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DEPARTMENT OF DEFENSE
HANDBOOK
AEROSPACE FUELS CERTIFICATION

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AMSC N/A **FSG 91GP**

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FOREWORD

1. This handbook is approved for use by the Department of the Air Force and is available for use by all Departments and Agencies of the Department of Defense.

2. This military handbook provides guidance for evaluating and certifying aviation fuels and aviation fuel additives and is consistent with MIL-HDBK-516, Airworthiness Certification Criteria.

Users of this handbook are not expected to read it cover-to-cover, but rather to use the sections of it which are relevant to their particular areas of interest and need for guidance. Most fuel certifications are likely to be for drop-in fuels, which are evaluated in comparison with the baseline fuel into which they will be "dropped." This allows some significant simplifications in the certification process (see Appendix N). Each certification or evaluation effort demands its own scope, depending on the degree of difference between the candidate fuel and the existing experience with fuels with similar properties. If some properties of the candidate fuel differ significantly from the experience, the effects of those differences should be determined in order to assess and, if necessary, mitigate the risks. The guidance in this handbook is intended to help identify the risks and address them, while allowing the certification program to be tailored to bypass activities which are not applicable or which provide little or no added value.

3. Section 2 provides a listing of applicable documents. Section 3 provides pertinent definitions and acronyms. Sections 4 and 5 provide guidance and approach for planning and conduct of a fuel certification program using a disciplined systems engineering process.

4. Appendix A provides fuel requirements decomposition and traceability. Appendix B provides recommendations for fuel properties/characteristic testing. Appendix C provides baseline aerospace fuel property information or reference thereto. Appendix D provides a material compatibility test protocol and baseline information. Appendix E provides a toxicity test protocol and baseline information. Appendix F provides the fire protection and survivability/vulnerability guidance. Appendix G provides aircraft propulsion fuels certification process. Appendix H provides aerospace fuels infrastructure requirements guidance. Appendix I provides information obtained from the various risk assessments conducted for each candidate fuel. Appendix J provides lessons learned. Appendix K provides an environmental assessment. Appendix L provides a property traceability index. Appendix M provides the details of precertification actions. Appendix N describes the streamlined program. Appendix O addresses the potential that changes in commercial fuel specifications may impact the airworthiness and operational functionality of some military systems when using commercial fuel.

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TABLE OF CONTENTS

APPENDICES

FIGURES

Number **Page**

TABLES

1. SCOPE.

1.1 Scope.

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This military handbook documents a lean, knowledge-based process to evaluate, approve, and certify fuels and fuel additives for use in military aviation-fuel using and handling equipment. This document was developed to fill the knowledge and experience gaps that currently exist when considering all aspects of the military enterprise related to fuels in a single integrated and cost effective manner instead of a system by system evaluation. This document defines an approach and process to assure that a candidate fuel is suitable for aviation, support equipment and vehicles, interchangeable in the logistics infrastructure, and meets military standards related to the environment, safety and health. Any new fuel or fuel additive will be compared to a baseline (e.g., JP-8 for kerosene fuels) in terms of safety of operation, performance, durability, survivability, material compatibility, environmental impact, safety and health. A streamlined process, specifically aimed at certifying fuels that are "drop-in" (functionally interchangeable and fully mixable) relative to the baseline, is described in Appendix N. Any new fuel found to be suitable might be listed specifically in technical orders like TO 42B-1-1-14 with a reference to the pertinent fuel specification, or an allowance may be made for this fuel in terms of specific requirements in a fuel specification like MIL-DTL-83133, the specification for JP-8. Any new fuel additive found to be suitable might be added to an already-existing Qualified Products List (QPL) for that particular type of additive or might be listed specifically in revisions to fuel specifications like MIL-DTL-83133.

While this handbook is intended primarily for certification of military aviation fuels and additives, there are situations in which the airworthiness and military functionality of some military systems may be negatively affected when using commercial jet fuel. Changes in the commercial specifications, like the addition of alternative fuel types not evaluated as a part of military fuel certification, may produce unknown risks to some military systems. Appendix O, "Evaluation of Commercial Fuel Specification Changes," describes a process to reduce those risks to an acceptable level.

1.1.1 Department of Defense energy policy.

1.1.1.1 U.S. Air Force direction and energy policy.

In 2006 the Secretary of the Air Force, the Honorable Michael Wynne, recognized the need to develop fuels from domestic alternative and unconventional resources as a way to reduce the U.S. dependence on foreign oil. This dependence is a national security issue and could potentially impact military operations in the future. Promising information was evolving on Fischer-Tropsch fuels that could be produced from domestic resources such as coal, natural gas, biomass, petroleum coke and blends of biomass with fossil sources. Fischer-Tropsch fuels produced from coal were being used by military and commercial aircraft in South Africa and demonstrating improved characteristics compared to petroleum derived fuels in studies being conducted by the U.S. Air Force, Army and Navy. To accelerate the development and pave the way for use by the U.S. Air Force, Mr. Wynne directed a U.S. Air Force Materiel Command (AFMC) team to demonstrate the use of this fuel in a manned aircraft, the B-52, in 2006. In addition, he directed an AFMC team to develop a lean, knowledge-based process for the approval and certification of this fuel as well as future generations of fuel and fuel additives.

The official Air Force Energy Program Policy Memorandum AFPM 10-1.1, 16 Jun 2009, provided specific goals and guidance which became the foundation for the establishment of this handbook and the use of the processes it describes:

Paragraph 3.4.2.4. Implementation Objectives:

- Test and certify aircraft fleet/systems on 50/50 alternative fuel blend by 2011.
  - This was a direct tasking to the Alternative Fuels Certification Office (AFCO), addressed first by the JP-8/SPK certification program.

Paragraph 4.18.7. Alternative Fuels Certification Office (AFCO):

- Execute and manage all aspects of the alternative fuel certification process across all USAF platforms (including all aircraft, future weapon systems, appropriate ground support equipment, and fuel delivery systems) in support of SECAF "Assured Fuels" initiative to decrease US dependence on foreign oil.
  - This was a direct tasking to the AFCO addressed first by the JP-8/SPK certification program and by the subsequent certification efforts of other types of alternative fuels.

AFPM 10-1-1 Acquisition & Technology Working Group B:

Paragraph B-2 Goals:

- Increase supply by utilizing alternative fuels to meet 50 percent of Air Force CONUS consumption by 2016.
  - Since the USAF does not control fuel production, this can only be influenced indirectly by fuel certification, which enables the purchase and use of alternative fuels. This opens potential market (the USAF customer) for fuel producers who may choose to enter that market by increasing the supply of alternative fuels and offering it for purchase for USAF use.
- Certify entire Air Force fleet to use synthetic fuel blend by early 2011.
  - This was a direct tasking to AFCO addressed first by the JP-8/SPK certification program.
- By 2016, be prepared to cost competitively acquire 50% of the Air Force's domestic aviation fuel requirement via an alternative fuel blend in which the alternative component is derived from domestic sources produced in a manner that is greener than fuels produced from conventional petroleum.
  - Since the USAF does not control fuel production, this can only be influenced indirectly by fuel certification, which enables the use of alternative fuels, which may or may not be available and which may or may not be purchased for USAF use, if available, depending on price and other legal restrictions.

Paragraph B-3 Objectives:

B-3.1. Alternative fuels:

- Flight test F-T and JP-8 blend.
  - This is addressed by the multiple flights using JP-8/SPK which were part of its certification effort.
- Certify entire Air Force aircraft fleet on F-T and JP-8 blend by 2011.
  - This was a direct tasking to AFCO addressed by the JP-8/SPK certification program.

- Evaluate biofuels for CO_2 reduction in accordance with the Energy Independence and Security Act of 2007 (reference [h]).
  - This is part of the AFRL responsibility before a fuel becomes a candidate for certification.
- Evaluate pure synthetic fuels in accordance with the Energy Independence and Security Act of 2007.
  - This is part of the AFRL responsibility before a fuel becomes a candidate for certification.
- Evaluate infrastructure and vehicles and ground support equipment.
  - This is a standard part of the certification process addressed in Appendix B herein.

B-3.7. Alternative fuel:

- In order to support the primary goal of being prepared to cost competitively acquire 50% of the Air Force's domestic aviation fuel requirement via an alternative fuel blend in which the alternative component is derived from domestic sources produced in a manner that is greener than fuels produced from conventional petroleum by 2016. By 2011, the Air Force will have certified the entire inventory of aircraft, vehicles, ground support equipment, and fuels logistics infrastructure for operations with a 50/50 synthetic fuel blend.
  - This was directly addressed by the JP-8/SPK certification program.
- To execute the fleet certification process, an Alternative Fuels Certification Office (AFCO) located within the Aeronautical Systems Center (ASC) at Wright-Patterson AFB has been chartered to staff and manage elements associated with timelines, budget and certification requirements
  - This has been accomplished.
- Since the intent is to initially use a standard 50/50 synthetic iso-paraffinic/JP-8 blend for all certification testing, under Executive Agency charter, the Defense Energy Support Center (DESC) will capitalize the 50/50 blend, which will be named as SJ8 (synthetic jet [JP] 8 product code)
  - According to the Defense Logistics Agency (DLA Energy) personnel, capitalization would not occur until SJ8 was out of the RDT&E phase (when bases began receiving SJ8 operationally).
- Per Air Force Energy Program Policy Memorandum AFPM 10-1.1, B-3.7 "A collaborative effort will be maintained with the Federal Aviation Administration and the commercial aviation industry through the Commercial Aviation Alternative Fuels Initiative (CAAFI) to define a synthetic fuels standard specification by FY09"
  - This effort was an integral part of the JP-8/SPK certification process used in large part to accomplish the certification of the USAF Commercial Derivative Aircraft.

1.1.1.2 U.S. Navy energy policy TBD

1.1.1.3 U.S. Army energy policy TBD

1.1.2 The certification process.

The current process for certifying fuel requires each weapon system manager to independently determine if the fuel or fuel additive is fit for purpose, meets operational, performance, durability, safety and other weapon system considerations, and then document the suitability for use as a primary, alternate or emergency fuel. Lessons learned from the conversion from JP-4 to JP-8, implementation of the thermal stability improving "+100" additive and the use of Russian TS-1 provided the basis to develop a lean knowledge-based process to replace the current process. In addition, the current process emphasis for fuels has primarily focused on aviation with minimal focus on other key elements of the military enterprise such as logistics, support equipment and vehicles, environment, health and safety. A new process that includes all military equipment destined to use the fuel or additive would allow a more cost effective and streamlined approach to field a fuel or a fuel additive. The process that is documented in this handbook does not replace or supplant the role of the weapon system manager. Within this handbook, the term System Manager (SM) will be used to reference the person(s) that has (have) ultimate responsibility for approving fuel or fuel additives for military process(es), weapon system, piece(s) of equipment or logistics infrastructure for which they are responsible. The term System Manager will include not only weapon system or equipment managers, but persons responsible for environmental, operational, safety, health or logistics processes related to fuels. Ultimately each SM will need to make the final determination of suitability for use; however this standardized process provides the key technical data needed for System Manager evaluations. The intent is to continuously improve the fidelity of this handbook with lessons learned during the certification of fuels or fuel additives, using Fisher-Tropsch fuel blends as the initial validation. Since most military-specified fuels are used across all services, there is significant advantage in the services collaborating by sharing the planning, expenses, and results of certification-related testing and developing the content of the resulting specification(s).

1.1.3 Candidate fuel characteristics.

This handbook is for fuel candidates or fuel additives having the general characteristics of a kerosene fuel that meets safety of flight, performance, durability and operational characteristics comparable to the baseline fuel (example JP-8). The intent is to compare the new fuel or fuel additive to the baseline fuel and assess the potential to qualify the new fuel to the requirements of an existing fuel as a "drop in" (e.g., the MIL-DTL-83133 specification for JP-8) or the potential to qualify the fuel to a new grade definition (nomenclature and specification). To do this requires verifying and documenting the suitability of the fuel for use in affected weapon systems as either a primary fuel, alternate fuel, or emergency fuel. To warrant consideration, the candidate fuel or fuel additive will meet one or more of the following requirements: 1) logistical availability in an expeditionary operation or 2) improved weapon system performance, durability, operational characteristics, logistics, or cost, or 3) be produced from an advantageous alternative or unconventional (non-petroleum) and preferably renewable resource. Candidate fuels or fuel additives will demonstrate technical maturity in the form of test reports, technical data, property lists, documentation on the resource and processing used to make the fuel or additive, and information on the environmental, safety and health aspects. In addition, information on the economic viability of the fuel or additive will be provided. This information should include cost estimates, volume of fuel or additive that can be produced, any requirements for special handling or logistics, environmental impacts, and general production information. If the entrance criteria to initiate an evaluation that will lead to the approval and certification of the fuel or fuel additive are met, then the handbook process will be used to provide the data set that includes requirements from all aspects of the affected military enterprise, which will be used by the SMs for the approval/certification process. As lessons are learned during the execution of the process, they will be used to update this handbook.

1.2 Baseline fuels.

The early pioneers in gas turbine development, Whittle in England and Von Ohain in Germany, faced a wide variety of options in choosing a fuel for gas turbines. Whittle had considered diesel fuel, but ended up choosing illuminating kerosene because of an expected requirement for a lower freezing point than that available with diesel. In contrast, Von Ohain originally demonstrated his turbine engine with hydrogen, but vehicle considerations led to a switch to liquid fuel. The world's first turbojet-powered flight was made on 27 August 1939 in a Heinkel 178 aircraft burning aviation gasoline. However, most of the jet engines developed before the end of World War II utilized conventional kerosene as a fuel. The first jet fuel specification was the Directorate of Engine Research and Development 2482 (DERD 2482), published in England in 1947.

1.2.1 Fundamental fuel characteristics.

As engines and specifications developed, it became apparent that several fuel properties were fundamental to bounding the envelope of jet fuel characteristics. High-altitude operation meant fuel freezing point required attention. However, the lower the freezing point, the lower the fraction of crude oil that was suitable, therefore, freezing point had to be balanced against availability. Higher fuel volatility/vapor pressure aided vaporization-controlled engine performance requirements such as altitude relight, which had to be traded against boil-off and entrainment losses from fuel tanks at altitude (as well as safety concerns from explosive mixtures in tank vapor spaces.) In the United States, JP-1, JP-2, and JP-3 were (ultimately unsuccessful) attempts to balance the conflicting requirements of volatility, freezing point, and availability/cost. Two fuels emerged in the late 1940s and early 1950s from this chaotic situation: a wide-cut naphtha/ kerosene mixture called JP-4 in the United States (MIL-F-5624 in 1950) and a kerosene fuel with a -50°C (-58°F) freezing point (DERD-2494 in England and Jet A-1 in ASTM D-1655 in the United States). This freezing point was arrived at through a significant research effort. ASTM D-1655 also specified Jet A with a –40°C (-40°F) freezing point. The Jet A-1 freezing point was changed from -50°C to -47°C (-58°F to -53°F) in the late 1970s to increase the number of petroleum feedstocks that could be used to manufacture the fuel and thus increase availability and reduce cost. The differences between the major aviation gas turbine fuels are summarized in Table I. Civil aviation currently uses Jet A-1 (or its equivalent) throughout the world. This includes the Former Soviet Union (FSU) which has made Jet A-1 available since the year 2004 under their GOST R52050 specification. However, domestic carriers in the United States, use Jet A to reduce cost. The freezing point requirements in the specification is often the most difficult (and costly) for the refiner to meet. Land-based Air Force aircraft primarily used JP-4 until converting to JP-8 in the 1980s. JP-8 (MIL-DTL-83133) is essentially Jet A-1 with three military-specified additives. The conversion to JP-8 occurred primarily to improve the safety of aircraft, although the "single fuel for the battlefield" concept (and the similarity of jet fuel to diesel fuel) is centered on the use of aviation kerosene in all U.S. Air Force and U.S. Army aircraft, support equipment and vehicles. A similar process is occurring in the U.S. Navy, where the large variety of liquid fuels has shrunk down to just two, JP-5 (for aircraft) and F-76 diesel for all other liquid fuel requirements. The Navy also uses JP-8 in many Naval Air Stations on land. Logistical considerations may drive commercial jet fuel to be the single battlefield fuel in the future. Currently, the military consumes about 10% of the jet fuel produced in the United States, so the commercial market is dominant.

1.2.2 Jet fuel evolution.

The history of the evolution of conventional, widely available jet fuels from the late 1950s to the present is mainly the story of the evolution of test methods and fuel additives to maintain the integrity of the jet fuel supply and to improve safety and correct operational problems. Specialty fuels were developed for various applications throughout the second half of the 20th century. In the early 1950s, JP-5 (included in MIL-F-5624) was developed. JP-5 is a high-flash-point (minimum 60°C/140°F) aviation kerosene used onboard U.S. Navy ships to enhance safety. The development of higher Mach aircraft led to several specialty fuels. As flight velocity increases, aerodynamic heating leads to larger amounts of heat being rejected to the fuel, both in the tanks and in the engine, leading to vapor pressure and thermal stability concerns. The cutoff point between the use of conventional Jet A-1/JP-8 fuels and specially produced fuels is between Mach 2.2 and 3. Thus, the Mach 2.2 Concorde uses Jet A-1, whereas the Mach 3 XB-70 and the Mach 3 SR-71 used specialty fuels. JP-6 (MIL-F-25656) was a low-volatility kerosene developed for the Mach 2 XB-70. The Mach 3 SR-71 required JP-7 (MIL-T-38219), a low-volatility/high thermal stability, highly processed (low sulfur and aromatics) kerosene. The U-2 high-altitude reconnaissance aircraft required both improved thermal stability and lower freezing point in its fuel (JP-TS, MIL-T-25524) because of its high-altitude, long-duration cruise. These specialty fuels gave higher performance than conventional aviation kerosenes, at the expense of higher fuel and logistical costs (JP-7 and JP-TS are roughly three times the cost of JP-8 and Jet A-1). The accepted operational temperature limits of these various fuels are approximately 163°C (325°F) for Jet A/Jet A-1/JP-8/JP-5, 219°C (425°F) for JP-TS, and 288°C (550°F) for JP-7. These temperatures are the maximum temperature achieved by the fuel, typically in the engine nozzles. The accepted limit for gas turbine operation is approximately Mach 4.

1.2.3 Russian fuel parallel evolution.

Russian jet fuels underwent a parallel evolution throughout this period. In most areas, current Russian fuels TS-1, RT, and Russian specifications (GOST 10227) are interchangeable with Jet A-1/JP-8, with the exception of the US additive package listed in the MIL-DTL-83133. The main difference between fuels TS-1 and RT is in the area of thermal stability: TS-1 is a straight-run fuel, whereas RT is hydrotreated. By comparison with Jet A-1/JP-8, TS-1 and RT are typically lighter (have a lower initial boiling point and 10% recovery point in distillation) and have a correspondingly lower flash point and freezing point. Thus, worldwide there are three major specifications in civil use: ASTM D1655, British Defence Standard (Def Stan) 91-91, (successor to DERD 2494), (See A.3.3) and Russian GOST 10227-86. International oil companies have created the "Joint Check List" to standardize jet fuel deliveries worldwide under Jet A-1/Def Stan 91-91. The International Air Transport Association has also issued guidance material for its members codifying the Jet A/Jet A-1/TS-1 specifications. Two specialty Russian fuels are specified in GOST 12308: T-8V, a higher density/higher flash-point kerosene and T-6, a high-density kerosene (specific gravity 0.84 versus 0.8 for Jet A-1/JP-8), which has no commercial or military counterpart in Europe or the United States. U.S. Air Force programs in the 1980s demonstrated the production of fuels similar to T-6, but no specification was published in the absence of user requirements. Historically, flight characteristics have driven changes in aviation fuels. Now logistics are also driving the introduction of alternatives. This establishes the need to document fuel property requirements for the future developer to understand why all properties are important.

TABLE I. Summary of major jet fuel characteristics (additives explained in 1.4).

	JP-8	Jet A	Jet A-1	TS-1
Flash point (min), °C (°F)	38 (100)	38 (100)	38 (100)	28 (82)
Freezing point (max), °C (°F)	-47 (-53)	-40 (-40)	-47 (-53)	n/a*
Additives	CI/LI, FSII, SDA	None	SDA	n/a**

* Russian freezing point test method differs from other fuels, but has been found to meet the -47 °C (-53°F) spec in all cases.

** Russian additives are chemically different than their Western counterparts, although they fill the same roles (icing inhibitor, static dissipater, etc.)

1.3 Alternative fuels.

The term "alternative fuels," for the subject of this handbook, is used to differentiate them from kerosene-type jet fuels produced from crude oil (petroleum). Alternative fuels are liquid fuels (synthetic or otherwise) produced from non-crude oil sources such as coal, natural gas, biomass, etc. The meaning of the phrase "alternative fuel" can vary depending on who is using it. In some scientific circles, alternative fuels refer to the use of hydrogen or ethanol as a fuel. Alternative fuels, the subject of this handbook, are intended to be used in the same way as the baseline fuels in military equipment. Therefore, an alternative fuel should emulate the baseline fuel's properties to increase its fungibility within military assets. In contrast, the term "alternate fuel" (often incorrectly used to mean "alternative fuel") has a specific and very different meaning in military aviation. An "alternate fuel" for a system is one whose use is allowed in the system, but it is not the one for which the system was designed (the "primary fuel"), and its use may bring with it a different set of operating limits, performance characteristics, and maintenance requirements. Primary, alternate, and emergency fuels and their associated requirements for individual systems are identified in their operations and maintenance manuals (technical orders).

1.3.1 Fuel source specification.

The JP-8 specification, MIL-DTL-83133E, effective from 01 April 1999 until 11 April 2008, Section 3.1, and its predecessors limited the source of the feedstock that could be used to make JP-8:

> "Fuel supplied under this specification shall be refined hydrocarbon distillate fuel oils containing additives in accordance with Section 3.3. The feedstock from which the fuel is refined shall be crude oils derived from petroleum, tar sands, oil shale, or mixtures thereof."

Earlier versions of Def Stan 91-91 had similar language for Jet A-1:

> "The fuel shall consist wholly of hydrocarbon compounds derived from conventional sources including crude oil, natural gas liquid condensates, heavy oil, oil shale and oil sands, and qualified additives as listed in Annex A."

Thus, jet fuel purchased to MIL-DTL-83133E could (and did) contain molecules from conventional crude oil (petroleum) as well as components derived from Canadian oil sands. The properties of jet fuels derived from petroleum, oil/tar sands, and shale are somewhat different, but are similar enough to be lumped together in the specification. In the U.S., oil shale has not been a source of jet fuel components, but that could change. Subsequent changes like MIL-DTL-83133H, amendment 2, dated 24 December 2013, have allowed additional sources, like Synthesized Paraffinic Kerosenes derived from Hydroprocessed Esters and Fatty Acids (HEFA). Similarly Def Stan 91-91 had changed, primarily to remain consistent with what is allowed by the ASTM jet fuel specifications.

1.3.2 Potential sources for the Fischer-Tropsch process.

MIL-DTL-83133F, dated 11 April 2008, allowed for the use of blending material derived from a Fischer–Tropsch process, independent of the F-T source materials, which has potential to enter the jet fuel market. Techniques such as "indirect" liquefaction, the Fischer-Tropsch process, or "direct" liquefaction can yield hydrocarbon fuel components similar to current petroleum based jet fuels. The Fischer-Tropsch (F-T) process converts synthesis gas, a mixture of carbon monoxide and hydrogen, into a "wax" - a collection of long chain paraffinic hydrocarbon molecules. With some further changes by such processes as hydrocracking and isomerization, hydrocarbons suitable for use in jet fuel are produced. Coal and natural gas are converted into the F-T feedstock synthesis gas through "gasification". The Fischer-Tropsch process was used by the Germans during World War II to produce liquid fuels from coal, and has been used since the 1970's in South Africa to produce liquid fuels also from coal. In several countries which have a surplus of natural gas, F-T plants are producing liquid fuels and chemicals from the available natural gas. Fischer-Tropsch fuels are composed almost entirely of n- and iso-paraffins, and are absent the cyclo-paraffins and aromatics found in petroleum-derived fuels. Fuels produced by direct liquefaction of coal preserve the ring structure of coal, but require extensive hydrotreatment to meet jet fuel specifications. Thus, a jet fuel derived from direct liquefaction is composed primarily of cyclo-paraffins. Table II compares the chemical composition among average petroleum-based, F-T, and coal liquefaction jet fuels.

TABLE II. Fuel compositional analysis via ASTM D2425.

	World survey average jet fuel, vol %	**F-T Jet A-1**	**Jet fuel from coal liquefaction**
n- + iso-paraffins	58.78	99.7	0.6
monocycloparaffins	10.89	<0.2	46.4
dicycloparaffins	9.25	<0.2	47.0
tricycloparaffins	1.08	<0.2	4.6
alkyl benzenes	13.36	<0.2	0.3
indanes+tetralins	4.9	<0.2	1.1
naphthalene	0.13	<0.2	<0.2
substituted naphthalenes	1.55	<0.2	<0.2

1.3.3 Applicable alternative fuels.

The alternative fuels applicable to this handbook are not limited to sources derived from a fossil fuel. Research has investigated biofuels created from items such as biomass, animal fat, vegetable oil, switch grass, algae, etc. as potential liquid fuel sources. Biofuels may be gasified into carbon monoxide and hydrogen. These gas streams would then follow a Fischer-Tropsch process leading to a jet fuel. A different approach starts with bio-oils which are hydrotreated thereby creating long, unbranched hydrocarbons. These hydrocarbon chains are fed into an isomerization reactor which reforms long, unbranched hydrocarbons into the various combinations of branched, unbranched, and ringed hydrocarbons comprising jet fuels. These two processes for biofuels represent a small fraction of the ideas under investigation. As with coal liquefaction and F-T processing of natural gas, alternative fuels from biological sources are different from petroleum derived jet fuels. These differences come in the form of chemical composition and contamination which effect the fuel's physical properties and thereby its performance in engines. Due to the environmental benefits and domestic location of biofuels, the military cannot ignore their potential as alternative fuels.

1.4 Fuel Additives.

1.4.1 JP-8 Additives.

1.4.1.1 Fuel System Icing Inhibitor (FSII).

Ethylene Glycol Monomethyl Ether (EGME) was the original FSII, introduced to inhibit free water from freezing after a 1958 aircraft incident. The first FSII (MIL-I-27686) formulation consisted of 87.3% EGME and 12.7% glycerol. The initial use of glycerol was to protect the sealants and coatings used in fuel tanks from attack by EGME. Field experience with MIL-I-27686 indicated it was causing problems due to glycerol not completely dissolving in the fuel. The specification was changed several times reducing the concentration of glycerol before finally removing it completely. EGME was later replaced with Diethylene Glycol Monomethyl Ether (DiEGME) due to carcinogenic concerns with EGME and is currently (2012) the only FSII (MIL-DTL-85470) listed in the MIL-DTL-83133 specification. A Study was completed to determine the freezing effectiveness and biostat efficiency of DiEGME at lower concentrations. These new limits have been incorporated in MIL-DTL-83133. Additional work is underway to identify a FSII less aggressive toward fuel tank sealants and coating. Interestingly, due to DiEGME being widely accepted as a biostat, any changes to the concentration or type of icing inhibitor will need to address the effects of same on micro-organisms.

1.4.1.2 Static Dissipater Additives (SDA).

Static electrical charge can be generated when unlike surfaces move across one another, e.g., a glass rod and a wool cloth. Similarly, when jet fuel (a relatively poor conductor) moves through a hose, valve, or filter, a static charge can be created. If the charge does not dissipate more rapidly than it is produced, a discharge in the form of a spark could be experienced. The energy of this spark may induce an explosion if the fuel vapor and air mixture is within flammability limits. The rate of charge dissipation is proportional to the electrical conductivity of the fuel. Military jet fuels require the use of a conductivity improver additive - Static Dissipater Additive (SDA). The SDA does not prevent charge generation but, enhances the rate of charge dissipation by increasing fuel conductivity. Currently, the only static dissipater available for use in aviation fuel is Innospec Fuel Specialties, LLC Stadis 450.

1.4.1.3 Corrosion Inhibitor/Lubricity Improver (CI/LI).

CI/LI additives are primarily composed of fatty acids and/or their derivatives. They were originally introduced to provide pipelines with corrosion protection for direct shipment of fuel to government facilities. In 1954 the USAF issued the Inhibitor, Corrosion, Fuel Soluble specification (MIL-I-25017) and has maintained a Qualified Product List of approved additive manufacturers/formulations. The original MIL-I-25017 requirements were that "the inhibitor (a) must protect ferrous metals when added to fuels in low concentrations, (b) must not be extracted from the fuel by water that might be present with the fuel, (c) must be soluble in all Avgas and jet fuels of interest, (d) must be low in ash, (e) must be compatible with all other approved fuel additives, (f) must not adversely affect the fuel performance in the aircraft." The first US specification mandating use of MIL-I-25017 was MIL-T-5624 Revision C in May 1955. In 1965 the mandatory use of MIL-I-25017 corrosion inhibitor (CI) was deleted but, was soon reinstated after occurrences of aircraft engine fuel control malfunctions were experienced and attributed to the CI removal. It was determined that MIL-I-25017 additives increased the lubricating properties of the fuel itself. When MIL-I-25017 was later revised (MIL-I-25017E, dated 15 June 1989), the title was changed to "Inhibitor, Corrosion/Lubricity Improver, Fuel Soluble (Metric)" to reflect that the material was both a corrosion inhibitor and a lubricity improver.

1.4.1.4 Metal Deactivator Additive (MDA).

Even in trace quantities, active metals such as copper or zinc may degrade thermal oxidative stability of aviation fuel by catalytic action. The function of metal deactivators is to form stable complexes with such metals so as to inhibit their ability to promote the formation of deposits (fuel oxidation). Currently, the only metal deactivator additive approved for use in MIL-DTL-83133 is N, N'-disalicylidene-1, 2-propane diamine. The allowed concentration of active material used on initial batching of fuel at the refinery is limited to 2.0 mg/L. Cumulative addition of metal deactivator is capped at 5.7 mg/L if fuel is re-treated and should only be permitted if the fuel is determined to contain active metals. MDA cannot be used in military jet fuel unless the supplier has obtained written consent from the procuring activity and end user.

1.4.1.5 Antioxidants.

Reactive compounds in aviation turbine fuel respond to oxygen from the small amount of dissolved air in fuel setting off a chain of oxidation reactions that result in the formation of peroxides, soluble gums, and insoluble particulates. Antioxidants interrupt this chain of reactions when present before the fuel is exposed to the atmosphere. When fuel is hydrogen treated, the natural antioxidants found in straight run fuels are removed resulting in a less stable fuel. For this reason, an approved antioxidant will be added (during rundown into feed/batch tankage) to all JP-5 jet fuel and all JP-8 jet fuel containing blending stocks that have been hydrogen treated.

1.4.1.6 Thermal Oxidative Stability Improver (+100) Additive.

In the late 1980's the Air Force Research Laboratory (AFRL) initiated an effort to improve the thermal stability of USAF used jet fuel through the use of additives. After several years of evaluating hundreds of additives, one single additive was selected. The additive selected is currently manufactured by GE Betz (formerly BetzDearborn) and is designated, for DoD applications, as Spec-Aid® 8Q462. It is also available commercially in the U.S. as Turboline FS100 and overseas as Aeroshell Performance Additive 101 (APA101). This additive improved thermal stability of jet fuel by up to 100°F (38°C) – increasing fuel thermal heat sink by 50% when used at a dosage rate of 256 mg/L. A second approved +100 additive, BASF KeroJet™ 100, was approved for use and added to MIL-DTL-83133 in 2013. The additive has since been used in military-purchased Jet A fuel as well.

1.4.1.6.1 Extensive testing performed.

Since its introduction to the field in 1994, hundreds of thousands of flight hours have been logged using this additive in JP-8 with no flight safety or performance issues. Extensive testing has been done on the additive and it has been found to be fully compatible with materials used in aircraft systems—both airframe and engine—and it has been shown to be of no impact to flight operations—including altitude relights and fuel gauging systems. Toxicologically, the additive is no more hazardous than the baseline fuel.

1.4.1.6.2 Equivalent or reduced maintenance.

Many studies have been conducted to determine if the additive has any impact on aircraft engine maintenance. In most cases, the impact has been that maintenance due to coking and fouling where the additive is in use has been reduced. The amount of the reduction is dependent upon the engine, local maintenance procedures and policies and the flight mission. There have also been documented instances when use of the additive was terminated for one reason or another and after additive use was discontinued, engine maintenance due to coking and fouling increased. When use of the additive was resumed, maintenance requirements were reduced. There have been no instances where the additive had a negative impact on flight operability or maintenance. When initially fielded, there was concern that the additive's detergent/dispersant elements might cause filter/coalescer problems but recent tests conducted at Southwest Research Institute (SwRI®) have shown that Spec-Aid® 8Q462 is no worse than the baseline fuel for filter coalescers meeting API/IP 1581 5th Edition specifications. Current AF policy regarding handling of JP-8+100 is that it can be returned to bulk fuel storage in a 1:10 ratio.

1.5 Alternate Fuels

Alternate fuels are not a specific fuel type, but rather a designation within specific system operating manuals (technical orders) which authorize the use of specific fuel grades in that system in addition to the "primary" fuel (normally the most commonly used fuel in the system and often the one to which the system was certified to). The authorized alternate fuels may carry with them different operating limits of which the crew needs to be aware when the system is using this fuel. A good example of primary and alternate fuels in military systems are the primary JP-8 and alternates like commercial Jet A or Jet A-1 fuel. Jet A fuel, having a higher freezing point, normally limits the outside air temperature at which an aircraft is allowed to operate to a higher value, consistent with that higher freezing point. The methodology described in this handbook can be used for determining such different operating limits of a specific system and establishing and certifying the system to use the candidate fuel with the designation of "alternate fuel."

2. APPLICABLE DOCUMENTS.

2.1 General.

The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2000	Air System
JSSG-2001	Air Vehicle
JSSG-2006	Aircraft Structures
JSSG-2008	Vehicle Control and Management System (VCMS)
JSSG-2009	Air Vehicle Subsystems
JSSG-2010	Crew Systems
MIL-DTL-83133	Turbine Fuel, Aviation, Kerosene Type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37)

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-882	System Safety
MIL-STD-3004	Quality Assurance/Surveillance for Fuels, Lubricants and Related Products

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-515	Weapon System Integrity Guide (WSIG)
MIL-HDBK-516	Airworthiness Certification Criteria

(Copies of these documents are available on line at http://quicksearch.dla.mil/.)

(Copies of the Joint Service Specifications Guides Compact Disc (JSSG CD) are available from, Engineering.Standards@us.af.mil)

2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein.

UNITED STATES AIR FORCE POLICY DIRECTIVES

AFPD 62-6	USAF Airworthiness

(Copies of this Directive are available at http://static.e-publishing.af.mil/production/1/saf_aq/publication/afpd62-6/afpd62-6.pdf.)

UNITED STATES AIR FORCE TECHNICAL ORDER (TO)

TO 42B1-1-1 Fuels for USAF Piston and Turbine Support Equipment and Administrative Vehicles, USAF

(Copies of the above documents can be requested at https://www.my.af.mil/etims/ETIMS/index.jsp.)

2.3 Non-Government publications.

The following document forms a part of this document to the extent specified herein.

FEDERAL AGENCY ON TECHNICAL REGULATING AND METROLOGY

GOST 10227-86 Jet Fuels

(Copies of this document may be obtained at http://global.ihs.com/doc_detail.cfm?document_name=GOST%2010227 .)

3. DEFINITIONS.

A

Acceptable Products: An acceptable product is one which can be used in place of another product for extended periods without technical advice.

Additives**:** Compounds used in small quantities to impart new properties to a product or to improve a property which it already possesses - for example, mixed tertiary butylphenols when added to a fuel to improve its resistance to oxidation.

Airworthiness: The property of a particular air system configuration to safely attain, sustain, and terminate flight in accordance with the approved usage and limits.

Alternative Fuels: An alternative fuel is any fuel determined to be substantially not petroleum, (e.g., non-crude oil sources for liquid hydrocarbons), that yields energy security benefits and environmental benefits. The term "alternative" fuels, as defined in this handbook, is used to differentiate between kerosene-type jet fuels produced from crude oil and similar fuels produced from alternative sources such as coal, natural gas or biomass.

Alternative Fuels Certification Office (AFCO): The organization initially chartered to perform the Fuel Certification Organization (FCO) functions, with the objective of certifying the first two alternative fuels: the Fischer-Tropsch and Hydroprocessed Renewable Jet fuel blends.

Alternate Fuel: An alternate fuel is one on which the air vehicle can be flown without significant negative impact but which can have different operating limits and could have long-term durability or maintainability impact if used for continuous operation (multiple flights). Alternate fuels are normally used only on an occasional or intermittent basis. Use of an alternate fuel should cause no significant adverse effect on the air vehicle mission(s).

Approved Fuel: A fuel(s) approved for use in an aircraft with restrictions or limitations defined, if any.

B

Baseline Fuel: Baseline fuel is defined as a kerosene type turbine fuel that established this handbook's pass/fail criteria to which all candidate fuels will be compared. JP-8 in accordance with MIL-DTL-83133 was chosen as the baseline fuel for the handbook as of April 2007.

Biofuel: Fuel composed of or produce from biological raw materials.

Blending: Blending refers to the procedures by which predetermined quantities of two or more similar products are homogenously mixed to upgrade one of the products or to produce an intermediate grade or quality. The term is also used to define the injection of additives, such as corrosion or icing inhibitors, into fuels.

C

Certified Fuel: Fuel(s) first approved (to a standard) for use in a system certification for flight.

Clean (Clear) and Bright: Clean is the absence of visible solids, a cloud, a haze, an emulsion, or free water in the product. Bright is the sparkle of clean, dry product in transmitted light.

Commingling: Commingling is the mixing of two or more products of different ownership or grade.

D

Decomposition of Requirements: For this handbook, requirements are broken down into parts from requirements documents until the relevant fuel properties/characteristics are identified.

Derived Requirements: Derived requirements trace back to a driving requirement. For this handbook, the derived requirements are the relevant fuel properties/characteristics, and/or interfaces with other systems and other elements.

Drop-in Fuel: A fuel which is functionally interchangeable and fully mixable with the baseline fuel, meeting the baseline fuel's performance and quality specification requirements. NOTE: if the drop-in fuel is defined in the specification as a blend (e.g., not more than 50% Fischer-Tropsch Synthetic Paraffinic Kerosene [FT-SPK] with the balance being petroleum-derived fuel), it is the blend, not "synthetic" blending component alone (e.g., the FT-SPK), that is functionally interchangeable and fully mixable.

E

Emergency Substitute: A product which may be used in an emergency only, in place of another product, after local exploration of adequacy of the product, using locally available technical manuals and personnel. However, technical advice will be sought from the nation's service, as soon as possible after the event as to whether or how long; the emergency substitute could safely be retained in use.

Emergency Fuel: A fuel which may cause significant damage to the engine or other systems; therefore, its use is to be limited to one flight. The applicable aircraft flight manual or system manager should be consulted regarding operating restrictions and post flight maintenance actions necessary when using an emergency fuel. Examples of conditions that might warrant use of emergency fuels

- Accomplishing an Important Military Mission
- Countering Enemy Actions
- Emergency Evacuation Flights
- Emergency Aerial Refueling

Entrance Criteria: Key information required to make a determination whether to initiate the fuel certification process. All fuel candidates will meet the general characteristics of a kerosene fuel that meets safety, performance, durability and operational characteristics comparable to the baseline fuel.

F

Finish System: Any organic coating (e.g., Corrosion inhibiting) or other surface preparation (e.g., Acid anodizing) that could exist on equipment.

Fit for Purpose: A classification of property types which refers to properties inherent of a fuel that are not controlled by specification.

FRAC Tank: mobile steel storage tanks used to hold liquids. Typically used for fracing wells in the oil and gas industry

Fuel Certification Organization (FCO): The government team responsible for the implementation and coordination of the fuel certification process. This is the relatively small management organization, 1) either formally chartered (via Program Management Directive or other similar documents) and specifically funded for fuel certification-related activities or 2) ad hoc, made up of personnel from affected or interested organizations (e.g., Air Force Life Cycle Management Center [AFLCMC] engineering, AFLCMC system program offices, Air Force Research Laboratory, Air Force Petroleum Agency, members from the US Army Aviation, members from the US Navy NAVAIR) who, as a team, perform the FCO functions. Those functions include the following: arranging for the purchase of fuel through DLA Energy; arranging for segregated storage, handling, and transportation of test fuel; arranging for component , subsystem, and system testing at government and contractor facilities; collecting, storing, and disseminating relevant data for use by affected organizations and system managers; developing specifications and specification content to define the fuel(s) being evaluated; collaborating with commercial aviation's fuel specification development efforts; maintaining and updating the content of MIL-HDBK-510. In the past, the formally chartered Air Force organization was known as the Alternative Fuels Certification Office (AFCO), with office symbols 77AESW/LF, followed by ASC/WNN, and the Alternative Fuels Certification Division (AFCD), with office symbol AFLCMC/WNN.

Fuel Evaluation Organization: The government team responsible for the airworthiness and functional evaluation of a fuel which is not intended to be certified as military fuel in a US military specification. Its function and makeup is similar to that of the FCO, but its goal is limited to determining functional equivalence of the candidate fuel with a baseline fuel or obtaining data needed to identify whether and what new operating limits need to be applied when using the candidate fuel.

Fuel Holdup: A layer of frozen fuel attached to the inner wall of a fuel tank

Fungibility: Full interchangeability and mixability with the baseline

G

Gap Analysis: Refers to the study and comparison performed to identify those missing pieces of information between 1) the fuels information outlined in the Mil Handbook and documented for the candidate fuel/fuel additive and 2) the systems level analysis of the weapon system, piece of equipment, environmental, safety, occupational health or logistics process required to qualify or certify the fuel for use.

H

Hydroprocessed Esters and Fatty Acids (HEFA): Biofuel derived from hydroprocessing plant oils, animal fats, or algal oils, also called Hydroprocessed Renewable Jet (HRJ).

High Flash Point Kerosene Type: High flash point kerosene fuel has essentially the same characteristics as kerosene type fuels, but with a minimum flash point of 60°C (140°F). This higher flash point fuel is required by the Navy for fire safety purposes aboard aircraft carriers.

Hydroprocessed Renewable Jet (HRJ): Another term used to identify HEFA fuels.

I

J

K

Kerosene Fuels: Petroleum distillates with an approximate boiling range of 165° − 300°C (330° − 550°F).

Kerosene Type: Hydrocarbon liquid that has similar chemical and physical properties / characteristics as kerosene fuel.

L

M

Micron: One micron (micrometer, 10^{-6} meter) is a thousandth part of one millimeter.

N

O

Operational Safety: The condition of having acceptable risk to life, health, property, and environment caused by a system or end-item when employing that system or end-item in an operational environment.

Operational Suitability: The degree to which a system or end-item can be placed satisfactorily into field use, with consideration given to availability, compatibility, transportability, interoperability, reliability, wartime use rates, maintainability, full-dimension protection, operational safety, human factors, architectural and infrastructure compliance, manpower supportability, logistics supportability, natural environmental effects and impacts, and documentation and training requirements.

P

Primary Fuel: The fuel(s) on which the air vehicle is designed to operate continuously without restrictions and is (are) also used to demonstrate contract compliance for complete steady state and transient operating conditions.

Q

Qualified Fuel: Fuel(s) that is (are) certified for use in a system with no restrictions.

R

Requirements Decomposition: For this handbook, requirements are broken down into parts from source requirements documents, (JSSG, etc.) until the relevant fuel properties/ characteristics are identified.

S

Shared Verification Product: The totality of relevant data associated with a fuel candidate for certification.

Subset 1 Testing: Fuel properties/characteristics critical to personnel safety, system safety and/or system performance.

Subset 2 Testing: Fuel properties/characteristics critical to system performance and/or durability. This second subset also contains component level tests that do not directly correlate to a fuel property.

Subset 3 Testing: Fuel properties/characteristics critical to the system durability, and supportability requirements.

Suitable for Use: May be a certified, qualified, approved, or other fuel which may or may not have flight restrictions.

Standardized Product: A product is deemed to be standardized when it conforms to specifications which either have the same technical requirements, or which, in the opinion of the responsible working party, have equivalent technical requirements.

Synthetic Fuel: Any liquid fuel produced from sources other than petroleum (sources include coal, natural gas or biomass.)

System: A specific grouping of subsystems, components, or elements designed and integrated to perform a military function.

System Manager: The single individual specifically designated, under the integrated weapon system management architecture, to be responsible for the life cycle management of a system or end-item. The System Manager is the program manager vested with full authority, responsibility, and resources to execute and support an approved military program. The term, “System Manager” will include not only weapon system or equipment managers, but persons responsible for environmental, operational, safety, health or logistics processes related to fuels. The US Air Force has also used the term “Single Manager” to identify this individual.

T

Technology Readiness Level: See Appendix M for details.

U

Unified Product: A standardized product which is used by all Allied nations for (a) given use(s).

V

Value Stream: All the steps (both value added and non-value added) in a process that the customer is willing to pay for in order to bring a product or service through the main flows essential to producing that product or service.

W

Wide-Cut Type: Mixtures of gasoline and kerosene distillate fractions with an approximate boiling range of 35° − 315°C (95° − 600°F).

X

Y

Z

3.1 Alphabetical listing of acronyms and abbreviations.

ACGIH	American Conference of Governmental Industrial Hygienists
AECG	Acute Exposure Guidelines Levels
AEDC	Arnold Engineering Development Center
AFCD	Alternative Fuels Certification Division (same as AFCO)
AFCESA	Air Force Civil Engineer Support Agency (now the Air Force Civil Engineer Center)
AFCO	Alternative Fuels Certification Office
AFFF	Aqueous Film Forming Foam
AFGS	Air Force Guide Specification
AFI	Aerospace Fuels Infrastructure
AFIOH	Air Force Institute for Occupational Health
AFLCMC	Air Force Life Cycle Management Center
AFMC	Air Force Materiel Command
AFOSR	Air Force Office of Scientific Research
AFPA	Air Force Petroleum Agency
AFPD	Air Force Policy Directive
AFRL	Air Force Research Laboratory
AFRL/RX	Air Force Research Laboratory, Materials and Manufacturing Directorate
AFRL/RQTF	Air Force Research Laboratory, Fuels and Energy Branch
AFRL/RZPF	Air Force Research Laboratory, Fuels Branch (predecessor to RQTF)
AIT	Autoignition Temperature
AMS	Aerospace Materials Specifications
AMT	Accelerated Mission Test

APA101	Aeroshell Performance Additive 101
API	American Petroleum Institute
APU	Auxiliary Power Unit
ARP	Aerospace Recommended Practice
ASI	Advertising Specialty Institute
ASTM	Formerly known as American Society for Testing and Materials, it is now known as ASTM, International
ATJ	Alcohol to Jet
ATSDR	Agency for Toxic Substances and Disease Registry
BEE	Bioenvironmental Engineering
BMS	Boeing Materials Specifications
BOCLE	Ball On Cylinder Lubricity Evaluator
BSFC	Brake Specific Fuel Consumption
CAE	Component Acquisition Executive
CAP	Compound Action Potential
CATEX	Categorical Exclusion
CDA	Commercial Derivative Aircraft
CDC-ATSDR	Centers for Disease Control and Prevention, Agency for Toxic Substances and Disease Registry
CFR	Code of Federal Regulations
CHPPM	Center for Health Promotion and Preventive Medicine
CI	Compression Ignition
CI/LI	Corrosion Inhibitor/Lubricity Improver
CO	Carbon Monoxide
CONUS	Continental United States
COT	Committtee On Toxicology
CO2	Carbon Dioxide
CRC	Coordinated Research Council
cSt	Centistokes
DARPA	Defense Advanced Research Projects Agency
DCN	Derived Cetane Number
DESC	Defense Energy Support Center (now DLA Energy)
DiEGME	Diethylene Glycol Monomethyl Ether

DLA Energy	Defense Logistics Agency Energy
DLS	Dynamic Light Scattering
DoD	Department of Defense
DODAAC	Department Of Defense Activity Address Code
DoT	Department of Transportation
DTIC	Defense Technical Information Center
E^3	Electromagnetic Environmental Effects
EGME	Ethylene Glycol Monomethyl Ether
EA	Environmental Assessment
EIAP	Environmental Impact Analysis Process
EIS	Environmental Impact Statement
EO	Executive Order
EPA	Environmental Protection Agency
EPU	Emergency Power Unit
ESC	Electronic Systems Center
ERMI	Ecological Research and Management Incorporated Environmental Laboratories
ESOH	Environmental Safety and Occupational Health
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FBP	Final Boiling Point
FCO	Fuel Certification Organization
FEO	Fuel Evaluation Organization
FRAC	See "FRAC Tank" definition in the Glossary
FSE	Field Service Evaluation
FSII	Fuel System Icing Inhibitor
FT	Fischer-Tropsch
FY	Fiscal Year
F-T	Fischer-Tropsch
F/A	Fuel to Air ratio
Gal	Gallon
GC	Gas Chromatograph
GC x GC	Two-Dimensional Gas Chromatography

GHG	Green House Gases
HAPs	Hazardous Air Pollutants
HAZMAT	Hazardous Material
HC ratio	Hydrogen/Carbon ratio
HDBK	Handbook
HEL	Higher Explosive Limit
HEFA	Hydroprocessed Esters and Fatty Acids
HFRR	High Frequency Reciprocating Rig
HHA	Health Hazard Assessment
HRI	Hazard Risk Index
HRJ	Hydroprocessed Renewable Jet
HSI	Human Systems Integration
HSMCT	Hot Section Materials Compatibility Test
IAW	In Accordance With
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrometry
IH	Industrial Hygiene
IMP	Integrated Master Plan
IPK	Iso-Paraffinic Kerosene
IPT	Integrated product Team
IR	Infrared
JFTOT	Jet Fuel Thermal Oxidation Tester
JRF	Jet Reference Fuel
JSSG	Joint Service Specification Guide
KOH	Potassium Hydroxide
LCSE	Life Cycle Systems Engineering
LEL	Lower Explosive Limit
LFL	Lower Flammable Limit
LL	Lesson Learned
LOAEL	Lowest Observed Adverse Effect Level
MDA	Metal Deactivator Additive
MIE	Minimum Ignition Energy
MIL	Military
MLSA	Medical Laboratory Scientists Association

MN	Micronuclei
MRL	Manufacturing Readiness Level
MSEP	Micro-Separatometer
NAC	National Academies Council
NACA	National Advisory Committee for Aeronautics
NAC-AEGL	National Advisory Committee for Acute Exposure Guidelines for Hazardous Substances
NAS	National Aerospace Standard
NATO	North Atlantic Treaty Organization
NEA	Nitrogen Enriched Air
NEP	Neutral Endopeptidase
NEPA	National Environmental Policy Act
NHRC	Naval Health Research Center
NIC	Notice of Intended Changes
NIST	National Institute of Standards and Technology
NOAEL	No Observed Adverse Effect Level
NOx	Oxides of Nitrogen
NRC	National Research Council
NSE	National Security Exception
NSN	National Stock Number
N/A	Not Applicable
OEM	Original Equipment Manufacturer
OFD	Optical Fire Detection
OSS&E	Operational Safety, Suitability, & Effectiveness
OPPTS	Office of Prevention, Pesticides and Toxic Substances
PAH	Polycyclic Aromatic Hydrocarbons
PCE	Polychromatic Erythrocytes
PDF	Portable Document Format (Adobe Acrobat)
PEA	Programmatic Environmental Analysis
PEL	Permissible Exposure Level
PEO	Program Executive Officer
PESHE	Programmatic Environmental, Safety, and occupational Health Evaluation
PM	Particulate Matter

PN-EI	Particle Number-Emission Index
PPE	Personal Protective Equipment
ppm	Parts per million
PQIS	Petroleum Quality Information System
Pub. L.	Public Law
P-V-T	Pressure-Volume-Temperature
QPL	Qualified Parts List
RAP	Risk Assessment Process
REL	Recommended Exposure Level
RZPF	Propulsion Directorate, Fuels Branch
SAE	Society of Automotive Engineers
SAF/AQ	Assistant Secretary of the Air Force for Acquisition
SCAT	Self-Contained Above-ground Tanks
SDA	Static Dissipater Additives
SDAPCD	San Diego Air Pollution Control District
SDS	Safety Data Sheet
SECAF	Secretary of the Air Force
SE&V	Support Equipment & Vehicles
SG	Specific Gravity
SM	System Manager
SME	Subject Matter Expert
SOF	Safety of Flight
SPK	Synthesized Paraffinic Kerosene
STEL	Short-Term Exposure Limit
SVP	Shared Verification Products
TAC	Toxic Air Contaminants
TBD	To Be Determined
TEOM	Tapered Element Oscillating Microbalance
TLV	Threshold Limit Value
TMO	Transportation Management Office
TPHCWG	Total Petroleum Hydrocarbon Criteria Working Group
TPM	Technical Performance Measures
TRL	Technology Readiness Level

TWA	Time-Weighted Average
UEL	Upper Explosive Limit
UFC	Unified Facilities Criteria
UFL	Upper Flammable Limit
UHC	Unburned Hydrocarbons
UFGS	Unified Facility Guide Specification
USAF	United States Air Force
USAFSAM	USAF School of Aerospace Medicine
UV	Ultraviolet
VIL	Vehicle Identification Link
VOC	Volatile Organic Compound
WR-ALC	Warner Robins Air Logistics Center
Y/N	Yes/No

4. GENERAL GUIDANCE.

4.1 Aerospace fuel certification process goals.

The aerospace fuel certification process applies the tenets of systems engineering which involves decomposing requirements to the lowest level and developing the verification activity required to demonstrate that the requirements are achieved. The main goal of the aerospace fuel certification process is to ensure the desired level of safety, performance, durability, supportability, interoperability, etc. with the least possible economic burden to military systems, equipment and infrastructure. Additionally, the process is to certify the fuel in the most cost-effective manner by minimizing duplication of effort and maximizing sharing of data among all affected systems.

4.2 Primary tasks.

The primary tasks involved in certifying an aerospace fuel for use in military systems involves executing the certification process, evaluating the risk using the risk assessment process and performing field service evaluations as appropriate. The streamlined process specifically aimed at certifying drop-in fuels is described in Appendix N.

4.3 Expeditionary fuels.

When tasked and funded, the Fuels Certification Organization (FCO) will evaluate kerosene type fuel that is available in a location of expeditionary military activities, which has been used for aviation but has not been certified by the System Managers or their equivalents as suitable for use in U.S. military equipment, if the fuel is intended for use in U.S. military equipment. In general, the Defense Logistics Agency Energy (DLA Energy), combatant commander, and/or NATO commander will identify the fuel and request an evaluation of the expeditionary fuel to ease logistics burden, reduce cost, and/or more effectively conduct operations. Since the fuel has previously been used in aviation, fuel use information related to the aircraft type, engine system, and any other equipment will be required along with the fuel properties and characteristics defined later in this section.

4.4 Improved fuels and additives.

When tasked and funded, the FCO will evaluate advanced fuels and fuel additives that have been developed in military research and development programs or by the commercial sector that have been demonstrated to a Technology Readiness Level (TRL) of 6 or higher. These new fuels / additives will demonstrate an equal or improved performance, operability, durability, maintenance, cost or reduced logistics footprint when compared to the baseline and all relevant test data, test reports, and related documentation to determine technical maturity and economic viability will be provided to the FCO.

4.5 Fuels from alternative or unconventional resources.

When tasked and funded, the FCO will evaluate fuels produced from alternative and unconventional resources that are liquid fuels that can be used for aviation, support equipment and vehicles. In general, these fuels will be evaluated by military research and development organizations or the commercial sector and be at a TRL of 6 or higher and demonstrated to be equal to or better than the baseline fuel (see Appendix M). The FCO will be provided with information on the resource used to produce the fuel, general information on the processes used to manufacture the fuel, all relevant test data, test reports and related documentation to determine technical maturity and economic viability. In addition, information related to the environmental, safety and health aspects of the fuel are required.

4.6 Segregation of candidate fuels and additives.

During the certification process two important issues will be considered regarding the segregation of a candidate fuel and/or additive from the normally supplied grades of fuel used for operations. The first issue applies to the fuel or additive used for the certification process and associated testing. The second issue applies after the decision to implement use of the fuel or additive.

4.6.1 Certification fuel.

During the certification process, the certification product (whether a fuel, a fuel blend, or a fuel-additive mixture) used for testing will be kept separate from fuel in the operational fuel supply. Use and special cleaning procedures of separate tanks and fuel transfer systems will be implemented. The purpose is to avoid contamination of the normal fuel supply and to avoid compromising the certification product by uncontrolled blending with other fuel stocks. When the candidate fuel is a blend, blending should be done using defined procedures developed by the fuel or additive supplier and overseen by the applicable Fuel Service Control Point (e.g., AFPA for USAF) to ensure the proper mix. Under no circumstances should the certification product be mixed with the standard fuel supply beyond limits specified by the applicable Fuel Service Control Point. At completion of the certification testing, blend back ratios will be provided in writing by the applicable Fuel Service Control Point. Blend-back will not begin until these procedures are received by the test location.

4.6.2 Fleet implementation.

The simplest fleet implementation is when a fuel can be mixed with, or fully replace, existing fuel stocks. This involves only limited transition planning, with the transition being transparent to the user. When a fuel or additive cannot be mixed with existing stocks, the sustainment and infrastructure impacts will be fully identified. A plan for transition will be included as a part of the decision to implement use of the new fuel or additive. Similarly when the new fuel or additive drives more restrictive operating limitations or performance impacts or can be implemented to only a limited fleet, it will be necessary to keep it permanently segregated and specifically identified by its own grade designation. The sustainment and infrastructure implications of such segregation may be significant and will be given proper weight in the implementation decision. Again, a transition plan coordinated through the applicable Fuel Service Control Point will be part of that implementation decision process.

5. DETAILED REQUIREMENTS.

5.1 Aerospace fuel certification process.

The aerospace fuel certification process is applicable to any candidate fuel for utilization in aerospace applications. The certification process herein was developed to be consistent with Air Force Materiel Command Instruction 63-1201 "Implementing Operational Safety Suitability and Effectiveness (OSS&E) and Life Cycle Systems Engineering (LCSE)" which states that the SM has OSS&E responsibility. The role of the FCO in this certification process is to minimize duplication of effort to the maximum extent possible by working with each SM to identify opportunities for sharing verification test and analysis results herein referred to as shared verification products (SVP). The fuel certification process is depicted on Figure 1 and each step of the process is described below.

5.1.1 Entrance criteria.

The FCO will ensure that all entrance criteria testing requirements identified in Appendix B, D, E, F, G, and H are accomplished prior to execution of the certification process. The FCO will evaluate the entrance criteria test results for the candidate fuel and compare the data to the baseline results described in Appendix C, D, E, F, G and H. Based on this comparison and considering performance, cost and risk, the FCO will determine whether or not to proceed with the certification process. If the FCO determines the candidate fuel cannot be certified for use, the FCO will document this conclusion with the supporting rationale.

5.1.1.1 Fuel property/characteristic testing.

The entrance criteria fuel property/ characteristic tests described in Appendix B will be conducted and the results compared to the baseline results in Appendix B.

5.1.1.2 Material compatibility testing.

The entrance criteria material compatibility tests described in Appendix D will be conducted and the results compared to the baseline results contained in Appendix D.

5.1.1.3 Toxicity.

The entrance criteria toxicity tests described in Appendix E will be conducted and the results compared to the baseline results contained in Appendix E.

5.1.1.4 Fire protection and survivability/vulnerability.

The entrance criteria fire protection tests described in Appendix F will be conducted and the results compared to the baseline results contained in Appendix F.

5.1.1.5 Aircraft propulsion.

The entrance criteria aircraft propulsion tests described in Appendix G will be conducted and the results compared to the baseline results contained in Appendix G.

5.1.1.6 Aerospace fuels infrastructure.

The entrance criteria logistics tests described in Appendix H will be conducted and the results compared to the baseline results contained in Appendix H.

5.1.2 Conduct Subset 1 testing.

The FCO, in conjunction with the Single Manager, will ensure that the Subset 1 testing requirements identified in Appendix B, D, E, F, G, and H are conducted to evaluate the primary set of fuel properties/characteristics, to ensure compatibility with the materials commonly used in military equipment that comes into contact with fuel and fuel vapors, and to ensure personnel safety. This initial subset of tests is critical to personnel safety, system safety, and/or system performance. For each test result that did not meet the baseline requirements, the FCO, in conjunction with the Single Manager, will initiate the risk assessment process described in 5.3 to determine the impact to military systems and personnel, additionally involving the affected SM. The FCO, in conjunction with the Single Manager, will evaluate the results of Subset 1 testing, the entrance criteria testing, and the risk assessments and determine if the candidate fuel:

(a) Cannot be certified for use.

(b) Exhibits the same properties or performs like the baseline fuel.

(c) Can be certified for utilization without further testing.

(d) Requires additional testing.

If the FCO, in conjunction with the Single Manager, determines the candidate fuel cannot be certified for use, the fuel will be rejected, the process will be terminated, and the FCO, in conjunction with the Single Manager, will document this conclusion with the supplemental test data. If the FCO, in conjunction with the Single Manager, determines that the candidate fuel exhibits the same properties or performs like the baseline fuel, the FCO, in conjunction with the Single Manager, will recommend that the fuel be accepted and that the fuel specification be updated accordingly. If the FCO, in conjunction with the Single Manager, determines the candidate fuel can be certified without additional testing, this recommendation will be provided to each SM with supporting rationale and the process will proceed as described in 5.2. If the FCO, in conjunction with the Single Manager, determines additional testing is required on the fuel candidate, the process will be continued as described in 5.1.3.

5.1.2.1 Fuel property/characteristic testing.

The Subset 1 fuel property/ characteristic tests described in Appendix B will be conducted and the results compared to the baseline results in Appendix B.

5.1.2.2 Material compatibility testing.

The Subset 1 material compatibility tests described in Appendix D will be conducted and the results compared to the baseline results also contained in Appendix D.

5.1.2.3 Toxicity.

The Subset 1 toxicity tests described in Appendix E will be conducted and the results compared to the baseline results also contained in Appendix E.

5.1.2.4 Fire protection and survivability/vulnerability.

The Subset 1 fire protection tests described in Appendix F will be conducted and the results compared to the baseline results contained in Appendix F.

5.1.2.5 Aircraft propulsion.

The Subset 1 aircraft propulsion tests described in Appendix G will be conducted and the results compared to the baseline results also contained in Appendix G.

5.1.2.6 Aerospace fuels infrastructure.

The Subset 1 logistics tests described in Appendix H will be conducted and the results compared to the baseline results contained in Appendix H.

5.1.2.7 Conduct Subset 2 testing.

The FCO, in conjunction with the Single Manager, will ensure that the Subset 2 testing requirements identified in Appendix B, D, F, G, and H are conducted (if required) to evaluate the secondary set of fuel properties/ characteristics, to ensure compatibility with the materials commonly used in military equipment that comes into contact with fuel and fuel vapors and to ensure personnel safety. Additionally, the component/system level tests described in Appendix B not directly correlated to a fuel property/characteristic will be performed and evaluated. This second subset of tests is critical to system performance and/or durability and a failure to meet these requirements will be thoroughly evaluated. For each test result that does not meet the baseline requirements, the FCO, in conjunction with the Single Manager, will initiate the risk assessment process described in 5.3 to determine the impact to military systems and personnel, additionally involving the affected SMs. The FCO, in conjunction with the Single Manager, will evaluate the results of Subset 2 testing, all previous testing, and the risk assessments to determine if the candidate fuel:

(a) Cannot be certified for use.

(b) Exhibits the same properties or performs like the baseline fuel.

(c) Can be certified for utilization without further testing.

(d) Requires additional testing.

If the FCO determines the candidate fuel cannot be certified for use the FCO will document this conclusion with supporting rationale and the process will be terminated. If the FCO determines that the candidate fuel exhibits the same properties or performs like the baseline fuel, the FCO will recommend that the fuel be accepted and that the fuel specification be updated accordingly. If the FCO determines the candidate fuel can be certified without additional testing, this recommendation will be provided to each SM with supporting rationale and the process will proceed as described in 5.2. If the FCO determines additional testing is required, the process will be continued as described in 5.1.3.

5.1.2.8 Fuel property/characteristic testing.

The Subset 2 fuel property/characteristic and component/system tests described in Appendix B will be conducted and the results compared to the baseline results in Appendix B.

5.1.2.9 Material compatibility testing.

The Subset 2 material compatibility tests described in Appendix D will be conducted and the results compared to the baseline results contained in Appendix D.

5.1.2.10 Toxicity.

The Subset 2 toxicity tests described in Appendix E will be conducted and the results compared to the baseline results contained in Appendix E.

5.1.2.11 Fire protection and survivability/vulnerability.

The Subset 2 fire protection tests described in Appendix F will be conducted and the results compared to the baseline results contained in Appendix F.

5.1.2.12 Aircraft propulsion.

The Subset 2 aircraft propulsion tests described in Appendix G will be conducted and the results compared to the baseline results contained in Appendix G.

5.1.2.13 Aerospace fuels infrastructure.

The Subset 2 logistics tests described in Appendix H will be conducted and the results compared to the baseline results contained in Appendix H.

5.1.3 Conduct Subset 3 testing.

The FCO, in conjunction with the Single Manager, will ensure that the Subset 3 testing requirements identified in Appendix B, D, F, G, and H are conducted (if required) to evaluate the final set of fuel / additive properties/characteristics, to ensure compatibility with the materials commonly used in military equipment that comes into contact with fuel, and to ensure personnel safety. In addition, the component/system level tests described in Appendix B not correlated to a fuel property results will be conducted and evaluated. This third subset of tests is generally related to durability, supportability, interoperability, etc. and a failure to meet these requirements will be evaluated. For each test result that did not meet the baseline requirements, the FCO, in conjunction with the Single Manager, will initiate the risk assessment process described in 5.3 to determine the impact to military systems and personnel, additionally involving the affected SM. The FCO, in conjunction with the Single Manager, will evaluate the results of Subset 3 testing, all previous testing, and the risk assessments to determine if the candidate fuel:

(a) Cannot be certified for use.

(b) Can be certified for utilization

(c) Can be certified with limitations and appropriate documentation

If the FCO determines the candidate fuel cannot be certified for use, the FCO will document this conclusion with supporting rationale. If the FCO determines the candidate fuel can be certified, or can be certified with limitations and appropriate documentation, this recommendation will be provided to each SM with supporting rationale and the process will proceed as described in 5.2.

5.1.3.1 Fuel property/characteristic testing.

The Subset 3 fuel property/characteristic and component/system tests described in Appendix B will be conducted and the results compared to the baseline results in Appendix B.

5.1.3.2 Material compatibility testing.

The Subset 3 material compatibility tests described in Appendix D will be conducted and the results compared to the baseline results contained in Appendix D.

5.1.3.3 Toxicity testing.

The Subset 3 toxicity tests described in Appendix E will be conducted and the results compared to the baseline results contained in Appendix E.

5.1.3.4 Fire protection and survivability/vulnerability.

The Subset 3 fire protection tests described in Appendix F will be conducted and the results compared to the baseline results contained in Appendix F.

5.1.3.5 Aircraft propulsion.

The Subset 3 aircraft propulsion tests described in Appendix G will be conducted and the results compared to the baseline results contained in Appendix G.

5.1.3.6 Aerospace fuels infrastructure.

The Subset 3 logistics tests described in Appendix H will be conducted and the results compared to the baseline results contained in Appendix H.

5.2 Develop initial certification plan.

For systems requiring testing and evaluation, each SM will develop an initial certification plan and supporting rationale considering the recommendation from the FCO. If the SM agrees with the FCO recommendation, the certification plan should simply state this conclusion and no additional effort is required. If the SM determines additional testing or gap analysis is required to certify the candidate fuel in his/ her respective system, the SM will provide a certification plan including the requirements impacted and the proposed verification analysis and/or testing activities identified using their gap analysis and the risk assessment process described in 5.3. Each affected SM will submit an initial certification plan to the FCO for evaluation. Airworthiness assessments will comply with the applicable Service’s requirements (like the Air Force’s AFI 62-601, “USAF Airworthiness”).

5.2.1 Evaluate initial certification plan.

The FCO will evaluate each SM’s initial certification plan. For initial certification plans that involve additional testing or analysis, the FCO will identify opportunities to eliminate duplication of effort and to maximize the sharing of verification products. The FCO will recommend to each SM changes to his/her initial certification plan that will minimize the cost to the military while still providing sufficient data for the SM to certify (or reject) the fuel for utilization.

5.2.2 Finalize certification plan.

The SM and FCO will finalize the certification plan and the Shared Verification Products SVP list. The FCO will maintain the SVP library and ensure this information is accessible to all impacted SM.

5.2.3 Execute certification plan.

The SM will execute the certification plan and provide all SVP results to the FCO.

5.2.4 Share verification data.

The FCO will provide the SVP results generated by the SM and provide the SVP to the appropriate SM for his / her evaluation.

5.2.5 Certify or reject fuel.

The SM will evaluate the SVP, resulting from executing the certification plan described in 5.2.3 and 5.2.4 and determine if the fuel can be certified for use in his / her system considering safety, performance, durability, supportability, interoperability, etc. If the fuel can be certified for use, the SM will update the appropriate Technical Orders authorizing use of the fuel / additive to include any applicable limitations or restrictions. If the fuel cannot be certified for use, this result will be provided to the FCO with supporting rationale and the FCO will incorporate these results and the supporting rationale.

5.2.6 Commercial Derivative Aircraft.

Certifying Commercial Derivative Aircraft (CDAs) for a new fuel offers a special challenge as well as a unique opportunity. Both the challenge and the opportunity are driven by the commercial certification methodology which requires the participation of another agency, the Federal Aviation Administration (FAA), which controls the approval of aircraft type certificates. The challenge is to ensure that the type certificates allow the use of military-designated fuel. The opportunity comes from the potential that the commercial certification may cover the military-designated fuel if the military fuel meets all of the requirements of the commercially certified fuel, and could be designated as such, if necessary.

In order for CDAs to be allowed to use a specific fuel grade (like JP-8, JP-5, Jet A, Jet A-1, etc.), that fuel needs to be listed as authorized in the type certificate itself, in a document referenced in the type certificate, like a fuel specification or an engine manufacturer's service bulletin, or addressed by a supplemental type certificate. If the new fuel is included within the identifier for an already-authorized fuel grade as it is listed in the type certificate or in its referenced documents (e.g., the JP-8 specification allowing up to 50% Synthetic Paraffinic Kerosene while still being designated as just JP-8), then the type certificate would not need to be changed. On the other hand, if the type certificate or the referenced document is too specific (e.g., the version of the specification defining the fuel; e.g., MIL-DTL-83133**E**, which does not allow synthetic fuel components) or if the new fuel is identified (either temporarily or permanently) as a separate grade (e.g., "JP-8/SPK" in MIL-DTL-83133**F**), then the type certificate or the reference document will likely need to be appropriately modified to allow the fuel to be used on the aircraft. For many CDAs, the type certificates address the fuels that are allowed in referenced documents, like specifications or service bulletins, which are controlled and maintained by manufacturers of the engines used on the certificated aircraft.

5.2.6.1 Military fuel with no commercial equivalent.

A new military fuel, with a specific fuel grade designation, which has no commercial equivalent needs to be added to the aircraft type certificates, their referenced documents, or via supplemental type certificates for each aircraft with FAA approval. This normally requires a technical package acceptable to the FAA for each aircraft in which the fuel is to be used, describing why the aircraft is safe to operate with this fuel, what its associated operating limitations are, and what analyses and testing have been done to demonstrate validity of those assertions. Such packages normally also require concurrence with those assertions from both the engine and the aircraft original equipment manufacturers (OEMs). In fact, most certification packages are prepared by the OEMs.

5.2.6.2 Military fuel WITH a commercial equivalent.

Commercial industry normally works to define the new fuel via an ASTM specification, which when approved and implemented is included in aircraft type certificates or their referenced document(s). The FAA certification of commercial aircraft to use a fuel requires a degree of justification by the FAA consistent with the safety risks associated with using that new fuel. If the new fuel is very similar to and fungible with a currently authorized fuel, the FAA would be willing to accept a simple change to the ASTM specification including the new fuel within the definition of the already-authorized fuel and would not require a new grade designation for that fuel. The FAA acceptance would be on the basis of the research done on the new fuel used to support the ASTM balloting and the resultant acceptance by the ASTM committee members, which include the aircraft and engine manufacturers. The aircraft and engine manufacturers take a very conservative attitude toward changes because of their legal liability in the event of an aircraft mishap. The motivations associated with this ensure that an accepted change has a sufficiently low safety risk that the FAA does not need to be concerned that a change arrived at by this method is likely to reduce aircraft safety.

The commercial process has the potential to bypass the control that System Managers of the CDAs have over the characteristics of the commercial fuels supplied to their aircraft. Once a new fuel specification accepts a component which is fully fungible with the previously accepted fuel, it is possible that any commercial supplier (e.g., airport) may supply the new fuel and neither supplier nor user may know whether it is the new fuel, the old fuel, or a blend of the two. The only preventive recourse a System Manager has in such a case is to restrict his or her systems from using the commercial fuel grade in question. That may be operationally and logistically unacceptable.

On a more positive note, when a military fuel (with its own military designation) being certified in accordance with the guidance herein is equivalent to a fuel which is already commercially certified, an opportunity for benefit to the military certification presents itself. If the military specification for the fuel is the same as, or slightly more conservative than the commercial fuel, then the military fuel should meet all of the requirements of the commercial specification, and any given quantity of the military fuel could at any time be designated by the commercial identifier without violating the commercial specification instead of being designated by its military designation (e.g., JP-8 meets Jet A-1 requirements and the Jet A-1 specification allows JP-8's military additives, though it does not require them; conversely, most Jet A-1 fuels can be made into JP-8 just by adding the military additives). That would allow the re-designated quantity of fuel to be used in the CDAs as readily as its commercial equivalent. What this means is that no further justification for using the equivalent military fuel would be needed, and similarly, no further justification for its certification should be needed as well. There should not be a need for additional testing or significant amounts of additional technical supporting data to obtain approval from the FAA to allow use of the military fuel via one or more supplemental type certificates for these aircraft, since the technical justification was already accomplished via the commercial specification approval process. All it should take is documentation of the equivalence of the military fuel to the commercial fuel and agreement by both the System Manager and the FAA on how to document the approval (e.g., via supplemental type certificate).

If both the military and equivalent commercial fuels are being certified in parallel, a mutually beneficial cooperative arrangement may be a worthwhile approach to pursue. Harmonizing both the military and commercial specifications in their overlapping areas would set common objectives for obtaining the necessary supporting data. This should be done with the recognition that some military-unique mission-driven requirements may keep the specifications from being identical in some areas. Test data relevant to the overlapping areas of the commercial and military certifications can be shared, reducing duplication of effort and providing an opportunity to reduce the scope of both efforts while still obtaining all of the data needed to support both certifications. Needless to say, some coordination among the efforts is required to avoid the duplication and achieve the largest savings. The participation of both military and commercial members in the FAA-chaired Commercial Aviation Alternative Fuels Initiative and the accomplishments it achieved for the Fischer-Tropsch fuel blends provide a meaningful example of the benefits of this kind of collaboration.

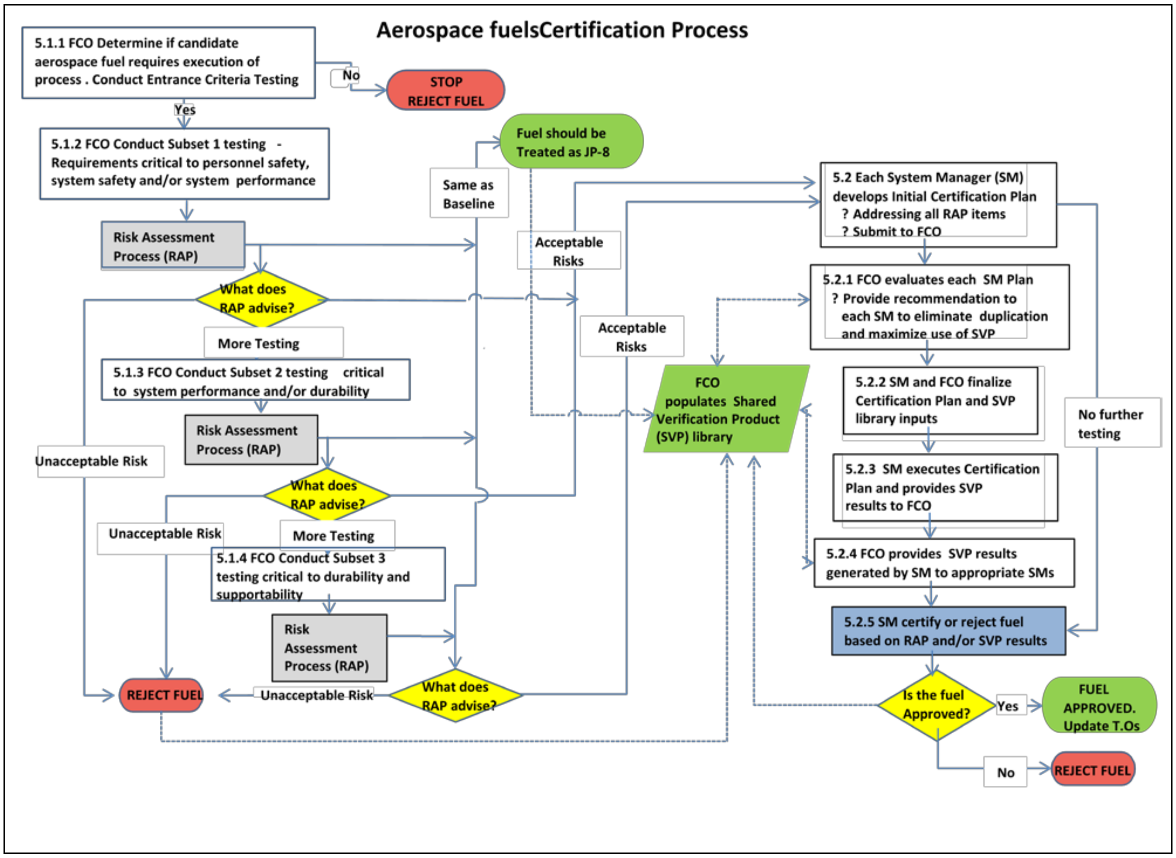


FIGURE 1. Aerospace fuels certification process.

5.3 Risk assessment process.

The risk assessment process is applied when candidate fuel or additive properties fall outside the baseline requirements described in the appendices below. The objective is to address potential risks and impacts driven by those deviations from the common experience with the baseline fuel. The risk assessments take on three distinct sequential styles depending on the timing and the responsibility level of the decision authority. The first style is used by the FCO when a candidate fuel or additive has been proposed for certification. This assessment has a general whole-fleet focus and is based on whether foreseeable benefits, risks, and impacts balance in favor of the potential benefits. If they are a potential benefit, the candidate passes and is handed to the System Managers, who apply the second style of risk assessment. This focuses on the specific system and tries to quantify, where possible, the benefits, risks, and impacts with the aim of determining whether or not the system should be certified to use the candidate fuel or additive. If needed, all System Manager assessments are consolidated and along with an FCO recommendation are transmitted to the high level decision authority. The final style is then applied by the high level decision authority responsible for resolution of whole-fleet certification should there be any uncertified systems within the affected fleet. This again focuses on the whole fleet, and has several potential outcomes, depending on the aggregate of the certification decisions of the System Managers. In this context, the term "fleet" applies to the systems in which the candidate fuel is intended to be used. This could range all the way from a single aircraft model to all DoD jet-fuel using systems. The decision authority would vary depending on who has authority over the affected fleet.

5.3.1 The FCO risk assessment process.

Fuel properties which are outside the military and commercial operational experience with the baseline fuel (and its additives) are the key drivers of FCO decisions about whether or not to proceed with the certification process for a candidate fuel or additive. Such a situation is especially likely for new additives. Since the FCO does not have detailed insight into the specifics of all systems, its decisions are necessarily based on limited information. Because of this, the risk assessment takes on a qualitative characteristic in determining if risks or impacts associated with the out-of-bounds properties are sufficiently significant to overcome the potential benefit of the candidate (e.g., lower cost, greater availability, better functionality, improved life, etc.). The systems engineering process applies as part of the assessment, but other considerations, like those listed in B.4.1, are involved as well. If the chemistry of the candidate deviates little from the existing military and commercial operational experience, the FCO could decide to proceed with System Manager certification without knowing or considering the impacts of Subset 2 and Subset 3 properties, opting instead to rely on the expertise of the System Managers' organizations to assess the applicability and influence of these properties on their individual certification decisions. The FCO risk assessment process is shown in the diagram on Figure 2.

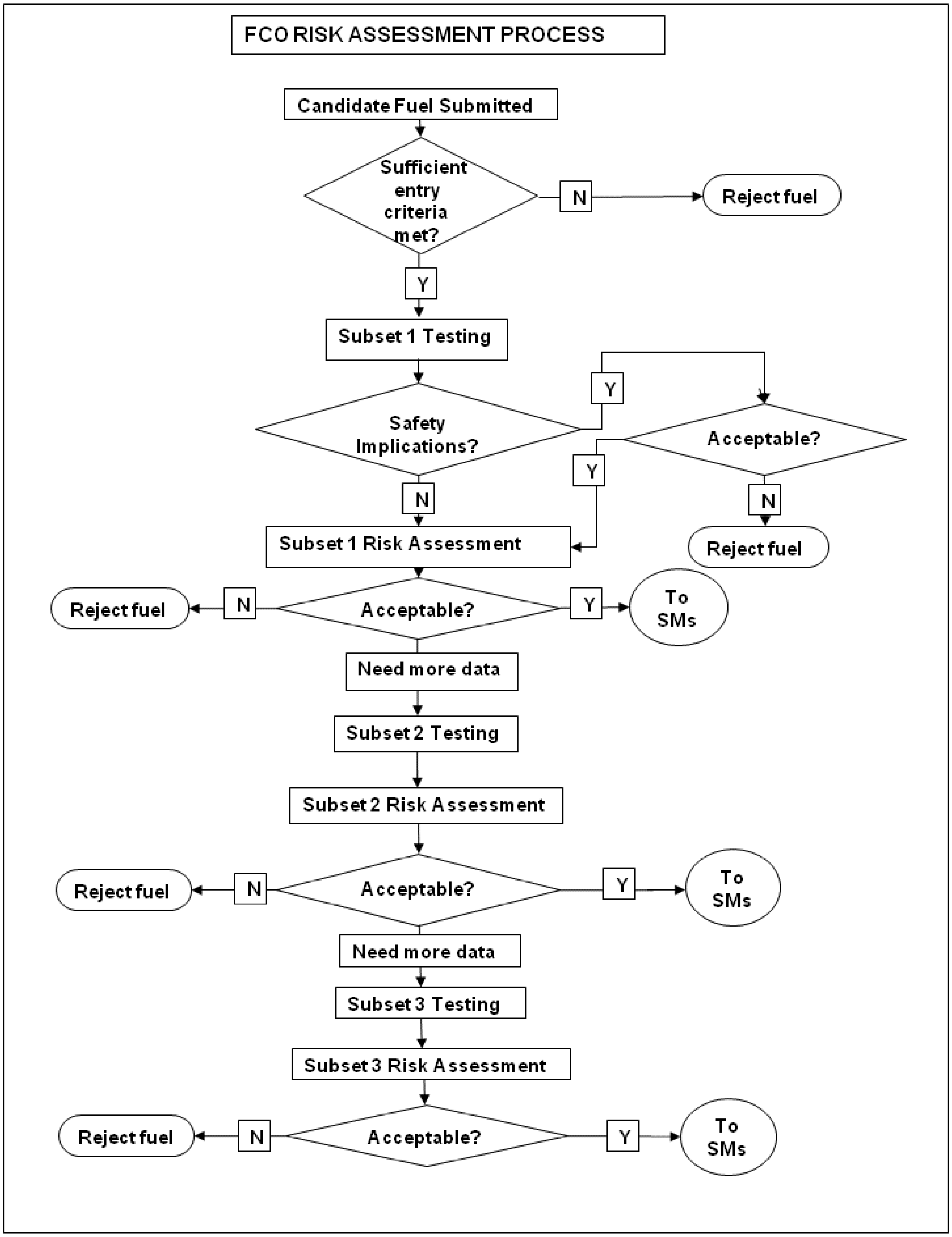


FIGURE 2. FCO risk assessment process.

5.3.1.1 FCO risk assessment considerations.

5.3.1.1.1 Business case.

Potentials in terms of economic viability, produceability, technical maturity, logistics availability, etc., addressed in B.4.1 are part of the decision process. Though difficult to quantify in terms of their overall fleet impact, these potentials can be the first filter of whether or not to proceed with the certification process. If the candidate shows insufficient potential in these areas, it likely will not warrant the time, effort, and expense of certifying it for use in its intended fleet.

5.3.1.1.2 Benefits case.

Advantageous impacts of using the candidate fuel or additive form a key element of the balance between risks and the other impacts of using the candidate fuel. The advantageous impacts have to balance all of the negative impacts, including the cost of certifying the candidate for its intended fleet.

5.3.1.1.3 Risks and negative impacts.

The following outline shows the risks and impacts which may need to be considered and a qualitative ranking method for each:

- Safety impacts (none, minor, medium, major)
  - Mitigating actions (none, easy, moderate, hard)
    - Change procedures (minor, medium, major)
    - Change operating limits (minor, medium, major)
    - Change hardware (minor, medium, major)
    - Potential costs (low, medium, high)
  - Potential costs beyond mitigating actions (e.g., system loss/damage) (low, medium, high)
- Operational/performance impacts (none, minor, medium, major)
  - Change limitations (minor, medium, major)
  - Change procedures (minor, medium, major)
  - Potential costs beyond mitigating actions (e.g., reduced system efficiency requiring more fuel, reduced range, reduced payloads) (low, medium, high)
  - Mitigating actions (none, minor, medium, major)
    - Change procedures (minor, medium, major)
    - Change hardware (minor, medium, major)
    - Potential costs (low, medium, high)
- Supportability impacts (none, minor, medium, major)
  - Change procedures (minor, medium, major)
  - Change maintenance interval (minor, medium, major)

Change spare parts requirement (minor, medium, major)

Potential costs (low, medium, high)

Mitigating actions (none, minor, medium, major)

Change procedures (minor, medium, major)

Change hardware (minor, medium, major)

Potential costs (low, medium, high)

Durability impacts (none, minor, medium, major)

Change procedures (minor, medium, major)

Change maintenance (minor, medium, major)

Change parts replacement interval (minor, medium, major)

Potential costs (low, medium, high)

Mitigating actions (none, minor, medium, major)

Change procedures (minor, medium, major)

Change hardware (minor, medium, major)

Potential costs (low, medium, high)

Both safety and operational considerations have the potential to have impacts in addition to any impacts caused by the mitigating actions that may be applied because of the use of the candidate fuel or additive. For example, such impacts could include an increase (temporary or permanent) in the aircraft mishap rate due to increased frequency of engine flameouts (safety) or reduced range, payload, or loiter time due to lower energy content of the fuel (operations). Note that the Hazard Risk Index (HRI) is not included in the FCO assessment. While the HRI concepts of frequency and severity can be used, the FCO has insufficient insight into risks associated with individual systems to be able to aggregate them into a meaningful HRI for the entire intended fleet for the candidate fuel or additive.

5.3.1.1.3.1 Definitions of qualitative impact descriptors.

5.3.1.1.3.1.1 Minor or low.

Change can be made locally and/or minor change to system Technical Orders. One time training session required, no long-term detrimental impact.

5.3.1.1.3.1.2 Medium.

Change(s) require modification to system Technical Orders, formal training required for crew and maintainers, with long-term impact to personnel and equipment. It may require increased purchases of additional equipment. Component redesign may be required to retain full mission capability.

5.3.1.1.3.1.3 Major or high.

Extensive alterations to Technical Orders, mission planning, maintenance procedures/personnel, and formal training required have a long-term impact to the entire fleet. This will require additional funds for maintenance, component redesign, or increased spare parts purchase. Component redesign will be required or full mission capability may never be attained.

5.3.2 The System Manager risk assessment process.

Once the candidate fuel or additive has been approved by the FCO for continuation in the certification process and submitted to the affected System Managers, the System Manager's systems engineering, risk assessment, and decision-making processes are applied to determine if it is appropriate to certify the system for the use of the candidate fuel or additive. The System Manager risk assessment and associated systems engineering processes look at the same things as the FCO processes, but focused specifically on the System Manager's system, or systems, and at a much more detailed level, at a greater depth with the objective of providing some quantitative definition to some or all of the relevant risks and impacts. The System Manager risk assessment process is shown in the diagram on Figure 3.

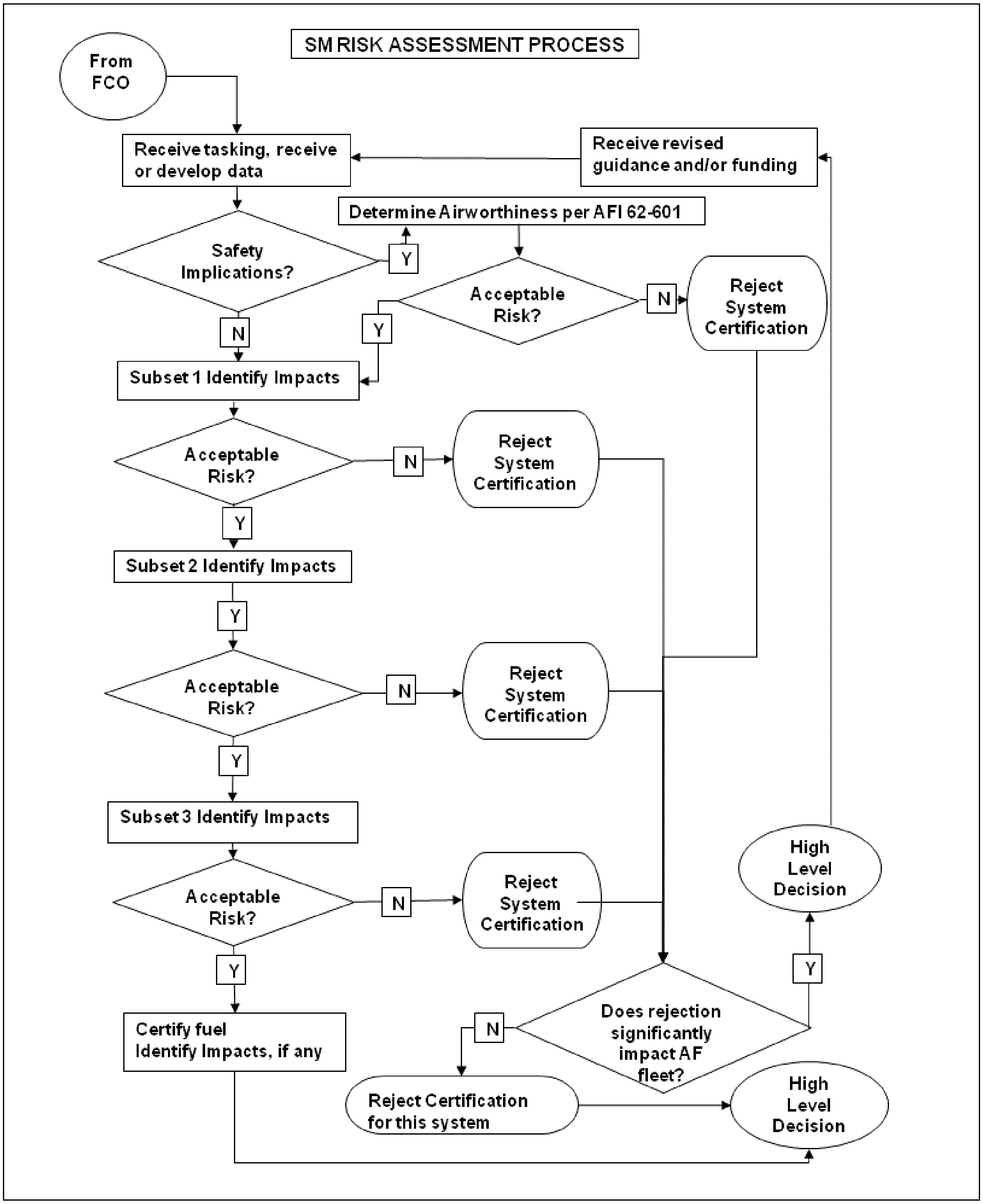


FIGURE 3. System Manager risk assessment process.

5.3.2.1 System Manager risk assessment considerations.

5.3.2.1.1 Business case.

The business considerations from the System Managers' viewpoint focus on their systems' life-cycle costs associated with the use of the candidate fuel or additive. There should be no need for the System Managers to assess the viability or producibility of a candidate. Logistics availability, however, is a significant element of life cycle cost and direction received or assumptions made about this need to be clearly identified with the assessment results.

5.3.2.1.2 Benefits case.

Benefits of using the candidate fuel or additive in the System Manager's system(s) should be identified and quantified, where possible. While it is desirable for benefits to outweigh risks and negative impacts for the System Manager's system(s), a neutral result should normally be sufficient grounds for certifying the candidate. Further, it is possible that negative results for one System Manager's system(s) are offset by positive results for other System Managers' systems. In such a case, input from the High-Level decision process addressed in 5.3.3 could still drive certification for all affected systems, including the one(s) with negative results.

5.3.2.1.3 Risks and negative impacts.

The desired quantitative results involve a fair degree of uncertainty, given that they are dependent on the accuracy (or lack of accuracy) of predictive models and their underlying assumptions. These uncertainties should be identified along with the results. The following outline shows the risks and impacts which may need to be considered:

- Safety impacts
  - Determine Airworthiness (e.g., use Hazard Risk Index [HRI])
    - Frequency and Severity of Impact
  - Mitigating actions (none, easy, moderate, hard)
    - Change procedures -- identify
    - Change operating limits -- identify
    - Change hardware -- identify
    - Potential costs -- quantify
  - Potential costs beyond mitigating actions (e.g., system loss/damage) -- quantify
    - Operational/performance impacts (none, minor, medium, major)
    - Change limitations -- identify
    - Change procedures -- identify
    - Potential costs beyond mitigating actions -- quantify
    - Mitigating actions
    - Change procedures -- identify
    - Change hardware -- identify

Potential costs -- quantify

Supportability impacts (none, minor, medium, major)

Change procedures -- identify

Change maintenance interval -- identify

Change spare parts requirement -- identify

Potential costs -- quantify

Mitigating actions

Change procedures -- identify

Change hardware -- identify

Potential costs -- quantify

Durability impacts (none, minor, medium, major)

Change procedures -- identify

Change maintenance -- identify

Change parts replacement interval -- identify

Potential costs -- quantify

Mitigating actions

Change procedures -- identify

Change hardware -- identify

Potential costs -- quantify

5.3.3 The high-level decision authority risk assessment process.

If all systems of the affected fleet are certified to use the candidate fuel, the high-level decision authority may only need to be the authority responsible for changing or establishing the fuel specification which defines the candidate fuel. However, because most candidate fuels or additives are applicable to multiple systems rather than to a single system, it is possible that not all affected systems will be certified by their System Managers and a decision authority at a higher level than a System Manager's (e.g., Headquarters USAF, DoD) may be needed to accept the risks and impacts, both negative and positive, associated with the use of a candidate fuel or additive and authorize it for broader operational use for the intended fleet and for implementation into the logistics system supporting that operational use. While the output of this process is an authorization, it does not necessarily mean that candidate fuel or additive will actually be available for operational use at the time of the decision, nor does the authorization require that availability. There are situations, however, in which the requirement to use the candidate fuel or additive is mandated as a part of the high-level decision in order to ensure timely receipt of the benefits it provides. This would be especially relevant if the candidate provides a significant safety benefit. Figure 4 shows the High-Level decision process. One of the unique aspects of this process is a feedback loop that provides for adjustment of direction or funding from the High Level to potentially change some or all affected System Managers' negative certification decisions. For example, additional funding could allow modification of the system to mitigate the negative impacts of the candidate fuel or additive or revised direction could allow acceptance of system performance losses or life cycle cost increases for the sake of achieving other benefits to the whole fleet or its logistics system. The FCO's role in this process is twofold. First, the FCO collects and consolidates all of the System Managers' certification decisions, associated rationale, and supporting data and makes it available to the decision authority in the form desired by the decision authority. Second, the FCO recommends a course of action, whether it is to reject the fuel, to use the feedback loop to force reconsideration of negative certification decisions, or to proceed with certifying the fleet. If certifying the fleet has negative consequences, the FCO will identify those consequences to the decision authority along with the FCO's recommendation.

