessarily in a system of additional items. High-speed centrifugal fuel pumps are currently used extensively in the augmentors of military engines; thus, a significant amount of data on the reliability of the basic component already exists.

TEST RESULTS - PUMP/DEGRADER PROOF OF CONCEPT

The General Electric pump/degrader concept was proven in component tests conducted under Contract DOT-FA79NA-6043 in 1981. The results of these tests are reported in Reference 4. The tests showed that a high-speed centrifugal pump could provide acceptable levels of AMK degradation over the speed and fuel flow range of the CF6-80A engine used on the B767 and A310 commercial aircraft. An F101 augmentor fuel pump was modified for these tests and, by virtue of the results, became the baseline configuration for the degrader flight test program. The component-test conditions are listed below.

Condition	Engine Speed, %	Pump Speed, rpm	Fuel Flow, pph
Ground Idle	66.8	16,634	1,226
Cruise	98.5	24,528	5,506
Takeoff	104.6	26,022	15,637

The usual method of determining the effectiveness of an AMK degrader is by a measurement of filter ratio (FR). Filter ratio is determined by measuring the time needed for a given amount of AMK to gravity flow through a filter screen divided by the time needed for a similar amount of Jet A to flow through the same size filter screen. Standard procedures have been developed for filter ratio measurement by the United States/United Kingdom AMK Technical Committee; Reference 10 describes the apparatus and procedure used in determining filter ratio. In general, undegraded AMK will have a filter ratio over 60; highly degraded AMK will have a filter ratio at or below 1.2. Of course, perfectly degraded AMK would have a theoretical filter ratio of 1.0.

The pump was tested with three diffuser configurations: standard (No. 1), close-clearance standard diffuser (No. 2), and increased recirculation (No. 3). Diffuser No. 3 was chosen as the baseline design for the degrader flight test program. Figure 3 summarizes the filter-ratio results of the different diffusers at three operating conditions. Further data analysis indicated no detrimental side effects from the diffuser modifications in terms of pumping performance or pressure stability.

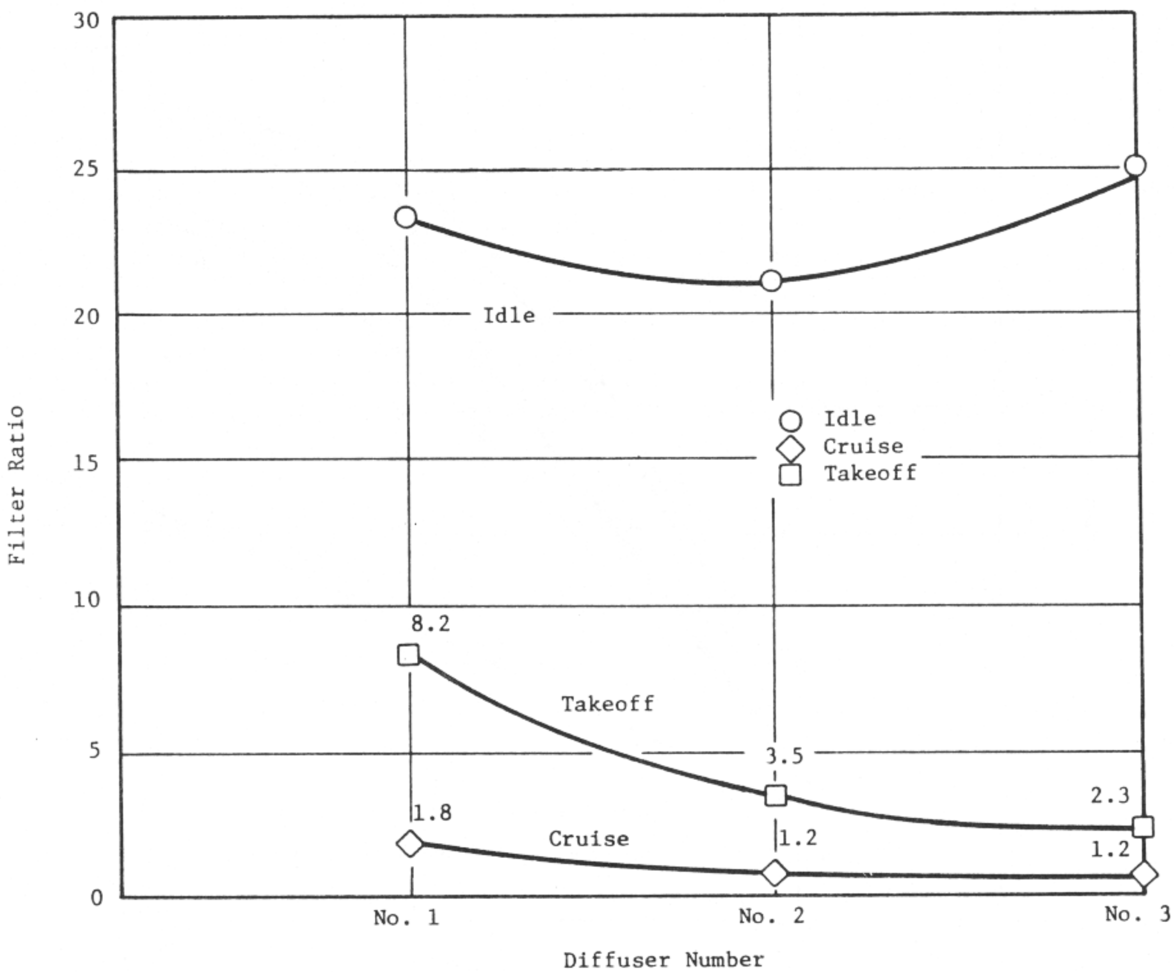

FIGURE 3. FILTER RATIO RESULTS FROM PROOF-OF-CONCEPT TESTS

At low idle flows, a threshold pump speed required for any significant AMK degradation was identified. Also, it was noticed that increasing fuel flow at a given pump speed reduced the level of degradation. Results achieved with the No. 3 refined diffuser were considerably better than the results with a standard diffuser. Although absolute input power levels were high, a significant improvement in degradation was achieved by a means other than a large increase in power input. For example, at a constant idle flow with the No. 3 refined diffuser, the filter ratio dropped from 23.2 to 1.3 by increasing pump speed from 16,634 to 18,000 rpm. That speed increase required a modest power increase of 6 horsepower. At takeoff flow (15,600 pph), 25 additional horsepower were required to reduce filter ratio results from 8.2 with the standard diffuser to 2.3 with the refined No. 3 diffuser. By using filter ratio for a qualitative comparison, it can be seen that impeller speed and diffuser design refinements yielded significant improvements at a relatively low increase in power requirement. Figure 4 compares the required input power of the three degrader configurations to the power requirements of the standard CF6-80A fuel pump with the higher fuel flow.

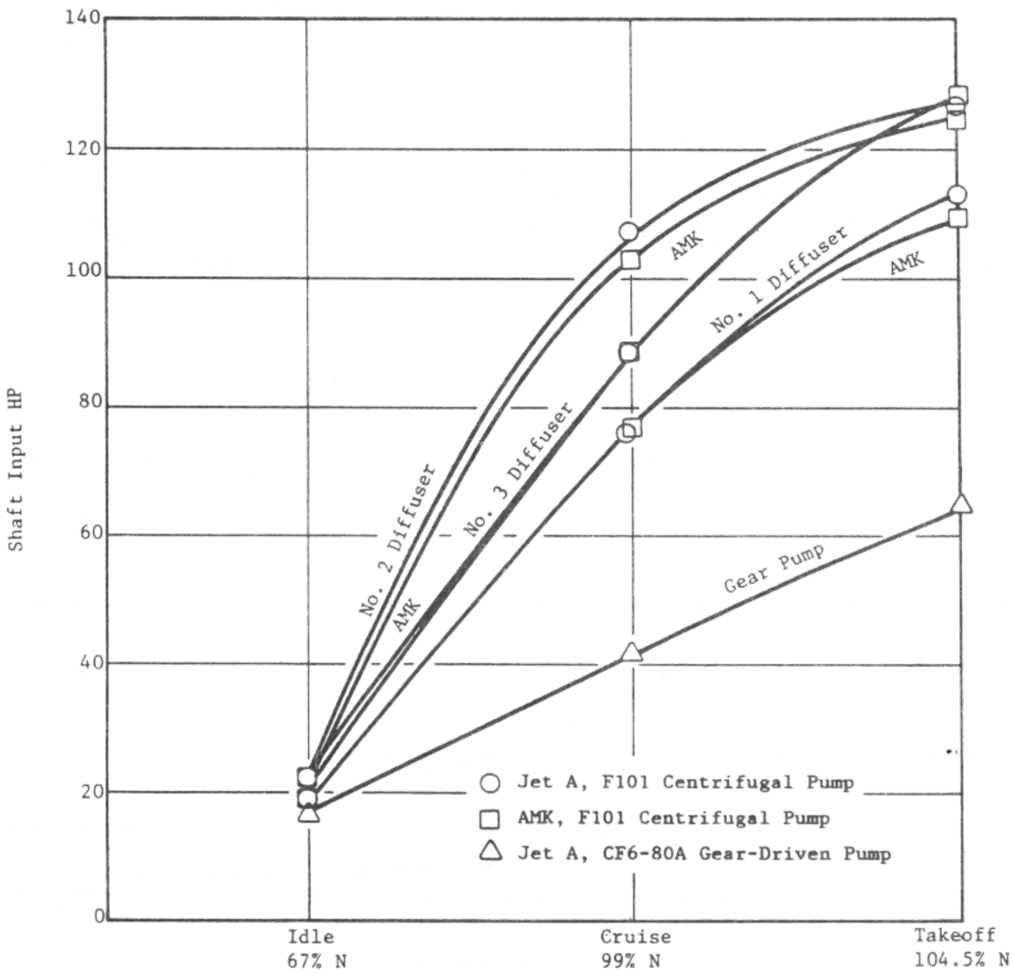

FIGURE 4. DEGRADER/PUMP POWER REQUIREMENTS

The test results were then used to construct a plot of filter ratio as a function of CV880 engine fuel flow and degrader speed (Figure 5). Initial test results also showed that a minimum, or threshold, speed for degrading with the F101 impeller was 18,500 rpm. Filter ratio increased to 23 below this speed. Based on the speed parameter alone, the test results generally appeared consistent. For filter ratios near 1.0 (Jet A), the degrader/pump speed envelope for the CV880 was defined from initiation of engine start (600 pph at 12% N_2) to takeoff (8,600 pph at 103% N_2). A degrader speed of 20,000 rpm was selected as the necessary minimum at idle conditions. For the CV880 takeoff flow (8,600 pph) 28,000 rpm was required as the upper limit for degrader speed. When the B720 takeoff flow of 10,500 pph was addressed later on in the program, 32,000 rpm was required to maintain filter ratio near 1.0.

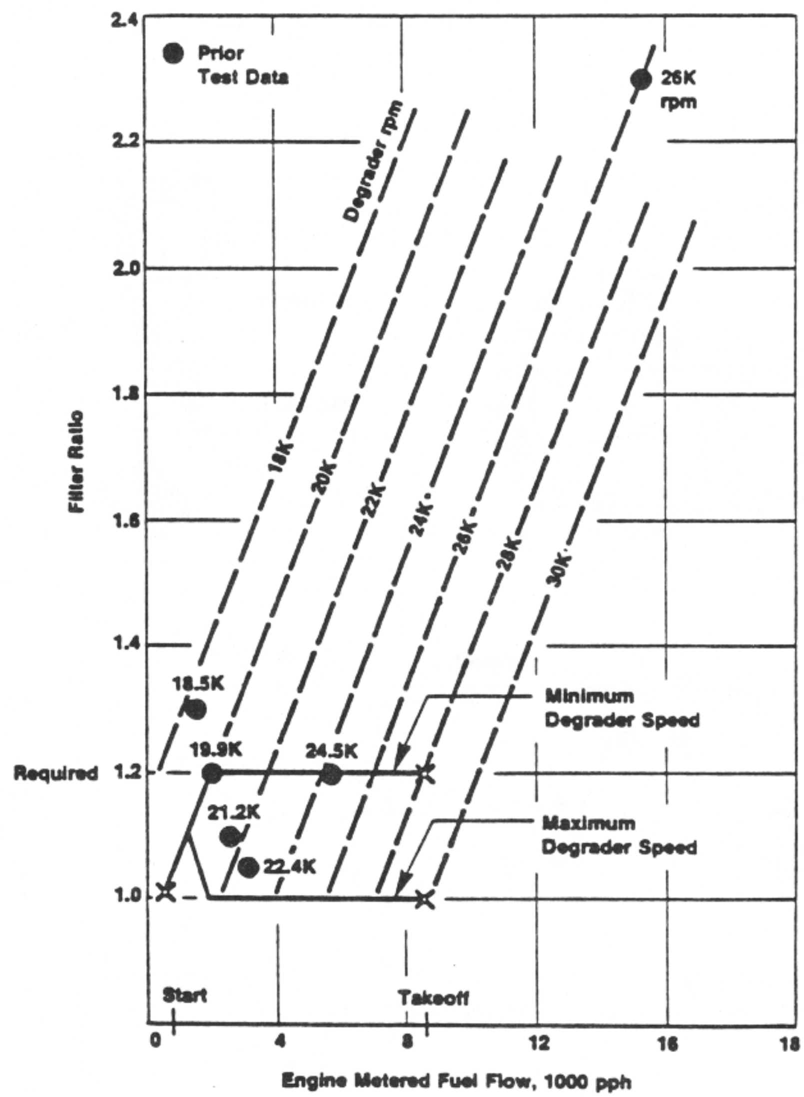

FIGURE 5. DEGRADER SPEED SCHEDULE RELATIONSHIP TO FLOW AND FILTER RATIO

DEGRADING MECHANISM OF THE HIGH-SPEED CENTRIFUGAL PUMP

There are many ways to degrade AMK fuel; potential methods range from simple food blenders to high-pressure-drop-orifice devices. All of these devices impart energy to the fluid in an attempt to fracture the long-chain FM-9 molecule and revert the characteristics of the AMK back to those of untreated Jet A. General Electric has taken the approach of using a pulsating field of high-velocity fluid shear in the region of the discharge of a high-speed, centrifugal pump. Figure 6 shows the the degrading region of a centrifugal pump where very rapidly alternating inward and outward fluid pulsation creates what is called a molecular stress zone. Selective changes to the diffuser-blade angle, along with scallops in the diffuser housing, were incorporated into the design of the General Electric degrader. These changes tended to increase pump recirculation and enhanced the degrading characteristics of the pump.

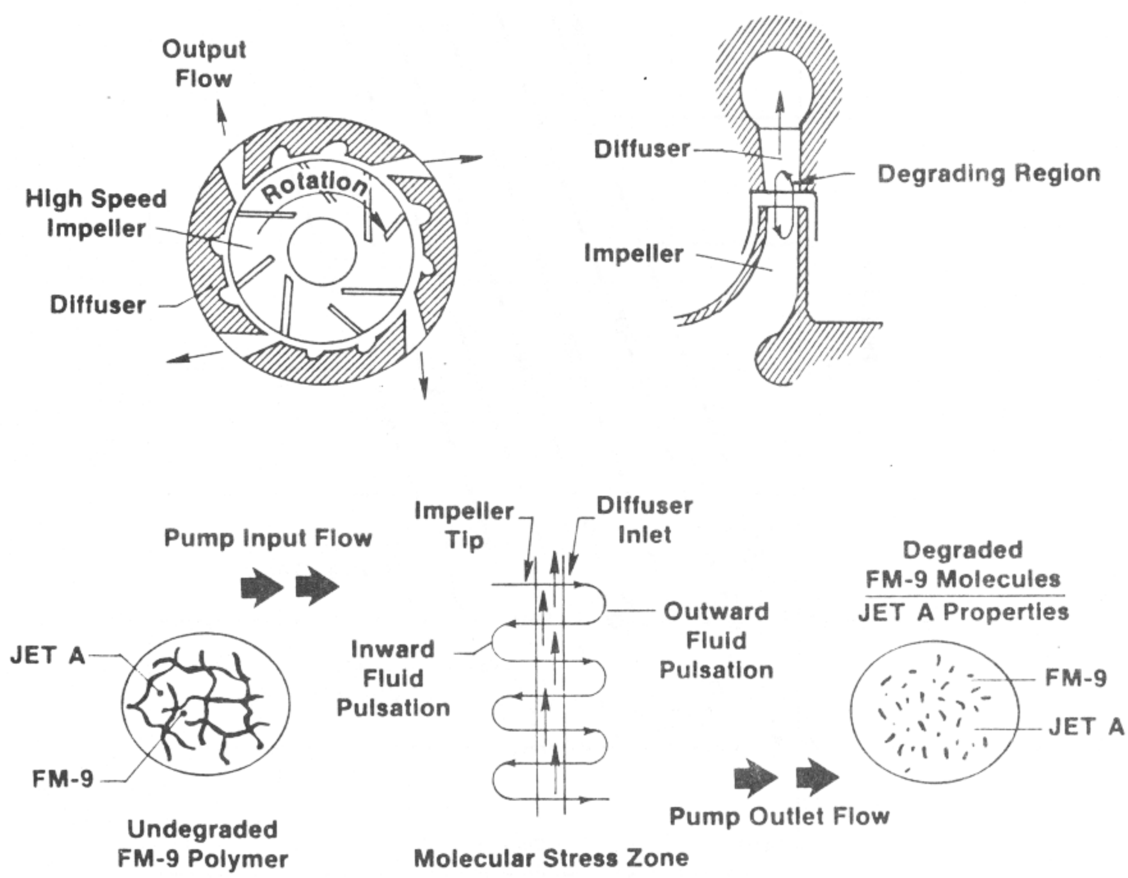

FIGURE 6. MODIFIED CENTRIFUGAL PUMP DEGRADING MECHANISMS

DESIGN OF THE FLIGHT TEST DEGRADER SYSTEM

INTRODUCTION. Once the operating requirements and characteristics of the pump/degrader had been defined, the challenge of integrating the degrader into the aircraft fuel system had to be addressed. The proof-of-concept degrader tests had shown the effectiveness of the modified centrifugal pump in degrading AMK fuel. Demonstrating the operational feasibility of the device in an aircraft was a major thrust in the flight test program.

Earlier in this section, the advantages of a fully developed and optimized pump/degrader component were discussed. The overall degrader system designed for this program was not a fully developed and optimized configuration. The design was developed to the extent necessary to assure reasonable success in completing the required program tasks.

Sixteen months elapsed from the program inception to the originally scheduled B720 CID. The schedule required degrader hardware to be available for initial testing in the CV880 during the tenth month of the program and available for the B720 installation in the eleventh and twelfth months of the program. This necessitated that readily available components be chosen for the system.

The degrader system designed for this program had to serve the dual purpose of being both an experimental tool, to investigate AMK degradation in the CV880 program, and a functional degrading device in the B720 CID program. In the CV880 flight test program, the degrader was mounted on the No. 3 engine for the purpose of evaluating the pump/degrader performance over the complete operating envelop of the aircraft. Any problems uncovered in this phase of the program were to be resolved prior to the B720 CID program.

Since the schedule did not comprise the time necessary to design a centrifugal pump dedicated solely to degrading AMK fuel, prudence dictated a very conservative approach in the choice of components and design of the degrader system. The goal was to facilitate changes that might be necessary during the program or to afford more latitude in the investigation of the use of AMK fuel.

For example, the air turbine motor chosen for the program was capable of producing up to 200 horsepower. In the program, the maximum that was required turned out to be approximately 140 hp. An area of concern in the program was the amount of heat the degrader would introduce into the fuel. There was early concern that the fuel inlet temperature to the engine might be too high at certain conditions and lead to problems. One of the modes of concern was ground operation of the degrader at engine idle with high ambient air temperatures and relatively warm fuel tank temperatures. Since this condition was likely to occur during the B720 CID, originally planned for July 1984 at Edwards Air Force Base, a complete fuel-cooling loop was added to the degrader system to alleviate the potential problem. Actually, fuel inlet temperatures were not a particular problem during the CID program.

The life requirements for the degrader system hardware in the program were modest, a minimum of 50 hours. Nevertheless, the intent was to use existing, flight-proven components in the system such that there would be no limitation on the length of time the degrader system could be operated during either the CV880 or B720 programs. Considerable design margin was provided for critical items such as bearings, seals, valves, and other wear-sensitive parts. All components were capable of satisfactory operation under environmental extremes more severe than those expected to be encountered in the flight test program. Specific details of the hardware design are discussed later in this report and in Reference 7.

DEGRADER SYSTEM FLUID/THERMODYNAMIC MODEL. The AMK degrader system computer model was an extremely useful design and analysis tool. The model was based on the architecture of an existing DC10/CF6-80 model, outlined in Figure 7. Figure 8 is a schematic of the AMK degrader system model. Table 1 lists the nomenclature for the modeled components and parameters. The model included analyses of temperatures, pressures, flows, speeds, and other parameters for the following systems:

- Aircraft Fuel Tank - Bulk fuel temperature for worst-case conditions
- Degrader - Required speed as a function of fuel flow, bleed air energy extraction and effect on specific fuel consumption (SFC) and exhaust-gas temperature (EGT), fuel-cooling capability (heat exchanger and fan)
- Engine Fuel System - All parameters
- Engine Lube System - Heat rejection to fuel across oil cooler

Development of the AMK degrader/engine computer model began with data from the earlier proof-of-concept tests of the pump/degrader. Throughout the preliminary design phase of the degrader system and at pertinent milestones during the program, the model was updated and modified to reflect the operational characteristics of the actual degrader system.

The first step in developing the model was to formulate the computer logic and mathematical equations needed to make the model function. Since the CJ805 engine and all degrader components had known characteristics, this generally was a matter of simple calculation. Computer-generated curve-fits were used for such items as air turbine motor (ATM) power, pump input power, and heat exchanger performance.

Because computerized engine cycle data were not readily available for the CJ805, engine performance curves, generally a function of corrected speed, were curve-fitted or tabulated into the model. The model was run at selected flight envelope points, shown in Figure 9. Parameters such as altitude, air speed, air temperature, engine thrust, and fuel-tank temperature at selected points were included in the model.

The model run yielded degrader steady-state performance needed to determine the adequacy of the degrader system design. Fuel cooling, air turbine motor

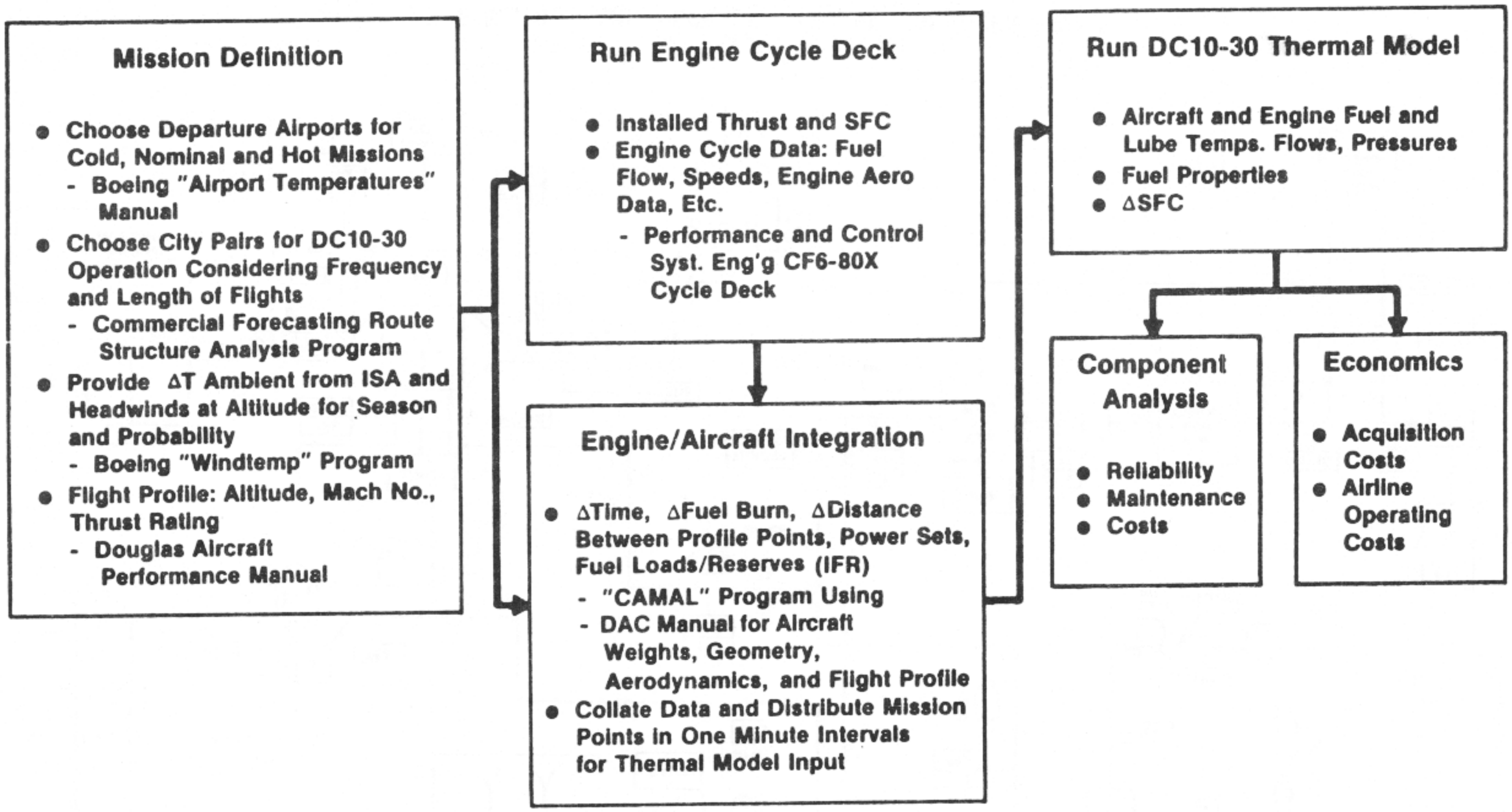

FIGURE 7. DC10/CF6-80 COMPUTER MODEL FLOWCHART

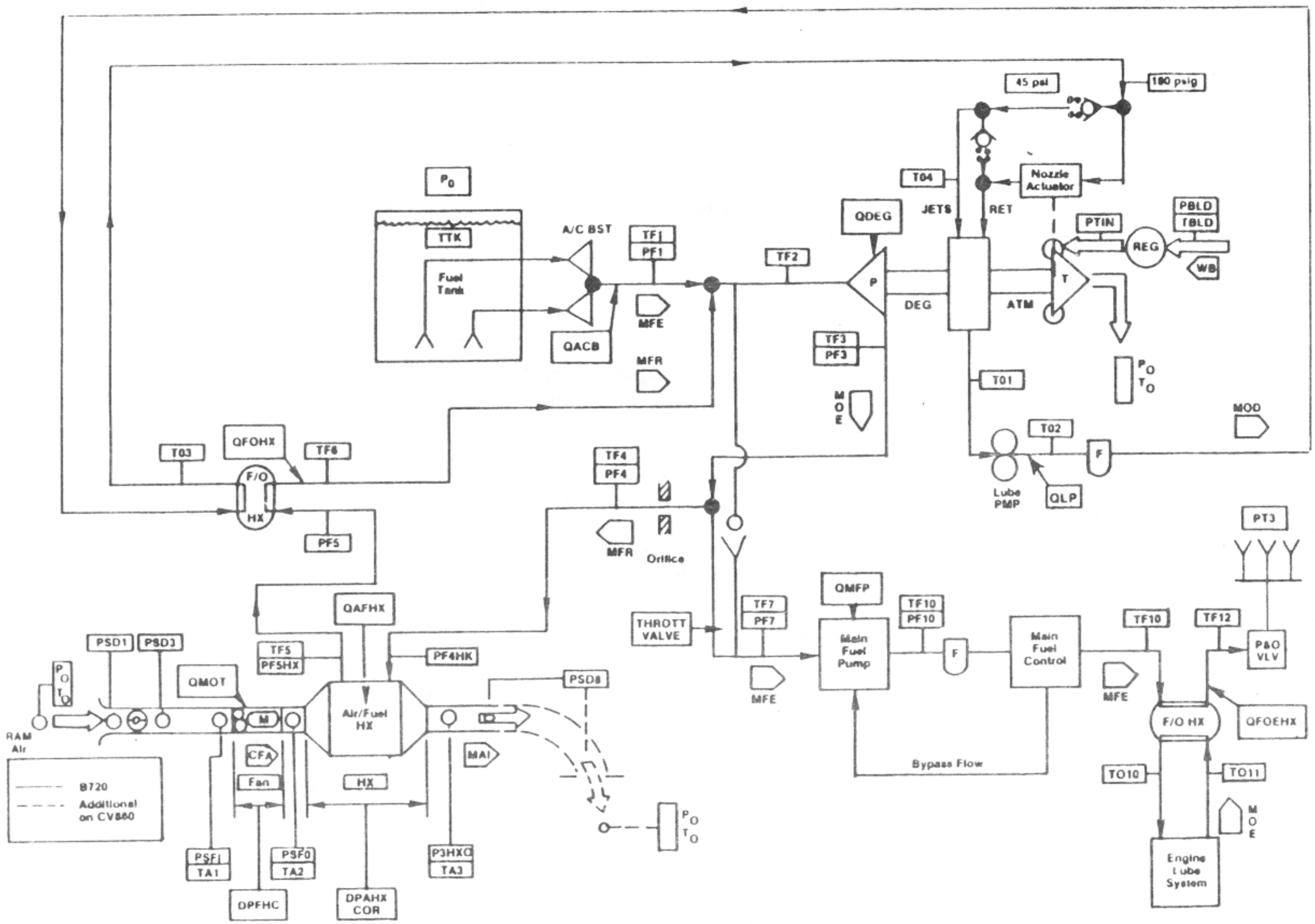

FIGURE 8. AMK DEGRADER/ENGINE COMPUTER MODEL

TABLE 1. AMK COMPUTER MODEL NOMENCLATURE

Fuel System

P0	Ambient Static Pressure	psia
TTK	Fuel Tank Temperature	° F
QACB	Aircraft Boost Pump Heat Rejection	Btu/min
TF1	Aircraft Boost Discharge Temperature	° F
PF1	Aircraft Boost Discharge Pressure	psia
TF2	Degrader Inlet Temperature	° F
QDEG	Degrader Pump Heat Rejection	Btu/min
TF3	Degrader Discharge Temperature	° F
PF3	Degrader Discharge Pressure	psia
TF4	Orifice Discharge Temperature	° F
PF4	Orifice Discharge Pressure	psia
PF4HX	Fuel/Air Heat Exchanger Inlet Pressure	psia
TF5	Fuel/Air Heat Exchanger Outlet Temperature	° F
PF5HX	Fuel/Air Heat Exchanger Outlet Pressure	psia
PF5	Fuel/Oil Heat Exchanger (Degrader/ATM Lube) Inlet Pressure	psia
TF6	Fuel/Oil Heat Exchanger Outlet Temperature	° F
TF7	Main Fuel Pump Inlet Temperature	° F
PF7	Main Fuel Pump Inlet Pressure	psia
PF10	Main Fuel Pump Discharge Pressure	psia
TF10	Fuel/Oil Heat Exchanger (Engine Lube) Inlet Temperature	° F
TF12	Fuel/Oil Heat Exchanger Outlet Temperature	° F
QAFHX	Air/Fuel Heat Exchanger Heat Transfer	Btu/min
QFOHX	Fuel/Oil (Degrader/ATM Lube) Heat Exchanger Heat Transfer	Btu/min
QMFP	Main Fuel Pump Heat Rejection	Btu/min
QFOEHX	Fuel/Oil (Engine Lube) Heat Exchanger Heat Transfer	Btu/min
MFE	Engine Fuel Flow Rate	lbm/min
MF2	Degrader Fuel Flow Rate	lbm/min
MFR	Recirculation Rate	lbm/min

ATM/Degrader Lube System

QLP	Lube Pump Heat Rejection	Btu/min
T01	Lube Pump Inlet Temperature	° F
T02	Fuel/Oil Heat Exchanger Inlet Temperature	° F
T03	Fuel/Oil Heat Exchanger Outlet Temperature	° F
T04	Lube Jet Inlet Temperature	° F
MOD	Lube Flow Rate	lbm/min

Engine Lube System

T010	Fuel/Oil Heat Exchanger Outlet Temperature	° F
T011	Fuel/Oil Heat Exchanger Inlet Temperature	° F
MOE	Lube Flow Rate	lbm/min

TABLE 1. AMK COMPUTER MODEL NOMENCLATURE (CONTINUED)

ATM Air

WB	Bleed Air Rate	lbm/s
PBLD	Bleed Air Pressure at Regulator Valve Inlet	psia
TBLD	Turbine Inlet Temperature	° R
PTIN	Turbine Inlet Total Pressure	psia
TO	Ambient Static Temperature	° R
PO	Ambient Static Pressure	psia
XND	ATM/Degrader Speed (Physical)	rpm

Fuel/Air Heat Exchanger Installation

PO	Ambient Static Pressure	psia
PSD1	Duct Entrance Static Pressure	psia
PSD3	Valve Exit Static Pressure	psia
PSFI	Fan Inlet Static Pressure	psia
PSFO	Fan Outlet Static Pressure	psia
PSHXO	Heat Exchanger Outlet Static Pressure	psia
PSD8	Exhaust Inlet Static Pressure	psia
TO	Ambient Static Temperature	° R
TA1	Fan Inlet Static Temperature	° F
TA2	Fan (Motor) Outlet Static Temperature	° F
TA3	Heat Exchanger Outlet Static Temperature	° F
QMOT	Fan Motor Heat Rejection	Btu/min
QAFHX	Fuel Heat to Air	Btu/min
DPFHC	Total Pressure Differential Across Fan	in. H_2O
DPAHXCOR	Total Pressure Differential Across Heat Exchanger	in. H_2O
MA1	Air Flow Rate	lbm/s
CFA	Air Flow Rate	ft^3/min
FRPM	Fan Windmill Speed	rpm

CJ805 Performance

ALT	Altitude	ft
PO	Ambient Static Pressure	psia
TO	Ambient Static Temperature	° R
PCN2	Physical Rotor Speed	%
XMP	Mach Number	---
XNC	Corrected Rotor Speed	%
P2QPO	Ram Pressure Ratio (PT_2/P_0)	---
RNI	Reynolds Number Index	---
T2	Compressor Inlet Total Temperature	° R
P2	Compressor Inlet Total Pressure	psia
FG	Gross Thrust	lbf

TABLE 1. AMK COMPUTER MODEL NOMENCLATURE (CONCLUDED)

CJ805 Performance (Concluded)

FN	Net Thrust	lbf
FR	Ram Drag	lbf
WA	Compressor Inlet Airflow	lbm/s
WB	Bleed Airflow	lbm/s
WBR	Bleed Air Ratio (WB/WA)	---
WF	Engine Fuel Flow	lbm/hr
PT3	Compressor Discharge Total Pressure	psia
PTX	(PBLD) Bleed Air Pressure	psia
TTX	(TBLD) Bleed Air Total Temperature	° R
T5	Exahust Gas Temperature (EBT)	° R
EGTC	Exhaust Gas Temperature	° C
PT5	Turbine Discharge Pressure	psia
SFC	Specific Fuel Consumption	lbm/hr/lbf
BPR4	Bleed Pressure Ratio	---

Degrader Data

XND	Degrader Speed	rpm
SHPDEG	Degrader Shaft Power	hp
DEGT	Degrader Shaft Torque	ft-lb
QF2	Degrader Total Flow	gpm
QFE	Fuel Flow to the Engine	gpm
MF2	Degrader Total Flow	ppm
DF2	Degrader Fuel Average Density	lbm/ft^3
DPKE	Theoretical ΔP from Kinetic Energy Available for Degrading	psid
XKE	Theoretical DPKE/MF2	psid/ppm

air inlet pressure, and degrading capability were the predominant issues. ATM inlet air pressure setting was verified by these results. The fuel-cooling fan was analyzed from the standpoint of overspeed. AMK degrading capability was predicted early in the program as a function of fuel flow and degrader speed.

The usefulness of the computer model during the degrader system development cannot be overstressed. Early in the program, the model provided steady-state performance data necessary to ascertain the adequacy of the degrader system design and integration into the engine fuel system. The need for a fuel/air heat exchanger in the degrader system to maintain 160° F engine inlet temperature was one of the first design decisions based on computer model data. Supply pressure necessary for the degrader air-turbine motor was estimated

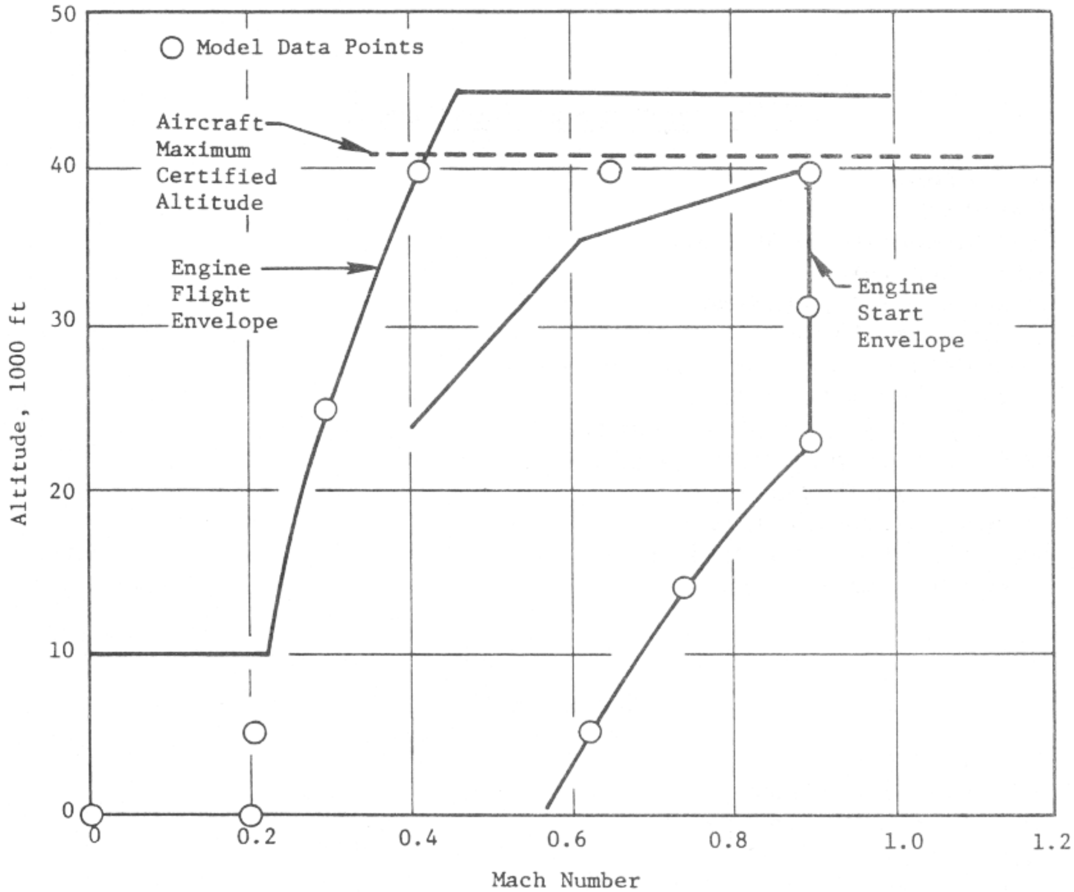

FIGURE 9. ENGINE FLIGHT ENVELOPE DATA POINTS FOR COMPUTER MODEL

using the model. Significant failure effects could be estimated at the component level; for instance, a failure-and-effects analysis of the cooling fan or degrader throttling valve could be readily developed. The computer model was also used to predict test results. This was quite important during bench testing of the degrader systems and during initial ground and flight tests.

Once sufficient test data were obtained and appropriate modifications were included, the model could be used to enhance and broaden the usefulness of the available test data. For instance, the model and test data could be used to compute SFC (which could not be measured directly during the test program). Any missing or suspicious data could generally be calculated by the model with reasonable accuracy. A main thrust in the data analysis was to compare the performance of the No. 3 AMK engine with the reference No. 2 Jet A engine and to assess the difference caused by the operation of the degrader and the use of AMK. In a number of instances the computer model offered valuable insight into interpretation and comparison of the data from different series of tests. Figure 10 shows typical output from the CV880 computer model for takeoff,

CV880 AMK MODEL NO BLEED
CASE NO. 1

CONDITIONS AND ENGINE DATA

ALT	PO	TO	XMP	P2	T2	PCN2	XNC	PTX	TTX
FT	PSIA	DEG R		PSIA	DEG R	%	%	PSIA	DEG R
0.	14.70	518.7	0.	14.70	518.7	103.0	103.0	191.7	1224.2

PT5	T5	EGTC	P2QPO	WA	WB	WBR	WF	BPR4
PSIA	DEG R	DEG C	RATIO	PPS	PPS	RATIO	PPH	RATIO
41.1	1558.5	592.5	1.00	163.3	0.	0.	8677.	0.

FG	FR	FN	SFC
LBS	LBS	LBS	
11233.	0.	11233.	0.772

FUEL SYSTEM DATA

TEMPERATURES-DEG F

TTK	TF1	TF2	TF3	TF4	TF5	TF6	TF7	TF10	TF12
70.	70.	100.	158.	167.	137.	145.	169.	181.	195.

PRESSURES-PSIA

PO	PF1	PF3	PF4	PF4HX	PF5HX	PF5	PF7	PF10	PT3
15.	45.	1549.	275.	182.	178.	85.	105.	631.	192.

HEAT TRANSFER-BTU/MIN FUEL FLOW-PPM

QACB	QDEG	QAFHX	QFOHX	QMFP	QFOEHX	MFE	MF2	MFR
27.	6867.	1393.	367.	942.	1136.	144.6	233.9	89.3

ATM/DEGRADER LUBE SYSTEM

TEMPERATURES-DEG F HEAT TRANS-BTU/MIN LUBE FLOW RATE-PPM

TO1	TO2	TO3	TO4	QLP	MOD
216.	218.	180.	181.	13.	19.4

ENGINE LUBE SYSTEM

TEMPERATURES-DEGF LUBE FLOW-PPM

TO10	TO11	MOE
214.	245.	69.

ATM AIR

TEMPERATURES-DEG R PRESSURES-PSIA AIR FLOW-PPS

TBLD	TO	PBLD	PTIN	PO	WB
1224.	519.	191.7	74.7	14.7	2.4

FUEL/AIR HX INSTALLATION

TEMPERATURES-DEG F HEAT TRANSFER-BTU/MIN AIR FLOW-PPM;CFM

TA1	TA2	TA3	QMOT	QAFHX	MA1	CFA
59.	69.	154.	171.	1393.	68.	892.

SIGMA DELTA P-IN.H2O FAN-RPM (WINDMILL)

DPAHXCOR	DPFHC	FRPM
16.00	17.02	0.

PRESSURES-PSIA

PSD1	PSO3	PSFI	PSFO	PSHXO	PSD8	PO
14.696	14.640	14.640	15.254	14.696	14.696	14.696

DEGRADER DATA

SPEED-RPM HP (SHAFT) TORQUE (SHAFT)-FT*LBS FLOWS-GPM MASS FLOW/RHO

XND	SHPDEG	DEGT	QF2	QFE	MF2	DF2
31964.	193.	32.	35.8	21.5	233.9	48.9

THEO DPKE-PSID THEO DPKE/MF2-PSID/PPM

DPKE	XKE
1501.7	6.4

CV880 AMK MODEL WITH BLEED
CASE NO. 1

CONDITIONS AND ENGINE DATA

ALT	PO	TO	XMP	P2	T2	PCN2	XNC	PTX	TTX
FT	PSIA	DEG R		PSIA	DEG R	%	%	PSIA	DEG R
0.	14.70	518.7	0.	14.70	518.7	103.0	103.0	191.7	1224.2

PT5	T5	EGTC	P2QPO	WA	WB	WBR	WF	BPR4
PSIA	DEG R	DEG C	RATIO	PPS	PPS	RATIO	PPH	RATIO
41.1	1579.1	603.9	1.00	163.6	2.4	0.015	8825.	0.995

FG	FR	FN	SFC
LBS	LBS	LBS	
11137.	0.	11137.	0.792

FIGURE 10. TYPICAL CV880 COMPUTER MODEL OUTPUT

standard-day conditions. Reference 6 presents results from a total of 22 different conditions within the flight envelope of the CV880.

DEGRADER SYSTEM DESIGN INTEGRATION. Data obtained during the proof-of-concept testing was used to integrate the degrader system into the flight-test aircraft. The goal was to produce an installation that could perform the tasks of the program with a minimum effect on aircraft and engine performance.

Figure 5, shown earlier, contains a family of curves which relate the required speed of the pump/degrader, at a given flow, that is necessary to produce the required filter ratio of 1.2. To incorporate the degrader into an aircraft fuel system, the power input to the pump/degrader and the corresponding fuel temperature rise downstream of the degrader had to be addressed. There were two related areas of concern: (1) engine fuel inlet temperature and (2) engine oil-cooler fuel discharge temperature (see Figure 11).

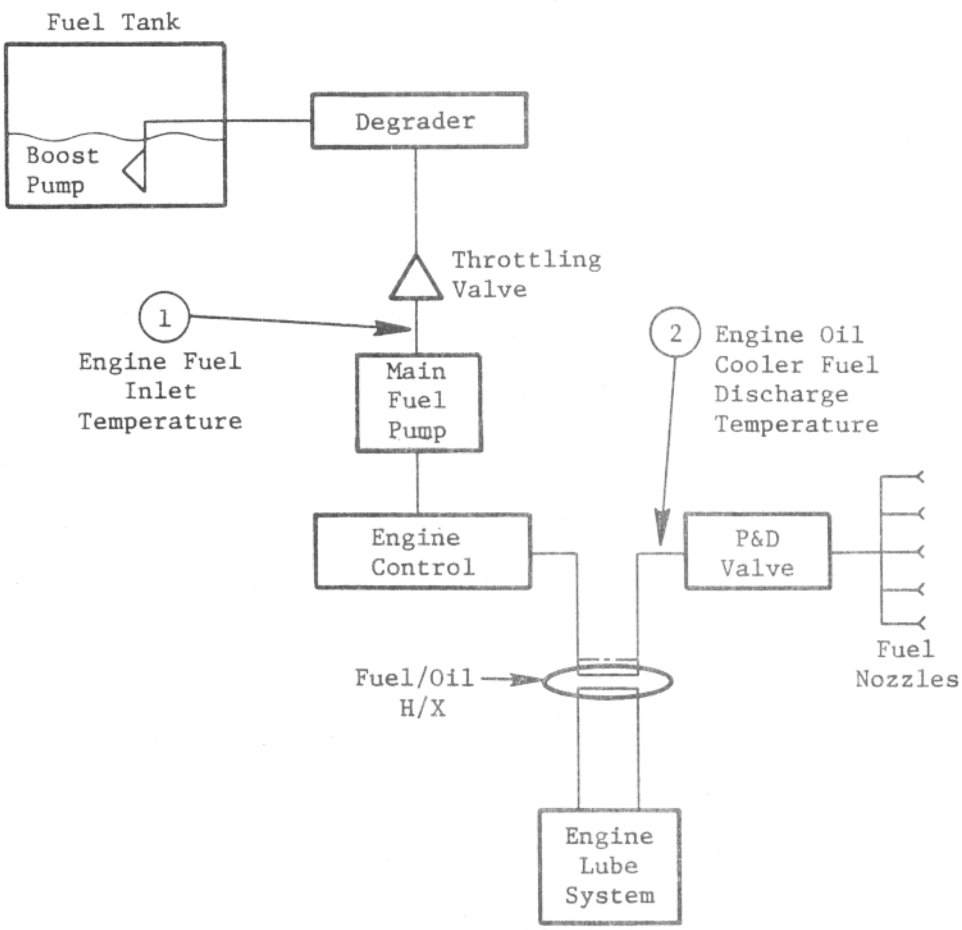

FIGURE 11. SIMPLIFIED DEGRADER INSTALLATION SCHEMATIC

Engine fuel inlet temperatures reach a maximum of 120° F in commercial aircraft. For military applications, engine fuel inlet temperature may be as high as 210° F. The fuel system of the CJ805 engine installed on the CV880 is similar to that of the J79 engine. Known fuel inlet temperatures on the J79/F-4 aircraft are as high as 160° F. Consequently, 160° F was established as a maximum for the engine fuel inlet temperature for this program. The CJ805 engine oil cooler incorporates a thermal valve that senses fuel temperature at the discharge of the oil-to-fuel heat exchanger. Between 241° and 255° F, this thermal valve will bypass scavenge oil around the cooler. Fuel and oil cooling were of primary concern during ground static operation because of the potential of relatively high air temperatures.

A nominal 60° F fuel-loading temperature at standard conditions was assumed. The AMK program computer model then considered extreme conditions of component performance characteristics without the degrader installed. The heat rise in the system due to the CJ805 fuel pump and lube system was calculated based on existing engine data. The results indicated that a 160° F engine fuel inlet temperature would not cause any difficulty in either the combustion system or the lubrication system. However, with the degrader installed, there was some concern that the fuel inlet temperature could be held below 160° F. Simply stated, the input power to the degrader, at a higher tank temperature with low fuel flow, might lead to a degrader discharge (engine inlet) temperature hotter than 160° F.

Knowing the desired filter ratio, degrader speed, and engine fuel inlet temperature limits, it was possible to determine the degrader input power envelope in Figure 12. The figure shows typical aircraft operating points corresponding to the engine flight envelope shown in Figure 13. Referring first to Figure 13, limits of standard-day fuel flow and engine speed were established over the range from initiation of ground start to maximum takeoff power. Also shown, for altitudes up to 35,000 feet, are the minimum (emergency) idle flow of 500 pph and the limit of maximum corrected engine speed (105 percent).

Referring to Figure 12, it can be noted that there are two upper bounds on degrader power and speed. The computer model of the degrader as installed on the CJ805 engine indicated that during engine start, with the degrader running at 20,000 rpm, engine fuel inlet temperature could exceed 160° F transiently. To obviate this possibility, a fuel-to-air heat exchanger was added with an electric-motor-driven fan to cool the fuel at certain operating conditions. If fuel temperature increased (above 160° F), the cooling performance of the additional fuel/air cooler would also increase. In addition, the thermal capacity of the engine lube system would tend to cool the fuel (through the fuel/oil cooler) and avoid any downstream fuel system problems. At altitude, the combination of ram air pressure and colder ambient temperatures would improve the performance of the fuel/oil cooler.

As shown in Figure 12, with the addition of the fuel-to-air heat exchanger, the degrader could operate between the limits of the upper curve (air-cooled fuel) and the lower curve which was set by a required filter ratio of 1.2. Figure 14 shows the fuel-temperature margin that existed in the CJ805 engine with the additional fuel-to-air cooler installed.

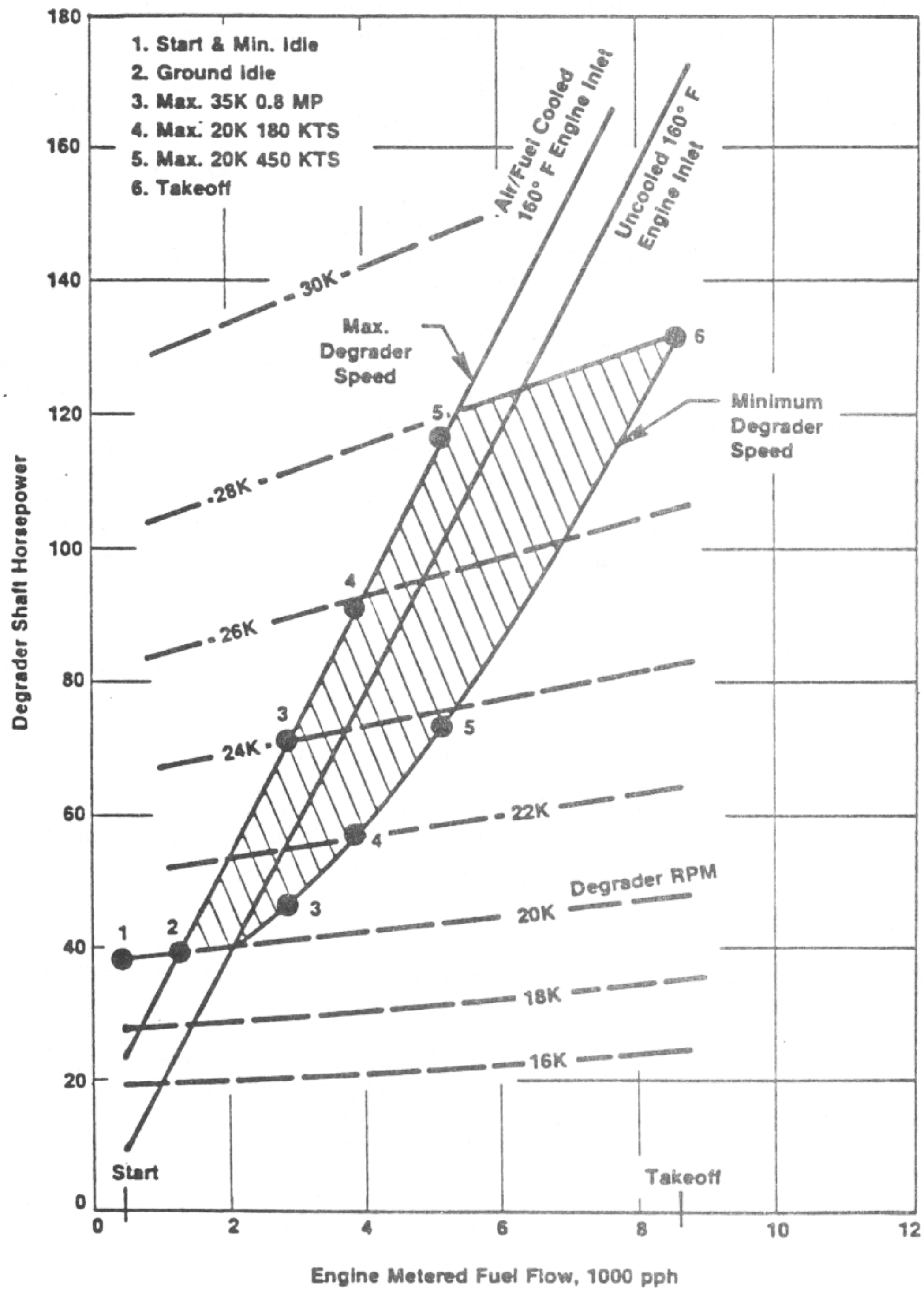

FIGURE 12. CJ805 DEGRADER SPEED SCHEDULE RELATIONSHIP TO FLOW AND POWER

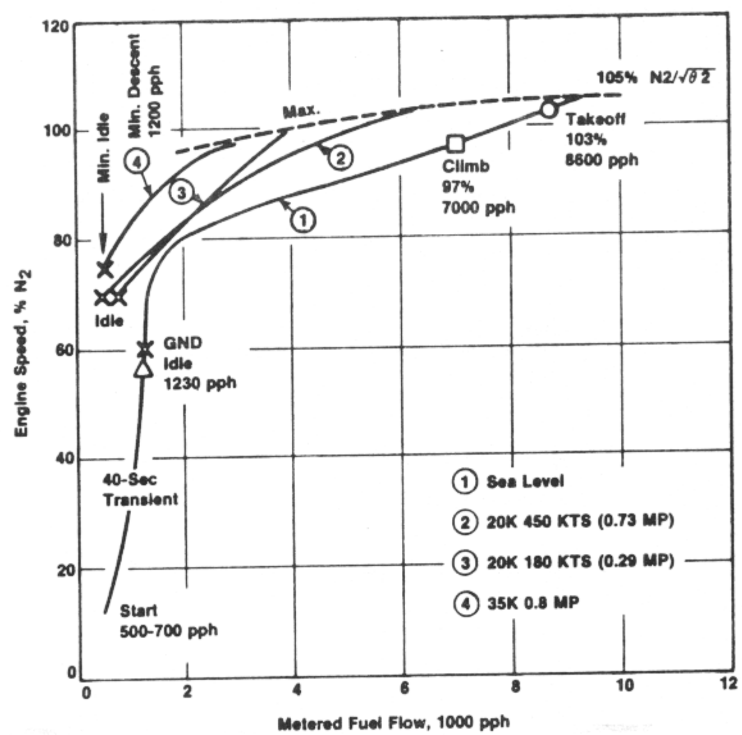

FIGURE 13. CJ805 ENGINE UNCORRECTED SPEED VERSUS FUEL FLOW - STANDARD DAY

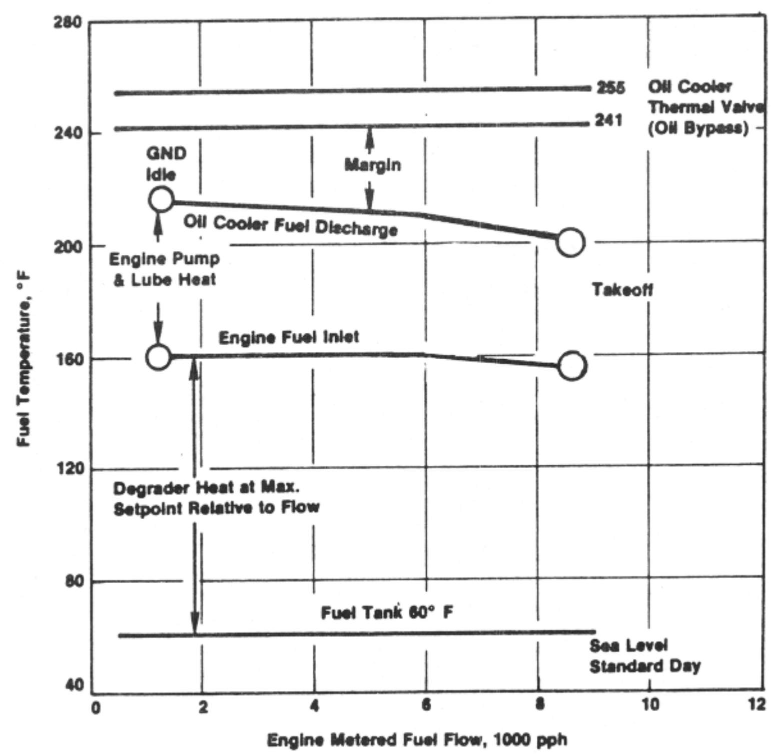

FIGURE 14. FUEL TEMPERATURE LIMITS

Additional details concerning the modeled temperatures are shown in Table 2. The pump power curves used to develop the data in Table 2 have been adjusted upward by 13.3 percent, from standard F101 augmentor pump performance curves, to reflect the influence of the recirculation channels added to the diffuser (No. 3) used in the flight test program.

INSTALLATION DESIGN. The installation of the components is discussed in the next section. It should be noted that the choice of the degrader components was influenced by the available space on the CV880 and B720 aircraft. On the CV880, the goal was to install the degrader with a minimum of modifications to the external cowling of the engine. Mounting brackets had to be designed to facilitate this installation, and the existing fuel and pneumatic supply lines were modified. Due to the limited capability of changing the configuration of much of the hardware, some compromises were necessary.

TABLE 2. CJ805 DEGRADER TEMPERATURE RISE (TYPICAL VALUES)

	Standard Day					
	Sea Level, Static				20,000 Feet 450 knots	
Parameter	Idle	Cruise	Climb	Takeoff	Minimum	Maximum
% N_2	60	80	97	103	80.4	100
% $N_2/\sqrt{\theta_2}$	60	80	97	103	82.3	102
WF, pph	1233	1970	7000	8600	1200	5162
WF, gpm	3.08	4.92	17.5	21.5	3.0	12.9
Recirculation, gpm	5.0	5.7	7.1	7.1	5.0	7.0
Pump Flow, gpm	8.08	10.6	24.6	28.6	8.0	19.9
Pump Speed, rpm (1000's)	20	22	28	28	20	28
Pump ΔP, psid	587	773	1175	1175	587	1138
% Design-Point Flow	4.8	5.7	10.4	12.1	4.7	8.5
Pump Shaft Power, hp	39	53	126	132	39	116
Pump Heat Flux, Btu/min	1655	2249	5347	5602	1655	4923
Fuel Cooling, Btu/min	637	637	0	0	637	637
Fuel Tank Temperature, °F	60	60	60	60	60	60
Pump Inlet Temperature, °F	95	91	84	77	95	85
Heat Exchanger Discharge, °F	118	118	143	129	156	152
Pump Discharge Temperature, °F	156	152	143	129	156	152
Engine Inlet Temperature, °F	160	160	152	138	160	160

III. DEGRADER SYSTEM COMPONENTS AND AIRCRAFT INSTALLATION

COMPONENT DESCRIPTION

The five pump/degrader systems produced for this program were fabricated by Garrett Pneumatic Systems Division of Phoenix, Arizona to General Electric's specifications (Reference 7). One degrader system was installed on a CV880 for testing and evaluation, and four additional systems were installed on the B720 CID test vehicle. The components of the CV880 and B720 systems were virtually identical. Only minor changes were necessary to accommodate the different installation configurations of the CV880 and B720. The degrader system comprised the following major subassemblies:

- ATMP80-1 Pump/Degrader Assembly - Air Turbine Motor Drive Unit
  - Centrifugal Pump/Degrader
- Drive Air System - Pressure Regulating and Shutoff Valve
  - Shutoff Valve
- Lubrication System - Electrically Driven Lube Pump Motor
  - Oil/Fuel Heat Exchanger
- Fuel-Cooling Bypass System - Fuel/Air Heat Exchanger
  - Electrically Driven Fan
- Electronic Control Panel
- Fuel Pressure Throttling Valve (The throttling valve was supplied directly to Garrett by GE with all modifications and calibrations completed for use in the degrader system).

ATMP80-1 PUMP/DEGRADER ASSEMBLY. A cross section of the degrader assembly, designated model ATMP80-1 by Garrett, is shown in Figure 15. A photograph of the component is shown in Figure 16. This degrader assembly consisted of the air-turbine motor drive and the centrifugal pump/degrader. All of the other subassemblies listed above were quite necessary for the operation of the degrader but were peripheral to the actual function of fuel degradation that was performed by the degrader assembly.

Air Turbine Motor Drive. The air-turbine drive was close-coupled to the pump/degrader. It was derived from the Garrett Model ATM80-4 air-turbine motor used in the C-5A military transport aircraft. The air-turbine drive included the turbine air inlet scroll, the variable-area nozzle assembly, and the turbine wheel assembly.

The inlet scroll received bleed air at a regulated pressure from the inlet valve. The scroll was designed to allow an equal pressure distribution at the inlet to the variable-area nozzles. The scroll was a brazed and welded 347 stainless steel sheet-metal-and-casting fabrication. The inner shroud of the

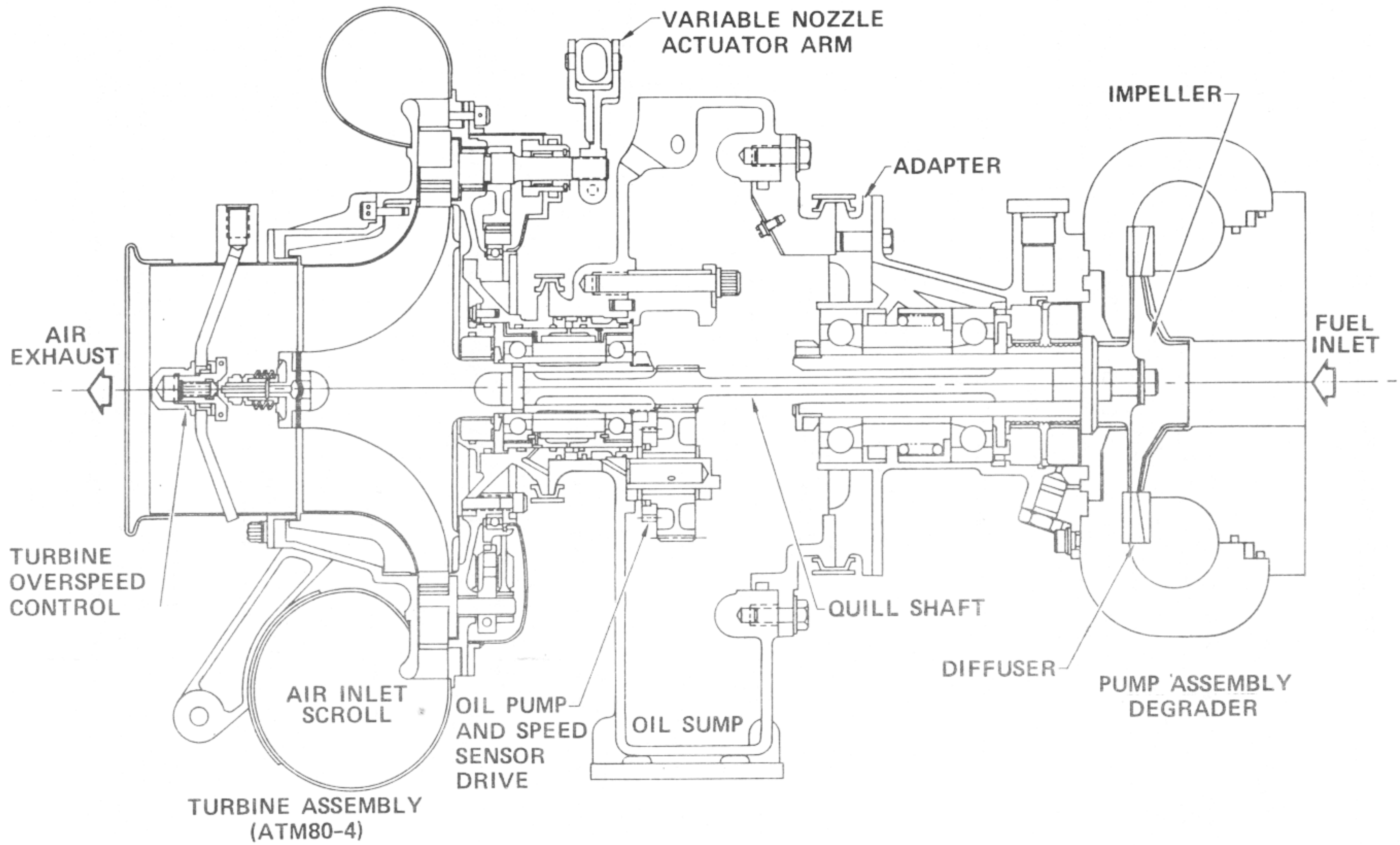

FIGURE 15. CROSS SECTION OF DEGRADER ASSEMBLY ATMP80-1

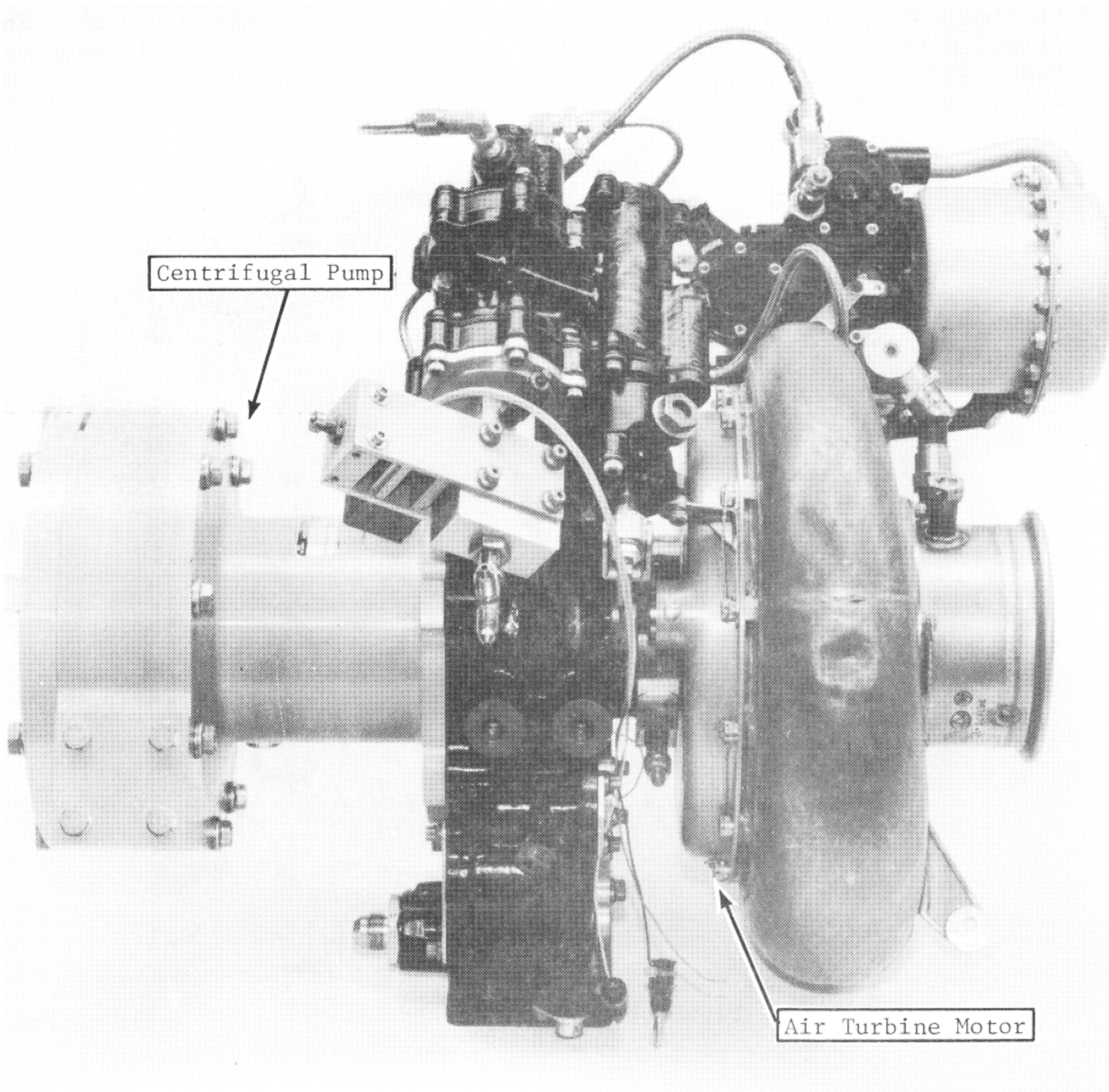

FIGURE 16. ATMP80-1 PUMP/DEGRADER ASSEMBLY

scroll was a mechanically retained, machined titanium forging. This inner shroud was the containment ring for the turbine wheel; it was designed to contain the rotor in the radial direction in the event of a turbine burst.

The variable-area nozzle, Figure 17, eliminated throttling and overexpansion losses and resulted in near-optimum efficiency of the turbine over a broad range of operating conditions. The 17-4 PH CRES nozzle vanes were supported on sleeve bearings and designed to be aerodynamically loaded to close. Therefore, in the event of failure of the servoactuator or linkage between nozzle vanes and servoactuator, the nozzles would close, and the air-turbine motor would shut down.

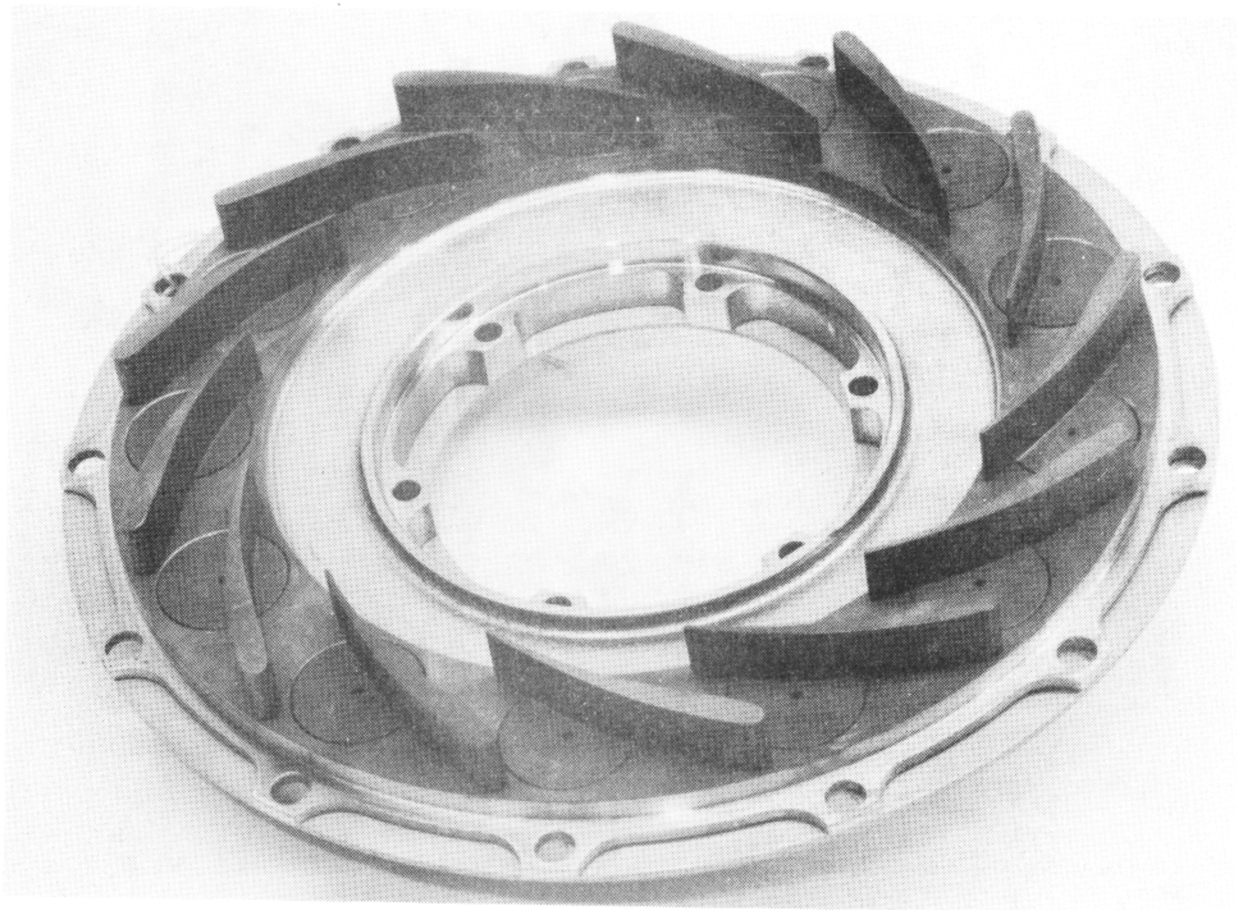

FIGURE 17. VARIABLE-AREA NOZZLE

The turbine wheel was a one-piece, radial-in-flow unit with integral, exducer-type blades. The 5.75-inch turbine wheel was manufactured from a titanium forging and was supported by an integral shaft mounted within two resiliently mounted ball bearings.

Speed control of the air-turbine motor was effected by means of the variable-area nozzles in the turbine assembly. The turbine nozzles were positioned by means of a slide-type, electropneumatic hydraulic servovalve and actuator that responded to signals from the electronic speed controller. The slide valve modulated the hydraulic pressure appropriately on either side of the actuator piston. The hydraulic servovalve and actuator components were integral to the air-turbine drive.

The electronic controller responded to a signal from a gear and a stationary monopole pickup held by a web in the turbine discharge duct. In the event of turbine overspeed, the electrical speed signal would cause the degrader speed controller to signal the turbine nozzle and both air-shutoff valves to the closed positions.

Centrifugal Pump/Degrader. The pump/degrader subassembly included the impeller, diffuser, housings, shafts, seals, bearings, oil lubrication system, and mounting points (Figure 18). Oil at 45 psid provided bearing and spline lubrication. Oil drained from the drive end of the pump assembly into the oil sump. The quill shaft from the turbine drive interfaced with the ID spline in the pump shaft; both splines were oil-jet lubricated.

