Designation: D4054 – 16

An American National Standard

Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives[1]

This standard is issued under the fixed designation D4054; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice covers and provides a framework for the qualification and approval of new fuels and new fuel additives for use in commercial and military aviation gas turbine engines. The practice was developed as a guide by the aviation gas-turbine engine Original Equipment Manufacturers (OEMs) with ASTM International member support. The OEMs are solely responsible for approval of a fuel or additive in their respective engines and airframes. For the purpose of this guide, "approval" means "permission to use;" it is not an endorsement of any kind. Standards organizations such as ASTM International (Subcommittee D02.J0), United Kingdom Ministry of Defence, and the U.S. Military list only those fuels and additives that are mutually acceptable to all OEMs. ASTM International and OEM participation in the evaluation or approval procedure does not constitute an endorsement of the fuel or additive.

1.2 The OEMs will consider a new fuel or additive based on an established need or benefit attributed to its use. Upon OEM and regulatory authority approval, the fuel or fuel additive may be listed in fuel specifications such as Pratt & Whitney (P&W) Service Bulletin No. 2016; General Electric Aviation (GE) Specification No. D50TF2; and Rolls Royce (RR) engine manuals. Subsequent to OEM approval and industry (ASTM) review and ballot, the fuel or fuel additive may be listed in fuel specifications such as Specification D1655, Defence Standard 91-91, United States Air Force MIL-DTL-83133, and the United States Navy MIL-DTL-5624. This qualification and approval process has been coordinated with airworthiness and certification groups within each company, the Federal Aviation Administration (FAA), and the European Aviation Safety Agency (EASA).

1.3 Units of measure throughout this practice are stated in International System of Units (SI) unless the test method specifies non-SI units.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A240/A240M Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

B36/B36M Specification for Brass Plate, Sheet, Strip, And Rolled Bar

B93/B93M Specification for Magnesium Alloys in Ingot Form for Sand Castings, Permanent Mold Castings, and Die Castings

D56 Test Method for Flash Point by Tag Closed Cup Tester

D86 Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure

D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

D257 Test Methods for DC Resistance or Conductance of Insulating Materials

D395 Test Methods for Rubber Property—Compression Set

D412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension

D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

D471 Test Method for Rubber Property—Effect of Liquids

D790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

D924 Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids

[1] This practice is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.J0.04 on Additives and Electrical Properties.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

D1002 Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)
D1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
D1331 Test Methods for Surface and Interfacial Tension of Solutions of Paints, Solvents, Solutions of Surface-Active Agents, and Related Materials
D1405 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
D1414 Test Methods for Rubber O-Rings
D1655 Specification for Aviation Turbine Fuels
D2240 Test Method for Rubber Property—Durometer Hardness
D2386 Test Method for Freezing Point of Aviation Fuels
D2425 Test Method for Hydrocarbon Types in Middle Distillates by Mass Spectrometry
D2624 Test Methods for Electrical Conductivity of Aviation and Distillate Fuels
D2717 Test Method for Thermal Conductivity of Liquids
D2887 Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography
D3114 Method of Test for D-C Electrical Conductivity of Hydrocarbon Fuels (Withdrawn 1985)[3]
D3241 Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels
D3242 Test Method for Acidity in Aviation Turbine Fuel
D3338 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
D3359 Test Methods for Measuring Adhesion by Tape Test
D3363 Test Method for Film Hardness by Pencil Test
D3701 Test Method for Hydrogen Content of Aviation Turbine Fuels by Low Resolution Nuclear Magnetic Resonance Spectrometry
D3703 Test Method for Hydroperoxide Number of Aviation Turbine Fuels, Gasoline and Diesel Fuels
D3828 Test Methods for Flash Point by Small Scale Closed Cup Tester
D3948 Test Method for Determining Water Separation Characteristics of Aviation Turbine Fuels by Portable Separometer
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
D4066 Classification System for Nylon Injection and Extrusion Materials (PA)
D4529 Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
D4629 Test Method for Trace Nitrogen in Liquid Petroleum Hydrocarbons by Syringe/Inlet Oxidative Combustion and Chemiluminescence Detection
D4809 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)
D5001 Test Method for Measurement of Lubricity of Aviation Turbine Fuels by the Ball-on-Cylinder Lubricity Evaluator (BOCLE)
D5291 Test Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Petroleum Products and Lubricants
D5304 Test Method for Assessing Middle Distillate Fuel Storage Stability by Oxygen Overpressure
D5363 Specification for Anaerobic Single-Component Adhesives (AN)
D5972 Test Method for Freezing Point of Aviation Fuels (Automatic Phase Transition Method)
D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
D6378 Test Method for Determination of Vapor Pressure (VP_X) of Petroleum Products, Hydrocarbons, and Hydrocarbon-Oxygenate Mixtures (Triple Expansion Method)
D6379 Test Method for Determination of Aromatic Hydrocarbon Types in Aviation Fuels and Petroleum Distillates—High Performance Liquid Chromatography Method with Refractive Index Detection
D6732 Test Method for Determination of Copper in Jet Fuels by Graphite Furnace Atomic Absorption Spectrometry
D6793 Test Method for Determination of Isothermal Secant and Tangent Bulk Modulus
D7042 Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity)
D7111 Test Method for Determination of Trace Elements in Middle Distillate Fuels by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
D7171 Test Method for Hydrogen Content of Middle Distillate Petroleum Products by Low-Resolution Pulsed Nuclear Magnetic Resonance Spectroscopy
D7566 Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons
E411 Test Method for Trace Quantities of Carbonyl Compounds with 2,4-Dinitrophenylhydrazine
E659 Test Method for Autoignition Temperature of Chemicals
E681 Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases)
E1269 Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry

2.2 *Federal Specifications:*[4]
FED-STD-791 Testing Method of Lubricants, Liquid Fuels, and Related Products

2.3 *Department of Defense Specifications:*[4]
DOD-L-85645 Lubricant, Dry Film, Molecular Bonded
MIL-A-8625 Anodic Coatings for Aluminum and Aluminum Alloys
MIL-C-83019 Coating, Polyurethane, for Protection of Integral Fuel Tank Sealing Compound

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Copies of these documents are available online at http://quicksearch.dla.mil/ or http://assist.dla.mil.

MIL-DTL-5541 Chemical Conversion Coatings on Aluminum and Aluminum Alloys
MIL-DTL-5624 Turbine Fuel, Aviation, Grades JP-4 and JP-5
MIL-DTL-24441 Paint, Epoxy-Polyamide, General Specification for
MIL-PRF-25017 Inhibitor, Corrosion/Lubricity Improver, Fuel Soluble (NATO S-1747)
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-DTL-83054 Baffle and Inerting Material, Aircraft Fuel Tank
MIL-DTL-83133 Turbine Fuel, Aviation, Kerosene Type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37)
MIL-H-4495 Hose Assembly, Rubber, Aerial Refueling
MIL-DTL-17902 Hose, End Fittings and Hose Assemblies, Synthetic Rubber, Aircraft Fuels
MIL-HDBK-510 Aerospace Fuels Certification
MIL-P-25732 Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Limited Service at 275 °F (135 °C)
MIL-PRF-370 Hose and Hose Assemblies, Nonmetallic: Elastomeric, Liquid Fuel
MIL-PRF-6855 Rubber, Synthetic, Sheets, Strips, Molded or Extruded Shapes, General Specification for
MIL-PRF-8516 Sealing Compound, Synthetic Rubber, Electric Connectors and Electric Systems, Chemically Cured
MIL-PRF-46010 Lubricant, Solid Film, Heat Cured, Corrosion Inhibiting, NATO Code S-1738
MIL-PRF-81298 Dye, Liquid for the Detection of Leaks in Aircraft Fuel Systems
MIL-PRF-81733 Sealing and Coating Compound, Corrosion Inhibitive
MIL-PRF-87260 Foam Material, Explosion Suppression, Inherently Electrostatically Conductive, for Aircraft Fuel Tanks
MIL-S-85334 Sealing Compound, Noncuring, Low Consistency, Silicone, Groove Injection, for Integral Fuel Tanks
MIL-DTL-5578 Tanks, Fuel, Aircraft, Self-Sealing
MMM-A-132 Adhesives, Heat Resistant, Airframe Structural, Metal to Metal
QPL-25017 Qualified Products List for MIL-PRF-25017 (Inhibitor, Corrosion/Lubricity Improver, Fuel Soluble) (NATO S-1747)

2.4 *SAE International:*[5]

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, Non-Chromated Corrosion Inhibiting for Intermittent Use to 360 °F (182 °C)
SAE-AMS-3276 Sealing Compound, Integral Fuel Tanks and General Purpose, Intermittent Use to 360 °F (182 °C)
SAE-AMS-3277 Sealing Compound, Polythioether Rubber Fast Curing Integral Fuel Tanks and General Purpose, Intermittent Use to 360 °F (182 °C)
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 °F (177 °C)
SAE-AMS-3281 Sealing Compound, Polysulfide (T) Synthetic Rubber for Integral Fuel Tank and Fuel Cell Cavities Low Density for Intermittent Use to 360 °F (182 °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, 150 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, 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 4.5Cu – 0.85SI – 0.80Mn – 0.50Mg (2014; –T6 Sheet, –T651 Plate) Solution and Precipitation Heat Treated
SAE-AMS-4037 Aluminum Alloy, Sheet and Plate 4.4Cu – 1.5Mg – 0.60 Mn (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 Eutectic 63Sn – 37Pb
SAE-AMS-4901 Titanium Sheet, Strip, and Plate Commercially Pure Annealed, 70.0 ksi (485 MPa)
SAE-AMS-4915 Titanium Alloy Sheet, Strip, and Plate 8Al –1V – IMo Single Annealed
SAE-AMS-5330 Steel Castings, Investment, 0.80Cr – 1.8Ni – 0.35Mo (0.38–0.46C) (SAE 4340 Modified) Annealed
SAE-AMS-5338 Steel, Investment Castings 0.95Cr – 0.20Mo (0.35–0.45C) (SAE 4140 Mod) Normalized or Normalized and Tempered
SAE-AMS-5504 Steel, Corrosion and Heat–Resistant, Sheet, Strip, and Plate 12.5Cr (SAE 51410) Annealed

[5] Available from SAE International, 400 Commonwealth Dr., Warrendale, Pennsylvania 15096, http://www.sae.org/servlets/index

SAE-AMS-5525 Steel, Corrosion and Heat Resistant, Sheet, Strip, and Plate 15Cr – 25.5Ni – 1.2Mo – 2.1Ti – 0.006B –0.30V 1800 °F (982 °C) Solution Heat Treated
SAE-AMS-5604 Steel, Corrosion Resistant, Sheet, Strip, and Plate 16.5Cr – 4.0Ni – 4.0Cu – 0.30 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 – 4.0Cu 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 °F (899 °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 (0.93–1.05C) (SAE 52100) Premium Aircraft-Quality, Consumable Electrode Vacuum Remelted
SAE-AMS-6470 Steel, Nitriding, Bars, Forgings, and Tubing 1.6Cr – 0.35Mo – 1.13Al (0.38–0.43C)
SAE AMS 6472 Steel, Bars and Forgings, Nitriding 1.6Cr – 0.35Mo – 1.1Al (0.38-0.43C) Hardened and Tempered, 112 ksi (772 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 Rings, Sealing, Fluorocarbon (FKM) Rubber High-Temperature-Fluid Resistant Low Compression Set 70–80
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 °F (121 °C)
SAE AMS-I-7444 Insulation Sleeving, Electrical, Flexible
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 °F (135 °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 Aerospace Standard Test Methods for Aerospace Sealants Two-Component Synthetic Rubber Compounds

2.5 *American Welding Society (AWS):*[6]
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

2.6 *IPC:*[7]
J-STD-004 Requirements for Soldering Fluxes
J-STD-005 Requirements for Soldering Pastes
J-STD-006 Requirements for Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders for Electronic Soldering Applications

2.7 *Boeing Material Specifications (BMS):*[8]
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

2.8 *International Organization for Standardization (ISO):*[9]
ISO 20823 Petroleum and Related Products Determination of the Flammability Characteristics of Fluids in Contact with Hot Surfaces Manifold Ignition Test

2.9 *United Kingdom Ministry of Defence (UK MOD):*[10]
Defence Standard 91-91 Turbine Fuel, Kerosine Type, Jet A-1, NATO Code: F-35 Joint Service Designation: AVTUR

2.10 *Environmental Protection Agency (EPA):*[11]
Method 8015 Nonhalogenated Organics by Gas Chromatography
Method 8260 Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS)
Method 8270 Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS)

[6] Available from American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126; http://www.aws.org/
[7] Available from IPC, 3000 Lakeside Drive, Suite 309S, Bannockburn, Illinois 60015; http://www.ipc.org
[8] Available from Boeing.
[9] Available from ISO, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland; http://www.iso.org/
[10] Available from Defence Equipment and Support, UK Defence Standardization, Kentigern House, 65 Brown Street, Glasgow, G2 8EX; http://www.dstan.mod.uk
[11] Available from US EPA, Office of Resource Conservation and Recovery (5305P), 1200 Pennsylvania Avenue, NW, Washington, DC 20460; http://www.epa.gov/

2.11 *American Petroleum Institute (API)*[12]
API/EI 1581 Specifications and Qualification Procedures for Aviation Jet Fuel Filter/Separators, Fifth Edition

3. Significance and Use

3.1 The intent of this document is to streamline the approval process. The objective is to permit a new fuel or additive to be evaluated and transitioned into field use in a cost effective and timely manner.