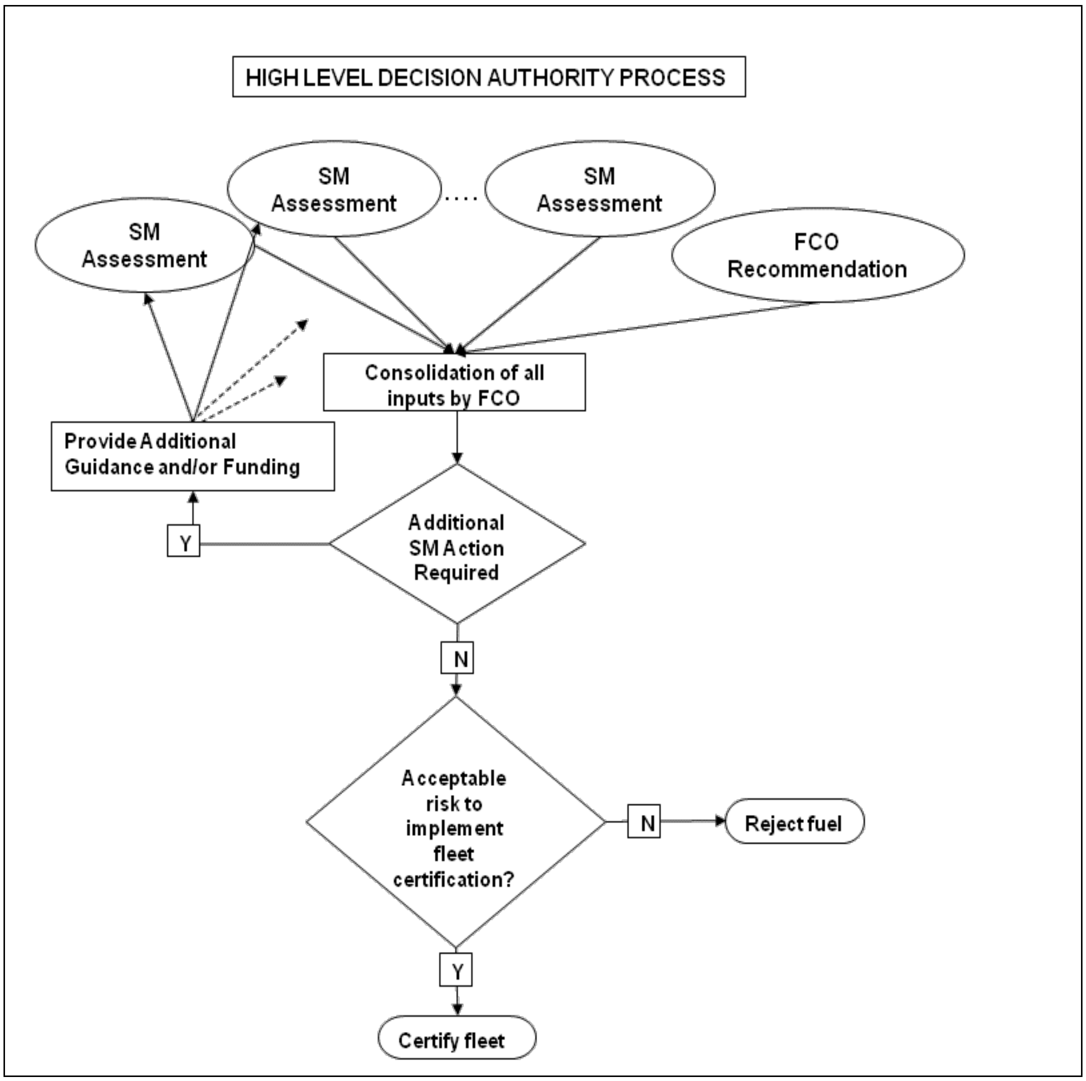


FIGURE 4. High-level decision authority risk assessment process.

5.3.3.1 High-level decision authority risk assessment considerations.

5.3.3.1.1 Business case.

At the high-level, the business considerations revolve around the impacts of meeting mission requirements for the entire affected fleet, the impacts on its life cycle cost, and the impacts on the logistics system that have to be able to effectively and efficiently handle the candidate fuel or additive.

5.3.3.1.2 Benefits case.

The balance between benefits and risks and negative impacts has to favor the benefits clearly, but from the perspective of the entire affected fleet. This means that some elements may sum to be negative, but overall, the benefits have to override all of those negatives.

5.3.3.1.3 Risks and negative impacts.

The following outline shows the risks and impacts which may need to be considered if issues remain when the fleet is certified:

- Accepting changes in system capability or availability for some systems
- Accepting additional sustainment costs/impacts for some systems
- Dealing with the uncertified systems
  - Unique fuel supply requirements
  - Providing funding for system modifications which then enable certification
- Transitioning to the new fuel or additive
  - The most desirable logistics implementation would be for the new fuel or additive to be capable of being mixed with the old with no impact to system performance or operability.
  - If the new fuel or additive needs to be kept separate from the old significant logistics issues arise.
    - A potential need for dual fuel capability at transitioning bases.
    - Significant additional workload in defueling and handling the removed fuel.

5.4 Field service evaluation.

The SM will consider the need to conduct field service evaluations (FSEs) to monitor durability and service life. This task is consistent with the force management activities described in the Aircraft Structural Integrity Program, Engine Structural Integrity Program, Mechanical System Integrity Program and others to ensure continued airworthiness and is essential for certification of new fuels as well. In particular, when the relationship between durability of fuel pumps, sealants, finish systems, o-rings, etc. cannot be adequately correlated to fuel properties/characteristics or component/system tests, a field service evaluation may be warranted. However, unless degradations in durability or supportability are considered possible for a candidate fuel or additive, the FSE does not need to be completed before certification of the system with the candidate fuel or additive. Rather, the system can be certified (allowing but not mandating use of the candidate fuel or additive) and the FSE can be performed at a later time, more consistent with the availability of fuel, supporting infrastructure, and/or evaluation assets. The FSE can take two approaches:

(1) Broadening the experience with the candidate fuel or additive over a larger sample of fleet elements (e.g., aircraft) and

(2) Gathering quantitative data on changes in durability and supportability.

Depending on how the FSE is structured, it can focus on either or both of these approaches. The first can be addressed in a relatively short period of time using multiple elements of a fleet (e.g., multiple aircraft). The second is likely to be much longer in duration to ensure that the impacts on durability and supportability clearly show themselves before the FSE ends. In either case, the more systems (e.g., aircraft) that are involved, the more statistically relevant the data will be, but also the more expensive in terms of impacts on cost, logistics, and operations (e.g., the cost of FSE fuel itself, segregating the FSE fuel supply, limiting where aircraft can operate so that they can almost always get the FSE fuel, etc.) The complexity, expense, and operational impacts associated with doing an FSE have to be balanced against the potential benefits that can be obtained from it. The results have to favor the benefits clearly to justify doing an FSE. One of the primary considerations needs to be whether an unadulterated comparison can be made between the results of the FSE with the new fuel or additive and the previous operational experience without it (i.e., the baseline against which the FSE results are compared). If multiple changes relative to the baseline are being evaluated in a single FSE (e.g., revised combustor fuel nozzles in addition to the change in fuel or additive) it may not be possible to identify which FSE results are associated with which specific change, thereby losing a significant benefit of doing the FSE. The SM will consider options contained in 5.4.1, 5.4.2, and 5.4.3 to obtain the engineering data required to adjust the maintenance intervals as appropriate.

5.4.1 Data collection and evaluation.

The SM will determine what data should be collected and evaluated to monitor durability. These data could include part replacement history, part overhaul history, inspection results, and maintenance trends by subsystem such as fuel, propulsion, etc.

5.4.2 Pacer programs.

The SM will consider the utilization of pacer programs to monitor durability. These programs could include exchanging of components between systems to maximize exposure (lead-the-fleet) that would be subjected to thorough evaluation such as a teardown inspection as described in 5.4.3.

5.4.3 Teardown inspections.

The SM will consider conducting periodic teardown inspections to monitor durability. Teardown inspections involve disassembly and inspection of a component, typically to a greater extent than what occurs during routine or special maintenance. The SM will determine what data should be collected and evaluated to monitor durability. This data could include part replacement history, part overhaul history, inspection results, and maintenance trends by subsystem such as fuel, propulsion, etc.

5.5 Certification criteria elevation potential.

During the certification process, the potential exists that certain fuel properties once deemed acceptable at the lower subset levels (or perhaps were not previously considered at all) may be elevated to higher subset levels. As a result, already certified platforms may need to be reinvestigated. The FCO will work with the SMs on a case-by-case basis to determine whether or not additional testing/investigation is necessary to ensure that certification is complete for these systems.

6. NOTES.

6.1 Intended use.

This handbook provides guidance on the certification of alternative fuels, fuel alternates, and fuel additives.

6.2 Subject term (key word) listing.

Alternative fuels

JP-8

Synthesized Paraffinic Kerosene (SPK)

Hydroprocessed Renewable Jet (HRJ)

Hydroprocessed Esters and Fatty Acids (HEFA)

Alcohol-to-Jet (ATJ)

6.3 Changes from previous issue

Marginal notations are not used in this revision to identify changes with respect to the previous issue due to the extent of the changes. Major changes include the following:

1. Addition of a public releasable version of the Requirements Decomposition Matrix to Appendix A (similar to that included in MIL-HDBK-510-2), which allows cancellation of MIL-HDBK-510-2 because it becomes redundant.

2. Updates to the Tables and Figures of Appendix C.

3. Added lessons learned to Appendix J addressing piggyback testing, changing the fuel specification, getting authority to task, and managing test fuel logistics.

4. Updates of the Streamlined Certification Process described in Appendix N.

5. Addition of a new Appendix O, “EVALUATION OF COMMERCIAL FUEL SPECIFICATION CHANGES.”

APPENDIX A

REQUIREMENTS DECOMPOSITION AND TRACEABILITY

A.1 SCOPE.

A.1.1 General.

This Appendix contains a discussion of the process of requirements decomposition of airworthiness certification criteria as defined in MIL-HDBK-516 "Airworthiness Certification Criteria" traced to requirements in the JSSG as well as other military specifications and handbooks for support equipment, ground refueling equipment, and logistical infrastructure. The concept of using a "Systems Engineering V", as described on Figure A-1, should be used as the approach for decomposing requirements. This concept identifies requirements at the highest level then traces them to lower level requirements. Additionally, properties should be identified for each requirement. Finally, based on the results of the certification process identified in Appendix B, risks are identified and fuel applicability is assessed.

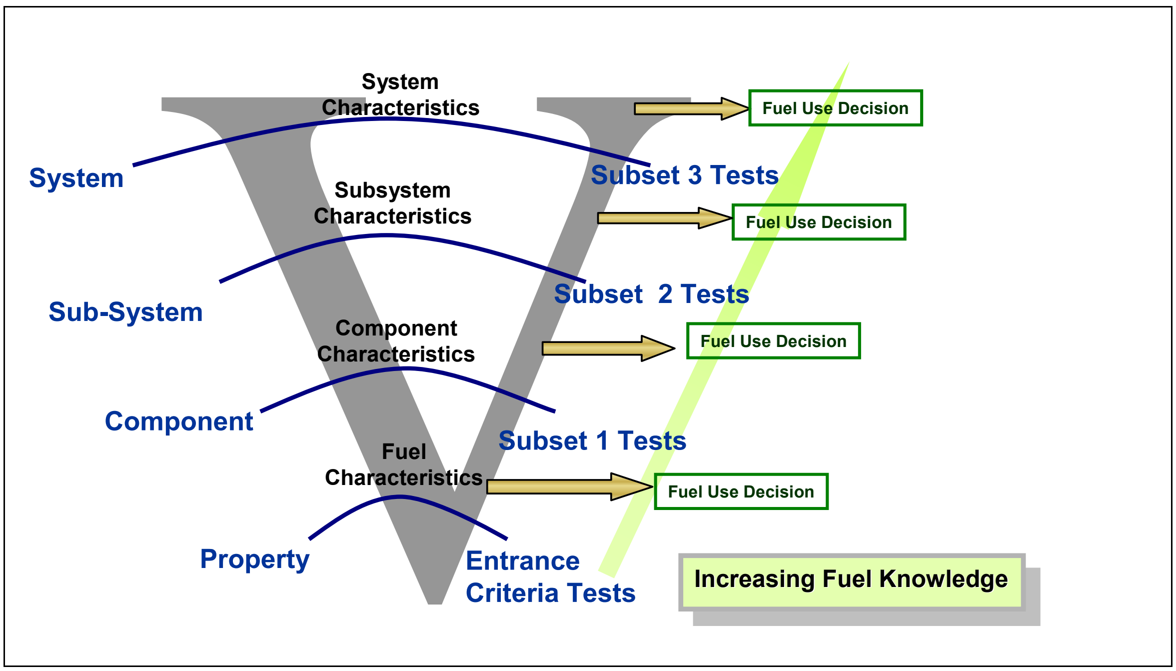


FIGURE A-1. Functional system decomposition.

A.2 APPLICABLE DOCUMENTS.

A.2.1 General. Applicable documents that identify requirements for OSS&E should be used to identify requirements and verification methods that may be affected by a change in fuel type or fuel configuration. The JSSG can be used to provide requirements and detailed guidance for requirements and verification methods, which are described in each JSSG appendix. A list of recommended documents for various systems is identified.

A.2.2 Government documents.

A.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards and handbooks form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE SPECIFICATIONS

AFGS-87139	Landing Gear Systems
AFGS-87233	Support Systems and Equipment

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-464	Electromagnetic Environmental Effects, Requirements for Systems
MIL-STD-1787	Aircraft Display Symbology

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-516	Airworthiness Certification Criteria

(Copies of these documents are available on line at http://quicksearch.dla.mil/.

JOINT SERVICE SPECIFICATION GUIDES COMPACT DISC (JSSG CD)

(This product is available from email Engineering.Standards@us.af.mil.)

A.2.2.2 Other Government documents, drawings, and publications. The following other Government publications provide additional information related to the fuels certification process and are included in this document for information.

DoD 4140-25	DoD Management of Bulk Petroleum Products, Natural Gas and Coal

(Copies of the above document is available on line at http://www.dtic.mil/whs/directives/corres/pub1.html.)

UFC 3-460-03	Operation and Maintenance: Maintenance of Petroleum Systems
UFGS-09 97 13.17	Three Coat Epoxy Interior Coating of Welded Steel Petroleum Fuel tanks

(Copies of these documents are available on line at http://www.wbdg.org/ .)

EO13423	Strengthening Federal Environmental, Energy, and Transportation Management

(Copies of this document are available on line at https://www.fedcenter.gov/programs/eo13423/.)

TR-89-D-22	USAAVSCOM, Aircraft Crash Survival Design Guide

(Copies of the above document are available on line at http://www.dtic.mil/dtic/.

UNITED STATES AIR FORCE TECHNICAL ORDER (TO)

TO 42B1-1-1	Fuels for USAF Piston and Turbine Support Equipment and Administrative Vehicles

(Copies of the above documents can be requested at https://www.my.af.mil/etims/ETIMS/index.jsp.)

A.2.3 Non-Government publications.

SAE INTERNATIONAL

SAE ARP 1256	Procedure for the Continuous Sampling and Measurement of Gaseous Emissions from Aircraft Turbine Engines
SAE ARP 1258	Qualification of Hydraulic Tube Joints to Specified Flexure Fatigue Requirements

(Copies of these documents are available on line at www.sae.org or approved users may access the documents on line at http://www.global.ihs.com/.)

A.3 DEFINITIONS.

A.3.1 Alphabetical listing of terms and definitions.

Derived Requirements: Characteristics needed to complete the requirements set for item design that are dependent on the nature of the item solution for their initial identification and have a functional relationship to each other. Derived requirements show the traceability from higher general system level requirements to detailed requirements.

Requirements Decomposition: For this handbook, requirements are broken down into parts from source requirements documents, (e.g., JSSG, etc.) until the relevant fuel properties/characteristics are identified.

A.4 DECOMPOSITION PROCESS.

The process for identifying fuel properties associated with all applicable requirements can be developed using the following process. The flow chart describing this process is depicted on Figure A-2. Figure A-3 is an embedded file, referred to herein as "the matrix," which documents the results of the decomposition process. The embedded file will launch when the icon is double-clicked.

A.4.1 Use of the matrix.

The primary purpose for the matrix is to provide reminders of what should be considered when evaluating a fuel for certification. It can act as a checklist to ensure that important aspects of the certification evaluation are not overlooked or forgotten. The matrix was derived from MIL-HDBK-516 and relevant JSSGs by the appropriate Subject Matter Experts (SMEs) using the knowledge available at the time. For the sake of completeness, it includes all criteria even though some were judged by the SMEs to be not applicable to fuel, and identified as such in the "Applicable (Y/N)" column. This matrix should be reviewed for each candidate fuel 1) to ensure that no new criteria or requirements are affected because of a unique characteristic of a new fuel and 2) to determine the applicability of each of the listed criteria to the particular candidate fuel being evaluated. Experience has shown that a large number of criteria are not applicable to "drop-in" fuels, and these need not be addressed by fuel certification efforts. For some criteria, equivalence of fuel properties between the baseline fuel and the candidate fuel will satisfy the requirement. For others, the complexity of the interactions between properties will not allow simple comparison of properties to satisfy the requirement. In such cases, some kind of functional or performance test or analysis will be needed to validate that a requirement has been met.

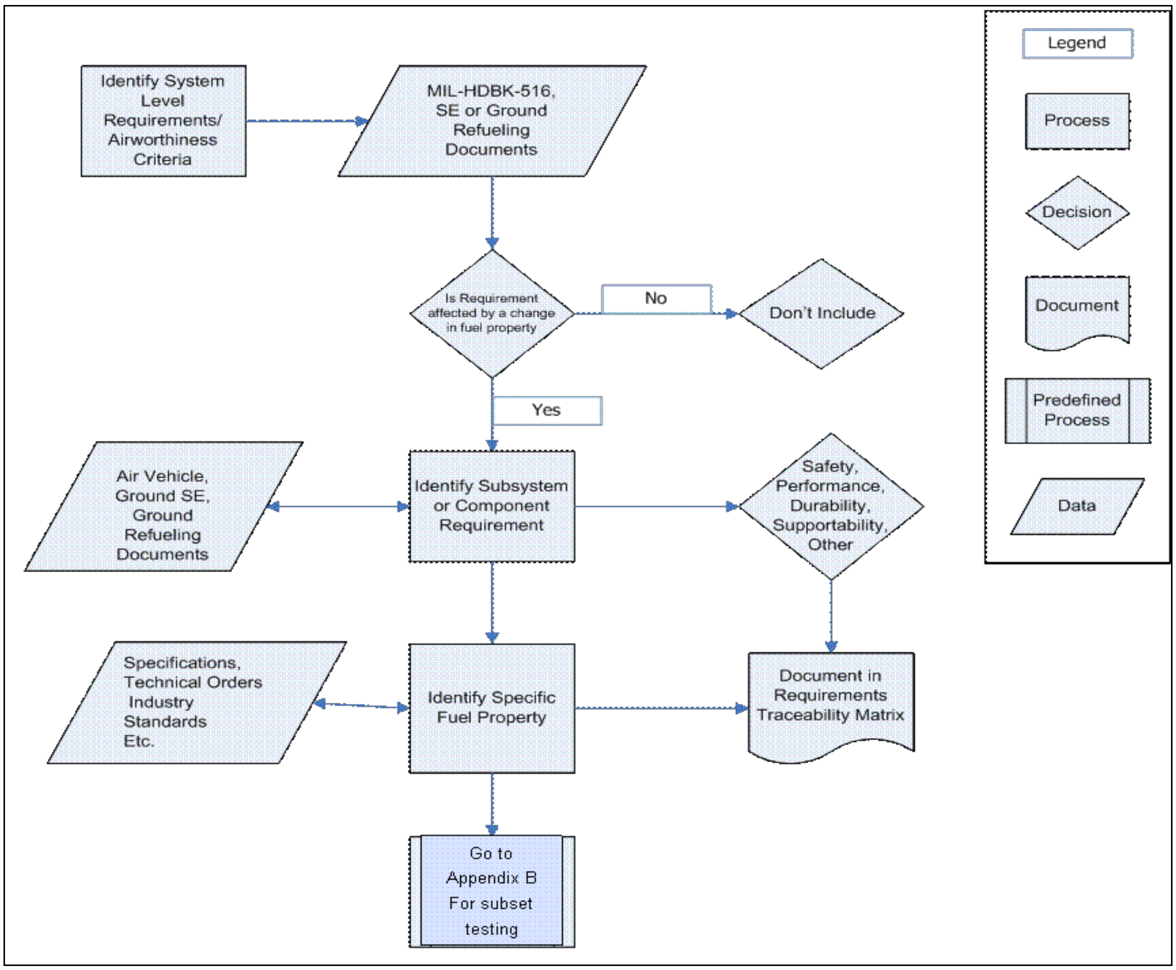


FIGURE A-2. Requirements decomposition and traceability.

(Double-click the icon, above, to view the contents in a PDF file.)

FIGURE A-3. Results of the decomposition process.

APPENDIX B

FUEL PROPERTIES/CHARACTERISTIC TESTING

B.1 SCOPE.

B.1.1 General.

This Appendix defines where each fuel property/characteristic belongs and the significance of its placement in the fuels certification process. This Appendix also includes component tests that should be conducted to further evaluate the candidate fuel for those attributes that cannot be directly related to a fuel property. In the initial creation of this handbook, United States Air Force Subject Matter Experts (SMEs) evaluated all fuel properties and characteristics based on the requirements decomposition process that correlated requirements to safety, performance, durability, and supportability, as described in Appendix A. The properties and characteristics were further categorized according to the number of times a property or characteristic affected a requirement and the experiences of the handbook authors.

B.2 APPLICABLE DOCUMENTS.

B.2.1 General.

The documents listed below are not necessarily all of the documents referenced herein but are those needed to fully understand the information provided by this handbook.

B.2.2 Government documents.

B.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-83133	Turbine Fuels, Aviation, Kerosene Types, JP-8, (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37)
AFGS-87233	Support Systems and Equipment

(Copies of these documents are available on line at http://quicksearch.dla.mil/.)

B.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein.

ASTM INTERNATIONAL

ASTM D975	Standard Specification for Diesel Fuel Oils

SAE INTERNATIONAL

SAE ARP1247 Aircraft Ground Support Equipment – General Requirements

(Approved users may access these documents on line at http://global.ihs.com/standards.cfm?publisher=ASTM&RID=Z06&MID=5280 . They are also available at www.astm.org and www.sae.org.)

B.3 DEFINITIONS.

B.3.1 Alphabetical listing of terms and definitions.

Entrance Criteria: Key information required to make a determination whether to initiate the fuel certification process. All fuel candidates need to meet the general characteristics of a kerosene fuel that meets safety, performance, durability, and operational characteristics comparable to the baseline fuel.

SE&V: Support Equipment and Vehicles, all deployable aircraft support equipment on the ground including vehicles, powered equipment such as air conditioners, fuel handling equipment, including flight line and deployable assets.

Subset 1 Testing: Fuel properties/characteristics critical to personnel safety, system safety, and/or system performance.

Subset 2 Testing: Fuel properties/characteristics critical to system performance and/or durability. This second subset also contains component level tests that do not directly correlate to a fuel property.

Subset 3 Testing: Fuel properties/characteristics critical to the system durability, and supportability requirements.

B.4 ENTRANCE CRITERIA AND FUEL PROPERTIES/CHARACTERISTIC SUBSET TESTING.

B.4.1 Entrance Criteria.

Key information is required for the FCO to make a determination whether to initiate the certification process. All fuel candidates need to meet the general characteristics of a kerosene fuel that meets safety, performance, durability, and operational characteristics comparable to the baseline fuel. The intent is to compare the new fuel or fuel additive to the baseline fuel and assess the potential to incorporate the new fuel into the appropriate military fuel specification or to create a new military specification. To warrant consideration, the candidate fuel or fuel additive need to provide some anticipated worthwhile benefit, for example: 1) expand fuel logistical availability in an expeditionary operation or 2) meet or exceed weapon system performance, durability, operational characteristics, or improve logistics or 3) be produced from a domestic alternative or unconventional resource. Data will be provided to the FCO to prove technical maturity of the fuel or fuel additive including test reports, technical data, property lists, information on the resource and processing used to make the fuel or additive, and information on the environmental, safety, and health aspects. In addition, information on the economic viability of the fuel or additive should be provided to the FCO. This information should include cost and time estimates for production, volume of fuel or additive that can be produced, any requirements for special handling or logistics, environmental impacts, and general production information.

B.4.1.1 The Entrance Criteria definition. The entrance criteria are determined by the following, and failure to meet the provided pass criteria could constitute rejection of the fuel. As a minimum the following fuel property or fuel characteristics data should be provided (at the maximum intended blend ratio of the new component, if the candidate is a blend with conventional petroleum fuel).

1. A chemical description of the fuel, Gas Chromatograph (GC) to include molecular composition. Test Method and Pass Criteria are defined in Appendix C.
2. Safety Data Sheet (SDS) issued by the supplier.
3. Environment, Safety, and Occupational Health (ESOH) review.
4. All property tests as required by appropriate military fuel.
5. The fuel properties defined in Table B-I are related to system safety. Failure to meet the provided pass criteria should constitute rejection of the fuel.

TABLE B-I. System-safety related fuel property/characteristic.

Fuel Property and Significance	Test Method	Pass Criteria
Flash Point, affects combustibility. It is also a leading factor determining fire safety in fuel handling.	Appendix C	Temperature Range: 28°C to 68°C
Freezing Point, affects low temperature fuel behavior. It can cause issues with pumps and nozzle operations.	Appendix C	Max -40°C
Viscosity @ -20 °C, affects pumpability over the operating temperature range. It also relates to droplet size in sprays produced by burner nozzles.	Appendix C	Max 8.0 cSt

B.4.2 Subset 1 fuel property/characteristics. Subset 1 fuel properties/characteristics are critical to personnel safety, system safety and/or system performance.

B.4.2.1 Subset 1 fuel property/characteristic tests. The following Fuel Property/Characteristic tests as described in Table B-II should be conducted to characterize the fuel:

TABLE B-II. System safety and performance related fuel properties.

Fuel Property/Characteristic and Significance	Test Method and Evaluation Criteria
VOLATILITY	
Autoignition Temperature, a factor determining fire safety.	Appendix C
Vapor Pressure, True, versus Temperature indicates venting loss of light ends at altitude and in hot climates. Also relates to cold starting. Affects vapor losses, vapor lock effects on pumping, and engine starting characteristics.	Appendix C
Hot Surface Ignition, lowest temperature required for spontaneous ignition of a substance by a hot surface. Affects fire protection design.	Appendix C
Flame Speed affects personnel safety during fire emergency and fire protection design.	Appendix C
COMBUSTION	
Flammability Limits, affects propulsion system, fuel systems design, fuel tank safety design, and fire protection design.	Appendix C
FLUIDITY	
Viscosity versus Temperature (-40 ^{0}C to 60 ^{0}C), affects pumping fuel over the operating temperature range. Relates to droplet size in sprays produced by burner nozzles.	Appendix C
Density versus Temperature (-40 ^{0}C to 60 ^{0}C), affects aircraft weight and balance calculations. Also relates to specific energy, thermal expansion, flow calculations, fuel gauging, and metering devices.	Appendix C
Bulk Modulus versus Pressure, measure of the compressibility of a fluid. Important factor in servomechanisms, where natural frequency of the system is directly proportional to the square root of the bulk modulus. Affects diesel engine injection system operation.	Appendix C

TABLE B-II. System safety and performance related fuel properties - Continued.

Fuel Property/Characteristic and Significance	Test Method and Evaluation Criteria
CONTAMINANTS	
Water Solubility affects the ability to absorb water. *Trace Elements* affects propulsion system hot section and thermal stability.	Appendix C Appendix C
ELECTRICAL CHARACTERISTICS	
Dielectric Constant versus Density versus Temperature (-40 ^{0}C to 90 ^{0}C), direct effect on accuracy of dielectric compensated gauging systems.	Appendix C
OTHERS	
Lubricity refers to the effectiveness of lubricating moving parts such as pumps and control units.	Appendix C
Additive Compatibility, important in the compatibility and performance of approved DoD Fuel Mandatory Additives.	Appendix C
Storage Stability affects shelf life and determination of peroxide formation.	Appendix C
Specific Heat versus Temperature (-40 ^{0}C to 150 ^{0}C), the amount of heat-energy that a fuel can absorb at a specific temperature, recorded in kJ/kg K., direct impact to the amount of heat that the fuel can absorb, critical to heat exchanger design.	Appendix C
Surface Tension versus Temperature (-10 ^{0}C to 40 ^{0}C), important in gas evolution and solubility. It also affects atomization characteristics of the fuel and hence combustion.	Appendix C
Thermal Conductivity versus Temperature (30 ^{0}C to 200 ^{0}C), refers to effectiveness of fuel as primary heat sink.	Appendix C

B.4.2.2 Component level evaluation Subset 1.

B.4.2.2.1 Auxiliary and Emergency Power Units (APU/EPU) evaluation. Auxiliary Power Units and EPUs that perform an in-flight emergency function should be evaluated for impacts that may affect their ability to start and operate at anticipated pressure altitudes and thermally soaked conditions. Differences in key fuel property characteristics that influence fuel supply pressure, atomization, vaporization, and ignition would be indicators of the need for additional component and or unit level evaluations. Key properties for assessment would include but not be limited to flash point, flammability, freezing point, viscosity, and vapor pressure.

B.4.2.2.2 Support Equipment and Vehicles (SE&V).

B.4.2.2.2.1 SE&V certification process. This section provides information to aid in the determination of a fuel's suitability for use in the compression ignition (CI) engine fleet of US military support equipment and vehicle fleet. It is intended to provide the FCO and SM a methodology to identify, evaluate, and mitigate safety, performance, durability, and supportability risks associated with a candidate fuel for the SE&V.

Currently there are 133 engine models, 247 vehicles, and 50 types of support equipment. Clearly a new fuel cannot be tested in each application without incurring high costs or be limited due to availability of the test fuel. An approach to this problem is to select a test engine or engine component which is known to be sensitive to fuel properties. For example, a database of US Air Force SE&V has been built which captures the technical description of the engines and fuel systems. The database is used to identify engines or engine subsystems which are known to be sensitive to a particular fuel property and selected as a test article in the subset testing.

B.4.2.2.2.1.1 Fuel functions. SE&V rely on fuel for three purposes: 1) provide heat of combustion for power generation in diesel type engines and spray combustion heaters, 2) lubricate fuel pumps and injection equipment, and 3) provide cooling for the fuel injection system.

B.4.2.2.2.1.2 Power generation. There are several steps as the fuel makes it way from the tank to the combustion chamber. Safely stored fuel in the tank has to be picked up by the transfer pump and conveyed to the injection pump, intermittently pressurized to high pressures, sprayed into the engine cylinder at the correct time and with the correct droplet size and spray pattern, vaporized, mixed with air and burned within the time available. To perform these functions it needs to have certain properties within acceptable ranges such as, vapor pressure, viscosity, lubricity, cetane index, density, and bulk modulus.

The fuel is also used in personal heaters which utilize a combustion can, spray nozzle, and spark ignition. The output of the combustor heats cabin air via a heat exchanger. The requirements imposed on the fuel for this application are similar to the turbine engine though not as critical.

B.4.2.2.2.1.3. Lubrication. The diesel engine fuel injection equipment is comprised of precision hardened and ground steel elements with extremely close tolerances. The fuel provides both hydrodynamic and boundary lubrication of these critical areas. The demands on the fuel to perform as a lubricant are higher for the diesel engine compared to the gas turbine application.

In hydrodynamic lubrication a journal rotates in a bearing shell, separated by an extremely thin film of oil. The journal is made of hardened steel which is carefully ground and polished. The bearing is made of a soft metal which, when it is installed, is designed to deform and conform to the shape of the journal. Thus a very small clearance is formed between the journal and the bearing. When the journal begins to turn it lifts slightly, creating a wedge shaped clearance. The oil is pumped, or dragged, into this wedge shaped space between the journal and bearing by virtue of its viscosity. Too low a viscosity will not lift the journal sufficiently, resulting in damage as the rotating surfaces will contact.

Not all moving parts can be designed to utilize hydrodynamic lubrication which except for startup, never contact each other. Boundary lubrication occurs when two surfaces contact each other without the benefit of the hydrodynamic layer maintaining separation. The property of a lubricant which applies in boundary lubrication is called lubricity. A lubricious fluid contains compounds which plate out on the surfaces and provide an interface between them. In effect the compound takes the wear, not the surfaces. The compound prevents the fusing, or galling, of the surfaces. Very low concentrations of the compounds can be effective as the layers can be only molecules thick. Additives are usually used to improve fuel lubricity to an acceptable level.

B.4.2.2.2.1.4 Heat removal. The fuel carries away heat generated by friction of the fuel injection system by returning the unused heated fuel to the fuel tank. The ability of the fuel to remove excessive heat relies on fuel properties such as specific heat, density, and thermal stability in extreme temperature conditions. The demands for the fuel to serve as a coolant in the diesel engine are not as severe as in the aircraft.

B.4.2.2.2.2 SE&V properties. In addition to the fuel properties for air vehicles the following are of significance to SE&V:

Flash Point, same as for air vehicles systems.

Cetane Number and Cetane Index, indicators of the diesel ignition quality of a fuel (see also C.9 and C.10). Operation on a fuel with too low a value can introduce cold starting issues and possible damage due to overstressing the structure which will immediately damage the engine. A Cetane Number minimum of 37 provides protection from over-stressing the diesel engine structure. Cetane Index is based on a correlation between cetane number and distillation data for a typical petroleum-based hydrocarbon fuel. Cetane index is a quick calculation based on a specific fuel chemistry (petroleum) to give a surrogate of running a cetane engine to obtain cetane number. However, for some synthetic fuels, such as Sasol SPK and Gevo ATJ, the cetane number is very low (mid 20s for Sasol SPK and high 10s for ATJ) while the cetane index is in the 50s. The cetane index for those fuels is not useful for providing protection for diesel engines, making the cetane number the appropriate property to use.

Lubricity, for compression ignition engines, BOCLE scar diameter less than 0.65 mm is needed to protect the injection system.

Viscosity @ 40°C, affects hydrodynamic lubrication of the fuel injection system. For jet fuels used in compression ignition engines in SE&V applications, low viscosity at higher temperatures can damage parts that use the fuel as a lubricant. Typically it is highly desirable to have a viscosity at +40°C somewhere between 1.9 cSt (mm2/s) and 4.1 cSt. For unlimited use, viscosity consistent with ASTM D975 should be greater than or equal to 1.3 centistokes at 40°C. Viscosities below 1.2 centistokes could show an increasing degree of damage over time. Viscosities below 1.0 may limit durability to such a degree that failure could occur in a very short time. (These values apply to SE&V procured after 2007.)

Freezing Point, same as for air vehicles systems.

Viscosity @ -20 °C, same as for air vehicles systems. Viscosities at cold temperatures are not limited in diesel fuel, but their importance to turbine operation and the limits imposed on jet fuel produce no problems for SE&V applications at cold temperatures when they use jet fuel.

Vapor Pressure, True versus Temperature, same as for air vehicles systems.

Flammability Limits, same as for air vehicles systems.

Heat of Vaporization, same as for air vehicles systems.

Heat of Combustion, impacts Brake Specific Fuel Consumption (BSFC) of engines and heat output of heaters.

Density, same as for air vehicles systems, and affects the injection spray penetration.

Sulfur weight %, leads to the formation of acids which need to be neutralized by the engine lubricant additives to prevent corrosive attack. Sulfur compounds destroy catalytic exhaust after-treatment devices if the engine is so equipped.

B.4.2.2.2.2.1 Subset 1, safety and performance testing. The lubricity test method correlation and MIL-PRF-25017 CI/LI response is given by the following. The BOCLE (Ball on Cylinder Lubricity Evaluator) lubricity test, ASTM D5001, although not required in the JP-8 specification, is routinely reported for JP-8 as the BOCLE test method was originally devised for turbine engine applications. A different lubricity test, the HFRR (High Frequency Reciprocating Rig) at 60°C, ASTM D6079, is the specification requirement given in ASTM D975 for diesel fuel. Generally commercial diesel engines are approved by their manufacturer for use on grade 1-D diesel fuel. Manufacturers' warranties allowing the use of JP-8 generally require the fuel to meet the grade 1-D diesel fuel requirements for cetane number, viscosity at +40°C, and lubricity.

B.4.2.2.3 Additional equipment evaluations. The SM will initiate the risk assessment process and determine if additional component related evaluation/testing should be accomplished.

B.4.3 Subset 2 fuel properties/characteristics. Subset 2 fuel properties/characteristics are critical to system performance and/or durability. This second subset also contains component level tests that do not directly correlate to a fuel property.

B.4.3.1 Subset 2 fuel property/characteristic tests. The following Fuel Property/Characteristic Tests as described in Table B-III should be conducted to further characterize the proposed fuel:

TABLE B-III. System performance related fuel properties/characteristics.

Fuel Property/Characteristic and Significance	**Test Method and Evaluation Criteria**
Hot Surface Ignition, under turbulent airflow lowest temperature required for spontaneous ignition of a substance by a hot surface. Affects fire protection design.	Appendix C
Thermal Expansion, another approach in showing the effect of temperature on the density of a fluid. Important to fuel tank ullage.	Appendix C
Ignition Energy, Minimum the least amount of energy required for a spark discharge to ignite an optimum stoichiometric mixture. Critical to fire safety. (Can be tested simultaneously with flammability limits.)	Appendix C
Ostwald Coefficient, determines solubility of gases (Oxygen, Nitrogen) in fuel. Affects design of fuel pumps.	Appendix C
Cetane Number, affects diesel engine performance.	Appendix C
Electrical Conductivity versus Temperature *(-40 ^{0}C to 90 ^{0}C)*, particularly important with regards to logistical issues when the fuel needs to dissipate static electricity which has built up during transportation.	Appendix C
Velocity of Sound, used by some fuel quantity gauging systems and as a method for determining Bulk Modulus when used with Density.	Appendix C

B.4.3.2 Critical component level evaluation Subset 2.

B.4.3.2.1 APU and Emergency Power Unit (EPU) evaluation. Fuel characteristics that may impact durability, such as thermal stability's influence on nozzle coking, should also be considered for their potential impact to the system's in-flight operability and reliability. Recommended evaluation methods may include combustor rig testing, unit level cold soaked altitude tests and/or field service evaluations. Units that perform ground only functions may be suited to analytical assessments along with field service evaluations.

B.4.3.2.2 SE&V. In addition to the fuel properties for air vehicles the following are of significance to SE&V:

Cetane Number, a measure of the ignition quality of a fuel in a diesel engine as determined in an actual engine. Value can differ from cetane index if the fuel is a non-hydrocarbon, and/or has a discontinuous distillation curve.

Bulk Modulus versus Temperature (-40 °C to +90°C), affects the compressibility of the fuel which impacts the fuel injection system ability to accurately deliver fuel to the engine cylinder with the correct timing.

B.4.3.2.2.1 Subset 2, performance verification.

Evaluate the impact of the new fuel on pump performance by testing a representative pump(s) to determine its full capacity (flow rate, pressure) versus time.

Determine the impact of the new fuel on engine performance by performing dynamometer testing of a representative engine(s) to assess the effect of the new fuel on engine full power, fuel consumption, exhaust emissions, noise, and idle stability.

Determine the impact of the new fuel on engine cold start performance by evaluation of a representative engine(s) installed in a cold test chamber or at a cold weather location.

Determine the impact of the new fuel on US military portable heater cold start performance by testing a representative heater installed in cold chamber or at a cold weather location.

B.4.3.2.3 Additional equipment evaluations/testing. The SM will continue to assess the system risk and determine if additional component and/or subsystem level evaluation/testing should be accomplished.

B.4.4 Subset 3 fuel properties/characteristics. Subset 3 is composed of fuel properties and characteristics that are critical to the system durability and supportability requirements.

B.4.4.1 Subset 3 fuel property/characteristic tests. The following Fuel Property/Characteristic tests as described in Table B-IV should be conducted to further characterize the fuel:

TABLE B-IV. System durability and supportability related fuel properties/characteristics.

Fuel Property/Characteristic and Significance	Test Method
Enthalpy versus Temperature (0 ^{0}C to 250 ^{0}C), affects the ability to cool fuel wetted components	Appendix C

B.4.4.2 Critical component level evaluation Subset 3.

B.4.4.2.1 Fuel System Icing Inhibitor (FSII) rig test. Conduct FSII additive concentration performance rig test with candidate fuel or blends per Appendix C.

B.4.4.2.2 SE&V Evaluation. In addition to fuel properties for air vehicles the following are of significance to SE&V:

Thermal Stability, same as for air vehicle systems.

Thermal Conductivity, same as for air vehicle systems.

Specific Heat versus Temperature (-40 °C to +150 °C), same as for air vehicle systems.

B.4.4.2.2.1 Subset 3 performance/durability/supportability verification. The third subset tests for diesel engines are long-term engine durability testing which could be conducted on engine dynamometer and vehicle fleet studies. Long-term tests, such as a captive fleet test, Engine Manufactures Association 400 Hour Endurance Test or the Army's 210 Hour Wheeled Vehicle Test Cycle, will reveal issues of fuel, lubricant, and engine interactions.

Determine the impact of fuel on injection pump durability by performing an injection pump rig test of 500 hour duration. Poor lubricity and or low viscosity will result in fuel delivery decreasing below established minimum or complete failure of the pump before 500 hours.

Perform a High Temperature Engine Durability Test with operation of an engine at a high temperature condition to determine the engine/fuel/lubricant interactions.

B.4.4.2.2.2 Field test management

A cognizant, government entity and/or prime contractor will manage a field test of candidate fuels to ensure the approach, resources, and processes associated with the field test will enable successful completion of the effort. Effective and organized management practices will provide the necessary personnel, facilities, equipment, and materials, and provide scientific and technical expertise to conduct the field test on schedule and within the prescribed budget. Management of a candidate fuel field test from both the managerial and technical perspectives will include, but not be limited to, the following activities:

B.4.4.2.2.2.1 Administration

1. General oversight and coordination with all field test stakeholders
2. Generating and maintaining schedules with associated planning software tools
3. Generating financial projections and managing the field test budget throughout execution
4. Coordinating and conducting periodic test reviews

B.4.4.2.2.2.2 Planning

1. Generating and updating a Test Plan to be utilized as a primary guide to executing a field test of candidate fuels. The Test Plan includes, but is not limited to, Technical Performance Measures (TPM), field test locations, test periods, preparation requirements, and execution activities as described below.
2. Proactive communications and coordination with stakeholders at field test locations

B.4.4.2.2.2.3 Preparation

1. Coordination of candidate fuel supply(amount) and delivery
2. Coordination of SE&V selection and preparation (see B.4.4.2.2.4 & B.4.4.2.2.5)
3. Coordination of preparation of test site fuel distribution infrastructure (see B.4.4.2.2.4 & B.4.4.2.2.5)

B.4.4.2.2.2.4 Execution

1. Collect and archive data on dates/times of operation of individual pieces of SE&V involved in the field test
2. Collect and archive data on environmental conditions for individual pieces of SE&V involved in the field test
3. Collect and archive fuel usage rates
4. Collect and archive information and observations on candidate fuel performance during use and handling from operators, maintainers, fuel managers, etc. on a scheduled/routine basis
5. Collect and archive SE&V maintenance information
6. Continuous coordination and communication with test site POCs

B.4.4.2.2.2.5 Data compilation and analysis

Data, information and observations collected during field test execution is organized, quantified, and analyzed to clearly show performance of a candidate fuel.

B.4.4.2.2.2.6 Field test documentation

Generating and coordinating requisite documentation to allow informed decisions on candidate fuel certification and approval for use in the USAF

B.4.4.2.2.3 Field testing location selection and coordination

An optimum location for each military Service to conduct a field test of candidate fuel in SE&V should have the following attributes:

1. The field testing location experiences wide seasonal weather variations or extremes.
2. The mission(s) of the field testing location requires a number of different SE&V.
3. The facilities at the test location are largely representative of fuel delivery infrastructure common to most of the military Service's bases.
4. Optimally, aircraft located at the field testing location are also being tested with the candidate fuel, making it readily available.

If a single optimum site is not readily available or feasible, two host sites may be used to conduct the demonstration. Given a divergence of missions and locations, the use of two field testing sites will ensure a diversity of SE&V and operational conditions and environments. Ideally, one demonstration site will have a northern climate (cold), and one will have southern/desert (hot) climate.

The use of two sites will also leverage a larger pool of available pieces of equipment and vehicles, which will potentially decrease the demonstration time. Moreover, different mission requirements (deployments) will reduce the potential for operational requirements to impact availability of the designated testing SE&V. While it is best to conduct field testing of a candidate fuel at a base location already flying aircraft on candidate fuel, that scenario may not be feasible, and the use of two field test locations utilizing the different fuel transportation/distribution avenues will allow flexibility in the testing schedule.

Other considerations when selecting a demonstration site:

1. Previous experience conducting field demonstrations.
2. Fuel management personnel with broad operational experience and a strong willingness to support the demonstrations.

Hosting test site stakeholder organizations are critical to the success of the project and should be contacted through meetings and/or discussions to coordinate requirements, approaches/methods, and support for the field tests. Coordination will focus on identification of the selected pieces of equipment, fuel infrastructure preparation and use, and the data collection methods employed.

B.4.4.2.2.4 SE&V selection

The primary source of information used in determining the SE&V for a field test of a candidate fuel is the organization responsible for management of each military Service's SE&V. For example, the Air Force SE&V database (as stated in Para B.4.2.2.2.1) is available and maintained at Warner Robins Air Logistics Center (WR-ALC). Use of the SE&V database ensures a given fleet test of a candidate fuel efficiently applies to the complete spectrum equipment and vehicles across the USAF. The information in the database includes a cross-indexed listing of USAF SE&V with associated engine data (specifications, fuel control system, usage locations etc.), national stock numbers (NSN), and other stakeholder-determined information. This information facilitates the selection of equipment and vehicles for testing covering all related engine types while reducing duplication. This will shorten timelines and reduce costs of fleet demonstrations while providing complete operational assessment to the SE&V System Manager.

Additionally, preliminary discussions for field testing preparation should occur between cognizant offices/personnel representing the Service's equipment mangers, and item managers to match the best candidate pieces of equipment and vehicles to utilize for the field test thereby ensuring the best data collection representative for the entire Service.

B.4.4.2.2.5 SE&V preparation

Standard equipment identification procedures for SE&V should be applied as follows. For flight line ground support equipment, each piece of equipment should be assigned a field number by the maintenance or transportation group. This particular field number designates each piece of equipment for refueling with the candidate fuel only, and establishes a system of controls for tracking usage. Each field number is uniquely specific to one particular piece of equipment at the respective base, therefore ensuring accurate fuel tracking. Similarly, each ground vehicle is issued a Registration Number that is associated with a Vehicle Identification Link (VIL) key that is used to identify the vehicle and operate the fuel pump during refueling operations. Those ground vehicles participating in the test demonstration will have their VIL keys turned over to the fuels personnel in order to ensure they are refueled exclusively from the candidate fuel tank. All fuel caps should be painted yellow and also marked "Refuel with Alternative Fuel Only" to alert those outside of the fuels group that special refueling requirements are in place for this vehicle.

1. Track and record fuel consumption of SE&V.
2. Maintain refueling vehicles in accordance with applicable Operators Manuals or Technical Orders.

3. Perform surveillance, quality control, and inspection of candidate fuel to insure compliance with Military Specifications.
4. Establish physical controls to ensure issue of candidate fuel to proper SE&V.
5. Record all applicable fuel transactions and reconcile daily, weekly, monthly and at the end of the year.
6. Implement proper candidate fuel security and environmental considerations.
7. Maintain all fuels processes identified in AFI 23-201 and the Fuels Technical Letter for Handling and Testing of Aviation Synthetic Fuels.

B.4.4.2.2.6 Base-level fuel storage and distribution infrastructure

In addition to demonstrating the use of new fuels in aircraft and SE&V, for a new fuel to be considered as successful, it should be tested at one or more sites representative of the fuel storage and delivery infrastructure to demonstrate its acceptable behavior. Certification of fixed fuels infrastructure is accomplished by each Service's organizations responsible for infrastructure management and control (e.g., for USAF by AFPA and AFCESA) IAW Appendix H of this Handbook. Personnel planning the SE&V demonstration will coordinate with these agencies to ensure facilities are compatible with the fuel being tested.

B.4.4.2.2.6.1 Fuel storage

Fuel storage capability will be determined in coordination with AFPA. If it is determined a fuel storage system is unavailable for use during the SE&V demonstration, AFPA will coordinate use of an R-11 refueler to support the demonstration.

B.4.4.2.2.6.2 Preparation procedures

1. The use of a candidate fuel in a field test should be nearly transparent to the fuel management operations when it is actually used to fill fuel tanks in various pieces of equipment or when used to run vehicles. In addition, the anticipated handling and control of the fuel by experienced Fuels personnel at a base should present no unforeseen problems. Test fuel integration/ conversion will be accomplished IAW the Fuels Technical Letter for Handling and Testing of Aviation Synthetic Fuels.

2. Although candidate fuels are similar to conventional fuels, they need to be segregated from base operational stocks to ensure the integrity of the SE&V demonstration.

3. It is important to carefully establish the introduction of candidate fuels into base fuels infrastructure and SE&V. Candidate fuels are subject to the same fire safety and general environmental standards as conventional fuels, and are transferred, stored, dispensed, and logistically handled with the same identical care as conventional fuels. However, because a candidate fuel is not yet certified for vehicles and equipment, the new fuel will be segregated from conventional fuel. Specific controls are necessary to limit when and how the candidate fuel is received, stored, distributed and accounted for as well as which vehicles and equipment are allowed to use the new fuel. Host fuels personnel will follow the instructions outlined in the Fuels Technical Letter for Handling and Testing of Aviation Synthetic Fuels when converting to/from conventional to candidate fuel.

Clipboards/lock keys will be strictly controlled to prevent accidental commingling or issue to non-test SE&V.

B.4.4.2.2.7 Base-level fuel management

Proper management of fuel on bases is critical to ensuring base operations continue uninterrupted and the military mission gets accomplished during field testing of a candidate fuel. Fuels management on a base is governed by a set of procedures that apply across the board when field testing uncertified fuels. When candidate fuels are introduced to a base, these fuel management policies still apply.

B.4.4.2.2.8 Operational performance and data/observation collection

B.4.4.2.2.8.1 Operational performance metrics

Technical Performance Measures (TPMs) identified for SE&V in field tests for candidate fuel should as a minimum include the following.

1. Engine performance: start-up, idle, power under load, shut-down
2. Fuel Efficiency
3. Maintenance Characteristics: leaks, filters, break-downs
4. Work Environment Characteristics: sound, vibration, smoke, odor

In the course of executing the field test, base personnel (equipment and vehicle operators and maintainers) should observe the performance of the SE&V operating on the candidate fuel, and compare its performance and operability to the conventional JP-8 baseline. Per the TPMs, operators/maintainers will observe and report candidate fuel effects on engine performance, fuel efficiency, and engine power in a range of operational conditions. Observed abnormalities, or evidence of changes in the vehicle's performance, fuel consumption, or engine power will be further investigated to determine the root cause of the problem(s). Operators/maintainers using the candidate fuel will also monitor any fuel leakage that might be the result of insufficient seal swell.

B.4.4.2.2.8.2 Data/observation collection

Performance information and fuel consumption logs for field test locations will be gathered weekly and stored in media such as a Microsoft Excel® spreadsheet. Operator observations will be gleaned from interviews and questionnaires. Ambient weather conditions (temperature and humidity) for equipment operational periods will also be gathered and maintained. Maintenance records such as the AFTO Form 244 for the demonstration SE&V should be reviewed, and then determine if the SE&V operating on the candidate fuel underwent less than, the same as or more scheduled and unscheduled maintenance than SE&V using JP-8/Jet A with military additives.

B.4.4.2.3 Additional equipment evaluations. The SM will continue to assess the system risk and determine if additional system level evaluation/testing should be accomplished. The SM should consider field service evaluations to monitor durability and service life, and in particular, the relationship between durability of pumps, sealants, finish systems, O-rings, etc.

APPENDIX C

BASELINE AEROSPACE FUEL PROPERTY INFORMATION

C.1 SCOPE.

The scope of this Appendix is to educate the reader on basic definitions, test methods and established values for each of the properties discussed in the Handbook. Listed within each property section below, in addition to the aforementioned items, are noteworthy comments and historical data, specific to the property or its known behavior in certain systems. Additionally, all of the properties in this section are presented in a table. This table is a rating value, consisting of a green, and in some cases, a yellow and a red weighting. These colors and their corresponding values have been established by AFMC SME to reflect “safe for use” (green values), “unknown if safe for use, more testing required” (yellow values), and “unsafe for use” (red values). These values have been created as a guide for the reader and are based on past experiences and prior fuel behavior knowledge.

Unless otherwise noted, the summaries of the ASTM Standards included in this Appendix have been written by the USAF. ASTM International has neither approved nor endorsed the summaries as written by USAF. The complete ASTM Standards may be purchased direct from ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428, phone: 610-832-9585, fax: 610-832-9555, e-mail: service@astm.org, website: www.astm.org.

C.2 APPLICABLE DOCUMENTS.

C.2.1 General. The documents listed below are not necessarily all of the documents reference herein, but are those needed to understand the information provided by this Appendix.

C.2.2 Government documents.

C.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

JOINT SERVICE SPECIFICATION GUIDES Compact Disc (JSSG CD)

(This product is available from the email Engineering.Standards@us.af.mil)

FEDERAL SPECIFICATIONS

FED-STD-791, Method 6053	Lubricants, Liquid Fuels, and Related Products, Testing Method of

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-5624	Turbine Fuel, Aviation, Grades JP-4 and JP-5
MIL-F-16884	Fuel, Naval Distillate
MIL-PRF-25017	Inhibitor, Corrosion / Lubricity Improver, Fuel Soluble, (NATO S-1747)
MIL-DTL-38219	Turbine Fuel, Low Volatility, JP-7

MIL-DTL-83133	Turbine Fuel, Aviation, Kerosene Type, JP-, (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37)

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-3004	Quality Assurance/Surveillance for Fuels, Lubricants, and Related Products

(Copies of these documents are available on line at http://quicksearch.dla.mil/.)

C.2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein.

UNITED STATES AIR FORCE TECHNICAL ORDERS AND REPORTS (TOs) (TRs)

TO 42B1-1-1	Fuels for USAF Piston and Turbine Support Equipment and Administrative Vehicles
TO 42B1-1-14	Fuels for USAF Aircraft

(Copies of the above documents can be requested at https://www.my.af.mil/etims/ETIMS/index.jsp.)

AFAPL-TR-73-54	Fuels and Lubricants Influence on Turbine Engine Design and Performance

(Copies of the above document are available on line at http://www.dtic.mil/dtic/.)

PQIS (Petroleum Quality Information System) 2013 Annual Report, Defense Logistics Agency, Energy

(Copies of the above document are available at the email: pqis@dla.mil.)

C.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein.

ASTM INTERNATIONAL

ASTM D56	Standard Test Method for Flash Point by Tag Closed Cup Tester
ASTM D86	Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure
ASTM D93	Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
ASTM D97	Standard Test Method for Pour Point of Petroleum Products
ASTM D129	Standard Test Method for Sulfur in Petroleum Products (General Bomb Method)-British Standard 4454
ASTM D130	Standard Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
ASTM D156	Standard Test Method for Saybolt Color of Petroleum Products (Saybolt Chromometer Method)

ASTM D323	Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method)
ASTM D381	Standard Test Method for Gum Content in Fuels by Jet Evaporation
ASTM D445	Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)-Designation: D 445–06; British Standard 2000
ASTM D613	Standard Test Method for Cetane Number of Diesel Fuel Oil
ASTM E659	Standard Test Method for Autoignition Temperature of Liquid Chemicals
ASTM E681	Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases)
ASTM D924	Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids
ASTM D971	Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method
ASTM D976	Standard Test Method for Calculated Cetane Index of Distillate Fuels
ASTM D1094	Standard Test Method for Water Reaction of Aviation Fuels
ASTM D1266	Standard Test Method for Sulfur in Petroleum Products (Lamp Method)
ASTM D1298	Standard Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
ASTM D1319	Standard Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
ASTM D1322	Standard Test Method for Smoke Point of Kerosine and Aviation Turbine Fuel
ASTM D1655	Standard Specification for Aviation Turbine Fuels
ASTM D1840	Standard Test Method for Naphthalene Hydrocarbons in Aviation Turbine Fuels by Ultraviolet Spectrophotometry
ASTM E2071	Standard Practice for Calculating Heat of Vaporization or Sublimation from Vapor Pressure Data
ASTM D2276	Standard Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling
ASTM D2386	Standard Test Method for Freezing Point of Aviation Fuels
ASTM D2622	Standard Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry

ASTM D2624	Standard Test Methods for Electrical Conductivity of Aviation and Distillate Fuels
ASTM D2779	Standard Test Method for Estimation of Solubility of Gases in Petroleum Liquids
ASTM D2887	Standard Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography
ASTM D3120	Standard Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry
ASTM D3227	Standard Test Method for (Thiol Mercaptan) Sulfur in Gasoline, Kerosine, Aviation Turbine, and Distillate Fuels (Potentiometric Method)
ASTM D3240	Standard Test Method for Undissolved Water in Aviation Turbine Fuels
ASTM D3241	Standard Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels (Jet Fuel Thermal Oxidative Test Procedure)
ASTM D3242	Standard Test Method for Acidity in Aviation Turbine Fuel
ASTM D3338	Standard Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
ASTM D3343	Standard Test Method for Estimation of Hydrogen Content of Aviation Fuels
ASTM D3701	Standard Test Method for Hydrogen Content of Aviation Turbine Fuels by Low Resolution Nuclear Magnetic Resonance Spectrometry
ASTM D3948	Standard Test Method for Determining Water Separation Characteristics of Aviation Turbine Fuels by Portable Separometer
ASTM D4052	Standard Test Method for Density and Relative Density Gravity of Liquids by Digital Density Meter
ASTM D4054	Standard Practice for Evaluating the Compatibility of Additives with Aviation Turbine Fuels and Aircraft Fuel System Materials
ASTM D4294	Standard Test Method for Sulfur in Petroleum and Petroleum Products by Energy-Dispersive X-Ray Fluorescence Spectrometry
ASTM D4529	Standard Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
ASTM D4737	Standard Test Method for Calculated Cetane Index by Four Variable Equation
ASTM D4809	Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)
ASTM D4952	Standard Test Method for Qualitative Analysis for Active Sulfur Species in Fuels and Solvents (Doctor Test)

ASTM D5001	Standard Test Method for Measurement of Lubricity of Aviation Turbine Fuels by the Ball-On-Cylinder Lubricity Evaluator (BOCLE)
ASTM D5006	Standard Test Method for Measurement of Fuel System Icing Inhibitors (Ether Type) in Aviation Fuels
ASTM D5191	Standard Test Method for Vapor Pressure of Petroleum Products (Mini Method)
ASTM D5304	Standard Test Method for Assessing Middle Distillate Fuel Storage Stability by Oxygen Overpressure
ASTM D5452	Standard Test Method for Particulate Contamination in Aviation Fuels by Laboratory Filtration
ASTM D5453	Standard Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
ASTM D5972	Standard Test Method for Freezing Point of Aviation Fuels (Automatic Phase Transition Method)
ASTM D6379	Standard Test Method for Determination of Aromatic Hydrocarbon Types in Aviation Fuels and Petroleum Distillates—High Performance Liquid Chromatography Method with Refractive Index Detection
ASTM D6793	Standard Test Method for Determination of Isothermal Secant and Tangent Bulk Modulus
ASTM D6890	Standard Test Method for Determination of Ignition Delay and Derived Cetane Number (DCN) of Diesel Fuel Oils by Combustion in a Constant Volume Chamber
ASTM D7111	Standard Test Method for Determination of Trace Elements in Middle Distillate Fuels by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
ASTM D7170	Standard Test Method for Determination of Derived Cetane Number (DCN) of Diesel Fuel Oils—Fixed Range Injection Period, Constant Volume Combustion Chamber Method
ASTM D7171	Standard Test Method for Hydrogen Content of Middle Distillate Petroleum Products by Low-Resolution Pulsed Nuclear Magnetic Resonance Spectroscopy
ASTM D7566	Standard Specification for Aviation Turbine Fuels Containing Synthesized Hydrocarbons

(Copies of these documents may be ordered on line at www.astm.org. Approved users may access the documents on line at www.ihs.com.)

"Data Book on Hydrocarbons, Application to Process Engineering," J. B. Maxwell, University of Michigan, 1950

"Effects of JP-8+100 Fuel on Fuel Gauging System Performance," BF Goodrich Aerospace, Military Fuels and Integrated Systems, CAGE Codes: 89305, 1995

"Handbook of Aviation Fuel Properties, 2004, Third Edition," Report No. 635, Coordinating Research Council, Inc. (CRC)

"Military Jet Fuels," C.R. Martel, AFWAL-TR-87-2062, USAF, November 1987

"Properties of Aircraft Fuels," Henry C. Barnett and Robert R. Hibbard, National Advisory Committee for Aeronautics (NACA), NACA 3276, August 1956.

"World Fuel Sampling Program," Hadaller, O., Johnson, J., Coordinating Research Council Report 647, June 2006.

"Variation of JP-8 Properties in CONUS and Potential Implications During Blending with Synthetic Paraffinic Kerosene (SPK)," Dewitt, M.; et al.; publication pending.

(Copies of these documents are available on line at http://www.dtic.mil/whs/directives/corres/dir.html.)

BRITISH DEFENCE STANDARD

British Defence Standard 91-91: Turbine Fuels, Aviation Kerosine Type, Jet A-1, NATO Code: F-35, Joint Service Designation: AVTUR, Ministry of Defence.

(Copies of this document are available on line at: http://www.dstan.mod.uk/closure_notice.html or https://www.gov.uk/uk-defence-standardization)

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

ISO-20823 Petroleum and Related Products -- Determination of the Flammability Characteristics of Fluids in Contact with Hot Surfaces Manifold Ignition Test - First Edition

(Copies of this document are available on line at www.ihs.com .)

C.3 BACKGROUND.

There is a long list of fuel properties that are relevant to the operation of Air Force systems. These properties are discussed in detail in this Appendix. Military Specification MIL-DTL-83133 controls a relatively small number of properties and describes permitted fuel additives. A number of these properties directly affect Air Force mission performance, such as density and heat of combustion. Some properties address operability (freezing point, low temperature, viscosity), safety (flash point, conductivity) and combustion behavior (hydrogen content, aromatics, smoke point). Many properties in the specification are included to ensure that the fuel has not become contaminated (particulates, existent gum, etc.). In general, the properties included in the specification are assessed by fairly simple, standardized "quality control" type of tests. Ensuring that a fuel is "fit for purpose" might require other, more complex tests. These types of tests are also included in this Appendix as well as other Appendices.

The fuel specification typically allows a range of property values, or specifies a maximum or minimum property value. Thus the specification provides the boundaries of a "box" that bounds the fuel composition. Kerosene fuels contain hundreds, if not thousands, of hydrocarbons - with the mixture varying with crude source and processing conditions. Thus, describing fuel properties becomes a statistical exercise. Fuel specification test results are compiled by the DLA Energy in the PQIS database. Summary reports are available from DLA Energy at PQIS@dla.mil. Available statistical data on properties are discussed in this Appendix and referenced as "PQIS database". The PQIS database actually only contains the test results of a subset of all the test measurements required by the specification. An excellent source of fuel property data is the CRC Report 635, Handbook of Aviation Fuel Properties. This report is typically referenced in this Appendix as "CRC, 2004". A third source of data referenced in this Appendix is CRC Report 647, "World Fuel Sampling Program, June 2006". Since the first version of this Handbook was published on 1 October 2007, ASTM D4054-09 was published – it is the commercial version of the alternative fuel approval process. In addition, ASTM D7566 has been published, with two annexes for alternative fuels. All of the documents will be referred to as sources of data or limits in Appendix C.

C.4 ACID NUMBER, TOTAL -- ENTRANCE CRITERIA.

C.4.1 Definition.

Acid number is a measure of the acidity of a fuel. It is the amount of potassium hydroxide (KOH) in milligrams required to neutralize (pH = 7) one gram of a substance. High acid numbers are not desirable in fuels. The higher the acid number, the greater the acidic property of the fuel which would correspond to a greater affinity of the fuel to negatively react with components.

C.4.2 Standard Acid Number Test Methods.

C.4.2.1 Acidity by ASTM D3242.

The fuel sample is dissolved in a mixture of toluene and isopropyl alcohol containing a small amount of water. The resulting single phase solution is blanketed by a stream of nitrogen bubbling through it and is titrated with alcoholic potassium hydroxide to an end point indicated by the color change of p-naphtholbenzein. Results are reported in mg KOH/g.*

* Reprinted, with permission, from *ASTM D3242: Standard Test Method for Acidity in Aviation Turbine Fuel*©, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428; www.astm.org.

C.4.3 Comments.

Acid level is related to how aggressively the fuel degrades components, hoses and nozzles in aircraft and logistical supply chain. Therefore it is best suited for a Subset 2 test which addresses durability. However, more research should be carried out to investigate possible safety links which would move it into a Subset 1 test. In the JP-8+100LT program in AFRL/RZPF (now AFRL/RQTF), it was found that a JP-8 additive that improved low-temperature fuel flowability caused the fuel to fail the acid number test. However, the fuel still passed the Jet Fuel Thermal Oxidative Test thermal stability test and showed no problems during combustion testing, so it was concluded that the acid number result was an artifact in this case. This test measures both strong and weak acids, so it has been suggested that the test might be modified to differentiate between the two, on the assumption that the "bad actors" would be the more-strongly-acidic species. Note that the Jet A specification requirement (<0.1 mg KOH/g) is different from the MIL-DTL-83133 specification (<0.015 mg KOH/g), although it is rare to find a Jet A fuel that exceeds 0.015 mg KOH/g. In a recent test program to evaluate material response to a fuel containing the maximum level permitted in Jet A, an existing low-acid fuel was treated with 133 mg/L m-cresol and 267 mg/L cyclohexylbutyric acid (400 mg/L total) to create a 0.1 mg KOH/g fuel. The testing found that the metallic and non-metallic materials on the short list (Appendix F) were unaffected by the 0.1 acid number fuel.

C.4.4 Data / Property Occurrence.

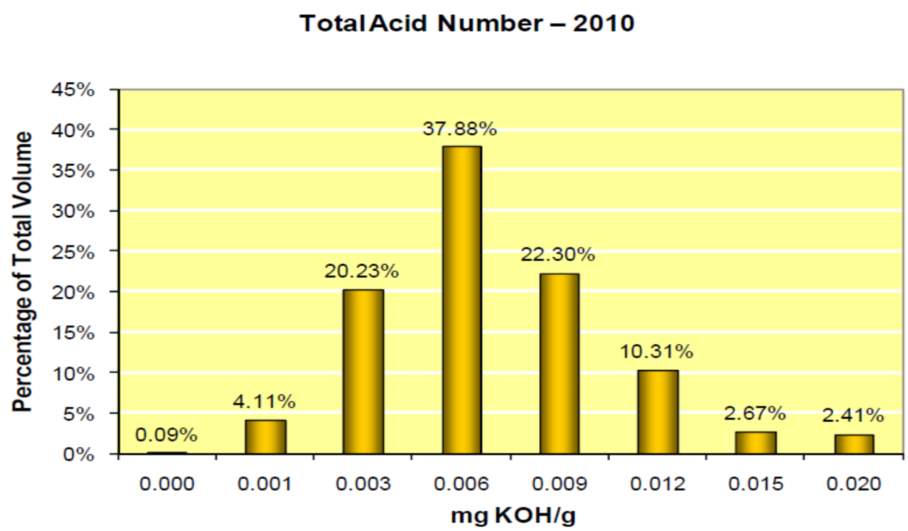


FIGURE C-1. Total acid number histogram JP-8 (2010) *taken from PQIS.*

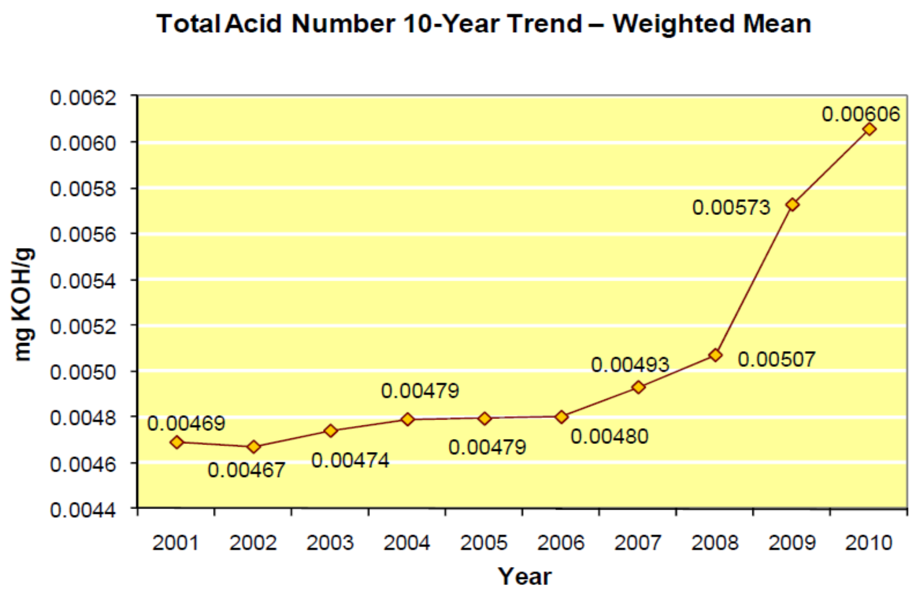


FIGURE C-2. Total acid number average JP-8 (year trend 2001-2010) taken from PQIS.[1]

[1] There are several plots in which trends of fuel properties are shown; statistical variances are deliberately excluded due to their complexity. However, a detailed discussion is presented in the paper titled, "Variation of JP-8 Properties in CONUS and Potential Implications During Blending with Synthetic Paraffinic Kerosene (SPK)" by Matthew Dewitt, et al.; Copies of this document are available from the Air Force Research Laboratory, AFRL/RQTF, Aerospace Systems Directorate, Fuels Branch, 1790 Loop Road, Bldg 490, Wright-Patterson AFB OH 45433-7251; (937) 255-2525; email AFRL.Office40a3c@us.af.mil.

TABLE C-I. Acid number, total fuel property rating value.

	New Fuel
R	>0.1
Y	0.015 to 0.10
G	0 to 0.015

TABLE C-II. Reserved.

C.5 ADDITIVE COMPATIBILITY – SUBSET 1.

C.5.1 Definition.

To increase certain performance characteristics of the fuel, or to mitigate certain risks possible with military missions using typical jet fuel, the USAF has certified use of various additives for its fuel. Any new fuel or additive that would be introduced into a USAF system needs to have the compatibility of that fuel / additive candidate tested with the currently used additives to ensure both physical compatibility (miscibility) as well as equal or better performance than baseline within the fuel.

C.5.2 Standard Additive Compatibility Test Methods.

C.5.2.1 Additive Compatibility by ASTM D4054. Tests are conducted with Jet A/A-1 fuel at four times the maximum additive concentration as recommended by the additive supplier for individual additives in the fuel and two times the maximum additive concentration for approved additive packages in new fuels. The samples need to pass ASTM D1655 requirements along with additional tests listed in ASTM D4054. The samples also will be evaluated with cold storage testing which consists of placing duplicate samples into dark cold storage (-17.8°C) for 24 hours and then inspecting for indications of precipitation, cloudiness, darkening, or other visual evidence of incompatibility. The samples are then warmed, remixed, and held at 38°C for 24 hours and then inspected again for the same evidence of incompatibility as the cooled samples. Similar tests are performed for additive to additive comparisons as well.

C.5.3 Comments. As noted in ASTM D4054, the use of some additives can adversely affect other fuel properties or the ground-handling systems for fuels. Application of procedures of this practice is intended to disclose these adverse effects. Additional, combination of additives may exhibit antagonistic effects on fuel properties or performance. Compatibility testing with previously approved additives is intended to disclose such antagonistic effects of incompatibilities. In most testing, the high-concentration FSII additive is typically the additive that fails this test. The level of FSII was reduced in MIL-DTL-83133H Amendment 1.

C.5.4 Data / Property Occurrence.

TABLE C-III. Additive compatibility fuel property rating value.

	New Fuel
R	Not Miscible
G	Miscible

TABLE C-IV. Reserved.

C.6 AROMATICS – ENTRANCE CRITERIA.

C.6.1 Definition. Aromatics are a class of hydrocarbons that are typically visualized as containing a six-carbon ring with alternating single and double bonds between the carbon atoms. Since aromatics are such a broad group of hydrocarbons, there exists a large variety of aromatics contained within traditional petroleum based jet fuels.

C.6.2 Standard Aromatics Test Methods.

C.6.2.1 Aromatic Content by ASTM D1319. Fuel is percolated through a column of silica gel containing special fluorescent dyes. When desorbed by alcohol, the fuel separates into three layers (olefins, aromatics and saturates (paraffins)) of differing hydrocarbon types which become visible under ultraviolet light. The relative length of each band is translated into the volume percent of each hydrocarbon type.

C.6.3 Comments. The minimum value needs to be evaluated. Ground support equipment placed an upper limit at 35%, consistent with operation with diesel fuel. The jet fuel aromatic specification AN-F-58a (JP-3) lowered the aromatic level to 25 vol% in March 1949, where it has remained. This was done to "control carbon-forming tendency" (presumably soot) [Barnett and Hibbard, 1956]. The lower limit is still unclear, although the Jet A-1 specification cites 8% in an appendix dealing with synthetic fuels (Def-Stan 91-91, Annex D). This limit is driven by elastomer swell issues. ASTM D7566 also uses the 8% lower limit for synthetic fuel blends. It has been suggested that continuing research on levels with less than 8% aromatics would be advisable, since millions of gallons of JP-8 are apparently burned each year with less than 8% aromatics, according to the PQIS database. ASTM D1319 is less accurate at low aromatic concentrations; ASTM D6379 is an alternative. ASTM D2425 and comprehensive two-dimensional gas chromatography (GCxGC) can be used to determine speciated aromatics (alkyl benzenes, indans/tetralins, etc.).

C.6.4 Data /Property Occurrence.

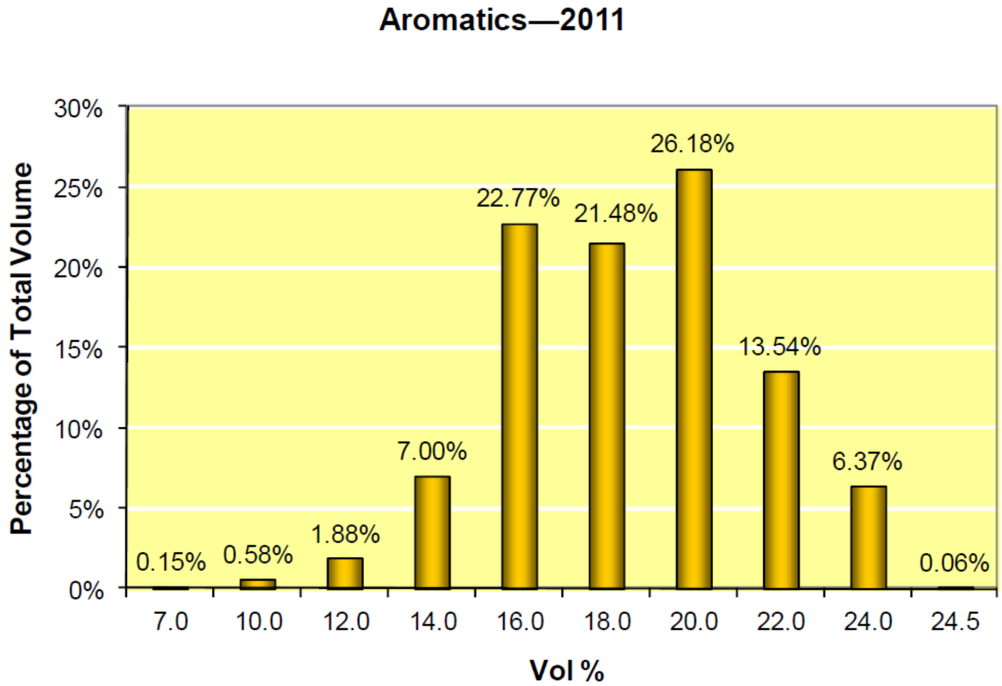


FIGURE C-3. Aromatic content histogram JP-8 (2011) ***taken from PQIS.***

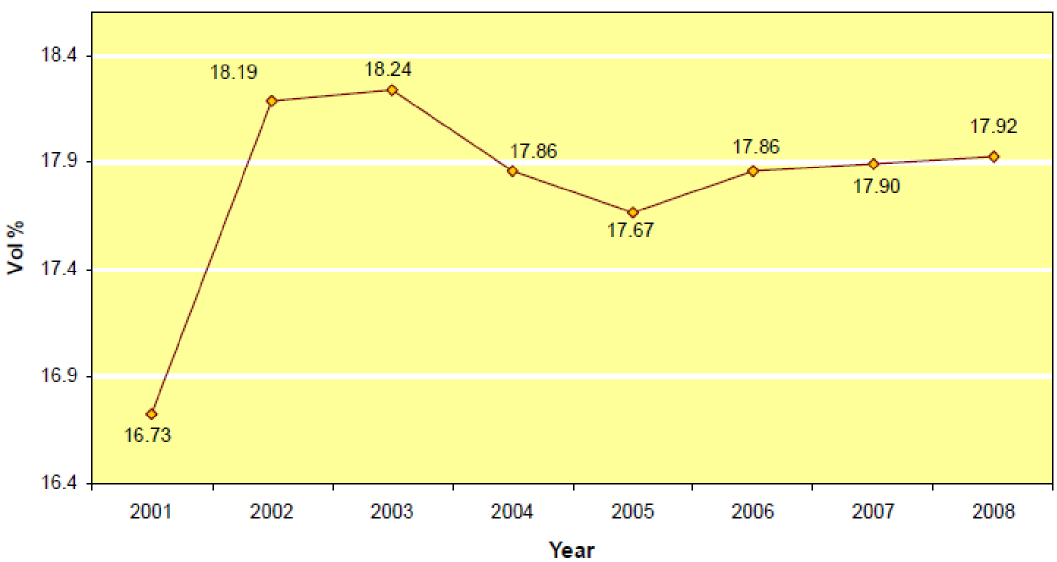


FIGURE C-4. Aromatic content average JP-8 (year trend 2001-2008) ***taken from PQIS.***

TABLE C-V. Aromatics fuel property rating value.

	New Fuel
R	>25%
G	8% to 25%
Y	0% to 8%

TABLE C-VI. Reserved.

C.7 AUTOIGNITION TEMPERATURE – SUBSET 1.

C.7.1 Definition. Autoignition temperature is also referred to as spontaneous ignition temperature, self-ignition temperature, and by the acronyms AIT and SIT. AIT is the lowest temperature to which a combustible mixture needs to be raised, so that the rate of heat released by the exothermic oxidation reaction will overbalance the rate at which heat is lost to the surroundings and cause ignition. The autoignition temperature of a jet fuel is not well understood or firmly fixed because of the number of factors that affect it. For example:

"The auto-ignition temperature of fuels will vary because of a variety of factors (ambient pressure, dwell time, fuel type, etc.), but the value generally accepted without further substantiation for kerosene type fuels, such as Jet A, under static sea level conditions, is 450°F." [FAA Advisory Circular 25.981]

"Comparisons of autoignition temperatures for hydrocarbon fuels … indicate that minimum AIT temperatures range between 400-500°F ... It should be noted there is no unique threshold temperature for hot-surface ignition since it is influenced by numerous factors, such as geometry of surface—whether concave or convex, whether in a closed environment or open environment such as the hot-manifold test, local air velocities, and residence time of the fluid." [DOT/FAA/AR-98/26].

The CRC Handbook shows values for autoignition temperature for JP-4, JP-5, JP-7, and JP-8 that range from 238-246°C (460-475°F) [also Zabetakis, 1965]. This indicates the autoignition temperature is a fairly weak function of fuel composition, so the lower limit 200°C (392°F) is adopted as a conservative limit.

C.7.2 Standard Autoignition Temperature Test Methods.

C.7.2.1 ASTM E659. A small, metered sample of the product to be tested is inserted into a uniformly heated 500-ml glass flask containing air at a predetermined temperature. The contents of the flask are observed in a dark room for 10 min following insertion of the sample, or until autoignition occurs. Autoignition is evidenced by the sudden appearance of a flame inside the flask and by a sharp rise in the temperature of the gas mixture. The lowest internal flask temperature at which hot-flame ignition occurs for a series of prescribed sample volumes is taken to be the hot-flame AIT of the chemical in air at atmospheric pressure. Ignition delay times (ignition time lags) are measured in order to determine the ignition delay-ignition temperature relationship.*

C.7.3 Data / Property Occurrence.

TABLE C-VII. Autoignition temperature fuel property rating value.

	New Fuel
Y	>260°C
G	200 to 260°C
Y	<200°C

TABLE C-VIII. Reserved.

* Reprinted, with permission, from *ASTM E659: Standard Test Method for Autoignition Temperature of Liquid Chemicals*©, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428; www.astm.org.

C.8 BULK MODULUS – SUBSET 1.

C.8.1 Definition. The bulk modulus of a substance measures that substance's resistance to uniform compression. It is defined as the pressure increase needed to affect a given relative decrease in volume. A fluid with a high bulk modulus shows a small change in volume for a given change in pressure and is, therefore, difficult to compress. Applying this principle, a fuel used to activate hydraulic equipment should have a high bulk modulus to make a responsive system.

C.8.2 Standard Bulk Modulus Test Methods.

C.8.2.1 Bulk Modulus by ASTM D6793. Bulk moduli can be calculated from pressure-volume-temperature (P–V–T) measurements or determined directly from ultrasonic velocity measurements. The P–V–T measurements method is used primarily in isothermal conditions. Since the ultrasonic velocity method uses actual measured quantities rather than their derivatives, this method is more accurate and yields the adiabatic bulk modulus directly. Figures C-5 and C-6 (JP-5, Jet A, Jet A-1, and JP-8) (CRC, 2004) show the adiabatic bulk moduli versus pressure and temperature. The bulk modulus of JP-4 is typically slightly less (~50 MPa) than that of JP-5/JP-8.

C.8.3 Comments. Bulk modulus impacts the velocity that pressure changes propagate through the fuel. A deviation from the baseline fuel for which the injection system was calibrated will significantly change the fuel injection timing and shape. Acceptable limits for a test fuel and the different types of injection equipment are not known at this time and will be the subject of further research.

The relationship between adiabatic (or isentropic) Bulk Modulus and the Velocity of Sound is given by the following equation:

$$\text{Bulk Modulus} = (\text{Velocity of Sound})^2 * \text{Density}$$

Velocity of sound is relatively straightforward to measure over a range of temperature and pressure. An effort to use this approach to develop a database for isentropic bulk modulus for conventional and alternative jet fuels is underway (2013).

C.8.3 Data / Property Occurrence.

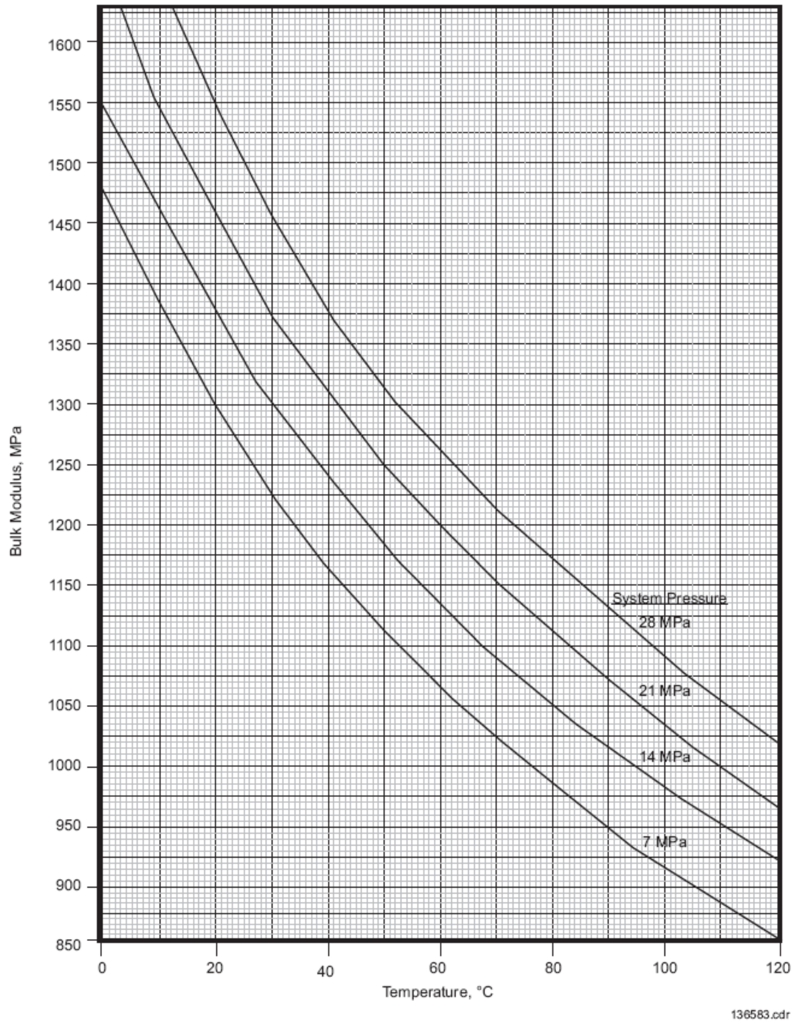


FIGURE C-5. Bulk modulus as a function of fuel temperature for JP-5/JP-8/Jet A/Jet A-1 *[CRC 2004]*.

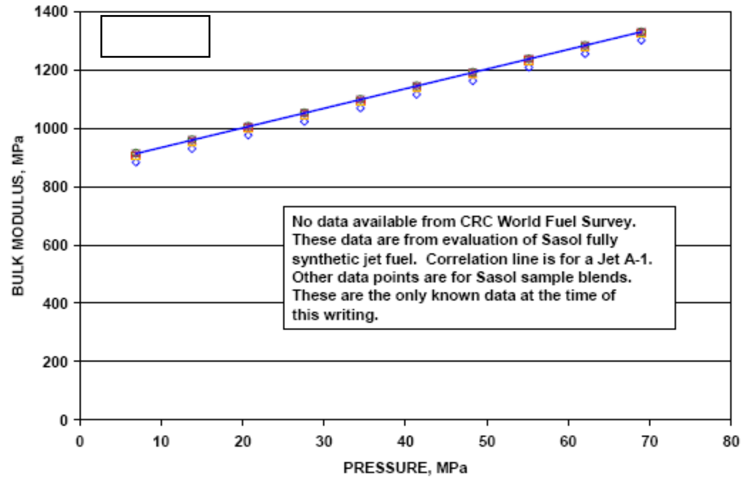


FIGURE C-6a. Bulk modulus as a function of fuel pressure for JP-5/JP-8/Jet A/Jet A-1.

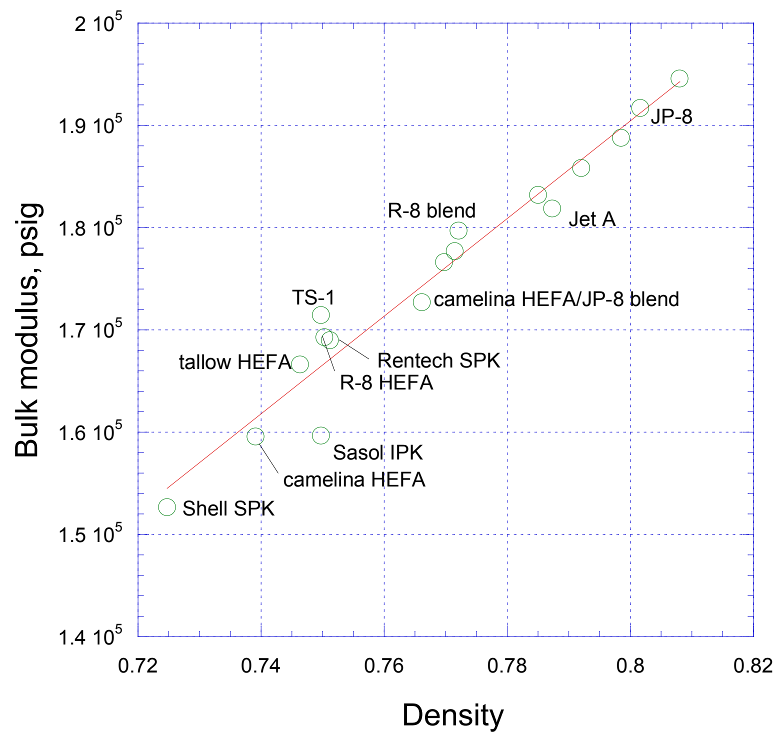


FIGURE C-6b. Isentropic bulk modulus at 30° C for various fuels.

TABLE C-IX. Bulk modulus fuel property rating value.

	New Fuel **Isentropic Bulk Modulus @ 30°C and ambient pressure**
R	> 210k psia
Y	200k psia < Y ≤ 210k psia
G	170k psia ≤ G ≤ 200k psia
Y	100k psia ≤ Y <170k psia
R	< 100k psia

TABLE C-X. Reserved.

C.9 CALCULATED CETANE INDEX – ENTRANCE CRITERIA.

C.9.1 Definition. The calculated cetane index is a mathematical estimation of cetane number. Cetane number is the measure of a fuel's ignition delay; the time period between the start of injection and start of combustion of the fuel.

C.9.2 Cetane Index Test Methods.

C.9.2.1 Calculated Cetane Index ASTM D976. The calculated dimensionless cetane index is determined from the following equations:*

Calculated cetane index = $-420.34 + 0.016G^2 + 0.192G \log M + 65.01(\log M)^2 - 0.0001809 M^2$

or

Calculated cetane index = $454.74 - 1641.416D + 774.74D^2 - 0.554B + 97.803(\log B)^2$

Where: G = API gravity

M = mid-boiling temperature, °F

D = density at 15°C, g/mL

B = mid-boiling temperature, °C

* Reprinted, with permission, from *ASTM D976: Standard Test Method for Calculated Cetane Index of Distillate Fuels*©, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428; www.astm.org.

C.9.3 Comments. Cetane index can also be calculated by ASTM D4737. Cetane number is an experimental measurement relevant to the operation of diesel engines. The cetane index is a calculation that provides an estimate of the cetane number. For fuels outside of the validation range (i.e., petroleum based) of the cetane index correlation, the index may not provide a realistic estimate of the cetane number. For example, Sasol IPK has a cetane index of 51 but a derived (ASTM D6890) cetane number of 31. Baseline cetane values established in this section are based on historical performance of fuels. Low cetane values can cause operational problems in diesel engines. It has also been seen that as the cetane number begins to increase past 65, performance impacts are observed due to combustion timing effects in diesel engines.

C.9.4 Data / Property Occurrence.

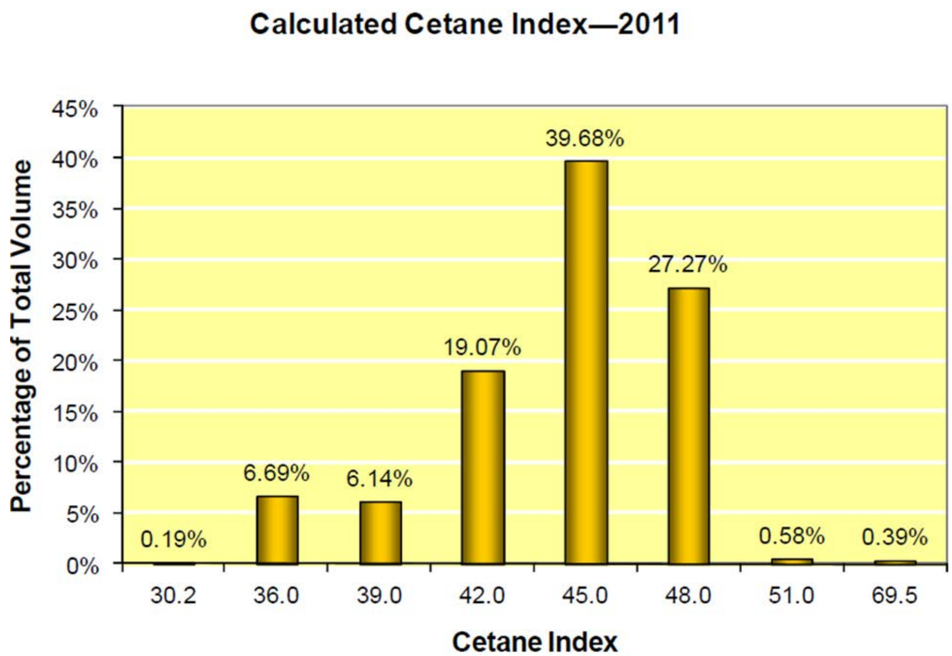


FIGURE C-7. Calculated Cetane index histogram JP-8 (2011) ***taken from PQIS.***

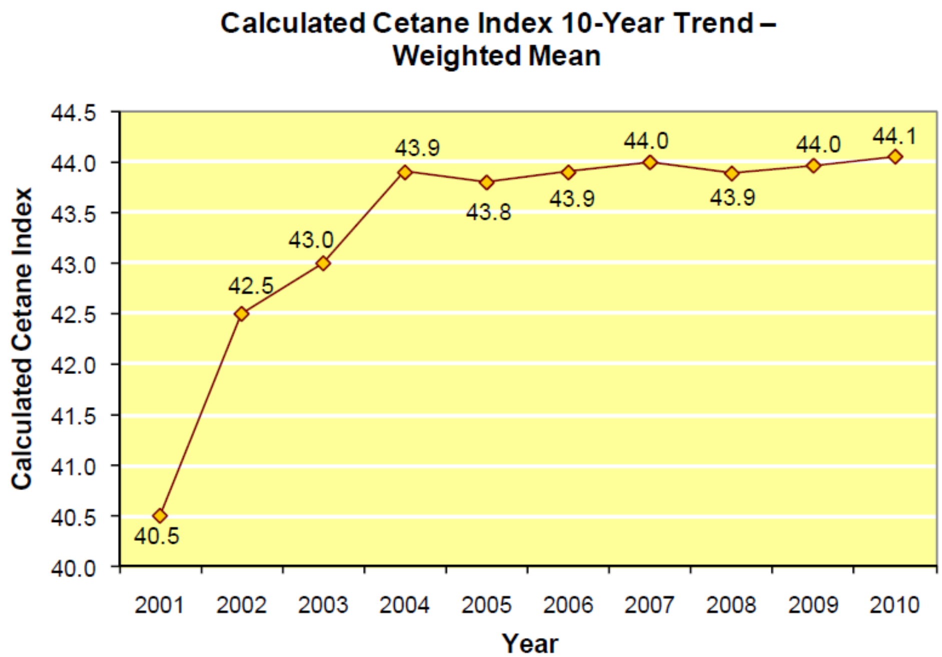


FIGURE C-8. Calculated Cetane index average JP-8 (year trend 2001-2010) *taken from PQIS.*

TABLE C-XI. Calculated cetane index fuel property rating value.

	New Fuel
Y	>65
G	40 to 65
Y	<40

TABLE C-XII. Reserved.

C.10 CETANE NUMBER – SUBSET 2.

C.10.1 Definition.

Cetane number is a measure of the ignition performance of a diesel fuel obtained by comparing it to reference fuels in a standardized engine test. A more common alternative test is ASTM D6890-08, "Standard Test Method for Determination of Ignition Delay and Derived Cetane Number (DCN) of Diesel Fuel Oils by Combustion in a Constant Volume Chamber".

C.10.2 Standard Test Method.

C.10.2.1 ASTM D613.

The cetane number of a diesel fuel is determined by comparing its combustion characteristics in a test engine with those for blends of reference fuels of known cetane number under standard operating conditions. This is accomplished using the bracketing handwheel procedure which varies the compression ratio (handwheel reading) for the sample and each of two bracketing reference fuels to obtain a specific ignition delay permitting interpolation of cetane number in terms of handwheel reading.*

C.10.2.2 ASTM D6890.

This test method measures the ignition delay in a constant volume combustion chamber with direct fuel injection into heated, compressed air. The ignition delay determination is correlated to cetane number by Test Method D613, resulting in a derived cetane number (DCN) in the range of 33 to 64.

C.10.2.3 ASTM D7170.

This test method uses ignition delay as determined in a constant volume bomb lab bench apparatus and correlations with D613 data to produce a derived cetane number in the range of 35.0 to 59.6.

C.10.3 Comments. Cetane number is a measure of the self-ignition and ignition delay characteristics of the fuel. Very low cetane numbers will result in difficult cold starting, cold smoke, and reduced life for most diesel engines and immediate structural failure of others. The entrance requirement specifies the calculated cetane index rather than the more conclusive cetane number, as determined in a special test engine. This was done for cost and time considerations. In Subset 1 the actual cetane number test is to be done. Interestingly, Zabetakis (1965) shows data that autoignition temperature was relatively constant at about 230°C for 4 diesel fuels that ranged from 41 to 68 cetane. Thus it appears that cetane number and autoignition temperature are not interchangeable tests for the purpose of ensuring fuel ignition properties remain within the experience base.

* Reprinted, with permission, from *ASTM D613: Standard Test Method for Cetane Number of Diesel Fuel Oil*©, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428; www.astm.org.

C.10.4 Data / Property Occurrence.

TABLE C-XIII. Cetane number fuel property rating value.

	New Fuel
Y	>65
G	40 to 65
Y	< 40

TABLE C-XIV. Reserved.

C.11 COPPER STRIP CORROSION – ENTRANCE CRITERIA.

C.11.1 Definition. An ASTM test method used to determine the corrosiveness to copper of liquid hydrocarbons that have a vapor pressure no greater than 124 kPa (18 psi) at 37.8°C.

C.11.2 Standard Copper Strip Corrosion Test Methods.

