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DOT/FAA/CT-82/12

Commercial Aircraft Airframe Fuel Systems Survey and Analysis

Simmons Precision
Instrument Systems Division

FEDERAL AVIATION ADMINISTRATION

MAR 9 1982

TECHNICAL CENTER
ATLANTIC CITY, NJ

February 1982

Interim Report

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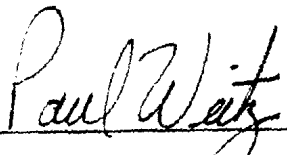


U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, N.J. 08405

ANTIMISTING KEROSENE FUEL
COMMERCIAL AIRCRAFT AIRFRAME FUEL SYSTEMS SURVEY
INTERIM REPORT
November, 1981

PREPARED FOR: ENGINE/FUEL SAFETY BRANCH
FAA TECHNICAL CENTER
ATLANTIC CITY AIRPORT
NEW JERSEY 08405

CONTRACT: DTFA03-80-C-0080



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1. Report No. DOT/FAA/CT-82/12		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle COMMERCIAL AIRCRAFT AIRFRAME FUEL SYSTEMS SURVEY			5. Report Date February 1982		
			6. Performing Organization Code		
7. Author(s) P. G. WEITZ			8. Performing Organization Report No. Report E-2304		
9. Performing Organization Name and Address SIMMONDS PRECISION PRODUCTS INSTRUMENT SYSTEMS DIVISION PANTON ROAD VERGENNES, VERMONT 05491			10. Work Unit No.		
			11. Contract or Grant No. DTFA03-80-C-0080		
12. Sponsoring Agency Name and Address U.S. DEPARTMENT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION FAA TECHNICAL CENTER ATLANTIC CITY AIRPORT, NEW JERSEY 08405			13. Type of Report and Period Covered October 1980 - October 1981		
			14. Sponsoring Agency Code ACT 320		
15. Supplementary Notes					
16. Abstract A selection of commercial aircraft airframe fuel systems has been studied to determine areas where incompatibility with antimisting kerosene fuel (AMK) may exist. Incompatibility can be due to reduced fuel system component performance with AMK or shear degradation of the AMK by the fuel system components. Survey results, to date, indicate that potential component performance problems with AMK are more significant than loss of AMK flammability protection due to shear degradation. Components of interest include ejector pumps, fuel filters, and auxiliary power units. The solubility of water in AMK and its effect on fuel system performance under actual operating conditions is also of major importance.					
17. Key Words JET FUEL, FIRE SAFETY, AIRCRAFT FUEL, FUEL ADDITIVES			18. Distribution Statement		
19. Security Classif. (of this report) UNCLASSIFIED		20. Security Classif. (of this page) UNCLASSIFIED		21. No. of Pages	22. Price

ACKNOWLEDGEMENTS

The information required for this study was obtained with the helpful cooperation of the many companies and individuals listed below. Their willingness to gather information and spend their time discussing aircraft fuel systems and components is greatly appreciated. Errors and omissions that may appear in this work are the responsibility of the author.

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SECTION 1 INTRODUCTION

Over the past 15 years much interest has been shown in developing aircraft turbine fuels that do not generate an easily ignitable mist cloud in an aircraft crash situation. The latest development in a series of experimental fuels of this type utilizes an additive called FM-9, produced by Imperial Chemical Industries of America (ICI Americas). It is added to commercial jet fuel at a concentration of approximately 0.3 percent.

The resulting mixture has been shown to have great benefit in reducing fireball generation in post-crash fire situations. However, other properties of this fuel mixture can present some difficulties in the normal handling of the fuel both on the ground and in flight.

A memorandum of understanding between the governments of the United Kingdom of Great Britain and Northern Ireland and the United States has been established to thoroughly study and investigate the feasibility of using this fuel additive in all commercial jet aircraft in order to significantly reduce the deaths caused in post-crash fire situations.

SECTION 2 OBJECTIVE

This study was performed as part of the Federal Aviation Administration's (FAA) Antimisting Fuel Engineering and Development Plan, FAA-ED-18-4.

The objective was to study the fuel systems of a representative sample of commercial aircraft covered by the Code of Federal Regulations, Title 14, parts 23, 25, and 29 for turbine powered aircraft to determine the range of conditions to which the antimisting kerosene fuel (AMK) would be exposed.

This information is required in the effort to minimize the need for changes in established aircraft fuel systems when using the AMK fuel.

SECTION 3 STUDY AIRCRAFT

Based on discussions with various airframe manufacturers and consideration of factors such as aircraft quantity, expected usage, passenger capacity, aircraft age, and unusual features, the aircraft listed in table 3-1 were chosen for the study.

TABLE 3-1. FUEL SYSTEMS SURVEY AIRCRAFT

<u>Aircraft</u>	<u>Engine Type</u>	<u>No. of Engines</u>	<u>Passenger Capacity</u>	<u>Total Fuel Quantity Gallons</u>
LARGE TRANSPORTS				
Boeing 737	Turbofan	2	115-130	5,974
Boeing 747	Turbofan	4	442	51,100
Concorde	Turbojet	4	108-128	31,516
DC-10	Turbofan	3	250-380	36,200
L1011	Turbofan	3	250-330	32,000
A-310	Turbofan	2	205-255	14,531
BAC 111	Turbofan	2	119	3,722
DC-8-71	Turbofan	4	259	24,259
COMMUTER TRANSPORTS				
Beech 99	Turboprop	2	15	368
Piper-PA-42	Turboprop	2	8	580
Embraer 110-P2	Turboprop	2	18	464
Swearingen Metro	Turboprop	2	20	648
Shorts SD3-30	Turboprop	2	30	573
de Havilland Twin Otter	Turboprop	2	20	378
de Havilland Dash 7	Turboprop	4	50	1,480
Cessna 441 Conquest	Turboprop	2	9	475
Convair 580	Turboprop	2	40	1,730
ROTARY WING AIRCRAFT				
Bell 212	Turboshaft	2	14	212
Aerospatiale AS350D	Turboshaft	1	6	140
Aerospatiale SA365N	Turboshaft	2	14	300
Boeing Vertol Comm. Chinook	Turboshaft	2	44	2,100
Sikorsky Spirit S-76	Turboshaft	2	12	286

SECTION 4

BASIS OF INVESTIGATION

In order to understand the development of AMK and its unusual properties, a literature survey was performed. This information was obtained through the FAA, National Technical Information Service, and other sources. In addition, personal communication with AMK researchers yielded valuable information on the properties and limitations of the most recent AMK fuel.