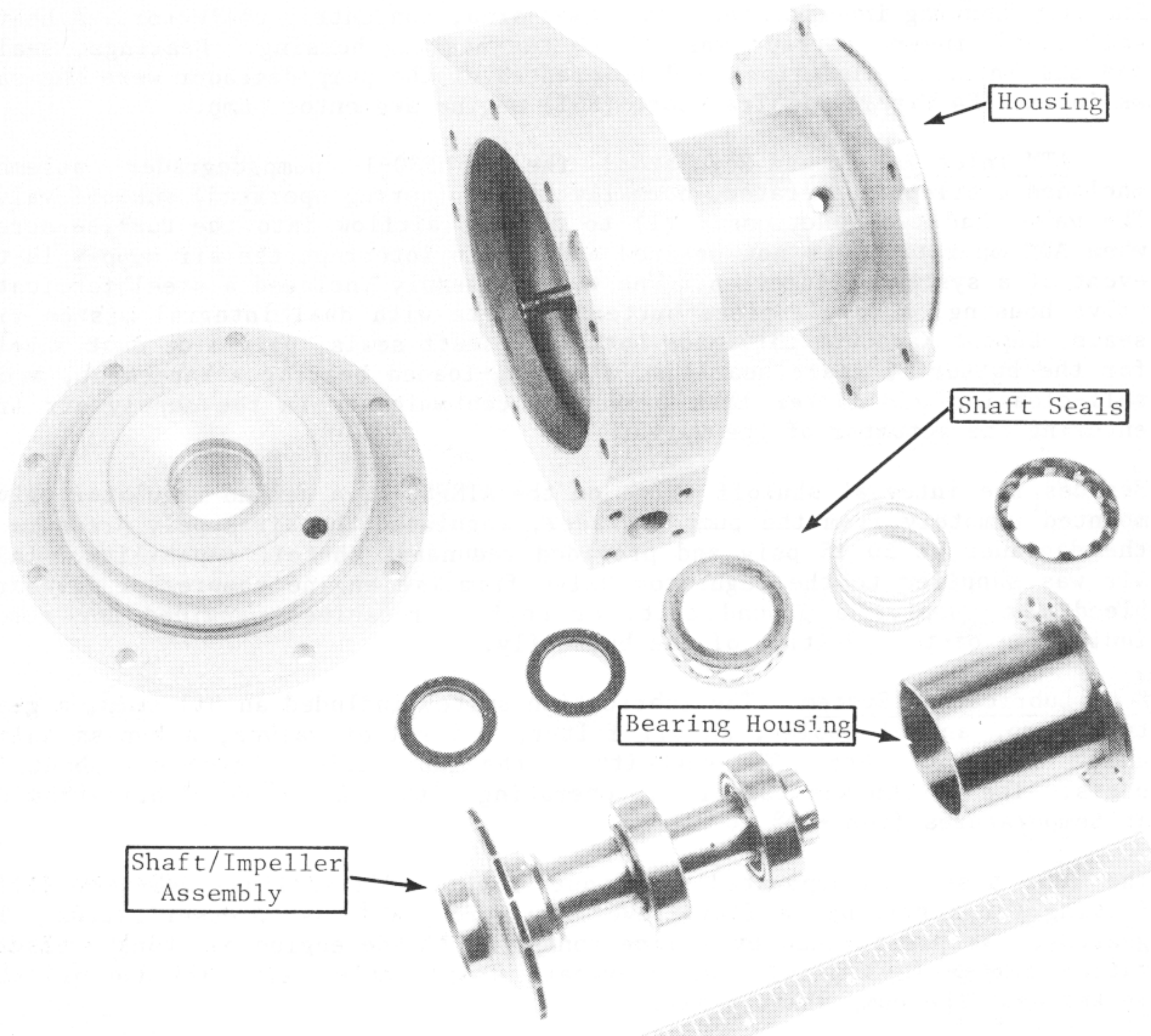

FIGURE 18. CENTRIFUGAL PUMP/DEGRADER COMPONENTS

The impeller was identical to that used on the General Electric F101 augmentor fuel pump and was a stainless steel brazed assembly. The impeller design had been tested previously in the initial proof-of-concept laboratory tests of the pump/degrader. Additionally, a modified interchangeable design was available during system bench tests to assess enhancement of degrading characteristics with an alternate impeller design.

Two sets (five parts per set) of anodized aluminum diffusers were designed and manufactured. The first set was identical to the recirculation channel design used during the previous degrader proof-of-concept program. The second set included refinements aimed at enhancing degrading and was interchangeable with the first set.

The pump case and the bearing housing were fabricated from aluminum barstock. The pump housing incorporated a constant-area, concentric collector. A heavy-wall steel insert carrier was fit to the bearing housing. Bearings, seals, and all internal dimensions and tolerances of the pump/degrader were the same as in the GE4 Supersonic Transport (SST) engine augmentor pump.

ATM Inlet Valves and Regulator. The ATMP80-1 pump/degrader assembly included a solenoid-operated, normally closed (spring operated) shutoff valve. The valve had two functions: (1) to prevent airflow into the turbine scroll when ATM operation was not desired and (2) to interrupt the air supply in the event of a system malfunction. The valve assembly included a steel fabricated valve housing, a single-piece butterfly plate with dual integral piston ring seals, Dupont Kaptontm polyimide butterfly shaft seals, polyimide dust shields for the butterfly shaft bearings, a spring-loaded bearing arrangement, and a self-cleaning air filter that prevented contaminants in the supply air from entering the actuator of the valve.

Besides the integral shutoff valve on the ATMP80-1, a second regulator valve, mounted remotely from the pump/degrader, regulated the air-supply pressure to the degrader at 50 ±5 psig and provided redundant shutoff capability. Inlet air was supplied to the regulator valve from the engine compressor discharge bleed air supply, a ground cart, or engine crossbleed provided for remote indication of the position of the butterfly.

Lubrication System. The lubrication system included an oil sump, a gear-type pump, an oil cooler, an oil filter, two relief valves, a bypass valve, and a series of jets. The capacity of the lubrication system was about 1.5 pints. The system was capable of operating with MIL-L-23699 lubricating oil at temperatures from -40° to 250° F.

The lube system incorporated a pressure-tight, self-sealing, QAD-type filler fitting for servicing, a fluid-level dip stick, and case pressurization. The gearcase was pressurized by a line connected to the engine oil tank pressurization system (2-3 psig). An overboard drain vented any fuel and oil that leaked past the pump shaft seals.

The oil-recirculating gear pump was driven by a 28-V d.c. electric motor. Oil was discharged from the pump to the filter and cooler and then to oil jets for bearing and shaft spline lubrication. Oil was also supplied to the hydraulic nozzle actuator. The pump provided approximately 2.75-gpm flow at 160 psid. The lubricating oil was cooled by an oil/fuel heat exchanger that was a welded and brazed aluminum assembly. Necessary ports and bosses were incorporated for directing fluid through the cooler core and mounting the heat exchanger to the engine. The oil cooler and the recirculating pump were both mounted separately from the pump/degrader assembly.

Fuel-Cooling Bypass System. As discussed in Section II, the AMK computer model indicated that long-duration ground operation of the degrader with high ambient air temperatures might lead to unacceptable fuel inlet temperatures. To add more flexibility and safety margin to both the CV880 and CID programs, a provision was made to recirculate and cool the degraded fuel. The cooling system consisted of an air/fuel heat exchanger and a fan.

The heat exchanger was similar to the Garrett AiResearch air/air precooler used on the Boeing 727-200. The bleed-air manifold of the precooler was modified to accommodate fuel rather than air, and the tube sheet thickness of the core was increased. The manifolds and ducting for the cooling-air stream and all mounting brackets were not changed.

The unit was a plate-fin heat exchanger constructed of stainless steel with nickel fins. The configuration was a folded-crossflow arrangement with the fuel making four passes through the core and the ram/fan air making a single pass. The tube sheets, hot and cold fins, and solid passage-closure bars formed an integral, brazed assembly. The manifolds and the mounting structure were all attached by welding.

The function of the fan was to provide cooling air to the fuel/air heat exchanger when ram air was not available. Each fan impeller blade was twisted from hub to tip for uniform loading in the radial direction. Deswirl vanes were located downstream of the impeller. The deswirl vanes supported the fan motor and provided extended surfaces for motor cooling. Downstream of the deswirl vanes was a tail cone to diffuse the airflow. The central body for mounting the motor and the deswirl vanes was a one-piece, aluminum casting fitted into an aluminum outer housing. The impeller was an aluminum die casting.

The fan motor was a three-phase, 400-Hz, 115/200-V a.c., "squirrel cage," induction type and was designed for continuous operation at approximately 12,000 rpm. The motor stator was constructed of steel laminations wound with copper wire with high-temperature insulation, vacuum-impreganted for maximum dielectric resistance. The electrical rotor was constructed of steel laminations with cast aluminum end rings and conductor bars. The rotor was mounted on a steel shaft.

Fuel Pressure Throttling Valve. Since the degrader/pump was capable of producing discharge flows in excess of 1500 psid, a throttling valve was necessary to reduce the pressure to a level typical of normal engine operating conditions. The engine fuel pump was not designed for excessively high inlet pressures, and the engine fuel control related functionally and structurally to the level of inlet fuel pressure. The fuel throttling valve used in the AMK program was two modified GE F404 augmentor throttling valves functioning in series as primary and secondary stages. Modification, fabrication, and calibration of the AMK throttling valves were performed by General Electric.

The valves closed under a spring force of approximately 25 pounds (equivalent to 25-psid differential pressure). This assured that undegraded AMK could not migrate into the fuel system once the degrader was shut down. The dual-valve redundancy also gave an added margin of safety in the event one of the valves stuck open at high-flow and high-pressure operation. Extremely high inlet pressures at the engine could have catastrophic effects.

The primary valve was calibrated for a 40-psid increase relative to engine fuel supply pressure, and the secondary valve was calibrated to 50 psid. The reference pressure was the discharge of the fuel tank boost pumps; therefore, with the degrader operating, the engine fuel pump would receive 40 psi higher pressure than in normal operation without the degrader. On the CJ805 engine, installed on the CV880, a peak of 85 psig was the expected maximum pressure in operation over the entire flight envelope of the aircraft. A maximum fuel inlet pressure of 85 psig presented no problems to either the CJ805 engine on the CV880 or the JT3C-7 engines on the B720 CID test vehicle.

The modifications to the F404 throttling valves were necessary to provide high flow gain for improved stability and erosion resistance. Special "holed" valve sleeves were developed to accomplish these goals. It was recognized that the throttling process might enhance degradation of the AMK fuel. This consideration was addressed in the design of the special sleeves and was evaluated in the bench and flight tests of the degrader.

Electronic Control Panel. Each degrader system included an electronic speed controller located in the aircraft cockpit. This electronic controller held the speed of the degrader at the set point by controlling inlet airflow to the turbine motor. A monopole indicated ATMP80-1 pump speed to the controller. The speed set point (18,000 to 32,000 rpm) could be selected by engaging contacts of an eight-position, rotary switch on the controller. The controller adjusted inlet airflow by actuating a torque motor that caused the hydraulic servo to position the vanes located in the ATMP80-1 air-turbine inlet. Speed-control tolerance was ±500 rpm. The controller also included a switch and appropriate electronic circuitry to permit the degrader to be operated in an automatic mode. For automatic-mode operation, the controller received a d.c. voltage signal proportional to engine fuel flow and set the speed from 20,000 to 32,000 rpm in response to this signal. A diagram of the controller features is shown in Figure 19.

DEGRADER SYSTEM AIRCRAFT INSTALLATION

DEGRADER SYSTEM FLIGHT TEST VEHICLE. The program required that the first of the five degrader systems be installed and evaluated on a representative commercial aircraft. General Electric chose a Convair 880 aircraft as the degrader flight test vehicle for the following reasons:

FIGURE 20. CV880 DEGRADER FLIGHT TEST VEHICLE

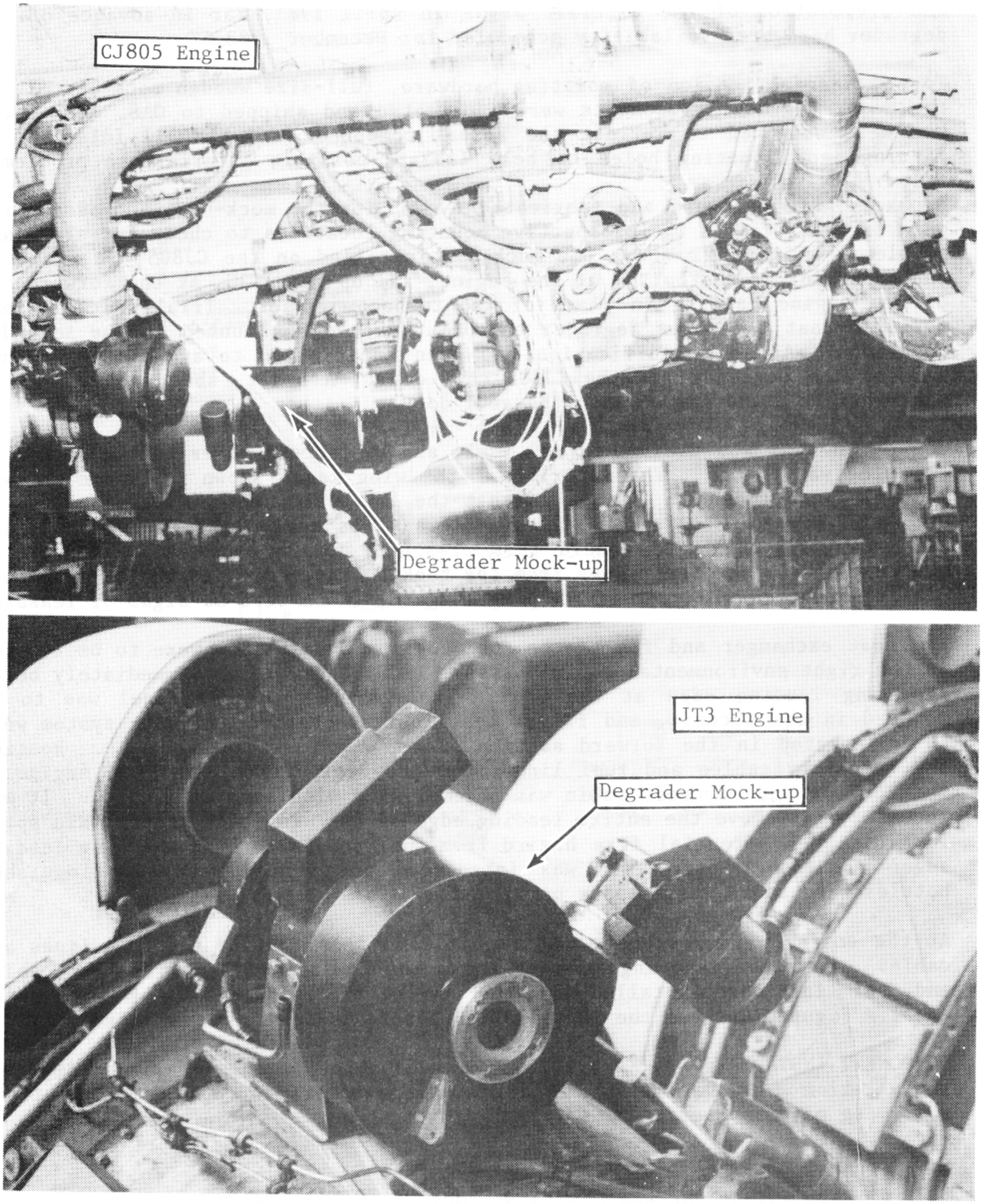

FIGURE 22. INSTALLATION OF DEGRADER MOCK-UPS

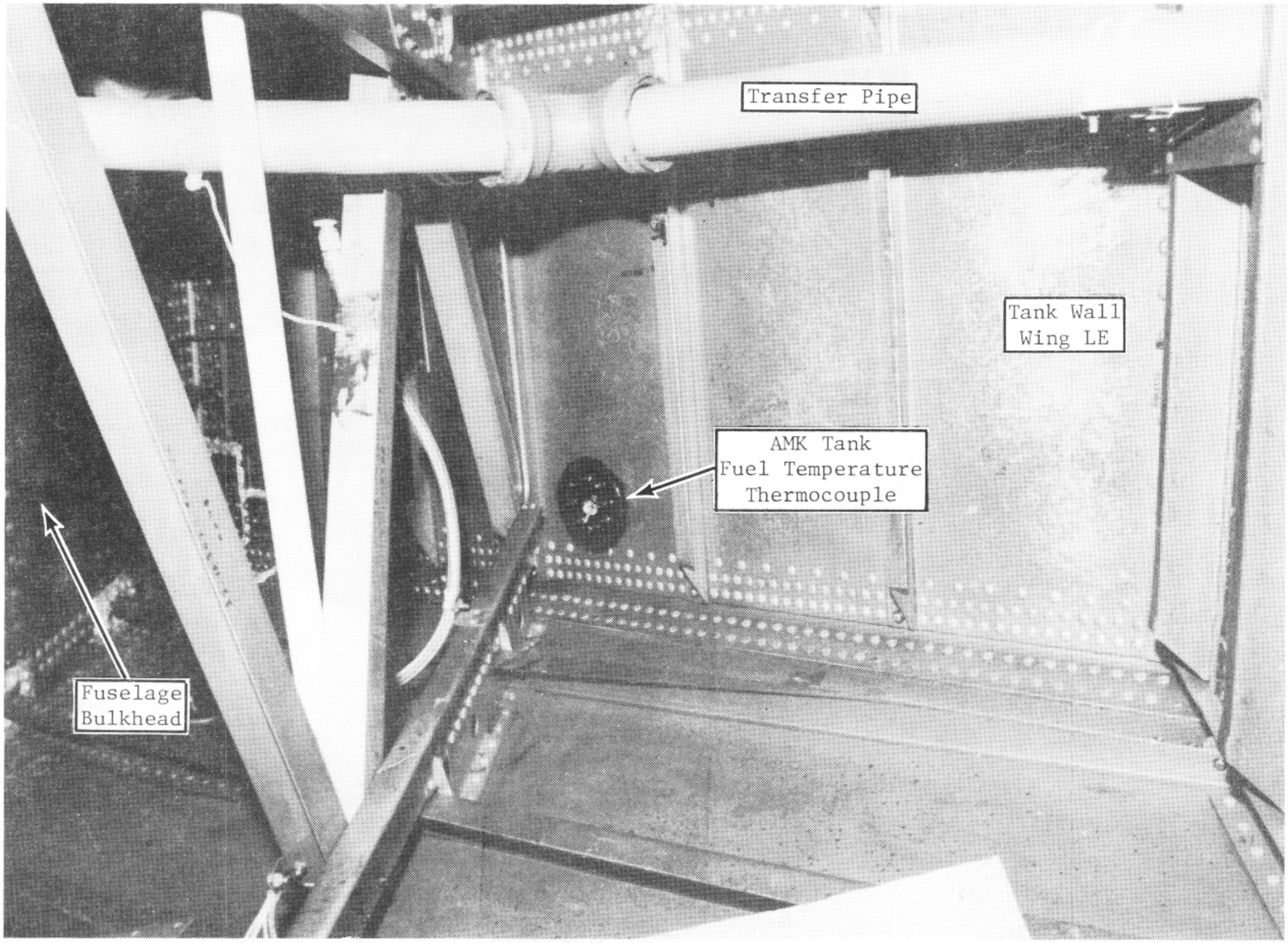

FIGURE 23. INTERIOR OF NUMBER 3 WING TANK

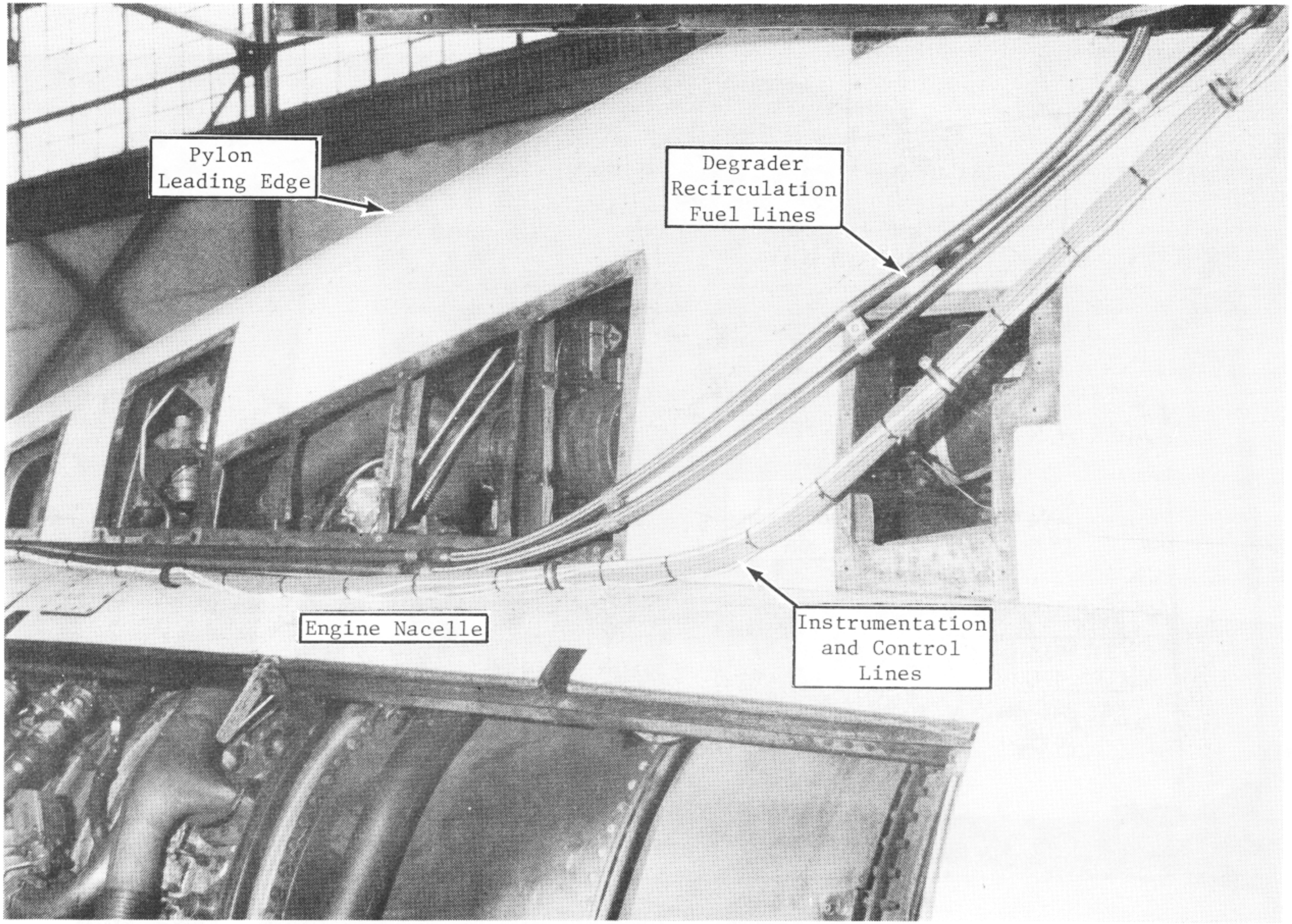

FIGURE 24. INSTALLATION OF CONTROL AND FUEL LINES, NO. 3 PYLON

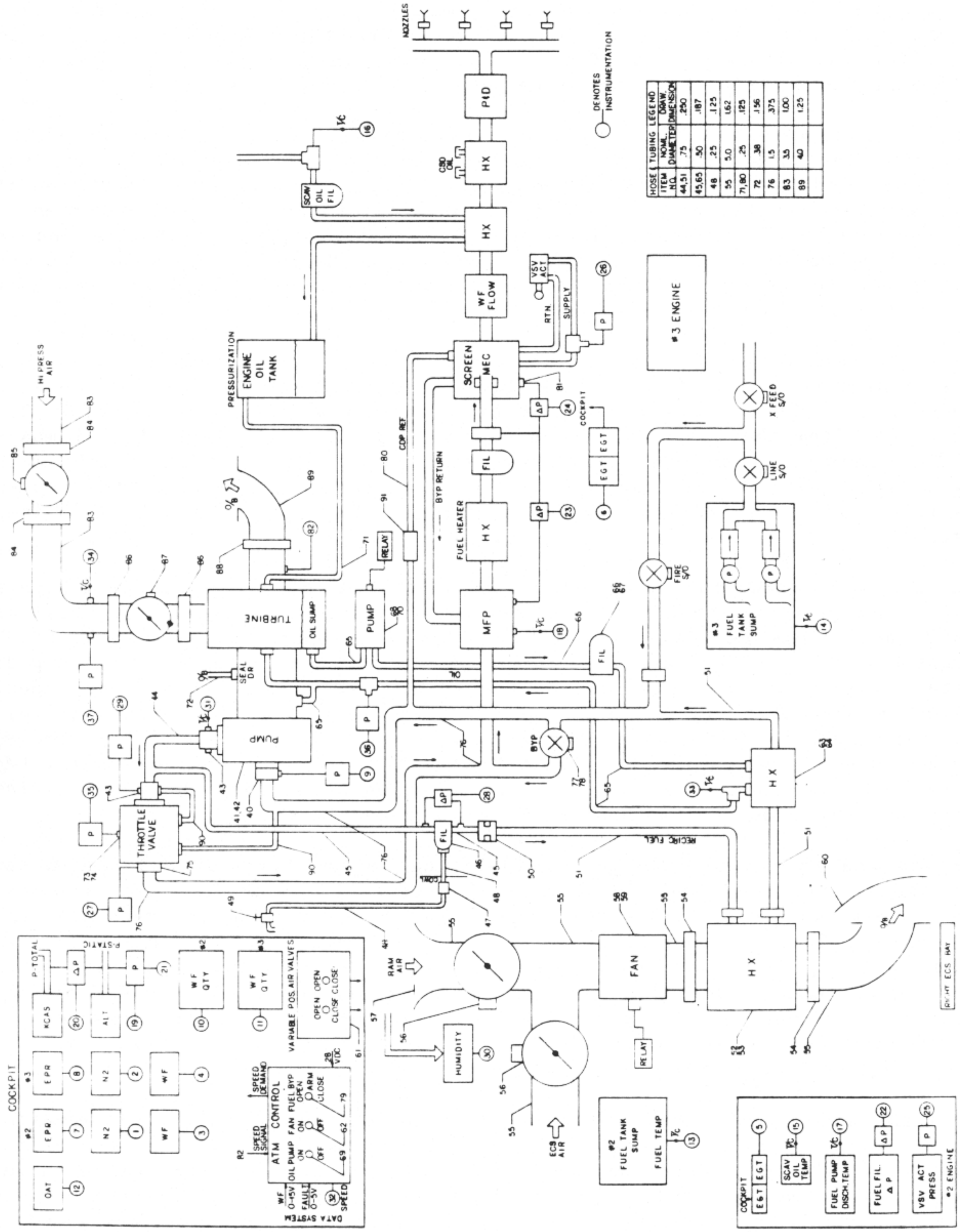

FIGURE 25. CV880 AMK INSTALLATION SCHEMATIC

The degrader lube system consisted of a pump, oil/fuel cooler, and a filter. It was located in the bottom forward section of the engine nacelle. Figure 26 shows the installation. The figure also shows where additional holes were opened in the cowling to provide more purge air for the engine cowl.

The left side of the CJ805 engine contains the main fuel pump and the engine control. For this reason, the fuel components of the degrader system were also installed on this side of the engine. Figure 27 shows an overall view of the left side of the engine and locates the major degrader fuel components. The fuel-supply line enters from the pylon at the top of the engine and is routed down the side of the compressor case to the degrader pump inlet out the bottom of the engine (Figure 28) or through a bypass around the degrader directly to the main fuel pump.

Figure 27 also shows the degrader discharge port. High-pressure degraded fuel flow from this port either to the throttling valve or to the fuel-cooling bypass loop. The inlet to the throttling valve can also be seen in Figure 27. The outlet from the valve is hidden somewhat in the photograph, but it makes a "T" connection with the degrader bypass circuit and then enters the main engine fuel pump. From this point, the remainder of the engine fuel system was unmodified (see Reference 6 for a complete description of the CJ805 fuel system).

Figure 27 also shows the "sampler" filter installed in the fuel cooling bypass loop. The purpose of the sampler filter (see Figure 29) was to provide an easily accessible device to monitor any gelling tendencies of degraded AMK downstream of the degrader. A 40-μm screen was selected for the sampler filter element as an equivalent to the servo wash-screen filter, the finest filter in the CJ805 engine fuel system. Downstream from the sampler filter, the high-pressure fuel passed through an orifice that substantially reduced the pressure. The piping then exited at the top of the engine through the nacelle. From there it was routed up the pylon and across the wing leading edge (see Figure 30) to the heat exchanger located in the ECS bay.

The fan and the heat exchanger installation in the aircraft ECS cooled the fuel during extended ground operation at high ambient and fuel temperatures. Figure 31 shows a drain valve that was an additional feature incorporated into the cooling loop. This drain valve permitted samples of degraded AMK to be taken on the ground, with the engine and degrader operating, without opening the engine cowls. The valve was operated by reaching inside the ECS bay air inlet scoop (Figure 32). After the fuel passed through the heat exchanger, it returned to the engine via the wing leading edge and reconnected with the fuel system supply line at the base of the engine pylon.

The right side of the engine, shown in Figure 33, was chosen for the mounting of the degrader pneumatic-supply piping. The pneumatic supply for the engine starter was already located on the right side, away from all the fuel-handling components on the left side. (Degrader pneumatic supply inlet temperature can approach 750° F at takeoff conditions.) An additional cowl vent was added in the vicinity of the degrader to enhance flow of the increased cowl-purge air around the degrader and the supply piping.

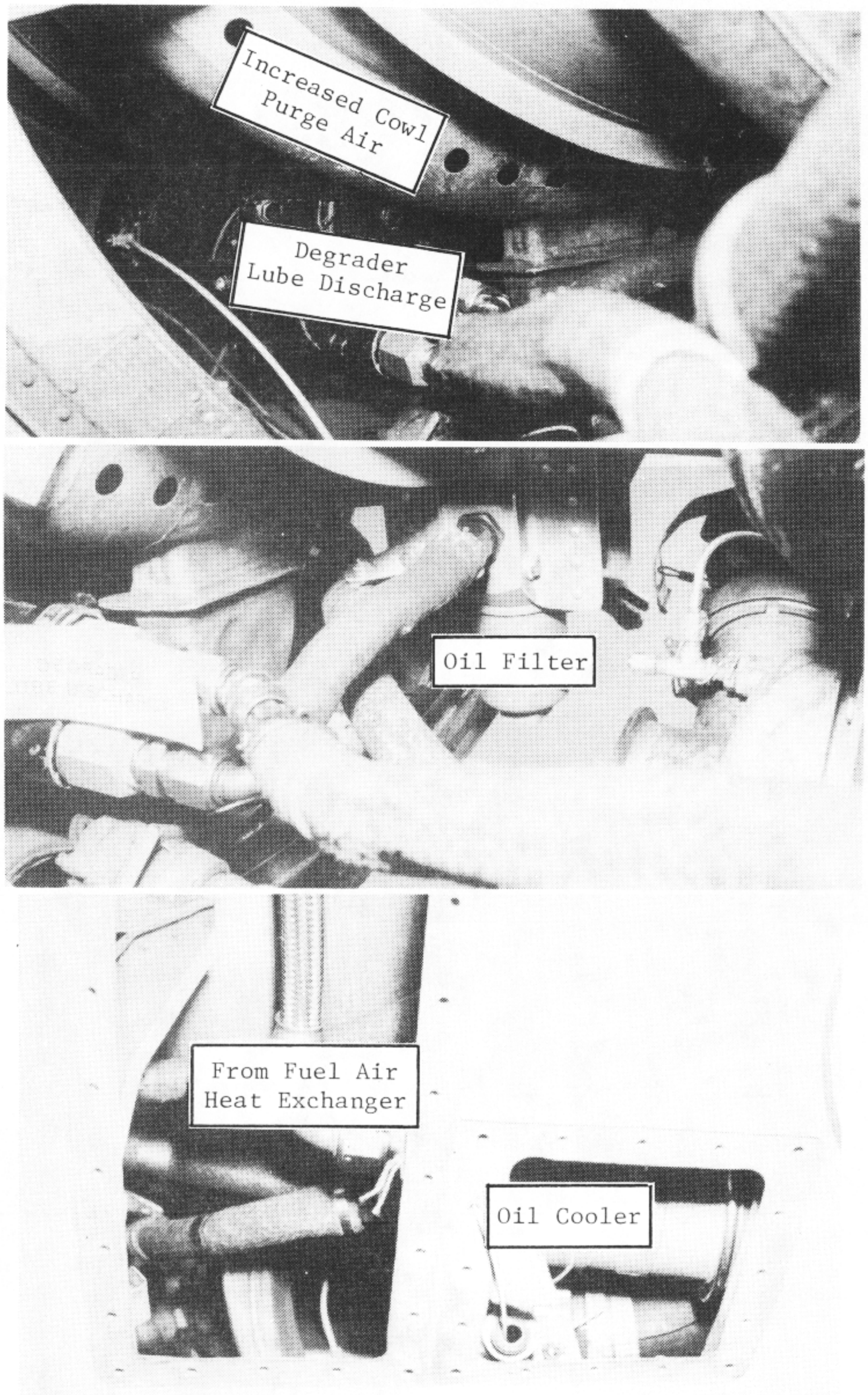

FIGURE 26. LUBE SYSTEM COMPONENTS

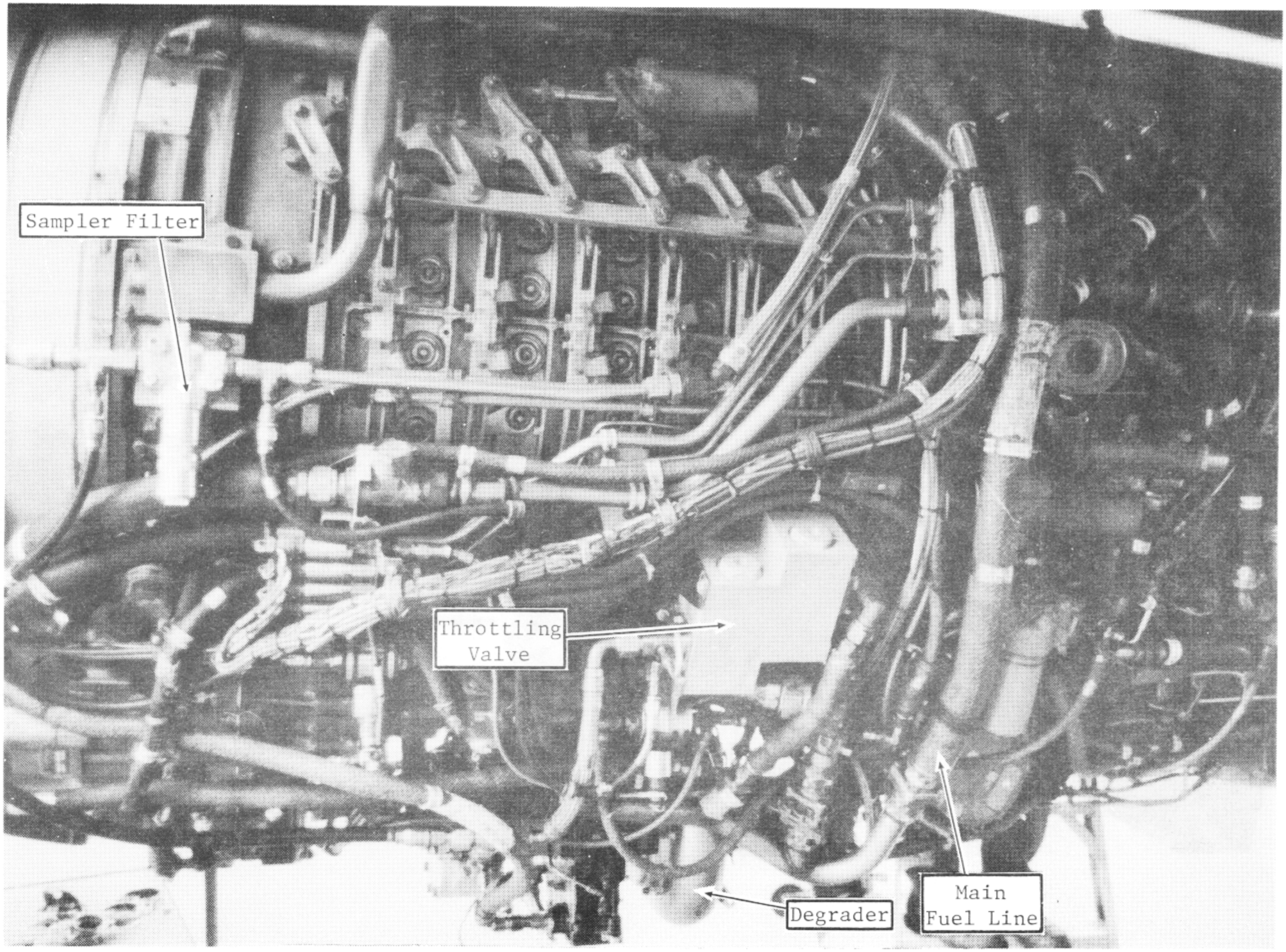

FIGURE 27. OVERALL VIEW LEFT SIDE OF NUMBER 3 ENGINE

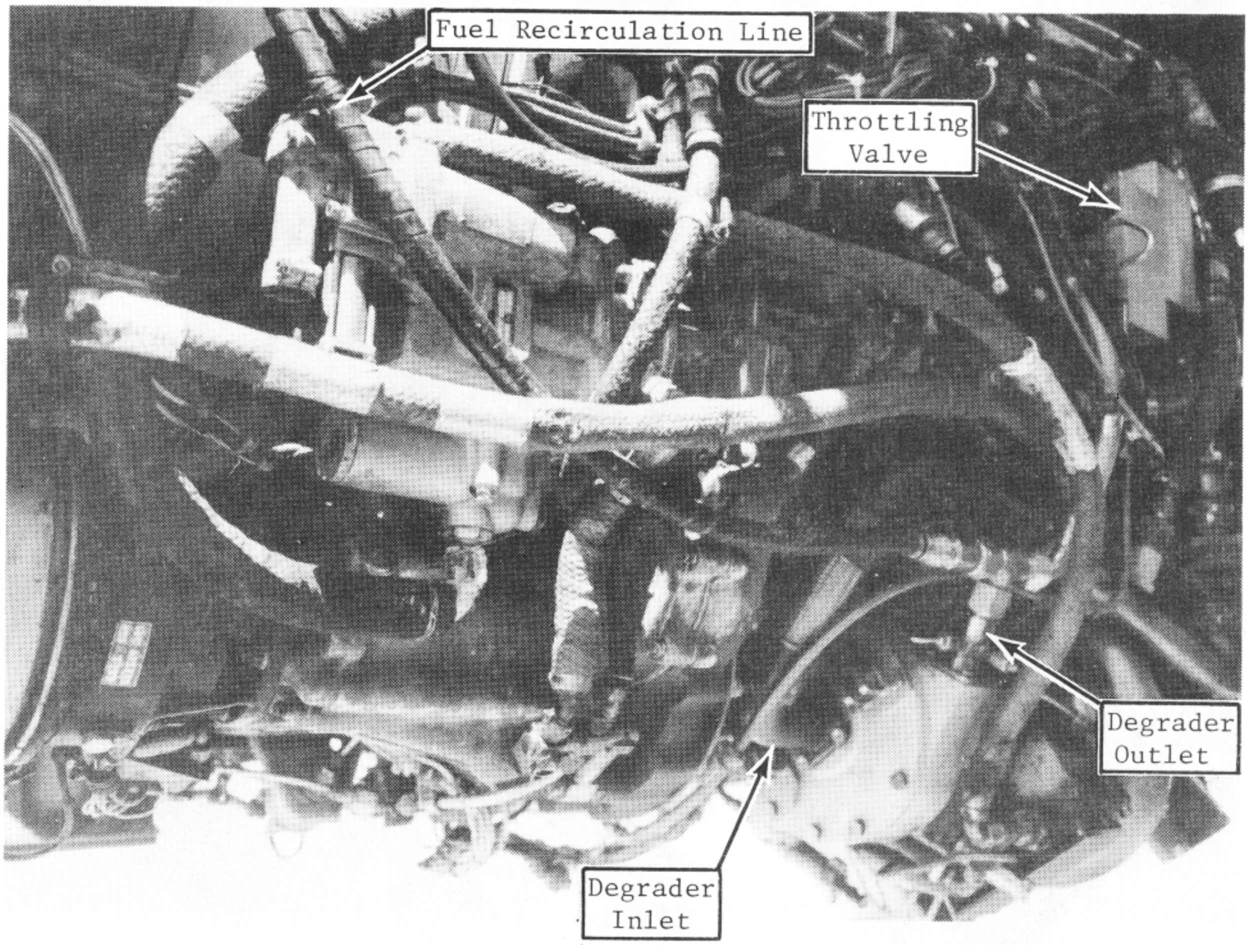

FIGURE 28. DEGRADER INLET AND OUTLET

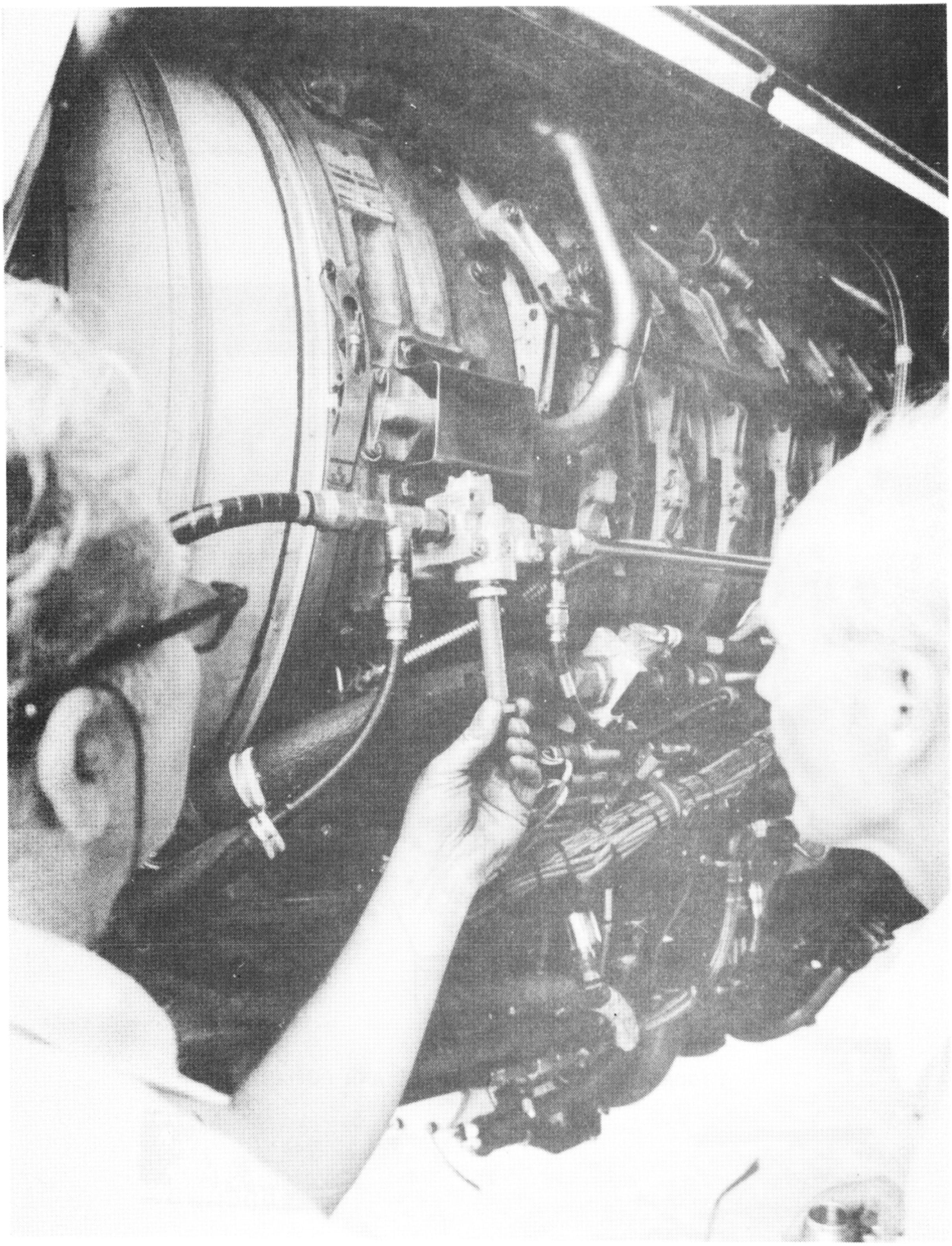

FIGURE 29. SAMPLER FILTER

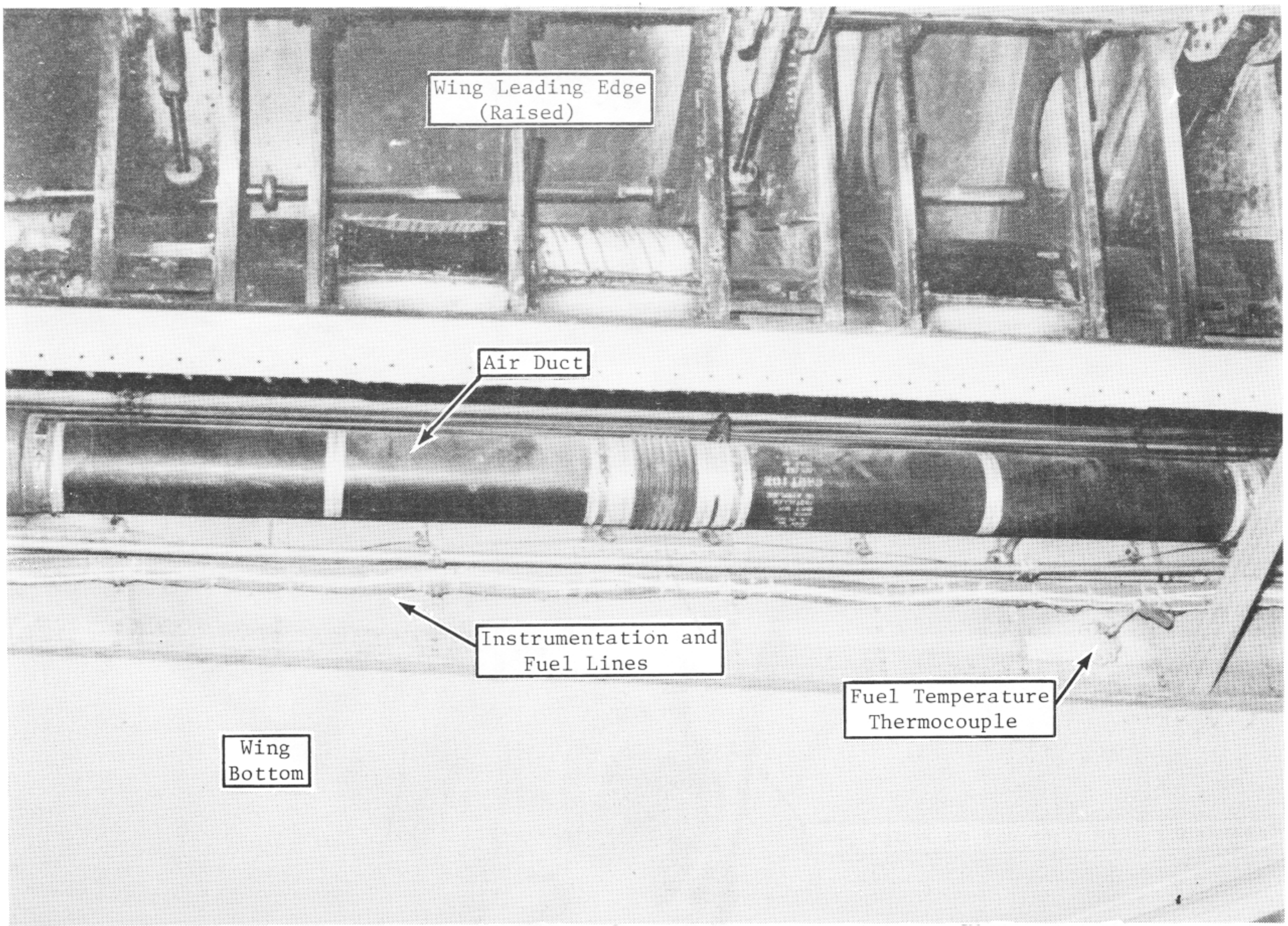

FIGURE 30. ROUTING OF INSTRUMENTATION AND FUEL LINES WITHIN WING LEADING EDGE

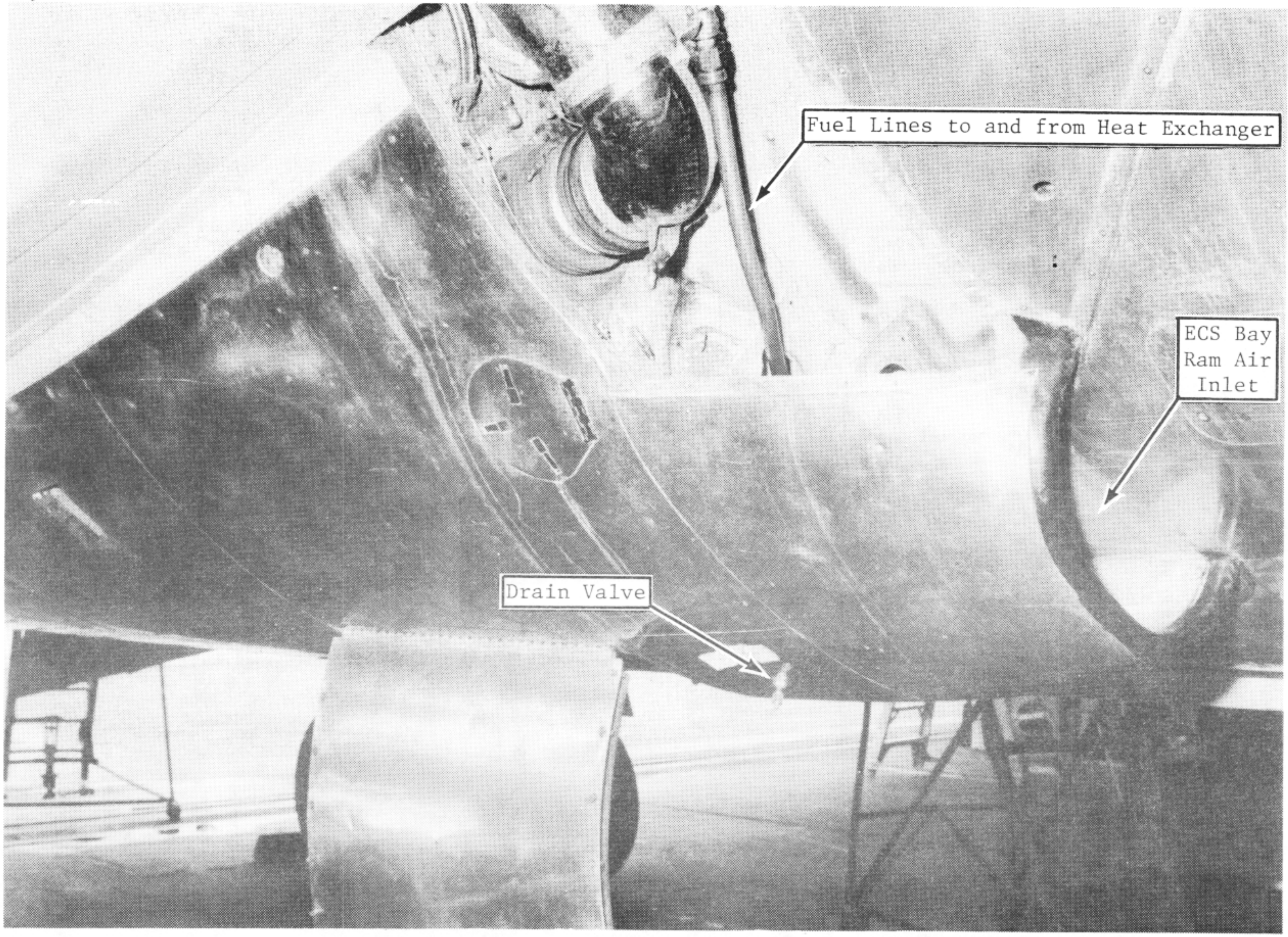

FIGURE 31. OUTSIDE VIEW OF ECS BAY

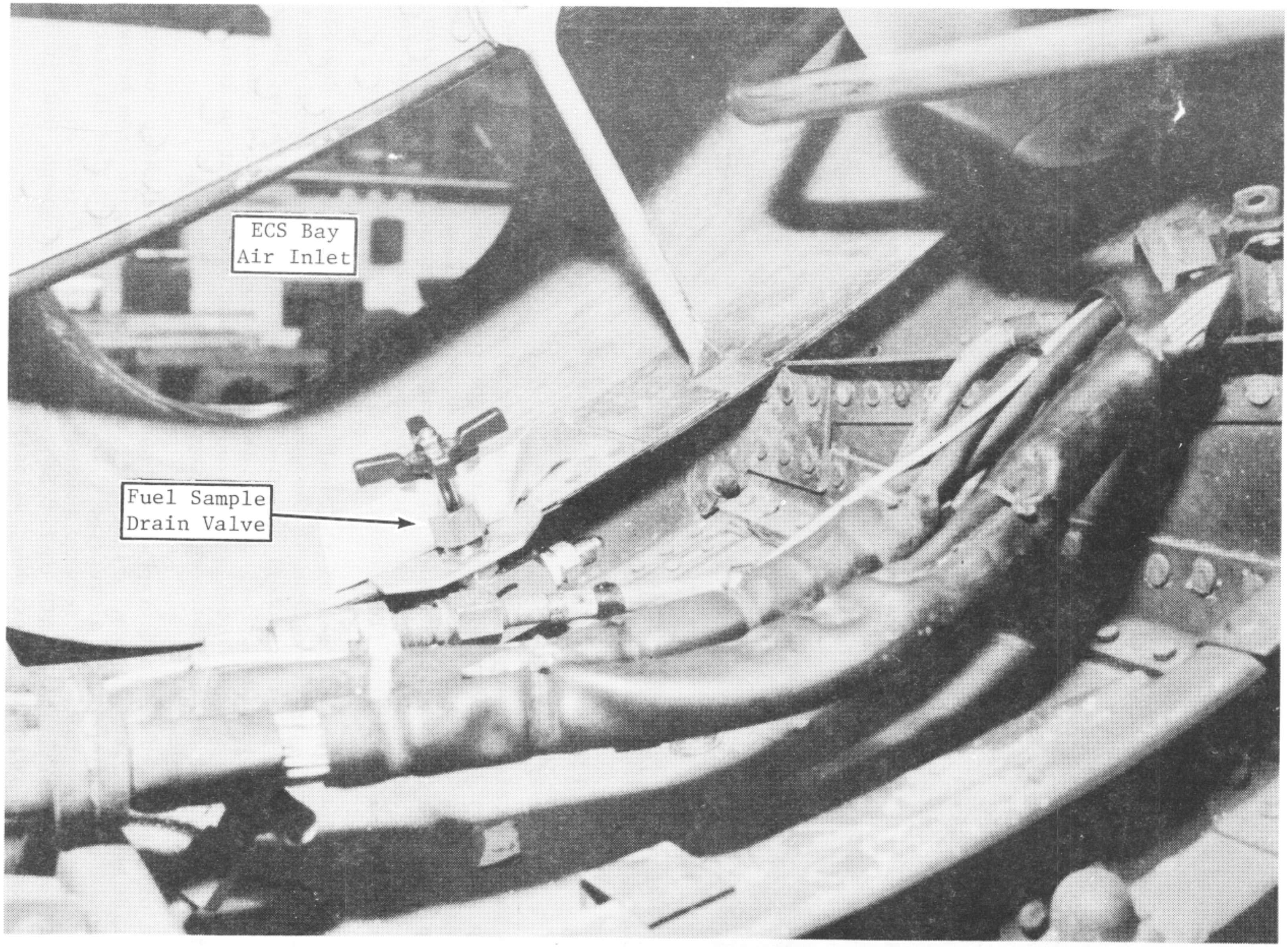

FIGURE 32. FUEL SAMPLE DRAIN VALVE

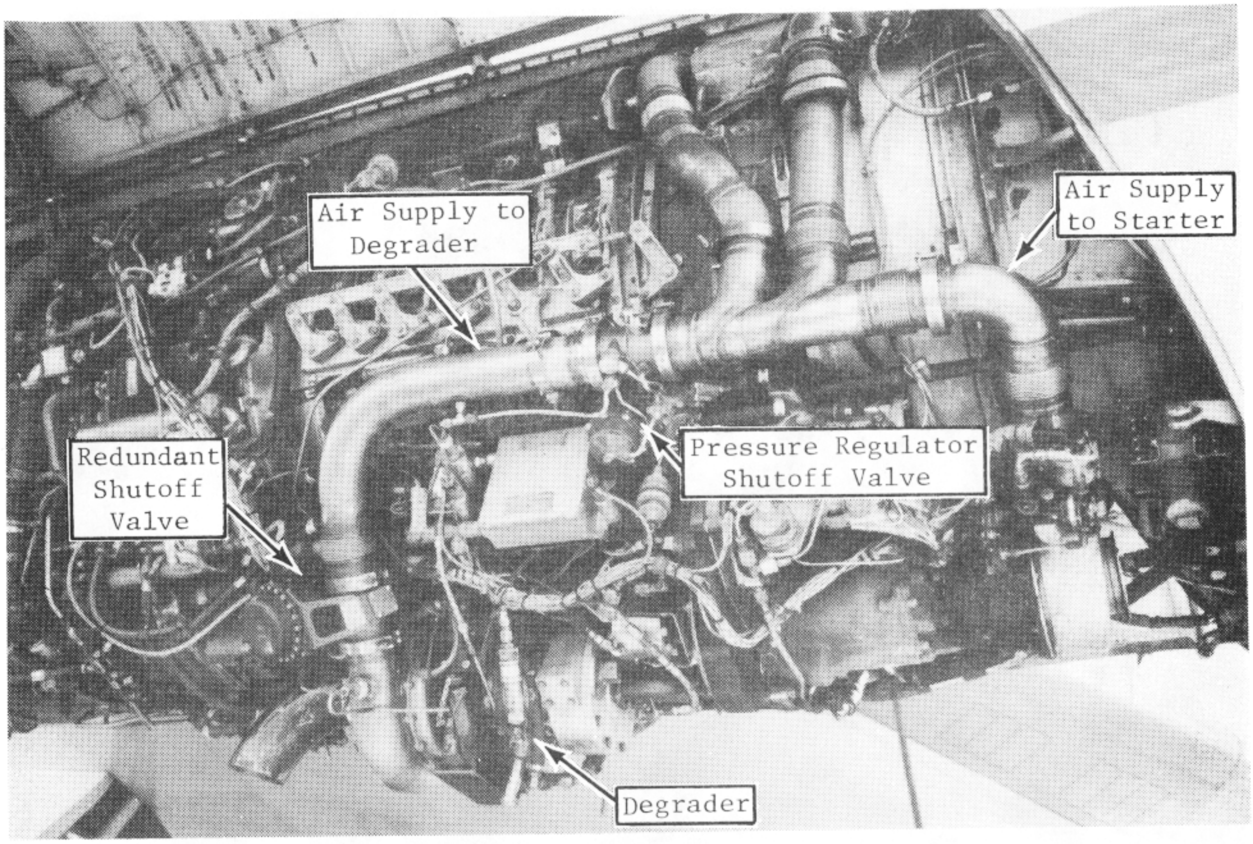

FIGURE 33. VIEW OF RIGHT SIDE OF NUMBER 3 ENGINE

The original single supply pipe for the air starter resulted in a pressure drop that was too severe at high degrader power settings and prohibited the degrader from achieving maximum speed. Accordingly, a second, parallel, supply pipe was added to the side of the compressor casing. The addition of the parallel line alleviated the duct pressure losses so the degrader could operate at all speeds and flow conditions.

Figure 33 shows the location of the dual air-control valves of the degrader. The first valve, just downstream of the junction of the parallel supply ducts, is the pressure regulator/shutoff valve. The redundant shutoff valve, located at the degrader turbine scroll inlet, is shown in Figure 34. It should be noted that bellows were added at numerous locations for vibration isolation and stress relief of the custom-fitted supply ducts.

Most of the preceding photographs have shown mounting of degrader components in side views of the engine. Figure 35, a view of the engine from below, is included to complete this discussion. The ATMP80-1 was installed in place of the engine generator. The forward mounts are visible in Figure 35. The rear mount of the cantilevered ATM cannot be seen in the photograph, but it is a 3/8-inch steel rod with adjustable, uniball ends.

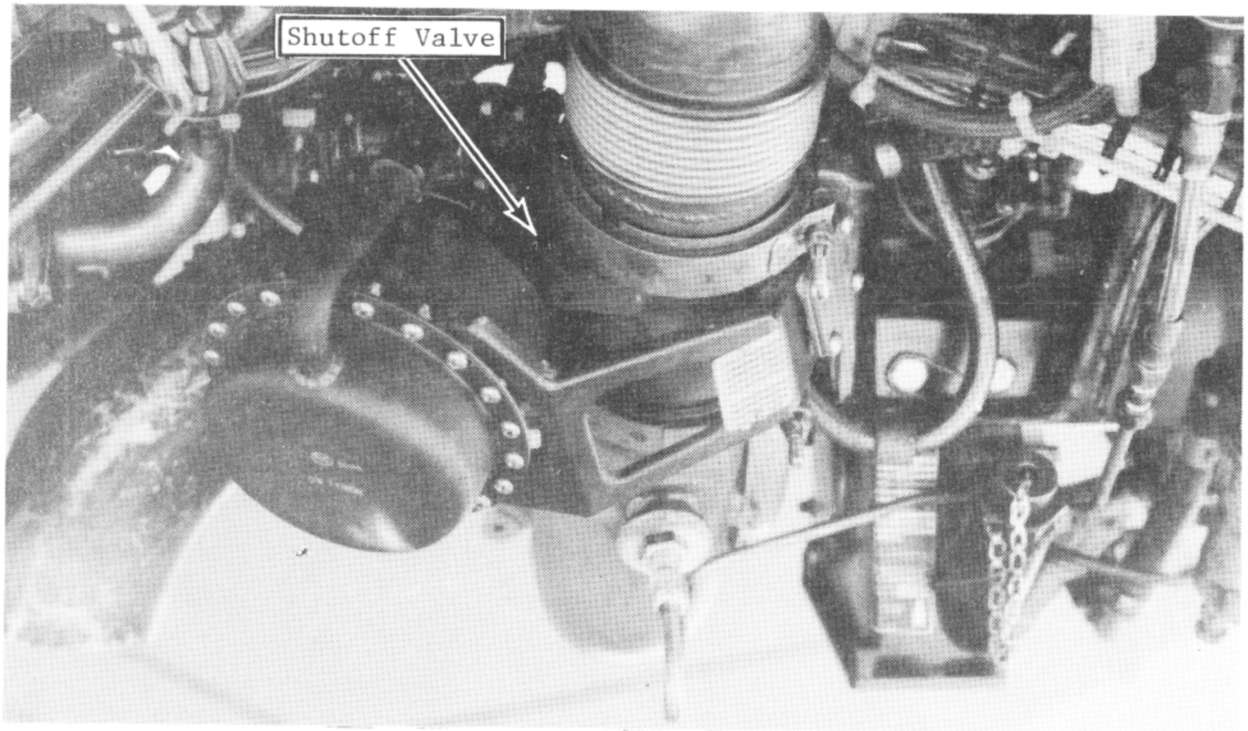

FIGURE 34. REDUNDANT SHUTOFF VALVE

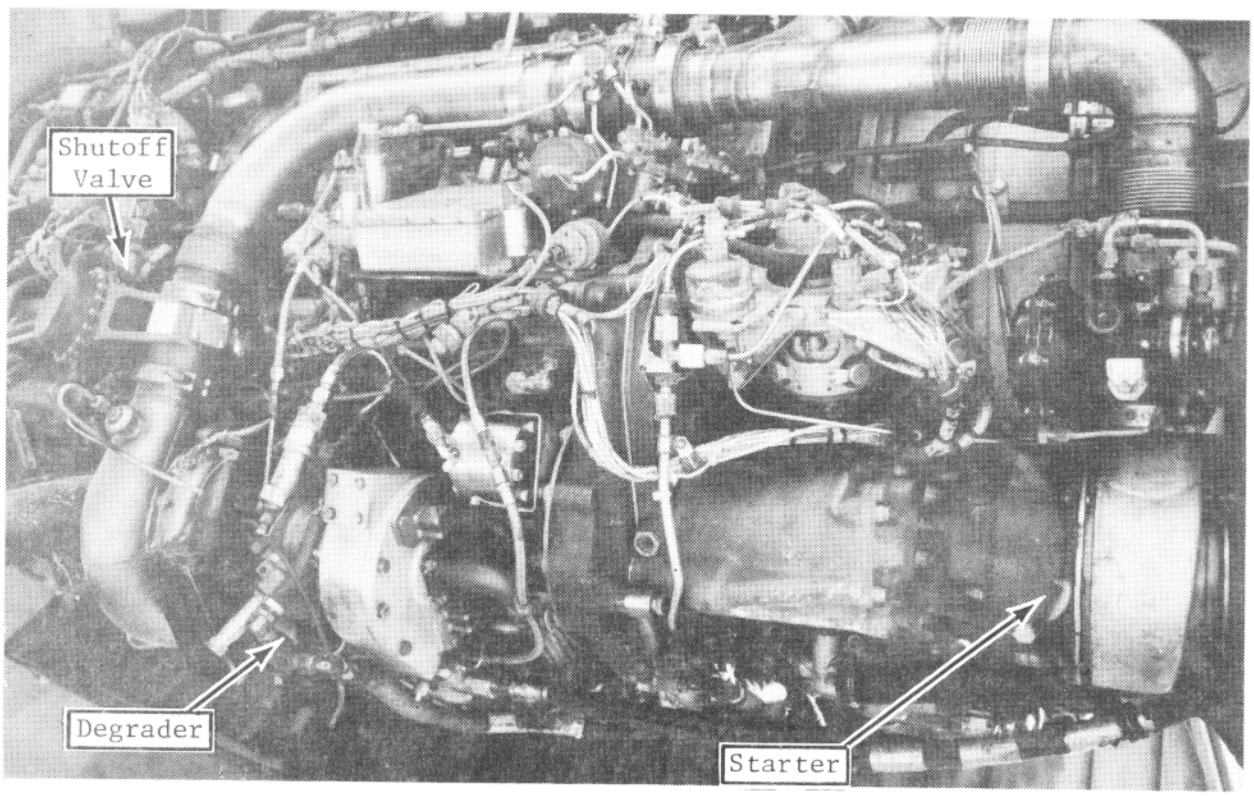

FIGURE 35. BOTTOM VIEW OF NUMBER 3 ENGINE

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IV. INSTRUMENTATION SYSTEM DESIGN AND CONFIGURATION

INSTRUMENTATION SYSTEM DESIGN OBJECTIVES

The instrumentation system used in the testing of the AMK degrader system on the CV880 aircraft was designed, assembled, and bench tested by the General Electric Edwards Flight Test Center (GE-Edwards). Installation of the system in the aircraft was performed by General Air Services under the supervision of an instrumentation designer from GE-Edwards. After the on-board system had been calibrated and checked and the initial flight tests were completed, the responsibility of operating the instrumentation system during the balance of the flight testing was assumed by General Air Services technicians.

A prime objective of the test program was to evaluate the performance of AMK in a representative commercial aircraft. To meet this goal, the instrumentation had to provide data that would allow comparison of two very similar engines operating on the CV880 under identical conditions. Standard engine performance data for the No. 3 AMK engine and the No. 2 reference Jet A engine were recorded to allow this comparison. The degrader system, installed on the No. 3 engine, was of prime interest; therefore, sufficient data had to be acquired to enable evaluation of fluid, thermodynamic, and mechanical performance. Ambient conditions and aircraft data also had to be recorded for the calculation of engine and degrader performance and to verify the parameters under which the degrader had been tested.

Schedule and cost constraints dictated use of as much existing aircraft and engine instrumentation as possible. Purchased equipment was standard, readily available hardware proven in earlier flight tests conducted by GE-Edwards. A final consideration in the design of the instrumentation system was that the test data be stored on magnetic tape in a format compatible with existing data processing and plotting equipment at GE-Evendale.

DATA SYSTEM COMPONENTS

Figure 36 shows the on-board data system installed in the cabin of the CV880 aircraft. A remote video-display monitor was also mounted in the cockpit above the navigator's console as shown in Figure 37. The following lists tabulate the major data-system components along with some of the features and performance specifications.

Daytronics 10K6 Data Pac. The center of the on-board data acquisition system was a Daytronics Model 10K6 computer. The 10K6 combined multiprocessor architecture with modular design and provided the following system functions:

- Multi 8088 processors sharing a data bus management system with a scan rate of 2500 channels per second
- 14 kilobytes of random-access memory (RAM) for data

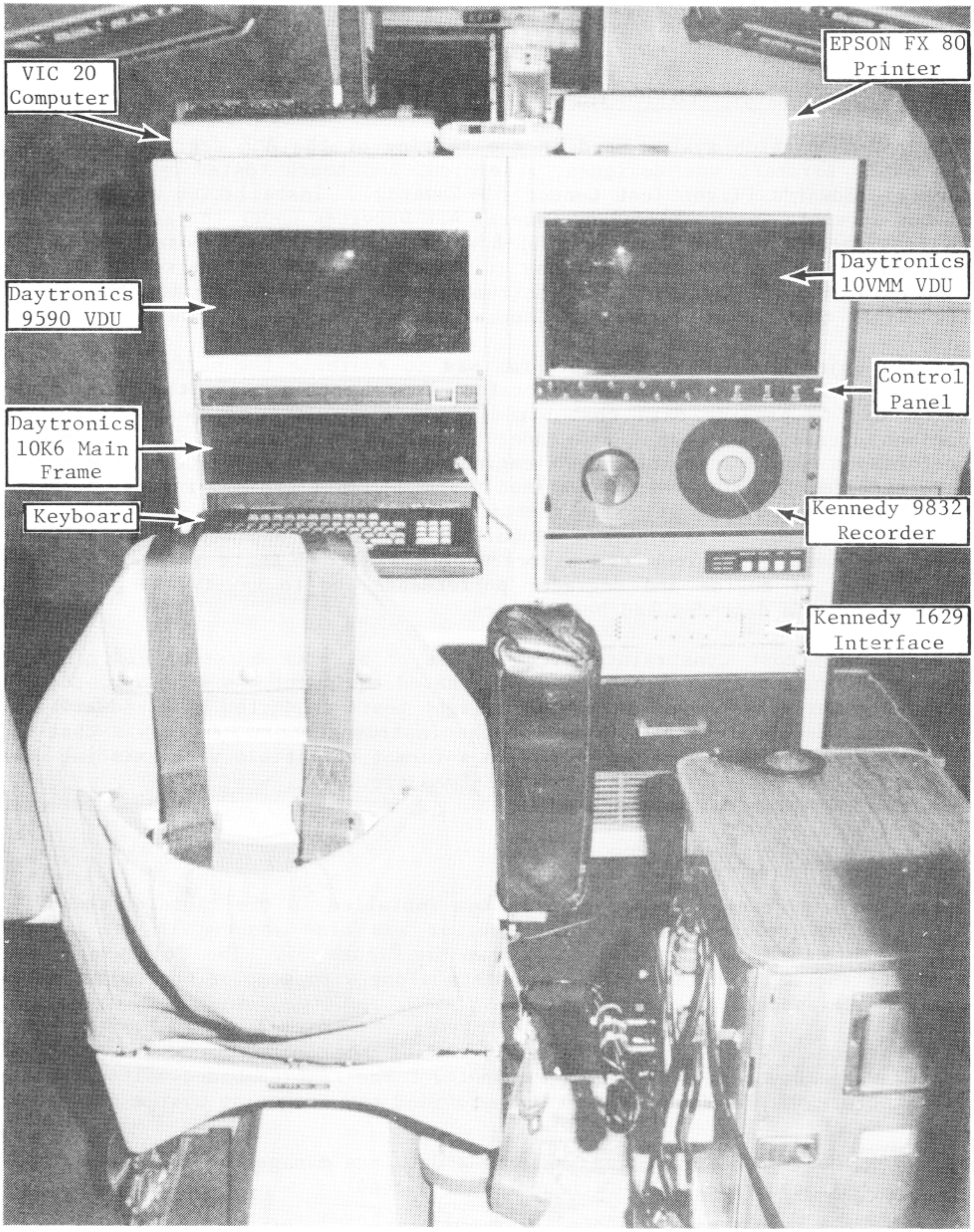


FIGURE 36. ONBOARD INSTRUMENTATION DATA SYSTEM

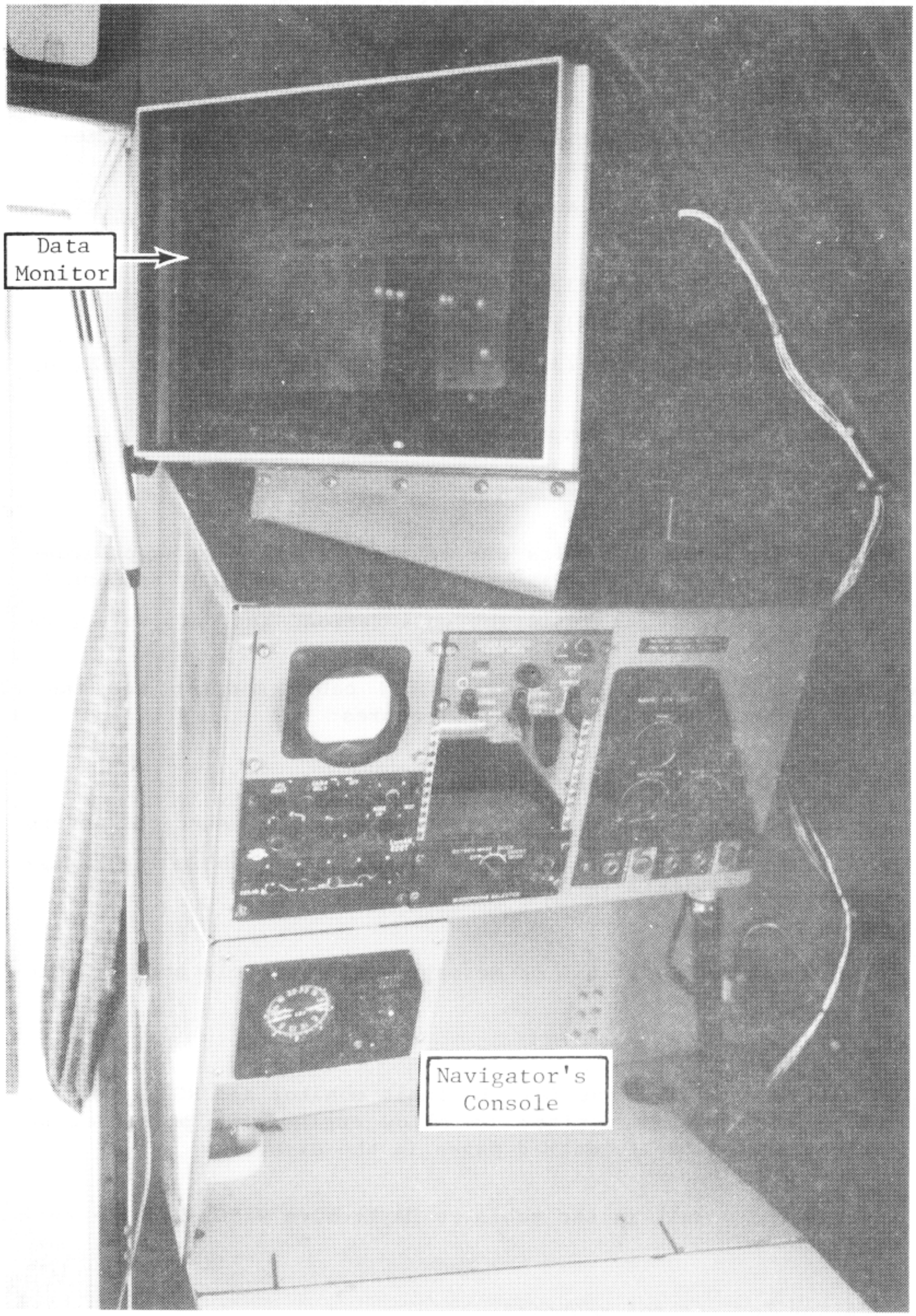


FIGURE 37. COCKPIT DATA MONITOR

- 14 kilobytes of read-only memory (ROM) for the operating system
- 32 kilobytes of electronically erasable, programmable read-only memory (EEPROM, nonvolatile system) for system configuration and calibration
- Multipole analog filtering plus nine digital smoothing factors, selectable on a per-channel basis
- Digital filter per channel with individual quieting factors
- Signal conditioning
- Thermocouple linearization
- Digital zeroing and scaling
- 14-bit analog/digital (A/D) resolution (better than 0.02% of full scale)
- Limited crosschannel computation
- Computer interface for major computations and control
- Real-time clock and date
- Fault monitoring (2 limits per channel, 3 alarm zones programmable to effect any combination of 16 logic inputs/channel)
- Keyboard control for in-flight calibrations and data selection

Video Display Units. The Daytronics 10VMM cabin monitor and the 10VCM (color) cockpit monitor had the following features:

- Self contained for live, multichannel display
- Up to 100 pages that can be formatted with multisize characters
- Available combinations of visual highlighting (blinking, image reversing, variable intensity, etc.)
- Field composable
- Each displayed logic bit or message field remotely controllable
- Nonscrolling
- In-place updating
- RS 170 composite input for the cabin monitor and RGB input for the color cockpit monitor to allow engineering personnel to select any of the formatted pages in the directory

A second video display unit in the cabin, a Daytronics 9590, had the following uses and features:

- Monitor for control keyboard
- Hard-copy output port to the printer

- Live play-back monitor for the Kennedy tape recorder
- Requires RS232C ASCII for an input
- Uses 10 internal PROM's remotely controlled to display up to 40 selected sets of data
- Switchable input and output baud rate, parity, and number of stop bits

Digital Tape Recording System. The primary means of collecting data was the Kennedy 9832 buffered magnetic tape recorder. It used ½-inch by 1200-foot reel tape in conjunction with a dual RAM. The other specifications are:

- Data density: 800 characters per inch
- Number of Tracks: 9
- Tape format: NRZI, IBM compatible
- Maximum recording length: 512 characters
- Tape speed: 25 inches/second

The Kennedy 9832 recorder required a Kennedy 1629 half-duplex interface to connect a buffered tape system to RS232C-compatible devices. This interface has the following specifications:

- Selectable baud rate from 110 to 19,200 baud in 9 switch steps
- In the receive mode, the 1629 accepts RS232C serial data and converts it into parallel data bytes for recording on tape
- In the transmit mode, the parallel data bytes are converted back to serial-transmission mode for playback display on a RS232C VDU or printer

Hard-Copy Printer. An Epson FX80 dot-matrix printer was used for hard-copy output. A 9594 printer interface was installed in the 9590 VDU in order to accommodate the printer. The VDU had an alternate control input plug which, when hooked up, allowed instant page-format selection by the viewer as well as a hard-copy printout of the page format displayed on the 9590. Play-back data could be printed by removing the input cable from the 9590 and plugging it directly into the printer.