C.11.2.1 Corrosivity of Copper by ASTM D130. A polished strip of copper is immersed into 30 mL of test fuel and placed into a pressure vessel where it is heated for 2 hours at 100°C. After washing, the strip appearance is compared to the ASTM copper strip corrosion standard for rating. Corrosion ratings range from 1 (no significant corrosion) to 4 (corrosion) with each numbered category having two or more lettered subdivisions that describe the copper strip after the test has been completed. Consequently, any letter designation coupled with a number only provides extra information pertaining to the test. For example, a test result of "1a" corresponds to a description of "no significant corrosion with the copper strip exhibiting light orange color, almost the same as a freshly polished strip."

C.11.3 Comments. Copper is typically avoided in aircraft fuel systems, so this test is not designed to directly assess fuel system corrosion, but rather the tendency of a fuel to corrode metals in general.

C.11.4 Data / Property Occurrence.

TABLE C-XV. Copper strip corrosion fuel property rating value.

	New Fuel
G	1 (with any letter designation)
R	2, 3, or 4 (with any letter designation)

TABLE C-XVI. Reserved.

C.12 DENSITY – ENTRANCE CRITERIA

(versus Temperature – Subset 1, Thermal Expansion – Subset 2).

C.12.1 Definition. Density is the mass per unit volume relationship of fuels. Generally, specific gravity (also known as "relative density") is the ratio of the fuel density to the density of water at 15.5 °C.

Thermal expansion is the change in volume of a fluid corresponding to an increase or decrease in the fluid temperature.

C.12.2 Standard Density Test Methods.

C.12.2.1 Density by Hydrometer by ASTM D1298. A hydrometer is floated in fuel in a cylinder or graduate and is spun to avoid wall contact. After the hydrometer comes to rest, fuel density is read on the scale in the hydrometer at the top of the fuel level. Simultaneously the fuel temperature is measured with a thermometer. Both density and temperature are reported. If desired, the density can be corrected to a standard temperature. Results are reported in kg/m^3.

C.12.2.2 Density by Digital Density Meter by ASTM D4052. A small volume of liquid sample is introduced into an oscillating sample tube. The oscillating frequency is established using water or other calibrating liquid. The change in the frequency caused by the change in the tube mass while testing is compared to the calibration data and determines the density of the sample. Results are reported in kg/m^3 and are measured at -40°C, -20°C, 20°C, and 60°C.*

C.12.2.3 No standard test method for Thermal Expansion. Thermal expansion is a derived property from temperature and density data. A reference temperature is established in order to set a reference volume, which is defined as 1.00. The volume change may be reported as a multiple of the reference volume. It may also be reported as a percent change from the reference volume. For example, MIL-DTL-83133 fuel expands about 5% as it is heated from 16°C (60°F) to 60°C (140°F).

C.12.3 Comments. Density at 15°C is an Entrance Criterion, and Density versus Temperature is a Subset 1 test because of its ties to numerous systems and subsystems including safety. Many fuel properties scale directly with density, such as dielectric constant and heat capacity. There are several groups researching both the lower and upper limits of density. There is an ongoing study by the CRC to research the history of the density limits in the jet fuel specifications. The JP-4 specification had a lower limit for specific gravity of 0.751. Often the density/specific gravity (SG) is reported in the units of "API gravity" (conversions listed below). Additionally, fuel density is roughly linear with temperature over typical operating temperature ranges. The specification density range for JP-8/Jet A/Jet A-1 is 775-840 kg/m^3; the JP-5 specification range is 788-845 kg/m^3. Figure C-10 displays the average density of JP-8 over a recent five-year period. Typical density data as a function of temperature is then shown on Figure C-11 [CRC, 1983].

* Reprinted, with permission, from *ASTM D4052: Standard Test Method for Density and Relative Density of Liquids by Digital Density Meter*©, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428; www.astm.org.

Conversion:

SG at 60 °F = 141.5/(API gravity + 131.5)

In developing the jet fuel density versus temperature limits, a decrease of 731 micrograms per milliliter for every increase of 1 degree Celsius was selected for the slope of Figure C-11. This limitation was based on data from the World Fuel Sampling Program, CRC Report 647. A line with this slope was then drawn from the 15°C limitations to establish the usable limitations. The density values are valid from -40°C to 100°C; outside of this range no limitations have been set.

With regards to thermal expansion, excess expansion can result in fuel tanks overflowing and spilling on the ground when fuel is heated by solar heating. The fact that the density-versus-temperature of different fuels may be parallel does not imply that the coefficient of thermal expansion is the same - the volume expansion is inversely related to density. Thus, lower density fuels like JP-4 have a higher coefficient of thermal expansion. Fuels that fall within the JP-4 to JP-5 range of densities will fall within the historical experience base for coefficient of thermal expansion. The thermal expansion figure below shows that MIL-DTL-83133 fuel expands about 5% as it is heated from 16°C (60°F) to 60°C (140°F). An upper thermal expansion boundary of JP-4 was used to help account for fuel tank overflowing. Little data exists on concerns for small thermal expansions therefore no limit was set.

C.12.4 Data / property occurrence @ 15°C.

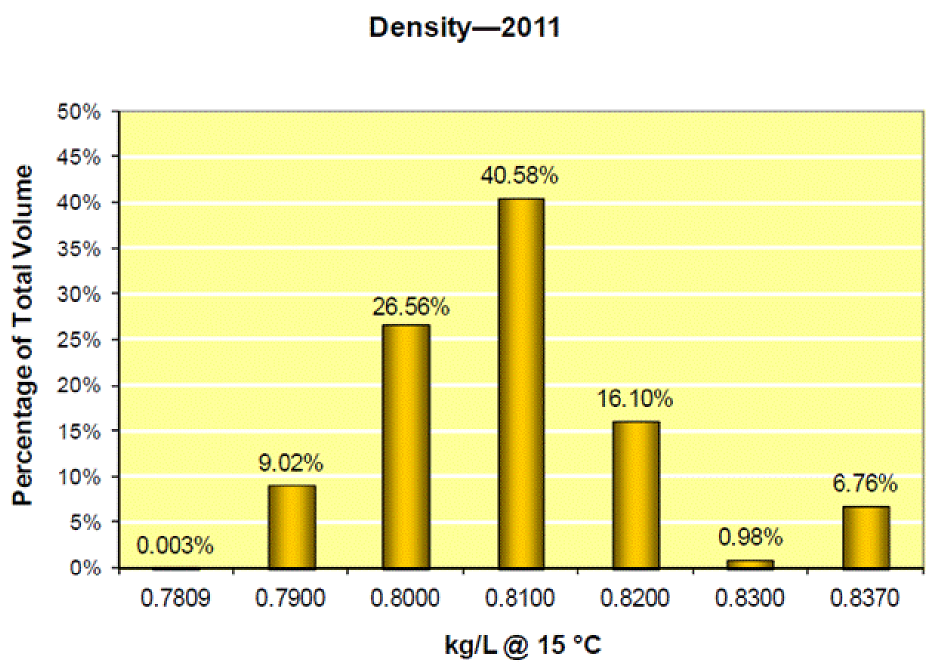


FIGURE C-9. Density histogram JP-8 (2011) ***taken from PQIS.***

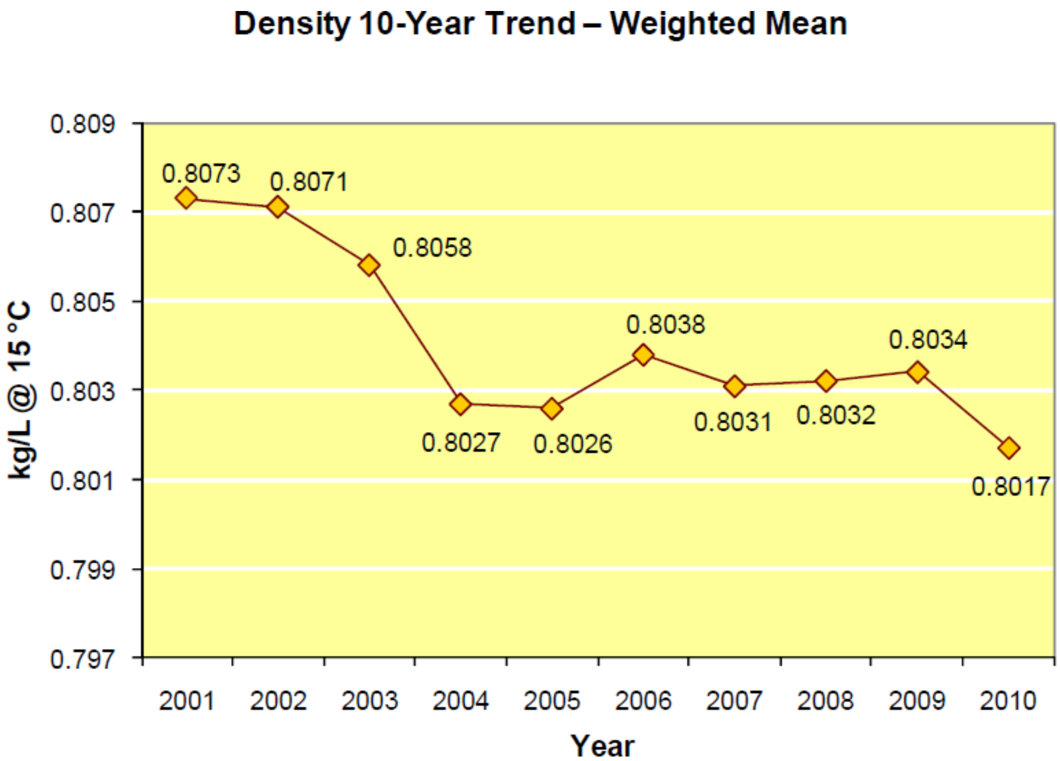


FIGURE C-10. Density average JP-8 (year trend 2001-2010) ***taken from PQIS.***

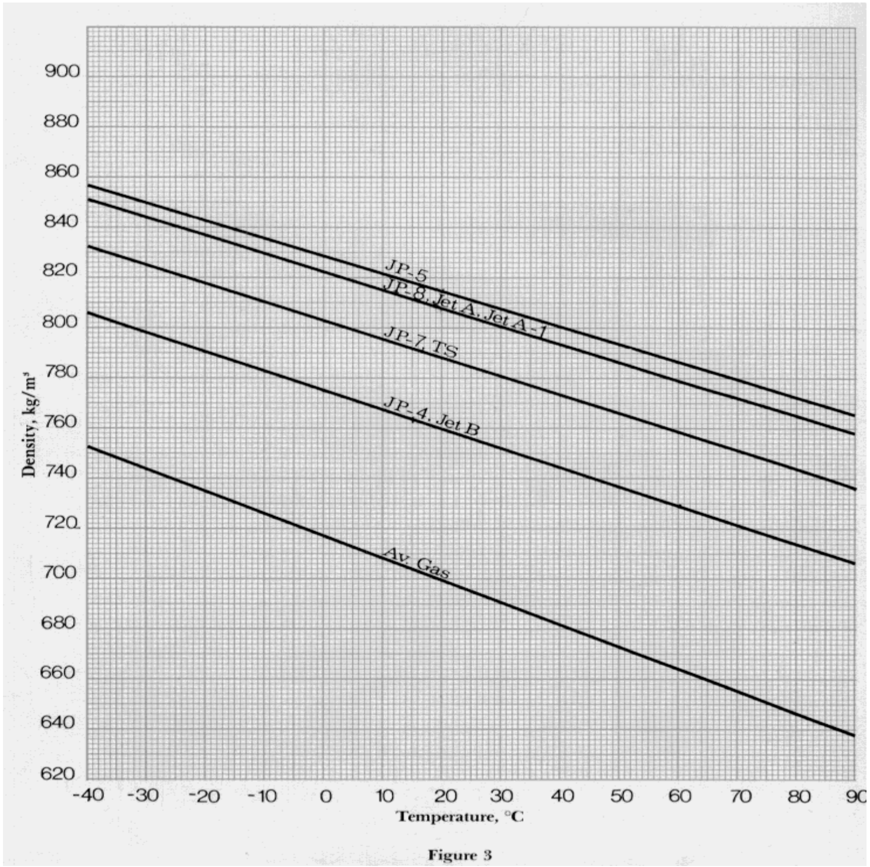


FIGURE C-11. Typical density as a function of temperature *[CRC, 1983]*.

TABLE C-XVII. Density (specific gravity) fuel property rating value at 15°C.

	New Fuel
R	>0.845 g/mL
Y	0.841 to 0.845 g/mL
G	0.775 to 0.840 g/mL
Y	<0.775 g/mL

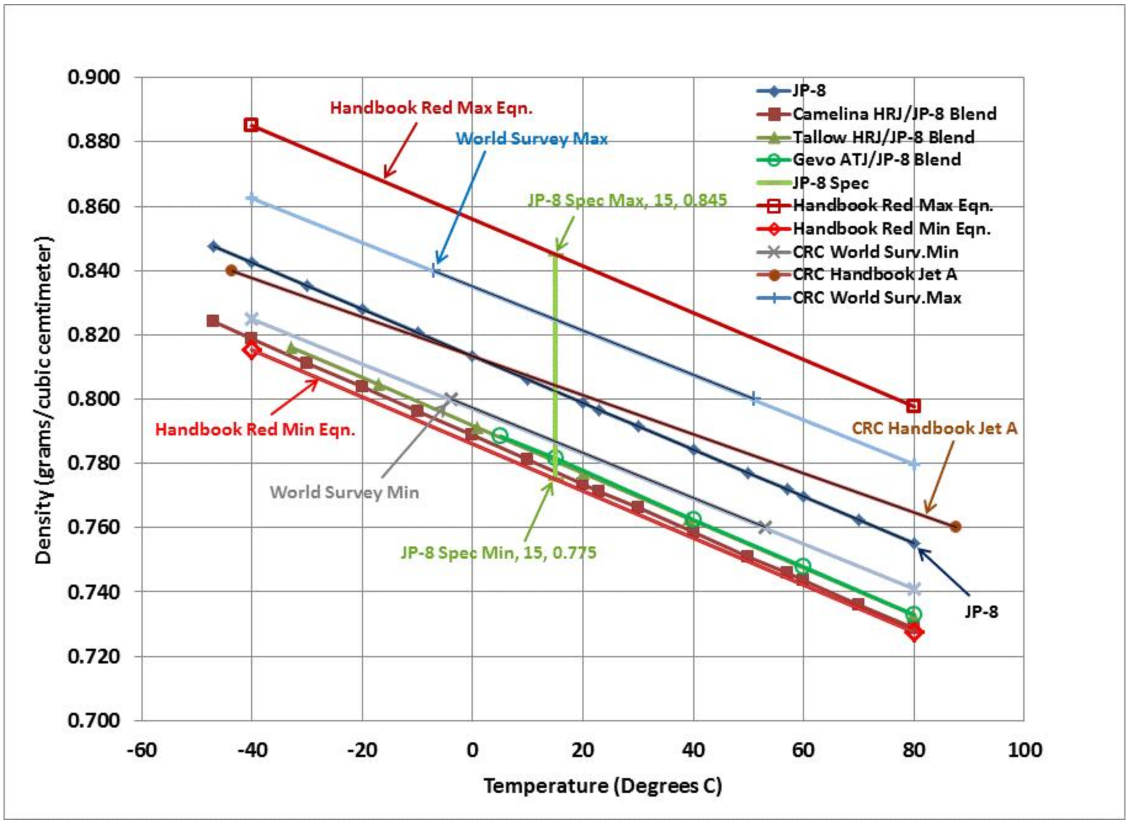


FIGURE C-12. Density versus temperature limitations.

TABLE C-XVIII. Density fuel property rating value at temperature, *T*.

	New Fuel
R	Greater than 0.845 g/mL at 15 C and Greater than [(-0.000731×T$^{o}{}_{C}$) + 0.8560], g/mL
Y	Greater than World Survey maximum density fuel, but within spec density at 15 C
G	Within limits of fuels in World Survey, i.e., Less than or equal to [(-0.000690 × T$^{o}{}_{C}$) + 0.835], g/mL and Greater than or equal to [(-0.000702 × T$^{o}{}_{C}$) + 0.797], g/mL
Y	Less than World Survey minimum density fuel, but within spec density at 15 C
R	Less than 0.775 g/mL at 15 C and Less than [(-0.000731 T$^{o}{}_{C}$) + 0.786], g/mL

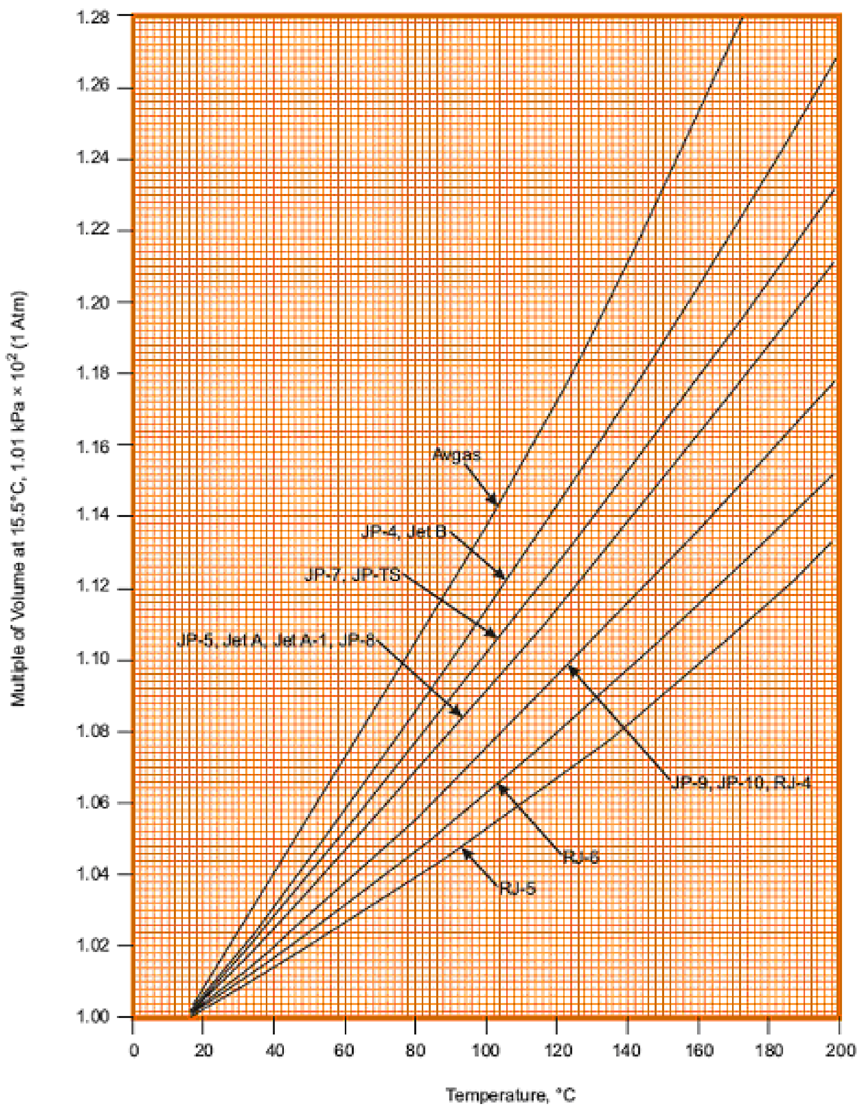


FIGURE C-13. Thermal expansion *[CRC 2004]*.

TABLE C-XIX. Thermal expansion fuel property rating.

	New Fuel
Y	> JP-4
G	<JP-4

C.13 DIELECTRIC CONSTANT – SUBSET 1 (versus Density, versus Temperature).

C.13.1 Definition. The dielectric constant of a fuel is the ratio of the electrical capacitance of a fuel to the electrical capacitance of air.

C.13.2 Standard Dielectric Constant Test Methods.

C.13.2.1 Dielectric Constant by ASTM D924. The electrical capacitance of an air filled vessel is measured at a set frequency and temperature. The vessel is then filled with a fuel. The capacitance of the fuel is then measured. The ratio of fuel capacitance to air capacitance is reported as the dielectric constant at that temperature and frequency. While the ideal measurement for the capacitance used in the denominator of the ratio would use a vacuum in the vessel, the use of air is more practical and results in an acceptable level of fidelity for the resulting ratio.

C.13.3 Comments. Measurements of the dielectric constant (also called relative permittivity) of a fuel at various temperatures show that the dielectric constant is a linear function of temperature, decreasing with increasing temperature and varying with the applied frequency.

Figure C-14 (CRC, 2004) illustrates the relationship of dielectric constant versus temperature of various fuels for data collected at 400 Hz, an often-used frequency in commercial and military aircraft.

Evidence indicates that fuel dielectric constant can be scaled by density (Figure C-15), resulting in similar values for all jet fuels within the apparent accuracy of the technique. This data set includes isoparaffinic kerosene, so it appears that ensuring that fuel density range falls within the experience base will ensure that the dielectric constant also falls within the experience base. Changes in the electric frequency result in different values of dielectric constant; presently, there are no methods to correlate between dielectric constants observed at different electrical frequencies. Therefore only dielectric constants taken at the same frequency can be properly compared.

Dielectric constant data are recorded versus temperature, but usually presented as versus density. For evaluation purposes, the differences shown in dielectric constant versus temperature provide a better means for differentiating between acceptable and unacceptable fuels.

Dielectric constant is an important property because numerous aircraft fuel quantity indicating systems utilize capacitance probes in their tanks to measure the fuel level and many include measurement of and/or compensation for fuel density. Aircraft fuel quantity systems typically have accuracy requirements of 2 to 3 percent, so any new fuel's dielectric constant may not vary substantially from values the aircraft systems assumed in their designs in order to provide an accurate value for the aircraft's true fuel quantity.

C.13.4 Data / Property Occurrence.

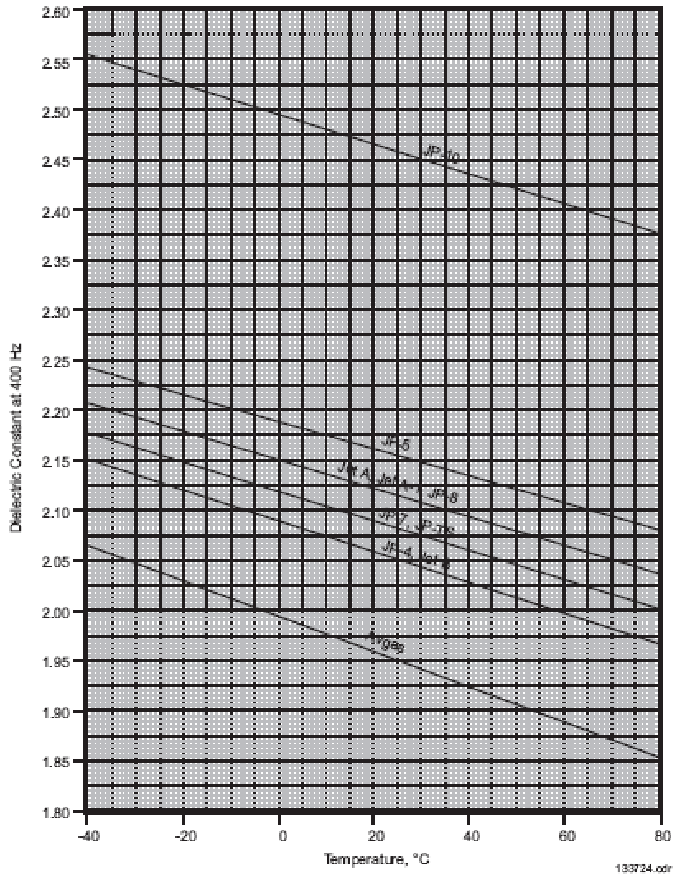


FIGURE C-14. Dielectric constant as a function of temperature *[CRC, 2004]*.

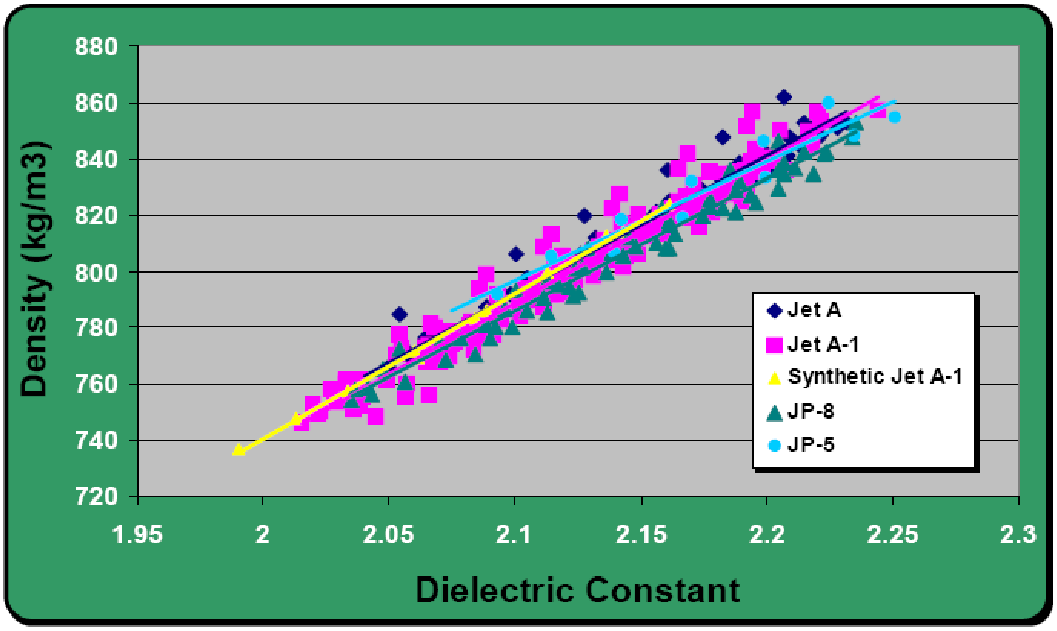


FIGURE C-15. Dielectric constant as a function of density *[CRC World Fuel Survey, 2006].*

TABLE C-XX. Dielectric constant (as a function of T) fuel property rating value.

	New Fuel
Y	<JP-4, >JP-5
G	JP-4<G<JP-5

TABLE C-XXI. Reserved.

C.14 DISTILLATION CURVE – ENTRANCE CRITERIA.

C.14.1 Definition. Distillation curves are the range of temperatures over which a fuel boils at 1 bar. Typically, jet fuels are composed of a mixture of varying lengths of hydrocarbon chains causing a particular range of boiling temperatures. Lighter compounds (i.e. shorter hydrocarbon chains) boil initially and heavier compounds (i.e. longer hydrocarbon chains) boil later in the process. Varying the fractional composition and distribution of these hydrocarbon chains will affect the behavior of the final product.

C.14.2 Standard Distillation Test Methods.

C.14.2.1 Distillation of Petroleum Products by ASTM D86. Fuel is heated at a constant rate in a flask and the vapors are boiled off. The vapors are condensed and collected. The distillation curve is the relationship between the percent of condensed vapor and the vapor temperature. Results are reported in temperature (ºC) at which a given percentage of fuel is recovered.

C.14.2.2 Distillation (Simulated) by ASTM D2887. Fuel is passed through a chromatographic column which separates hydrocarbons in boiling point order. Boiling temperatures are assigned from a calibration curve, obtained by running a known mixture of hydrocarbons under the same conditions, and a boiling point distribution is obtained. Results are reported in ºC versus percent recovered.

C.14.3 Comments. The current MIL-DTL-83133 specification is bounded only at the 10% (<205°C by D86) and final boiling (<300°C) points, with the other points (initial, 20, 50, and 90%) listed as "report" for all fuel types, petroleum-derived and neat synthetic samples. The 10% point is closely correlated to the flash point. Tables A-I, A-II, B-I, and B-II of MIL-DTL-83133 list specifications and test methods for the chemical and physical requirements of FT-SPK and HEFA-SPK neat fuels and also when blended with at least 50% JP-8 by volume. In these tables, values for distillation temperature are to be reported at 10%, 20%, 50%, and 90% product recovered. The JP-4 specification evolved into specifying the 20%, 50%, and endpoint, primarily to prevent the use of low boiling materials which could be lost in storage [Barnett and Hibbard, 1956]. The possible introduction of narrow-boiling synthetic fuels has led to the additional definition of a T90-T10 limit in the distillation specification in ASTM D7566 Specification for Aviation Turbine Fuels Containing Synthesized Hydrocarbons. MIL-DTL-83133 includes additional minimum distillation "temperature gradient" requirements (T50 - T10 and T90 - T10) for neat synthetics and JP-8s blended with synthetics. The distillation requirement in 83133 is presented below. Efforts should continue to keep MIL-DTL-83133 and ASTM D7566 harmonized. Table XXII below is an example from MIL-DTL-83133H of what can be specified in this regard.

TABLE C-XXII. MIL-DTL-83133H Amendment 1 distillation specification requirement.

	Min	Max
Distillation temperature, °C *		
Initial boiling point		
10 percent recovered …………………		205
20 percent recovered		
50 percent recovered		
90 percent recovered		
Final boiling point ……………………....		300
Residue, vol percent …………………..		1.5
Loss, vol percent ……………………..		1.5
90 percent recovery gradient (Neat Synthetics) **	22	
50 percent recovery gradient (Blends)***	15	
90 percent recovery gradient (Blends)****	40	

* "A condenser temperature of 0°C to 4°C (32° to 40°F) shall be used for the distillation by ASTM D86."

** "The temperature difference between the temperature that demarks the 10 percent recovered point and the temperature that demarks the 90 percent recovered point must be at least 22 °C."

*** "The temperature difference between the temperature that demarks the 10 percent recovered point and the temperature that demarks the 50 percent recovered point must be at least 15 °C for JP-8 containing FT or HEFA."

**** "The temperature difference between the temperature that demarks the 10 percent recovered point and the temperature that demarks the 90 percent recovered point must be at least 40 °C for JP-8 containing FT or HEFA."

C.14.4 Data / Property Occurrence.

TABLE C-XXIII. Reserved.

TABLE C-XXIV. Initial boiling point property rating value.

Initial BP	New Fuel
G	Report

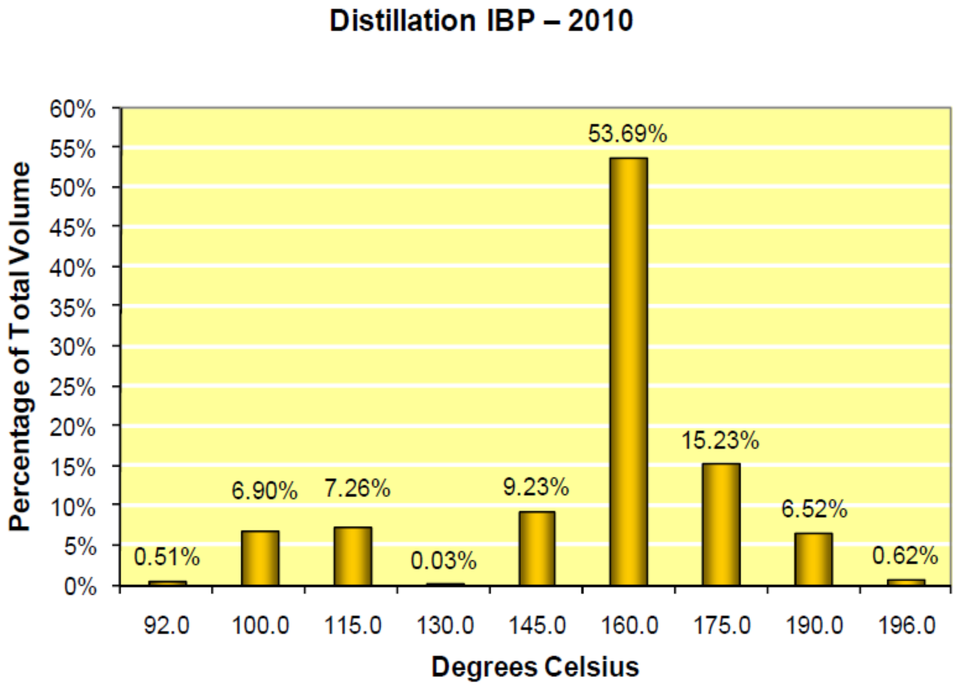


FIGURE C-16. Initial boiling point distillation histogram JP-8 (2011) *taken from PQIS.*

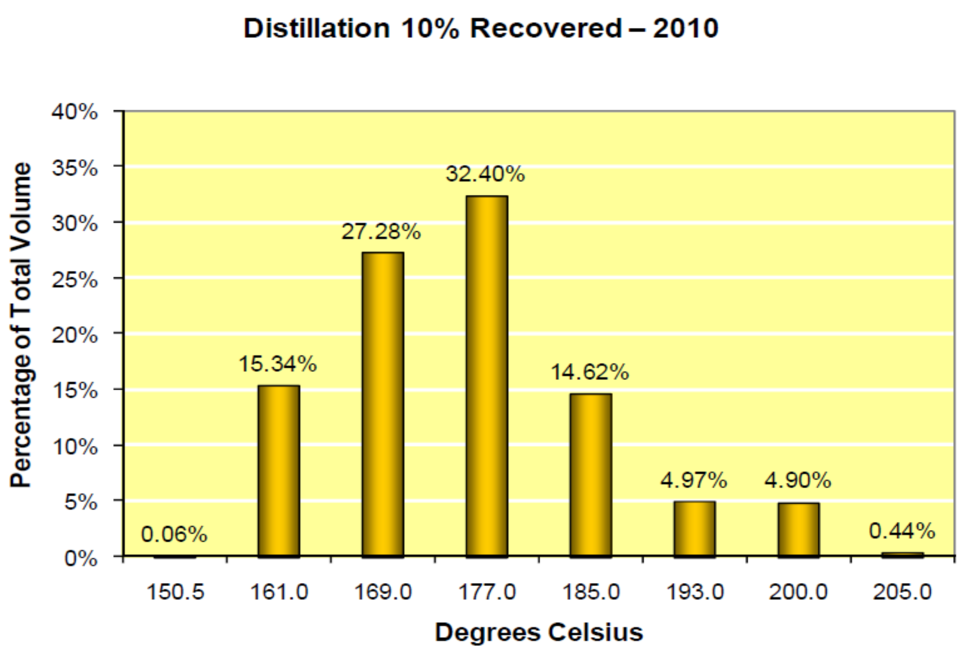


FIGURE C-17. 10% recovered distillation histogram JP-8 (2010) *taken from PQIS.*

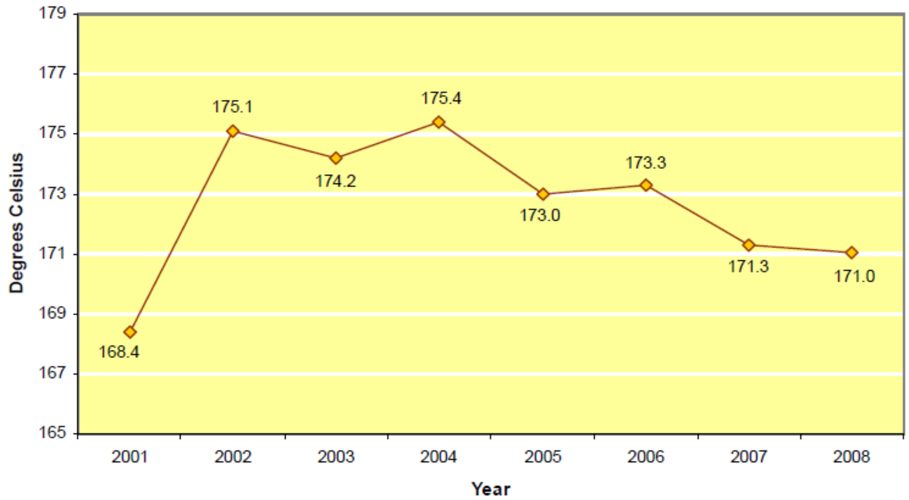


FIGURE C-18. 10% recovered distillation averageJP-8 (year trend 2001-2008) *taken from PQIS.*

TABLE C-XXV. 10% recovered distillation curve fuel property rating value.

10%	New Fuel
Y	>205°C (D 86) or >186°C (D 2887)
G	≤205°C (D 86) or ≤186°C (D 2887)

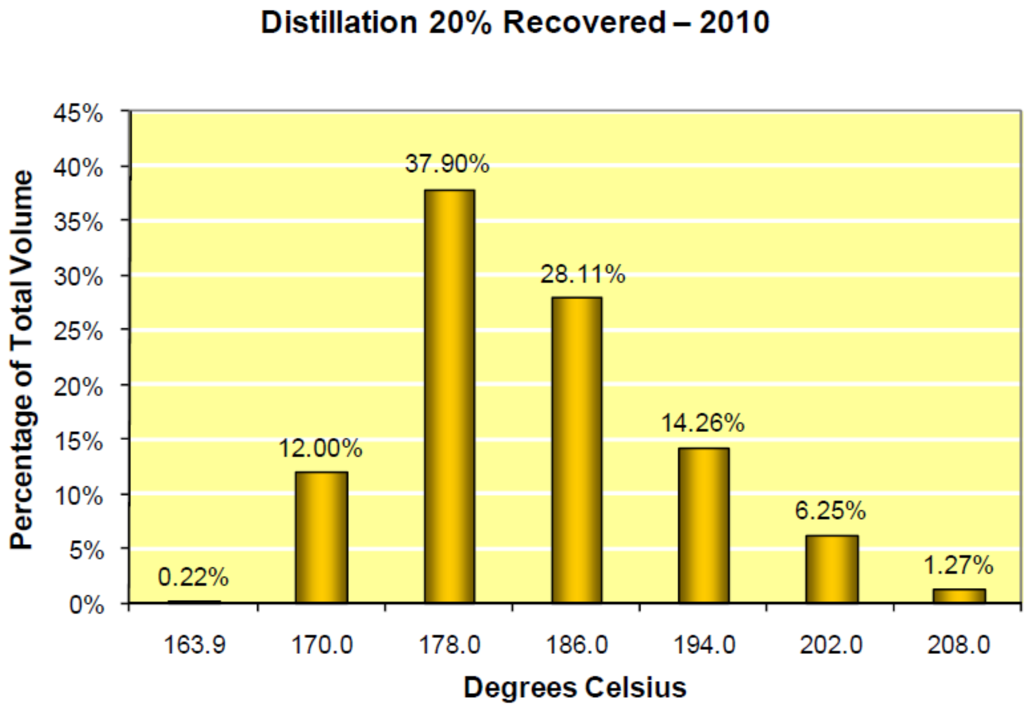


FIGURE C-19. 20% recovered distillation histogram JP-8 (2010) *taken from PQIS.*

TABLE C-XXVI. 20% recovered distillation property rating value.

20%	New Fuel
G	Report

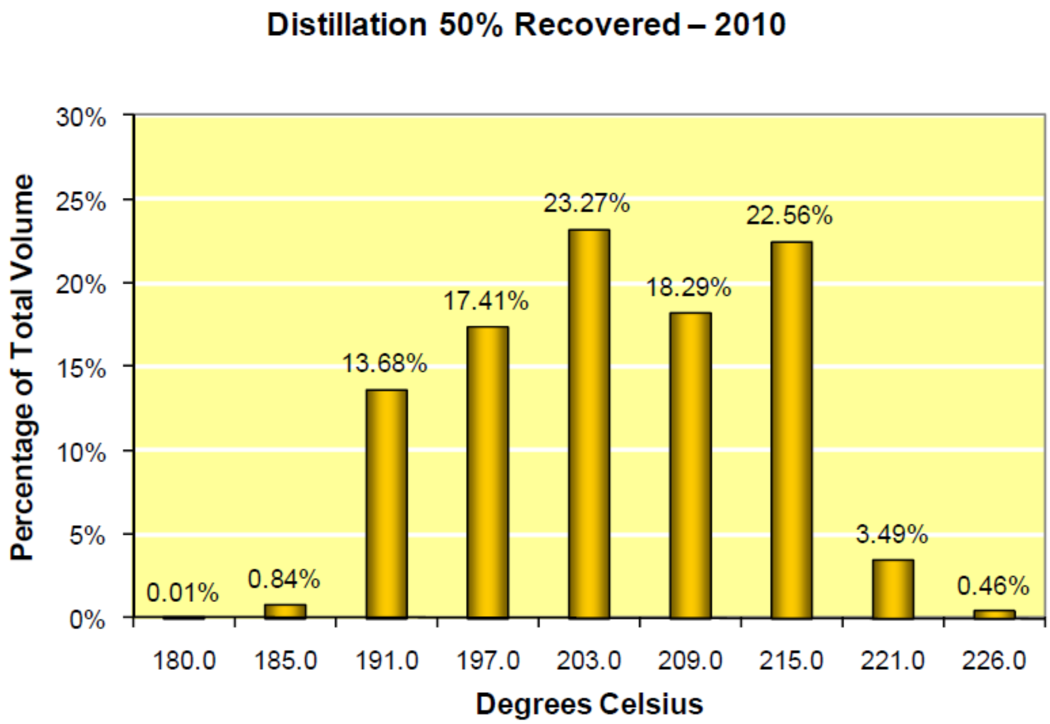


FIGURE C-20. 50% recovered distillation histogram JP-8 (2010) *taken from PQIS.*

TABLE C-XXVII. 50% recovered distillation property rating value.

50%	**New Fuel**
Y	>229°C (D 86)
G	168°C to 229°C
Y	<168°C (D 86)

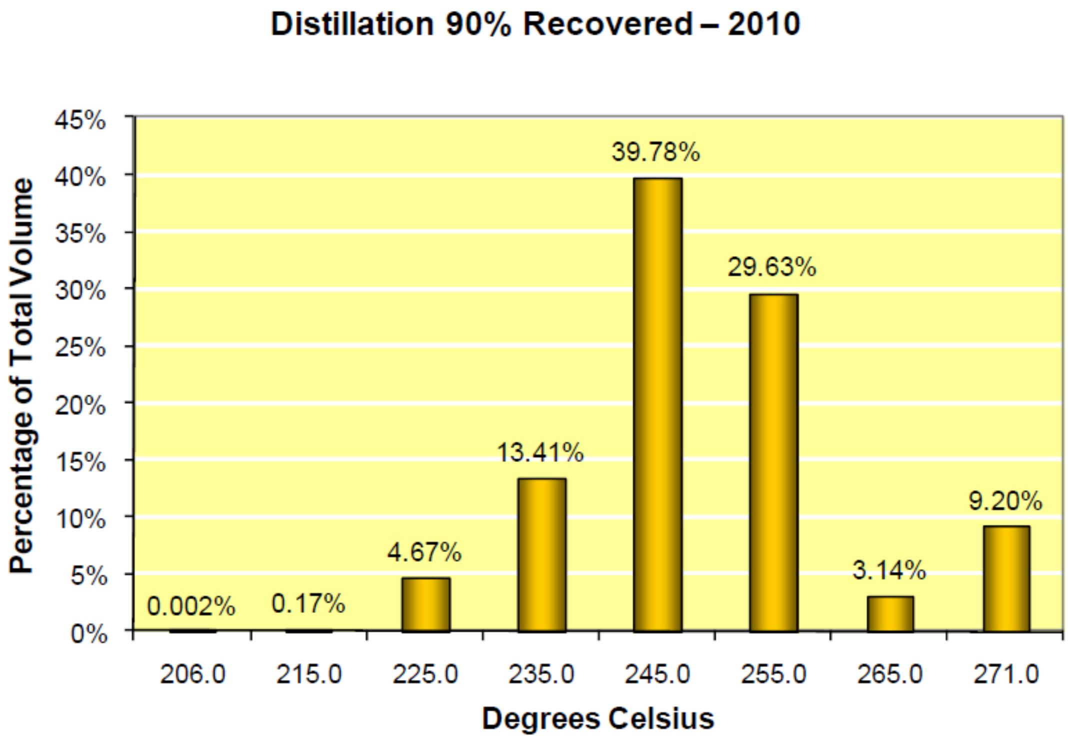


FIGURE C-21. 90% Recovered distillation histogram JP-8 (2010) *taken from PQIS.*

TABLE C-XXVIII. 90% recovered distillation property rating value.

90%	**New Fuel**
Y	>262°C (D 86)
G	183°C to 262°C
Y	<183°C (D 86)

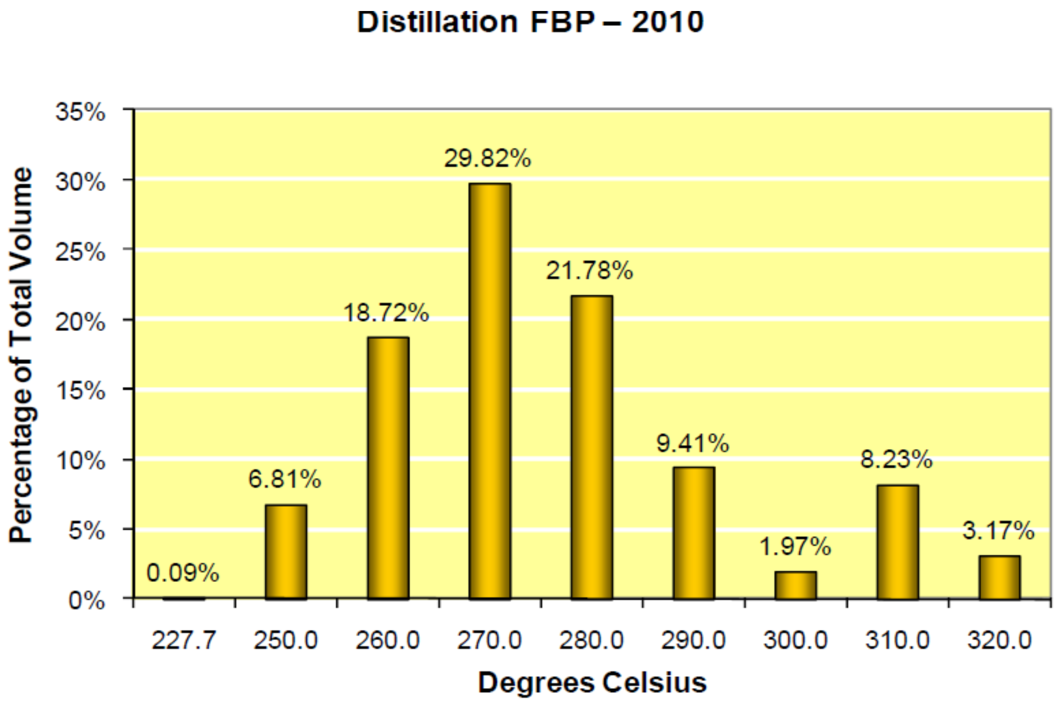


FIGURE C-22. Final boiling point distillation histogram JP-8 (2010) *taken from PQIS.*

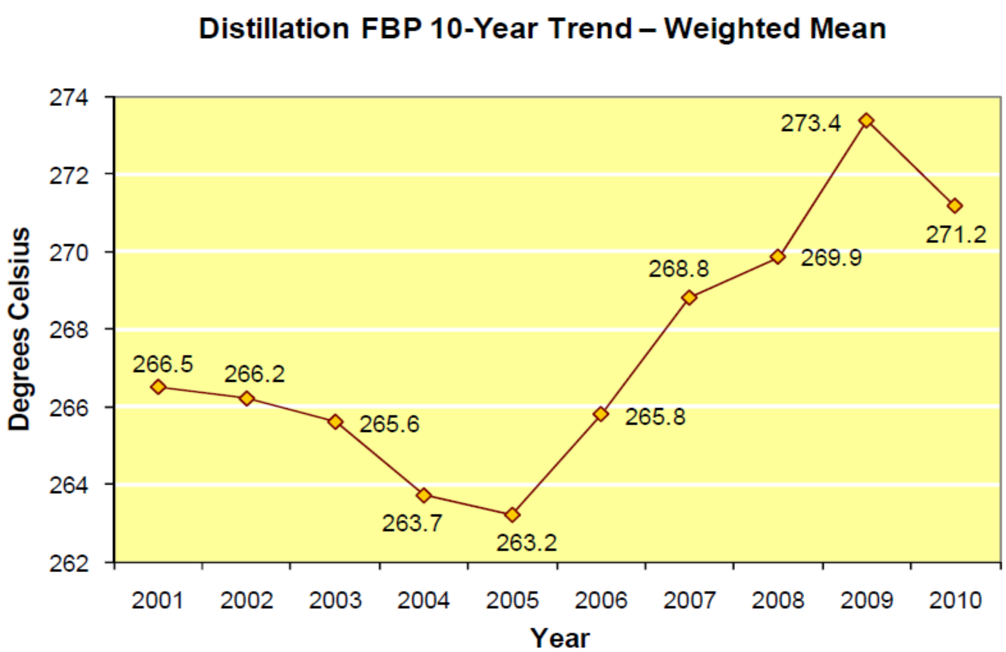


FIGURE C-23a. Final boiling point distillation average JP-8 (year trend 2001-2010).

taken from PQIS.

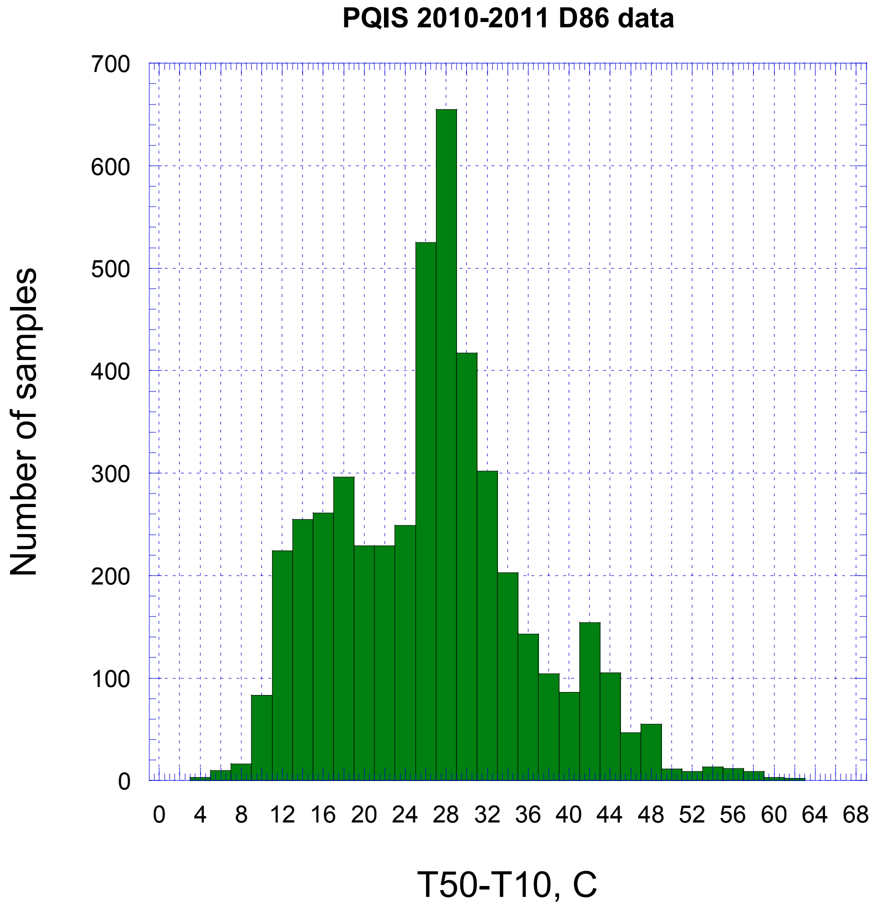


FIGURE C-23b JP-8 ASTM D86 Test distillation midpoint slope histogram.

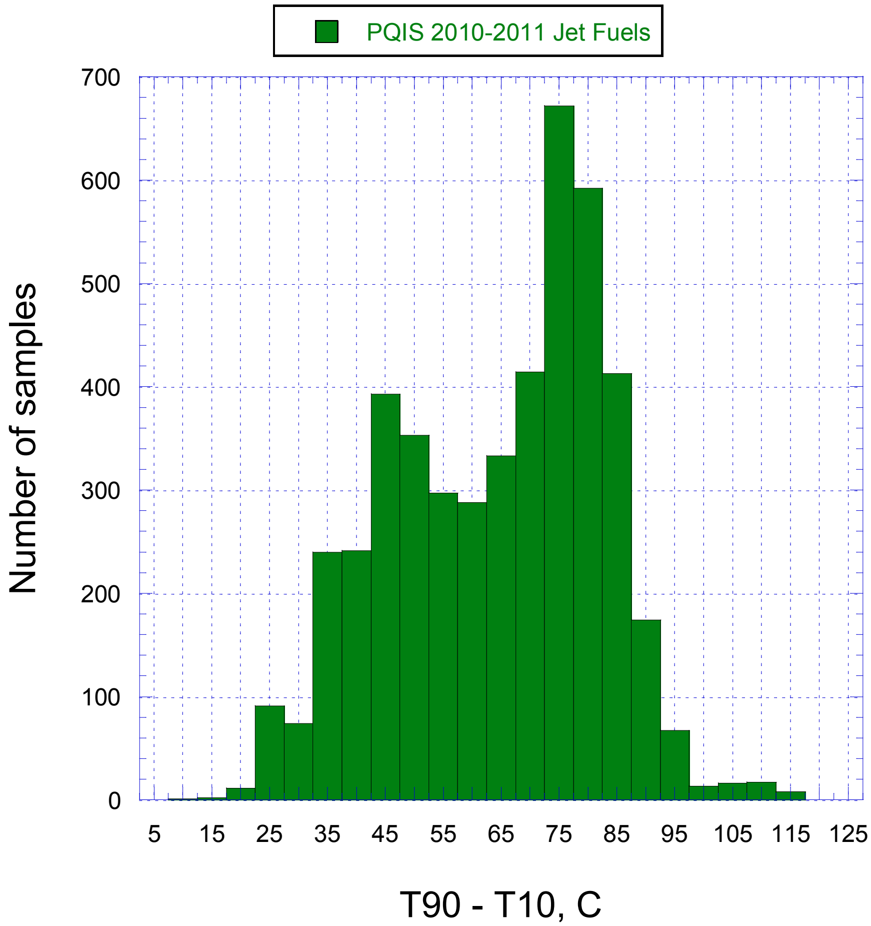


FIGURE C-23c JP-8 ASTM D86 Test distillation full slope histogram.

TABLE C-XXIX. Final boiling point distillation property rating value.

Final Boiling Point	New Fuel
Y	>300°C (D 86)
G	≤300°C (D 86)

TABLE C-XXX. Distillation residual property rating value.

Residue	New Fuel
Y	>1.5% vol
G	≤1.5% vol

TABLE C-XXXI. Distillation loss property rating value.

Loss	New Fuel
Y	>1.5% vol
G	≤1.5% vol

TABLE C XXXII. T50-T10 difference distillation property rating value.

T50-T10	New Fuel
Y	<15°C
G	≥15°C

TABLE C-XXXIII. T90-T10 difference distillation property rating value.

T90-T10	New Fuel
Y	<40°C
G	≥40°C

C.15 ELECTRICAL CONDUCTIVITY AT STANDARD TEMPERATURE – ENTRANCE CRITERIA (Electrical Conductivity versus Temperature – Subset 2).

C.15.1 Definition. Electrical conductivity is a measurement of a substance used to determine at what rate it conducts an electric charge.

C.15.2 Standard Electrical Conductivity Test Methods.

C.15.2.1 Electrical Conductivity by ASTM D2624. A probe is immersed into the fuel sample and the conductivity is read directly on the conductivity meter. Depending on the manufacturer, the probe may be attached to the meter or be at the end of a flexible cable. Conductivity is reported in pS/m. Sample temperature is also measured and reported.

C.15.3 Comments. The measurements and reported data for electrical conductivity can sometimes be very misleading. First, electrical conductivity measurements are very sensitive to temperature variation and contamination generating wide scatter in reported data. Additionally, fuels with low conductivity can typically be additized with a static dissipater additive (SDA) to bring them within specification limits. Therefore, reported data and the subsequent analysis have to take into account if the fuels were additized and the effectiveness of a SDA on the fuel's conductance. Figure C-24 is a plot of the minimum and maximum acceptable conductivity of the hydrocarbon fuel with and without SDA.

C.15.4 Data / Property Occurrence.

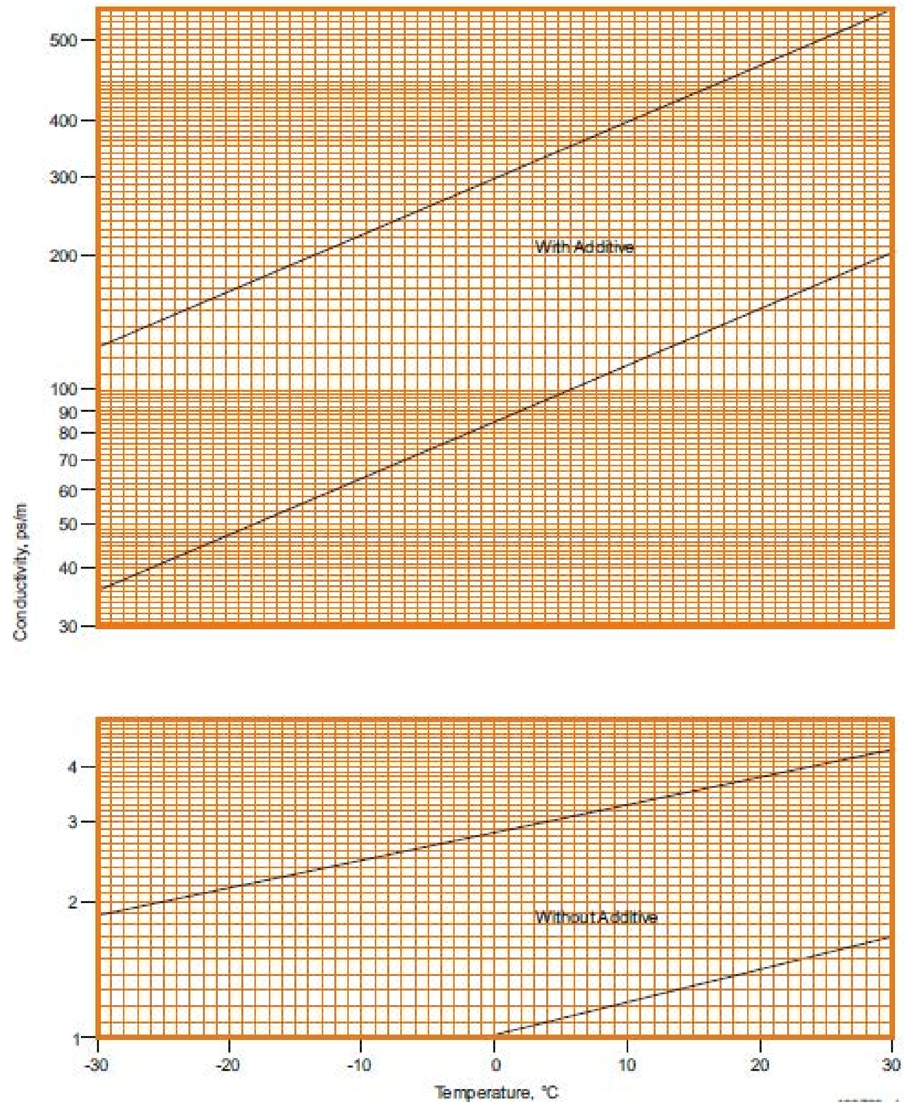


FIGURE C-24a. Maximum and minimum acceptable fuel conductivity as a function of temperature for fuel with and without SDA additive *[CRC, 2004].*

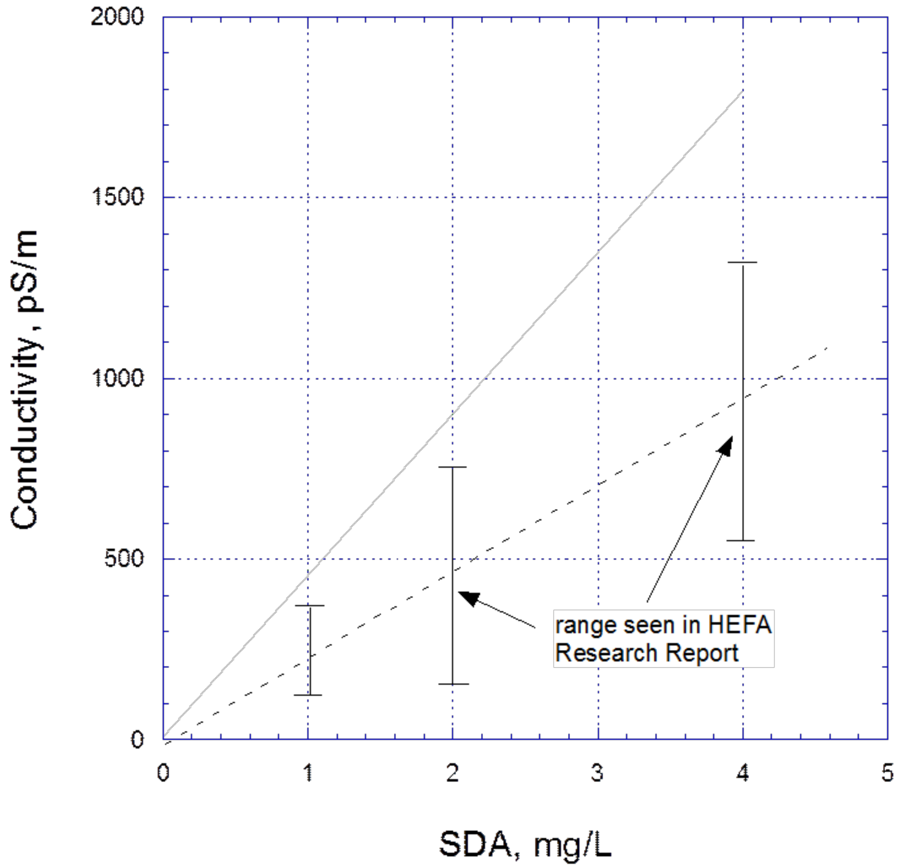


FIGURE C-24b. Sensitivity of Conductivity to SDA in HEFA SPK.

TABLE C-XXXIV. Electrical conductivity at standard T fuel property rating value with additive.

	New Fuel @ 29.4°C
R	> 900 pS/m
Y	900 pS/m ≥ Y > 600 pS/m
G	600 pS/m ≥ G ≥ 150 pS/m
Y	150 pS/m > Y ≥ 50 pS/m
R	< 50 pS/m

TABLE C-XXXV. Reserved.

C.16 ENTHALPY VERSUS TEMPERATURE (see Specific Heat) – SUBSET 3.

C.16.1 Definition.

Enthalpy is the heat energy required to bring a fuel from one reference state to another state. It is a function of the integral of the specific heat between the two states, and any latent heat of vaporization that was required in the interval. Enthalpy is quantified in terms of kJ/kg. Figure C-25 (CRC, 2004) is an enthalpy diagram for typical JP-5. On this figure, the saturated liquid curve represents the heat that can be absorbed in the liquid phase alone, and the saturated vapor curves depict the heat absorbed to completely vaporize the fuel. The intermediate area denotes partial vaporization, while the curves above this saturated vaporization line indicate super-heated vapor. The line of constant pressure provides the pressure relationship to determine the state of vaporization of the fuel for the addition of a given amount of heat.

C.16.2 Standard Enthalpy Test Methods.

C.16.2.1 TBD. Currently, Enthalpy test methods are under discussion and the recommended test method is listed as "to be determined." Enthalpy can be calculated using Specific Heat (Heat Capacity) data.

C.16.3 Comments. None.

C.16.4 Data / Property Occurrence.

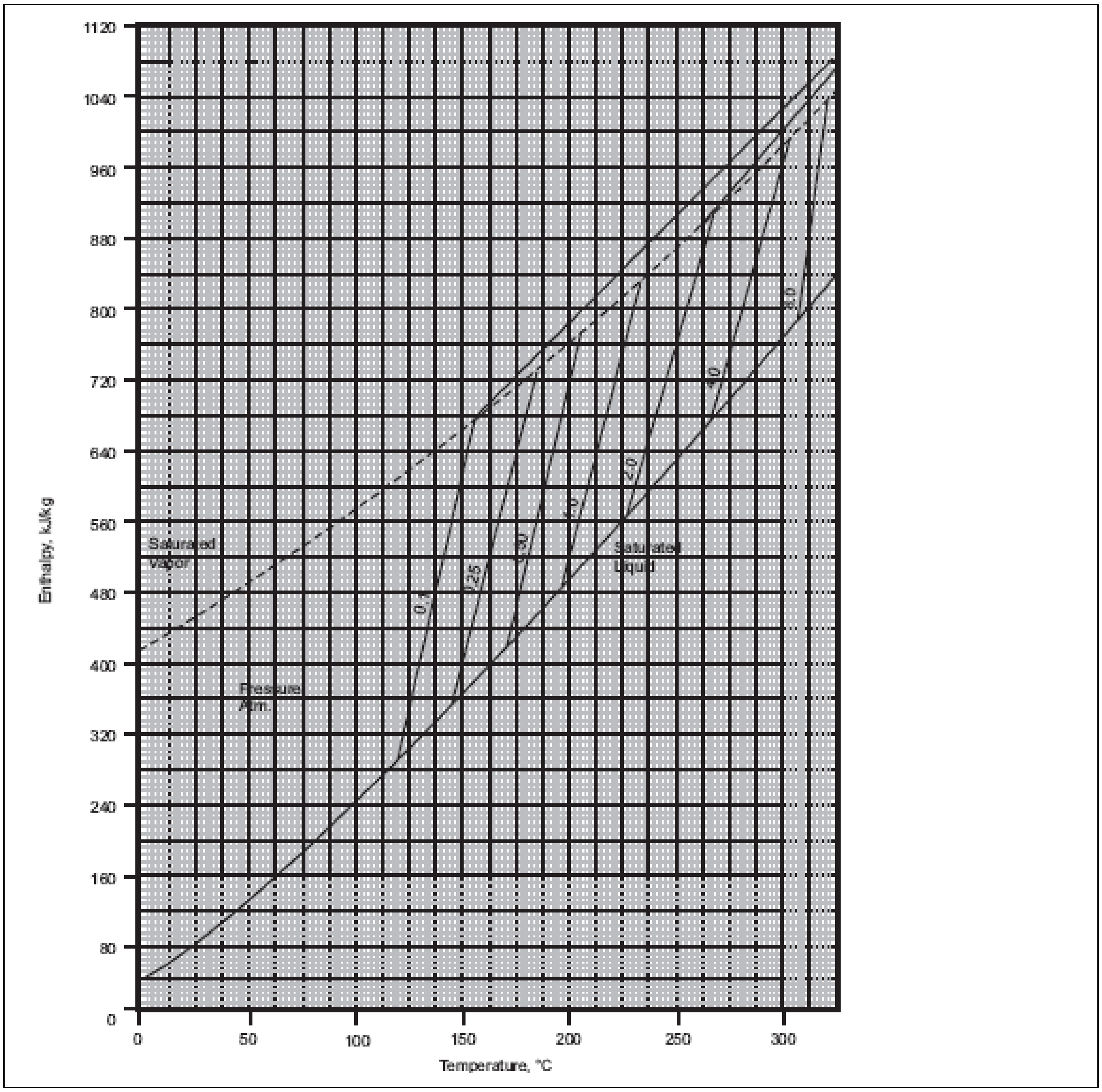


FIGURE C-25. JP-5 enthalpy data *(Courtesy CRC).*

TABLE C-XXXVI. Reserved.

TABLE C-XXXVII. Reserved.

C.17 EXISTENT GUM – ENTRANCE CRITERIA

C.17.1 Definition. Existent Gum is the evaporation residue of hydrocarbon liquids.

C.17.2 Standard Existent Gum Test Methods

C.17.2.1 Gum Content (Existent) by ASTM D381. A weighed sample quantity is evaporated at 232°C (450°F) by blowing with superheated steam. After evaporation the residue is weighed and reported as existent gum. Solvent washing of the gum, as is done for motor gasoline, is not permitted. Gum content is reported as mg/100 mL.

C.17.3 Comments. This test is typically a 'strong indicator of contamination;' however, in the JP-8+100LT program, it was found that the low temperature additive produced a "fail" on existent gum, yet passed the Jet Fuel Thermal Oxidative Test and combustion tests with no problems. In this case it was an indication that the very high content of high molecular weight compounds in the LT was not being vaporized. The gum test was originally designed to give an indication of the storage stability of the fuel in long-term storage. The ASTM D381 test evolved from a similar test for gasoline. From this information it should be noted that other high molecular weight additives will probably have a similar result as the LT additive.

C.17.4 Data / Property Occurrence.

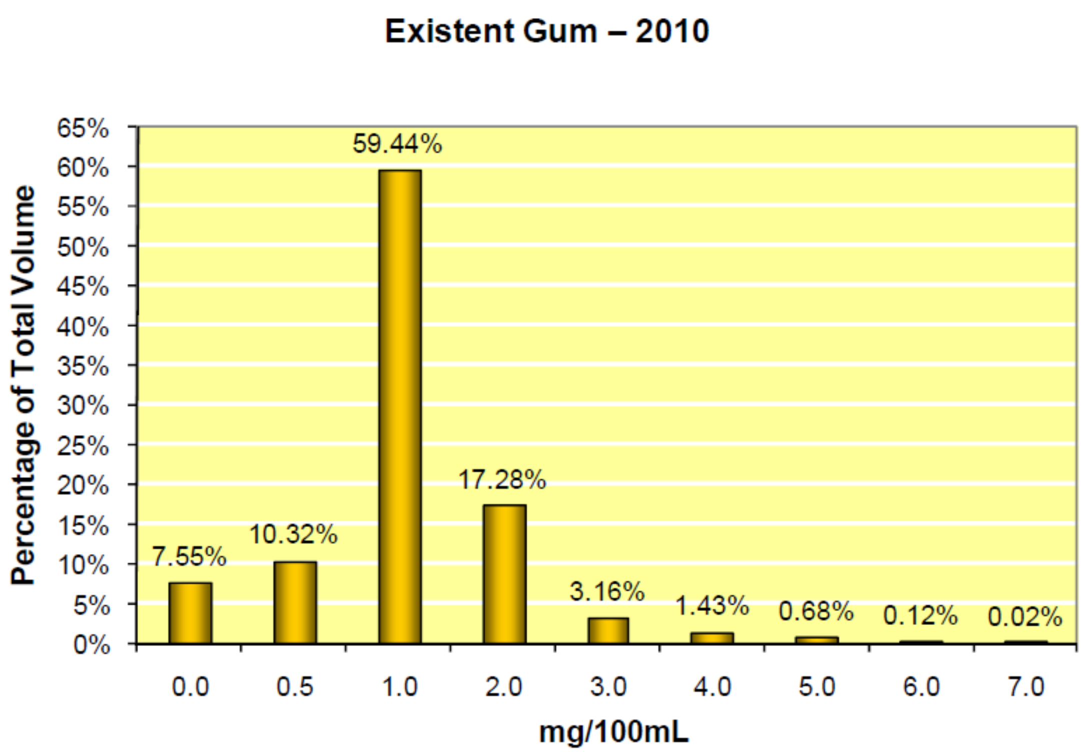


FIGURE C-26. Existent gum histogram JP-8 (2010) *taken from PQIS.*

TABLE C-XXXVIII. Existent gum fuel property rating value.

	New Fuel
G	≤7 mg / 100 mL
R	>7 mg / 100 mL

TABLE C-XXXIX. Reserved.

C.18 FILTRATION TIME – ENTRANCE CRITERIA

C.18.1 Definition. The filtration time test provides an indication of very fine particulate matter or some other unusual compound inherent in the fuel that could lead to the clogging of fuel filters and filter-coalescer cartridges by sticking to and accumulating on the filter media.

C.18.2 Standard Filtration Time Methods.

C.18.2.1 Filtration Time Test by MIL-DTL-83133. In the laboratory, a vacuum, with a minimum rating of 50 mm (20 in) Hg, is used to pump one gallon of the sample fluid through a 0.8 micrometer membrane filter. The time required to filter the sample and the weight gain of the membrane are recorded.

C.18.3 Data / Property Occurrence.

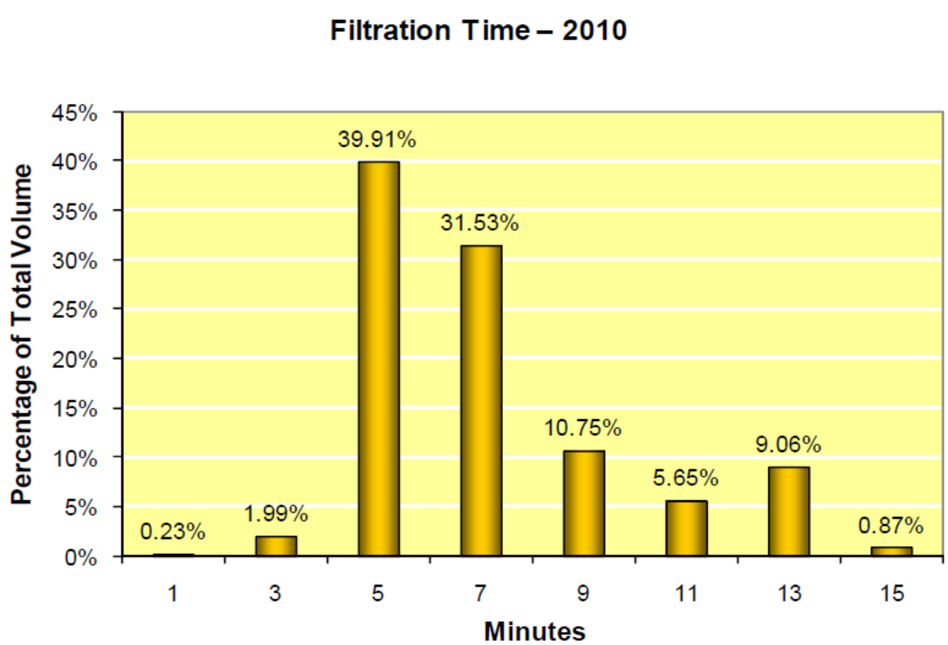


FIGURE C-27. Filtration time histogram JP-8 (2010) ***taken from PQIS.***

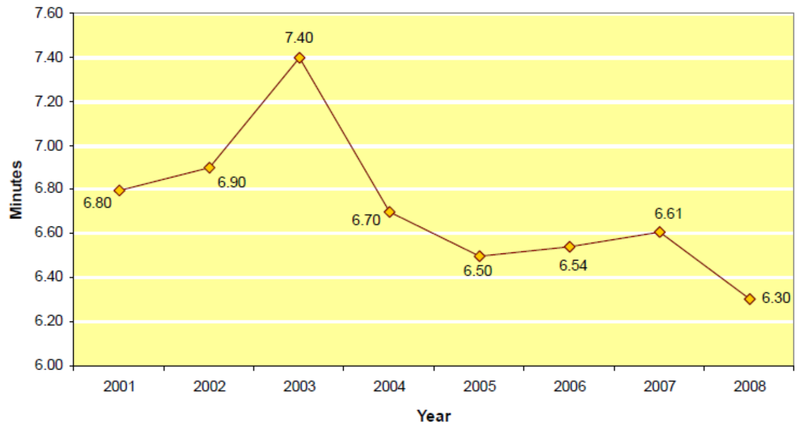


FIGURE C-28. Filtration time average JP-8 (year trend 2001-2008) *taken from PQIS.*

TABLE C-XL. Filtration time fuel property rating value.

	New Fuel
G	≤ 15 Minutes
R	> 15 Minutes

TABLE C-XLI. Reserved.

C.19 FLAME SPEED TEST – SUBSET 1.

C.19.1 Definition. The speed of propagation of a flame front through a gaseous mixture (fuel and oxidizer) relative to a reference point; see Appendix F for pool fire information.

C.19.2 Standard Flame Speed Test Methods. None identified.

C.19.2.1 See Appendix F.

C.19.3 Data / Property Occurrence.

TABLE C-XLII. Flame speed test fuel property rating value.

	New Fuel
Y	>0.6 m/s
G	0.3 to 0.6 m/s
Y	<0.3 m/s

TABLE C-XLIII. Reserved.

C.20 FLAMMABILITY LIMITS – SUBSET 1.

C.20.1 Definition. Self-sustained combustion occurs within certain ranges of fuel vapor/air ratios which are functions of temperature and pressure. Therefore at any given pressure, a fuel will have a lean flammability temperature limit (corresponding to the lean flammability of about 1vol% jet fuel in air), and at a higher temperature, a rich flammability limit (corresponding to about 5 vol%). Outside these limits, combustion will not occur if the system is in equilibrium with no spray or mist present. Figure C-29 (CRC, 2004) gives the flammability temperature limits for fuel versus altitude in meters. This classic plot has been in existence in various forms since at least 1946.

C.20.2 Standard Flammability Limits Test Methods.

C.20.2.1 ASTM E681. A uniform mixture of a gas or vapor with air is ignited in a closed vessel, and the upward and outward propagation of the flame away from the ignition source is noted by visual observation. The concentration of the flammable component is varied between trials until the composition that will just sustain propagation of the flame is determined.

C.20.3 Comments. It should be noted that Figure C-29 is based on the specification limits for fuel properties, such as the lean limit at sea level being the specification flash point limit. The typical flash points for MIL-DTL-83133 and MIL-DTL-5624 are not as different as shown on the figure. For example, the average flash points for MIL-DTL-83133 and MIL-DTL-5624 in 2005 were 47 and 63°C, respectively. It is not clear how much actual data underlies Figure C-29. Additionally it has been noted that repeatability of the test is poor, and further research into this area is recommended. Figure C-30 is an updated version of the figure from DOT-FAA-AR-9826 [1998]. There are some differences in flammability limits between fuels such as aviation gasoline, JP-4, and current kerosene fuels. For example, flammability limits have been reported as avgas (1.3-7.1 vol% fuel in air), JP-4 (1.3-8.2 vol%), JP-5 (0.6-4.5 vol%), JP-8/Jet A (0.6-4.7 vol%) [AFWAL-TR-85-2057, Aircraft Mishap Fire Pattern Investigations].

C.20.3 Data / Property Occurrence.

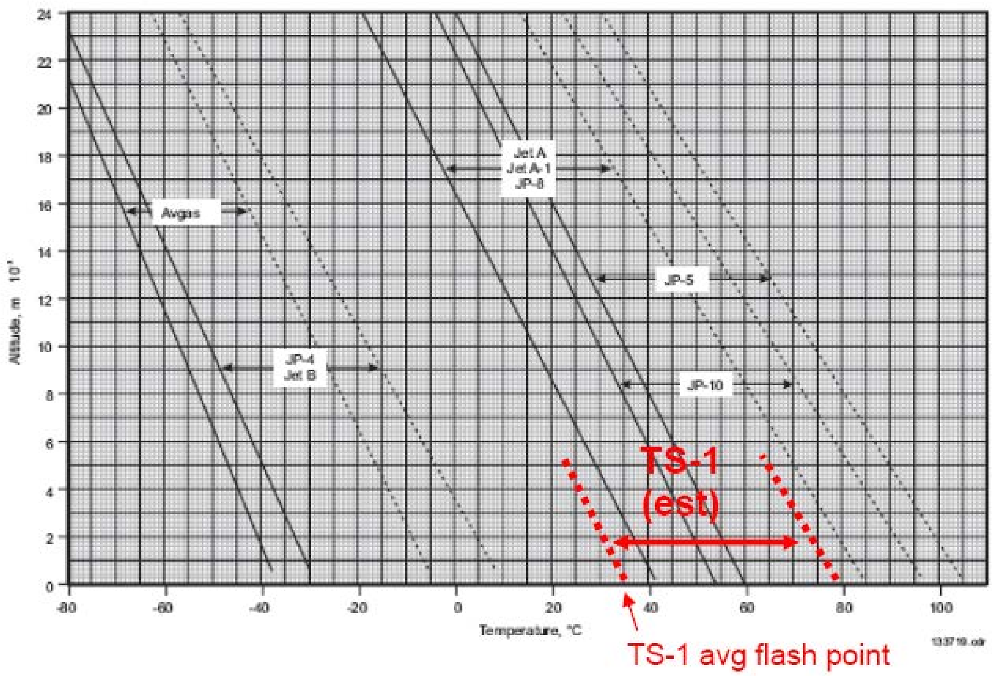


FIGURE C-29. Fuels flammability limits versus altitude (CRC, 2004).

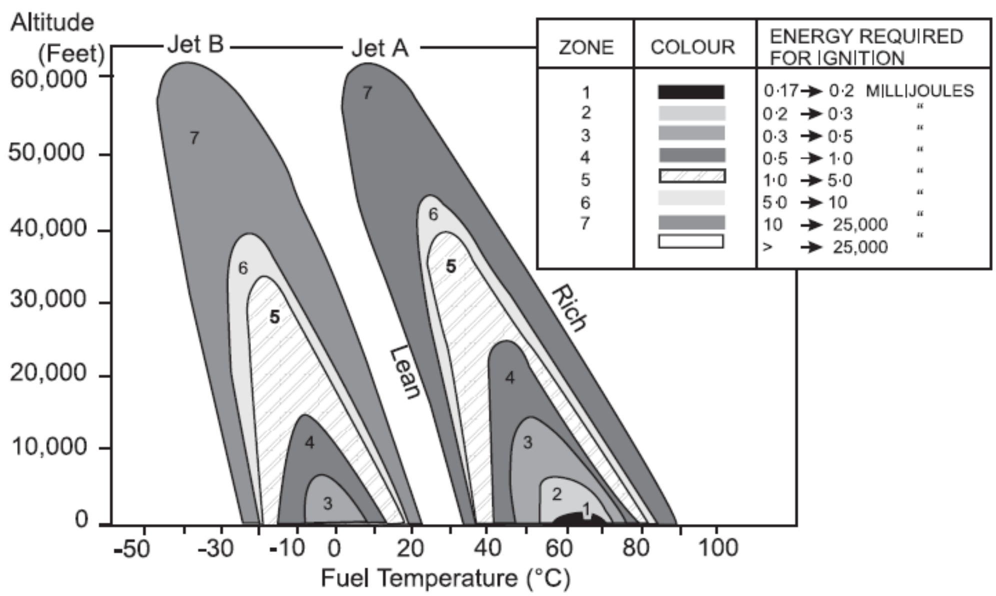


FIGURE C-30. Fuels flammability limits versus altitude [DOT, 1998].

TABLE C-XLIV. Flammability limits @ 25°C fuel property rating value.

	New Fuel
Y	> 4.7 vol %
G	0.6 to 4.7 vol %
Y	< 0.6 vol %

TABLE C-XLV. Reserved.

C.21 FLASH POINT – ENTRANCE CRITERIA.

C.21.1 Definition. Flash point is the lowest temperature at which vapors evolving from a liquid can mix with air to form an ignitable vapor mixture. Flash point is most frequently used as a measure of the volatility or flammability hazard of combustible liquids, because the lower the flash point temperature, the more volatile the liquid.

C.21.2 Standard Flash Point Test Methods.

C.21.2.1 Flash Point by ASTM D56 or ASTM D93. A sample is heated at a prescribed rate in a closed container. Periodically the container is opened slightly and a small flame is introduced to try to ignite the vapors. The flash point is the minimum temperature at which vapors ignite and then go out. Flash points are reported in ºC.

C.21.3 Comments. Flash point is an Entrance Criteria test because of its direct link to safety. The green range starts at MIL-DTL-83133's value of 38°C, and the yellow range starts at MIL-DTL-5624's value of 60°C. On the lower limits, the military has experience using Russian TS-1, but we are unsure of where to draw the yellow line. Army units have had fires from cook stoves which used TS-1. JP-4's flash point is definitely red because this was a large driver in the JP-4 to JP-8 conversion. Also, there is a possible relation between upper limits of flash point which would link to problems igniting or re-igniting engines. Additionally for vehicles and ground support equipment, flash point is the temperature at which the fuel vapor over an open container will ignite. Experience has shown that by placing a requirement for the flash point temperature above a typical ambient temperature a reasonable level of safety can be maintained. Thus 28°C (82°F) as a minimum flash point is an entry requirement.

C.21.4 Data / Property Occurrence.

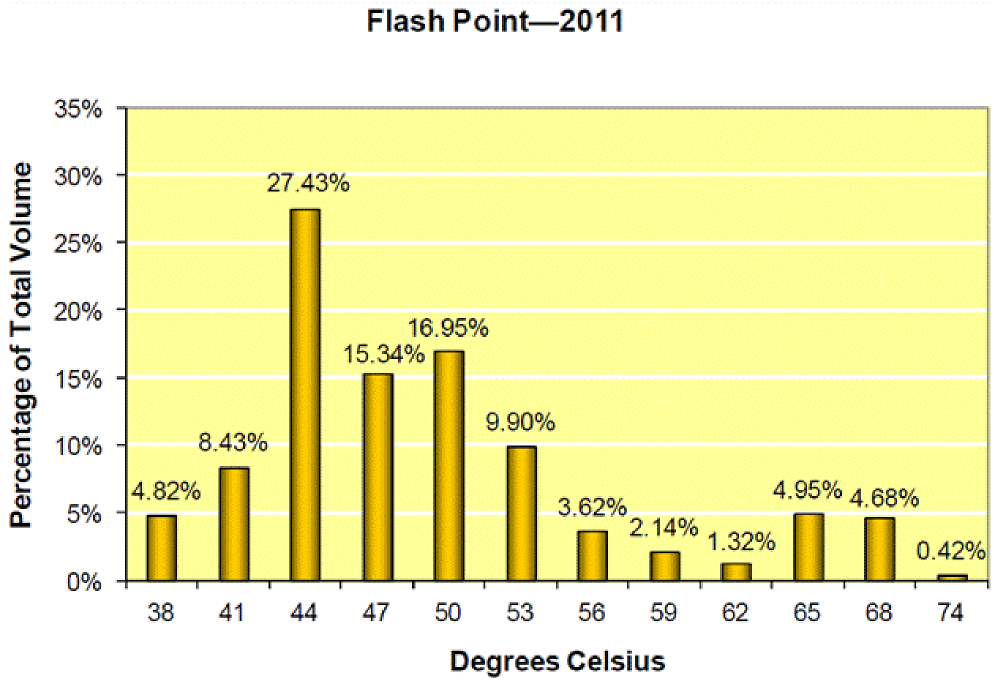


FIGURE C-31. Flash point histogram JP-8 (2011) ***taken from PQIS.***

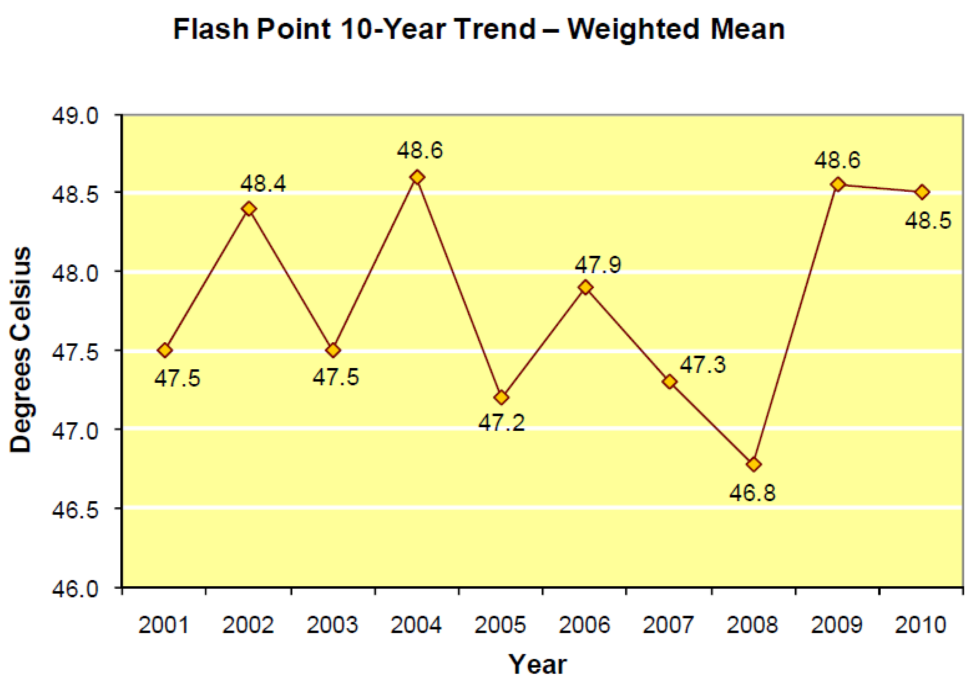


FIGURE C-32. Flash point average JP-8 (year trend 2001-2011) ***taken from PQIS.***

TABLE C-XLVI. Flash point fuel property rating value.

	New Fuel
Y	> 60 °C
G	38 °C to 60 °C
Y	28 °C to 37.9 °C
R	< 28 °C

TABLE C-XLVII. Reserved.

C.22 FREEZING POINT – ENTRANCE CRITERIA.

C.22.1 Definition. Multicomponent fuels do not freeze (become solid) at a single temperature. As temperature is lowered, n-paraffins (waxes) begin to come out of solution. The typical method used requires a sample to be chilled until wax crystals appear; then, the sample is warmed until the last fuel wax crystal melts. This point is defined as the freezing point of jet fuels.

C.22.2 Standard Freezing Point Test Methods.

C.22.2.1 Freezing Point (Manual Method) by ASTM D2386. The sample is placed into a test tube which is in a vacuum flask containing a mixture of dry ice and isopropyl alcohol. The tube contains a thermometer and a stirring rod immersed in the sample. The fuel is cooled at prescribed rate until wax crystals appear. (Water/ice crystals are ignored.) The fuel is then warmed until the last crystal melts. The freezing point is the temperature at which the last crystal melts.

C.22.2.2 Freezing Point (Phase Change Method) by ASTM D5972. A 0.15mL sample is placed into apparatus with micropipette. A built-in cooler controls the sample cooling rate. Crystal appearance and disappearance is monitored by 130 light detectors focused on a concave, shallow lens. The test sequence is automatic and the freezing point is read directly on the instrument in °C.

C.22.3 Comments. Freezing point is an Entrance Criteria test because it is linked directly to operation of aircraft in freezing temperatures. Other low temperature property tests (viscosity, pour point) are inter-dependent with freezing point and will eventually be grouped together with freezing point. Freezing point can affect pump, valve and fuel nozzle operations primarily through the increase in viscosity seen at low temperatures, and from long-duration cold soaks resulting in fuel "hold-ups" in any surface where fuel can become frozen; e.g., components, tubes, tank walls.

C.22.4 Data / Property Occurrence.

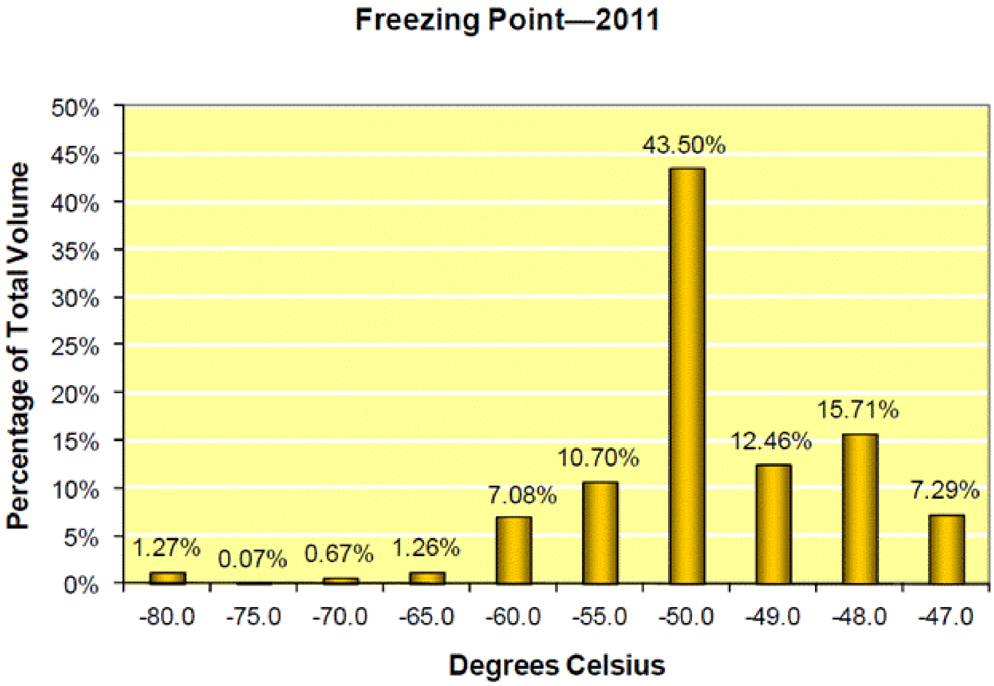


FIGURE C-33. Freezing point histogram JP-8 (2011) ***taken from PQIS.***

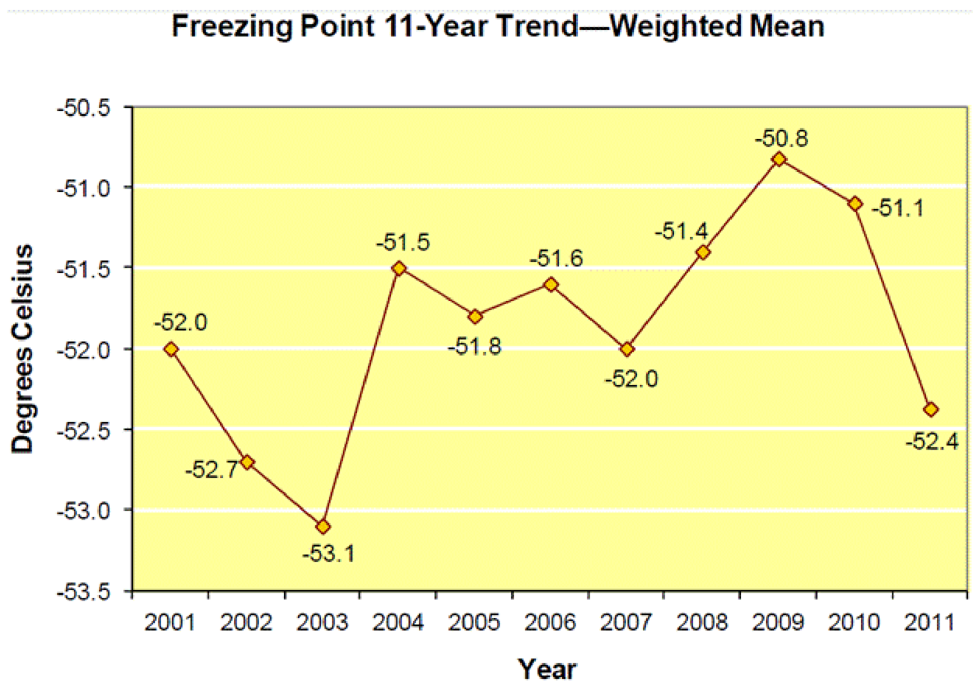


FIGURE C-34. Freezing point average JP-8 (year trend 2001-2011) ***taken from PQIS.***

TABLE C-XLVIII. Freezing point fuel property rating value.

	New Fuel
R	>-40°C
Y	-40°C to -46.9°C
G	<-47°C

TABLE C-XLIX. Reserved.

C.23 FUEL SYSTEM ICING INHIBITOR (FSII) – ENTRANCE CRITERIA.

C.23.1 Definition. The United States Military uses additives within their liquid hydrocarbon fuels to aid in performance. One of these additives is Diethylene Glycol Monomethyl Ether, more commonly known as DiEGME, to help minimize icing within the liquid hydrocarbon. Ongoing studies are examining the potential for reducing the required amount of FSII. This is a test for an additive concentration, not an inherent fuel property.

C.23.2 Standard Icing Inhibitor Test Methods.

C.23.2.1 Fuel System Icing Inhibitor by ASTM D5006. The FSII in a measured volume of fuel is extracted with a fixed ratio of water. A few drops of the water extract are placed on the prism of a refractometer. In one refractometer method, FSII content is read directly in volume percent. In a different refractometer method a temperature correction is followed by minor calculations to obtain FSII content in volume percent.

C.23.3 Data / Property Occurrence.

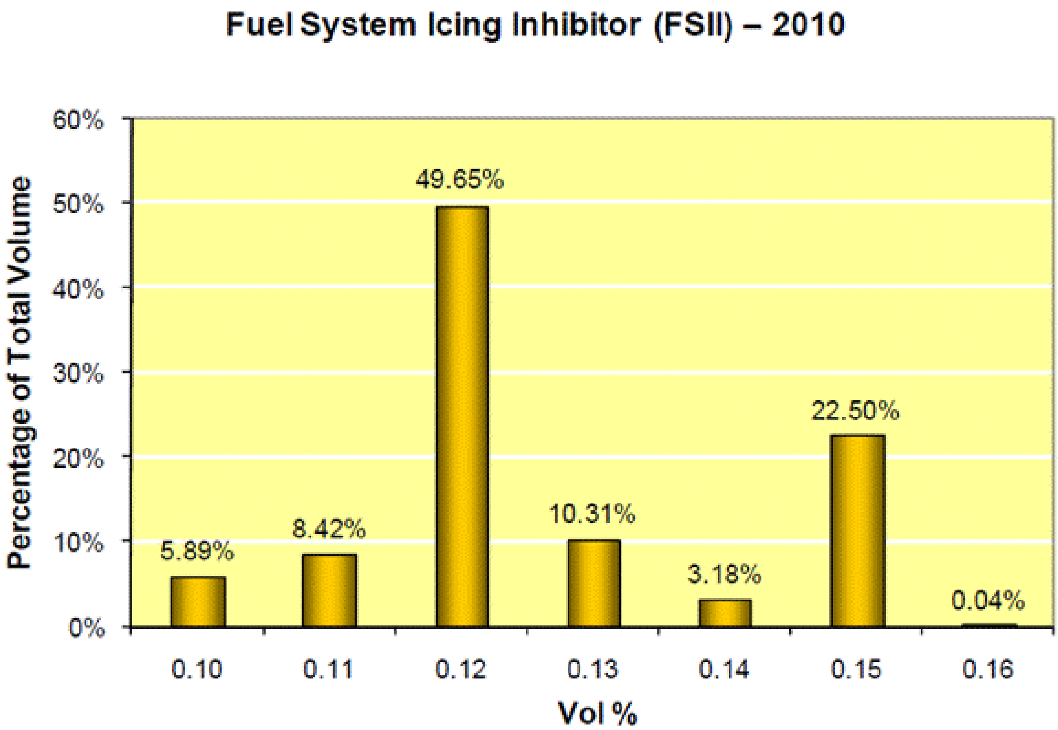


FIGURE C-35. FSII histogram JP-8 (2010) *taken from PQIS.*

TABLE C-L. FSII fuel property rating value.