3.2 Its purpose is to guide the sponsor of a new fuel or new fuel additive through a clearly defined approval process that includes the prerequisite testing and required interactions with the engine and airframe manufacturers; standards organizations; and airworthiness agencies such as the FAA and EASA. This practice provides a basis for calculating the volume of additive or fuel required for assessment, insight into the cost associated with taking a new fuel or new fuel additive through the approval process, and a clear path forward for introducing a new technology for the benefit of the aviation community.

3.3 This process may also be used to assess the impact of changes to fuels due to changes in production methods and/or changes during transportation. An example is assessment of incidental materials on fuel properties. In the context of Practice D4054, incidental materials shall be considered as an additive.

[12] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org or Energy Institute (EI), 61 New Cavendish St., London, W1G 7AR, U.K., http://www.energyinst.org.

4. Overview of the Qualification and Approval Process

4.1 An overview of the approval process is shown in Fig. 1. The approval process is comprised of three parts: *(1)* Test Program, *(2)* OEM Internal Review, and *(3)* Specification Change Determination.

4.1.1 *Test Program*—The purpose of the test program is to ensure that the candidate fuel or additive will have no negative impact on engine safety, durability, or performance. This is accomplished by investigating the impact of the candidate fuel or additive on fuel specification properties, fit-for-purpose properties, component rig tests, or engine tests. Fig. 2 lists elements of the test program; it should be considered a guideline. It is unlikely that all of the tests shown in Fig. 2 will need to be performed. The OEMs should be consulted and will provide guidance on which tests are applicable. Applicability will be based on chemical composition of the new fuel or additive, similarity to approved fuels and additives, and engine/airframe manufacturer experience. Departure from engine or airframe manufacturer experience requires more rigorous testing. The product of the test program is a research report submitted by the fuel or additive sponsor to the engine and

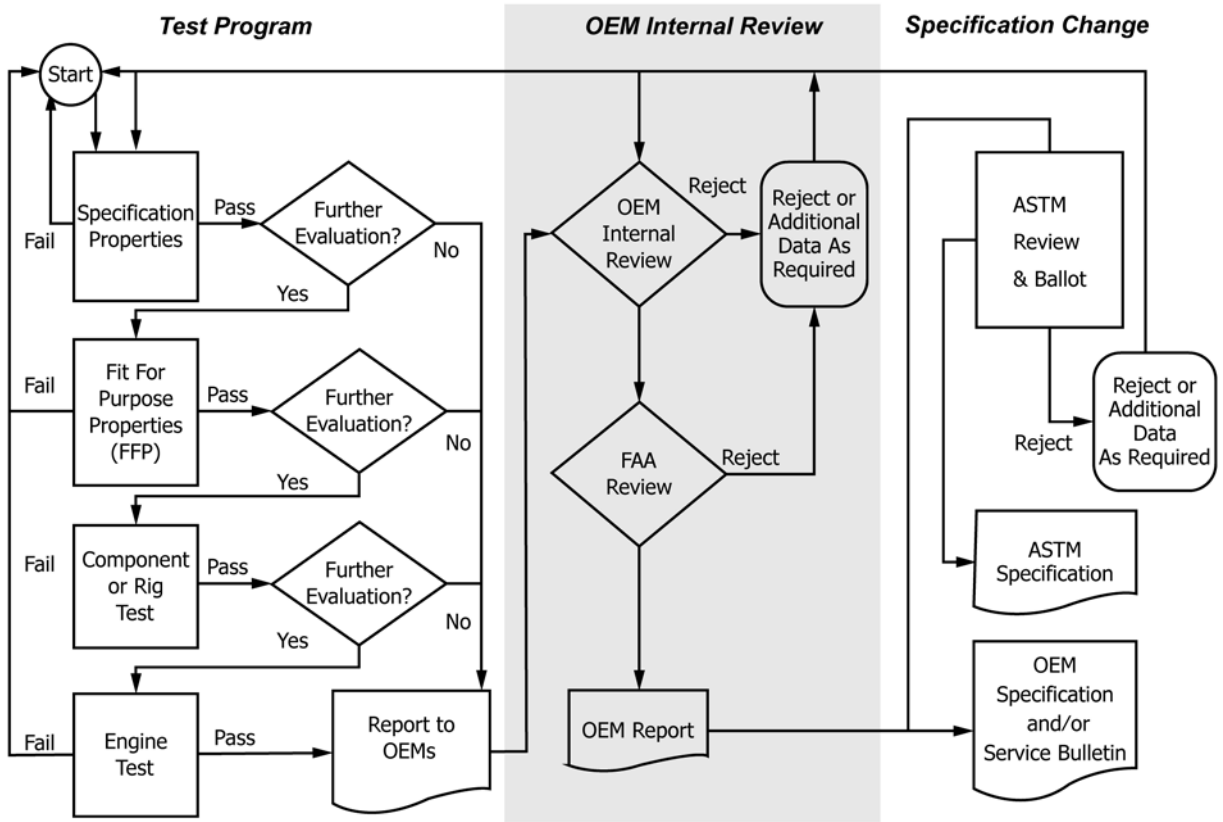
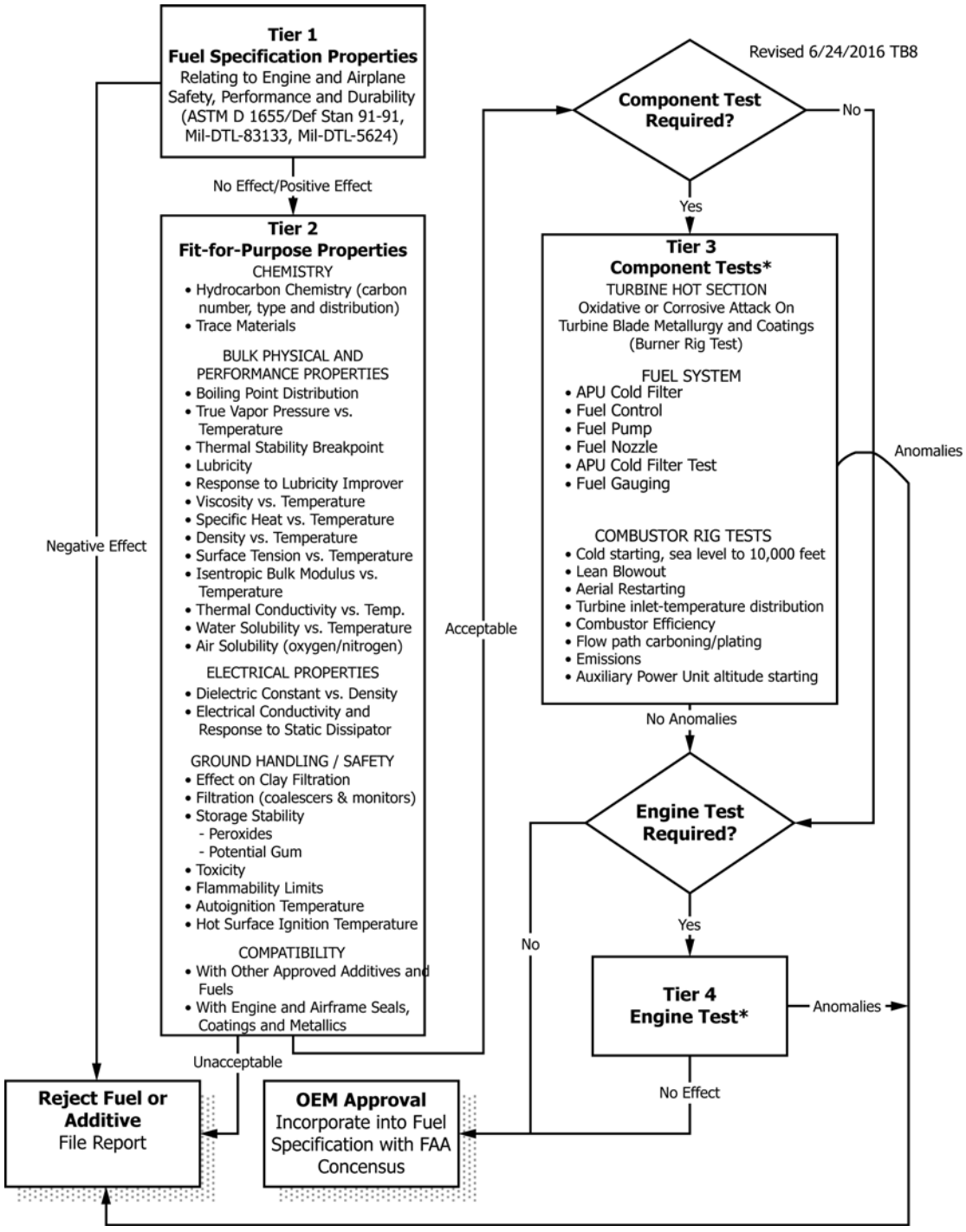


FIG. 1 Overview Fuel and Additive Approval Process



* Testing must be performed at P&W, GE, Rolls Royce, Snecma, Honeywell, or in other locations per OEM agreement due to proprietary concerns and test methods.

NOTE 1—Additive testing to be performed at 4× the concentration being requested for approval except for filtration.

FIG. 2 Test Program

airframe manufacturers. The research report facilitates a comprehensive review of the test data by the engine and airframe manufacturers, specification writing organizations, and regulatory agencies.

4.1.2 *OEM Internal Review*—During the OEM review, results of the test program are carefully studied by the respective OEM chief engineers and their discipline chiefs. An OEM airworthiness representative interfaces with the appropriate airworthiness authority, for example, the FAA and EASA, to determine extent of FAA/ EASA involvement. Discipline Chiefs and their staff engineers from organizations responsible for combustion, turbine, fuel system hardware, performance system analysis, system integration, and airworthiness engage in iterative meetings and reviews until the concerns and potential impacts on the engine have been explored and satisfactorily addressed. This exercise can result in requests for additional information or testing. Final approval is made at the executive level based on the recommendation of the chief engineer. The product of the OEM internal review is a document or report that either rejects or approves the new fuel or additive. After the approval of the new fuel or additive, there may be a requirement for a Controlled Service Introduction (CSI). Under a CSI, engines in the field that are exposed to the new fuel or additive are monitored for an increased level of fair wear and tear. The CSI is directed at identifying possible long-term maintenance effects.

4.1.3 *Specification Change Determination*—Approval by the OEMs of a new fuel or additive may only effect OEM internal service bulletins and engine manuals and have no impact on Specification D1655. If the OEM proposes changes to Specification D1655, then the proposed changes must be reviewed and balloted by ASTM D02.J0. Changes to Specification D1655 could include listing the additive or fuel as acceptable for use, changes to published limits, special restrictions, or additional precautions. Fig. 1 includes an overview of the ASTM review and balloting process, which is quite rigorous and typically goes through several iterations before a ballot is successful, culminating in a change to Specification D1655. The OEMs and the regulatory agencies regard the ASTM review and balloting process, and the subsequent scrutiny of industry experts, as an additional safeguard to ensure that issues relating safety, durability, performance, and operation have been adequately addressed. Although not a requirement, the OEMs typically wait for a successful ASTM ballot before changing their service bulletins and engine manuals to accommodate the new fuel or additive.

5. Key Participants and Request for Qualification

5.1 *OEMs*—Engine OEMs include but are not limited to Pratt & Whitney (P&W), GE Aviation (GE Av), Rolls Royce (RR), and Honeywell. Airframe OEMs include but are not limited to Boeing, Airbus, Bombardier, and Lockheed. OEM approval is required for use of a new fuel or additive in aviation gas-turbine engines. OEM review and approval is required to ensure safety of flight, engine operability, performance, and durability requirements are not impacted by the new fuel or additive.

5.2 *Regulatory Authorities*—While approval of a new fuel or additive is at the discretion of the OEMs, regulatory organizations such as the FAA and EASA participate in the process. Approval by the regulatory authorities is necessary under the following conditions:

5.2.1 The new fuel or additive impacts specification properties to the extent that the fuel does not conform to Specification D1655,

5.2.2 A new specification must be written to accommodate the new fuel or additive, or

5.2.3 Recertification of the engine or aircraft and aircraft operating limitations is required.

5.3 *Airlines*—Airline advocacy for the candidate fuel or additive is important to warrant consideration for qualification. The OEMs need strong support from the airlines to justify committing internal resources to evaluating a new fuel or new fuel additive for use in an aircraft. Interested airlines or other users (for example, U.S. Military and air cargo) must submit formal written requests to the OEM customer service groups expressing a need and requesting that the fuel or additive be evaluated for qualification and approval. Requests from the airlines facilitate OEM management support, resulting in multi-discipline (combustor, turbine, fuel system hardware, materials, etc.) involvement in assessing impact on engine and aircraft operation.

5.4 *Military*—Military participation in the approval process is important because many commercial engines have military derivatives. The U.S. Air Force and U.S. Navy, respectively, have an approval protocol that is specific to the unique considerations of military engines. The protocols are based largely on this practice. Every effort is made to harmonize the commercial and military protocols such that they complement each other.

5.5 *ASTM International:*

5.5.1 ASTM Subcommittee D02.J0 on Aviation Fuels promotes the knowledge of aviation fuels by the development of specifications, test methods, and other standards relevant to aviation fuels. Issuance of an aviation fuel specification or test method by ASTM International represents the culmination of a comprehensive evaluation process conducted by ASTM members representing the petroleum industry, aerospace industry, government agencies, and the military. ASTM members are classified as producers (petroleum, additive and other fuel companies); users (aircraft or engine manufacturers, airlines); consumers (pilot or aerospace representative organizations); or general interest (government agencies and other parties). All such organizations or individuals showing ability and willingness to contribute to the work of Subcommittee D02.J0 are eligible for membership and participation in standards development.

