AEROSPACE INFORMATION REPORT

AIR4023™	REV. C
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Aircraft Turbine Fuel Contamination History and Endurance Test Requirements

RATIONALE

This document has been revised to: (1) Add reference to JSSG 2007, (2) Include the EASA CS-E670 requirements for contaminated fuel testing, (3) Include a paragraph discussing SAP contamination from Filter Monitors, (4) Update paragraph 3.9 to reference biofuels and FAME contamination, (5) Clarify the cyclic endurance test time for the 92 hour Cold testing in specification XPP-36C, (6) Add footnotes on the current status of the referenced MIL standards, and (7) Include editorial changes for clarity.

FOREWORD

Information for this document was provided by members of SAE Committee AE-5, Aerospace Fuel, Inerting & Lubrication Systems and other government and civilian sources. This document provides background information as to the origin and evolution of fuel contamination and contaminated fuel endurance test requirements imposed on aircraft turbine engine fuel system components for certification and qualification. Included is a history of the inconsistencies of commercially available contaminant materials in meeting specification requirements and the recent successful effort to provide high-quality, certified constituents. This document is to be used for information only.

The fuel system of a modern aircraft gas turbine engine is complex. The protection of components from suspended fuel contaminants includes fuel filtration and contamination-resistant component design. To prove a design, standard tests have evolved that subject fuel system components to a controlled, severe, contaminated-fuel environment. These tests, although used in Military Specification documents, have frequently been criticized by industry spokesmen and some within the military as well. This document is an overview of existing contamination problems, contamination testing requirements, and the future outlook.

After World War II, the number of incidents of fuel contamination increased for turbine-powered aircraft as compared to those for piston-powered aircraft. Contamination was worse due to the higher viscosity of jet fuels and high fuel flow rates. Reports, from the Korean and Vietnam conflicts of jet fuel being hand pumped into aircraft from uncovered tarpaulin-lined pits, have documented real field contamination problems. In Vietnam a number of fighter bombers were put out of action due to contaminated fuel from an offshore tanker. Helicopters in combat, refueled on-the-fly, also were subjected to severe fuel contamination. These events created the need for test requirements reflecting typical severe field conditions.

The concern about military aviation turbine fuel contamination increased in the late 1940s and early 1950s. The initial concern was probably generated in the Navy by the fuel storage requirements imposed by carrier operations. Only naval aircraft were fueled at high rates from rusty "water bottom" tanks, with only a single filter water removal operation between storage and aircraft. It soon became apparent that piston-engine components were able to cope with more sediment and water than turbine engine components. Turbine engine fuel control valves differed greatly from the reciprocating-engine carburetor. Very close clearances were required in turbine engine control valves to provide the accuracy necessary for successful operation. These small clearances made components susceptible to solid contamination and water-related corrosion. Other problems included the frequent plugging of engine fuel filters with ice and other solids.

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The quality problem of turbine fuel supplies was further complicated by other factors. A large piston engine required 90 to 120 gallons of aviation gasoline per hour, while the turbine engine used at least 500 to 800 gallons of fuel per hour. Assuming the same level of contamination, the turbine engine was required to handle five times as much solid contamination and water per hour as the piston engine.

The nature of jet fuel also contributed to the problem. High viscosity, wide cut distillation, high density and the low interfacial tension of turbine fuel complicated the problem of sediment and water removal. Filter separators rated at 225 gpm with gasoline had to be operated at 160 to 180 gpm to perform satisfactorily with JP-4. In storage tanks, a 5 µm solid particle that settled approximately 1.5 feet per hour in aviation gasoline, would settle only 4 inches per hour in JP-4 fuel, and only 2 inches per hour in JP-8 (Jet-A). Jet fuels also tended to loosen more rust from the walls of storage tanks than gasoline.

One aspect not addressed by most of the current test specifications is the potential for fuel contamination by new aircraft fuel tanks, which can contain large amounts of debris until it is flushed out by use. Particles of explosion suppression foam, cotton linters, metal chips, excess sealant, silica sand, etc. have been found in heat exchangers, fuel strainers, and filters of new aircraft. These problems may be further complicated by the increased use of composites, which may produce new types of contamination for which there is a limited experience base for their impact on fuel system operation and component wear; for example, carbon fibers can pass through relatively fine filters, end on, whereas other polymeric fibers (such as Kevlar) could matt and block filters. Specifications requiring the addition of carbon fiber contamination to traditional fuel contamination are emerging, and future specifications may include other types of contaminants referenced above.

Other fuel contamination issues include: (1) Copper contamination in jet fuel and its impact on fuel thermal stability, (2) The impact of contamination in low lubricity fuels (low sulfur fuels, synthetic fuels such as Fischer Tropsch fuels, or potential bio-fuels) on fuel system components and operation, and (3) The impact of filter monitor media migration on fuel control systems.