	New Fuel
Y	> 0.15 vol %
G	0.04 to 0.15 vol %
Y	< 0.04 vol %

TABLE C-LI. Reserved.

C.24 GAS CHROMATOGRAPH (CHEMICAL DESCRIPTION) – ENTRANCE CRITERIA.

C.24.1 Definition. A gas chromatograph (GC) is an analytical chemistry instrument which helps to identify the chemical composition of substance by separating complex mixtures into components on a column. Regarding jet fuel samples, GC's can yield information on the hydrocarbon distribution, the chain branching, the hydrocarbon rings, and the aromatic compounds within a fuel, depending upon the detector employed. Despite its analytical powers, a GC does not positively identify every substance within a sample, due to detection and separation limits. A GC and a mass selective detector can be used to identify separate jet fuel compound classes in a fuel sample using the ASTM D2425 procedure [AIAA 2006-7972].

C.24.2 Standard GC Test Methods.

C.24.2.1 Distillation (Simulated) by ASTM D2887. Fuel is passed through a chromatographic column which separates hydrocarbons in boiling point order. Boiling temperatures are assigned from a calibration curve, obtained by running a known mixture of hydrocarbons under the same conditions, and a boiling point distribution is obtained. Results are reported in ºC versus percent recovered.

C.24.3 Comments. Distillation curves are the range of temperatures over which a fuel boils at 1 bar, as discussed in the distillation section, above. The intent of this section is to use the GC "fingerprint" to ensure that the prospective fuel has an apparent composition that falls within the experience base. In combination with the boiling range limits, this is designed to ensure that the molecular distribution of species in the fuel is not unusually weighted (e.g., bimodal). For example, GCs of a Fischer-Tropsch synthetic jet fuel and a petroleum-derived JP-8 are shown on Figures C-36 and C-37, respectively. The even distribution of species (with molecular weight/boiling temperature generally increasing with residence time) is typical. In contrast, some biodiesel fuels consist of only 3-5 species and boil in a very narrow range. There may be combustion and other operational impacts for such a narrow-boiling distribution. A properly configured fuel will have a balanced distribution of carbon numbers without undue proportion of light or heavy fractions. Figure C-37 is an example of a typical GC distribution of JP-8 fuel and is considered a good model for any new fuel type. Fuels that have a narrow carbon distribution should be considered as being in the yellow range.

C.24.4 Data / Property Occurrence.

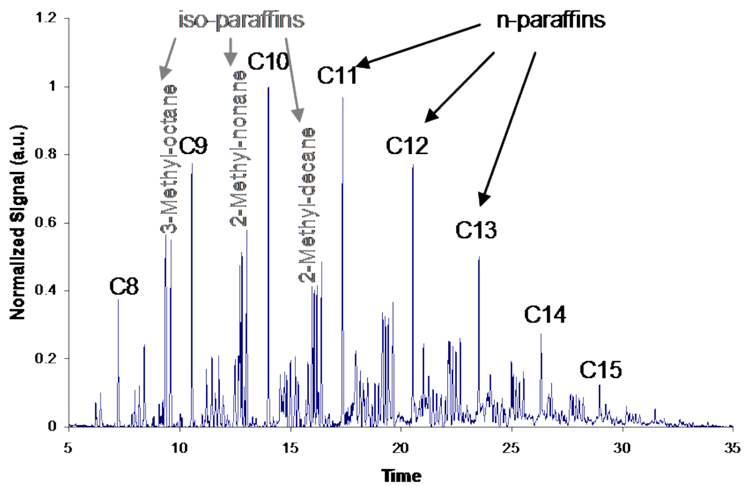


FIGURE C-36. Gas chromatograph of FT synthetic fuel (Courtesy AFRL, USAF).

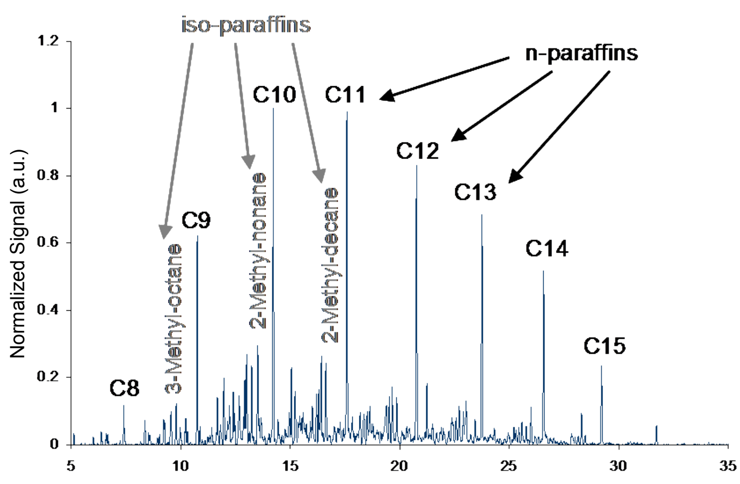


FIGURE C-37. Gas chromatograph of JP-8.

TABLE C-LII. Gas chromatograph fuel property rating value.

	New Fuel
Y	Narrow carbon distribution
G	Figure C-37, Typical JP-8 carbon distribution

TABLE C-LIII. Reserved.

C.25 HEAT OF COMBUSTION, NET – ENTRANCE CRITERIA.

C.25.1 Definition.

The net amount of heat energy released per unit mass when a substance is completely combusted with air, forming CO_2 and water vapor as products. The "gross" heat of combustion corresponds to the formation of liquid water as a product.

C.25.2 Net Heat of Combustion Test Methods.

C.25.2.1 Net Heat Content by Bomb Calorimeter by ASTM D4809. A weighed quantity is burned in a closed pressure vessel while immersed in a water bath. The total heat released by the substance is calculated from an accurate measurement of the rise in temperature of the water. Net specific energy is calculated by correcting for the condensation of water and sulfur reaction products. Net specific energy is reported in MJ/kg or BTU/lb. The net specific energy can also be calculated by measuring other properties which have been shown to correlate with heat content. These properties include density, aniline point, boiling point, and aromatic content in ASTM D3338, or aniline point and density of ASTM D4529.

C.25.3 Comments. More research required to establish upper limits from existing systems.

C.25.4 Data / Property Occurrence.

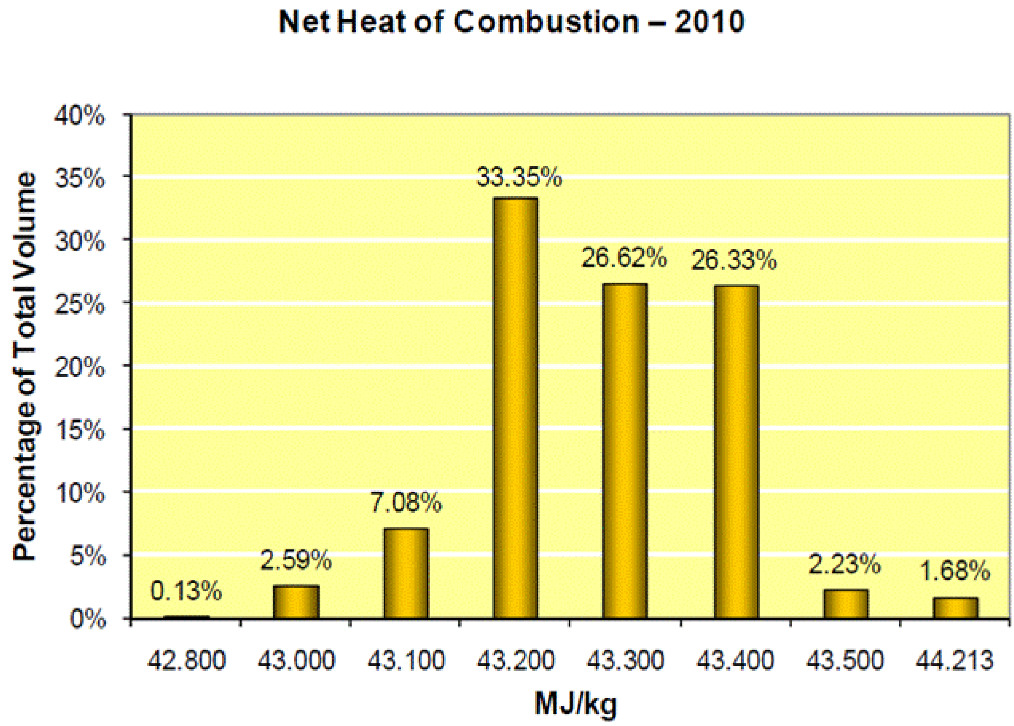


FIGURE C-38. Net heat of combustion histogram JP-8 (2010) *taken from PQIS.*

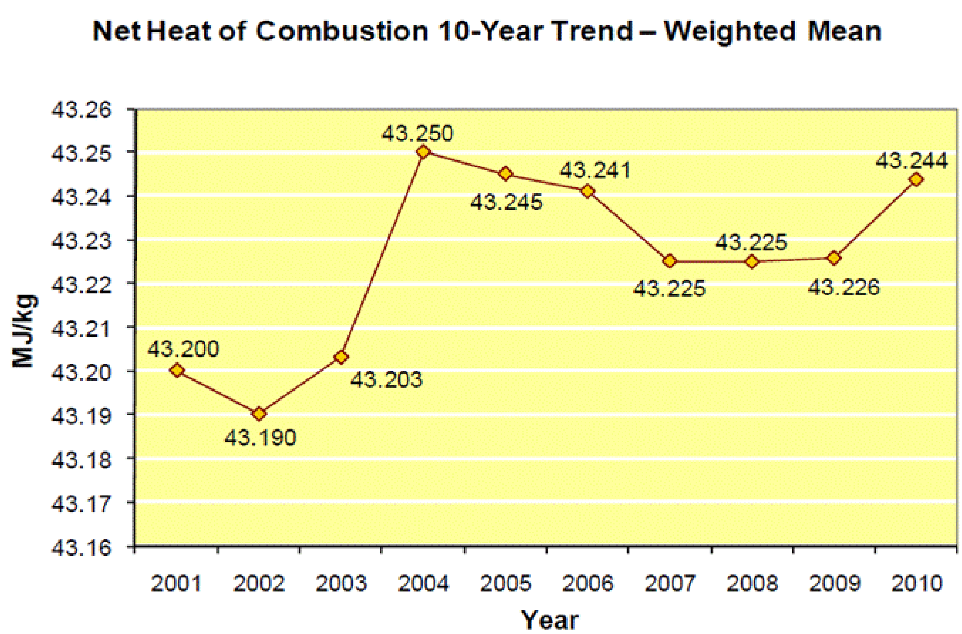


FIGURE C-39. Net heat of combustion average JP-8 (year trend 2001-2010) *taken from PQIS.*

TABLE C-LIV. Net heat of combustion fuel property rating value.

	New Fuel
Y	< 42.8 MJ/kg
G	≥ 42.8 MJ/kg

TABLE C-LV. Reserved.

C.26 HEAT OF VAPORIZATION, LATENT.

See C.46, Vapor Pressure.

FIGURE C-40. Reserved.

C.27 HOT SURFACE IGNITION – SUBSET 1.

C.27.1 Definition. Hot surface ignition temperature is the temperature of a material that will ignite a fuel upon contact. This property has obvious implications to safety involving fuel leaks. Criteria can be hard to set for hot surface ignition because surface geometry, closed or open test, air flow velocity, and residence time can all affect this property.

C.27.2 Standard Test Methods.

C.27.2.1 Federal Test Standard 791C Method 6053. The fuel is dripped onto an internally heated manifold until the fuel ignites.

C.27.2.2 ISO 20823 Hot Surface Temperature. The fuel is dripped onto an internally heated manifold until the fuel ignites.

C.27.3 Comments. Appendix F discusses more involved fire safety testing. In general the concern for new fuels would be hot surface ignition values outside of the general experience range for jet fuels (800-1200°F).

C.27.4 Data / Property Occurrence.

TABLE C-LVI. Hot surface ignition fuel property rating value.

	New Fuel
G	≥ 1000°F
Y	800°F < Y< 1000°F
R	< 800°F

TABLE C-LVII. Reserved.

C.28 HYDROGEN CONTENT – ENTRANCE CRITERIA.

C.28.1 Definition. The amount of hydrogen contained within a hydrocarbon sample. The MIL-DTL-5624 and MIL-DTL-83133 specifications require >13.4 mass % hydrogen, while this requirement is absent in the Jet A and Jet A-1 specifications.

C.28.2 Hydrogen Content Test Methods.

C.28.2.1 Hydrogen Content by ASTM D3701. A sample is compared with a pure liquid hydrocarbon standard (n-dodecane) in a low resolution nuclear magnetic resonance spectrophotometer (NMR). Based on this comparison the instrument calculates and indicates the hydrogen content in mass percent. D3701 is the preferred test method.

C.28.2.2 Hydrogen Content by ASTM D3343. Hydrogen content is calculated by using an equation relating hydrogen content with distillation range, density and aromatic content. Hydrogen content is reported as percent by mass.

C.28.2.3 Hydrogen Content by ASTM D7171. This "Standard Test Method for Hydrogen Content of Middle Distillate Petroleum Products by Low-Resolution Pulsed Nuclear Magnetic Resonance Spectroscopy" is a newer test method using updated equipment.

C.28.3 Comments. ASTM D3343 may be inaccurate outside of the range of fuels for which the equation was developed. Hydrogen content may be converted to fuel H/C (hydrogen/carbon) ratio using the below equation (which assumes the fuel contains only carbon and hydrogen). In extensive previous testing of engines with fuels of varying composition, it was found that engine smoke/soot emissions correlated most strongly with fuel hydrogen content. The ratio of hydrogen to carbon can be determined using the following equation derived from the mass balance:

H/C Equation: H/C(molar)=11.9161*(wt%H)/(100-wt%H)

C.28.4 Data / Property Occurrence.

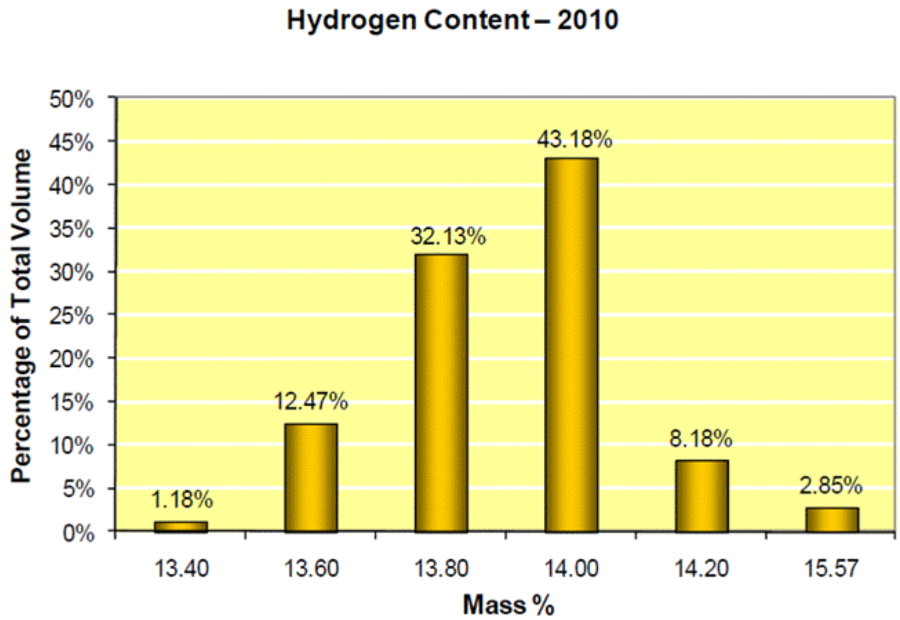


FIGURE C-41. Hydrogen content histogram JP-8 (2010) *taken from PQIS.*

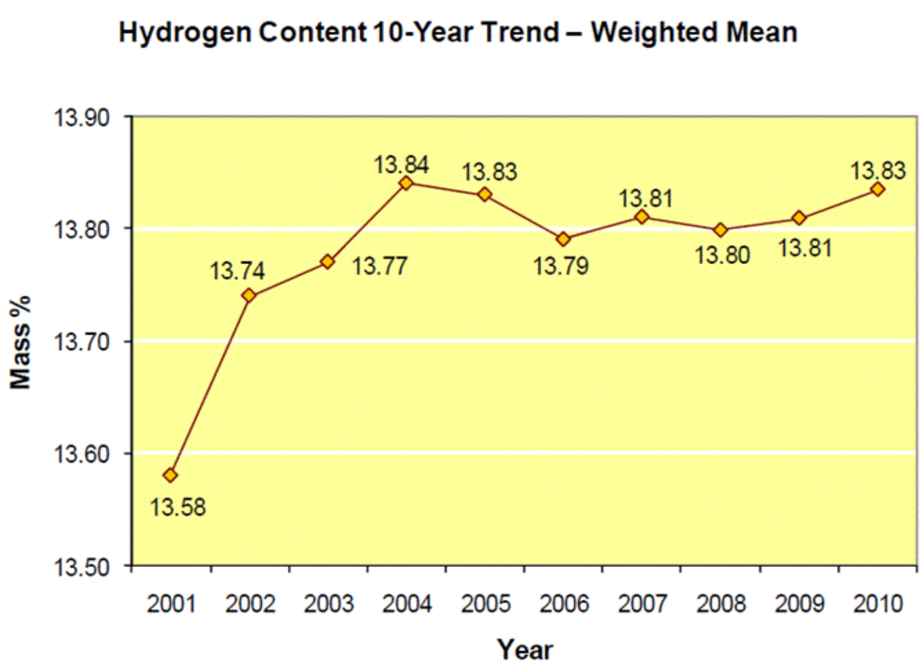


FIGURE C-42. Hydrogen content average JP-8 (year trend 2001-2010) *taken from PQIS.*

TABLE C-LVIII. Hydrogen content fuel property rating value.

	New Fuel
Y	<13.4 mass %
G	>13.4 mass %

TABLE C-LIX. Reserved.

C.29 LUBRICITY – SUBSET 1 CRITERIA.

C.29.1 Definition. Aviation turbine fuel serves as a lubricant in fuel pumps, engine controls, and servo valves. Straight-run fuels normally contain boundary lubricants in trace amounts. These are primarily polar compounds containing oxygen, nitrogen, or sulfur. Such polar compounds form thin films on metal surfaces, protect against corrosion, and provide boundary lubrication. Lack of lubrication can result in high friction and metal-to-metal contact leading to increased wear rates and possible scuffing. Severe refining conditions, such as hydrocracking, remove these natural lubricants from the fuel and severely hydrotreated or hydrocracked fuels are, therefore, more likely to have poor lubricity.

C.29.2 Standard Lubricity Test Methods.

C.29.2.1 Lubricity by ASTM D5001. In the Ball-on-Cylinder Lubricity Evaluator (BOCLE) test a fixed steel ball, under load, is pressed against a rotating cylinder, covered by fuel, for a predetermined period of time. Both the temperature and humidity of the air around the test section are controlled during the test. Fuel lubricity is based on the size of the resulting elliptical wear scar on the ball. The reported wear scar size, in millimeters, is the major axis plus the minor axis divided by two. Wear scar is reported in mm. Fuels giving high wear scars have poor lubricity or have been called hard fuels.

C.29.2.2 Other test methods. Other lubricity test methods include the Scuffing BOCLE (ASTM D6078) and HFRR (ASTM D6079).

C.29.3 Comments. Lubricity problems are mitigated in JP-8 by the mandated addition of the corrosion inhibitor/lubricity improver (CI/LI). These additives are qualified by MIL-PRF-25017.

C.29.4 Data / Property Occurrence.

TABLE C-LX. Lubricity fuel property rating value.

	New Fuel
R	>0.85 mm
Y	0.65 to 0.85 mm
G	0 to 0.65 mm

TABLE C-LXI. Reserved.

C.30 MINIMUM SPARK IGNITION ENERGY – SUBSET 2.

C.30.1 Definition. According to the CRC Handbook, 2004, the minimum amount of energy required for a spark discharge to ignite an optimum hydrocarbon fuel/air mixture is in the 0.20 to 1 mJ range. The optimum fuel/air mixture is normally found at a point on the rich side near the stoichiometric point. As conditions depart from an ideal state, the energy requirements increase. Changing the fuel/air mixture, the electrode geometry, or the gap distance will change the amount of energy required for ignition. If the fuel is present in the form of a mist or spray, as opposed to a vapor, the ignition energy requirements will increase. On the other hand, an increase in the oxygen concentration of the air, such as found in aircraft ullage at altitude, will decrease the amount of energy required for ignition.

The minimum ignition energy for fuels is illustrated on Figures C-43 and C-44. The minimum spark ignition energy required to ignite a fuel varies with the temperature and is dependent upon the volatility of the fuel in question. For sprays, other variables include the configuration of the nozzle delivering the spray and pressure on the fuel which determines the droplet sizes in the spray.

C.30.2 Standard Spark Ignition Energy Test Methods.

C.30.2.1 ASTM E 582-7.

This test method covers the determination of minimum energy for ignition (initiation of deflagration) and associated flat-plate ignition quenching distances. The complete description is specific to alkane or alkene fuels admixed with air at normal ambient temperature and pressure. This method is applicable to mixtures of the specified fuels with air, varying from the most easily ignitable mixture to mixtures near the limit-of-flammability compositions.

C.30.3 Comments. The minimum energies provide a basis for comparing the ease of ignition of gases. The flat-plate ignition quenching distances provide an important verification of existing minimum ignition energy data and give approximate values of the propagation quenching distances of the various mixtures. It is emphasized that maximum safe experimental gaps, as from “flame-proof” or “explosion-proof” studies, are less than the flat-plate ignition quenching distances. Given the lack of a standard test method and the difficulty of measuring the minimum spark ignition energy, the criterion is defined as "no easier to ignite than Jet A/JP-8". This definition is driven by safety. In terms of operability, an engine designer might prefer to have a fuel that is easier to ignite than current fuels—but that is not the constraint used in this handbook.

C.30.3 Data / Property Occurrence.

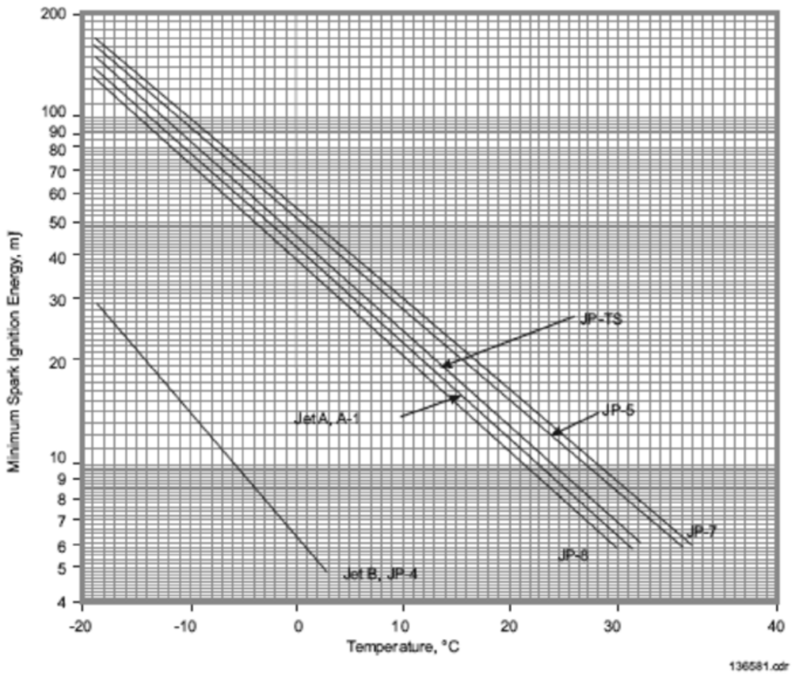


FIGURE C-43. Minimum spark ignition energy *[CRC, 2004].*

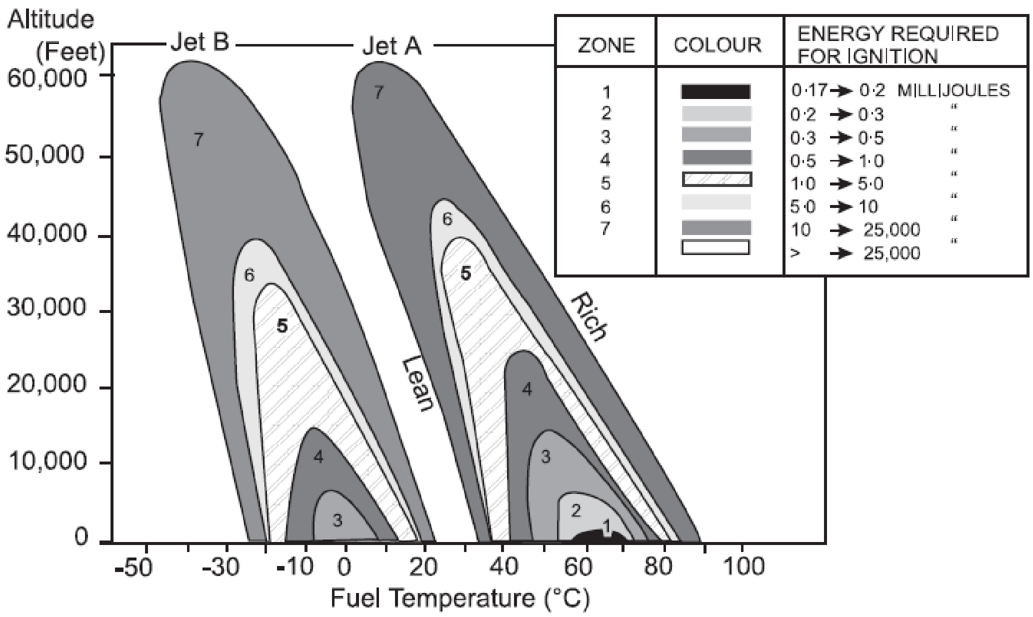


FIGURE C-44. Fuels flammability limits versus altitude [DOT, 1998].

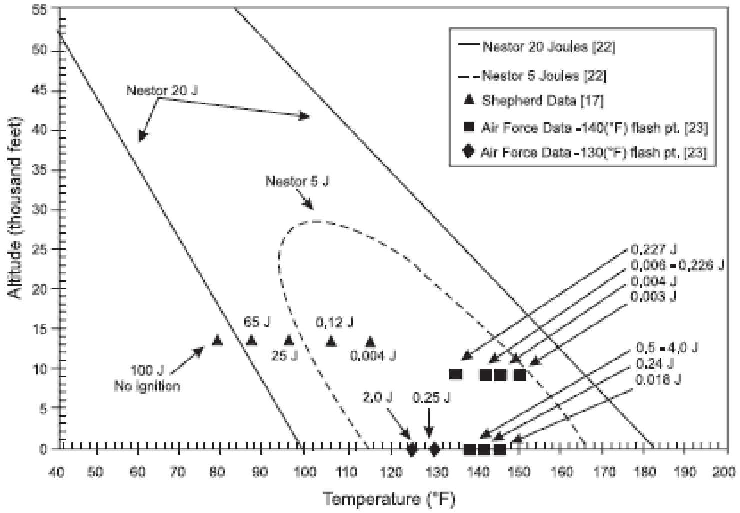


FIGURE C-45. Effect of temperature and altitude on Jet A flammability [DOT-FAA-AR-9826].

TABLE C-LXII. Minimum spark ignition energy fuel property rating value.

	New Fuel
R	<JP-4 values
Y	between JP-4 and JP-8 values
G	JP-5/JP-8 values
Y	>JP-8 values

TABLE C-LXIII. Reserved.

C.31 NAPHTHALENES – ENTRANCE CRITERIA.

C.31.1 Definition. Naphthalene is an aromatic hydrocarbon, structurally consisting of two benzene rings fused together. Jet fuel often contains the molecule naphthalene ($C_{10}H_8$), as well as naphthalene with alkyl group substituents (such as 1-methyl naphthalene, 2-ethyl naphthalene etc.). The sum of the naphthalene ($C_{10}H_8$) content and substituted naphthalene content is defined as "naphthalenes" and is typically assessed using ASTM D 1840. Napthalenes are typically found in jet fuels at about 1 vol% (see Figure C-46B).

They are generally tested for in conjunction with smoke point, as naphthalenes can increase the smoke point of a liquid hydrocarbon.

C.31.2 Naphthalene Test Methods.

C.31.2.1 Naphthalenes Content by ASTM D1840. The naphthalene content is determined by ultraviolet absorption at a wave length of 285 nm. Naphthalene concentration is established by using the average response of a standard blend of naphthalene. Naphthalene content is reported in mass percent.

C.31.3 Comments. Naphthalenes are effective at generating soot (which was the reason behind the limit in the specification), as well as being effective in swelling elastomers.

C.31.4 Data / Property Occurrence.

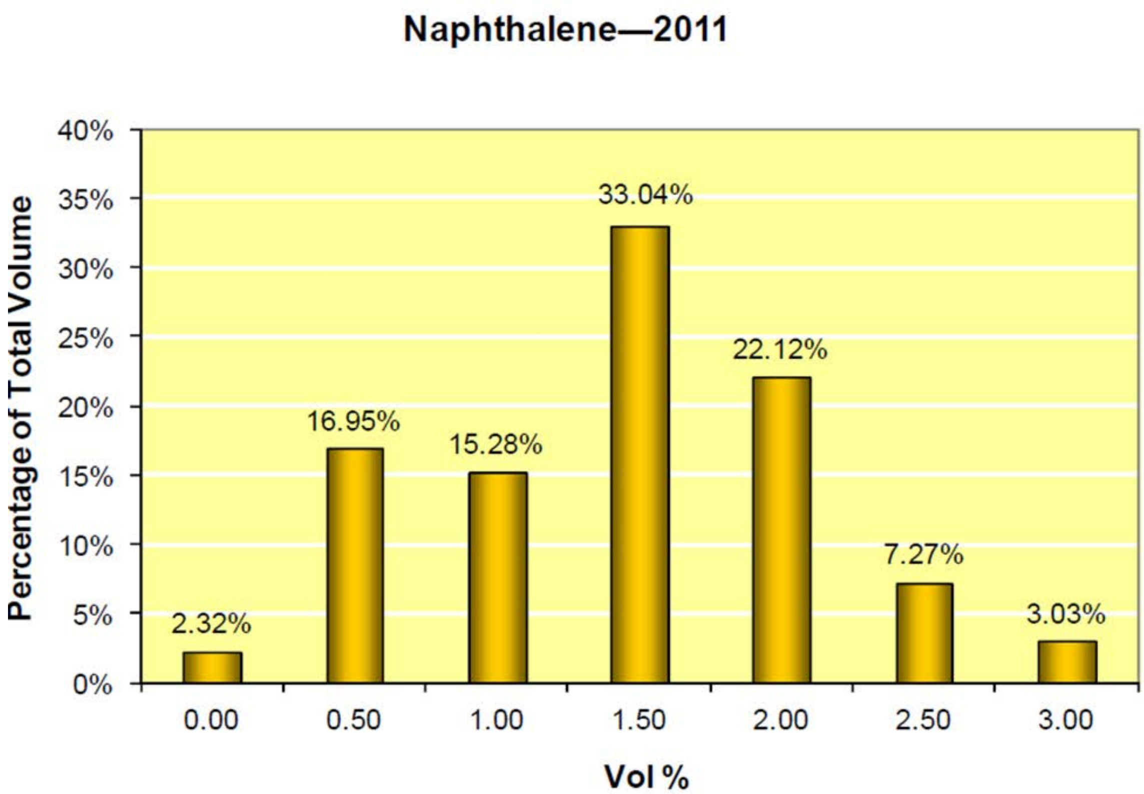


FIGURE C-46a. Naphthalenes histogram JP-8 (2011) ***taken from PQIS.***

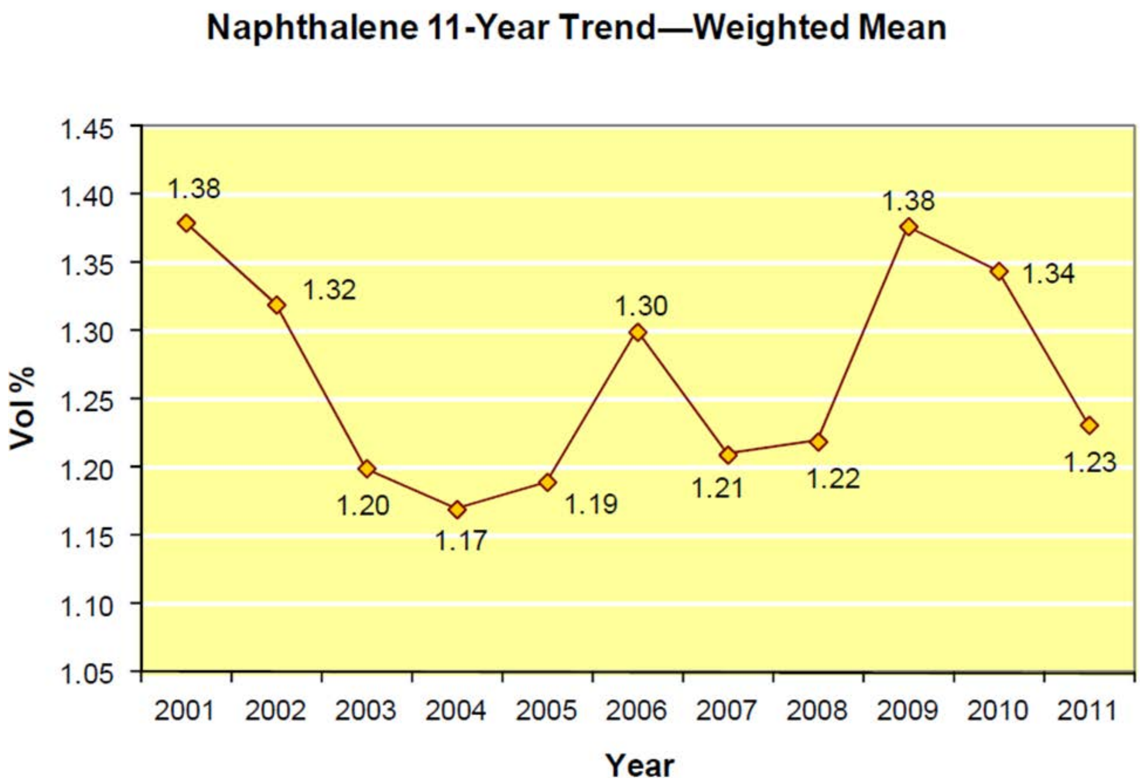


FIGURE C-46b. Naphthalene average JP-8 (year trend 2001-2011) ***taken from PQIS.***

TABLE C-LXIV. Naphthalenes fuel property rating value.

	New Fuel
G	≤ 3%
R	> 3%

TABLE C-LXV. Reserved.

C.32 OSTWALD COEFFICIENT / GAS SOLUBILITY - SUBSET 2.

C.32.1 Definition. The solubility of gases in fuels is of high importance to the proper design of fuel systems and their components. High evolution of gases during climb can cause decreased pressure resulting in loss of fuel and when pumping fuel, gas phase separation can occur leading to vapor lock or cavitation problems. The Ostwald Coefficient is the volume of gas dissolved in one volume of solvent. While several variables affect the solubility of gases in fuels including temperature, pressure, nature of fuel, and the gas itself, Ostwald Coefficient is independent of pressure, and the gas volume is measured at the conditions of the solution. Figure C-47A (CRC 2004) gives the typical solubility of O_2, and N_2 in aviation fuels. Figure C-47B depicts the typical solubility of CO_2 in aviation fuels. Carbon dioxide, unlike the other gases, decreases in solubility with increasing temperature. The solubility of this gas is very high.

C.32.2 Standard Gas Solubility Test Methods.

C.32.2.1 Solubility of Gas by ASTM D2779. Correlations have been established by the National Aeronautics and Space Administration (NASA) (formerly National Advisory Committee on Aeronautics) in NACA Technical Note 3276 (1956). Their work was extended to include most of the data published since that time, and extrapolated by semi-empirical methods into regions where no data are available. The only data required are the density of liquid at 288 K (59°F) and the nature of the gas. These are used to estimate the Ostwald coefficient.*

* Reprinted, with permission, from *ASTM D2779: Standard Test Method for Estimation of Solubility of Gases in Petroleum Liquids*©, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428; www.astm.org.

C.32.3 Data / Property Occurrence.

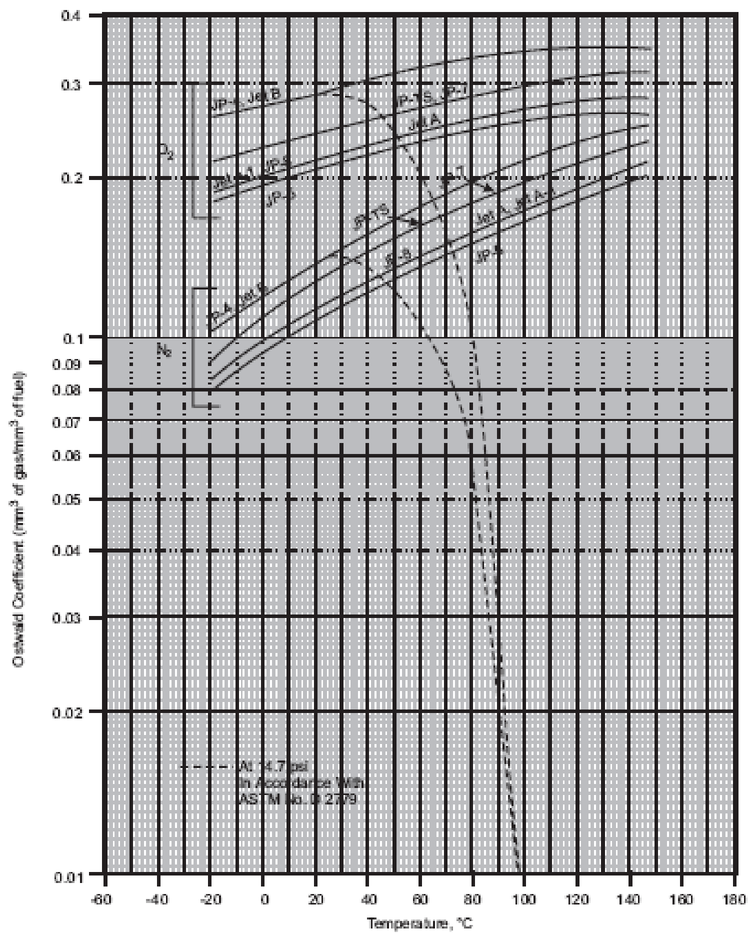


FIGURE C-47a. Ostwald coefficient as a function of temperature *[CRC, 2004]*.

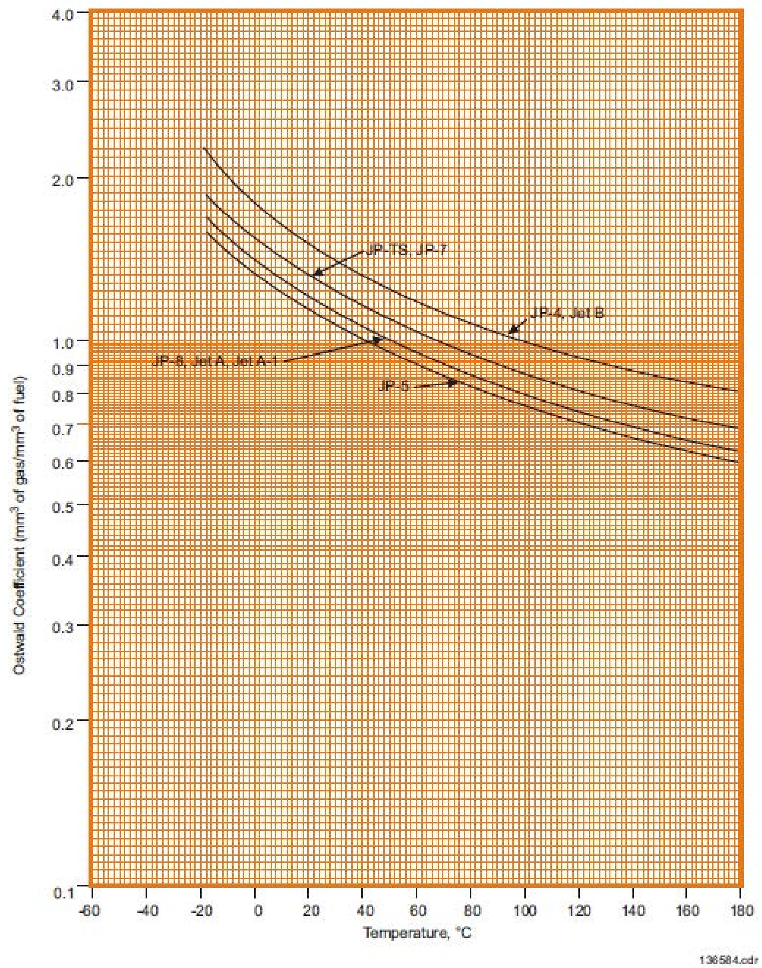


Figure 2-29. Solubility of CO_2 in Aviation Fuels

FIGURE C-47b. Solubility of CO_2 in aviation fuels.

TABLE C-LXVI. Ostwald coefficient / gas solubility fuel property rating value.

	New Fuel
R	>JP-4 values
Y	JP-4 to JP-8 values
G	≤JP-5/JP-8 values

TABLE C-LXVII. Reserved.

C.33 PARTICULATE MATTER – ENTRANCE CRITERIA.

C.33.1 Definition.

Particulate matter is any minute and separate particles contained within the hydrocarbon sample.

C.33.2 Standard Particulate Test Methods.

C.33.2.1 Particulates by Field Filtration by ASTM D2276.

A fixed volume of fuel (usually 4 L or 1 gal) is forced, under line pressure, through a membrane having a pore size of 0.8 micrometer. After drying the membrane, its color is rated by comparing it to a color standard. In a different version of the procedure the weight gain of the membrane, after field filtration, is determined in a laboratory. The weighing procedure is the same as in ASTM D5452, Particulates by Laboratory Filtration.

C.33.2.2 Particulates by Laboratory Filtration by ASTM D5452.

A known volume, usually 4 L, is filtered through two pre-weighed, matched weight membranes in series, having a pore size of 0.8 m, using a vacuum downstream of the membranes. The increase in weight of the upper membrane is determined after washing and drying of the membrane. Any change in weight of the second or control membrane is also determined. The particulate contaminant level is the difference in weight gain of the two membranes. Results are reported in mg/L or mg/gallon. The method can also be used to conduct the Time Filtration test.

C.33.3 Comments.

Setting limits on the tolerable size distribution and total mass of particulate contamination in fuel was at the very heart of a CRC effort (Av-04-04) initiated in FY05. This effort included a survey of engine OEMs and component OEMs and was being worked by Vic Hughes Associates Limited. As of June, 2006 no finalized agreement or final conclusion had been reached. Survey responses are varied and highly dependent on the particular OEM.

C.33.4 Data / Property Occurrence.

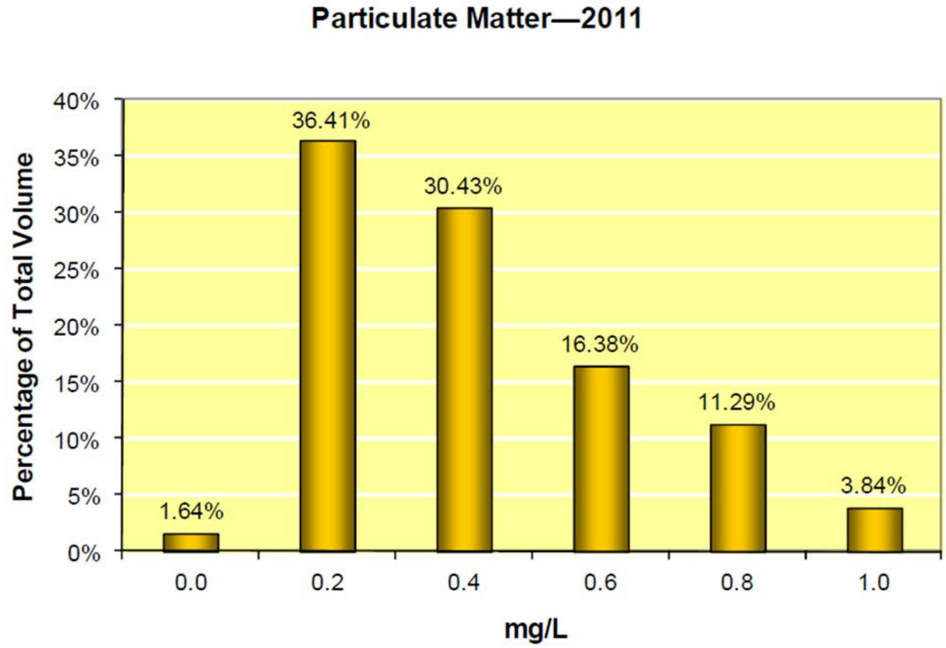


FIGURE C-48. Particulate matter histogram JP-8 (2011) *taken from PQIS.*

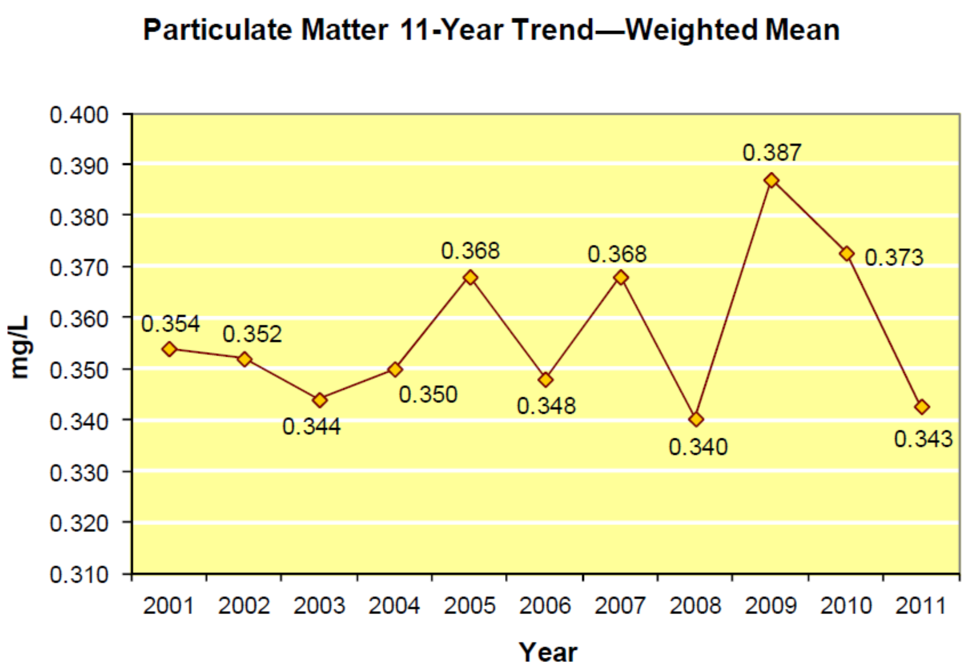


FIGURE C-49. Particulate matter average JP-8 (year trend 2001-2011) *taken from PQIS 2011.*

TABLE C-LXVIII. Particulate matter fuel property rating value.

	New Fuel
G	≤1 mg/L
R	>1 mg/L

TABLE C-LXIX. Reserved.

C.34 POUR POINT.

C.34.1 Definition. Pour point is the lowest temperature at which a liquid will flow without a significant pressure behind it. Pour point is an indication of the pumping ability of a fuel at cold temperatures. In typical petroleum based fuels, failure to flow can be linked to the separation of wax from the fuel. However, it can also be caused by the high viscosity in the case of very viscous fuel oils.

C.34.2 Standard Test Methods.

C.34.2.1 Pour Point of Petroleum Products by ASTM D97. After preliminary heating, the sample is cooled at a specified rate and examined at intervals of 3°C for flow characteristics. The lowest temperature at which movement of the specimen is observed is recorded as the pour point.*

C.34.3 Comments. The pour point is lower than the freezing point, which is the point where the last visible crystal of fuel disappears upon warming. Pour point is also related to the dramatic increase in viscosity-versus-temperature curves. See viscosity versus temperature, section C.47. Both in the fuel specifications and in aircraft operations, the more conservative (warmer) Freezing Point (C.22) is used to address concerns about fuel solidifying at cold temperatures via a lower limit.

C.34.4 Data / Property Occurrence.

TABLE C-LXX. Reserved.

TABLE C-LXXI. Reserved.

C.35 SAYBOLT COLOR – ENTRANCE CRITERIA.

C.35.1 Definition. A color based indicator that fuel is required to obtain as a quality test of both the manufacturing process and the fuel.

C.35.2 Standard Saybolt Color Test Methods.

C.35.2.1 Color by Saybolt Chromometer by ASTM D156. Fuel is placed into a sample tube and its color is observed by looking through the length of the sample tube and comparing the color to the standard in an adjacent tube. (Both tubes are visible in the eye piece.) The sample height is decreased until the sample color matches the color of the standard in the other tube. The reported fuel color is based on the final height of the fuel column and the particular standard used. Results are reported as values ranging from +30 (water white) to -16 (straw color).

C.35.3 Comments. Saybolt color helps fuels personnel in the logistical fuel supply chain identify potential problems most commonly linked to contamination. Other fuels contamination and particulate tests that have to be run on new fuels give yield more quantifiable information.

C.35.4 Data / Property Occurrence.

TABLE C-LXXII. Saybolt color fuel property rating value.

	New Fuel
G	Report

TABLE C-LXXIII. Reserved.

C.36 SMOKE POINT – ENTRANCE CRITERIA.

C.36.1 Definition. The smoke point of a substance is the point at which a wick-fed flame begins to generate visible smoke. It provides an indication of the relative smoke-producing properties of a liquid hydrocarbon in a diffusion-controlled flame, and the smoke point is related to the hydrocarbon composition. Generally the more aromatic the sample is, the smokier the flame becomes. The smoke point (and Luminometer number with which it can be correlated) is quantitatively related to the potential radiant heat transfer from the combustion products of the sample.

C.36.2 Smoke Point Test Methods.

C.36.2.1 Smoke Point by ASTM D1322. A sample is placed into a wick-fed kerosene lamp and the wick is ignited. A scale marked in millimeters is behind the flame. The wick is raised until the tip of the flame starts to smoke. The wick is then lowered until smoke disappears. The smoke point is the maximum height of the flame at which no smoke is noted. Smoke point is reported in mm.

C.36.3 Data / Property Occurrence.

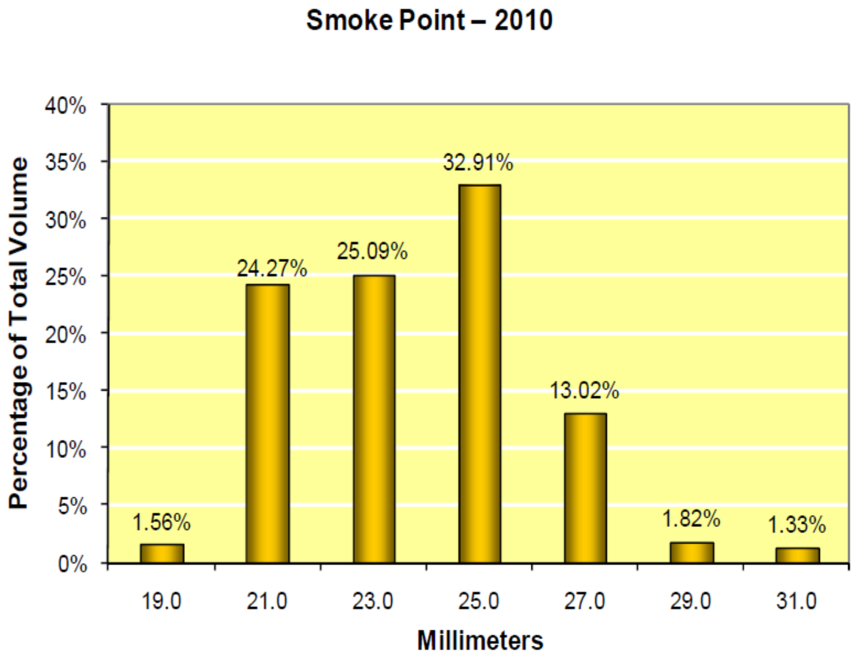


FIGURE C-50. Smoke point histogram JP-8 (2010) *taken from PQIS.*

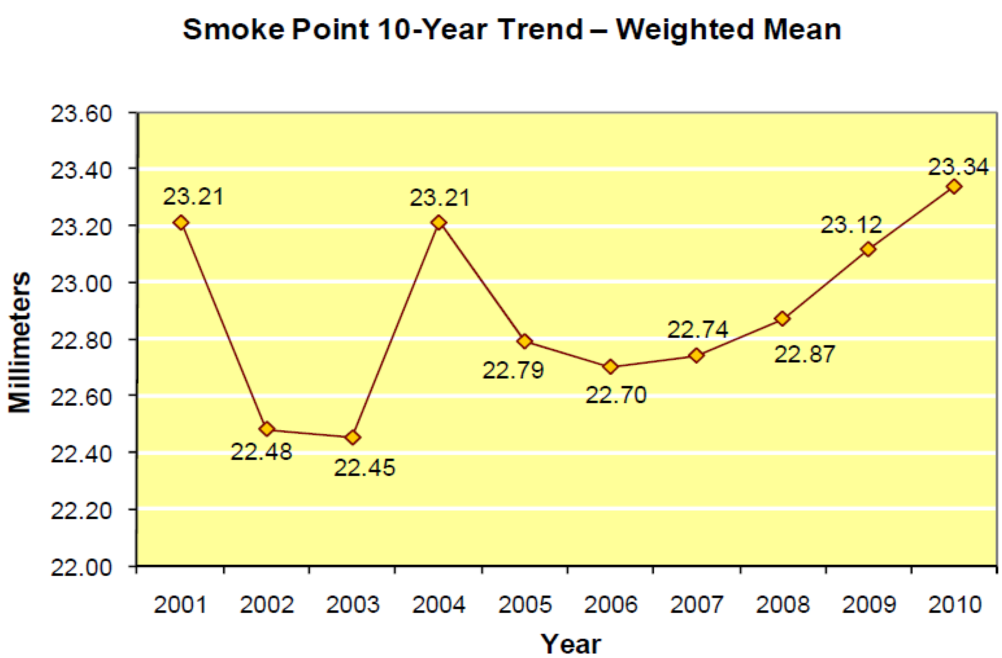


FIGURE C-51. Smoke point average JP-8 (year trend 2001-2010) *taken from PQIS.*

TABLE C-LXXIV. Smoke point fuel property rating value.

	New Fuel
Y	< 25 mm
G	≥ 25mm

	New Fuel
Y	< 19 mm w/ <3% vol Naphthalenes
G	≥ 19mm w/ <3% vol Naphthalenes

TABLE C-LXXV. Reserved.

C.37 SPECIFIC HEAT (AS A FUNCTION OF TEMPERATURE) – SUBSET 1.

C.37.1 Definition. The specific heat of a fuel is the amount of heat-energy transferred into or out of a unit mass of the fuel when increasing or decreasing its temperature. In fuel system analysis, specific heats are used in the calculation of heat transfer, using the fuel as a coolant or as a heat sink.

C.37.2 Standard Specific Heat Test Methods.

C.37.2.1 ASTM D 4054 calculates specific heat via ASTM E 1269 method. Figure C-52 shows the specific heat as a function of temperature [CRC, 2004]. These data were derived from experimental and calculated methods. The experimental data were developed using a differential scanning calorimeter, while the bulk of the determinations were calculated from a correlation published by J. B. Maxwell using averaged fuel gravity and distillation data.

C.37.3 Comments. Typically, the specific heat at constant pressure (C_p) is the property of interest. The energy (enthalpy) absorbed during a heat transfer process that increases a volume of fuel by a temperature increment (T_2-T_1) is the product of C_p and T_2-T_1. The specific heats (and enthalpies) of most jet fuels are very similar. Generalized aviation fuel correlations typically include only temperature and density [Barnett and Hibbard, 1956], so controlling fuel density within the experience base should maintain the specific heat within the experience base also. The specific heat is a weak function of density, typically approximated as proportional to density to the negative 0.5 power.

C.37.4 Data / Property Occurrence.

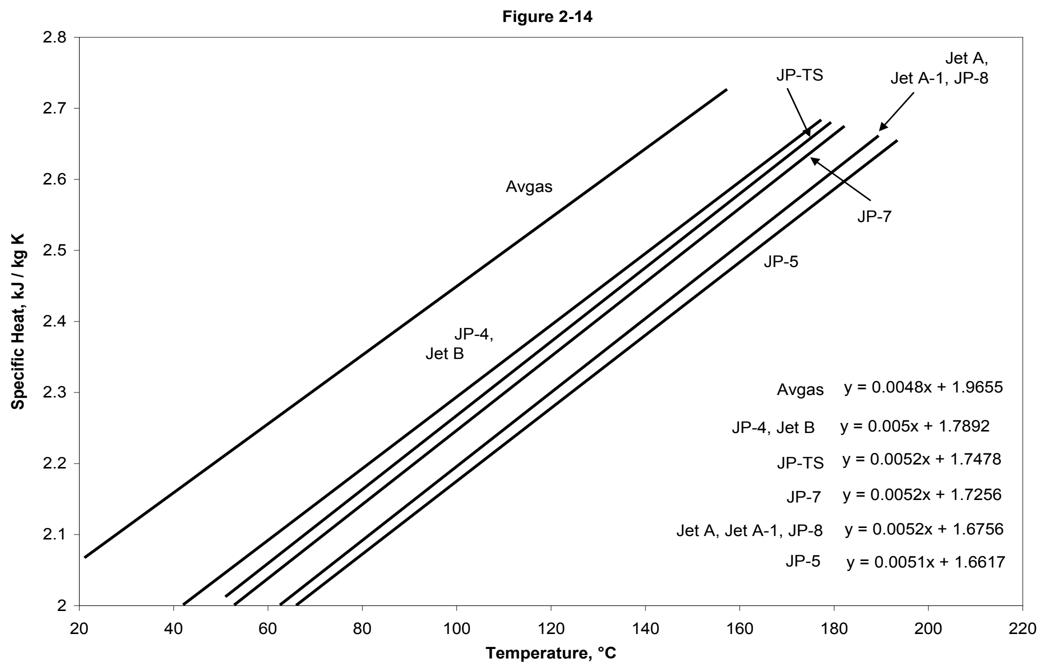


FIGURE C-52. Specific heat as a function of temperature *[CRC,2004].*

TABLE C-LXXVI. Specific heat as a function of temperature fuel property rating value.

	New Fuel
R	<JP-5 values
Y	>JP-8 values
G	JP-5/JP-8 values

TABLE C-LXXVII. Reserved.

C.38 STORAGE STABILITY – SUBSET 1.

C.38.1 Definition.

The ability of a substance to remain chemically unaltered while in a storage environment.

C.38.2 Storage Stability Test Methods.

C.38.2.1 MIL-STD-3004. MIL-F-16884 defines the Storage Stability Requirement for F-76 Naval Distillate Fuel. Based on this and MIL-STD-3004 (Quality Surveillance for Fuels, Lubricants and Related Products), the ASTM D5304 test method (Assessing Distillate Fuel

Storage Stability by Oxygen Overpressure) was developed to evaluate the storage stability of fuel.

C.38.3 Comments. Conventional jet fuels do not have a storage stability requirement in their specifications. Storage stability of fuel is important but difficult to test in a reasonable time frame. A fuel that is not stable during storage will form gums and other insoluble material, which can affect fuel and engine system operation and durability. The JP-7 specification (MIL-DTL-38219D) required a one-year storage test in a drum at 130°F. The JP-7 had to meet the specification requirements at the end of three-month intervals during this period. There is no corresponding requirement for MIL-DTL-83133 fuel - which is not surprising given the differences between the two fuels. JP-7 was typically purchased from a single manufacturer and stored at just a few bases. A corresponding storage stability test regime for MIL-DTL-83133 fuel would require hundreds of drums being stored (and storage stability problems identified long after the fuel was burned). Several organizations have identified accelerated storage stability tests, where tests are run at higher temperatures and/or elevated oxygen concentrations to decrease the test duration to days rather than years. ASTM D4054 uses ASTM D5304 to check for potential gums and lists a maximum value of 7 mg/100 mL and ASTM D3703 to check for peroxides with a maximum value of 8 ppm.

C.38.4 Data / Property Occurrence.

TABLE C-LXXVIII. Storage Stability, potential gums fuel property rating value.

	New Fuel
G	≤ 7 mg/100ml
R	> 7 mg/100ml

TABLE C-LXXIX. Storage Stability, peroxides fuel property rating value.

	New Fuel
G	≤ 8 ppm
R	> 8 ppm

C.39 SULFUR, MERCAPTAN – ENTRANCE CRITERIA.

C.39.1 Definition.: Mercaptan sulfur, also referred to as thiols or sulfides, is a class of organic compounds that contain a sulfur-hydrogen group (SH) bound to a hydrocarbon chain (R) to form R-SH. The sulfur group in mercaptans increase the reactivity of the compound and this can lead to a corrosive attack on fuel wetted metal components within a system.

C.39.2 Standard Mercaptan Test Methods.

C.39.2.1 Mercaptan Sulfur by ASTM D3227. The fuel sample is dissolved in an alcoholic sodium acetate titration solvent and titrated potentiometrically with silver nitrate solution, mercaptan sulfur content is then reported in mass percent.

C.39.2.2 Doctor Test, ASTM D4952. This is a test in which the sample is shaken with sodium plumbite solution to which a small amount of powdered sulfur is added. The presence of mercaptans or hydrogen sulfide will result in discoloration of the sulfur at the interface or discoloration of either liquid phase. Results are reported as pass or fail.

C.39.3 Comments. Mercaptan sulfur is a test directly relating to durability of aircraft and logistics.

C.39.4 Data / Property Occurrence.

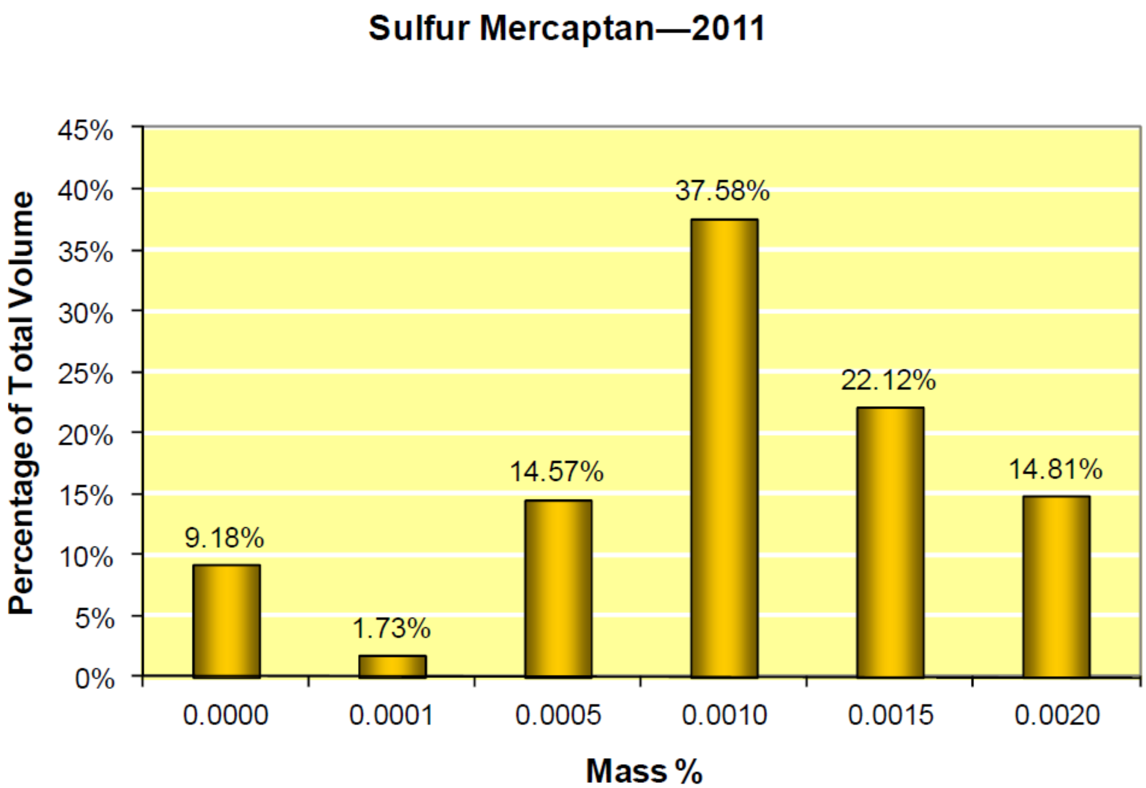


FIGURE C-53. Mercaptan sulfur histogram JP-8 (2011) *taken from PQIS.*

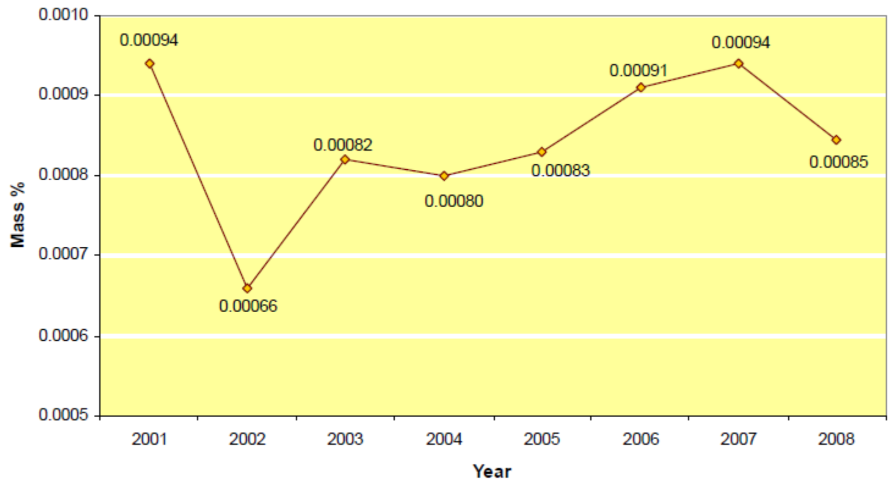


FIGURE C-54. Mercaptan sulfur average JP-8 (year trend 2001-2008) ***taken from PQIS.***

TABLE C-LXXX. Mercaptan sulfur fuel property rating value.

	New Fuel
R	>0.003 mass %
Y	0.0021 to 0.003 mass %
G	0.00 to 0.002 mass %

TABLE C-LXXXI. Reserved.

C.40 SULFUR, TOTAL – ENTRANCE CRITERIA.

C.40.1 Definition. Total sulfur for fuels includes any and all forms of sulfur, either elemental or in a compound. This includes but is not limited to mercaptan sulfur (thiol, R-S-H, where R is a hydrocarbon chain), hydrogen sulfide, free sulfur, sulfides (R-S-R,), disulfides (R-S-S-R), and thiophenes (sulfur incorporated into carbon ring structures). All fuels derived from the distillation of petroleum contain some form of sulfur unless some type of sulfur removal process like hydrotreating is employed.

C.40.2 Standard Sulfur Test Methods.

C.40.2.1 Sulfur Content ASTM D129, ASTM D1266, ASTM D2622, ASTM D3120, ASTM D4294, or ASTM D5453. A variety of methods are available for the quantitative determination of sulfur content. These include combustion methods in which the resultant sulfur oxides are measured, measurement of the X-ray fluorescence of the sulfur compounds or measurement of the fluorescence of sulfur oxides exposed to ultraviolet radiation. Sulfur content is reported in mass percent.

C.40.3 Comments. Further work and review of historical data is required to determine if there is a yellow limit on the amount of sulfur allowable. There may be a lower limit linked to the lubricity of the fuel but that relationship has yet to be verified. Diesel and gasoline have much more stringent sulfur limits currently than jet fuel. There is a Current National Security Issue (waiver) for using jet fuel in diesel-powered vehicles.

C.40.4 Data / Property Occurrence.

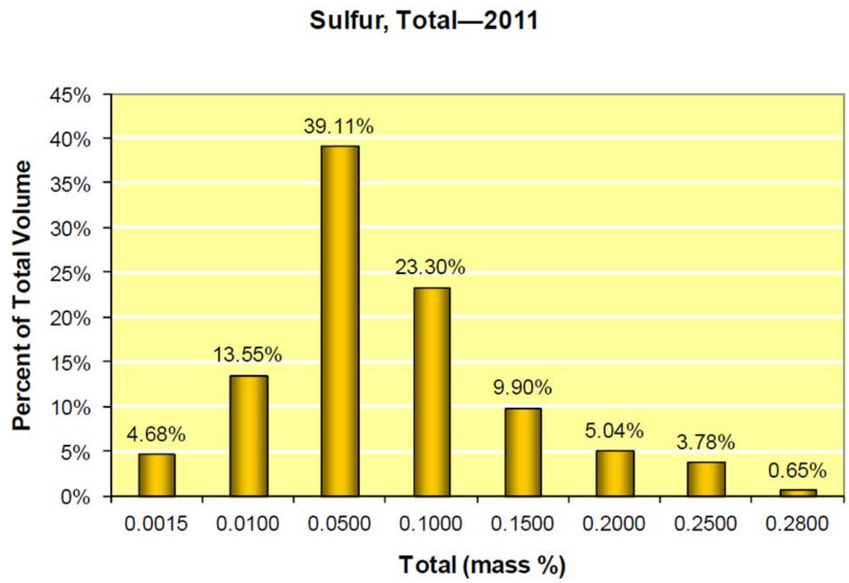


FIGURE C-55. Total sulfur histogram JP-8 (2011) *taken from PQIS.*

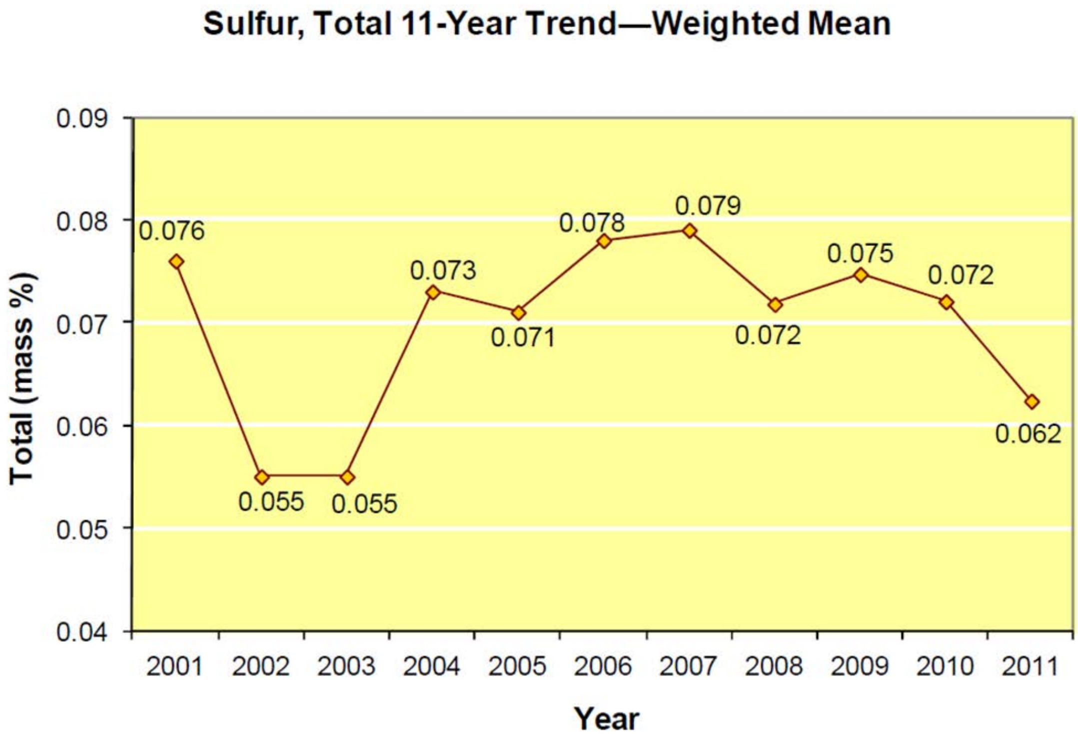


FIGURE C-56. Total sulfur average JP-8 (year trend 2001-2011) *taken from PQIS.*

TABLE C-LXXXII. Total sulfur fuel property rating value.

	New Fuel
G	0 to 0.3 mass %
R	>0.3 mass %

TABLE C-LXXXIII. Reserved.

C.41 SURFACE TENSION VERSUS TEMPERATURE – SUBSET 1.

C.41.1 Definition. The specific free energy of a liquid surface at interface with another fluid is surface tension. Values for surface tension are usually given when the surface of the liquid is in contact with air. Of importance in gas evolution and solubility, it has a pronounced effect on atomization characteristics of fuels. Fluids with large cohesive forces among molecules, like those found in water, exhibit high surface tensions. Non-polar fluids such as hydrocarbons have lower internal cohesive forces and lower surface tensions. Surface tensions decrease toward zero as temperature increases, and cohesive forces are overcome until, at the fluid's critical temperature, surface tension ceases to exist. Surface tension can be estimated by using the Ramsey and Shields correlation if density, molecular weight, and the critical temperature of the fluid are known. The surface tension data for fuels on Figure C-57 of the CRC 2004 Handbook have been estimated from the Ramsey and Shields correlation, and the figure shows the reduction of surface tension caused by increasing temperature. Impurities, in particular surfactants, have a very strong effect, causing a reduction in surface tension. In such situations, a direct measure of surface tension is necessary to obtain meaningful data.

C.41.2 Standard Surface Tension Test Methods.

C.41.2.1 Surface Tension by ASTM D971. Standard Test Method for Interfacial Tension of Oil against Water by the Ring Method is commonly used for jet fuel. This method is, typically, used for mineral oils. However, since a standard test method for the surface tension of aviation fuels does not exist, it is occasionally used for this purpose. Surface tension in this method is a function of the force required for a platinum ring to be pulled through a fuel/water interface, the densities of the fuel and water, and the dimensions of the ring (CRC World Fuel Survey). Additionally, data reported below deviates from values in CRC's fuel handbook because the values were calculated using Ramsey and Shields correlation and do not directly correlate to the experimental results below.

C.41.2.2 Surface Tension by ASTM D1331. An alternative method for the measurement of surface tension is ASTM D1331, "Standard Test Methods for Surface and Interfacial Tension of Solutions of Surface-Active Agents". This method uses a precision tensiometer to measure the force required to pull a platinum ring through the test fluid.

C.41.3 Comments. Surface tension is currently not measured or controlled in jet fuel specifications. The temperature range to be measured is -10 to 40°C.

C.41.4 Data / Property Occurrence.

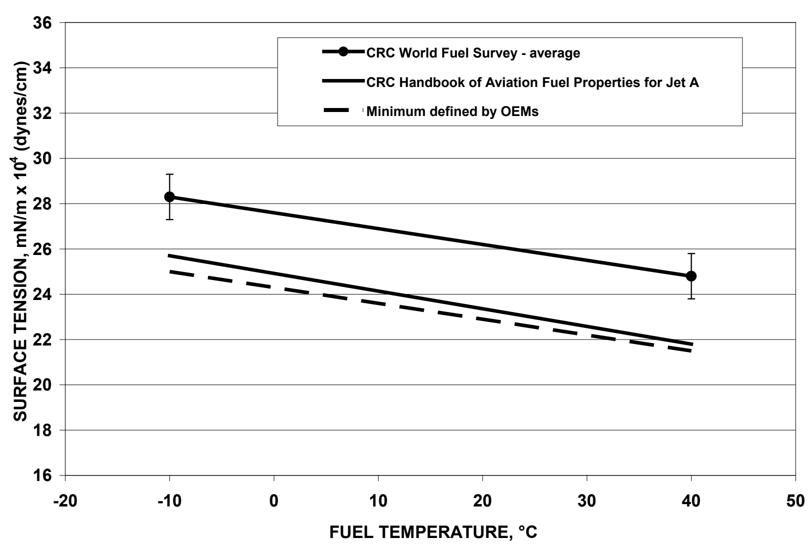


FIGURE C-57. Typical surface tension characteristics of jet fuel [per ASTM D4054 and CRC "Comparative Evaluation of Semi-Synthetic Jet Fuels"].

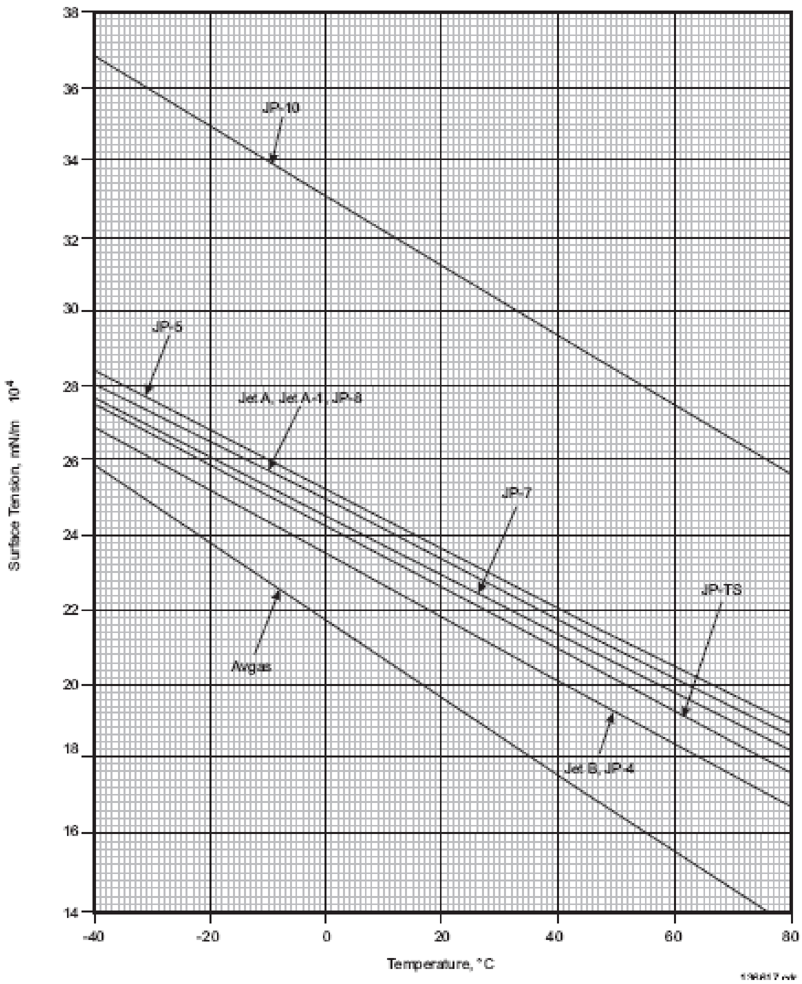


FIGURE C-58. Surface tension as a function of temperature *[CRC, 2004]*.

TABLE C-LXXXIV. Surface tension fuel property rating value at 25°C.

	New Fuel
R	> JP-8 +10%
G	JP-8 ± 10%
Y	JP-8 – 10% > Y ≥ JP-4
R	< JP-4

TABLE C-LXXXV. Reserved.

C.42 THERMAL CONDUCTIVITY VERSUS TEMPERATURE – SUBSET 1.

C.42.1 Definition. The thermal conductivity of a fuel is the property that controls the rate at which heat can flow by conduction through that fuel and is expressed as watts per meter Kelvin (W/m K). It is used extensively in heat-transfer calculations when fuel temperature is elevated in heat exchangers, used as a heat sink, when fuel is heated or cooled in flight or on the ground, or whenever there is a temperature gradient within the fuel.

C.42.2 Standard Thermal Conductivity Test Methods.

C.42.2.1 Thermal Conductivity by ASTM D2717. In ASTM D2717, "Standard Test Method for Thermal Conductivity of Liquids," thermal conductivity is measured in a borosilicate glass tube (cell) with a calibrated platinum resistance thermometer. Thermal conductivity is determined by measurement of the temperature gradient produced across the liquid sample by a known amount of energy introduced into the cell by electrically heating the platinum element.

C.42.2.2 Transient Hot-Wire Test Method. In the transient hot-wire technique (essentially similar to ASTM D2717), small diameter wires are immersed in the fluid and used simultaneously as electrical resistance heaters and as resistance thermometers to measure the resulting temperature rise due to the resistance heating. The hot-wire cells are designed to approximate a simple 1-dimensional transient line-source of heat in an infinite medium as closely as possible to minimize corrections for the actual geometry. Two hot wires of differing length are operated in a differential mode to eliminate axial conduction effects due to the large diameter leads attached to the ends of each hot wire. Based on the transient line-source model, the thermal conductivity can be found from the slope of the measured linear temperature rise as a function of elapsed time with a typical uncertainty of less than 1%. The thermal diffusivity can be found from the intercept of this same linear temperature rise curve with a typical uncertainty of less than 10%. Independent measurements of the thermal diffusivity of fluids can also be made by dynamic light scattering (DLS) measurements at low angles with a typical uncertainty of 2%. (courtesy of National Institute of Standards and Technology (NIST), Physical and Chemical Properties Division, Experimental Properties of Fluids Group, Mail Stop 838.07, 325 Broadway, Boulder CO 80305-3328)

C.42.3 Comments. Thermal conductivity is currently not measured or controlled in jet fuel specifications. The measurements are difficult to perform accurately, hence the variations in the data from edition-to-edition in the CRC Handbook. More research is ongoing. The thermal conductivity of typical jet fuels is very similar, thus the CRC Handbook shows a single line for all jet fuels, as reproduced on Figure C-59. Thermal conductivity data is needed in the temperature range from 30-200°C.

C.42.4 Data / Property Occurrence.

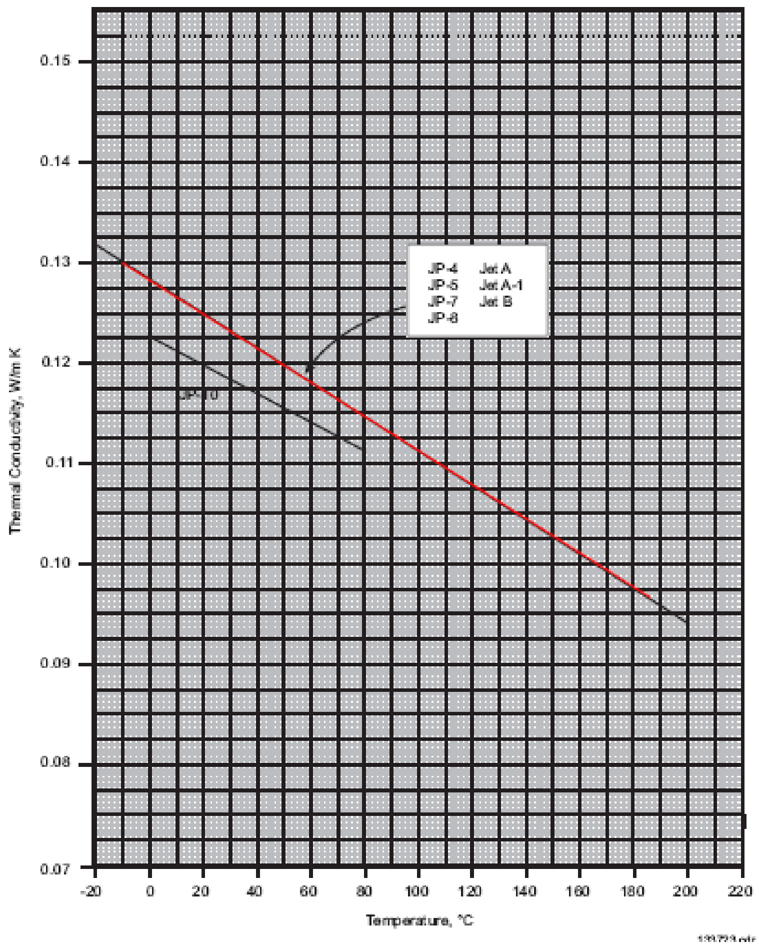


FIGURE C-59. Thermal conductivity as a function of temperature *[CRC, 2004].*

TABLE C-LXXXVI. Thermal conductivity fuel property rating value.

	New Fuel
G	JP-8/JP-5 values ±10%
Y	< JP-8/JP-5 values -10%

TABLE C-LXXXVII. Reserved.

C.43 THERMAL EXPANSION (COEFFICIENT OF)

C.43.1 Definition. The effect of temperature on density may also be demonstrated by the thermal expansion of a fuel as it is heated. Figure C-60 depicts the expansion of aircraft and missile fuels volume caused by the increase of temperature as compared with their volumes at 15.5°C. Since this volumetric increase tends to be slightly depressed by highly elevated pressures, pressure is specified. (See also C.12 Density)

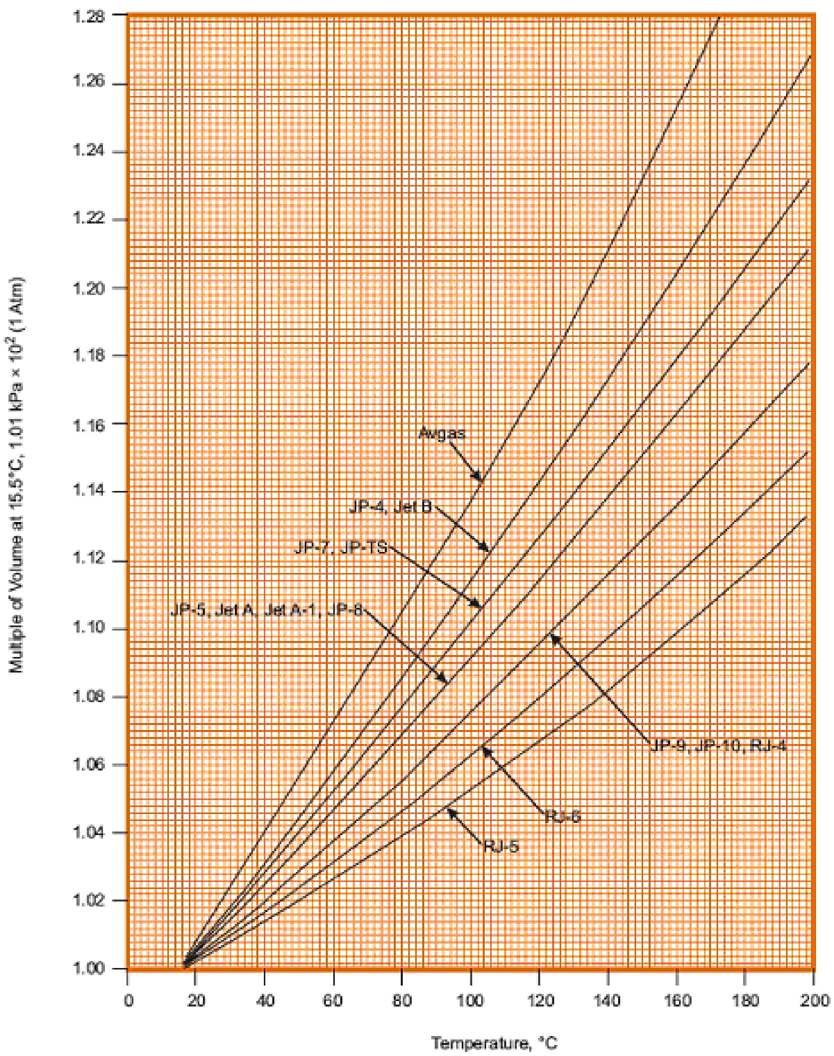


FIGURE C-60. Thermal expansion vs temperature [CRC 2004].

TABLE C-LXXXVIII. Reserved.

TABLE C-LXXXIX. Reserved.

C.44 THERMAL STABILITY – ENTRANCE CRITERIA.

C.44.1 Definition: Thermal Stability is the measure of a substance's ability to handle increased temperatures without compromising the substance's chemical integrity.

C.44.2 Standard Thermal Stability Test Methods.

C.44.2.1 Jet Fuel Thermal Oxidation Tester by ASTM D3241. Nitrogen Pressure System. The 450 mL of fuel is placed into a closed system that is pressurized by nitrogen to 500 psi (3,500 kPa). The fuel flows over a heated aluminum tube into a filter screen, through a cooler and then a metering pump which regulates the flow rate. The maximum tube temperature is the test control variable. The fuel makes one pass through the system. A fuel's oxidation resistance is measured by the color and extent of deposits on the tube and the pressure drop across the filter at the end of the test. Color ratings range from 0 to 4, with 0 being a clean tube, while 4 represents dark deposits. Pressure drop is reported in mm of Hg.

C.44.2.2 Hydraulic System. In this later version of the method, fuel is pushed through the system by a hydraulic piston driven by a screw. The test section, operating conditions and the evaluation of test results are identical to the nitrogen pressure system.

C.44.3 Comments. The specification thermal stability test is a quality control, "go/no go" test. Note that the PQIS data reproduced below shows that fuels typically are not close to failing the test on change in pressure. Thus the Jet Fuel Thermal Oxidative Test results are not particularly informative. An alternative method for assessing thermal stability is running the test at increasing temperatures until the fuel fails the test criteria. The temperature at which the fuel fails the test is termed its "break point". The break point distribution for a recent world fuel survey is shown below. Typically, the temperature limit of jet fuels (JP-5/8, Jet A/Jet A-1) during use is considered to be 300-325°F. The USAF developed a thermal stability additive to raise this temperature limit 100°F in the 1990s - hence it was termed "JP-8+100". Additionally, many other thermal stability tests have been performed. The draft ASTM "Standard Practice – Guideline for the Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives" recommends that the Jet Fuel Thermal Oxidative Test tube deposit be assessed by the standard visual technique and the alternate ellipsometer technique to minimize the risk that changes in alternative fuel deposit appearance would cause them to be overlooked.

C.44.4 Data / Property Occurrence.

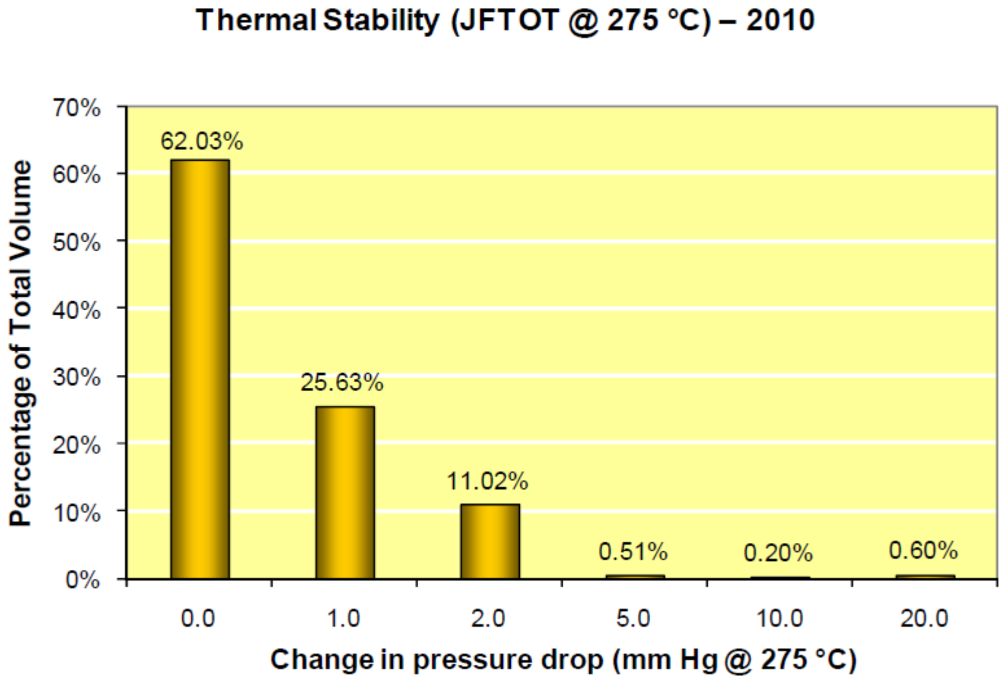


FIGURE C-61. Thermal stability (Jet Fuel Thermal Oxidative Test ΔP at 260 C) histogram JP-8 (2010) *taken from PQIS.*

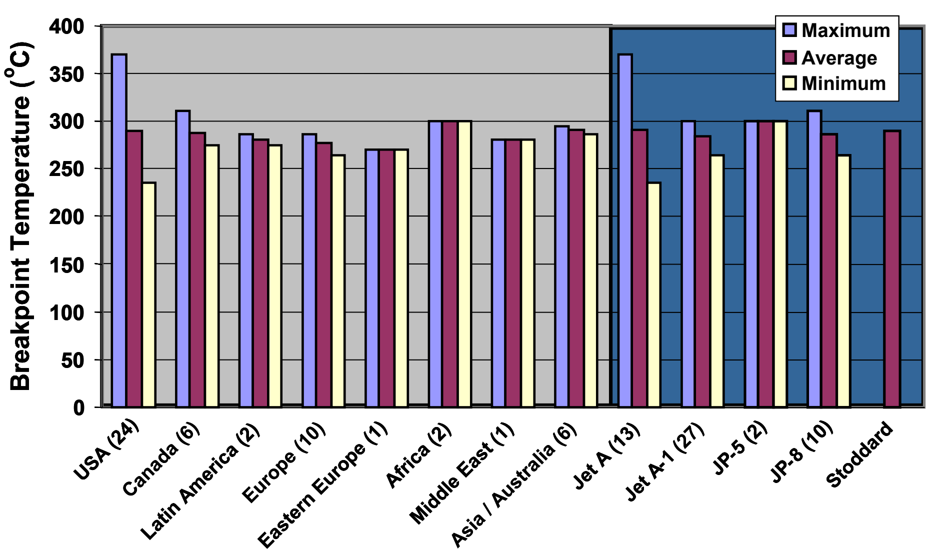


FIGURE C-62. Jet fuel break point temperature distribution *[CRC World Fuel Survey, 2006].*

TABLE C-XC. Thermal stability pressure drop.

ΔP	New Fuel
G	≤25 mm Hg
R	>25 mm Hg

TABLE C-XCI. Thermal stability color rating.

Tube Rating	**New Fuel**
G	1 to 2
R	≥ 3

TABLE C-XCII. Reserved.

C.45 TRACE SPECIES – SUBSET 1.

C.45.1 Definition. The category of Trace Species includes trace metals and trace organics, as described below. Other trace contaminants are described elsewhere (sulfur, acid number), as are dissolved gases. The trace elements of concern are Al, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Pd, Pt, Sn, Sr, Ti, V, Zn [ASTM D7566]. ASTM D4054 has a similar list: Zn, Fe, V, Ca, Li, Pb, P, Na, Mn, Mg, K, Ni, Si as described below in C.45.2. The trace organic species of concern are the oxygen-containing species carbonyls, alcohols, esters, and phenols, as described in C.45.3, as well as organic nitrogen.

C.45.2 Trace Metals.

C.45.2.1 Determination of Trace Elements in Middle Distillate Fuels by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) by ASTM D7111. Calibration standards are prepared by mixing organometallic standard materials in kerosene. An internal standard material is added to the calibration standards and fuel samples. The calibration standards and the fuel samples are aspirated into the ICP-AES instrument. The concentrations of the elements in the fuel are calculated by comparing emission intensity ratios of the fuel and calibration standards to the internal standard.*

C.45.2.2 Trace Metals Comments. There are a number of trace metals that can be found in jet fuels that can have deleterious effects on the fuel/engine systems. For example, one set of trace contaminants that were harmful to engines consisted of V (vanadium), Na (sodium), K (potassium), Pb (lead), and Ca (calcium) [Boyce, M. P., Gas Turbine Engine Handbook, Elsevier, 2006]. Na, K, and S (sulfur) lead to "hot corrosion" of turbine blade materials. Note that sodium would be prevalent in sea spray (from salt, sodium chloride); obviously an issue for jet engines operating near the oceans. Copper (Cu) is the most notorious fuel contaminant that leads to thermal stability problems (deposit formation) [Hazlett, R. N., *Thermal Oxidation Stability of Aviation Turbine Fuels*, ASTM Monograph 1, American Society for Testing and Materials, Philadelphia, PA, 1991]. Zinc (Zn), is also a noted reactive metal and is typically tested for in most jet fuels.

C.45.3 Trace Organic Species.

C.45.3.1 - Determination of trace organic species. Trace organic species are typically measured by gas chromatographic or other sensitive techniques, as outlined in methods such as EPA 8015B, EPA 8260C, EPA 8270C, UOP624, and UOP 626. Some of the trace organic species would also be detected in other tests, such as acid number and existent gum. Chemically-bound nitrogen is measured by ASTM D4629.