VIC Computer. A VIC-20 personal computer was used as a peripheral device to run the routine used to calculate Mach number and air speed. This was necessary due to the limited cross channel computational capability of the Daytronics 10K6.

DATA SYSTEM CONFIGURATION AND OPERATION

As previously shown in Figure 36, the on-board data system was installed in the forward cabin section of the CV880 aircraft. The system was controlled from the console in the cabin by the instrumentation engineer. Originally, the data-system control console was to be installed so that the test engineer in the cockpit could view critical on-line data on the console monitor. This installation configuration proved to be impractical because of the distance between the cockpit and the nearest suitable place to mount the console racks in the cabin. An additional monitor was mounted in the cockpit and proved to be much more convenient for the test engineer. A remote control was also installed which allowed the cockpit crew to select the desired data to be displayed on their monitor. Headsets were used for communication between the test engineer in the cockpit and the instrumentation engineer in the cabin to coordinate the functions of the data system with the various degrader test sequences being performed at different times throughout the flight.

Figure 38 shows an operational schematic of the data system. Once power was available and the system had been brought on-line, the operator used a software program to initiate the continuous recording of data by the Kennedy 9832. Data read by the Daytronics 10K6 from the sensor signals were conditioned and directed to the Kennedy tape system for permanent storage. All parameters were scanned and recorded every two seconds. The data were also displayed on the Daytronics 10VMM and 10VCM units in the cabin and cockpit at the same time it was recorded. If data verification was required, the tape could be rewound and played back on the Daytronics 9590 monitor. If hard copy was desired, the playback could be routed through the printer interface of the 9590 VDU to the Epson FX80 dot-matrix printer.

At the end of a test sequence, the tape reel was removed from the recorder and forwarded to Evendale where it was read into the general data base of a Honeywell 6000 computer system. The data could then be accessed by standard plotting routines and output to Versatec plotters for easier analysis of the test results.

Figure 39 is a typical example of a Versatec plot. All data were plotted against time as the independent variable in the computerized plots used in this program. The units of time were minutes after midnight. Therefore, in Figure 39, the test began at approximately 712 minutes past midnight or 11:52 AM. There were only two instances when the use of computer-generated graphs was somewhat cumbersome. When the duration of the test required a second tape to record the data, two plots of each of the test parameters were produced. A similar problem arose when the test continued beyond midnight (1440 minutes), even when all the data were recorded on a single tape. For the most part, however, the computerized plots were very useful in analyzing the multitude of data gained during the flight test program.

Critical test data displayed on the monitors in the cabin and cockpit were also transferred onto video tape. This feature proved to be very useful for a number of reasons. Backup was provided in the event the master Kennedy tape was lost, damaged, or could not be read by the GE-Evendale Honeywell 6000

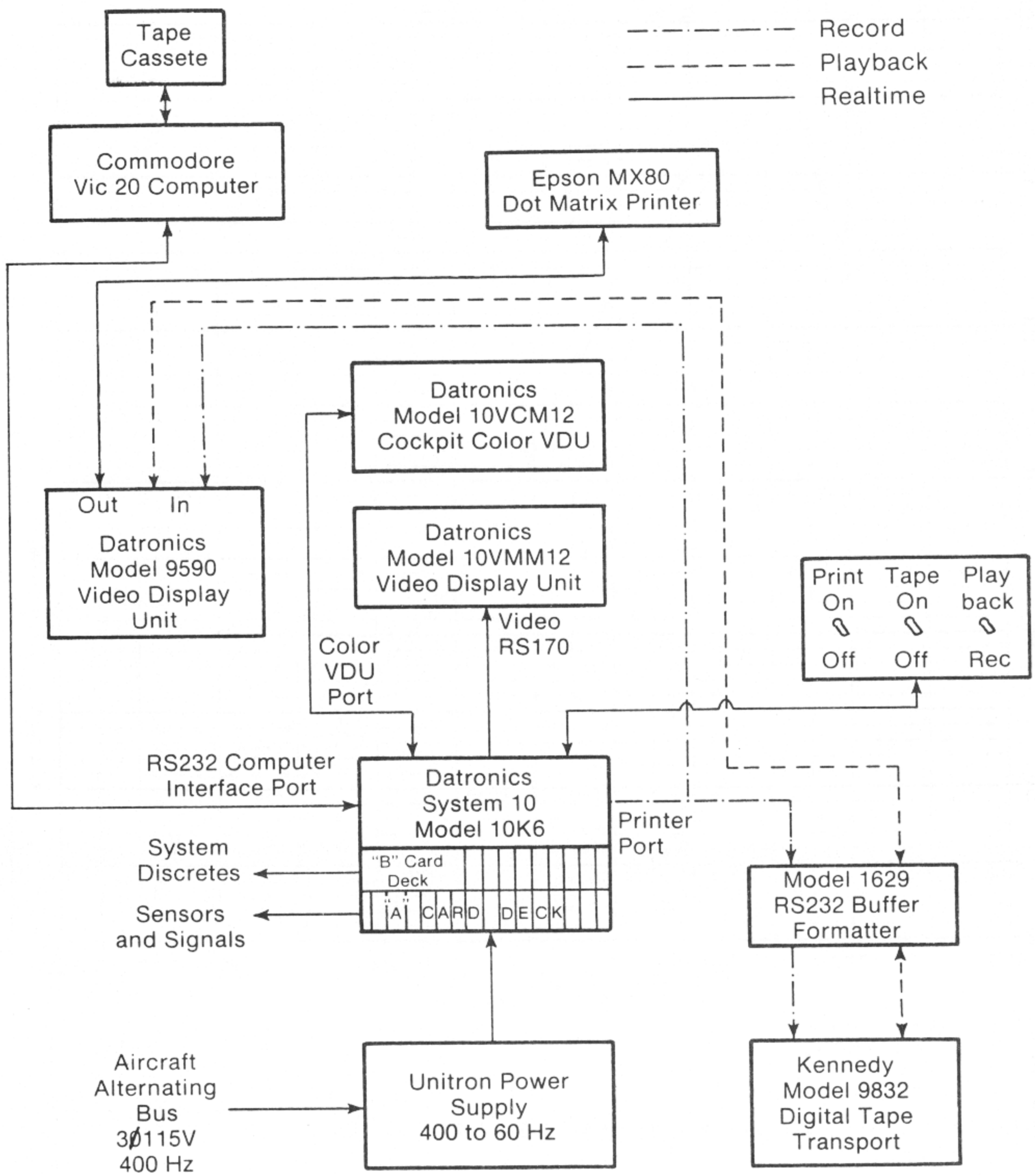


FIGURE 38. ONBOARD INSTRUMENTATION DATA SYSTEM SCHEMATIC

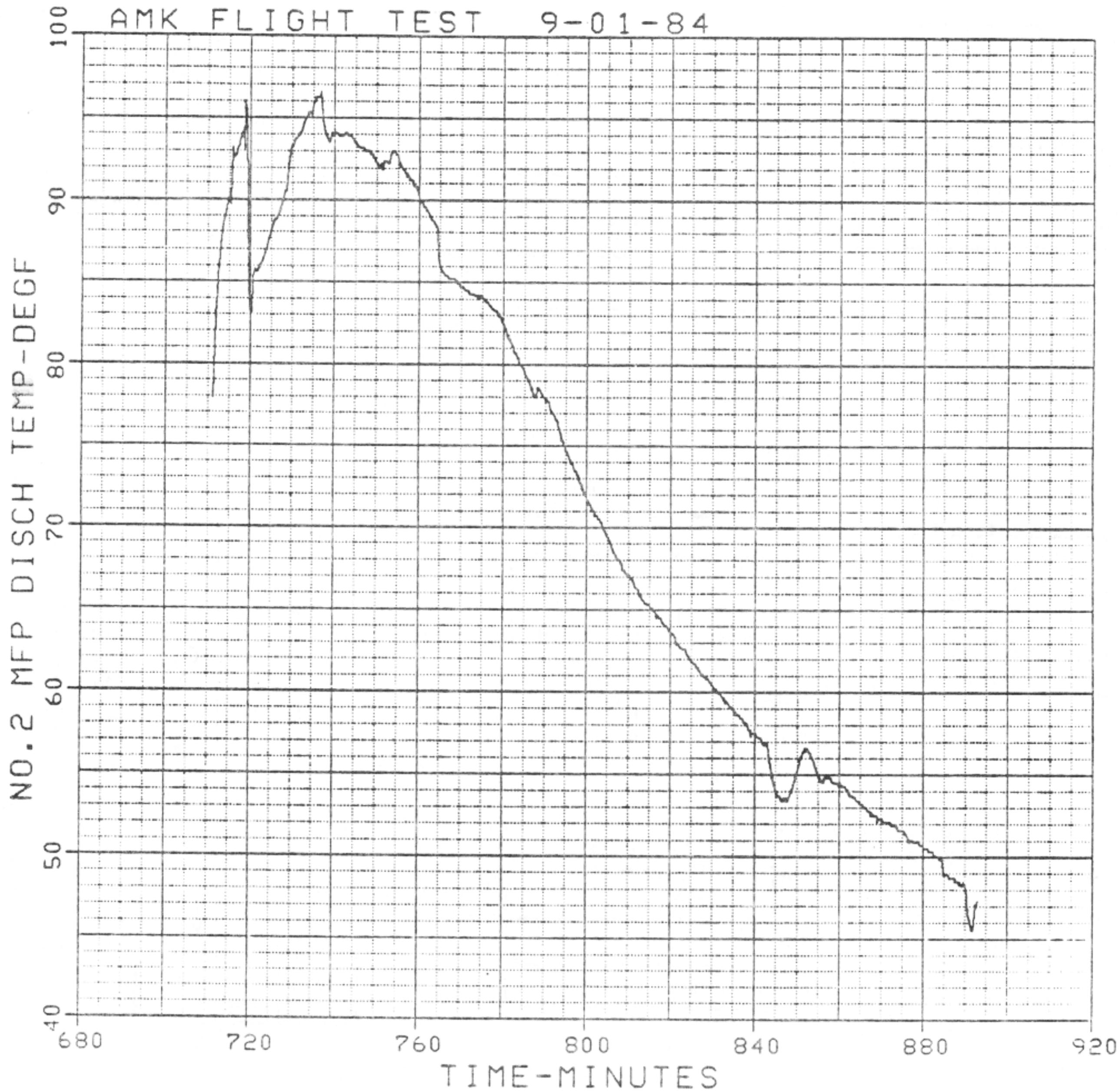


FIGURE 39. TYPICAL DATA PARAMETER PLOT

system. Test data could be reviewed at any location where VCR equipment was available. The alternative, without the video tape capability, was to review the test data in the aircraft by playing back the test tape on the Kennedy recorder through the Daytronics 9590 VDU. The fact that the on-board system required the aircraft 400-cycle power to remain on-line complicated review of the data after the aircraft had been secured on the hangar ramp after a test flight.

Besides the acquisition and storage of data, the data system functioned as a warning device for certain critical degrader parameters during the testing (system discretes shown in Figure 38). Whenever any of these parameters drifted out of limits, an audible alarm was sounded to focus attention on potential problems. Early in the program the degrader was actually shut down if an out-of-limit signal was sensed. This mode of fault monitoring had to be abandoned due to unnecessary system shutdowns caused by electrical surges in the aircraft power bus during switching of generators and hydraulic pumps.

RECORDED PARAMETERS AND SENSOR LOCATIONS

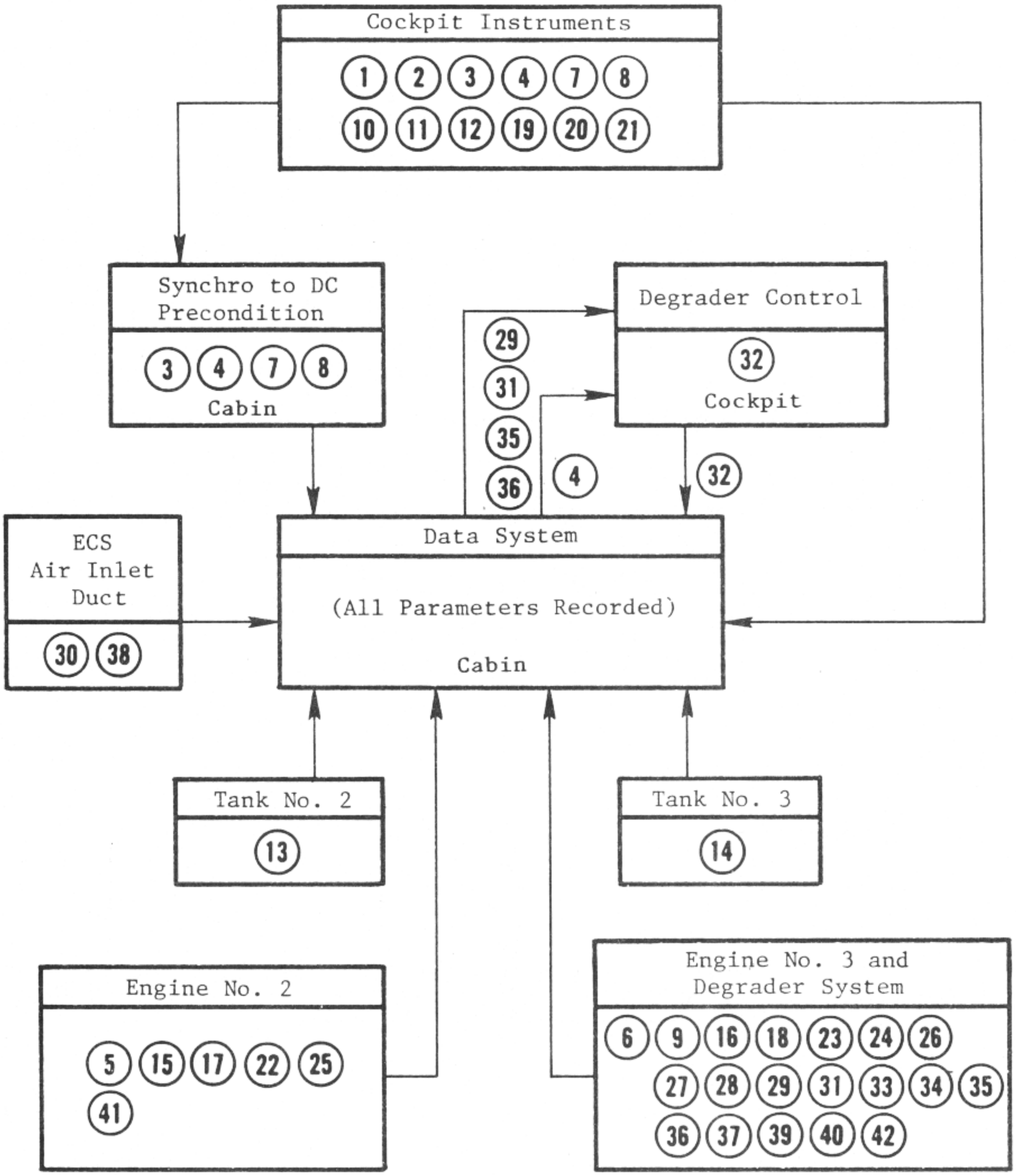
Table 3 lists all the significant parameters that were recorded during the CV880 testing of the degrader system along with the source and typical range of the readings. Figure 40 summarizes the locations of the various sensors and shows the interfaces of signals used in controlling the degrader. The details of the sensor locations, with special emphasis placed on the degrader system installed on the No. 3 engine, was previously shown in the Degrader Installation Schematic, Figure 25.

TABLE 3. CV880 RECORDED PARAMETERS

Item Number, Parameter		Signal Source	Range
1	No. 2 Engine Speed	N_2 Tach Generator Signal	0 to
2	No. 3 Engine Speed	in Cockpit	105%
3	No. 2 Fuel Flow	WFE Signal in Cockpit	0 to
4	No. 3 Fuel Flow		15,000 pph
5	No. 2 EGT	Secondary Thermocouple (T/C)	0° to
6	No. 3 EGT	Loop on Engine	1000° C
7	No. 2 Engine Pressure Ratio	EPR Signal in Cockpit	1-3
8	No. 3 EPR		Ratios
9	No. 3 Fuel-Supply Pressure	PF4 Transducer on Engine	0-5 psig
10	No. 2 Fuel Tank Quantity	WTK Signal in Cockpit	0 to
11	No. 3 Fuel Tank Quantity		21,000 lb
12	Outside Air Temperature	OAT Signal in Cockpit	-40° to 110° F

TABLE 3. CV880 RECORDED PARAMETERS (CONCLUDED)

Item Number, Parameter	Signal Source	Range
13 No. 2 Fuel Tank Temperature 14 No. 3 Fuel Tank Temperature	TTK Thermocouple in Tank	-40° to 110° F
15 No. 2 Scav. Oil Temperatue 16 No. 3 Scav. Oil Temperature	T011 Thermocouple in Oil Line Tee	0° to 350° F
17 No. 2 Fuel Pump Disch. Temp. 18 No. 3 Fuel Pump Disch. Temp.	TF10 Thermocouple in Pump Housing	0° to 300° F
19 Altitude	ALT Transducer in Cockpit	0 - 50,000 ft
20 Air Speed	XMP Transducer in Cockpit	Mach 0 to 1.0
21 Ambient Pressure (P0)	ALT Transducer in Cockpit	0 to 15 psia
22 No. 2 Main Fuel Filter ΔP 23 No. 3 Main Fuel Filter ΔP	DPFF Transducer on Engine	0 to 50 psid
24 No. 3 MEC Servo Screen ΔP	DPSWC Transducer on Engine	0 to 24 psid
25 No. 2 VSV Actuator Pressure 26 No. 3 VSV Actuator Pressure	Variable Stator Vane Transducer on Engine	0 to 1000 psig
27 No. 3 Fuel Pump Inlet Press.	PF7 Transducer on Engine	0 to 150 psig
28 Sampler Screen ΔP	DP17 Transducer on Engine	0 to 25 psid
29 Degrader Disch. Pressure	PF3 Transducer on Engine	0 to 2000 psig
30 Realtive Humidity	RH Sensor in Right ECS Bay	0 to 100%
31 Degrader Disch. Temperature	TF3 T/C in Adapter Nipple	0° to 250° F
32 ATM Speed (XND)	Signal from ATM Controller	0-35,000 rpm
33 ATM Oil Temperature	T03 T/C in Oil Line Tee	0° to 325° F
34 ATM Air Inlet Temperature	TBLD T/C in Air Line	0° to 859° F
35 Fuel Throttling Valve Press.	Transducer on Engine	0 to 2000 psig
36 ATM Oil Pressure	Transducer on Engine	0 to 200 psig
37 ATM Air Inlet Pressure	PBLB Transducer on Engine	0 to 300 psia
38 OAT ECS Bay	Thermocouple in ECS	-76° to 140° F
39 Degrader Fuel Inlet Temp.	Thermocouple in Fuel Line	-40° to 200° F
40 No. 3 Manifold Pressure	Transducer on Engine	0 to 100 psig
41 No. 2 MEC Wash Screen ΔP	Transducer on Engine	0 to 50 psid
42 No. 3 MFP Discharge Pressure	Transducer on Engine	0 to 1000 psig



Data item descriptions are listed in Table 3.

FIGURE 40. SENSOR LOCATIONS AND SIGNAL INTERFACES

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V. DEGRADER SYSTEM TESTING

BACKGROUND

The testing of the centrifugal pump/degrader system in this program addressed a wide range of design and performance considerations. The scope and focus of the degrader aircraft testing expanded significantly during the program as the result of two important developments:

1. Unexpected test results early in the program necessitated much more on-wing ground testing than was originally planned. The additional ground tests were parametric in nature and attempted to isolate and identify the suspected causes of gel formation in the fuel system.

2. As the program evolved, it became clear that CV880 testing should become more directly involved with preparation for the B720 CID Program. Therefore, much of the later degrader tests on the CV880 took place at Mojave, California and were integrated with the CID. Originally, the plan was to perform the CV880 testing separately from the B720. Test results and operational procedures developed during the CV880 tests were thought to be reasonably transferable to the B720 program due to the commonality of the degrader hardware.

The primary objective of the degrader flight test program was to determine the effectiveness of the centrifugal pump/degrader to "condition" AMK fuel for use in an engine throughout the operational envelope of a representative transport aircraft. Reasonable success in meeting this objective logically led to the consideration of the effect AMK fuel and the degrader had on the performance of the engine.

Prior to this test program, no flight data existed on the operation of an engine on AMK fuel. Achievement of this goal had obvious implications in not only the B720 CID program but also in the larger context of the total AMK program.

Many of the following objectives, considered in the degrader tests, had been addressed by previous lab and simulator tests; therefore, these objectives were considered to be secondary or supporting technologies investigated in the test program.

- The effects of AMK on nonmetallic components of the fuel tank and aircraft/engine fuel system.

- The effects of the aircraft fuel system on the fire-preventive characteristics AMK fuel.

- The effects of flight on the fire-preventive characteristics of AMK and on the suitability of the fuel for use in the aircraft/engine fuel system; these included environmental effects such as pressure, temperature, and humidity along with such effects as flight dynamics and fuel "sloshing" producing unwanted degrading of AMK still in the tank.

- Preliminary assessment of the use of in-line blended AMK fuel in large quantities.

SUMMARY OF PROGRAM TESTS

This section outlines the nature and purpose of the different series of tests conducted during this program.

AMK Compatibility Test. This test was a straightforward soak test of various fuel tank sealants, gaskets, O-rings, and hoses that were expected to come into contact with AMK fuel in the CV880 Program.

Aircraft Baseline Tests. During preparation of the CV880 and immediately preceding the initial on-wing AMK degrader tests, the aircraft was tested to determine the operational characteristics of the No. 3 AMK engine on Jet A fuel at various operating conditions. The results of the Jet A operation could later be compared to engine operation on AMK fuel.

Degrader Systems Acceptance and Endurance Tests. These were performed at Garrett Pneumatic Systems Division prior to delivery of the degraders for use in the CV880 and B720 Programs. The degrader systems were configured to represent the CV880 installation and were "bench tested" in a pneumatic turbine test cell. The tests served a number of purposes:

- Evaluation of the effectiveness of the modified centrifugal pump to degrade AMK fuel

- Verification of the fluid/thermodynamic model of the degrader system

- Establishment of the mechanical integrity of system components

Degrader System Aircraft Testing - Phase I and Phase II. The tests of the degrader system on the CV880 were wide and varied in nature and were divided roughly into two phases. The first phase involved the development of a data base relating to the use of AMK fuel in a aircraft flight environment. The second phase of the testing dealt with more flight testing that supported the B720 program and with investigation of gelling phenomena uncovered during Phase I of the test program.

On-wing tests of the degrader system without the engine operating were conducted in both phases of the test program. These tests are referred to as systems tests. The fuel was transferred to a catch tank after it had flowed through the degrader rather than being consumed in the engine. These tests were used to assess the degradability of small "blends" of AMK fuel before a larger quantity was blended for an engine ground or flight test.

The engine and degrader were operated using AMK fuel in ground tests. The advantage of these tests was that samples of degraded AMK fuel could be obtained from the drain cock in the ECS bay (degrader cooling loop) while the system was in operation. The disadvantage was that the engine could not be operated at full power for any significant length of time without the risk of exceeding the exhaust gas temperature (EGT) limits of the engine.

Degrader flight tests were performed to assess the performance of the AMK fuel in the No. 3 engine of the CV880 over the entire operating envelope of the aircraft. These tests were conducted to expose the AMK fuel and the engine to as wide an operating environment as possible within the limits and constraints of the program.

Early in the test program, FAA Technical Center personnel were responsible for blending and characterization of the AMK fuel. These tests were conducted to evaluate the quality of different blends of AMK fuel. The characterization tests included filter ratio, cup clarity (NTU), and transition velocity (for some blends). The characterization tests were performed for degraded and undegraded samples. Midway through the Phase I testing, the task of blending and characterizing the AMK was assumed by General Air Services personnel under the direction of the General Electric program manager. An additional technician was brought to the program to conduct AMK characterization and record the results. While the analysis of the quality of different blends of AMK was outside the strict scope of this program, the relevance and importance of AMK quality to degrader testing are obvious. Characterization data, therefore, are discussed along with the analyses of degrader test results.

PRELIMINARY TESTS - CV880 PROGRAM

Prior to initiation of degrader testing, a number of preparatory tests were conducted in support of the aircraft tests.

AMK FUEL COMPATIBILITY TESTS. A number of AMK material-compatibility tests were conducted under the sponsorship of the FAA Technical Center, and the behavior of most materials in contact with AMK was fairly well established (see Reference 1). In an effort to be thorough in identifying any possible problems of material compatibility that might arise in the program, General Electric conducted a straightforward soak test of various O-rings, gaskets, hoses, and tank sealants that would be used during the program. The test was conducted in General Electric's Combustion and Fuels Laboratory at Evendale, Ohio.

The fuel system components were soaked for 93 days in 3 AMK samples supplied by the FAA; duplicate components were soaked in conventional Jet A fuel. Some samples were not exposed to any fuel and were used as a baseline reference.

Table 4 lists the parts supplied for evaluation. Three basic types of parts were tested: tank sealants, Items 1 to 3; O-rings, Items 4 to 7; and AN hose, Item 8; Table 5 is the item-number/fuel-type test matrix. Tank sealant, hose, and some O-rings were cut to provide a sufficient number of test pieces.

TABLE 4. AMK COMPATIBILITY TEST SPECIMENS

Item No.	Item	Description
1	Tank Sealant	PRC1422-B2
2	Tank Sealant	Proseal 890 B2
3	Tank Sealant	Scotchseal EC1290, EC1293, EC776
4	Gasket	011157-015-32B
5	O-Ring	P/N M83248/1-12B, Fluorocarbon
6	O-Ring	P/N M83248/1-14, Fluorocarbon
7	O-Ring	P/N M59021-021, Nitrile
8	AN Hose	P/N MIL-H8794-4

TABLE 5. AMK COMPATIBILITY TEST MATRIX

Item	Dry Reference	Jet A	AMK 1	AMK 2	AMK 3	Comment
1	×	×	×	×	×	Cut into Five Pieces
2	×	×	×	×	×	Cut into Five Pieces
3	×	×	×	×	×	Cut into Five Pieces
4	×		×		×	Not Cut
5	×	×	×			Cut into Three Pieces
6	×		×	×	×	Cut into Four Pieces
7	×	×	×		×	Cut into Four Pieces
8	×	×	×	×	×	Cut into Five Pieces

Following the 93-day soak period, the test pieces were removed from the fuel, dried, and examined. The condition of each test piece after soaking in AMK was compared to the condition of the reference (no soak) test pieces and the Jet A test pieces. Microscopic examination, to check for loss of surface material that might weaken the part or contaminate the fuel, revealed no loss of material or change in characteristics on any test piece. All tank-sealant specimens retained good bonding to the parent material and good elasticity. The O-rings also retained good elasticity.

Based on the good condition of all test pieces after this compatibility test, it was concluded that the materials would perform satisfactorily when used with any of the AMK fuels to be tested.

AIRCRAFT PERFORMANCE ASSESSMENT. On two occasions prior to the installation of the degrader on the CV880, the aircraft was flown to ascertain the general mechanical condition and assess the overall performance at various flight conditions.

During the second month of the program, on April 14, 1983, the title to CV880, N5863, was transferred from the previous owner to General Air Services, Inc. The aircraft was then ferried from Hobby Field in Houston, Texas to Miami

International Airport, Florida. The following day, the aircraft was flown to the Dade-Collier Training Center in South Florida, 58 miles west of Miami, and a generalized version of the AMK baseline flight test was performed using Jet A fuel:

- Nos. 2 and 3 engine throttle bursts and chops
- Nos. 2 and 3 engine windmill relights
- Simulated Category II instrument-approach waveoffs, 50 ft above ground level (AGL)
- Simulated aborted landings (touch and go)
- Full-stop landings with thrust reversal

These tests were performed without the benefit of the special instrumentation that was added later in the program with the degrader system. The data were obtained from the standard aircraft instrumentation and recorded by hand. The activity during the flights was also recorded on video tape.

The aircraft proved to be in good condition during the ferry flight, and most of the minor problems encountered were repaired by GAS mechanics upon arrival at Miami. Particulars for the April 15 simulation of the AMK baseline test were as follows.

- Block Time: 2 hours, 30 minutes
- Flight Time: 2 hours, 10 minutes
- Fuel Burned: 28,000 lbm (4200 gallons)

It was originally estimated that fuel burn would be 600 gallons per hour per engine. The April 15 checkout used 485 gal/hr - about 20% lower than anticipated; however, this was at low aircraft gross weight.

- Zero-Fuel Weight: 121,500 lbm
- Gross Takeoff Weight: 155,500 lbm
- Gross Landing Weight: 127,500 lbm

The special nature of the AMK flight tests requires more fuel loading, hence a higher fuel-burn rate. Maximum landing weight for the CV880-22M is 155,000 pounds, and maximum takeoff weight is 193,500 pounds.

Figure 41 shows the flight data points for altitude relights during the tests. All relights were satisfactory (5 to 11 seconds) except at 41,000 ft/Mach 0.7 where relight did not occur and at 38,000 ft where EGT rise (after 60 seconds) indicated a hot-start (tailpipe lightoff). This test confirmed that it would be possible to define a meaningful reference relight point upon which AMK performance could be compared. It should be noted that only windmill engine starts are permitted with the CV880 in flight. In later AMK tests, crossbleed air would be used only to operate the degrader; the engine starter valve

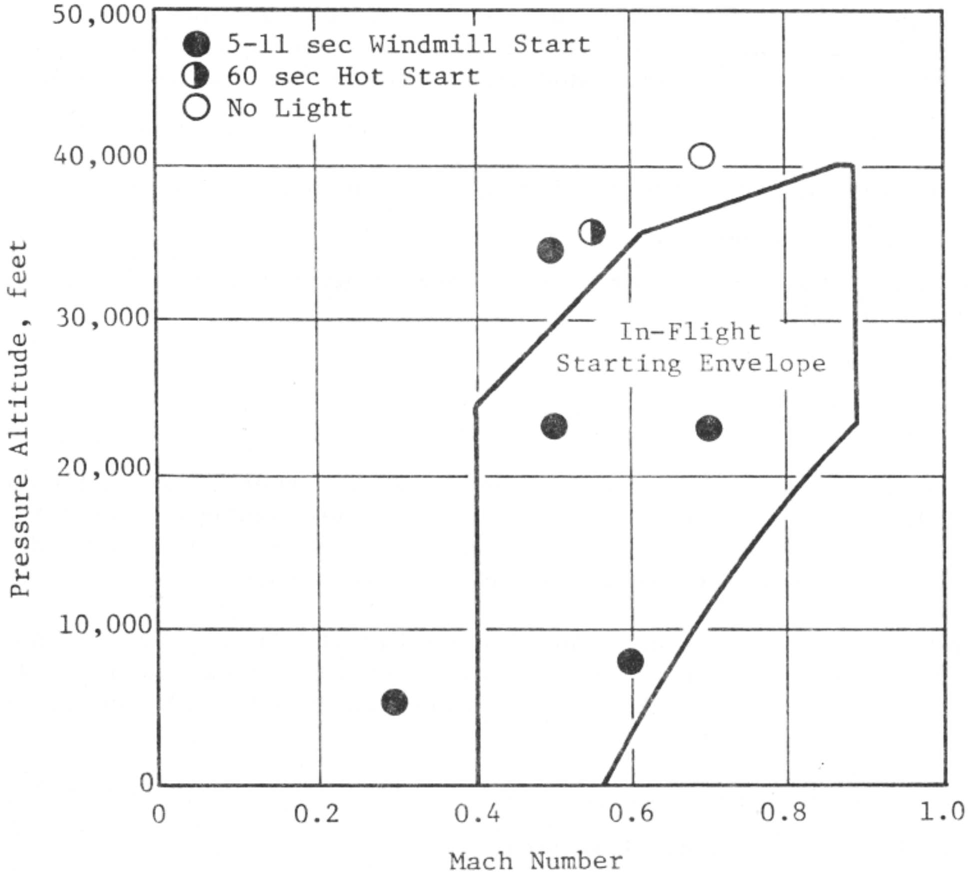


FIGURE 41. CV880 ENGINE IN-FLIGHT STARTING ENVELOPE

remained closed. The flight test verified that the flight maneuvers planned for the baseline test produced more than a sufficient response in the aircraft instrumentation to allow the differentiation between Jet A and AMK operation by observing the following parameters in terms of value, rate of change, and sequence of change: EGT, EPR, RPM, fuel flow, response time.

In June 1983 the aircraft was flown a second time for approximately 2 hours to verify that all mechanical systems were functioning properly after repairs and to assess the possibility of any flutter problems which might have resulted from modifications to the No. 3 nacelle and pylon. All systems functioned as expected, and no problems were encountered as a result of the modifications to the No. 3 engine position.

After this test the aircraft was deemed to be in excellent shape. Attention was switched to finalizing the configuration of the degrader system with Garrett.

DEGRADER SYSTEMS BENCH TESTING

SUMMARY. By the end of October 1983, enough degrader system hardware had been fabricated to permit testing of one complete system. The tests began in early November and were completed in late January 1984 with endurance testing of the final B720 degrader system. Five functionally identical systems were produced, one for flight tests on the CV880 and four for installation on the B720.

The tests were conducted at Garrett Pneumatic Systems Division in Phoenix, Arizona. The objectives of the tests were threefold:

- To evaluate the effectiveness of a high-speed centrifugal pump in degrading AMK fuel
- To verify the fluid and thermodynamic modeling of the system
- To establish the mechanical integrity of the system components

All of the degraders were operated for a minimum of 5 hours to identify any component malfunctions. Three B720 units underwent the minimum 5-hour test using Jet A fuel. A 15-hour endurance test was conducted on the fourth B720 degrader to assess any signs of unusual wear or distress. The CV880 unit was used to test the effectiveness of the system to degrade AMK fuel.

Twenty-eight test runs were conducted at various fuel flows and pump speeds with different blends of AMK. The time between AMK blending and the test run was also varied. Limited fuel-storage capacity in the pneumatic turbine motor test cell necessitated short test runs ranging from 1 to 5 minutes depending upon the fuel flow required for the test. A filter ratio of 1.2 was achieved for fuel-flow rates ranging from engine idle to takeoff. Inspection of a special, 40-μm sampler filter showed formation of some AMK gel on the upstream side of the filter during the last test series.

Operation of both the pump/degrader and the throttling valve was completely stable (pressure and flow) over all ranges of speed and flow. Power requirements for a given flow and pressure were lower than expected. No pump cavitation problems were encountered at simulated degrader start with the engine shut down (no metered flow).

During the initial AMK tests, unacceptable leakage was observed through the degrader-pump shaft seal. A modification was identified and incorporated into all the degraders. During the later endurance tests, the new seal and all other components performed as expected. The controller exhibited excellent response and stability characteristics during all the tests in both the manual mode and automatic.

Upon completion of all the testing, which was monitored at various times by GE, FAA, and NASA-Dryden personnel, all units were approved for delivery by General Electric and the FAA. Reference 7 is a complete description of the Garrett Tests.

TEST CONFIGURATION. The setup shown schematically in Figure 42 was installed in a fully instrumented, standard, Garrett pneumatic turbine test cell with equipment installed or connected as described below:

- Suitable ducts and connections for supplying compressed air were connected to the ATM pneumatic inlet port, together with provisions for measuring airflow to the unit.
- The necessary electrical connections between the turbine drive, shutoff valve, and regulating valve and the electrical control panel were made.
- An instrumented section of duct was installed just upstream of the pneumatic inlet of the unit to facilitate measurement of the inlet air pressure and inlet total temperature.
- The air source for testing was clean shop air or an equivalent uncontaminated source, properly heated and regulated.
- A vibration pickup mount was securely installed to the unit housing, utilizing one of the bolts at the interface between the turbine drive unit and the fuel pump.
- The fuel pump inlet lines between the laboratory AMK fuel tanks and the test unit were connected.
- A new set of production control valves, comprising a pressure-regulating/shutoff valve and a redundant shutoff valve, were installed. The regulating valve was adjusted to provide downstream pressure at 45 +5/-0 psig.
- A production configuration of the electronic control panel was installed to a suitable fixture to receive control cables from the degrader assembly.

The test configuration was designed to simulate the CV880 installation as closely as possible. Figures 43 through 45 show sequential views of the degrader components in the overall test configuration starting at the rear of the test cell and moving toward the control room. Figure 43 shows the pneumatic supply line and the air control valves for the degrader. Figure 44 shows the ATMP80-1 pump degrader assembly installed on a test dolly that enabled easy mounting of the degrader assembly outside the test cell. It should be noted that each of the five pump/degrader assemblies and respective throttling valves were individually tested. A single configuration of the balance of the degrader system hardware was installed in the test cell for testing of all five degrader/throttling valve test specimens.

Figure 45 shows the coils incorporated in the tests to simulate the length of fuel line needed to reach from the No. 3 engine to the heat exchanger installed in the CV880 ECS bay. Figures 46, 47, and 48 are photos of the fuel cooling heat-exchanger assembly and the lubrication-system components.

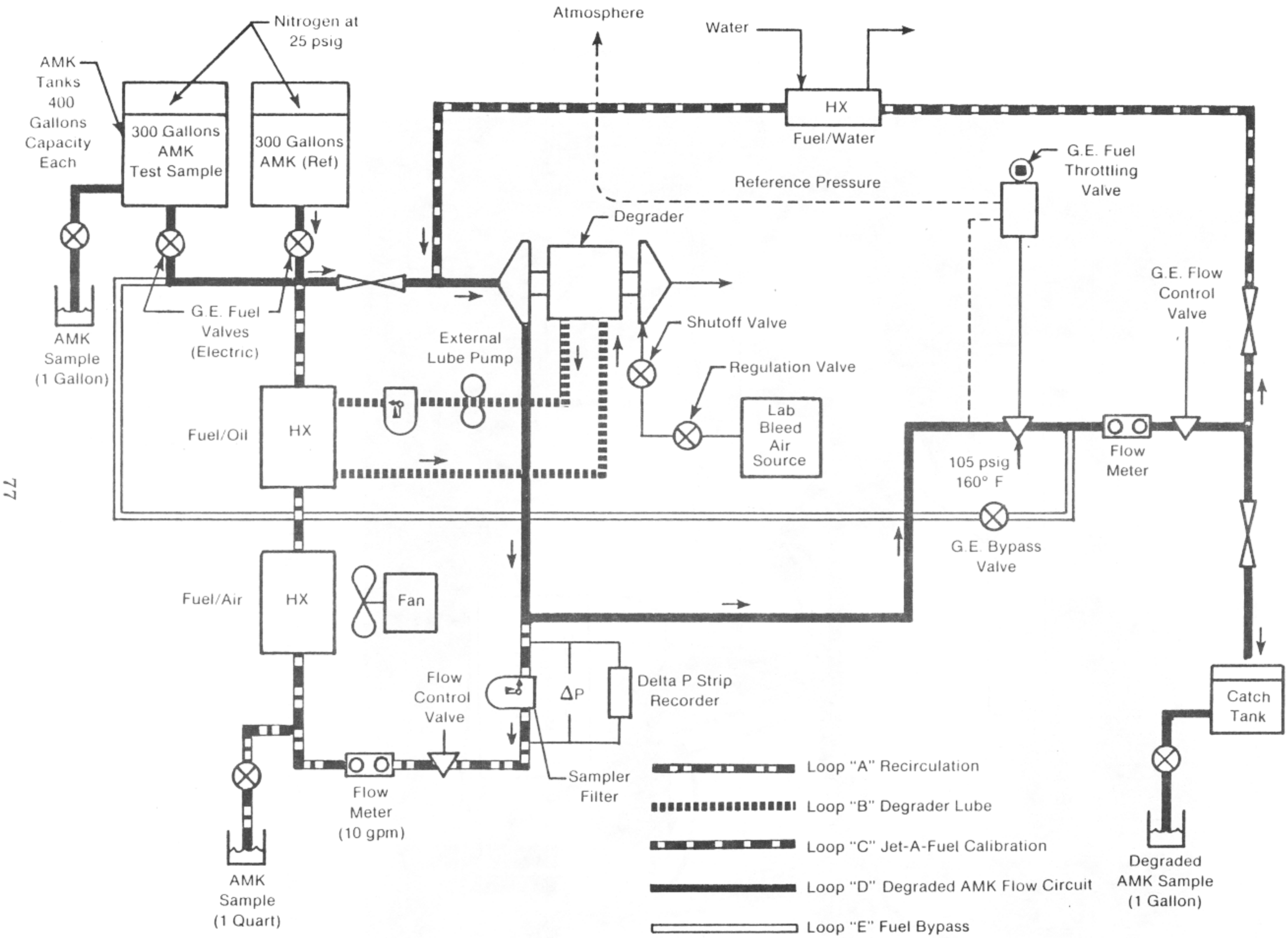


FIGURE 42. AMK FUEL DEGRADER SYSTEM TEST SCHEMATIC

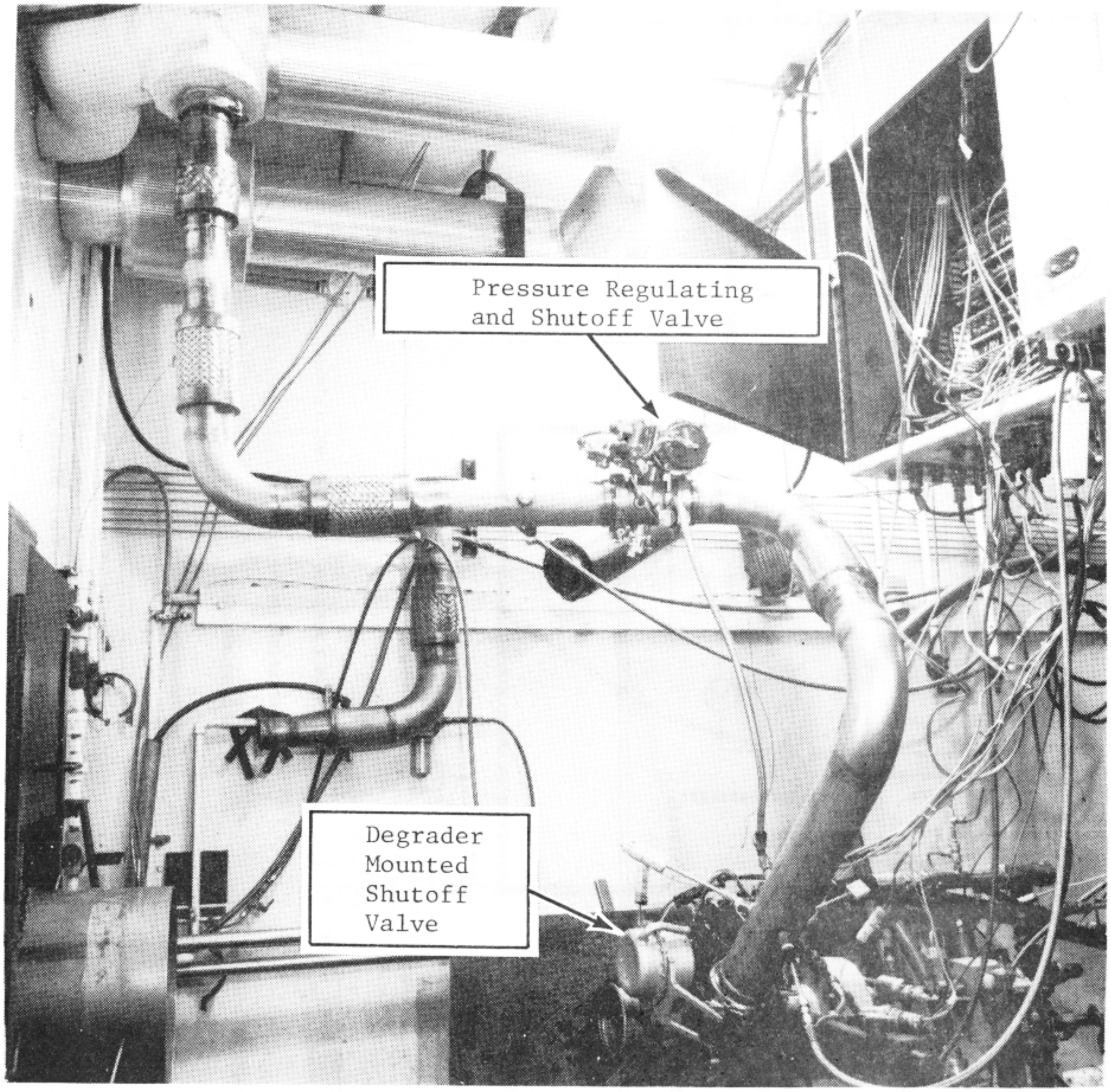


FIGURE 43. PNEUMATIC SUPPLY AND REGULATION/SHUTOFF VALVES

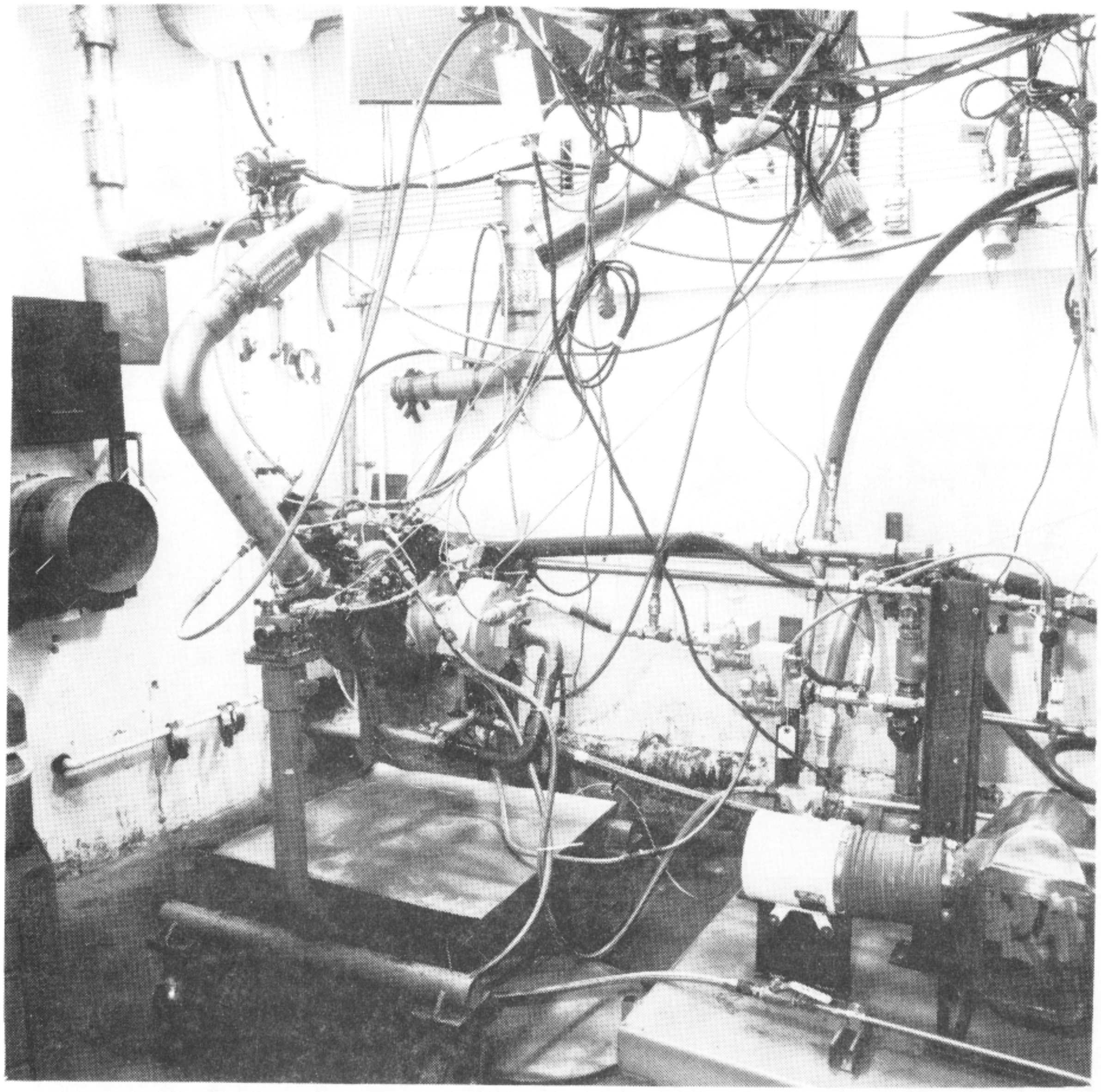


FIGURE 44. ATMP80-1 PUMP/DEGRADER TEST MODULE

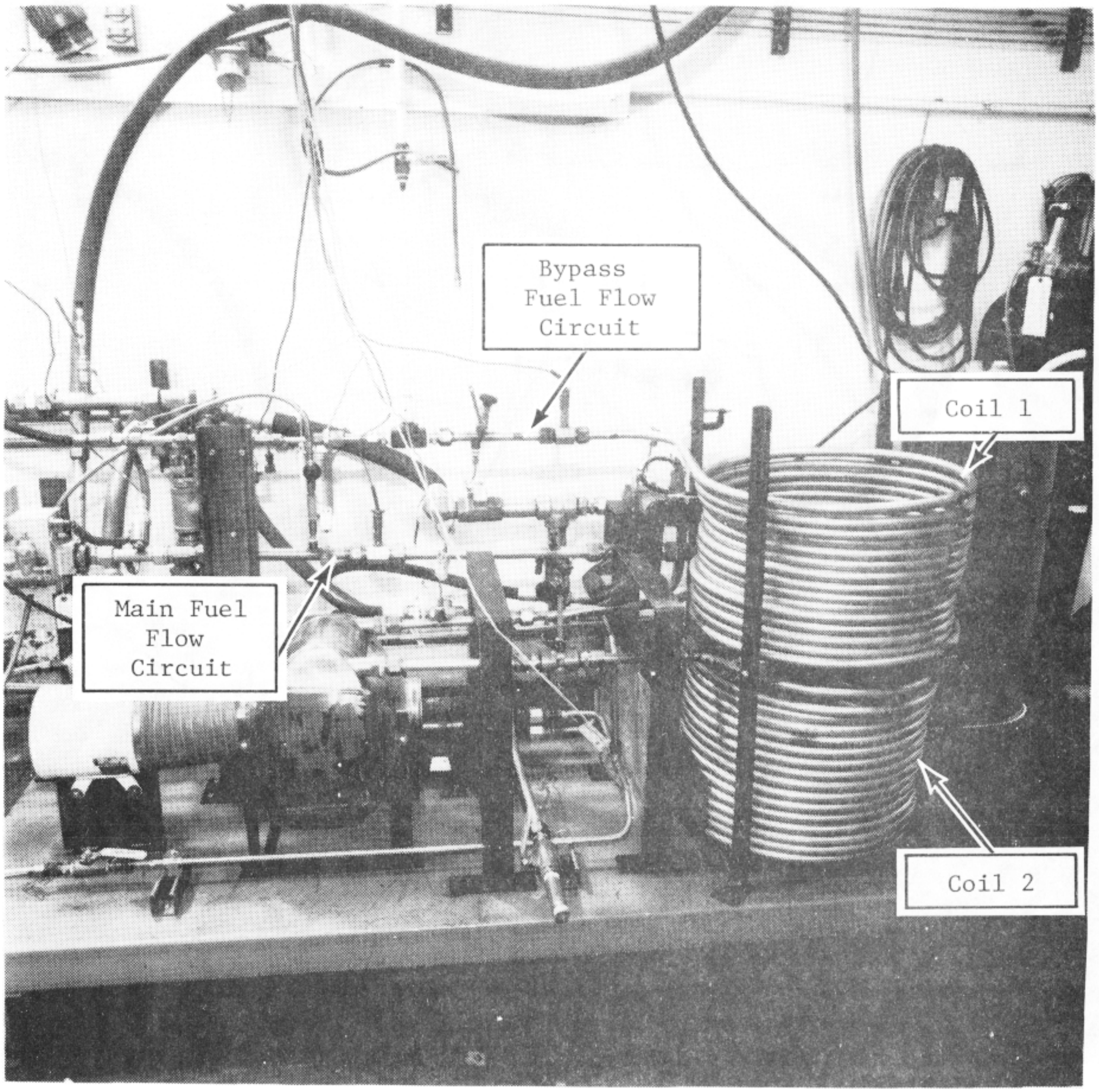


FIGURE 45. FUEL FLOW CIRCUITS

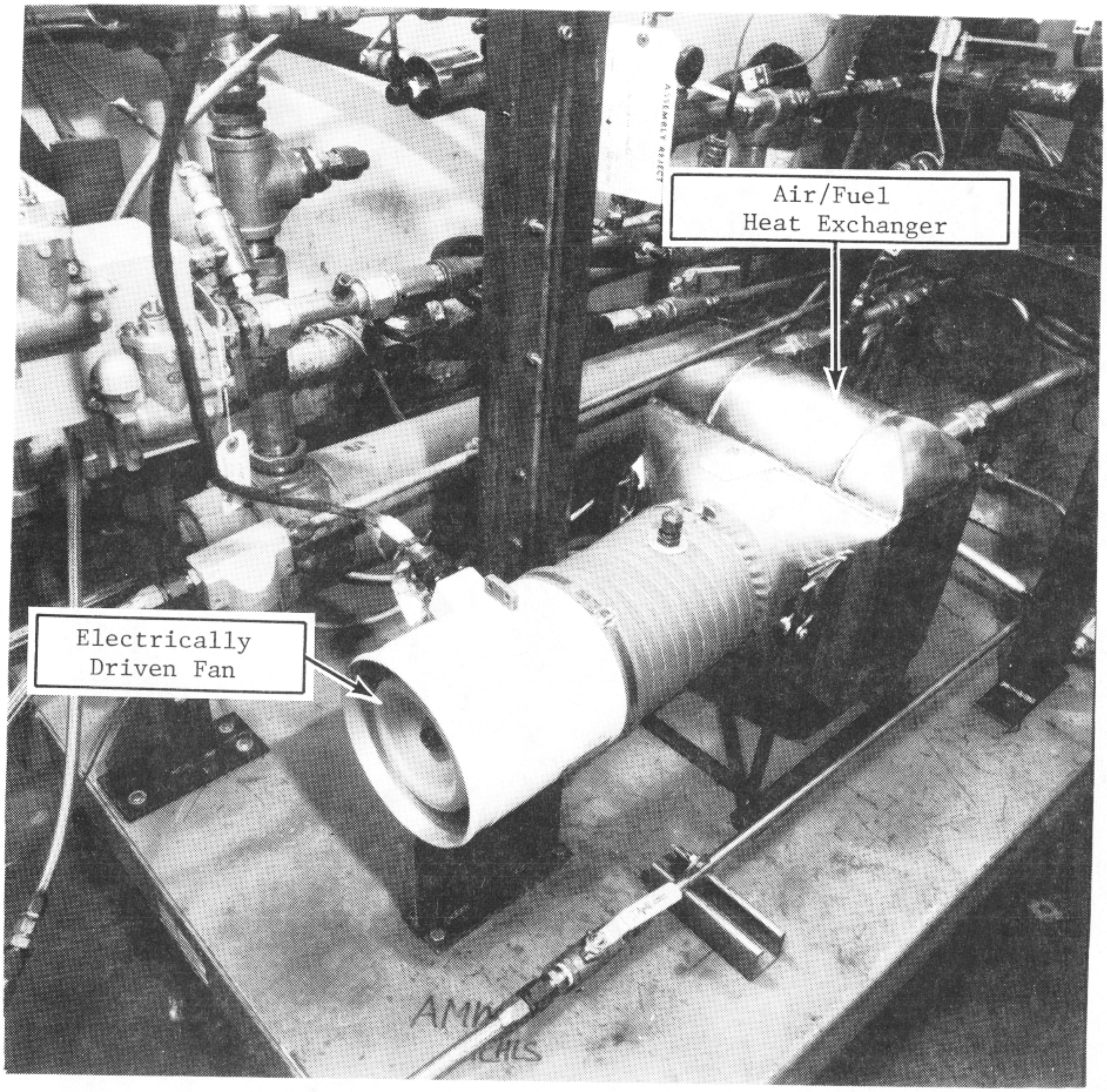


FIGURE 46. FUEL COOLING HEAT EXCHANGER AND FAN

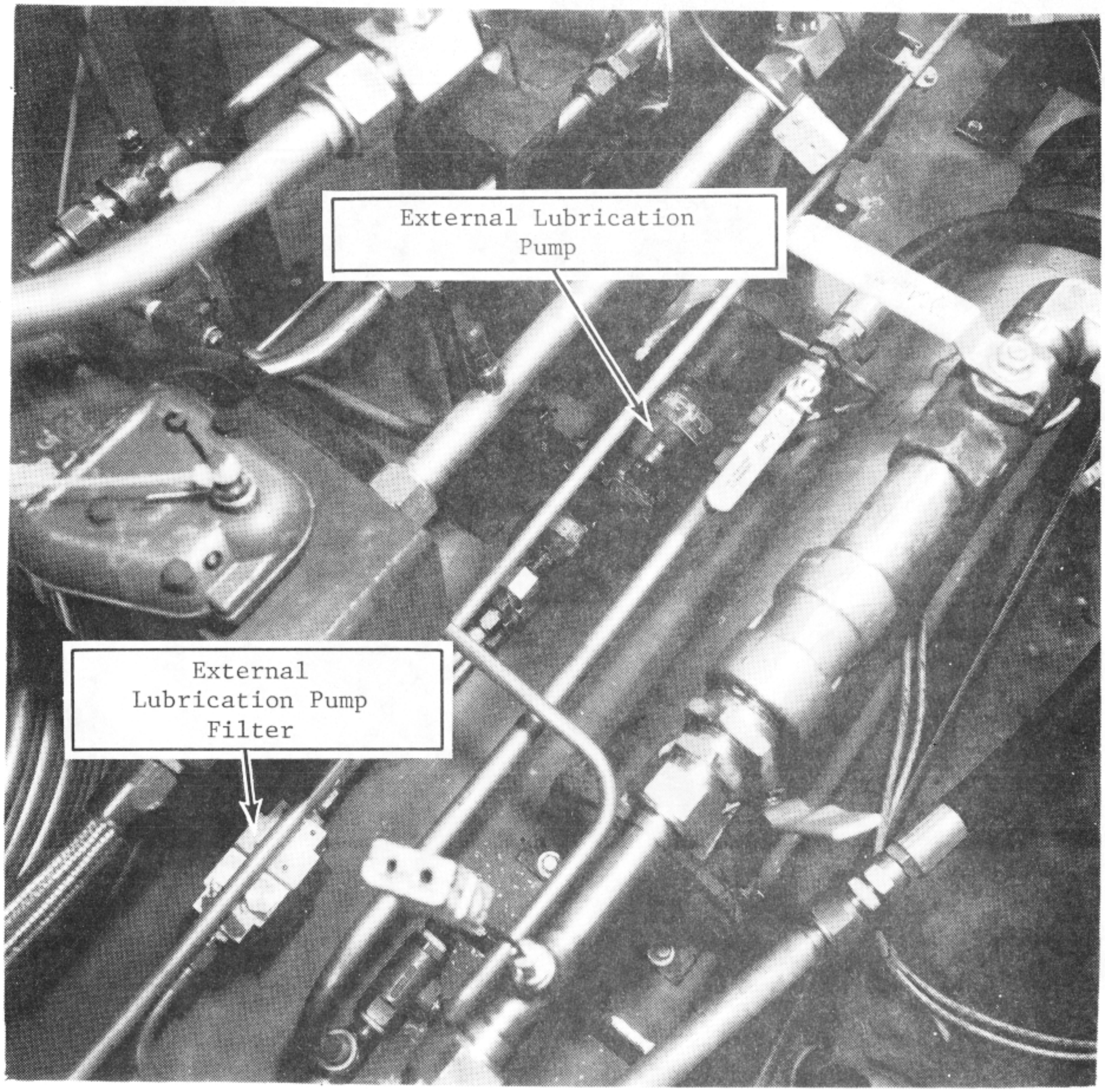


FIGURE 47. LUBE PUMP AND FILTER

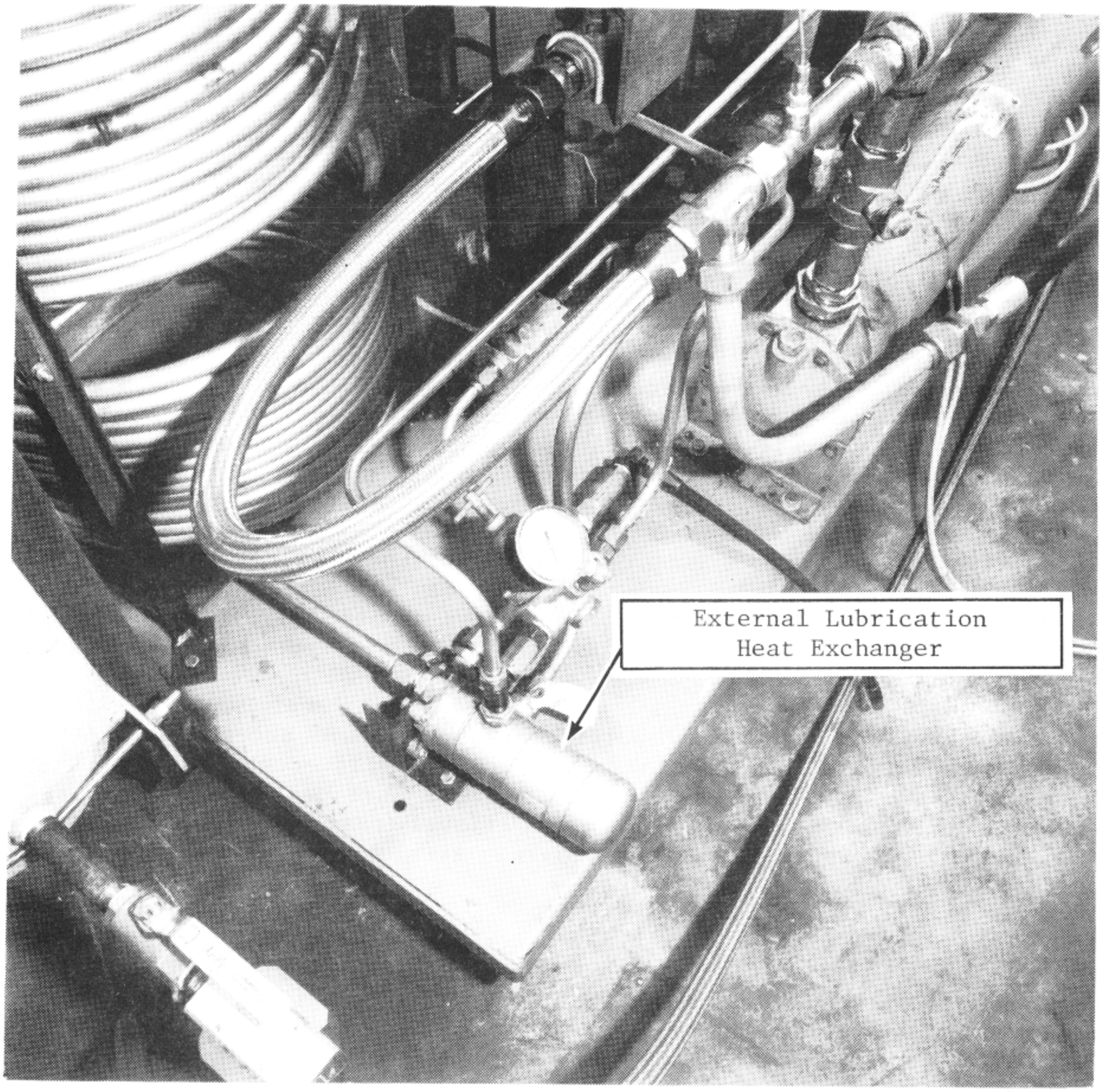


FIGURE 48. LUBE SYSTEM OIL/FUEL HEAT EXCHANGER

AMK TESTING. This test was conducted to assess the degrading characteristics of the systems designed for the program. This "single-pass" testing also served as the endurance acceptance test for the CV880 unit. In this testing, AMK fuel went through the system in a manner similar to that intended for the aircraft installation. AMK fuel entered from the sample tank, was degraded in the system, and emptied into a catch tank. The limited fuel quantities (200 to 300 gallons, typical) necessitated test runs of less than 5 minutes. In the endurance tests, run with Jet A, the pump/degrader was run continuously, and additional fuel cooling was available from a fuel/water heat exchanger in Loop C (see Figure 42). All flow was recirculated, and the catch tank was not needed.

Two tanks were available to supply AMK fuel. One tank was used as a reference or control and contained a single blend of AMK fuel available throughout the test sequence. The second tank contained the sample blend of AMK that was to be used in a given test run.

A break-in run was performed prior to the AMK testing. ATMP 3505540-2 was installed in the test cell, and the system was operated on Jet A fuel during break-in to verify that the degrader system and test setup would function as designed. During the break-in, the AMK testing sequence was established to minimize the amount of AMK fuel being used in any particular test run.

During normal operation, the limit for total oil leakage through the turbine seal was 15 cm^3/hr. The maximum acceptable combined leakage of lube oil and fuel was 25 cm^3/hr. Oil leakage elsewhere in the system was not permitted under any condition. During and after break-in, the unit was checked for oil leakage through the turbine seal; leakage was found to be within acceptable limits. The oil filter was inspected for accumulation of metal particles.

To initiate testing of a given pump/degrader unit, the degrader turbine inlet was supplied with pressure sufficient to rotate the turbine at 500 rpm. While unusual noises were noted, pressure gages, manometers, thermocouples, and operating conditions were checked. Then the turbine speed was increased in 500-rpm increments until 18,000 rpm was reached.

During the break-in, all measured parameters were within acceptable limits, and approximate settings were established for the flow-control valve that would simulate the flow requirements of the main fuel pump in the aircraft installation. Following the break-in run, visual examination of the unit revealed no signs of excessive wear or damage. All lubrication and fuel lines were checked for leaks; none were found.

Fuel flow rates, established during break-in on Jet A, were adjusted as needed with the unit operated from the reference AMK fuel tank. Unit speed and fuel-discharge quantities were also established using fuel from the reference AMK tank. When the test conditions were established, the reference AMK tank valve and the sample AMK tank valve were simultaneously closed and opened, respectively, initiating the test.

DEGRADING CHARACTERISTICS. Tables 6 through 11 summarize the three days of AMK testing at Garrett. Figure 49 is a simplified test schematic illustrates the flow circuits and sample points listed in the tables. All AMK fuel-blending and characterization tests were performed by FAA personnel (see Reference 11). For the 28 test runs listed in the tables, four different blends of AMK were used; one was the reference or control blend, and three additional blends were used in the various tests. The in-line AMK blender, developed by JPL for the FAA (Reference 10), was used to blend all the AMK for these tests. The significant variables to be noted in the test results were as follows:

TABLE 6. NOVEMBER 12, 1983 AMK TESTS - NO. 4 (HOLED) DIFFUSER, NO. 2 (HOLED) VALVE

- Jet A Cup Test (Viscosity) = 7.6, Clarity = 1.1
- Test Sample Tank AMK (0.26% Polymer Concentration, 12.5-Hour Stabilization) Cup = 1.9, Clarity = 5.5, Filter Ratio = 87.0

Run	Speed, RPM	Sample Point	Flow, gpm	Filter ΔP, End of Run	Cup Test	Clarity	Filter Ratio
N12A	17,400	W_F	3.1		7.2	4.3	1.4
5 Minutes		W_L	7.1	27	7.0	4.1	1.3
N12B	19,400	W_F	3.2		7.0	4.4	14.2
1 Minute		W_L	8.3	27	7.1	4.4	1.2
N12C	21,500	W_F	9.3		7.2	4.7	2.5
2 Minutes		W_L	8.7	34	7.2	4.7	11.9
N12D	27,900	W_F	22.1		7.2	4.3	2.6
1 Minute		W_L	10.6	40	7.2	4.2	2.6
N12E	30,800	W_F	22.3		7.0	4.1	1.6
1 Minute		W_L	12.1	30	7.2	4.1	2.0
N12F	31,800	W_F	22.5		7.0	3.9	1.4
1 Minute		W_L	12.8	25	7.2	3.9	1.5
N12H	24,000	W_F	9.3		7.2	4.1	1.3
2 Minutes		W_L	10.5	22	7.2	4.2	1.7
N12I	22,000	W_F	3.2		7.2	3.9	1.3
5 Minutes		W_L	9.6	14	7.2	4.0	1.4

TABLE 7. NOVEMBER 15, 1983 AMK TESTS - NO. 4 (HOLED) DIFFUSER, NO. 2 (HOLED) VALVE, SINGLE PASS (W_F) THROUGH DEGRADER, BYPASS LOOP TO DISCHARGE

- Jet A Cup Test (Viscosity) = 7.6, Clarity = 1.1
- Test Sample Tank AMK (0.27% Polymer Concentration, 13.5-Hour Stabilization) Cup = 1.8, Clarity = 6.9, Filter Ratio = 73.0

Run	Speed, RPM	Sample Point	Flow, gpm	Filter ΔP End of Run	Cup Test	Clarity	Filter Ratio
N15H	19,900	W_F	3.0		6.7	4.7	17.4
2.5 Minutes		W_L	1.4	2	7.2	4.2	1.3
N15I	23,900	W_F	9.0		7.2	4.4	1.4
2 Minutes		W_L	4.4	12	7.1	4.5	1.3

- Reference Tank AMK (0.26% Poymer Concentration, 89.0-Hour Stabilization) Cup = 1.9, Clarity = 5.3, Filter Ratio = 90

Run	Speed, RPM	Sample Point	Flow, gpm	Filter ΔP End of Run	Cup Test	Clarity	Filter Ratio
N15K	31,600	W_F	21.7		7.2	4.7	1.2
3 Minutes		W_L	5.6		7.2	4.6	1.3

TABLE 8. NOVEMBER 15, 1983 AMK TESTS - NO. 4 (HOLED) DIFFUSER, NO. 2 (HOLED) VALVE

- Jet A Cup Test (Viscosity) = 7.6, Clarity = 1.1
- Test Sample Tank AMK (0.27% Polymer Concentration, 13.5-Hour Stabilization) Cup = 1.8, Clarity = 6.9, Filter Ratio = 73.0

Run	Speed, RPM	Sample Point	Flow, gpm	Filter ΔP, End of Run	Cup Test	Clarity	Filter Ratio
N15A	20,000	W_F	3.0		6.8	4.7	1.2
5 Minutes		W_L	8.6	24	6.4	4.3	1.2
N15B	22,000	W_F	3.0		7.1	3.9	1.2
5 Minutes		W_L	9.3	25	6.7	3.7	1.2
N15C	24,000	W_F	3.0		7.2	4.5	1.2
5 Minutes		W_L	10.4	25	7.1	3.5	1.2
N15D	24,000	W_F	9.3		7.0	4.9	1.3
2 Minutes		W_L	9.8	38	7.2	5.0	17.0
N15E	25,900	W_F	9.2		7.3	4.3	1.3
2 Minutes		W_L	10.6	36	7.2	4.1	1.3
N15F	29,500	W_F	21.7		7.2	3.7	1.3
1 Minute		W_L	11.7	50	7.2	3.8	1.7
N15G	31,500	W_F	21.9		7.2	4.0	1.3
1 Minute		W_L	12.8	42	7.3	4.1	1.4

TABLE 9. NOVEMBER 17, 1983 AMK REPEAT TESTS - NO. 4 (HOLED) DIFFUSER, NO. 2 (HOLED) VALVE

- Jet A Cup Test (Viscosity) = 7.6, Clarity = 1.1
- Reference Tank AMK (0.26% Polymer Concentration, 134.5-Hour Stabilization) Cup = 1.9, Clarity = 5.3, Filter Ratio = 90.0

Run	Speed, RPM	Sample Point	Flow, gpm	Filter ΔP, End of Run	Cup Test	Clarity	Filter Ratio
N17A	19,800	W_F	3.3		7.2	4.8	1.2
5 Minutes		W_L	8.5		7.2	4.8	1.2
N17B	19,900	W_F	3.1		7.2	4.8	1.2
5 Minutes		W_L	8.4	28	7.2	4.8	1.2
N17C	24,000	W_F	9.2		7.2	4.9	1.3
3.3 Minutes		W_L	9.7	40	7.0	4.9	1.2

TABLE 10. AMK TESTS, NOVEMBER 17, 1983 - SHORT-TIME TANK STABILIZATION, SINGLE PASS (W_F) THROUGH DEGRADER, BYPASS LOOP TO DISCHARGE

- No. 4 (Holed) Diffuser, No. 2 (Holed) Valve
- Single Pass (W_F) Through Degrader, Bypass Loop to System Discharge
- Jet A Cup Test (Viscosity) = 7.6, Clarity = 1.1
- Test Sample Tank AMK (0.28% Polymer Concentration, 0.75-Hour Stabilization) Cup = 7.2/5.9, Clarity = 2.2/2.0, Filter Ratio = 44.3/46.4

Run	Speed, RPM	Sample Point	Flow, gpm	Filter ΔP, End of Run	Cup Test	Clarity	Filter Ratio
N17D	19,900	W_F	3.2		6.6	3.0	56.6
5.2 Minutes		W_L	8.5	24	6.8	3.0	36.3
N17E	23,900	W_F	9.2		6.9	2.9	40.7
2 Minutes		W_L	9.8	28	7.1	2.9	46.2
N17F	31,000	W_F	22.2		7.2	2.9	33.3
1.3 Minutes		W_L	12.0	34	7.0	2.8	43.4
N17G	31,500	W_F	22.2		6.6	2.9	46.3
2.3 Minutes		W_L	12.7	28	7.0	2.9	32.2

- No. 3 (Channeled) Diffuser, No. 2 (Holed) Valve
- Test Sample Tank AMK (3.5-Hour Stabilization)

Run	Speed, RPM	Sample Point	Flow, gpm	Filter ΔP, End of Run	Cup Test	Clarity	Filter Ratio
N17J	31,400	W_F	21.6		6.8	2.7	42.7
1.4 Minutes		W_L	14.0	40	6.6	2.7	16.2

TABLE 11. AMK TESTS, NOVEMBER 17, 1983 - MIXED-RUN TANKS, SINGLE PASS (W_F) THROUGH DEGRADER, BYPASS LOOP TO DISCHARGE

- No. 3 (Channeled) Diffuser, No. 2 (Holed) Valve
- Single Pass (W_F) Through Degrader, Bypass Loop to System Discharge
- Jet A Cup Test (Viscosity) = 7.6, Clarity = 1.1, Aromatics = 17.6%, Water = 56 ppm (ASTM-D1533)
- 50% Test Sample Tank (4.0-Hour Stabilization) + 50% Reference Tank (139-Hour Stabilization)

Run	Speed, RPM	Sample Point	Flow, gpm	Filter ΔP, End of Run	Cup Test	Clarity	Filter Ratio
N17I	23,800	W_F	9.1		7.2	3.6	2.4
2 Minutes		W_L	10.9	36			
N17H	19,900	W_F	3.1		7.2	3.5	1.5
5 Minutes		W_L	8.5	20	7.1	3.5	1.5

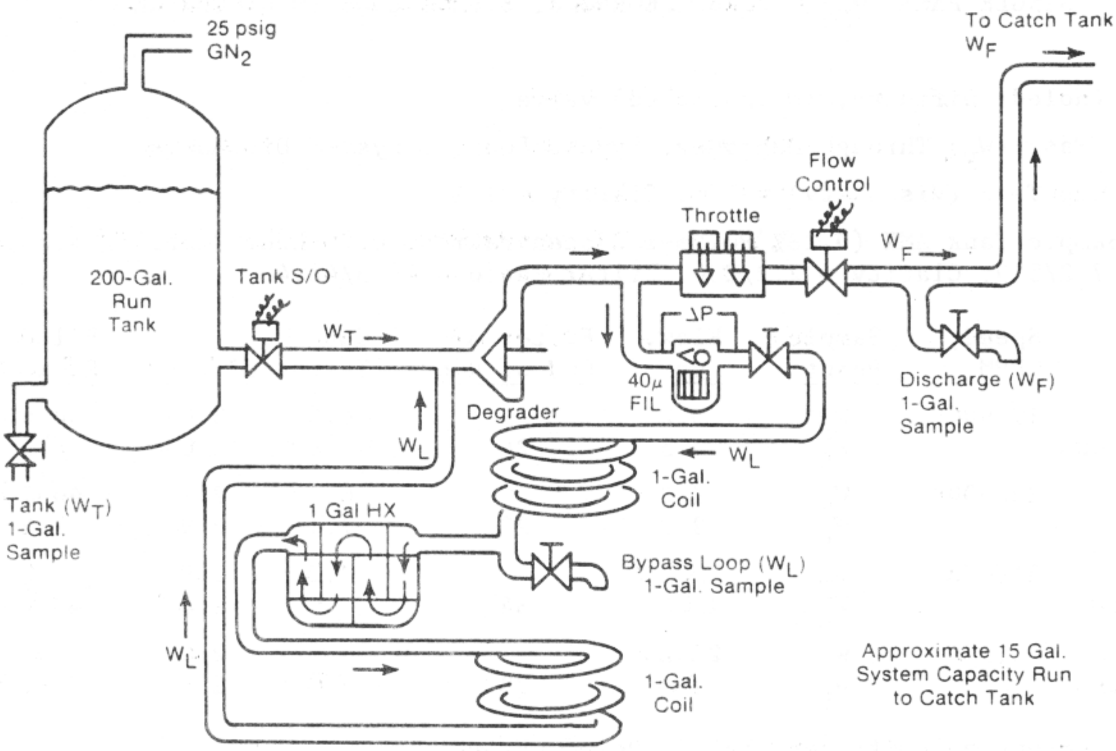


FIGURE 49. SIMPLIFIED AMK TEST SCHEMATIC

- Degrader Speed and Fuel Flow
- Length of Test Run
- Stabilization Time for AMK after Blending
- Testing with and without Recirculation

Considering the above factors, the following results and conclusions were reached. Filter ratios of 1.2 were obtained for all flows and power settings from idle through takeoff except in the case of the short AMK stabilization tests. In Tables 6 through 8, the high filter ratios, in the range of 10 to 20, were the result of samples being contaminated with undegraded fuel. When a sample was taken after a test run, the system had to be back-filled with undegraded AMK or Jet A before the next test could be run. During the next run, gradual mixing in the recirculation loop resulted in an initial filter ΔP rise that gradually decreased. If AMK had been used to back-fill the system, the increase in pressure differential was due to shear-induced gel, a normal phenomenon of undegraded AMK flowing through a filter.