It should be noted that there is a diversity of test requirements and an unlikelihood of agreement on what the universal test and contamination requirements should be for the near future.

TABLE OF CONTENTS

1. SCOPE

1.1 Evolution

This document discusses the history and development of endurance requirements, provides an analysis of test contaminant material and includes a discussion of future requirements.

1.2 Field of Application

This document provides the reader with a background of aircraft turbine engine fuel system component endurance test requirements needed by engineers working on component design evaluation.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

MAP749	Aircraft Turbine Engine Fuel System Component Endurance Test Procedure (Room Temperature Contaminated Fuel)
AIR790	Considerations on Ice Formation in Aircraft Fuel Systems
AIR4246	Contaminants for Aircraft Turbine Engine Fuel System Component Testing
ARP8615	Fuel System Components: General Specification For

2.2 Military Publications

Available from DLA Document Services, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6396, http://quicksearch.dla.mil/.

JSSG-2009	Air Vehicles Subsystems
JSSG-2007	Engines, Aircraft, Turbine
MIL-E-005007E(AS)	Engines, Aircraft, Turbojet and Turbofan, General Specification for
MIL-E-5007	Engines, Aircraft, Turbojet and Turbofan, General Specification for
MIL-E-5009	Engines, Aircraft, Turbojet and Turbofan, Tests for
MIL-E-5007A	Engines, Aircraft, Turbojet and Turbofan, General Specification for
MIL-E-5007B	Engines, Aircraft, Turbojet and Turbofan, General Specification for
MIL-E-5007C	Engines, Aircraft, Turbojet and Turbofan, General Specification for
MIL-E-5007D	Engines, Aircraft, Turbojet and Turbofan, General Specification for
MIL-E-5009A	Engines, Aircraft, Turbojet and Turbofan, Tests for

MIL-E-5009B	Engines, Aircraft, Turbojet and Turbofan, Tests for
MIL-E-5009C	Engines, Aircraft, Turbojet and Turbofan, Tests for
MIL-E-5009D	Engines, Aircraft, Turbojet and Turbofan, Tests for
MIL-E-8593	Engines, Aircraft, Turboprop, General Specification for
MIL-E-8595	Engines, Aircraft, Turboprop, Qualification Tests for
MIL-E-5009A	AMENDMENT-1
MIL-E-8593A	Engines, Aircraft, Turboshaft and Turboprop, General Specification for
MIL-E-87231	Engines, Aircraft, Turbojet and Turbofan
MIL-F-8615D	Fuel System Components, General Specification For (ASG)
MIL-DTL-5624V	Turbine Fuel, Aviation, Grades JP-4 and JP-5
MIL-DTL-83133J	Turbine Fuels, Aviation, Kerosene Types, Nato F-34 (JP-8), Nato F-35, And JP-8 + 100

NOTES:
1. MIL-E-5009 (all revisions) is inactive. MIL-E-5009D has been superseded by MIL-E-5007D.
2. MIL-E-5007 (all revisions) is inactive for new engine designs.
3. MIL-E-87231 is cancelled and replaced by JSSG 2007.
4. MIL-E-8593 (all revisions) is inactive.
5. MIL-E-8595 is cancelled and superseded by MIL-E-8593.
6. MIL-F-8615D is cancelled and superseded by ARP8615.

2.3 ISO Publications

Available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, www.iso.org.

ISO 12103-1 Road vehicles - Test dust for filter evaluation; Part 1: Arizona test dust

2.4 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D1655-06d Standard Specification for Aviation Turbine Fuels

ASTM D6615-06 Standard Specification for Jet B Wide-Cut Aviation Turbine Fuel

2.5 Other Publications

XPP-36C	Endurance Tests of Fuel Metering Components for Advanced Application
NAMC-AEL-1670	Naval Air Engineering Center, Proposed Optimum Method of Conducting Contaminated Fuel Tests on Engine Components Per Specifications MIL-E-5007B and MIL-E-5009B
EN 4106	Woodward Governor Company, Contaminated Fuel Test Method to MIL-E-5007B and MIL-E-5009B
63-AHGT-42	American Society of Mechanical Engineers, Contaminated Fuel Testing of Engine Controls to MIL-E-5009B Using the USN Aeronautical Engine Laboratory Technique