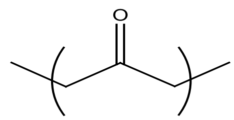
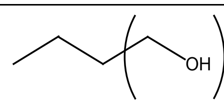
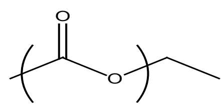
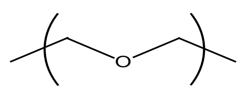
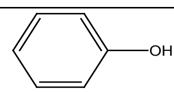
C.45.3.2 Trace Organics Comments. Trace organic species are mostly a concern from the standpoint of their effect on fuel thermal stability [Hazlett].

C.45.4 Data / Property Occurrences. Data for trace metals and trace organics is fairly sparse. Some data is listed in Hazlett.

TABLE C-XCIII. Trace metals property rating value (from MIL-DTL-83133H Amendment 1).

Aluminum (Al)	<100 ppb	G	Palladium (Pd)	<100 ppb	G
	≥100ppb	Y		≥100ppb	Y
Calcium (Ca)	<100 ppb	G	Phosphorus (P)	<100 ppb	G
	≥100ppb	Y		≥100ppb	Y
Copper (Cu)	<100 ppb	G	Platinum (Pt)	<100 ppb	G
	≥100ppb	Y		≥100ppb	Y
Chromium(Cr)	<100 ppb	G	Potassium (K)	<100 ppb	G
	≥100ppb	Y		≥100ppb	Y
Iron (Fe)	<100 ppb	G	Silicone (Si)	<100 ppb	G
	≥100ppb	Y		≥100ppb	Y
Lead (Pb)	<100 ppb	G	Sodium (Na)	<100 ppb	G
	≥100ppb	Y		≥100ppb	Y
Lithium (Li)	<100 ppb	G	Tin (Sn)	<100 ppb	G
	≥100ppb	Y		≥100ppb	Y
Magnesium (Mg)	<100 ppb	G	Titanium (Ti)	<100 ppb	G
	≥100ppb	Y		≥100ppb	Y
Manganese (Mn)	<100 ppb	G	Vanadium (V)	<100 ppb	G
	≥100ppb	Y		≥100ppb	Y
Molybdenum (Mo)	<100 ppb	G	Zinc (Zn)	<100 ppb	G
	≥100ppb	Y		≥100ppb	Y
Nickel (Ni)	<100 ppb	G			
	≥100ppb	Y			
Total Metals	<100ppb	G			
	≥100ppb	Y			

TABLE C-XCIV. Trace organics property rating value.

Trace organic	Chemical functional group	Limit	
Carbonyls	-C=O 	G	Report
Alcohols	-C-O-H	G	<5 ppm
		Y	>5 ppm
Esters/ Ethers	-C(=O)-O-C- 	G	<50 ppm
	/-C-O-C- 	Y	>50 ppm
Phenols	aromatic ring – OH	G	<50 ppm
		Y	>50 ppm

C.46 VAPOR PRESSURE, TRUE VERSUS TEMPERATURE - SUBSET 1.

C.46.1 Definition. Vapor pressure is the pressure exerted by the vapor of a liquid when in equilibrium with the liquid at a specific temperature.

The heat of vaporization (ΔH_{vap}), often termed the latent heat of vaporization or evaporation or just latent heat, is the amount of heat added to vaporize a unit weight of a liquid at a constant pressure below the critical point. For multicomponent fluids such as jet fuel, heat of vaporization can be calculated from vapor pressure versus temperature data.

C.46.2 Standard Vapor Pressure Test Methods.

C.46.2.1 Vapor Pressure by ASTM D5191. A volume of chilled, air-saturated sample is introduced into a thermostatically controlled, evacuated test chamber with a moveable piston that expands the volume after sample introduction. After introduction into the test chamber, the test specimen is allowed to reach thermal equilibrium at the specified test temperature. The resulting rise in pressure in the chamber is the vapor pressure.

C.46.2.2 Reid Vapor Pressure by ASTM D323. The Reid vapor pressure is the pressure exerted by a fuel when heated to a specified temperature in a pressure vessel with a vapor-to-liquid ratio of 4:1. Prior to the test the sample is saturated with water. Reid Vapor Pressure includes the partial pressures of air and water vapor.

Reid vapor pressure deviates from a liquid's vapor pressure by 1 to 5%. Correlations exist to convert between vapor pressure and Reid vapor pressure. Frequently, this test method may be more commonly found at certain test labs.

C.46.2.3 Heat of Vaporization by ASTM E2071. Using vapor pressure versus temperature data, the heat of vaporization can be correlated via the Clausius Clapeyron equation as described in the following equation

$$\ln\left(P^{vap}\right) = -\frac{\Delta H^{vap}}{RT} + C$$

P^{vap} = Vapor Pressure,

ΔH^{vap} = Heat of Vaporization,

R = Ideal Gas Constant,

T = Absolute Temperature

C = Constant of Integration.

By plotting the natural log of the vapor pressure versus the inverse of the absolute temperature, the slope of the line created is the average heat of vaporization divided by the ideal gas constant. If the line created is curved or otherwise non-linear, then the heat of vaporization changes as temperature changes and the heat of vaporization has to be evaluated over the desired temperature range.

C.46.3 Comments. For safety considerations when dealing with vehicles and ground support equipment, gravity feed of the fuel from the tank to the engine is not permitted in ground support equipment. A pump is necessary to lift the fuel from the tank. Since the vapor pressure of MIL-DTL-83133 fuel is so low the lifting of the fuel never presented a consideration of vapor lock in the design of the fuel system. The lift pump is usually located at the engine rather than close to the fuel tank. Had vapor lock been a consideration the pump would have been located close to the tank, or as is the standard practice in automotive design, placed inside the tank. A maximum vapor pressure specification for the fuel which would prevent vapor lock for the SE&V is not known at this time and will be the subject of further research. From experience using Russian TS-1, vapor pressure maximum of 0.16 psi at 40 °C will not cause vapor lock in the current fleet.

Vapor pressure is not currently specified for JP-5, JP-8, Jet A, Jet A-1, or TS-1. JP-4 does have specified vapor pressure limits of 14-21 kPa at 38°C. Operational experience in 2005, has shown that TS-1's vapor pressure was higher than JP-8 and caused some difficulties, therefore it should be an upper limit vapor pressure. Unfortunately, thorough data on the vapor pressure of TS-1 is not presently available so JP-8 will be considered the upper limit until such time as TS-1 vapor pressure data is established.

Additionally, a 'round robin' on wide cut, kerosene and other fuels has been completed by Subcommittee 14 of ASTM with the goal of being able to measure fuel vapor pressure over a range of temperatures from 25°C up to 70°C using the triple expansion method of VP measurement and in support of the special certification fuel described in ASTM D7223.

Currently, the latent heat of vaporization is not controlled or monitored by either military or commercial specifications. The risk of deviations from typical jet fuel values has not been examined. Therefore, the heat of vaporization should be reported without limitation until better data is available.

C.46.3 Data / Property Occurrence.

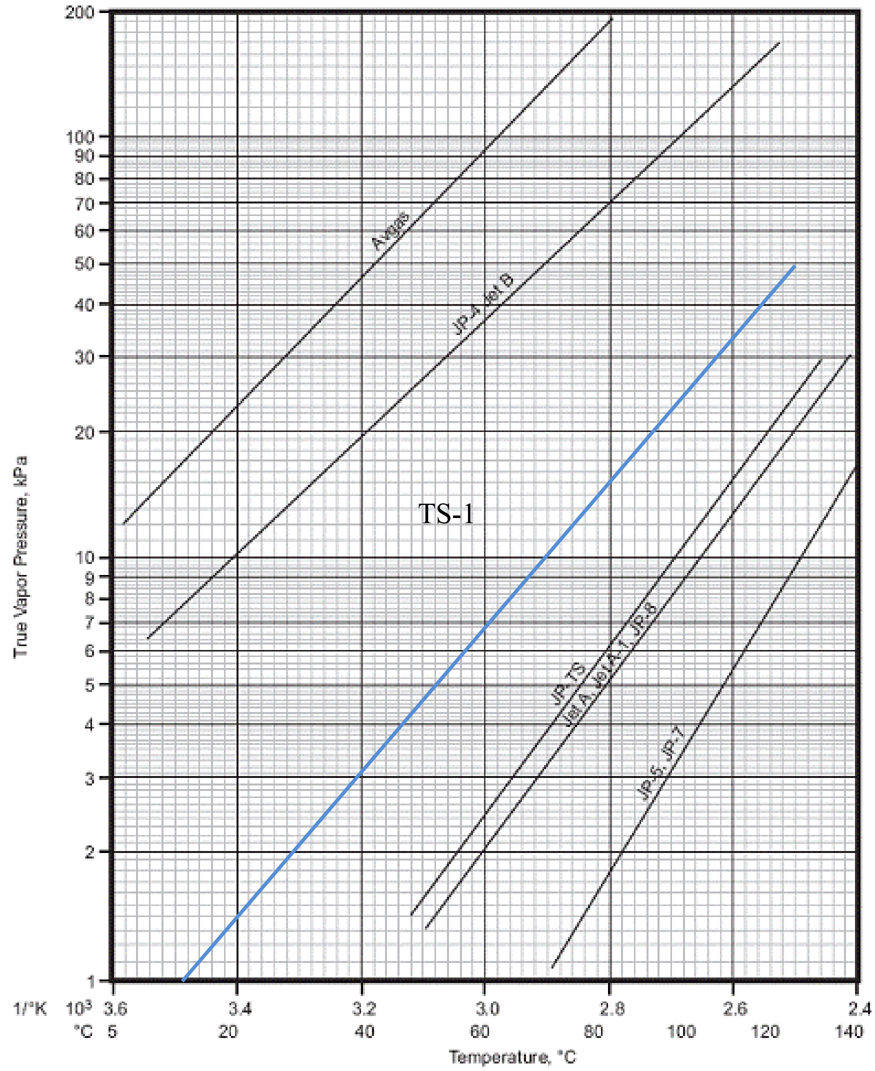


FIGURE C-63. Vapor pressure as a function of temperature [CRC, 2004].

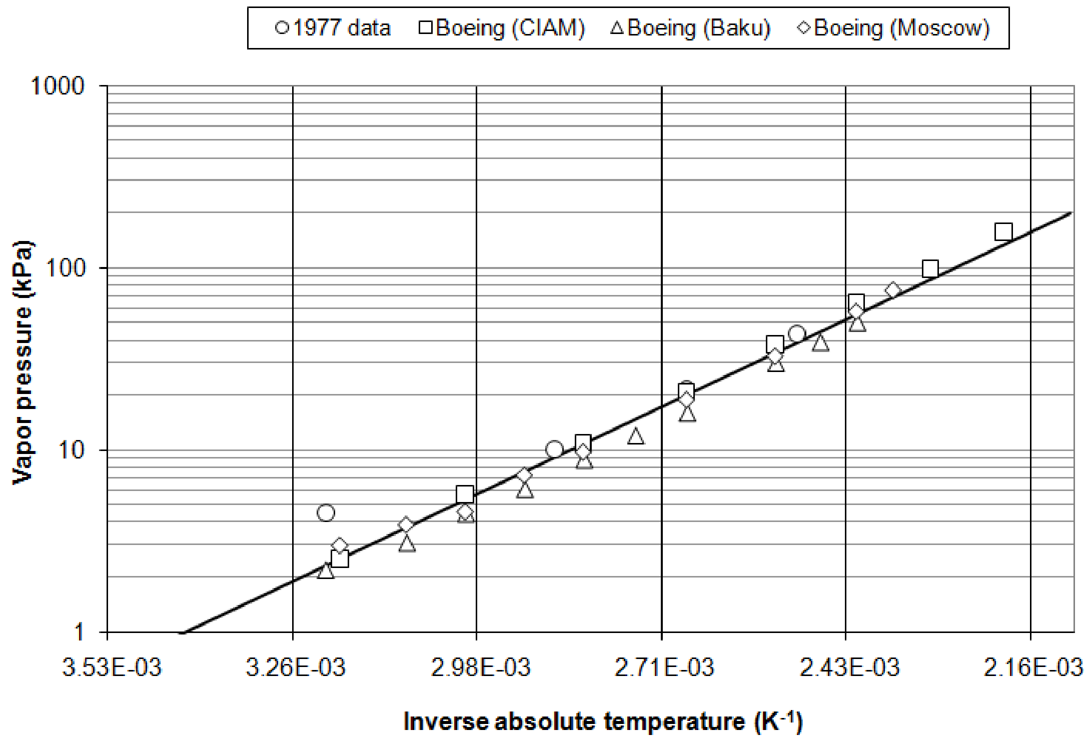


FIGURE C-64. TS-1 vapor pressure as a function of inverse absolute temperature *[courtesy AFPA]*

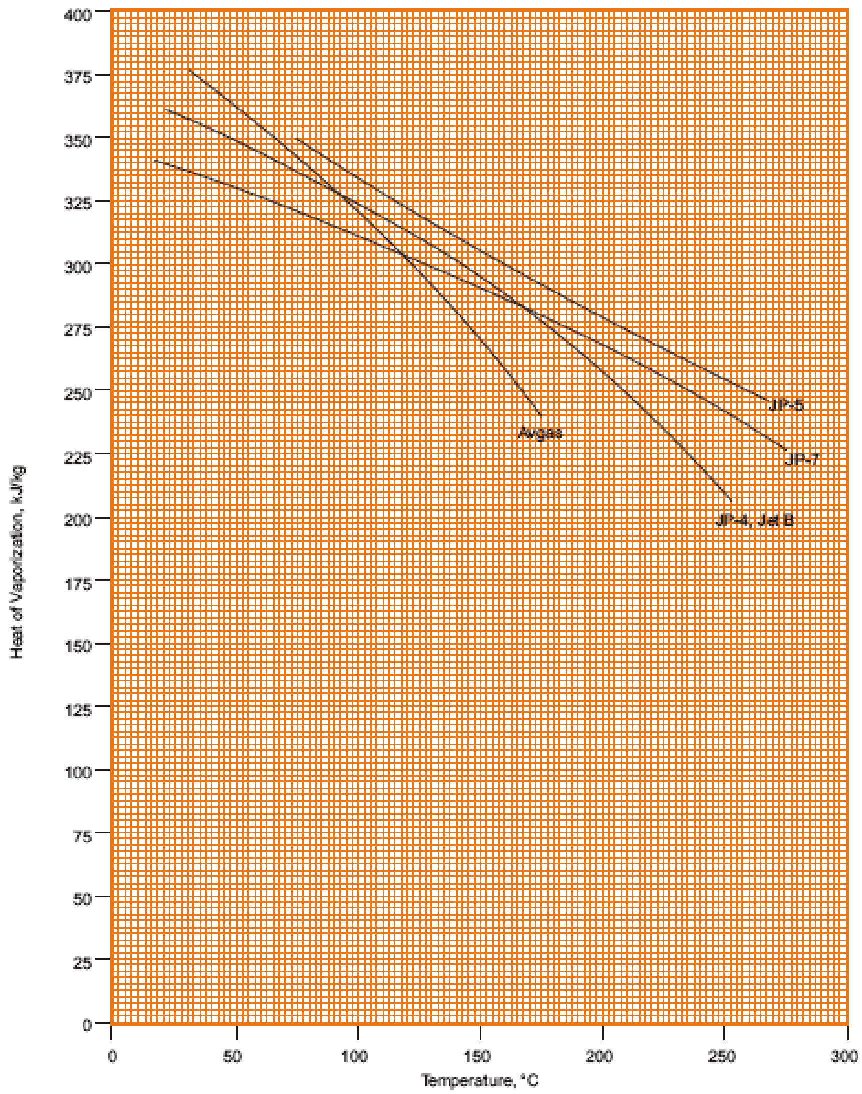


FIGURE C-65. Heat of vaporization as a function of temperature *[CRC, 2004]*.

TABLE C-XCV. Vapor pressure versus temperature fuel property rating value.

	New Fuel
R	> TS-1 values
Y	TS-1 ≥ Y > JP-8 values
G	≤ JP-8 values

C.46A Velocity (Speed) of Sound (versus T) – Subset 2.

C.46A.1 Definition. The velocity of sound in a fuel is used in the design of some ultrasonic fuel gauging systems.

C.46A.2 Standard Velocity of Sound Test Methods. Standard test methods are not available.

C.46A.3 Comments. Data are available in the CRC World Fuel Survey, where it is noted that velocity of sound is proportional to density (sound moves faster in denser fuels). The data presented on Figure C-66 is not completely consistent with that statement, where the separation due to density is much less than that seen when the velocity of sound is plotted versus density (Figure 5.3.2 in the World Survey). A standard device often used is a Mapco/Nusonics 6080 analyzer [WL-TR-95-2158]. See also C.8.

The relationship between Velocity of Sound and Bulk Modulus and is given by the following equation:

Velocity of Sound = Square Root of (Bulk Modulus / Density),

C.46A.4 Data/Property Occurrence.

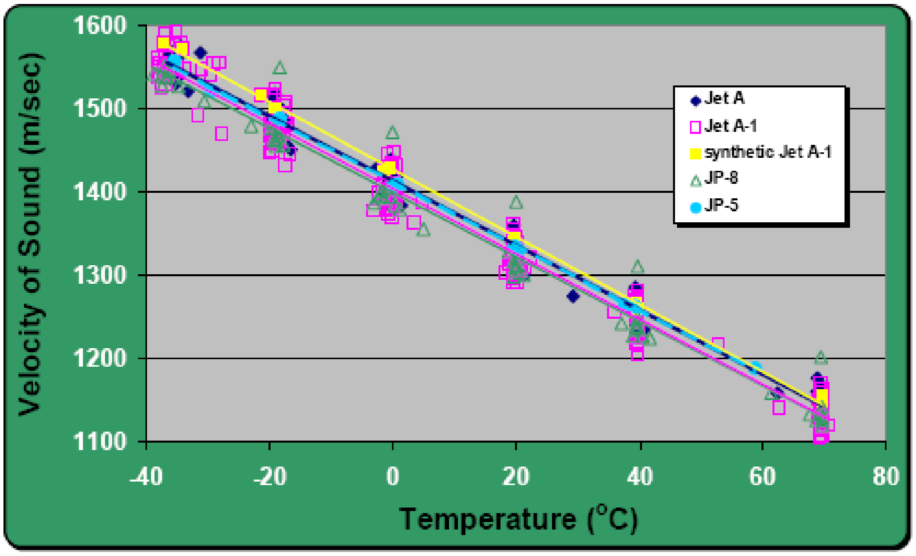


FIGURE C-66. Velocity of sound versus temperature *[CRC World Fuel Survey, 2006].*

TABLE C-XCVI. Velocity (speed) of sound fuel property rating value.

	New Fuel **Velocity of Sound @ 30°C and ambient pressure**
R	<1370 m/s
Y	1349m/s < Y ≤ 1370 m/s
G	1247 m/s ≤ G ≤ 1349 m/s
Y	1235 m/s ≤ Y < 1247 m/s
R	< 1235 m/s

The green criteria in Table C-XCVI were derived from the maximum and minimum which would keep the error of the fuel quantity system of an existing aircraft model, which uses velocity of sound, within specified limits. The maximum and minimum of the world survey data from Figure C-66 interpolated to 30^{o} C are 1345 and 1245 respectively. The limits of the yellow are approximately 5% above and below the 1300 m/s average of the world survey data at 30^{o} C.

C.47 VISCOSITY AT -20°C – ENTRANCE CRITERIA
(Viscosity versus Temperature – Subset 1).

C.47.1 Definition. The viscosity of a fluid is a measure of its internal resistance to motion caused by cohesive forces among the fluid molecules. Absolute viscosity is the shear stress at a point divided by the velocity gradient at that point, and the unit of absolute viscosity is the Pascal second (P/s). In practice, absolute viscosity is used in conjunction with density, particularly in the calculation of Reynolds number. This relationship between viscosity and density is defined as kinematic viscosity, the ratio of the absolute viscosity of a fluid to the density with both properties measured at the same temperature and pressure, usually expressed as centistoke (cSt), where one cSt is equivalent to one mm^2/sec. Since viscosity varies inversely with temperature, lowering the temperature of the fuel has the effect of increasing its viscosity.

C.47.2 Standard Viscosity Test Methods.

C.47.2.1 Viscosity by ASTM D445. A fixed volume of fuel flows through capillaries of specific diameters and lengths at standard temperatures. The viscosity or resistance to flow is calculated from the flow time and the capillary constant. Viscosity is reported in mm^2/s or cSt.

C.47.3 Comments. Fluid viscosity is critical to proper equipment operations. For aircraft the greatest concern is typically the viscosity at lower temperatures. Aircraft are exposed to extremely low temperatures at high altitudes. As the fuel cools, its viscosity begins to exponentially increase as it approaches the freezing point. Therefore a viscosity ceiling of 8.0 centistokes cannot be exceeded at temperatures equal to or warmer than -20° C. Honeywell has indicated that exceeding 12 cSt at -40° C will impair APU cold start (see J.5.6).

Military SE&V frequently use jet fuel in their diesel compression ignition engines. Within these applications, fuels can have a low viscosity at higher temperatures and thereby damage parts that use the fuel as a lubricant. For unlimited use, viscosity should be consistent with ASTM D975-09b, greater than or equal to 1.3 centistokes at 40° C. Viscosities below 1.2 centistokes could show an increasing degree of damage over time. Viscosities below 1.0 may limit durability to such a degree that failure could occur in a very short time. (These values apply to SE&V procured after 2007.).

For new fuels, viscosity should be measured at (as a minimum) -20° C, 25° C, 40° C, and 60° C. Viscosity should be measured at -40° C if possible.

C.47.4 Data / Property Occurrence.

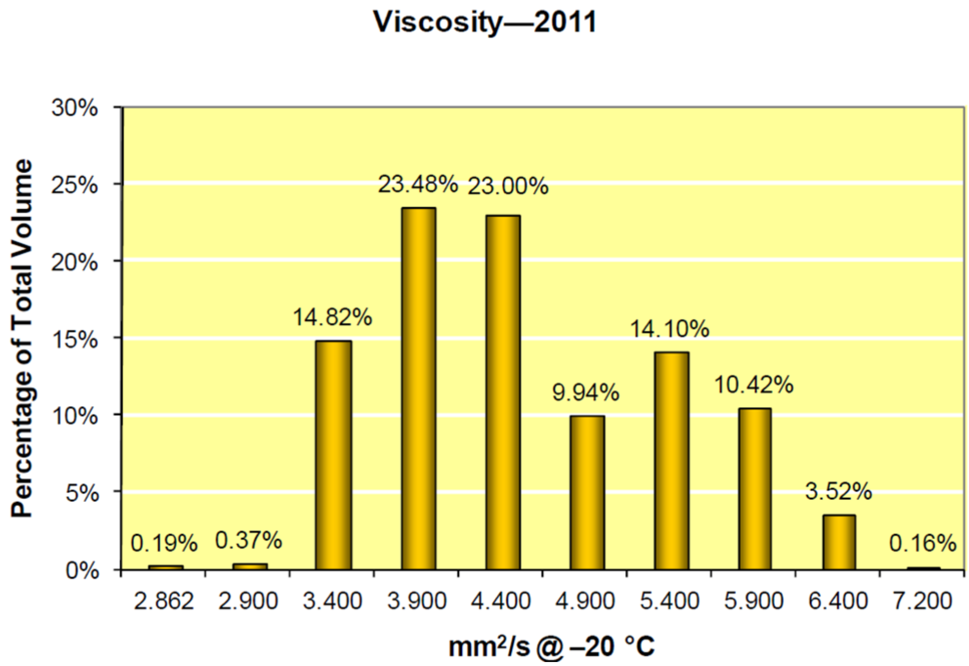


FIGURE C-67. Viscosity (@-20°C) histogram JP-8 (2011) *taken from PQIS.*

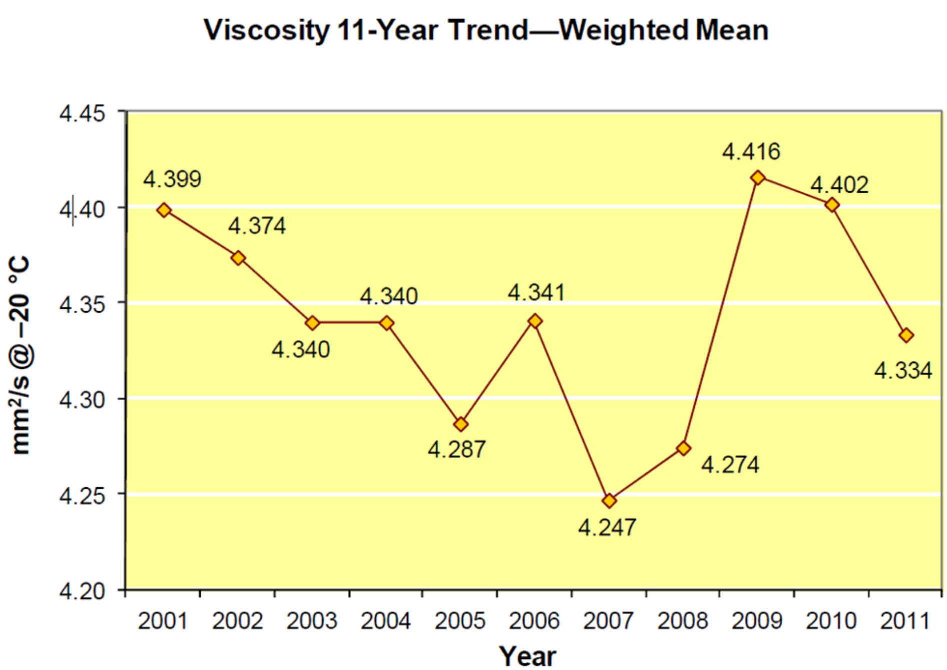


FIGURE C-68. Viscosity (@-20°C) average JP-8 (year trend 2001-2011) *taken from PQIS.*

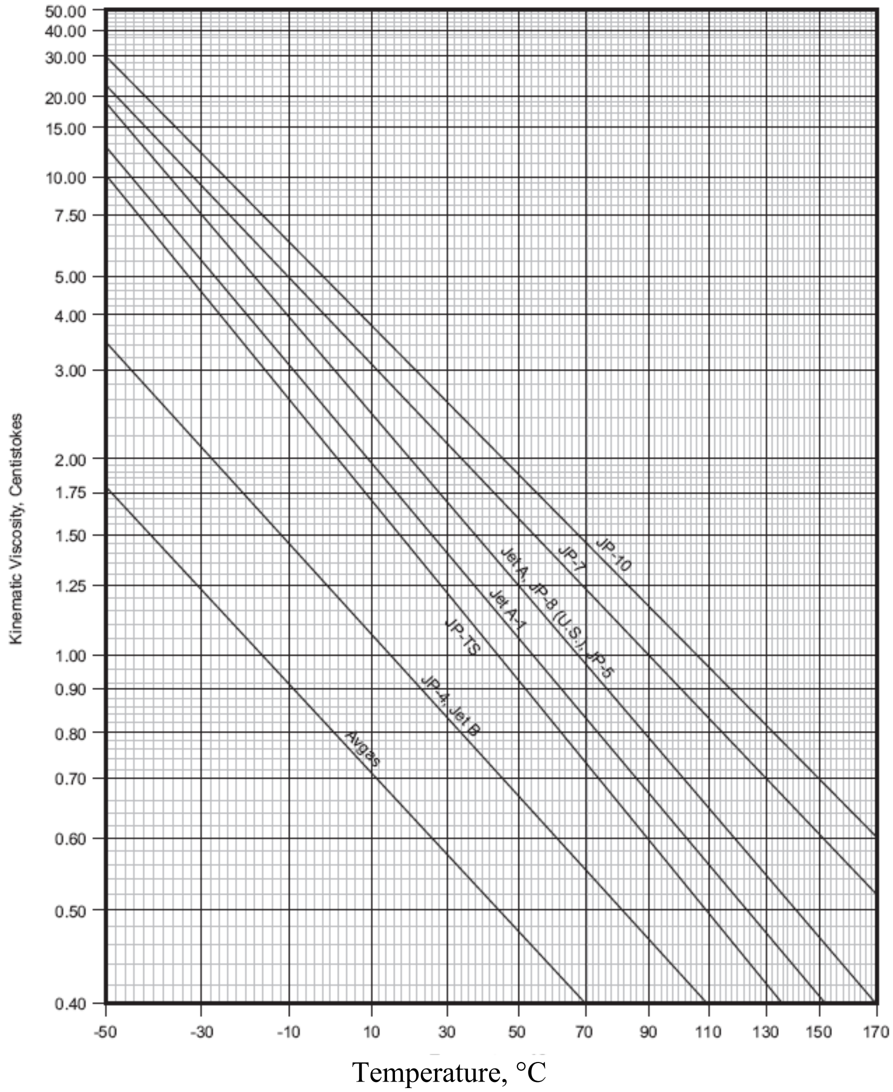


FIGURE C-69. Viscosity as a function of temperature ***[CRC, 2004].***

TABLE C-XCVII. Viscosity fuel property rating value: aircraft.

-20° C	New Fuel
R	> 8 cSt
G	≤ 8 cSt

TABLE C-XCVIII. Viscosity fuel property rating value: support equipment & vehicles.

40° C	New Fuel
R	<1.3 cSt
G	≥1.3 cSt

-40° C	New Fuel
R	>12.0 cSt
G	≤12.0 cSt

25° C	New Fuel
G	Report

60° C	New Fuel
G	Report

TABLE C-XCIX. Reserved.

C.48 WATER REACTION INTERFACE RATING – ENTRANCE CRITERIA.

C.48.1 Definition. Water Reaction Interface is a rating method that covers the determination of the presence of water-miscible components in hydrocarbon liquids, and the effect of these components on volume change and on the fuel-water interface.

C.48.2 Standard Water Interface Rating Test Methods.

C.48.2.1 Water Reaction by ASTM D1094 acidity by ASTM D3242. Twenty mL of buffered water is added to 80 mL of test fuel in a graduated glass cylinder and is shaken by hand. After 5 minutes of settling any volume change of either the fuel or the water is reported. For jet fuel the appearance of the interface between fuel and water is rated by comparison to a series of written descriptions which are numbered 1 for the cleanest and 4 for the dirtiest. A letter designation may be assigned to the interface rating to provide additional test result descriptions such as 1B. These tests, while more applicable to AVGAS than to jet fuel, are still required by the JP-8 specification for finished fuel, so need to be considered until removed from the specification.

C.48.3 Data / Property Occurrence. This property is superseded in MIL-DTL-83133 for the neat alternative fuel blending components by Water Separation Index Modified (WSIM), ASTM D3948 or D7224, but D1094 remains for the finished fuel.

TABLE C-C. Water reaction interface rating fuel property rating value.

	New Fuel
Y	> 1B
G	≤ 1B

TABLE C-CI. Reserved.

C.49 WATER SEPARATION INDEX – ENTRANCE CRITERIA.

C.49.1 Definition. This is an ASTM test method that addresses the ability of hydrocarbon liquids to release entrained or emulsified water when passed through fiberglass coalescing material.

C.49.2 Standard Water Separation Index Test Methods.

C.49.2.1 Water Separation Characteristics by Portable Separometer by ASTM D3948. A fuel/water emulsion is created in a disposable syringe with a high speed mixer. The emulsion is then pushed through a special fiber glass filter intended to strip the water from the emulsion. The presence of water in the filtrate is then determined by exposing the filtrate to a light beam and measuring the resultant light scatter due to water droplets. Results are given in MSEP units, with a fuel having an MSEP rating of 100 showing no light dispersion due to free water, while a rating of 0 indicates a filtered fuel heavily contaminated with free water.

C.49.3 Data / Property Occurrence.

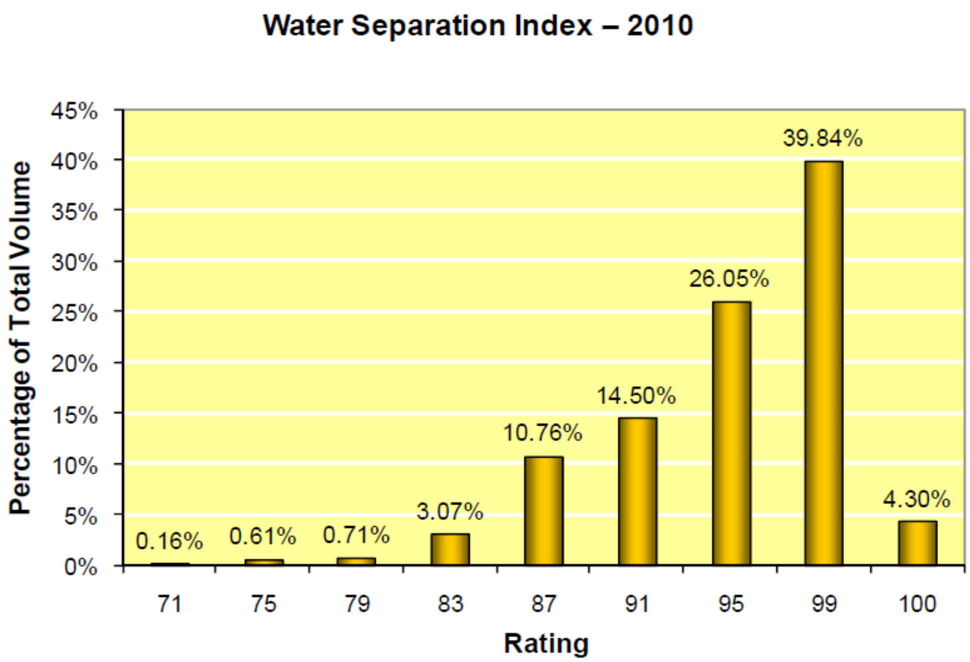


FIGURE C-70. Water separation index histogram JP-8 (2010) *taken from PQIS.*

TABLE C-CII. Water separation index fuel property rating value.

	New Fuel
G	Report

TABLE C-CIII. The minimum microseparometer rating using a Micro-Separometer (MSEP).

JP-8 Additives	MSEP Rating, min.	Limit	
Antioxidant (AO), Metal Deactivator (MDA)	90	>90	G
		<90	Y
AO, MDA, and Fuel System Icing Inhibitor (FSII)	85	>85	G
		<85	Y
AO, MDA, and Corrosion Inhibitor/Lubricity Improver (CI/LI)	80	>80	G
		<80	Y
AO, MDA, FSII and CI/LI	70	>70	G
		<70	Y

C.50 WATER SOLUBILITY – SUBSET 1.

C.50.1 Definition. The quantity of water dissolved in aircraft fuels is determined by the partial pressure of water in the vapor space above the fuel. When this vapor space is saturated with water at a given temperature; i.e., 100 percent relative humidity, the water dissolved in fuel at equilibrium will reflect the saturation values shown on Figures C-71 and C-72; CRC, 2004; and PQIS, 2010

C.50.2 Standard Water Solubility Test Methods.

C.50.2.1 Water Solubility by ASTM D6304. An aliquot is injected into the titration vessel of a coulometric Karl Fischer apparatus in which iodine for the Karl Fisher reaction is generated coulometrically at the anode. When all of the water has been titrated, excess iodine is detected by an electrometric end point detector and the titration is terminated. Based on the stoichiometry of the reaction, 1 mol of iodine reacts with 1 mol of water; thus, the quantity of water is proportional to the total integrated current according to Faraday's Law.

C.50.3 Comments. At relative humidity values less than 100 percent, the amount of water dissolved in fuel will be correspondingly less than saturation values in accordance with Henry's Law. Because water solubility is sensitive to temperature, a drop of 10°C in water-saturated fuel's temperature will create from 15 to 25 ppm of undissolved or "free water." It is difficult to visually detect "free water" at levels below 30 ppm. Several go / no-go tests, including the Shell Water Detector, can be used to detect levels in the range of 15 to 30 ppm. For quantitative measurement in the range of 1 to 60 ppm, ASTM D3240 is frequently used.

C.50.4 Data / Property Occurrence.

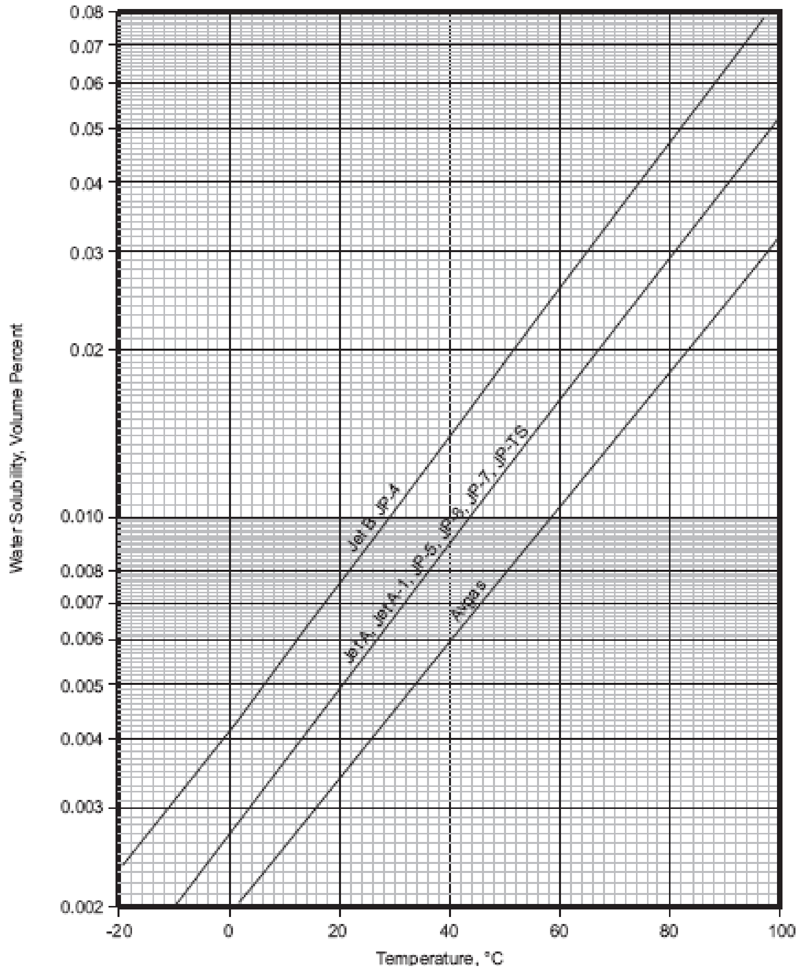


FIGURE C-71. Water solubility versus temperature for aircraft fuels *(CRC, 2004).*

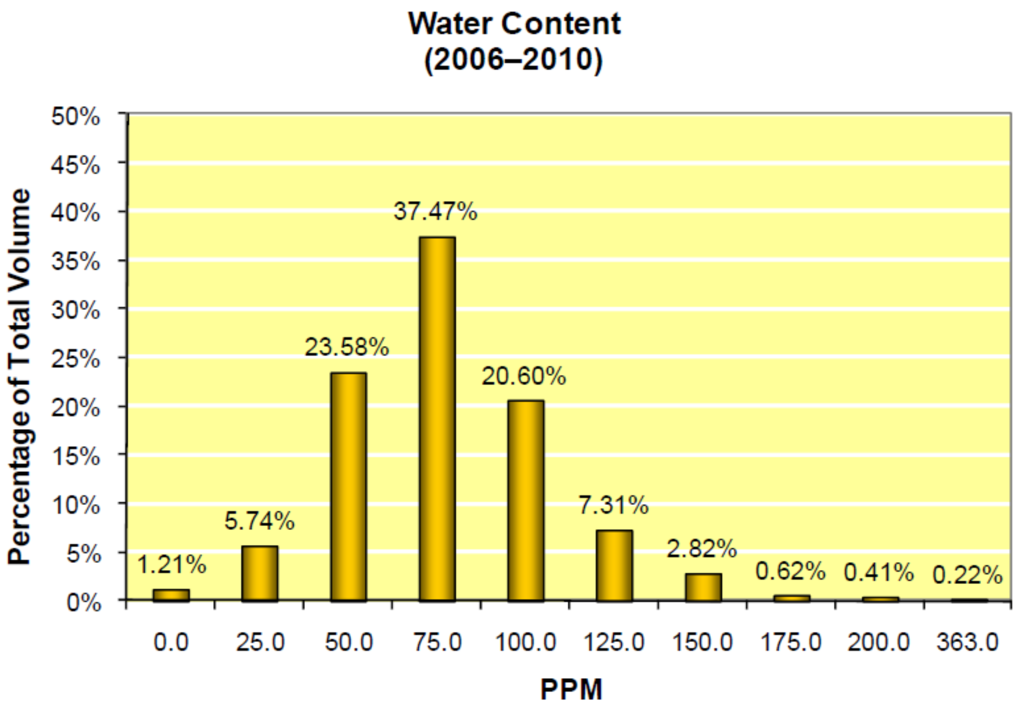


FIGURE C-72. Water solubility histogram JP-8 (2010) *taken from PQIS.*

TABLE C-CIV. Water solubility fuel property rating value.

	New Fuel
Y	>JP-8/JP-5 values
G	JP-8/JP-5 values

TABLE C-CV. Reserved.

APPENDIX D

EVALUATING THE COMPATIBILITY OF ADDITIVES OR ALTERNATIVE FUELS WITH FUEL SYSTEM MATERIALS

D.1 SCOPE.

D.1.1 General.

This Appendix describes the recommended practice for testing and approving the material compatibility of fuel additives or alternative fuels with the materials found in aircraft fuel tanks, fuel systems, engines, ground supply vehicles, and the supply chain.

D.1.2 Entrance Criteria and Subset Testing.

Air Force Subject Matter Experts (SMEs) evaluated all fuel properties and characteristics based on the requirements decomposition process that correlated requirements to safety, performance, durability, and supportability, as described in Appendix C. This Appendix defines the subset to which each material compatibility characteristic belongs and the significance for its selection. It also includes component tests to be conducted to further evaluate the material compatibility characteristics of the candidate fuel requiring further investigation, as deemed appropriate by the Fuels Certification Organization (FCO).

D.2 APPLICABLE DOCUMENTS.

D.2.1 General.

The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this Appendix.

D.2.2 Government documents.

D.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. In all cases, the most current revision of each document is to be used.

FEDERAL SPECIFICATIONS

A-A-3097	Adhesives, Cyanoacrylate, Rapid Room Temperature-Curing, Solventless
QQ-S-571	Solder, Electronic (96 to 485 Deg. C)
MMM-A-132	Adhesives, Heat Resistant, Airframe Structural, Metal to Metal

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-PRF-370	Hose and Hose Assemblies, Nonmetallic: Elastomeric, Liquid Fuel
MIL-H-4495	Hose Assembly, Rubber, Aerial Refueling

MIL-DTL-5541	Chemical Conversion Coatings on Aluminum and Aluminum Alloys
MIL-DTL-5578	Tanks, Fuel, Aircraft, Self-Sealing
MIL-R-6855	Rubber, Synthetic, Sheets, Strips, Molded or Extruded Shapes
MIL-PRF-8516	Sealing Compound, Synthetic Rubber, Electric Connectors and Electric Systems, Chemically Cured
MIL-A-8625	Anodic Coatings for Aluminum and Aluminum Alloys
MIL-H-17902	Hose, End Fittings and Hose Assemblies, Synthetic Rubber, Aircraft Fuels
MIL-DTL-24441	Paint, Epoxy-Polyamide, General Specification for
MIL-P-25732	Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Limited Service at 275 Deg. F (135 Deg. C)
MIL-DTL-25988	Rubber, Fluorosilicone Elastomer, Oil and Fuel Resistant, Sheets, Strips, Molded Parts, and Extruded Shapes
MIL-DTL-26521	Hose Assembly, Nonmetallic, Fuel, Collapsible, Low Temperature with Non-Reusable Couplings
MIL-PRF-46010	Lubricant, Solid Film, Heat Cured, Corrosion Inhibiting
MIL-C-83019	Coating, Polyurethane, For Protection of Integral Fuel Tank Sealing Compound
MIL-DTL-83054	Baffle and Inerting Material, Aircraft Fuel Tank
MIL-DTL-83133	Turbine Fuel, Aviation, Kerosene Type, NATO F-34 (JP-8), NATO F-35, and JP-8 + 100 (NATO F-37)
MIL-S-85334	Sealing Compound, Noncuring, Low Consistency, Silicone, Groove Injection, for Integral Fuel Tanks
DOD-L-85645	Lubricant, Dry Film, Molecular Bonded
MIL-PRF-81733	Sealing and Coating Compound, Corrosion Inhibitive
MIL-PRF-87260	Foam Material, Explosion Suppression, Inherently Electrostatically Conductive, for Aircraft Fuel Tanks
MIL-R-46082	Retaining Compounds, Single Component, Anaerobic

(Copies of these documents are available on line at http://quicksearch.dla.mil/.)

D.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. In all cases, the most current revision of each document is to be used.

ASTM INTERNATIONAL SPECIFICATIONS

ASTM A 240/A 240M	Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications
ASTM B36	Standard Specification for Brass Plate, Sheet, Strip, and Rolled Bar
ASTM B93	Standard Specification for Magnesium Alloys in Ingot Form for Sand Castings, Permanent Mold Castings, and Die Castings
ASTM D257	Standard Test Methods for DC Resistance or Conductance of Insulating Materials
ASTM D395	Standard Test Methods for Rubber Property—Compression Set
ASTM D412	Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
ASTM D471	Standard Test Method for Rubber Property-Effect of Liquids
ASTM D1002	Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)
ASTM D1414	Standard Test Methods for Rubber O-Rings
ASTM D2240	Standard Test Method for Rubber Property—Durometer Hardness
ASTM D2624	Standard Test Methods for Electrical Conductivity of Aviation and Distillate Fuels
ASTM D3359	Standard Test Methods for Measuring Adhesion by Tape Test
ASTM D3363	Standard Test Method for Film Hardness by Pencil Test
ASTM D4066	Standard Classification System for Nylon Injection and Extrusion Materials (PA)
ASTM D4308	Standard Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter
ASTM D5363	Standard Specification for Anaerobic Single-Component Adhesives (AN)
ASTM D6272	Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending

(Copies of these documents are available on line at www.astm.org or f approved users may access the documents at www.ihs.com.)

SAE INTERNATIONAL

SAE-AMS-2410	Plating, Silver Nickel Strike, High Bake
SAE-AMS-2427	Aluminum Coating Ion Vapor Deposition
SAE-AMS-3215	Acrylonitrile Butadiene (Nbr) Rubber Aromatic Fuel Resistant 65 - 75
SAE-AMS-3265	Sealing Compound, Polysulfide (T) Rubber, Fuel Resistant, Nonchromated Corrosion Inhibiting for Intermittent Use to 360 Deg. F (182 Deg. C)
SAE-AMS-3276	Sealing Compound, Integral Fuel Tanks and General Purpose, Intermittent Use to 360 Deg. F (182 Deg. C)
SAE-AMS-3277	Sealing Compound, Polythioether Rubber Fast Curing Integral Fuel Tanks And General Purpose, Intermittent Use to 400 MDF (204 MDC)
SAE-AMS-3278	Sealing and Coating Compound: Polyurethane (PUR) Fuel Resistant High Tensile Strength / Elongation for Integral Fuel Tanks / Fuel Cavities / General Purpose
SAE-AMS-3279	Sealing Compound, Sprayable, for Integral Fuel Tanks and Fuel Cell Cavities, for Intermittent Use to 350 Deg. F (177 Deg. C)
SAE-AMS-3281	Sealing Compound, Polysulfide (T) Synthetic Rubber for Integral Fuel Tank and Fuel Cell Cavities Low Density (1.20 to 1.35 Sp Gr), for Intermittent Use to 360 Deg. F (182 Deg. C)
SAE-AMS-3283	Sealing Compound, Polysulfide Non-Curing, Groove Injection Temperature and Fuel Resistant
SAE-AMS-3361	Silicone Potting Compound, Elastomeric, Two-Part, General Purpose, 140 to 400 Poise (15 to 40 Pa-s) Viscosity
SAE-AMS-3375	Adhesive/Sealant, Fluorosilicone, Aromatic Fuel Resistant, One-Part Room Temperature Vulcanizing
SAE-AMS-3376	Sealing Compound, Non-Curing, Fluorosilicone Groove Injection Temperature and Fuel Resistant
SAE-AMS-4017	Aluminum Alloy, Sheet and Plate, 2.5Mg 0.25Cr, (5052-H34), Strain-Hardened, Half-Hard, and Stabilized
SAE-AMS-4027	Aluminum Alloy, Sheet and Plate, 1.0Mg - 0.60Si - 0.28Cu - 0.20Cr, (6061; -T6 Sheet, - T651 Plate) Solution and Precipitation Heat Treated
SAE-AMS-4029	Aluminum Alloy Sheet and Plate (2014; -T6 Sheet, -T651 Plate) Solution and Precipitation Heat Treated

SAE-AMS-4037	Aluminum Alloy Sheet and Plate 4.4Cu - 1.5Mg - 0.60Mn (2024;-T3 Flat Sheet, -T351 Plate) Solution - Heat Treated
SAE-AMS-4107	Aluminum Alloy Die Forgings (7050-T74) Solution Heat Treated and Overaged
SAE-AMS-4260	Aluminum Alloy, Investment Castings, 7.0Si - 0.32Mg (356.0-T6), Solution and Precipitation Heat Treated
SAE-AMS-4750	Solder, Tin-Lead, 45Sn-55Pb
SAE-AMS-4751	Tin - Lead Alloy Eutectic, 63Sn - 37Pb (NONCURRENT)
SAE-AMS-5504	Steel, Corrosion and Heat Resistant, Sheet, Strip, and Plate 12.5Cr (SAE 51410) Annealed
SAE-AMS-5525	Steel, Corrosion and Heat Resistant, Sheet, Strip, and Plate 15Cr - 25.5Ni - 1.2Mo - 2.1Ti - 0.006B - 0.30V 1800 Deg. F (982 Deg. C) Solution Heat Treated
SAE-AMS-5604	Steel, Corrosion Resistant, Sheet, Strip, and Plate 16.5Cr - 4.0Ni - 4.0Cu - 0.30Cb Solution Heat Treated, Precipitation Hardenable
SAE-AMS-5613	Steel, Corrosion and Heat Resistant, Bars, Wire, Forgings, Tubing, and Rings 12.5Cr (SAE 51410) Annealed
SAE-AMS-5643	Steel, Corrosion Resistant, Bars, Wire, Forgings, Tubing, and Rings 16Cr - 4.0Ni - 0.30Cb - 4.0 Cu Solution Heat Treated, Precipitation Hardenable
SAE-AMS-5688	Steel, Corrosion Resistant, Wire 18Cr - 9.0Ni (SAE 30302) Spring Temper
SAE-AMS-5737	Steel, Corrosion and Heat Resistant, Bars, Wire, Forgings, and Tubing 15Cr - 25.5Ni - 1.2Mo - 2.1Ti - 0.006B - 0.30V Consumable Electrode Melted, 1650 Deg. F (899 Deg. C) Solution and Precipitation Heat Treated
SAE-AMS-6277	Steel Bars, Forgings, and Tubing 0.50Cr - 0.55Ni - 0.20Mo (0.18 - 0.23C) (SAE 8620) Vacuum Arc or Electroslag Remelted
SAE-AMS-6345	Steel, Sheet, Strip and Plate 0.95Cr-0.20Mo (0.28 - 0.33C) (SAE 4130) Normalized or Otherwise Heat Treated
SAE-AMS-6415	Steel, Bars, Forgings, and Tubing 0.80Cr - 1.8Ni - 0.25Mo (0.38 - 0.43C) (SAE 4340)

SAE-AMS-6444	Steel Bars, Forgings, and Tubing 1.45Cr (0.93 - 1.10C) (SAE 52100) Premium Aircraft-Quality, Consumable Electrode Vacuum Remelted
SAE-AMS-6470	Steel, Nitriding, Bars, Forgings, and Tubing 1.6Cr - 0.35Mo - 1.1Al (0.38 -0.43C) (135 Mod)
SAE-AMS-6472	Steel Bars and Forgings, Nitriding 1.6Cr-0.35Mo-1.1Al (135Mod) (0.38-0.43C) Hardened and Tempered, 112ksi (770 MPa) Tensile Strength
SAE-AMS-7257	Rings, Sealing, Perfluorocarbon (Ffkm) Rubber High Temperature Fluid Resistant 70 – 80
SAE-AMS-7271	Rings, Sealing, Butadiene-Acrylonitrile (NBR) Rubber Fuel and Low Temperature Resistant 60 – 70
SAE-AMS-7276	Rubber: Fluorocarbon (FKM) High-Temperature-Fluid Resistant Low Compression Set for Seals in Fuel systems and Specific Engine Oil Systems
SAE-AMS-I-7444	Insulation Sleeving, Electrical, Flexible
SAE-AMS-7902	Beryllium Sheet and Plate, 98Be
SAE-AMS-C-27725	Coating, Corrosion Preventative, Polyurethane for Aircraft Integral Fuel Tanks for Use to 250 Deg. F. (121 Deg. C.)
SAE-AMS-DTL-23053/5	Insulation Sleeving, Electrical, Heat Shrinkable, Polyolefin, Flexible, Crosslinked
SAE-AMS-P-5315	Butadiene - Acrylonitrile (Nbr) Rubber for Fuel-Resistant Seals 60 to 70
SAE-AMS-P-83461	Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance at 275 Deg. F (135 Deg. C)
SAE-AMS-QQ-A-250/12	Aluminum Alloy 7075, Plate and Sheet
SAE-AMS-QQ-P-416	Plating, Cadmium (Electrodeposited)
SAE-AMS-R-25988	Rubber, Fluorosilicone Elastomer, Oil-and-Fuel-Resistant, Sheets, Strips, Molded Parts, and Extruded Shapes
SAE-AMS-R-83485	Rubber, Fluorocarbon Elastomer, Improved Performance at Low Temperatures
SAE-AMS-S-4383	Sealing Compound, Topcoat, Fuel Tank, Buna-N Type
SAE-AMS-S-8802	Sealing Compound, Temperature Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion

SAE AS5127/1	Test Methods for Aerospace Sealants Two-Component Synthetic Rubber Compounds

(Copies of these documents are available on line at www.sae.org.)

BOEING MATERIAL SPECIFICATIONS (BMS)

BMS 5-267	Fuel Tank Coating
BMS 10-20	Corrosion Resistant Finish for Integral Fuel Tanks
BMS 10-39	Fuel and Moisture Resistant Finish for Fuel Tanks

(Copies of these documents may be obtained by contacting your local Boeing representative.)

AMERICAN WELDING SOCIETY

AWS C3.4	Specification for Torch Brazing
AWS C3.5	Specification for Induction Brazing
AWS C3.6	Specification for Furnace Brazing
AWS C3.7	Specification for Aluminum Brazing

(All four specifications can be ordered on line at http://www.aws.org.)

D.3 BACKGROUND.

Over the years many material compatibility programs have been performed on various fuels and fuel additives; however, none of these programs were standardized. In 1994, the Air Force Research Laboratory, Materials and Manufacturing Directorate (AFRL/RXSA) was asked to conduct material compatibility testing on JP-8+100 additives. After a survey of fuel tank, fuel system and engine materials, a list of 256 different materials were tested. As a result of the JP-8+100 program, short lists of metallic and nonmetallic materials were compiled for future testing. These two short lists were intended to be representative or worst case products from each type of material. For example, many different polysulfide sealants are used in fuel tanks, but a representative manganese dioxide cured product and a representative chromate cured product were selected for the short list. Soak temperatures and durations, test methods, and acceptance criteria were also called out in the short lists. Since the JP-8+100 program, other fuels and additives have been successfully tested for material compatibility using the short lists.

In 2006, an Integrated Product Team (IPT) was assembled to standardize and centralize the process for certifying new fuels. This IPT was charged with reviewing the current process and recommending a standardized process for certification. This materials compatibility appendix is one of the results of that effort. It reflects not only aircraft and engine materials, but also vehicles, ground support, and supply chain materials. The short lists were revisited and updated, evaluation criteria became better defined, and a Subset program was documented. Subset 1 is the revised short list testing, Subset 2 defines further testing required should there be a failure during Subset 1, and Subset 3 is large scale functional testing and/or flight testing based on the results of Subset 2.

D.4 TESTING APPROACH AND ENTRANCE CRITERIA.

Entrance Criteria for materials testing is a chemical description of the fuel. Based upon this chemical description AFRL/RXSA will conduct an analysis to determine if Subset 1 testing is necessary. Subset 1 is laboratory scale testing which compares representative metallic and nonmetallic materials after soaking in a baseline fuel and after soaking in the new fuel or additized fuel being tested. It is designed as a first level screening test to provide an indication of any compatibility problems. If all tests pass then the risk level of the new additive or fuel is minimal. If there are material compatibility concerns (see D.5.10 for evaluation criteria), then a Subset 2 program is required that is designed to further investigate those material families that failed. Subset 2 involves a complete testing of all the materials in the family of materials that failed, an analysis of the root cause of failure, or possibly component or system level tests. A Subset 3 program based on the findings of Subset 2 could be conducted to further reduce risk and determine compatibility. Subset 3 may consist of large scale functional testing and/or flight testing.

D.5 SUBSET 1 TESTING.

D.5.1 Objective. Determine the effect of a candidate additive or an alternative fuel on fuel system materials, ground handling equipment, and supply chain materials.

D.5.2 Additives. The additive supplier will recommend a concentration to be tested. An evaluation will be made to determine the maximum possible concentration of the additive in the fuel, the water layer and the vapor. Fuel system additives are to be evaluated at four times the concentration being sought for approval or the maximum possible concentration, whichever is less. This increased concentration is meant to simulate a worst-case fuel and aid in identifying any potential material incompatibilities.

D.5.3 Alternative fuels. Alternative fuels will be characterized for chemical consistency. If the chemical consistency causes variation in properties between batches, high and low boundaries for each property will be determined. At a minimum, sulfur content, acid number, aromatic content, flash point and conductivity will be determined. If there is a significant variation in any property, the alternative fuel will be tested at the anticipated maximum and minimum of the affected properties.

D.5.4 Test temperatures. Materials are to be tested at the highest temperature to which it will be subjected for its specific application within an aircraft and engine fuel system. Testing at temperatures beyond these maximums result in diminished baseline material performance and significantly reduced test sensitivity for the additive evaluation. The appropriate test temperature for each material is listed in Tables D-I and D-II.

D.5.5 Baseline test fluids. Two baseline test fluids are approved for use in determining compatibility of a new fuel or new fuel additive with fuel system materials. Either of the two test fluids may be used. It is not required that materials be tested in both fluids. A JP-8 conforming to the most recent version of MIL-DTL-83133 and having an aromatic content between 20–25 % may be used. Alternatively, Jet A or Jet A-1 plus US military additives conforming to the most recent version of MIL-DTL-83133 and having an aromatic content between 20–25 % may be used. The same lot of fuel should be used for the baseline as for the test fluid. For example if an additive is being tested, the same lot of JP-8 is used with (i.e., test fluid) and without (i.e., baseline) the additive.

D.5.6 Additive testing. Candidate additives will be evaluated by adding the required concentration (D.5.2) to at least one of the two test fluids. A control test will be performed using the test fluid without the additive to establish a baseline for comparison. The material tests to be performed are shown in Tables D-I and D-II.

D.5.7 Alternative fuel testing. Control testing will be performed using a baseline test fluid (D.5.5) to establish a baseline for comparison. Alternative fuels as determined in D.5.3 will be tested. The material tests to be performed are shown in Tables D-I and D-II.

D.5.8 List of materials. Table D-I is a list of representative nonmetallics and Table D-II is a list of representative metals used in the airframe and gas turbine engine fuel systems. Table D-I and Table D-II also show the properties to be tested for each material class, the temperature at which the test will be performed, and the evaluation criteria.

D.5.9 Testing procedure.

D.5.9.1 Procedure for soaking (aging) test materials in fuel

D.5.9.1.1 Material procurement for the soak procedure:

1. Sealant, coating, composite, and adhesive materials are typically procured in their raw (uncured) form. This often consists of a two-part mixture, pre-impregnated composite fiber (prepreg), or film. This then relies on the expertise of the lab performing the testing to be able to fabricate the specimens required for the various tests. For example, once prepared, sealant specimens are required to be cured in environmentally controlled rooms (77°F ± 2°F and 50 % ± 5% relative humidity) and the composites are cured in an autoclave.
2. Sealant peel strength testing is done using AMS-C-27725 coated panels as a substrate. Adhesive lap shear testing is done using anodized aluminum adherends with the manufacturer's recommended surface preparation and cure cycle.
3. Bladder, hose, foam, and wire insulation materials are procured as a sheet of the material from the applicable vendor. These sheets are then utilized to die-out (cut out) the specimens required for the testing. For example, a dumbbell shaped die conforming to the required test coupon dimensions, is used to obtain specimens for tensile testing.
4. O-rings are also obtained directly from the vendors who manufacture materials meeting the various specifications (found on the Qualified Products Listing (QPL)).
5. Metallic specimens are obtained from various sources who can certify the materials to meet the applicable specifications. Typically, three specimens of each material are utilized in the aging of the metallic specimens. For materials available in sheet form, specimens are a nominal one inch by two inch. Thickness is not relevant as we are only looking at surface effects. Metallic material specimens should be degreased (to remove mill oils and/or grime), rinsed with deionized water, rinsed with isopropanol and wiped dry with lint-free wipes. Each specimen should then be weighed and their weights recorded.
6. Bladder materials and wire insulation films may not be isotropic; therefore, before performing tensile/elongation testing, determine the direction of the material with the highest tensile strength. Cut specimens so that tensile and elongation testing is performed along that direction.

D.5.9.1.2 Fuel soak:

1. Materials are typically exposed to the fuel in separate lidded glass jars (quart-size). For example, the tensile and volume swell specimens of the AMS-S-8802 polysulfide sealant are aged in a separate jar from the AMS-3281 lightweight polysulfide tensile and volume swell specimens. Specimens of different materials are not aged in the same container because it is possible that components may leach out into the fuel and react with other material specimens or components.

For the metallic materials, three specimens per material are used for each fuel. During the fuel exposure the individual test coupons comprising the three specimen set should not be in contact with one another. One approach to isolating the specimens is to place individual test coupons inside separate small (e.g., 30-ml) glass beakers. The three beakers are then placed inside the aging jar prior to filing with the fuel.

2. Tensile and elongation, volume swell, and hardness specimens are suspended in the fuel and not just laid in the bottom of the jar. This can be done by using a rack and wires to hang the specimens, which can then be placed in the jar.
3. The resistivity specimen for the MIL-PRF-87260 conductive foam is the only specimen not aged in a quart jar. It is aged in a larger container, for example, a non-reactive glass casserole/bowl with a lid.
4. A piece of foil is placed over the mouth of the jar and then the lid is screwed into place to prevent evaporation of the fuel while aging. The foil should extend roughly one inch over all sides of the mouth of the jar. The heating of the quart-jars is done using explosion-proof ovens. These ovens can hold a large number of jars, so many specimens which require the same temperature can be aged simultaneously.
5. Fuel change out, that is, replacement of old fuel with fresh fuel, is performed after 14 days for the 28-day aging of nonmetallic specimens and after 7 days for the metallic specimens. Change out of the fuel is necessary because properties of the fuel can change significantly when exposed to high temperatures for an extended period of time.

D.5.9.2 Metallic material tests are as follows:

Corrosion Testing

a. Light-Optical Evaluation
b. Microstructural Evaluation.

D.5.9.3 Metallic specimens are weighed during the temperature aging process. The weight gain/loss measurements are taken at four different points in the process: before starting the aging, after seven days of aging, after 14 days of aging, and after the 28-day end of the aging.

D.5.10 Evaluation criteria.

D.5.10.1 The test materials will be evaluated using the evaluation criterion provided for each test of a given material.

D.5.10.2 The evaluation criteria for nonmetallics are listed in Table D-I.

In analyzing the mechanical and physical properties data, a logical evaluation criterion is to compare the results after aging in the baseline fuel with the results after aging in the new fuel or additive and identify any significant differences. For each test, "allowable" variations have been determined based on the standard deviations in the test methods. Differences greater than these allowable variations indicate an increased possibility the variations in the data are significant and cannot be attributed to normal data scatter for this type of test. Also, for most of the materials there are test requirements expressed as maximum or minimum values. These test requirements are taken from the material specifications when applicable. When specification limits are not available, the test requirements are based on experience with similar materials and previous test programs.

If the test results are within the allowable variation and pass the test requirements then the risk level of the new additive or fuel for the particular material is minimal. If the test results are not within the allowable variation and the test requirements are not met then a Subset 2 program is required that is designed to further investigate that material family. If one of the evaluation criteria is met but the other is not met, then the magnitude and effects of the failure is evaluated to determine if Subset 2 testing is necessary.

D.5.10.3 The evaluation criteria for metallics are as follows: No signs of increased corrosion after aging in the new fuel or additive when compared with the results after aging in the baseline fluid.

D.6 SUBSET 2 TESTING.

D.6.1 Objective. Perform additional testing to further investigate failures from Subset 1. This Subset requires an assessment of Subset 1 failures and a test plan to evaluate risks discovered under Subset 1. The assessment should identify risks of using the new additive or fuel to material durability, subsystem functionality, and flight worthiness. A comprehensive test plan that assesses each risk should be executed under Subset 2**.**

D.6.2 Additives. The same concentration of additive used in Subset 1 will be used in Subset 2. The batch of fuel used for Subset 2 will be the same as that used in Subset 1, whenever possible.

D.6.3 Alternative fuels. The batch of fuel used for Subset 2 will be the same as that used in Subset 1, whenever possible.

D.6.4 Complete materials testing. For each material that failed in Subset 1, that complete material family will be tested. For example if one polysulfide sealant failed, then all polysulfide sealants will be tested. The complete list of materials is found in Table D-III. The results of these tests will be used to evaluate the extent of compatibility.

D.6.5 Related materials testing. The cause of failures from Subset 1 will be evaluated. Some common failure causes are lack of swell, hardening, loss of flexibility, reversion due to polymer chain scission, acid attack, sulfur or mercaptan attack, corrosion, etc. The root cause of each Subset 1 failure will be determined. Those materials that are not in the same family, but that may be prone to similar attack will be tested for the appropriate physical properties.

Based upon the results of Subset 1 and/or the results of Complete Material Testing and Related Material Testing in Subset 2, a determination will be made if functional testing is required to assess risks. The functional testing would correspond to the failed material physical property. For example, if lack of swell was a cause of failure in o-rings, then functional testing would be required to determine if fuel leaks are likely. Flowing rig fuel coupling tests, static seal tests, pump seal tests, and fuel control valve tests are examples of functional tests that can be used to assess the risk of fuel leaks. These functional tests should address subsystem or system level concerns.

D.7 SUBSET 3 TESTING.

D.7.1 Objective. Perform system level or flight testing to further investigate concerns from Subset 2. This Subset requires an assessment of Subset 2 results and a test plan developed to evaluate risks not resolved under Subset 2. The assessment should identify risks of using the new additive or fuel to system functionality. A comprehensive test plan that assesses each risk should be executed under Subset 3.

D.7.2 Additives. The same concentration of additive used in Subset 1 and 2 will be used in Subset 3. The batch of fuel used will be the same for Subset 3 as was used for Subset 1 and 2, whenever possible.

D.7.3 Alternative fuels. The batch of fuel used for Subset 3 will be the same as that used in Subset 1 and 2, whenever possible.

D.7.4 System level testing. If concerns still exist after Subset 2, then system level functional tests should be performed to assess the risks. A test plan that addresses each risk will be executed. For example, if sealant tensile strength has failed in Subset 1 and dynamic cycling tests are inconclusive or marginal in Subset 2, then large scale integral fuel tank testing that simulates tank structure, thermal cycling, and lifetime stress/strain criteria could be accomplished.

D.7.5 Flight tests. Flight testing could also be accomplished to assess the risks and concerns from Subset 2. For example if sealant functionality and/or durability are still concerns, flight testing can be used to assess those concerns. The flight testing should be of sufficient duration and flight envelope to evaluate the worst case scenario. Flight testing should have predetermined pass/fail criteria.

D.8 REFERENCES.

AFRL-PR-WP-TR-2000-2015 Fuel and Fuel System Materials Compatibility Test Program for a JP-8 +100 Fuel Additive

(Copies of the above document are available on line at The Defense Technical Information Center Website http://www.dtic.mil/dtic/and are available from DTIC Headquarters, 8725 John J. Kingman Rd., Ft. Belvoir VA 22060-6218; telephone (800) 225-3842.)

TABLE D-I. Nonmetallic materials, tests, and test temperatures.

Material	Description	Spec/Product	Soak Temperature/ Duration	Test	Test Procedure	Evaluation Criteria	
						Test Requirements	Allowable Variation from Baseline
Adhesive	Vinyl Phenolic	MMM-A-132 Type 1, Class 3	200 °F / 28 days	Lap Shear	ASTM D 1002	> 1500 psi	300 psi decrease
Adhesive	Epoxy Resin	~Epon 828/DTA	200 °F / 28 days	Lap Shear	ASTM D 1002	> 1500 psi	300 psi decrease
Adhesive	Nitrile Phenolic	MMM-A-132 Type 1, Class 2	200 °F / 28 days	Lap Shear	ASTM D 1002	> 1500 psi	250 psi decrease
Adhesive	Epoxy Paste	MMM-A-132 Type 1, Class 3	200 °F / 28 days	Lap Shear	ASTM D 1002	> 1500 psi	300 psi decrease
Adhesive	Nitrile Epoxy Film	MMM-A-132 Type 1, Class 2	200 °F / 28 days	Lap Shear	ASTM D 1002	> 1500 psi	400 psi decrease
Adhesive	Methacrylate	ASTM D5363 Group 4, Class 1, Grade 1	200 °F / 28 days	Static Shear	MIL-R-46082, Method A	> 1200 psi	250 psi decrease
Bladder (Inner Liner)	Nitrile	EF 51956	160 °F / 28 days	Tensile Strength	ASTM D 412	> 1500 psi	200 psi decrease
				Elongation	ASTM D 412	> 300%	50% decrease
				Volume Swell	ASTM D 471	< 25%	± 5%
Bladder (Inner Liner)	Polyurethane	~EF 5904C	200 °F / 28 days	Tensile Strength	ASTM D 412	> 1500 psi	200 psi decrease
				Elongation	ASTM D 412	> 300%	40% decrease
				Volume Swell	ASTM D 471	< 25%	± 5%
Bladder (Self Sealing)	Nitrile	MIL-DTL-5578	RT / 30 mins	Volume Swell	ASTM D 471	~	-5%
Coating	Nitrile	SAE-AMS-S-4383	200 °F / 28 days	Hardness (Pencil)	ASTM D 3363	≥ unaged	1 pt decrease
				Tape Adhesion	ASTM D 3359, Method A	Pass	
Coating	Polyurethane	SAE-AMS-C-27725 Type II	200 °F / 28 days	Hardness (Pencil)	ASTM D 3363	≥ unaged	1 pt decrease
				Tape Adhesion	ASTM D 3359, Method A	Pass	
Coating	Epoxy	BMS 10-39	200 °F / 28 days	Hardness (Pencil)	ASTM D 3363	≥ unaged	1 pt decrease
				Tape Adhesion	ASTM D 3359, Method A	Pass	
Bulk Tank Coating	Epoxy-Polyamide	MIL-DTL-24441	120 °F / 28 days	Hardness (Pencil)	ASTM D 3363	≥ unaged	1 pt decrease
				Tape Adhesion	ASTM D 3359, Method A	Pass	

TABLE D-I. Nonmetallic materials, tests, and test temperatures – Continued.

Material	Description	Spec/Product	Soak Temperature/ Duration	Test	Test Procedure	Evaluation Criteria	
						Test Requirements	Allowable Variation from Baseline
Sealant	Polysulfide Dichromate Cured	SAE-AMS-S-8802 Type I, Class B-2	200 °F / 28 days	Peel Strength	SAE AS5127/1	> 20 lb/in / 100% cohes.	8 lb./in. decrease
				Hardness, Shore A	ASTM D 2240	> 35 pts	± 10 pts
				Tensile Strength	ASTM D 412	> 200 psi	35 psi decrease
				Elongation	ASTM D 412	> 150%	30% decrease
				Volume Swell	ASTM D 471	-10% to 10%	5% increase
Sealant	Polysulfide Manganese Cured	SAE-AMS-S-8802 Type II, Class B-2	200 °F / 28 days	Peel Strength	SAE AS5127/1	> 20 lb/in / 100% cohes.	8 lb./in. decrease
				Hardness, Shore A	ASTM D 2240	> 35 pts	± 5 pts
				Tensile Strength	ASTM D 412	> 200 psi	35 psi decrease
				Elongation	ASTM D 412	> 150%	25% decrease
				Volume Swell	ASTM D 471	-10% to 10%	5% increase
Sealant	Fluorosilicone	SAE-AMS-3375	200 °F / 28 days	Peel Strength	SAE AS5127/1	> 10 lb/in / 100% cohes.	4 lb./in. decrease
				Hardness, Shore A	ASTM D 2240	> 35 pts	± 5 pts
				Tensile Strength	ASTM D 412	> 200 psi	35 psi decrease
				Elongation	ASTM D 412	> 150%	25% decrease
				Volume Swell	ASTM D 471	-10% to 10%	5% increase
Sealant	Polyurethane	SAE-AMS-3278 Type II Class B-1	200 °F / 28 days	Peel Strength	SAE AS5127/1	> 20 lb/in / 100% cohes.	8 lb./in. decrease
				Hardness, Shore A	ASTM D 2240	> 35 pts	± 10 pts
				Tensile Strength	ASTM D 412	> 700 psi	35 psi decrease
				Elongation	ASTM D 412	> 300%	100% decrease
				Volume Swell	ASTM D 471	-10 % to 35%	40% increase
Sealant	Polythioether	SAE-AMS-3277 Type II Class B-2	200 °F / 28 days	Peel Strength	SAE AS5127/1	> 20 lb/in / 100% cohes.	8 lb./in. decrease
				Hardness, Shore A	ASTM D 2240	> 35 pts	± 10 pts
				Tensile Strength	ASTM D 412	> 200 psi	35 psi decrease
				Elongation	ASTM D 412	> 150%	25% decrease
				Volume Swell	ASTM D 471	0% - 25%	5% increase
Sealant	Polysulfide Lightweight	SAE-AMS-3281 Type I, Class B-1/2	200 °F / 28 days	Peel Strength	SAE AS5127/1	> 20 lb/in / 100% cohes.	8 lb./in. decrease
				Hardness, Shore A	ASTM D 2240	> 35 pts	± 10 pts
				Tensile Strength	ASTM D 412	> 200 psi	35 psi decrease
				Elongation	ASTM D 412	> 150%	25% decrease
				Volume Swell	ASTM D 471	-10% to 10%	5% increase
Sealant (Groove Injection)	Polysulfide	SAE-AMS-3283	160 °F / 28 days	Volume Swell	ASTM D 471	1% to 12%	± 5%
Sealant (Groove Injection)	Fluorosilicone	MIL-S-85334	160 °F / 28 days	Volume Swell	ASTM D 471	1% to 12%	± 5%

TABLE D-I. Nonmetallic materials, tests, and test temperatures – Continued.

Material	Description	Spec	Soak Temperature/ Duration	Test	Test Procedure	Evaluation Criteria	
						Test Requirements	Allowable Variation from Baseline
Composite,	Graphite/Epoxy	AS4/3501-6	200 °F / 28 days	Interlaminar Shear	ASTM D 6272	> 5000 psi	500 psi decrease
Composite,	Graphite/ Bismaliemide	IM7/5250-4	200 °F / 28 days	Interlaminar Shear	ASTM D 6272	> 5000 psi	500 psi decrease
Composite,	Graphite/ Epoxy	IM7/977-3	200 °F / 28 days	Interlaminar Shear	ASTM D 6272	> 5000 psi	500 psi decrease
Foam	Polyurethane	MIL-PRF-87260	200 °F / 28 days	Tensile Strength	ASTM D 412	> 10 psi	5 psi decrease
				Elongation	ASTM D 412	> 100%	20% decrease
				Resistivity	ASTM D 257	< 1.0E12 Ohm-cm	
Gasket, O-ring	Nitrile	SAE-AMS-P-5315	160 °F / 28 days	Hardness, Shore M	ASTM D 2240	± 10 pts from unaged	± 7 pts
				Tensile Strength	ASTM D 1414	> 1000 psi	125 psi decrease
				Elongation	ASTM D 1414	> 200%	35% decrease
				Compression Set	ASTM D 395	< 50%	5% increase
				Volume Swell	ASTM D 471	0% to 25%	± 10%
Gasket (Ground Refueling)	Nitrile Phenolic		325 °f / 28 days	Hardness, Shore M	ASTM D 2240	± 5 pts from unaged	± 5 pts
				Tensile Strength	ASTM D 1414	> 1000 psi	125 psi decrease
				Elongation	ASTM D 1414	> 150%	35% decrease
				Compression Set	ASTM D 395	< 40%	5% increase
				Volume Swell	ASTM D 471	0% to 25%	± 10%
Gasket, O-ring	Fluorosilicone	SAE-AMS-R-25988, Type I, Class 1, Grade 70	225 °F / 28 days	Hardness, Shore M	ASTM D 2240	- 20 pts from unaged	± 7 pts
				Tensile Strength	ASTM D 1414	> 500 psi	125 psi decrease
				Elongation	ASTM D 1414	> 125%	35% decrease
				Compression Set	ASTM D 395	< 50%	5% increase
				Volume Swell	ASTM D 471	0% to 15%	± 10%
Gasket, O-Ring	Fluorosilicone	SAE-AMS-7379	325 °F / 28 Days	Hardness, Shore M	ASTM D 2240	± 5%	± 7 pts
				Tensile Strength	ASTM D 1414	> 1000 psi	125 psi decrease
				Elongation	ASTM D 1414	> 155%	35% decrease
				Compression Set	ASTM D 395	< 50%	5% increase
				Volume Swell	ASTM D 471	0% to 10%	± 10%
Gasket, O-ring	Fluorocarbon	SAE-AMS-7276	325 °F / 28 days	Hardness, Shore M	ASTM D 2240	± 5 pts from unaged	± 7 pts
				Tensile Strength	ASTM D 1414	> 1000 psi	125 psi decrease
				Elongation	ASTM D 1414	> 150%	35% decrease
				Compression Set	ASTM D 395	< 50%	5% increase
				Volume Swell	ASTM D 471	0% to 10%	± 10%

TABLE D-I. Nonmetallic materials, tests, and test temperatures – Continued.

Material	Description	Spec	Soak Temperature/ Duration	Test	Test Procedure	Evaluation Criteria	
						Test Requirements	Allowable Variation from Baseline
Gasket, O-ring	Low Temperature Fluorocarbon	SAE-AMS-R-83485 Type I	325 °F / 28 days	Hardness, Shore M	ASTM D 2240	± 5 pts from unaged	± 7 pts
				Tensile Strength	ASTM D 1414	> 1000 psi	125 psi decrease
				Elongation	ASTM D 1414	> 150%	35% decrease
				Compression Set	ASTM D 395	< 40%	5% increase
				Volume Swell	ASTM D 471	0% to 10%	± 10%
Hose (Ground Refueling)	Nitrile	EI 1529	160 °F / 28 days	Hardness, Shore M	ASTM D 2240	± 10 pts from unaged	± 7 pts
				Tensile Strength	ASTM D 1414	> 1000 psi	125 psi decrease
				Elongation	ASTM D 1414	> 150%	35% decrease
				Volume Swell	ASTM D 471	-8% to 8%	± 5%
Hose (Ground Refueling)	Epichloro-hydrin	MIL-DTL-26521	160 °F / 28 days	Hardness, Shore M	ASTM D 2240	± 10 pts from unaged	± 7 pts
				Tensile Strength	ASTM D 1414	> 1500 psi	125 psi decrease
				Elongation	ASTM D 1414	> 300%	35% decrease
				Volume Swell	ASTM D 471	-8% to 8%	± 5%
Control Valve Diaphragm (Ground Refueling)	Nitrile		160 °F / 28 Days	Hardness, Shore M	ASTM D 2240	± 10 pts from unaged	± 7 pts
				Tensile Strength	ASTM D 1414	> 1500 psi	125 psi decrease
				Elongation	ASTM D 1414	> 300%	35% decrease
				Volume Swell	ASTM D 471	-8% to 8%	± 5%
Floating Roof Wiper Seal (Ground Refueling)	Urethane		160 °F / 28 Days	Hardness, Shore M	ASTM D 2240	± 10 pts from unaged	± 7 pts
				Tensile Strength	ASTM D 1414	> 1500 psi	125 psi decrease
				Elongation	ASTM D 1414	> 300%	35% decrease
				Volume Swell	ASTM D 471	-8% to 8%	± 5%
Flexible Membrane Liner	Elvalloy Coated Fabric	UFGS 33 56 13.13	160 °F / 28 Days	Tensile Strength	ASTM D 751(Grab)	> 1000 lbs	125 psi decrease
				Adhesion	ASTM D 751	> 20 lbs	85 psi decrease
				Volume Swell	ASTM D 543	< 15%	± 5%
				Change in Mass	ASTM D 471	± 10%	± 5%
Carbon Bushing	Purebon	P-658RCH	160 °F / 28 days	Wt. Loss		Report	5% Increase
				GC Mass Spec. On Fuel		None	No Change
Wire Insulation	PTFE Film	AMS3660	160 °F / 28 Days	Tensile Strength	ASTM D 412	> 1500 psi	150 psi decrease
				Elongation	ASTM D 412	> 125%	15% decrease
Wire Insulation	Nylon	Nylon 101	160 °F / 28 days	Tensile Strength	ASTM D 412	> 8000 psi	850 psi decrease
				Elongation	ASTM D 412	> 25%	5% decrease

TABLE D-I. Nonmetallic materials, tests, and test temperatures – Continued.

Material	Description	Spec	Soak Temperature/ Duration	Test	Test Procedure	Evaluation Criteria	
						Test Requirements	Allowable Variation from Baseline
Wire Insulation	Polyethylene	HDPE	160 °F / 28 days	Tensile Strength	ASTM D 412	> 500 psi	250 psi decrease
				Elongation	ASTM D 412	> 25%	50% decrease
Wire Insulation	Kapton	~Upilex	200 °F / 28 days	Tensile Strength	ASTM D 412	> 10,000 psi	1800 psi decrease
				Elongation	ASTM D 412	> 25%	5% decrease
Potting Compound	Polysulfide	MIL-PRF-8516, Cure B	160 °F / 28 days	Hardness, Shore A	ASTM D 2240	> 30 pts	± 7 pts
				Tensile Strength	ASTM D 412	>100 psi	35 psi decrease
				Elongation	ASTM D 412	> 100%	25% decrease
				Peel Strength	SAE AS5127/1	> 10 lb/in / 100% cohes.	8 lb./in. decrease
				Volume Swell	ASTM D 471	> - 20%	± 10%

TABLE D-II. Metallic materials, tests, and test temperatures.

Material	Material Specification	Coating Specification	Soak Temp.
7075 T6 Aluminum Chromic Acid Anodize Type I	SAE-AMS-QQ-A-250/12	MIL-A-8625, Type I	200º F
7075-T6 Sulfuric Acid Anodize Type IIB	SAE-AMS-QQ-A-250/12	MIL-A-8625, Type II B	200º F
7075-T6 Chromate Conversion Coated Class IA	SAE-AMS-QQ-A-250/12	MIL-DTL-5541, Class 1A	200º F
7050-T74	SAE-AMS-4107	N/A	200º F
2024-T3 Bare	SAE-AMS-4037	N/A	200º F
6061-T6 Bare	SAE-AMS-4027	N/A	200º F
5052-H34 Bare	SAE-AMS-4017	N/A	200º F
356 T6 Cast Aluminum	SAE-AMS-4260	N/A	200º F
AZ91 T6	ASTM B93	N/A	200º F
CU/NI 90/10		N/A	200º F
Sn 60 Pb 40 Solder		N/A	200º F
304 SS	ASTM A240	N/A	325º F
17-4 pH	SAE-AMS-5604	N/A	325º F
440 SS	ASTM A240	N/A	325º F
TI 8Al -1V -1MO	SAE-AMS-T-9046	N/A	325º F
TI CP 70	SAE-AMS-T-9046	N/A	325º F
TI 3AL – 2.5V	SAE-AMS-T-9046	N/A	325º F
4130 IVD Coating	SAE-AMS-6345	SAE-AMS-2427	325º F

TABLE D-III. Metallic materials, tests, and test temperatures - Continued.