As a result, the basis of this investigation was centered around three major factors: Safety, AMK Degradation, and Fuel System Component Performance. The following established factors related to AMK properties are of interest:

- a. Jet pump performance is significantly reduced with undegraded AMK (reference 1).
- b. Undegraded AMK filtration can result in filter plugging under some conditions (references 1, 2).
- c. Dynamic response of Fuel System Components can be slowed with undegraded AMK (reference 1).
- d. Boost pump performance is reduced with AMK (reference 1).
- e. AMK degrades under shear, reducing its resistance to flame propagation (references 1, 2, 3, 4).
- f. Undegraded AMK heat transfer capability is less than Jet A fuel.
- g. The spray patterns obtained in standard jet engine burner nozzles with undegraded AMK are inadequate for proper fuel combustion (references 3, 5).
- h. Water Absorption of AMK is greater than Jet A fuel (references 2, 4).

SECTION 5 INDIVIDUAL AIRCRAFT

The following discussion briefly describes the basic low pressure airframe fuel system as supplied by the airframe manufacturer, for each of the study aircraft. The aircraft engines were not included in this study except for the auxiliary power units applicable.

McDonnell Douglas DC-10-40

- a. Fuel System Discussion - The DC-10-30 and -40 are the long range versions of this aircraft, which have a fuel capacity of 36,200 gallons (gal). There are three main tanks, one for each engine, plus auxiliary tanks in the center wing box.

Aircraft refueling can be accomplished through either two or four standard 2 1/2 inch MIL-A-25896D adapters, two of which are installed on each wing. The maximum initial flow rate through each adapter at 50 pounds per square inch gauge (psig) supply pressure is approximately 600 gal/min. This system utilizes refueling valves and controllers to initiate and terminate the refueling flow. This system can also be used to defuel the aircraft.

The fuel transfer philosophy during flight is as follows:

Fuel is transferred from the auxiliary tanks to the main wing tanks for use. The main wing tank fuel is used in three segments consisting of the inboard, outboard, and wing root areas.

The inboard compartment fuel is used first, with the outboard compartment held full for wing structural considerations. Late in the flight the outboard fuel is transferred inboard for use, and then fuel in the wing root area is used last. Float switches and indicator lights are used to indicate the fuel usage scheduling and status to the flight engineer.

A water scavenging system employing jet pumps is used to remove water from the tank low points and mix it with the fuel near the boost pump inlets. The motive flow comes from the engine feed lines and the secondary flow of water and fuel is drawn up through tubing rakes whose inlets are located in the tank low points.

- b. Fuel System Components And Features
1. Line Sizes - The main fuel system uses 2.0 inch to 3.0 inch outside diameter pipe. The scavenge and transfer system, uses 1/2 inch to 5/8 inch pipe.
 2. Boost Pumps - Electrically driven 8000 revolutions per minute (rpm) centrifugal pumps rated at 46,000 lb/hr at 17 psig are used. Twelve are supplied for boost and transfer and at least 4 run continuously. Five are in each inboard wing tank and two are in

recirculates fuel back to the gear pump inlet, not to the bulk fuel.

- c. Potential AMK Degradation Sources - The primary source of AMK shear degradation is the continuous pumping and recirculation through the 8000 rpm boost pumps. Results given in reference 1 indicated that boost pump shear degradation was not severe, but the flammability test criteria presently being used have been revised. The high shear gear pump on the APU will probably result in some degradation, but since fuel bypassed in the APU is not returned to the tanks this will not affect the safety aspects of the bulk fuel. Some shearing action may occur in the refuel/defuel valve during the partially open condition but the effect will probably be small due to the short time spent at this condition.

Discussions with the Southwest Research Institute where AMK shear degradation studies are being done (reference 2) indicate that pre-gelling of the fuel may occur when it is passed through the pump so that subsequent passes may cause gelling to occur.

- d. Potential Component Performance Problems - Based on ejector pump performance studies reported in reference 1, the 14 ejector pumps used in this aircraft will have greatly reduced performance. According to reference 1, this can result in reduced scavenging efficiency. The tests reported on in this reference indicated that the ejector pumps were unable to keep the pump collector boxes full with AMK fuel. This caused the fuel level in these boxes to fall with the tank level, which could lead to uncovering of the boost pump inlets even though fuel still remained in the tanks. This did not occur with the standard Jet A.

In the DC-10, this can also affect the tip tank recirculation when the ejector pump loop is utilized under certain attitude conditions.

Boost pump performance will also be reduced but may not be a critical factor.

Small fluid passages present in the automatic shut-off valves and float transfer valves may result in increased response time with AMK.

Discussion with Southwest Research indicates that the 5 mesh pump inlet screens and the perforated distribution lines should function satisfactorily with AMK.

- e. Potential Safety Considerations - Possible pre-gelling of the AMK could result in some plugging of the pump inlet screens. Reduced jet pump performance may increase unuseable fuel. Based on references 1, 2 and 3, the fine filters on the APU will probably experience plugging with AMK. Liquid water, if present, that is drawn up by the scavenge system and deposited in the bulk fuel near the boost pump inlet may cause sudden polymer precipitation.

6. Jettison System - The tank pumps are used to jettison fuel overboard during flight. This operation is automatically stopped when collector tank levels fall to an underfull condition.
7. Deaeration System - Fuel deaeration systems are provided in tanks where fuel remains static for long time periods. Deaeration prevents momentary increases in tank pressure and formation of air pockets around pump inlets due to air release from the fuel with decreasing tank pressure. These systems pump the fuel through spray nozzles with 0.060 inch diameter holes. Twenty-seven nozzles are used, each with 6 holes.
8. Pressure Refueling - Pressure refueling can be performed from both sides of the aircraft through four standard 2 1/2-inch MIL-A-25896D adapters.

The refueling system employs automatic shut off valves and pilot valves which have 1/16 inch to 1/8 inch orifices.