EN 4106 Supp I	Woodward Governor Company, Improved Method for Testing Components per MIL-E-5007B and MIL-E-5009B
NAEC-AEL-1791	Naval Air Engineering Center, Proposed Revision to MIL-E-5007B and MIL-E-5009B Standardized Method of Conducting Contaminated Fuel Tests
Nov/Dec 1972	Filtration & Separation, Fuel Filters for Aero Gas Turbine Engines
Volume XXXIV	Douglas Service
AFLRL No. 90	Definition of Aviation Turbine Fuel Contamination Under Simulated Combat Conditions
Letter Report	Majac Division, Donaldson Corporation, Analysis of SAE Test Samples, MIL-E-5007
Report #266	Scientific and Laboratory Services Dept., Pall Corporation, Evaluation of MIL-E-05007D Test Contaminant
NAPC-P-79002	Engines, Aircraft, Turbojet and Turbofan, General Specification for
AS/AV-E-8593C-2	Engines, Aircraft, Turboshaft and Turboprop, General Specification for

3. HISTORY AND DISCUSSION

3.1 Events That Influenced Early Turbine Engine Specifications

3.1.1 1940s

Two F-80s crashed because of contamination that plugged the fuel filters and caused dirty fuel to bypass the filter, thus contaminating the engine fuel system. A need was created for testing requirements to address these problems.

3.1.2 1950-51

Engine failures led to a USAF study of turbine fuel supplies. Contamination consisting of iron oxides, aluminum oxides, and silica sand with concentrations of 1.7 to 34.5 gm/1000 U.S. gallons were found during the study. Endurance requirements were generated for MIL-E-5007A and MIL-E-5009A that called for 150 hours of contaminated endurance, with 148 hours at 8 gm/1000 gallons and the last 2 hours at 80 gm/1000 gallons. The test contaminant was silica (fine Arizona road dust). A separate 50 minute salt water slug test and 72 hour soak was included.

3.1.3 1959

A USN study of 126 JP-4 and JP-5 fuel samples found contaminants of iron oxide, silica, and linters in the 0 to 200 µm range. The result of this and the previous USAF study, was MIL-E-5007B and MIL-E-5009B, which introduced the level of 41 gm/1000 gallons for an entire 300 hour endurance test. Contaminants were iron oxides, silica (coarse Arizona road dust), cotton linters, and saltwater. The separate salt water slug and soak test was eliminated.

3.1.4 1965

A USAF study of fuel samples from receiving, storage, refuelers, and aircraft at SAC bases revealed contamination levels of 1.0 to 7.2 gm/1000 gallons. This resulted in revisions MIL-E-5007C and MIL-E-5009C, which reduced the cotton linter quantity to one tenth that of MIL-E-5007B and introduced the term "micron" rather than "mesh size" for describing large particles.

3.1.5 1973

Specifications MIL-E-5007C, MIL-E-5009C, and MIL-E-5009D were combined into MIL-E-5007D. The total quantity of contaminants was increased from 40.1 gm/1000 gallons to 42.6 gm/1000 gallons and the iron oxides were erroneously split 50/50 into 14.5 gm Fe_3O_4 magnetite and 14.5 gm Fe_2O_3 hematite. Three controlled-environment shutdowns were added to the engine control system test. The reason they were added could not be determined.

3.1.6 1977

A joint industry and military conference held at Wright-Patterson AFB, Ohio to review the component endurance testing requirements in MIL-E-5007D concluded the following:

a. The correct split for the iron oxides should have been 1.5 gm magnetite and 27 gm hematite.

b. The 420- to 1500- µm crushed quartz should be moved to a "to be created" slug test.

c. The crushed quartz was intended to represent aluminum chips frequently found in fuel samples and supposedly "difficult" to obtain in graded form.

d. The naphthenic acid requirement should be eliminated in tests where service fuel is used.

e. Test cycles should be the same for all components and should be mission-oriented.

f. A dirt slug test and a low-lubricity-fuel endurance test should be added as separate requirements.

g. The three 120 hour engine control system shutdowns, introduced in MIL-E-5007D, should be replaced with a maximum of two overnight shutdowns. This requirement should be applied to all fuel system components including fuel nozzles.

h. The military should continue to review and refine endurance requirements based on field experience.

3.2 Test Contaminants

3.2.1 Contaminant Requirements

The following pages tabulate significant fuel-contamination-material requirements that were imposed on turbine engine fuel system components. While the emphasis of this AIR is on solid contamination (in conjunction with salt water in many specifications), a more comprehensive background on water contamination and icing in aircraft fuel systems due to free water in fuel, and proper simulation of aircraft fuel systems in icing tests of fuel systems, is discussed in AIR790.

