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AIRCRAFT TURBINE FUEL CONTAMINATION HISTORY AND ENDURANCE TEST REQUIREMENTS

FOREWORD

Information for this document was provided by members of SAE Committee AE-5, Aerospace Fuel, Oil, and Oxidizer Systems and other government and civilian sources. It describes the evolution of 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 provides background information as to the origin and evolution of fuel contamination and endurance test requirements for aircraft turbine engine fuel system components, and the information herein 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 types. 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.

FOREWORD (Continued)

One aspect not addressed by 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 will be further complicated by the use of composites, which may produce new types of contamination for which there is very little experience base for solving.

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.

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.

The quality problem of turbine fuel supplies was further complicated by other factors. A large piston engine required 90 to 120 gal of aviation gasoline per hour, while the turbine engine used at least 500 to 800 gal 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. Since turbine fuels had a much greater affinity for water than aviation gasoline, filter separators often failed to remove all excess water. In storage tanks, a 5 μm solid particle that settled approximately 1.5 ft per hour in aviation gasoline, would settle only 4 in per hour in JP-4 fuel, and only 2 in per hour in JP-5 (Jet-A). Jet fuels also tended to loosen more rust from the walls of storage tanks than gasoline.

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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 specification to the extent specified herein. The latest issue of all SAE Technical Reports shall apply.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP749	Aircraft Engine Fuel Pump Endurance Test (Contaminated Fuel)
MAP749	Aircraft Turbine Engine Fuel System Component Endurance Test (Contaminated Fuel)

2.2 Military Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

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

2.2 (Continued):

MIL-E-8593A	Engines, Aircraft, Turboshaft and Turboprop, General Specification for
MIL-E-87231	Engines, Aircraft, Turbojet and Turbofan

2.3 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. DISCUSSION:

3.1 Events That Influenced Early Turbine Engine Specifications:

3.1.1 1940s: Two F-80's 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 US gal were found during the study. Endurance requirements were generated for MIL-E-5007A and MIL-E-5009A that called for 150 h of contaminated endurance, with 148 h at 8 gm/1000 gal and the last 2 h at 80 gm/1000 gal. The test contaminant was silica (fine Arizona road dust). A separate 50 min saltwater slug test and 72 h 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 0-200 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 gal for an entire 300 h 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 gal. 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.

3.1.4.1 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 because they were increased from 40.1 to 42.6 gm/1000 gal and the iron oxides were erroneously split 50/50 into 14.5 gm Fe3 04 magnetite and 14.5 gm Fe2 03 hematite. Three controlled-environment shutdowns were added to the engine control system test. The reason they were added could not be determined.

3.1.4.2 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.

3.1.4.2 (Continued):

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

e. The three 120 h 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.

f. 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.

a. MIL-E-5007A, 27 July 1951 and
b. MIL-E-8593, 3 September 1954

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

FIGURE 1 - Fine Arizona Road Dust

3.2.1 (Continued):

c. XPP-36C, 3 June 1957

Contaminant	Particle Size	Quantity
Iron Oxide................ James H. Rhodes & Co. #340 London Red Rouge, or equivalent	0-10 Microns.......	36 gm/1000 gal
Road Dust................. AC Div., GMC, Coarse Grade test dust, or equivalent	....	3.0 gm/1000 gal
Organic Fibers............ James H. Herron Co. #7 cotton linters or equivalent	....	1.0 gm/1000 gal
Crude Naphthenic acid......	....	0.03 % by volume
Standard salt water solution paragraph 41b of QQ-M-151a Amendment 3	....	To saturate the test fluid at 60°F and to provide 0.01% entrained salt water

FIGURE 2 - Paragraph 4.1.1 - Fuel Contamination

3.2.1 (Continued):

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

Contaminant	Particle Size	Quantity
Iron Oxide................	0-5 Microns........	28.5 gm/1000 gal
Iron Oxide................	5-10 Microns.......	1.5 gm/1000 gal
Sharp silica sand.........	40-50 Mesh.........	1.0 gm/1000 gal
Sharp silica sand.........	50-100 Mesh........	1.0 gm/1000 gal
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 gal
US 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 gal
Crude Naphthenic acid......	....	0.03 % by volume
Salt water in accordance.. with salt spray solution per MIL-E-5272	....	0.01 % entrained

FIGURE 3 - Table I Fuel Contamination

e. 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 gal of test fluid Standardized Coarse Air Cleaner Test Dust (AC Spark Plug Div.)