Material	Material Specification	Coating Specification	Soak Temp.
Alloy Steel Fastener MS24694 HL21PN20-16	SAE-AMS-6415	SAE-AMS-QQ-P-416, Type II, Class 2	325º F
A286 Fastener MS24694 HL49GU20-16	SAE-AMS-5737	Silver Plate SAE-AMS-2410	325º F
CPM 10V		N/A	325º F
INCO 625		N/A	325º F
INCO 718		N/A	325º F
Nitralloy 135	SAE-AMS-S-22141	N/A	325º F
IN 200 Ni		N/A	325º F
Monel 400		N/A	325º F
Waspalloy		N/A	325º F
Lead	SAE-AMS-4751	N/A	325º F
268 Brass Sheet	ASTM B36	N/A	325º F
TAP MS 285		N/A	325º F
Mag Wire Type I		N/A	325º F

TABLE D-III. Complete list of materials.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.A.1	Adhesive	Epoxy/Polyamide EC3569, BR-127	Epoxy/Polyamide
I.A.2	Adhesive	FM 47 Vinyl Phenolic, BR-127	Vinyl Phenolic
I.A.3	Adhesive	AF 126-2 Nitrile Mod. Epoxy, BR-127	Nitrile
I.A.4	Adhesive	AF 143-2 Mod. Hi. Temp. Epoxy	Epoxy
I.A.5 (I.P.1)	Adhesive	Epon 828/DTA Un. Mod. Epoxy	Epoxy
I.A.6	Adhesive	FM 73W/BR-127 Primer	Nitrile Epoxy
I.A.7	Adhesive	AF-10E/EC 1290, Primer Scotchweld	Primer Scotchweld
I.A.8	Adhesive	AF-10 W/EC 3950, Primer Scotchweld	Primer Scotchweld
I.A.9 (I.C.1)	Adhesive	EC 776 Coating Explosion Suppression Foam Adhesive, SAE-AMS-S-4383	Nitrile
I.A.10	Adhesive	EA 9446	Acrylic
I.A.11.1	Adhesive	Fusor 309 (1:1 mix)	Epoxy
I.A.11.2	Adhesive	Fusor 309 (2:1 mix)	Epoxy
I.A.12	Adhesive	Henkel EA9309.1NA, Epoxy	Epoxy
I.A.13	Adhesive	Henkel EA9394	Epoxy
I.A.14	Adhesive	Loctite 609 (Methacrylate)	Methacrylate
I.A.15	Adhesive	Loctite 495 (Cyanoacrylate)	Cyanoacrylate
I.B.1	Fuel Bladder	AMFUEL, PS-598 Innerliner	Nitrile
I.B.2	Fuel Bladder	AMFUEL, U5200B, Innerliner	Nitrile
I.B.3	Fuel Bladder	AMFUEL, PU-339, Innerliner	Polyurethane
I.B.4	Fuel Bladder	Engineered Fabrics, P/N 51956 Innerliner	Nitrile
I.B.5	Fuel Bladder	Engineered Fabrics, P/N 5904C Innerliner	Polyurethane

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.B.6	Fuel Bladder	Goodyear 26950, Self Sealing	Nitrile
I.B.7	Fuel Bladder	Goodyear 51956, Innerliner	Nitrile
I.B.8	Fuel Bladder	Goodyear 80C29, Innerliner	Urethane
I.B.9	Fuel Bladder	Goodyear 80C39, Innerliner	Nitrile
I.B.10	Fuel Bladder	(Repair Material) Goodyear 80C29	Polyurethane
I.B.11	Fuel Bladder	Engineered Fabrics T/N 3572N Cloth	Nylon (36"x60")
I.B.12	Fuel Bladder	Engineered Fabrics T/N 491 Cloth	Polyester (42"x48")
I.B.13	Fuel Bladder	Amfuel Cloth PN C121	Nylon cloth
I.B.14	Fuel Bladder	Amfuel Cloth PN C130	Nylon cloth
I.B.15	Fuel Bladder	Amfuel 1316-1A, Self Sealing	Nitrile
I.B.16	Fuel Bladder	Engineered Fabrics P/N 320-4-49274/FTL-107, Self Sealing	Polyurethane
I.C.1 (I.A.9)	Int. Fuel Tank Coating	EC 776, 3M, SAE-AMS-S-4383	Nitrile
I.C.2	Int. Fuel Tank Coating	Coating, SAE-AMS-C-27725	Polyurethane
I.C.3	Int. Fuel Tank Coating	Coating, BMS 10-20	Epoxy
I.C.4 (I.D.2)	Int. Fuel Tank Coating	PR1440B2 Pro-Seal 890, BMS 5-267, SAE-AMS-S-8802, Type 2	Manganese Cured Polysulfide
I.C.5	Int. Fuel Tank Coating	PR2911 MMS 425 New Spray/PreCoat-PR2904S-2	Polyurethane
I.C.6	Int. Fuel Tank Coating	MIL-C-83019	Polyurethane

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.C.7	Int. Fuel Tank Coating	Akzo Nobel Aerospace Coatings, product code 454-4-1/CA-109	Epoxy
I.C.8	Ground Tank Fuel Storage	Note: Test at 100º F 3 part epoxy system MIL-DTL-24441 A-36 plate steel, lapweld /20 Form 150 Type III /30 Form 151 Type IV /31 Form 152 Type IV 6010 carbon steel	Epoxy Polyamide 2-4 mil thick 8-10 mil max thick
I.D.1	Int. Fuel Tank Sealant	PR 1422 Type I, B2 SAE-AMS-S-8802, Type I	Dichromate Cured Polysulfide
I.D.2 (I.C.4)	Int. Fuel Tank Sealant	PR1440 (PS 890) SAE-AMS-S-8802, Type 2	Manganese Cured Polysulfide
I.D.3	Int. Fuel Tank Sealant	PR1750, B2, SAE-AMS-3276	Polysulfide
I.D.4	Int. Fuel Tank Sealant	PR1221, B2, SAE-AMS-3278	Polyurethane
I.D.5	Int. Fuel Tank Sealant	Q4-2817, W 1200 Primer SAE-AMS-3375	Fluorosilicone
I.D.6	Int. Fuel Tank Sealant	PR2911, SAE-AMS-3279	Polyurethane
I.D.7	Int. Fuel Tank Sealant	PR1828, B2, SAE-AMS-3277	Polythioether
I.D.8	Int. Fuel Tank Sealant	PR1776, SAE-AMS-3281	Polysulfide
I.D.9	Int. Fuel Tank Sealant	PR1775 B2, SAE-AMS-3265	Polysulfide
I.D.10	Int. Fuel Tank Sealant	P/S 870 B-2, MIL-PRF-81733	Polysulfide
I.D.11	Int. Fuel Tank Sealant	PR705, SAE-AMS-3283, Groove Injection	Polysulfide
I.D.12	Int. Fuel Tank Sealant	Q4-2805, MIL-S-85334, Groove Injection	Fluorosilicone
I.D.13	Int. Fuel Tank Sealant	DC 94031, MIL-S-85334, Groove Injection	Fluorosilicone

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.D.14	Int. Fuel Tank Sealant	SAE-AMS-3376, Groove Injection	Fluorosilicone
I.D.15	Int. Fuel Tank Sealant	G651, Groove Injection	Cyanosilicone
I.E.1	Composite	Composite, AS 4/3501-6	Graphite/Epoxy
I.E.2	Composite	Composite, IM 7/5250-4	Graphite/Bismaliemide
I.E.3	Composite	Composite, AS7/8551-7A	Graphite/Epoxy
I.E.4	Composite	Composite, IM7/977-3	Graphite/Epoxy
I.E.5	Composite	Composite, IM7/8552	Graphite/Epoxy
I.E.6	Vent Lines	Composite	Fiberglass
I.E.7	Isolator Tube	Composite	Epoxy Resin
I.F.1 I.F.1.1 I.F.1.2	Fuel Filter 11/18/97 11/18/97	 AC-B683F-2435 AC-B253F-2435Y1, 1/4	 F-100 Eng. F-110 Eng.
I.F.2	Fuel Filter 14 Aug '97	AC-9985F-10	T-700 Eng.
I.F.3	Fuel Tank Explosion Suppression	Foam, Fomex Yellow Type II, MIL-DTL-83054	Polyurethane (Ester)
I.F.4	Fuel Tank Explosion Suppression	Foam, Fomex Blue IV, MIL-DTL-83054	Polyurethane (Ether)
I.F.5	Fuel Tank Explosion Suppression	Foam (ESM), Fomex, Charcoal Gray, Class I MIL-PRF-87260	Polyurethane (Ether)
I.F.6	Fuel Tank Explosion Suppression	Foam Crest Charcoal Gray, Class II, MIL-PRF-87260	Polyurethane (Ether)
I.F.7	Fuel Tank Explosion Suppression	Foam Fomex Charcoal Gray, Class II, MIL-PRF-87260	Polyurethane (Ether)

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.F.8	Fuel Tank Explosion Suppression	Foam Crest Yellow, Type II, Non-conductive, MIL-DTL-83054	Polyurethane (Ester)
I.F.9	Fuel Tank Explosion Suppression	Beige (tan), Type II, Non-conductive, MIL-DTL-83054	Polyester (Ester)
I.G.1	O-Ring	O-Ring, N-756 Parker, SAE-AMS-P-83461 (Hydraulic)	Nitrile
I.G.2	O-Ring	O-Ring, N304-75 Parker MIL-P-25732 (Hydraulic)	Nitrile
I.G.3	O-Ring	O-Ring, N602-70 Parker, SAE-AMS-P-5315	Nitrile
I.G.4	O-Ring	O-Ring, N506-65 Parker, SAE-AMS-7271 / MS9201	Nitrile
I.G.5 (II.G.2)	O-Ring	O-Ring, L677-70 Parker, MIL-DTL-25988	Fluorosilicone
I.G.6 (II.G.9)	O-Ring	O-Ring, V747 Viton Parker, SAE-AMS-7276	Fluorocarbon
I.G.7 (II.G.3)	O-Ring	O-Ring, Viton (GLT) Parker, SAE-AMS-R-83485	Fluorocarbon
I.G.8 (II.G.4)	O-Ring	O-Ring, Kalrez 92344G, Dupont, SAE-AMS-7257	Perfluoroelastomer
I.G.9	O-Ring	O-Ring, #74-2, CIS8715 Coast-Craft, ABE3, F1	Type S Nitrile
I.G.10 (II.G.1)	O-Ring	O-Ring, EX2000 Bendix, MIL-DTL-25988	Fluorosilicone
I.G.11 (II.G.10)	Seal	Washer, PN 212147, JT8 PO-652, Argo-Tech, PN 21247	Urethane
I.G.12 (II.G.11)	Seal	Tang, JT90, Parker Compound/ P4662A90, ArgoTech, PN 212351	Urethane

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.G.13 (I.O.5)	Cork Seal	Cork P/N 30-155-5-1 Parker	Cork
I.G.14	Door Seal	Parker N406-60, MIL-R-6855, Class 1, Grade 60	Nitrile
II.G.1 (I.G.10)	Engine Plumbing	O-Ring, ES2000/953591 Bendix MIL-DTL-25988	Fluorosilicone
II.G.2 (I.G.5)	Engine Plumbing	O-Ring, Parker L677 MIL-DTL-25988	Fluorosilicone
II.G.3 (I.G.7)	Engine Plumbing	O-Ring, Parker PN/VO835 GLT SAE-AMS-R-83485 (Low Temp.)	Fluorocarbon
II.G.4 (I.G.8)	Engine Plumbing	O-Ring, DuPont Kalrez 93-244G SAE-AMS-7257	Perfluoroelastomer
II.G.5	Engine Plumbing	O-Ring, ESS928, Bendix Jonal MIL-DTL-25988	Fluorosilicone
II.G.6	Engine Plumbing	O-Ring, GTC-777, SAE-AMS-R-83485	Fluorocarbon
II.G.7	Engine Plumbing	O-Ring, GTC 409, MIL-DTL-25988	Fluorosilicone
II.G.8	Engine Plumbing	O-Ring, GTC-505 FFKM, SAE-AMS-7257	Perfluoroelastomer
II.G.9 (I.G.6)	Engine Plumbing	O-Rings, V747 Viton Parker SAE-AMS-7276	Fluorocarbon
II.G.10 (I.G.11)	Plumbing Gasket	Washer, PN 212147, JT8 PO-652, Argo-Tech, PN 21247	Urethane (See I.G.11.)
II.G.11 (I.G.12)	Plumbing Gasket	Tang, JT90, Parker Compound/P4662A90, Argo-Tech PN 212351	(See I.G.12.)
II.G.12	Plumbing Gasket	O-Ring, GTC-778, SAE-AMS-R-83485	Fluorocarbon (Improved 777)
II.G.13	Plumbing Gasket	O-Ring, GTC-B-95, MIL-DTL-25988	Fluorosilicone 677

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
II.G.14	Plumbing Gasket	O-Ring, Stillman P/N TH-1384 MIL-DTL-25988	Fluorosilicone (Teflon®)
II.G.15	Plumbing Gasket	O-Ring, Parker P/N L 1186-80 MIL-DTL-25988	Fluorosilicone (Teflon®)
I.H.1	Hose	Self-Sealing, AR-184	
I.H.2	Hose Aerial Refueling Tanker	PN AC 603-01 Durodyne, MIL-H-4495	Acrylic/Nitrile
I.H.3	Hose (Ground Refueling)	MIL-PRF-370 PN AC 646-01 Durodyne Ground Refueling	Nitrile
I.H.4	Hose (Navy Aircraft Carrier)	PN AC 6611-06 MIL-H-17902 Durodyne Ground Refueling System	Nitrile
I.H.5	Hose (Ground Refueling)	PN EC 614-01 Durodyne MIL-DTL-26521	Epichlorohydrin
I.I.1	Insulation/ Electrical Wire /Clamps/Misc.	Teflon®	TFE (Teflon®) (Film)
I.I.2	Insulation/ Electrical Wire / Clamps/Misc.	Zytel 101, DuPont ASTM D4066	Nylon 101 Film OLD Film NEW Film
I.I.3	Insulation/ Electrical Wire /Clamps/Misc.	Polyethylene Film	Polyethylene (HDP) (Film)
I.I.4	Insulation/ Electrical Wire /Clamps/Misc.	UPILEX	Kapton (Film)
I.I.5	Insulation/ Electrical Wire /Clamps/Misc.	Marmon clamp	KKK-125 (Pacific Molded)
I.I.6	Insulation/ Electrical Wire /Clamps/Misc.	AMS-I-7444, Type 1	Vinyl Plastic

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.I.7	Fuel Line Clamps & Electrical Ties	Kynar	Kynar
I.I.8	Conduit Clamp	Kirkhill TA, SAE-AMS-3215	Nitrile
I.I.9	Tube Clamp Cushions	SAE-AMS-DTL-23053/5	Polyolefin
I.I.10	Bladder Tanks	See I.B.11, .12, .13, and .14.	Nylon Cloth
I.I.11	Engine Fuel Control Stepper Motor	Magnetic Wire Insulation, Type I	HML Varnish
I.I.12	Wire Insulation	Teflon® / Kapton®	Hybrid Teflon / Kapton® (Wire)
I.I.13	Wire Bundle Wrap	Shrink Wrap	
I.I.14	Wire Insulation	Teflon Insulation, Wire Insulation	Wire
I.I.15	Wire Insulation	Nylon Insulation, Wire Insulation	Wire
I.I.15.1	Wire	Nylon Wire, Coax Center	Wire
I.J.1	Joining Material	2219-T87 (AL), Welded	UNS A 92319 4191D9 (AMS)
I.J.2	Joining Material	6AL-4V (Ti), Welded	Match Fill
I.J.3	Joining Material	3AL-2.5V (Ti), Welded	Match Fill
I.J.4	Joining Material	Inco 718 (Ni), Welded	Match Fill
I.J.5	Joining Material	Inco 625 (Ni), Welded	Match Fill
I.J.6	Joining Material	321 (SS), Welded	Match Fill
I.J.7	Joining Material	IN200/201 (Ni), Welded	Match Fill
I.J.8	Joining Material	IN200/201 (Ni), Welded	BNI (5 or 6)
I.J.9	Joining Material	Waspalloy (Ni), Brazed	AMS 4786 Au
I.J.10	Joining Material	321 SS, Brazed	B Ag (5 or 6)
I.J.11	Joining Material	QQ-S-571, SN60 (Tin 60%, Lead 40%), B-36-21A	Tin & Lead (Solder Spots)
I.J.12	Joining Material	6061 T-6 MIL-B-7883, Type V, Grade B, Dip Braze	4145 or 4147 fill
I.J.13	Joining Material	Ti, Cu, Ni Braze P & W	Ti, Cu, Ni

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.J.14	Joining Material	6061-T6 Welded with 4043 filler	Aluminum
I.J.15	Joining Material	5052 H-34 Welded w/ 6061T6 w/ 5356 Filler	Aluminum
I.J.16	Joining Material	Sn 95, Sb 05 Base Material, B 36-21A	Copper w/Solder Spots
I.K.1	Airframe, Coatings	Cover Ink Stamp, EC 776, Top Coating SAE-AMS-QQ-A-250/11	(1 per test fuel) Shaw Aerospace
I.K.2	Airframe, Coatings	Dry Film Lubricant, Dicronite DoD-L-85645	Dicronite
I.K.3	Airframe, Coatings	Dry Thread Lubricant	Graphite
I.K.4	Airframe, Coatings	Name Plate, SAE-AMS-QQ-A-250/1, Color A11136 (Fed Std-596)	Shaw Aerospace
I.K.5	Airframe, Coatings	Dry Film Lubricant	Molybdenum Disulfide
I.K.6.1	Airframe, Coatings		Aluminum Varnish
I.K.6.2	Airframe, Coatings	Resin: No 48-C-31, ES #11110 Midland Div.	
I.K.6.3	Airframe, Coatings	Reducer: LAMNERX500, Spec. No. 66-C-28, ES #11110 Midland Div.	
I.K.7	Airframe, Coatings	Pump, Carbon Bearing, #6001 (CR Plate)	SS, 410, RC 26-34, SAE-AMS-5613
I.K.8.1	Airframe, Coatings	Pump, Carbon Bearing, Pure Carbon Co. PG18RCH	PureBon OP-658 (Carbon)
I.K.8.2	Airframe, Coatings	Pump, Carbon Bearing, Pure Carbon Co. P658RCH	Bearings
I.K.8.3	Airframe, Coatings	Pump, Carbon Bearing, Pure Carbon Co. P5N2	Bearings
I.K.9	Airframe, Coatings	Seal, MIL-PRF-46010, Type I, Micro-Seal Green Tweed	Sliding Seal
I.K.10.1	Airframe, Qty. Probe	B. F. Goodrich Probe P/N 391002-250	Coating

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.K.10.2	Airframe, Qty. Probe	B. F. Goodrich Electronics Fuel Quantity Probe P/N 391002-250	Coating
I.K.11	Airframe, Qty. Probe	Ragan Data Systems, Probe P/N 75-108-2F	Coating
I.K.12	Airframe, Qty, Probe	Fuel Quantity Probe, Ametek Aerospace Products CH-5851-L	Polyphenylene Sulfide 40% glass filled
I.L.1	Locking Devices	Threadlock, MIL-S-22473 Grade A or AV, Loctite	Cyanoacrylate
I.L.2	Locking Devices	Threadlock, MIL-S-22473, (Red)	Cyanoacrylate
I.L.3	Locking Devices	Threadlock, MIL-S-22473 (Brown)	Cyanoacrylate
I.L.4	Locking Devices	Lockwire, See Metals Category (I.M.19/II.M.10)	SAE-AMS-5688 wire (30302)
I.M.1	Airframe, Tank, & Plumbing	5052-0 Bare	Aluminum
I.M.2	Airframe, Tank, & Plumbing	6061-T4 Bare	Aluminum
I.M.3	Airframe, Tank, & Plumbing	6061-T6 Bare	Aluminum
I.M.4	Airframe, Tank, & Plumbing	7075-T6 Chromic Acid Anodize	Aluminum
I.M.5	Airframe, Tank, & Plumbing	7075-T6 Alodine/200	Aluminum
I.M.6	Airframe, Tank, & Plumbing	7075-T6 Bare	Aluminum
I.M.7	Airframe, Tank, & Plumbing	2024-T3 Bare	Aluminum
I.M.8	Airframe, Tank, & Plumbing	2219-T87 Bare	Aluminum
I.M.9	Airframe, Tank, & Plumbing	3003 Bare	Aluminum
I.M.10 (II.M.17)	Airframe, Tank, & Plumbing	C-355-T6	Aluminum

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.M.11 (II.M.18)	Airframe, Tank, & Plumbing	C-356-T6	Aluminum
I.M.12	Airframe, Tank, & Plumbing	7050-T74	Aluminum
I.M.13 (II.M.13)	Airframe, Tank, & Plumbing	316	Stainless Steel
I.M.14 (II.M.14)	Airframe, Tank, & Plumbing	321	Stainless Steel
I.M.15 (II.M.12)	Airframe, Tank, & Plumbing	304	Stainless Steel
I.M.16 (II.M.6)	Airframe, Tank, & Plumbing	INCO 718	Nickel
I.M.17 (II.M.11)	Airframe, Tank, & Plumbing	440C	Stainless Steel
I.M.18 (II.M.8)	Airframe, Tank, & Plumbing	347	Stainless Steel
I.M.19 (II.M.10)	Airframe, Tank, & Plumbing	30302, SAE-AMS-5688 (Wire) (Lockwire)	Stainless Steel
I.M.20 (II.M.22)	Airframe, Tank, & Plumbing	17-4 PH SAE-AMS-5604/5643	Stainless Steel
I.M.21	Airframe, Tank, & Plumbing	1010 Cadmium Plate (Class 2)	Ferrous
I.M.22	Airframe, Tank, & Plumbing	1010 Zinc	Ferrous
I.M.23	Airframe, Tank, & Plumbing	4130 Cadmium Plate (Class II, Type 2, Gold)	Ferrous
I.M.24 (II.M.1)	Airframe, Tank, & Plumbing	6AL-4V	Titanium

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.M.25	Airframe, Tank, & Plumbing	950 Bronze Aluminum	Copper/AL
I.M.26.1	Airframe, Tank, & Plumbing	Naval Brass	Copper/Nickel - 70/30
I.M.26.2	Airframe, Tank, & Plumbing	Naval Brass	Copper/Nickel - 90/10
I.M.27	Airframe, Tank, & Plumbing	Brass, Sheet 268 Substitute 260	Copper
I.M.28	Airframe, Tank, & Plumbing	Lead, SAE-AMS-4751/4750	Lead
I.M.29	Airframe, Tank, & Plumbing	Barium, Ferrite (Shaw Aerospace)	Barium
I.M.30	Airframe, Tank, & Plumbing	Neo-dymium (Shaw Aerospace)	(1 per fuel)
I.M.31	Airframe, Tank, & Plumbing	Brass Sheet, B36-91A	Copper
I.M.32	Airframe, Tank, & Plumbing	1010 Bare	Ferrous
I.M.33	Airframe, Tank, & Plumbing	B-29 (Shaw Aerospace) P/N 79-1527-RM Spec ASTM	Soft Lead
I.M.34 (II.M.25)	Airframe, Tank, & Plumbing	Monel 400, Sheet	Nickel/Copper
I.M.35	Airframe, Tank, & Plumbing	15-5 PH	Ferrous Cr, Ni, Cu
I.M.36	Airframe, Tank, & Plumbing	5052-H34	Aluminum
I.M.37	Airframe, Tank, & Plumbing	1045 Bare	Ferrous
I.M.38	Airframe, Tank, & Plumbing	Magnesium AZ91 T-6 (Substitute AZ31-H24)	Magnesium
I.M.39	Airframe, Tank, & Plumbing	4130 Bare	Ferrous, Steel

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.M.40	Airframe, Tank, & Plumbing	Sn 95, Sb 05	Solder (0.020)
I.M.41	Airframe, Tank, & Plumbing	2014-T6, SAE-AMS-4029	Aluminum
I.M.42	Airframe, Tank, & Plumbing	4340 , SAE-AMS-6415, 280KSI Tensile	Steel Bar Stock
II.M.1 (I.M.24)	Eng. Fuel lines & Components	6AL-4V	Titanium
II.M.2	Eng. Fuel lines & Components	3AL-2.5V (Tubing)	Titanium
II.M.3	Eng. Fuel lines & Components	Hastalloy	Nickel
II.M.4	Eng. Fuel lines & Components	Waspalloy	Nickel
II.M.5	Eng. Fuel lines & Components	INCO 625	Nickel
II.M.6 (I.M.16)	Eng. Fuel lines & Components	INCO 718	Nickel
II.M.7	Eng. Fuel lines & Components	Stellite 30	Chromium/ Carbide
II.M.8 (I.M.18)	Eng. Fuel lines & Components	347	Stainless Steel
II.M.9	Eng. Fuel lines & Components	Greek Ascolloy (30302)	Ferrous
II.M.10 (I.M.19)	Eng. Fuel lines & Components	SAE-AMS-5688 (S.S. Wire) (30302)	Ferrous
II.M.11 (I.M.17)	Eng. Fuel lines & Components	440C	Stainless Steel
II.M.12 (I.M.15)	Eng. Fuel lines & Components	304	Stainless Steel

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
II.M.13 (I.M.13)	Eng. Fuel lines & Components	316	Stainless Steel
II.M.14 (I.M.14)	Eng. Fuel lines & Components	321	Stainless Steel
II.M.15	Eng. Fuel lines & Components	ASI 51410 SS (SAE-AMS-5504)	Stainless Steel
II.M.16	Eng. Fuel lines & Components	CPM 10-V	Powder Metallurgy rolled Fe, V, Cr, C, Mn, Si, T, S, Mo
II.M.17 (I.M.10)	Eng. Fuel lines & Components	C-355 T6	Aluminum
II.M.18 (I.M.11)	Eng. Fuel lines & Components	C-356 T6	Aluminum
II.M.19	Eng. Fuel lines & Components	A-286 SAE-AMS-5525 Silver Plate (2410)	Ferrous
II.M.20	Eng. Fuel lines & Components	135 Modified (MIL-S-6709, SAE-AMS-6470)	Nitralloy
II.M.21.1	Eng. Fuel lines & Components	Bronze, Leaded (Tap MS 285) .1) Saw Cut, Cut up Bearing	Copper
II.M.21.2	Eng. Fuel lines & Components	.2) Polished Cylinder (Argo-Tech)	Polished Cylinder Dry Lub End
II.M.21.3	Eng. Fuel lines & Components	.3) Coated Cylinder (Indium) (Argo-Tech “A”)	Indium Cyl. Surf. Dry Lub End
II.M.21.4	Eng. Fuel lines & Components	.4) Coated Cylinder (Indium) (Argo-Tech “B”)	Indium All Cu Surf. Dry Lub End
II.M.22 (I.M.20)	Eng. Fuel Line & Components	17-4 PH Stainless Steel SAE-AMS-5604	Ferrous (S.S.)
II.M.23	Eng. Fuel Line & Components	IN 200 Nickel	Nickel
II.M.24	Eng. Fuel lines & Components	Augmentor Spray Bar P & W	Stainless Steel Nr,Ci,Co,Au Braze Nozzles
II.M.25 (I.M.34)	Eng. Fuel lines & Components	Monel 400, Sheet	Nickel Copper

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
II.M.26	Eng. Fuel lines & Components	Incoloy 909	Ni, Co, Fe
II.M.27	Eng. Fuel lines & Components	Titanium 6-2-4-2, (4919C) Sheet	Titanium
II.M.28	Eng. Fuel lines & Components	Haynes 188	Co, Cr, Ni
II.M.29	Eng. Fuel lines & Components	Haynes 214	Ni, Cr, Fe, Al
II.M.30. 1	Eng. Fuel lines & Components	SAE-AMS-7902 AlBeMet 162 Reactive Material Sheet & Plate, Beryllium Alloy	.1) as cast alloy (310)
II.M.30. 2	Eng. Fuel lines & Components		.2) investment cast high strength alloy with machined surfaces (157)
II.M.30. 3	Eng. Fuel lines & Components		.3) AM 162 rolled Standard grind finish
II.M.31	Eng. Fuel lines & Components	UNS C17200 Be Cu Spring	Cu, Be
II.M.32	Eng. Fuel lines & Components	DB Inconel 718 Diffusion Bonded	Ni,Cr
II.M.33	Eng. Fuel lines & Components	Si C Reinforced Ti, MMC	Titanium, MMC
II.M.34	Eng. Fuel lines & Components	8 Al-1V-1 Mo	Titanium
II.M.35	Eng. Fuel lines & Components	Ion Vapor Deposit IVD onto 4130	4130 Steel, Fe, Cr, Mo
II.M.36	Eng. Fuel lines & Components	52100 SAE-AMS-6444	Steel
II.M.37	Eng. Fuel lines & Components	8620 SAE-AMS-6277	Steel
II.M.38	Eng. Fuel lines & Components	303 Stainless	Steel
II.M.39	Eng. Fuel lines & Components	TI-CP-70	Titanium

TABLE D-III. Complete list of materials – Continued.

I.D. No.	AIRCRAFT USE	MATERIAL DESIGNATION	MATERIAL TYPE
I.O.1	Float	HR Textron Inc.	Unicellular Buna-N
I.O.2	Float	HR Textron Inc., Foam Molders Inc.	Polyurethane Unicellular
I.O.3	Float	HR Textron Inc.	Polyurethane
I.O.4	Float	XAR Industries Inc.	
I.O.5 (I.G.13)	Float	Parker 30-155-5-1	Cork
I.P.1 (I.A.5)	Potting Compound	Epon 828 / DTA Unmodified Epoxy (See I.A.5)	Epoxy
I.P.2.1	Potting Compound	Chem Seal, CS3100, MIL-PRF-8516, Cure B	Polysulfide
I.P.2.2	Potting Compound		Electrical Connector Application
I.P.3	Potting Compound	SAE-AMS-3361, Fluorosilicone	Fluorosilicone
I.P.4	Potting Compound	Urethane	Urethane

APPENDIX E

TOXICITY TEST PROTOCOL AND ESOH BASELINE INFORMATION

E.1 SCOPE.

E.1.1 General.

This appendix provides a toxicity testing review and baseline of known information regarding JP-8 jet fuel. JP-8 baseline knowledge is detailed in E.3. When candidate fuels and additives are tested, certified results will be compared with this baseline knowledge.

Toxicology is the study of the adverse effects of chemical, physical or biological agents on living organisms and the ecosystem, including the prevention and amelioration of such adverse effects. The acronym for "Environmental Safety and Occupational Health" is "ESOH". When sufficient toxicity data are available, environmental and occupational exposure standards can be developed that are protective of ecosystems (the environment) and workers (occupational medicine and health). Environmental Safety and Occupational Health should be addressed during development of new fuels and weapon systems, not after they are fielded.

E.1.2 Entrance Criteria and subset testing.

Air Force SMEs evaluated all fuel properties and characteristics that were decomposed from system requirements via the systems engineering process, as described in Appendix A. Consequently from this decomposition, Appendix E defines the entrance criteria, subset testing and supporting rationale for all of the properties / characteristics related to personnel and environmental health and safety.

E.1.3 Testing rationale.

The following indexing table, Table E-I, provides an overview of the toxicity tests used for fuel evaluation, in the format of the testing performed on candidate fuels and additives. The table also includes the rationale for the proposed tests and the location of the baseline information for JP-8 contained within this appendix. The toxicity testing is also listed in Appendix M, which addresses the full TRL requirements for development and certification of a new jet fuel.

TABLE E-I. Toxicity research in support of fuel evaluation and certification.

TRL	Description	Tests used for candidate fuels and additives	Purpose/Action	Related Ref. JP-8 Baseline Test
1	Basic Fuel Properties Observed and Reported			
	Review Safety, Toxicity and Occupational Health		SDS provided by supplier per Appendix B and Appendix E, Entrance Criteria, E.4.1	
2	Fuel Specification Properties			
	Initial Toxicity Review		Literature search on the fuel candidate and components per Appendix E, Subset 1, E.4.2	
3	Fit for Purpose			
	ESOH review		Perform based on SDS and literature search. Identify additional guidance on safe handling beyond SDS, if required. per Appendix B and Appendix E, Entrance Criteria	

TABLE E-1. Toxicity activity in support of fuel evaluation and certification – Continued.

TRL	Description	Tests used for candidate fuels and additives	Purpose/Action	Related Ref. JP-8 Baseline Test
4	Extended Laboratory Fuel Property Testing			
	Toxicity Screen	Analytical comparison to JP-8	per Appendix E, Subset 1	
		In vitro genotoxicity bacterial reverse mutation test	Screen for possible mutagens and carcinogens using bacteria.	E.3.2.8
		Dermal irritation	Determine potential irritant effects.	E.3.2.1.2
		Acute oral or inhalation test	Identify effects from single exposure or 4-hr exposure.	E.3.2.1.1
	(Additional toxicity screen potentially required by Army)	Eye irritation	Determine potential irritant effects.	E.3.2.1.3
	(Additional toxicity screen potentially required by Army)	Dermal sensitization	Determine allergic potential after repeated exposure.	E.3.2.1.3
5	Component Rig Testing			
	Toxicity Screen		per Appendix E, Subset 1	
		Inhalation rangefinder (2-wk)	Screen for signs of toxicity and gross pathology. Sets dosage for 90-day test	

TABLE E-1. Toxicity activity in support of fuel evaluation and certification – Continued.

TRL	Description	Tests used for candidate fuels and additives	Purpose/Action	Related Ref. JP-8 Baseline Test
		In vivo genotoxicity – micronucleus	Screen for possible mutagens (part of 2-wk or 90-day).	E.3.2.8
		In vitro Comet assay	Can be conducted to verify micronucleus results.	E.3.2.8
		In vitro genotoxicity - human lymphocyte gene mutation test	Additional screen if any mutagen or carcinogen screen was positive.	E.3.2.8
6	Small Engine Demonstration			
	Toxicity Testing		per Appendix E, Subset 1	
		90-day inhalation toxicity with full histology and exposure chamber chemical analysis	Repeated dose study required for HHA: - fully characterize vapor versus aerosol in fuel - doses based on 2-wk rangefinder study or similar jet fuel	E.3.2.4
		Test for alpha 2 microglobulin as part of 90-day study	To support mode of action for predicted kidney toxicity in male rats when exposed to hydrocarbons.	E.3.2.4

TABLE E-1. Toxicity activity in support of fuel evaluation and certification – Continued.

TRL	Description	Tests used for candidate fuels and additives	Purpose/Action	Related Ref. JP-8 Baseline Test
	Additional Test for Fuels Containing Aromatic Compounds	Sensory Irritation (Alarie Respiratory Depression Test)	Compare respiratory tract irritation with JP-8.	E.3.2.1.3
7	Pathfinder			
	Toxicity Test Protocol and Baseline Information		per Appendix E, Subset 1	
			- Industrial Hygiene (IH) Review (Bioenvironmental Engineering (BEE)): Identifying potential exposure hazards based on the toxicity evaluation and recommend interim personal protection (PPE) or engineering controls (IH controls) to prevent exposure to personnel. - Conduct a Health Hazard Assessment (HHA) using an exposure assessment and the toxicity data. - Environmental Review: Review ecotoxicity data, fate and transport data and potential pathways of exposure.	

TABLE E-1. Toxicity activity in support of fuel evaluation and certification – Continued.

TRL	Description	Tests used for candidate fuels and additives	Purpose/Action	Related Ref. JP-8 Baseline Test
8	Validation / Certification		Per Appendix E, Subset 2	
		Toxicity Testing	Conduct additional studies that were recommended based on the results of the 90-day study and Health Hazard Assessment.	
		Exposure Assessment	The Health Hazard Assessment should be reviewed or revised using additional exposure assessment and toxicity data. This would result in verification or an update of exposure limits (standards) for safe use of the alternative fuel.	

TABLE E-1. Toxicity activity in support of fuel evaluation and certification – Continued.

TRL	Description	Tests used for candidate fuels and additives	Purpose/Action	Related Ref. JP-8 Baseline Test
		Environmental	Conduct additional studies that were recommended based on the results of Subset 1.	
TBD	Additional Tests for Candidate Fuels and Additives		per Appendix E, Subset TBD	
		Immunotoxicity	Assess effects on immune system.	E.3.2.5
		Genetic Biomarkers	Screen for genetic biomarkers of exposure.	JP-8 Baseline
TBD	Optional Effort to Support Testing			
	Model Development		Physiologically Based Pharmacokinetic (PBPK) model to predict blend effects and for future alternative fuels and additives	JP-8 Baseline

E.2 APPLICABLE DOCUMENTS.

E.2.1 General.

The documents listed below are comprehensive toxicity reviews for JP-8. A more complete list of references can be found in E.5.

E.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein.

ATSDR 1998* Toxicological Profile for JP-5 and JP-8. Agency for Toxic Substances and Disease Registry, Atlanta, GA http://www.atsdr.cdc.gov/toxprofiles/index.asp http://www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=773&tid=150

NRC 1996 Permissible Exposure Levels for Selected Military Fuel Vapors. National Research Council Committee on Toxicology, ed. Washington, D.C.: National Academy Press. http://www.nap.edu/catalog.php?record_id=9133

NRC 2003 Toxicologic Assessment of Jet-Propulsion Fuel 8. National Research Council Committee on Toxicology, ed. Washington, D.C.: National Academy Press. http://www.nap.edu/catalog.php?record_id=10578

Ritchie, G. D., Still, K. R., Rossi, J., Bekkedal, M. Y. V., Bobb, A. J., and Arfsten, D. P. 2003*. Biological and health effects of exposure to kerosene-based jet fuels and performance additives. J. Toxicol. Environ. Health B. 6:357-451

* References are available on line at http://www.dtic.mil/dtic/.

E.3 BASELINE INFORMATION. (Knowledge of JP-8 toxicity forms the baseline to which candidate fuels and additives are assessed.)

E.3.1 Regulatory issues.

In 1996, the National Research Council (NRC), Committee on Toxicology (COT), Subcommittee on Permissible Exposure Levels for Military Fuels was convened on behalf of the Navy to review their interim guidelines for fuels, including JP-8. The NRC 1996 report identified major data gaps in human occupational studies of possible JP-8 toxicity (NRC, 1996). The expert panel proposed occupational JP-8 exposure standards 8-h time weighted averages with a threshold limit value (TLV) of 350 mg/m^3 and a 15-min short-term exposure limit (STEL) of 1000 mg/m^3. The Air Force accepted these proposed values as interim permissible exposure limits. In addition, the Centers for Disease Control and Prevention, Agency for Toxic Substances and Disease Registry (CDC-ATSDR), prepared an extensive document, the Toxicology Profile for Jet Fuels (JP-5 and JP-8) (ATSDR, 1998). This report further concluded that possible jet fuel toxicity and underlying physiological mechanisms are not well defined or understood.

In 2000, an American Conference of Governmental Industrial Hygienists (ACGIH) Draft Notice of Intended Changes (NIC) was filed to recommend reduction of the current 8-h threshold limit value (TLV)–time-weighted average (TWA) standards for both kerosene and diesel fuel, from 350 mg/m^3 to 100 mg/m^3. At the same time, the NRC COT convened a second expert panel at the request of the Air Force to review the occupational JP-8 exposure standards of 350 mg/m^3. The findings of this panel were published and represent a comprehensive investigation of JP-8 toxicity. The NRC panel found JP-8 to be potentially toxic to the immune system, respiratory tract and nervous system at exposure concentrations near the interim value of 350 mg/m^3 (NRC, 2003). The ACGIH proposed a threshold limit value for kerosene and jet fuels in 2003, as a total hydrocarbon vapor, of 200 mg/m^3. Based on the ACGIH and NRC, the Air Force adopted TLV-TWA of 200 mg/m^3 as the permissible exposure limit for JP-8. In 2004, the ACGIH lowered the TLV-TWA to 100 mg/m^3. National Institutes for Occupational Safety and Health (NIOSH) currently states a recommended exposure level (REL) TWA for kerosene of 100 mg/m^3 (NIOSH, 2011).

In 2011, the National Academies Council on Acute Exposure Guidelines Levels (NAC-AEGL) published guidelines for JP-5 and JP-8 acute inhalation exposure. The Acute Exposure Guideline 1 (AEGL-1) for non-disabling exposure was determined to be 290 mg/m^3 at all durations (10 or 30 minutes, 1, 4 or 8 hours). This level was based on slight sensory irritation extrapolated to a human exposure from the mouse respiratory depression assay. The AEGL-2 (disabling exposure) was calculated at 1,100 mg/m^3 (all durations), also extrapolated from the sensory irritation assay, as well as numerous rat and mouse studies where exposures to 1000 mg/m^3 resulted in no clinical signs. An AEGL-3 (lethal exposure) was not determined as lethal exposures of these jet fuels have not been generated in any study (NAC-AEGL, 2011).

E.3.1.1 References.

ACGIH, 2003. Kerosene / Jet Fuels. In: 7th Edition Documentation of TLVs and BEIs, American Conference of Governmental Industrial Hygienists, Cincinnati, OH. http://www.acgih.org/Store/ProductDetail.cfm?id=1616

NAC/AEGL 2011. Jet Propellant Fuels 5 and 8 Acute Exposure Guideline Levels. In: Acute Exposure Guideline Levels for Selected Airborne Chemicals. Volume 10. In: Washington, D.C.: National Advisory Committee on Acute Exposure Guideline Levels, Committee on Toxicology, National Research Council, National Academies Press. Ch. 2. pp. 72-139.

NIOSH, 2011. Kerosene. In: National Institutes for Occupational Safety and Health Pocket Guide to Chemical Hazards. Page reviewed 4 Apr 2011, Page updated 18 Nov 2010.http://www.cdc.gov/niosh/npg/.

E.3.2 Summary of baseline fuel toxicity.

The USAF has been using JP-8 as its standard fuel since the mid-1980s; therefore, all data for toxicity will be compared to JP-8 as this fuel has the largest database for jet fuels currently used. JP-8 toxicity studies are still being released. Periodically, further investigation of the effects of interest for JP-8 is necessary in order to update the baseline and compare to new alternative fuels. The following is a brief summary of JP-8 effects for studies most appropriate to a new or current risk assessment.

E.3.2.1 Acute/short term toxicity.

E.3.2.1.1 Lethality.

Lethality tests indicate that JP-8 is considered slightly toxic given the concentrations tested. Male and female F344 rats were gavaged with neat jet fuel and monitored for 14 days. The oral dose in rats that resulted in lethality of 50% of the tested population (LD_{50}) was greater than 5.0 g/kg (highest dose tested) for both JP-8 and JP-8+100. Similarly, in the acute inhalation tests, male and female F344 rats were exposed (whole-body) to vapor only or vapor plus aerosol fuel for 4 hours and monitored for 14 days. The inhaled vapor concentration LC_{50} was >3.43 mg/L, while the vapor and aerosol combined LC_{50} was >4.39 mg/L, the highest concentrations tested in both fuels (Wolfe et al., 1996). Patches on the back of male and female New Zealand white rabbits were clipped and neat jet fuel was applied evenly and occluded for 24 hours; the rabbits were monitored for 14 days. The dermal LD_{50} in rabbits was >2.0 g/kg (highest dose tested) for both fuels.

E.3.2.1.2 Short term inhalation

Sweeney et al. (2013) presents two 14-day studies which assessed potential airway and immune effects of Jet A in two strains of female rats exposed to 500, 1000 or 2000 mg/m^3 Jet A for 4 hours daily. In the first study, female Sprague-Dawley (SD) rats exposed to 2000 mg/m^3 responded with elevated protein and lactate dehydrogenase in the nasal lavage fluid on the seventh day post-exposure. These signs of potential upper airway inflammation resolved by day 14 post-exposure. A decrease in heart weight was also observed at 2000 mg/m^3. Significant changes in spleen immune cell populations or in the histology of any other tissues were not observed after the first study.

In the second study, body weights of the Fischer 344 (F344) rats in the 2000 mg/m^3 group were depressed, as compared to the controls, on the 14th day of exposure. Some lung lavage fluid inflammation markers were increased at 24 hours post-exposure in this high dose group. No histological changes were observed in the lungs, nasal cavities, or other tissues at any of the exposure levels after the second study. Together, the 14-day studies demonstrate limited effects of 14 days of Jet A exposure in female SD and F344 rats, with no remarkable differences between strains (Sweeney et al., 2013).

E.3.2.1.3 Irritation/Sensitization.

JP-8 was evaluated in an acute toxicity test battery including the primary eye irritation and skin irritation protocols by Draize. JP-8 was found to be non-irritating in the rabbit primary eye irritation test. New Zealand white rabbits were given a topical anesthetic in both eyes; one eye was exposed to 0.1 mL JP-8 and the other used for control response comparison (Smith et al., 1981; Kinkead et al., 1992). Results in the corresponding rabbit skin irritation test ranged from non-irritating to slightly irritating and back to non-irritating. In each test, 0.5 mL JP-8 was applied to clipped skin on the backs of New Zealand white rabbits, occluded and evaluated at multiple time points. A more recent study (Hurley et al., 2011) evaluated similarly treated rabbits following occlusion or semi-occlusion of the exposure site. JP-8 was found to be moderately irritating when the skin was occluded, but only slightly irritating when the skin was semi-occluded.

Similarly in the Buehler guinea pig skin sensitization test, results ranged from non-sensitizing to a weak dermal sensitizer and back to non-sensitizing. In this test, Hartley albino guinea pigs were dermally exposed to 0.1 mL JP-8 on 4 separate occasions within 10 days; after a 2-week induction period, a dermal challenge of 0.1 ml JP-8 was applied to a different skin location and the response scored (Smith et al., 1981; Kinkead et al., 1992; Wolfe et al., 1996; respectively). JP-8+100 packages were all negative in the skin irritation and sensitization tests (Wolfe et al., 1996). Minor differences in how the different studies were conducted may have resulted in slightly different outcomes. However, murine local lymph node assays also indicate that JP-8, but not JP-8+100, is a weak dermal sensitizer. In this assay, 25 µL JP-8 was applied to the ear flaps of female CBA/Ca mice for 3 consecutive days; allergic response was measured by increased uptake of [^{3}H]-methyl thymidine into auricular lymph node cells compared to concurrent controls (Kanikkannan et al., 2000).

Respiratory tract sensory irritation was studied for both JP-8 and JP-8+100 in male Swiss-Webster mice. Groups of mice were exposed nose-only to JP-8 (681, 708, 1090, 1837 or 3565 mg/m^3) or JP-8+100 (777, 1519 or 2356 mg/m^3) for 30 minutes. The calculated concentration at which the respiratory rate decreased 50% (RD_{50}) was 2876 and 1629 mg/m^3 for each fuel, respectively (Whitman and Hinz, 2001).

E.3.2.2 Dermal toxicity.

Few dermal systemic toxicity tests, aside from the acute irritation tests above, have been performed with JP-8 itself. A good review of the dermal toxicity of petroleum distillates closely related to JP-8 can be found in McDougal and Rogers (2004). A review of JP-8 dermal toxicity alone was more recently published (McDougal et al., 2011). One example is the dermal study of JP-8 conducted by Baker and coauthors in 1999. Dermal histological changes were investigated in male F344 rats. A daily un-occluded dermal exposure to 0.156 mL JP-8, JP-8+100 or JP-4 for 4 weeks was followed by a 3-week recovery period. Proliferative, degenerative and inflammatory changes were significantly greater in the fuel exposed skin versus non-exposed control skin sites on the same animal immediately post-exposure. JP-8, JP-8+100 and JP-4 fuel treatment results did not differ from each other. Following the recovery period, the dermal histology of all the exposed skin sites had returned to control scores.

Much work has been done on the absorption and local effects of JP-8, including several *in vitro* studies, as outlined in the reference list. It is clear from the body of knowledge combined with reports from military personnel working with JP-8 that the fuel does cause considerable skin irritation over continued use and exposure.

E.3.2.3 Hearing loss.

JP-8 exposure increases hearing damage from noise in rats. Male Long-Evans rats were exposed, nose-only, to 1000 mg/m^3 JP-8 for 4-hours. A subset was then exposed to noise (97 or 102 dB) for 1 or 4 hours. Exposures were performed either singularly or repeated for 5 consecutive days. JP-8 alone did not affect hearing but JP-8 followed by noise resulted in small but consistent disruption of outer hair cell function and hair cell loss greater than for noise alone. The effect was only partially reversible with time (4 weeks) (Fechter et al., 2007). A later study indicated that the no observed adverse effect level (NOAEL) for noise induced hearing loss in rats under the same exposure scenario was 500 mg/m^3 (Fechter et al., 2010). Further studies at

200, 750 or 1500 mg/m^3 also indicated that the similar exposure level, 750 mg/m^3, resulted in noticeable hearing impairment (not statistically significant) when the noise exposure was 85 dB, a non-damaging level without concurrent jet fuel exposure. Significant concentration-related impairment of auditory function measured by distortion product otoacoustic emissions (DPOAE) and compound action potential (CAP) threshold was seen in rats exposed to combined JP-8 levels of 1500 mg/m^3 plus noise. The authors also tested high JP-8 exposure levels (1500 mg/m^3) for longer durations (6 hours/day, 5 days/week for 4 weeks) combined with intermittent loud noise (102 dB for 15 min each hour). Significant high frequency hearing loss was observed among the rats exposed to both high levels of jet fuel and loud intermittent noise (Fechter et al., 2012).

Animal study results are corroborated with an occupational study among jet fuel and noise exposed military workers. JP-8 estimated exposures below 350 mg/m^3 (the permissible exposure limit (PEL) at the time the study was performed) for 3 or 12 years, combined with noisy working environments, were associated with increased odds of hearing loss. Odds of hearing loss also increased with time on the job (Kaufman et al., 2005).

E.3.2.4 Subchronic studies.

Subchronic 90-day studies were conducted through inhalation and oral pathways. Male and female F344 rats and C57BL/6 mice were exposed (whole-body) to JP-8 vapor (0, 500 or 1000 mg/m^3) continuously over 90 days. Decreased bodyweight occurred in male rats, along with renal hydrocarbon nephropathy, a male rat specific response to hydrocarbons that is not related to human health. Male mice were significantly decreased in survivability over the 21-month recovery period due to complications from fighting. No additional treatment related adverse effects were found (Mattie, et al.; 1991). In a subsequent study, male Sprague-Dawley rats were dosed with 0, 750, 1500 or 3000 mg/kg neat JP-8 by gavage daily for 90 days. Decreased bodyweight and hydrocarbon nephropathy occurred in all JP-8 dosed rat groups. Additional effects included gastritis, perianal dermatitis and increased liver enzymes (AST and ALT). JP-8 was concluded to have minimal toxic effects outside the male rat specific nephropathy (Mattie et al., 1995).

E.3.2.5 Immune.

Immunological parameters, host resistance and thyroid hormones were evaluated by Keil et al. (2003), in F1 mice exposed *in utero* to JP-8. C57BL/6 pregnant dams (mated with C3H/HeJ males) were gavaged daily on gestation days 6–15 with JP-8 in a vehicle of olive oil at 0, 1000 or 2000 mg/kg. At weaning (3 weeks of age), no significant differences were observed in body, liver, spleen or thymus weight, splenic and thymic cellularity, splenic CD4/CD8 lymphocyte subpopulations, or T-cell proliferation. Yet, lymphocytic proliferative responses to B-cell mitogens were suppressed in the 2000 mg/kg treatment group. In addition, thymic CD4-/CD8+ cells were significantly increased. By adulthood (8 weeks of age), lymphocyte proliferative responses and the alteration in thymic CD4-/CD8+ cells had returned to normal. However, splenic weight and thymic cellularity were altered, and the IgM plaque forming cell response was suppressed by 46% and 81% in the 1000 and 2000 mg/kg treatment groups, respectively. Furthermore, a 38% decrease was detected in the total T_4 serum hormone level at 2000 mg/kg. In F1 adults, no significant alterations were observed in natural killer cell activity, T-cell lymphocyte proliferation, bone marrow cellularity and proliferative responses, complete blood counts, peritoneal and splenic cellularity, liver, kidney, or thymus weight, macrophage phagocytosis or nitric oxide production, splenic CD4/CD8 lymphocyte subpopulations, or total T_3 serum hormone levels. Host resistance models in treated F1 adults demonstrated that immunological responses were normal after challenge with *Listeria monocytogenes*, but heightened susceptibility to B16F10 tumor challenge was seen at both treatment levels. This study demonstrates that prenatal exposure to JP-8 can target the developing murine fetus and result in impaired immune function and altered T_4 levels in adulthood.

A 2004 study by Keil et al. examined the effects of JP-8 on humoral and cell-mediated and hematological parameters. A suite of immunotoxicological endpoints was evaluated in adult female B6C3F1 mice gavaged with JP-8 (in an olive oil vehicle) ranging from 250–2500 mg/kg/day for 14 days. One day following the last exposure, significant increases in liver mass were detected beginning at exposure levels of 1000 mg/kg/day, while thymic mass was decreased at exposure levels of 1500 mg/kg/day and above. Decreases in thymic cellularity, however, were only observed at exposure levels of 2000 mg/kg/day and above. Mean corpuscular volume was increased (1500–2500 mg/kg/day), while the hematocrit, hemoglobin concentration, and red blood cell count were decreased only at the 2500 mg/kg/day exposure level. Natural killer cell (NK) activity and T- and B-cell proliferation were not altered. Decreases in the plaque forming cell (PFC) response were dose responsive at levels of 500 mg/kg/day and greater, while unexpectedly, serum levels of anti-SRBC immunoglobulin M (IgM) were not altered. Alterations were detected in thymic and splenic CD4/8 subpopulations, and proliferative responses of bone marrow progenitor cells were enhanced in mice exposed to 2000 mg/kg/day of JP-8. This study showed that humoral immune function is impaired with lower exposure levels of JP-8 than are required to affect primary and secondary immune organ weights and cellularities, CD4/8 subpopulations and hematological endpoints (Keil et al., 2004).

Jet fuel (JP-8) applied to the skin of mice will cause suppression of the immune system. JP-8 activates oxidative stress which in turn leads to the production of the nuclear factor, kappa B (NF-kb). Activation of these pathways contributes to COX-2 up-regulation and induction of immune suppression (Ramos et al., 2009). Dermal exposure to jet fuel affects the cell-mediated immune reactions, but not antigen-specific antibody formation *in vivo*. A review of how dermal exposure to jet fuels affects the immune system can be found in Ramos and Ullrich (2011).

In a recent immunological study, female B6C3F1 mice and Crl:CD rats were exposed by nose-only inhalation to a vapor and aerosol mixture of 0, 500, 1000 or 2000 mg/m^3 Jet A fuel for 6 hours/day over 28 days. Body, spleen and thymus weights were measured. Immune assays including T-dependent antibody forming plaque assay, delayed-type hypersensitivity response, spleen cell number/phenotype counts and natural killer cell activity were performed. No exposure related effects were seen in any assay in either rats or mice; these assays covered humoral, cell-mediated and innate immune functions (White et al., 2013).

E.3.2.6 Neurobehavioral.

Multiple neurobehavioral studies have been undertaken to assess JP-8 effects. Neurobehavioral effects were assessed in adult rats following JP-8 vapor inhalation. Changes in behavioral response were observed in two studies where rats were exposed to 0, 500 or 1000 mg/m^3 for 6 hours/day 5 days a week for 6 weeks. JP-8 inhalation affected performance on very specific tasks and did not cause a generalized deficit. When animals were subjected to different operant tasks with varying levels of complexity, the low and high exposure groups scored the same as control animals on all tests except for the most complex tasks. In these two operant tests, group differences emerged; low dose animals demonstrated better performance than high dose animals while neither group performed differently from controls (Ritchie et al.,2001). In a second study using the same exposure methods, animals were tested in a large battery of neurobehavior tasks. No exposure group differences were found in acoustic startle responses, forelimb grip strength, nociception, social interaction, the forced swim test, spontaneous locomotor activity, passive avoidance or Morris watermaze performance. However, differences were found in a test for behavioral sensitization. The appetitive stimulus approach sensitization assay (ARAS) measures the time an animal spends proximal to an appetitive stimulus versus a neutral stimulus. Animals exposed to JP-8 spent more time than control animals investigating the appetitive stimulus, suggesting behavioral sensitization and altered neural pathways related to the dopaminergic system (Rossi et al., 2001). Overall, the data suggest very specific, versus generalized, neurobehavioral effects of JP-8 vapor exposure in adult rats.

As a continuation of the reproductive study by Mattie et al., 2000, the pups from the female study were assessed for potential developmental neurobehavioral deficiencies after exposure *in utero* and during lactation to JP-8 (Mattie et al., 2001). Litters were standardized to 4 male and 4 female pups at PND 4; all 8 pups in a litter were tested for surface righting and negative geotaxis. JP-8 did not affect age of onset for surface righting reflex in pups tested on PND 4. Negative geotaxis abilities, tested on PNDs 5 through 8, developed at the same age for pups in all JP-8 groups; however, all females met the criterion sooner than males. Development of motor coordination related to swimming was tested in one male and one female pup from each litter every other day from PNDs 6 through 20. A dose-related difference in composite scores for swimming abilities was observed on PNDs 8 and 14, indicating a delay in development of coordinated motor movements related to the swimming task. On PND 8, pup scores from all doses were ≥20% lower than control scores. On PND 14, composite swimming scores were 8% lower in the 750 and 1500 mg/kg-day dose groups versus controls. Pups were tested in an M swimming maze on PNDs 70 and 77. JP-8 did not affect the number of trials to criterion on either test date; on PND 77, male pups met the criterion of 5 errorless trials in fewer attempts than females. The effects of JP-8 exposure found in results from developmental neurobehavioral testing indicated developmental delays in pups caused by exposure of dams to JP-8 *in utero* and during lactation may be associated with key developmental milestones in the developing cerebellum of the pups. Although recovery occurred, a delay in motor development has potential adverse impacts. The lowest dose of 325 mg/kg-day would be the lowest observed adverse effect level (LOAEL) for developmental neurobehavioral effects (Mattie et al., 2001).

A study by Smith et al. (1997) used the postural stability technique to investigate the neurological effects of cumulative low-level exposure to JP-8 jet fuel vapors in aircraft maintenance personnel. All subjects performed 2 sets of four 30-second postural sway tests. The results of mean cumulative exposure levels (in parts per million ± standard error of the mean) were as follows: naphthas, 1308 ± 292; benzene, 21.2 ± 5.7; toluene, 23.8 ± 6.1; and m-, o-, p-xylenes, 22.7 ± 5.4. Covariate adjusted regression analysis of the exposed group data showed a statistically significant association ($p<0.05$) between the solvents (benzene, toluene and xylenes) and increased postural sway response. For all solvent exposures, the “eyes closed, on foam” test provided the strongest association between sway length and JP-8 benzene (r^2 range, 0.45 to 0.52), implying subtle influence on vestibular/proprioception functionalities.

The studies summarized above are a portion of the work conducted to assess neurobehavioral effects of JP-8. Good reviews of the subject can be found in Ritchie et al. (2001 and 2011).

E.3.2.7 Developmental/reproductive.

A developmental toxicity study indicated that JP-8 is not a teratogen in the rat (Cooper and Mattie, 1996). Female rats were dosed with 0, 500, 1000, 1500 or 2000 mg/kg neat JP-8 daily by gavage on days 6 through 15 of gestation. Maternal body weights significantly decreased in the 1000, 1500 and 2000 mg/kg-day dose groups while fetal weights decreased in the 1500 and 2000 mg/kg-day groups. Fetal malformations and variations did not differ significantly between control and treatment groups (Cooper and Mattie, 1996).

Two reproductive studies were performed as part of an aforementioned multi-step investigation (Mattie et al., 1995). JP-8 was shown not to be a reproductive toxicant in rats. In the first study, male rats were given 0, 750, 1500 or 3000 mg/kg neat JP-8 daily by gavage for 70 days prior to mating with naïve females to assess fertility and sperm parameters. After 70 days of dosing, body weights in the 3000 mg/kg group were over 30% lower than control weights. There were no significant changes for pregnancy rate, gestation length or sperm parameters as compared to control values (Mattie et al., 2000).

In the second reproductive study, general toxicity, fertility and reproductive endpoints were assessed in female rats dosed with neat JP-8 (0, 325, 750 or 1500 mg/kg) daily by gavage for a total of 21 weeks (90-days plus mating with naïve males, gestation and lactation). Results of general toxicity revealed a significant dose-dependent decrease in body weights of the female rats. Significant organ weight ratio increases were seen for the liver:body, liver:brain and kidney:brain weights. Corresponding histopathologic changes and increases in liver enzymes (ALT, AST) were not observed although there was an increase in liver weight. Significant pathological changes were limited to squamous hyperplasia of the stomach and perianal dermatitis. There were no statistically significant changes from control values for gestation length, pregnancy rate and numbers of pups per litter. There was a trend for decreased pup weight with increasing dose from postnatal days 4 through 21 with the 1500 mg/kg pups statistically and biologically significantly lower on these days. Recovery occurred by 90 days. Based on the results of both reproductive studies, the “no observed adverse effect level” (NOAEL) for JP-8 reproductive and development effects is 750 mg/kg with 1500 mg/kg as a LOAEL based on decreased pup weights (Mattie et al., 2000).

E.3.2.8 Mutagenicity/oncogenicity.

Brusick and Matheson (1978) tested JP-8 for mutagencity in a number of test systems. JP-8 was not mutagenic for *Salmonella* in the Ames Bacterial Reverse Mutation Test. The chemical was toxic to most of the bacteria strains at concentrations above 1 μL per plate. In the Mouse Lymphoma Assay, JP-8 did not induce gene mutation in mouse cells. The material was moderately toxic in this assay at 0.16 μL/mL. JP-8 induced significant levels of ^{3}H-thymidine incorporation in the Unscheduled DNA Synthesis Assay. The increase in activity of the WI-38 cells was moderate and the effect plateaued and was not dose related. The dose of 5.0 μL/mL was beginning to show clear evidence of cytotoxicity. These data suggest that the material could interact with DNA producing nonspecific lesions. The Dominant Lethal Assays showed that JP-8 was only moderately toxic for mice and rats. The dose levels used for mice were 0.13, 0.4 and 1.3 mL/kg per day for 5 days. The dose levels employed for rats were 0.1, 0.3 and 1.0 mL/kg per day for 5 days. Mouse and rat test results for JP-8 were negative. None of the parameters measured in either study showed compound-induced effects. The positive control values for this study were clearly elevated but were not as high as usual. No evidence for mutagenicity was evident in the test battery and the indications for mutagenic and carcinogenic potential for JP-8 are minimal at best. There is no suggestion of significant genetic risk associated with this material according to Brusick and Matheson (1978).

Jet A was tested in a number of test systems by Hazleton Laboratories America, Inc. in 1979. Jet A was not mutagenic for Salmonella in the Ames Bacterial Reverse Mutation Test. However, Jet A was shown to induce mutations in the presence of metabolic activation when tested in the Mouse Lymphoma Assay. Jet A was also tested in an *in vivo* Bone Marrow Cytogenicity Study that is now called the Mammalian Bone Marrow Chromosome Aberration Test. Jet A has the ability to produce structural alterations (chromosomal aberrations) in the bone marrow cells of rats exposed by inhalation to 100 and 400 ppm (methane equivalent). Rats exposed to 100 ppm received 19 exposures (6 hours per day) and rats exposed to 400 ppm received 5 exposures (6 hours per day).

Mice were treated dermally with either a single or multiple applications of JP-8 and Jet A fuels in the Mammalian Micronucleus Test. Peripheral blood and bone marrow smears were prepared to examine the incidence of micronuclei (MN) in polychromatic erythrocytes (PCEs). In all experiments, using several different exposure regimens, no statistically significant increase in the incidence of MN was observed in the bone marrow and/or peripheral blood of mice treated with JP-8 or Jet-A when compared with those of untreated control animals (Vijayalaxmi et al., 2006; Vijayalaxmi, 2011).

Concern for the potential of carcinogenicity among humans prompted a retrospective study of U.S. Air Force fuel handling personnel. No association was found between invasive cancer incidence and working in moderate or high jet fuel exposure jobs, based on data from a U.S. military cancer registry (D'Mello and Yamane, 2007). DNA damage biomarkers were correlated with measured benzene and naphthalene concentrations among fuel-exposed U.S. Air Force personnel; however, benzene concentrations were higher prior to work shifts among these personnel, indicating off-duty exposures. DNA damage biomarkers also increased with the measured urinary concentration of (2-methoxyethoxy) acetic acid, a metabolite of the anti-icing agent diethylene glycol monomethyl ether, which is a JP-8 additive (Krieg et al., 2012).

E.4 TOXICITY TEST REVIEW AND PROTOCOL.

E.4.1 Entrance Criteria.

A Safety Data Sheet (SDS) will be provided with the alternative fuel to be evaluated. A SDS provides basic safety information for the handling and safe use of a chemical or material. If exposure standards or regulations are known, then they will be available in the SDS. A thorough SDS actually provides toxicity data summaries and references but often this information is not provided or is not available. New candidate fuels may not have exposure standards or regulations yet and if there are any toxicity data, they will most likely be limited.

E.4.2 Subset 1: toxicology and environmental evaluation and tests.

E.4.2.1 Toxicity evaluation.

Initial evaluation of a new fuel involves identifying components of the fuel, performing literature searches on the fuel and its components for any known toxicity data, and identifying research that is necessary to complete the development of exposure standards. This handbook was written to formalize the process for ESOH review for the DoD. In the Air Force, ESOH reviews have been performed by the Air Force Institute for Occupational Health (now USAF School of Aerospace Medicine Occupational and Environmental Health Department (USAFAM/OE), the Air Force Research Laboratory (AFRL) or an outside contractor. See E.4.5, which lists ESOH contacts for assistance in developing the toxicity testing program.

Based on the initial evaluation identified in the above paragraph, acute toxicity studies, genotoxicity tests and a range-finder study for a long-term toxicity test should be conducted with comparisons to JP-8. For the new fuel, conduct a 90-day toxicity test with doses based on the 2-week rangefinder study. This 90-day study is the minimum study required for development of exposure standards. Additional studies may be recommended based on the results of the 90-day study and the health hazard assessment.

A Health Hazard Assessment (HHA) should be conducted using an exposure assessment and the above toxicity data. The HHA would result in a recommendation for an occupational exposure limit (standard) for the safe use of the alternative fuel.

E.4.2.2 Industrial Hygiene (IH) review (Bioenvironmental Engineering (BEE)). This involves identifying potential exposure hazards based on the toxicity evaluation and recommending interim personal protection (PPE) or engineering controls (IH controls) to prevent exposure to personnel. In the Air Force, this has been performed by the Air Force Institute for Occupational Health (now USAF School of Aerospace Medicine Occupational and Environmental Health Department (USAFSAM/OE)) or by the base Bioenvironmental Engineering Office. IH sampling can be performed by USAFSAM/OE and/or base Bioenvionmental Engineering (BEE) office with results reviewed by USAFSAM/OE and recommendations made for safe handling of the fuel.

E.4.2.3 Environmental review.

This involves reviewing ecotoxicity data, fate and transport data and potential pathways of exposure. In the Air Force, this has been performed by the Air Force Institute for Occupational Health. Below are listed comprehensive resources for this type of assessment.

Johnson, Mark S.; Ruppert, William H.; Taylor, Patrick J.; Packer, Bonnie; Watts, Kimberly; Byrd, Edward F. C.; Hurley, Margaret M.; McQuaid, Michael J.; Rice, Betsy M. and McAtee, Matthew J. Assessing the Potential Environmental Consequences of a New Energetic Material: A Phased Approach. U.S. Army Center for Health Promotion and Preventative Medicine (USACHPPM), Technical Report 87-XE-03N3-01 (December 2007).

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Wentsel, R. S., La Point, T. W., Simini, M., Checkai, R. T., Ludwig, D., and Brewer, L. W. 1996. Tri-Service procedural guidelines for ecological risk assessments. Volume 1. U.S. Army Edgewood Research, Development and Engineering Center, Aberdeen Proving Ground, MD.

See Total Petroleum Hydrocarbon Working Group (TPHCWG) references in E.5.1.13 for issues related to establishing soil cleanup levels protective of human health at contaminated sites.

E.4.2.4 Decision points.

The section E.4.2 evaluation and review results will be compared to the JP-8 results, and if the candidate fuel provides equal or less toxic results as JP-8, the candidate fuel poses minimal risk to personnel and the environment. If the candidate fuel is much more toxic than JP-8, then this should be documented and the candidate fuel could be rejected and the process terminated. If the candidate fuel is slightly different than JP-8, then the candidate fuel would be recommended for additional testing. At this time, the Air Force can proceed with testing but will need to use increased IH controls and PPE until a revised Health Hazard Assessment (HHA) is complete.

E.4.3 Subset 2: toxicology and environmental evaluation and tests.

E.4.3.1 Toxicity testing. Conduct additional studies that were recommended based on the results of the 90-day study and health hazard assessment.

E.4.3.2 Exposure assessment. The Health Hazard Assessment should be reviewed or revised using additional exposure assessment and toxicity data. This would result in verification or an update of exposure limits (standards) for safe use of the alternative fuel.

E.4.3.3 Environmental. Conduct additional studies that were recommended based on the results of Subset 1.

E.4.4 Subset 3: toxicology and environmental evaluation and tests.

E.4.4.1 Toxicity testing. Review toxicity data and update health hazard assessment if necessary.

E.4.4.2 Exposure assessment. Review exposure data and update health hazard assessment if necessary.

E.4.4.3 Environmental effects. Review environmental data and update environmental assessment if necessary.

E.4.5 ESOH Points of contact.

E.4.5.1 Toxicity testing.

Air Force Research Laboratory, 711 Human Performance Wing, Human Effectiveness Directorate, Bioeffects Division, Molecular Bioefffects Branch (711 HPW/RHDJ, Wright-Patterson AFB OH)

Naval Medical Research Unit – Dayton (NAMRU-D, Environmental Health Effects Research Directorate, Wright-Patterson AFB OH)

Army Institute of Public Health, Health Effects Research Program, U.S. Army Public Health Command

E.4.5.2 Environmental.

Tri-Service Environmental Risk Assessment Working Group (http://usaphcapps.amedd.army.mil/erawg/charter.htm)

E.4.5.3 Exposure assessment.

IH sampling

USAF School of Aerospace Medicine ESOH Service Center; esoh.service.center@wpafb.af.mil; Toll Free: 1-888-232-ESOH (3764); Comm: (937) 938-3764; DSN: 798-3764

Navy and Marine Corps Public Health Center (NMCPHC)

US Army Public Health Command

E.4.5.4 Health hazard assessment.

Occupational exposure limits

USAF School of Aerospace Medicine ESOH Service Center and 711 HPW/RHDJ

Navy and Marine Corps Public Health Center (NMCPHC)

US Army Public Health Command

E.5 REFERENCES.

E.5.1 JP-8 toxicity.

The following is a listing of JP-8 specific and jet fuel relevant references maintained by 711 HPW/RHPB, Wright-Patterson AFB OH.

E.5.1.1 Acute/short-term.

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E.5.1.2 Hearing loss.

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APPENDIX F

FIRE PROTECTION AND SURVIVABILITY/VULNERABILITY

F.1 SCOPE.

F.1.1 General. The following guidelines provide the process for evaluation and final recommendation for approval of a new fuel from a fire safety and aircraft vulnerability perspective. Fire detection, extinguishing, suppression, and protection technologies for JP-8 are considered as the baseline when evaluating a candidate alternative fuel. Regardless how close the candidate fuels' characteristics and behavior are to JP-8, the candidate fuel has to be evaluated against established standards to show that no changes are necessary in equipment, material, or procedures for fire detection, extinguishing, suppression, and protection. Five basic areas have to be evaluated: (1) fire detection on-aircraft, (2) fire extinguishing / suppression on-aircraft, (3) ground fire detection (including fuel storage and aircraft hangars) where fuel is present, (4) ground fire extinguishing/suppression, and (5) vapor detection for maintainers and fuel handlers' safety. When testing candidate alternate fuels for detection, extinguishing, suppression, and protection, it is critical to test neat candidate fuel as well as blended forms for ground operations. Even though candidate fuel may not be used operationally in a neat form, handling and testing phases with un-blended fuel poses unique risk requiring the same standards be applied to ensure neat fuel does not pose hazards beyond the capabilities in place for detection, extinguishing, suppression, and protection.

F.1.2 Entrance Criteria and Subset Testing. In the initial creation of this handbook, United States Air Force SMEs evaluated all fuel properties and characteristics based on the requirements decomposition process that correlated requirements to safety, performance, durability and supportability, as described in Appendix A. Consequently, Appendix F defines which subset each fire safety and aircraft vulnerability compatibility characteristic belongs to and the significance for its selection. Appendix F also includes component tests that should be conducted to further evaluate the candidate fuel/fuel additive for those fire safety and aircraft vulnerability compatibility characteristics requiring further investigation, as deemed appropriate by the FCO.

F.2 APPLICABLE DOCUMENTS.

F.2.1 General.

The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this Appendix.

F.2.2 Government documents.

F.2.2.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

FEDERAL STANDARDS

FED-STD-791	Lubricants, Liquid Fuels, and Related Products, Testing Method of

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-5578	Tanks, Fuel, Aircraft, Self-Sealing
MIL-F-24385	Fire Extinguishing Agent, Aqueous Film-Forming Foam (AFFF) Liquid Concentrate, for Fresh and Sea Water
MIL-DTL-27422	Tank, Fuel, Crash-Resistant, Ballistic-Tolerant, Aircraft
MIL-PRF-87260	Foam Material, Explosion Suppression, Inherently Electrostatically Conductive, for Aircraft Fuel Tanks

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-882	System Safety
MIL-STD-2105	Hazard Assessment Tests for Non-Nuclear Munitions

(Copies of these documents are available on line at http://quicksearch.dla.mil/.)

F.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein.

ASTM INTERNATIONAL

ASTM D56	Standard Test Method for Flash Point by Tag Closed Cup Tester
ASTM D93	Standard Test Methods for Flash Point by Pensky-Martin Closed Cup Tester
ASTM D240	Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter
ASTM D1655	Standard Specification for Aviation Turbine Fuels
ASTM D3828	Standard Test Method for Flash Point by Small Scale Closed Cup Tester
ASTM D4809	Standard Test Method for Heat of. Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)
ASTM E659	Standard Test Method for Autoignition Temperature of Liquid Chemicals

(Copies of the above documents may be ordered on line at www.astm.org; or approved users may access the document on line at www.ihs.com.)

"The Fundamentals of Aircraft Combat Survivability Analysis and Design", Second Edition, Ball, Robert E., Ph.D., AIAA Education Series, Blacksburg, VA, 2003

"Survivability, Safety, and Reliability Analyses Integration Process," Dotseth, W. D., World Aviation Congress, Paper 97WAC-16, Society of Automotive Engineers and AIAA, Oct 1997.

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"Hot Surface Ignition and Aircraft Safety Criteria", Clodfelter, Robert G., SAE 901950, October 1990

"Reticulated Polyurethane Safety Foam Explosion Suppressant Material for Fuel Systems and Dry Bays, "Society of Automotive Engineers, SAE AIR 4170, Nov 1998

"Vaporization of JP-8 Jet Fuel in a Standard Aircraft Fuel Tank Under Varying Ambient Conditions," Ochs, R.I., and Polymeropoulos, C. E., Society of Automotive Engineers, SAE 2006-01-2445, August 2006

"Limiting Oxygen Concentration of Aviation Fuels," Society of Automotive Engineers, Summer Steven M., SAE 2006-01-2446. August 2006

(Copies of the above documents may be ordered on line http://www.sae.org/.)

"Aviation Fuels with Improved Fire Safety," A Proceeding, Committee on Aviation Fuels with Improved Fire Safety, National Academy Press, Washington, DC, 1997

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Automatic Fire Detectors; part of the National Fire Protection Association Handbook; Cote, Arthur (editor); Seventeenth Edition; July 1991

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(Copies of the above may be ordered on line at http://www.amazon.com/.)

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"Comparative Evaluation of Semi-synthetic Jet Fuels", Moses, Clifford A., Report for Coordinating Research Council, Inc. and Universal Technology Corporation, CRC Project No. AV-2-04a, September 2008.

(Copies of the above document can be ordered on line at http://www.crcao.org/ .)

"A Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks," US. Dept. of Transportation, FAA, DOT/FAA/AR-98/26, June 1998

"Enhancing Aircraft Survivability: A Vulnerability Perspective," National Defense Industrial Association, Arlington, VA 1997

"Optical Fire Detection (OFD) for Military Aircraft Hangars: Final Report on OFD performance to Fuel Spill Fires and Optical Stresses.", Gottuk, D.T. NRL/MR/6180--00-8457. 1999.

"Assessment of JP-8 as a Replacement Fuel for the Air Force Standard Jet Fuel JP-4 Part 1, Assessment of JP-8/JP-4 Fuel in a Noncombat Environment,"AFAPL-TR-74-71, Part 1, June 1975

"Evaluation of Suppression of Synthetic Paraffinic Kerosene (SPK) Fuel Fires with Aqueous Film Forming Foam (AFFF)", Burnette, Parren, F., Applied Research Associates, Tyndall AFB, FL 32403, Interim Technical Report, AFRL-RX-TY-TR-2008-4510, Dec 2008

(Copies of the above documents are available on line at http://www.dtic.mil/dtic/.)

F.3 ENTRANCE CRITERIA.

Prior to beginning this process the candidate fuel will meet the Entrance Criteria defined in Appendix B.4.1.

F.4 SUBSET 1 CRITERIA.

Subset 1 is composed of fuel properties and characteristics that affect fire protection, fire detection and protection technology for ground fires, on-aircraft fire detection and other safety-related items including vapor detection and the flame speed relating to the candidate fuel. The baseline fire detection sensor characteristics and flame speed criteria for these characteristics are provided in Table F-I.

TABLE F-I. Baseline fire detection sensors and flame speed criteria.

Fire Safety Property and Significance	Nominal Baseline Fuel Value
Detection limit of Vapor Detectors – Ability of current vapor detectors to protect personnel entering spaces that contained fuel	10% Lower Explosive Limit
Detection Threshold of flame when seen by optical flame detectors (UV and/or IR)– Ability of currently used flame detectors to detect a fire	(Equivalent threshold detection as compared to JP-8) Example: Flame from 5 inch diameter pan, 6 feet away, detected in less than 5 seconds. UV detection is between 185- 245 nanometers and/or IR is 960 – 5000 nanometers.
Visibility of flame – How easily is the flame seen under different conditions, basic safety consideration	Easily visible under variety of conditions. Visible range is 400 - 720 nanometers.
Flame speed – Rate at which flame front moves across a pool of fuel, important for ground safety	Varies by fuel temperature. Typically <5 in/s below flash point and up to 70 in/s above flash point

F.4.1 Overall Subset 1 test objectives. Determine if the new candidate fuel is compatible with current methodology and equipment used for (1) fire detection on-aircraft, (2) fire detection on-ground (including fuel storage and aircraft hangars) where fuel is present, (3) ground fire extinguishing/suppression, and (4) vapor detection for maintainers and fuel handlers' safety involving the candidate fuel.

F.4.2 Flammability limits. The basic flammability limits of the fuel and standard test methods are described in Appendix C. The flammable (explosive) temperature range is an extremely important characteristic from a firefighting perspective due to the fact that the gas or vapor concentration will burn or explode if an ignition source is introduced. The limiting concentrations are commonly called the "Lower Explosive or Flammable Limit" (LEL/LFL) and the "Upper Explosive or Flammable Limit" (UEL/UFL). Below the lower explosive or flammable limit the mixture of fuel and oxygen is too lean to ignite and above the upper explosive or flammable limit the fuel/oxygen mixture is too rich to ignite. The lower and upper explosion concentration limits for aviation fuels currently in use by the U.S. are provided on Figures C-29 and C-30. Data have to be generated for any new / alternative fuel used in the aircraft.

F.4.2.1 Test plan. Standard flammability test procedures for aviation fuels are described in ASTM E681. For the aviation industry, flammability limit results are typically presented over a temperature range for a given pressure environment that is related to realistic aircraft operating conditions. Additional testing may be performed for an alternative fuel using established test procedures. The flammability limits of a fuel can be determined by testing the upper and lower fuel temperature limits to determine the fuel rich and fuel lean conditions, respectively, at different pressure environmental conditions.

F.4.2.2 Expected outcome. The basic flammability limits of the fuel will be established for a range of conditions to assure that the fuel is comparable to the baseline (JP-8) see C.20.

F.4.3 Fuel vapor detector compatibility. Vapor detector compatibility should be determined by testing equipment currently in use against established standards.

F.4.3.1 Test objective. Determine if the current vapor detectors will accurately sense if a flammable fuel vapor exists.

F.4.3.2 Test plan. Tests will be conducted in a controlled environment at the upper and lower fuel temperature limits at fuel rich and fuel lean conditions, respectively, at different pressures and record the detectors response.

F.4.3.3 Expected outcome. Data for interpreting vapor detector readings will be generated in order to give guidance to ground safety and other support personnel who use these detectors to ensure a safe work environment.

F.4.4 Flame visibility. Flame visibility by ultraviolet/visible/infrared or multispectral infrared optical flame detectors should be determined based on standard practices and guidance provided by; American National Standard for Radiant Energy-Sensing Fire Detectors for Automatic Fire Alarm Signaling ANSI/FM Approvals 3260; June 2004, Automatic Fire Detectors; National Fire Protection Association Handbook; Cote, Arthur (editor); Seventeenth Edition; July 1991, and per the test plan described below.

F.4.4.1 Test objective. The purpose of this test series is to determine if existing technologies used for detecting JP-8 flames will work for candidate fuels. The existing detectors have to alarm with the candidate fuel blends at the same thresholds (fire size, distance, and time) as they do with the baseline JP-8. Secondly, the test has to confirm that the flames are visible to the human eye. Since there are numerous flame detector manufacturers, each with proprietary algorithms designed to avoid false alarms by using flicker rates; data on flicker rate will also be collected and made available. These flicker data are considered essential since only detectors representative of the different methods will be tested rather than every detector in the military inventory.

F.4.4.2 Test plan. There are several ways of detecting visible flame. One method is to examine the air for smoke using ionization or a photo-detector. Smoke detectors have advantages in looking for fires that are in the smoldering stage and/or in large spaces by placing the detectors within the heating and air conditioning ductwork. Another detection method is to look for heat buildup, which is a slower but very robust and false-alarm resistant method. There can also be an advantage if fire is not the only heat source of concern. Overheat detectors in aircraft engine bays serve to detect fires as well as potentially dangerous bleed air duct ruptures. However, if speed is critical, generally the quickest method to detect Class B fires (liquid fuels) is to ‘see’ the flame. Flames are visible across a wide spectrum. Most fuels, excepting hydrogen and some alcohols, generate flames that can be seen within the spectrum visible to the human eye, (~400 – ~700 nm). Flames also emit in the ultra-violet (UV) and infrared (IR) spectrum. Of course many objects emit in the visible, UV and IR spectra; e.g., sunlight. Therefore there need to be methods to distinguish actual flames from background sources. Fortunately, as hydrocarbons burn their flames generate many byproducts of combustion such as water vapor and carbon dioxide (CO_2). By looking for emissions at certain wavelengths, flame detectors can use algorithms to determine if a flame is present. These algorithms may look for a signal to reach a certain threshold or they may look for flicker at frequencies in the 5 – 30Hz range to distinguish a flame from a static light source; e.g., sunlight. Since the detectors may also use multiple frequencies and compare ratios among those frequencies, the testing will depend on the type of detector is used in the device. The commercially available flame detectors that provide the greatest detection distances and superior false alarm immunity are multispectral IR devices (typically three IR sensors) as reported in NRL/MR/6180--00-8457, "Optical Fire Detection (OFD) for Military Aircraft Hangars: Final Report on OFD performance to Fuel Spill Fires and Optical Stresses". There are several manufacturers that have detectors of this type available and some of these detectors have previously been listed by Factory Mutual for jet fuel fires. No matter what the technique, the goal is to detect a fire quickly while avoiding nuisance false alarms.

F.4.4.3 Expected outcome. The measure of confidence of the ability and responsiveness of currently used fire detectors to detect a flame from the candidate fuel under consideration will be determined.

F.4.5 Flame speed. Flame speed across pooled fuel is an important consideration from a ground fire-fighting perspective. Knowledge of the candidate fuel is required to determine if it poses a greater hazard to ground personnel or in a post-crash scenario because the flame spread rate is much greater than the baseline fuel. Flame speed typically has a close relationship to flash point.

F.4.5.1 Test objective. Determine the rate of progression of the flame front of the candidate fuel in a tightly controlled environment. The flame speed of the candidate fuel will be compared with the baseline JP-8 fuel at various fuel temperatures.

F.4.5.2 Test plan. A standard test procedure for flame speed currently does not exist. Tests were performed using a triangular shaped steel trough, 48 in long x 3.9 in width at the top (open) x 1.2 in depth (internal). The flame spread rate is measured by pouring water into the trough to a depth of 0.6 in (half the trough depth), and filling the remainder with fuel. The fuel is allowed to reach the top of the trough in an attempt to negate any edge effects from the steel sides of the trough. The fuel is ignited at one end of the trough using a propane torch and allowed to propagate and become fully involved.

Thermocouples (and/or video analysis) are used to measure the advancement of the flame front beginning 10 in from the ignition end of the trough and every 8 in for a total of 5 thermocouples. The flame spread rates are calculated using the time at which the temperature is measured exceeding a set temperature at each thermocouple. Flame propagation rates for JP-8 are typically less than 5 in per second (in/s) at a fuel temperature below the flash point. However, at fuel temperatures above the flash point, the flame front reaches speeds of up to 70 in/s.

F.4.5.3 Test results. Some measured flame spread rates at temperatures well above and well below than the fuel's flash points are provided in Table F-II below:

TABLE F-II. Measured flame speed rates.

Fuel/Blend	JP-8	Shell FT-SPK	Camelina HRJ	Tallow HRJ
Rate (in./s) <<Flash Point	2.0 @ 72 F	2.0 @ 77 F	2.3 @ 69 F	2.0 @ 71 F
Rate (in./s) >>Flash Point	64 @ 190 F	57 @ 168 F	64 @ 174 F	60 @ 182 F

F.4.6 Flash point. The flash point for aviation fuels, a required fuel property specified in Appendix C, specifies the temperature at which a fuel releases a sufficient amount of vapors to yield an ignition in air corrected to a pressure of 760 mm Hg in the presence of an ignition source. As a result, flash point is a key physical property that is often reported in Safety Data Sheet (SDS) and other chemical property handbooks for the safe handling and transport of a fuel. The flash point is an important parameter for determining the explosion and fire hazard, or volatility, of the specimen. These tests should be performed at varying pressures and temperatures.

F.4.6.1 Test objective. Determine the minimum liquid fuel temperature required to generate an ignitable mixture of fuel vapor and air immediately above the liquid fuel.

F.4.6.2 Test plan. For aviation fuels, the recognized methods for the determination of flash temperature according to the ASTM D1655 are the Tag Closed Cup (ASTM D56), Pensky-Martin Closed Cup (ASTM D93), and Small Scale Closed Cup (ASTM D3828). The Small Scale Closed Cup Method has been an established ASTM method since 1979 and is considered an “equilibrium” method since it allows for the fuel vapors to diffuse into the vapor space at a set temperature. However, it does not have the extensive library of results for comparison that is available to the Tag method and is not widely employed in current fuel testing laboratories. The Tag Closed Cup Method, ASTM D56, is the preferred flash point method due to its well documented history and prevalent use in current national laboratories.

F.4.6.3 Test results. Studies of the physical properties have been performed on some candidate alternative fuels, and comparative analyses were performed on each fuel category (e.g., kerosene fuels and diesel fuels) by following the military specification for jet fuel. Some of these physical properties pertinent to combustion and flame spread are presented in Appendix C.

The ASTM D93 standard was used determine the flash points of the synthetic fuels available. The measured values are comparable to the flash points given in the SDS from the manufacturer. However, some minor differences were found between values in the literature and those presented in the SDS.

TABLE F-III. Measured density and flash point.

Fuel	Measured Density	SDS Reported Density	Measured Flash Point	SDS Reported Flash Point
Conventional JP-8 Jet Fuel	0.81 g/cm^3	0.78-0.84g/ cm^3	54 °C	> 38°C
Synthetic Diesel (S-2)	0.76 g/cm^3	0.77 g/cm^3	59 - 60 °C	> 60.5°C
Synthetic JP-8 (S-8)	0.75 g/cm^3	0.76 g/cm^3	52°C	37.8 - 51.5 °C
Shell FT-SPK	0.73 g/cm^3	0.80-0.82 g/cm^3	39 - 40 °C	38°C
Camelina HRJ	0.75 g/cm^3	0.75-0.80g/ cm^3	41 °C	> 38°C
Tallow HRJ	0.75 g/cm^3	0.75-0.80g/ cm^3	50 °C	> 38°C

Flash point measurements have shown that the JP-8 fuels which are more aromatic have higher flash point temperatures than the Shell FT-SPK fuel (non-aromatic), indicating a higher flammability (theoretically) for the Shell FT-SPK fuel. Aromatic hydrocarbons typically have a higher flash point (and lower vapor pressure) than their aliphatic counterparts with the same carbon number. For example, xylene isomers (C_8H_{10}) have a flash point (averages of isomers) of 28.1°C with a vapor pressure of 8.3 torr (1.1 kPa), while n-octane (C_8H_{18}) has a flash point of 13°C and vapor pressure of 14 torr (1.9 kPa). Isooctane (2,2,4-trimethylpentane, isomer of n-octane) has an even lower flash point of -12°C and a higher vapor pressure of 41 torr (5.5 kPa).

F.4.7 Auto ignition temperature. The auto ignition temperature for aviation fuels is an important parameter for determining the explosion and fire hazard, or volatility, of the fuel as specified in Appendix C.

F.4.7.1 Test objective. The objective of this test is to determine the minimum fuel temperature, or self-ignition temperature, required to generate an ignitable mixture of fuel vapor in air at atmospheric pressure in the absence of an ignition source.

F.4.7.2 Test plan. Determination of the auto ignition temperature of a fuel sample will adhere to the Auto Ignition Temperature of Liquid Chemicals (ASTM E659) testing standards using an automated auto ignition apparatus specifically constructed for this method. In a darkened test facility (lights are shuttered off), an enclosed flask is heated and maintained at a testing temperature. An electrically heated furnace and temperature control system maintains a high temperature test environment. An internal flask of sufficient thermal conductivity is used to hold the sample and provide a suitable testing environment. Surrounding the flask is a lining of aluminum foil with the top of the flask insulated within the temperature controlled furnace. Once the flask is heated and maintained at the desired test temperature, a 100-µL sample of liquid fuel is carefully measured and extracted using a hypodermic syringe and injected into the borosilicate flask. The vapor space in the flask is visually monitored for the presence of an ignition for a specified length of time. At the completion of the test, the combustion gases are purged from the flask and the sample is then safely discarded. For each test temperature, an "ignition" or "no ignition" is determined.

F.4.7.3 Expected outcomes. Data gathered and recorded are fuel amount, fuel temperature, ambient pressure, temperature, and temperature rise. These data will then be compared to a concurrently generated baseline JP-8 fuel. A successful test is determined by visual confirmation of a flame within the test article.

F.4.8 Heat of combustion. The heat of combustion for aviation fuels is a standard test required by the fuel specification covered in Appendix C.

F.4.8.1 Test objective. Measure the heat of combustion of the alternative fuel based on established standards.

F.4.8.2 Test plan. The standard test procedure employs a bomb calorimeter to measure the heat release of a fuel sample. Determination of the heat of combustion of aviation turbine fuels by oxygen bomb calorimetry is the preferred test method ASTM D1655-07, which specifies aviation fuel properties testing. The standard indicates that the heat of combustion should be determined using the standards of either ASTM D240 or ASTM D4809, which apply to oxygen bomb calorimetry. The active standard D4809 was designed specifically for use with aviation fuels, where the difference between repeated measurements should be on the order of 0.2%, and was therefore followed in the current procedure.

F.4.8.3 Expected outcome. The **r**esulting energy released measurements from the combustion of the alternative fuel sample will be compared to the baseline JP-8 and provide valuable data to update the design of fire detectors and firefighting agents if required.

F.4.9 Ground fire suppression agents. The military typically uses a firefighting agent, Aqueous Film-Forming Foam (AFFF), to extinguish liquid fuel fires. MIL-F-24385 (mil-spec) is an AFFF procurement specification produced by the military that gives chemical and physical properties required for the agent. Part of this document includes requirements of extinguishment and burnback time for experimental test fires using AFFF on unleaded gasoline. The test fire standards outlined in the mil-spec are more challenging than other known extinguishment standards. The National Fire Protection Association incorporated the 50 ft^2 (4.6 m^2) mil-spec fire test into their own standard that allows for use of any foam agent. The procedures used in the mil-spec fire tests were applied to experiments using fuels from conventional (petroleum) and alternative (synthetic) sources, comparing the extinguishment and burnback characteristics to those of the Air Force's JP-8 fuel.

F.4.9.1 Test objective. Perform fire extinguishment tests on conventional and synthetic jet fuels following the military specification MIL-F-24385 for aqueous film forming foam. Record Time of extinguishment and burnback, and compare to the baseline fuel (e.g., JP-8, the current primary fuel used by the U.S. Air Force).

F.4.9.2 Test plan. Fire suppression agent tests will be performed using JP-8 (baseline fuel) and the candidate fuel(s). This test series will be performed in accordance with parameters set forth in the MIL-F-24385, Section 4.7.13 for the twenty-eight-square-foot fire test in an indoor facility with quiescent air, allowing for repeatable and stable conditions between tests. The test apparatus consists of a stainless steel 6 ft. (1.83 m) diameter pan with a height of 4 in (10.2 cm). To help protect the pan, a shallow layer of water (0.25-0.5 in [0.6-1.3 cm]) is placed in the pan. Approximately 10 gal (37.9 L) or 0.57 in (1.44 cm) of the desired fuel is then added. The pan is ignited around the perimeter with a propane torch, and the flames are allowed to propagate towards the center of the pan, creating a fully developed fire plume. The mil-spec specified that the unleaded fuel flame burn freely for 10 s (preburn time [t_{pb}]). Since unleaded gasoline has a flash point of -40°C, the 10 s preburn time is sufficient for the fire plume to become fully developed. However, kerosene fuels with higher flash points (37-62°C) propagate more slowly than gasoline, thus more preburn time is required with values ranging from 15-33 s among tested fuel configurations. A test manager determines the time when the flames are fully developed. After the initial preburn time, the fire is "attacked and extinguished as expeditiously as possible" by a 2 gal/min (0.13 L/s) nozzle. After extinguishment, a burnback pan filled with flaming fuel is placed in the center of the 6 ft. diameter (agent) pan. When the fuel in the agent pan reignites, the burnback pan is removed. Time is measured when flames in the agent pan cover 25% of the agent pan area.

AFFF firefighting agent will be evaluated for ability to suppress a fuel-on-water fire. Evaluation will include extinguishment effectiveness, flame knockdown time, extinguishment time, and burn back time.

F.4.9.3 Test results. Experimental fire tests were performed on various alternative fuels including synthetic paraffinic kerosene (SPK) and hydroprocessed renewable jet (HRJ). Multiple fire suppression tests were performed for each fuel type as well as fuel blends using aqueous film forming foam on a liquid pool fire following the prescribed military specification (mil-spec), MIL-F-24385. One set of tests were conducted with SPK fuels and JP-8 as a baseline. A second set of tests were conducted with HRJ fuels and JP-8 as a baseline.

The firefighters who performed these experimental runs were DoD certified. Test results show AFFF will extinguish these alternative fuel and fuel blend fires just as effectively as conventional fuel fires. The measured burnback times show that AFFF is equal to or more effective at preventing burnback of these alternative fuels and fuel blends than with JP-8 fuel.

Tables F-IV and F-V display the results of two separate trials of fuels evaluated for AFFF fire extinguishment and burnback as well as their confidence intervals (95%). The average for extinguishment and burnback time as well as their confidence intervals (95%) are plotted on Figures F-1 through F-4. The results show that AFFF is a very effective firefighting agent against these alternative fuel fires and that the performance of AFFF on these alternative fuels is similar to that of JP-8 fuel.

TABLE F-IV. Average extinguishment and burnback times.

Fuel	Average Pre-Burn Time (sec)	Average Extinguishing Time (sec)	Average 25% Burnback Time (min)
JP-8	23.5	23.8 ± 6.1	679.5 ± 112.8
S-8	24.8	25.3 ± 4.6	797.0 ± 87.8
Shell FT-SPK	19.6	25.6 ± 5.5	837.0 ± 59.4
S-8/JP-8 Blend	22.2	23.0 ± 3.5	835.2 ± 26.8
Shell FT-SPK/JP-8 Blend	24.3	25.5 ± 2.4	678.8 ± 64.3
S-2	26.5	27.5 ± 6.4	843.0 ± 381.2

TABLE F-V. Average pre-burn, extinguishing and burn-back results.

Fuel	Average Pre-burn Time (sec)	Average Extinguishing Time (sec)	Average 25% Burn-back Time (min)
JP-8	27.8	22.2 ± 1.8	626 ± 0:31
Camelina HRJ	27.0	23.8 ± 1.6	636 ± 1:05
Camelina HRJ/JP-8 Blend	24.8	23.0 ± 4.3	612 ± 0:34
Tallow HRJ	30.2	23.2 ± 1.8	619 ± 1:18
Tallow HRJ/JP-8 Blend	28.8	22.0 ± 2.0	622 ± 0:21

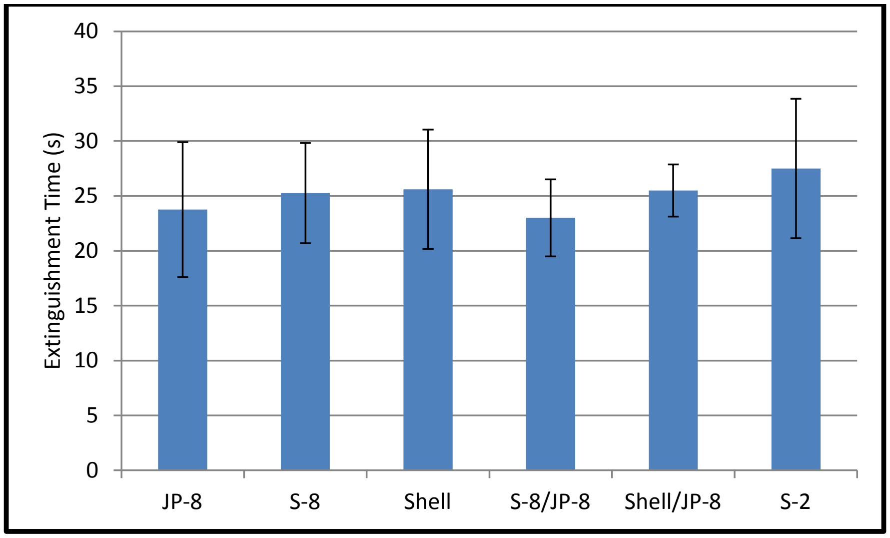

FIGURE F-1. Average extinguishment times for SPK fuel mil-spec experiments with corresponding 95% confidence intervals.

The mil-spec standard for extinguishment time is "less than" 30 seconds

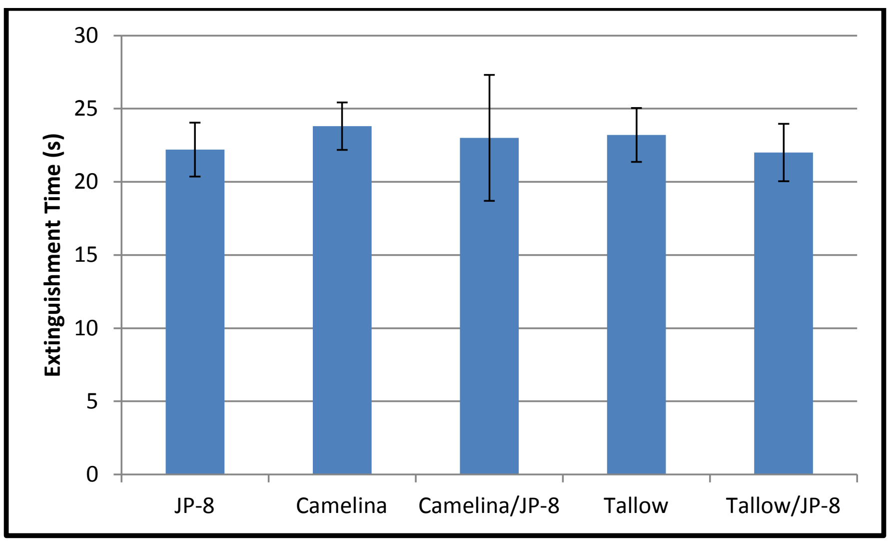

FIGURE F-2. Average extinguishment times for HRJ fuel mil-spec experiments with corresponding 95% confidence intervals.

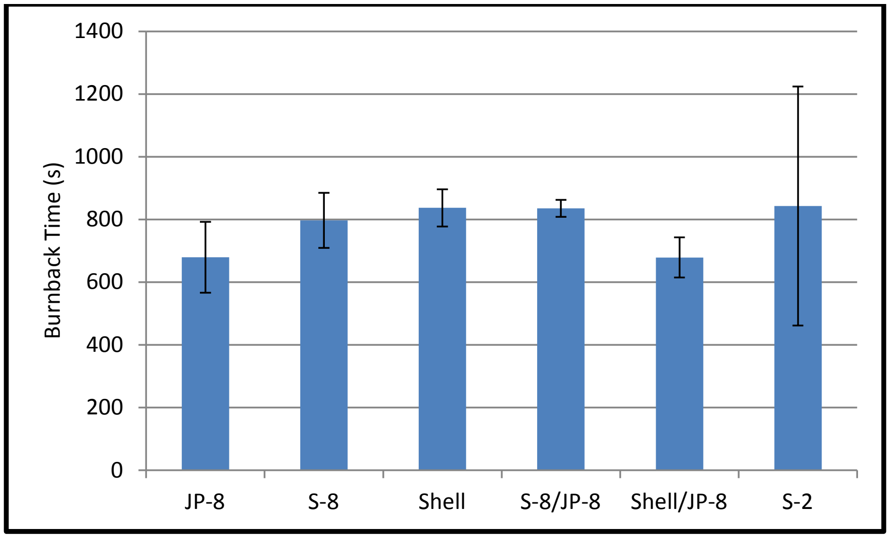

FIGURE F-3. Average burn-back times for SPK fuel mil-spec experiments with corresponding 95% confidence intervals.

The mil-spec standard for burn-back time is "greater than" 360 seconds

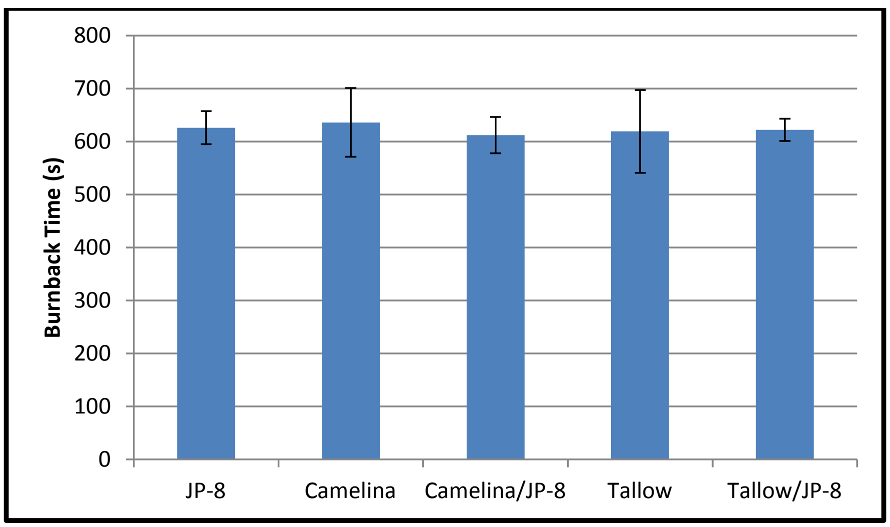

FIGURE F-4. Average burnback times for HRJ fuel mil-spec experiments with corresponding 95% confidence intervals.

F.5 SUBSET 2 CRITERIA.

F.5.1 Safety related fuel characteristics. Subset 2 consists of a test to determine the effects of the Minimum Ignition Energy of the candidate fuel on-aircraft fire suppression equipment and the evaluation of Aircraft Engine Fire Suppression Agents. This evaluation is critical for personnel ground safety and for classification of surfaces that require insulation to prevent a hot surface ignition on board military vehicles. These evaluations will play a key role in determining the vulnerability of the fuel tank and the overall survivability of the aircraft.

F.5.2 Overall Subset 2 test objectives. Determine if current requirements for minimum ignition energy and the effectiveness of the Fire Suppression Agents are acceptable for the candidate fuel.

F.5.3 Minimum ignition energy. The Minimum Ignition Energy required for a spark discharge to ignite a hydrocarbon fuel/air mixture is defined in Appendix C for the currently-used jet fuels. The Minimum Ignition Energy for the proposed alternative fuel will be determined using an Atomization Characterization test described below.

TABLE F-VI. Baseline fuel values and candidate fuel criteria.

Fuel Property and Significance	Baseline Fuel Value
Minimum Ignition Energy (at altitude) – Least amount of energy required to start a sustained reaction in a mixture of fuel vapor and air.	0.25 mJ

F.5.3.1 Test objective. Determine the minimum energy required to ignite a flammable mixture of air/fuel for a range of fuel vapor concentrations.

F.5.3.2 Minimum ignition energy test plan. No standard test currently exists for measuring the minimum ignition energy. The Minimum Ignition Energy (MIE) of a fuel may be tested in a spherical, 20 L, stainless steel combustion chamber. The chamber will contain electrical igniter rods at variable spacing to ignite the fuel vapors. Furthermore, optical access and instrumentation ports will confirm the presence of an ignition as well as record the pressure, temperature, hydrocarbon concentration and oxygen concentration throughout the test. Prior to testing, the chamber will be evacuated and then filled to the desired pressure altitude conditions. The sample will be introduced to the chamber. The chamber is placed inside a heated enclosure that circulates temperature controlled air on the outside of the combustion chamber. The distance between the igniter rods and the voltage on the DC electrical power supply are set to yield the ignition testing conditions specified in the test matrix. The electrical igniter is triggered and the presence of an ignition is verified visually and with a measured pressure rise in the vapor space. The conditions in the chamber and the electrical signal on the igniter circuit are recorded as well as verification of an ignition. The fuel is evacuated and the combustion products removed with the vacuum pump prior to cleaning the igniter rods and the chamber. For each pressure altitude examined, testing is conducted over a flammable chamber temperature range and a series of ignition energies to determine the minimum amount of energy required for ignition at the different fuel temperature and pressure altitude environments. A graphical range of the Minimum Ignition Energy for the range of fuel temperature conditions at each examined pressure altitude is reported.

F.5.3.3 Expected outcome. The expected outcome is a comparison between data generated from baseline JP-8 and the candidate fuel. The data gathered will provide a measure of the ignition energy versus changing fuel vapor temperature, under a constant pressure. This assumes a constant fuel input pressure with a nozzle that remains the same and controls the fuel spray and droplet size. These later variables can be changed while keeping the fuel vapor temperature and pressure constant to get a different ignition energy value.

F.5.4 Aircraft engine fire suppressant agents. The effectiveness of fire suppressant agents in extinguishing a given combustion of alternative fuels for an aircraft engine test scenario will be determined.

F.5.4.1 Test objective. Measure the effectiveness of fire suppressant agent in an engine fire scenario involving alternative fuel.

F.5.4.2 Test plan. These tests will be performed in a strategically designed fixture using fire suppression testing techniques and incorporating airflow as appropriate. Input data include ignition energy, amount of fuel, fire suppressant agent, bottle nozzle location and nozzle type. These tests are system specific and may be conducted at the discretion of the System Manager.

F.5.4.3 Expected outcomes. Gathered data consist of time to extinguish fire and amount of fire suppressant agent needed.

F.6 SUBSET 3 CRITERIA.

Subset 3 is composed of tests to provide additional safety, survivability, and fire protection related information. These tests are usually performed by the System Managers to select and fund, based on their individual aircraft, ground vehicle, equipment, or facility in order to identify and reduce the potential risk, validate if risk mitigation will work, or determine the best choice of mitigation for their configuration. Historically, these tests have been highly individualized per airframe, customized per combat threats and environments, and scope has been limited to a single aircraft configuration captured in time. These tests involve direct simultaneous testing and comparison to the baseline fuel and the new candidate fuel.

F.6.1 Overall Subset 3 test objectives. Determine parameters for the candidate fuel necessary to answer additional safety and survivability related questions. These data can be used directly by decision makers as well as feed into other analysis tools to help answer other questions such as the impact on aircraft vulnerability.

F.6.2 Component level aircraft fire protection technology. The expected outcome is similar to system level testing, but without the complication and sophistication of a system level test. Performed at the aircraft system manager's discretion, the candidate fuel will be tested with the aircraft system fire protection technology to determine its effectiveness in eliminating a candidate fuel fire.

F.6.2.1 Test objective. The objectives are: a) to determine the effectiveness of fire protection technology when eliminating a candidate fuel fire, in a mockup or surrogate type of environment; and b) to verify that existing technology will still function properly when using a candidate fuel in the fire environment. The component level fire protection technology testing will assess and evaluate the fire protection technology, associated with the aircraft system of the

System Manager, and the candidate fuel. There needs to be compatibility between the candidate fuel and the fire protection technology present, whatever that system might be. This is important because fire protection technologies are sized and optimized to work in a specific environment and extinguish JP-8 fires. By changing to the candidate fuel a key variable has been changed and needs to be evaluated in a cost-effective manner.