1. MIL-E-5007A, 27 July 1951 and

2. MIL-E-8593, 3 September 1954

Table 1 - Fine Arizona road dust

Particle Size-Microns	Percent of Total
0-5	39 ± 2 by weight
5-10	18 ± 3 by weight
10-20	16 ± 3 by weight
20-40	18 ± 3 by weight
Over 40	9 ± 3 by weight
Through a 200-mesh screen	100 by weight

3. XPP-36C, 3 June 1957

Table 2 - Paragraph 4.1.1 - fuel contamination

Contaminant	Particle Size	Quantity
Iron Oxide James H. Rhodes & Co. #340 London Red Rouge, or equivalent	0-10 Microns	36 gm/1000 gallons
Road Dust AC Div., GMC, Coarse Grade test dust, or equivalent	....	3.0 gm/1000 gallons
Organic Fibers.................................... James H. Herron Co. #7 cotton linters or equivalent	....	1.0 gm/1000 gallons
Crude Naphthenic acid........................	....	0.03 % by volume
Standard salt water solution paragraph 4lb of QQ-M-151a Amendment 3	....	To saturate the test fluid at 60 °F and to provide 0.01% entrained salt water

4. MIL-E-5007B, 22 January 1959

Table 3 - Fuel contamination in MIL-E-5007B, Table I

Contaminant	Particle Size	Quantity
Iron Oxide .... Iron Oxide	0-5 Microns .... 5-10 Microns	28.5 gm/1000 gallons 1.5 gm/1000 gallons
Sharp silica sand .... Sharp silica sand	40-50 Mesh .... 50-100 Mesh	1.0 gm/1000 gallons 1.0 gm/1000 gallons
Prepared dirt conforming to AC Spark Plug Part No. 1543637 (coarse Arizona road dust)	Mixture as follows. 0-5 Microns (12%) 5-10 Microns (12%) 10-20 Microns (14%) 20-40 Microns (23%) 40-80 Microns (30%) 80-200 Microns (9%)	8.0 gm/1000 gallons
U.S. Standard Staple No. 7 Prime cotton linters	As ground in a No. 4 Wiley mill and screened through a 4 mm screen	1.0 gm/1000 gallons
Crude Naphthenic acid............................	....	0.03% by volume
Salt water in accordance with salt spray solution per MIL-E-5272	....	0.01% entrained

5. In 1959, an internal Navy memo advocated using the following contamination requirements for satisfactory maximum severity advanced application testing:

    1. Silica - 8.37 gm per 1000 gallons of test fluid Standardized Coarse Air Cleaner Test Dust (AC Spark Plug Div.)

    2. Iron Oxide - 12.02 gm per 1000 gallons of test fluid Ferric Oxide (Fisher I-116)

    3. Cotton Linters - 0.34 gm per 1000 gallons #7 Cotton Linters (Air Maze Co.)

    4. Free Synthetic Sea Water - 632 cm^3 per 1000 gallons of test fluid. Test fluid must be water saturated at test temperature prior to addition of free synthetic sea water. Synthetic sea water defined is Federal Test Method Std. No. 791, Method 4011.3 Procedure B.

5. MIL-E-5007C, 30 December 1965

Table 4 - Fuel contamination in MIL-E-5007C, Table I

Contaminant	Particle Size	Quantity
Iron Oxide	0-5 Microns	28.5 gm/1000 gallons
Iron Oxide	5-10 Microns	1.5 gm/1000 gallons
Sharp silica sand	300-420 Microns	1.0 gm/1000 gallons
Sharp silica sand	150-300 Microns	1.0 gm/1000 gallons
Prepared dirt conforming to AC Spark Plug Part No. 1543637 (coarse Arizona road dust)	Mixture as follows. 0-5 Microns (12%) 5-10 Microns (12%) 10-20 Microns (14%) 20-40 Microns (23%) 40-80 Microns (30%) 80-200 Microns (9%)	8.0 gm/1000 gallons
Cotton linters......................................	Staple below 7 USDA Grading Standards	1.0 gm/1000 gallons
Crude Naphthenic acid	....	0.03% by volume
Salt water prepared by dissolving salt in distilled water or other water containing not more than 200 ppm of total solids	....	0.01% entrained