5.5.2 The process for qualifying and approving a fuel or additive is initiated by a sponsor who acts as an advocate for promotion of the new aviation fuel. The sponsor approaches the ASTM aviation fuels subcommittee and solicits their support. ASTM members are volunteers and there is no obligation on the part of ASTM members to participate in the specification development activity. Participation of ASTM will

be influenced by the quality of the presented material. Participation is unlikely if the initial data is considered sketchy or otherwise inadequate.

5.5.3 The new fuel or additive formulation must be thoroughly established prior to approaching ASTM. Compositional changes cannot be accommodated during the review process without written approval by the OEMs. The additive or fuel shall be identified by its specific chemical name or trade name. A chemical description of the fuel or additive shall be provided. If qualification is being sought for an additive, the carrier solvent and recommended concentration shall be provided. If the additive chemistry is proprietary, a generic description shall be provided. If merited, nondisclosure agreements can be placed between the additive manufacturer, the OEMs, and any task force member organization assisting in the investigation. ASTM and the Coordinating Research Council (CRC)[13] cannot enter into nondisclosure agreements or guarantee confidentiality.

5.5.4 A specification for the fuel or additive shall be agreed upon by the producer and OEMs. The specification shall define appropriate limits in sufficient detail that the purchaser can use it to ensure the receipt of the approved material. In cases where the approved material is a single named chemical, the specification shall, at a minimum, define the purity level of the approved chemical.

5.5.5 A technical case shall be presented to the OEMs and Subcommittee D02.J0 establishing need for the fuel or additive. Verifiable data performed by an industry-recognized laboratory shall be presented supporting performance for the specified application. The OEM/ASTM technical body will assess value and need based on the technical case. The assessment will consider scientific approach, source, and credibility of the data presented. The sponsor or investigating body shall submit a written report containing nonproprietary information to the OEMs.

5.6 *Coordinating Research Council (CRC)*—The CRC Aviation Fuels Committee has a mission to foster scientific cooperative aviation fuels research. The vision is to be a worldwide forum for the aviation fuel technical community and the leader in cooperatively funded aviation fuel research. CRC typically will respond to a request from ASTM to investigate a fuel-related issue. A fuel or additive will be considered for qualification if the OEMs and Subcommittee D02.J0 determines that the fuel or additive fulfills a need or provides a significant benefit to the aviation industry. If additional data or research is required, ASTM may request CRC or other cooperative research group investigate the fuel or candidate additive in more detail. Involvement of CRC or other cooperative research group can range from a review of data presented by the additive manufacturer or sponsor to actual testing and research performed by CRC task force members. The acceptance by the CRC to carry out the requested research is independent of the ASTM process and contingent on CRC steering committee approval.

[13] Coordinating Research Council, Inc., 5755 North Point Pkwy, Suite 265, Alpharetta, GA 30022. www.crcao.org

6. Funding the Investigation and Qualification Process

6.1 The organization (for example, the additive manufacturer or refiner) seeking approval of a new fuel or fuel additive is responsible for funding all aspects of the fuel or additive qualification process. Costs include laboratory, rig, or engine tests, if required, as well as interpreting, communicating, and reporting data. Depending on how beneficial the fuel or additive is considered to be to the aviation industry, CRC may organize task forces and may solicit its members to perform work using available funding within their organizations. The U.S. military or other government organizations will sometimes consider participating in a Cooperative Research Program if the fuel or additive is deemed to be of significant benefit to the military.

7. Elements of the Test Program

7.1 Elements of the test program to be performed are shown in Fig. 2. The purpose of the test program is to investigate the impact of the candidate fuel or additive on fuel specification properties, fit-for-purpose properties, fuel system materials, turbine materials, fuel system components, other approved additives, and engine operability, durability, and emissions. “Fit-for-Purpose properties” refers to properties inherent of a petroleum-derived fuel and assumed to be within a given range of experience. Fit-for-Purpose Properties are not controlled by specification but are considered critical to engine and airframe fuel system design. Examples include fuel lubricity, seal swell, and dielectric constant. During the course of the test program, special considerations may be identified and investigated to resolve anomalies. Examples include minimum aromatic level, maximum flash point, and minimum lubricity.

7.2 A complete chemical description of the candidate fuel or additive is required for defining the test program. Additionally, a description of the manufacturing process is required for a new fuel. This information can be provided under a nondisclosure agreement (NDA) with the OEMs. If the new material is an additive, its carrier solvent and recommended concentration must also be provided. This information is important for determining test requirements and the order that the tests should be performed. The chemical nature of the fuel or additive defines criticality of the following issues:

7.2.1 Compatibility with fuel system seals and metallics.
7.2.2 Hot section compatibility.
7.2.3 Cold flow properties.
7.2.4 Thermal stability.
7.2.5 Rig tests for performance and operability.
7.2.6 Emissions.
7.2.7 Fuel handling.

7.3 It is important to note that during the evaluation process or subsequent approval, any change in the formulation of the fuel or additive, method of manufacture, or the way it is to be used, must be brought to the attention of the OEMs and the ASTM advisory committee. It is possible that such changes will render data collected previously invalid and require the qualification process be started anew.

7.4 Much experience has been garnered from ASTM, CRC, U.S. Military and OEM past efforts directed at investigating

fuels and fuel additives. Additive investigations have included biocides, leak-detectors, thermal oxidative stability improvers, pipeline drag reducers, anti-static additives, and a water solubilizer for use in jet fuel. Fuel evaluations have included oil sands, shale oil, Fischer-Tropsch synthetic kerosines and biofuels. Lessons learned include the importance of prioritizing testing and performing those tests first that have the greatest potential to be cause for rejection.

7.5 A test program directed at evaluating a fuel or additive for use in a gas turbine engine shall contain the elements shown in the paragraphs that follow. The engine and airframe manufacturers have agreed to the order of testing. The order of testing, as well as the tests that must be performed, may be redefined based on the specific nature and composition of the fuel or additive. Similarity to currently qualified fuels or additives is a chief consideration. In most cases, testing of a candidate fuel additive shall be performed at four times (4×) the concentration being requested for qualification. If solubility of the additive prevents blending at 4×, then the maximum level that is soluble should be used. The requirement to test at 4× is a means for assessing the impact of accidental additive overdose. It also lends itself to early detection of possible negative impacts. Additionally, testing at 4× permits more flexibility in selecting the baseline fuel to be used in the qualification process. Fuels can vary in their sensitivity to a particular additive. Testing at 4× negates the need to spend resources searching for a sensitive fuel for use as the baseline test fuel.

7.6 If a problem is identified with an additive at 4×, consideration will be given to assessing the impact of the additive at a lower concentration. Tests shall be performed with and without the candidate additive in the baseline test fuel. The baseline test fuel shall be Jet A or Jet A-1 conforming to the most recent revision of Specification D1655 or Defence Standard 91-91; JP-8 conforming to the most recent revision of MIL-DTL-83133 (NATO F-34); or JP-5 conforming to the most recent version of MIL-DTL-5624 (NATO F-44). The same batch of test fuel should be used in performing tests directed at impact on fuel specification properties. The same batch of test fuel should be used for as many of the Fit-for-Purpose Property tests as possible. The material compatibility tests should be performed using the same batch of test fuel. Some notable exceptions to using the same batch of test fuel might be component and engine tests.

7.7 A passing or failing test result is defined by the type of test performed. In the case of specification testing, minimum or maximum specification requirements must be met. Some areas of investigation called out in this practice may not be amenable to a "pass" or "fail" result. In these cases (such as the Fit-for-Purpose Tests), significant deviation from the baseline fuel or from what the OEMs judge to be the norm could result in a failure. Results may be considered as failing when expected levels of equipment performance are compromised, that is, not functioning optimally. Further, test results that extend beyond OEM experience, such that a degree of risk is introduced, could result in a failure or a need for further testing.

8. Performing the Test Program

8.1 The test program is comprised of four tiers. Each tier consists of a distinct set of tests focused on a critical consideration that impacts engine and airplane design, safety, durability, performance, and reliability. The four tiers of testing are comprised of (*1*) Fuel Specification Properties; (*2*) Fit-for-Purpose Properties; (*3*) Component and Rig Tests; and (*4*) Engine Test.

8.1.1 The four-tier system provides an orderly approach to the evaluation of a new fuel or fuel additive. Testing is typically performed in sequence of the tier and builds upon the successful completion of each. Tiers act as a gate. Technical and financial resources should not be expended on moving to the next tier of testing if the tier just completed yields negative results. In many cases, the negative result can be resolved. In others, testing and evaluation of the additive or fuel should be terminated. Each successive tier tends to require more sophisticated testing and more specialized facilities. The engine and airplane OEM team will assist in directing the sponsor of the new fuel or additive to a qualified testing facility. Progressing to each tier will be accompanied by the requirement to provide greater volumes of the new fuel or additive. Table 1 shows the approximate volume of fuel required for each of the four tiers.

8.2 *Tier 1—Fuel Specification Properties*—All property tests as required in Specification D1655, Defence Standard 91-91, MIL-DTL-83133, and MIL-DTL-5624. When evaluating a new fuel, tests should be performed on the synthetic blend material as well as the final blend. The OEM team will provide guidance on which tests are appropriate for the synthetic blend material.

8.2.1 A special consideration under Tier 1 testing for a new fuel is that heat of combustion be measured using Test Method D4809. Alternative methods for determining heat of combustion such as Test Methods D1405, D3338, and D4529 are estimation methods. Test Method D3338 states in subsection 1.2: This test method is purely empirical and is applicable to liquid hydrocarbon fuels that conform to the specifications for

TABLE 1 Typical Fuel Volume Requirements to Evaluate a New Fuel or New Fuel Additive

NOTE 1—Fuel volumes shown are for a single test fuel. In most cases, a baseline fuel of equal volume will be required in addition to the new fuel blend stock, new fuel finished blend, or fuel additive blend being evaluated.

Tier	Tier Testing Description	Fuel Volume U.S. Gallons (Litres)	Note
1	Fuel Specification Properties	10 (37.8 L)	
2	Fit-for-Purpose Properties	80 (320.8 L)	
3	Component and Rig Tests	250 to 10 000 (946.3 L to 37 854.1 L)	Fuel volume depends on component type
4	Engine Test	450 to 225 000 (1703 to 851 718 L)	Fuel volume depends on engine type and whether it is a performance or endurance test

aviation gasolines or aircraft turbine and jet engine fuels of grades Jet A, Jet A-1, Jet B, JP-4, JP-5, JP-7 and JP-8. Test Method D4529 has a similar statement. The estimation methods are not appropriate for a new fuel not yet demonstrated to be equivalent to the above conventional fuels. Subsequent to measuring heat of combustion using Test Method D4809, the fuel should be tested to D1405, D3338, and D4529 to demonstrate that estimation methods hold true for the proposed drop-in fuel.

8.3 *Tier 2—Fit-for-Purpose Properties*—When evaluating a new fuel, some of the Fit-for-Purpose Properties may be required to be performed on both the synthetic blend material as well as the final blend. The OEM team will provide guidance as to which tests will need to be performed.

8.3.1 *Accepted Test Methods and Limits*—Fit-for-Purpose Properties as agreed upon by the engine and airplane manufacturers are shown in Table 2. Accepted test methods for evaluating the Fit-for-Purpose Properties are shown along with limits. Some Fit-for-Purpose Properties have no well defined limits. In these cases, the effect of the new fuel or new additive on a Fit-for-Purpose property must fall within the scope of experience of the engine manufacturers. The basis for the engine manufacture's scope of experience for these properties is described in Table 2.

8.3.2 *Performance of and Compatibility with Additives Currently Permitted in Specification D1655*—The procedures utilized to determine compatibility of the new additive with additives currently approved for use in aviation fuels, and the procedures to evaluate performance of a new additive for its intended function are shown in Annex A2.

8.3.3 *Compatibility with Fuel System Materials*—A list of generic materials used in P&W, GE Av, RR, Honeywell, Boeing, Airbus, and Lockheed gas-turbine engine fuel systems is shown in Tables A3.2 and A3.3 in Annex A3. The engine and airframe manufacturers have agreed to these generic classes of materials for the purpose of evaluating compatibility with fuels and fuel additives. The generic list of materials to be tested includes 37 non-metallics and 31 metals. Materials known to be sensitive to a specific fuel or additive chemistry shall be tested first. The types of tests to be performed are defined in Tables A3.2 and A3.3 for each material.

8.3.3.1 Additive concentration for the material compatibility tests shall be 4× the concentration being sought for qualification. Test temperatures shall be the highest temperature the materials are subjected to in their specific application within an aircraft or engine fuel system. The test temperature for each material is shown in Tables A3.2 and A3.3 in Annex A3 along with the standard test procedure and pass/fail criteria.

8.4 *Tier 3—Component and Rig Tests:*

8.4.1 *Turbine Hot-Section Erosion and Corrosion:*

8.4.1.1 Metallurgy.

8.4.1.2 Coatings.

8.4.1.3 Oxidative or corrosive attack is defined as hardware degradation of a degree and at a rate that oxidation or corrosion would likely be a primary cause of hardware failure or rejection of in-service hot section hardware.