If Jet A had been used to purge the system, a different gelling mechanism was responsible for the increased pressure differential and higher filter ratio. This gel, called "precipitate gel" by General Electric, collected on the up-stream side of the filter; it was filtered from the flow in the same way as a contaminant. A complete discussion of gelling is documented later in this report and in (References 8 and 9). In normal test sequences, the precipitate gel was dissolved readily by either degraded AMK or Jet A flowing through the test apparatus; however, the low fuel flows and short duration of the last test sequence did not permit this to happen (the AMK ran out), and the gel remained on the filter after the test. When the gel was observed after the last bench test, the mechanism of precipitate gel had not yet been identified. Only through later testing was it determined that the gel encountered during the bench tests was precipitate gel, not shear-induced gel, and therefore was not a function of the performance of the degrader. In Figure 50, precipitate gel accumulated on the upstream side of the sample filter can be seen.

The filter ratio results of the Short-Time Tank Stabilization Test (Table 10) appeared to be unsatisfactory, and further investigation into the use of AMK fuel after short stabilization time was warranted in aircraft testing of the degrader. It should be noted that the high filter ratios (30 to 60), which normally denote poor degradation, might not necessarily mean that the fuel would be unsuitable (produce gel) in the engine. In this test series, two hours elapsed between the time the degrader sample was taken and the time the fuel was characterized for filter ratio.

The tests shown in Table 7 were performed without the benefit of any fuel recirculation; all AMK went through the pump/degrader only one time. This test assessed the performance of the pump/degrader in a configuration without the fuel-cooling loop. These tests showed that the pump/degrader was a viable system without the benefits of recirculation which reintroduced degraded fuel to the pump in multiple passes. This capability was investigated further during the aircraft testing of the degraders.

- Flow Passes Through Filter from Outside to Inside

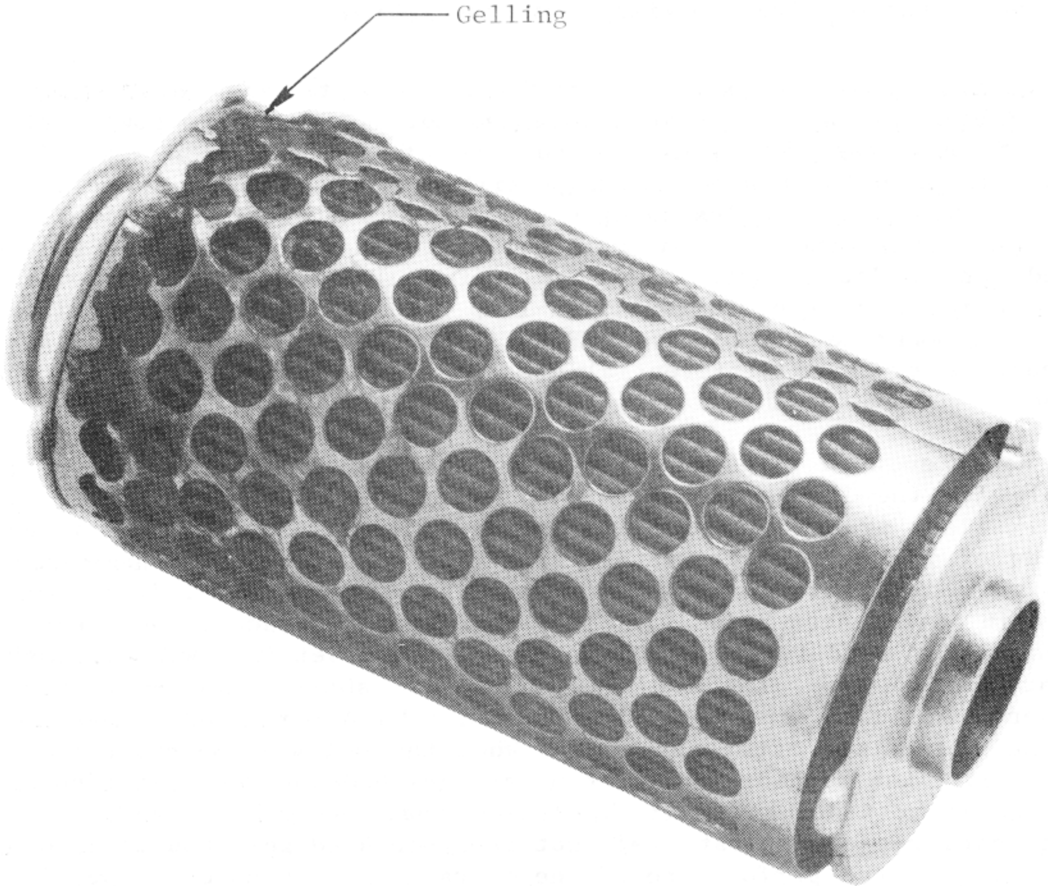


FIGURE 50. FUEL BYPASS FILTER SHOWING EVIDENCE OF AMK PRECIPITATE GEL

A special diffuser (designated No. 3, channeled) was tested. This diffuser was thought to offer the potential of enhanced degrading capability. Test data did not support these expectations. Possibly, a redesign of the impeller might gain the expected benefits of this diffuser design.

FLUID/THERMODYNAMIC PERFORMANCE. The degrader system, that is, the pump and the throttling valve, were completely stable in terms of pressure and flow during the tests at all ranges of speed and flow. This was a significant accomplishment over the given speed range of 18,000 to 32,000 rpm for this type of centrifugal fuel pump. Typically, this type of pump is designed to be a fixed-speed device operating at a maximum of about 26,000 rpm.

Input power levels, shown in Figure 51, were approximately 25 percent lower than expected and were similar to power levels of the F101 augmentor pump with a closed shutter. This indicated low impeller-internal-recirculation power. Input-power data were checked by calculating the mixed-fuel inlet temperature at the degrader (supply tank temperature plus recirculation loop temperature). The results of the input-power check, shown in Figure 52, indicated data accuracy within ±8 horsepower based on data points where tank temperature and bypass temperature were available for thermal-balance comparison. Pressure rise with the No. 4 (holed) diffuser was as expected. The decision to use the No. 4 diffuser in the degrader system necessitated modification of the computer model. The model had been developed to reflect the No. 3 (channeled) diffuser which had enhanced kinetic energy recovery and therefore higher expected pressure rise. Incorporation of the lower pressure rise and lower input-power requirement into the computer model was the last major adjustment needed in the model for this program. The lower power requirement of the degrader relieved some concerns relating to fuel inlet temperature (downstream of the degrader) during ground operation at high ambient temperatures.

A worst-case condition, simulated degrader starts with the engine shut down (no metered flow), showed good results with the engine pump inlet pressure below 42 psig and acceptable fuel temperatures of 160° F or less after 4 minutes of running at 20,000 rpm. Also, response to the control signal was excellent; the degrader accelerated from 0 to 20,000 rpm in less than one second with minimum speed overshoot. Figure 53 shows actual strip-chart plots of the start-up cycle. Figure 54 shows the performance of the degrader during another extreme condition: fuel depletion at 32,000 rpm. Speed control was good, and system shutdown occurred automatically with no adverse pressure conditions.

MECHANICAL PERFORMANCE. The general mechanical performance of the degrader system components was very good during the break-in and the testing. The only exception was the mechanical carbon face seal of the pump. During the AMK Test, this seal began leaking at an unacceptable rate, and an excessive amount of carbon particles was found in fuel around the nose of the seal. Testing was temporarily interrupted, and the fuel pump cavity was instrumented to measure cavity fuel pressure. Testing resumed following fuel pump reassembly. The new instrumentation indicated that excessively high seal cavity pressure was causing the problem. Testing was completed with provisions to accommodate the leaking seal. Following the test, the seal rotor and carbon element were redesigned for better balance. The new seal was fabricated, installed in another unit, and checked prior to the 15-hour endurance test. Performance of the new balanced seal design was excellent, in terms of leakage, and at 32,000 rpm seal cavity pressure measured 275 psig with 50-psig supply pressure. The decision was made to proceed with the 15-hour endurance and 5-hour endurance/acceptance tests.

ENDURANCE AND ACCEPTANCE TESTS. The degrader system tested during the first series of AMK tests was shipped with all hardware to GAS for installation in the CV880. The pump was returned at a later date for installation of the improved, balanced, shaft seal. The first B720 degrader system was used in the second test, a 15-hour endurance run on recirculating Jet A. The purpose

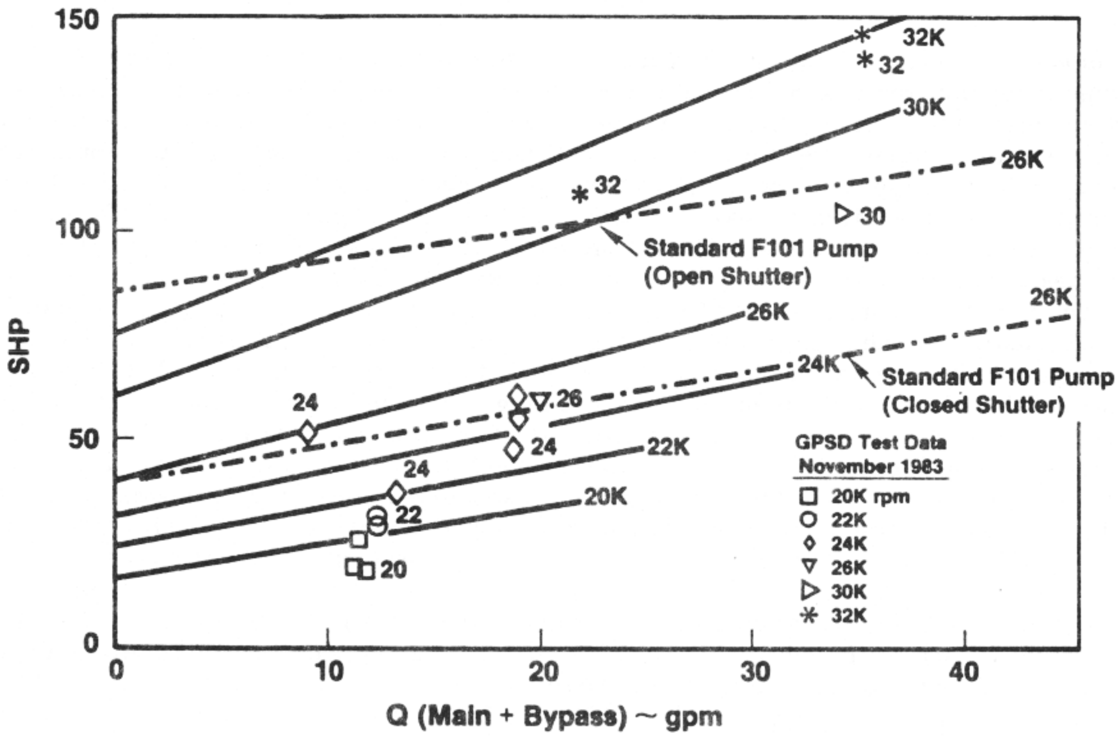


FIGURE 51. DEGRADER SHAFT HORSEPOWER

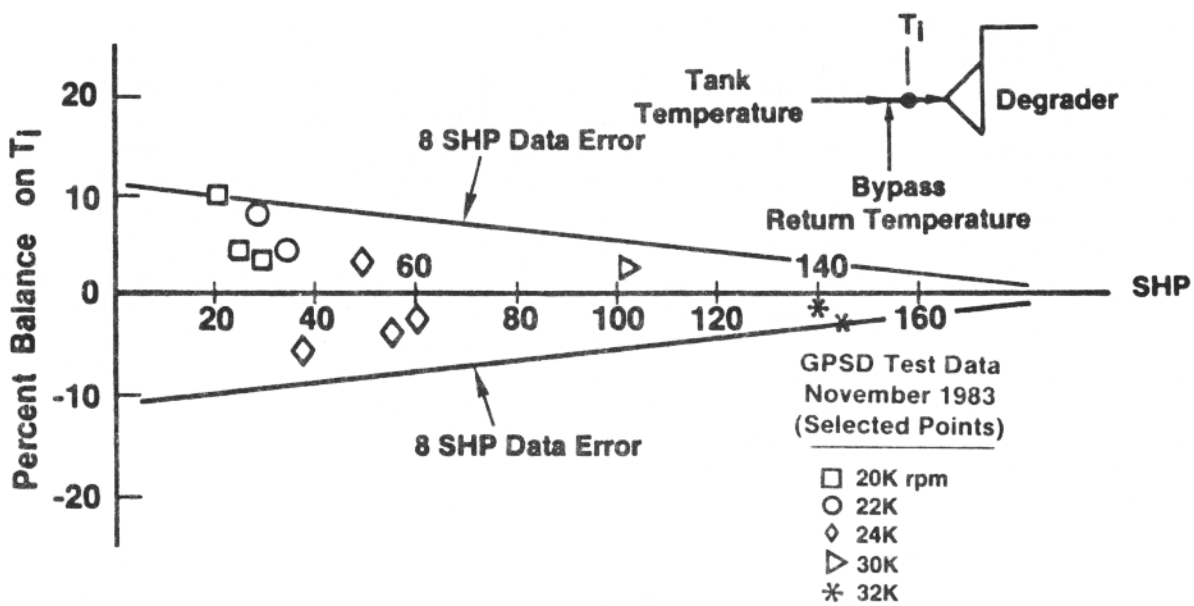


FIGURE 52. DEGRADER SHAFT HORSEPOWER CHECK

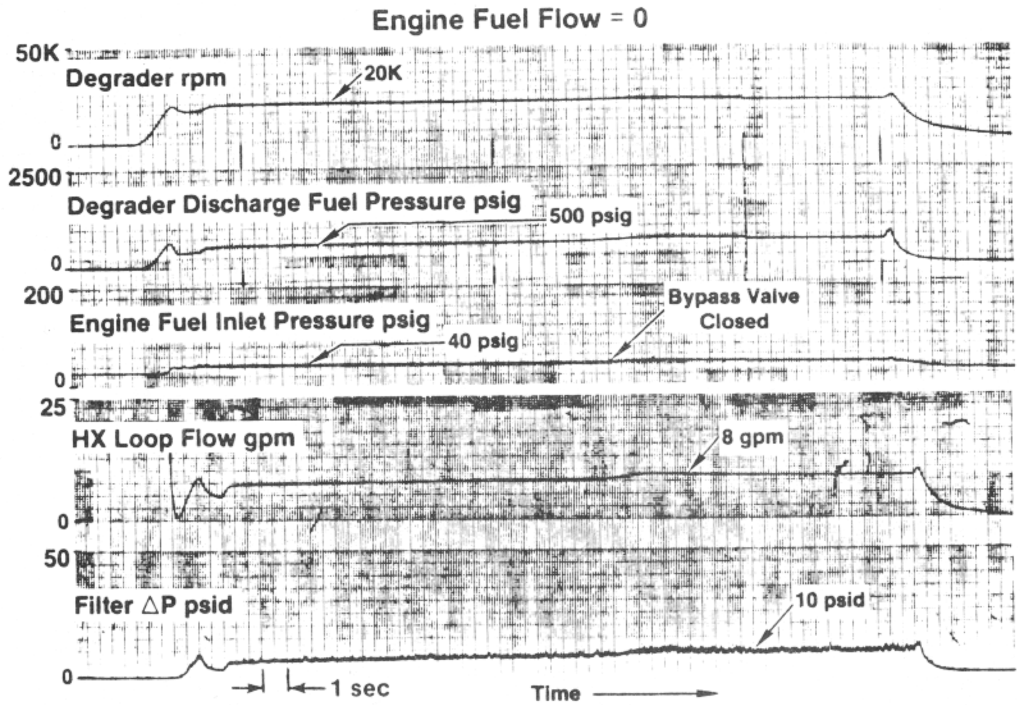


FIGURE 53. FILTER ΔP RESULTS DURING START-UP

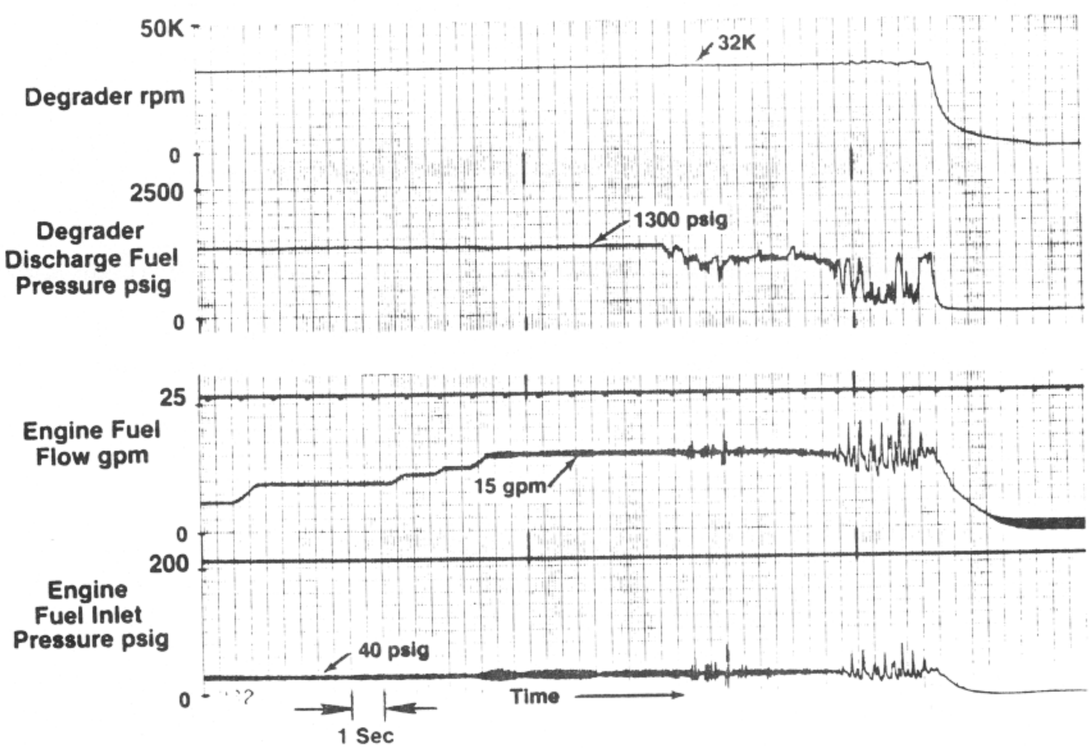


FIGURE 54. RESULT OF FUEL DEPLETION

of the endurance test was to establish the integrity of the mechanical system components.

Prior to the endurance test, the degrader system was examined for conformance to design intent and brought up to speed gradually (as in the original break-in run) to reveal any unusual operating characteristics. Everything appeared in order, and the test was commenced. During the endurance test, the unit was operated at 32,000 rpm for approximately 4 hours and at 20,000 rpm for 1 hour. The remaining 10 hours of testing were divided evenly with 2 hours of each at 22,000, 24,000, 26,000, 28,000, and 30,000 rpm. Fuel-flow schedules were similar to those established in the AMK tests for a given degrader speed.

By the time the 15-hour endurance test was conducted, most minor problems with operation of the system in the test configuration had been obviated, and the endurance test was completed in a little more than two 8-hour shifts.

The redesigned shaft seal exhibited minimal leakage, and posttest teardown inspection found it in as-new condition. The seal seemed to be operating totally on a hydrodynamic fuel film between the carbon nose piece and mating ring. After the endurance test, no component appeared to be life limited for intended use in either the CV880 or BJ20 programs.

The three remaining B720 degrader units were each tested for five hours to evaluate the mechanical integrity of the components. The units were tested at different speeds in increments of 2000 rpm from 18,000 to 32,000 rpm. As with the 15-hour test, no problems were encountered with any of the units during these acceptance tests.

DEGRADER SYSTEM AIRCRAFT TESTS - PHASE I

INTRODUCTION. After the degrader systems had been bench tested at Garrett, confidence was high relating to the mechanical integrity of the components and the control/stability of the system. AMK fuel degradation characteristics were good. The occurrence of gel during the final sequence was associated with mixing of degraded and ungraded AMK in the test apparatus; therefore, General Electric deems it to be a function of the test configuration rather than the performance of the degrader.

Much of the CV880 installation had been completed by the time the first pump/degrader assembly was delivered to General Air Services in December 1983. Final installation was completed early in January, and the degrader system was checked using Jet A in ground and flight tests. By the end of January all minor problems had been solved, and testing with AMK was ready to commence. The AMK in-line blender had been shipped from the FAA Technical Center to General Air Services. A small lab area to perform AMK fuel characterization tests was established in GAS's hangar. Blending and characterization of the fuel were performed by the FAA during the early tests.

PHASE I AND PHASE II AIRCRAFT TESTING. The discussion of CV880 degrader test results is divided into Phase I and Phase II to differentiate the types and purposes of the tests conducted during the program. The original intent of the AMK degrader flight test program was to perform the following test elements within approximately 18 hours of flight testing:

Baseline AMK Flight Test: Assess general aircraft performance with No.3 engine operating on AMK. Test was to be similar to previous flights on Jet A fuel. Altitude-relight was to be evaluated.

High-Altitude, Long-Duration Test: Assess the ability of the system to degrade very cold fuel, down to -40° F if possible.

Fuel-Sloshing Tests: Evaluate effects of turbulence or maneuvers on AMK fuel.

Power Excursions: Determine the engine response at low, medium, and high altitudes.

Go-arounds, Touch-and-Goes, Thrust Reversals: Explore the response of the engine at very low altitudes and on the ground.

Environmental Effects: Investigate effects of ambient temperature, pressure, and especially humidity on AMK.

As the actual test sequences developed, much of Phase I testing was devoted to on-wing ground tests of the degrader and AMK to investigate gelling phenomena encountered in these early tests. Phase II testing involved much more flight testing that was representative of the originally planned testing. A number of the Phase II tests supported the B720 program, and much of the testing was performed at Mojave, California.

A prime degrader-performance goal was to revert the AMK fuel as closely as possible to Jet A characteristics. The presence of gel in the fuel system was not expected and unacceptable. Moreover, the type of gel encountered during the Phase I tests seemed to be much more tenacious than the shear-induced gel, caused by insufficient AMK degradation, which had been reported by earlier investigators. Therefore, after the first AMK ground and flight tests, much of the Phase I testing addressed the nature and possible cause of the gel.

There were some disadvantages to pursuing the investigation of gel by using the CV880 as an on-wing laboratory. Nevertheless, general program objectives included evaluation of AMK in a real-world, aircraft environment. This fact, coupled with the pressing need to develop a data base on the use of AMK and the degrader for the CID program, prompted the engine and degrader system ground tests.

SUMMARY - PHASE I TEST RESULTS. Phase I testing comprised the first 13 on-wing tests of the General Electric AMK degrader system. Table 12 summarizes the results of these tests. Operation of the degrader system throughout these tests was reliable and within the predicted boundaries for power input and system fluid-temperature rise. The system permitted ignition and operation of the No. 3 CJ805 engine throughout the aircraft flight envelope.

TABLE 12. PHASE I TESTS

Date, Type, AMK Operating Time	Purpose	Results and Comments
2/09/84, Ground Engine, 0:40	First engine operation with degrader and AMK.	Engine and degrader ran well. Gel found on main fuel filter and sampler filter.
2/10/84 Flight 1:15	First flight operation on AMK fuel.	Heavy buildup of gel on downstream side of main and sampler filters.
2/18/84 Ground System 0:18	Check to see if gel would reform. Same AMK used as first two tests (10 days old).	Sampler filter ΔP indicated gel formation. Gel not visible on filter.
3/02/84 Ground System 0:38	Compare new and old AMK blends. Monitor effects of switching Jet A, old AMK, new AMK.	Jet A to old AMK (idle flow 1200 pph): no hard gel, ΔP mixing spike. Old to new AMK (idle flow 1200 pph): no hard gel, no mixing spike; very high degraded filter ratios (51.9 and 21.7). New AMK (max cruise 3400 pph): no hard gel. New to old AMK (max cruise 3400 pph): slight gel formation on sampler filter.
3/03/84 Ground System 0:20	Assess ability of pump alone to degrade AMK. Assess degradation due to throttling valve, recirculation loop, and boost pumps.	Old (2/8/84) fuel, 1500 pph. Jet A to AMK pressure spike on first of two filters in series → precipitate filters out, no hard gel; filter ratio from tank = 45, through pump/degrader = 1.5, through throttling valve = 1.2. Boost pump operation had little effect on degrader performance.
3/06/84 Ground Engine 0:28	Use old (2/8/84) AMK to complete ground run without gel.	No visible gel, slight pressure rise on main fuel filter, none noticed on other filters.
5/08/84 Ground System 0:30	Jet A with glycol to remove mixing spike. Correlate transition velocity with gelling. New AMK blend.	No mixing spike. Transition velocity results as expected. No visible gel; microscopic inspection showed gel initiation.

TABLE 12. PHASE I TESTS (CONCLUDED)

Date, Type, AMK Operating Time	Purpose	Results and Comments
5/09/84 Ground Engine 0:20	Basic repeat of 5/8/84 system test.	No ΔP mixing spike. Microscopic evidence of gel on sampler and main fuel filters; ΔP more noticeable on main fuel filter.
5/31/84 Ground System 0:35	Test new batch of AMK slurry. Note water content of base Jet A.	High H_2O content led to AMK blend with 286 ppm, showed up as high NTU (18-20). Heavy buildup of hard gel on sample filter; F/R = 2.2. Tank boost pumps and fuel lines induce unintentional degradation.
6/01/84 Ground System 0:30	Assess bidirectional filter flow, 5/31/84 fuel, 900 pph.	No filter ΔP evident. No gel evident.
6/20/84 Flight 0:36	Long-duration flight	Test shortened due to loss of cabin pressure. Severe hard-gel buildup on sampler and main fuel filters.
6/22/84 Flight 3:26	Long-duration flight. Attempt higher degrader specific power.	Hard-gel buildup on sampler and main fuel filters severe, clogged some fuel nozzles. Higher degrader speed at fixed flow had little effect on gel formation.
6/27/84 Ground Flight 1:00	Assess performance of 8-day old AMK. Determine if fuel nozzles will plug without filters.	Hard gel on sampler filter. Nozzles did not clog without filters.

during the initial ground and flight tests, gel formation was noticed on some of the fuel-system filters. It should be noted that no other significant problems relating to the degrader, engine, or aircraft fuel system resulted due to exposure to or operation on AMK and that, even in the case of gel formation, problem areas were isolated. Except for the gel, little difference could be detected between operation of the No. 3 AMK engine and the No. 2 reference (Jet A) engine. For this reason, a more detailed discussion of the degrader and engine performance characteristics will be included in the Phase II test results. The narrative for the Phase I test results will focus on the

However, investigation of gelling phenomena. The test results led General Electric to conclude that there were actually three types of gel encountered during the program: shear-induced, precipitate, and "hard" gel.

SHEAR-INDUCED GEL. Shear-induced gel forms on the downstream side of a screen when fluid flow through the screen is above a critical velocity. This gel-formation mechanism involves the nature of AMK non-Newtonian viscous flow; that is, the fluid shear-thickens. Shear-induced gel can be observed on the downstream side of the screen used for the filter ratio test. It is the mechanism that causes AMK to flow at a slower rate than Jet A during this test. This is a transient gel, however, and quickly dissolves when the flow falls below a critical velocity. With No. 3 engine fuel filters instrumented to measure ΔP across the filter, formation of shear-induced gel would appear as a "step" response. In other words, when flow conditions allowed formation of shear-induced gel, the filter would exhibit a ΔP increase that would level off rather quickly and maintain the reading under steady-state conditions.

One function of the degrader is to break the bonds of the FM9 polymer to the point where shear-induced gel will not form on the screens and filters of the engine fuel system. By the end of Phase I testing, the other two types of gel encountered were easily differentiated from shear-induced gel in nature and occurrence. The appearance of the other two gels did not seem to correlate well with occurrence of shear-induced gel. Both precipitate and hard gels formed during the tests when degraded filter ratios were low (1.2 to 1.4) and, in one experiment, hard gel formed when the flow through a filter element was below the critical transition velocity associated with shear-induced gel.

PRECIPITATE GEL. Precipitate gel was produced by the spontaneous mixing of AMK and Jet A fuels. AMK contains glycol in a concentration of 0.6 to 0.9 percent by weight. Glycol dissolves and disperses very rapidly in kerosene and provides the means for dispersion of FM9 polymer in Jet A. However, when AMK came into contact with Jet A containing no glycol, General Electric theorized that there was competition between the two fuels for the glycol. The glycol apparently dissolved so quickly in untreated Jet A that it left the FM9 in localized concentrations; thus, the mixture of the two fuels was not homogeneous. When the heterogeneous mixture flowed through a screen, filtering took place and gel collected on the upstream side of the screen. Once the interface of the Jet A and AMK passed through the filter, the normal flow of either Jet A or degraded AMK would take the precipitated gel into solution.

In almost every instance, precipitate gel was very easy to identify in plotted test data. It showed up as approximately a 45-psi pressure spike across the 40-μm sampler filter and persisted for about 2 minutes. Figure 55 shows this spike occurring at two different occasions during the first AMK flight test. Until the degrader-system test run on May 8, this characteristic pressure spike occurred in all tests when Jet A and AMK were mixed. In the May 8 test, the Jet A was treated with 0.6 percent (weight) glycol (7.4 pounds of glycol to 1246 pounds of Jet A). The test setup is shown in Figure 56. The degrader outlet was disconnected from the engine, so fuel ran to a catch tank. Fuel was supplied at gravity feed (no boost pumps) from the aircraft No. 4 tank (Jet A), a four-barrel pallet of AMK, or a four-barrel pallet of glycol-treated Jet A. A hand-operated flow control valve was used to set degrader

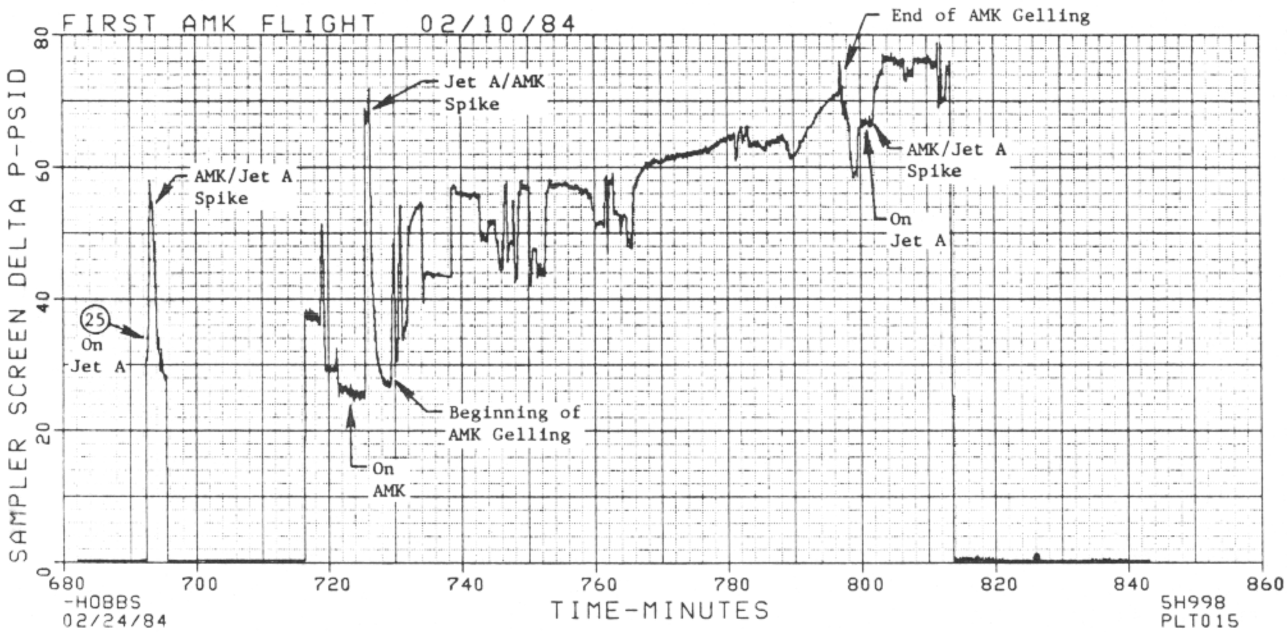


FIGURE 55. DEGRADER RECIRCULATION SAMPLER FILTER ΔP - FUNCTION OF DEGRADER PRESSURE

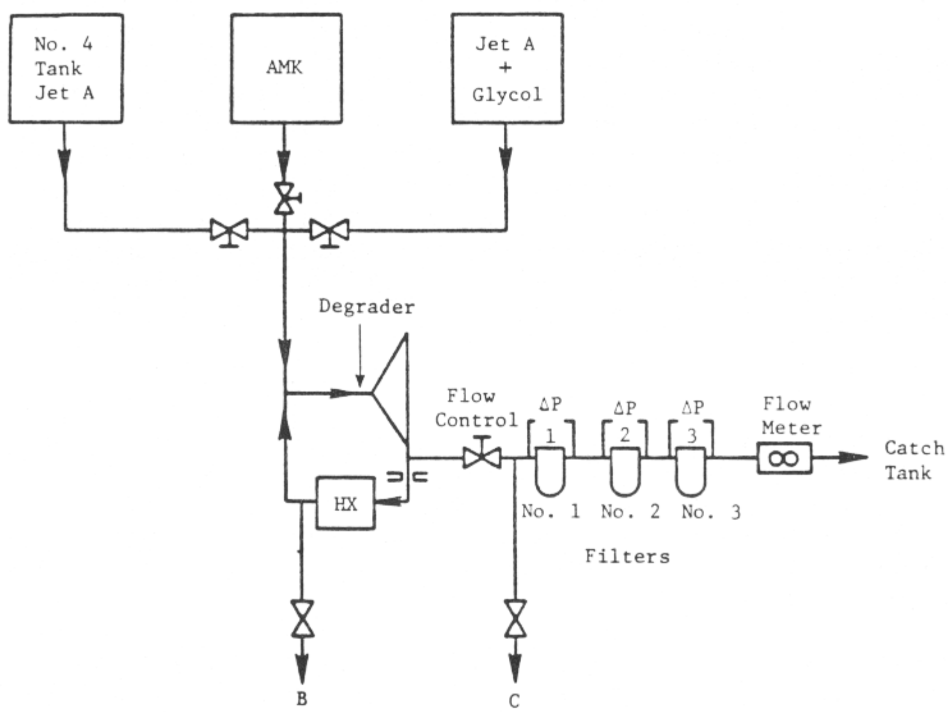


FIGURE 56. SYSTEM TEST SETUP

system through flow. An engine-type flowmeter provided speed scheduling for the degrader. Three filters were installed downstream of the degrader: a CJ805 main filter (No. 1), a sampler filter (No. 2), and a sampler filter with half the filter screen blocked (No. 3).

System tests began at 23:00 (1380 computer tape time). First, the system was flushed with Jet A from the No. 4 tank. Jet A plus glycol was introduced at 1386 minutes. Then the degrader was restarted at 1388 on AMK. There were no filter ΔP spikes as the result of the transfer from Jet A plus glycol to AMK. Runs were made at 500, 2700, and 4700 pph. Figure 57 shows the fuel flow and test events. Figures 58, 59, and 60 are plots of pressure drop across the filters in the system; the typical spike did not appear.

An interesting aspect relating to precipitate gel was noticed in the system test conducted on March 3. This test was run before the idea of treating Jet A with glycol was developed. Figure 61 is a schematic of the March 3 test configuration. On one of the test runs that was started on Jet A and then switched to AMK, the sampler filter upstream of the throttling valve indicated a pressure spike while the sampler filter downstream of the valve showed no signs of pressure increase. These results support the theory that precipitate gel is not flow- or shear-induced; it is simply filtered out of the fluid as though it were a contaminant.

THE NATURE OF HARD GEL. The second type of gel discovered during degrader flight tests of the CV880 was called hard gel. This gel attached tenaciously to the downstream side of screens, was cumulative with additional flow, and became hard when removed from the fuel system and allowed to dry. Due to the cumulative nature of the gel, filter ΔP response at stable conditions would show a steady, gradual increase with the formation of hard gel. From microscopic inspection, General Electric theorized that hard gel accumulated by a three-step filtration processes. First, the screen wires become coated with a microscopic thickness of hard gel. Second, the gel grows from the intersection of screen wires. Finally, the screen openings are filled with gel. Magnified photos of sampler filters used in the May 8 and 9 tests illustrate this process. Figure 62 shows the initial-coating phase at three different levels of magnification. Figure 63 shows the growth of gel beginning at the intersection of screen wires. Figure 64 shows the filter becoming blocked with gel that has a noticeably higher concentration at the intersection of the filter wires.

Flow would continue through a filter even with a heavy accumulation of gel on the filter element. This suggested to General Electric that the gel was anisotropic in nature, exhibiting a structure through which fuel would flow with sufficient pressure gradient across the filter. Figure 65 shows an area of a sampler filter element (downstream side) at a 45° camera angle. The grainy or porous nature of the hard gel can be seen in this photograph which is magnified 1200 times.

When dry, however, this gel became very hard and impervious to flow, much like several coats of paint. Dry gel could be softened by prolonged soaking in

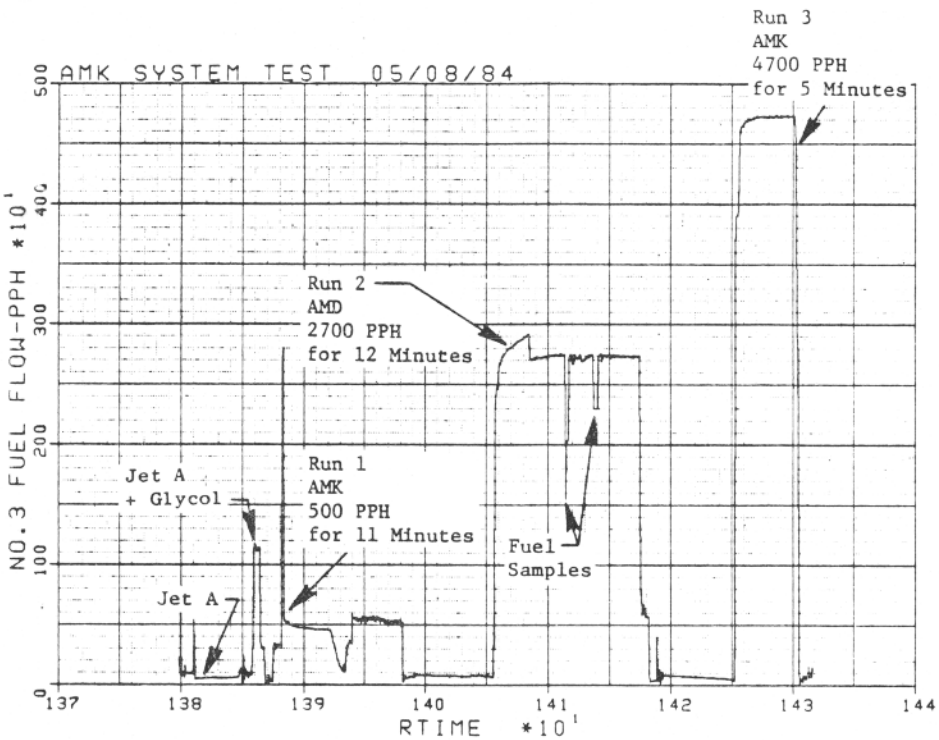


FIGURE 57. SYSTEM TEST FUEL FLOW AND TEST EVENTS

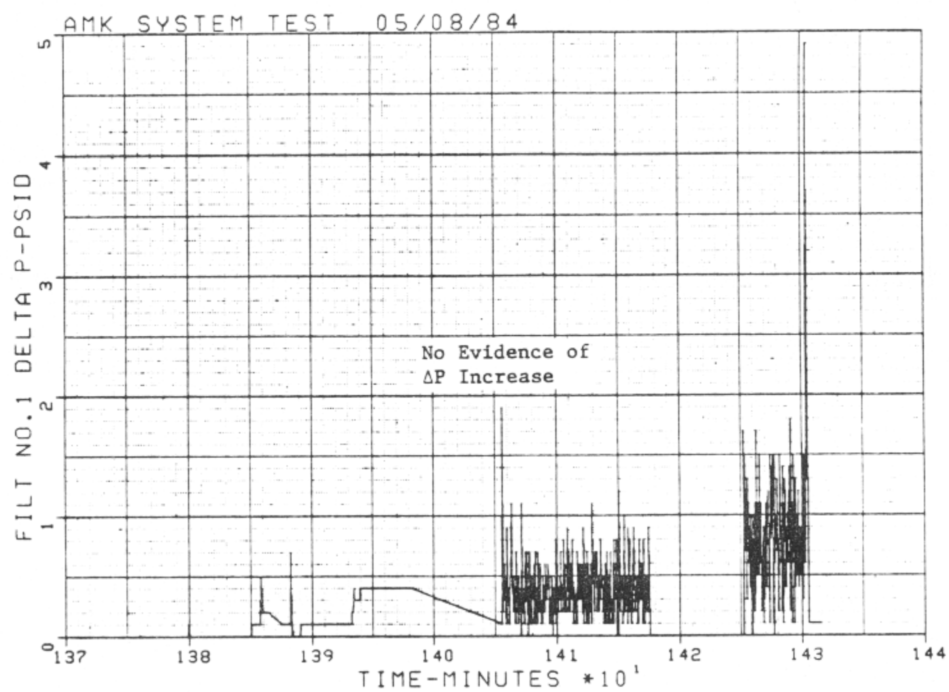


FIGURE 58. NUMBER 1 (MAIN) FILTER ΔP

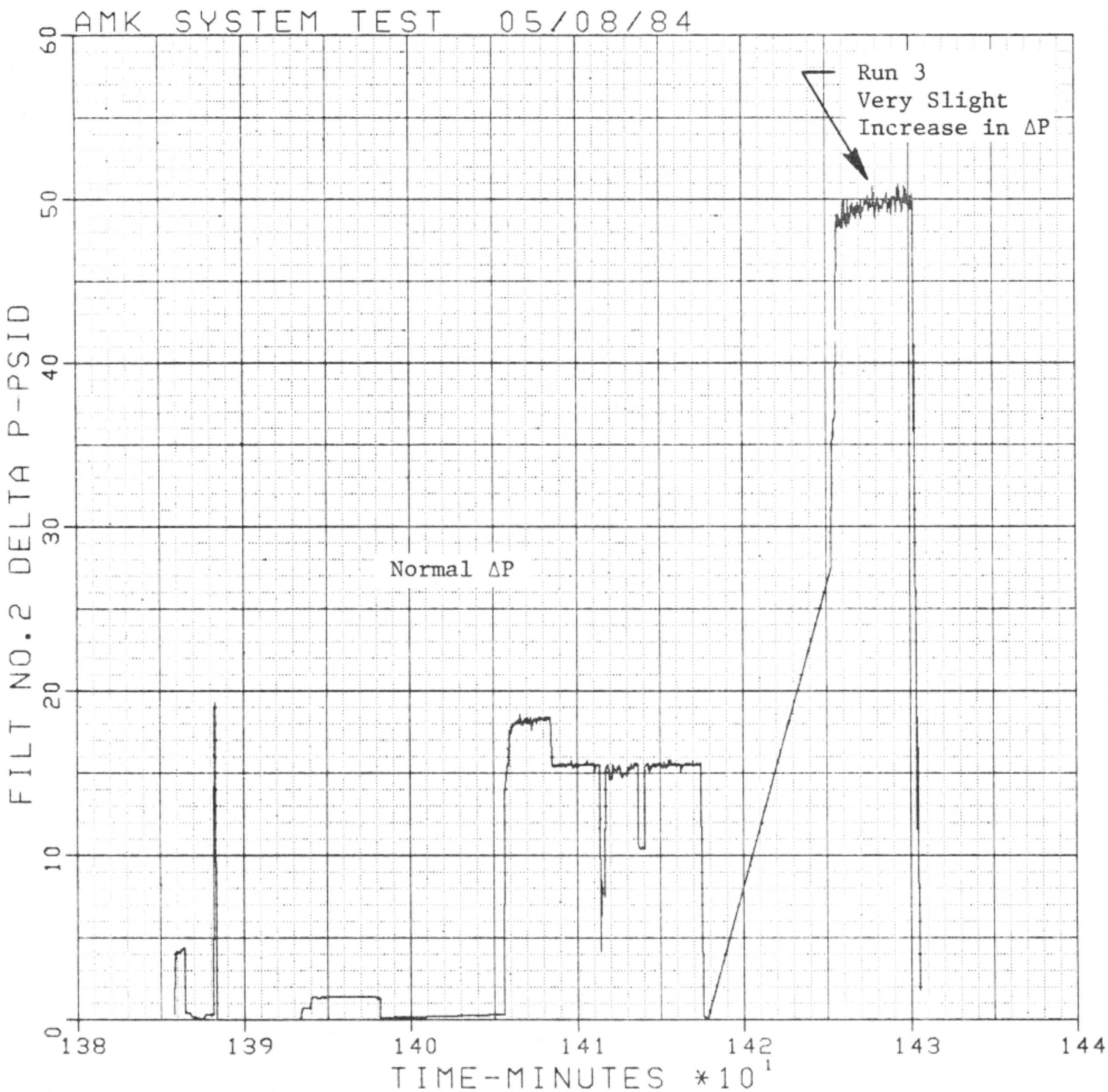


FIGURE 59. NUMBER 2 SAMPLER FILTER ΔP

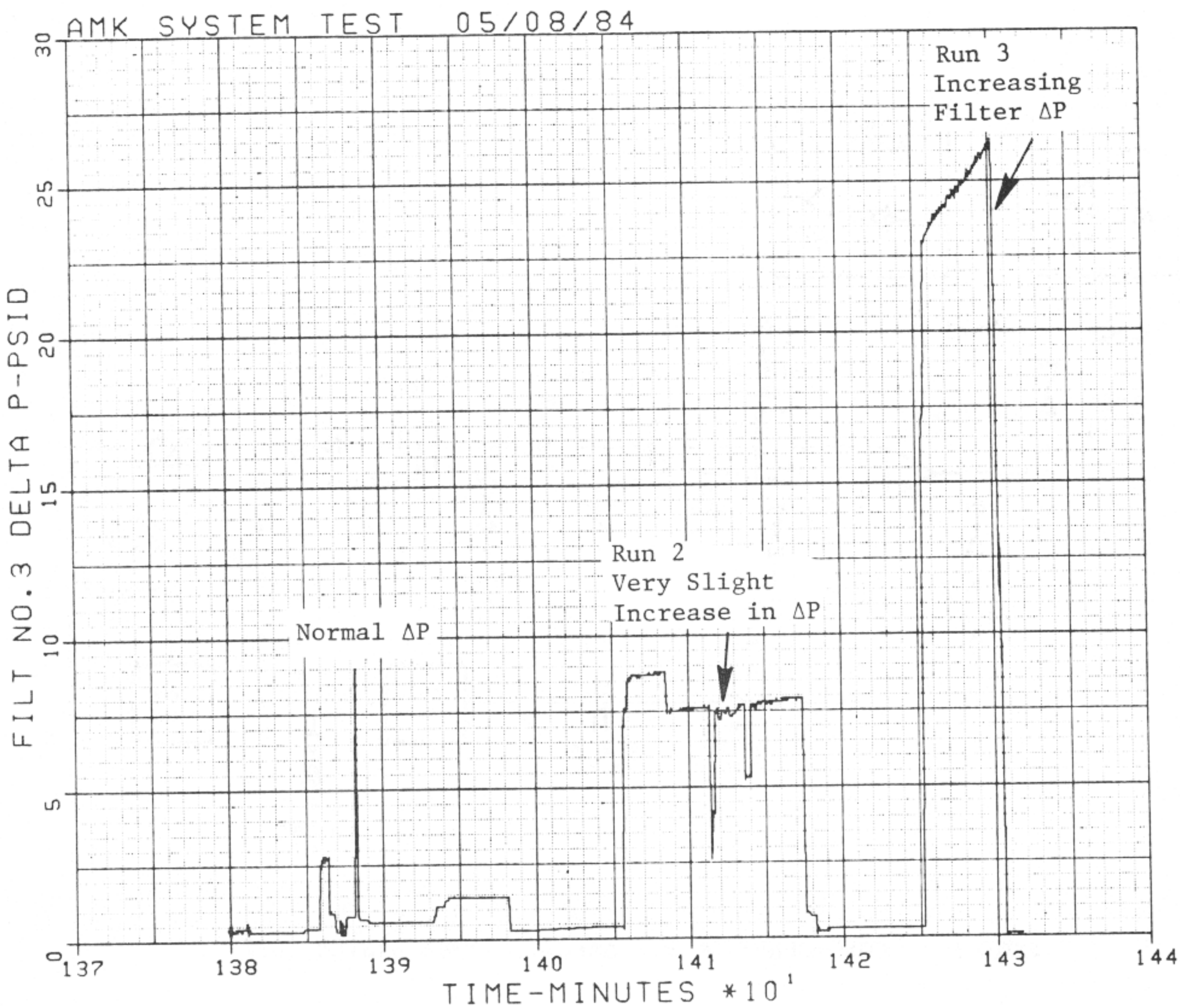


FIGURE 60. NUMBER 3 SAMPLER FILTER ΔP

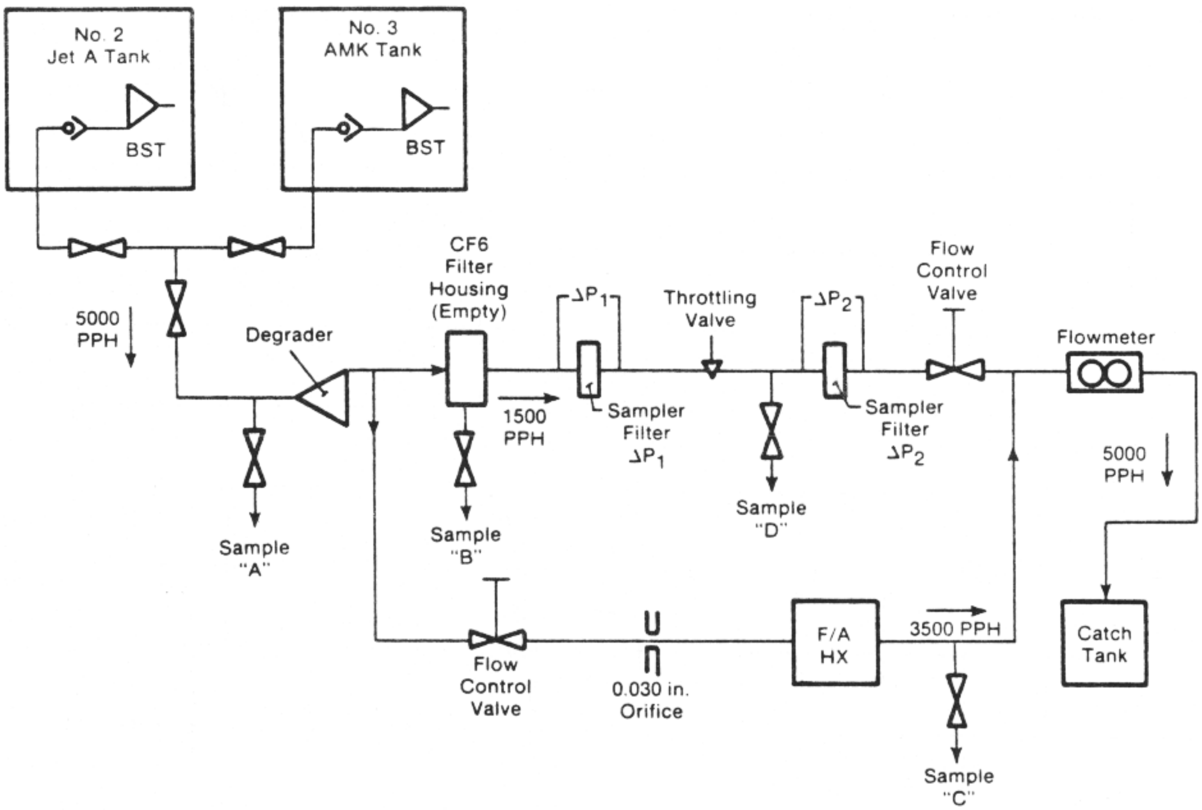


FIGURE 61. CONFIGURATION FOR MARCH 3, 1984 SYSTEM TEST

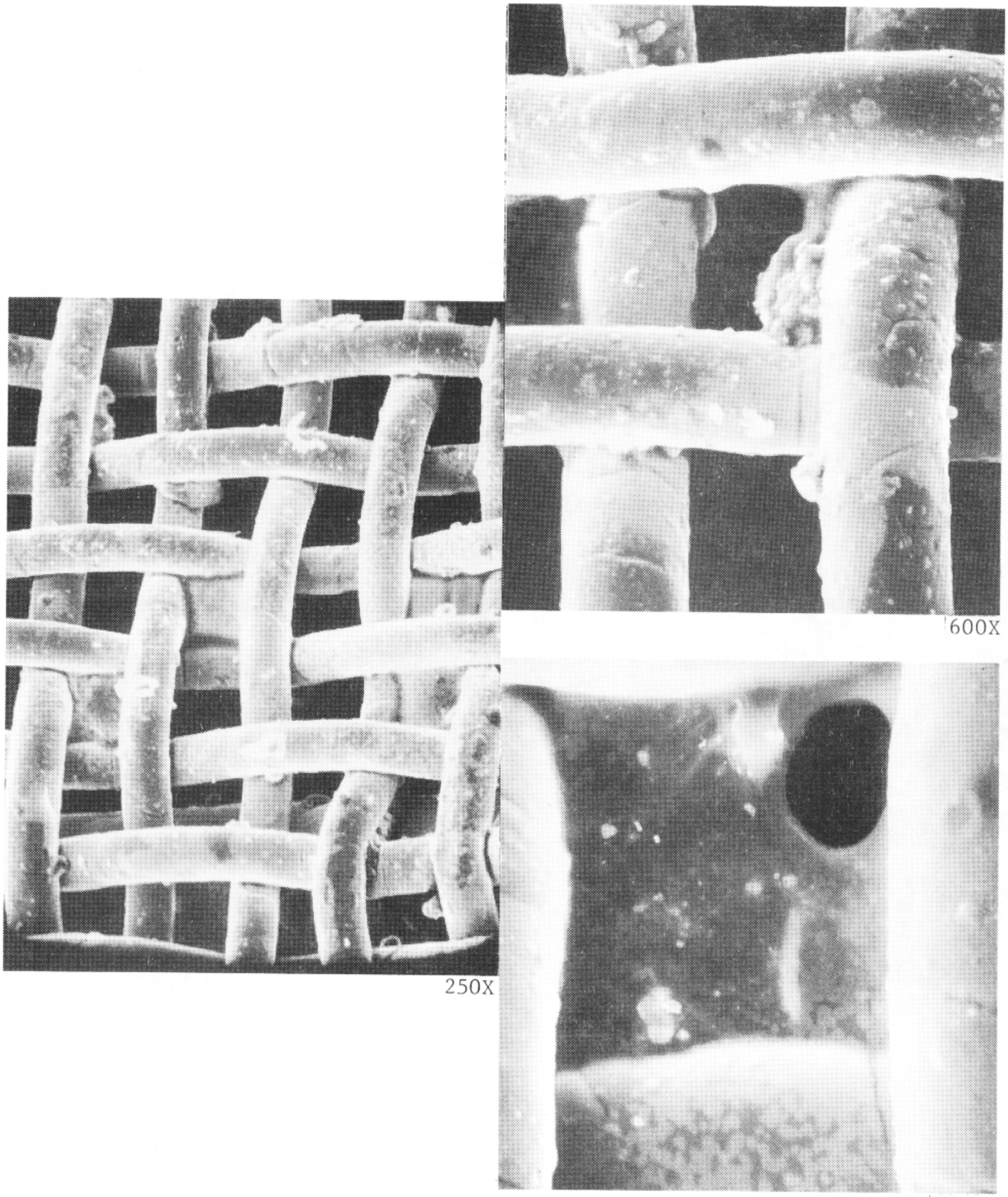


FIGURE 62. INITIAL COATING PHASE OF HARD GEL FROM UPSTREAM SIDE OF FILTER

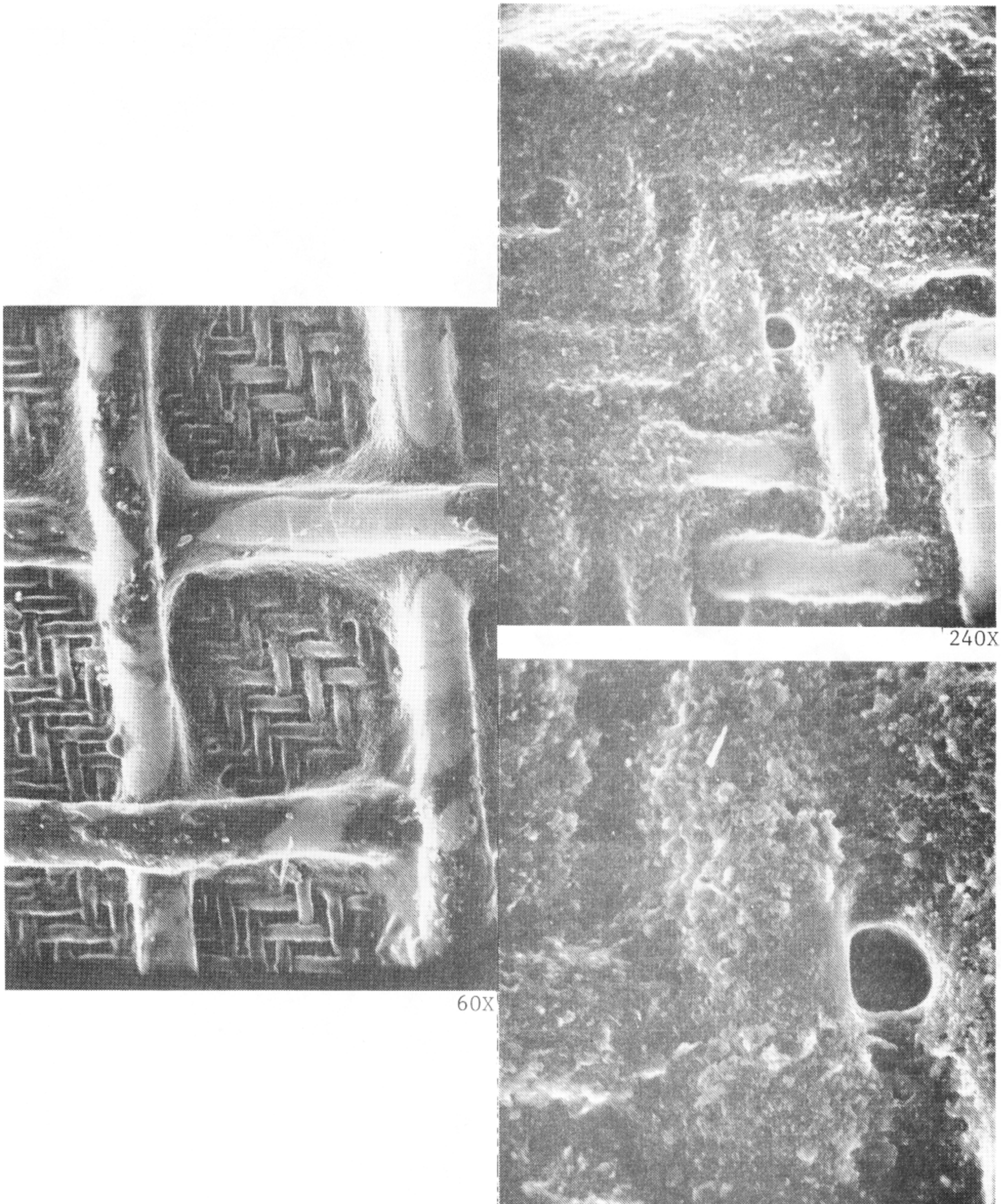


FIGURE 63. GROWTH OF HARD GEL FROM WIRE INTERSECTIONS, VIEW OF DOWNSTREAM SIDE OF FILTER

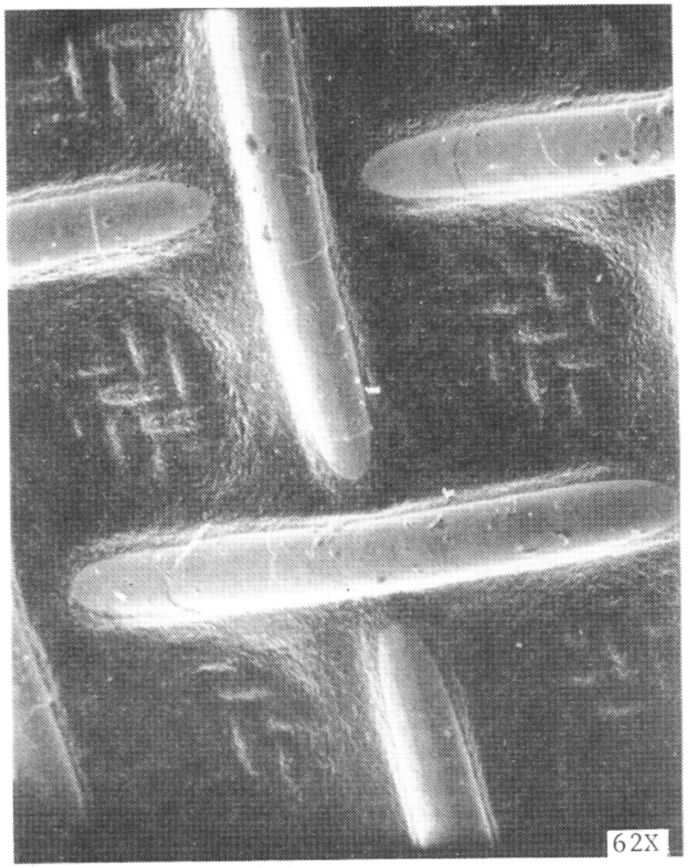
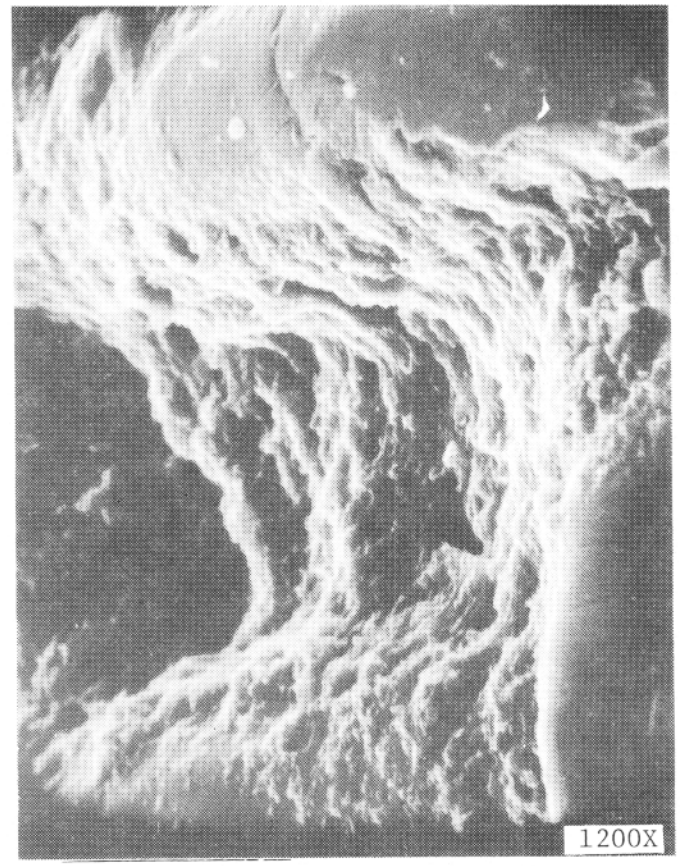


FIGURE 64. PROGRESSIVE BLOCKING OF FILTER (DOWNSTREAM VIEW)



45° Camera Angle

FIGURE 65. GRAINY OR POROUS NATURE OF AMK HARD GEL

methylene chloride (lacquer remover) and then removed with ordinary solvents. Figure 66 shows a fuel-nozzle screen retaining spring coated with dry, hard gel. Figure 67 shows a wash screen coated with softer, more pliable hard gel that had not yet fully dried.

OCCURRENCE OF HARD GEL DURING TESTING. The following discussion describes a flight test on June 20 from Atlantic City Airport (ACY) to Greater Cincinnati Airport (CVG). The occurrence of hard gel during this test was typical of the results of the three other flight tests conducted during the Phase I testing on February 10, June 22, and June 27.

To aid interpretation of the computerized plots for the degrader aircraft testing in either Phase I or Phase II, it is helpful to understand some of the basics of the CV880 and CJ805 fuel systems.

Aircraft Fuel Supply System Operation. Figure 68 is a schematic of the relevant aircraft fuel-supply components as related to the degrader in this program. In test configuration, the No. 3 engine received fuel from the No. 3 main tank or the center tank. AMK was used only in the No. 3 tank. The tank or fuel selected could be determined by the magnitude of degrader fuel inlet pressure. The center tank, with hydraulic motor boost pumps, produced nearly twice the pressure of the No. 3 tank that had electric motor pumps. Thus, to determine which fuel (AMK or Jet A) was delivered to the engine, simply note the relative difference in degrader inlet pressure. An exception is during the time in which the center tank feeds several engines. This caused a drop in center-tank boost pressure, nearer to that of the No. 3 boost pump. This situation is typical during taxi, takeoff, and landing when the center-tank boost was used as a backup to the main tank boost pumps.

Degrader speed in the automatic mode was directly proportional to engine fuel flow and varied from 20,000 rpm at 1,200 pph (or less) to 32,000 rpm at 8,700 pph (or more). Degrader fuel-discharge pressure varied approximately as the square of speed, plus inlet pressure. In the manual mode, degrader speed was constant.

The recirculation line provided cooling for the degraded fuel. Recirculation flow rate was controlled by a fixed orifice. The pressure drop across this orifice was approximately the degrader discharge pressure minus the degrader inlet pressure. Hence, recirculation flow was approximately proportional to the square root of this pressure difference. Sampler filter ΔP was proportional to this pressure difference (degrader discharge minus degrader inlet).

The throttling valve automatically maintained a 40-psig pressure at all times to the engine fuel pump inlet. Throttling valve pressure was measured at the interstage between a 40-psig valve (first stage) and a 50-psig valve (second stage). In attempting to regulate 50 psig, the second stage of the valve was always wide open since this stage was trying to increase pressure above 40 psig. The second stage provided only failure protection for the first stage.