9. Recirculation Control Valves - Recirculation control valves with tapered needles are used to control heat exchanger outlet flow.
 10. Float Level Sensors - These sensors utilize pilot valves with 1/16 inch to 1/8 inch orifices.
 11. Heat exchangers - Fuel is used in 10 heat exchangers, 6 for hydraulic fluid, 4 for air. Fuel is used in the shell side of the hydraulic fluid heat exchangers, and on the tube side of the air heat exchangers. Fuel flows through 0.040 inch by 0.060 inch passages in the fuel-air exchangers.
 12. Fuel Quantity Gauging System - A capacitance gauging system is used with thermistor point level sensors for high level shut-off and collector tank low level sensing.
 13. Flowmeter - Rotating vane volumetric flowmeters with capacitance-inferred density measurement are provided for each engine to measure the mass fuel flow rate. The afterburner flowmeter is located after the first stage engine fuel pump and the engine flowmeter is located after the second stage pump.
 14. Auxiliary Power Unit (APU) - There is no APU supplied with this aircraft.
- c. Potential AMK Degradation Sources - The primary source of AMK shear degradation is the continuous pumping and recirculation through the centrifugal pumps. Due to the extensive pumping through heat exchangers, control valves and de-aeration systems, more degradation will probably occur in this aircraft than in others studied.
- d. Potential Component Performance Problems - Based on reference 3, reduced heat exchanger performance will result with undegraded AMK. The deaeration spray nozzles will not perform satisfactorily with undegraded AMK. The thermistor bead point level sensors may have

7. Pressure refueling - Pressure refueling is performed through the 2 1/2 inch MIL-A-25896D adapters. The system uses an automatic shut-off valve with a pilot valve mechanism containing approximately 0.125 inch diameter passages.
 8. Heat Exchangers - Hydraulic fluid exchangers are used on this aircraft. The hydraulic fluid is on the tube side, and fuel is on the shell side. The fuel is used as a static heat sink.
 9. Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is used on the aircraft. No thermistor type point level sensors are included.
 10. Auxiliary Power Unit (APU) - The APU is supplied by Garrett Airesearch; their Part Number is CTCP-85-129. This unit has a 40 micron paper filter, and a 4245 rpm gear pump which supplies 480 pph at 500 psig. The max bypass ratio is 4:1; and it has one nozzle with a primary opening of 0.0185 inch and a secondary opening of 0.021 inch. The fuel control bypass metering system uses a flow passage which varies from 0.020 inch to 0.125 inch.
- c. Potential AMK Degradation Sources - The primary source of AMK shear degradation is the pumping and recirculation through the 11,200 rpm centrifugal pumps. Since transfer and scavenging are also performed with these pumps, instead of low shear jet pumps, a greater number of passes through them will take place. Some shearing action may occur in the refuel/defuel valve during the partially open condition, but the effect will probably be small. Based on discussions with Southwest Research, the use of AMK as a static heat sink in the hydraulic fluid heat exchangers will be equivalent to Jet A.
- d. Potential Component Performance Problems - The automatic shut-off pilot valve mechanism may have increased response time with AMK (reference 1). The APU will require the same type of degrader necessary for the main engines to insure proper combustor performance. The APU fuel control bypass metering system may not perform properly with undegraded AMK.
- e. Potential Safety Considerations - Possible pre-gelling of the AMK in the pumps could result in some plugging of the pump inlet screens. Based on references 1, 3 and 2, the fine filters on the APU will probably experience plugging with undegraded AMK. Liquid water drawn up by the scavenge system and deposited in the bulk fuel may cause sudden polymer precipitation. Some boost pump performance loss will be obtained with AMK but may not be critical.

Boeing 747

- a. Fuel System Discussion - The fuel in this aircraft is contained in a center wing tank, tip reserve tanks and 4 main wing tanks. Auxiliary tanks are added between the reserve tank and the outboard main tank in some models. The maximum fuel capacity is 51,100 gallons.

8. Heat Exchangers - Hydraulic fluid/fuel heat exchangers are used in this aircraft. Hydraulic fluid is on the tube side and fuel is on the shell side. The fuel is used as a static heat sink.
9. Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is used on this aircraft. No thermistor type point level sensors are used.
10. The APU is supplied by Garrett Airesearch; their part no. is GTCP-660-4. This unit has 10 micron and 25 micron paper filters and a 4000 rpm gear pump that has 4000 pph flow at 600 psig. The max bypass ratio is 3.6:1. There are 8 primary nozzles with a diameter of 0.012 inch and 8 secondary nozzles with a diameter of 0.014 inch. The fuel control bypass flow metering system uses a 0.020 inch to 0.060 inch flow passage.

- c. Potential AMK Degradation Sources - The primary source of AMK shear degradation is the continuous pumping and recirculation through the 7200 rpm pumps.

Results given in reference 1 indicated that boost pump shear degradation of AMK was not severe, but the flammability test criteria have since been revised.

The high shear gear pump on the APU will cause some degradation, but since fuel bypassed in the APU is not returned to the tanks this will not effect the bulk fuel flammability properties.

Some shearing action may occur in the refuel/defuel valve during the partially open condition, but the effect will probably be small.

Discussions with the Southwest Research Institute, where AMK shear degradation studies are being done (reference 2), indicate that pre-gelling of the fuel may occur when it is passed through the pump so that subsequent passes may cause gelling to occur.

- d. Potential Component Performance Problems - Based on reference 1, the eight jet pumps used in this aircraft will have greatly reduced performance. This can result in increased unuseable fuel and reduced scavenging efficiency.

Boost pump performance will also be reduced, but this may not be a critical factor.

Small fluid passages present in the automatic shut-off valves may have increased response time with AMK.

Discussion with Southwest Research indicates that the 4 mesh screens on the pump inlets should function properly with AMK.

The APU will require the same type of degrader necessary for the main engines to insure proper combustor performance. The APU fuel control bypass metering system may not function properly with AMK.

used to distribute the fuel and reduce static charge build-up during the fueling operation.