8.4.2 *Fuel System Component Testing:*

8.4.2.1 Fuel Pump.

8.4.2.2 Fuel Control.

8.4.2.3 Fuel Nozzle.

8.4.2.4 APU Cold Filter Test.

8.4.2.5 Fuel Gauging

8.4.3 *Combustor Rig Testing:*

8.4.3.1 Cold starting at sea level to 10 000 ft.

8.4.3.2 Lean blowout.

8.4.3.3 Aerial restarting after a flame-out event.

8.4.3.4 Turbine inlet-temperature distribution.

8.4.3.5 Combustor efficiency.

8.4.3.6 Flow path carboning/plating.

8.4.3.7 Emissions.

8.4.3.8 Auxiliary Power Unit (APU) altitude starting.

8.5 *Tier 4—Engine Test*—The qualification process may require an engine test. Not all fuel or additive qualifications will require an engine test. The necessity for an engine test is based on the nature and chemical composition of the fuel or additive and is at the discretion of the engine manufacturers. The elements of an endurance test, or a combination of a performance test and an endurance test, are defined by the engine manufacturer. Engine tests are engine specific and, consequently, cannot be predefined. Typically, the endurance portion of the test is a minimum of 150 h and 450 cycles. A cycle is defined as moving through a set of engine-throttle settings that include start, idle, accelerate to higher power, hold for a short period of time, decelerate to idle and stop. A typical cycle is 15 min to 20 min in duration.

9. Report

9.1 A research report shall be issued upon completion of the test program that formally documents all data and information compiled during the evaluation process. The report shall provide a conclusion regarding fit-for-purpose. The report shall include a specification of the approved material with sufficient detail and limits to permit a purchaser to confirm receipt of OEM approved material. It is the responsibility of the sponsor(s) to prepare and submit the report to the OEMs, specification authorities and ASTM. The OEMs, specification authorities and ASTM will require this report for use as supporting evidence for subsequent qualification via internal engineering groups and airworthiness authorities.

10. Keywords

10.1 additive evaluation; additive qualification; alternative fuels; approval protocol; ASTM; fuel additives; fuel evaluation; fuel qualification; jet fuel; material compatibility

TABLE 2 Fit-for-Purpose Properties

Fuel Property	Test Method[A]	Units	Min	Max	Comments
CHEMISTRY					
Hydrocarbon Types	ASTM D2425	mass %	Report		Determines normal and iso-paraffins, cyclo-paraffins, mono-aromatics, indans, indanes, tetralins, naphthalenes, acenaphthenes, acenaphthalenes, tricyclic aromatics.
Aromatics	ASTM D1319 or ASTM D6379	Vol %	8 8.4	25 26.5	
Hydrogen	ASTM D5291 , D3701, or D7171	mass %	Report		
Trace materials					
Organics					
Carbonyls	ASTM E411	µg/g (ppm by mass)	Report		No limits established.
Alcohols	EPA Method 8015	m % or mg/L (ppm)	Report		
Esters	EPA Method 8260	mg/L (ppm)	Report		
Phenols	EPA Method 8270	mg/L (ppm)	Report		
Inorganics: N	ASTM D4629	mg/kg (ppm by mass)	Report		
Trace Elements					
Cu	ASTM D6732	µg/kg (ppb by mass)		< 20	
Zn, Fe, V, Ca, Li, Pb, P, Na, Mn, Mg, K, Ni, Si	ASTM D7111 or UOP 389	mg/kg (ppm by mass)	Report		
BULK PHYSICAL AND PERFORMANCE PROPERTIES					
Boiling point distribution	ASTM D86	°C			Based on CRC World Survey and Defense Logistics Agency Energy Petroleum Quality Information System survey.
Initial Boiling Point		°C	Report		
10 % Recovery (T10)		°C	150	205	
20 % Recovery		°C	Report	Report	
30 % Recovery		°C	Report	Report	Minimum and maximum values are based on Coordinating Research Council World Survey and Defense Logistics Agency Energy Petroleum Quality Information System survey.
40 % Recovery		°C	Report	Report	
50 % Recovery (T50)		°C	165	229	
60 % Recovery		°C	Report	Report	
70 % Recovery		°C	Report	Report	
80 % Recovery		°C	Report	Report	
90 % Recovery (T90)		°C	190	262	
Final Boiling Point		°C		300	
T50 - T10		°C	15	—	
T90 - T10		°C	40	—	
Simulated Distillation	ASTM D2887		Report Full Range		
Thermal Stability, JFTOT Breakpoint	ASTM D3241, Appendix X2	°C	See Comment		Additives cannot degrade breakpoint.
Deposit Thickness at Breakpoint	ASTM D3241, Annex A3 (Ellipsometer) or ASTM D3241, Annex A2 (Interferometer)	nm	Report		
Lubricity	ASTM D5001	mm WSD		0.85	Based on Defence Standard 91-91 requirements.
Response to Corrosion Inhibitor/ Lubricity Additive	ASTM D5001	mm WSD	Conform[B]		See Fig. A1.2 for typical response.
Viscosity vs. Temperature	ASTM D445 or D7042	mm^2/s	Conform[B]		Plot viscosity at –40 °C (or freezing point plus 5 °C, whichever is higher), –20 °C, 25 °C, and 40 °C. See Fig. A1.1 for typical values.
Specific Heat vs. Temperature	ASTM E1269	kJ/kg/K	Conform[B]		See Fig. A1.3 for temperature ranges, typical values, and temperature variations. Specific Heat on a dodecane standard must run and submitted along with the fuel value.
Density vs. Temperature	ASTM D4052	kg/m^3	Conform[B]		Plot density at –20 °C, 20 °C, and 60 °C. See Fig. A1.4 for typical values.
Surface Tension vs. Temperature	ASTM D1331	mN/m	Conform[B]		See Fig. A1.5 for minimum values and typical variation.
Isentropic Bulk Modulus vs. Temperature and Pressure	ASTM D6793	MPa	690 MPa (100 000 psi)		Limits not known; see Fig. A1.6 for typical values and variation.
Thermal Conductivity vs. Temperature	ASTM D2717	watts/m/K	Conform[B]		Limits not known; see Fig. A1.7 for typical values and variation.
Water Solubility vs. Temperature	ASTM D6304	mg/kg	Conform[B]		See CRC Handbook of Aviation Fuel Properties for typical values.
Air Solubility (oxygen/nitrogen)	Ostwald & Bunsen Coefficient (mm^3 of gas/mm^3 of fuel)		Conform[B]		See Fig. A1.9 for typical values. OEM experience is based on the air solubilities of TS-1 and JP-5, which is the least and most dense and volatile to which engines are currently designed.
True Vapor Pressure vs. Temperature	ASTM D6378	kPa or psi	Report –28, 12, 25, 38, 78, and 200 °C		See Fig. A1.10 for typical true vapor pressures for various jet fuel types.
Flash Point	ASTM D56, D3828, or D93	°C		68	
Freezing Point Test Methods—Response to Manual vs. Automatic Phase Transition	ASTM D2386 and D5972	°C	Conform[B]		
ELECTRICAL PROPERTIES					
Dielectric Constant vs. Density	ASTM D924	N/A	Conform[B]		See Fig. A1.8 for typical values.

TABLE 2 *Continued*

Fuel Property	Test Method[A]	Units	Min	Max	Comments
Conductivity Response	ASTM D2624	pS/m	Conform[B]		See Fig. A1.9 for typical response.
GROUND HANDLING PROPERTIES AND SAFETY					
Effect on Clay Filtration	ASTM D3948	MSEP No.	See Comment		No impact when compared to Jet A
Filtration – Coalescer Filters &	API/EI 1581	ppm by	See Comment		No impact when compared to Jet A
Monitors (water fuses)		volume			
Storage Stability					
Peroxides	ASTM D3703	mg/kg (ppm by mass)	—	8.0	Store for 6 weeks at 65 °C.
Potential gums	ASTM D5304	mg/100 mL	—	7.0	Store for 16 h at 100 °C.
Toxicity	MSDS Review				
Flammability Limits	ASTM E681	°C	See Comment		No impact when compared to Jet A
Autoignition Temperature	ASTM E659	°C	See Comment		No impact when compared to Jet A
Hot Surface Ignition Temperature	FED-STD-791, Method 6053 or ISO 20823	°C	See Comment		No impact when compared to Jet A
COMPATIBILITY					
With Other Approved Additives	ASTM D4054, Annex A2	N/A	See Comment		Antioxidant, Corrosion Inhibitor/Lubricity Additive Fuel System Icing Inhibitor, Static Dissipator Additive No visible separation, cloudiness, solids, or darkening of color.
With Engine and Airframe Seals, Coatings and Metallics	ASTM D4054, Annex A3				

[A] Equivalent IP methods are acceptable.
[B] Conform = conform to typical response or values within engine/airframe manufacturers' experience. See Comment.

ANNEXES

(Mandatory Information)

A1. BASIS OF ENGINE AND AIRPLANE MANUFACTURERS' EXPERIENCE

A1.1 Figs. A1.1-A1.11 describe the limits or characteristics that make up the engine manufacturers' scope of experience in evaluating the impact of a new fuel or new additive on a fit-for-purpose property that does not currently have a well defined limit.

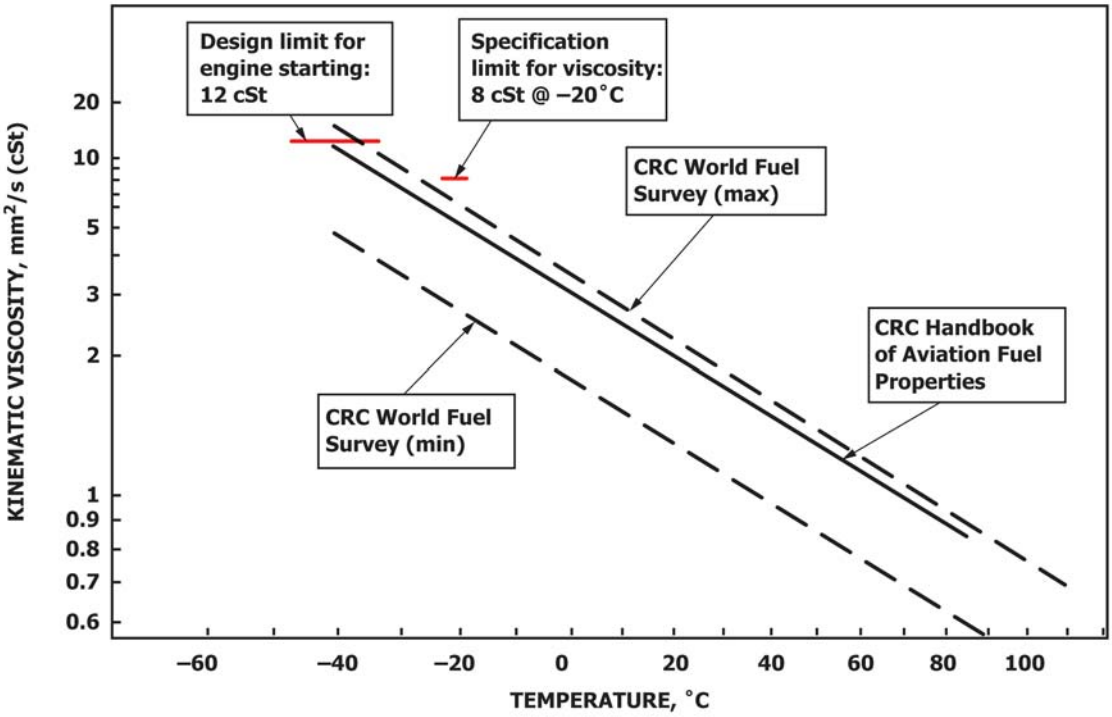


FIG. A1.1 Typical Viscosity Characteristics of Jet Fuel

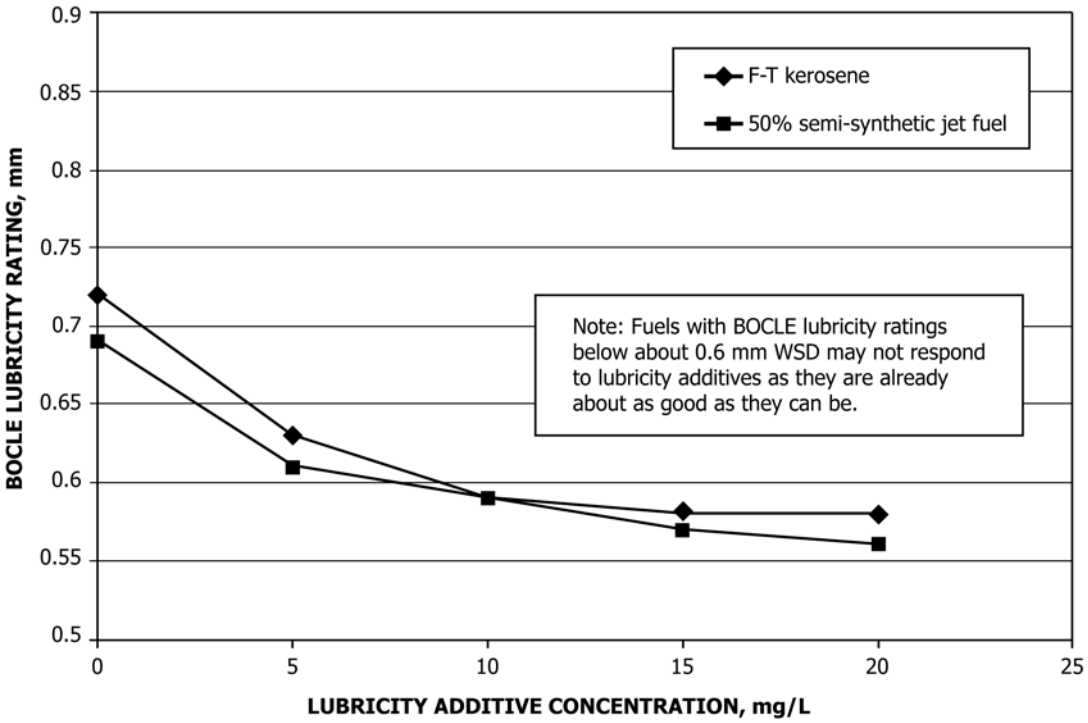


FIG. A1.2 Typical Response to Corrosion Inhibitor/Lubricity Improver (CI/LI) Additive