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

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

(4) Free Synthetic Sea Water - 632 cubic centimeters per 1000 gal 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.

3.2.1 (Continued):

(5) MIL-E-5007C, 30 December 1965

Contaminant	Particle Size	Quantity
Iron Oxide................	0-5 Microns........	28.5 gm/1000 gal
Iron Oxide................	5-10 Microns.......	1.50 gm/1000 gal
Sharp silica sand.........	300-420 Microns....	1.0 gm/1000 gal
Sharp silica sand.........	150-300 Microns....	1.0 gm/1000 gal
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 gal
Cotton linters............	Staple below 7..... USDA Grading Standards	0.1 gm/1000 gal
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

FIGURE 4 - Table I Fuel Contamination

3.2.1 (Continued):

(6) MIL-E-5007D, 15 October 1973

Contaminant	Particle Size	Quantity
Ferroso-Ferric Iron....... Oxide (Fe_3O_4, (Black color) Magnetite)	0-5 Microns............	14.5 gm/1000 gal
Ferric Iron Oxide......... (Fe_2O_3, Hematite)	0-5 Microns............	14.5 gm/1000 gal
Iron oxide................	5-10 Microns...........	1.5 gm/1000 gal
Crushed quartz............	1000-1500 Microns......	0.25 gm/1000 gal
Crushed quartz............	420-1000 Microns.......	1.75 gm/1000 gal
Crushed quartz............	300-420 Microns........	1.0 gm/1000 gal
Crushed quartz............	150-300 Microns........	1.0 gm/1000 gal
Prepared dirt conform-.... ing 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 gal
Cotton linters............	Staple below 7.......... USDA Grading Standards SRA-AMS 180 and 251	0.1 gm/1000 gal
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

FIGURE 5 - Table X Fuel Contamination

3.2.1 (Continued):

(7) MIL-E-8593A, November 1974

Contaminant	Particle Size	Quantity
erroso-Ferric Iron....... xide (Fe_3O_4, (Black col- r) Magnetite)	0-5 Microns.............	3.70 mg/L
erric 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 conform-.... ing to AC Spark Plug Part No. 1543637 (coarse Ari- zona 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

FIGURE 6 - Table X Fuel Contamination

3.2.1 (Continued):

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

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

FIGURE 7 - Table X Fuel Contamination

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

FIGURE 8 - Table XI Fuel Contaminant

3.2.1 (Continued):

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

Contaminant	Particle Size	Quantity
Ferroso-Ferric Iron....... Oxide (Fe_3O_4, (Black color) Magnetite)	0-5 Microns.............	1.5 gm/1000 gal
Ferric Iron Oxide......... (Fe_2O_3, Hematite)	0-5 Microns.............	27 gm/1000 gal
Iron oxide................	5-10 Microns............	1.5 gm/1000 gal
Crushed quartz............	1000-1500 Microns.......	0.25 gm/1000 gal
Crushed quartz............	420-1000 Microns........	1.75 gm/1000 gal
Crushed quartz............	300-420 Microns.........	1.0 gm/1000 gal
Crushed quartz............	150-300 Microns.........	1.0 gm/1000 gal
Prepared dirt conform-.... ing 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 gal
Cotton linters............	Staple below 7.......... USDA Grading Standards SRA-AMS 180 and 251	0.1 gm/1000 gal
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

FIGURE 9 - Table X Fuel Contamination

3.2.1 (Continued):

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

Contaminant	Particle Size	Quantity
Ferroso-Ferric Iron Oxide (Fe_3O_4, (Black color) Magnetite)	0-5 Microns	1.0 gm/1000 gal
Ferric Iron Oxide (Fe_2O_3, Hematite)	0-5 Microns	5.0 gm/1000 gal
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 gal
Cotton linters	Staple below 7 USDA Grading Standards SRA-AMS 180 and 251	0.02 gm/1000 gal