8. Vent System - The vent system contains fine honeycomb mesh flame arrestors.
9. Heat Exchangers - No fuel heat exchangers are supplied with airframe.
10. Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is used on this aircraft. Thermistor type point level sensors are used for high and low level sensing and to shut off the center tank pumps when the tank is empty.
11. Density Measurement - A fuel density measurement device called a Cadensicon is supplied with this aircraft.

It utilizes a mass balance method to measure fuel density and a sensor which measures fuel dielectric constant.

12. Auxiliary Power Unit (APU) - A Garrett GTCP-311-250 unit is supplied. This unit has a 10 micron synthetic fiber filter, and an 8300 rpm gear pump that supplies 2100 pph at 700 psig. Twelve fuel nozzles are used, 6 with an opening of 0.012 inch and 6 with an opening of 0.014 inch. The fuel control bypass metering line varies from 0 to 0.020 inch.

Potential AMK Degradation Sources - The primary source of AMK shear degradation is the continuous pumping and recirculation through the 6000 rpm boost pumps. The rpm of these pumps is significantly lower than some of the others encountered, and the degradation experienced will probably be less.

The high shear gear pump on the APU will probably result in some degradation, but since fuel bypassed in the APU is not returned to the bulk fuel this will not affect the bulk fuel flammability characteristics.

Discussions with Southwest Research, where degradation studies are being done, indicate that pre-gelling of the fuel may occur as it passes through the pump so that subsequent passes may cause gelling to occur.

- c. Potential Component Performance Problems - Based on reference 1, the two ejector pumps will have greatly reduced performance with undegraded AMK. This can result in inability to keep the boost pump collector box full.

Small fluid passages in the automatic shut-off valve and the level control valves may cause increased response time with undegraded AMK.

The 8 mesh screens on the pump inlets should function properly with undegraded AMK.

2. Boost Pumps - Electrically driven, radial flow, 8000 rpm, 13,000 pph at 8 psig boost pumps located in the inboard section of each wing are used. Four are supplied, two run continuously. Cruise flow is approximately 3000 pph.
 3. Ejector Pumps - Two are supplied, both run continuously to transfer fuel from the center tank to the wing tanks.
 4. Filters - Screens with 1/8 inch openings are used at the boost pump inlets and the jet pump inlets. No other airframe fuel filters are supplied.
 5. Suction Feed - Suction feed during normal flight would occur only as a result of major pump and/or electrical failure. The aircraft can operate on suction feed if required.
 6. Pressure Refueling - Pressure refueling is performed through one standard 2 1/2 inch adapter on the right-hand side of the aircraft. An automatic shut-off mechanism using a pilot valve is used in this system. Provision for gravity fueling is also supplied.
 7. Fuel Quantity Gauging System - A capacitance-type fuel quantity gauging system is used. No thermistor type point level sensors are included.
 8. Auxiliary Power Unit (APU) - A Garrett GTCP-85-115CK unit is supplied. This unit has a 40 micron paper filter, 4245 rpm gear pump, max flow of 480 pph at 500 psig, and a max bypass ratio of 4:1. The fuel nozzles are 0.01185 inch and 0.021 inch, and the fuel control bypass metering system uses a 0.020 inch to 0.060 inch flow passage.
- c. Potential AMK Degradation Sources - The primary source of AMK shear degradation is the continuous pumping and recirculation through the two 8000 rpm boost pumps. Reference 1, again, indicates that boost pump shear degradation may not be severe. The high shear gear pump on the APU will cause some degradation but since the bypassed fuel is not circulated back to the tanks this will not affect the bulk fuel. As in the other aircraft, possible pre-gelling of the AMK in the boost pumps may occur.
- d. Potential Component Performance Problems - Based on reference 1, the two ejector pumps will have greatly reduced performance with undegraded AMK. The boost pump performance will also be decreased, to a lesser degree.

Small fluid passages in the automatic shut-off pilot valve may cause increased response time in this system.

The 1/8 inch pump inlet screens should perform properly with undegraded AMK.

5. Suction Feed - The suction feed condition during aircraft flight would occur only as a result of major pump and/or electrical failure.
6. Vent System - The vent system contains honeycomb mesh flame arrestors with less than 0.01 inch openings.
7. Pressure Refueling - Pressure refueling is performed using the 2 1/2 inch MIL-A-25896D adapters, four are supplied, two on each wing. Automatic shut-off valves with pilot valves are used in this system which contain small lines 0.060 inch or greater.
8. Heat exchangers - No heat exchangers are used in the fuel system of this aircraft.
9. Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is used on this aircraft.

Thermistor bead point level sensors are used for low level jettison pump shut-off and low level transfer shut-off functions.

10. Auxiliary Power Unit (APU) - The APU is supplied by Hamilton Standard, part No. ST-6L-73. The engine portion of this unit consists of a Pratt & Whitney Canada ST6L-73 engine and a fuel control supplied by Aviation Electric.

The fuel control internal bypass metering valve utilizes a piston in a sleeve with 1/8 inch holes.

The engine utilizes a 6500 rpm, 1400 pph, 1000 psi gear pump with a bypass system that returns bypassed fuel to the pump inlet. The pump outlet has a 10 micron paper filter.

- c. Potential AMK Degradation Sources - The primary source of AMK shear degradation is the continuous pumping and recirculation through the 10,000 rpm boost pumps. Results given in reference 1 indicated that boost pump shear degradation was not severe, but the flammability test criteria presently being used have been revised. The high shear gear pump on the APU will probably result in some degradation, but since fuel bypassed in the APU is not returned to the tanks this will not affect the safety aspects of the bulk fuel.

Some shearing action may occur in the automatic shut off valve during the partially open condition, but the effect will probably be small.

Discussions with the Southwest Research Institute, where AMK shear degradation studies are being done (reference 2), indicate that pre-gelling of the fuel may occur when it is passed through the pump so that subsequent passes may cause gelling to occur.