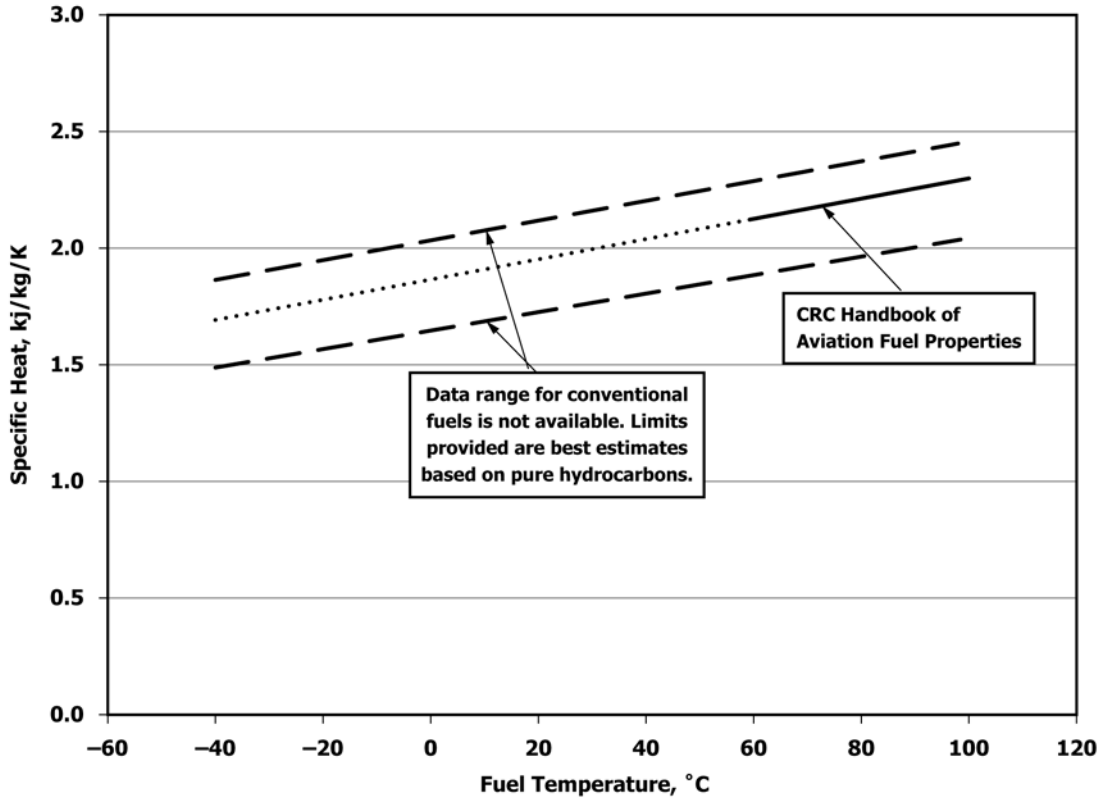


FIG. A1.3 Typical Specific Heat Characteristics of Jet Fuel

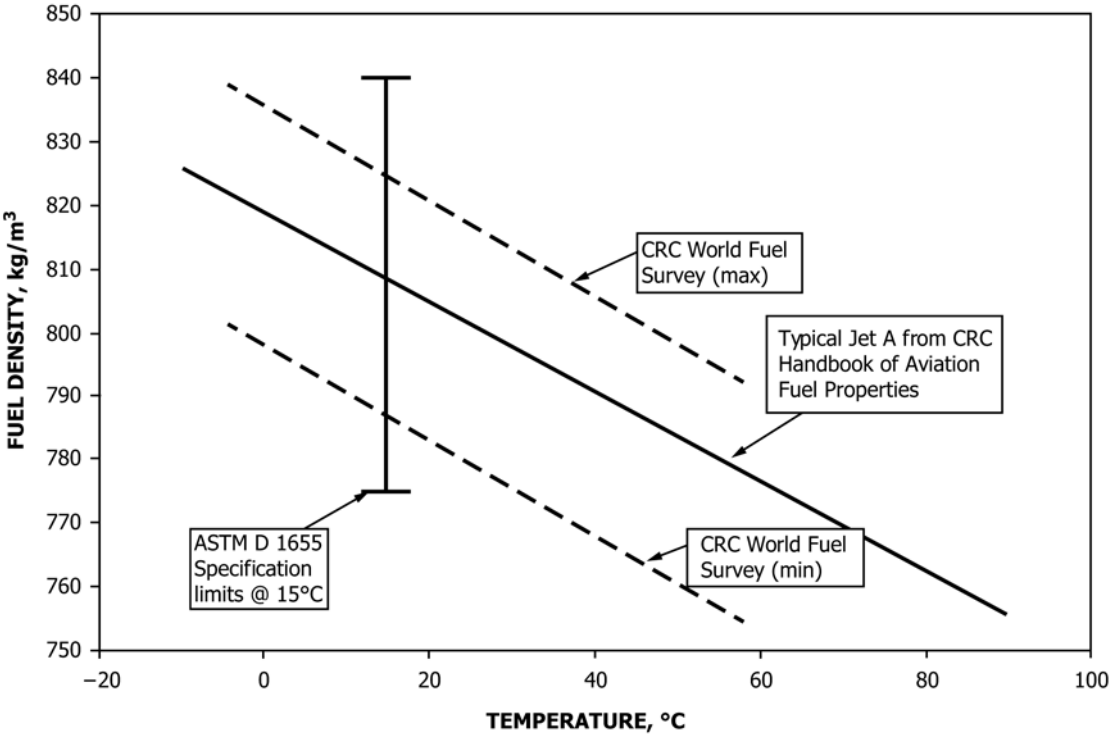


FIG. A1.4 Typical Density Characteristics of Jet Fuel

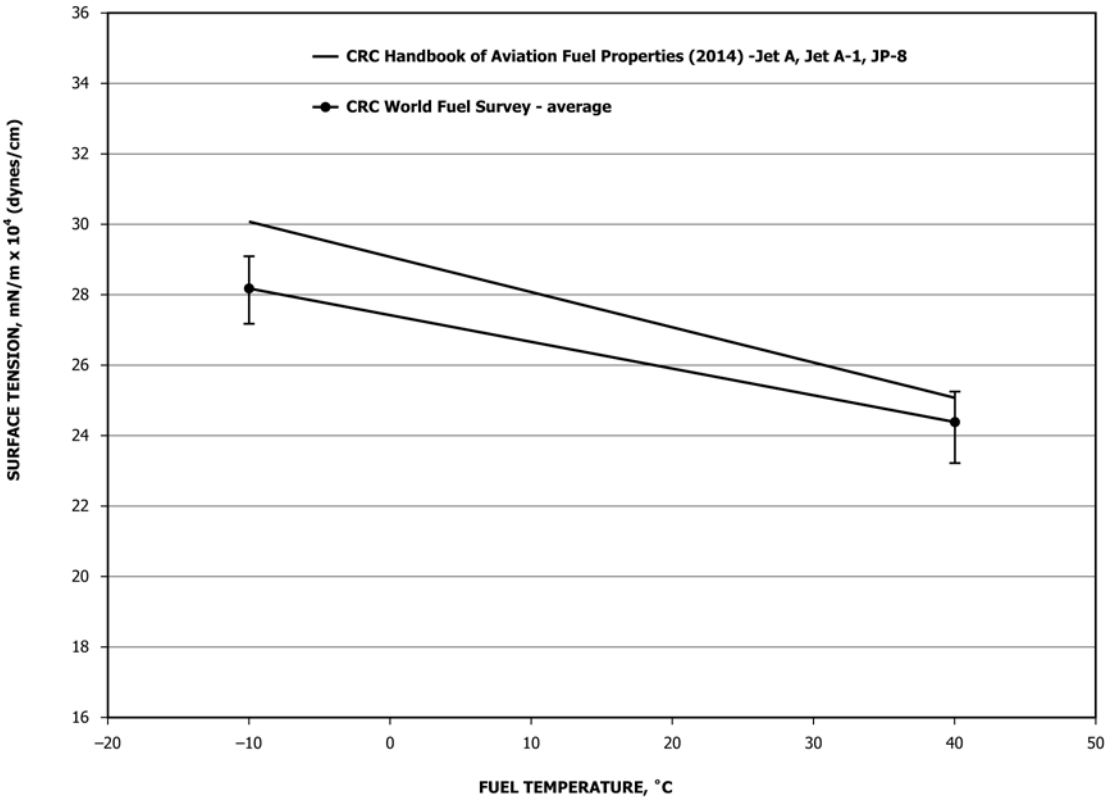


FIG. A1.5 Typical Surface Tension Characteristics of Jet Fuel

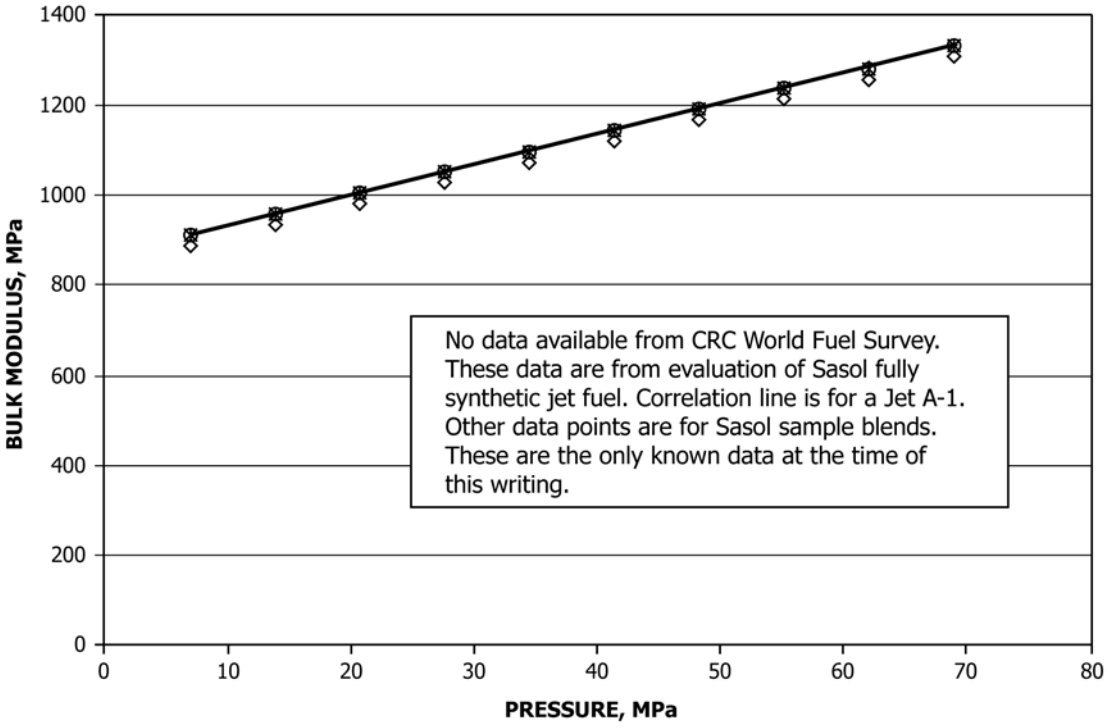


FIG. A1.6 Bulk Modulus Characteristics

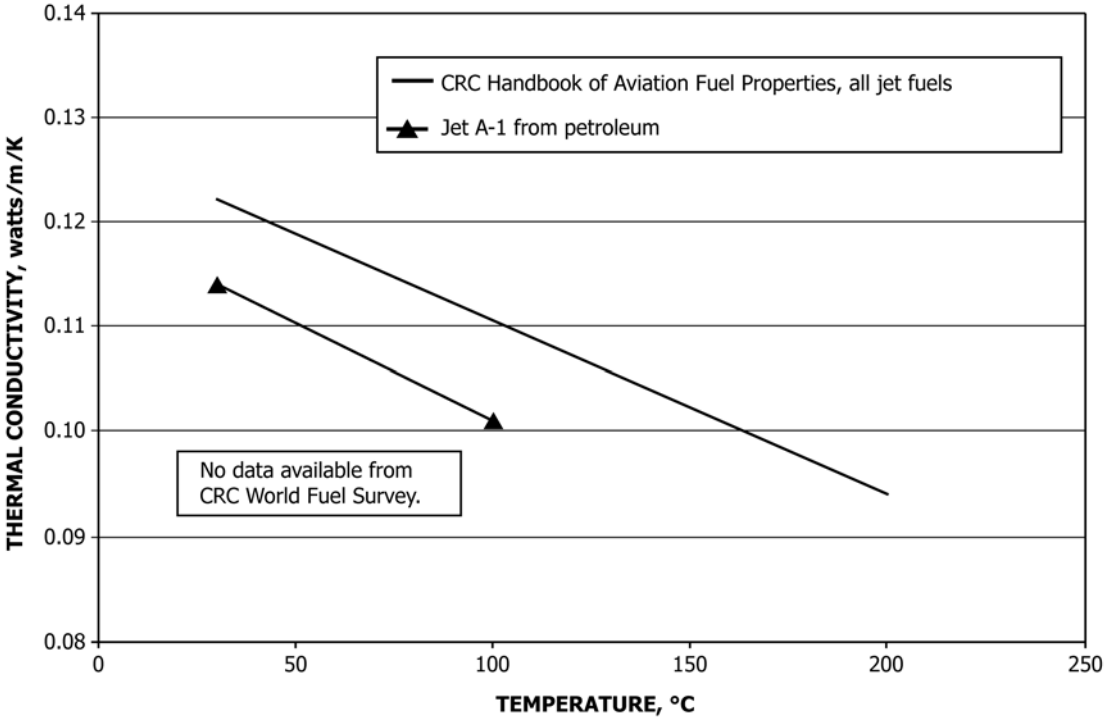


FIG. A1.7 Typical Thermal Conductivity Characteristics of Jet Fuel

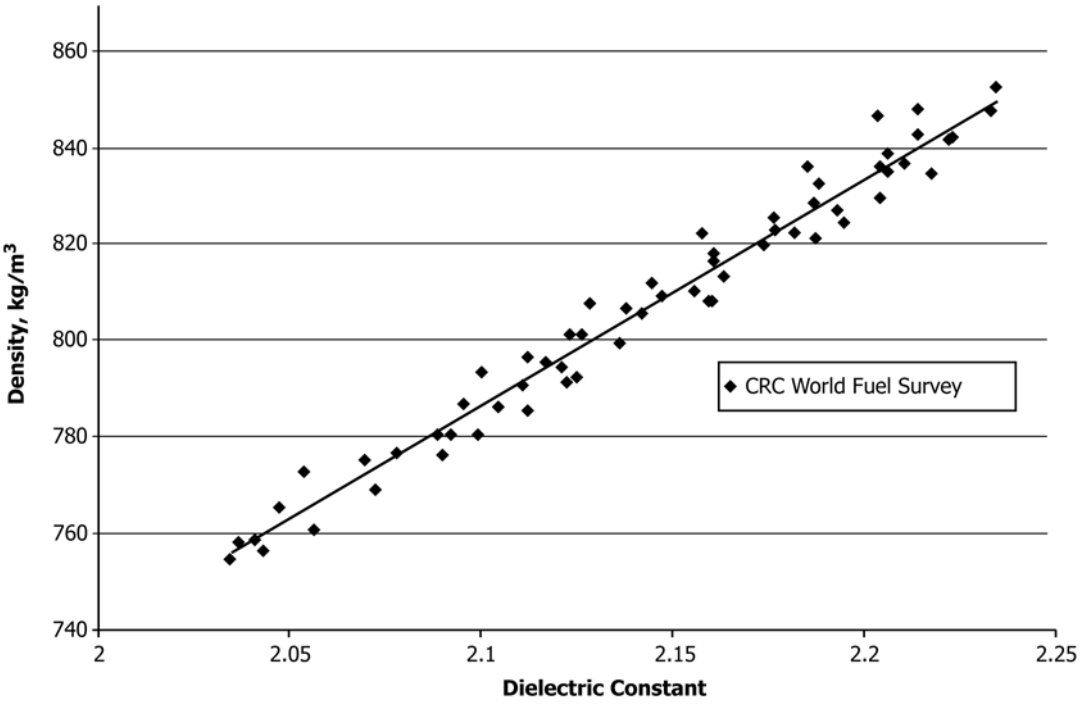


FIG. A1.8 Typical Dielectric-Density Characteristics for Jet Fuel

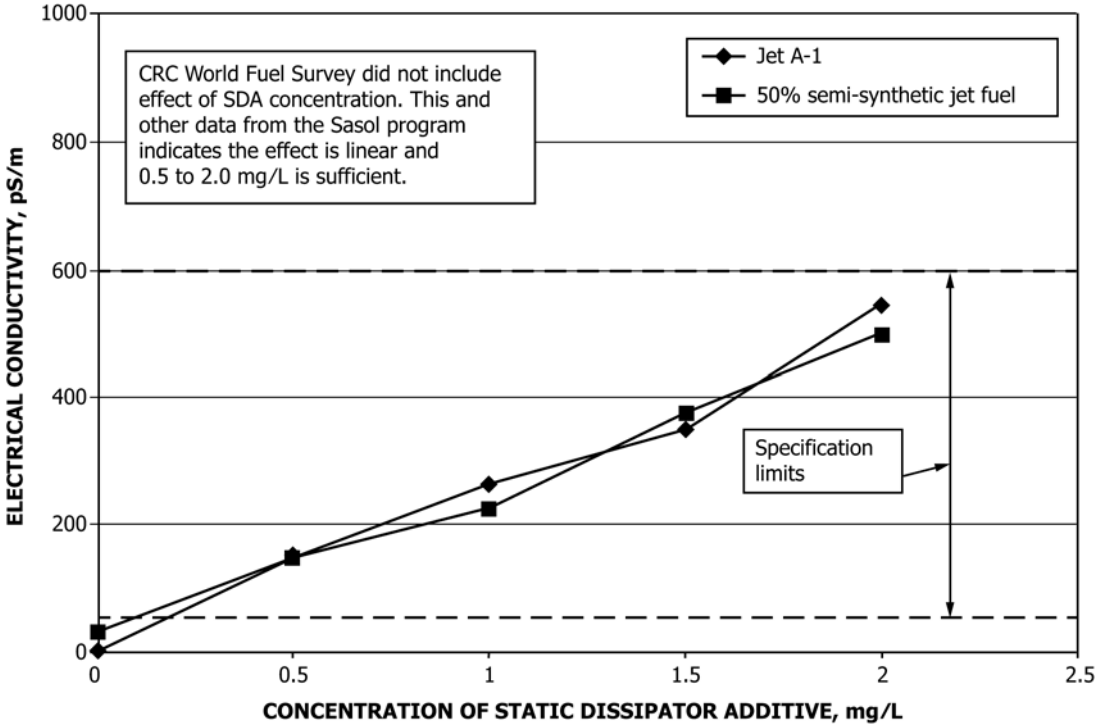


FIG. A1.9 Typical Response to Static Dissipator Additive

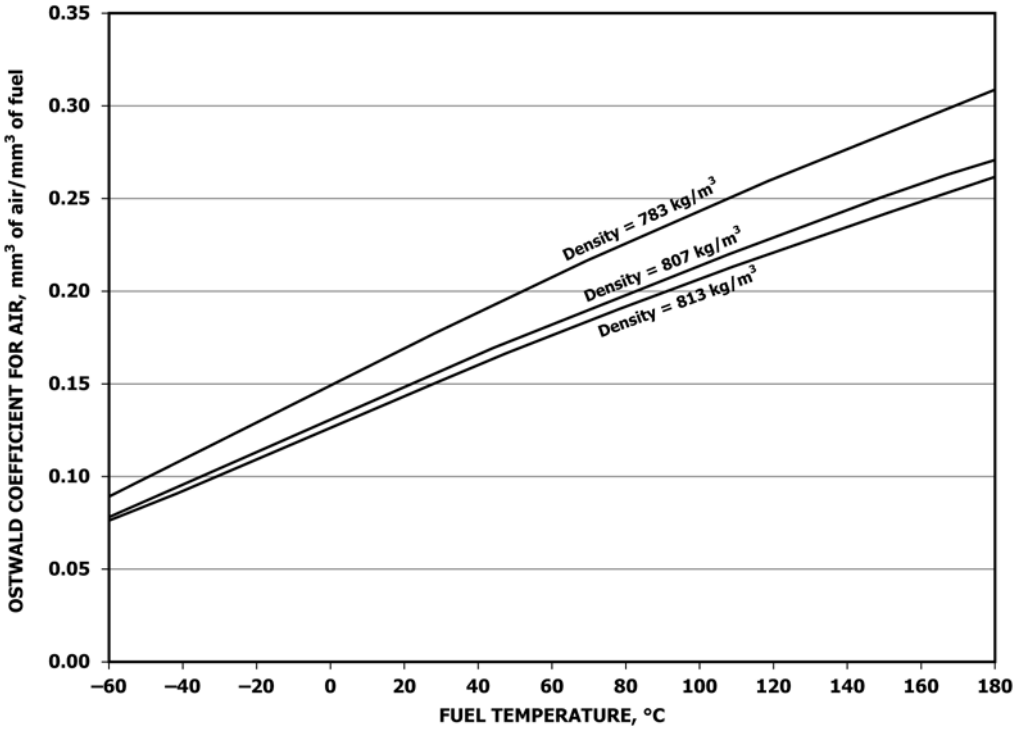


FIG. A1.10 Typical Air Solubilities Based on Least and Most Dense Fuels for which Engines are Designed

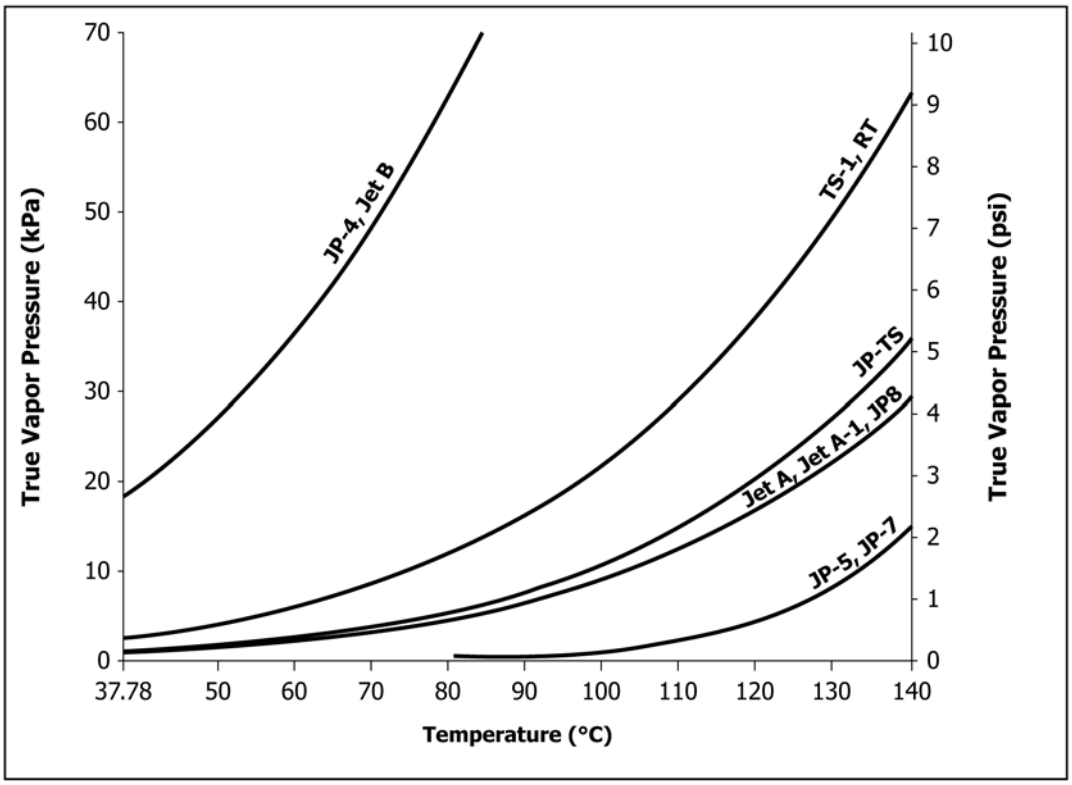


FIG. A1.11 Typical True Vapor Pressure of Jet Fuel

A2. PERFORMANCE AND COMPATIBILITY WITH ADDITIVES CURRENTLY PERMITTED IN SPECIFICATION D1655

A2.1 Scope

A2.1.1 The section provides detailed parameters, processes, and guidelines to evaluate the performance of the new additive for its intended function and to determine the compatibility of the new additive with additives currently approved for use in aviation fuels.

A2.1.2 *Additive Evaluation Fundamentals:*

A2.1.2.1 The sections encompass testing protocols for additive functional types currently utilized in aviation fuel as listed in Specification D1655 Table A2 Detailed Information for Additives for Aviation Turbine Fuels, and also types of additives and chemistries not currently in use in the aviation industry.

A2.1.2.2 The protocol for evaluating new candidate additive will address additive "Compatibility," and additive "Performance for its Intended Function." Compatibility evaluation encompasses testing to evaluate physical properties of the additive to including solubility of the additive in fuels, and the propensity for adverse interaction between the candidate additive and the currently approved additives. The "Performance for its Intended Function" section is geared to ensure the additive enhances or corrects the fuel property for which it is being added to the fuel.

A2.1.2.3 The evaluation procedures were developed with guidance from industry experts to outline testing protocols which will give the proponent of the additive a clear path to generate the type of data required by the aviation industry in support the qualification process. The procedures describing blending and testing protocols, and control and test fluids are recommended experimental guidelines for performing the various additive evaluation procedures. Minor modifications of the published testing protocol may be made, but shall be clearly stated in the report. It is recommended that the proposed test program or any significant changes in the testing procedures be reviewed with the task force prior to initiation of the testing.