Engine Fuel System Operation. Figure 69 is a schematic of the CJ805 fuel system showing the major components which are addressed in the computer plots

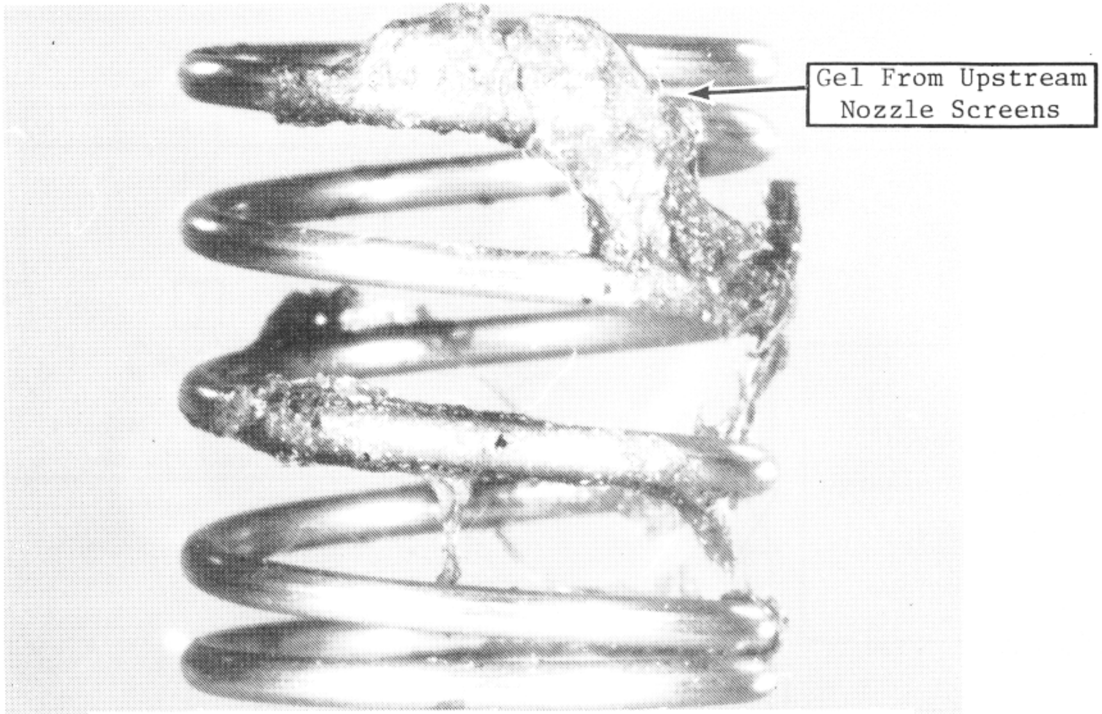


FIGURE 66. DRIED HARD GEL ON RETAINING SPRING

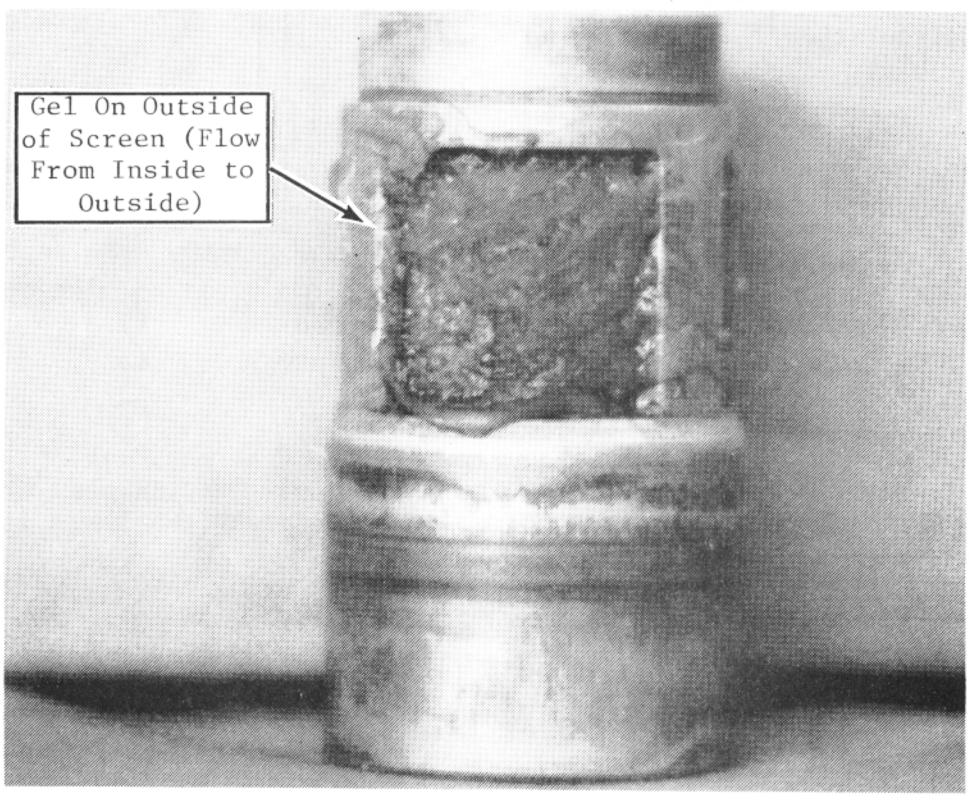


FIGURE 67. WET HARD GEL ON WASH SCREEN

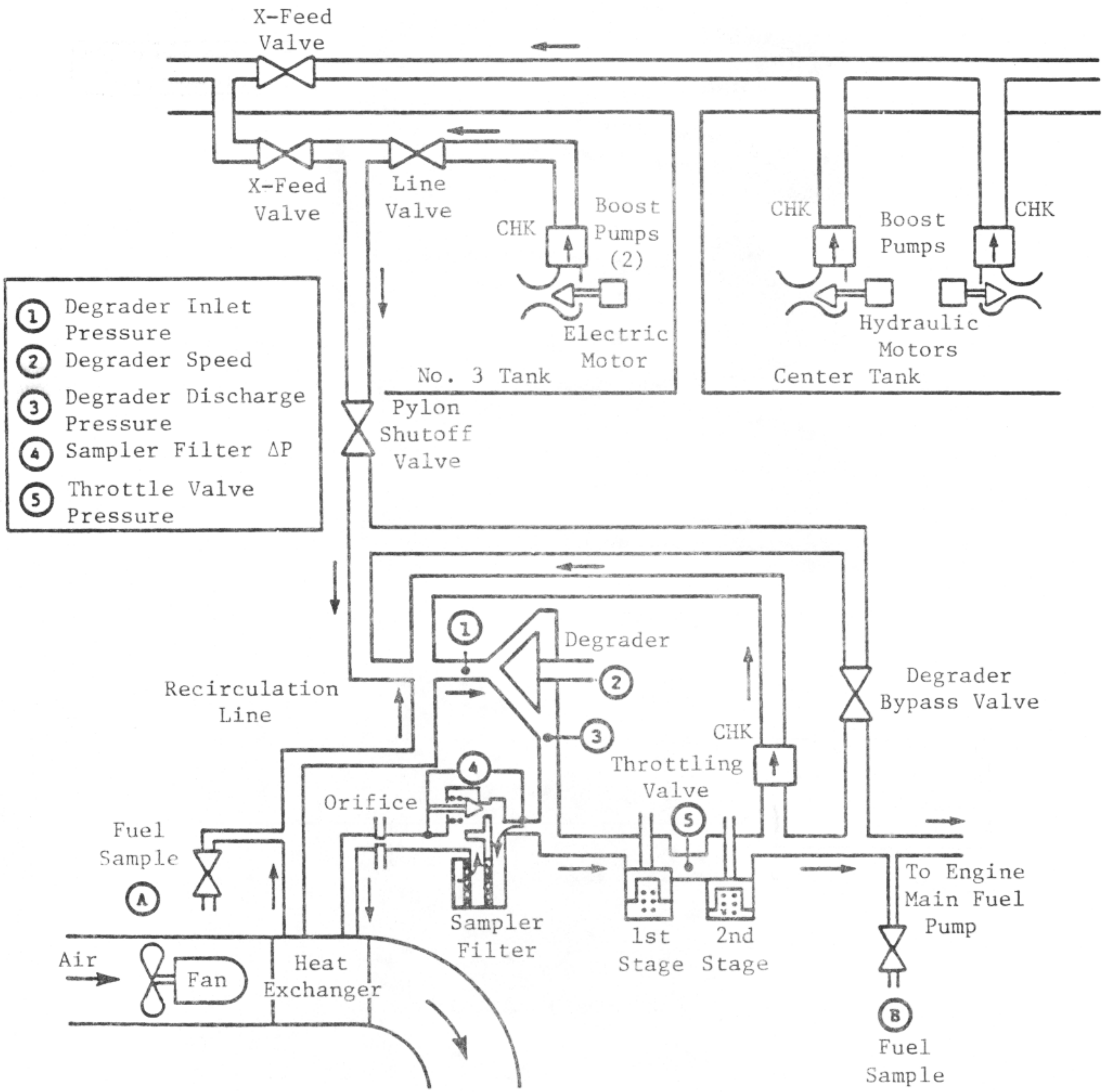


FIGURE 68. AIRCRAFT FUEL SUPPLY SCHEMATIC

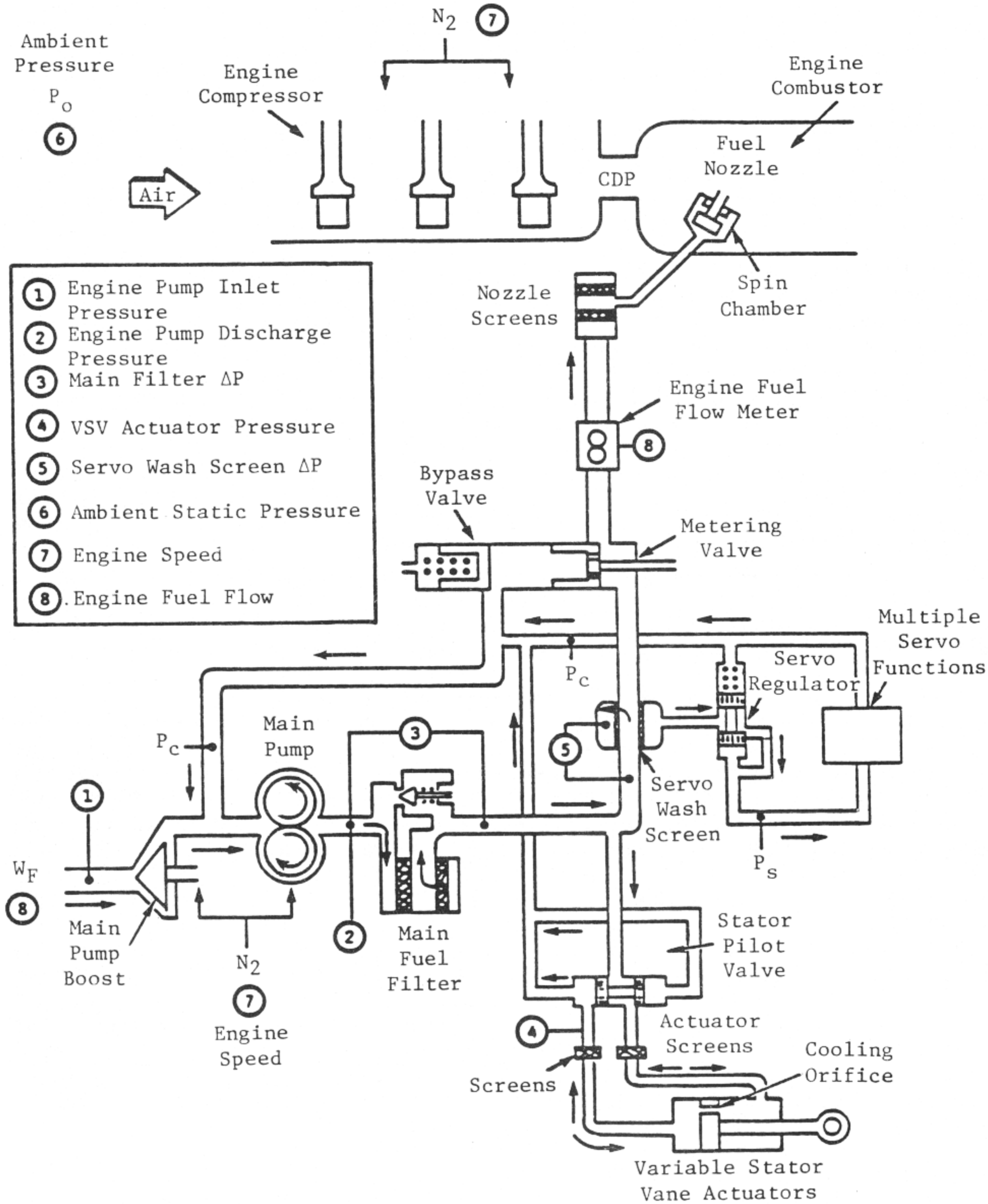


FIGURE 69. ENGINE FUEL SYSTEM SCHEMATIC

of the flight test data. The engine would not run satisfactorily if there were a lack of pressure at the inlet to the engine pump boost stage. If the degrader shut down, the lack of pressure would cause the throttling valve to close. This would immediately starve the engine pump of fuel and pressure.

The high-pressure gear stage of the main pump is driven by the engine gearbox. Hence, the gear flow or total pump flow was directly proportional to engine speed (N_2). The main fuel filter received the total pump flow. Hence, filter flow was proportional to engine speed, and filter ΔP was proportional to the square of engine speed.

Total pump flow passes through the center of the control servo wash screen. Servo flow is taken from the sides of the wash screen and then directed to the servo regulator. This close-clearance slide valve regulates discharge servo flow to 135 psi above case pressure (Ps = Pc + 135 psi). Case pressure is the same as engine fuel boost-stage discharge pressure. The boost stage produces 15 to 45 psi above pump inlet pressure. Hence, servo pressure was 190 psig at low engine power and 220 psig at high power (with the degrader running).

Servo pressure at 190 to 220 psig was the reference or actuation pressure in 13 of the fuel-control functions. The engine would malfunction or fail to produce power without the correct limits of servo pressure. The only flow through the servo wash screen was leakage through the 13 functional devices. There was no need for servo flow other than make-up for leakage. In total, the servo leakage (wash screen flow) was about 0.5 gpm (200 pph). All of the servo leakage went to the control case (Pc) and then back to the interstage between the boost and gear elements of the fuel pump.

Pressure at the discharge of the fuel pump gear stage (engine pump discharge pressure) varied from 190 to 850 psig. The pressure was supplied to the inside of the servo wash screen. If there were no flow at all through the wash screen (total blockage), pressure outside the screen would be the same as pump interstage pressure (55 to 85 psig). The servo wash screen would rupture with a pressure differential much above 25 psid. Hence, a 10-psid limit on servo wash screen ΔP was always used during any AMK tests.

The engine compressor variable stator vane (VSV) actuators received flow and pressure from the control stator pilot valve. This was a close-clearance shuttle valve that directed flow to the head end, rod end, or both ends of the VSV actuators. The pilot valve received flow and pressure directly from the control at 190 to 850 psig (idle or above). The fuel lines from the pilot valve to the head and rod end of the actuator each contained a screen. The direction of flow reversed across the screens when the actuator moved (volume displacement) or when the head-end/rod-end pressure differential reversed (actuator cooling flow). Displacement and cooling flow returned to the control case and back to the fuel pump interstage.

Static pressure was measured in the line supplying flow and pressure to the head end of one actuator. Allowing flow supply and return pressure losses, this measured pressure could be between the case pressure and pump-discharge pressure. Differential pressure or VSV actuator motion was not obvious from this measurement; however, the static or measured pressure should normally follow the trend in pump-discharge pressure and fall in a range between 100 and 300 psig. Blockage of an actuator screen or other malfunction would show up as an excessively high pressure or inconsistency with supply pressure (pump discharge).

Flow to the engine combustor was set by the control metering valve. The control-bypass valve maintained a constant 55 psid across the metering valve. Consequently, metered flow (combustor flow) was determined by the metering valve position or metering area. Since the fuel-pump gear stage always put out more flow than used by the engine, the excess flow passed through the bypass valve back to the pump interstage. Compressibility of the fuel allowed the bypass valve to maintain the supply side of the metering valve at 55 psi above the metering valve discharge side.

Static pressure downstream of the metering valve is the sum of all pressure losses between the valve and the engine combustor plus combustor pressure. Essentially, this pressure is:

$$P = K1WF + K2W2F + CDP$$

where K is a constant, WF is metered fuel flow, and CDP is combustor pressure. CDP is a function primarily of engine compressor speed (N_2) and engine inlet pressure (P_0). CDP will increase as N_2 or P_0 increase. Consequently, the combination of recorded data including fuel flow, pump discharge pressure, engine speed, and ambient air pressure reveal, as a trend, the change in flow restriction between the metering valve and the combustor. In other words:

$$\text{Pump Discharge Pressure} = 55 + K1WF + K2W2F + CDP$$

where K1 and K2 are the variables. Included in the effects on K1 and K2 are the screens at the fuel-nozzle inlets. Each of the 10 nozzles contains an inlet screen, and all metered flow passes through these screens. Therefore, observing the value of pump discharge pressure at constant fuel flow and CDP indicates the change in flow resistance across the nozzle screens.

Flight-Test Results. At 10:30 EDT the morning of June 20, the CV880 was on the FAA Technical Center ramp at Atlantic City and ready for engine start. All tanks were full with a total fuel load of 83,000 pounds. Tanks 1, 2, and 4 contained Jet A, most of which had been loaded at Atlantic City. The center tank contained Jet A that had been treated with 0.6% glycol before leaving Miami. A small amount of this center tank fuel had been used on June 19 to purge the No. 3 engine during landing at ACY. Thus, the No. 3 engine would be started on glycol-treated Jet A followed by AMK. The No. 3 tank contained 2,900 gallons of AMK (19,400 pounds) that had been blended at Atlantic City.

Preparations were made for the flight by bringing the degrader on line and then starting the engine. Lightoff on AMK was satisfactory; however, within less than five minutes, unusually high filter ΔP's were noted on the AMK system data monitor. The engine was shut down, and the sampler and main filters were removed for examination. Both showed downstream coatings of hard gel. A new ½-area (25 cm^2) sampler screen and new main filter were installed. Subsequently, the No. 3 engine started on AMK with totally clean sampler and main filters.

By 11:06 (667.5 minutes data time) the flight was ready to commence; the data system was activated, and the start sequence was initiated for the No. 3 engine. Figures 70 through 82 are computer plots of the pertinent test parameters for this test. By 11:12 hours (671.5 minutes data time), the Nos. 2 and 3 engines had been running for over 3 minutes. At this time, the No. 2 engine throttle was reduced to idle (Figure 78). Simultaneously, the degrader shut down. Figure 81 shows degrader shutdown was caused by loss of 28-volt power to the degrader control panel since the degrader oil pump shut off simultaneously. The precise cause of power interruption is not known but could have been related to the No. 2 engine generator and aircraft tie bus arrangement that existed when No. 2 engine power was reduced. In any case, the degrader was reset within 30 seconds (Figure 73) and restarted within 1.2 minutes.

The degrader shutdown had no detrimental effect on gel formation. This can be seen by examination of the data. Figures 70 and 82 show No. 3 engine fuel flow and fuel pump inlet pressure. These two degrader parameters are of prime concern to the engine since the engine will keep running with adequate fuel supply and pressure. Consequently, loss of fuel pressure and flow shut the engine down at 671.5, and reestablishment of fuel pressure permitted it to run at 672.7. Except for the time between 671.5 and 672.7 the degrader was online, and the AMK was being degraded in the usual manner. Figure 82 shows that the AMK throttling valve was closed during the shutdown time. Hence, with the degrader-bypass system disarmed at the control panel, no undegraded AMK could have gotten to the engine. Consequently, it was impossible to account for gel formation on the engine main fuel filter as the result of exposure to undegraded AMK.

Hard gel did form on the filter, and the history can be seen in Figures 75 and 77. Figure 75 shows the rise in sampler filter ΔP that began at 675. Gel formation and increase in sampler filter ΔP occurred as soon as the degrader started to pass recirculation flow. Recirculation-line flow rate and hence sampler filter ΔP is a function of degrader pressure rise. At 668.5 (before shutdown) the filter ΔP was 5 psid with a degrader discharge pressure of 400 psig. At 673, filter ΔP was 6 psid with 400-psig degrader discharge pressure. At 676, ΔP was 9 psid, increasing to 12.5 at 680 while the degrader discharge pressure stayed constant at 570 psig. Up to time 705, while on AMK, sampler filter ΔP was increasing, but the filter screen was not in bypass. Filter bypass occurs above 63 psid, and the filter ΔP reached only 33 psid. Main filter ΔP rise and gel formation can be seen by analyzing Figures 70, 77, 78, 79, and the following data:

	No. 3 Engine (AMK)		No. 2 Engine (Jet A)	
Time	$\%N_2$	ΔP	$\%N_2$	ΔP
675	77	8.5	77	13.5
680	80	19.0	78	13.7
682	98	35.0	101	22.0
705	94	45.0	94	20.5

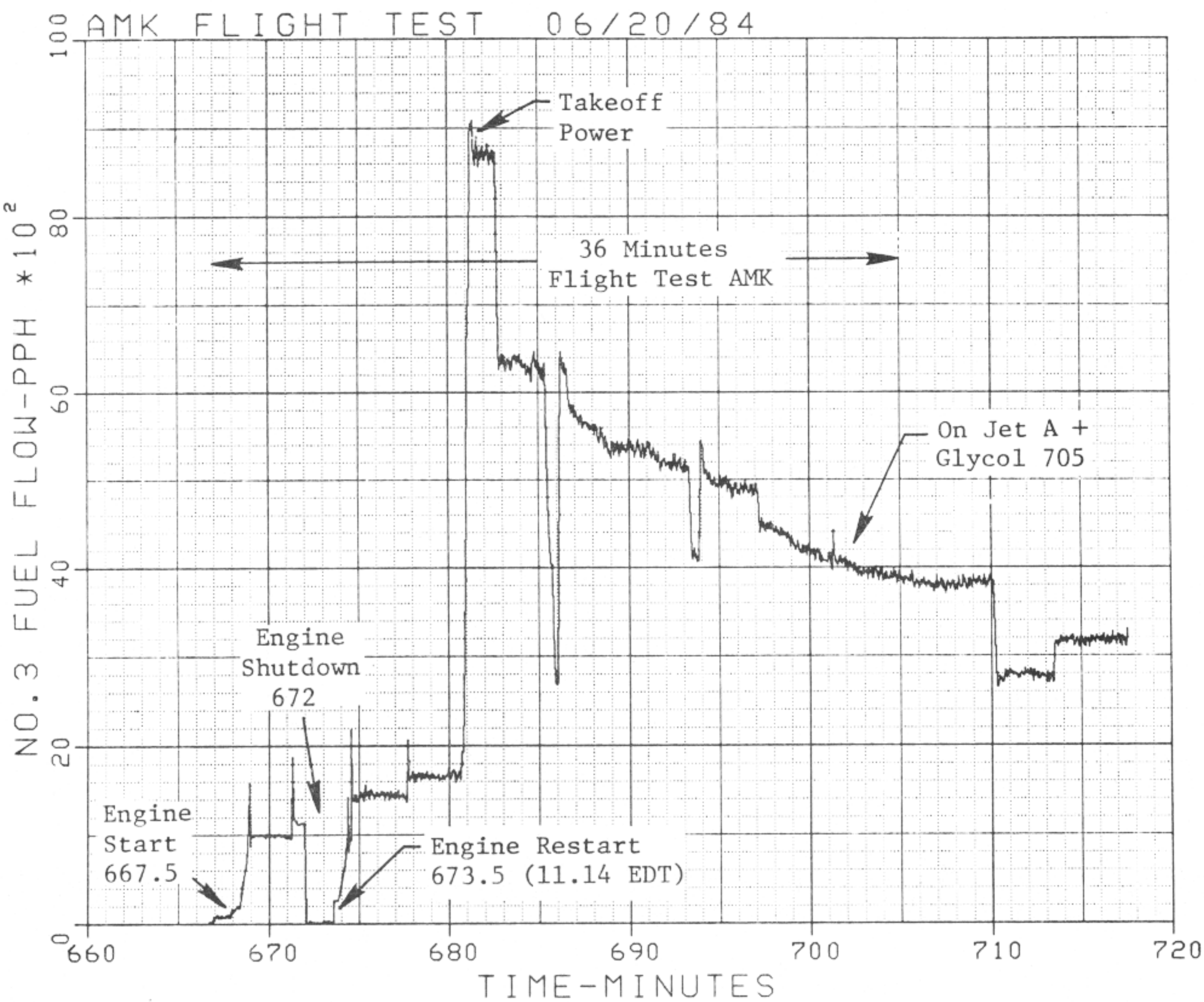


FIGURE 70. NUMBER 3 ENGINE FUEL FLOW

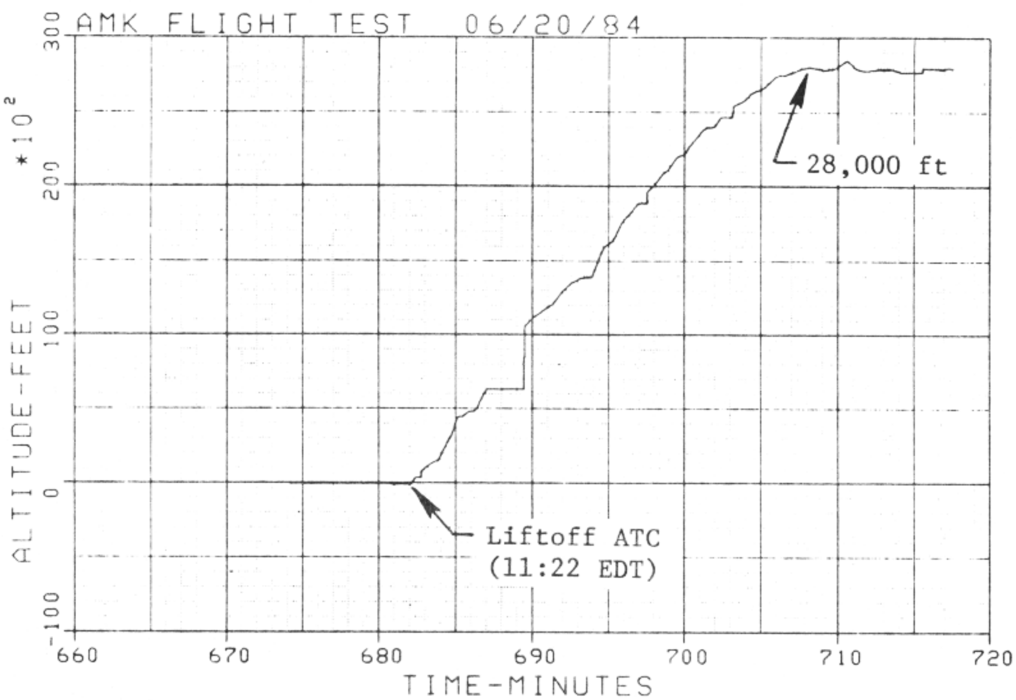


FIGURE 71. PRESSURE ALTITUDE

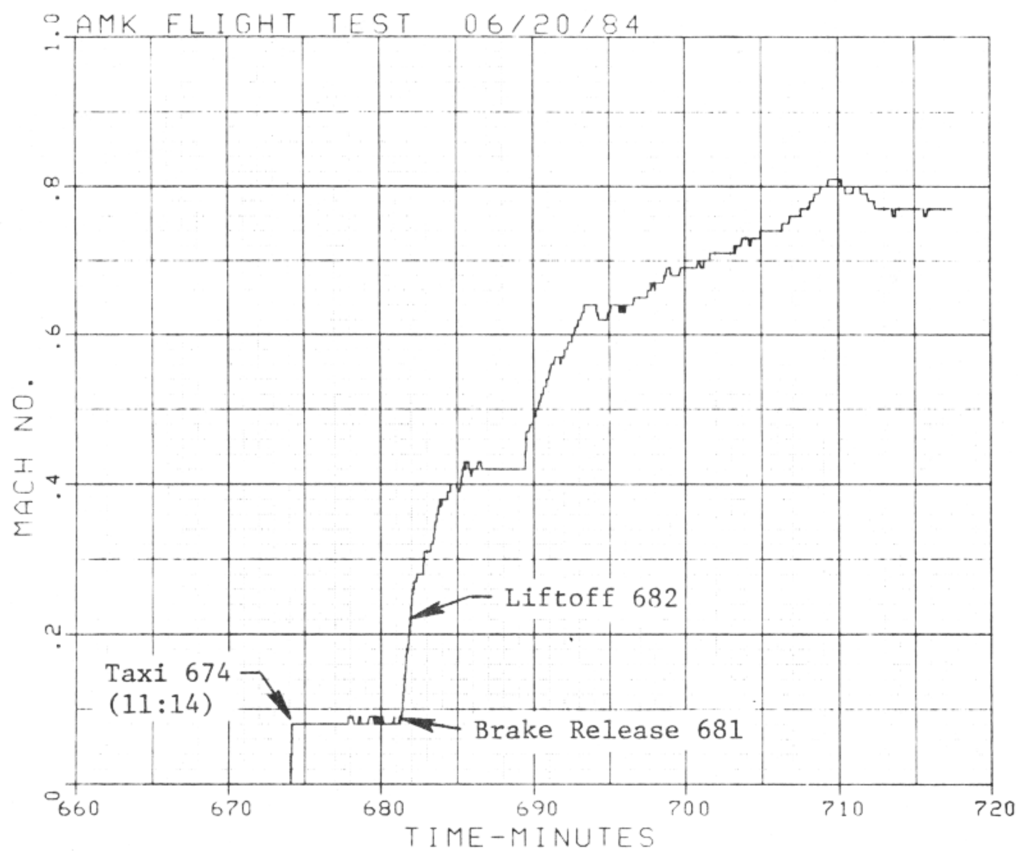


FIGURE 72. MACH NUMBER

Note: See Figure 70
For Correlation

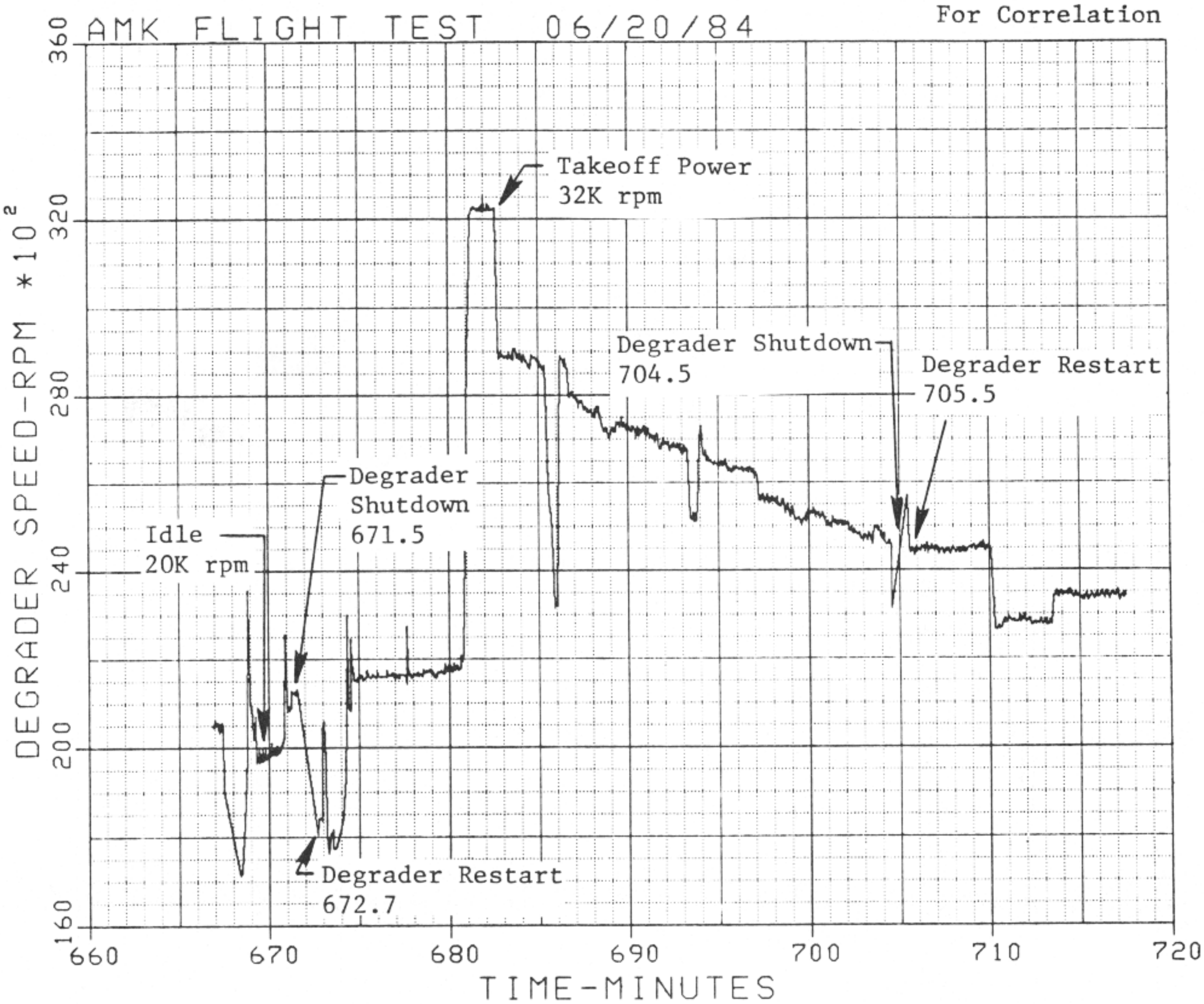


FIGURE 73. DEGRADER SPEED

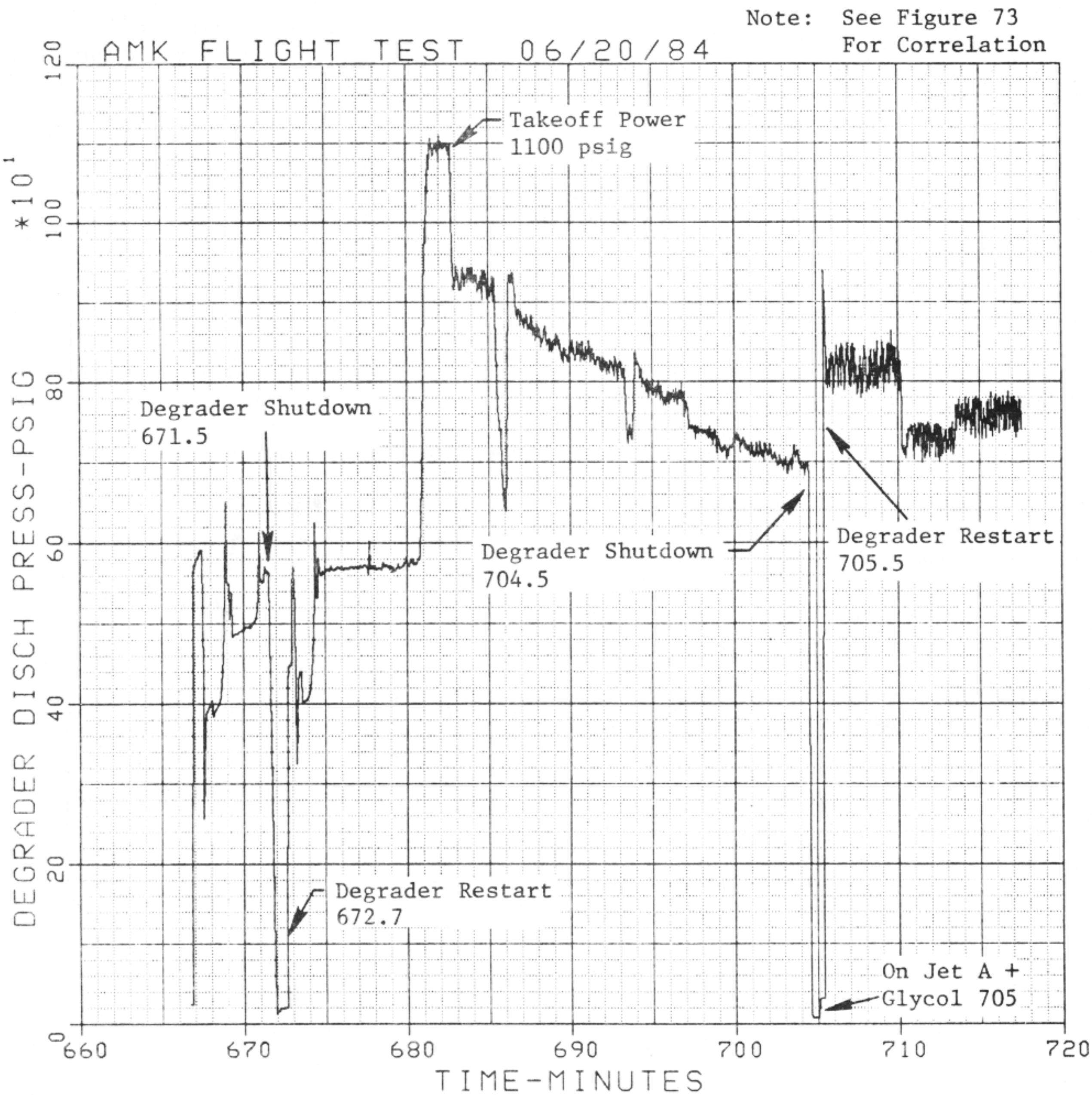


FIGURE 74. DEGRADER FUEL DISCHARGE PRESSURE

Note: See Figure 74
For Correlation

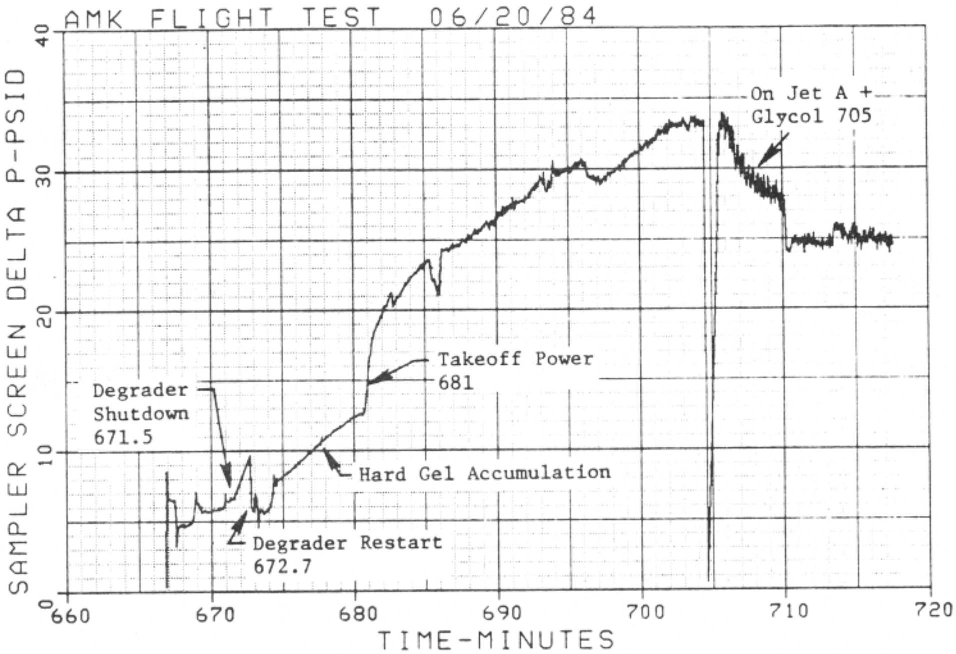


FIGURE 75. SAMPLER FILTER ΔP

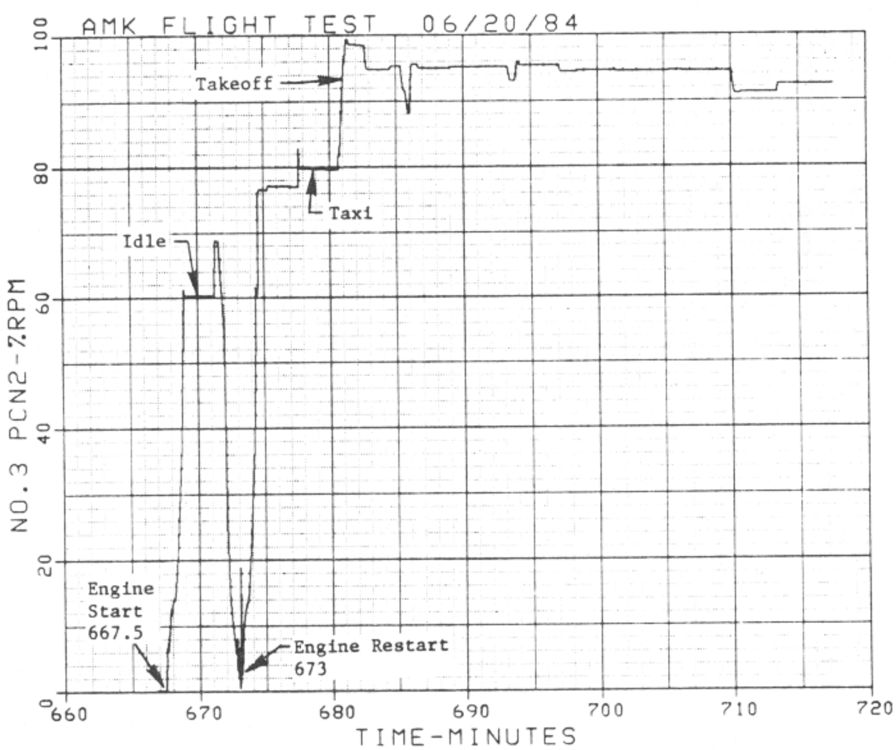


FIGURE 76. NUMBER 3 ENGINE SPEED

Note: See Figure 76
For Correlation

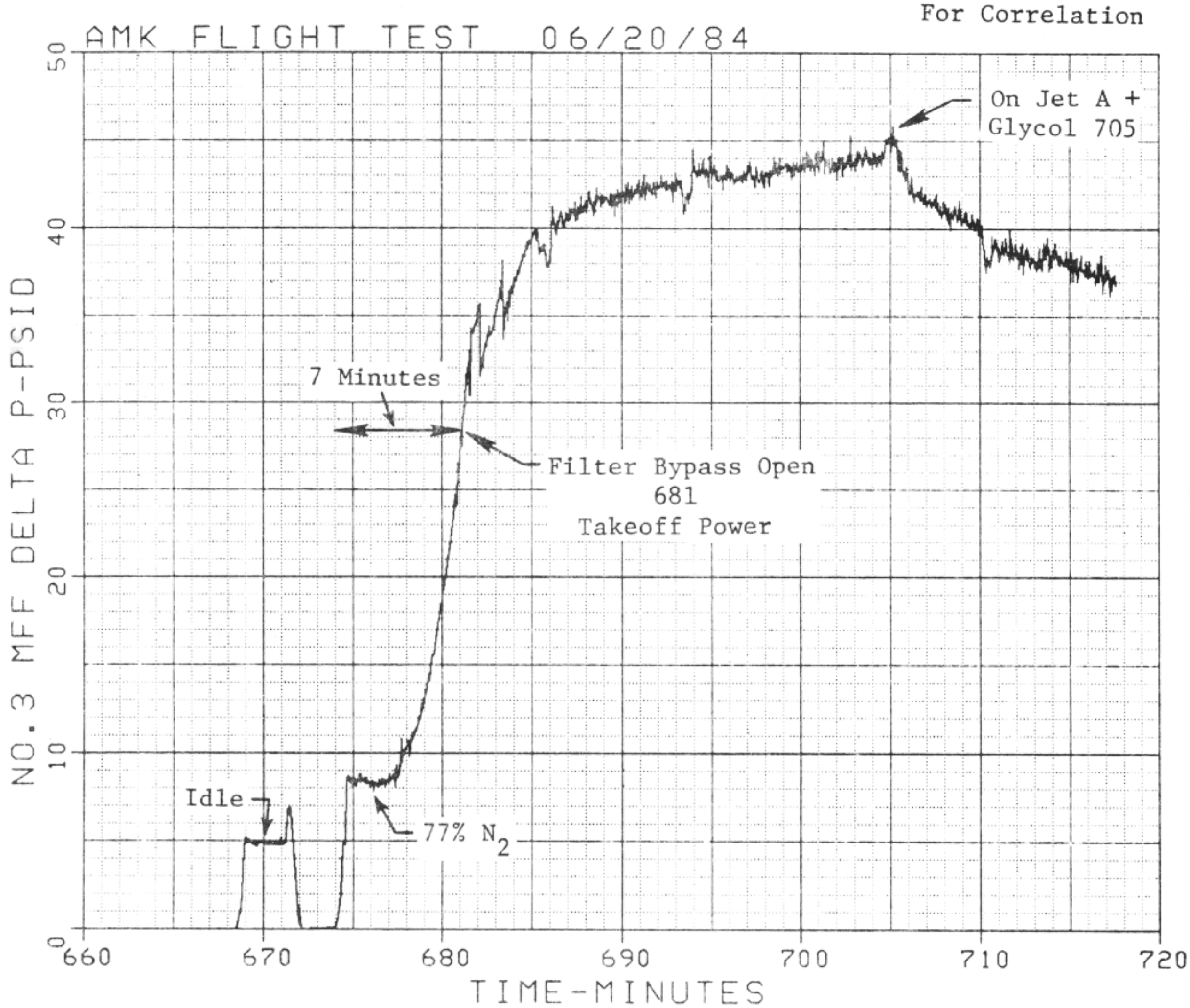


FIGURE 77. NUMBER 3 ENGINE MAIN FILTER ΔP

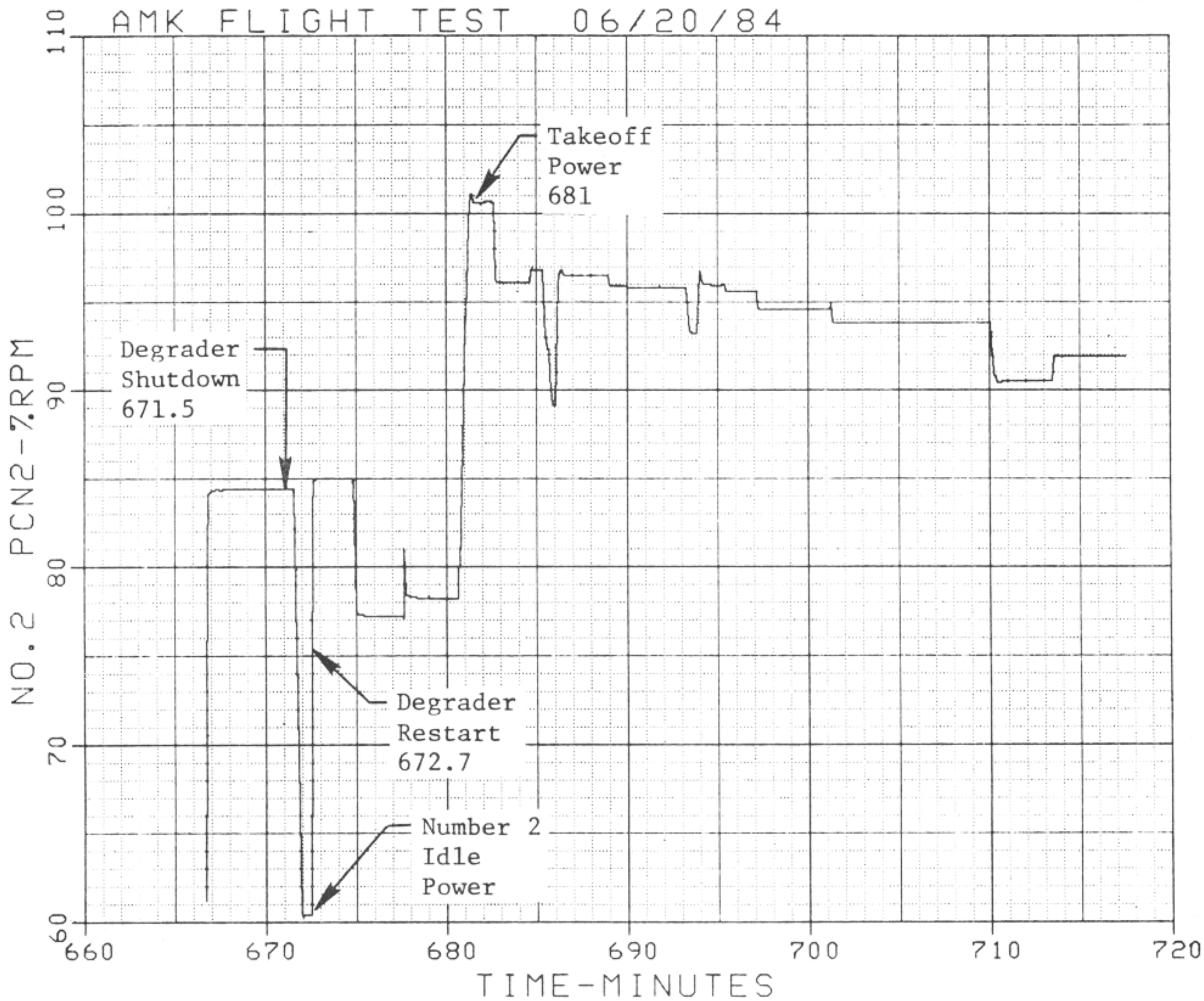


FIGURE 78. NUMBER 2 ENGINE SPEED

Note: See Figure 78
For Correlation

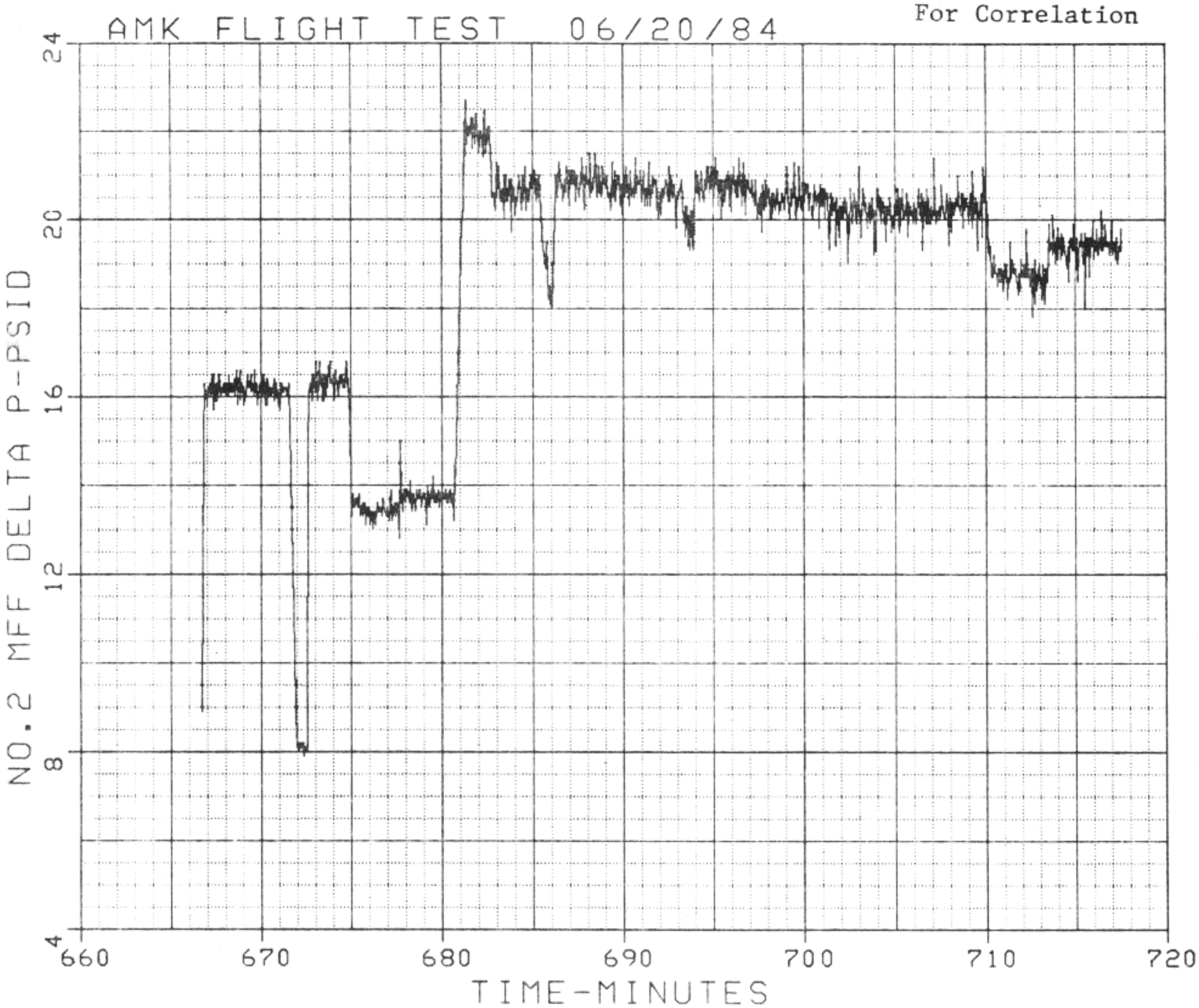


FIGURE 79. NUMBER 2 ENGINE MAIN FUEL FILTER ΔP

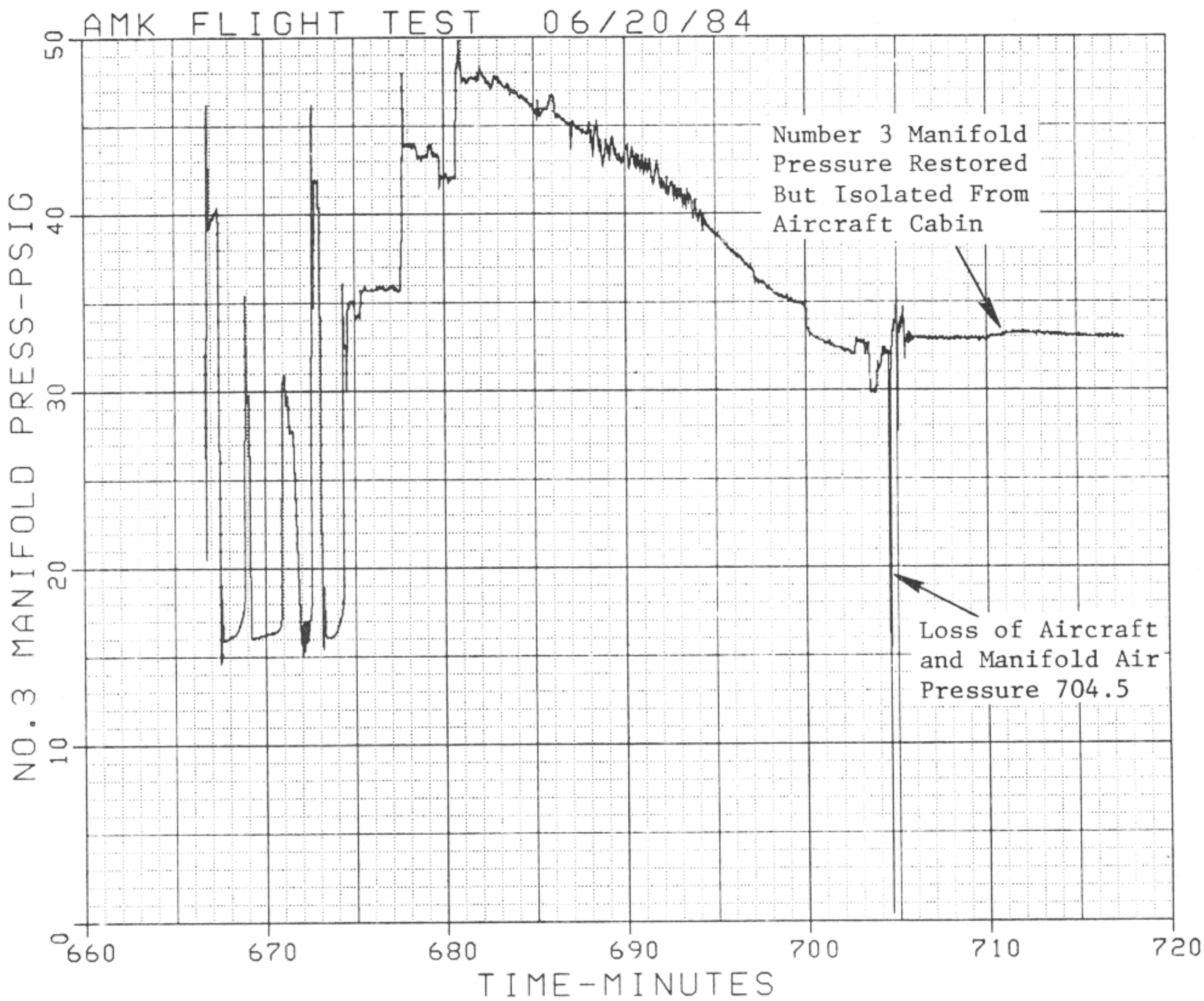


FIGURE 80. AIR MANIFOLD PRESSURE

FIGURE 81. DEGRADER OIL PRESSURE

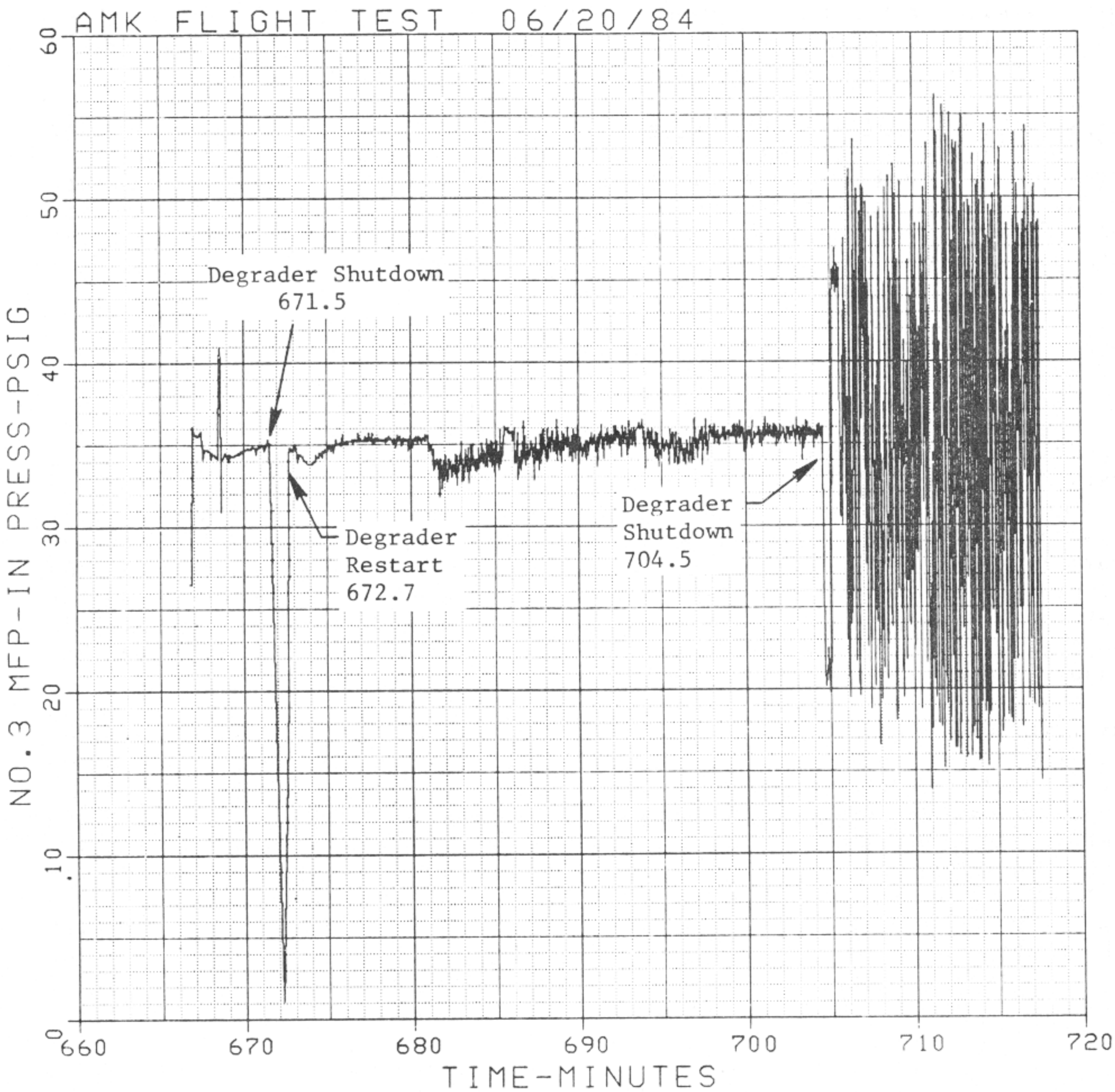


FIGURE 82. NUMBER 3 ENGINE FUEL PUMP INLET PRESSURE

In a longer flight test on June 22 from Cincinnati to Mojave, accumulation of hard gel on the main engine and sampler filters was even heavier. Examination of the engine fuel system revealed that gel had also formed on the fuel-nozzle screens. Of the 10 fuel nozzles, one was completely clogged with gel and could pass no flow; at least half of the remaining nozzles were partially blocked. In this instance, the porous nature of hard gel was not a factor. The proximity of the fuel nozzles to the combustor had baked and hardened the gel, negating the normal porosity of hard gel. The June 22 test illustrates the significant effect hard gel could have in an engine fuel system.

SYSTEMS TESTS - INVESTIGATION OF HARD GEL. Following the first flight using AMK on February 10, a number of degrader system tests and engine ground tests were run to investigate the nature and possible causes of the gel observed during the test. As discussed earlier, the cause of precipitate gel was identified during these tests, and a procedure was developed (treating Jet A with glycol) to alleviate the effects. The following is a discussion of what was discovered relating to hard gel during these tests.

When development of hard gel was pronounced, it was easy to detect visually. The most reliable means of detecting hard gel formation in initial stages was the observation of increased differential pressure across filters. In ground and system tests prior to May 8, simple visual inspection of the filters was used to detect gel formation on the filters. In some of the short-duration tests, pressure drop across the filters was beginning to increase at the end of the test run; however, close visual inspection revealed no signs of gel. This was the case for the system test and engine ground test conducted on May 8 and 9 respectively; gel was not visible to the naked eye. However, filter screen specimens from the sampler and main filters were returned to General Electric's Materials Laboratory at Evendale for scanning electron microscope inspection. The results were shown in Figures 62 through 65. Gel clearly had begun to form, and simple visual examination did not detect it.

The occurrence of hard gel did not show the strong correlation with critical velocity typically associated with shear-induced gel. The tests conducted on May 8 and 9 investigated hard gel and critical velocity. A schematic of the May 8 system test was previously shown in Figure 56. A hand-operated, flow-control valve was used to set the degrader system through-flow. An engine-type flowmeter sensed the flow rate and provided speed scheduling for the degrader. The three filters installed downstream of the degrader were: a CJ805 main filter (No. 1), a sampler filter (No. 2), and a sampler filter with half of the filter screen blocked (No. 3). These filters and flow rates for the test were intended to show the influence of critical velocity on gelling tendency. The following relationships were established prior to the test:

Filter	Micron Rating	Screen Area, cm^2	Critical Velocity (VC), cm/s	Flow Rate gpm	Flow Rate pph
No. 1 Main	40	1020	12	206	78,280
		255 (Effective)	12	51.5	19,750
No. 2 Sampler	40	50	12	9.5	3,610
No. 3 ½-Sampler	40	25	12	4.75	1,805

Assuming 25 percent effective open area for the highly pleated main filter, the flow rate at critical velocity would be 19,570 pph. A test was conducted at midafternoon (5:30 PM) to establish flow rates and opening position for the flow-control valve. Jet A was used, and no elements were installed in the filter housings. The results are tabulated below:

Valve Position, Turns	Filter Flow, pph	Degrader Speed, rpm	Design Target Speed, rpm
1/2	902	20.8	20.0
3/4	2707	23.4	22.6
1-1/2	4512	24.0	24.8

This led to the following predictions:

Run		Filter		
No.	Flow, pph	No. 1	No. 2	No. 3
1	902 or Less	Below Vc	Below Vc	Below Vc
2	2700	Below Vc	Below Vc	Above Vc
3	4500	Below Vc	Above Vc	Above Vc

Accordingly, no rise in ΔP or gelling should occur for filter No. 1. Filter No. 2 should show a ΔP rise during Run 3. Filters No. 2 and 3 should show a ΔP rise during Run 3. Plots of pressure rise for the Nos. 2 and 3 filters were shown previously in Figures 59 and 60, and indeed the results were as predicted by critical velocity for these two filters. However, in an engine ground test performed the next day (May 9), gel formed on the main engine filter (filter No. 1 in the May 8 system test). Analysis of Figures 83 and 84 clearly shows a substantial rise in main filter ΔP from test time 1020 to 1040 with the engine running at constant speed (constant fuel flow). The fuel flow of approximately 4,500 pph is far below the 19,570-pph flow rate estimated to produce the critical velocity of 12 cm/s for the main fuel filter. In other words, the filter should not have gelled. As a matter of fact, qualitative analysis of magnified photos from the May 8 and 9 tests and other supporting test data seemed to indicate that hard gel forms more readily at low filter velocities. Also, the designs of some wire-mesh filter elements seem to be more prone to hard gelling than others. There were a couple of instances in the Phase I system tests when the CJ805 main filter was more sensitive to hard gel than the sampler filter was.

In summary, the mechanism that produces hard gel, though not fully understood by General Electric, is considered to be different from that which produces shear-induced gel. The accumulation of hard gel is a function of the quantity of degraded AMK that passes through a given area of filter mesh and is not a direct function of critical velocity.

Hard Gel and Water. The affinity of FM9 for and reaction to water in fuel is well known. Water dissolved in the base Jet A fuel or high humidity during the blending of the AMK were therefore thought to be possible causes of

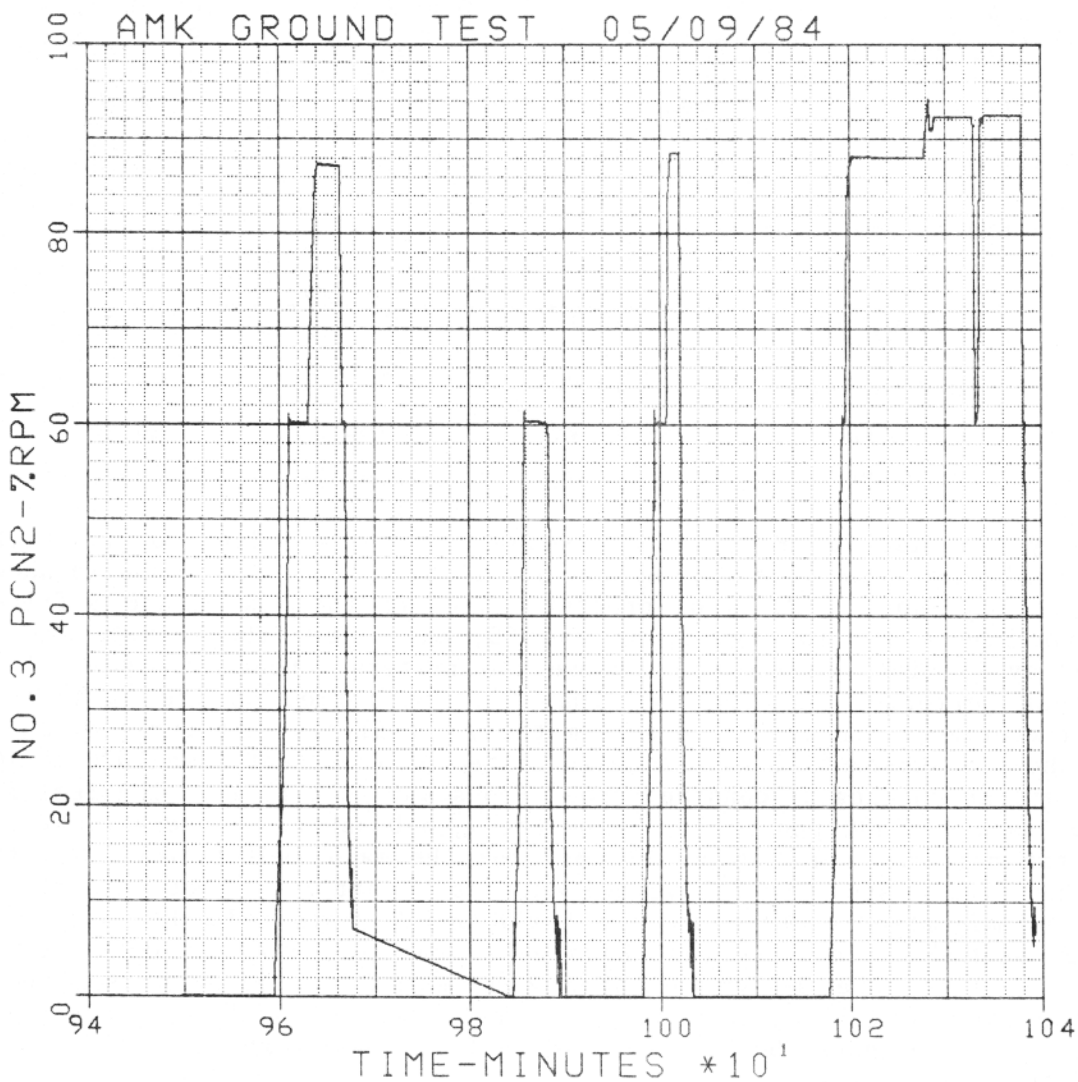


FIGURE 83. NUMBER 3 ENGINE SPEED

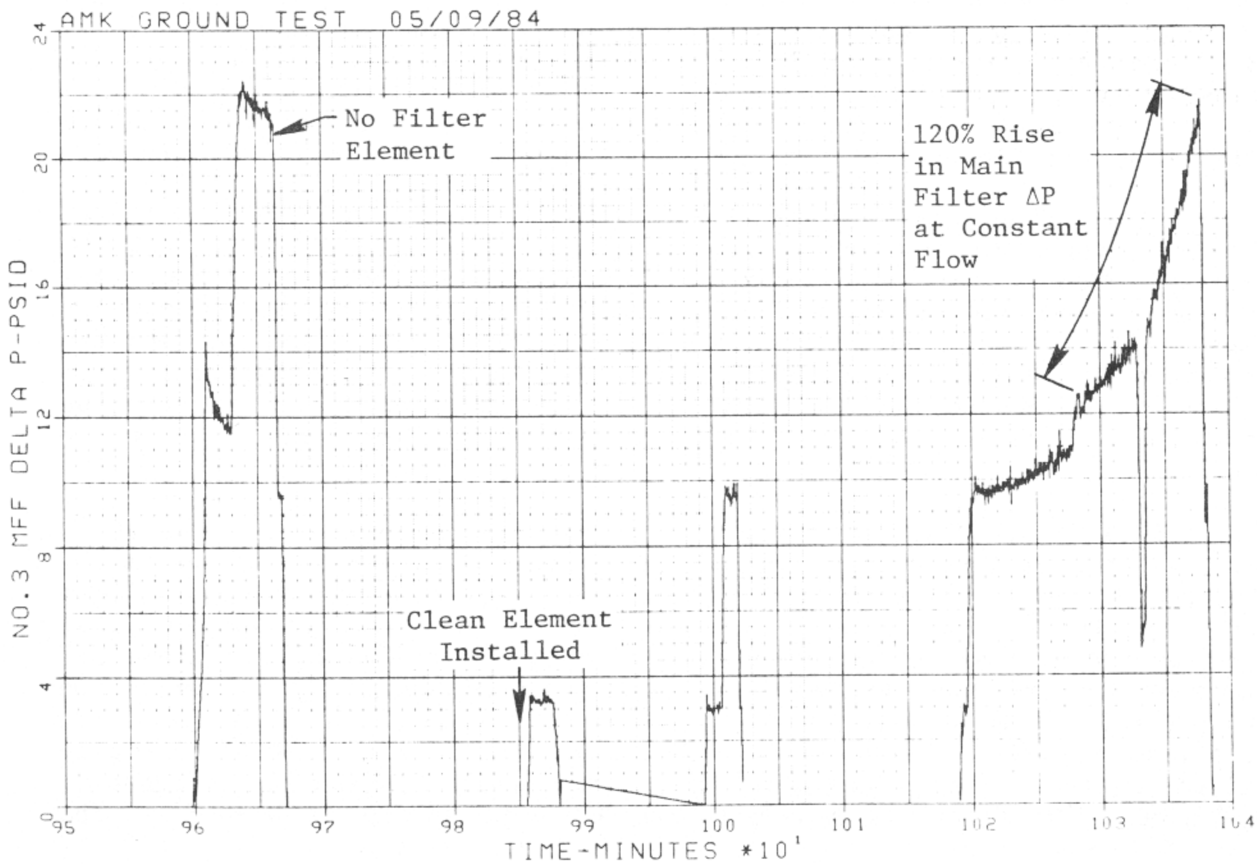


FIGURE 84. MAIN FUEL FILTER ΔP

hard gel. The concern over moisture was accentuated with the tests being performed in Miami where relative humidity is normally very high. Nevertheless, after completion of the Phase I Tests, conclusive evidence had not been uncovered to link the formation of hard gel to moisture in the air or to water in the fuel. The main effect of moisture was noticed as "cloudy" AMK blends that produced poor fuel clarity.

Hard Gel and Bidirectional Flow Filters. Hard gel accumulation was only observed on the downstream side of unidirectional flow filters. Bidirectional flow filters, such as the variable stator vane filters, did not exhibit hard gel during any of the tests. A systems test was performed on June 1 to assess this phenomenon (see Reference 8). Unfortunately, this test did not produce conclusive data relative to the absence of hard gel. The lack of gel formation on bidirectional-flow filters might give some direction to future study of the mechanism responsible for the formation and accumulation of hard gel.

Hard Gel and AMK Stabilization Time. There was some evidence from Phase I testing suggesting that prolonged stabilization of AMK had a beneficial effect in reducing hard gel formation. Fully equilibrated AMK usually produced lower (more favorable) degraded filter ratios. However, there did not appear to be a strong correlation between the presence of hard gel and the degradation of the AMK fuel as measured by filter ratio. In other words, hard gel may be present in the fuel system, but nozzle atomization can still be sufficient to produce reasonable combustor operation over a period of a few hours.

OTHER PHASE I TEST RESULTS. As stated earlier, the performance of the No. 3 engine on AMK, as measured by normal performance parameters, was virtually identical to that of the reference (No. 2) Jet A engine during the four flight tests of Phase I. This is surprising in view of the amount of hard gel that collected during some of these tests. Even in the presence of extreme gel formation, the AMK fuel delivered to the No. 3 engine had good atomization characteristics. This observation is supported by the data from the first flight test of AMK on February 10, 1984. Figure 85 is a plot of No. 3 engine speed during the flight. The plot shows four successful windmill relights of the engine. The first was attempted on Jet A at 10,000 ft/Mach 0.5. The second start was on AMK at 10,000 ft/Mach 0.54, the third on AMK at 20,000 ft/Mach 0.6, and the fourth on AMK at 30,000 ft/Mach 0.6. As shown in the Figure, all the starts were very similar. This could not be the case at 30,000 feet on AMK if nozzle atomization was not excellent. Besides the engine performance noted above, the following non-gel-related phenomena were noted during Phase I testing.

Unintentional AMK Degradation. During the May 31 system test, it was noted that the tank boost pumps and feed lines led to some unintentional AMK degradation. A filter ratio of 63 in the tank had declined to 28 at the degrader inlet with very modest flow rates. This suggests that a small amount of AMK with slightly reduced fire-prevention capability might exist in the aircraft fuel system during operation. Researchers addressing the relationship between filter ratio and fire-preventive characteristics of AMK have established that acceptable fire protection is provided by AMK fuel with filter ratios down to 17 (Reference 10).

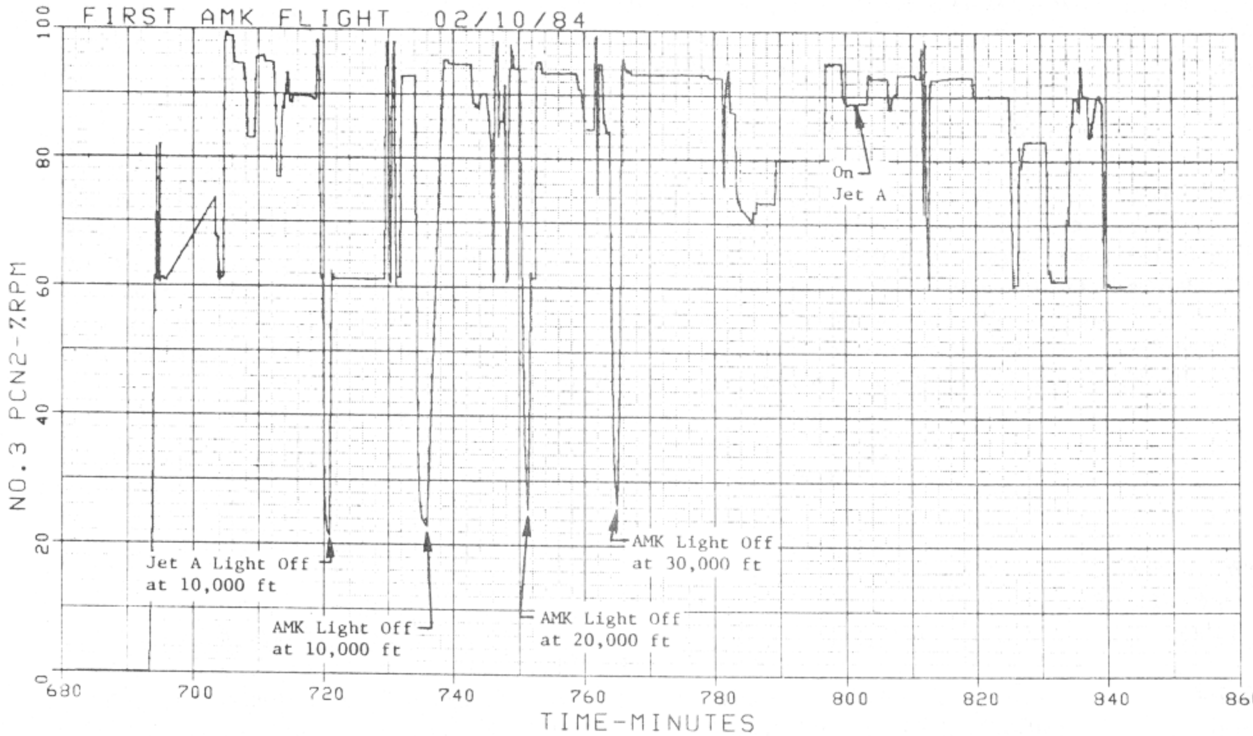


FIGURE 85. ENGINE SPEED (N_2)

Contamination of Fuel Tanks. Prior to Phase I Testing, the No. 3 tank had been inspected and cleaned by completely draining the tank and swabbing the tank walls and sump with a rag and clean Jet A. Throughout Phase I, even in the humid Miami weather and with the use of high-water-content Jet A, no sign of contaminant settling in the tank as result of AMK was noticed.

DEGRADER SYSTEM AIRCRAFT TESTS - PHASE II

INTRODUCTION. By the end of Phase I Testing, only two significant operational concerns had arisen: precipitate and hard gel. The effects of precipitate gel were not severe enough to cause great concern during the experimental test program since instrumentation was ample to monitor transient occurrence and since the effects could be alleviated by treating the Jet A with glycol.

The occurrence of hard gel was a greater concern; in extreme cases, it could result in clogged fuel nozzles and eventual engine shutdown. At the beginning of Phase II testing, the cause of hard gel was investigated by focusing on factors that might inhibit the dispersion of FM9 polymer into the Jet A fuel.