- d. Potential Component Performance Problems - Based on ejector pump performance studies reported in reference 1, the 34 jet pumps on this aircraft will have greatly reduced performance. This could result in increased unuseable fuel, reduced scavenging efficiency, slower fuel

b. Fuel System Components And Features

1. Line Sizes - Engine feed and transfer lines are 1 1/2 inch and 2 inch.
2. Boost Pumps - Ten 8000 rpm, 35,000 pph, electrically driven centrifugal pumps are supplied for boost, crossfeed and transfer. Four run continuously for boost during climb, cruise, and descent. Cruise flow is approximately 3000 pph, pump zero flow pressure is 18 psig.
3. Ejector Pumps - Four ejector pumps are used one in each main tank. They run continuously, using motive flow from the centrifugal pumps, to scavenge fuel and water and to keep the boost pump collector boxes full.
4. Filters - The boost pump inlets utilize 5 mesh screens. No other filters are supplied with the airframe.
5. Suction Feed - Suction feed is used during aircraft landing and take-off. The boost pumps are used during climb, cruise, and descent.
6. Vent System - The vent system utilizes vent float valves. No flame arrestors are used.
7. Jettison System - The DC-8 uses a gravity jettison system.
8. Pressure Refueling - Pressure refueling is performed using two standard 2 1/2 inch adapters. Automatic shut-off valves incorporating pilot valves and small bleed lines are used.
9. Heat Exchangers - No fuel heat exchangers are supplied with the airframe.
10. Flowmeters - No fuel flowmeters are supplied with the airframe.
11. Fuel Quantity Gauging System - A capacitance fuel quantity gauging system is used. No thermistor type point level sensors are included.
12. Auxiliary Power Unit (APU) - The APU is supplied by Garrett Airesearch, part number GTCP85-98CK. This unit has a 40 micron paper filter, and a 4245 rpm gear pump which supplies 480 pph at 500 psig. The max bypass ratio is 4:1; and it has one nozzle with a primary opening of 0.0185 inch and a secondary opening of 0.021 inch. The fuel control bypass metering system uses a flow passage which varies from 0.020 inch to 0.125 inch.

- c. Potential AMK Degradation Sources - The primary source of AMK shear degradation is the pumping and recirculation through the 8000 rpm centrifugal boost pumps. Some shearing action may occur in the refuel/defuel adapter during the partially open condition, but the effect will probably be small.

5. Filters - The boost pump inlets have 8 mesh screens, and two 74 micron paper filters and two 10 micron paper filters are used in the engine feed lines.
 6. Heat Exchangers - No heat exchangers are supplied with the airframe fuel system.
 7. Auxiliary Power Unit (APU) - No APU is supplied with this aircraft.
 8. Suction Feed - The suction feed condition during flight would occur only as a result of major pump and/or electrical failure.
 9. Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is used on this aircraft. No thermistor type point level sensors are used.
 10. Flow transmitter - A turbine type flow transmitter is used to measure fuel flow to each engine. It is located downstream of the pump and fuel filter.
 11. Vent System - Fine mesh flame arrestors are utilized in the vent system.
- c. Potential AMK Degradation Sources - The only source of AMK shear degradation is the continuous pumping and recirculation through the 2000 rpm boost pumps. Due to the relatively low speed of these pumps, degradation will be less than in other aircraft with high speed pumps.
- d. Potential Component Performance Problems - Based on ejector pump performance studies discussed in reference 1, the two ejector pumps used in this aircraft will have reduced performance. Since both gravity flow and the ejector pumps are used to keep the collector box full, reduced jet pump performance may not be a significant problem. Boost pump performance will also be reduced based on reference 1.

The level control valves may have increase time response with undegraded AMK.

The 8 mesh screens should perform properly with undegraded AMK.

Based on reference 3, the turbine flow meter will have accuracy and calibration problems with undegraded AMK.

- e. Potential Safety Considerations - Possible pre-gelling of the AMK in the boost pumps could result in some plugging of the inlet screen.

The 74 micron and 10 micron paper filters will probably experience plugging with undegraded AMK.

DeHavilland Dash 7

- a. Fuel System Discussion - The fuel in this aircraft is contained in four integral wing structure tanks, one for each engine. The total fuel

- c. Potential AMK Degradation Sources - There are no significant sources of AMK degradation during normal fuel system operation. The 12,000 rpm centrifugal pump may cause some degradation when it is operating, but is normally not used.
- d. Potential Component Performance Problems - Based on reference 1, ejector pump performance will be greatly reduced. This may have a more significant impact on this aircraft than on others, since the main boost pump is of this type.

The automatic shut-off system may experience slower time response with undegraded AMK.

Based on reference 3, the turbine type flowmeters will have accuracy and calibration problems with AMK.

- e. Potential Safety Considerations - Based on references 1, 2, and 3, the 74 micron paper filters may experience plugging with undegraded AMK. The reduced jet pump performance with undegraded AMK will significantly affect engine driven pump inlet conditions.

Shorts SD3-30

- a. Fuel System Discussion - The fuel in this aircraft is contained in two box-shaped containers mounted fore and aft within a faired compartment on top of the fuselage center section. The forward container is divided into 3 cells and the aft container is considered to be cell 4. Cells 1 and 2 are considered the forward tank, and cells 3 and 4 the aft tank.

Each tank gravity feeds a collector tank mounted in the fuselage right-hand sidewall.

A boost pump is mounted in each collector tank. Fuel passes from the boost pump through the filter to the engine. Crossfeed capability is provided with a manually operated valve.

Pressure refueling is done through a standard 2 1/2 inch adapter, utilizing automatic shut-off valves. Gravity refueling can also be utilized.

- b. Fuel System Components and Features

1. Line Sizes - The fuel system uses 3/4 inch and 5/8 inch lines, and 1 inch refuel/defuel lines.
2. Boost Pumps - Electrically driven, 10,800 RPM, 1400 pph centrifugal pumps are used. Two are supplied and both run continuously. If both failed, the engines can operate on suction feed up to an altitude of 20,000 feet.
3. Ejector Pumps - No ejector pumps are supplied with this aircraft.