6. MIL-E-5007D, 15 October 1973

Table 5 - Fuel contamination in MIL-E-5007D, Table X

Contaminant	Particle Size	Quantity
Ferroso-Ferric iron .... Oxide (Fe_3O_4, (Black color) Magnetite)	0-5 Microns.......................................	14.5 gm/1000 gallons
Ferric Iron Oxide .... (Fe_2O_3, Hematite)	0-5 Microns.......................................	14.5 gm/1000 gallons
Iron oxide	5-10 Microns.....................................	1.5 gm/1000 gallons
Crushed quartz	1000-1500 Microns...........................	0.25 gm/1000 gallons
Crushed quartz	420-1000 Microns.............................	1.75 gm/1000 gallons
Crushed quartz	300-420 Microns...............................	1.0 gm/1000 gallons
Crushed quartz	150-300 Microns...............................	1.0 gm/1000 gallons
Prepared dirt conforming to AC Spark Plug Part No. 1543637 (coarse Arizona road dust)	Mixture as follows............................. 0-5 Microns (12%) 5-10 Microns (12%) 10-20 Microns (14%) 20-40 Microns (23%) 40-80 Microns (30%) 80-200 Microns (9%)	8.0 gm/1000 gallons
Cotton linters......................................	Staple below 7 .... USDA Grading Standards SRA-AMS 180 and 251	0.1 gm/1000 gallons
Crude Naphthenic acid	....	0.03% by volume
Salt water prepared by dissolving salt in distilled water or other water containing not more than 200 ppm of total solids	4 parts by weight NaCl 96 parts by weight H_2O	0.01% by volume entrained

7. MIL-E-8593A, November 1974

Table 6 - Fuel contamination in MIL-E-8593A, Table X

Contaminant	Particle Size	Quantity
Ferroso-Ferric iron Oxide (Fe_3O_4, (Black color) Magnetite)	0-5 Microns	3.70 mg/L
Ferric Iron Oxide (Fe_2O_3, Hematite)	0-5 Microns	3.83 mg/L
Iron oxide	5-10 Microns	0.396 mg/L
Crushed quartz	1000-1500 Microns	0.0661 mg/L
Crushed quartz	420-1000 Microns	0.463 mg/L
Crushed quartz	300-420 Microns	0.264 mg/L
Crushed quartz	150-300 Microns	0.264 mg/L
Prepared dirt conforming to AC Spark Plug Part No. 1543637 (coarse Arizona road dust)	Mixture as follows 0-5 Microns (12%) 5-10 Microns (12%) 10-20 Microns (14%) 20-40 Microns (23%) 40-80 Microns (30%) 80-200 Microns (9%)	2.11 mg/L
Cotton linters	Staple below 7 USDA Grading Standards SRA-AMS 180 and 251	0.0264 mg/L
Crude Naphthenic acid		0.03% by volume
Salt water prepared by dissolving salt in distilled water or other water containing not more than 200 ppm of total solids	4 parts by weight NaCl 96 parts by weight H_2O	0.01% by volume entrained

8. AS/AV-E-8593C-2, 15 June 1982

Table 7 - Fuel contamination in AS/AV-E-8593C, Table X

Contaminant	Particle Size	Quantity
Ferroso-Ferric iron Oxide (Fe_3O_4, (Black color) Magnetite)	0-5 Microns	0.396 mg/L
Ferric Iron Oxide (Fe_2O_3, Hematite)	0-5 Microns	7.136 mg/L
Iron oxide	5-10 Microns	0.396 mg/L
Crushed quartz	1000-1500 Microns	0.0661 mg/L
Crushed quartz	420-1000 Microns	0.463 mg/L
Crushed quartz	300-420 Microns	0.264 mg/L
Crushed quartz	150-300 Microns	0.264 mg/L
Prepared dirt conforming to AC Spark Plug Part No. 1543637 (coarse Arizona road dust)	Mixture as follows 0-5 Microns (12%) 5-10 Microns (12%) 10-20 Microns (14%) 20-40 Microns (23%) 40-80 Microns (30%) 80-200 Microns (9%)	2.11 mg/L
Cotton linters	Staple below 7 USDA Grading Standards SRA-AMS 180 and 251	0.0264 mg/L
Crude Naphthenic acid		0.03% by volume
Salt water prepared by dissolving salt in distilled water or other water containing not more than 200 ppm of total solids	4 parts by weight NaCl 96 parts by weight H_2O	0.01% by volume entrained

Table 8 - AS/AV-E-8593C-2 fuel contaminant, Table XI

Contaminant	Particle Size	Quantity
Ferroso-Ferric iron Oxide (Fe_3O_4, (Black color) Magnetite)	0-5 Microns	0.25 mg/L
Ferric Iron Oxide (Fe_2O_3, Hematite)	0-5 Microns	1.25 mg/L
Prepared dirt conforming to AC Spark Plug Part No. 1543637 (coarse Arizona road dust)	Mixture as follows 0-5 Microns (12%) 5-10 Microns (12%) 10-20 Microns (14%) 20-40 Microns (23%) 40-80 Microns (30%) 80-200 Microns (9%)	0.5 mg/L
Cotton linters	Staple below 7 USDA Grading Standards SRA-AMS 180 and 251	0.005 mg/L