A2.1.2.4 The specific additive task force, the OEMs, or the Sub J committee as a whole may with technical justification request additional other test to be performed or other requirements incorporated into the qualification process. There may be instances where testing not detailed in this document is required. Examples include an additive with a completely new function or chemistry, or where specific concerns regarding the additive impact on unique engine or airplane designs features. A reduced level of testing may be appropriate when the candidate additive clearly demonstrates functionally near-identical chemistry to currently approved additives used in Specification D1655 aviation fuels. The proponent should

clearly describe the similarity by comparative compositional analysis of the candidate and the approved additive.

A2.1.2.5 The evaluation of the new candidate additive for "Compatibility," and "Performance for its Intended Function" and any sub sections or phases in the particular evaluation protocol may be performed stepwise or concurrently at the discretion of the additive proponent.

A2.1.2.6 Comparative data between the candidate additive and an approved additive of the same class shall be utilized to evaluate the solubility and non-interaction attributes ("Compatibility") of the candidate additive. Comparative testing on performance of the additive ("Performance for its Intended Function") is not mandatory for all tests. However, the use of direct performance comparisons with an approved additive and the candidate additive may be required for certain testing protocols depending on the results of the particular test or as directed by the committee.

A2.1.2.7 The testing protocols are drafted to incorporate "control" samples in the testing methodology to allow (if necessary, or desired by the candidate) for the collection of data for the currently approved additive under identical evaluation conditions as the candidate additive.

A2.1.2.8 There is no pass/fail criteria incorporated in the evaluation process for the tests cited in the protocol. The cumulative data received from the initial evaluation process shall be used by the additive task force, or the OEMs to recommend additional testing if necessary, and by the committee Sub J as a whole in determining the approval to incorporate the candidate additive into the jet fuel specifications.

A2.1.3 *Quality Assurance:*

A2.1.3.1 The candidate additive to be evaluated must meet two fundamental quality control criteria. First, the additive chemical composition used for the D4054 evaluation protocol shall be fixed. This entails submitting typical inspection criteria of the additive being evaluated, a Certificate of Analysis indicating that the sample being used in the D4054 process meets the listed properties in the inspection criteria, and a Safety Data Sheet for the additive.

A2.1.3.2 Second, the additive sample used in the Practice D4054 evaluation shall be produced using a representative manufacturing/production process, and if the additive evaluation is conducted on a material produced at a different scale than the scale at which the additive will be offered to the industry, then commercial scalability of the additive shall be demonstrated. This is required to ensure that the sample being tested will be directly comparable to the additive that will eventually be produced for use in the aviation industry.

A2.1.4 *Additive Classes*—There are two classes of candidate additives, Existing Additive Class already included in Specification D1655, and New Additive Class not currently included in Specification D1655.

A2.1.4.1 *Existing Additive Class of the type included in Specification D1655:*

(1) The candidate will be considered part of the "Existing Additive Class" for the purpose of following an established evaluation protocol, if the additive is of a similar chemical class and performs similar function to an additive already approved for use in Specification D1655.

(2) The existing approved additive classes are listed in Specification D1655 Table A2 Detailed Information for Additives for Aviation Turbine Fuels, and are included in Table A2.1 of this practice.

(3) When selecting an individual additive from an existing class with multiple approved additives any available additive approved for use in aviation fuel for that class of additive can be utilized in the evaluation.

A2.1.4.2 *New Additive Class of the Type NOT Included in Specification D1655:*

(1) The candidate additive will be considered a part of the "New Additive Class" for the purpose of following an established evaluation protocol if, the additive is of a different chemical functionality or performs a different function than additives currently approved and listed in Specification D1655 Table 2.

A2.1.5 *Fuel Selection:*

A2.1.5.1 The types of fuels selected for the two evaluation sections (Compatibility and Performance for its Intended Function) shall entail samples of fuels that represent a broad range of fuels available across the aviation industry. The range shall address both the source of the crude as well as refining techniques used to process the crude. In the most simplistic terms, crude oils can be characterized as either heavy or light and sweet or sour. Jet fuel can be processed from crude oil by simple distillation, with or without sweetening or with increasing severity of hydro-treating to reduce sulfur and aromatics. The kerosine yield of heavy crude oils can also be increased by hydrocracking or thermal cracking. The fuels selected in the evaluations shall incorporate these variations and should also include samples of synthetic fuels as listed in Specification D7566. The number of fuels utilized for each section is dictated by the type of testing being performed, specifically taking into consideration the impact of the fuel on the particular testing program.

A2.1.5.2 There are recommendations in the protocol for the number and types of fuels to be utilized in each particular evaluation protocol. It's the responsibility of the new additive proponent to put forth a list of possible fuels to be included in the study to address variability of fuels in the industry. The composition and properties of each fuel shall be tabulated and conveyed to the task force, and subsequently included in the research report.

A2.1.5.3 *Base Fluid/Fuel Preparation:*

(1) Base Fluid/Base Fuel—If un-additized fuels compliant with Specification D1655 or other international standards are available for use in the test program, the fuels can be used as

TABLE A2.1 Additive Classes Approved in Specification D1655

Antioxidants (AO)
Metal Deactivator (MDA)
Static Dissipator Additive (SDA)
Corrosion Inhibitor/Lubricity Improvers (CI/LI)
Fuel System Icing Inhibitor (FSII)
Leak Detection Additive[A]
Biocide Additives[A]

[A] Leak detection additive and biocides will not be evaluated in the additive compatibility study.

received, provided the fuel meets a minimum MSEP rating of 98 as measured by Test Method D3948.

(2) If un-additized fuels are not available, or the fuel does not meet the minimum MSEP rating then a Jet A/Jet A-1 conforming to Specification D1655 shall be clay filtered in accordance with the procedure described in Test Method D3948, Appendix X1, "Preparation of Reference Fluid Base." After clay treating, the fuel shall exhibit a minimum MSEP rating of 98 as measured by Test Method D3948.

A2.1.6 *Control and Test Fluid/Fuel Preparation Control Fluid* (unless otherwise stated in the section) is prepared by adding to the base fluid the approved additive at two times the maximum recommended concentration of the additive listed in Specification D1655. The same dosage concentration requirements shall be followed for mixed approved additive cocktails.

A2.1.6.1 *Test Fluid* (unless otherwise stated in the section) is prepared by adding to the base fluid the candidate additive at four times the maximum recommended concentration of the additive.

A2.2 Evaluation of Additive Compatibility

A2.2.1 *Impact on Additive Physical Properties (Solubility):*

A2.2.1.1 Additive compatibility evaluation comprises a series of tests to assess the physical properties of a candidate additive and the impact of the candidate additive on the physical properties of other approved additives listed in Specification D1655 Table 2. The study is designed to evaluate if a candidate additive by itself or in combination with other approved additives will form materials that can have a detrimental impact on fuel use and handling.

A2.2.1.2 The compatibility testing of the candidate additive shall be performed initially on a combine blend containing representatives from each of the approved classes of additives and subsequently with the representative blend containing the candidate additive (Table A2.2). If any dissimilarity is seen between the additive blend containing the candidate and the one without the candidate additive, then the solubility experiments shall be performed individually with a member from each of the approved additive classes (Table A2.3).

A2.2.1.3 The same compatibility evaluation shall be repeated with each fuel.

TABLE A2.2 Additive Cocktail—Visual Inspection for Compatibility Assessment

Storage and Testing Conditions	–18 °C (0 °F) for 24 h	Warm to Room Temp.	Heat to 43 °C (110 °F) for 7 days	–18 °C (0 °F) for 24 h
Control Fluid A				
Control Fluid B				
Test Fluid A				
Test Fluid B				

Control Fluid A (Cocktail of all Approved Additives—AO, MDA, SDA, and CI/LI, No FSII)
Control Fluid B (Cocktail of all Approved Additives—AO, MDA, SDA, CI/LI and FSII)
Test Fluid A (Candidate Additive and Cocktail of all Approved Additives, AO, MDA, SDA and CI/LI, No FSII)
Test Fluid B (Candidate Additive and Cocktail of all Approved Additives, AO, MDA, SDA, CI/LI and FSII)

TABLE A2.3 Individual Additives—Visual Inspection for Compatibility Assessment

Storage and Testing Conditions	–18 °C (0 °F) for 24 h	Warm to Room Temp.	Heat to 43 °C (110 °F) for 7 days	–18 °C (0 °F) for 24 h
Control Fluid C				
Control Fluid D				
Test Fluid C				

Control Fluid C (Candidate Additive)
Control Fluid D (Individual Approved Additive)
  Control Fluid D1 (AO)
  Control Fluid D2 (MDA)
  Control Fluid D3 (SDA)
  Control Fluid D4 (CI/LI)
  Control Fluid D5 (FSII)
Test Fluid C (Candidate Additive and Individual Approved Additive)
  Test Fluid C1 (Candidate + AO)
  Test Fluid C2 (Candidate + MDA)
  Test Fluid C3 (Candidate + SDA)
  Test Fluid C4 (Candidate + CI/LI)
  Test Fluid C5 (Candidate + FSII)

A2.2.1.4 If the candidate additive further fails the individual approved additive interaction test at four times the maximum proposed treat rate, then an approved additive of the same class should also be evaluated in the test at four times the treat rate. If the approved additive also fails the evaluation, then a lesser concentration (three times and if still fails then at twice the concentration) of the candidate additive can be tested. The same evaluation shall be performed for the approved additive at the same diminished treat rate multiplier as the candidate additive. If no other approved additive exists in the class, then approval to proceed should be sought from the committee.

NOTE A2.1—The evaluation of additive compatibility in the fuel by this evaluation does not address whether neat additives can be blended together as a combination package for single point injection.

A2.2.2 *Base Fuel, and Control and Test Fluids/Fuels for Physical Compatibility Evaluation:*

A2.2.2.1 Compatibility of an additive can be greatly influenced by the chemical composition, and in particular the aromatic content of the fuel. It is therefore recommended that a broad survey of fuels be used to evaluate the candidate additive and ensure universal compatibility in all field operations. Compatibility testing shall be performed using a set of fuels to encompass industry aviation fuel composition and processing variables.

A2.2.2.2 It is recommended that the fuel test set contain a diversity of fuels; with multiple samples of aviation fuel produced from common refinery processes (including straight run, hydro treated, severely hydro treated, and Merox fuels), and a set of samples produced using blending components as listed in Specification D7566. The total aromatic content of each fuel used in the evaluation shall be listed.

A2.2.2.3 *Control Fluid A (Cocktail of all Approved Additives no FSII)*—To 200 mL of the base Fuel add each approved additives (AO, MDA, SDA, CI/LI) at two times the maximum recommended concentration listed in Specification D1655. Control Fluid A is for use in evaluation as listed in Table A2.2.

A2.2.2.4 *Control Fluid B (Cocktail of all Approved Additives with FSII)*—To 200 mL of the base Fuel add each approved additives (AO, MDA, SDA, CI/LI and FSII) at two

times the maximum recommended concentration listed in Specification D1655. Control Fluid B is for use in evaluation as listed in Table A2.2.

A2.2.2.5 *Control Fluid C (Candidate Additive)*—To 200 mL of the base Fuel add the candidate additive at four times the maximum recommended concentration of the additive. Control Fluid C is for use in evaluation as listed in Table A2.3.

A2.2.2.6 *Control Fluid D (Individual Approved Additives)*—To 200 mL of the base fuel add a sample of each approved class of additives listed in Table A2.1 at two times the maximum recommended concentration of each approved additive listed in Table A2.1. This procedure shall be separately followed for each class of approved additive. Control Fluid D is for use in evaluation as listed in Table A2.3.

A2.2.2.7 *Test Fluid A (Candidate Additive and Cocktail of all Approved Additives, no FSII)*—To 200 mL of the base Fuel add the candidate additive at four times the maximum recommended concentration. Then to the same fuel containing the candidate additive, add each approved additives (except FSII) in able 1 at two times the maximum recommended concentration listed in Specification D1655. Test Fluid A is for use in evaluation as listed in Table A2.2.

A2.2.2.8 *Test Fluid B (Candidate Additive and Cocktail of all Approved Additives with FSII)*—To 200 mL of the base Fuel add the candidate additive at four times the maximum recommended concentration. Then to the same fuel containing the candidate additive add each approved additive in Table A2.1 at two times the maximum recommended concentration listed in Specification D1655. Test Fluid B is for use in evaluation as listed in Table A2.2.

A2.2.2.9 *Test Fluid C (Candidate Additive and Individual Approved Additive)*—To 200 mL of the base fuel add the candidate additive at four times the maximum recommended concentration. Then to the same fuel containing the candidate additive add each of the approved additives listed in Table A2.1 individually at two times the maximum concentration listed in Specification D1655. This procedure shall be separately followed for class of approved additives. Test Fluid C is for use in evaluation as listed in Table A2.3.

A2.2.3 *Testing of Control Fluids and Test Fluids:*

A2.2.3.1 The fluids containing the control additives as a cocktail, and the blend of the control additives cocktail with the candidate additive as described in Table A2.2, shall be evaluated for physical compatibility.

A2.2.3.2 The evaluation shall be carried out in an identical manner for each fluid. The sample clarity shall be documented and the sample container shall be photographed using a checkerboard background. It is recommended that all samples for physical compatibility be prepared and evaluated in duplicate to limit the possibility of anomalous results.

A2.2.3.3 If there are no differences seen between the cocktail control and cocktail test fluid, then this portion of the compatibility testing is complete. If there are any differences seen between the two samples, then the candidate additive should be tested individually with each approved additive as described in Table A2.3.