An open vent system is supplied with no flame arrestors.

b. Fuel System Components and Features

1. Line Sizes - Engine feed and ejector pump total flow lines are 3/4 inch and ejector pump motive flow lines are 3/8 inch. Engine feed lines after the firewall shut-off valve are 1/2 inch.
2. Boost Pumps - Electrically driven, 9000 rpm centrifugal pumps with a flow rating of 960 pph at 19.5 psi are used. Four are supplied, two run continuously.
3. Ejector Pumps - Four ejector pumps are used for transfer, scavenging, and to keep the boost pump collector boxes full. All four run continuously.
4. Filters - Sixteen mesh screens are used on the boost pump inlets. No other filters are supplied with the airframe.
5. Suction Feed - Suction feed during flight would occur only as a result of a major pump and/or electrical failure.
6. Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is supplied with this aircraft. No thermistor type point level sensors are used.
7. Pressure Refueling - Pressure refueling is not used on this aircraft.
8. Heat Exchangers - No fuel heat exchangers are supplied with the airframe fuel system.
9. Auxiliary Power Unit (APU) - No APU is supplied with this aircraft.

c. Potential AMK Degradation Sources - The only source of AMK shear degradation is the continuous pumping and recirculation through the 9000 rpm boost pumps.

d. Potential Component Performance Problems - Based on reference 1, the four ejector pumps will have greatly reduced performance with undegraded AMK. Boost pump performance will also be somewhat reduced.

The 16 mesh screens on the boost pump inlets should perform properly with undegraded AMK.

e. Potential Safety Considerations - Possible pre-gelling of AMK in the boost pumps may cause some plugging of the inlet screens. Water drawn up by the scavenge system and deposited in the bulk fuel may cause polymer precipitation.

- e. Potential Safety Considerations - Possible pre-gelling of AMK in the boost pumps could cause some plugging of the inlet screens. Liquid water drawn up by the ejector pumps and deposited in the bulk fuel could cause sudden precipitation of polymer.

Convair 580

- a. Fuel System Discussion - The fuel in this aircraft is contained in two integral wing fuel tanks, one for each engine. Either tank can supply one or both engines using a crossfeed system. The total fuel quantity is 1730 gallons.

Refueling is performed with gravity only.

Fuel is fed by gravity to the boost pump inlets. The boost pumps are not submerged, and fuel bypassed in the pump is returned to the dump inlet, not to the bulk fuel. The boost pump inlets are not located in the tank low point, and sump drains are provided at the low points to keep water from entering the pump inlets. Fuel management other than crossfeeding is not performed.

- b. Fuel System Components and Features
 1. Line Sizes - The engine feed lines are 1 inch, and the tank to pump lines are 1 1/4 inch.
 2. Boost Pumps - Electrically driven, 2250 rpm, 640 gal/hr vane type pumps are used. Two are supplied, both run continuously.
 3. Ejector Pumps - No ejector pumps are supplied with this aircraft.
 4. Filters - No. 2 mesh brass wire cloth is used on the tank fuel exit ports. No other filters are supplied with the airframe.
 5. Suction Feed - Suction feed conditions during flight would occur only as a result of major pump or electrical failure.
 6. Pressure Refueling - Pressure refueling is not used on this aircraft.
 7. Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is supplied. No thermistor type point level sensors are used.
 8. Auxiliary Power Unit (APU) - A Garrett GTCP 85-90 unit is installed. This unit has a 40 micron paper filter, and a 4245 rpm gear pump which supplies 480 pph at 500 psig. The maximum bypass ratio is 4:1; and it has one nozzle with a primary opening of 0.0185 inch and a secondary opening of 0.021 inch. The fuel control bypass metering system uses a flow passage which varies from 0.020 inch to 0.125 inch.

b. Fuel System Components and Features

1. Line Sizes - All lines are 1/2 inch or 3/8 inch.
2. Boost Pumps - Engine driven, 3665 rpm, 1100 pph, vane pumps are used, one for each engine. They run continuously. An electrically driven, 9750 rpm, 600 pph submerged pump in each wing is used for engine starting and if fuel pressure falls below 15 psi.
3. Ejector Pumps - Four ejector pumps are supplied. Two run continuously and two are used only during engine start and shutdown.
4. Heat Exchangers - No fuel heat exchangers are supplied with the airframe.
5. Suction Feed - Suction feed to the engine driven fuel pumps is continuous.
6. Filters - Two metal element filters with a pore size of 0.0015 inch x 0.018 inch are used. Each is located upstream of the engine driven pump.
7. Auxiliary Power Unit (APU) - No APU is supplied.
8. Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is supplied. No thermistor type point level sensors are used.
9. Vent System - The vent system uses honeycomb mesh flame arrestors.
10. Flowmeters - A turbine type flowmeter is used to measure fuel flow to each engine. It is located in the engine high pressure line downstream of the fuel control.

c. Potential AMK Degradation Sources - The only source of AMK shear degradation is pumping and recirculation through the engine driven vane pump.

d. Potential Component Performance Problems - Pressure drop through suction feed to the engine driven fuel pumps may be high with undegraded AMK. Based on reference 1, jet pump performance will be greatly reduced with undegraded AMK. Based on reference 3, the fuel flowmeter may have accuracy and calibration problems.

e. Potential Safety Considerations - Based on references 1, 2, and 3 the fine engine fuel filter may experience plugging with undegraded AMK.

Embraer 110-P2

a. Fuel System Discussion - The fuel in this aircraft is contained in two integral fuel tanks, one in each wing. Each tank has two interconnected fuel cells, separated by the main landing gear

11. Auxiliary Power Unit (APU) - No APU is supplied with this aircraft.

- c. Potential AMK Degradation Sources - The only source of AMK degradation is the pumping and recirculation through the centrifugal boost pumps.
- d. Potential Component Performance Problems - Based on reference 1, boost pump performance will be somewhat reduced. The stacked metal disk filter may experience plugging with undegraded AMK. Based on reference 3, the fuel flowmeter may have accuracy and calibration problems.
- e. Potential Safety Considerations - No potential safety considerations are apparent. Plugging of the engine fuel filter would result in the bypass valve opening, allowing the engine fuel supply to continue.

Beech 99

- a. Fuel System Discussion - The fuel in this aircraft is contained in 10 bladder cells, with a total capacity of 368 gallons. Each wing contains 3 interconnected cells, and there are two nacelle cells and two center cells.

The fuel drains by gravity from the wing cells to the center and nacelle cells. It is drawn from the center cells to the nacelle cells with jet pumps, where it is pumped to the engine with an engine driven vane pump. Crossfeed capability is provided.

Refueling is performed by gravity only.