9. MIL-E-005007E(AS), 1 September 1983 (NAVY)

Table 9 - Fuel contamination in MIL-E-005007E(AS), Table X

Contaminant	Particle Size	Quantity
Ferroso-Ferric iron Oxide (Fe_3O_4, (Black color) Magnetite)	0-5 Microns	1.5 gm/1000 gallons
Ferric Iron Oxide (Fe_2O_3 Hematite)	0-5 Microns	27 gm/1000 gallons
Iron oxide	5-10 Microns	1.5 gm/1000 gallons
Crushed quartz	1000-1500 Microns	0.25 gm/1000 gallons
Crushed quartz	420-1000 Microns	1.75 gm/1000 gallons
Crushed quartz	300-420 Microns	1.0 gm/1000 gallons
Crushed quartz	150-300 Microns	1.0 gm/1000 gallons
Prepared dirt conforming to AC Spark Plug Part No. 1543637 (coarse Arizona road dust)	Mixture as follows 0-5 Microns (12%) 5-10 Microns (12%) 10-20 Microns (14%) 20-40 Microns (23%) 40-80 Microns (30%) 80-200 Microns (9%)	8.0 gm/1000 gallons
Cotton linters	Staple below 7 USDA Grading Standards SRA-AMS 180 and 251	0.1 gm/1000 gallons
Crude Naphthenic acid		0.03% by volume
Salt water prepared by dissolving salt in distilled water or other water containing not more than 200 ppm of total solids	4 parts by weight NaCl 96 parts by weight H_2O	0.01% by volume entrained

10. MIL-E-87231 (USAF), 30 September 1985

Table 10 - Fuel contaminants for continuous operation, Table XII, MIL-E-87231

Contaminant	Particle Size	Quantity
Ferroso-Ferric iron............................. Oxide (Fe_3O_4, (Black color) Magnetite)	0-5 Microns	1.0 gm/1000 gallons
Ferric Iron Oxide............................... (Fe_2O_3, Hematite)	0-5 Microns	5.0 gm/1000 gallons
Prepared dirt conforming to AC Spark Plug Part No. 1543637 (coarse Arizona road dust)	Mixture as follows .... 0-5 Microns (12%) 5-10 Microns (12%) 10-20 Microns (14%) 20-40 Microns (23%) 40-80 Microns (30%) 80-200 Microns (9%)	2.0 gm/1000 gallons
Cotton linters	Staple below 7.................................. USDA Grading Standards SRA-AMS 180 and 251	0.02 gm/1000 gallons

11. MIL-E-87231 (USAF), 30 September 1985

Table 11 - Fuel contaminants for equivalent mission time, MIL-E-87231, Table XIII

Contaminant	Particle Size	Quantity
Ferroso-Ferric iron............................. Oxide (Fe_3O_4, (Black color) Magnetite)	0-5 Microns	1.5 gm/1000 gallons
Ferric Iron Oxide............................... (Fe_2O_3, Hematite)	0-5 Microns.......................................	29 gm/1000 gallons
Crushed quartz.................................	1000-1500 Microns	0.25 gm/1000 gallons
Crushed quartz.................................	420-1000 Microns	1.75 gm/1000 gallons
Crushed quartz.................................	300-420 Microns	1.0 gm/1000 gallons
Crushed quartz.................................	150-300 Microns	1.0 gm/1000 gallons
Prepared dirt conforming to AC Spark Plug Part No. 1543637 (coarse Arizona road dust)	Mixture as follows. 0-5 Microns (12%) 5-10 Microns (12%) 10-20 Microns (14%) 20-40 Microns (23%) 40-80 Microns (30%) 80-200 Microns (9%)	8.0 gm/1000 gallons
Cotton linters	Staple below 7 .... USDA Grading Standards SRA-AMS 180 and 251	0.1 gm/1000 gallons
Salt water prepared by dissolving salt in distilled water or other water containing not more than 200 ppm of total solids	4 parts by weight NaCl 96 parts by weight H_2O	0.01% by volume entrained

12. MIL-F-8615D, 3 September, 1986

Table 12 - Contaminant mixture in MIL-F-8615D, Table V

Contaminant	Particle Size (Microns)	Quantity (gms per 1000 liters)
Iron Oxide	0 - 5	19
	5 - 10	1.0
Sharp Silica Sand	150 - 300	0.7
	300 - 420	0.7
Prepared dirt conforming to AC Spark Plug Part No. 1543637 (coarse Arizona road dust)	Mixture as follows: 0 - 5 (12%) 5 - 10 (12%) 10 - 20 (14%) 20 - 40 (23%) 40 - 80 (30%) 80 - 200 (9%)	5.3
Cotton linters	Staple below 7 U.S. Dept of Agriculture Grading Standards	0.07
Iron Chips	150 - 500	10
Aluminum Chips	150 - 500	10