F.6.2.2 Test plan. The specific test plan will need to be developed for each aircraft subsystem test being performed. The test article for component level testing is much scaled down when compared to system level testing. The test article for this level of investigation would be a steel mock up, duplicating environment and the space being protected, by the fire protection technology. Examples of this environment include, but are not limited to wing dry bay spaces next to fuel tanks, engine nacelles, cargo bays, and fuselage dry bays that capture flammable fuels and hydraulic fluids. This is going to be highly dependent on the aircraft system being evaluated. The steel test article will then have a production fire protection technology system installed, as it is on the aircraft system. The resulting test article will be simple and easy to fabricate, and cost effective compared to procuring a system level test article. This technology needs to be in the same location, same orientation, and have the same fire extinguishing amounts like the production unit. Enough fire protection units need to be purchased to have a number of repetitions to testing. Any unplanned deviations from this replication will result in invalid test data. The fuel and ignition source need to be introduced into the test article in a realistic capacity. The fire will have to be introduced into the test article by a fuel spray nozzle, which simulates the damage from a combat event or mechanical problem. The fire protection technology was designed to extinguish a fire in a certain scenario, and this scenario needs to be duplicated during the test. Past research indicates a fuel spray between 2-8 gallons per minute is a realistic flow rate comparable to the flows resulting from combat damage. Some test articles will require a modest amount of airflow. It has been shown that airflow has a bearing on the fire propagation and fire protection technology effectiveness. Research will need to be accomplished to determine the type of flow that exists within the real system and corresponding bays. These data are best retrieved from the manufacturer through the System Manager of the aircraft system in question. These flow conditions are then duplicated in the test article. There are many methods to reproduce airflow in a test article. This can be accomplished by fans or by pressurized bottles, to name a few. By not including the airflow in the test article, the technology may be biased to either work or not work. The bottom line is the tester may be generating erroneous data if airflow is present in the actual system but not part of the evaluation testing. Once the test article has been fabricated, repetitive fire tests are possible on the component level with the production fire protection technology. The tests need to be run a number of times, with at least five successful tests in a row.

F.6.2.3 Expected outcome. The data collected will include test verification and a video record of a candidate fuel fire being extinguished by the aircraft system specific fire protection technology. A test is successful when the fire is extinguished by the fire protection system. From previous experience, 10 tests are planned in an attempt to achieve at least 5 successful tests in a row. This isn't to be confused with 5 successful tests out of 10. Once the former test record has been achieved, the data provides good statistical confidence to say the system works with the candidate fuel. If no baseline JP-8 data exist, the system will have to be tested with the baseline fuel.

F.6.3 Aircraft fire protection from ballistic threats. Component level tests should be performed for risk reduction prior to conducting advanced systems level tests. The effectiveness of various fire protection technologies and damage assessments from ballistic threats are scenario and aircraft system specific and are usually performed by the Aircraft System Managers based on Live Fire Test requirements for that system.

F.6.3.1 Test objective. Determine the relative effectiveness of several fire protection technologies that are designed to protect an aircraft from ballistic ignited fires with the candidate fuel.

F.6.3.2 Test plan. These tests are aircraft and system specific and will need to be developed for each aircraft and subsystem tested.

F.6.2.3 Expected outcome. Data that measure any change in effectiveness of currently used technologies designed to protect aircraft fuel tanks and dry bays from fire and explosion as well as minimize fuel loss.

F.6.4 Ballistic testing of self-sealing fuel bladders. Self-sealing fuel system components typically incorporate a fuel resistant inner liner, a fuel activated self-sealing layer, and an outer environmental (abrasion) layer. The self-sealing layer has to swell rapidly when it comes into contact with fuel. The standard performance test for self-sealing bladders is a ballistic test which is required to validate the results of the volume swell tests.

F.6.4.1 Test objective. The objective of this test is to determine if self-sealing ballistic test cells will seal sufficiently within a period of two minutes after ballistic testing when filled with the candidate fuel.

F.6.4.2 Test plan. Testing will be accomplished in accordance with MIL-T-5578, Phase-I, protection level A (Sections 4.6.5.3 – 4.6.5.4). The test cells will be unpressurized when testing is performed. The gunfire will be at service velocity. Vendor provided self-sealing bladders designed to MIL-T-5578, Phase I Test Cells (Type II, Class B, Style I) will be tested to the Protection Level A with the candidate alternative fuel.

F.6.4.3 Expected outcome. The pass/fail criteria for the self-sealing bladders as specified in MIL-T-5578 will be determined.

F.6.5 Hydrodynamic ram. Testing for this parameter is not mandatory and should be decided by the aircraft System Manager. If the alternative fuel parameters are very similar to JP-8 then this test can and should be bypassed. The parameters to compare with the baseline fuel are specific gravity, bulk modulus, thermal expansion, and viscosity. If these parameters compare closely with JP-8, then no hydrodynamic ram testing needs to be accomplished on the candidate fuel because of a lack of key differences. How much variation in the four parameters and how that impacts the hydrodynamic ram effect, isn't known. If a noticeable variation exists in one of the four mentioned parameters, then the testing should proceed at the System Manager's discretion.

F.6.5.1 Test objective. Measurements of the overpressure generated during the pressure wave cycle in a fuel sample contained in strategically designed container or tank, using standard vulnerability test methods, may be accomplished for specific threat projectiles.

F.6.5.2 Test plan. These are system specific tests that can be accomplished at a component level versus a more involved system level test using aircraft specific parameters and geometry. The amount of over pressure and tank damage generated by a given projectile will depend on the threat type, impact velocity, projectile trajectory and impact location in the tank. A component level test is usually recommended for this type of testing. This would consist of a steel construction tank that measures 5 ft. × 3 ft. × 3 ft. required to hold the appropriate amount of fuel and sturdy enough to withstand the induced ram pressures. The tank is constructed with an easily replaceable projectile entrance and exit panels which would be replaced after every shot. Ram pressures will be measured for both the 12.7mm AP and 23mm AP projectiles fired at their design service velocity. Five shots per ammunition type should be fired at a minimum. These repetitions will bring credibility to the data gathering and overall data set. Test instrumentation should consist of Kistler pressure transducers (PTs) and a data acquisition system capable of 10,000 Hz range for a sampling rate. The minimum number of PTs required in the cluster is four. Three 2 kpsi capable PTs and one 10 kpsi PT are recommended to gather the required data for each shot. These PTs have to be spaced and suspended around the shot line location for the best data pick up in the tank. A system level test, using full scale components, may also be performed following the same basic procedures.

F.6.5.3 Expected outcomes. The overpressure will be measured in the fuel container or tank. These data will then be compared to archive data generated for a baseline aviation fuel.

F.6.6 Fuel tank inerting. Fuel tank inerting with nitrogen enriched air (NEA) is used for explosion prevention on select aircraft. These tests are system specific and may be conducted at the discretion of the System Manager.

F.6.6.1 Test objective. Determine if fuel tank inerting requirements (percent oxygen allowed) are different for candidate fuels under consideration as compared to baseline JP-8.

F.6.6.2 Test plan. These tests are system specific and may be designed and conducted at the discretion of the System Manager.

F.6.6.3 Expected outcome. The expected outcome is comparison data between the baseline and the candidate fuel. The data will consist of overpressure (psi) versus % oxygen. Other data collected will include time to peak pressure. These data will determine if existing inerting criteria and systems would provide an equivalent level of protection to what is seen with the existing aircraft systems currently using the baseline fuel.

F.6.7 Minimum hot surface ignition temperature under turbulent air flow. The minimum hot surface ignition temperature or hot manifold ignition temperature is a key safety parameter to the aviation industry due to the range of environments where fuel delivery and usage occurs within close proximity to heated surfaces. The minimum hot surface ignition temperature is defined as the lowest external surface temperature that can yield an ignition of a resident hydrocarbon fuel. Hot surface ignition should be evaluated per test plan described below.

TABLE F-VII. Baseline fuel values and candidate fuel criteria.

Fuel Property and Significance	Baseline Fuel Value
Minimum Hot Surface Ignition Temperature Under Turbulent Airflow – Lowest Surface Temperature at which a fluid will ignite.* Criterion is used to determine which surfaces require insulation.	650 °F - 1100 °F

* varies by Test Method

F.6.7.1 Test objective. Determine the minimum temperature of a surface at which the candidate fuel will ignite. Historically, any aircraft component that has a hot surface has required a risk assessment be conducted to determine whether the component is to be treated as an ignition zone or a fire zone. If a component is determined to be a fire zone, then some form of mitigation is required.

F.6.7.2 Test plan. The hot surface ignition temperature of a fuel is to be tested on a flat, uniformly heated circular plate which resides in an optically conducive, octagon-shaped enclosure. A fuel conditioning and delivery system regulates the temperature of the fuel as well as the fuel release condition from the nozzle. Three separate delivery modes (spray, continuous stream, steady drip) and two different fuel temperatures (ambient and heated) are tested in three precisely controlled airflow environments. The three airflow environments are documented with a high accuracy velocity, turbulence and temperature measurement system prior to conducting hot surface ignition tests. For the ignition tests, a set amount of fuel (10 mL) is delivered to the uniformly heated surface at a fixed flow rate. The probability of ignition at a range of fuel temperatures is determined for each test condition through ten repeated instances for a given fuel and environmental condition. The resulting statistical probability value is reported graphically and provided along with the facility documentation to allow comparison between multiple test facilities and different fuel specimens.

F.6.7.3 Expected outcome. An evaluation of the candidate fuel as to whether procedures need to be altered or if surface temperature-based requirements are no longer valid or if aircraft fire zones need to be reclassified for fire hazard purposes.

APPENDIX G

AIRCRAFT PROPULSION FUELS CERTIFICATON PROCESS

G.1 SCOPE.

G.1.1 General. This Appendix provides information to aid in the determination of a fuel's acceptability for use in aircraft propulsion systems. It is intended to provide the FCO and System Manager (SM) a methodology to identify, evaluate and mitigate safety, performance, durability, and supportability risks associated with candidate fuels used in propulsion systems. Additional component and system level tests are suggested to help identify and reduce any associated risk.

G.1.2 Entrance Criteria and subsets. The Aircraft Propulsion SMEs have evaluated all fuel properties and characteristics based on the requirements decomposition process described in Appendix A. The results of this analysis were used to develop propulsion process Entrance Criteria and three Subsets of propulsion properties. The Entrance Criteria contains a list of fuel properties and characteristics that the candidate fuel has to satisfy. Subset 1 includes those properties that can affect safe operation of the propulsion system, Subset 2 includes those properties that can affect the performance of the propulsion system and Subset 3 includes those properties that can affect the durability and supportability of the propulsion system. These properties are documented in tables for each of the Subsets.

G.1.3 Fuel functions on aircraft propulsion systems.

G.1.3.1 Fuel functions. Aircraft Propulsion systems use fuel to accomplish four main functions: 1) provide performance, 2) lubricate wear surfaces and bearings, 3) provide fueldraulic muscle for actuation devices and 4) remove excessive heat. Each of these functions depends on different properties of the fuel. In order to properly evaluate a candidate fuel one needs to consider each of these functions and weigh their relative importance to proper operation of the aircraft propulsion system.

G.1.3.1.1 Performance. Fuel has to burn to start and operate a propulsion system to provide the amount of thrust necessary to operate the aircraft. There are several steps in the overall combustion process. The fuel has to be atomized and vaporized when passing through the fuel nozzles into the combustor. In the combustor, it is vaporized, ignited and burned to provide the needed heat release and thus required thrust. In order to get the fuel to the combustor it has to be pumped from the aircraft tank and metered according to an established set of schedules. Performance relies on fuel properties such as flammability, viscosity, lubricity and density.

G.1.3.1.2 Wear surface lubrication. Many propulsion system components rely on fuel lubrication for proper operation and to minimize wear and degradation. Pumps, actuators, hydromechanical controls and servo valves all contain fuel wetted bearings and surfaces that depend heavily on proper fuel lubrication. Proper fuel lubrication relies on fuel properties such as viscosity, lubricity and density.

G.1.3.1.3 Fueldraulics. Aircraft Propulsion system control and thrust scheduling involves many moving parts and depends on fuel driven actuators to move them. Most of today's modern propulsion systems rely on the fuel as a medium for producing the hydraulic muscle (fueldraulics) for these actuators. Fueldraulics relies on fuel properties such as density, bulk modulus and viscosity.

G.1.3.1.4 Heat removal. One of the biggest propulsion system durability drivers is the ability to remove and dispose of excessive heat. This "thermal management" capability is a major problem because fuel can only absorb so much heat and only so much fuel can be burned through the combustor. Whatever fuel is not burned, is either recirculated to the aircraft tank or recirculated within the fuel system itself, resulting in continual heat loading on the fuel. This high heat loading can result in a number of issues including coking, varnishing and the overheating of electronic components. The ability of the fuel to remove excessive heat relies on fuel properties such as specific heat, thermal conductivity and thermal stability.

G.2 APPLICABLE DOCUMENTS.

G.2.1 General.

The documents listed below are not necessarily all of the documents reference herein, but are those needed to understand the information provided by this Appendix.

G.2.2 Government documents.

G.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2007 Engines, Aircraft, Turbine

(Copies of this document are available on line at http://quicksearch.dla.mil/.)

G.2.2.2 Non-Government documents, drawings, and publications.

The following non-Government documents, drawings, and publications form a part of this document to the extent specified herein.

PCOE - BP-01-14	Lead the Fleet Pacer/ACI Programs
PCOE - BP-02-17	Accelerated Mission Testing (AMT)
PCOE - BP-03-18	Propulsion/Engine Test Planning

(Copies of these documents are available on line at https://cs.eis.afmc.af.mil/sites/Propulsion/PCoE/default.aspx)

G.3 THE PROPULSION SYSTEM FUEL EVALUATION PROCESS.

G.3.1 Process overview. There is an inherent, time-phasing associated with the steps of this process. The Entrance Criteria, Subset 1, Subset 2 and Subset 3 properties are evaluated in order, at different points in time, using the same methodology.

G.3.2 Process methodology. The first step requires the Propulsion Entrance Criteria properties to be evaluated. The results of this analysis are provided to the FCO who determines if there is sufficient justification to proceed. If the FCO determines the process is to continue, the next step requires Subset 1 properties to be evaluated. These results are used to accomplish a Risk Assessment Process (RAP). The RAP will generate three possible recommendations for the fuel: 1) rejection, 2) acceptance or 3) pursue additional risk reduction activities. The appropriate recommendation is made to the FCO who will give permission to proceed further in the process. If the FCO determines the process is to be continued, the same steps applied to Subset 1 are repeated for Subsets 2 and 3, including RAPs for each. Each time a RAP is performed, it will be based on an increasing body of knowledge. In addition to the increasing body of knowledge from Subset evaluations, there will also be knowledge obtained from any risk reduction activities. Each time, the RAP will recommend rejecting, accepting or pursuing additional risk reduction activities. The following sections provide more details on the process.

G.3.3 Entrance Criteria evaluation. The first step involves evaluation of the Entrance Criteria using Appendix B. The Entrance Criteria contains the basic information required to determine if there is sufficient justification to initiate the propulsion evaluation process. The Entrance Criteria for the propulsion system evaluation process is provided in Table G-I. The results of this analysis are provided to the FCO who determines if there is sufficient justification to proceed. Additional information on Entrance Criteria is provided in Appendix B.

TABLE G-I. Propulsion system Entrance Criteria.

Fuel Property and Significance	Test Method	Pass Criteria
Flash Point, affects combustibility. It is also a leading factor determining fire safety in fuel handling.	Appendix C	Temperature Range: 28°C to 68°C
Freezing Point, affects low temperature fuel behavior. It can cause issues with pumps and nozzle operations.	Appendix C	Max -40°C
Viscosity @ -20 °C, affects pumpability over the operating temperature range. It also relates to droplet size in sprays produced by burner nozzles.	Appendix C	Max 8.0 cSt

G.3.4 Subset 1. Subset 1 properties are those that can affect the system safety and performance. The propulsion system Subset 1 properties are provided in Table G-II.

TABLE G-II. Propulsion system Subset 1 properties.

Fuel Property/Characteristic and Significance	Test Method and Evaluation Criteria
Viscosity versus Temperature (-40 ^{0}C to +90 ^{0}C), affects pumping fuel over the operating temperature range. Relates to droplet size in sprays produced by burner nozzles.	Appendix C
Surface Tension, affects the droplet size when the fuel is atomized, which affects combustion and air starting.	Appendix C
Vapor Pressure (Reid vapor pressure), affects vaporization, which affects combustion and air starting. Also affects vapor lock effects on pumps.	Appendix C
Heat of Combustion, Net, affects the amount of heat released per unit quantity of fuel which affects Specific Fuel Consumption (SFC)	Appendix C
Latent Heat of Vaporization, is the ability to change the fuel from a liquid to a gas. Affects vaporization, which affects combustion and air starting.	Appendix C
Flammability Limits, affect ignition characteristics which affect air starting.	Appendix C
Trace Elements, could result in excessive deposition or erosion of hot section components and materials, resulting in their failure.	Appendix C
Density versus Temperature (-40° C to +90° C), affects thermal expansion, flow calculations and metering devices.	Appendix C

G.3.5 Subset 2. Subset 2 properties are those that can affect the performance of the propulsion system. Many of the properties listed in Subset 1 (Safety) also affect propulsion system performance and are not repeated in Subset 2. The propulsion system Subset 2 properties are provided in Table G-III.

TABLE G-III. Propulsion system Subset 2 properties.

Fuel Property/Characteristic and Significance	Test Method and Evaluation Criteria
Bulk Modulus versus Temperature (-40 ^{0}C to +90 ^{0}C), affects the compressibility of the fuel which affects the ability to accurately pump the fuel. Also affects overall system stability.	Appendix C

G.3.6 Subset 3. Subset 3 properties are those that can affect the durability and supportability of the propulsion system. The propulsion system Subset 3 properties are provided in Table G-IV.

TABLE G-IV. Propulsion system Subset 3 properties.

Fuel Property/Characteristic and Significance	Test Method
Enthalpy versus Temperature (0 ^{0}C to +250 ^{0}C), affects the ability to cool fuel wetted components.	Appendix C
Thermal Stability, affects cooling, coking and varnishing of fuel wetted components.	Appendix C
Lubricity, affects the lubrication of moving parts such as pumps and hydromechanical controls.	Appendix C
Thermal Conductivity, affects the suitability of a fuel as a primary heat sink which affects the ability to cool fuel wetted components.	Appendix C
Specific Heat versus Temperature (-40 ^{0}C to +150 ^{0}C), affects the amount of heat a fuel can absorb which affects the ability to cool fuel wetted components.	Appendix C

G.4 AIRCRAFT PROPULSION SYSTEM RISK ASSESSMENT PROCESS (RAP) CONSIDERATIONS.

Section 5.2 defines the overall Risk Assessment Process. Several observations can be made by examining the overall process:

The risk to be assessed is the risk associated with certifying a candidate fuel for use in a fleet.

There are at least three entities that conduct risk assessments: The FCO, the System Manager, and the High Level Decision Authority.

Both the FCO and System Manager RAP conduct a series of assessments, each one done when another subset of fuel properties become available.

The entity most likely to conduct a detailed risk assessment for a propulsion system is the System Manager.

The Higher Level Decision Authority can override the recommendation of one System Manager and impose fuel use for the Service.

It is important that the System Manager include the Original Equipment Manufacture on the risk assessment team. The System Manager may need to conduct tests on a given propulsion system before a recommendation for certification can be given. Examples of such tests are given in the next section of this appendix. Many of these tests can be expensive and lengthy. The SM needs to ensure that the OEM applies knowledge from all product lines in minimizing the number of tests needed for a particular system. Consideration should be given to develop collaborative efforts between the FCO, other System Managers, and OEMs for particularly difficult tests (durability tests typically fall into this category).

For those cases when the Higher Level Decision Authority directs the use of a fuel, the System Manager should use the risk assessment data and team to define any needed mitigating actions.

G.5 RISK ASSESSMENT TESTING.

G.5.1 Summary. This Section provides a list of potential risk assessment activities that may be used at any stage of the fuel certification process. Any time a list is created, there is a possibility that it may not be complete, hence this list should be used as a guide and consideration given to any additional recommended activities that are not on this list As noted earlier, System Managers should try to minimize the testing needed for their individual propulsion system by collaborating with the FCO, other System Managers, and OEM's.

G.5.2 Flame tube test. The RAP may indicate the existence of unacceptably high amounts of trace elements in the candidate fuel. These elements may be harmful to engine hot section components. During the combustion process, these elements may become liberated and deposit themselves in critical areas such as cooling holes and passageways. Some of these elements may also result in high amounts of erosion or delamination. A flame tube test is one way to evaluate the existence and effects of a fuel's trace elements.

G.5.3 Combustor rig testing. The RAP would take into account known fuel properties, the influence of additives, trace element concentrations, batch-to-batch variability, compatibility with non-metals, and compatibility of combustion products with hot section materials. The results of this assessment may indicate one or more combustor rigs, such as a fuel injector coking rig, sector rig, hot section materials test rig, or full annual rig are needed.

G.5.3.1 Fuel injector coking rig description. Coking can cause serious problems with propulsion systems. In its worst form coking in fuel nozzles can cause a mal-distribution in fuel, resulting in combustor hot spots that could cause structural failure and possible loss of aircraft. The results of the RAP may recommend this type of test to reduce any perceived risk of coking. While this type of testing is sometimes accomplished using a Jet Fuel Thermal Oxidative Test rig, the decision on what type rig or where to conduct this testing should be decided by collaboration between the FCO and affected System Managers.

G.5.3.2 Combustor sector rig. A combustor sector rig may be used to address any concerns associated with ignition, re-light, or lean blowout. Although these characteristics could be evaluated in a full scale engine test, a combustor sector rig would potentially offer evaluations over a wider range of conditions at a lower cost.

G.5.3.3 Full annular rig. Full annular rigs can evaluate overall combustor performance, emissions and pattern and profile factors. Although full scale engines could be instrumented to obtain the same information, the full annular rig would offer evaluations over a wider range of conditions at a lower cost.

G.5.4 Sea level and simulated altitude engine testing. Determining the propulsion system's ability to meet safety, performance and durability requirements is critical to mission accomplishment. Sea level and simulated altitude engine testing has been determined to be a very reliable evaluation method. These tests can be accomplished under ambient conditions, or in a test facility to simulate atmospheric conditions at altitude. The data obtained can be used to evaluate performance (thrust and specific fuel consumption), lean blow out margin, transient times and starting. The extent of testing depends on several different criteria including mission applicability, fuel property categorization and risk acceptance tolerance levels. Great care needs to be taken in selecting which engine or engine families will be tested and what data is needed to support fuel use on other non-tested engine families. Proper test planning is critical to a successful and economically viable sea level and simulated altitude engine test program. Propulsion system engineers, Propulsion Best Practice PCoE - BP-03-18, Rev. A and the JSSG-2007 should be consulted when developing engine test plans.

G.5.5 Engine flight testing. Based on the results of the RAP, it may be necessary to conduct some level of engine flight testing. Propulsion flight testing for alternative fuel use would likely be focused on performance and operability characteristics. For example, USAF engine flight testing is usually conducted at the Air Force Flight Test Center at Edwards AFB CA. The depth of engine flight testing depends on several different criteria including mission applicability, fuel property categorization, risk acceptance tolerance levels and the results from any sea level engine testing. Great care needs to be taken in selecting which engine or engine families will be flight tested and what data is needed to support fuel use on other non-flight tested engine families. Proper test planning is critical to a successful and economically viable engine flight test program. Propulsion system engineers and JSSG-2007 should be consulted when developing engine flight test plans.

G.5.6 Field Service Evaluations (FSE). An FSE is a proven way to obtain engine performance, operability and durability data under real world operational conditions. It provides a way to evaluate alternative fuels for "unknown-unknown" risks prior to full field implementation. In addition, an FSE can provide invaluable data on maintenance and sustainment (supportability) impacts. FSEs can be conducted at almost any operational base but require significant coordination and a willingness of the warfighter community to accept the extra responsibility and workload associated with them. In addition, the selected FSE base will have to be able to handle the logistical impacts of carrying the fuel under evaluation. Propulsion system engineers, Propulsion Best Practice PCoE - BP-01-14 and JSSG-2007 should be consulted when developing an FSE plan. Ultimately, the warfighter accepts or rejects any FSE recommendations.

G.5.7 Engine test durability qualification and Accelerated Mission Testing (AMT). The RAP may indicate concerns associated with durability. Durability tests could be conducted to clear an engine for varying durations, depending on need. For example, a short duration durability test could be conducted to clear an engine for a limited flight test program or Field Service Evaluation. In other cases, known durability risks could indicate a longer term test to characterize hot section life or define inspection intervals. Propulsion system engineers, Best Practice PCoE - BP-02-17 and JSSG-2007 should be consulted when developing an engine durability (AMT) test plan.

G.5.8 Engine subsystem component testing. The RAP may indicate a need to conduct individual engine component or subsystem testing. These types of tests provide the ability to identify and isolate potential fuel related risks on individual components such as pumps, valves, actuators, heat exchangers and hydromechanical controls. These tests can be accomplished using component test stands or system (wet) rigs.

G.5.9 Inspections. The RAP may indicate the need to visually verify the condition of engine components while under test or field operation. Routine or Special inspections are a proven way to observe and gather this information and assess risk. While inspections provide visual verifications, it should be noted that some are very labor intensive and require skilled personnel in order to obtain the most accurate information.

APPENDIX H

AEROSPACE FUELS INFRASTRUCTURE REQUIREMENTS

H.1 SCOPE.

H.1.1 General. The Aerospace Fuels Infrastructure (AFI) includes the systems and procedures for the storage, handling, and distribution of aviation fuels within the U.S. military. This portion of the aerospace fuels certification process includes all of the AFI related certification requirements that define the desired level of safety, performance, durability, supportability, interoperability, etc., that need to be maintained in the use of a candidate fuel. By meeting or exceeding the requirements of already-approved fuels, the candidate alternative fuels testing will have demonstrated that the alternative fuel is completely compatible with the existing fuels infrastructure.

H.1.2 Entrance Criteria and subset testing. Air Force Subject Matter Experts (SMEs) have categorized all fuel property requirements, based on a requirements decomposition process, which classifies these requirements in subsets in terms of safety, performance, durability and supportability, as described in Appendix A. This appendix (Appendix H) identifies the subset to which each infrastructure compatibility characteristic belongs and the significance for its selection. This appendix also includes component tests that should be conducted to further evaluate the candidate fuel for other infrastructure compatibility requirements.

H.1.3 Background. Although the U.S. military operates under a DoD directive to minimize the number and complexity of their aviation fuels, the supply chain infrastructure remains fairly complex. Fuel is shipped to military bases using one or more transportation modes that include ocean going tanker, overland truck, pipeline and rail car. In the simplest of supply chains, fuel is shipped directly from a refinery to a base but for most bases, fuel is received from intermediate terminals operated by the Defense Logistics Agency Energy. In addition to this, into-plane fueling contracts provide fuel servicing of military aircraft at commercial airports both within and outside of the U.S. In many foreign countries, this represents the sole source of fuel and provides the foundation for fuel support to rapidly deploying forces. All fuels entering this relatively complex system of fuel distribution and storage will come into contact with the variety of handling systems and materials that constitute the AFI. All candidate fuels should demonstrate a compatibility with these infrastructure systems and materials prior to certification.

H.2 APPLICABLE DOCUMENTS.

H.2.1 General. The documents listed below are not necessarily all of the documents referenced herein but are considered to be those which are most important in providing the user a clear understanding of the information provided by this appendix.

H.2.2 Government documents.

H.2.2.1 Government specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-24441	Paint, Epoxy-Polyamide, General Specification for
MIL-DTL-83133	Turbine Fuel, Aviation, Kerosene Type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37)
MIL-DTL-5624	Turbine Fuel, Aviation, Grades JP-4 and JP-5
MIL-PRF-370	Hose and Hose Assemblies, Nonmetallic: Elastomeric, Liquid Fuel
MIL-PRF-32233	Tanks, Collapsible, 3,000, 10,000, 20,000, 50,000, & 210,000 U.S. Gallons, Fuel
MIL-T-52983	Tanks, Fabric, Collapsible: 3,000, 10,000, 20,000, and 50,000 Gallon, Fuel

FEDERAL STANDARDS

FED-STD-141	Paint, Varnish, Lacquer and Related Materials: Methods of Inspection, Sampling and Testing

(Copies of these documents are available on line at http://quicksearch.dla.mil/

H.2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein.

UNITED FACILITIES CRITERIA/GUIDE SPECIFICATIONS

UFC 3-460-01	Design: Petroleum Fuel Facilities
UFC 3-460-03	Operation and Maintenance: Maintenance of Petroleum Systems
UFGS 09 97 13.15	Epoxy/Fluoropolyurethane Interior Coating of Welded Steel Petroleum Fuel Tanks
UFGS 33 08 55	Commissioning of Fuel Facility Systems
UFGS 33 52 43	Aviation Fuel Distribution (Non-Hydrant)
UFGS 33 52 44	Aviation Fueling Systems
UFGS 33 52 80	Liquid Fuels Pipeline Coating Systems
UFGS 33 56 10	Factory-Fabricated Fuel Storage Tanks
UFGS 33 56 13.13	Steel Tanks With Fixed Roofs
UFGS 33 56 63	Fuel Impermeable Liner System
UFGS 33 58 00	Leak Detection for Fueling Systems
UFGS 33 65 00	Cleaning Petroleum Storage Tanks

(Copies of these documents are available on line at http://www.wbdg.org/ccb/browse_cat.php?c=3.)

H.2.3 Non-Government standards and other publications. The following documents form a part of this document to the extent specified herein.

AMERICAN PETROLEUM INSTITUTE (API)

API SPEC 5L	Specification for Line Pipe
API SPEC 6D	Specifications for Pipeline Valves
API STD 610	Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries

(Copies of these documents are available on line at http://www.api.org.)

ENERGY INSTITUTE (EI)

EI 1529	Aviation Fueling Hose and Hose Assemblies
EI 1540	Design, Construction, Operation and Maintenance of Aviation Fueling Facilities
EI 1570	Handbook on Electronic Sensors for the Detection of Particulate Matter and/or Free Water During Aircraft Refuelling
EI 1581	Specifications and Qualification Procedures for Aviation Jet Fuel Filter/Separators
EI 1598	Design, functional requirements and laboratory testing protocols for electronic sensors to monitor free water and/or particulate matter in aviation fuel

(Copies of these documents are available on line at http://www.energyinstpubs.org.uk/)

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

ASME B16.21	Nonmetallic Flat Gaskets for Pipe Flanges

(Copies of this document are available on line at http://www.asme.org/.)

ASTM INTERNATIONAL

ASTM D412	Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
ASTM D471	Standard Test Method for Rubber Property - Effect of Liquids
ASTM D1414	Standard Test Methods for Rubber O-Rings
ASTM D1655	Standard Specification for Aviation Turbine Fuels
ASTM D1903	Standard Practice for Determining the Coefficient of Thermal Expansion of Electrical Insulating Liquids of Petroleum Origin, and Askarels
ASTM D2240	Standard Test Method for Rubber Property—Durometer Hardness

ASTM D2717	Standard Test Method for Thermal Conductivity of Liquids
ASTM D3363	Standard Test Method for Film Hardness by Pencil Test
ASTM F146	Standard Test Methods for Fluid Resistance of Gasket Materials

(Copies of these documents are available on line at http://www.astm.org/.)

H.3 ENTRANCE CRITERIA.

The AFI Entrance Criteria is composed of all fuel property test requirements specified in the specifications for military-approved fuels and described in Appendix B.

H.3.1 Entrance Criteria evaluation. The FCO or AFI System Manager will determine if the candidate fuel meets or fails to meet the AFI Entrance Criteria requirements for entrance into the certification process. The results of the AFI Entrance Criteria testing will be documented by the FCO or AFI System Manager.

H.4 SUBSET 1 TESTING.

H.4.1 Electrostatic charge dissipation. Since the electrical conductivity of hydrocarbon fuels is minimal, the risk of static electric charge accumulation and the potential for a subsequent catastrophic discharge event taking place during the transfer of fuel can be significant. This is equally valid for all transfers including from the point of manufacture, upon up-loading, off-loading, and receipt. The measurement of the change in the electrical conductivity of the candidate fuel due to the addition of Static Dissipater Additive (SDA) at a single temperature is a part of the entrance criteria in Section H.3. However, the change in this conductivity as a function of temperature is a characteristic of the candidate fuel that should be determined in order to maintain safe and consistent fuel handling operations. For this reason, the electrical conductivity of the candidate fuel after treating with SDA, per the requirements of the baseline fuel, should be determined and reported as a function of temperature as discussed in Appendices B and C.

H.4.2 Aviation fuel storage and transport interface materials. A candidate fuel should not adversely affect the ability of materials to provide leak-free interfaces between the various components of fuel distribution and storage systems and to function as intended within the fuel storage and distribution system. This includes fuel resistant gaskets, sealing interfaces, elastomeric diaphragms in surge suppressors and control valves, collapsible fuel storage tank materials, and internal tank and pipeline coating systems.

The candidate fuel should demonstrate this by exhibiting performance similar to that demonstrated by JP-8, JP-5, or Jet A with the DoD military additive package (FSII, CI/LI, and SDA, as required by their specifications), referred to as the "baseline fuel" throughout this appendix, when tested by the method described in Table H-I of this handbook. This includes Volume Change, Tensile Properties Hardness and Solubility as outlined for each material in the table. The data from immersion tests will be collected at 14, 28, 42 and 56 days to allow for trend analysis to be performed to determine if the impact of the fuel stabilizes during that time.

Compatibility with metallic components should be evaluated as outlined in Table D-III of this handbook.

H.4.3 Aviation fueling hose and hose assemblies. A candidate fuel should not adversely affect the properties of fueling hose or hose assemblies. This is demonstrated by meeting or exceeding the performance as demonstrated by the baseline fuel when tested as specified in EI 1529 for Volume Increase, Fuel-soluble Matter, Adhesion, Fuel Contamination, Fuel Discoloration (see sections 4.3.3, 4.3.4, 4.4.5, 4.4.10, and 4.4.11 of EI 1529). In these tests, the candidate fuel will be used as the test fuel.

H.4.4 Single-element filter/separator performance. The capability of fuel Filter Separators (F/S) to separate and extract free water from the fuel as the fuel flows through the distribution system should not be adversely affected by the candidate fuel. The candidate fuel should not lead to a lower performance of F/S qualified to EI 1581 when compared to the performance when using the baseline fuel. This may be demonstrated through testing the F/S hardware or may be done by fuel-similarity considerations.

If the System Manager deems that testing is required in this section, representative F/S hardware will be selected based on manufacturer and type and will be tested in accordance with the single-element and materials compatibility testing sections of EI 1581 using the test fuel in a category M and/or M100 configuration at 100% rated flow. The results of the single element testing should be compared to the same test configuration using the baseline fuel. Acceptance criteria will include the ability of the filtration to effectively remove water and solids from the test fuel with consideration of the differential pressures across the filtration media during the first three phases of the test.

If filtration results are dissimilar between the baseline fuels, the System Manager may deem additional testing be required to determine the variance root cause. This testing may include but not be limited to fuel testing with unadditized fuel and fuel additized with various mixtures of additives. The purpose of this testing will be to determine whether a specific additive or combination of additives are incompatible with the test fuel.

H.4.5 Electronic sensors. The capability of electronic sensors to detect particulate matter and free water as the fuel flows through the distribution system may not be adversely effected by the candidate fuel. The candidate fuel should not lead to a lower performance of electronic sensors qualified to EI 1598 and EI 1570 when compared to the performance using the baseline fuel. This comparison may be done by demonstration through testing the electronic sensor hardware or by fuel similarity considerations.

If the System Manager deems testing is required in this section, a representative electronic sensor will be selected based on manufacturer and type and will be tested in accordance with the operational and material compatibility testing sections of EI 1598 using the test fuel. The results of the test fuel will be compared with the same test configuration using the baseline fuel. Acceptance criteria will be the ability of the electronic sensor to detect particulate matter and free water to the same level in both the fuel and the baseline fuel.

H.4.6 Subset 1 criteria evaluation. The System Manager will determine if the candidate fuel meets or fails the above requirements. The results of the AFI Subset 1 testing will be documented by the FCO or System Manager.

H.5 SUBSET 2 TESTING.

H.5.1 Impact on fuel distribution components durability. The candidate fuel should not exhibit thermal expansion, thermal conductivity, or lubricity characteristics that would be problematic in the current operation of bulk fuel storage containers and fuel transfer pipelines. This is confirmed by measuring these by the standard methods ASTM D 1903, ASTM D 2717, and ASTM D5001. These fuel properties are described in Appendix C.

H.5.2 Automatic storage tank gauging and metering systems evaluation. The candidate fuel should not adversely affect the operation of automatic storage tank gauging or fuel metering systems. This is demonstrated first by similarity analysis in which the pertinent physicochemical properties of the candidate fuel will be compared to those of the baseline fuel. This comparison demonstrates that automatic gauging systems will operate in the candidate fuel to the same level of performance as that found when operating in the baseline fuel. In addition, the performance of any automatic gauging or metering systems used in the storage of the candidate fuel during the fuel certification process needs to be examined closely and demonstrates operational capability with the candidate fuel.

H.5.3 Long term storage evaluation. The candidate fuel should not be adversely affected by long term storage in a storage tank or pipeline. This evaluation considers water solubility, water separation (without loss of key chemical components of the base fuel) as well as degradation of key fuel properties such as conductivity, lubricity, etc. Phase separation of blended fuels is not acceptable during any long term storage test regardless of water concentration.

Appendix C.38 addresses the formation of gums and peroxides due to long term storage of fuels referencing ASTM D5304 and ASTM D3703 respectively. Both of these standards include guidance on "accelerating" the aging process by increasing temperature and pressure during the test. The fuel exposed to this "aging" process should be evaluated for change in the additional properties listed above. This procedure can also be modified to include changes in the storage system (i.e. the standard procedure uses a glass container; options could include using a coated steel container during the exposure period.)

H.5.4 Microbial growth and microbially induced corrosion evaluation. The candidate fuel should not be susceptible to growth of bacteria or other microbial growth that can affect fuel quality or the integrity of the fuel storage and distribution systems. This evaluation should include comparison of the propensity for microbial growth in the candidate fuel compared to the baseline fuel, including consideration for the most common bacteria known to create internal corrosion in carbon steel storage systems. (Reference Paper: "Characterization of microbial contamination in United States Air Force aviation fuel tanks"; Michelle E. Rauch, Harold W. Graef, Sophie M. Rozenzhak, Sharon E. Jones, Charles A. Bleckmann, Randell L. Kruger, Rajesh R. Naik and Morley O. Stone; published 2004)

H.5.5 Subset 2 criteria evaluation. The System Manager will determine if the candidate fuel meets or fails to meet the requirements described above. The results of this second subset testing and evaluation will be documented by the FCO or System Manager.

H.6 SUBSET 3 TESTING.

H.6.1 Fuel storage and delivery system demonstration. Based upon the results of the previous evaluations made under Subsets 1 & 2, a full scale demonstration of any affected component or system should be developed to completely evaluate the impact of the candidate fuel. The full scale test should target specific effects anticipated from the candidate fuel.

Typical fuel storage and delivery systems represent an assembly of various components such as pumps, valves, tanks and piping. The candidate fuel needs to be compatible with these systems and their operation over extended periods of time and during multiple fuel transfer operations. This compatibility needs to match or exceed that which is demonstrated by the use of the baseline fuel in the same systems or components.

A demonstration of this compatibility is accomplished through the extended operation of a system that imitates an operational environment using the candidate fuel. During this demonstration, each of the system components will be monitored for any sign of incompatibility due to the candidate fuel. An example of full scale testing would be to perform filtration testing with full scale multi-element filter/separator systems as opposed to the single element tests performed under Subset 1.

H.6.2 Subset 3 criteria evaluation. The System Manager will determine if the performance of the candidate fuel is acceptable with regard to fuel storage and delivery systems as described in the results of this Subset 3 testing and evaluation will be documented by the FCO or System Manager.

TABLE H-I. Nonmetallic material compatibility tests (fuels infrastructure materials, extracted from Table D-I).

Material	Description	Spec	Soak Temperature	Test	Test Procedure	Evaluation Criteria: Min Rqmt	Evaluation Criteria: Allow Variation
Hose (ground refueling)	Nitrile	EI 1529	160 °F	Tensile Strength Elongation Hardness, Shore A Volume Swell Solubility	ASTM D412 (D471) ASTM D412 (D471) ASTM D2240 ASTM D471 ASTM D471	>1200 psi 150% ±5 pts fm unaged <10%	± 10% ± 10% ± 5 pts ± 10% ± 10%
Gasket	Nitrile seal/ Phenolic		160 °F	Tensile Strength Elongation Hardness, Shore A Volume Swell Solubility	ASTM D1414 (D471) ASTM D1414 (D471) ASTM D2240 ASTM D471 ASTM D471	>1000 psi >150% ±5 pts fm unaged <10%	± 10% ± 10% ± 5 pts ± 10% ± 10%
Surge Suppressor Bladder	Niltrile		160 °F	Tensile Strength Elongation Volume Swell Solubility	ASTM D412 (D471) ASTM D412 (D471) ASTM D471 ASTM D471	>1500 psi >300% <25%	± 10% ± 10% ± 10% ± 10%

TABLE H-I. Nonmetallic material compatibility tests concluded (fuels infrastructure materials, extracted from Table D-I) - (Continued).

Material	Description	Spec	Soak Temperature	Test	Test Procedure	Evaluation Criteria: Min Rqmt	Evaluation Criteria: Allow Variation
Control Valve Diaphragm	Nitrile		160 °F	Tensile Strength Elongation Volume Swell Solubility	ASTM D412 (D471) ASTM D412 (D471) ASTM D471 ASTM D471	>1500 psi >300% <25%	± 10% ± 10% ± 10% ± 10%
Control Valve Diaphragm	FKM (Viton)		160 °F	Tensile Strength Elongation Volume Swell Solubility	ASTM D412 (D471) ASTM D412 (D471) ASTM D471 ASTM D471	>1500 psi >300% <25%	± 10% ± 10% ± 10% ± 10%
Material	Description	Spec	Soak Temperature/ Duration	Test	Test Procedure	Evaluation Criteria: Min Rqmt	Evaluation Criteria: Allow Variation
Floating Roof Wiper Seal	Urethane		160 °F /28 days	Tensile Strength Elongation Hardness, Shore A Volume Swell Solubility	ASTM D412 (D471) ASTM D412 (D471) ASTM D2240 ASTM D471 ASTM D471		± 10% ± 10% ± 5 pts ± 10% ± 10%

TABLE H-I. Nonmetallic material compatibility tests concluded (fuels infrastructure materials, extracted from Table D-I) - (Continued).

Material	Description	Spec	Soak Temperature	Test	Test Procedure	Evaluation Criteria: Min Rqmt	Evaluation Criteria: Allow Variation
Secondary Containment Flexible Membrane Liner	Elvalloy Coated fabric	UFGS 33 56 13.13	160 °F /28 days	Tensile Strength Adhesion Volume Swell Change in Mass	ASTM D751(Grab) ASTM D751 ASTM D543 ASTM D471	>1,000 lbs 20 lbs ± 15% ± 10%	± 10% ± 10% Same as JP8 Same as JP8
Collapsible Fuel Tank Material	Polyurethane coated fabric	MIL-T-52983	160 °F /28 days	(coating only) Tensile Strength Elongation Adhesion Volume Swell (coasted fabric) Adhesion	 ASTM D412 ASTM D412 ASTM D543 ASTM D471 FED-STD-191	 >1,500 lbs 300% ± 15% ± 25% 30 lb/in	 80% retained 80% retained Same as JP8 Same as JP8 ± 50%
Bulk Tank Interior Coating	Epoxy – Polyamide	MIL-DTL-24441	120 °F / 28 days	Hardness (Pencil) Adhesion	ASTM D3363 FED-STD-141	>= unaged Pass	1 pt decrease

APPENDIX I

RISK ASSESSMENT RESULTS

(Reserved)

For the fuels certified thus far, each system management organization performed its own risk assessments of the candidate fuels it was asked to certify for the systems they managed. Because of the wide varaiety of assessments and the sensitivity of some the data used to support them, whether limited distribution or proprietary, it is not feasible to provide a meaningful public releasable version of the results of a specific assessment and a generalized summary would just duplicate the process described in this handbook. For those reasons this appendix is shown as reserved.

APPENDIX J

CERTIFICATION LESSONS LEARNED

J.1 SCOPE

J.1.1 General. This Appendix provides a set of lessons learned during the certification process. Additional details regarding origin and contact information may be obtained by contacting the FCO/System Manager.

J.2 APPLICABLE DOCUMENTS

J.2.1 General. The documents listed below are not necessarily all of the documents referenced herein but are considered to be those which are most important in providing the user an understanding of the information provided by this Appendix.

J.2.2 Government documents.

J.2.2.1 Government specifications, standards, and handbooks.

UNITED STATES AIR FORCE INSTRUCTION (AFI)

AFI 90-1601 Air Force Lessons Learned Program - 22 September 2010

(This AFI is available on line at www.e-Publishing.af.mil.)

J.3 DEFINITIONS

J.3.1 Alphabetical listing of terms and definitions.

Capitalize: Capitalized fuel: DLA Energy owned bulk petroleum products from the point of purchase until their final point of issue to aircraft, ships, and ground equipment.

Inter-modal containers: Container or vehicle, using multiple modes of transportation (rail, ship, and truck), without any handling of the fuel itself when changing modes.

FT: Fischer-Tropsch

Refueler: Mobile refueling vehicle

SCAT: Self-Contained Above-ground Tanks

SPK: Synthesized Paraffinic Kerosene

Vitalic Coupler: Fuel system component

J.4 SELECTION CRITERIA

A set of selection criteria was developed to screen potential lessons learned (LL) for inclusion in this handbook. This set is depicted on Figure J.1.

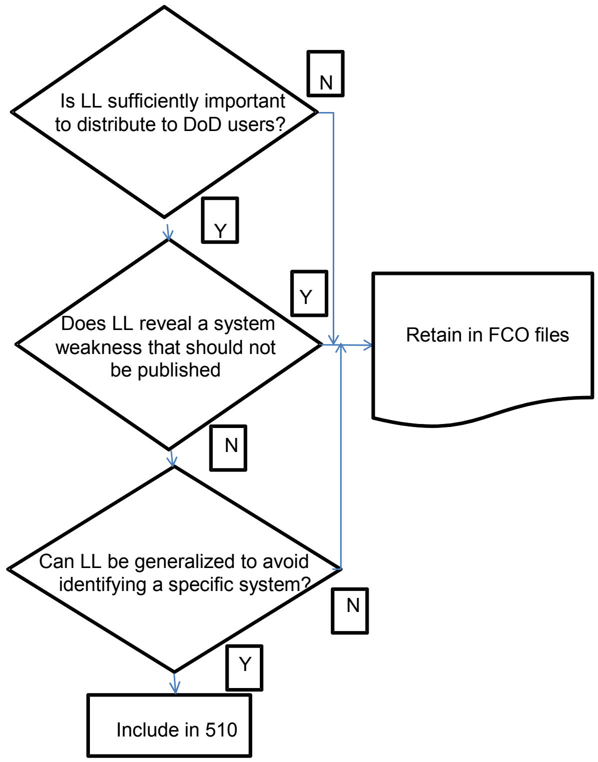

FIGURE J-1. Lessons learned selection criteria.

J.5 LESSONS LEARNED

The following is a listing of the lessons included herein:

J.5.1 Direct measurement of critical characteristic

J.5.2 Specification for and acquisition of the synthetic fuel component – JP 8 correspondence.

J.5.3 Establish baseline JP-8 test first

J.5.4 Change only one variable from a previous baseline.

J.5.5 Assure certification testing relates to field usage.

J.5.6 Fuel specification maximum viscosity limit.

J.5.7 Adjusting the evaluation aircraft's fuel gauging system.

J.5.8 Engine re-trim between fuel tests

J.5.9 Combining engine test assets and test projects at a common site

J.5.10 Incorporating a drop-in fuel certification candidate in the baseline fuel specification

J.5.11 Authority to Task

J.5.12 Test Fuel Logistics

J.5.1 Direct measurement of critical characteristic

EVENT NAME: Test of a 50/50 blend of Fischer-Tropsch (FT) Synthesized Paraffinic Kerosene (SPK) and JP-8.

OBSERVATION: A direct calibration of the critical characteristics of a candidate alternative fuel can more precisely define any correction factors to fuel quantity readings, needed to safely operate a test aircraft.

DISCUSSION: During a test of a blend of FT SPK and JP-8 there was concern over the effect of this fuel, its density, and its dielectric characteristics on the accuracy of the fuel quantity measuring system of the aircraft into which it was being loaded. The gauging system was calibrated by incrementally filling the fuel tanks with measured volumetric quantities of fuel (gallons) calculating the weight of each increment by multiplying by density (a function of fuel temperature), adding the result to the total for the previous increments and comparing the results with the output of the aircraft fuel quantity system (pounds). The resulting data showed some unusual characteristics, which may have been due to errors in measuring quantities or temperatures or analyzing the measured results.

LESSON LEARNED: A more direct calibration would have been possible by measuring the weight of the aircraft at least at the two endpoints of the fueling operation – when empty and when filled to the final level – and comparing the difference in those measured weights with the change in fuel quantity indicated by the quantity measuring system. Such a direct calibration could have more precisely defined any correction factors to fuel quantity readings needed to safely operate the aircraft and potentially avoided the 2% added fuel used in subsequent operations because of the quantity system uncertainty during the operations with the FT SPK/JP-8 blend.

J.5.2 Specification for and acquisition of the synthetic fuel component – JP-8 correspondence.

EVENT NAME: Low Density Fuel Batch

OBSERVATION: Both the requirement definition (specification) and the resulting purchase of fuel, fuel component, or additive to be used for the certification process of the systems for which it is intended needs to be carefully controlled. When a new fuel candidate is ready for certification by the Single Managers of the systems on which it is to be used, a quantity of fuel needs to be purchased for testing and demonstrations related to those certification efforts. The specification for a new fuel, fuel component, or additive should clearly define those properties that are critical and prevent introduction of undesirable characteristics (e.g., contaminants, unusual distributions of molecular constituents, etc.). Once the critical parameters have been defined, these need to be included in the specification used to purchase the fuel, fuel component, or additive. Further, the purchase of fuel or additive quantities for system certification should adhere to that specification without waivers.

DISCUSSION: A batch of FT SPK fuel, purchased in FY2007 as components of a fuel blend of 50% FT SPK and 50% JP-8, was used for certification testing of the blend. The FT SPK was low in density, partially due to the refinery producing a distribution of hydrocarbon molecules more heavily concentrated in the smaller molecules. The density was low enough that it did not meet the specification to which it was purchased, and the fuel batch was accepted on waiver. When mixed with JP-8, the blend was just within the JP-8 specification limits. However, because of the low density, additional analysis and review was required for both engine and aircraft fuel system tests for several weapon systems in order to determine if this characteristic would affect the test results and the resulting certification.

LESSON LEARNED: To prevent recurrence of this problem, the specification for the FT SPK component was revised to include a distillation curve that will yield a distribution of molecule sizes more similar to that for JP-8, the baseline fuel. This extra work and uncertainty incurred could have been avoided if the specification for the test fuel had been sufficiently specific and if the specification had been adhered to during the purchase.

J.5.3 Perform baseline fuel test first

EVENT NAME: Test system deficiencies obscure fuel test results

OBSERVATION: When conducting tests of candidate fuels, baseline fuel tests should be conducted first to clearly establish the test unit's characteristics and any shortcomings.

DISCUSSION: As a result of trying to improve engine test efficiency, the FT SPK blend candidate fuel was tested before the JP-8 baseline was tested. These initial FT SPK test results did not meet the engine start envelope or the afterburner light-off envelope. It was only after the baseline JP-8 testing was subsequently performed that the problem was determined to be due to the engine hardware not meeting the specification envelopes. Test results were the same for both fuels. However, initial reports had quickly been circulated that the FT SPK fuel did not meet specification requirements implying incorrectly that it was not as good as JP-8. These initial reports went quickly to very high levels in the USAF and widely outside of the USAF and required much time and effort to completely turn around.

LESSON LEARNED: Always establish the current fuel's baseline characteristics and its test results prior to testing with any new fuel or fuel additive.

J.5.4 Change only one variable from a previous baseline.

EVENT NAME: High Temperature Corrosion Test

OBSERVATION: When conducting ground tests of candidate fuels it is important to change only one variable from the previously established baseline.

DISCUSSION: A high temperature corrosion test was run on several metal coupons with various coatings. The test results were expected to be benign but proved otherwise. These initial test results were quickly circulated and appeared to condemn the FT SPK fuel blend. After looking at the details of the test, it was determined that the previous baseline had been established with Jet A-1 fuel rather than JP-8 (which includes the military fuel additives). Subsequent re-tests with JP-8 cleared the FT SPK blend but it took a lot of time and much effort to correct the widespread initial misinformation. The two variables that were changed were: 1) testing with JP-8 (which has additives that Jet A-1 did not on previous testing) and then blending with 2) FT SPK, a fuel previously untested in this rig.

LESSON LEARNED: When performing tests, change only one variable from the previous baseline to clearly determine its sole effect.

J.5.5 Assure certification testing relates to field usage.

EVENT NAME: High Temperature Corrosion Test

OBSERVATION: When running a test, make sure the test can be related to field usage.

DISCUSSION: A high temperature corrosion ground test was run; however, the results could not be correlated to field operation. The test appeared to be extremely severe compared to field usage and was therefore of little or no value. In fact, the test only raised concerns about long-term warranty issues, but the manufacturer has not been able to clearly correlate test results to previous field return hardware conditions.

LESSON LEARNED: Fuel certification testing should relate to field usage.

J.5.6 Fuel specification maximum viscosity limit.

EVENT NAME: Critical weakness in fuel specification identified

OBSERVATION: MIL-DTL-83133 and ASTM D1655 (i.e., the commercial Jet A and Jet A-1 specification) define the maximum fuel viscosity at -20°C. A more realistic temperature at which to define maximum fuel viscosity is -40°C, consistent with the potential operational temperature at which some engines and auxiliary power units are required to start in flight.

DISCUSSION: One of the most challenging conditions at which a turbine engine, be it a propulsion engine or an auxiliary power unit (APU), may be the requirement to start at high altitude in-flight conditions. This is especially challenging for APUs, which generally do not windmill and which may be cold-soaked in their non-operating condition during high altitude flight. Not only is the air thin, providing poor conditions for air-blast to assist fuel-air mixing, but the APU cold soak at close to the in-flight recovery temperature (i.e., just slightly lower than in-flight total temperature) may be very close to the fuel freezing point, at which viscosity is high enough to inhibit the formation of the small droplets which are crucial for combustor light-off. The engine OEM identified a critical weakness in the fuel specifications (for JP-8, Jet A, and Jet A-1), which limit maximum viscosity at a temperature of -20^{0}C, rather than the more realistic -40^{0}C. The latter is much more representative of the actual flight conditions at which engine and APU starting may be required in response to in-flight emergencies.

The specification maximum viscosity limit for JP-8, Jet A, and Jet A-1 is 8 mm^2/sec at -20^{0}C. The engine OEM recommends specifying a maximum viscosity limit of 12 mm^2/sec at -40^{0}C, based on the in-flight starting requirement and the fuel droplet size distribution needed to ensure combustor light-off.

The Russian TS-1 jet fuel specification requires a more conservative 8 mm^2/sec maximum viscosity at -40^{0}C.

LESSON LEARNED: Some current engine and APU designs require starting capability with fuels whose undefined viscosity at temperatures below -20^{0}C can significantly affect their starting capabilities. This could call into question the ability of these systems to start with an approved fuel whose cold-temperature viscosity is unusually high. To alleviate this uncertainty, it may be appropriate when updating the fuel specifications, to consider adding a maximum viscosity limit at -40^{0}C to better control the fuel's influence on engine and APU designs and to improve the likelihood that these systems will be able to start consistently at temperatures colder than -20^{0}C.

J.5.7 Adjusting the evaluation aircraft's fuel gauging system.

EVENT NAME: Field service evaluation of a blend of Fischer-Tropsch synthesized paraffinic kerosene (FT) and JP-8 on the F-15 aircraft.

OBSERVATION: Misunderstandings or ineffective communication between involved parties can lead to unintended and/or unnecessary system adjustments and cause inaccurate results.

DISCUSSION: During a field service evaluation of a blend of FT SPK and JP-8, there was concern over the effect of this fuel's lower density characteristics on the accuracy of the F-15 aircraft's fuel quantity measuring system. The F-15's fuel gauging system was designed to be adjustable to account for the density difference between JP-4 and JP-8 fuel. At the beginning of the evaluation period, the maintenance group adjusted the evaluation aircraft's gauging system to reflect the density of this new fuel. This was not the intention of the evaluation team. The evaluation was intended to be a direct comparison of the system's performance without recalibration between JP-8 and JP-8/SPK. Additionally, the unnecessary calibration adjusted the system to the wrong fuel density, that of the "neat" (100%) SPK fuel, rather than the density of the blended fuel. This mistaken adjustment resulted in intermittent fuel tank weight indication inaccuracies during flight. Once the system was recalibrated to the correct fuel density, within the JP-8 limits, no further reports of inaccuracies occurred.

LESSON LEARNED: Communication between all parties in a test or evaluation can be critical. In this instance, a maintenance procedure was performed because the users had received incomplete information about the density of the fuel and believed that an adjustment was needed and/or desired. Evaluations of new fuels need to be direct "apples to apples" comparisons with JP-8 in order to obtain useful results. System adjustments or settings outside of those used for standard JP-8 operations are not recommended. This point should be clearly stated in all test plans and Memorandums of Agreement/Understanding and in detailed instructions to maintenance and ground crew personnel.

J.5.8 Engine re-trim between fuel tests

EVENT NAME: Avoid engine re-trims in between back-to-back fuel tests.

OBSERVATION: Re-trimming an engine's performance level in between fuel tests with two different fuels will mask the effect of the fuel change.

DISCUSSION: Flight testing by a flight test organization was needed to support certification of the T-38 to use JP-8/SPK. The testing included starting with JP-8 to establish a baseline for the systems performance and operating characteristics. This was followed by a repeat of the same tests using the JP-8/SPK synthetic fuel blend. A direct comparison of the system's performance and operating characteristics could then be made to determine the new fuels acceptability. This is the standard approach which has been used on numerous engine and aircraft tests by the USAF's Alternative Fuels Certification Division and has been proven very efficient and successful. The ultimate objective for the new fuel is that it should be a drop-in replacement fuel equal to JP-8 and that it will ultimately be transparent to users whether they have JP-8 or JP-8/SPK in their aircraft. With this objective in mind, the systems undergoing evaluation have been restricted from making adjustments to specific gravity settings on engines and restricted from re-calibrating the aircraft's fuel tank gauging systems. However, the flight test organization's personnel took the position that "they could not knowingly fly an engine that was out of trim" and required the engine to be re-trimmed if ground test cell testing showed it to be out of trim when using the JP-8/SPK blend. After flying the JP-8 baseline flights, the flight test organization re-trimmed both T-38 engines and performed the JP-8/SPK flights. During subsequent analysis of the flight test data it became clear to the flight test organization that the engine re-trims had totally obscured the effects of the fuel change.

During their final briefing on the T-38 flight test, the flight test organization recommended that additional T-38 flight testing be performed with JP-8/SPK but without re-trimming the engines after the JP-8 baseline flights. Because of cost, schedule, fuel availability, test asset availability, and organizational performance issues, this recommendation could not and was not implemented.

LESSON LEARNED: When performing a test, if the effect of one variable being changed is sought, then no other changes to the system under test should be made after the baseline has been established. In this case, two variables were changed: one was the fuel and the second was the performance level of the engines (via re-trim). Since the system responded to the two changes, however, the effects attributable to just the fuel change could not be separated from the total system response. In test planning and test implementation efforts for comparative evaluations of changes (e.g., to fuel, to hardware, etc.) which involve engines which can be trimmed; ensure that test points which are to be compared are run with unchanged trim settings.

J.5.9 Combining engine test assets and test projects at a common site

EVENT NAME: Piggybacking Alternative Fuel Tests

OBSERVATION: In order to obtain adequate quantitative engine data, it may be necessary to test a turbine engine in a ground test facility. In many cases a ground test using a facility that simulates a wide range of altitudes, flight velocities, and inlet temperatures is preferred to a flight test because the test conditions can be controlled more accurately than with a flight test. Another advantage to ground testing is that the test conditions are more stable and can be maintained longer so that the engine becomes stabilized and thus reduces the uncertainty of the data. In addition, for augmented engines, stabilization times while in augmentor are limited in flight test due to the limited amount of fuel that is carried onboard the aircraft, whereas for a ground test, the fuel constraint is less severe since the fuel available for a test period will be greater. The downside to a ground test is having a test asset available in the desired time frame. Once a suitable test asset is identified, additional project costs occur due to the cost of shipping the engine to the test site, installing test instrumentation on the engine, installing the engine in the test cell, then removing the engine from the test cell, removing the instrumentation from the engine, and returning the engine to the user.

DISCUSSION: The USAF's former Alternative Fuels Certification Division (AFCD) had worked with several engine Program Offices and the engine OEMs to locate a suitable test asset. This usually results in the use of a spare engine that has been recently refurbished, and obtained from an active Air Force base. The AFCD had then coordinated with the user, the Program Office, and OEM to ship the engine to the test site, usually Arnold Engineering Development Center. It can take from four to six weeks to transport, instrument, and install the engine in the test cell. If a test asset that is already scheduled for testing, or is currently being tested, can be identified, then the pre-test time, preparation, and expense are eliminated. In most cases, the amount of test time required for the alternative fuel can be accomplished in two test sessions, and in many instances no additional testing with baseline fuel is necessary since data at the desired test conditions already exists, thus saving test time and costs.

LESSON LEARNED: Whenever possible, an existing test program and test asset should be utilized for ground tests. It is usually easier and quicker to modify an existing test plan and test support contract to add additional testing, than it is to arrange for the use of a field engine to be shipped in and used for ground tests.

J.5.10 Incorporating a drop-in fuel certification candidate in the baseline fuel specification

EVENT NAME: Drop-In Fuel Candidate Incorporated within a Formal Military Specification

OBSERVATION: A valuable part of the certification evaluation of a drop-in fuel is the demonstration and evaluation of its use in operational systems at other than the formal flight test centers (e.g., operational assessments or field service evaluations). Without special waivers and approvals, only a fuel identified in a formal flight-manual-recognized specification is authorized to be used on operational (versus flight test) systems.

DISCUSSION: The ultimate objective for a drop-in fuel is to include the specification for the blend component as a normal, but optional, part of the definition of fuel identified as the baseline fuel (e.g., just “JP-8”). This would be accomplished via a change to a specification like JP-8’s MIL-DTL-83133. Such a change requires agreement by all of the US DoD military services that the new drop-in fuel is acceptable to them all. That level of change takes time, participation, and agreement by all of the services, a process which may not be sufficiently timely for any one of the services’ required or desired use of the fuel during the certification program.

To allow operational use of a certification candidate fuel during the certification program, the baseline fuel’s specification can be changed to incorporate the required characteristics of the candidate fuel and to require that use be approved by both the procuring activity (DLA Energy) and the fuel technical authority (as identified in the specification) of the affected military Service. That specification can be used to define the product to be procured and its associated quality assurance. Further, the specification can be used to apply a unique temporary identifying nomenclature to the candidate fuel to assist with keeping it segregated from the normal military fuel supply system (Section 4.6). This is what was done for the Fischer-Tropsch fuel blends, which were identified as “JP-8/SPK” in the JP-8 specification, MIL-DTL-83133F. Its properties were specified both for the non-petroleum blend component and for the resulting blend of up to 50% with JP-8. The procuring activity (DLA Energy) with the fuel technical authorities of each of the military services (identified in the specification) was given authority to allow or forbid the fuel’s use for their services. This allowed JP-8/SPK to be used in testing during the certification effort, and it allowed its operational use in field service evaluations in certified systems once that certification had been documented by the applicable Single Managers and the authorization to use fuel with that designation was incorporated via operational supplements to the operational technical orders (e.g., the Flight Manuals) for the certified systems.

A slightly different approach was used for the drop-in JP-8/HRJ (HEFA) fuel certification. The revised version of the JP-8 specification, MIL-DTL-83133H, specified the needed properties of both the HRJ (HEFA) blending component and the blended fuel. It required approval for use from the procuring activity (DLA Energy) and the applicable fuel technical authority for each of the services listed in the specification, if it was to be used; but it left the nomenclature of the fuel unchanged: ”JP-8,” i.e., there was no temporary identifier for the HRJ-blend. This simplified operational use for flight demonstrations and a field service evaluation because it did not require technical order supplements for the aircraft involved. Since availability of certification fuel was limited and under strict control of the applicable technical authority within each Service, each Service could adequately control use and ensure that the using systems were properly certified and the fuel was appropriately handled and segregated from the baseline fuel defined in the specification.

LESSON LEARNED: Incorporation of the specification requirements for a drop-in fuel candidate with special defined controls over its use in the baseline fuel specification can simplify its operational use during the certification program, prior to full incorporation in the specification without usage controls at the completion of certification.

J.5.11 Authority to Task

EVENT NAME: Authority to Task

OBSERVATION: After the establishment of the Air Force’s Alternative Fuels Certification Office (AFCO) within the Air Force Materiel Command’s Aeronautical Systems Center in August 2007, it was realized that the job of certifying alternative fuels for fleet-wide Air Force use required the participation of a large number of other Air Force organizations including significantly the System Manager’s organizations which would be required to certify their systems for the use of the candidate fuel as evidence for the justification for the “fleet-wide certification” of the fuel, which is formalized by incorporating the candidate fuel into the JP-8 specification (MIL-DTL-83133). Because those managing organizations have significant work to accomplish which does not involve evaluating candidate alternative fuels, and even though their fuel evaluation efforts would be reimbursed with funding from outside their normal budgets by the fuel certification organization, it was unlikely that these organizations would be responsive to taskings from the fuel certification organization without formal direction.

DISCUSSION: Because the establishment of the Alternative Fuel Certification Office (AFCO) was directed by the Secretary of the Air Force, there was significant support for the program from the Secretary’s staff organizations. The most direct in the chain of command to the system managers was the Assistant Secretary of the Air Force for Acquisition (SAF/AQ). A memorandum of direction to the Air Force’s acquisition organizations was prepared and provided to SAF/AQ for signature. The staff summary sheet and attached memorandum are shown on Figures J-2 and J-3 respectively. The memorandum authorized the AFCO to task Air Force acquisition and sustainment organizations to participate in the evaluation and certification of alternative fuels.

When the opportunity arose to certify biomass-derived alternative fuels, a second memorandum was requested and was provided by SAF/AQ directing the accomplishment of a biomass alternative fuel certification program and again authorizing the AFCO to task acquisition and sustainment organizations to participate in it (Figure J-4).

With these memoranda, AFCO was able to get the support of the necessary organizations. In most cases that support was immediate and outstanding. For some organizations, wartime commitments made it difficult to respond immediately, and evaluation activities were delayed to minimize impacts on those commitments. Eventually, however, all participated as required.

STAFF SUMMARY SHEET

	TO	ACTION	SIGNATURE (Surname), GRADE AND DATE		TO	ACTION	SIGNATURE (Surname), GRADE AND I
1	SAF/AQI	COORD	Gerner, Col, 11 Dec 07	5	SAF/IEE	COORD	Bollinger, Civ, 13 Dec 07
2	SAF/AQR	COORD	Jaggers, SES, 10 Dec 07	6	AF/A4/7P	COORD	Graham, SES, 6 Dec 07
3	SAF/AQQ	COORD	Gray, Maj Gen, 7 Dec 07	7	SAF/AQ	SIGN	A Payton 12/18/07
4	SAF/AQX	COORD	Durante, SES, 13 Dec 07				

SURNAME OF ACTION OFFICER AND GRADE	SYMBOL	PHONE	TYPISTS INITIALS	SUSPENSE DATE
Major Nathan Elliott	SAF/AQPC	703-588-6475	nje	20071214

SUBJECT	DATE
AQP071130-2: Direction to Support Alternative Fuels Certification Office Efforts	20071130

SUMMARY

1. Purpose. Obtain SAF/AQ direction for all Single Managers (SMs) to support efforts of the 77th Aeronautical Systems Wing's Alternative Fuels Certification Office (AFCO). In addition, request SAF/AQ authorize AFCO to task SMs with respect to current and future certification activities.

2. Background. AFCO stood up in Aug 07 to support the SECAF's Assured Fuels Initiative. The mission AFCO is to manage the certification of alternative fuels for use in all USAF aircraft, supporting equipment, and base-level fuel delivery systems. SECAF has identified the first fuel to be certified as a 50/50 synthetic and JP-8 blend and required fleet-wide certification be completed NLT Dec 2011.

3. Discussion. In an effort to expedite this project, AFCO has provided informational "Kick-Off" briefings all AFMC Logistics Centers and the Aeronautical Systems Center. The briefings explain that each SM will need to perform an end-to-end analysis of their respective systems to determine potential areas that might b affected by the introduction of the new fuel. Based on the results of these analyses, AFCO will formulate a all-encompassing program designed to identify and complete all testing/analysis required for individual syst certification. While AFCO will manage the overall effort, actual system certification responsibility will be retained by the SM. FY08 activities are being funded through $6.5M in the Aging Aircraft Program Eleme A new Program Element (PE), 64796F, is being created by transferring funds in FY09-13 from Aging Aircr Engine CIP, and Logistics Operations. AFCO will have $176.456M in the new PE to fund this effort. AQF has been designated the Program Element Monitor for this PE.

4. Recommendation. Sign memorandum (Tab) granting AFCO the authority to task SMs.

//Signed//
MARK D. SHACKELFORD, Maj Gen, USAF
Director, Global Power Programs
Assistant Secretary (Acquisition)

Tab
Proposed SAF/AQ Memo

Tab - Draft AQ AFCO Memo.doc

AF IMT 1768, 19840901, V5 PREVIOUS EDITION WILL BE USED

FIGURE J-2 Authority to Task Memo Staff Summary Sheet.

DEPARTMENT OF THE AIR FORCE
WASHINGTON DC 20330

OFFICE OF THE ASSISTANT SECRETARY

20 DEC 2007

MEMORANDUM FOR ASC/CC, ESC/CC, WR-ALC/CC, OO-ALC/CC, OC-ALC/CC

FROM: SAF/AQ

SUBJECT: Certification of Alternative Fuels

On several occasions, the President has pointed out the economic and national security risks of our dependence on foreign oil. As a result, SECAF determined that development of domestic, alternativ fuels is essential for the Air Force to continue to provide sovereign options in the defense of our country As the single largest user of aviation fuel in the federal government, it is critical that we expand the diversity of domestic fuels enabling us to fly, fight and win in the future.

In August of 2007, the Air Force Materiel Command formally stood up the 77th Aeronautical Systems Wing's Alternative Fuels Certification Office (AFCO) in direct support of the Secretary of the Air Force-championed Assured Fuels Initiative. The purpose of AFCO is to manage the certification efforts for using various alternative fuel stocks in all USAF aircraft, associate support equipment, and delivery infrastructure. To accomplish this tasking, the AFCO will work closely with platform single managers to provide certification process guidance, assist in system assessments and data collection. Single managers will retain all responsibility and authority for certification of their individual systems. The AFCO will, on behalf of the Air Force Program Executive Officer for Aircraft, provide overarching direction, distribute funding, coordinate non-platform specific activities (e.g. engine testing), and facilita data sharing to streamline the overall effort.

The first alternative fuel identified for platform certification is a synthetic blend consisting of 50% Fischer-Tropsch (FT) synthetic fuel and 50% JP-8. The SECAF has established that all certificatio actions for this fuel type be completed by early 2011. In addition, the SECAF has stated that the Air Force will acquire 50% of its CONUS fuel by 2016 from domestic, alternative fuel sources producing fu in an environmentally friendly manner, to include capture and effective reuse of CO2.

I hereby direct all USAF single managers and supporting organizations to provide their support and respond to taskings or data requests related to the certification of alternative fuels issued by the AFCO. Please direct any questions to the AFCO Director, Mr. Jeff Braun, 77AESW/AFCO, at DSN 67 4302, or COM. (937) 904-4302. The Alternative Fuels POC and PEM within SAF/AQ is Major Nathan Elliott, SAF/AQPC, DSN 425-6475.

SUE C. PAYTON
Assistant Secretary of the Air Force
(Acquisition)

FIGURE J-3 Initial Authority to Task Memorandum.

DEPARTMENT OF THE AIR FORCE
WASHINGTON DC 20330

OFFICE OF THE ASSISTANT SECRETARY

FEB 26 2009

MEMORANDUM FOR ASC/CC, ESC/CC, WR-ALC/CC, OO-ALC/CC, OC-ALC/CC

FROM: SAF/AQ
1060 Air Force Pentagon
Washington DC 20330-1060

SUBJECT: Biomass Alternative Aviation Fuel Certification Effort

Expanding upon the principles of the Energy Policy Act of 2005, the SECAF established a goal of early 2011 for the complete certification of aircraft, applicable vehicles and support equipment, and associated storage and distribution infrastructure for unrestricted operational use of a fuel blend consisting of up to 50% Fischer-Tropsch (FT)-derived alternative fuel and 50% JP-8. To meet this challenge, I directed all USAF single managers and supporting organizations to provide their support and respond to taskings or data requests from the Alternative Fuels Certification Office (AFCO) related to this initial certification effort (Certification of Alternative Fuels Memo, 20 Dec 07). Program Management Directive 07-006(1), 30 Apr 08, directed the AFCO to manage certifications of USAF platforms for unrestricted operational use of alternative fuel blends. To date, our collective efforts have resulted in certification of the B-52, C-17, and B-1 aircraft and almost all applicable vehicles and support equipment. Additionally, current certification activities for all other platforms remain on schedule and within budget.

The SECAF also established a goal for the USAF to be prepared to competitively acquire 50% of its domestic aviation fuel requirement from alternative domestic fuel components and blends by 2016. While current certification efforts have been quite successful, meeting this important energy goal requires us to certify our platforms to use additional types of alternative aviation fuel blends.

I direct the initiation of a biomass alternative aviation fuel certification effort, to be accomplished utilizing existing (FY09-11) alternative fuels program funding. The biomass fuel selected for this effort must be environmentally and technologically compatible with established USAF alternative aviation fuel and environmental standards. I further direct all USAF single managers and supporting organizations to provide their support and respond to taskings or data requests related to the certification of any biomass alternative aviation fuel issued by the AFCO. Not later than 31 Jul 09, I direct the AFCO to brief the SAE on accomplishments and the way forward to meeting the SECAF goal for 50% domestic fuel components by 2016

Please direct questions to the AFCO Director, Mr Jeff Braun, 77AESW/LF, DSN 674-4302 or Comm (937) 904-4302. The Alternative Fuels Program Point of Contact within SAF/AQ is Maj Kevin Sellers, SAF/AQPC, DSN 425-6475.

Sue C Payton

SUE C. PAYTON
Assistant Secretary of the Air Force
(Acquisition)

FIGURE J-4 Biomass Alternative Fuel Program Authority to Task Memorandum.

LESSON LEARNED: Having the authority to task is a critical enabler for a fuel certification organization to get the support it needs from key responsible supporting organizations to achieve the certification of candidate fuels in a reasonable period of time. Even so, the priority of military necessity may result in some delays of the testing and needs to be accommodated in the planning and execution of the certification program to minimize impact on the warfighters.

J.5.12 Test Fuel Logistics

EVENT NAME: Purchasing and managing the fuel needed for testing.

OBSERVATION: The need to purchase, store, dispense, and account for test fuel provides significant challenges and requires significant effort from the fuel certification or evaluation organization. The requirement to keep unapproved fuel separate from the normal fuel supply system is the source of many of the challenges of managing test fuel for a certification or evaluation program. Segregation of the fuel has two main objectives: 1) avoiding the contamination of the normal fuel supply, and 2) to ensuring the integrity of the test object – the fuel – i.e., knowing and controlling what is being tested.

DISCUSSION: Dealing with test fuel in 55-gallon drums is relatively easy for storage and transportation, but can produce problems when the neat candidate blending component has to be blended to its intended blend ratio with other fuels (like petroleum-derived JP-8, JP-5, or Jet A), especially if the test requires multiple drums. Care needs to be taken to make a blend as homogeneous as possible within the blending container and as consistent as possible between blendings for the same test or test series. Test quantities larger than what could be handled by drums provide additional challenges, with special care needed to ensure cleanliness of the tank or tanks used and to avoid contamination of the test fuel.

LESSONS LEARNED:

Purchase of Fuel

- Use DLA Energy to purchase large volumes to test fuel (tanker-truck load quantities).

- Establish a DODAAC account if it is necessary to pay for any needed already-spec-approved fuel for blending with a candidate blending component.

Fuel Transportation

- Set up and fund an account with DLA Energy ahead of time to pay for transportation costs of multiple fuel movements or send funding for individual movements at the time of request for transportation. This can be done through DLA Contracting and Finance.

  -- The funded account with DLA can be drawn on by DLA for any given shipment without the need to send funding documents for each individual fuel movement.

- Request fuel shipment via DLA Energy Transportation (dlaenergytrans@dla.mil). Lead time for this should be no closer than two weeks prior to pick-up date requested, preferably four weeks.

- Require that a certificate of cleanliness be presented for the tanker and its hoses and pumps upon arrival prior to loading the fuel. The trucker need to have a standard Bill of Lading for correct fuel.

- Clearly identify points of contact at pick-up and receiving locations so DLA or the contracted driver can contact if necessary.

- Ensure that receiving entity has proper storage of sufficient volume to hold the shipped fuel. Also ensure that there will be sufficient volume to hold both the shipped fuel and any additional fuel required for blending.

- The fuel pickup location needs to have applicable Department of Transportation (DoT) placards and seals to identify and secure the load prior to truck departure after loading. These are required before the truck can leave, and are not normally provided by the trucker, because they are not listed as requirements in the shipping contract. If the truck is delayed while these are being obtained, a demurrage charge may be assessed to the transportation contract.

Fuel Blending

- Obtain assistance from the Service Fuel Control Point for procedures to ensure proper blending of test fuel components.

- If personnel at blending location are not familiar with blending procedures an experienced fuels person involved with alternative fuels should be on-site until receiving personnel have sufficient experience and are comfortable with the process.

- Get the Service Fuel Control Point to define and document the special handling, blending, marking, and controlling processes for candidate test fuel, including procedures and blend ratios needed to disposition residual candidate test fuel to allow it to be used up rather than be disposed of. An example of Service Fuel Control Point documented requirements is shown in the following embedded Air Force Petroleum Agency's Fuels Technical Letter (double click the icon to open it) .

(Double-click on the icon to open the information in PDF file.)

FIGURE J-5. Air Force Petroleum Agency's Fuels Technical Letter.

Fuel Storage

- If DLA-owned tanks will be used, permission needs to be given by DLA well in advance of the effort beginning. Start the process with Service Fuel Control Point (e.g., for the USAF, the AFPA/Requirements Branch).

Use of Refueling Trucks

- The number of refuelers needed for the effort depends on the scope. If the fuel will be blended on receiving end and there will be multiple shipments, two refuelers may be needed; one for active refueling and the other available to receive subsequent fuel deliveries. For testing like Field Service Evaluations (FSE) where larger fixed tanks or temporary steel fixed-axle bulk (FRAC) tanks will be used and many aircraft will be refueled or defueled, a minimum of two dedicated refuelers may be necessary to ensure the capability to continuously supply FSE aircraft without interruption. When larger tanks instead of refuelers are used to store the fuel, the fuel will normally be blended either prior to shipment or upon receipt in the larger tanks.

- When multiple shipments are needed, fuel issue quantities need to be carefully tracked to determine when the next shipment should be sent (given the lead times for ordering and accomplishing the shipment) so that there are neither interruptions in fuel availability nor lack of ullage to receive the shipment.

Temporary Portable Tanks

- If FRAC tanks are being rented, the availability of a Government Purchase Card (GPC) to purchase incidentals such as fittings, hoses, spill materials, filters, and safety equipment greatly simplifies accomplishing those purchases.

- Ensure that there is sufficient equipment to properly interface the FRAC tanks with both the fuel-delivering tanker and any fuel dispensing refuelers.

- Site survey may be needed in order to place FRAC tanks properly. This requires proper coordination with owning location.

- Location needs to conform to federal, state, and local regulations regarding fuel tank placement.

- Use of FRAC tanks also requires additional fuels equipment to be properly set up for transferring fuel from the tanks into the refuelers. Equipment includes hoses, fittings, filter separator, and high capacity pump.

- All equipment can be shipped to receiving base via Transportation Management Office (TMO).

- The GPC can also be used to purchase sample cans, sample filters, and additives if necessary. Other expenses may include 55-gallon drums, hazardous cargo labels and seals for shipping fuel if not done by the TMO.

- DLA Energy will send out confirmation of transportation arrangements which needs to be filled out properly on shipment and receiving end. Paperwork is then sent back to DLA Energy Transportation office so bills can be paid.

Fuel Samples

- Samples of fuel need to be taken prior to shipment and tested for properties and contaminants by a reputable laboratory like the Air Force Petroleum Agency's (AFPA) Laboratory at Wright Patterson AFB.

- Samples should also be taken upon receipt, especially if blending will occur at the destination. The number and timing of samples should be determined during planning and implemented as part of the shipment process. Typically, two one-gallon samples are taken from each source. One is sent to a laboratory (like AFPA's) and the other is a retain sample, kept for the duration of the test effort unless it is needed for additional laboratory testing. These samples are in addition to any testing conducted at the local fuels laboratory.

- It is useful to establish an account with the laboratory doing the sample testing to reduce the number of funds transfers needed to pay for all sample analyses performed.

- Samples should also be taken periodically from any storage tank holding alternative fuel and sent for laboratory analysis (monthly, quarterly, semi-annually, etc., depending on the storage stability data already available for the candidate fuel).

- All sample cans, drums, and tanks need to be properly cleaned so as not to contaminate the fuel.

- Specific property test samples should be run before using the test fuel in a component, system, or subsystem test.

- When local jet fuel is used for blending with alternative fuel, samples of the local fuel should be taken and tested by the selected laboratory before blending the fuel. This information can be used in conjunction with the laboratory data from the alternative fuel blending component to do an analytical blend (calculation) to estimate the properties of the blend to determine if they may meet the requirements (e.g., specification compliance) for the blended test fuel. If the estimated results indicate that some requirements may not be met, some corrective action is still possible without having wasted fuel by actually creating an unacceptable blend.

APPENDIX K

ENVIRONMENTAL, SAFETY AND OCCUPATIONAL HEALTH

K.1 SCOPE.

K.1.1 General. The detailed guidelines for a program environmental assessment are provided in the "Development Guide for Program Managers," December 2003. The following paragraphs have been abstracted from this document in order to provide the reader with a better understanding of the process and steps required to accomplish this assessment.

K.1.2 Background.

K.1.2.1 Requirements. DoD Instruction (DODI) 5000.2 requires that all defense technology projects and acquisition programs, regardless of acquisition category, and throughout their life cycle, perform and maintain an Environmental, Safety and Occupational Health (ESOH) evaluation. This evaluation, the Programmatic Environmental, Safety and occupation Health Evaluation (PESHE), is a statutory requirement as stated in DODI 5000.2, Table E3.T1. It is a living document that is required at Program Initiation for Ships and at Milestone B, Milestone C, and Full Rate Production Decision Review for all systems, and have to be summarized in the Acquisition Strategy. The evaluation will include, as a minimum, the following:

ESOH risks

For acceptance of identified ESOH mishap risks, the Component Acquisition Executive (CAE) is the acceptance authority for high risks, the Program Executive Office (PEO) for serious risks, and the Program Manager (or System Manager, SM) for medium and low risks.

Strategy for integrating ESOH considerations into the systems engineering process

Identification of ESOH responsibilities

Method for tracking progress

Completion schedule for National Environmental Policy Act compliance

Identification of hazardous materials (HAZMATs) used in the system and plan for the system's demilitarization and disposal

K.1.2.2 ESOH evaluation. The ESOH evaluation is the program's way of assessing the environmental, occupational health and safety impacts of the weapon system on people and the environment and evaluating the impact of ESOH requirements on the mission readiness. The ESOH evaluation ensures potential "show stoppers" are identified and resolved as early in the acquisition process as possible.

In addition, ESOH considerations should be part of an overall Operational Safety, Suitability, and Effectiveness (OSS&E) plan. This plan should ensure OSS&E throughout the life cycle of the system and should include follow-on evaluations, systems engineering, and requirements review.

The ESOH analysis process shown on Figure K-1. The process is initiated by providing information like the Air Force Environmental Impact Analysis Request Form (AF IMT 813) (See Figure K-2), and its submission to Air Force Materiel Command, to the responsible organization for the appropriate Service.

K.1.2.3 PESHE content. The PESHE addresses a program's status concerning the National Environmental Policy Act (NEPA) of 1969, ESOH compliance, safety, health, hazardous materials (HAZMATs) management, pollution prevention, and explosives safety.

K.1.2.4 SM responsibilities. DoD systems acquisition policy clearly directs the SM to optimize total system performance, operational effectiveness and suitability, and affordability over the total life cycle. DoD acquisition policy states that the SM has to plan for human systems integration (HSI), which includes considerations, early in the acquisition process. As part of systems engineering, the SM will prevent ESOH risks, where possible, and will manage ESOH risks where they cannot be avoided. The process for integrating ESOH into systems engineering is documented in the PESHE.

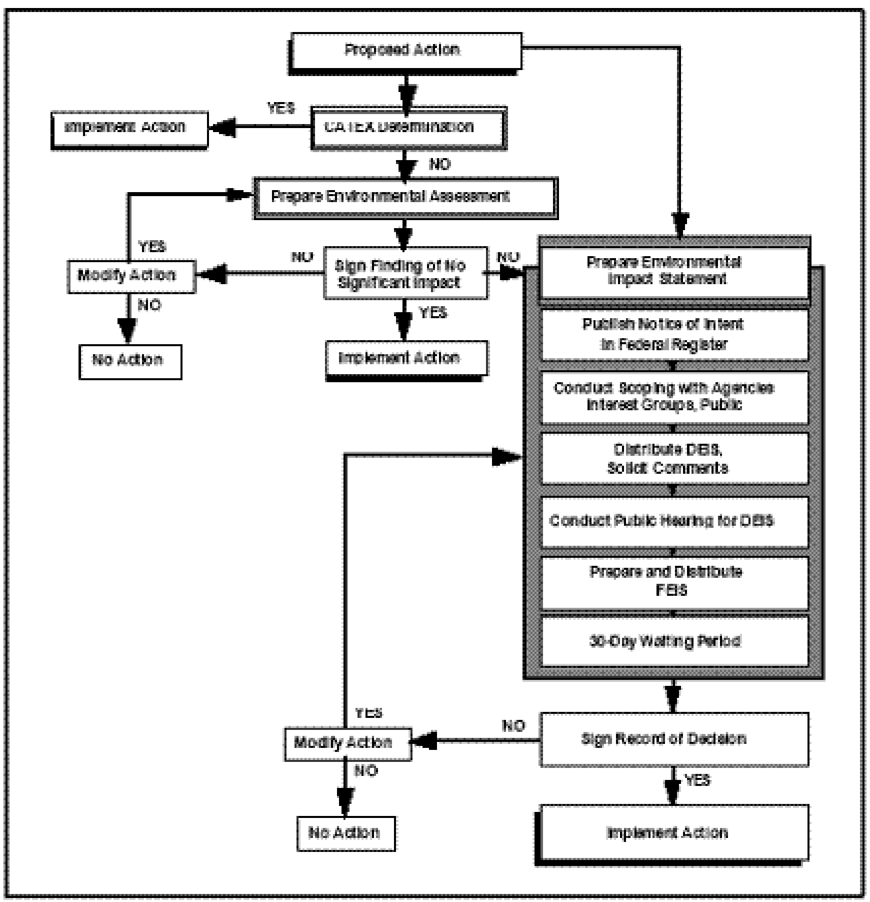

FIGURE K-1. Environmental impact analysis process.

REQUEST FOR ENVIRONMENTAL IMPACT ANALYSIS			Report Control Symbol RCS:
INSTRUCTIONS: Section I to be completed by Proponent; Sections II and III to be completed by Environmental Planning Function. Continue on separate sheets as necessary. Reference appropriate item number(s).			
SECTION I - PROPONENT INFORMATION			
1. TO (Environmental Planning Function) (Base CE Environmental POC)	2. FROM (Proponent organization and functional address symbol) (Single Manager of System demonstrating JP-8/SPK)		2a. TELEPHONE NO.
3. TITLE OF PROPOSED ACTION Domonstrate Fischer-Tropsch (F-T) Synthetic Paraffininc Kerosene (SPK) blended with JP-8, to fuel aircraft and equipment			
4. PURPOSE AND NEED FOR ACTION (Identify decision to be made and need date) Demonstrate (specify) aircraft and equipment using JP-8/SPK 50/50 blended fuel. Base approval to use JP-8/SPK (from date..... to date.....).			
5. DESCRIPTION OF PROPOSED ACTION AND ALTERNATIVES (DOPAA) (Provide sufficient details for evaluation of the total action.) Perform demonstion with JP-8/SPK to certify performance in aircraft and equipment. MIL-DTL-83133F specifies the use of JP-8/SPK for operational flight demonstration.			
6. PROPONENT APPROVAL (Name and Grade) (Single Manager of System)	6a. SIGNATURE		6b. DATE

SECTION II - PRELIMINARY ENVIRONMENTAL SURVEY. (Check appropriate box and describe potential environmental effects including cumulative effects.) (+ = positive effect; 0 = no effect; " = adverse effect; U= unknown effect)	+	0	-	U
7. AIR INSTALLATION COMPATIBLE USE ZONE/LAND USE (Noise, accident potential, encroachment, etc.)	☐	☒	☐	☐
8. AIR QUALITY (Emissions, attainment status, state implementation plan, etc.)	☒	☐	☐	☐
9. WATER RESOURCES (Quality, quantity, source, etc.)	☐	☒	☐	☐
10. SAFETY AND OCCUPATIONAL HEALTH (Asbestos/radiation/chemical exposure, explosives safety quantity-distance, bird/wildlife aircraft hazard, etc.)	☒	☐	☐	☐
11. HAZARDOUS MATERIALS/WASTE (Use/storage/generation, solid waste, etc.)	☐	☒	☐	☐
12. BIOLOGICAL RESOURCES (Wetlands/floodplains, threatened or endangered species, etc.)	☐	☒	☐	☐
13. CULTURAL RESOURCES (Native American burial sites, archaeological, historical, etc.)	☐	☒	☐	☐
14. GEOLOGY AND SOILS (Topography, minerals, geothermal, Installation Restoration Program, seismicity, etc.)	☐	☒	☐	☐
15. SOCIOECONOMIC (Employment/population projections, school and local fiscal impacts, etc.)	☐	☒	☐	☐
16. OTHER (Potential impacts not addressed above.)	☐	☒	☐	☐

SECTION III - ENVIRONMENTAL ANALYSIS DETERMINATION		
17. ☒ PROPOSED ACTION QUALIFIES FOR CATEGORICAL EXCLUSION (CATEX) # A2.3.7 ; OR ☐ PROPOSED ACTION DOES NOT QUALIFY FOR A CATEX; FURTHER ENVIRONMENTAL ANALYSIS IS REQUIRED.		
18. REMARKS Aircraft and equipment are being demonstrated with a 50/50 blend of JP-8/SPK aviation jet fuel (authorized by MIL-DTL-83133F) to acquire functional certification (outlined in MIL-HDBK-510, Aerospace Fuels Certification). Each systems' and equipments' capability to use JP-8/SPK will be recorded in their governing technical airworthiness/operational documents, following demonstration so that the fuel blend can be used to carry out assigned missions. Aircraft certificaton must be completed in preparation for the time when SPK fuel is readily availabel. Demonstrations of JP-8/SPK (2006-2008) have occured at Edwards, McChord, Dyess, Minot, Selfridge AEDC, and OC-ALC. The 50/50 blend presents no greater impact than JP-8.		
19. ENVIRONMENTAL PLANNING FUNCTION CERTIFICATION (Name and Grade)	19a. SIGNATURE	19b. DATE

AF IMT 813, 19990901, V1 THIS FORM CONSOLIDATES AF FORMS 813 AND 814. PREVIOUS EDITIONS OF BOTH FORMS ARE OBSOLETE. PAGE 1 OF PAGE(S)

FIGURE K-2. Request for environmental impact analysis.

AF IMT 813, SEP 99, CONTINUATION SHEET

Executive Summary

The Air Force has set a goal to certify all weapon systems to use a 50/50 blend of Fischer-Tropsch jet fuel and JP-8 by 2011. The use of a 50/50 Fischer-Tropsch SPK/JP-8 fuel blend in aircraft in place of current petroleum-derived JP-8 will create several minor environmental impacts – in this case, essentially all are positive. Fischer-Tropsch (F-T) SPK fuels will be procured under the same specification (MIL-DTL-83133F) as that for current jet fuels, thus the boiling range, molecular weight range, flash point, and freeze point, for example, will be similar to current fuels. Jet fuels contain four general classes of hydrocarbons: n-paraffins, iso-paraffins, naphthenes (cycloparaffins), and aromatics. F-T fuels do not contain the aromatic and naphthenic components present in JP-8 and commercial Jet A fuels, thus F-T fuels have a higher hydrogen/carbon ratio (note that the n-paraffins and iso-paraffins in F-T and JP-8 are similar). F-T fuels also do not contain the ~500 ppm of sulfur compounds present in current jet fuels (the specification allows up to 0.3 wt % (~3000 ppm)). Commercial and military experience in South Africa and military experience in the U.S indicates that engine performance (thrust, throttle response, ignition, flame stability, etc.) of the 50/50 F-T SPK/JP-8 fuel blend will be indistinguishable from that of 100% petroleum-derived jet fuel. Gas turbine engine emissions will be noticeably different in two areas: (1) 50% lower sulfur emissions, due to the sulfur-free nature of the F-T fuel component; and (2) a 10-45% reduction in particulate (soot) emissions, dependent upon engine type and power setting. Other pollutant emissions – CO, NOx, unburned hydrocarbons – are very similar to current fuels. JP-8 is also used in Air Force diesel engines. Emission results in diesel engines are similar – reductions in soot and sulfur emissions, with other emissions relatively unchanged. Because of the higher H/C ratio of the fuel, the CO2 emission index is a few percent lower (and the water emission index is correspondingly slightly higher) than current fuels. The fuel blend will be handled as JP-8, using the same infrastructure and procedures. Spills, fires, and cleanup of SPK neat or blended with JP-8 are handled the same as JP-8. Toxicity tests are ongoing, but the F-T fuel blend, so far results show that it is less toxic than current fuels (which are relatively non-toxic kerosene fuels) due to the reduced level of aromatics. This EIA covers only the impact of the use of the F-T fuel blend as a dispersed environmental impact from mobile sources, and does not cover the production process, which would have separate impact and permitting processes as a fixed source.

12 ADDITIONAL PAGES

V1 PAGE OF PAGE(S)

FIGURE K-2. Request for environmental impact analysis - Continued.

K.2 APPLICABLE DOCUMENTS.

K.2.1 General.

The documents listed below are not necessarily all of the documents referenced herein but are those needed to understand the information provided by this Appendix.

K.2.2 Government documents.

K.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

K.2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein.

DEFENSE ACQUISITION GUIDEBOOK SECTIONS 4.3.18.9.

Environment, Safety, and Occupational Health

(This information may be accessed at https://dag.dau.mil/Pages/Default.aspx.)

UNITED STATES AIR FORCE INSTRUCTIONS

AFI 32-7061 Environmental Impact Analysis Process (EIAP)

(Copies of this Instruction are available at http://www.e-publishing.af.mil.)

EXECUTIVE ORDER AND LAW

Executive Order 13423 of January 24, 2007, Strengthening Federal Environmental, Energy, and Transportation Management, and National Defense Authorization Act for Fiscal Year 2007, CHAPTER 173—ENERGY SECURITY, 2911. Energy performance goals and plan for Department of Defense, (c) SPECIAL CONSIDERATIONS.

(Copies of the executive order are available on line at https://www.fedcenter.gov/programs/eo13423/; copies of the Law are available at: http://www.gpo.gov/fdsys/pkg/FR-2007-01-26/pdf/07-374.pdf)

The ENERGY INDEPENDENCE AND SECURITY ACT of 2007 (PUBLIC LAW 110–140—DEC. 19, 2007) has been enacted to ensure that Federal Agencies only procure alternative or synthetic fuels that don't create more GHG. This law may constrain the procurement of alternative fuel to meet the Air Force's second goal. The pertinent section is excerpted for reference:

Energy Independence and Security Act of 2007, SEC. 526. PROCUREMENT AND ACQUISITION OF ALTERNATIVE FUELS: No Federal agency will enter into a contract for procurement of an alternative or synthetic fuel, including a fuel produced from nonconventional petroleum sources, for any mobility-related use, other than for research or testing, unless the contract specifies that the lifecycle greenhouse gas emissions associated with the production and combustion of the fuel supplied under the contract will, on an ongoing basis, be less than or equal to such emissions from the equivalent conventional fuel produced from conventional petroleum sources. Compliance with this law would rest with the procuring agency, DLA-Energy, through contracting action with suppliers.

(Copies of this Law are available at http://www.gpo.gov/fdsys/pkg/PLAW-110publ140/pdf/PLAW-110publ140.pdf)

MILITARY FUEL QUALITY DATA

"Petroleum Quality Information System Annual Report"

(Copies of this document are available from the email: pqis@dla.mil)

K.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein.

"Class- and Structure-Specific Separation, Analysis, and Identification Techniques for the Characterization of the Sulfur Components of JP-8 Aviation Fuel Energy & Fuels," Volume 17, pp. 1292-1302, 2003, Link, D. D.; Baltrus, J. P.; Rothenberger, K. S.; Zandhuis, P.; Minus, D. K.; Striebich, R. C.