FIGURE 10 - Table XII Fuel Contaminants for Continuous Operation

3.2.1 (Continued):

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

Contaminant	Particle Size	Quantity
Ferroso-Ferric Iron....... Oxide (Fe_3O_4, (Black color) Magnetite)	0-5 Microns.............	1.5 gm/1000 gal
Ferric Iron Oxide......... (Fe_2O_3, Hematite)	0-5 Microns.............	29 gm/1000 gal
Crushed quartz............	1000-1500 Microns.......	0.25 gm/1000 gal
Crushed quartz............	420-1000 Microns........	1.75 gm/1000 gal
Crushed quartz............	300-420 Microns.........	1.0 gm/1000 gal
Crushed quartz............	150-300 Microns.........	1.0 gm/1000 gal
Prepared dirt conform-.... ing 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 gal
Cotton linters............	Staple below 7.......... USDA Grading Standards SRA-AMS 180 and 251	0.1 gm/1000 gal
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

FIGURE 11 - Table XIII Fuel Contaminants for Equivalent Mission Time

3.2.2 Laboratory Analysis of Test Fuel Contaminate Samples: Figure 12 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.

In the early 1980s, through the efforts of SAE Subcommittees 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.

	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	--

FIGURE 12 - Table 3.2-1

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
0-1m	0.0	--
1-2	0.0	26.0
2-3	0.0	33.0
3-4	0.0	21.0
4-5	0.0	9.0
>5	100.0	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	39.5	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

FIGURE 12 - Table 3.2-1 (Continued)

Crushed Quartz 150 - 300m
% by Wt.

Size (Microns)		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 - 420m
% by Wt.

Size (Microns)		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 - 1000m
% by Wt.

Size (Microns)		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 1980's, through the efforts of SAE Subcommittees 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.

FIGURE 12 - Table 3.2-1 (Continued)

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 h

(a) Drained and static at 160 °F

(2) Saltwater, 73 h

(a) 30 min cyclic operation, introduce a 1 pt saltwater slug to component inlet followed by 20 min of additional cyclic operation and a 72 h nonoperating soak

(3) High Temperature Endurance, 51 h

(a) A static 1 h hot soak followed by 50 h of cyclic operation with clean hot fuel and hot ambient conditions

(4) Room Temperature Endurance, 400 h

(a) 250 h of cyclic operation with clean fuel, 148 h with 8 gm fine Arizona road dust contamination/1000 gal, 2 h with 80 gm fine Arizona road dust contamination/1000 gal

(5) Cold Testing, 92 h

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

b. XPP-36C, 3 June 1957

(1) Accelerated Aging, 168 h

(a) Drained and static at 160 °F

(2) High Temperature Endurance, 51 h

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

3.3.1 (Continued):

(3) Room Temperature Endurance, 400 h

(a) 200 h of cyclic operation with contaminated fuel, a 72 h soak filled with test fuel and a final 200 h of cyclic operation with contaminated fuel

(4) Cold Testing, 92 h

(a) A static 72 h cold soak, followed by 50 h of cyclic endurance while supplied with cold (-35 °F) contaminated fuel

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

(1) Accelerated Aging, 168 h

(a) Drained and static at 160 °F

(2) High Temperature Endurance, 100 h

(a) 100 h of cyclic operation with hot clean fuel and hot ambient conditions

(3) Room Temperature Endurance, 300 h

(a) 300 h of cyclic operation with MIL-E-5007B fuel contamination

(4) Cold Testing, 30 h

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

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

(1) Accelerated Aging, 168 h

(a) Drained and static at 160 °F

(2) High Temperature Endurance, 100 h

(a) 100 h of cyclic operation with hot clean fuel and hot ambient conditions

(3) Room Temperature Endurance, 300 h

(a) 300 h of cyclic operation with MIL-E-5007C fuel contamination