13. JSSG-2009 (Appendix E)

Table 13 - Contaminant mixture in JSSG-2009, Appendix E

Contaminant	Contaminant Mixture Particle Size (Microns)*	Quantity (gms per 1000 liters)
Iron Oxide	0 - 5	19
	5 - 10	1.0
Sharp Silica Sand	150 - 300	0.7
	300 - 420	0.7
Prepared dirt conforming to AC Spark Plug Part No. 1543637 (coarse Arizona road dust)	Mixture as follows:	
	0 - 5 (12%)	5.3
	5 - 10 (12%)	
	10 - 20 (14%)	
	20 - 40 (23%)	
	40 - 80 (30%)	
	80 - 200 (9%)	
Cotton linters	Staple below 7 U.S. Dept of Agriculture Grading Standards	0.07
Iron Chips	150 - 500	10
Aluminum Chips	150 - 500	10
** Graphite Epoxy Composite	0 - 500**	5.2**
*** Explosion Suppressant Foam particles	1 - 100***	5-10***

* NOTE: The contamination used for testing is graded by the sieve method. Particles considerably larger than 500 microns size can pass through the sieve. Particles in the 700 to 800 micron range have been found in certified test contamination samples.

** Change from MIL-F-8615.

*** For air vehicle with fuel tank explosion suppression foam installed in the tanks.

3.2.2 Laboratory Analysis of Test Fuel Contaminant Samples

Table 14 contains the 1980 analyses of contamination materials obtained from various component manufacturers. The origin of the samples dates back to the beginning of the aircraft turbine era. An exception is sample #12 (Fe_2O_3), which was custom graded after 1975. Except for Arizona coarse and fine road dust, the desired size distribution is assumed to be linear over the specified range. Except for #1, none of the materials met the desired size distribution and there was little similarity between samples of the same material. These data revealed that because a wide variation in "standard" contaminants existed, a consistent performance baseline was not established.

Very large differences in component performance resulted from variations in contaminants, such as red iron oxides. The imported red optical polishing Fe_2O_3 oxide behaved like the natural fuel storage tank corrosion. However, a chemically equivalent, Fe_2O_3 "orange" oxide, intended for use in paint pigment, plated out on internal component surfaces producing an unrealistically severe condition that caused proven, previously qualified components to fail.

Table 14 - Variability in test contaminant samples

Arizona Fine Test Dust % by Wt.		
Size (Microns)	Spec.	Sample 1
0-5	39 ± 2	37.0
5-10	18 ± 3	14.0
10-20	16 ± 3	21.0
20-40	18 ± 3	17.0
40-80	9 ± 3	11.0
80-200	--	--

Arizona Coarse Test Dust % by Wt.					
Size (Microns)	Spec.	Sample 2	Sample 3	Sample 4	Sample 5
0-5	12 ± 2	12.5	6.8	3.3	13.0
5-10	12 ± 3	8.5	6.2	2.7	23.0
10-20	14 ± 3	14.5	9.5	4.0	35.0
20-40	23 ± 3	30.5	17.5	17.0	27.0
40-80	30 ± 3	32.5	39.0	44.0	3.0
80-200	9 ± 3	1.5	21.0	29.0	--

Table 14 - Variability in test contaminant samples (continued)

Fe_2O_3 Red Iron Oxide (Hematite) 0-5 Micron % by Wt.						
Size (Microns)	Implied	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
0-1	20.0	39.0	20.0	41.0	13.4	--
1-2	20.0	47.5	33.0	48.5	46.9	50.0
2-3	20.0	3.5	3.0	3.5	39.6	39.0
3-4	20.0	2.5	2.0	1.8	0.0	7.0
4-5	20.0	2.5	2.0	2.0	0.0	2.5
>5	--	6.5	40.0	3.5	0.0	2.5

Fe_2O_3 Red Iron Oxide (Hematite) 0-5 Micron % by Wt.		
Size (Microns)	Implied	Sample 11
0-1	20.0	--
1-2	20.0	26.0
2-3	20.0	33.0
3-4	20.0	21.0
4-5	20.0	9.0
>5	--	11.0

Fe_2O_3 Red Iron Oxide (Hematite) Custom Graded for test by commercial lab % by Wt.		
Size (Microns)	Implied	Sample 12
0-1	20.0	6.5
1-2	20.0	23.5
2-3	20.0	36.0
3-4	20.0	22.0
4-5	20.0	12.0
>5	--	0.0

Fe_3O_4 Black Iron Oxide (Magnetite) % by Wt.					
Size (Microns)	Implied	Sample 13	Sample 14	Sample 15	Sample 16
0-1	20.0	49.0	41.0	51.0	12.0
1-2	20.0	34.0	35.0	39.0	16.0
2-3	20.0	3.5	9.0	3.0	4.0
3-4	20.0	1.8	5.0	1.0	3.0
4-5	20.0	2.0	3.0	1.0	2.0
>5	--	3.5	7.0	4.5	63.0