Most Phase II testing was performed at Mojave, California and was directed in part toward supporting preparation for the B720 CID. The absence of hard gel during Phase II allowed more flight testing than in Phase I, and recorded data relating to performance of aircraft systems and the No. 3 engine on AMK fuel were much more extensive. Gel phenomena were investigated by introducing single variables, suspected of causing gel, to try to induce formation.

Table 13 summarizes the 14 tests conducted during Phase II. Unlike Phase I, 10 of the 14 tests involved operation of the degrader in flight. As in Phase I, performance of the degrader system and the No. 3 AMK engine was excellent during this test series. This series of tests, and also those of the B720 during the same time frame, clearly established that the degrader performed the intended function. With the exception of very cold fuel, a condition for which test data were not available due to inability to reach low-temperature extremes, the full operational domain of typical jet engines and aircraft was demonstrated with the engine operating on AMK fuel.

TABLE 13. PHASE II TESTS

Date, Type, AMK Operating Time	Purpose	Results and Comments
7/05/84 Ground System 0:23	Side-by-side comparison of pump/degrader and high-pressure-drop needle-valve degrader.	Both degraders produced 1-2 F/R at 1 gpm with no evidence of gel.
7/05/84 Ground Engine 0:38	Standard engine run on new blend of AMK (Mojave).	Engine ran well on AMK, no sign of gel.
7/11/84 Flight 3:10	Compare No. 3 AMK engine to No. 2 reference engine.	Similar engine performance. No gel; evidence that filter ΔP with degraded AMK is less than with Jet A at same flow rate.
8/07/84 Flight 2:03	Repeat of 7/11/84 test with different blend of AMK.	No hard gel formation. No precipitate gel spike, probably due to high fuel flow (3000 pph). Flow of degraded AMK causes lower filter ΔP than Jet A under similar conditions. Nos. 2 and 3 engine performance similar.
8/11/84 Flight 2:00	Test AMK blended with larger blender used in B720 program.	Results similar to 7/11 and 8/7 tests. Precipitate gel formed at 400 pph but not at 3000 pph.

TABLE 13. PHASE II TESTS (CONTINUED)

Date, Type, AMK Operating Time	Purpose	Results and Comments
8/16/84 Flight 1:17	New blend with cool (70° F) slurry and Jet A (54° F) to explore effect on gel. Evaluate engine performance on undegraded AMK.	No hard gel formation; no precipitate gel spike at high flows. Degraded AMK caused lower ΔP than Jet A. Operation good on AMK without degrader; filter ΔP 50% increase due to shear-induced gel; gel dissipated quickly when degrader was turned on.
8/24/84 Flight 0:36	Assess effect of Biobar antifungus on gel. See if start-up procedures induce gel.	No gel evident.
8/25/84 Flight, 1:37	Evaluate effect of AMK use immediately after blending.	No gel formation. No measurable operational difference.
8/26/84 Ground System 0:18	Evaluate newly blended AMK; start test during blend.	Average age of AMK 23 minutes during test. No gel formation; 20% ΔP reduction AMK vs Jet A with new filter.
8/30/84 Flight 4:48	Assess high-altitude, long-duration flight with cold fuel.	No increase in degrader power. Sampler filter showed slight ΔP response thought to be shear-induced gel. Boost-pump pressure fell 12%. No hard gel evidence.
9/01/84 Flight 3:04	Assess cold fuel; AMK blended at Atlantic City.	Mild formation of hard gel on sampler filter. Assessment of cold fuel difficult. Boost-pump performance less AMK vs Jet A.
10/10/84 Ground, 0:27 Flight, 1:10	Use Mojave Jet A for AMK blend in Miami.	Good performance; no gel formation.
10/11/84 Ground, 1:23	Use Miami Jet A to blend AMK.	NTU values typical of Mojave tests (8.0). No evidence of gel.
10/15/84 Ground	Force large amounts of H_2O into Jet A before blending, try to produce hard gel.	Objective, 219 ppm H_2O; result, 159 ppm at 89° F. Results normal except for NTU. Engine/filter ΔP indicate hard gel, none visible.

TABLE 13. PHASE II TESTS (CONCLUDED)

Date, Type, AMK Operating Time	Purpose	Results and Comments
10/16/84 Ground, 0:11 Flight, 1:05	Introduce high-humidity during mixing of slurry.	Characterization results similar to 10/15/84. Evidence of gel via main engine and sampler filter ΔP; none visible.

SUMMARY OF TEST RESULTS The following factors, considered as possible causes of hard gel, influenced the objectives of various Phase II tests.

- FM9 slurry composition (chemistry)
- Blending technique
- Fuel or slurry temperature during blending
- Water content of Jet A
- Ambient humidity during blending
- Jet A composition (chemistry)
- Degrading mechanism
- AMK age
- AMK tank contamination
- Fuel system cleanliness and prior exposure to AMK

At this point in the program, none of the above factors had been conclusively tied to the severe accumulation of hard gel experienced during some of the Phase I tests.

Additional experiments were conducted to assess the start-up procedures of the degrader system as a possible cause of gel formation. The possibility that some aspect of the overall pump/degrader system was inducing gel formation was also investigated. An experiment was conducted comparing the pump/degrader with a needle-valve degrader. At 1-gpm flow, both degraders produced filter ratios of 1.2 with no evidence of gel.

Previous FAA Tech Center studies had shown that AMK exhibits reasonable fire-preventive characteristics within 20 minutes after blending. A flight and a ground system test were conducted to determine the degradability of freshly blended fuel that had not fully equilibrated. No measurable difference in engine performance or response of filter ΔP was noticed between the new and old AMK.

Flight tests were performed during which the degrader was turned off. These included degrader off/on cycling, landing approach and go-around, and post-takeoff transition from Jet A to undegraded AMK. The results showed about a 50% increase in engine filter ΔP for undegraded AMK, with an immediate return to normal values after restarting the degrader. Except for filter ΔP increase there was no immediate effect of operating on undegraded AMK

Two long-range flight tests were performed on August 30 and September 1, 1984 to investigate the effects of cold AMK. A trace accumulation of hard gel was visually observed on the sampler filter after the second flight from Atlantic City to Miami. The appearance of this hard gel was not thought to be caused by cold AMK. The degrader required no more power to degrade cold AMK than warm AMK. Tank boost-pump pressure on AMK fell 12% at low flows; losses would be expected to be greater at higher flow rates. Evidence of shear-induced gel was detected on the sampler filter at low AMK temperature.

Throughout the Phase II tests, there was evidence to suggest that AMK imparts some level of lubricity to Jet A. Lubricity was evidenced by the AMK reducing fluid flow resistance through filters in many tests and by very low or non-existent leakage through the 32,000-rpm degrader shaft seal.

CV880 SUPPORT OF THE CID MISSION. The results of the flight tests conducted on August 11 and 16 were typical of all the flight tests conducted at Mojave. These two tests were intended to support the B720 CID program directly. For the August 11 test, the No. 3 tank of the CV880 was fueled with AMK that was blended at NASA-Dryden using a much larger blender (50 to 125 gpm) than had been used previously in the CV880 program (5 to 10 gpm). The higher capacity blender was needed to fuel the B720 in a reasonable amount of time. After fueling with AMK, the CV880 flew the intended profile of the CID mission with an aborted landing (wave-off). The landing was also completed on AMK. A total of 12 climb/descent profiles were run on AMK over the full power range of the engine. Like the two previous flights at Mojave, there were no adverse effects of using AMK.

The following procedure was followed in all the Mojave tests. Prior to the flight, a degraded sample of AMK was taken. The degrader was operated with the No. 3 engine shut down; the No. 2 engine was used as an air source to drive the degrader air-turbine motor. Fuel was discharged from a fitting between the throttling valve and the inlet to the main engine pump and was dumped into a 55-gallon drum. After conditions stabilized at approximately 1-gpm through-flow on Jet A from the center tank (or No. 2 tank), the switch was made to AMK from the No. 3 tank. After passing at least 20 gallons of AMK through the system, a degraded sample was taken while filling the 55-gallon drum.

After obtaining a degraded AMK sample and a sample from the midpoint drain of the No. 3 tank for lab analysis, all engines were started on Jet A. Takeoff and climb were made to a reference altitude (usually 10,000 feet) on Jet A. No. 2 and No. 3 engines were brought to the same power setting (fuel flow), and a discrete data point was recorded. This provided a Jet A reference for both the No. 2 engine and the No. 3 engine.

Next, the No. 3 engine was switched to AMK with the degrader operating; after waiting about 2 minutes for stabilization, a comparative test point was retaken on AMK fuel. The test then continued according to the particular objectives. The landing was made on AMK so that any traces of gel on the No. 3 engine filters would not be influenced by Jet A. The sampler filter, main engine filter control wash screen, and nozzle screens were visually inspected for gel immediately after the flight. Sampler filters were replaced after each flight test. Residual degraded AMK was left in the engine. AMK was left in the tank and fuel feed system until the next test; then it was drained and discarded. The AMK tank was not opened except for the gravity-fill port.

Test Results - August 11. The first portion of the flight was to check the left-hand, pitot-static system of the aircraft for air-speed calibration. This was done at altitudes up to 36,000 ft on Jet A. After descending 10,000 ft, the degrader was started on Jet A; then the switch was made to AMK. The flight continued on AMK for 1 hour, 59 minutes. No performance difference was noticed between the AMK prepared by the larger B720 blender and that produced for the two previous tests by the CV880 blender.

The test also showed that precipitate gel did not occur when the flow rate of incoming AMK was high enough to satisfy the glycol affinity of residual Jet A in the system. As shown in Figure 86, precipitate gel formed on the sampler filter at 400 pph (AMK) during the ground fuel sampling run but did not form in flight during the Jet A to AMK switch-over at 3000-pph fuel flow. These results suggest that precipitate gel might not be a problem as long as steps are taken to inhibit the mechanism of formation. One such step is an over-abundance of AMK relative to any residual Jet A.

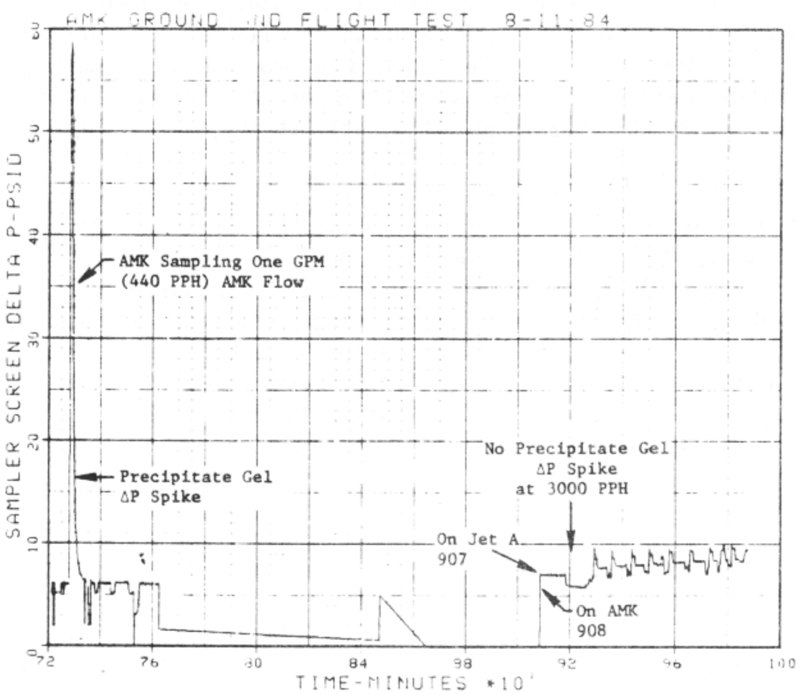


FIGURE 86. SAMPLER FILTER ΔP

Test Results - August 16. Concern had been voiced by NASA-Dryden over the consequences of a degrader failure. The August 16 test addressed emergency, in-flight shutdown of the degrader as well a new blend of AMK using slurry and Jet A at 70° and 54° F, respectively. Slurry and Jet A from the August 7 flight test were used. An extensive set of computer data plots is included for this test to illustrate results that were very typical of all the tests conducted at Mojave.

The AMK portion of the August 16 test lasted 1 hour, 17 minutes and included 9 climb/descent flight maneuvers over the full power range of the engine. Figures 87, 88, and 89 show the flight test profile.

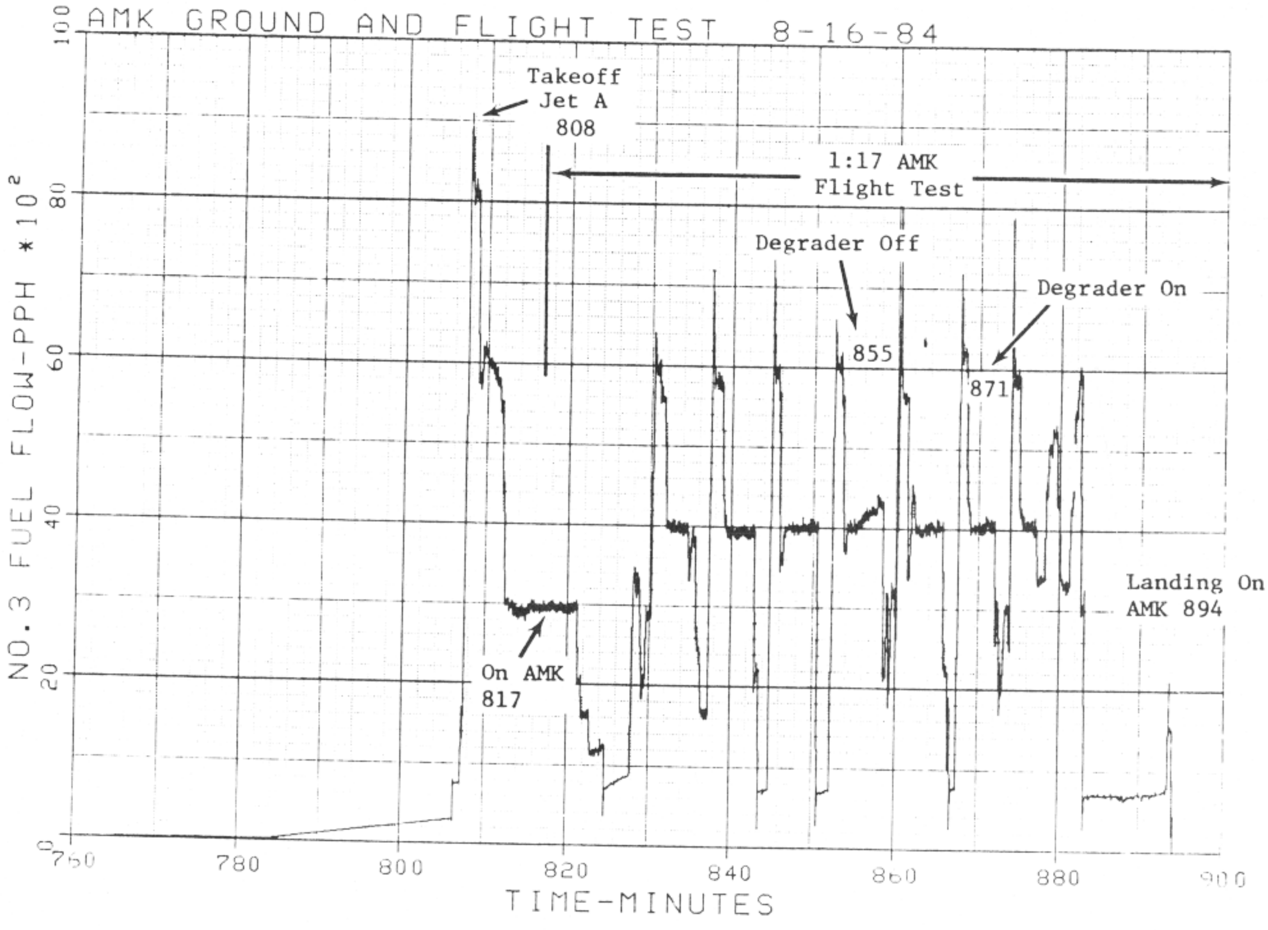


FIGURE 87. NO. 3 ENGINE FUEL FLOW

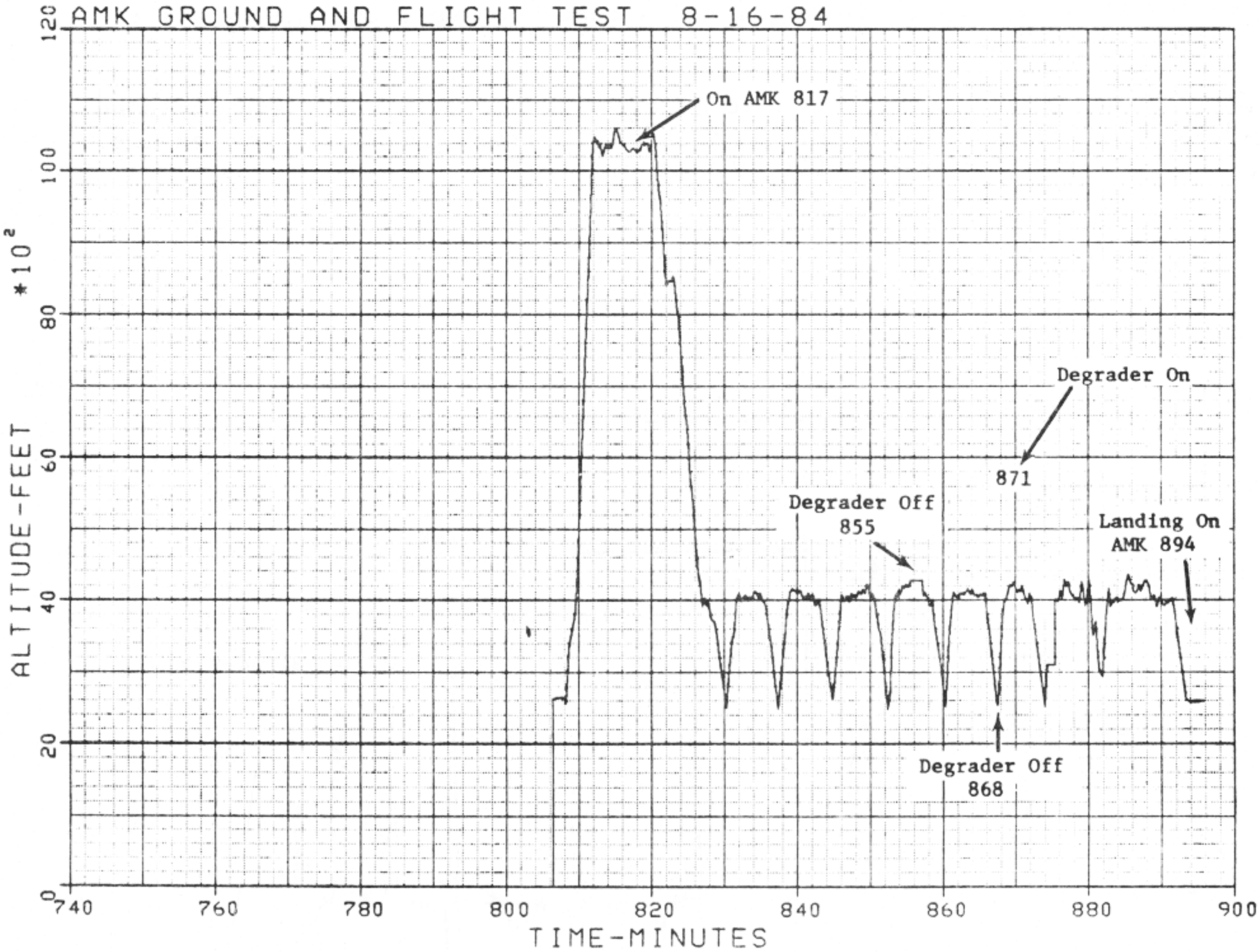


FIGURE 88. PRESSURE ALTITUDE

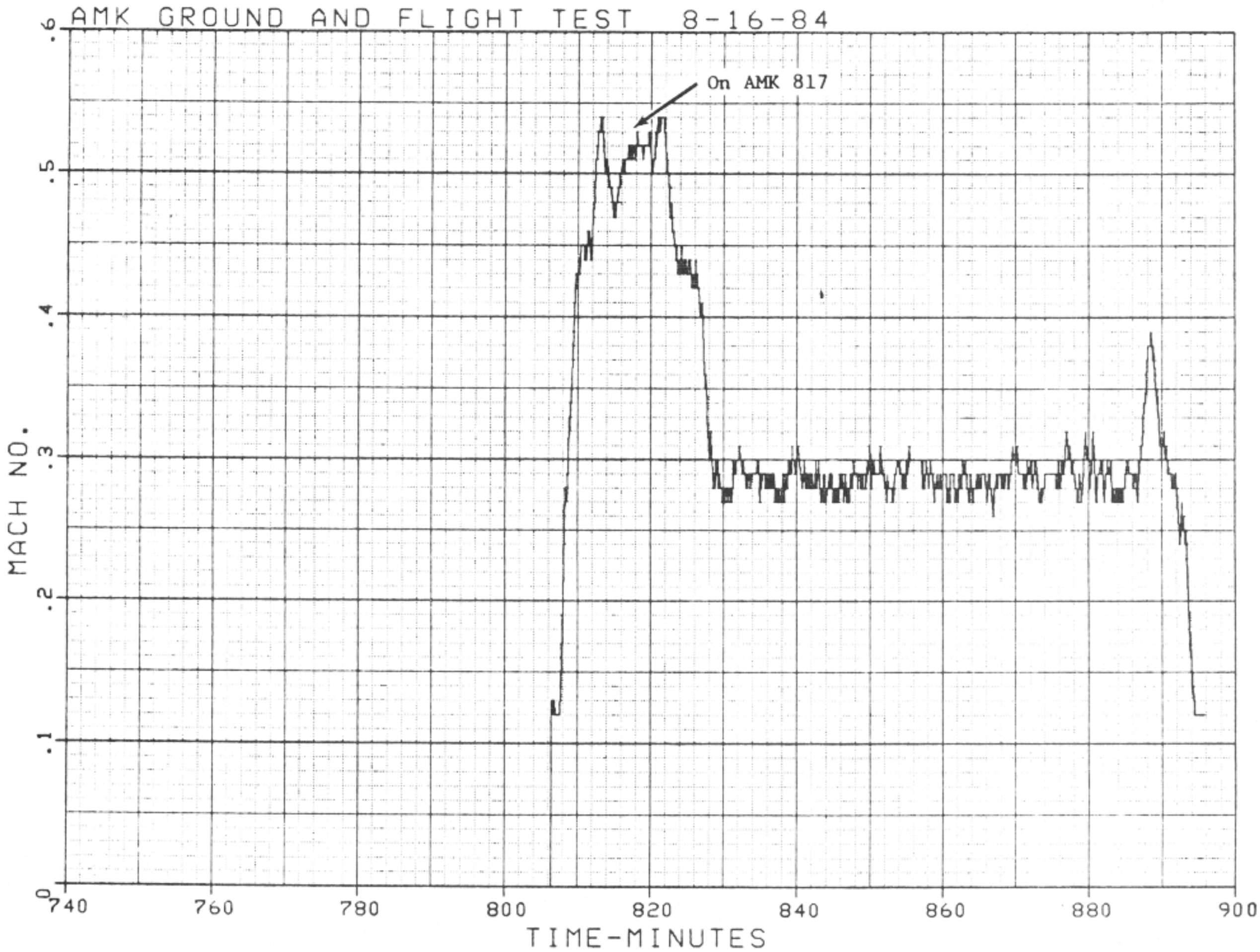


FIGURE 89. MACH NUMBER

Figure 90 shows ground degrader operation while a degraded-AMK sample was being obtained. Note the typical sampler filter precipitate gel ΔP spike, Figure 91; it lasted about three minutes before all traces of gel were gone. Note also, as in the August 11 test, that gel does not form during the switch to AMK at higher flow rates (more AMK relative to Jet A). This occurred at time 817 at 10,000 feet.

Figures 92 and 93 show No. 3 engine speed and EGT; degrader discharge pressure (Figure 94) provides a clear indication of degrader operation. The degrader was shut off 10 times. The first shutdown was for 2 minutes, and the last shutdown was for 5 minutes. During this period of degrader on/off cycling (time 855 to 871), the engine and aircraft were operated without constraint, including a 100-ft above-ground-level (AGL) go-around with the degrader off at

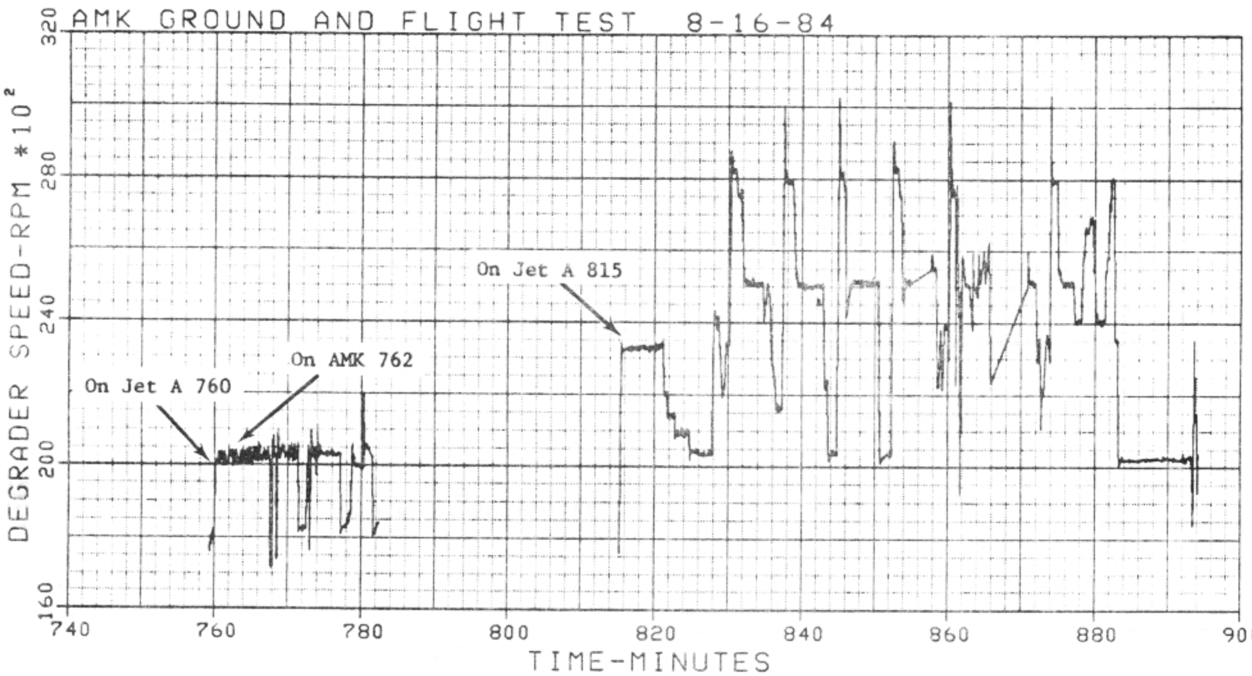


FIGURE 90. DEGRADER SPEED

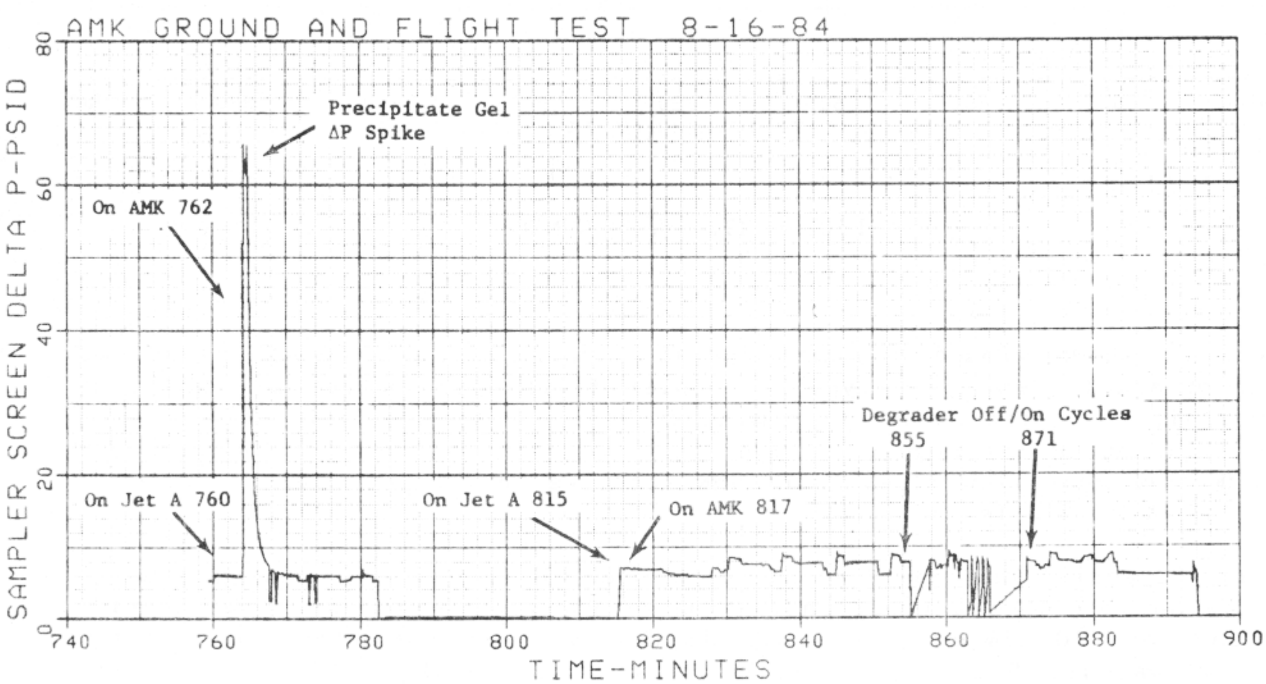


FIGURE 91. SAMPLER FILTER ΔP

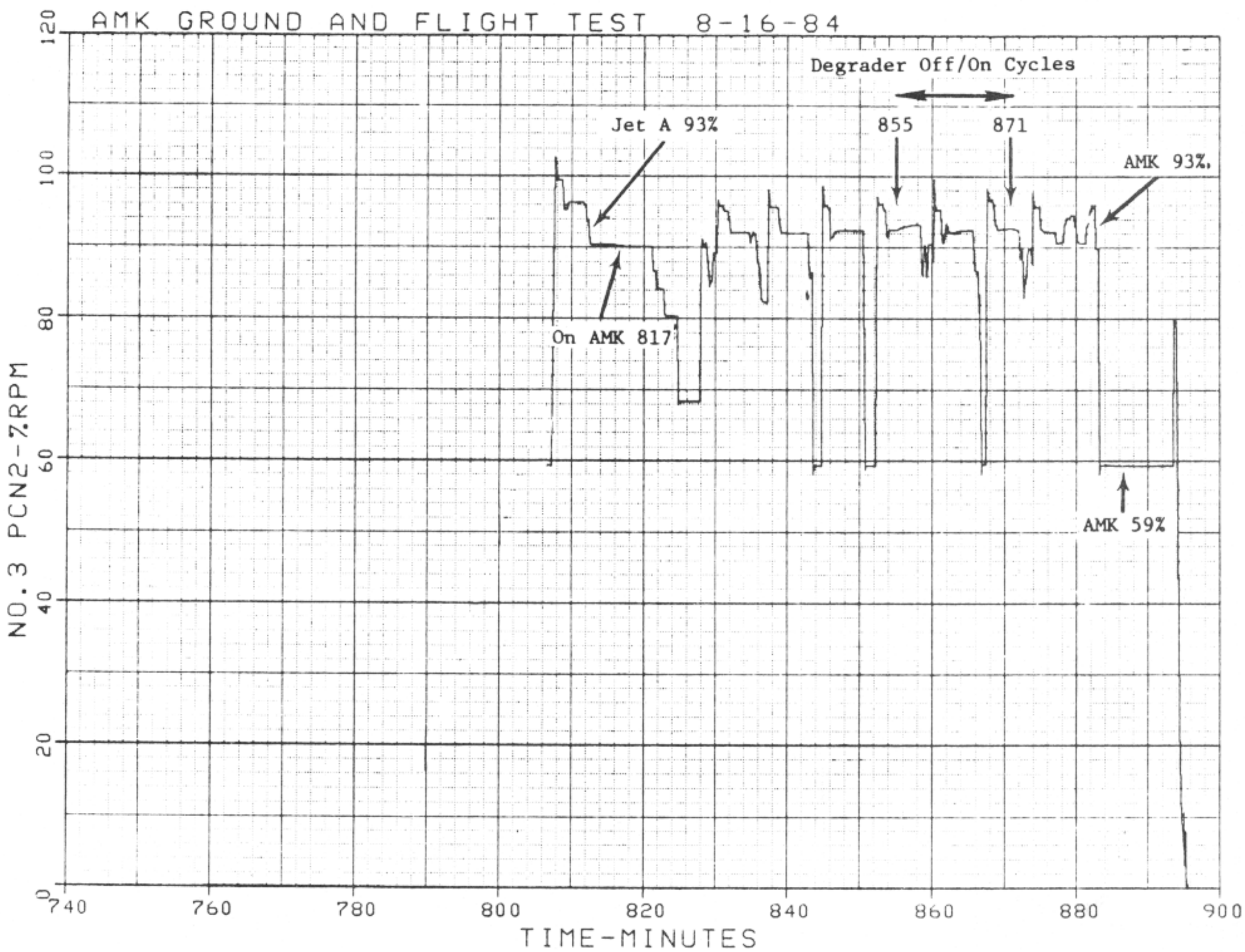


FIGURE 92. NUMBER 3 ENGINE SPEED

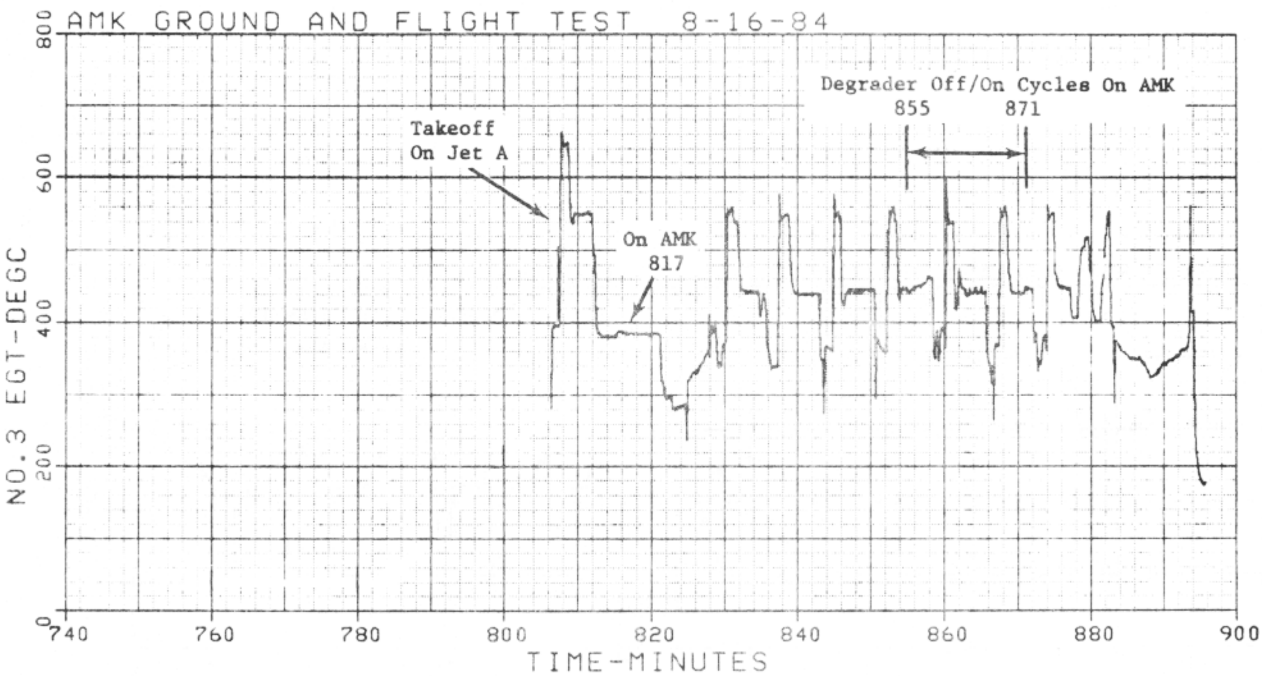


FIGURE 93. NUMBER 3 ENGINE EGT

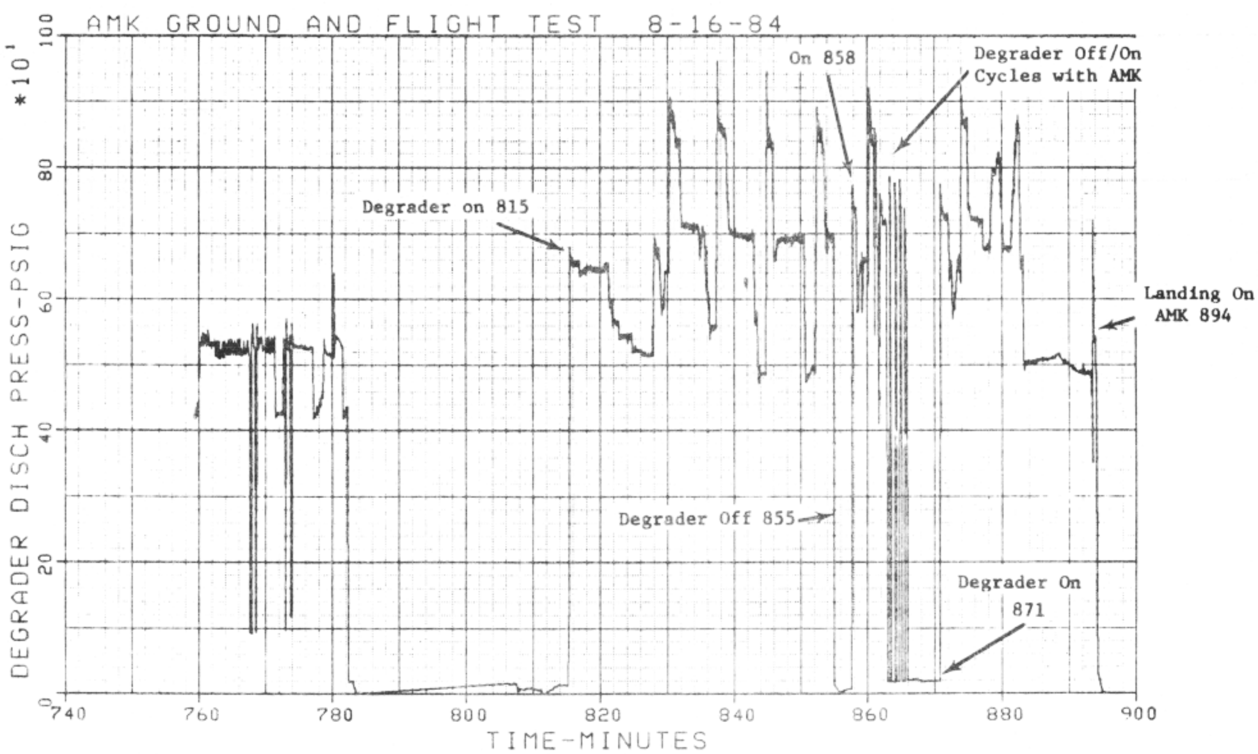


FIGURE 94. DEGRADER FUEL DISCHARGE PRESSURE

time 868. Aside from filter ΔP response, there was no observable difference between operation of the No. 3 engine on degraded AMK and undegraded AMK.

On/off cycling was simply a matter of actuating the degrader panel run/stop switch since the degrader fuel bypass valve opened and closed automatically in response to the degrader speed signal with the degrader bypass switch in the armed position. The effects of automatic bypass can be seen in Figures 91, 95, and 96. Sampler filter ΔP did not change during the test except to reach zero when the degrader was off (no recirculation flow). No gel of any kind showed up on the sampler screen during the flight. The control wash screen (Figure 97) showed a trend of decreasing ΔP during the test period. There was definite evidence of ΔP spikes during the period of degrader shutdown.

The main fuel filter responded readily to degrader operation, as can be seen in Figure 98. First, however, note the general decrease in ΔP for operation of the No. 3 engine and degrader on AMK compared to Jet A. Pressure drop was about 50 percent less on AMK for either 59 percent or 93 percent engine speed. This supports the contention that degraded AMK has less filter-flow resistance than Jet A. Next, note what happened when the degrader was shut off. Filter ΔP, with undegraded AMK, increased immediately to about 150 percent of degraded AMK value.

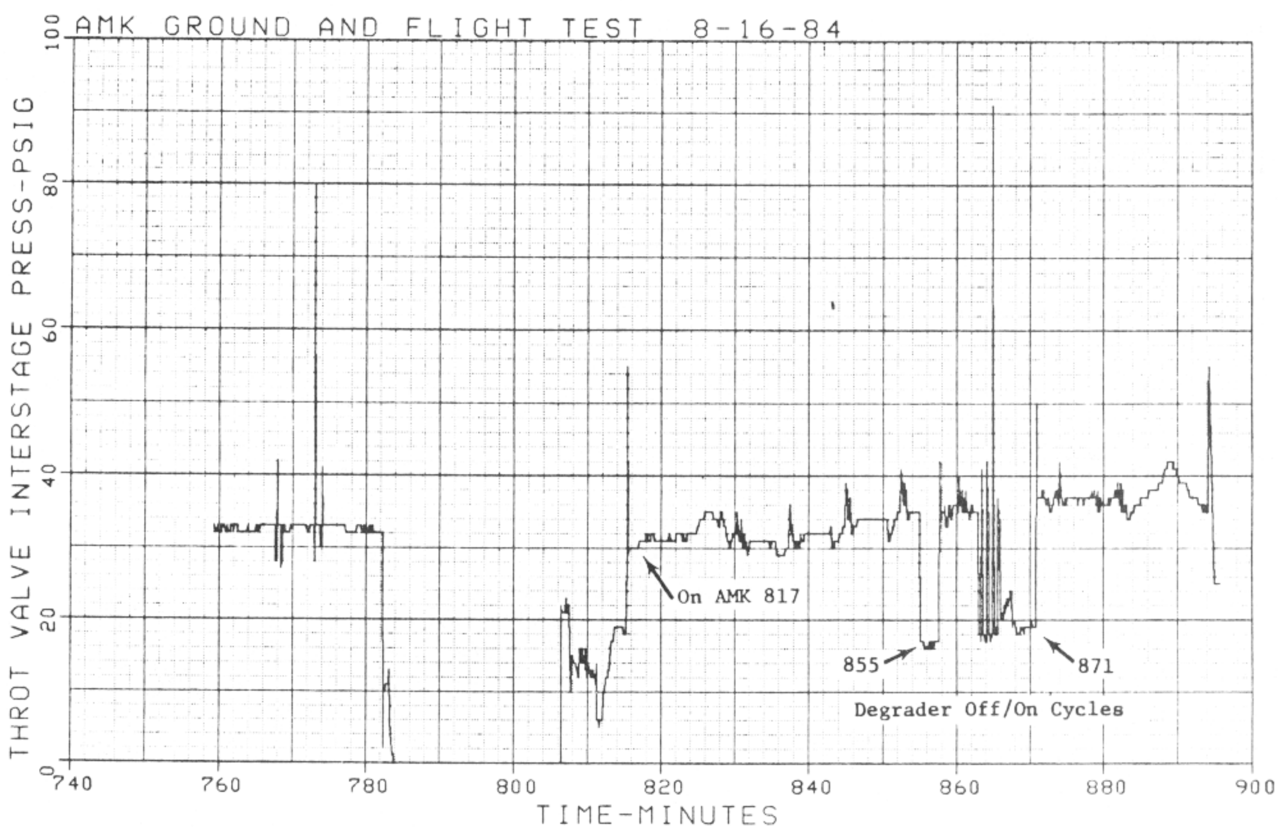


FIGURE 95. THROTTLING VALVE INTERSTAGE PRESSURE

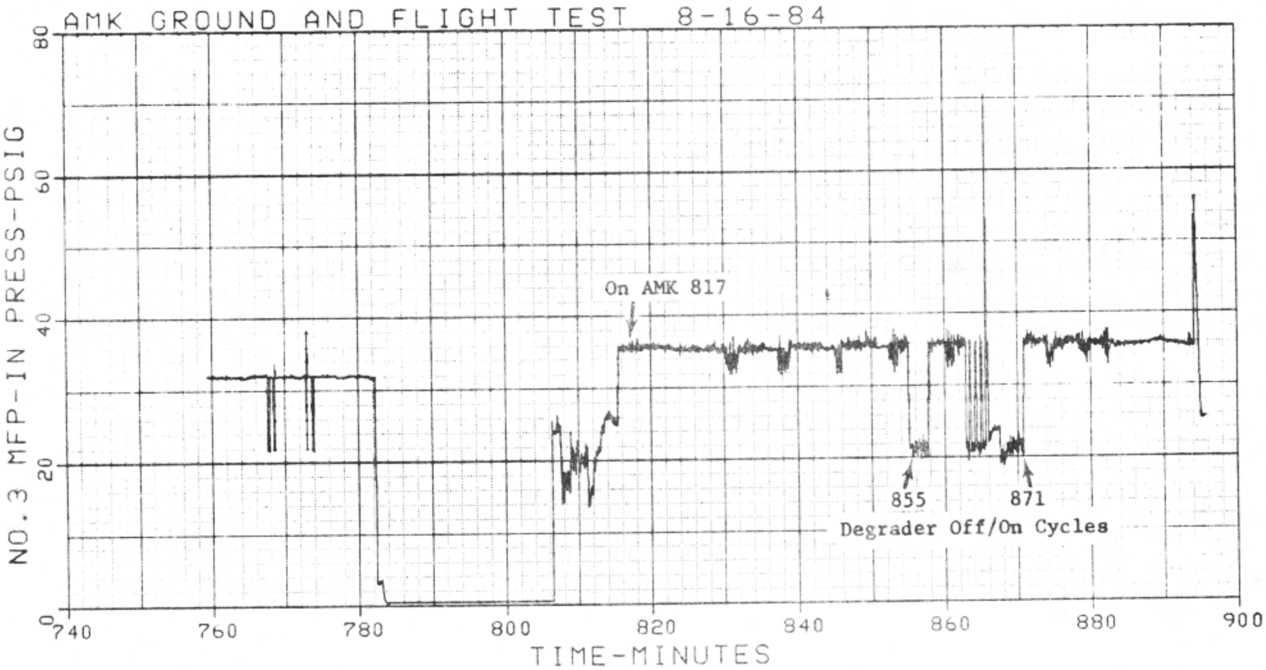


FIGURE 96. NUMBER 3 ENGINE MAIN FUEL FILTER INLET PRESSURE

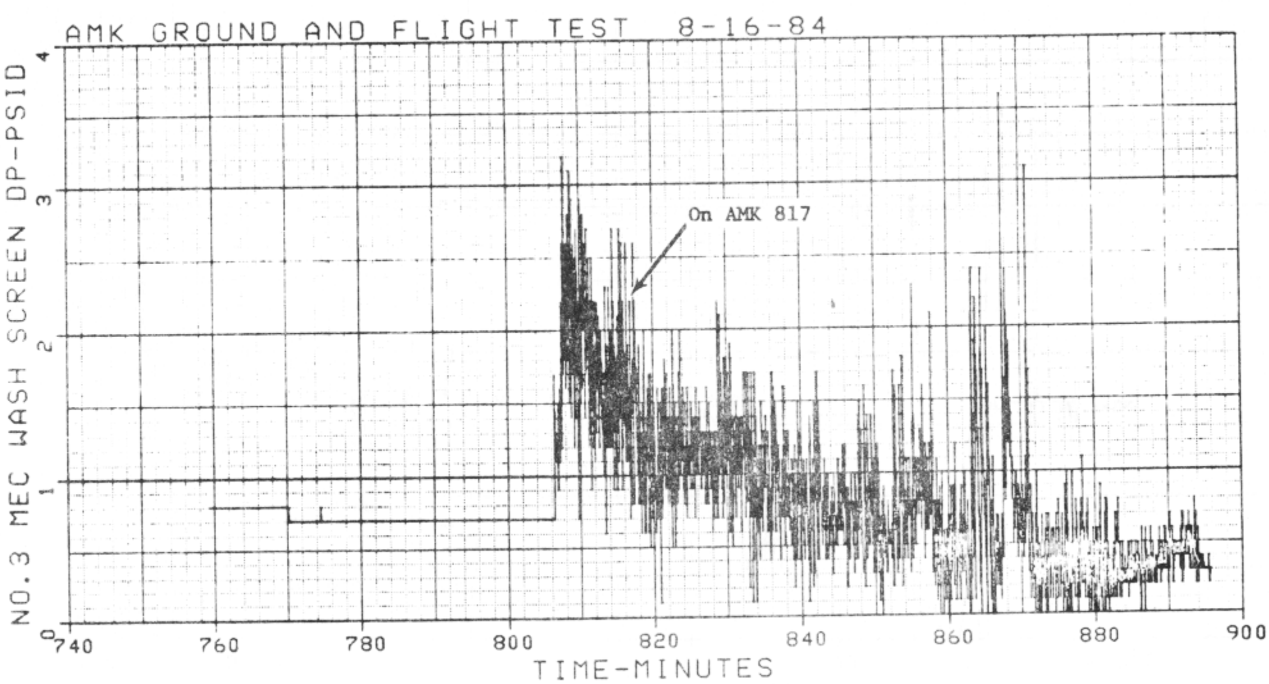


FIGURE 97. NUMBER 3 SERVO WASH SCREEN ΔP

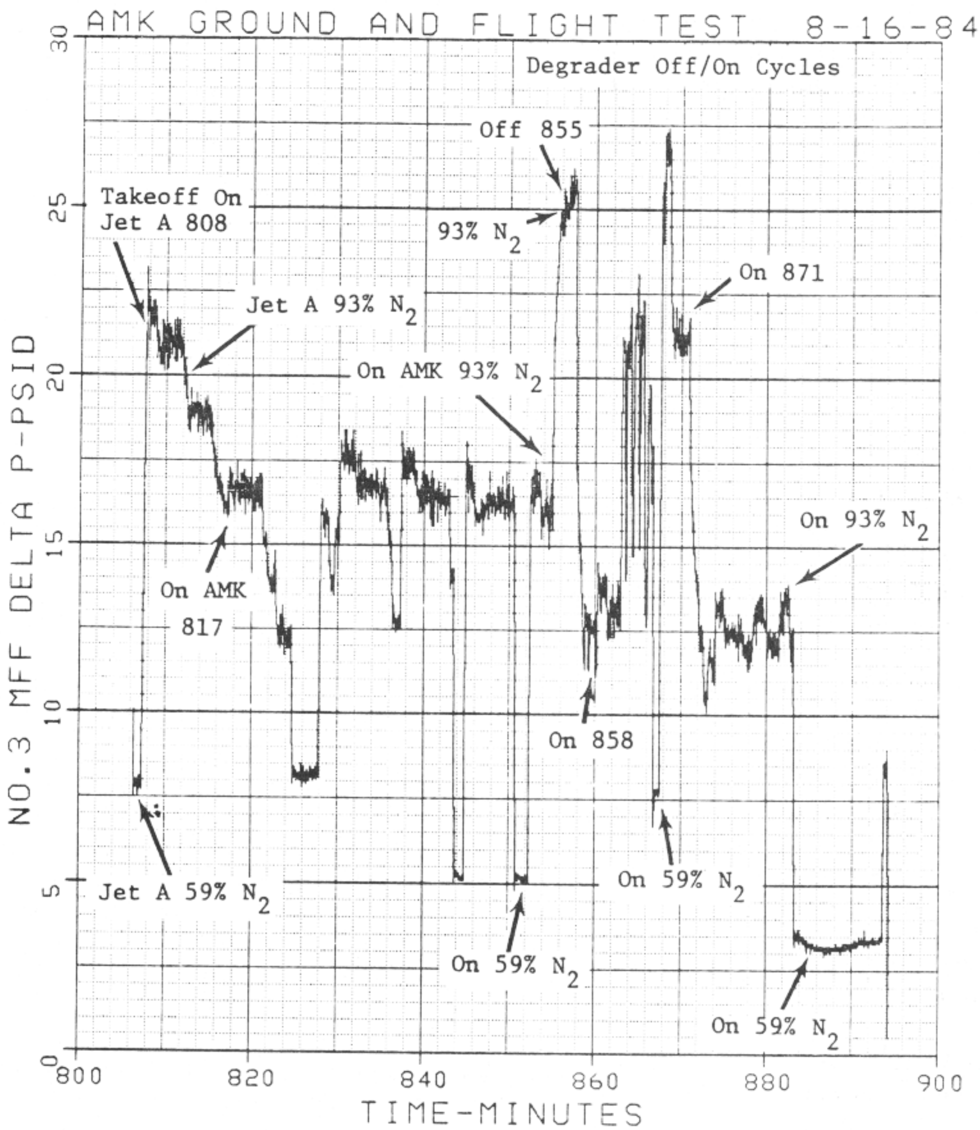


FIGURE 98. NUMBER 3 ENGINE MAIN FUEL FILTER ΔP

This ratio applies to both 59 percent and 93 percent N_2 (filter flow proportional to N_2). The increase in filter ΔP with undegraded AMK is a consistent ratio regardless of flow rate. With the degrader off, the characteristic shear-induced gel of AMK caused the pressure rise. The only instrumented parameters that showed the effects of undegraded AMK fuel were those related to ΔP across filters.

This test relieved the concern over a degrader failure while operating on AMK. While the test was not of long duration, the results suggested that a degrader failure could be tolerated. The question of emergency failure, however, is best answered by the hours of generally satisfactory in-flight performance of the engine with hard gel present (Miami 2/10/84 and Cincinnati to Mojave 6/22/84). Neither undegraded AMK nor hard gel led to an immediate engine performance deterioration. It should be noted there is evidence that fuel-nozzle spray patterns can be acceptable even when hard gel is present in the fuel system (see Figure 85 - altitude relights during the first AMK flight with heavy gel present). Nozzle atomization would be expected to be poor with undegraded AMK.

The landing for the August 16 test was completed on AMK; all filters were inspected, and there was no evidence of gel.

COMPARISON OF THE PUMP/DEGRADER AND NEEDLE-VALVE DEGRADER. As a result of the hard gel experienced during the flight from Atlantic City to Mojave on June 20 and 22, a number of possible causes of gel were explored. One concern was that the somewhat elaborate pump/degrader was more conducive to formation of hard gel than a simpler device would be. Consequently, a test was devised whereby General Electric's pump/degrader and a Southwest Research Institute (SWRI) degrader would be evaluated side-by-side on the CV800. NASA JPL built the test apparatus for this comparison and helped perform the test at Mojave.

Figure 99 shows the test setup used to evaluate the GE pump/degrader and the SWRI needle-valve degrader. AMK flowed by suction feed from the CV880 No. 3 tank to the degrader inlet. For the needle-valve degrader only, a large 100-mesh screen was used to protect the piston pump from solid contaminants. The piston pump bypass flow was hand-regulated to a 4000-psi pressure drop across the needle-valve degrader. With 1 gpm coming from the AMK tank, the degraded AMK passed through two 40-μm screens; the first had 4-in^2 surface area, and the second 1-in^2 surface area. Pressure drop across the 1-in^2 screen was recorded on a strip chart. A CV880 sampler filter (also 40-μm) was located downstream of the 1-in^2 screen. Finally, the flow went through a CV880 flow-meter and into a catch tank.

The pump/degrader was operated in a normal manner at 18,000 rpm, with the throttling valve discharge connected to the above-mentioned 1-in^2 screen. This connection is indicated by the dashed line in Figure 99.

Both the needle-valve and the pump/degrader produced a 1.2 filter ratio at the degrader system discharge. There was no rise in ΔP across the 1-in^2, 40-μm screen while testing either degrader. As can be seen in Figures 100 and 101, engine sampler filter ΔP was constant at 4.5 psid during the 23-minute test of the GE degrader at 400 pph (1 gpm). Inspection of all screens and filters following the tests showed no evidence of gel.

Following the comparative degrader tests, the engine was run for 38 minutes on AMK. The engine was started on Jet A from the No. 2 tank - which contained no glycol. Note the precipitate gel ΔP spike across the sampler filter at time 1416 in Figure 101. After all Jet A was out of the system, the line at the throttling-valve discharge (dashed line in Figure 99) was opened, allowing 1 gpm to pass through the 1-in^2, 40-μm screen.

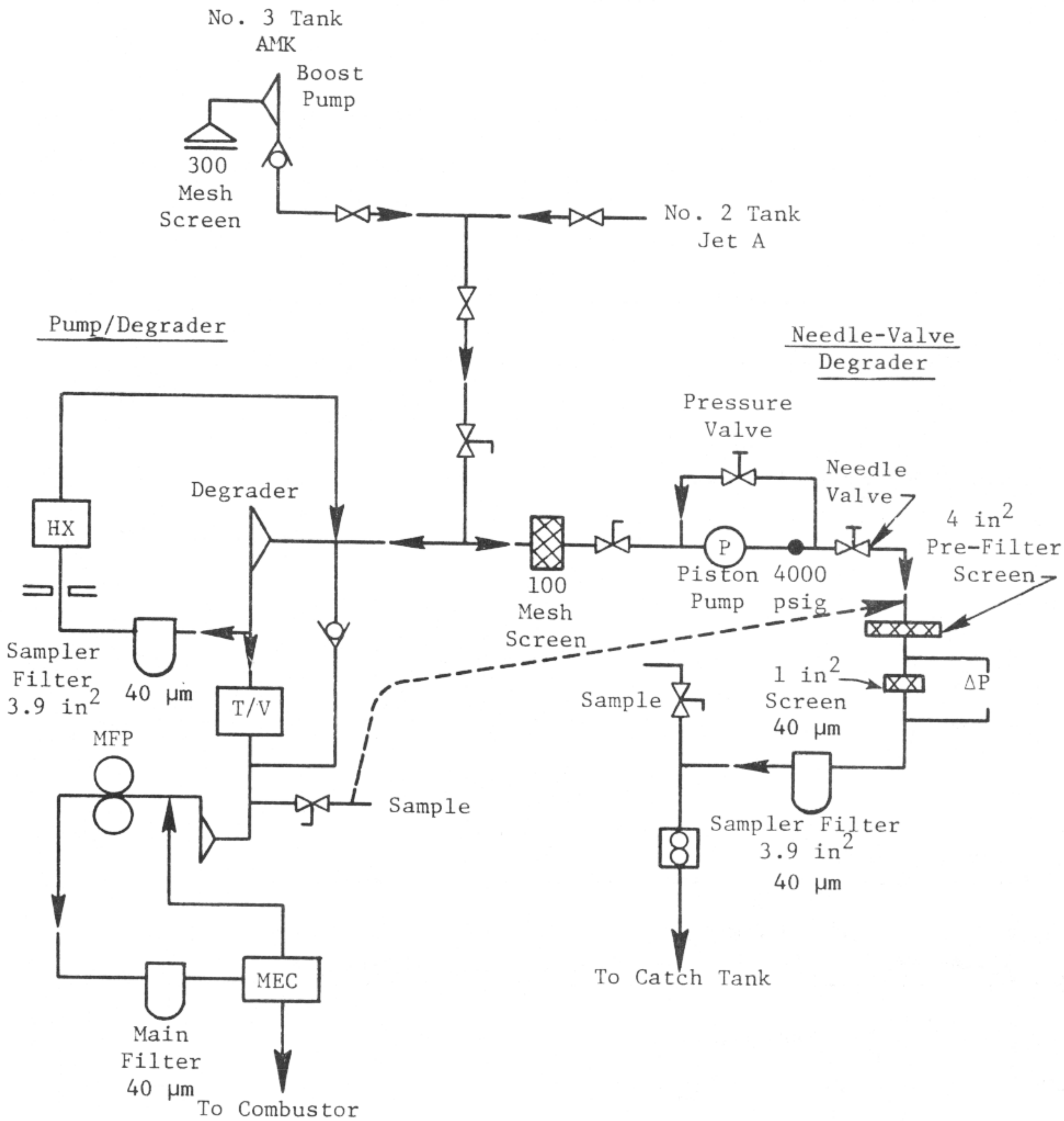
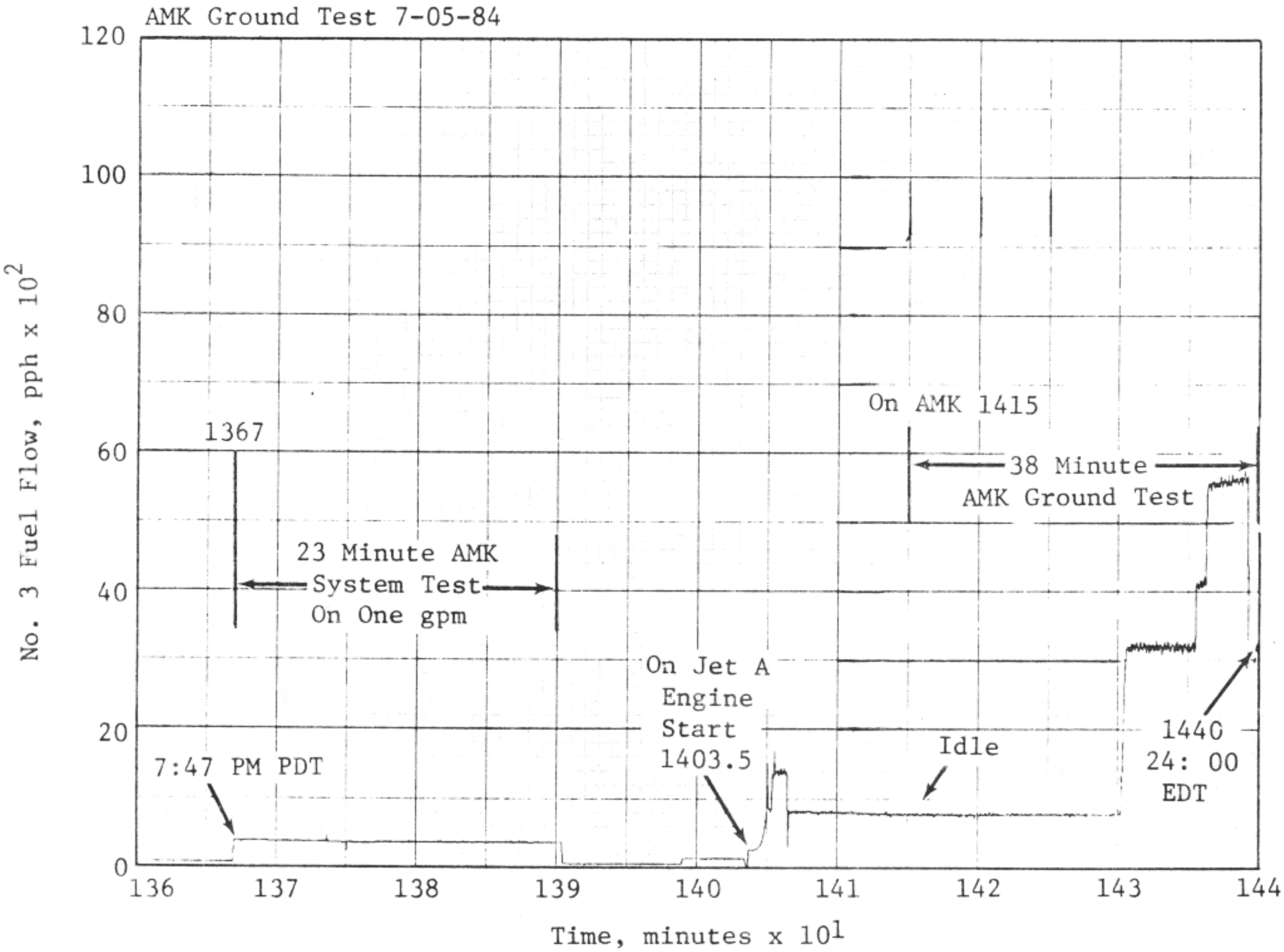


FIGURE 99. TEST SETUP FOR COMPARISON OF DEGRADERS



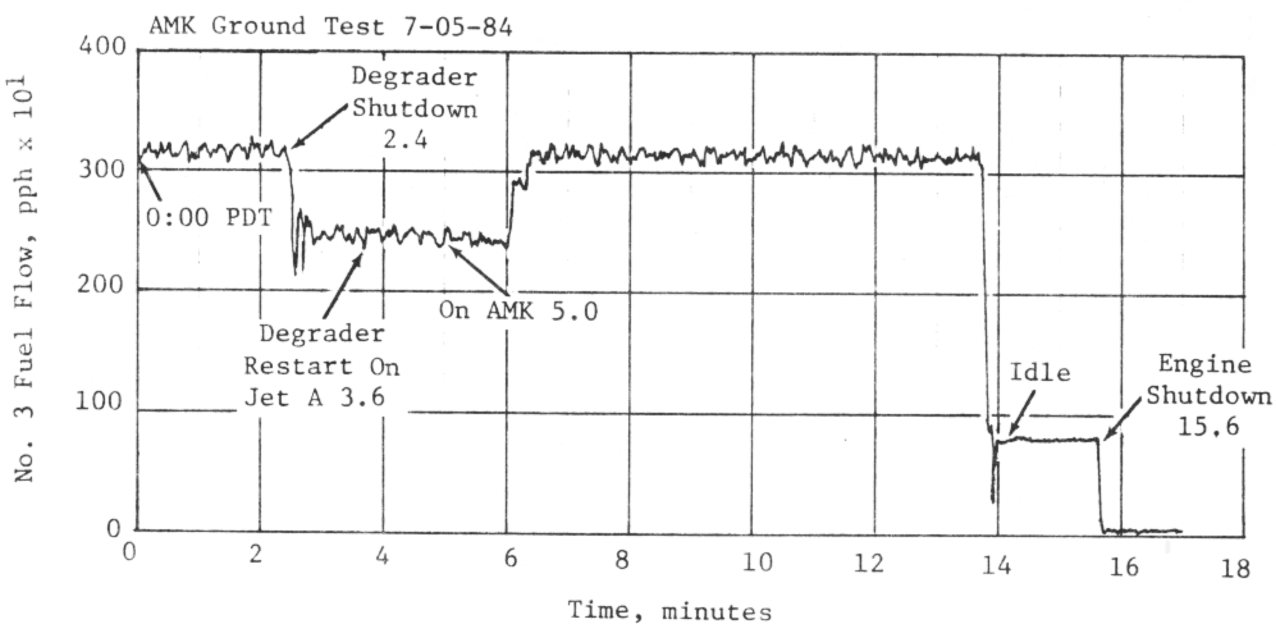


FIGURE 100. FUEL FLOW

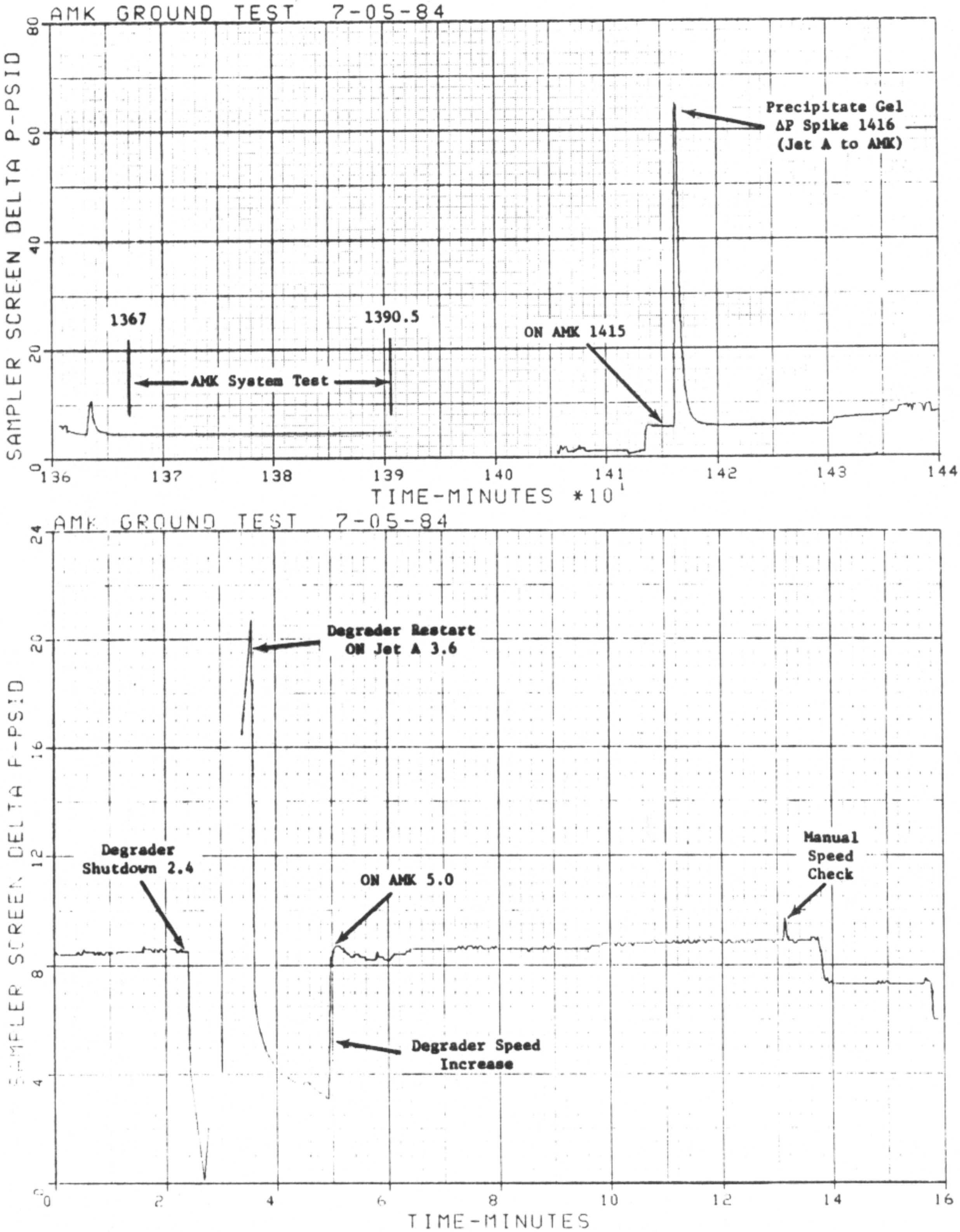


FIGURE 101. SAMPLER FILTER ΔP

During the test, a sudden loss of ATM air pressure was experienced; this was believed to have been caused by the No. 3 CV880 air-bleed valve. The engine and test screen were briefly exposed to undegraded AMK. The recorder for the ΔP screen went off scale due to shear-induced gel on the screen.

The test was resumed without difficulty, and the final results were totally satisfactory. There was no filter pressure rise and no evidence of residual gel. Precipitate and shear-induced gel behaved as expected. Shear-induced gel washed away, and precipitate gel disappeared after a brief time.

OPERATION ON FRESHLY BLENDED AMK. During the CV880 program, blends of AMK usually took 5 to 8 hours before characterization results stabilized. Earlier investigations, sponsored by the FAA Technical Center, had shown acceptable fire preventive properties of AMK could be achieved within 30 minutes of blending AMK fuel. Two tests were performed on August 25 and 26 at Mojave to evaluate engine operation on freshly blended AMK.

The first test on August 25 was a 1-hour, 37-minute flight. A 920-gallon blend of AMK into the No. 3 tank was started at 14:23 PDT and completed at 15:55. The engine started on AMK at 15:55 (955 computer time). Considering tank fuel mixing during blending and sloshing during the climb/descent, it is reasonable to assume average AMK age after blending of 45 minutes at the start of the test and 2 hours, 23 minutes at the end of the test.

After engine start on AMK and as the aircraft began to move off the parking ramp, No. 3 engine EGT rapidly exceeded limits. EGT reached the 750° F limit in 5 seconds. Examination of the recorded data shows that this problem was not related to AMK and most likely was the result of a hang-up in compressor inlet temperature (CIT) sensor input lever of the control (outside the fuel system). The problem disappeared completely after the engine was shut down and restarted on AMK. Following a full-power run-up, the test was resumed as planned.

Seven climb/descent cycles were performed. During one cycle at time 1026, the degrader was momentarily shut-off and restarted. A typical response, in terms of filter ΔP, to shear-induced gel can be seen in Figure 102.

Main fuel filter results shown in Figure 102 are of interest from the standpoint of ΔP reduction on AMK. For this test, the same filter element from the August 16 test was used without cleaning between tests. The element was removed and inspected on August 16 and then left in the empty (no fuel) filter bowl for 9 days, exposed to the hot desert environment. As can be seen in Figure 102 at time 955 to 960, pressure drops from 8.5 to 5.5 psid at constant fuel flow (shown in Figure 103). These results suggest a possible cleaning action of AMK relative to minute quantities of FM9 residue on the dry filter element. After the successful flight test, the filters were inspected, and no gel was evident.

On August 26 an 18-minute degrader system ground test further investigated the use of freshly blended AMK. This test also assessed the effect of high humidity during blending of the AMK.