"Qualification of a Semi-Synthetic Jet A-1 as Commercial Jet Fuel," SwRI-8531, November 1997, Moses, C. A., Stavinoha, L. L., Roets, P.

"Fischer-Tropsch Jet Fuels – Characterization for Advanced Aerospace Applications", AIAA 2004-3885, July 2004, Edwards, T., Don Minus, William Harrison, Edwin Corporan, Matt DeWitt, Steve Zabarnick, Lori Balster.

"World Fuel Sampling Program", CRC Report No. 647, June 2006, O J. Hadaller, J.M. Johnson.

"Chemical Class Composition of Commercial Jet Fuels and Other Specialty Kerosene Fuels," AIAA Paper 2006-7972, November 2006, Shafer, L, Striebich, R., Gomach, J., Edwards, T.

"Reduction of Turbine Engine Particulate Emissions Using Synthetic Jet Fuel," ACS Fuel Chemistry Division Preprints, Vol. 50(1), p. 338-341, 2005, Corporan, E., DeWitt, M. J., Monroig, O., Ostdiek, D., Mortimer, B., Wagner, M.

"Emissions Characteristics of a Turbine Engine and Research Combustor Burning a Fischer-Tropsch Jet Fuel," Energy & Fuels, 2007, Edwin Corporan, Matthew J. DeWitt, Vincent Belovich, Robert Pawlik, Amy C. Lynch, James R. Gord, and Terrence R. Meyer

"DoD Assured Fuels Initiative: B-52 Aircraft Emissions Burning a Fischer-Tropsch/JP-8 Fuel Blend", Edwin Corporan, Paper Presented at: IASH 2007, Tenth International Conference on Stability, Handling, And Use Of Liquid Fuels, Oct 2007. Approved for public release. Case number: AFRL-WS 07-2187.

(Copies of these documents may be requested from the email AFRL.Office40a3c@us.af.mil.)

K.3 Environmental Safety and Occupational Health. Appendix E provides a detailed discussion of the toxicity testing and a baseline of known information regarding JP-8 jet fuel. When sufficient toxicity data are available, environmental and occupational exposure standards can be developed that are protective of ecosystems (the environment) and workers (occupational medicine and health).

K.3.1 Toxicity and safety considerations. It is expected that all new aviation fuels or fuel blends will be handled the same as JP-8, using the same infrastructure and procedures. Toxicity tests will be conducted for all alternative fuels and fuel blends to determine whether the alternative fuel is more or less toxic than current fuels. This testing will cover only the impact of the use of the alternative fuel considering a dispersed environmental impact from mobile sources, and does not cover the production process for the fuel.

For example, the use of an alternative fuel in place of current petroleum-derived JP-8 may create several minor environmental impacts. In the case of a 50/50 SPK/JP-8 fuel blend, essentially all are positive. The Fischer-Tropsch SPK fuels are procured to a specification very similar to that for current jet fuels, thus the boiling range, molecular weight range, flash point, and freezing point and vapor pressure will be similar to current fuels. Jet fuels contain four general classes of hydrocarbons: n-paraffins, iso-paraffins, naphthenes (cycloparaffins), and aromatics. SPK fuels do not contain the aromatic and naphthenic components present in JP-8 and commercial Jet A fuels, thus SPK fuels have a higher hydrogen/carbon ratio (note that the n-paraffins and iso-paraffins in F-T and JP-8 are similar). SPK fuels also do not contain the ~500 ppm of sulfur compounds present in current jet fuels (the specification allows up to 0.3 wt % (~3000 ppm)).

Thus, toxicity tests have shown that personnel exposure to SPK fuel and fuel vapors are similar to that of conventional jet fuels, and since aromatics are widely accepted as the most toxic of the hydrocarbon components in jet fuel, the risk to personnel will be reduced. Refer to Appendix E for additional details.

Because the definition of the JP-8/SPK blend allows any ratio of JP-8 and SPK up to 50% SPK, the degree of risk reduction for blends with small percentages of SPK will be accordingly small. For that reason, and because ultimately the blend will not be readily identifiable, being included in the definition of "JP-8," the risk and associated exposure limits are set at the same level as those of petroleum-based JP-8.

K.3.2 HAZMAT summary. The 50/50 SPK/JP-8 fuel blend is a hazardous material. This material replaces JP-8 jet fuel. Although expected to be less hazardous than JP-8, the 50/50 fuel blend is still hazardous and will be treated as such. There are no new hazards expected with the implementation of use of this alternative fuel.

K.3.2.1 Locations and quantities of HAZMAT in the system. It is expected that alternative fuels could replace all JP-8 currently stored, maintained, used and disposed of on all AF installations. Quantities and locations are established by the installation.

K.3.2.2 Energetic qualification information. If the alternative fuel's energy content per unit volume, or per unit mass, is greater than the baseline fuel's energy content, the alternative fuel should be thoroughly assessed for each system where it is expected to be used.

K.3.2.3 Hazardous byproducts and discharges. Pollutant emissions, both from evaporation and from combustion are likely to contain hazardous byproducts. CO, NOx and unburned hydrocarbons, are some of the byproducts which need to be quantified and compared to those of the baseline fuel. If the alternative fuel's emissions are greater than those of the baseline, the impacts should be assessed.

K.3.2.4 Special HAZMAT training, handling, and storage needs. Alternative fuels are likely to be refined to the same flash point and distillation specification limits as their petroleum-derived counterparts, so their vapor pressures are similar. Thus, personnel exposure to alternative fuel vapors will be similar to that of conventional JP-8 jet fuel. However, if vapor pressure or toxicity is higher than the baseline fuel, impacts on training, handling and storage requirements need to be considered for any new alternative fuel.

K.3.2.5 Pollution Prevention (P2). Testing should be done on all alternative fuels, to determine if they provide lower emissions and fewer hazards than those that are regularly associated with the use of JP-8 fuels. If emissions or hazards are greater, an assessment should be made to determine if mitigating actions are required, and, if so, a plan developed to implement those mitigating actions.

K.3.2.6 Emissions measurements. Emissions measurements should be taken to allow quantitative comparison of those of the alternative fuel to those of the baseline.

K.3.2.6.1 TF33-P-103 emissions testing. As an example of an emissions test, which supported of the DoD Assured Fuels Initiative, the emissions of two TF33 P-103 engines burning JP-8 and a 50/50 blend by volume of JP-8 and Fischer Tropsch (FT) synthetic fuel (referred herein as FT blend) were characterized to determine the impacts of the synthetic fuel on the engine emissions. This effort represents the first emissions evaluation of an actual United States (US) military aircraft operating with a semi-synthetic fuel.

Gaseous and particulate matter (PM) emissions were quantified. Measurements of the mostly non-volatile PM emissions were performed using conventional instrumentation to determine particle number (concentration), size, mass and smoke number. Soot samples were collected on quartz filters for subsequent chemical analysis. The engines were operated with each fuel at four power settings, idle-to-maximum thrust, and a 50-hour engine endurance test with the FT blend was conducted in the test cell at normal rated thrust.

The particle numbers (PN) were normalized for the fuel consumed to obtain particle number emission indices (PN-EI) (number of particles per kilogram of fuel). This accounts for any variation in fuel-to-air (F/A) ratio between test runs of the same engine condition and provides a normalized basis for comparison of engine settings. The engine F/A ratios were determined based on CO_2 and CO emissions. Corrected PN-EI for the TF33 engine tested at Tinker and those at Edwards AFB with JP-8 were very similar and ranged from 4.6E+15 to 8.2E+15 particles per cubic centimeter ($\#/cm^3$). For the engines operating with the FT blend the PN-EI ranged from 3.4E+15 to 6.2E+15 $\#/cm^3$ for the same conditions.

Changes in TF33 engine PN-EI burning the FT blend relative to operation with JP-8 are shown on Figure K-3. These data are based on an average of multiple test runs sampled with two probes with each point including over 1000 data scans. The data uncertainty (random error) for each PN measurement was <7% for most conditions. As shown, significant reductions in PN-EI were measured when the engine was operated with the FT blend.

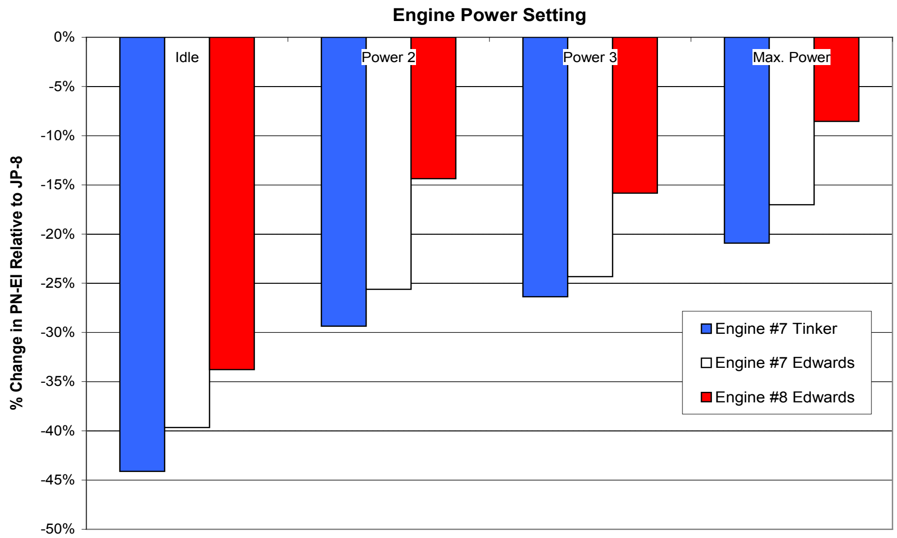

FIGURE K-3. Change in particle number emissions of TF33 engines burning JP-8 and FT blend.

For both engines, the results clearly show a trend of higher fuel impact (larger reductions) at the lower engine power settings. At low power, the engine produces small soot particles and relatively high concentrations of volatile organics, some of which condense in the sample lines to become particles. Due to the aliphatic-only nature of the FT fuel it produces even smaller particles than JP-8, which readily oxidize in the engine combustor. A relatively low but still significant effect on PN-EI at maximum power was observed. These results are in agreement with those observed in a previous study on a T63 engine operated on FT fuel blends. In general, the reduction in PM emissions is primarily the result of the reduced aromatics and higher H/C ratio in the FT blend. Aromatic species in the fuel act as seeds for the formation of PAH molecules, which coagulate to subsequently produce soot nuclei. The propensity of aromatics to produce soot has been well established and observed in large scale combustors and laboratory flames.

Significant reductions (50%) in sulfur-based particulate emissions are also anticipated as result of the sulfur-free FT fuel. These sulfur-based species exist in the gaseous phase at the engine exhaust and nucleate into particles (aerosols) as they react in the atmosphere.

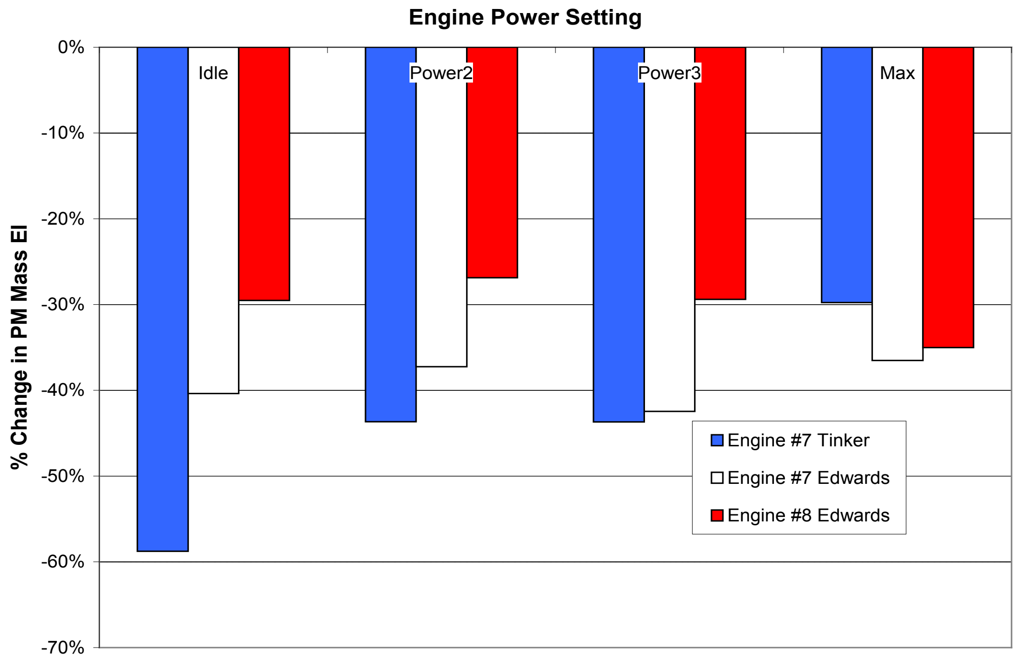

FIGURE K-4. Change in particle mass EI for TF33 engines using FT blend relative to JP-8.

Direct PM mass measurements were made with a Tapered Element Oscillating Microbalance (TEOM). The average calculated PM mass EI for the two TF33 engines on JP-8 ranged between 1.4 to 3.0 g/kg-fuel with the lowest PM mass EI at idle and highest at Power 2. The PM mass EI using the FT blend were reduced to 0.81-1.9 g/kg-fuel. Changes in PM mass EI as a function of power setting and engine are shown on Figure K-4. Consistent with all other particle emissions, excellent agreement was observed for the measurements and trends of Engine #7 at Tinker Air Force Base and Edwards Air Force Base. Average reductions in PM mass EI of 40% for engine #7 and 30% for engine #8 were observed with the FT blend relative to JP-8. The larger effect of the FT fuel on particle mass compared to PN-EI for the higher power settings is due to the reduction in particle size and the relation of particle diameter with mass.

Negligible differences in most measured gaseous emissions were observed for the engine burning JP-8 and FT blend. An approximate 10% reduction in the total unburned hydrocarbons (UHC) was observed at idle with the FT blend. As anticipated, reductions in sulfur oxide emissions with the FT blend were observed due to the sulfur-free nature of the FT fuel. These results are in good agreement with concurrent measurements made at Tinker AFB by AEDC. Although slight reductions in CO_2 emissions (~1.8%) and increases in water vapor were anticipated as result of the higher H/C ratio in the FT fuel blend, no statistically significant differences in these emissions were observed.

The results from this study further demonstrate the potential environmental benefits of using an FT fuel in turbine engine systems. In addition to the lower PM emissions, which help reduce the environmental burden of aircraft, use of FT fuels may potentially increase engine life and reduce engine maintenance and aircraft exhaust signature. Average reductions of 30-45% in PM mass emissions relative to JP-8 were observed in both engines burning the FT blend. In addition, significant reductions in particle number and engine smoke numbers were also observed. Chemical analysis of the soot samples showed reductions of 50-70% in three and four-ring polycyclic aromatic hydrocarbons (PAH) concentration with the FT blend. Effects of the synthetic fuel on gaseous emissions were negligible except for slight reductions in unburned hydrocarbons and the anticipated reductions in sulfur oxides. In summary, only beneficial impacts on TF33 engine emissions were observed with the use of the FT blend.

K.3.2.6.2 Hamilton Sundstrand turbine test. This paragraph gives an example of a series of emissions source tests which were conducted on the APS3240 gas turbine located at Hamilton Sundstrand Power Systems in San Diego, CA. The compliance test was required in order for the facility to operate the gas turbines on synthetic fuels as required by San Diego Air Pollution Control District (SDAPCD).

The compliance Evaluation Test was conducted in accordance with the procedures specified in the Source Test Protocol that was approved by the SDAPCD. The SDAPCD Monitoring division conducted the criteria pollutant emissions testing for oxides of nitrogen (NOx), carbon monoxide (CO) and volatile organic compound (VOC). Additionally the SDAPCD conducted an airflow rate measurement to serve as a QA/QC evaluation for the Venturi airflow measurements conducted by Hamilton Sundstrand Power Systems personnel. ERMI conducted the toxic air contaminants (TAC) measurements for benzene, ethyl benzene, toluene, xylene, 1,3-Butadiene, styrene, phenol, acetaldehyde, acrolein, and formaldehyde. The turbine operated at greater than 80% of full load throughout each of the sub tests. The operational parameters for load, exhaust temperature, fuel flow and airflow were monitored and recorded throughout each of the tests. In addition to the three consecutive TAC tests for synthetic fuel, ERMI collected a single test run sample for all of the TAC's while the engine operated at the same load with JP-8 fuel. Furthermore the Hamilton Sundstrand Power Systems continuous emission monitors were used to measure the gaseous concentration of CO, NOx, and VOCs throughout each of the tests including the JP-8 test run.

Based on the results from each of the tests and the emissions factors developed, the emissions from the Fischer-Tropsch fuel passed the emission test and were significantly below the criteria set forth in the AC for each of the TAC emission factors.

K.3.2.7 Ground support equipment emissions and alternative fuels. Exhaust emissions of the diesel engine are affected by the composition of the fuel. Normal variations in the composition of diesel fuel will be apparent in the exhaust emissions. Recognizing this, the EPA defines the fuel to be used during the engine testing required for emissions certification. The EPA Certification Diesel Fuel is intended to be an average of the fuel properties found in the US. After successful completion of the emissions testing of the engine on the 'cert fuel' it is then considered certified for use on diesel fuel meeting ASTM D975. Operation of the engine within the US on a fuel not meeting ASTM D975 is not permitted unless credible evidence is provided to the EPA which demonstrates that emissions and emissions' control system durability for the alternative fuel are equal or superior to the Certification Fuel. Such fuels are listed in the US EPA Code of Federal Regulations, Part 40 CFR 79, Registration of Fuels and Fuel Additives.

The EPA has recognized the need for the military to operate on JP-8 to fulfill its world-wide commitments and to use JP-8 when within the US to meet readiness requirements. The EPA has granted a National Security Exception, or NSE, for the military to operate on JP-8. In addition, the EPA also routinely grants exceptions for the military to purchase engines which do not met current emissions standards. Historically the engine exceptions have been on the basis of configuration management of legacy equipment but most recently have been due to the sulfur in JP-8. Since 2007 on-road vehicles have been equipped with exhaust after treatment and exhaust gas recirculation systems to meet emissions standards. These systems are not compatible with fuel sulfur levels over 15 ppm. Similar emissions requirements for industrial engines as used in AGE will take effect in 2011. Virtually all new purchases of JP-8 fuelled equipment are now required to obtain a NSE to proceed.

The EPA permits limited operation on an alternative fuel for the purpose of testing, including long term durability fleets. The test phase duration is not defined by EPA.

K.4 ACRONYMS.

AEDC	-	Arnold Engineering Development Center
AFMC	-	Air Force Materiel Command
CAE	-	Component Acquisition Executive
CATEX	-	categorical exclusion
CFR	-	Code of Federal Regulations
DESC	-	Defense Energy Support Center (now DLA Energy)
DLA	-	Defense Logistics Agency
DoD	-	Department of Defense
EA	-	Environmental Assessment
EIAP	-	Environmental Impact Analysis Process
EIS	-	Environmental Impact Statement
ERMI	-	Ecological Research and Management Incorporated Environmental Laboratories
EO	-	Executive Order
EPA	-	Environmental Protection Agency
ESC	-	Electronic Systems Center
ESOH	-	Environment, Safety and Occupational Health
F/A	-	Fuel to Air ratio
FAR	-	Federal Acquisition Regulation
FT	-	Fischer Tropsch
GHG	-	Green House Gases
HAPs	-	Hazardous Air Pollutants

HAZMAT	-	hazardous material
HC ratio	-	Hydrogen/Carbon ratio
IMP	-	Integrated Master Plan
NAS	-	National Aerospace Standard
NSE	-	National Security Exception
NEPA	-	National Environmental Policy Act
OSS&E	-	Operational Safety, Suitability, and Effectiveness
PAH	-	Polycyclic Aromatic Hydrocarbons
PEA	-	Programmatic Environmental Analysis
PEO	-	Program Executive Officer
PESHE	-	Programmatic Environmental, Safety and Occupational Health Evaluation
PM	-	Particulate Matter
PN	-	Particle Number
PN-EI	-	Particle Number- Emission Indices
Pub. L.	-	Public Law
ppm	-	Parts per Million
PQIS	-	The Petroleum Quality Information System
SDAPCD	-	San Diego Air Pollution Control District
SPK	-	Synthesized Paraffinic Kerosene
TEOM	-	Tapered Element Oscillating Microbalance
TAC	-	Toxic Air Contaminants
UHC	-	Unburned Hydrocarbons
VOC	-	Volatile Organic Compound

APPENDIX L

FUEL PROPERTY TRACEABILITY INDEX

L.1 SCOPE.

This Appendix provides a cross reference in Table L-I where each fuel property/characteristic appearing in Appendix C is listed along with the required test method and nominal certification criteria (Entrance, Subset 1,2, or 3). The table further shows where in the appropriate appendix or appendices (B-H) the property and test method are applied. The Air Force SMEs associated with each appendix have evaluated all fuel properties and characteristics based on the requirements decomposition process that correlated requirements to safety, performance, durability and supportability, as described in Appendix A. A spreadsheet containing this information in a sortable form is embedded on Figure L-1. The Appendix C Criteria column shows the highest priority of each property (Entrance, or Subset 1, 2, or 3) in the entire certification process. This priority may be higher than the priorities shown in the other appendices (listed in the last column of Table L-I) because the holistic view in the systems engineering process elevates the importance of the property above that of any of the more specialized subject areas addressed by each of the appendices.

TABLE L-I. Fuel property/test method application.

C-Para.	**Appendix C**			**Appendix Where Applied**	
	Property	**Test Method**	**Criteria**	**Paragraph**	**Criteria**
C.4	Acid Number, Total	ASTM D3242	Entrance	B.4.1.1 Entrance Criteria MIL DTL-83133	Entrance
				D.5.3 Alternative Fuels	1
C.5	Additive Compatibility	ASTM D4054	1	B.4.2.1 Fuel Property Tests	1
				D.5.5 Baseline Test Fluids D 5.6 Additive Testing	
				H 4.1 Electrostatic Buildup	
C.6	Aromatics	ASTM D1319	Entrance	B.4.1.1 Entrance Criteria MIL DTL-83133	Entrance
				D.5.3 Alternative Fuels	1
C.7	Autoignition Temperature	ASTM E659	1	B.4.2.1 Fuel Property / Characteristic Tests	1
				F.4.6 Autoignition Temperatures in Aviation Fuels	1

TABLE L-I. Fuel property/test method application - Continued.

C-Para.	Appendix C			Appendix Where Applied	
	Property	**Test Method**	**Criteria**	**Paragraph**	**Criteria**
C.8	Bulk Modulus	ASTM D6793	1	B.4.2.1 Fuel Property / Characteristic Tests	1
				B.4.2.2.2.1 SE&V certification process	1
				B.4.3.2.2 SE&V Bulk Modulus versus temperature	2
C.9	Calculated Cetane Index	ASTM D976	Entrance	B.4.1.1 Entrance Criteria MIL DTL-83133	Entrance
				B.4.2.2.2.2 Support Equipment & Vehicles (SE&V) (Cetane Index) Diesel ignition quality	1
C.10	Cetane Number	ASTM D613	2	B.4.3.2.2 SE&V A measure of the ignition quality of a fuel in a diesel engine	2
C.11	Copper Strip Corrosion	ASTM D130	Entrance	B.4.1.1 Entrance Criteria MIL DTL-83133	Entrance
C.12	Density (versus Temperature – Subset 1, Thermal Expansion – Subset 2)	ASTM D1298 ASTM D4052 ASTM D1903 (App H)	Entrance	B.4.1.1 Entrance Criteria MIL DTL-83133	Entrance
				B.4.2.1 versus Temperature, Fuel Property/Characteristic Tests	1
				B.4.3 Thermal Expansion, Fuel Properties/Characteristics	2
				G.3.4 Subset 1	1
				H.5.3 Fuel Distribution Utilities (Thermal Expansion)	2
				H.5.5 Subset 2 Criteria Evaluation (Thermal Expansion)	2
C.13	Dielectric Constant versus Density versus Temperature	ASTM D924	1	B.4.2.1 Fuel Property / Characteristic Tests	1

TABLE L-I. Fuel property/test method application - Continued.

C-Para.	Appendix C			Appendix Where Applied	
	Property	**Test Method**	**Criteria**	**Paragraph**	**Criteria**
C.14	Distillation Curve	ASTM D86 ASTM D2887	Entrance	B.4.1.1 Entrance Criteria MIL DTL-83133	Entrance
C.15	Electrical Conductivity at Standard Temp.	ASTM D2624	Entrance	B.4.1.1 Entrance Criteria MIL DTL-83133	Entrance
				D.6.3 Alternative Fuels	1
C.15	Electrical Conductivity versus Temperature	ASTM D2624	2	B.4.3.1 Fuel Property / Characteristic Tests	2
				H.4.1 Electrostatic Charge Dissipation	
C.16	Enthalpy versus Temperature	TBD	3	B.4.4.1 Fuel Property / Characteristic Tests	3
				G.3.6 Subset 3	
C.17	Existent Gum	ASTM D381	Entrance	B.4.1.1 Entrance Criteria MIL DTL-83133	Entrance
C.18	Filtration Time	MIL-DTL-83133	Entrance	B.4.1.1 Entrance Criteria MIL- DTL-83133	Entrance
C.19	Flame Speed	TBD	1	B.4.2.1 Fuel Property / Characteristic Tests	1
				F.4.4 Flame Speed	
C.20	Flammability Limits	ASTM E681	1	B.4.2.1 Fuel Property / Characteristic Tests	1
				B.4.2.2.2.2 SE&V Properties	
				F.4.1 Flammability Limits	
				G.3.4 Subset 1	

TABLE L-I. Fuel property/test method application - Continued.

C-Para.	Appendix C			Appendix Where Applied	
	Property	**Test Method**	**Criteria**	**Paragraph**	**Criteria**
C.21	Flash Point	ASTM D56 or ASTM D93	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
				B.4.2.2.1 Auxiliary and Emergency Power Units (APU/EPU) Evaluation	1
				D.5.3 Alternative Fuels	1
				F.4.5 Flash Point for Aviation Fuels	1
				G.3.3 Entrance Criteria Evaluation	Entrance
C.22	Freezing Point	ASTM D2386 ASTM D5972	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
				G.3.3 Entrance Criteria Evaluation	
				B.4.2.2.1 Auxiliary and Emergency Power Units (APU/EPU) Evaluation	1
C.23	Fuel System Icing Inhibitor	ASTM D5006	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
				B.4.4.2.1 Fuel System Icing Inhibitor (FSII) Rig Test	3
				D.5.5 Baseline Test Fluids	1
C.24	Gas Chromatograph	ASTM D2887	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
C.25	Heat of Combustion, Net	ASTM D4809 ASTM D4529	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
				G.3.4 Subset 1	1
				F.4.7 Heat of Combustion	1
C.26	Heat of Vaporization, Latent – see C.46 Vapor Pressure				

TABLE L-I. Fuel property/test method application - Continued.

C-Para.	Appendix C			Appendix Where Applied	
	Property	Test Method	Criteria	Paragraph	Criteria
C.27	Hot Surface Ignition	Fed Test Std 791C ISO 20823	1	B.4.2.1 Fuel Property / Characteristic Tests	1
				B.4.3.1 Fuel Property / Characteristic Tests Under Turbulent Airflow	2
				F.6.6 Minimum Hot Surface Ignition Temperature Under Turbulent Airflow	3
C.28	Hydrogen Content	ASTM D3701 ASTM D3343	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
C.29	Lubricity	ASTM D5001	1	B.4.2.1 Fuel Property / Characteristic Tests	1
				B.4.2.2.2.2 SE&V Properties	1
				B.4.4.2.2.1 SE&V Evaluation Injection Pump Durability	3
				G.3.6 Subset 3	3
C.30	Minimum Spark Ignition Energy	TBD The criterion is defined as "no easier to ignite than Jet A/JP-8."	2	B.4.3.1 Ignition Energy, Minimum	2
				F.5.2 Safety Related Fuel Characteristics Minimum Ignition Energy (MIE)	
C.31	Napthalenes	ASTM D1840	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
C.32	Ostwald Coefficient/ Gas Solubility	ASTM D2779	2	B.4.3.1 Fuel Property / Characteristic Tests	2
C.33	Particulate Matter	ASTM D2276 ASTM D5452	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
C.34	Pour Point	ASTM D.97	Use Viscosity vs. Temp.	C.34	Use Viscosity vs. Temp.
C.35	Saybolt Color	ASTM D156	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance

TABLE L-I. Fuel property/test method application - Continued.

C-Para.	Appendix C			Appendix Where Applied	
	Property	Test Method	Criteria	Paragraph	Criteria
C.36	Smoke Point	ASTM D1322	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
C.37	Specific Heat (as a Function of Temperature)	currently calculated	1	B.4.2.1 Fuel Property / Characteristic Tests	1
				B.4.4.2.2 SE&V Evaluation	3
				G.3.6 Subset 3	3
C.38	Storage Stability	MIL-STD-3004	1	B.4.2.1 Fuel Property/Characteristic Tests	1
C.39	Sulfur, Mercaptan	ASTM D3227 ASTM D4952	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
				D.5.5 Baseline Test Fluids	1
				D.6.5 Related Materials Testing	2
C.40	Sulfur, Total	ASTM D129 ASTM D1266 ASTM D2622 ASTM D3120 ASTM D4294 ASTM D5453	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
				B.4.2.2.2.2 SE&V Properties	1
				D.5.3 Alternative Fuels	1
				D.5.5 Baseline Test Fluids	1
				D.6.5 Related Materials Testing	2
C.41	Surface Tension versus Temperature	ASTM D971	1	B.4.2.1 Fuel Property / Characteristic Tests	1
				G.3.4 Subset 1	
C.42	Thermal Conductivity versus Temperature	CRC Handbook	1	B.4.2.1 Fuel Property / Characteristic Tests	1
				B.4.4.2.2 SE&V Evaluation	3
				G.3.6 Subset 3.	3
				H.5.3 Fuel Distribution Utilities. ASTM D2717	2
C.43	Thermal Expansion see C.12 Density (Thermal Expansion)				

TABLE L-I. Fuel property/test method application - Continued.

C-Para.	Appendix C			Appendix Where Applied	
	Property	**Test Method**	**Criteria**	**Paragraph**	**Criteria**
C.44	Thermal Stability	ASTM D3241	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
				B.4.2.1 Fuel Property / Characteristic—as affected by Trace Elements	1
				B.4.2.2.2.1.4 SE&V Heat Removal	1
				B.4.3.2.1 APU and Emergency Power Unit (EPU) Evaluation	2
				G.3.6 Subset 3	3
C.45	Trace Species	ASTM D7111	1	B.4.2.1 Fuel Property / Characteristic Tests	1
				G.4.4 Table G-II	1
				G.5.2 Risk Assessment Process - Flame Tube Test	3
C.46	Vapor Pressure, True versus Temperature	ASTM D323 or ASTM D5191	1	B.4.2.1 True, Fuel Property / Characteristic Tests	1
				B.4.2.2.1 Auxiliary and Emergency Power Units (APU/EPU) Evaluation	
				B.4.2.2.2.2 SE&V Properties	
				G.3.4 Subset 1	
C.46 A	Velocity of Sound		2	B.4.3.1 Subset 2 Fuel Property/Characteristic Tests	2
C.47	Viscosity at -20° C	ASTM D445	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
				G.3.3 Entrance Criteria Evaluation MIL-DTL-83133	Entrance

TABLE L-I. Fuel property/test method application - Continued.

C-Para.	Appendix C			Appendix Where Applied	
	Property	Test Method	Criteria	Paragraph	Criteria
C.47	Viscosity versus Temperature	ASTM D445	1	B.4.2.1 Fuel Property / Characteristic Tests	1
				B.4.2.2.1 Auxiliary and Emergency Power Units (APU/EPU) Evaluation	1
				B.4.2.2.2.2 SE&V Properties at -20° C and +40° C	1
				B.4.4.2.2.1 Impact of Fuel on Injection Pump Durability	3
				G.3.4 Subset 1	1
C.48	Water Reaction Interface Rating	ASTM D1094 ASTM D3242	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
C.49	Water Separation Index	ASTM D3948	Entrance	B.4.1.1 The Entrance Criteria Definition MIL-DTL-83133	Entrance
C.50	Water Solubility	ASTM D6304	1	B.4.2.1 Fuel Property / Characteristic Tests	1

(Double-click on icon to open the PDF File.)

FIGURE L-1. Index spreadsheet.

APPENDIX M

EVALUATION OF POTENTIAL CANDIDATE FUELS FOR CERTIFICATION

M.1 SCOPE.

M.1.1 Summary. Before fuel can become a candidate for certification, it needs to be evaluated for its potential to meet technical requirements as well as to satisfy viability criteria. This appendix describes the processes for evaluating potential candidate fuels in support of a decision to certify or not to certify them for their intended fleets. Evaluations in the following five areas of interest form the basis for candidate selection for certification: technical readiness, manufacturing readiness, life-cycle environmental analysis, sustainability, and cost. Each of these will be addressed in greater detail in Sections M.4 through M.8.

M.1.1.1 Candidate type. Two types of fuel candidates are identified here which require different approaches for the evaluations: a) single source fuels produced by a specific supplier using a specified process and b) classes of fuels produced by a specified process that can be produced by multiple suppliers. Examples of the former are the Sasol semi-synthetic coal-based Fischer-Tropsch Jet A-1 and the Sasol fully synthetic blend, both approved in the United Kingdom's Def-Stan 91-91 jet fuel specification. Examples of the latter are the generic blends of JP-8 with up to 50% Fischer-Tropsch-derived synthesized paraffinic kerosene which allow feedstocks for the synthetic component from one or any combination of coal, natural gas, or biomass.

M.1.1.1.1 Single source fuels. These fuels are normally produced to a strictly controlled proprietary process by the single supplier. Because of the lack of competition, the potential limitations on production capacity, and the vulnerability to supply interruptions from such a single source, this is not the preferred type of candidate. However, the evaluation process does not automatically eliminate such a candidate. It is just more difficult for such a candidate to pass the evaluation gates and be competitive with a more generic class of fuels.

M.1.1.1.2 Classes of fuels. When a process for making fuel is sufficiently well defined, controllable, and repeatable to produce fuel of sufficient character and quality for aviation use and the process can be used by multiple producers, the resulting fuel products can be addressed together as a class and can be certified as such. This would allow use of fuel from any producer whose product was made using that process and which met the fuel specification requirements. The Fischer-Tropsch aviation turbine/JP-8 blended fuels, cited as an example above, meet these requirements because the Fischer-Tropsch process limits the possible output molecules to such a degree that no undesirable constituents can pass into the final product from the Fischer-Tropsch blend stock.

M.1.1.2 Actors. Military laboratories, like the Air Force Research Laboratory (AFRL), are the principal evaluators of the potential certification candidates. The evaluating military laboratory will use its connections with other sources of evaluation expertise, both Government and contractor, to meet the evaluation objectives. Should an organization other than a military laboratory recommend a potential fuel candidate for certification and provide data for the assessments described herein, the military laboratory will validate those data, and supplement them as necessary with data from its own assessments, to ensure the total evaluation data set meets the needs of the military decision process. The FCO combines the laboratory-derived or laboratory-validated data with other information to determine whether and which fuel candidate(s) will proceed through the certification process.

M.2 APPLICABLE DOCUMENTS.

M.2.1 General. The documents listed below are not necessarily all of the documents referenced herein but are considered to be those which are most important in providing the user a clear understanding of the information provided by this appendix.

M.2.2 Government documents.

M.2.2.1 Government specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

M.2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE MANUFACTURING TECHNOLOGY PROGRAM

Manufacturing Readiness Level Deskbook

(Copies of this document are available on line at www.dodmrl.com.)

UNITED STATES AIR FORCE TECHNICAL MEMORANDUM

Alternative and Experimental Jet Fuel and Jet Fuel Blend Stock Evaluation Technical Memorandum #AFRL-RZPF-2009-FCFS-001

(Copies of this document are available from email at AFRL.Office40a3c@us.af.mil.)

M.2.3 Non-government standards and other publications. The following documents form a part of this document to the extent specified herein.

See C.2.3 for the ASTM Standards referenced.

(Copies of these documents may be ordered on line at www.astm.org; and approved users may access the documents on line at http://global.ihs.com/standards.cfm?publisher=ASTM&RID=Z06&MID=5280.)

M.3 DEFINITIONS.

M.4 TECHNICAL READINESS.

The assessment of technical readiness will act as the first set of screening gates for potential fuel candidates. It will use a tailored version of the Technology Readiness Level (TRL) methodology, employed by a number of Government agencies, to determine whether a candidate fuel is ready to proceed to more advanced steps in the certification process. The 9 TRLs are defined on Figure M-1.

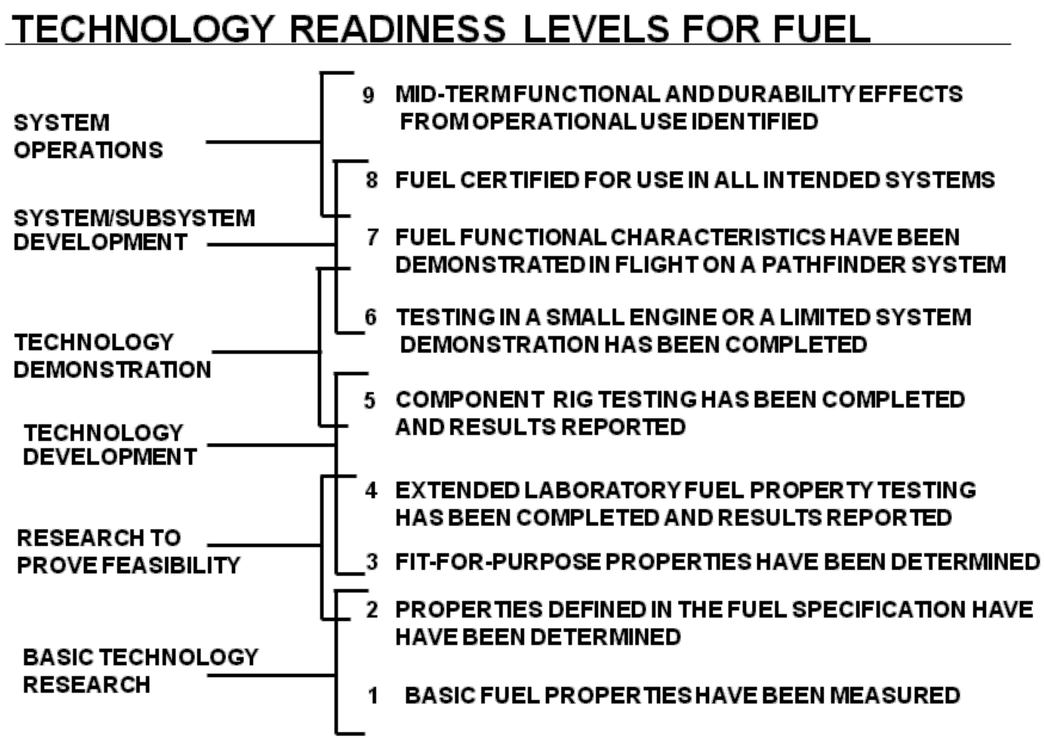

FIGURE M-1. Technology Readiness Levels.

M.4.1 Technology Readiness Level 1. Technology Readiness Level 1 is complete when basic principles have been observed and reported. For a fuel candidate, the properties associated with these basic "principles" are identified in Table M-I along with an estimated minimum quantity of fuel required to do the assessment and an estimated minimum time it would take to do so.

TABLE M-I. TRL 1 assessments.

TRL Objective	Test	Fuel Required	Duration
Basic Fuel Properties Observed and Reported	Thermal Stability (ASTM D3241) Quartz Crystal Microbalance (ASTM D7739)	500 ml	Approx. 1 week
	Freezing Point (ASTM D5972) [Note: ASTM D2386 is the referee freezing point test method for MIL-DTL-83133 and ASTM D1655]		
	Distillation (ASTM D 86 or D2887)		
	Hydrocarbon Range (ASTM D6379 & D2425)		
	Heat of Combustion (ASTM D4809)		
	Density, API Gravity (ASTM D4052)		
	Flash Point (ASTM D93)		
	Aromatics (ASTM D1319) [ASTM D1319 is valid only if the aromatic content of the fuel is 5 volume % minimum. ASTM D1319 may still be used for fuels with lower aromatic contents but may not give accurate aromatic content results.]		
	Review SDS provided by supplier for ESOH.		

M.4.2 Technology Readiness Level 2. Technology Readiness Level 2 is complete when the technology concept and/or application have been formulated. For a fuel candidate, this is completed when fuel specification properties have been determined and reported. Table M-II lists the properties, the tests to determine them, and the estimated minimum amounts of fuel and time needed to do so.

TABLE M-II. TRL 2 assessments.

TRL Objective	Test	Fuel Required	Duration
Fuel Specification Properties	Color, Saybolt (ASTM D156 or D6045)	3 gal	2 weeks
	Total Acid Number (ASTM D3242)		
	Aromatics (ASTM D1319 & D6379)		
	Sulfur (ASTM D2622)		
	Sulfur Mercaptan (ASTM D3227)		
	Distillation Temperature (ASTM D86)		
	Flash Point (ASTM D56, D93, or D3828)		
	Density (ASTM D1298 or D4052)		
	Freezing Point (ASTM D2386, D5972, D7153, or D7154)		
	Viscosity at -20°, -40°, 40°C (ASTM D445)		
	Net Heat of Combustion (ASTM D4809)		
	Hydrogen Content (ASTM D3343, D3701, or D7171)		
	Smoke Point (ASTM D1322)		
	Naphthalenes (ASTM D1840)		
	Calculated Cetane Index (ASTM D976 or D4737)		
	Copper Strip Corrosion (ASTM D130)		
	Existent Gum (ASTM D381)		
	Particulate Matter (ASTM D2276 or D5452)		
	Filtration Time (MIL-DTL-83133)		
	Water Reaction Interface Rating (ASTM D1094)		
	Electrical Conductivity (ASTM D2624)		
	Thermal Stability (ASTM D3241)		
	Initial Toxicity Review based on literature search		

M.4.3 Technology Readiness Level 3. Technology Readiness Level 3 is complete when the analytical and experimental critical functions and/or characteristic proofs-of-concept have been demonstrated. For a fuel candidate, this is completed when fuel "Fit for Purpose" properties have been determined and reported. Table M-III lists the properties, the test to determine them, and the estimated minimum amounts of fuel and time needed to do so.

TABLE M-III. TRL 3 assessments.

TRL Objective	Test	Fuel Required	Duration
Fit for Purpose	Lubricity Evaluation-BOCLE Test (ASTM D5001)	55 gal	3 months
	Low Temperature Properties - Scanning Brookfield Viscosity		
	Detect, Quantify, and/or Identify Polar Species - analyze as necessary		
	Detect, Quantify, and/or Identify Dissolved Metals - analyze as necessary		
	Initial Material Compatibility Evaluation - perform micro-optical dilatometry and partition coefficient measurements to determine the fuel-effected swell and the fuel solvency in 3 O-ring materials (nitrile, fluorosilicone, and fluorocarbon) and up to 2 additional fuel system materials listed in Table 1 from the ALTERNATIVE AND EXPERIMENTAL JET FUEL AND JET FUEL BLEND STOCK EVALUATION (AFRL-RZPF-2009-FCFS-001)		
	Material Compatibility Evaluation - Perform micro-optical dilatometry and partition coefficient measurements to determine the fuel-effected swell and fuel solvency of the remaining materials listed in Table 1 from the ALTERNATIVE AND EXPERIMENTAL JET FUEL AND JET FUEL BLEND STOCK EVALUATION (AFRL-RZPF-2009-FCFS-001) which are expected to have material performance differences in the experimental fuel than in a petroleum derived JP-8 sample		
	Fuel System Icing Inhibitor (FSII) (ASTM D5006)		
	Water Separation Index (ASTM D3948)		
	ESOH review (See Appendix E.)		
	Additive Compatibility (ASTM D4054)		

TABLE M-III. TRL 3 assessments - Continued.

TRL Objective	Test	Fuel Required	Duration
	Autoignition Temperature (ASTM E659)		
	Bulk Modulus (ASTM D6793)		
	Dielectric Constant (ASTM D924)		
	Flame Speed Test (See Appendix F.)		
	Flammability Limits (ASTM E681)		
	Hot Surface Ignition (ISO 20823 Hot Surface Temperature)		
	Specific Heat (as a Function of Temperature) (ASTM E 1269)		
	Storage Stability (MIL-STD-3004)		
	Surface Tension vs. Temperature (ASTM D971 or D1331)		
	Thermal Conductivity vs. Temperature (ASTM D2717)		
	Trace Elements (ASTM D7111)		
	Vapor Pressure , True vs. Temperature (ASTM D5191 or D323)		
	Water Solubility (ASTM D6304)		

M.4.4 Technology Readiness Level 4. Technology Readiness Level 4 is complete when component and/or breadboard validations in a laboratory environment have been successfully completed. For a fuel candidate, this is completed when Extended Laboratory Fuel Property Testing has been completed and the results reported. Table M-IV lists the properties, the tests to determine them, and the estimated minimum amounts of fuel and time needed to do so.

TABLE M-IV. TRL 4 assessments.

TRL Objective	Test	Fuel Required	Duration
Extended Laboratory Fuel Property Testing	Toxicology Screen Evaluation: Analytical comparison to JP-8 *In Vitro* genotoxicity: bacterial reverse mutation test Dermal irritation Acute oral or inhalation test Additional toxicity screen potentially required by Army – See Appendix E.	1 gal	6-10 months
	Estudios de Combustibles a Altas Temperaturas (ECAT) and Extended Duration Thermal Stability Test (EDTeST) to evaluate fuel's thermal-oxidative stability	125 gal	1 week
	Cetane Number (ASTM D613, D6890, D7170)	15 gal	1 month
	Minimum Spark Ignition Energy (ASTM E 582)		
	Ostwald Coefficient/Gas Solubility (ASTM D2779)		
	Viscosity vs. Temperature (ASTM D445)		
	Thermal Expansion (Coefficient of) derived		
	Hot Surface Ignition (FED-STD-791D Method 6053)		
	Electrical Conductivity vs. Temperature (ASTM D2624)		
	Velocity of Sound		
	Short List of Materials (Materials Compatibility) (Tables D-II and D-III)	100 gal	2 months
	APU Low Temperature Fuel Nozzle Spray Test	15 gal	2 months

M.4.5 Technology Readiness Level 5. Technology Readiness Level 5 is complete when component and/or breadboard validations in a relevant environment have been successfully completed. For a fuel candidate, this is completed when Component Rig Testing has been completed and the results reported. Table M-V lists the tests to be done and the estimated minimum amounts of fuel and time needed to do them.

TABLE M-V. TRL 5 assessments.

TRL Objective	Test	Fuel Required	Duration
Component Rig Testing	Combustor Sector Test	500 gal	2 months
	Pump Test	500 gal	1 month
	Hot Section Oxidation/Erosion	500 gal	2 months
	Toxicity Screen: Inhalation rangefinder (2 wk) In vivo genotoxicity – micronucleus In vitro genotoxicity – mammalian cell gene mutation test	2 gal	6-10 months

M.4.6 Technology Readiness Level 6. Technology Readiness Level 6 is complete when component and/or breadboard validations in a relevant environment have been successfully completed. For a fuel candidate, this is completed when small engine demonstrations have been completed and the results reported. Table M-VI lists the tests to be done and the estimated minimum amounts of fuel and time needed to do them.

TABLE M-VI. TRL 6 assessments.

TRL Objective	Test	Fuel Required	Duration
Small Engine Demonstration	Short Duration T-63 (or similar) Test or Laboratory Combustor	50 gal	2 months
	T-63 (or similar) Demonstration (extended)	500 gal	3 months
	Advanced Reduced Scale Fuel Simulator System-evaluation of fuel's coking tendency in large-scale test rig with actual airframe components (If required by the laboratory)	1000 gal	2 months
	APU Testing (Short Duration)	150 gal	2 months
	Demonstration with a Relevant Engine -- Performance/Functionality/Emissions	500 gal	2 months
	Toxicity Testing: 90-day inhalation toxicity study	5 gal	12 months

M.4.7 Technology Readiness Levels 7 through 9. Technology Readiness Levels 7 through 9 are dealt with after the decision to proceed into the certification process for the candidate fuel and are primarily the responsibility of the FCO, but with continuing military laboratory participation. TRL 7, "system prototype demonstration in a relevant environment," translates to "fuel functional characteristics demonstrated in flight." This is embodied in the preparation for flight (via ground testing of critical subsystems, like engines) and the accomplishment of a flight evaluation on one or more "pathfinder" aircraft. The most likely candidates for pathfinder aircraft include multi-engine aircraft that allow segregation of the fuel destined for each engine and are not the most functionally challenging aircraft models in the fleet of interest. Technology Readiness Level 8, "actual system completed and flight qualified through test and demonstration," translates to "fuel certified for use in all aircraft, ground systems (support equipment and vehicles), and fuel infrastructure" associated with the intended fleet in which the fuel is to be used. It can be accomplished by analysis, testing, similarity, or a combination of these for all the affected systems. Once completed, it allows operational use of the fuel in the certified systems, but it may not address many of the long-term effects (e.g., durability, system sustainment) of using the fuel. TRL 9, "actual system flight proven through successful mission operations," translates to "mid-term functional and durability effects from operational use identified." This is accomplished via "lead-the-fleet" usage of fuel in field service evaluations (FSEs) of representative aircraft models (described in Section 5.4). FSE's provide some meaningful insight into longer term effects; however, the small sample size and limited operational time are unlikely to identify all of the impacts (both good and bad) associated with the use of the newly certified fuel over the long term (e.g, an overhaul interval or full service life).). For Toxicology and ESOH in TRLs 7 through 9 see Table E-I, Toxicity research in support of fuel evaluation and certification.

M.5 MANUFACTURING READINESS

Although the Manufacturing Readiness Level process, described in the Manufacturing Readiness Level Deskbook, is aimed at readiness of hardware items, a tailored version of this process for a commodity, like fuel, can provide a meaningful method for identifying the level of maturity of the manufacturing processes used to produce that commodity. It should be noted that the DoD buys from existing developers and producers of commodities like fuel but will not normally involve itself in the development of their production methods, capabilities, and facilities like it might for hardware items for which the MRL process was developed. DoD is normally an observer and evaluator focused on identifying acceptable suppliers. The following describe each of the MRLs as tailored for the fuel commodity.

M.5.1 Manufacturing Readiness Level 1. "Manufacturing Feasibility Assessed" for the fuel commodity becomes "Production Feasibility Assessed." The word "production" is substituted to be more compatible with the concept of a commodity. This is the lowest level of production readiness. The focus is on a top-level assessment of feasibility of commercially producing an alternative fuel including the identification of feedstocks and maturity of potential technologies necessary for the production. Basic production principles are defined and initial plans are developed for laboratory studies. The initial assessment identifies the technical challenges and an initial market analysis is conducted.

M.5.2 Manufacturing Readiness Level 2. "Manufacturing Concepts Defined" for fuel becomes "Production Concepts Identified." Initial laboratory research has been done to determine the technical feasibility of the conversion of a feedstock to an alternative fuel. Process concepts are explored and small quantities of test samples are produced. The initial feasibility of the concept is demonstrated in a laboratory setting.

M.5.3 Manufacturing Readiness Level 3. "Manufacturing Concepts Developed" for fuel becomes "Production Concepts Developed." Research is conducted at a laboratory production level. Initial laboratory experiments are scaled up to the bench level to determine basic scientific and engineering parameters. Small fuel samples (500 ml) are produced for analysis. Process variables are studied and plans for scale up developed. Business plans, market assessments, and initial cost studies are initiated. It is at this point that the military laboratory TRL assessments can begin.

M.5.4 Manufacturing Readiness Level 4. "Capability to Produce the Technology in a Laboratory Environment" for fuel becomes "Production Capability in a Laboratory Environment." Research is conducted at a bench scale production level. Laboratory experiments are conducted in bench level equipment to determine basic scientific and engineering parameters needed for the design of a pilot plant. Small fuel samples (one to five gallons) are produced for analysis. Business plans, market assessments, and initial cost studies are completed. Production risks, cost drivers, key performance parameters (KPP's) and special needs for tooling, facilities, materials, fabrication, and operation are identified.

M.5.5 Manufacturing Readiness Level 5. "Capability to Produce Prototype Components in a Production Relevant Environment" for fuel becomes "Laboratory Production Capability in a Relevant Environment." Laboratory production is transitioned to pilot scale testing. Key physical and chemical properties for engineering design are identified and used for design of pilot scale equipment. Pilot scale equipment is fabricated and initial test runs conducted. Research plans are developed and key process variable studies are initiated. Fuel samples of approximately 50 gallons are produced for analysis. Cost studies and business plans are updated.

M.5.6 Manufacturing Readiness Level 6. "Capability to Produce a Prototype System or Subsystem in a Production Relevant Environment" for fuel becomes "Subscale Production Capability in a Representative Environment." Pilot scale production of representative samples of fuel is conducted. Research focuses on risk reduction for a commercial facility. Process efficiencies are measured and matured. Technical data for commercial scale process equipment are generated. Research quantities of fuels (500 – 1000 gallons) are produced for initial fuel pre-certification and certification efforts. Preliminary designs for a commercial demonstration plant are developed. Cost studies and business plans are updated.

M.5.7 Manufacturing Readiness Level 7. "Capability to Produce Systems, Subsystems or Components in a Production Representative Environment" for fuel becomes "Scalability of Production Capability Demonstrated." Pre-front-end engineering assessment (pre-FEED) is initiated. A site is selected for commercial plant. Initial project permitting is started. Pilot scale production continues to refine engineering design parameters. Research quantities of 1000 gallons or more are produced for fuel certification efforts. Supply chain vendors are selected. Cost studies and business plans are updated.

M.5.8 Manufacturing Readiness Level 8. "Pilot Line Capability Demonstrated; Ready to Begin Low Rate Initial Production" for fuel becomes a more limited "Pilot Plant Capability and Sample Production Demonstrated." A detailed front end engineering design study is conducted for the commercial facility. Pilot scale process variables are finalized for plant construction. A pilot scale facility produces fuel samples consistent with projected commercial production. Research quantities of fuel are produced for certification efforts (1000's of gallons). The supply chain is established and vendors are selected. Initial preparation of the commercial production site initiated. Permit applications are filed. Cost estimates and business plans are updated.

M.5.9 Manufacturing Readiness Level 9. "Low Rate Production Demonstrated; Capability in Place to begin Full Rate Production" for fuel becomes a more limited "Low Rate Production Demonstrated." The commercial scale production facility is constructed. The plant achieves critical startup milestones and starts initial production (on the order of tens of thousands of gallons per month). Commercial quantities of fuel are produced for fuel certification or early commercial usage. Supply chain and distribution efforts are refined.

M.5.10 Manufacturing Readiness Level 10. "Full Rate Production Demonstrated and Lean Production Practices in Place" for fuel becomes "Full Rate Production Demonstrated." This is the highest level of production readiness. Full-scale commercial production has begun. All engineering, performance, quality, and reliability requirements are being met. Sufficient feedstock, storage, and transportation are available to support fuel production levels of the order of hundreds of thousands of gallons/month.

M.5.11 MRL-TRL Alignment. Because all of the TRL assessments of a potential fuel candidate require some quantity of fuel, the MRL of a candidate needs to be at least at level 3, Production Capability in a Laboratory Environment. Beyond that, the MRLs should be at least at a level sufficient to allow production of the quantity of fuel needed to complete each of the TRL assessments described in Section M.4 in a sufficiently-timely fashion.

M.6 LIFE-CYCLE ENVIRONMENTAL ANALYSIS

The objective of this analysis is to comply with applicable laws, regulations, and policies, and to apply good sense. The objective is to determine and compare with conventional petroleum fuels the effect of emissions throughout the entire life cycle of the candidate fuel, beginning with feedstock production (if undertaken for the production of fuel) or with feedstock receipt from its source (if the feedstock is a byproduct of production for another purpose) and ending with combustion of the fuel and the disposal of fuel production byproducts. The accomplishment of this depends heavily on the models used for the analysis. These models are likely over time to continue to be developed and refined to improve their accuracy. For the evaluations done at a given point in time, it is wisest to use the same models to evaluate all the competing candidates so that the results can be used for comparison. Validated models are preferred over models that are not validated.

M.7 SUSTAINABILITY

This area of interest assesses the availability of sufficient resources (e.g., land, water, air, sunshine, etc.) to allow continued production at the needed capacity without unduly competing with higher priority needs like food production. If resources are depleted in the production of a candidate fuel, an assessment should be made of the projected availability of those resources given their expected use for the production of the subject fuel candidate, taking into consideration any potential competing uses as well.

M.8 COST

Cost operates on two fronts. The first is the set of costs associated with the certification effort including the fuel needed to complete it and the costs of any known actions to implement or accommodate the operational use of the fuel once it is certified. The second is the projected future costs of purchasing fuel for operational use including any identifiable production cost changes both downward (e.g., due to learning or to process improvements) and upward (e.g., due to changes in competing demand for the needed feedstocks or due to the need to comply with scheduled changes in environmental regulations).

M.9 GO / NO-GO GATES

There are thresholds of acceptability in most evaluations. The “Red” thresholds in Appendix C define candidate fuel properties (and their associated TRLs). Similar thresholds should be defined for MRLs, Life-Cycle Environmental Analysis results, Sustainability, and Cost. All of these thresholds become useful in eliminating unacceptable candidate fuels which do not warrant the expense of further evaluation or certification actions; and it should be an objective to identify no-go fuel candidates as early as possible in the evaluation process.

M.10 QUANTIFICATION OF EVALUATION RESULTS

For potential candidates that pass the go / no-go gates, a means of rank ordering or prioritizing competing candidates may be needed to allow selection of the best for further consideration. The relative importance of each of the five assessment areas will vary over time depending on the technical, environmental, political, economic, and societal influences in play at any given time. To assist with decisions regarding potential candidates, a scoring methodology should be developed for each of the assessment areas. Further, a weighting methodology should be applied to give relative value to each based on the importance of the influences in play at the time for the given decision. Transparency of this evaluation scoring method in competitive procurements of certification fuel quantities may help to sustain selection decisions subject to protest by losing bidders. The selection criteria for the purchase of fuels needed to certify a given class of fuels with multiple competing producers of examples of that class will be much different from those used to select from competing single source fuels or from competing classes of fuels. The latter two are much more difficult because of fewer areas of direct comparability.

APPENDIX N

STREAMLINED CERTIFICATION PROCESS

N.1 SCOPE

N.1.1 Background. There are circumstances in which significant cost savings and schedule improvements can be achieved in the certification of a candidate fuel. The objective is to reduce the amount of testing while retaining equivalent safety and functional insight into the candidate fuel's behavior when compared to the baseline fuel. The approach, described in the following is for drop-in fuels intended as additions to or replacements for the baseline fuel without change in identifying nomenclature. It parallels commercial aviation's technical methodology employed for a number of fuels approved for use in commercial aircraft by the FAA with the support of ASTM International.

N.1.1.1 Commercial Methodology. The commercial method determines the fuel properties of a candidate fuel and how they compare to the equivalent properties of the fuels for which there is substantial experience in commercial service. If the properties are within the requirements of existing fuel specifications and the experience of the "Fit for Purpose" properties, then systems analysis, component testing, a full engine test, and potentially a flight demonstration are accomplished on representative examples of engine and (if necessary) aircraft components and systems. This methodology takes advantage of qualification by similarity based on the participation of multiple original equipment manufacturers (OEMs), each doing part of the analysis and testing needed to assure safety and functionality, and all accepting the results of one another's work. If the engine and aircraft OEMs find the fuel to be acceptable from safety and functional perspectives, the candidate fuel can proceed to balloting for acceptance by the ASTM voting members (which include the OEMs and other interested parties) as an approved fuel within the relevant fuel specification (or as a new specification, if that is deemed appropriate).

N.1.2 DoD Streamlined Methodology Summary. The DoD streamlined methodology still requires the same AFRL up front work supporting the decision to certify (i.e., determining properties, initial material compatibility, and component testing). If results are favorable; i.e., Entrance Criteria and Subset 1 properties are within the green or yellow ranges of Appendix C and no issues are found in the component testing; it may be appropriate to use the streamlined process for this fuel candidate, subject to the determination of technical maturity and economic viability by the FCO addressed in Section 4. Because of the much wider range of functional requirements and operating environments seen by DoD systems, the scope of the selected representative examples to be tested, to form the basis of qualification by similarity for most DoD systems, is quite a bit broader than the commercial methodology. However, the scope is still less than the potential repetitious engine and flight testing of each system that might be necessary or desired by the responsible DoD system managers' organizations for a fuel with less benign properties or fuel which needs to be certified as a new grade.

N.2 APPLICABLE DOCUMENTS

N.2.1 General. The documents listed below are not necessarily all of the documents referenced herein but are considered to be those which are most important in providing the user a clear understanding of the information provided by this appendix.

N.2.2 Government Documents.

N.2.2.1 Government Specifications, Standards, and Handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-83133	Turbine Fuel, Aviation, Kerosene Type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37)

(Copies of this document are available on line at http://quicksearch.dla.mil/.)

N.3 DEFINITIONS

Class of Fuels: fuels, defined by a specification, which are capable of being produced by multiple sources (producers) to a specified process capable of producing fuel of sufficient character and quality to meet end use performance and functional requirements.

Single source fuel: a fuel produced by a specified supplier to that supplier's defined and controlled process (normally a proprietary process).

Technology Readiness Levels (TRLs): for fuels these are described in Appendix M, Section M.4 and subsections.

N.4 THE STREAMLINED FUEL CERTIFICATION PROCESS.

N.4.1 DoD Laboratory Assessments. DoD laboratories like AFRL are normally the starting point for evaluating candidate fuels, with the objective of determining in steps, using the Technology Readiness Level methodology, whether a candidate fuel is ready to proceed to more advanced steps in the certification process. Those assessments are described in Appendix M.

N.4.2 Fuel Certification Organization (FCO) Activities. In the streamlined certification process, the FCO's active involvement becomes significant during the time AFRL is performing its TRL 4 assessments. This process is shown in the flowchart on Figure N-1.

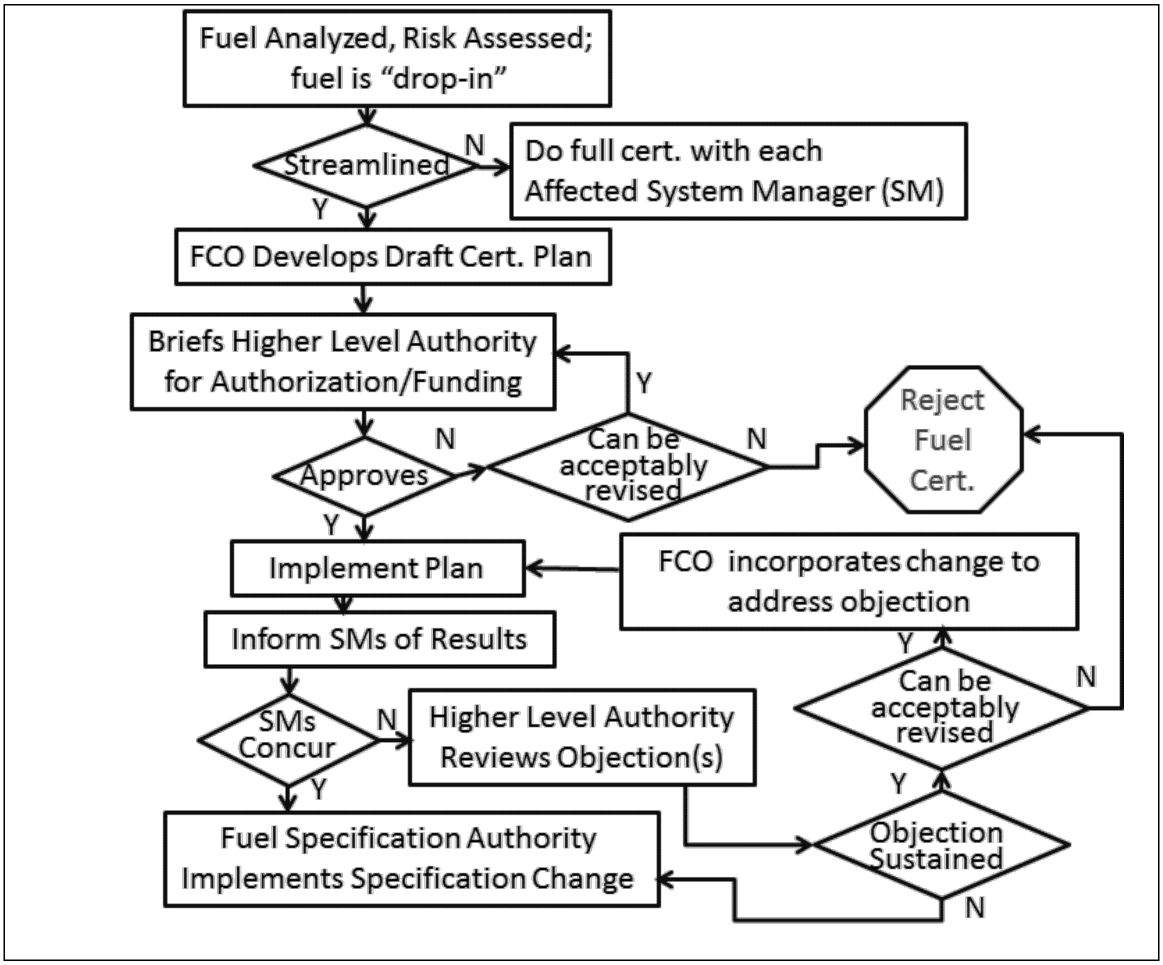

FIGURE N-1. Streamlined certification process.

N.4.2.1 The Kickoff Assessment. When most of the fuel candidate's properties have been determined and found to be acceptable (within the "Green" or "Yellow" limits of Appendix C) and some evaluation is possible of the economic, environmental, and manufacturing readiness characteristics of the candidate fuel, FCO, with inputs from the Laboratory (like AFRL), the Service Control Point for fuel (like AFPA), and the other military services, will assess the potential benefits and costs of certifying the candidate fuel(s) as a fully fungible addition to or drop-in replacement for the existing baseline fuel supply. They will determine whether to certify the candidate(s) as a class of fuels (capable of being produced by multiple sources to a defined process capable of producing fuel of sufficient character and quality to be used for aviation) or whether the certification is of one or more single sources (normally, each with its own proprietary process). And, they will decide whether or not the streamlined process is appropriate. If the determination is favorable and funding to certify is available, FCO will begin the certification effort.

N.4.2.1.1 FCO Risk Assessments. Based on its previous certification experience and the degree of risk of potential negative impacts associated with a candidate as determined by the FCO's risk assessment process, some degree of additional testing and analysis, beyond that done in laboratories' TRL 1 through TRL6 efforts, may be needed to achieve TRL 7 and TRL 8. With the assistance of the Laboratory (like AFRL), the Service Control Point for fuel (like AFPA), and the other military services, the FCO will determine the scope of the additional testing and analysis, as outlined in N.4.2.3 and N4.2.4, needed to reduce the risks to an acceptable level.

N.4.2.1.2 The Certification Plan. The FCO, in coordination with the Laboratory (like AFRL), the Service Control Point for fuel (like AFPA), the affected System Managers, and the other military services as required, will develop a certification plan for the fleet intended to use the candidate fuel, based on the risk assessments.

N.4.2.1.3 Higher Level Authority Approval. If funding and authority for this work is not in place to allow implementation of the certification plan, the potential program needs to be briefed to the organization responsible for funding and associated organizations to obtain the needed authority and funding. This may involve an iterative process to satisfy the higher level's requirements. Once these are obtained, it may be wise to get additional authority from the higher level allowing the FCO to task affected System Managers and their organizations to support the certification effort. (Obtaining authority to task proved very valuable for both the JP-8/SPK and the subsequent bio-fuel certification efforts. See J-5-11)

N.4.2.2 Fuel Purchase(s). The primary schedule limitation in fuel certification is getting a sufficient quantity of fuel to do the necessary testing and demonstrations. Unless the candidate fuel is already in mass production for other users, there may only be a limited supply available or a significant lead time for the required quantity of fuel. The FCO will develop an appropriate solicitation for one or more suppliers of the candidate fuels.

Candidate fuels which are blends of a new fuel component with the baseline (as were JP-8/SPK, JP-8/HRJ, and JP-8/ATJ) need not be purchased in blended form. In that case the specification in the solicitation can address only the new blending component and needs to be sufficiently limiting to provide reasonable assurance that, when blended with the baseline fuel at the maximum intended new-component percentage, the resulting blend will meet the existing specification for the baseline fuel. Because of the wide variation allowed for baseline fuels like JP-8, some consideration should be given to the potential range of fuel property values that could result when the new component is blended with baseline fuels expected to be used for blending. Baseline fuel properties can vary by region of the country to which they are delivered and even by time of year of delivery. This variation may need to be considered as well.

It is important to work with Service Control Point for fuel (e.g., the Air Force Petroleum Agency), the other participating military services (if applicable), and DLA Energy to define the appropriate specification for the purchase of the fuel, aimed at ensuring that the fuel purchased will be of sufficient character and quality to be safely usable for aviation. This specification will likely be very similar or identical to the requirements for the baseline fuel. Normally, DLA Energy will be the procuring agency for the large quantities of fuel needed for a certification program. Close coordination between FCO and DLA Energy is required throughout the solicitation, proposal evaluation, and source selection process to ensure that certification program objectives are fully supported by the quantities, timing, and quality of the fuel purchased.

Another task is to define a specific and unique identifier (name) that should be used consistently to identify and to differentiate each candidate fuel from other candidates and from other already-defined fuel grades and types during the certification process. During the certification process, it will be necessary to keep the candidate fuel separated in the fuel handling and supply system from other fuels used by the DoD (per Section 4.6). It may or may not be necessary to segregate the individual candidates from each other. If they are sufficiently similar and they are just examples of a class of fuels being certified, it may be appropriate to blend them for some certification tests. The production lead time and delivery capability (potentially incremental) of the chosen supplier(s) will be a key driver of the certification effort's schedule.

N.4.2.2.1 Selection Criteria. The selection criteria for the candidate fuel(s) need to be carefully crafted to fully identify the go / no-go gates for potential bidders as well as the scoring methodology to be used to rank order and select from those whose bids pass the go / no-go criteria. While it may be difficult to prevent a protest of the selection(s), the proper establishment and communication of the evaluation criteria and their fair and transparent application may help to avoid the more costly delays associated with a sustained protest.

N.4.2.3 Technology Readiness Level 7 Activity (the Pathfinder Program). The pathfinder approach is a set of initial steps to functionally evaluate a candidate fuel and determine if the reduced scope of the remaining streamlined certification effort is appropriate for the candidate fuel. If major problems with the fuel arise, the candidate may be disqualified from further certification efforts or the scope of those efforts may need to be increased to reduce the risks associated with certification on the basis of the more limited data available from the streamlined effort.

N.4.2.3.1 Auxiliary Power Unit (APU) Testing and Evaluation. An economical opportunity, to get functional data at operationally significant challenging conditions, is testing an APU at its cold temperature and altitude extremes in a ground test cell. The relatively low fuel consumption (i.e., less than 100 gallons per hour) allows this testing early in the TRL 7 activity when large quantities of fuel may not yet be available. Also, the relatively small size of these units make this testing fairly economical in terms of facility setup and operation, yet it provides valuable functional information (light-off, blowout, starting, etc.) at conditions that challenge the APU and so could identify show-stopping problems with the candidate fuel early, before the significant costs of the certification are incurred.

N.4.2.3.2 The Pathfinder Aircraft. The pathfinder precursor aircraft is a low-risk air vehicle flight demonstration or test that will provide initial insight into the safety and functional behavior of the candidate fuel at real operational conditions. This normally entails use of a multi-engine aircraft whose fuel system can segregate the candidate fuel and is able to feed the candidate fuel to just one of its engines. The methodology would follow the same philosophy applied during the certification of JP-8/SPK, using the B-52, C-17, and A-10 as early demonstrator vehicles. After successful functional testing of the fuel in the aircraft on the ground, flight with the candidate fuel feeding one of the engines can be performed. Once comfortable with use of the candidate fuel on one of the aircraft's engines, fuel use can be expanded either in increments or in a single step to all engines on the aircraft.

The pathfinder aircraft assessment may use one or more aircraft models which represent the most challenging functional operating conditions for the candidate fuel or represent aircraft models with large fleets. Challenging operating conditions can include afterburner operating limits, high altitude flight, or high Mach number flight. For fighters with afterburning engines the pathfinder would preferably be a twin-engine aircraft to reduce the risk, though a single-engine aircraft could be a pathfinder with acceptable risk if its engine model was sufficiently tested per N.4.2.3.3 prior to flight to clear as much as possible of the intended flight evaluation envelope.

N.4.2.3.2.1 Pathfinder Prerequisites. To ensure safe operation of the pathfinder aircraft, it is necessary that material compatibility of the candidate fuel with any fuel-wetted materials in the pathfinder aircraft and its fueling systems has been determined. Also, the laboratory (e.g., AFRL) should have completed all of its assessments through TRL 6 prior to flight and found no show-stopping issues. To protect operators and their support personnel during the pathfinder aircraft evaluations, an environmental review and an industrial hygiene review (addressing personnel safety equipment and procedures) should be performed, augmenting the toxicity evaluation done as part of TRL 4, prior to any fuel transfer to aircraft or to its fueling equipment.

N.4.2.3.3 The Afterburning Engine Evaluation. Afterburning fighter engines provide the greatest functional challenges for a fuel. The intricacies and subtleties of combustor and augmentor designs and the wide range of operating conditions, both steady-state and transient, which fighter aircraft see magnify the sensitivity to variations in fuel properties. This makes the fighter aircraft and its engine potentially the most conservative evaluators of a fuel candidate's functional performance. Evaluating the functional and performance behavior of an afterburning engine with the candidate fuel in an altitude test cell builds on the TRL 7 functional testing performed on the APU(s), operates as a more severe test than the pathfinder precursor flight(s), and prepares the way for the fighter flight evaluation, if required, either in the pathfinder program or in the TRL 8 effort (N.4.2.4.9). Evaluation of engine performance, starting, light-off, transients, and augmentor stability (rumble and screech) characteristics with the candidate fuel at or near the operating limits is needed to determine whether the candidate fuel's characteristics are better, comparable, or worse than with the baseline fuel (see Appendix G). During test planning, consideration should be given to varying the fuel-to-air ratio and engine pressure ratio about the nominal control schedules to map the engine's sensitivity to screech, rumble, light-off, blowout, and starting. This approach may locate the boundaries of acceptable operation or determine the degree of margin available. The resulting data may then be used to help assess the engine fleet's characteristics and margins with the candidate fuel. The engine model selected for this evaluation would best be the one whose operating characteristics in the aggregate are closest to the edge between functioning as intended and not doing so. Also, it would be best if the engine evaluated was the same model as that powering the fighter aircraft to be evaluated in flight. It may be necessary to test more than one afterburning engine model to satisfy the certification data needs. Normally, the first such test would be considered part of the Pathfinder Program with the subsequent testing considered part of the Full Validation / Certification effort described in N.4.2.4.

N.4.2.3.4 Commingled Fuel. Depending on the degree of chemical difference of the candidate fuel with previously certified non-petroleum blend components (e.g., Fischer-Tropsch-derived fuel), it may be advantageous to perform a functional evaluation of a commingled fuel (e.g., a tri-blend consisting of a blend of 50% petroleum-based fuel with 25% of the current fuel candidate's blend component and 25% of a previously certified non-petroleum blend component like the Fischer-Tropsch-derived fuel). Piggy-backing the evaluation of the commingled fuel onto the end of testing performed for the current fuel candidate would normally be most efficient and effective. This should save setup costs for the test article (e.g., engine or aircraft) and provide a closer back-to-back comparison of the commingled fuel with both the current candidate and with the baseline fuel, with all evaluated within the same test setup and with the same test article.

N.4.2.4 Technology Readiness Level 8 Activity (Full Validation / Certification). This activity builds on the data already developed by the TRL 1 through 7 activities to fill remaining gaps in the data needed to certify the rest of the fleet for which the candidate fuel is intended. The intent is to minimize additional testing by taking advantage of existing data as much as possible to support certification on the basis of similarity, either with the testing and analysis already accomplished for the candidate fuel or, if applicable, with the testing and analysis accomplished for sufficiently similar fuels.

N.4.2.4.1 Additional Material Compatibility Assessments. Material compatibility evaluations should be performed on fuel-wetted materials not already evaluated or not sufficiently similar to the materials evaluated in the TRL 1 through 7 efforts. The evaluation should now include materials that could be subject to fuel contact via leaks, spills, or overspray in additional to those which are normally fuel-wetted. Also, fuel wetted materials from support equipment, vehicles, and fueling infrastructure, which are expected to use the fuel, should be evaluated.

N.4.2.4.2 Toxicity Assessments. The assessments should follow the guidance provided in Appendix E.

N.4.2.4.3 Fuel System Component Evaluations. Analysis and some testing of selected fuel system components (e.g., quantity measuring systems, fuel pumps) should be performed to fill gaps in the knowledge of how these components might be affected by any peculiarities in the properties of the candidate fuel(s). This can also be an opportunity to evaluate durability impacts associated with using the candidate fuel.

N.4.2.4.4 Support Equipment and Vehicles Evaluation. Analysis and some testing of selected support equipment and vehicle systems should be performed to fill gaps in the knowledge of how these systems might be affected by any peculiarities in the properties of the candidate fuel(s).

N.4.2.4.5 Fuel Handling and Storage Infrastructure Assessment. The primary focus of this effort should be on the effects of the candidate fuel on filtration systems. Additional limited evaluations of unique or particularly sensitive components of the fuel infrastructure may also be performed to fill knowledge gaps for these components.

N.4.2.4.6 Ground Fire Protection Assessment. The assessments should follow the guidance provided in Appendix F.

N.4.2.4.7 Survivability and Vulnerability Protection Assessments. The assessments should follow the guidance provided in Appendix F.

N.4.2.4.8 Additional Engine Evaluations. If the pathfinder testing of an afterburning engine does not provide sufficient data to support certification of all engine models and their aircraft, it may be necessary to perform additional test cell engine evaluations. Like the testing described in N.4.2.3.3 for the first afterburning engine, such testing should address the unique functional aspects of the selected engine(s) which would provide the missing data.

N.4.2.4.9 Fighter Aircraft Flight Evaluation. If a fighter aircraft was not sufficiently evaluated during the Pathfinder Program, it is imperative that this evaluation be performed in this phase of the certification program. As with the afterburning engine, the fighter aircraft, especially one powered by an afterburning engine, provides the opportunity to evaluate the fuel at some of the most challenging operating conditions performing some of the most challenging functions at real operational flight conditions. The aircraft selected for this evaluation would best be one powered by an engine model the same as that used for the afterburning engine evaluation (N.4.2.3.3).

N.4.2.4.10 High-Altitude Aircraft Flight Evaluation. The other significantly challenging operational conditions are experienced on high-altitude aircraft that operate with cold low-density air which makes sustaining combustion difficult.

N.4.2.4.11 Baseline Fuel Specification Changes.

The ultimate objective for a drop-in fuel is to include the specification for the candidate blend component as a normal, but optional, part of the definition of fuel identified as the baseline fuel (e.g., just “JP-8”). This would be accomplished via a change to a specification like JP-8’s MIL-DTL-83133. Such a change requires agreement by all of the services that the blend component and its associated maximum blend percentage (e.g., 50% for Fischer-Tropsch derived fuel) are acceptable to them all. That level of change takes time, participation, and agreement by all of the services, a process which may not be sufficiently timely for any one of the services’ required or desired use of the fuel during the certification program.

To allow operational use of a certification candidate fuel during the certification program, the baseline fuel’s specification can be changed to incorporate the required characteristics of the candidate fuel and to require that use be approved by both the procuring activity (DLA Energy) and the fuel technical authority (as identified in the specification) of the affected military Service. That specification can be used to define the product to be procured and its associated quality assurance. Further, the specification can be used to apply a unique temporary identifying nomenclature to the candidate fuel to assist with keeping it segregated from the normal military fuel supply system (Section 4.6). This is what was done for the Fischer-Tropsch fuel blends, which were identified as “JP-8/SPK” in the JP-8 specification, MIL-DTL-83133F. Its properties were specified both for the non-petroleum blend component and for the resulting blend of up to 50% with JP-8. The procuring activity (DLA Energy) with the fuel technical authorities of each of the military services (identified in the specification) was given authority to allow or forbid the fuel’s use for their services. This allowed JP-8/SPK to be used in testing during the certification effort, and it allowed its operational use in field service evaluations in certified systems once that certification had been documented by the applicable System Managers and the authorization to use fuel with that designation was incorporated via an operational supplements to the operational technical orders (e.g., the Flight Manuals) for the certified systems.

A slightly different approach was used for the drop-in JP-8/HRJ (HEFA) fuel certification. MIL-DTL-83133H specified the needed properties of both the HRJ (HEFA) blending component and the blended fuel, required approval for use from the procuring activity (DLA Energy) and the applicable fuel technical authority for each of the services listed in the specification, but it left the nomenclature of the fuel unchanged:"JP-8," i.e., there was no temporary identifier for the HRJ-blend. This simplified operational use for flight demonstrations and a field service evaluation because it did not require technical order supplements for the aircraft involved. Since availability of certification fuel was limited and under strict control of the applicable technical authority within each service, each service could adequately control use and ensure that the using systems were certified and the fuel was appropriately handled and segregated from the unlimited-use baseline fuel defined in the specification.

Once the certification program has been completed, the final implementation will be by a formal change to the baseline specification, including fuel property requirements for the finished drop-in fuel over and above those for the baseline as well as specific requirements for properties of any new blending component(s) that are part of the new fuel. There will no longer be requirements for special approval to use the new fuel, and its identification nomenclature will be the same as the baseline fuel.

N.4.2.5 Technology Readiness Level 9 Activity (Field Service Evaluations). The purpose and scope of this activity is described in Section 5.4.

N.4.2.5.1 Fighter Aircraft Field Service Evaluation. Following the same philosophy used to select a fighter aircraft for flight evaluation, the same concept applies to identifying some mid-term impacts of using the candidate fuel over a longer period of time. Subject to the limitations of available fuel and the willingness of the operating organization to accommodate the additional effort needed, one or more aircraft, preferably of the same type and model as used for the fighter aircraft flight evaluation, should be used for a field service evaluation. While such an evaluation is of limited value for statistical analysis, it should point out any potential significant operating-time-related issues or benefits (to deterioration, wear, corrosion, etc.) over the midterm with the candidate fuel and, hopefully, identify trends for the long term. The information gained would then be usable for analytical assessments of the impacts to other aircraft models which operate in less severe conditions.

N.4.2.5.2 High-Altitude Aircraft Field Service Evaluation. Similarly, and again subject to the limitations of available fuel and the willingness of the operating organization to accommodate the additional effort needed, one or more high-altitude aircraft, preferably of the same type and model as used for the high-altitude aircraft flight evaluation, should be used for a field service evaluation. The information gained would then be usable for analytical assessments of the impacts to other aircraft models which operate at similar but less severe conditions.

APPENDIX O

EVALUATION OF COMMERCIAL FUEL SPECIFICATION CHANGES

O.1 SCOPE

O.1.1 Background. There may be circumstances in which a drop-in fuel or fuel class, being considered for implementation by commercial aviation via a change to an already approved commercial specification, is not considered for implementation by DoD or the Service responsible for the military specification (e.g., USAF for JP-8, Navy for JP-5) via a change to the military fuel specification. Most DoD jet fuel using systems are authorized to use commercial jet fuels (as an "Alternate Fuel"), some with special limitations or additional maintenance requirements. (For example, the freezing point of commercial Jet A [-40 deg C] being warmer than JP-8's freezing point [-47 deg C] limits operations with Jet A to warmer total outside air temperatures than those allowed for JP-8.) Such circumstances may require DoD or USAF to evaluate the effects of a new version of a commercial fuel on military-unique functions, system performance, operating limits, and durability impacts, since the commercial specification revision process would likely not by itself do such evaluations.

O.1.1.1 Commercial methodology. The commercial method determines the fuel properties of a candidate fuel and how they compare to the equivalent properties of the fuels for which there is substantial experience in commercial service. If the properties are within the requirements of existing fuel specifications and within the experience of the "Fit for Purpose" properties, then systems analysis, component testing, full engine testing, and potentially flight demonstration are accomplished on representative examples of engine and (if necessary) aircraft components and systems (ASTM D4054). This methodology takes advantage of qualification by similarity based on the participation of multiple Original Equipment Manufacturers (OEMs), each doing part of the analysis and testing needed to assure safety and functionality, and all accepting the results of one another's work. The results of the analysis and testing are documented in a "research report." When completed, the report is provided to voting members of the responsible ASTM committee for balloting to determine its adequacy in justifying the acceptability of the fuel from safety and functionality perspectives. Negative votes are adjudicated, either by resolving the objection of the "no" voter (e.g., by amending the report potentially based on additional analysis or testing) or by a determination by the committee that the reasons for the negative votes are not persuasive. If the report is rejected by one or more persuasive negative votes, the report is balloted again after the amendment is incorporated. Once the research report is accepted, the specification (either new or modified) and its content are balloted in the same way with similar resolution of negative votes required for acceptance. Voting members of the ASTM aviation fuel committee include aircraft and engine OEMs, major certification authorities (like the US Federal Aviation Administration), representatives of the military services of major countries, fuel producers, and other interested parties. DoD has voting members on the ASTM committees and can influence specifications that are balloted, but "persuasive" arguments supported by meaningful and relevant data need to accompany any attempts to influence the content of specifications and gain its acceptance by larger community of ASTM voters. DoD cannot by itself control the outcome of the ballots. Concerns over product liability or competitive position in the marketplace by the OEMs tends to apply an appropriate degree of caution to the balloting which keeps new or changed specifications from being too radically different or risky with regard to potential impacts of the fuel on safety, functionality, or system durability. However, this risk-avoidance is directed primarily at commercial systems and operations and does not normally consider military-unique requirements.

O.1.2 Military-unique requirements. There are a number of potential aspects of military systems which are outside both the interest and the capability-to-test of commercial aviation, who are the primary drivers of changes to the commercial jet fuel specifications. Changes tend to be driven by direct or indirect economic incentives, and these may not apply to military systems or to their users. In their operational safety, suitability, and effectiveness responsibility, System Managers of military systems need to be aware of the effects of such externally-driven changes on any of their systems which are authorized to use fuels procured to the commercial specifications. If changes to the fuel have the potential to negatively affect the safety, operational utility, or durability of the military systems, their System Managers need to make appropriate changes to operating limits, maintenance requirements, etc. when using the commercial fuel to ensure safe operation and to minimize the negative effects on military utility and durability.

Examples of military-unique functionalities include, but are not limited to, the following. The one that most readily comes to mind is afterburner thrust augmentation in aircraft engines. This function has not been used by commercial aviation since the demise of supersonic transports, yet it is a vital functional capability of some military systems – a function which can be sensitive to variations in fuel properties. Another functionality is high altitude flight, commonly used by military reconnaissance systems, above the altitude of commercial airways. Operation in the rarified air at very cold temperatures challenges engine operation. Still another, is support of the increased electrical power demand of airborne high-power radars, lasers, and directed energy weapons, which directly or indirectly could derive their power from the on-board jet-fuel supply.

O.1.3 Effect on system certification. For functions or operating conditions relevant to military systems which are not evaluated as part of the commercial certification process, there may be an effect of changes to the commercial fuel specification on the airworthiness certification of military systems when they use the changed commercial fuel. When the commercial fuel specification changes, an airworthiness decision needs to be made by the cognizant airworthiness authority about whether the change has the potential to affect system airworthiness and how to address it. There are three choices which can be made:

O.1.3.1 Do nothing. If the changed fuel is a drop-in version to its predecessor, and its name, as identified in the system's airworthiness certificate, has not changed, the system can legally be operated using new fuel, but operation may be at higher risk that safety and mission effectiveness may be negatively affected. The decision to use the fuel in the same way as its predecessor without additional evaluations or restrictions is a decision to accept those risks.

O.1.3.2 Prohibit or limit use. Usage limitations can range from prohibiting the use of the new fuel to changing how and under what conditions the fuel can be used, to avoid undesirable effects or avoid the risk that such affects could occur.

O.1.3.3 Test the fuel on the system. System or subsystem tests of the fuel can be used to determine what, if any, changes to system operating limits, to system software, or to system hardware may be necessary in order to safely and effectively operate the system when using the new commercial fuel. Sufficient data should be gathered to allow a recertification of the system for use of commercial jet fuel with revised operating limits which can be permanent or only temporary pending certification of needed system modifications.

O.2 APPLICABLE DOCUMENTS

O.2.1 General. The documents listed below are not necessarily all of the documents referenced herein but are considered to be those which are most important in providing the user a clear understanding of the information provided by this appendix.

O.2.2 Government documents.

O.2.2.1 Government specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-5624	Turbine Fuel, Aviation, Grades JP-4 and JP-5
MIL-DTL-83133	Turbine Fuel, Aviation, Kerosene Type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37)

(Copies of this document are available on line at http://quicksearch.dla.mil/.)

ASTM INTERNATIONAL STANDARDS

ASTM D1655	Standard Specification for Aviation Turbine Fuels
ASTM D7566	Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons
ASTM D4054	Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives

(Copies of these documents may be ordered on line at www.astm.org; or approved users may access the documents on line at http://global.ihs.com/standards.cfm?publisher=ASTM&RID=Z06&MID=5280.)

O.3 DEFINITIONS

Baseline Fuel: fuel meeting the requirements of the latest version of the commercial specification immediately prior to the changes which have incorporated or will incorporate the fuel(s) requiring further military-related evaluation.

Class of Fuels: fuels, defined by a specification, which are capable of being produced by multiple sources (producers) to a specified process capable of producing fuel of sufficient character and quality to meet end use performance and functional requirements.

Fuels Evaluation Organization (FEO): The organization responsible for the implementation and coordination of the fuel evaluation process for the US military.

O.4 THE PROCESS FOR EVALUATING THE EFFECTS OF CHANGES TO THE COMMERCIAL FUEL SPECIFICATION.

The military evaluation of a commercial fuel can take two forms, proactive or reactive. In the proactive approach, the effects of changes in a commercial fuel on military-unique functions are evaluated in parallel with commercial aviation's evaluation process. This allows DoD participation in the development of the specification change and provides an opportunity for DoD to apply some influence on the content of the final commercial specification to avoid potential negative impacts from the change. The degree of influence depends on the "persuasiveness" of DoD's input, which includes the relevance to commercial operations or to commercial concerns and the validity of the supporting test and analytical data. If, on the other hand, DoD's input is insufficiently persuasive or the evaluation results come too late to influence the specification, DoD needs to use evaluation results to determine and set any new operating limits, identify any system modifications, or establish new maintenance requirements for each affected system, if any are shown by the evaluation to be required. The reactive approach normally waits until after the commercial specification has been approved and implemented by ASTM. This event would be the trigger justifying individual program offices spending their resources on evaluating the changed fuel for airworthiness impacts, if specific funding for commercial fuel evaluation is not provided.

O.4.1 Military laboratory assessments. Military laboratories, like the Air Force Research Laboratory, are normally the starting point for evaluating candidate fuels, with the objective of determining in steps, using the Technology Readiness Level methodology, whether a candidate fuel is ready to proceed to more advanced steps in the certification or evaluation process. Those assessments are described in Appendix M. The military laboratory's participation can be either proactive or reactive depending on where and when the initiative to evaluate a candidate fuel originates. If a fuel or fuel class is tested as a result of a Government program (e.g., DARPA) the military laboratory may get an early look at a new fuel candidate and evaluate its specification and fit-for-purpose properties in collaboration with the interested parties (e.g., fuel producers and manufacturers of fuel-using systems and subsystems). If, on the other hand, the evaluation of a candidate fuel is initiated by industry, the military laboratory may have to wait until sample fuel and funding for testing is provided by the Government or by other affected parties. In the reactive approach, the existence of the ASTM research report (whether or not the military laboratory participated in its development) provides a meaningful starting point for the military evaluations.

O.4.2 Fuel Certification Organization (FCO) activities. If military laboratory's evaluation of a candidate fuel's properties indicates that there could be a potential negative effect from a new version of a commercial fuel, that information needs to be communicated to the organization with the FEO management responsibility for further dissemination to System Managers of potentially affected systems.

O.4.2.1 Proactive evaluation. If the FEO management is the responsibility of an organization specifically chartered and funded to evaluate new fuels, there may be an opportunity to do the evaluation proactively. The FEO can develop an evaluation plan, purchase fuel for testing, work with the System Managers of the potentially affected systems to evaluate the effects of the new fuel, share the resulting data, and help determine whether any changes to operating limits are needed for affected systems. If test results indicate that a revision to the proposed commercial specification could mitigate negative effects of the change, the FEO could work with the other DoD ASTM voting members to input that revision into the ASTM balloting process. If the action to mitigate the negative effects is not successful, the FEO should work with the System Managers of affected systems to accomplish the testing needed to define any changes in operating limits, system modifications, or changes in maintenance requirements that are applied when the new fuel is used. Actual implementation of these changes and funding that implementation remains the responsibility of the System Managers of the affected system. If negative effects could be mitigated by changes to hardware or software, System Managers can, at their option and expense, explore the viability of such a modification and, if justified, address it via their standard system modification and certification process.

O.4.2.2 Reactive evaluation. If the FEO management responsibility does not come with its own funding to implement fuel evaluation, the data from the ASTM research report and from the military laboratory evaluations still need to be disseminated to potentially affected System Managers; but in that case, the affected System Managers have the responsibility to fund the evaluation of the new fuel for their systems. If the FEO team is sufficiently manned and organized, it can assist with the planning, fuel purchase, test fuel logistics, evaluation management, and data sharing.

O.4.2.3 Efficiency. To avoid duplication of effort and increase evaluation efficiency, it may be possible to pool funding from multiple affected System Managers to allow a single purchase of fuel for all of the systems to be tested. Further, additional efficiencies might be achieved by limiting testing to only the most challenging or most representative of the systems believed to be affected, and then testing only those functions which could be affected by the changes in the fuel. Coordination among Program Offices is needed to determine which tests of which systems would be sufficient for providing the data each Program Office needs to determine whether and what, if any, changes in operating limits or support requirements are needed as a result of using the newly-defined commercial fuel. Appendix N can provide guidance for this if the term "Fuel Certification Organization" (FCO) is used to mean "FEO." The FEO can act as a key enabler for achieving possible efficiencies in the purchase of fuel, in facilitating the needed coordination, and in handling the test fuel logistics.

O.4.2.4 Fuel purchase(s). The primary schedule limitation in fuel evaluation is getting a sufficient quantity of fuel to do the necessary testing and demonstrations. Unless the candidate fuel is already in mass production for other users, there may only be a limited supply available or a significant lead time for the required quantity of fuel. The FEO will develop an appropriate solicitation for one or more suppliers of the candidate fuels. The initial step in this activity is to work with the Service Control Point for fuel (e.g., the Air Force Petroleum Agency), the other participating military services (if applicable), and DLA Energy to define the appropriate specification for the purchase of the fuel, aimed at ensuring that the fuel purchased will be of sufficient character and quality to be safely usable for aviation and be consistent with the expected or actual specification for the commercial fuel. Another task is to determine whether a specific and unique identifier (name) is required which will be used to differentiate each candidate fuel from other candidates and from other already-defined fuel classes and types during the certification process. During the certification process, it will be necessary to keep the candidate fuel segregated in the fuel handling and supply system from other fuels used by the DoD (per Section 4.6). It may or may not be necessary to segregate the individual candidates of the same class. If they are sufficiently similar and they are just examples of a class of fuels being certified, it may be appropriate to blend them for some certification tests. The production lead time and delivery capability (potentially incremental) from the chosen supplier(s) will be key drivers of the evaluation effort's schedule. Experience has shown that deliveries of test fuel early in pilot plant or full production plant operations may be delayed as the producer resolves problems getting the plant fully operational.

O.4.2.5 Test Scope. The airworthiness authority for each system should identify the testing which needs to be performed to make an adequately informed decision to recertify the system for the use of the revised commercial fuel. Coordination among affected system program offices is essential for eliminating duplication and maximizing the effective use of potentially scarce test fuel. Testing of more challenging systems should be considered, to support the needs of less challenging systems which can use data from the former to justify their recertification decisions without the need to test the less challenging systems or with reduced scope of testing for these less challenging systems. Some of the concepts described in Appendix N can be usefully applied to determine what testing is appropriate.

O.5 IMPLEMENTATION

Once the required testing has been accomplished, each system requiring recertification for the use of the revised commercial fuel needs to obtain an airworthiness determination for the system and needs to document the certification of the system for the use of the revised commercial fuel. The system certification may need to limit the identification of the authorized fuel to the specific version of the commercial specification (and earlier versions) applicable to the fuel evaluated and certified. This would prohibit use of a fuel acquired to a subsequently changed version of the specification until that change was also certified. Such limitations also need to be incorporated into the affected system Technical Orders (operating and maintenance manuals).

CONCLUDING MATERIAL

Custodian:
Air Force – 11

Preparing activity:
Air Force – 11
(Project 91GP-2013-005)

Review activities:
Air Force – 68

NOTE: The activities listed above were interested in this document as of the date of this document. Since Organizations and responsibilities can change, you should verify the currency of the information above using the ASSIST Online database at https://assist.dla.mil.

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