The vent system utilizes fine mesh flame arrestors.

- b. Fuel System Components And Features

- 1. Line Sizes - Fuel lines are 0.50 inch x 0.035 inch wall and 5/8 inch x 0.035 wall.

Vent lines vary from 0.25 x 0.035 inch wall to 0.75 inch x 0.035 inch wall.

- 2. Boost Pumps - The primary boost pump is an engine driven vane pump, 600 pph at 30 psia, 3665 rpm.

Two are supplied, both run continuously.

The standby boost pump is an electrically driven 1200 pph centrifugal pump.

Two are supplied, but are only used in case of primary pump failure and for crossfeeding.

- 3. Ejector Pumps - Two ejector pumps are used to transfer fuel from the center tanks to the nacelle tanks. Both run continuously.

the cells. Ejector pumps located in these cells are used to keep the box around the boost pumps fuel.

Complete crossfeed between tanks and engines is provided for by manual control.

b. Fuel System Components and Features

1. Line Sizes - The engine feed lines are 1/2 inch, all other lines are 5/8 inch and 3/4 inch.
2. Boost Pumps - Two 12,000 rpm, 635 pph centrifugal pumps are provided, one in each underfloor cell. Both pumps run continuously.
3. Ejector Pumps - Two are supplied, one in each underfloor cell, to keep the boost pump boxes full. They run continuously.
4. Suction Feed - Suction feed during flight would occur only as a result of major pump and/or electrical failure.
5. Filters - No. 6 mesh screens are used on the boost pumps inlets, and 10 micron paper filters with a bypass loop are used in each engine feed line.
6. Heat Exchangers - No fuel heat exchangers are supplied with the airframe fuel system.
7. Pressure Refueling - Pressure refueling is not performed on this aircraft.
8. Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is supplied. No thermistor type point level sensors are used.
9. Auxiliary Power Unit (APU) - No APU is supplied.
10. A bleed line for each engine fuel control is used to return excess flow from the hydromechanical fuel control. This line utilizes a 0.050 inch orifice, sized by the engine manufacturer to maintain minimum required pressure in the fuel control under all conditions.
11. Vent System - A vent system which interconnects all cells and utilizes two siphon breaker valves is supplied.

c. Potential AMK Degradation Sources - The only source of AMK shear degradation is pumping and recirculation through the 12,000 rpm boost pumps.

d. Potential Component Performance Problems - Based on reference 1, the two ejector pumps will have greatly reduced performance with undegraded AMK, and boost pump performance will also be somewhat reduced.

8. Pressure Refueling - Pressure refueling is performed through a single 2 1/2 inch MIL-A-25896D adapter. This system uses a level control valve and an automatic shut-off valve with 0.030 inch to 0.040 inch orifices, maximum flow is 300 gpm.
 9. Heat Exchangers - No fuel heat exchangers are supplied with the airframe fuel system.
 10. Flowmeter - A General Electric mass flow transmitter, which incorporates a turbine type element, is used to measure fuel flow to each engine. It is located downstream of the boost pump.
 11. Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is supplied. Thermistor type point level detectors are used for fuel low level sensing.
 12. Fuel Jettison - Fuel is jettisoned by gravity, at a rate of 35 gpm.
 13. Aircraft Cabin Heater - A jet fuel combustion type heater is used. This unit has its own gear pump and uses spark plug type ignition. A burner spray nozzle with an 0.050 inch spray nozzle is used.
 14. Auxiliary Power Unit (APU) - The APU for this aircraft is supplied by the Turbomach Division of International Harvester. It utilizes a 10 micron nominal, 25 micron absolute metal filter. The pump supplies 500 pph at 375 psig and 4,250 rpm. The fuel is sprayed through one 0.002 inch atomizing nozzle into a hot tube vaporizer before entering the burner. Fuel bypass ratio is 4 to 1.
- c. Potential AMK Degradation Sources - The only source of AMK shear degradation is pumping and recirculation through the 10,300 rpm centrifugal pump.
 - d. Potential Component Performance Problems - Based on reference 1, the boost pump and APU pump performance will be somewhat reduced.

The APU and fuel fired cabin heater will probably require a degrader.

Based on reference 3, the flowmeters may have accuracy and calibration problems.

The level control valves, automatic fuel shut-off valves, and the low level thermistor sensors may have increased response time with undegraded AMK.

The No. 4 mesh screens on the boost pump inlets should perform properly with undegraded AMK. The 10 micron APU filter may experience plugging with undegraded AMK.

- e. Potential Safety Considerations - The crash resistant bladder fuel cells and breakaway fittings should supplement the AMK fire protection qualities.

Aerospatiale AS350D Helicopter

- a. Fuel System Discussion - The fuel in this aircraft is contained in a single spin-molded polyamide (nylon) tank, holding 140 gallons. The tank is mounted behind the passenger compartment.

An electrically driven boost pump is mounted at the base of the tank, and fuel drains by gravity to the pump inlet. A drain plug and water bleed valve is located beneath the pump.

Gravity refueling is used, and the tank has an overboard vent line.

- b. Fuel System Components And Features

1. Boost Pumps - One electrically driven 550 rpm centrifugal pump with a rated flow of 250 liters/hr (66 gal/hr) is supplied. It runs continuously, varying flow with engine demand. Fuel is not bypassed back to the tank. Nominal flow is 44.9 gallons/hr.
2. Ejector Pumps - No ejector pumps are supplied with this aircraft.
3. Pressure Refueling - Pressure refueling is not performed on this aircraft.
4. Filters - One 10 micron metal filter equipped with a bypass valve and a mechanical bypass indicator is supplied. A coarse mesh screen is also used on the boost pump inlet.
5. Suction Feed - Suction feed to the engine is used only in the event of pump failure.
6. Heat Exchangers - No fuel heat exchangers are supplied.
7. Auxiliary Power Unit (APU) - No APU is supplied with this aircraft.
8. Fuel Quantity Gauging System - A float/potentiometer fuel quantity gauging method is used. There are no thermistor type point level sensors.

- c. Potential AMK Degradation Sources - There are no significant sources of AMK shear degradation.