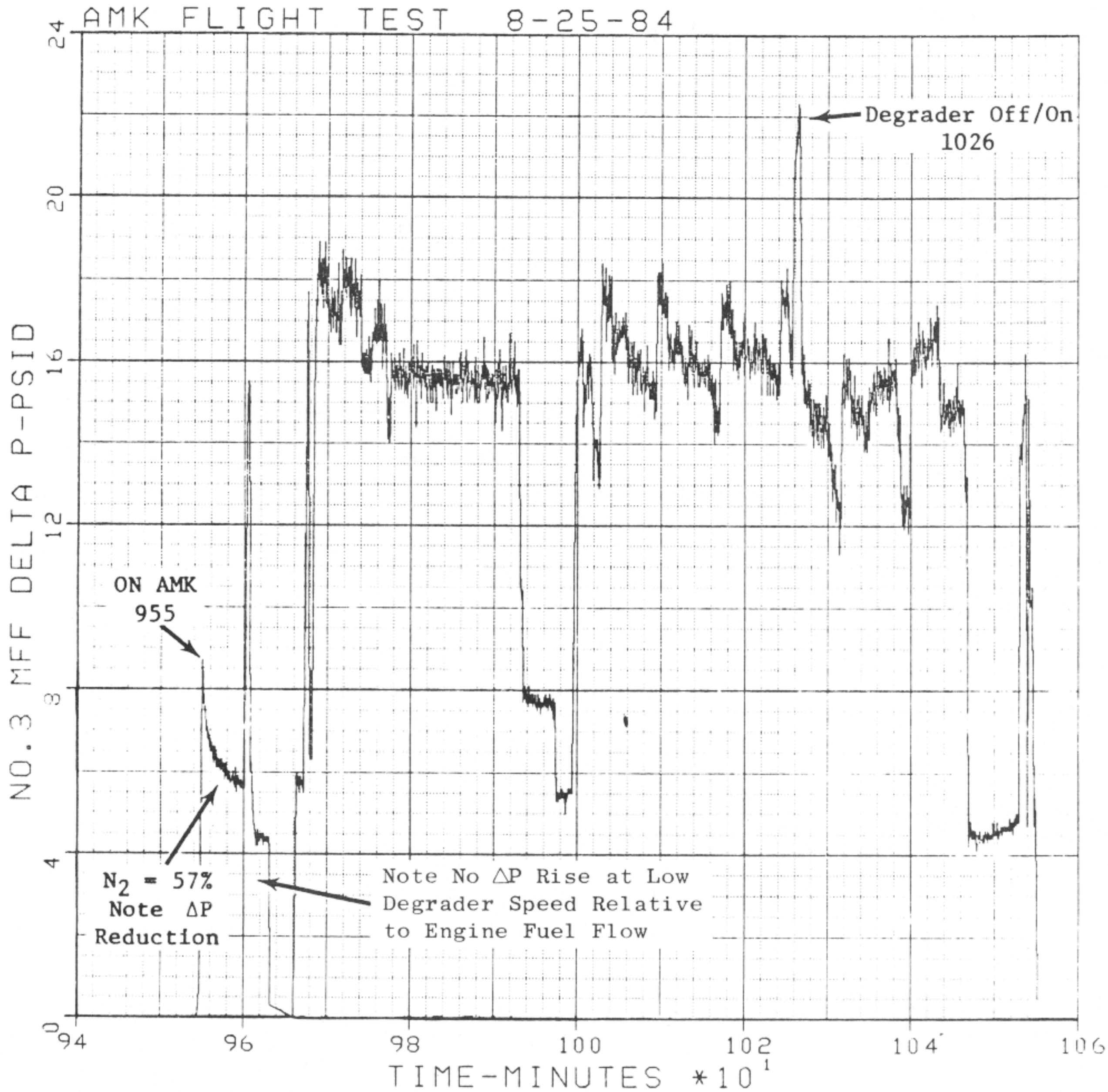


FIGURE 102. NUMBER 3 ENGINE MAIN FUEL FILTER ΔP

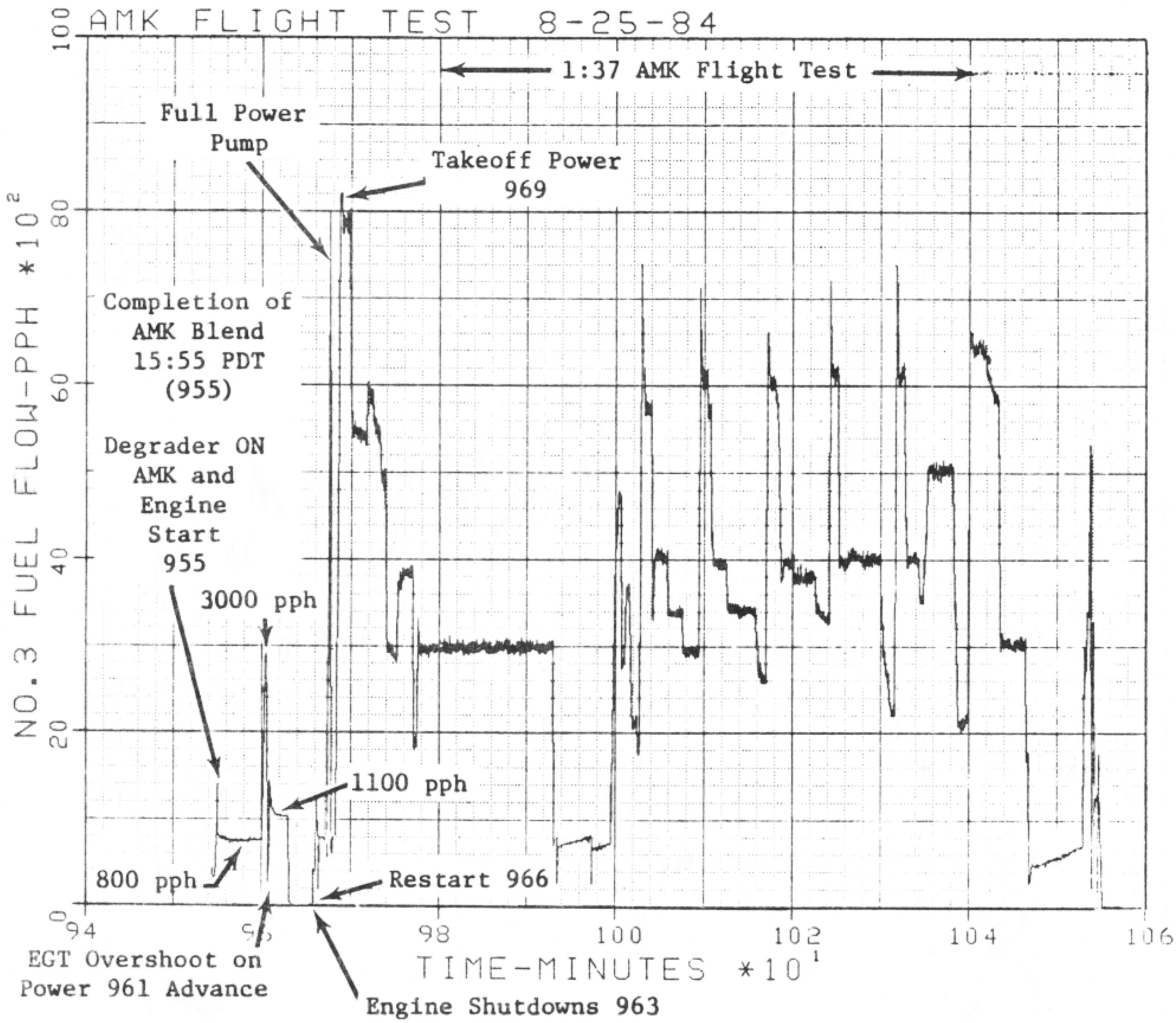


FIGURE 103. NUMBER 3 ENGINE FUEL FLOW

The 450-gallon blend of AMK was made under a tent; steam generators induced 100 percent relative humidity at 75° F ambient temperature. High humidity was used while calibrating the blender and during actual blending of the AMK, which took 45 minutes. Slurry homogenization was performed at ambient conditions with a relative humidity of approximately 30 percent.

Since the engine was not operated, the test could be started 1.5 minutes before completion of the blend. Forty five gallons of AMK were used (10 percent of the blend quantity). The consumed AMK would be 45-minutes old, assuming no mixing in the tank. Actually the tank AMK would be reasonably well mixed by the drop from the gravity-fill port to the bottom of the 2000-gallon tank at a fill rate of 10 gpm. Thus, the average AMK age was more of the order of 21 minutes during the test. Also, tank boost pumps draw from a wide horizontal surface, tending to average the fuel. It is concluded that the test results were at least representative of the objective of aircraft departure 15 minutes after fueling.

Test results for freshly blended AMK, shown in Figures 104 through 106, were excellent. In Figure 106, note that sampler filter ΔP decreased at near-constant fuel flow at the beginning of the test. This result was with a new sampler screen, not previously exposed to fuel of any type. Thus, this 20% reduction in filter ΔP with AMK could not be the result of "washing" residual FM9 from the filter.

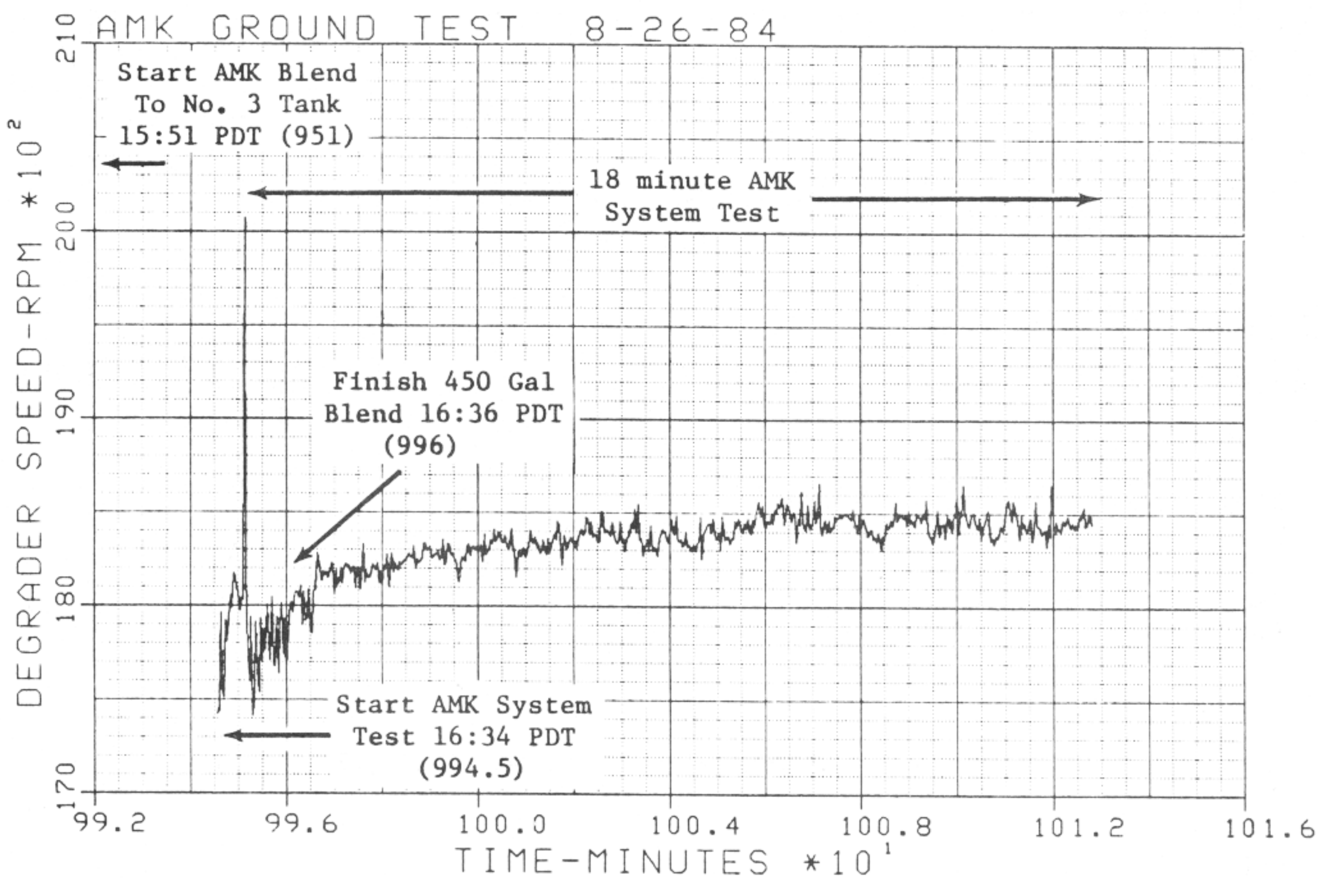


FIGURE 104. DEGRADER SPEED

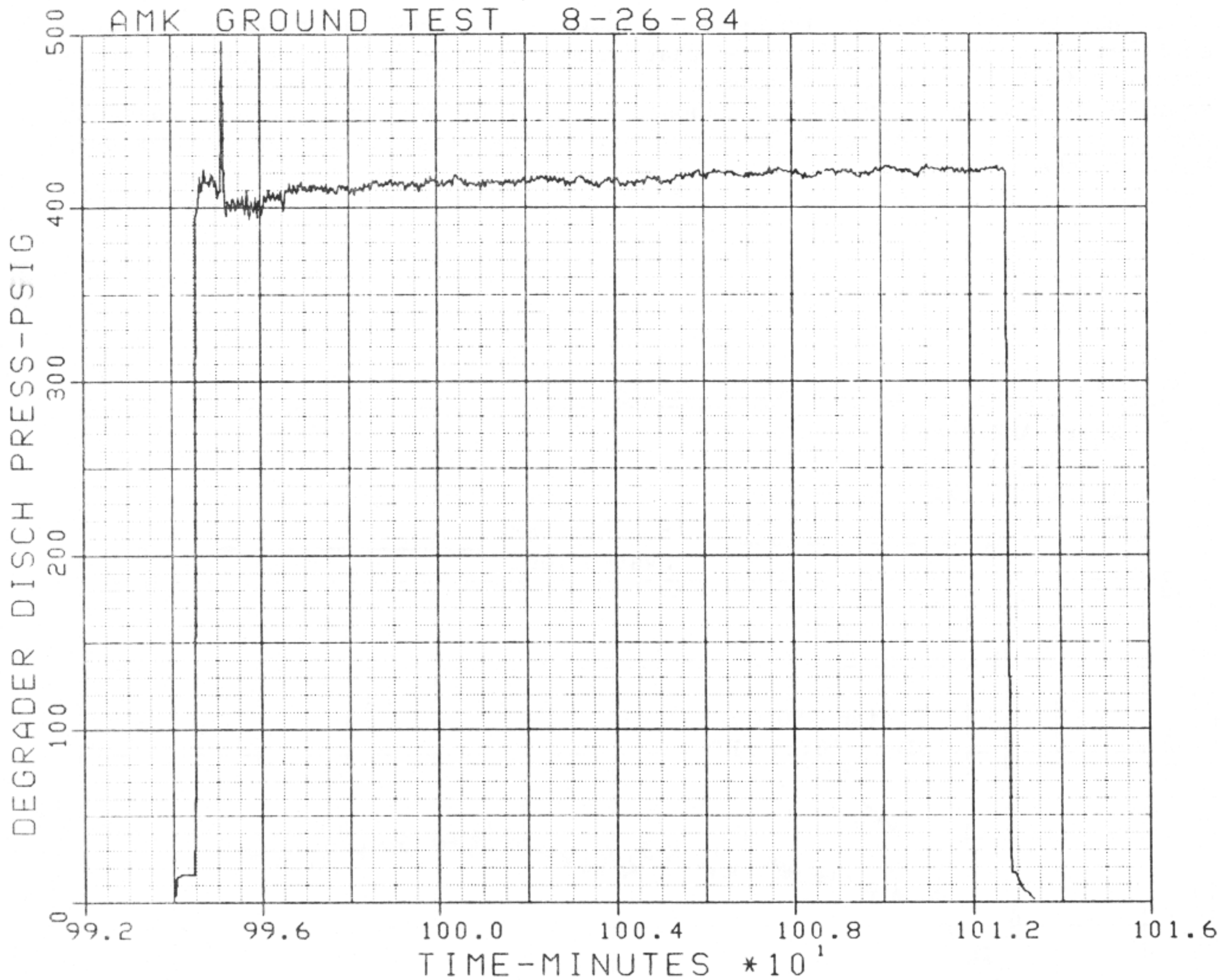


FIGURE 105. DEGRADER FUEL DISCHARGE PRESSURE

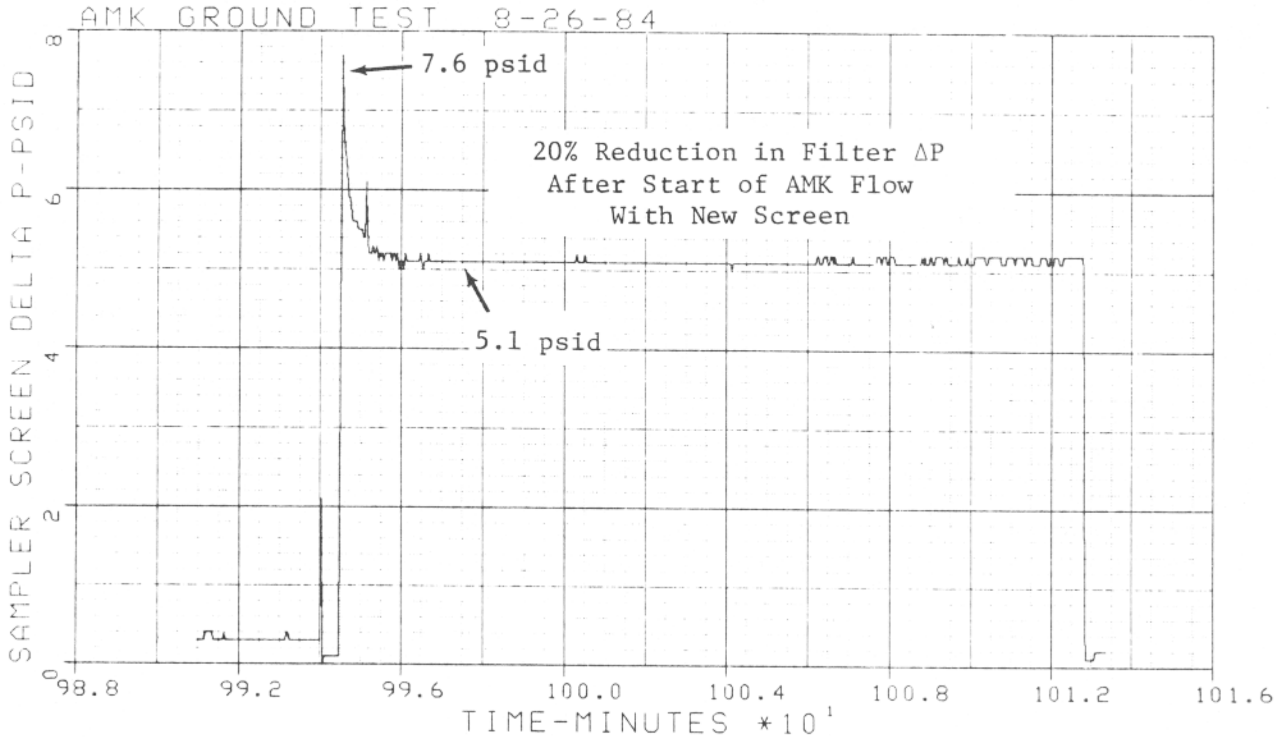


FIGURE 106. SAMPLER FILTER ΔP

Even though the average age of AMK in the August 25 and 26 tests was greater than the objective of 15 minutes between fueling and aircraft departure, it is doubtful that the operational results would have been significantly different if a large blend of AMK could have been completed in 15 minutes (the CV880 blender had a rather low blending-rate capability).

The filter ratio of freshly blended AMK, after passing through the degrader, might possibly have been as high as 20, but there was no evidence of gel forming on the engine filters. If the blending process results in homogenous dispersion of FM9 polymer in the Jet A, the AMK fuel should useable without waiting for a stabilization period of 5-8 hours.

OPERATION ON COLD AMK. Two flights were performed to assess the performance of the degrader with cold AMK fuel. The first flight was from Mojave to Atlantic City on August 30; the second flight was from Atlantic City to Miami on September 1. During the August 30 flight, the outside air temperature went only as low as -37° F. This, coupled with the necessity of an early descent (an hour prior to landing) due to poor weather conditions at Atlantic City, resulted in a bulk fuel tank temperature of 47° F. During the September 1 flight, the formation of hard gel precluded direct comparison of filter performance changes due to cold fuel. Nevertheless, from the standpoint of cold fuel, by analyzing data from both tests it was possible to assess cold AMK fuel performance to a reasonable degree.

Figures 107, 108, and 109 show No. 3 engine fuel flow, altitude, and Mach number for the August 30 flight. There are several considerations involved in analyzing the test findings. The temperatures of the fuel supplied to the degrader (AMK or Jet A) was measured at the engine fuel supply line about one foot upstream of the degrader system. All recirculation lines were downstream of this thermocouple; hence, only ambient air heating or cooling of the supply line would affect measured degrader fuel inlet temperature. Tank temperatures were measured by thermocouples installed at the midpoint (height) of the wing front spar; these thermocouples measure bulk fuel temperature. Degrader input power was determined by closing off cooling air to the fuel-recirculation heat exchanger (heat transfer out of system) and calculating power on the basis of fuel flow and temperature rise. This approach accounts for all degrader input power except cooling or heating from ambient air surrounding the degrader systems components and line; these effects should be minor at the power levels involved. Filter ΔP was a function of three predominant factors:

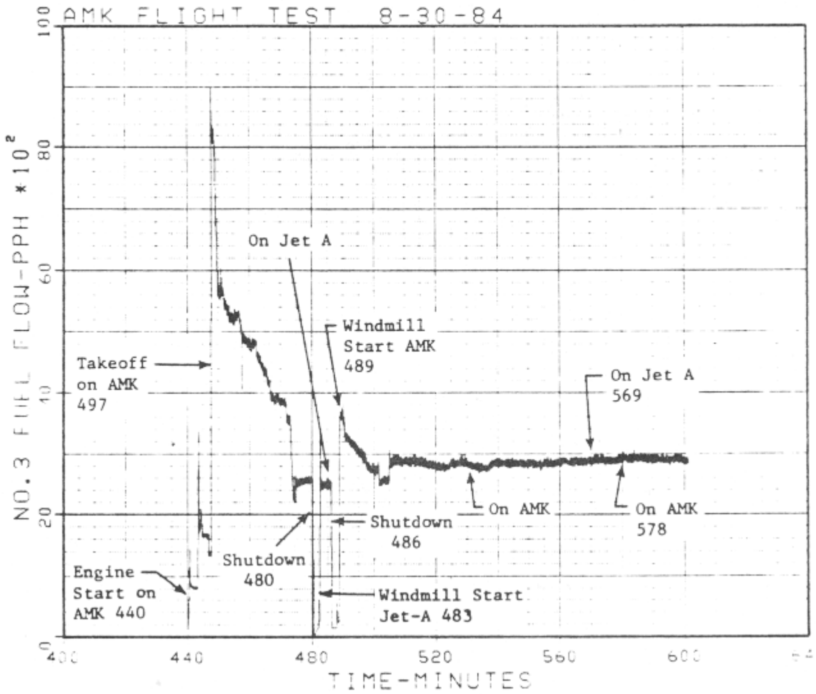
1. For the same level of degradation (lab standard 1.2 to 1.4 filter ratio) filter ΔP might increase as the result of colder degraded AMK.

2. The degrader might not degrade the AMK as well with a colder fuel supply temperature, thereby leading to higher pressure drop across the filter.

3. Either fuel (AMK or Jet A) is expected to result in higher filter pressure drop at cold-fuel conditions.

Degrader performance in terms of power input and degrading capability was assessed by operating the degrader in the automatic mode where speed was held at a reference value (proportional to engine metered fuel flow). The degrader then automatically consumed more power (more ATM air flow) as needed to hold reference speed. This shows up as higher fuel temperature. Thus, degrading capability would vary only as a function of supply temperature since speed is constant. In other words, the only reason for an increase in degrader power would have to be the result of increased fluid resistance within the degrader (fluid shear stress, for example). This is exactly the same situation that occurs with a centrifugal tank boost pump running at constant speed. The flight test also evaluated degradability at higher degrader speeds (manual-speed mode), but only marginal results were obtained. Higher speeds resulted in higher fuel temperatures with less than clear interpretation available as to the effect on filter ΔP.

There are several factors affecting the fuel temperature delivered to the engine (degrader inlet temperature). At 37,000 ft/Mach 0.85, the wing skin-friction temperature would be about 30° F with the measured static OAT of -30° F. This is the ram-air recovery temperature. At time 656 in Figure 110



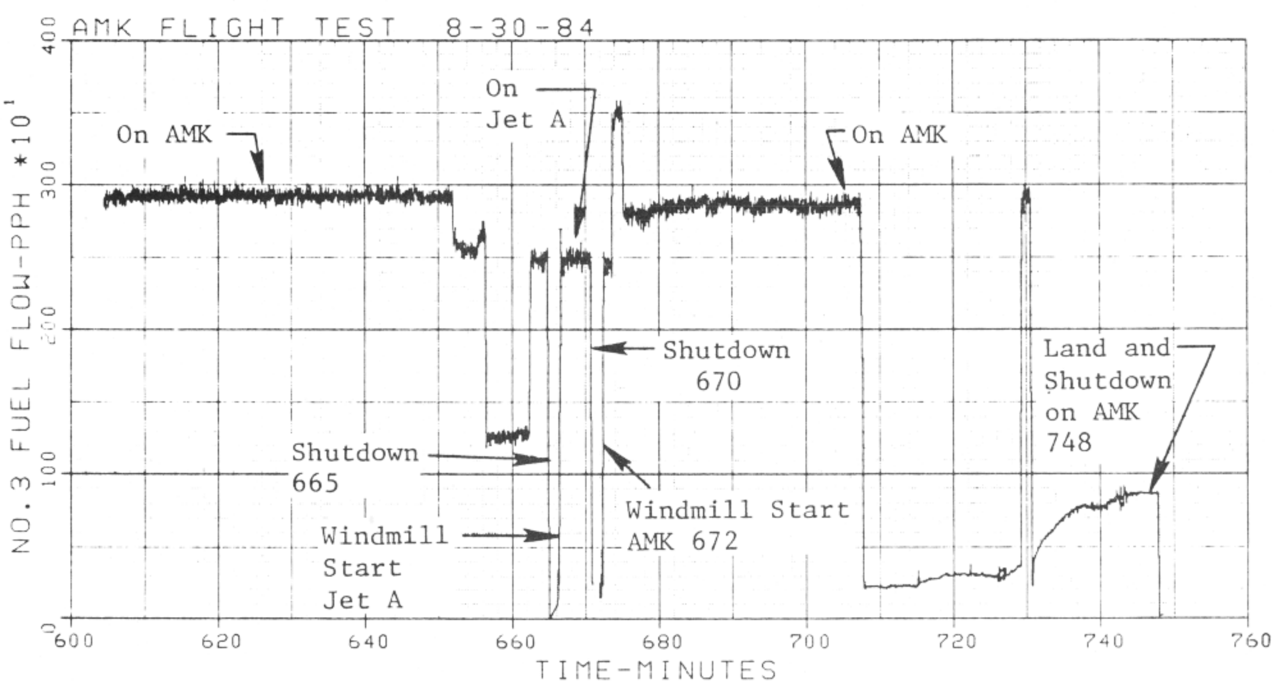
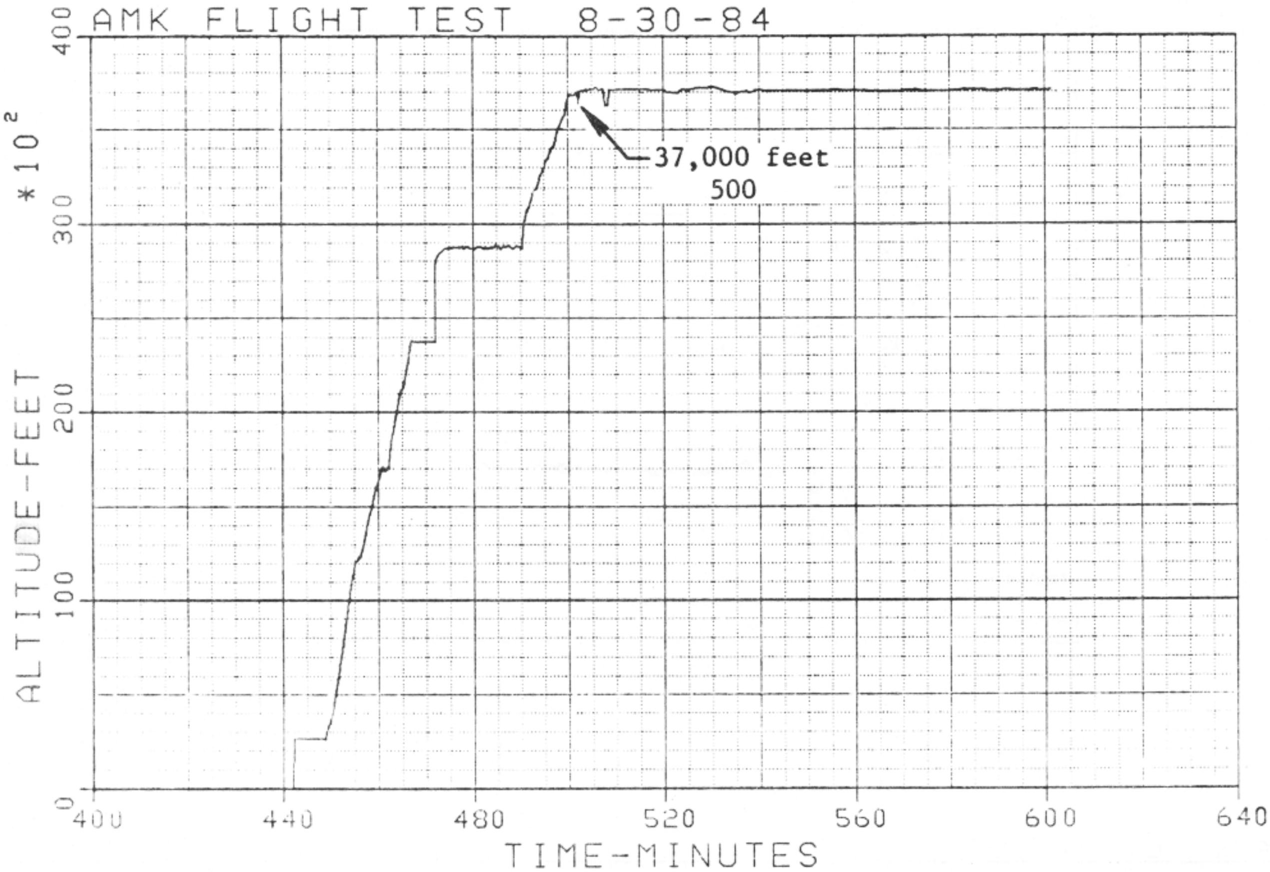


FIGURE 107. NUMBER 3 ENGINE FUEL FLOW



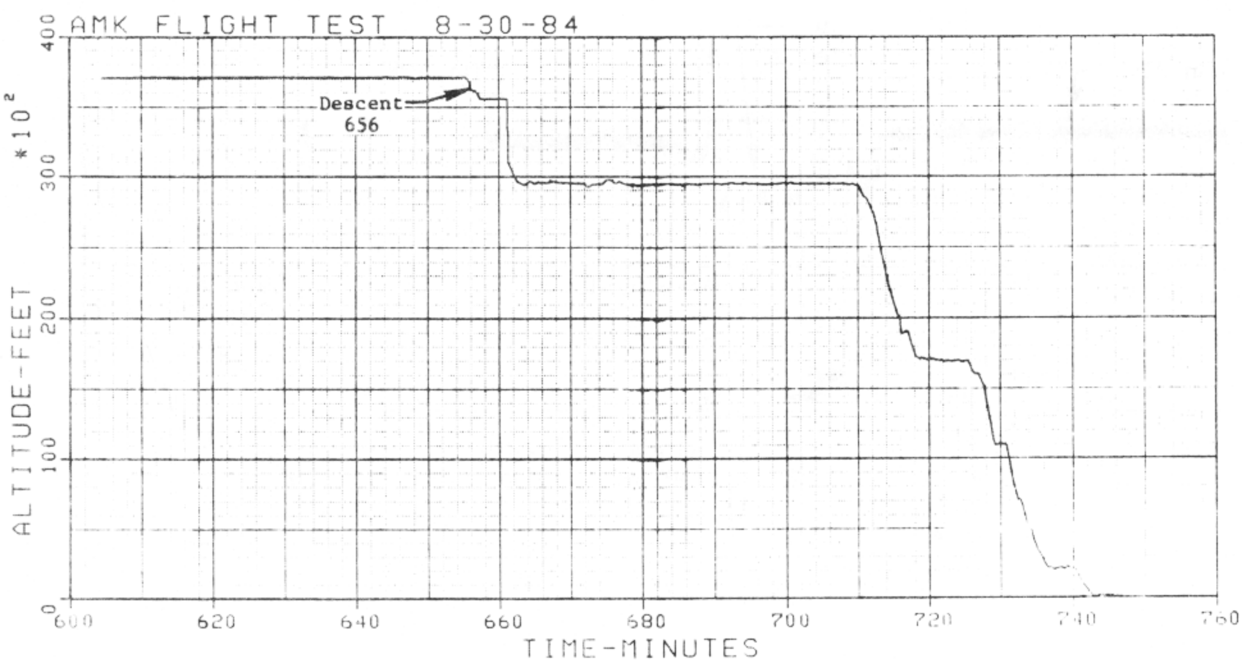
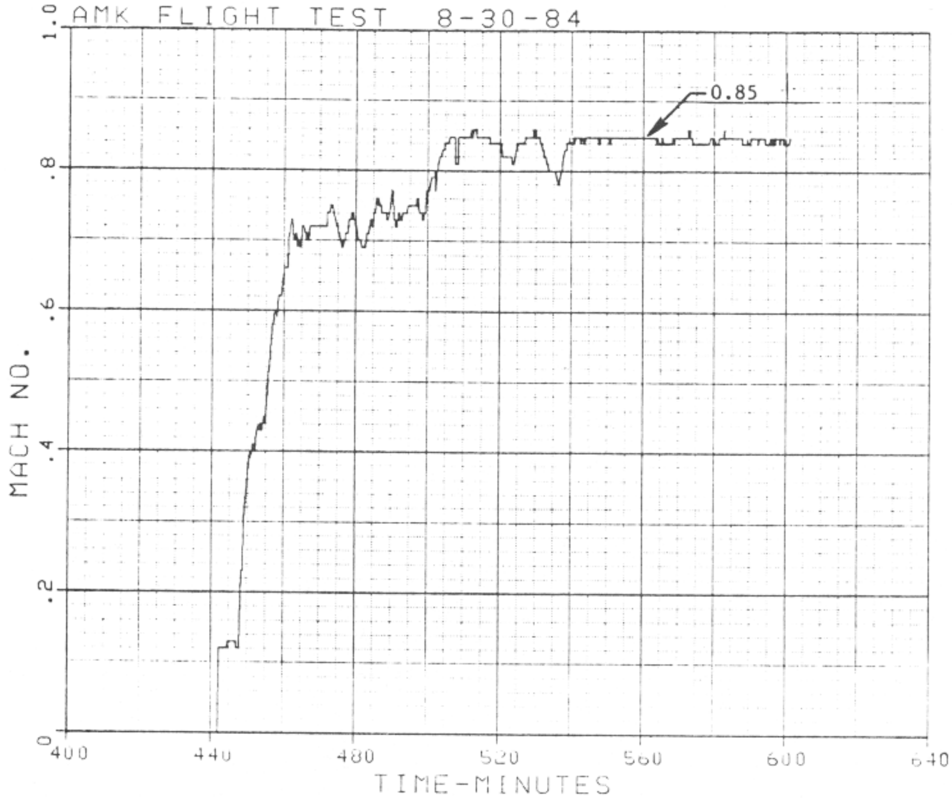


FIGURE 108. PRESSURE ALTITUDE



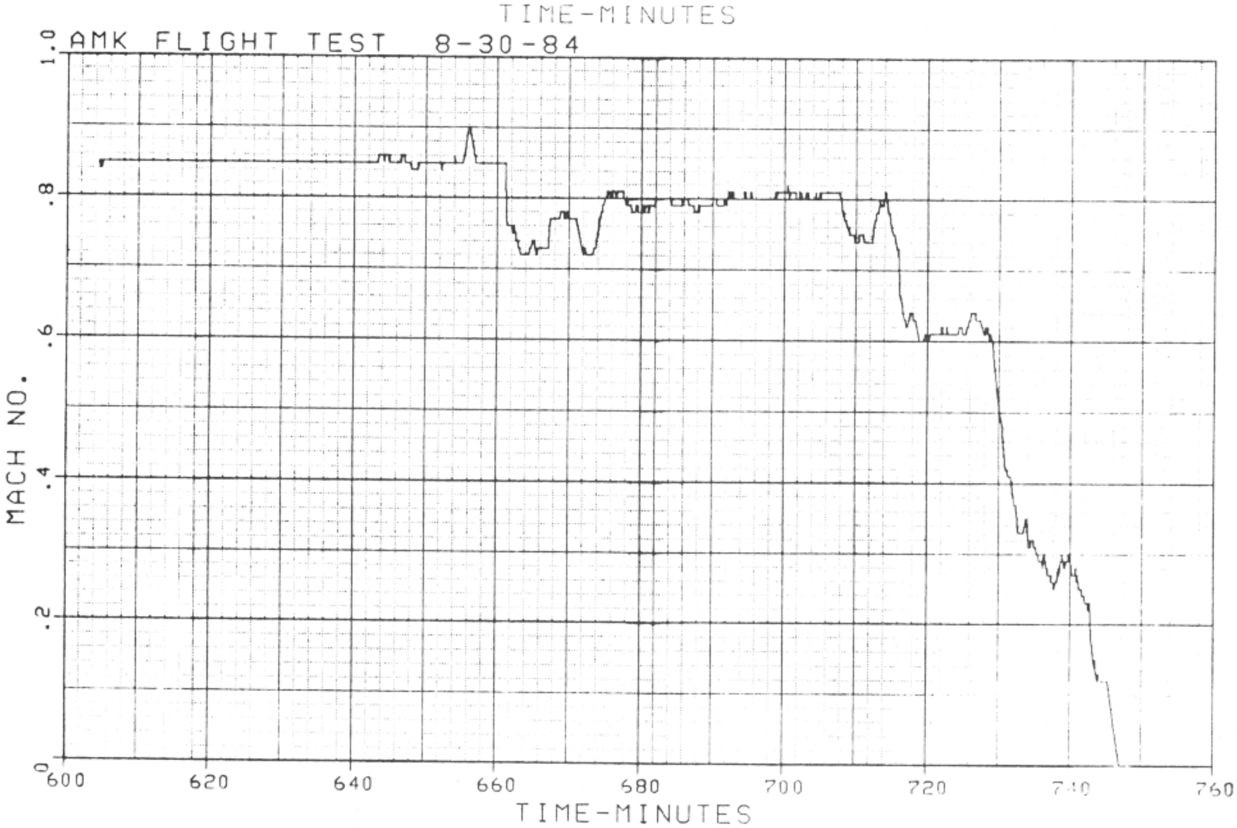
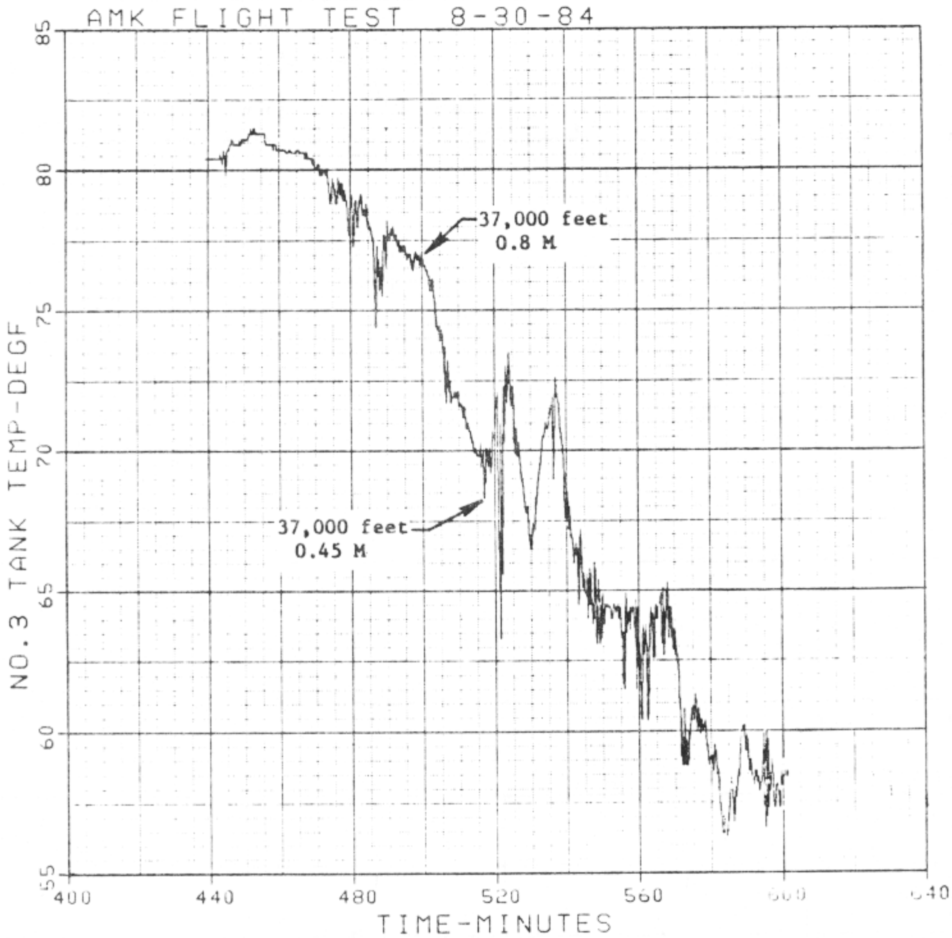


FIGURE 109. MACH NUMBER



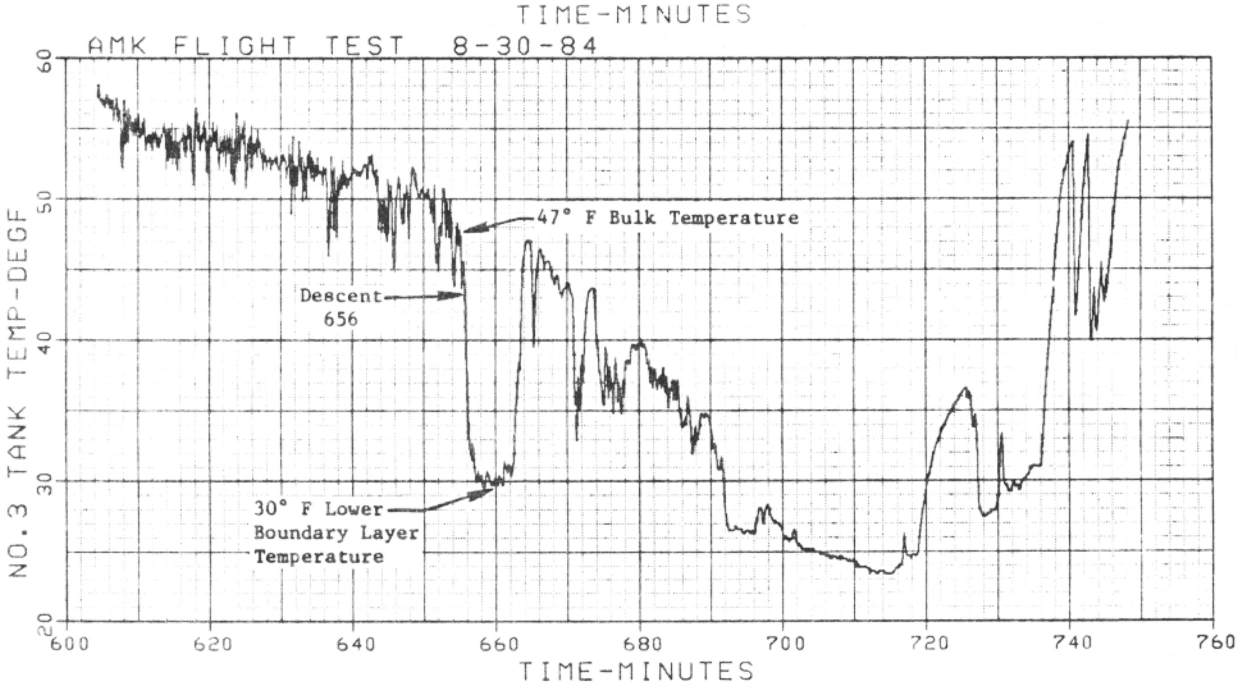


FIGURE 110. NUMBER 3 TANK TEMPERATURE

it is noted that AMK tank temperature was 30° F. In Figure 111, No. 2 tank Jet A temperature was 20° F at the same time. These tank temperatures occur in the vicinity of the front spar tank thermocouple when descent is initiated. Cold fuel in the boundary layer at the bottom of the tank rolls forward to the thermocouple. This illustrates the large thermal gradients that develop in the tank. Cold fuel at the bottom of the tank is pumped to the engine where it may even get colder as the result of heat transfer between the fuel supply line and ambient air. Thus degrader inlet fuel can be considerably colder than bulk tank temperature. When descending into warmer air, the opposite may occur, and the degrader or engine fuel inlet temperature may be higher than measured tank temperature. Figures 110, 111, and 112 show these differences between tank and degrader-inlet temperatures. Obviously, degrader-inlet temperature (not tank temperature) is more relevant for assessing degrader performance.

Degrader power was determined for all conditions where data were available with the heat exchanger cooling-air valve closed. These results for both the August 30 and September 1, 1984 flights are summarized in Table 14.

TABLE 14. SUMMARY OF TEST PARAMETERS, 8/30 AND 9/1/84

Flight Date	Mojave to Atlantic City August 30, 1984			Atlantic City to Miami September 1, 1984		
Time, Minutes	557	653	700	870	901	903
Tank Temperatures, ° F	64	48	26	-7	-11	-16
Degrader Inlet, ° F	32	22	28	4	8	0
Metered Fuel Flow, pph	2800	2600	2850	2700	2700	2700
Degrader hp	51.1	44.9	44.2	50.0	46.1	48.2
hp/pph	0.0182	0.0173	0.0156	0.0185	0.0170	0.0179
Fuel	AMK	AMK	AMK	AMK	AMK	Jet A
Degrader Speed, rpm	23,500	22,200	23,000	22,400	22,400	22,400

From these data, the average value of power-to-flow ratio (hp/pph) was 0.0174. Maximum variance from this value was -10 percent, +6 percent. At 32,000 rpm the power input would be 134 hp; this is in precise agreement with degrader development bench test data (135 hp at 3722 pph = 0.0155 hp/pph). It was also noted that there was no difference between degrader power using Jet A or AMK. Thus, it was concluded that the degrader demanded no excess drive power to degrade cold AMK at supply temperatures down to 4° F.

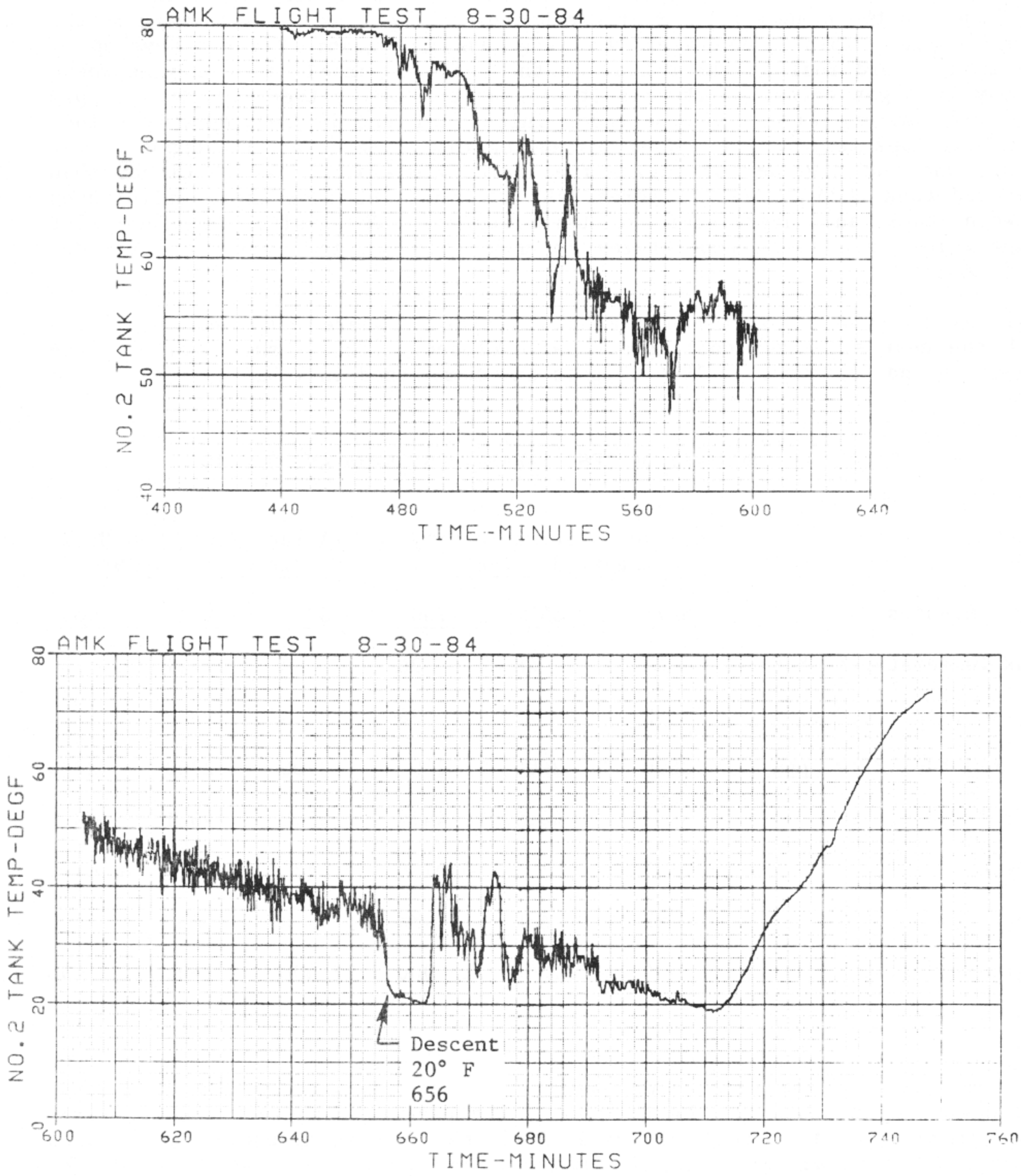
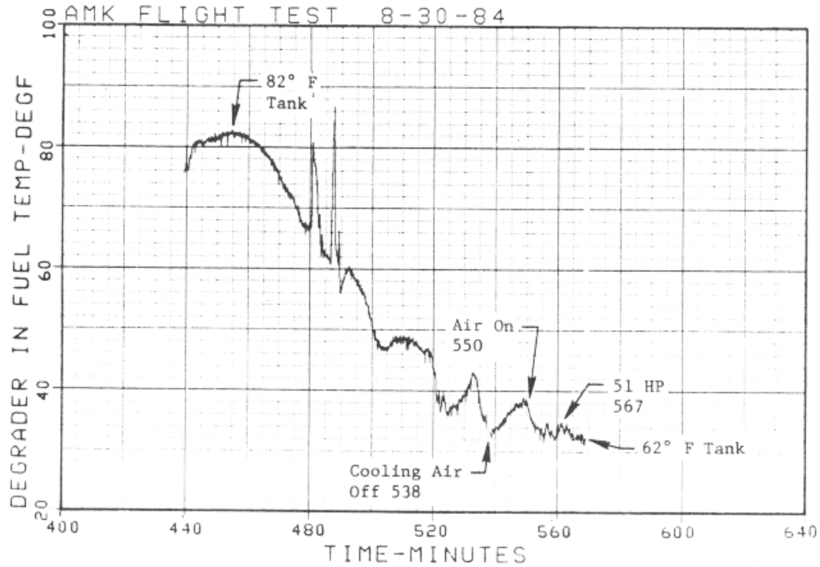


FIGURE 111. NUMBER 2 TANK TEMPERATURE



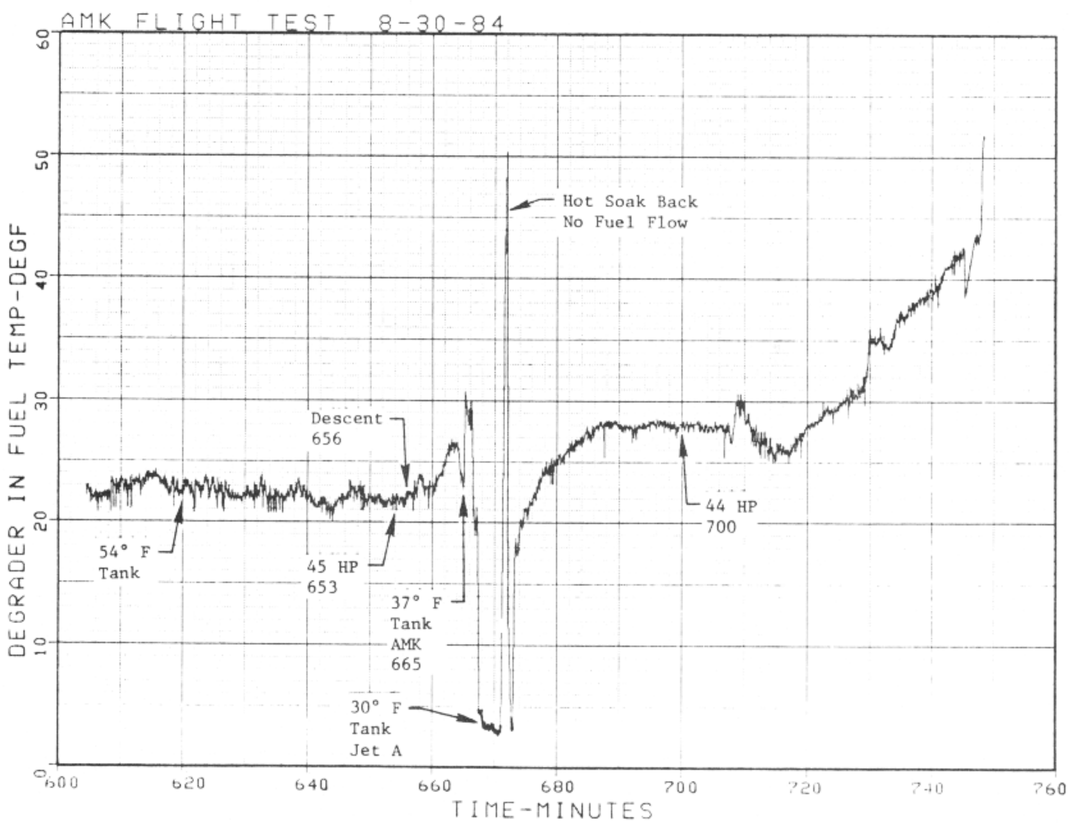


FIGURE 112. DEGRADER FUEL INLET TEMPERATURE

In order to assess the difference between scheduled degrader speed and higher manual speed on degrader performance (more degrading), it was necessary to divorce the effect of fuel temperature from the results. Only the main filter could be used to assess the effect of degrader speed and increased degradation power on filter pressure drop (see Figure 113). Sampler filter ΔP, shown in Figure 114, could not be used because this pressure rises as the square of degrader speed; hence, pressure drop always increases with degrader speed. Even with the main filter, the best result was a comparison between Jet A and AMK to rule out the filter-fluid temperature effect (varies with degrader speed). The data between time 569 to 594 (Figure 113) gives these conditions. Table 15 summarizes the results. In subsequent tables and figures where data were taken from the original computer flight data plots, main filter ΔP was corrected as a function of engine speed (N^2) squared. Sampler filter ΔP was corrected as a function of degrader ΔP (linearly).

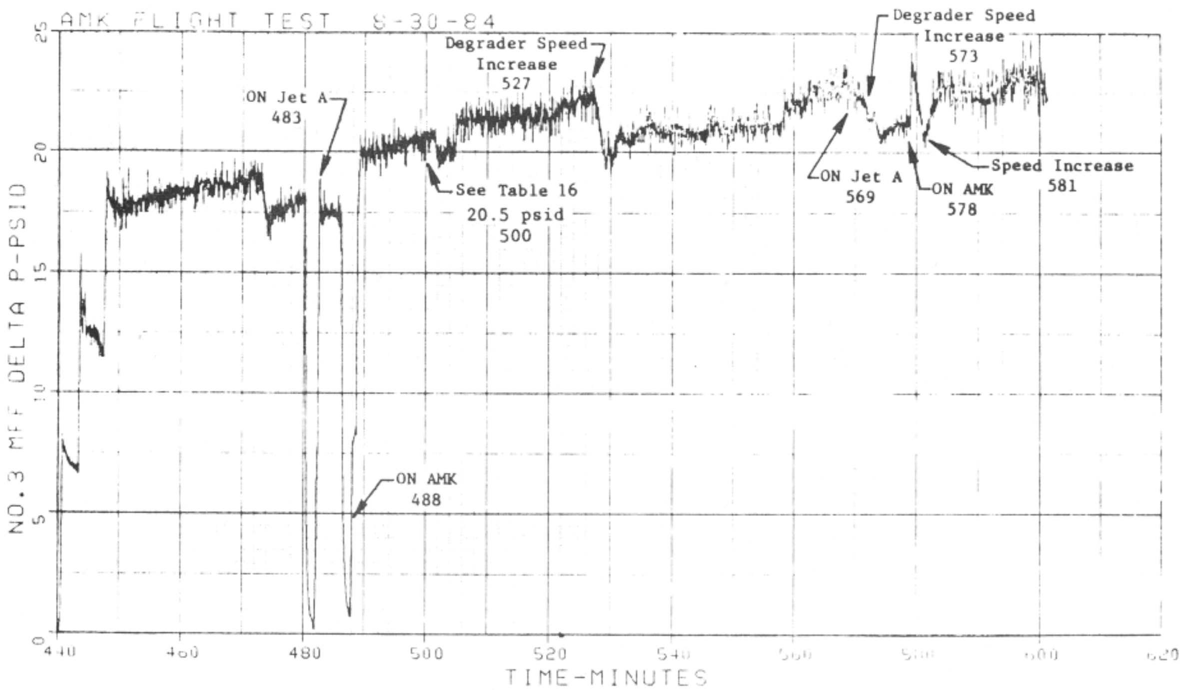
TABLE 15. EFFECT OF INCREASED DEGRADER SPEED ON MAIN FILTER ΔP

Time	569	563	578	581
Fuel	Jet A	Jet A	AMK	AMK
Degrader Speed, rpm	22,000	29,400	22,700	29,400
Filter Fuel Temperature, ° F	130	150	130	155
Engine Speed, $\%N_2$	94	94	94	94
Filter ΔP, psid	23.0	21.0	23.2	21.0
Increased Degrader Power, %	--	117	--	117

Within the accuracy of these data, Jet A and AMK both gave the same results. Increasing degrader speed and power did not reduce filter ΔP to any great extent other than the reduction apparently associated with the increase in fuel temperature. Thus, degrader power, per se, was not shown to have a direct effect on degrader performance in any regard.

Examination of all data recorded during the flight from Mojave to Atlantic City showed that only the sampler filter and main engine fuel filter were affected by in-flight conditions. There was no observed gel on any filter after the flight (on ground at Atlantic City). There was no change in wash screen ΔP or observable effect on any engine parameter (including AMK relight) during the test. Consequently, only the sampler and main filter in-flight data serve to indicate a change as the result of prolonged AMK operation. Figures 115 and 116 summarize these data during the course of the flight. Both filters showed a rise in ΔP as the fuel cooled, followed by return to normal (takeoff) conditions as the fuel warmed at the end of the flight. The sampler filter ΔP appeared to be more strongly influenced by fuel cooling than was main filter ΔP. This was to be expected since screen areas differ by a factor of 40 and flow velocities by a factor of about 10 (main filter: 40 µm, 160 in^2, 50 gpm; sampler: 40 µm, 3.9 in^2, 12 gpm).

Figures 113 and 114 show periods of more or less continuous operation on AMK where there appeared to be a trend toward increasing filter pressure drop.



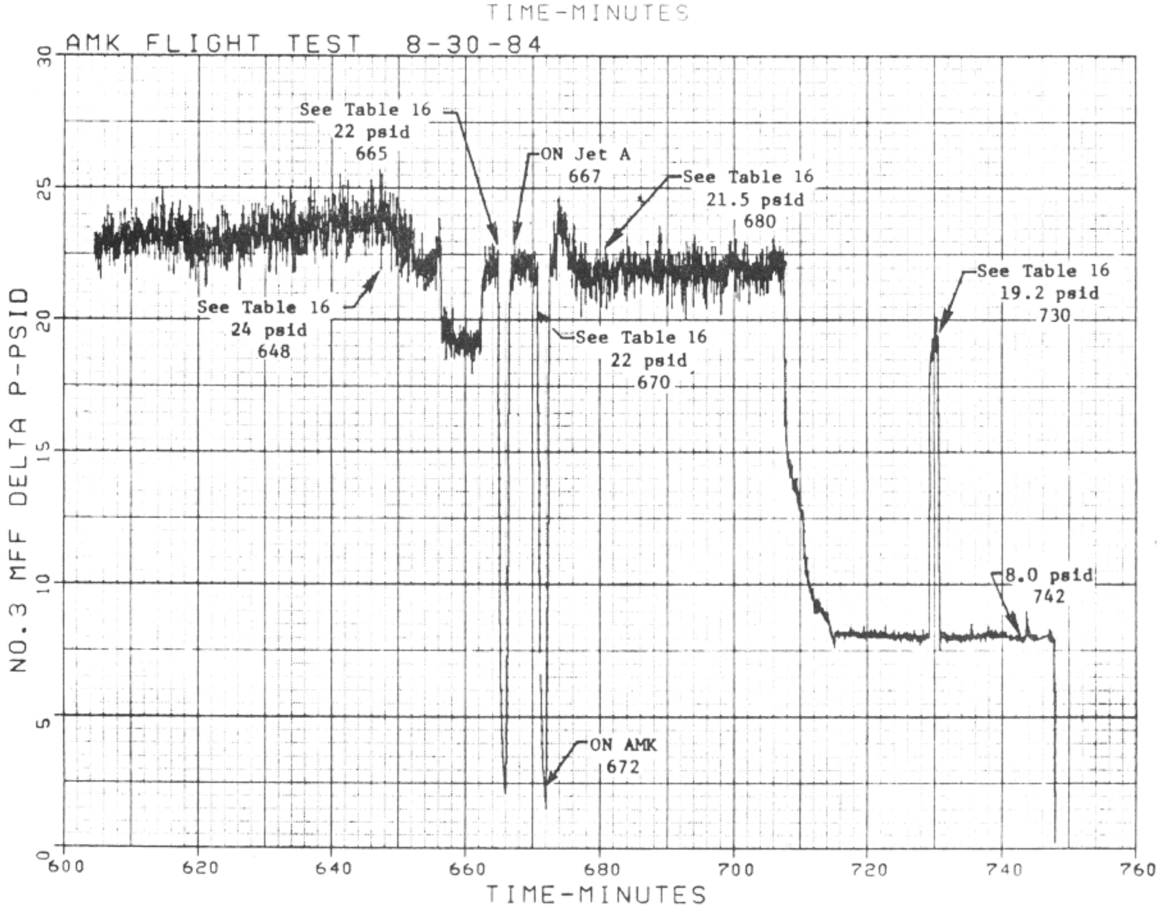
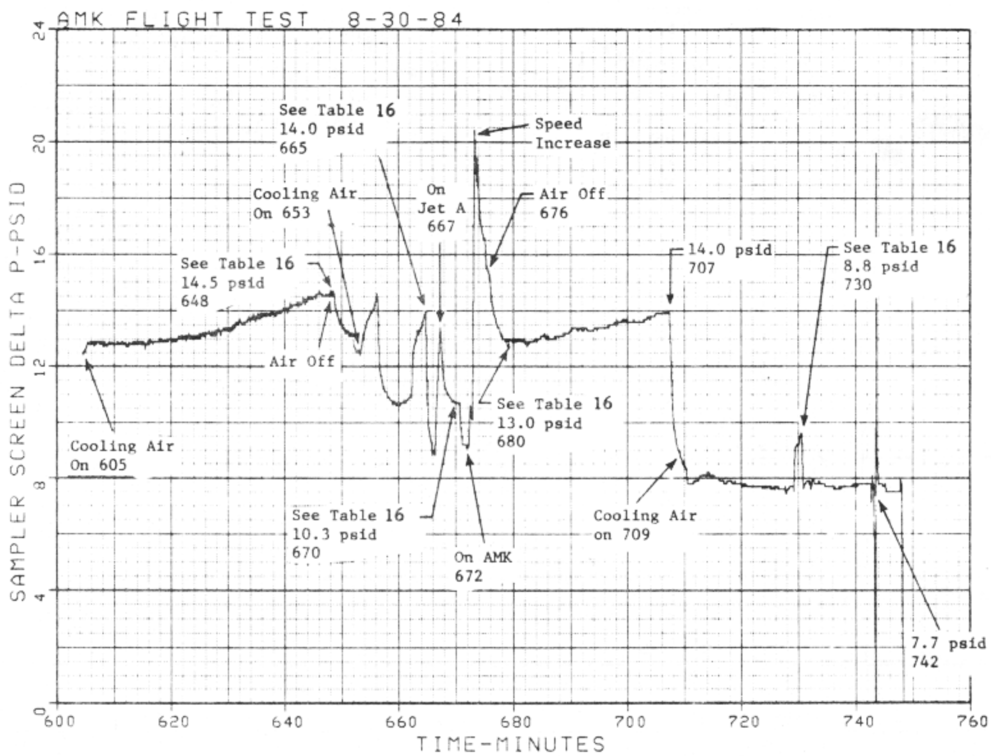


FIGURE 113. NUMBER 3 ENGINE MAIN FUEL FILTER ΔP



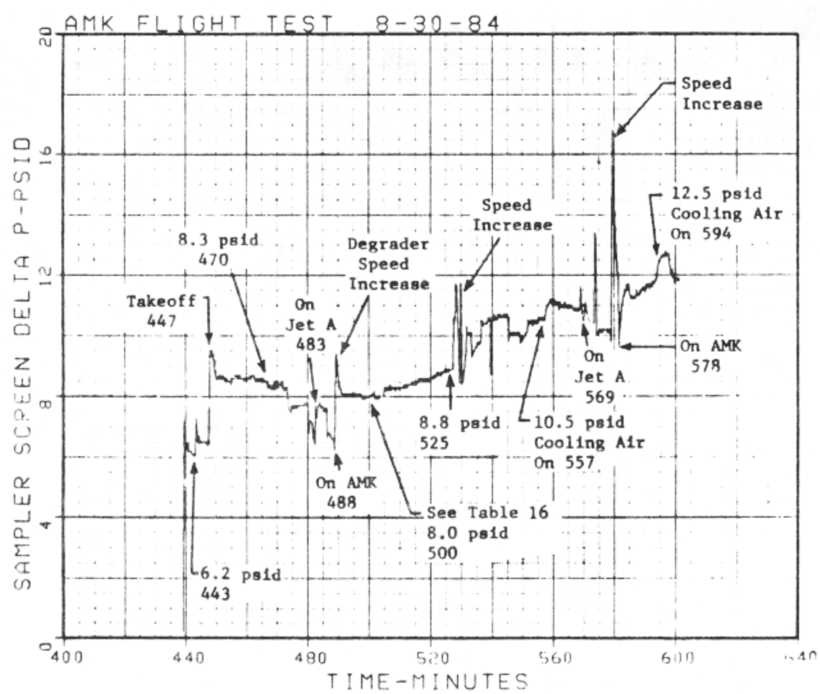


FIGURE 114. SAMPLER FILTER ΔP

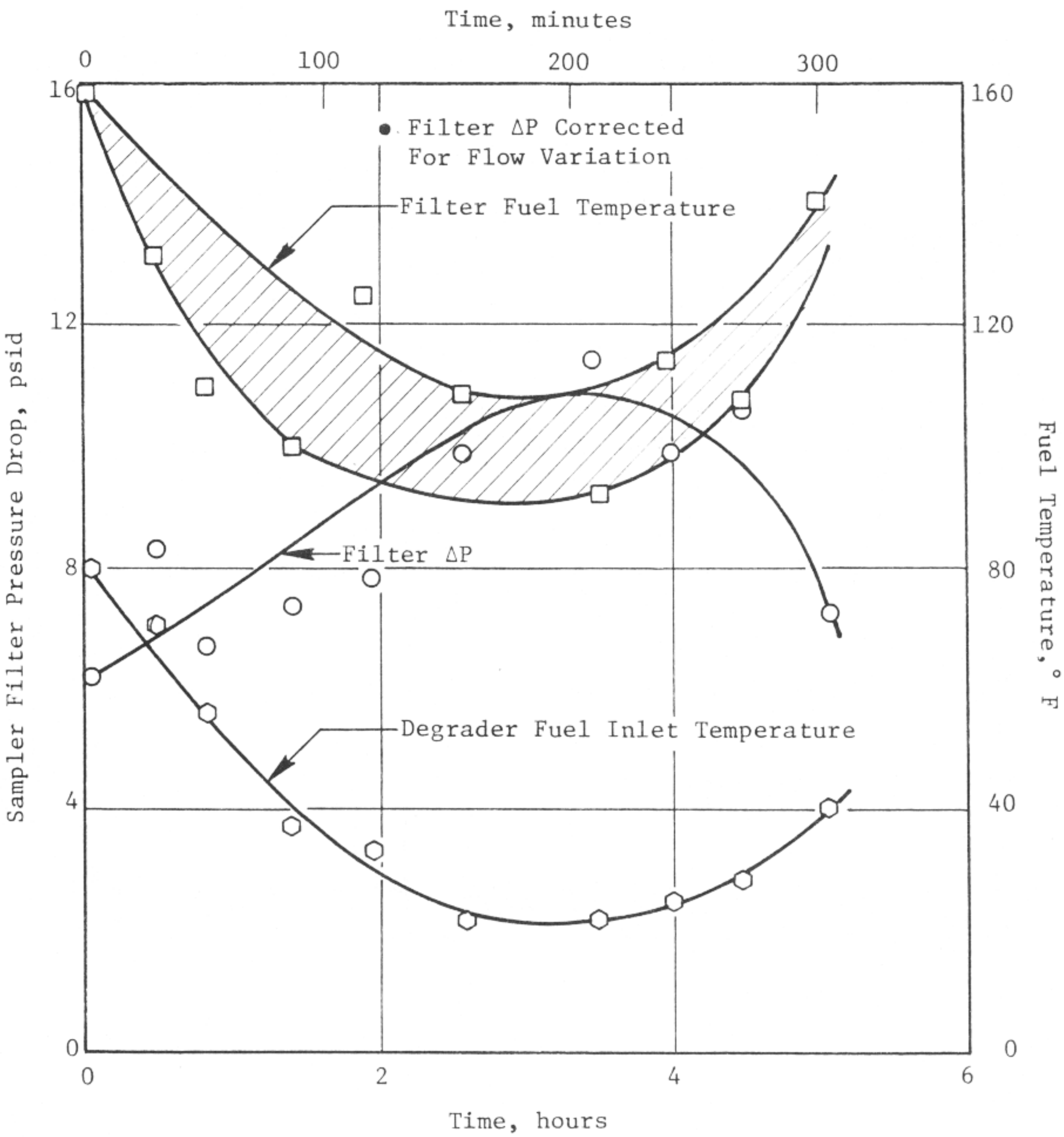


FIGURE 115. GENERAL INFLUENCE OF AMK FUEL TEMPERATURE ON SAMPLER FILTER ΔP (8-30-84) FLIGHT)

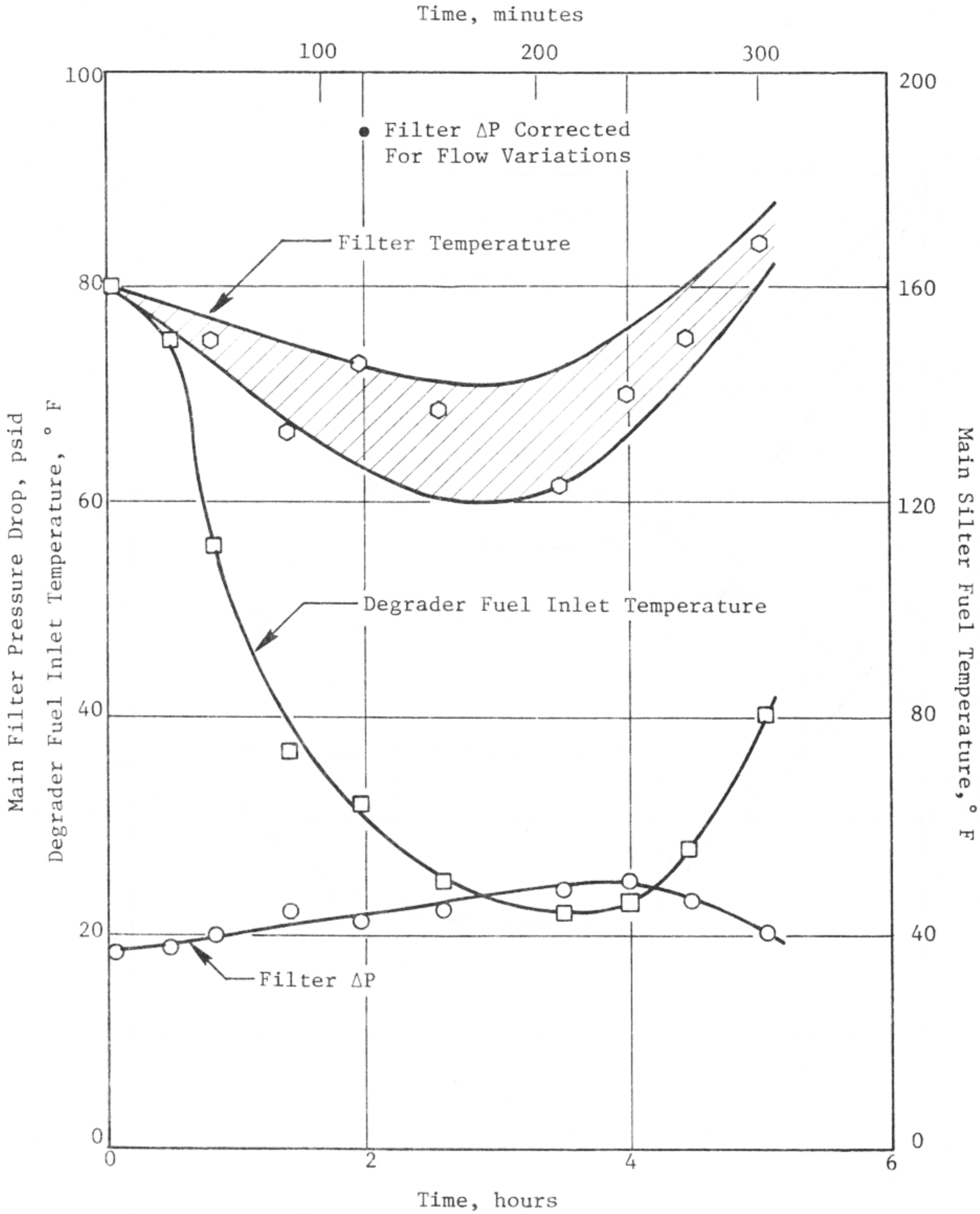


FIGURE 116. GENERAL INFLUENCE OF AMK FUEL TEMPERATURE ON NUMBER 3 ENGINE MAIN FUEL FILTER ΔP (8-30-84 FLIGHT)

Results for these periods of continuous operation and trends are listed in Table 16 and plotted in Figures 115 through 118. Also shown is the first hour of operation during the September 1, 1984 flight from Atlantic City to Miami. It should be noted that the sampler filter response to cold fuel was about 5 times that of the main filter (70 percent versus 15 percent increase in filter ΔP). For the sampler filter, there was a decrease in ΔP for Jet A compared with AMK (16 percent versus 75 percent increase in ΔP at about 4° F degrader inlet temperature). For the main filter, however, Jet A and AMK results were the same. This suggests that main-filter response during the flight was largely due to fuel temperature alone. After analyzing the available data, and considering the experience of the prior AMK flight tests, the formation of shear-induced gel was the most supportable theory proposed to explain the relatively greater ΔP response of the sampler filter. This could be the case because the shear-thickening tendency of the sampler filter should be much more pronounced than that of the low-velocity main filter. Since the sampler filter was included only as a device intended to be sensitive to gelling and was not designed or intended to be part of any normal engine fuel system, the occurrence of shear-induced gel was not a cause for great concern with fuel-inlet temperatures down to 4° F.