Table 14 - Variability in test contaminant samples (continued)

Crushed Quartz 150 – 300 μm % by Wt.			
Size (Microns)	Implied	Sample 18	Sample 19
<150	0	6.0	50.0
150-200	33.3	5.0	13.7
200-300	66.6	9.0	27.3
>300	0	80.0	9.1

Crushed Quartz 300 – 420 μm % by Wt.				
Size (Microns)	Implied	Sample 20	Sample 21	Sample 22
< 300	0	45.5	90.5	17.7
300-400	83.3	17.5	6.7	36.0
400-420	16.7	7.4	1.3	7.4
> 420	0	29.6	1.5	36.4

Crushed Quartz 420 – 100 m % by Wt.		
Size (Microns)	Implied	Sample 23
< 420	0	0
420-500	10.3	0
500-600	17.2	1.2
600-700	17.2	2.4
700-800	17.2	2.2
800-900	17.2	6.4
900-1000	17.2	13.5
>1000	0	74.2

In the early 1980s, through the efforts of SAE Subcommittee AE-5B, one company equipped to fraction and grade materials became interested in furnishing certified materials. For the first time it was possible to obtain certified contaminants that actually met the intent of the requirements. A goal of these efforts was to establish an SAE Aeronautical Standard (AS) that shall describe allowable variations in the particle distribution of contaminants for all suppliers.

3.3 Endurance Test Requirements

3.3.1 Military Test Requirements

Early test requirements reflected the short expectation of turbine engine life that was based on piston engine experience. Endurance test times with contaminated fuel reflected this projected overhaul life. The following data describe significant past requirements:

a. MIL-E-5009A, 27 July 1951

    1. Accelerated Aging, 168 hours

        a. Drained and static at 160 °F

    2. Salt water, 73 hours

        a. 30 minute cyclic operation, introduce a 1 pint salt water slug to component inlet followed by 20 minutes of additional cyclic operation and a 72 hour non-operating soak

    3. High Temperature Endurance, 51 hours

        a. A static 1 hour hot soak followed by 50 hours of cyclic operation with clean hot fuel and hot ambient conditions

    4. Room Temperature Endurance, 400 hours

        a. 250 hours of cyclic operation with clean fuel, 148 hours with 8 gm fine Arizona road dust contamination/1000 gallons, 2 hours with 80 gm fine Arizona road dust contamination/1000 gallons

    5. Cold Testing, 92 hours

        a. A static 72 hour cold soak, followed by ten 2 hour periods of cyclic endurance separated by simulated starts with clean cold fuel

b. XPP-36C, 3 June 1957

    1. Accelerated Aging, 168 hours

        a. Drained and static at 160 °F

    2. High Temperature Endurance, 51 hours

        a. A static 1 hour hot soak followed by 50 hours of cyclic operation with hot (230 °F) contaminated fuel and (250 °F) ambient conditions

    3. Room Temperature Endurance, 400 hours

        a. 200 hours of cyclic operation with contaminated fuel, a 72 hour soak filled with test fuel and a final 200 hours of cyclic operation with contaminated fuel

4. Cold Testing, 92 hours

   a. A static 72 hour cold soak, followed by 20 hours of cyclic endurance while supplied with cold (35 °F) contaminated fuel

c. MIL-E-5009B, 22 January 1959

   1. Accelerated Aging, 168 hours

      a. Drained and static at 160 °F

   2. High Temperature Endurance, 100 hours

      a. 100 hours of cyclic operation with hot clean fuel and hot ambient conditions

   3. Room Temperature Endurance, 300 hours

      a. 300 hours of cyclic operation with MIL-E-5007B fuel contamination

   4. Cold Testing, 30 hours

      a. A static 10 hour cold soak, followed by ten 2 hour periods of cyclic endurance separated by simulated starts with clean cold fuel

d. MIL-E-5009C, 30 December 1965

   1. Accelerated Aging, 168 hours

      a. Drained and static at 160 °F

   2. High Temperature Endurance, 100 hours

      a. 100 hours of cyclic operation with hot clean fuel and hot ambient conditions

   3. Room Temperature Endurance, 300 hours

      a. 300 hours of cyclic operation with MIL-E-5007C fuel contamination

   4. Cold Testing, 30 hours

      a. A static 10 hour cold soak, followed by ten 2 hour periods of cyclic endurance separated by simulated starts with clean cold fuel

e. MIL-E-5007D, 15 October 1973

   1. Accelerated Aging, 168 hours

      a. Drained and static at 160 °F

   2. High Temperature Endurance, 100 hours

      a. 100 hours of cyclic operation with hot clean fuel and hot ambient conditions