- d. Potential Component Performance Problems - Based on reference 1, the boost pump performance with undegraded AMK will be somewhat reduced. The 10 micron filter will probably experience plugging with undegraded AMK. Some problems due to increased drag with undegraded AMK may occur in the float type gauging system.

- e. Potential Safety Considerations - In the event of failure of the single boost pump, suction feed performance with undegraded AMK may not be satisfactory.

SECTION 6 ADDITIONAL FUEL SYSTEM COMPONENTS

In addition to the components and systems discussed in Section 5, various other components such as vent float valves, float level indicators, check valves, pressure switches, etc are used. A general discussion of some of these follows. Some applicable specifications are listed for these and the other major components discussed previously.

Some Component Specifications

Pressure Fuel Servicing Adapter	MIL-A-25896D, MS24484
Check Valves	MIL-V-7899C
Ejector Pumps	MIL-P-85315
Fuel Boost Pumps	MIL-P-5238C
Aircraft Fuel Pressure Switch	MIL-S-9395E
Aircraft Fuel Gauges	MIL-G-26988C
Level Control Valves	MIL-V-38003
General Specification For Fuel System Components	MIL-F-8615D
Vent Valves	MIL-V-81356A

Discussion

Check Valves - The check valves used in the aircraft fuel systems studied are either swing check or poppet type, most of which meeting MIL-V-7899 requirements. One of the requirements called out is the opening of the valve at a pressure differential of less than 8 inches of water. This could be a problem with AMK. Discussion with Sikorsky on their S-76 Helicopter has indicated that they only use swing type check valve because of the slightly higher pressure drop with the poppet type valves. Discussion with Boeing Vertol indicates that they have had contamination problems with poppet type valves on their aircraft.

Pressure Switches - Pressure switches meeting MIL-S-9395E should operate satisfactorily with AMK.

Vent Float Valves - Most of the aircraft use float vent valves in the vent system which are normally open when air or fuel vapor is in the vent line. If ground or flight attitude changes cause liquid to enter the vent line, the float rises and closes the vent to prevent liquid fuel from flowing out of the vent line. The valve also relieves positive or negative tank pressures. These valves should function properly with AMK.

Fuel Quantity Gauging System - All of the aircraft studied use capacitance type fuel quantity gauging systems. The primary specification covering this type of system is MIL-G-26988.

These gauges utilize the relationship between fuel dielectric constant and density to perform their function. Testing described in reference 1 indicated no significant difference in gauge operation on the C-141 aircraft fuel system simulator.

SECTION 7 FUEL SYSTEM PARAMETER RANGES

Dynamic Parameters

Based on this review of the selected aircraft fuel systems, the bulk antimisting kerosene fuel will be exposed to the following conditions induced by aircraft fuel system components:

Pressure : Pressure Refueling - 14.7 psia to 50 psig
Boost Pumps - 10 to 25 psig
Suction Defueling - 14.7 psia to -11 psig

Flow Rate : Pressure Refueling - 0 to 870,000 pph
Boost Pumps - 0 to 50,000 pph

Boost Pump rpm : 2000 to 12,000 rpm

Environmental Parameters

The bulk fuel will be exposed to the following environmental parameter ranges while being used in the aircraft studied:

Humidity - 0 to 100 percent relative humidity

Altitude & Pressure - Sea Level (14.7 psia) to 60,000 feet. (0.04 psia)

The 60,000 ft. pressure altitude would only be experienced in the Concorde fuel tanks if the pressurization system failed. Assuming this did not occur, the lowest pressure altitude experienced would be at 44,000 feet. (2.2 psia).

Temperature - Based on a review of references 6, 7, and 8 the lowest minimum bulk fuel temperature likely to be encountered is approximately -44° C (-47.2° F).

The studies described in references 6 and 8 involved the comparison of computer studies with actual flight fuel temperature measurements. The results were based on the expected one-day-a-year, 0.3 percent probability cold ambient temperature.

The calculation of the bulk fuel temperature with the models used involves various assumptions concerning fuel stratification and mixing. The comparison of the computer studies with actual data indicates that the stratification effect is small.

The highest bulk fuel temperature likely to be observed in the airframe fuel system will occur in the Concorde aircraft. Data indicates that fuel temperatures of approximately 80° C (176° F) will be experienced in some tanks near the end of the flight. Fuel that remains in tanks during landing can have a temperature of approximately 55° C (131° F).

The solubility of water in jet fuel varies with temperature. At 20° C, approximately 0.008 percent by weight of water is present in saturated commercial jet fuel, assuming all free water has been removed. At -10° C, this value is reduced to 0.0025 percent. This indicates that if the approximately 340,000 lbs. of 20° C fuel on a 747 was chilled to -10° C and all of the water coming out of solution was removed, approximately 2.24 gallons of water would result.

Humid air drawn into the vent system during descent causes condensation on the cold tank structure and fuel surface. Since the fuel tanks usually have considerable empty volume after a long flight, significant amounts of water can be drawn in at this time. About 1/4 pint of water per 1000 gallons of fuel tank space can be condensed in this way (reference 8).

Additionally, introducing warm fuel into the cold tanks during refueling can result in water being separated from the fuel as it is chilled.

Free water is continually being generated in the aircraft fuel tanks through these mechanisms.

SECTION 8 CONCLUSIONS

Based on the aircraft fuel systems studied and a review of the references in Section 10, the following conclusions concerning the use of AMK have been reached:

- Based on the fuel systems surveyed, the loss of the flammability protection of AMK during flight due to shear degradation from system components does not appear to be a major problem. Boost pumping is the primary source of such degradation, and previous studies (reference 1) indicate that this is not severe.
- The proper performance of some fuel system components with AMK will be of more concern than the loss of AMK flammability protection.
- The extensive use of ejector pumps in the aircraft fuel systems studied, and their previously established poor performance with undegraded AMK warrants further study.
- The coarse screen filters used in most of the aircraft fuel systems should not be a problem when AMK is used.
- The various fine micron size filters used in auxiliary power units and some aircraft fuel systems will require further study of AMK filterability under actual operating conditions.
- Auxiliary power unit testing with degraders will be required to insure that proper APU performance with AMK can be maintained.
- The solubility of and integration of water with AMK under actual fuel system operating conditions is of major interest in determining fuel system performance with AMK.

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