TABLE 16. FILTER ΔP DATA TRENDS

Flight Date	Mojave to Atlantic City August 30, 1984						Atlantic City to Miami September 1, 1984	
Time, Minutes	500	648	655	670	680	730	722	782
Δ Time, Minutes	60	208	225	230	240	290	11	71
Fuel	AMK	AMK	AMK	Jet A	AMK	AMK	AMK	AMK
Altitude, ft (1000's)	37	37	29.5	29.5	29.5	11	10	38
OAT, ° F	-27	-32	-8	-3	1	43	65	-40
Fuel Flow, pph	2800	2900	2500	2500	2850	2900	6500	2900
Tank Temperature, ° F	77	50	45	30	40	30	74	56
Degrader Inlet, ° F	50	22	29	3	25	35	74	4
Degrader rpm (1000's)	22.2	22.7	22.4	22.4	23	23.5	28	22
Degrader Inlet, psig	21	21	22	26	22.5	25	20	21
Degrader Outlet, psig	590	630	620	655	650	690	925	600
Sampler Filter, ° F	107	92	96	86	114	126	134	103
Sampler Filter ΔP, psid	8.0	14.5	14.0	10.3	13.0	8.8	9.2	10.3
Engine Speed, $\%N_2$	93	94	90	90	91	90	95	95
Main Filter, ° F	140	123	130	121	140	158	157	150
Main Filter ΔP, psid	20.5	24.0	22.0	22.0	21.5	19.2	20.5	23.0
Corr. Sampler ΔP, psid	8.0	13.5	13.3	9.3	11.8	7.5	9.2	16.1
Corr. Main Filter ΔP, psid	20.5	23.5	23.5	23.5	22.5	20.5	20.5	23

After descending to 29,000 feet near the end of the flight, a second check was made of engine-lightoff performance. As before, there was no difference beteen Jet A and AMK. After landing at Atlantic City on AMK, the No. 3

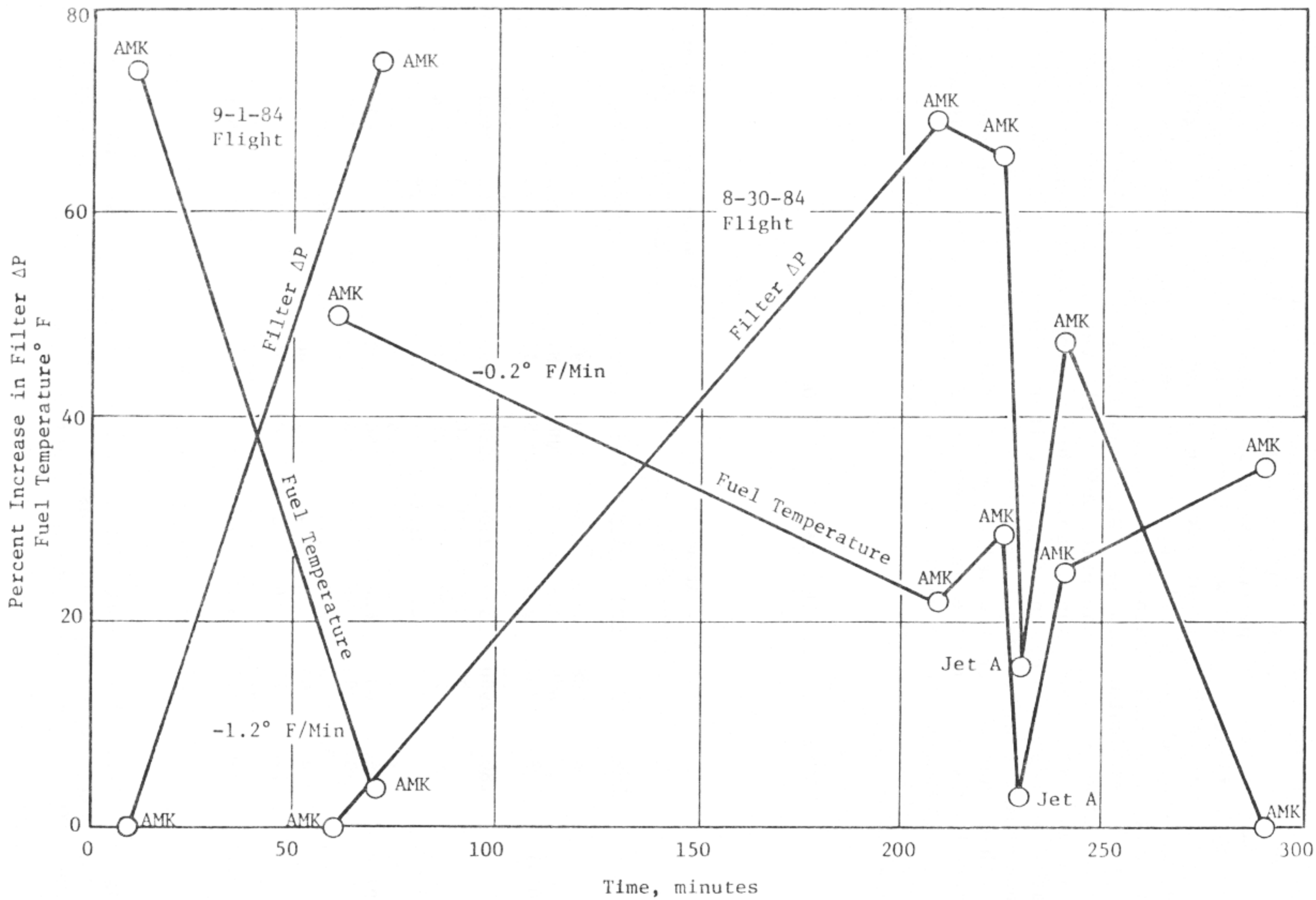


FIGURE 117. TREND OF SAMPLER FILTER ΔP AS A FUNCTION OF DEGRADER FUEL INLET TEMPERATURE

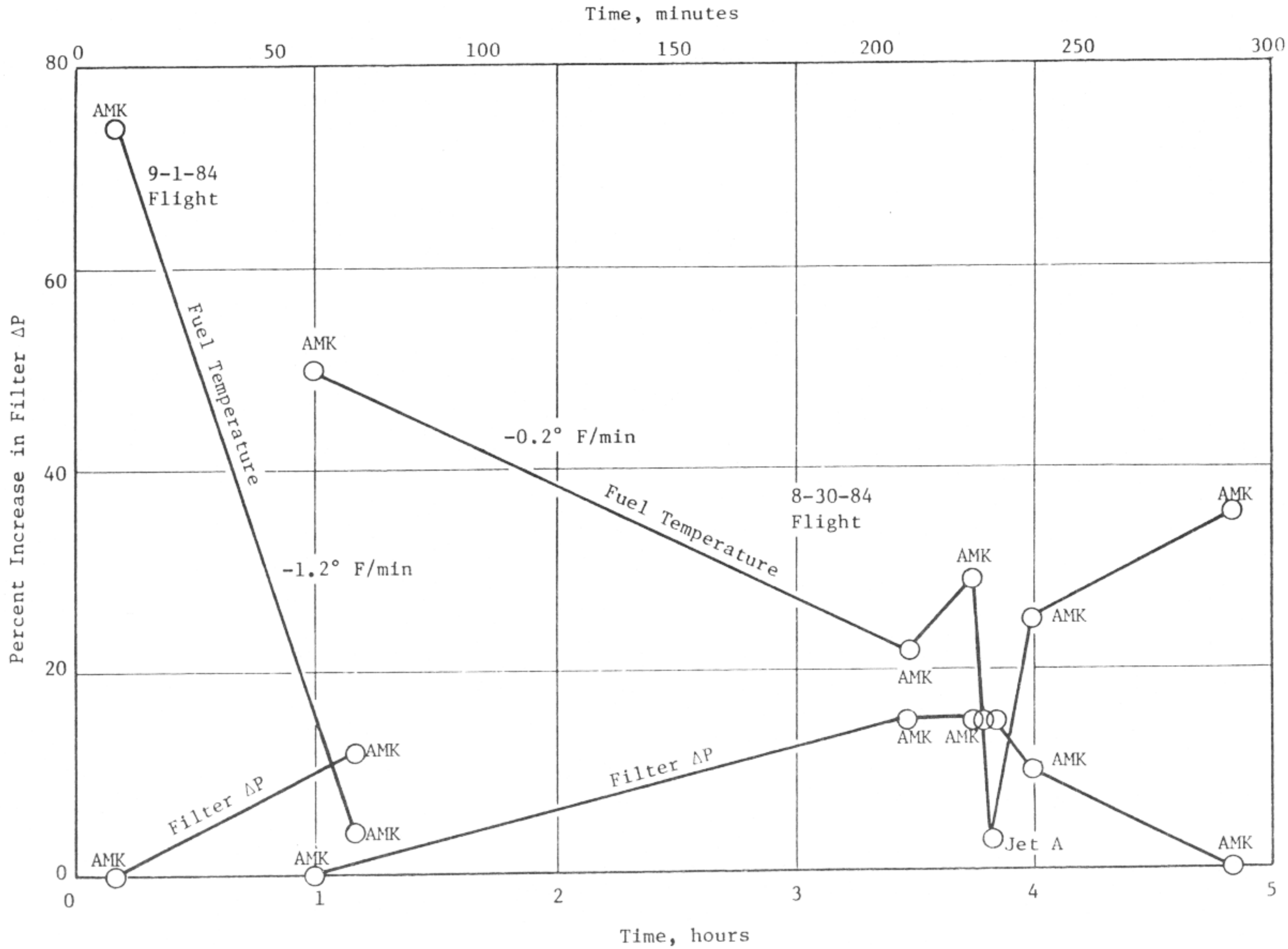


FIGURE 118. TREND OF MAIN FILTER ΔP AS A FUNCTION OF DEGRADER FUEL INLET TEMPERATURE

engine was restarted, and degraded-fuel samples were taken for analysis by the FAA.

On the following day, September 1, the aircraft was flown from Atlantic City to Miami to gain more data relating to operation on cold AMK. The results of the September 1, 1984 test cannot be used to interpret the influence of cold AMK on filter ΔP because hard gel formed, and this hard gel was not thought by General Electric to be a function of reduced fuel temperature. After landing at Miami, the sampler filter was visually inspected, and a trace of hard gel had formed on the sampler filter. Analysis of the test data shown in Figures 119 and 120 confirmed that hard gel was present on the main filter even after 38 minutes (computer time 901 to 939) of operation on Jet A (following AMK). While hard gel on the more sensitive sampler was visible, the gel on the main filter would be difficult to detect without microscopic examination. However, the characteristics of the gel found on the sampler filter left no doubt that it was permanent hard gel, not shear-induced gel, and would affect all unidirectional flow filters. Also, there is little question that the development of hard gel occurred with the AMK fuel blended at Atlantic City since the aircraft had just completed over 5 hours of flight on Mojave-blended AMK that produced no hard gel.

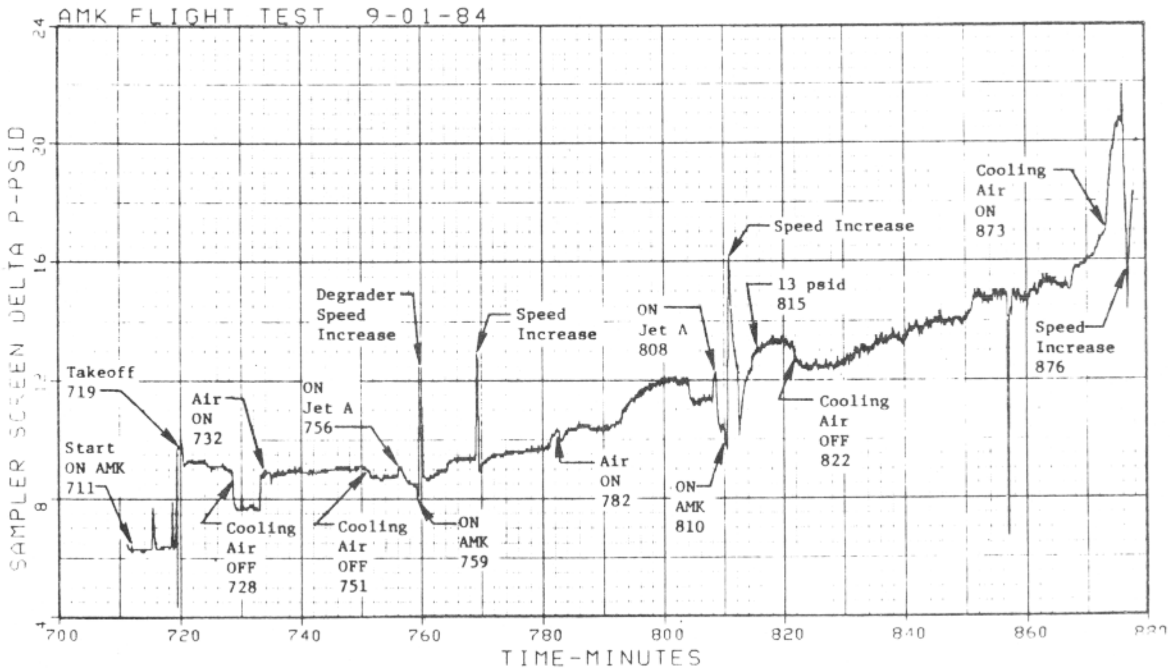
FINAL AMK DEGRADER AIRCRAFT TESTS. The CV880 program resumed at Miami on September 5, 1984 and continued through November 6. This phase of the program involved AMK blends and tests aimed at finding the cause of hard gel. The significant results are as follows.

Summary. Both Mojave Jet A and Miami Jet A yielded good results during ground and flight tests at Miami when fuel water content and ambient humidity during blending were low. There was no evidence of hard gel from examination of filters or recorded data. Data showed either the same or less filter ΔP after more than one hour of operation on AMK.

Trial blends were made with excessive amounts of water added to Jet A doped with additional glycol. This led to high filter ratios, low cup, and high NTU (poor clarity) as would be expected. NTU was lower with additional glycol in the Jet A, suggesting that more water went into solution. NTU, with 219-ppm total water in the Jet A, was 49, the highest achieved during this program. Since low NTU usually indicated a blend was not prone to hard-gel formation, this result led to speculation that high water content might be a factor in the mechanism of hard-gel formation.

A ground test was performed using AMK which contained 159-ppm total water in the Jet A prior to blending. Sampler filter ΔP increased by 11 percent and main filter ΔP by 14 percent after 77 minutes of testing with AMK. Thus, this single variable (water) caused some tendency toward promotion of hard gel.

The final Miami test used high humidity during FM9 slurry mixing in an attempt to produce hard gel. After ground and flight tests lasting 65 minutes, the sampler filter ΔP had increased 29 percent and main filter ΔP by 26 percent. These results suggest that water vapor introduced to the AMK slurry during blending by high ambient humidity could have an effect similar to water introduced through the Jet A.



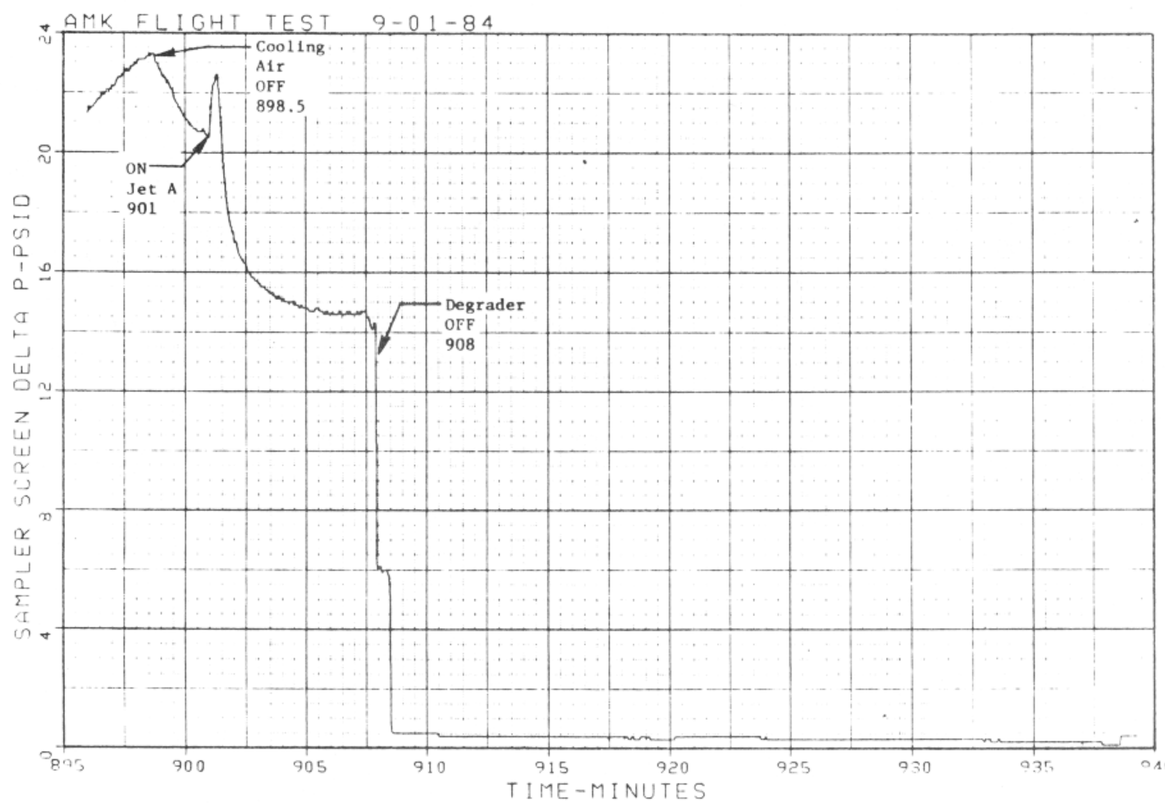
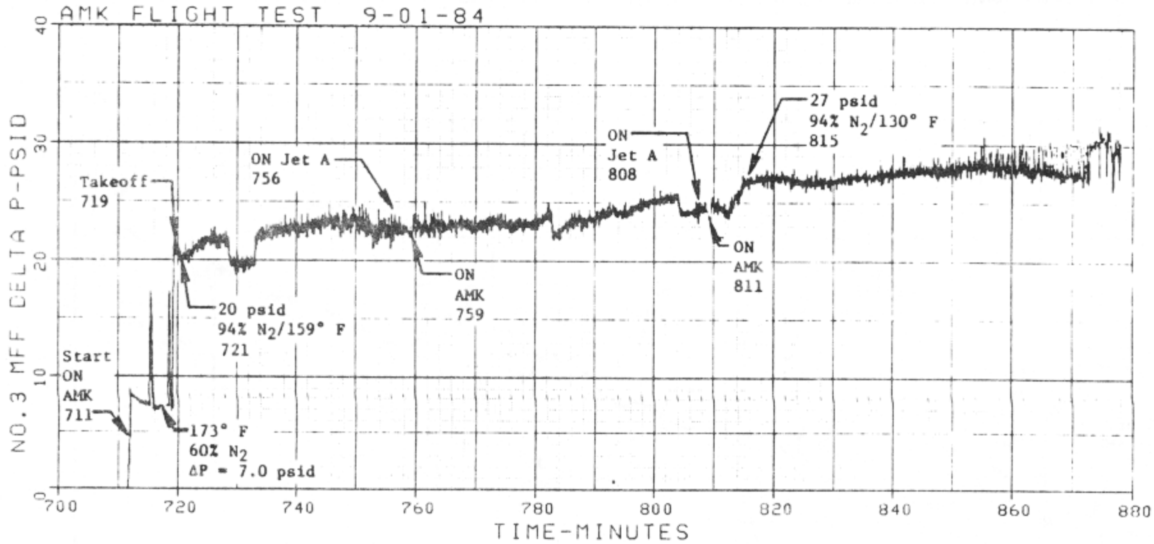


FIGURE 119. SAMPLER FILTER ΔP



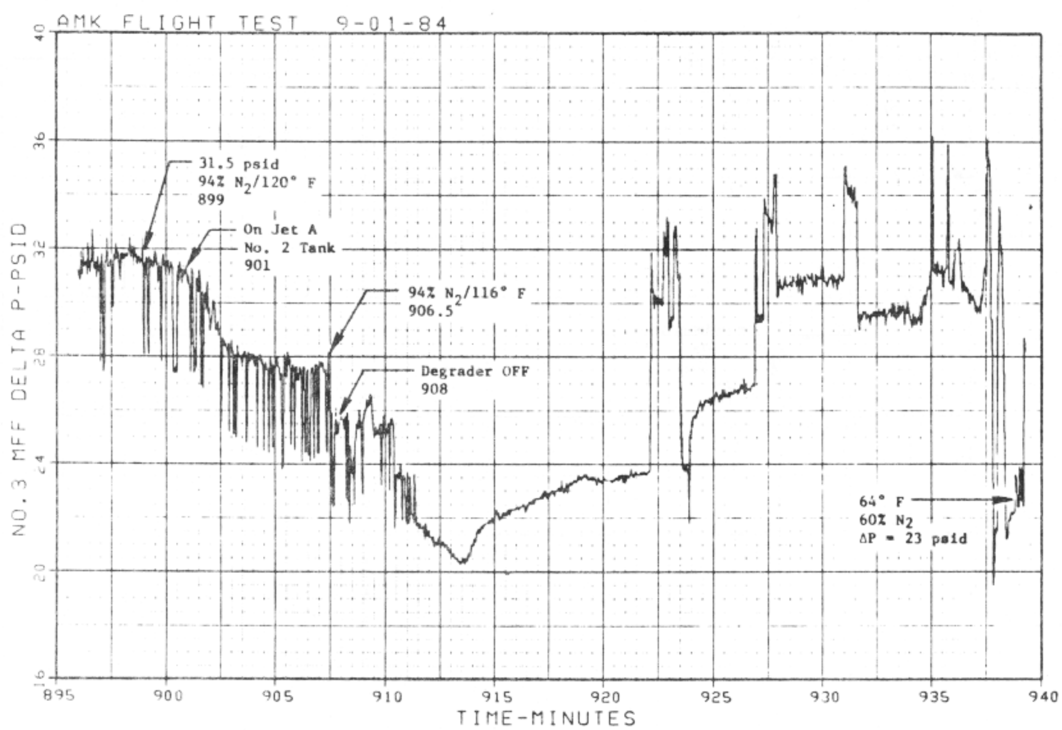


FIGURE 120. NUMBER 3 ENGINE MAIN FUEL FILTER ΔP

Although hard gel formation was suspected in both instances, with high water content Jet A and high humidity during blending, gel was not readily visible on the filters after the tests. In other words, extreme and immediate buildup of gel as experienced during some of the Phase I testing was not encountered during the final tests at Miami. While the observed filter ΔP response might suggest that water is a contributing factor in the mechanism that produces hard gel, lack of visible gel formation precluded any fundamental conclusions about the effects of water on AMK gelling characteristics.

The following is a description of the tests addressing the influence of water, in several forms, on the formation of hard gel.

Experimental Blends. Two 10-gallon blends were produced on October 13, 1984, in an attempt to create AMK conducive to hard gel. Since most of the AMK blends that were free of gel formation exhibited low NTU values (high clarity), the objective was to force a large amount of water into the base Jet A which, in turn, would cause high NTU values. These blends were made from the same FM9 slurry mixture and used the same Jet A. The only difference was that one contained 219-ppm total water in the fuel before blending and the other contained 388-ppm total water plus 0.8% glycol. Excess water and glycol were added by stirring while the AMK was blended.

The results after blending were as expected: high filter ratio, low cup, and poor clarity. Also, the addition of excess glycol tended to reduce the effect entrained free water had on NTU. General Electric theorizes that this was the result of the glycol increasing the ability of AMK to dissolve water. The NTU value for AMK made from Jet A containing 219 ppm of water was as high as 49; whereas 388 ppm water plus 0.8% glycol yielded an NTU of 24.

High-Water-Content Jet A. On October 11, a reference test was conducted using fresh Jet A fuel obtained at the Miami Airport; a 430-gallon blend was produced. Water content of the Jet A was 78 ppm, and for the AMK it was 250 ppm. Relative humidity was relatively low at 60%. This blend showed NTU values typical of AMK blended at Mojave, in the range of 8.0.

After 83.5 minutes of ground operation on AMK, including several engine starts and accels, sampler filter ΔP had not changed, but main filter ΔP had improved (reduced) by 16% over Jet A. These results were typical of those experienced at Mojave, and they represented the first really good AMK results using fuel obtained in Miami.

A 450-gallon blend was produced on October 15, 1984 using the same fuel and blending procedures as October 11. The only difference was that the Jet A was treated to hold abnormally high levels of water. The objective was to have 219-ppm total water in the Jet A during blending, as had been obtained during the prior 10-gallon trial blend on October 13. However, for the larger blend, it was necessary to mix the water and Jet A in the No. 2 tank before blending. The fast settling rate of so much free water reduced the water concentration by the time the fuel arrived at the blender. The result obtained was 159-ppm total water in the Jet A; this would be very difficult to obtain under real-world conditions. The fuel was at 89° F.

After blending, the characterization results were quite different from those obtained during the trial blend. Filter ratio and cup were typical of normal AMK results. NTU was between 12.5 and 18, still higher than Mojave fuel results but not 49 as achieved in the trial blend. No other characterization results, degraded or undegraded, suggested any differences between this blend of AMK and the best blend ever obtained, from the standpoint of eliminating hard gel. Thus, poor fuel clarity, determined by high NTU values, was thought to be the best indicator that AMK would be prone to producing hard gel.

The significant results of the ground test using the high-water Jet A are shown in Figures 121 through 125. After 77 minutes of testing, sampler filter ΔP had increased by 11% (Figure 123) and main filter ΔP had increased by 14% (Figure 125). The net difference between these results produced with AMK blended from high-water-content Jet A and the results from the reference test on October 11 with lower water-content Jet A was an increase in pressure drop of approximately 11% for the sampler filter and 30% for the main filter.

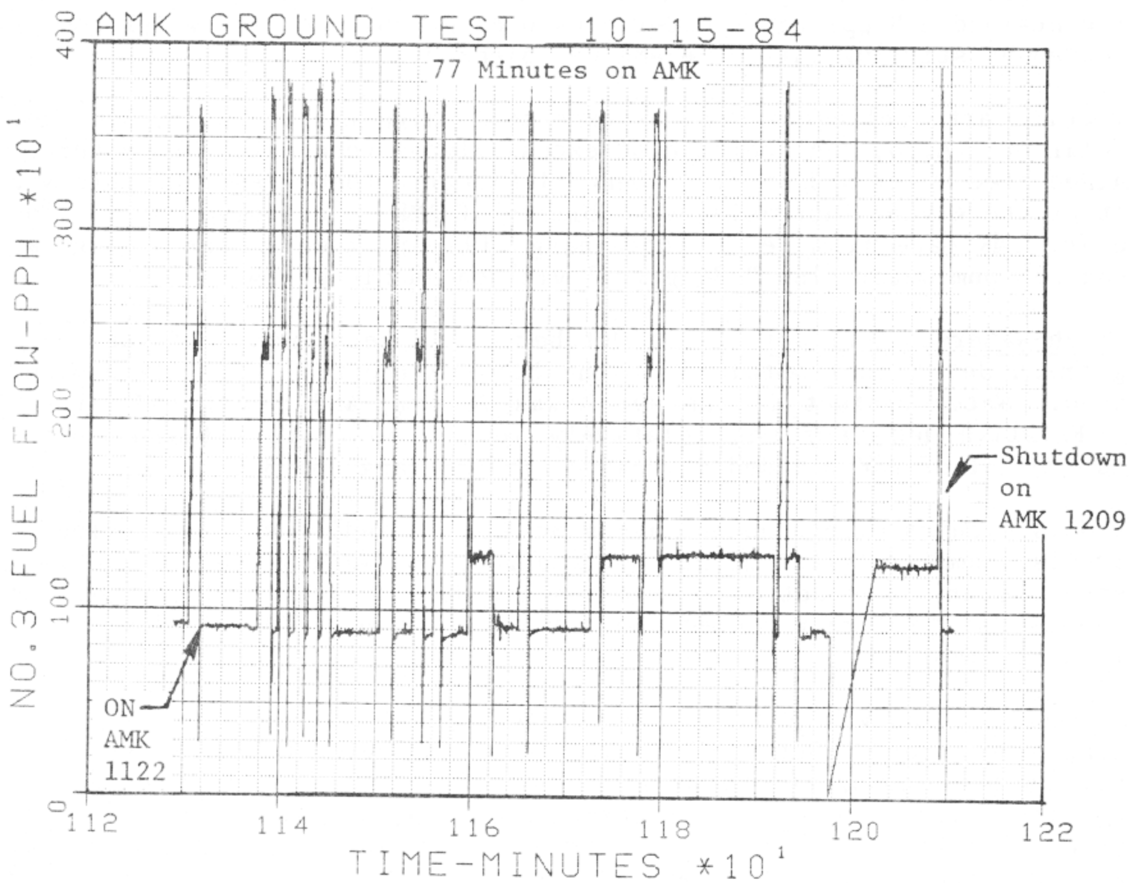


FIGURE 121. NUMBER 3 ENGINE FUEL FLOW

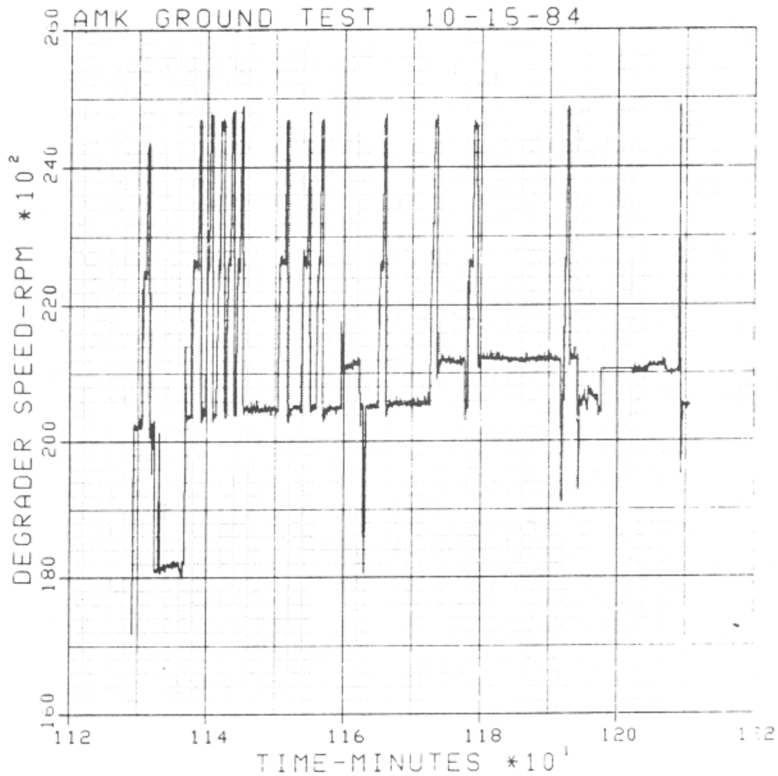


FIGURE 122. DEGRADER SPEED

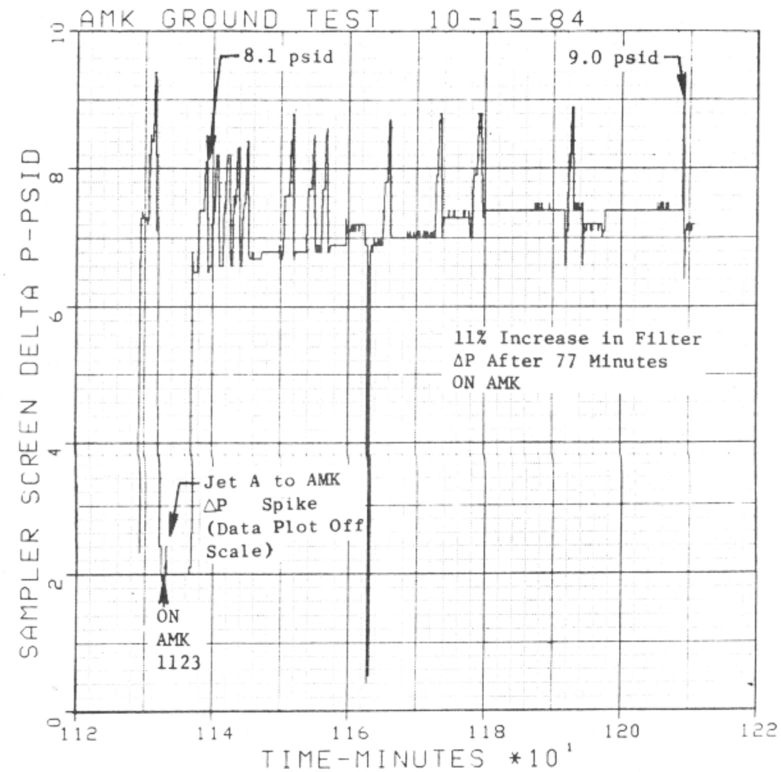


FIGURE 123. SAMPLER FILTER ΔP

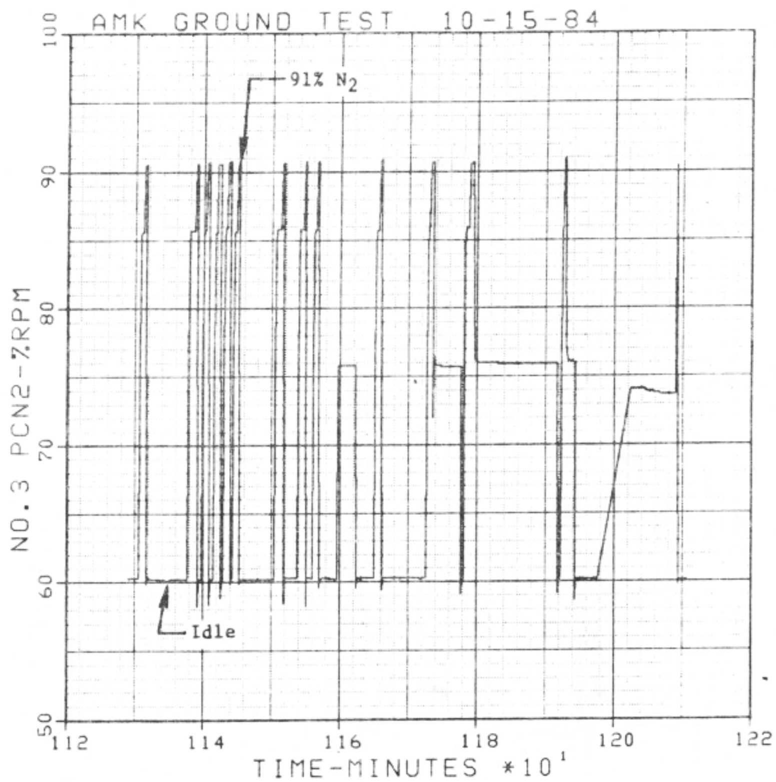


FIGURE 124. NUMBER 3 ENGINE SPEED

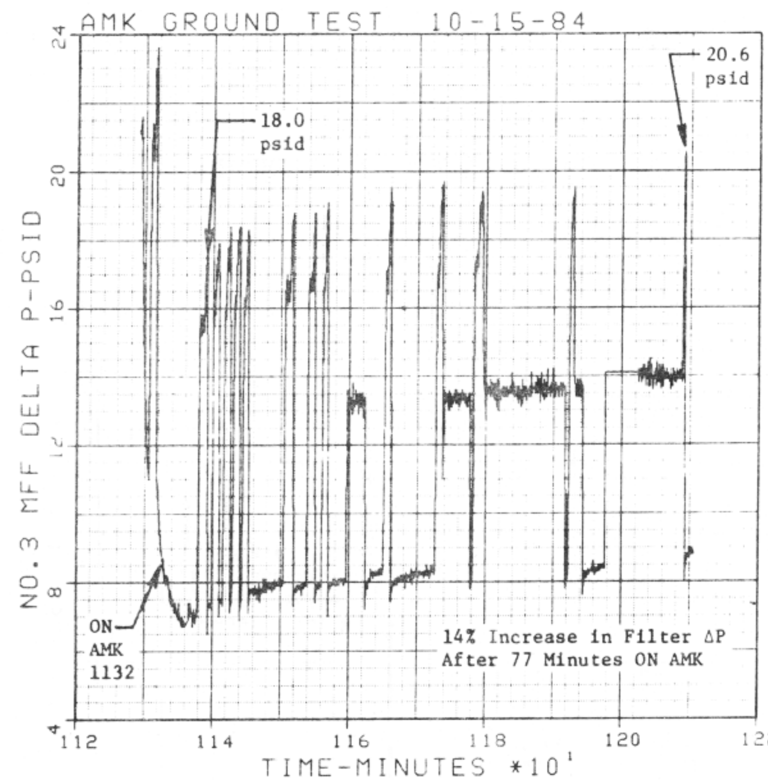


FIGURE 125. NUMBER 3 ENGINE MAIN FUEL FILTER ΔP

High Humidity During Blending. The final test at Miami on October 16 involved the use of high humidity during FM9 slurry mixing with the Hobart homogenizer. Nine hundred gallons of AMK were produced. Slurry mixing was performed in a closed room with the relative humidity maintained near 100%. Each slurry canister was mixed 15 minutes under the high-humidity conditions. Characterization results were similar to the October 15 blend that used excess water in Jet A. Initial fuel clarity (NTU) ranged from 14.8 to 16.5.

Following an 11-minute AMK ground test, a flight test was performed over Dade Collier Airport. The AMK portion of the test lasted 54 minutes. Significant results are shown in Figures 126 through 131. Sampler filter ΔP increased 29% during the total test period of 65 minutes. Main filter ΔP increased 26%. For procedural reasons, it was necessary to land at Miami using Jet A. Gel was not visible on the filters after the test, but the increase in pressure drop across the filters was typical of that which had occurred many times in the past with the formation of hard gel. These test results, along with those from the October 15 ground run, showed that moisture introduced through either the Jet A or the slurry during blending could have similar effects on the formation of hard gel.

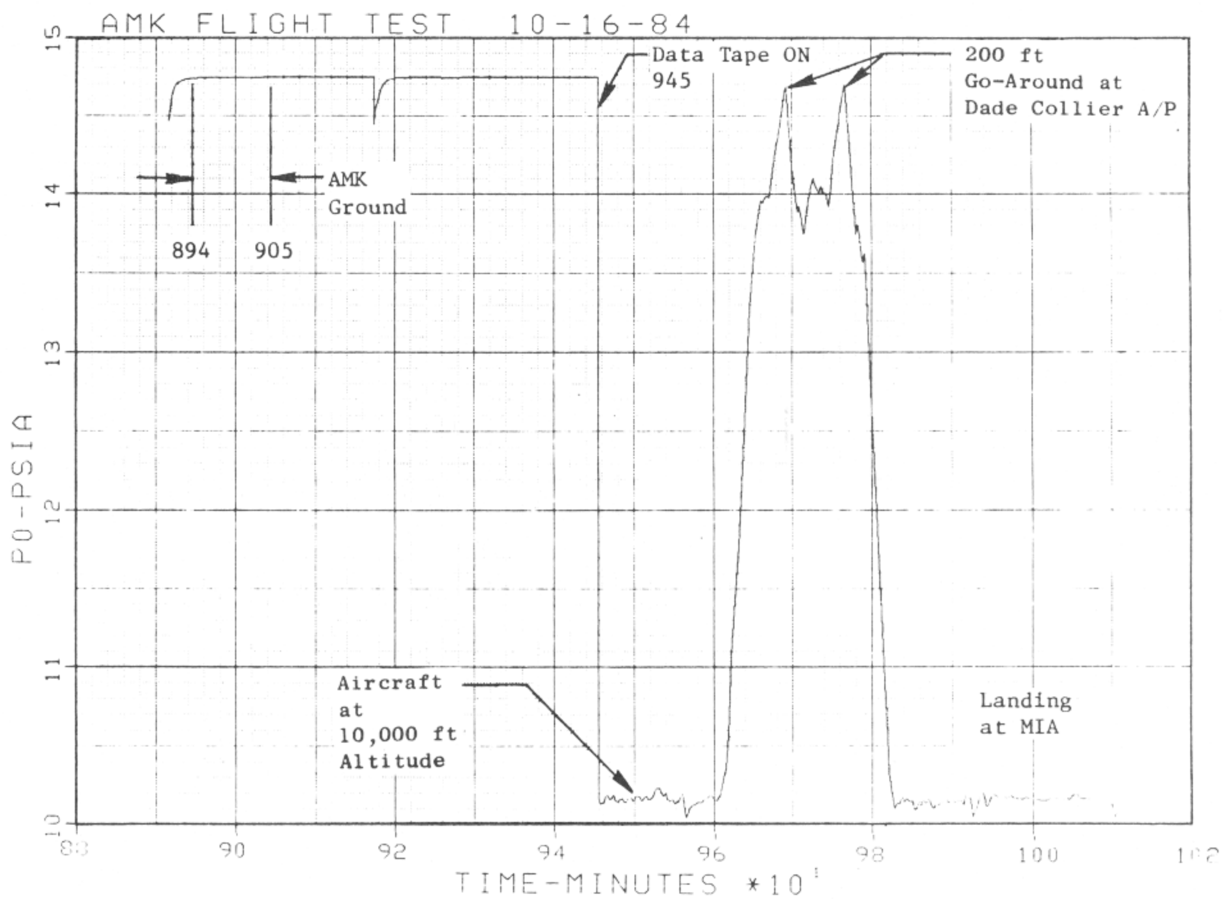


FIGURE 126. ALTITUDE PRESSURE

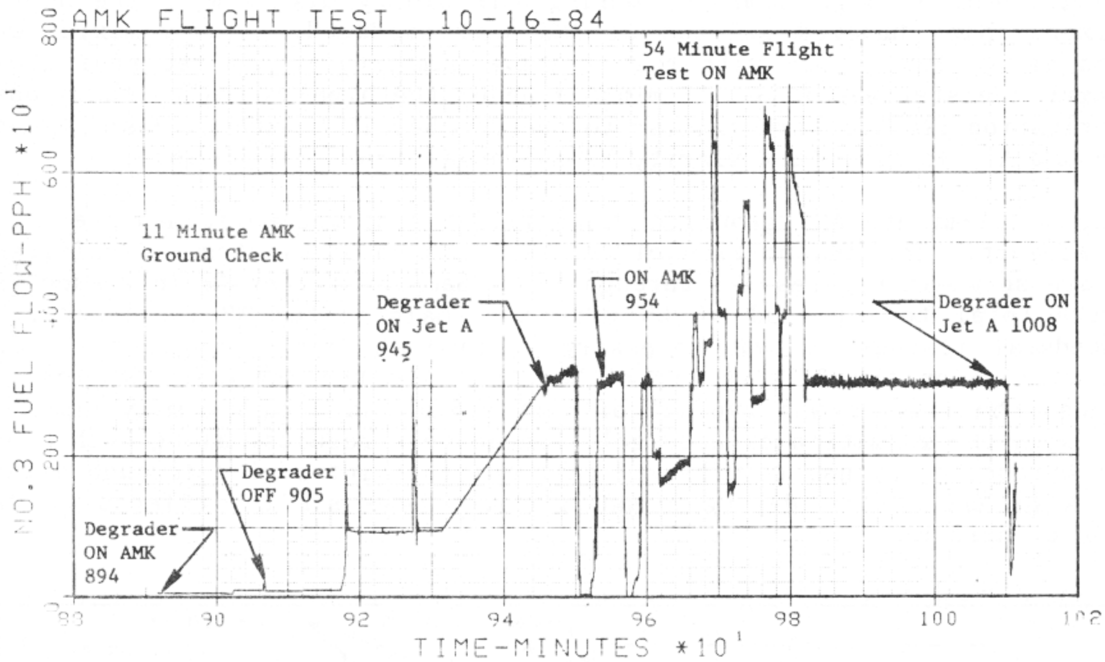


FIGURE 127. NUMBER 3 ENGINE FUEL FLOW

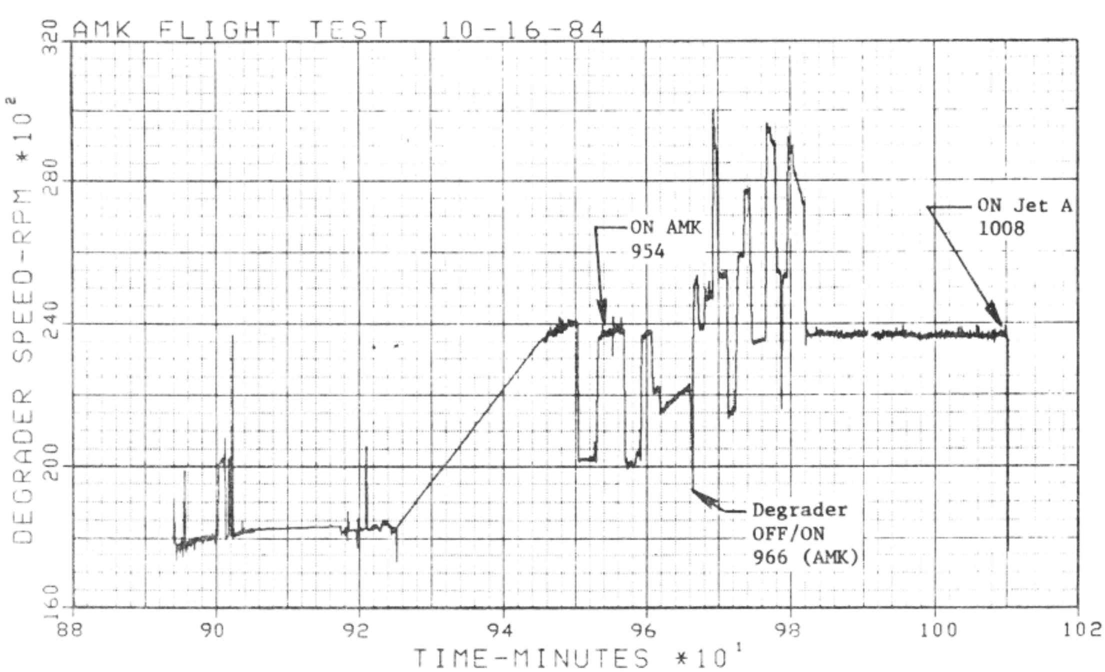


FIGURE 128. DEGRADER SPEED

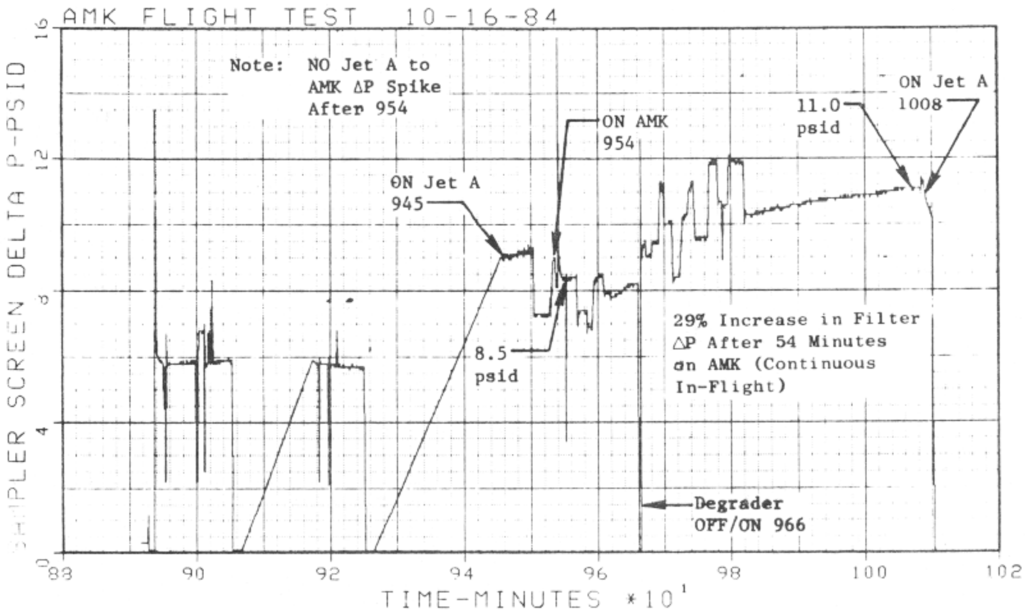


FIGURE 129. SAMPLER FILTER ΔP

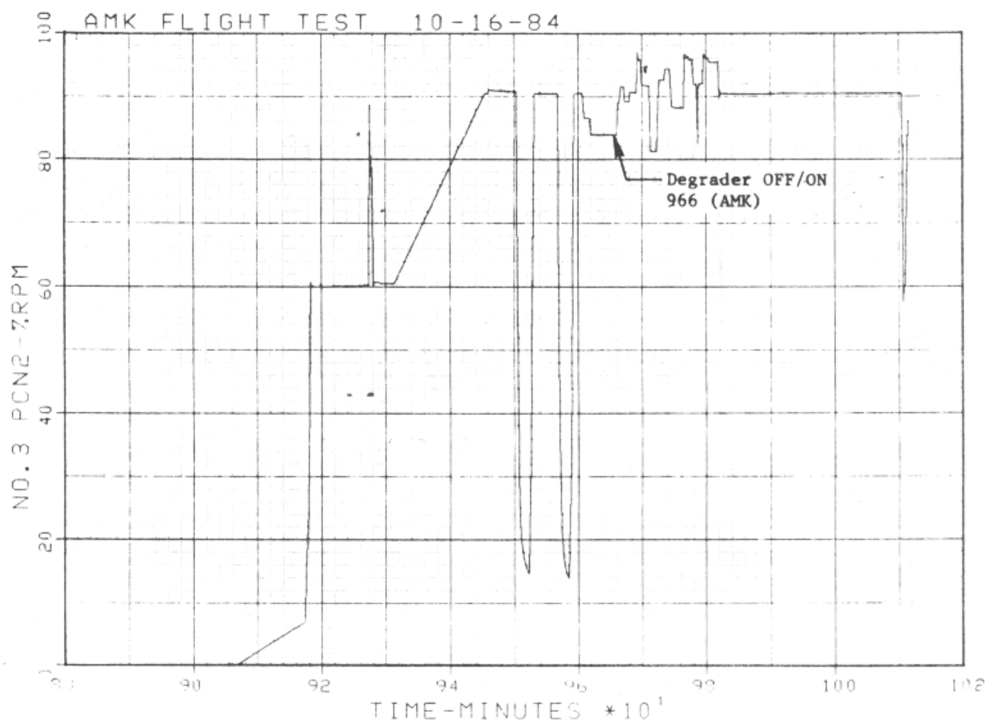


FIGURE 130. NUMBER 3 ENGINE SPEED

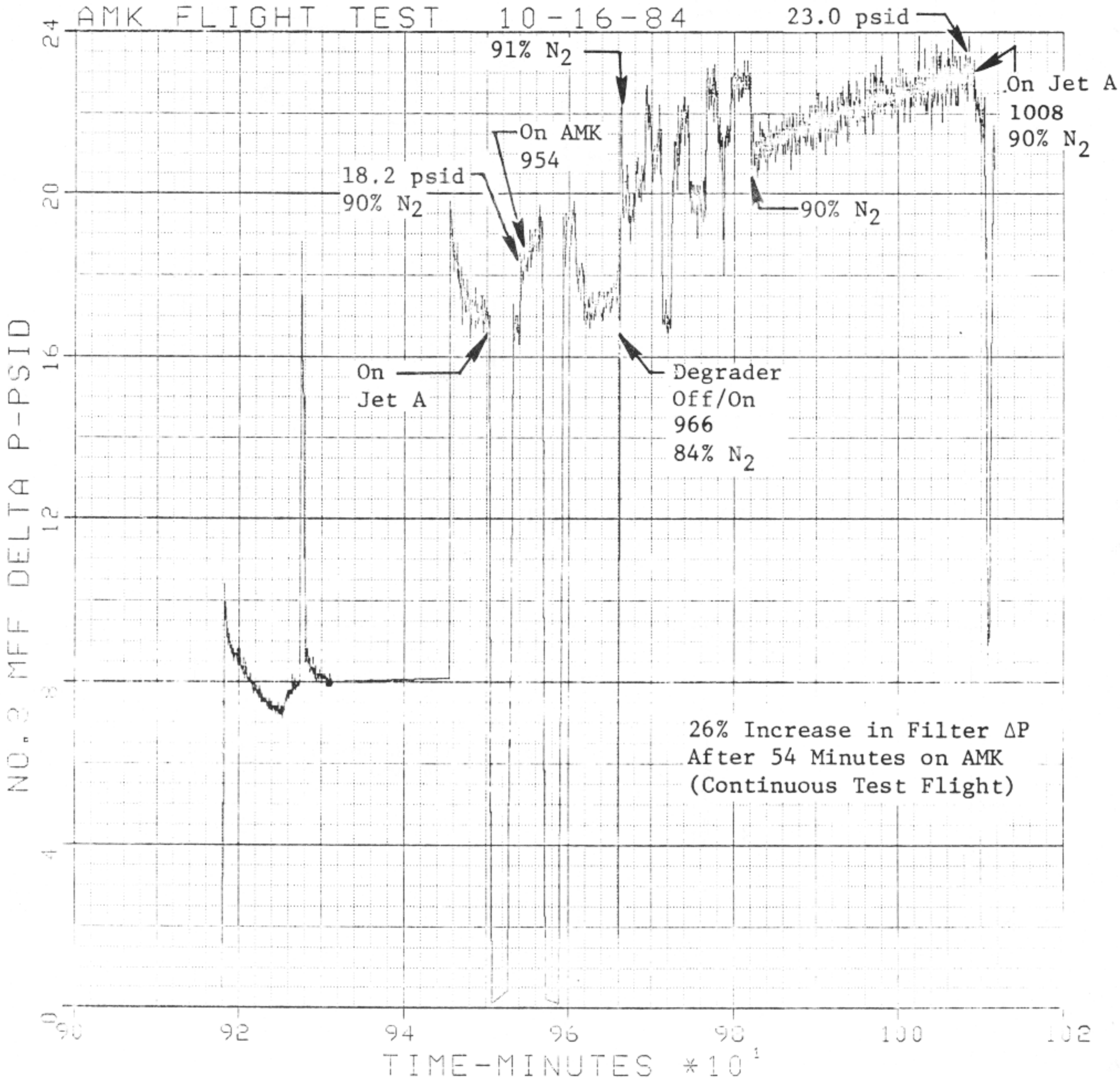


FIGURE 131. NUMBER 3 ENGINE MAIN FUEL FILTER ΔP

VI. SUPPORT OF FULL-SCALE TRANSPORT CONTROLLED-IMPACT DEMONSTRATION

PROGRAM RESPONSIBILITY

At the initiation of the program, the intent was to have General Air Services install the degrader hardware on the B720 CID test vehicle. In the fourth month of the program, the decision was made to have the four B720 degrader systems installed by General Electric's Edwards Flight Test Center under the direct technical management of NASA-Dryden. GE-Edwards' long-time working relationship with NASA-Dryden, the proximity of the GE facility to Dryden, and the need to coordinate degrader installation with several other concurrent B720 CID projects influenced the decision of the FAA and NASA-Dryden to have the degrader installation performed by GE-Edwards.

With responsibility for the B720 installation shifted to GE-Edwards under the auspices of NASA-Dryden, the following CID support tasks remained:

- Definition of the degrader installation on the B720
- Fabrication of four complete degrader systems and a four-in-one control panel
- Fabrication of B720 degrader mounting brackets
- Support of GE-Edwards during the installation effort
- Formulation of operating procedures for the degraders
- On-site consultation during the CID on matters relating to degrader performance and operation

All tests involving the degraders on the B720 were the responsibility of NASA-Dryden and the FAA, and details of these tests are reported in References 5 and 12. Although the operating envelope of the B720 in the CID program was limited, compared to that of the CV880, the test results are of interest since both the B720 aircraft and the degrader installation were slightly different from that of the CV880. The performance of the degraders during preparations for the CID will be briefly discussed below, with emphasis on differences from the CV880 testing and results.

COMPONENT DESIGN

The components comprising the four degrader systems installed in the B720 were identical to those used in the CV880 flight test program. The components were described in Section III of this report. While the control panel for the B720 operated four degrader systems, cursory inspection of Figure 132 shows that it was actually four single control panels ganged together.

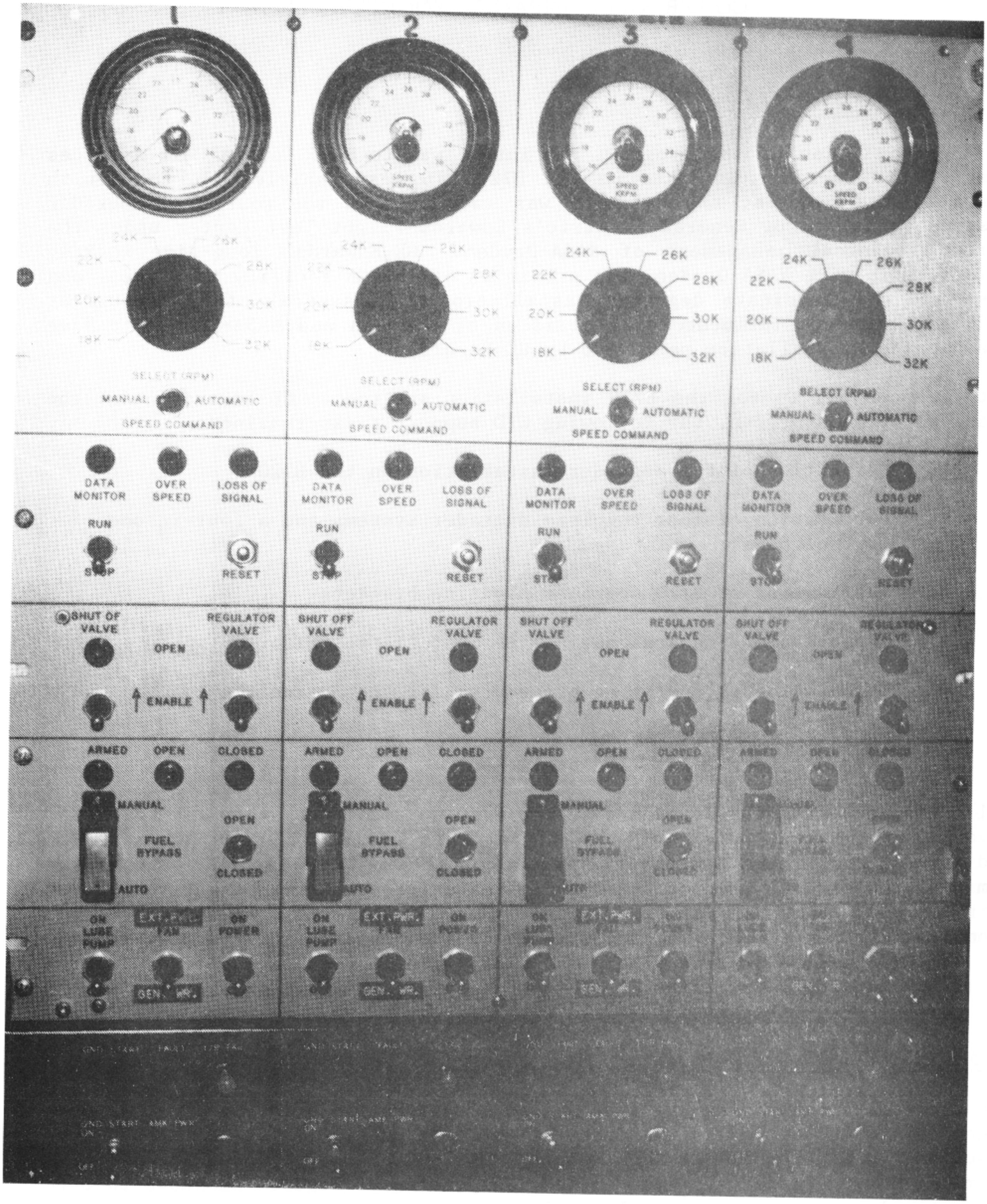


FIGURE 132. B720 DEGRADER CONTROL PANEL

B720 INSTALLATION SUPPORT

The installation of the pump/degrader assembly at the top of the JT3C had been proposed by General Electric from the onset of the Program. GAS had performed mockup installations of the degrader assembly in this location on a spare engine at Miami. When installation of the degraders on the B720 was transferred by the FAA to GE-Edwards and NASA-Dryden, significant preliminary work had already been completed and was useful to GE-Edwards in the final degrader installation.

Detailed design and analysis of the mounting brackets for the B720 degraders were conducted by Garrett Pneumatic Systems Division. The brackets were delivered to GE-Edwards with the degrader systems.

Figure 133 is a schematic of the B720 installation. Compared to the CV880 installation, shown previously in Figure 25, there is not a great deal of difference between the two installations.

INSTRUMENTATION. One objective of the CID was to demonstrate compatibility of AMK fuel in the airframe/engine fuel system of a representative transport aircraft during operational flight (Reference 12). Therefore, instrumentation was added to each of the four engines not only as required to control and monitor degrader performance but to evaluate critical fuel-system filter/screen response (four per engine), primary and secondary manifold pressure, and four primary engine performance parameters (References 5 and 12).

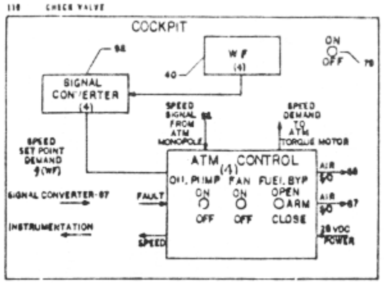
ATMP80-1 LOCATION. Figure 134 shows the pump/degrader assembly mounted at the top forward section of the JT3C engine. This location is usually occupied by the turbocompressor used for the cabin environmental control system.

FUEL/AIR HEAT EXCHANGER LOCATION. Figure 135 shows the heat exchanger pods, hung from the wing directly outboard of each respective engine. The supply and return lines were attached to the pylon and wing surfaces. This installation was possible due to the relatively modest flight envelope of the CID program. The location of the heat exchanger in the pod was a more "straight-through" design compared to the ECS bay installation on the CV880; therefore, it resulted in more efficient heat transfer. The wing-mounted pod precluded the use of ECS air for additional cooling capacity. Early in the program, the addition of electrical, Freon, air-conditioning systems had been considered. Early testing of the degrader system and analysis of the JT3C fuel system indicated that heat rise from the degrader was less than originally expected and that the JT3C was more tolerant of fuel inlet temperature than the CJ805. This lower heat rise and higher temperature tolerance, along with the enhanced cooling capability of the pod installation, obviated the need for ECS cooling air on the B720. The pod installation, which was proposed by NASA-Dryden, was therefore chosen as the most straightforward and low-risk installation available for the B720 application.

ENGINE DIFFERENCES. The configuration of the JT3C permitted easy access to the compressor discharge pressure (CDP) duct for a source of degrader ATM air. (The CDP air in the CF880 is extracted through the base of the pylon and could

B720 AMF 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 - 6 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-INCH W/ NIPPLE)	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 EXCH AIR FLANGE CLAMPS	2	NASA
55	HEAT EXCH AIR DUCT	1	GE
57	BELLMOUTH AIR SCOOP AND FAN/HX POD	1	GE
58	FAN AND RELAY (115 VAC - 3 PHASE - 400 Hz - 13 AMPS - INRUSH 90 AMP/PHASE FOR ONE 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 AMP - 135 AMP INRUSH 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 (CVEBM)	1	GE
76	ENGINE FUEL SUPPLY HOSE - 1000 PSI OPERATING (1.5-INCH NOM.)	1	GE
77	FUEL BYPASS VALVE (1.5-INCH - 15/28 VDC - 1 AMP)	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 AMP)	1	NASA
86	ATM AIR SHUTOFF VALVE AND ATM AIR INLET CLAMPS	3	NASA
87	ATM AIR SHUTOFF VALVE (28 VDC - 1 AMP)	1	NASA
88	ATM AIR EXHAUST DUCT CLAMP	1	NASA
89	ATM AIR EXHAUST DUCT (4.0-INCH NOM - 0.020 WALL STAINLESS STEEL)		GE
90	FUEL THROTTLING VALVE SERVO PRESS TUBE - 3000 PSI OPERATING (0.25-INCH)	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 1st SUBSTAGE PRESSURE (0-250 PSIG)	1	GE
97	FAULT CONVERTER (SOR 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 (0-30 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



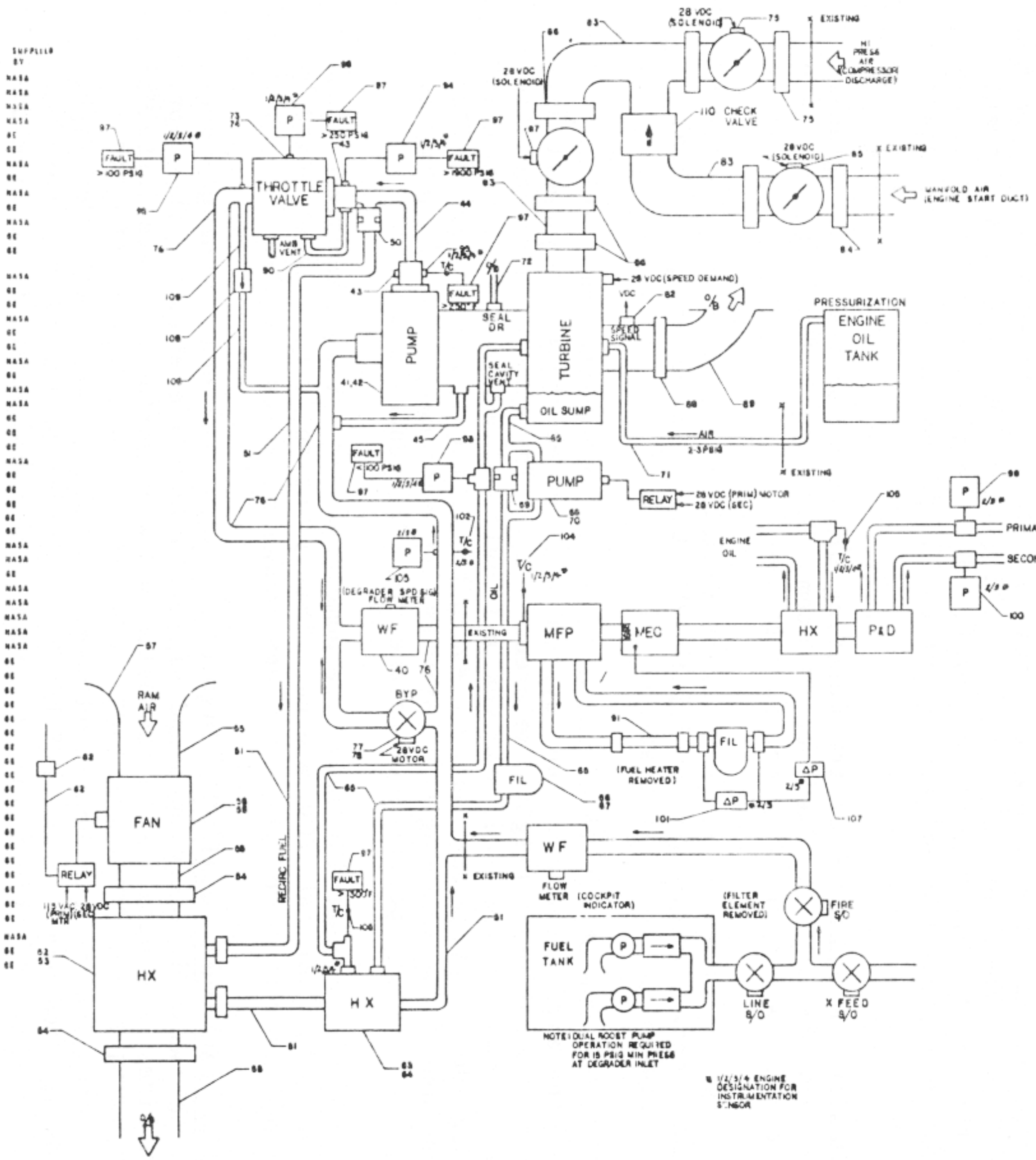


FIGURE 133. B720 INSTALLATION SCHEMATIC

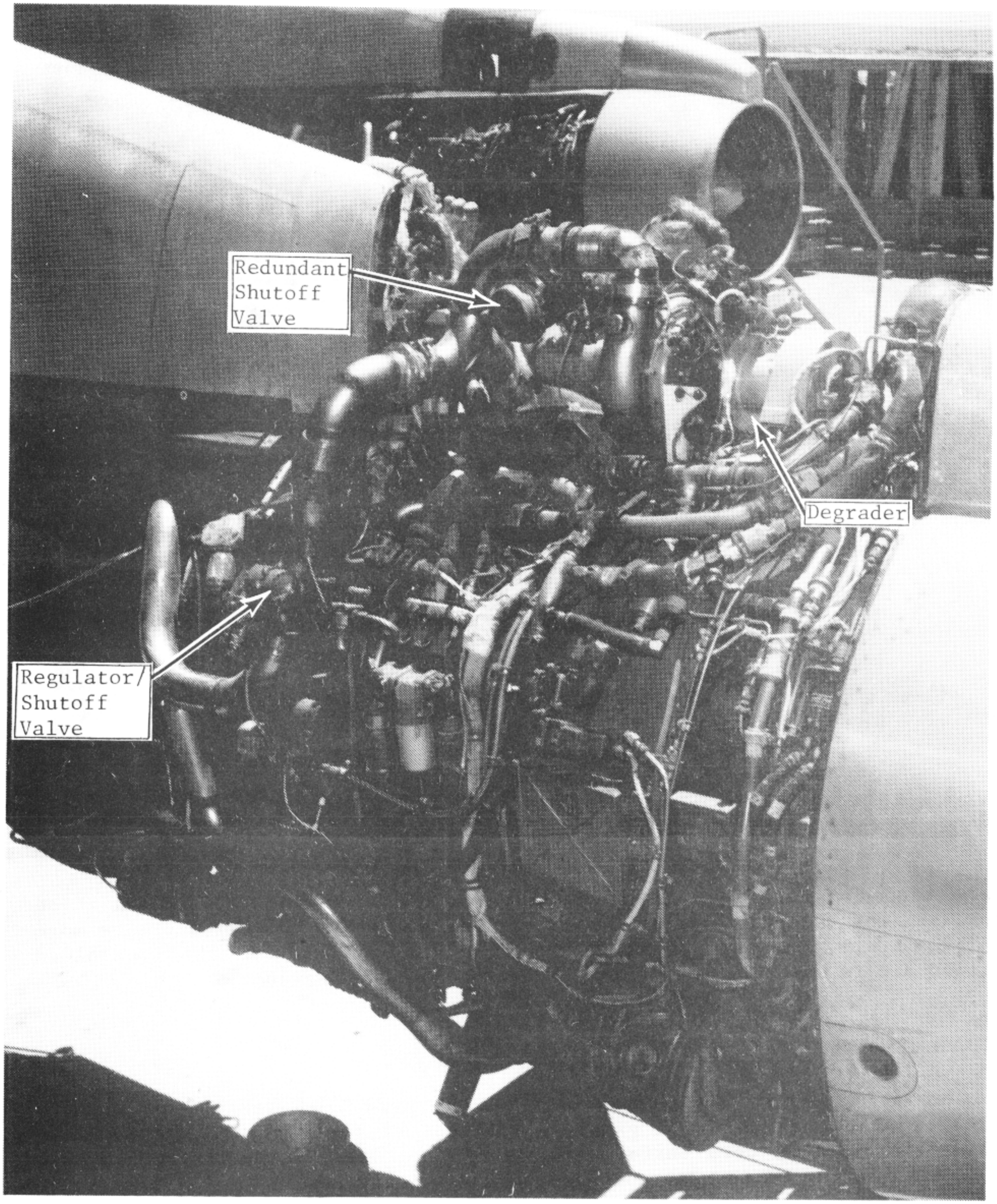


FIGURE 134. B720 PUMP/DEGRADER INSTALLATION

FIGURE 135. B720 HEAT EXCHANGER POD

not be tapped directly.) A second valve available in the JT3C installation takes air from the crossbleed air duct. (This valve and air circuit were more similar to the air supply ducts available in the CV880.) The crossbleed manifold air is used to start both the engine and the degrader.

PREPARATIONS FOR THE REMOTE IMPACT FLIGHT

In order to determine the suitability of the B720 test vehicle to perform the CID mission, a number of progressive tests of the degrader systems were performed after they were installed on the B720. These tests included ground and flight testing of the degraders on both Jet A and AMK.

The degraders functioned well during preparations for the CID, and no evidence of gel formation was encountered. Problems that arose were minor and were readily fixed. It was noticed that the placement of the degrader at the top of the engine made the pump more prone to cavitation in the B720 installation than in the CV880.

VII. CONCLUDING SUMMARY

The test results of this program, as in many research and development efforts involving broad goals and objectives, do not permit definitive conclusions to be reached on all aspects of the investigation. Nevertheless, the program did yield a multitude of data and was a significant first step in the use of AMK fuel in an aircraft environment. The following conclusions, for this program, should be interpreted within the framework of a research and development effort.

PERFORMANCE OF THE PUMP/DEGRADER

The feasibility of operating an aircraft on AMK fuel conditioned by a pump/degrader was demonstrated. The high-speed centrifugal pump/degrader performed well and met the objectives in the CV880 and B720 programs. In the CV880 testing, approximately 45 hours of operation on AMK were accumulated, 30 of which were in flight. The pump/degrader produced the required 1.2 filter ratio over the full power range of the CJ805 engine.

The performance of the pump/degrader over a speed range from 18,000 to 32,000 rpm was stable, predictable, and easily controlled. This basically sound operation of the system is important from the standpoint of the development of a prototype degrader, a device that would be designed to degrade AMK fuel and be easily integrated into engine fuel systems. The possibility of developing a truly prototype degrader was greatly enhanced by the results of the program.

USE OF AMK FUEL

In the absence of hard gel formation, it was difficult to discern any operational differences between the No. 3 AMK engine and the No. 2 reference Jet A engine. Even in the case of simulated emergency degrader shutdown or during the occurrence of severe hard gel formation, the engine continued to operate. While either of the above two conditions would be unacceptable in a normal operating scenario, analysis of the test results suggests that the effects of such conditions could be tolerated long enough to allow appropriate countermeasures to be taken. An increase in pressure drop across fuel filters was the prime indicator of the presence of unsuitable AMK fuel in the engine.

Data acquired during the program were inadequate for full assessment of the degrader operation on cold AMK fuel (in the vicinity of the freezing point of the fuel). No problems were encountered from the degrader standpoint with the use of the AMK at temperatures down to 4° F inlet temperatures. Tank boost-pump pressure was noted to be approximately 12 percent lower with this cold fuel.

Normal operation of the aircraft boost pumps and fuel delivery system led to some minor, unintentional degrading of the AMK in the fuel line between the fuel tank and the engine. On the other hand, normal aircraft maneuvers had little effect on the antimisting qualities of the AMK fuel. Long-term storage of AMK fuel (approximately 3 to 4 months at Miami and over a year at Mojave) did not lead to any contamination or residue in the aircraft AMK fuel tank that would be cause for concern.

GEL FORMATION

Occurrence of AMK gelling in the fuel system was the only significant negative result in the flight test program. As stated above, the formation of gel did not have an immediate adverse effect on engine/aircraft performance. Notwithstanding this fact, gel formation in the fuel system is considered by General Electric to be an unacceptable condition.

Shear-Induced Gel. Excluding instances during some Mojave tests when the degrader was intentionally turned off, thereby producing shear-induced gel characteristic of undegraded AMK flowing through filters, the formation of shear-induced gel was thought to have been encountered once during the entire flight test program. During the cold-fuel test on August 31, the sampler filter exhibited a pressure rise that General Electric attributed to formation of shear-induced gel. The design of the sampler filter intentionally resulted in a high flow-to-area ratio that made the filter sensitive to the formation of shear-induced gel. Since this condition was not typical of normal engine filter design, this singular test result was not considered to be a reason for concern.

Precipitate Gel. Precipitate gel, which forms with the mixing of Jet A and AMK, has potential in certain conditions to cause operational problems. Occurrence of this gel during the test program was predictable, and methods were developed to control it. However, methods of eliminating or controlling this type of gel would have to be addressed before AMK could be used in normal commercial service.

Hard Gel. Hard gel formation is of considerable concern due to cumulative formation and tenacious nature. Hard gel does not dissipate after fuel flow decreases or stops and is impervious to most standard solvents if allowed to dry. The best indicator of the potential of hard gel was fuel clarity as measured by NTU. Test results seem to indicate that hard gel does not have a direct connection with the level of AMK fuel degradation as measured by filter ratio. It was possible to obtain good filter ratio results and acceptable fuel-nozzle atomization characteristics in the engine with the presence of severe hard gel.

The fact that hard gel was not encountered with AMK blended at Mojave with West Coast Jet A led to the suspicion that moisture content of the base fuel or humidity during blending caused the hard gel. Later testing at Miami indicated that extreme levels of water in the Jet A or high humidity during the preparation of the slurry for blending the AMK produced high values of NTU and evidence of gel formation observable from increased pressure drop across filters. While these data showed that moisture could have an effect on the formation of hard gel, General Electric does not consider the experimental evidence in the overall program to be consistent enough to exclude all other factors as causes of hard gel. Possible causes that were not extensively investigated during the program include the consistency of the different AMK slurry lots and the composition of the Jet A used in the tests. AMK blended from Jet A procured at Mojave did not exhibit gelling tendencies.

OTHER RESULTS

During the CV880 flight tests, it was noticed that degraded AMK fuel exhibited low fluid drag, or improved lubricity, compared to Jet A. This was evidenced by lower pressure drop across filters and the very low leakage rate of AMK through the degrader-shaft seal. Further investigation of this phenomenon might show that certain engine components in the fuel system might benefit from this added lubricity.

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