A2.2.3.4 *Testing Procedure:*

(1) Transfer samples of each control and each test fluid to separate 250 mL, clear, centrifuge tubes. The tubes shall be stoppered to ensure limited loss of volume during storage and handling. Place the samples into dark cold storage at –17.8 °C (0 °F) for 24 h. At the conclusion of the 24 h storage period, remove the samples from cold storage and immediately inspect for evidence of incompatibility. Indications of evidence of incompatibility include precipitation, cloudiness, darkening, or other visible changes.

(2) Allow the sample to warm to room temperature. Inspect for evidence of incompatibility. Document results and photograph the test tubes.

(3) Heat samples to 43 °C (110 °F) and maintain temperature for 7 days. At the conclusion of the 7 days storage period, allow the samples to cool to room temperature. Inspect for evidence of incompatibility. Document results and photograph the test tubes.

(4) Place the heat stressed samples into dark, cold storage at –17.8 °C (0 °F) for 24 h. At the conclusion of the 24 h storage period, remove the duplicate samples from cold storage and immediately inspect for evidence of incompatibility. Document results in writing and by photographing the test tubes.

(5) A shorthand description of samples to be tested in each fuel approved for evaluating the Impact of candidate additive on physical properties of approved additives is depicted in Table A2.2 and Table A2.3.

A2.3 Evaluation of Additive Interaction

A2.3.1 *Impact of Candidate Additive on Approved Additive Performance:*

A2.3.1.1 The interaction testing is designed to evaluate impact of the candidate additive on the performance of other approved additives. This section is specific to evaluation of additives, and is in addition to other “no interaction” requirements already present in other sections of the document.

A2.3.1.2 The evaluation procedures were developed with guidance from industry experts based on current aviation knowledge and experience. Input from the specific additive task force is recommended to ensure adequacy of the test program when evaluating new additive chemistries.

A2.3.2 *Base Fuel, and Control and Test Fluids for Additive Interaction Evaluation:*

A2.3.2.1 It is recommended that the fuel set selected for performing the interaction testing should contain an adequate number of fuels to address types of fuels available across the aviation industry.

A2.3.2.2 *Base Fuel*—The preparation of the base fuels is described in A2.1.5.3.

A2.3.2.3 *Control Fluid E (Baseline Aviation Additive Package)*—Control Fluid E shall contain a base fuel with the additive package that includes all the additives (with the exception of biocide or leak detection additive) listed in the Table A2.1. For classes of additives containing multiple approved additives, unless otherwise specified, one available candidate listed in Table 2 of Specification D1655 from the class can be utilized in the evaluation. The additives shall be present in the control fluid at their maximum approved treat rate.

A2.3.2.4 *Test Fluid D (Baseline Aviation Additive Package Plus the Candidate Additive)*—The Test Fluid D shall contain all the same additives at their maximum approved treat rate as the Control Fluid E, and the candidate additive at its maximum recommended treat rate.

A2.3.2.5 *Existing Class*—When evaluating a candidate additive that imparts the same function or is from the same class of an "existing" approved additive, the additive included in the test fluid shall contain the candidate additive (at the proposed maximum initial treat rate) in place of the existing approved additive used to prepare the control fluid.

A2.3.2.6 *New Class*—When evaluating a candidate additive that imparts a different function than an existing approved additive, the candidate additive shall be included in the test fluid in addition to the approved additives contained in the control fluid. The candidate additive shall be dosed into the test fluid at its proposed maximum treat rate.

A2.3.3 *Testing of Control Fluids and Test Fluids:*

A2.3.3.1 The Control Fluid E containing a combination of all the approved additives shall be evaluated for performance of each approved additive type using a test method that is applicable for evaluating the performance of that given class of additives. The same testing protocol shall be carried out for the Test Fluid D to evaluate the impact on the performance of the candidate additive on the approved additives.

A2.3.3.2 After preparation, the control fluids and test fluids shall be stored at 43 °C (110 °F) for seven days to ensure adequate time for all possible chemical interaction to occur during common civil aviation storage timelines. At the conclusion of the seven day storage period, the samples are allowed to cool to ambient temperature and evaluated for performance of each additive utilizing the screening test for the specific additive as detailed in A2.3.4.

A2.3.4 *Additive Specific Performance Testing Methods:*

A2.3.4.1 *Antioxidants*—Antioxidant performance is conducted to evaluate the impact of the candidate additive on performance of an aviation-approved antioxidant. The test method chosen to evaluate non-interaction behavior of the candidate additive is Test Method D5304.

A2.3.4.2 *Metal Deactivator*—Metal deactivator performance is conducted to evaluate the impact of the candidate additive on the performance of an aviation approved metal deactivator. The test method chosen to evaluate non-interaction behavior of the candidate additive is Test Method D3241.

A2.3.4.3 *Static Dissipator*—Static dissipator performance shall be conducted to evaluate the impact of the candidate additive on performance of an aviation approved static dissipator additive. The test method chosen to evaluate non-interaction behavior of the candidate additive is Test Methods D2624.

A2.3.4.4 *Corrosion Inhibitor/Lubricity Improvers (CI/LI)*—CI/LI performance is conducted to evaluate the impact of the candidate additive on performance of an aviation-approved corrosion inhibitor. The test method chosen to evaluate non-interaction behavior of the candidate additive is Test Method D5001.

A2.3.4.5 *Fuel System Icing Inhibitor (FSII)*—The impact by the candidate additive on the performance of FSII is very difficult to evaluate. The evaluation could possibly be done by testing of the freezing point of water dropping out of the fuel. The main impact on FSII performance by a candidate additive would be in changing the partition coefficient of the FSII between fuel and water. However, it is not expected that an additive can greatly impact that property, thus it is recommended that impact by the candidate additive on FSII performance not be evaluated. The test methods to be used for evaluating the impact of candidate additive on the properties of approved additives, and the list of samples to be prepared and tested are listed in Table A2.4. The same testing protocol shall be performed for each base fuel.

A2.4 Evaluation of Additive Performance

A2.4.1 Each candidate additive requesting approval for use in aviation shall demonstrate the "performance of the additive for its intended function." The testing protocols are designed to evaluate the specific performance requirements for the particular type of additive.

A2.4.2 The specific testing methods and protocols described are a guide for evaluating "performance of the additive for its intended function." Minor modifications of the published testing protocol can be made, but must be clearly stated in the report. Any significant changes in the test procedures should be reviewed with the task force prior to initiation of the testing.

A2.4.3 The evaluations of the existing additive class listed in Specification D1655 certified fuels are described in the section dealing with each specific type of additive. The testing methods for candidate additives of the new additive class not currently included or approved for use in Specification D1655 certified fuels may require a custom tailored testing proposal submitted to the task force and the OEMs by the proponent of the additive. The protocol may include custom tests and ASTM test methods to evaluate additive performance.

A2.4.4 The test and procedures cited herein are the recommended baseline testing for evaluation of candidate additives "performance for its intended function." The task force, the OEMs or the committee as a whole may at given technical justification modify, change or add other tests to the performance evaluation protocol.

A2.4.5 *Candidate Additives of the Existing Additive Class included in Specification D1655:*

A2.4.5.1 *Antioxidants*—Antioxidant performance shall be conducted to evaluate the impact of the candidate additive on retardation of degradation processes associated with storage of hydrocarbon fuels. The test protocol was chosen to evaluate candidate additive ability to diminish peroxide formation and

TABLE A2.4 Additives and Performance Testing Methods

Additive Types	AO	MDA	SDA	CI/LI
Specific Performance Testing Methods	D5304	D3241	D2624	D5001
Control Fluid E				
Test Fluid D				

Control Fluid E (Cocktail of Representative Approved Additives AO, MDA, SDA, CI/LI and FSII)
Test Fluid D (Cocktail of Representative AO, MDA, SDA, CI/LI and FSII and Candidate Additive)

to retard subsequent oxidation chemistries such as those yielding soluble and insoluble gums. The methods recommended to be utilized for evaluating an antioxidant additive are: Test Method D3703 to evaluate the ability of the additive to diminish peroxide formation; and Test Method D5304 to evaluate the additives' ability to retard subsequent oxidation chemistries such as those yielding soluble and insoluble gums. The testing shall be conducted at the maximum allowable treat rate as specified in Specification D1655 (commonly 24 mg/L). At the option of the additive proponent, testing can be done at other treat rates in addition to the maximum specified treat rate.

(1) Preparation of Base Fuels, Control Fluids and Test Fluids:

(a) Base Fuel—The fuel set for antioxidant evaluation is recommended to be a minimum of two base fuels; a hydro-treated fuel and a blend of the hydro-treated fuel with a synthetic fuel compliant with Specification D7566. The fuels shall be used to prepare the control fluids and test fluids. The peroxide content (Test Method D3703) and acid value (Test Method D3242) of base fuel is measured prior to additive treatment. The preparation of the base fuels is described in A2.1.5.3, however it may be difficult to remove antioxidants present in the fuel by clay filtration, thus it is recommended that fuels used in this protocol be completely additive free.

(b) Control Fluids—The control fluids shall be prepared from each base fuel and contain the maximum treat rate of an aviation approved antioxidant.

(c) Test Fluids—The test fluids shall also be prepared from each base fuel, and contain maximum recommended treat rate or other treat rates of the candidate additive.

(2) Evaluation of Peroxide Inhibition:

(a) The testing shall entail heating sealed tubes separately containing the base fuels, the base fuel with approved additive (control fluids), and base fuel without additives (test fluids) for four weeks, and evaluating peroxide content and acid value weekly.

(b) Testing Procedure—Four sets of sealable jars shall be prepared with each jar separately containing 75 mL of the base fuel, 75 mL of the control fluid and 75 mL of the test fluid. The sealed jars shall be placed in an oven and heated to 43 °C. The peroxide content and acid value of each sample shall be measured at the end of each week. The peroxide content shall be measured using Test Method D3703, and the acid value shall be measured using Test Method D3242.

(c) At the weekly sampling point, all the samples shall be removed from the heating source and while sealed allowed to cool. After cooling to room temperature, the sample shall be left open to the atmosphere for at least 1 h. The set shall be evaluated is measured for peroxide content and acid value and the remaining fluid from that week's sample set can be discarded.

(d) The sets shall be evaluated for the subsequent weeks are resealed and returned to the 43 °C oven. At the conclusion of the each subsequent week, the peroxide content and acid value of the samples are shall be measured. A short hand description of samples shall be evaluated is listed in Table A2.5 and Table A2.6.

TABLE A2.5 Peroxide Content (measured in mg/kg using Test Method D3703)

	Initial	1 week	2 weeks	4 weeks	6 weeks
Base Fuels					
Control Fluids					
Test Fluids					

TABLE A2.6 Acid Values (measured in mg/100 mL using Test Method D3242)

	Initial	1 week	2 weeks	4 weeks	6 weeks
Base Fuels					
Control Fluids					
Test Fluids					

(e) The results of the study may be reported in two sets of graphs indicating change in peroxide content, and acid value respectively with duration of storage. Any visible changes in the color of the fuel shall also be reported.

NOTE A2.2—The validity of the test results should be demonstrate by a showing of the tendency of the untreated base fuel to form peroxides under the testing conditions.

(3) Evaluation of Retardation of Gum Formation—The testing shall entail evaluating the base fuel, the control and the test fluids using Test Method D5304 to measure the propensity of the additive to inhibit formation of insoluble materials and gums. A short hand description of samples to be prepared and tested is listed in Table A2.7.

A2.4.5.2 *Metal Deactivator*—Metal deactivator performance shall be conducted to evaluate the impact of the candidate additive to diminish transition metal catalyzed fuel instability. The performance evaluation shall be conducted in three phases. Phase I to determine the minimum amount of the candidate MDA required to complex a given amount of soluble copper and soluble zinc; Phase II to evaluate the solubility of complex formed by the candidate metal deactivator with copper and zinc; and Phase III to evaluate the performance of the additive to remediate transition metal (copper, and zinc) induced fuel instability.

(1) Phase I Stoichiometric Balance—The proponent of the candidate additive, based on chemical composition or laboratory evaluation shall recommend the molar stoichiometric equivalence of the additive required to completely complex a molar equivalent of active copper, and active zinc.

(2) Phase II Complex Solubility—Physical compatibility testing shall be carried out to determine the solubility of the complex formed with the transition metal and the candidate metal deactivator and to ensure the complex is soluble under appropriate field use conditions.

TABLE A2.7 Retard Oxidation Chemistries (measured in mg/100 mL using Test Method D5304)

	Fuel A	Fuel B
Base Fuels		
Control Fluids (Approved Additive)		
Test Fluids (Candidate Additive)		

(3) The stoichiometric recommendation (Phase I) shall be used to set the treat ranges for evaluation of the solubility of the complex formed by the metal and the additive.

(4) Preparation of Base Fuel, Control Fluids and Test Fluids:

(a) Base Fuel—It is recommended that the test fuel set contain a diversity of fuels; with multiple samples of aviation fuel produced from common refinery processes (including straight run, hydro treated, severely hydro treated and Merox fuels), and a set of samples produced using blending components as listed in Specification D7566. The total aromatic content of each fuel used in the evaluation shall be listed. The preparation of the Base Fuels is described in A2.1.5.3.

(b) Control Fluids—Control fluids shall be prepared by treating 75 mL of each base fuel with four times the recommended treat rate of an aviation approved MDA. Samples of each control fluid shall be prepared in 100 mL clear centrifuge tubes. To the treated fuel is added sufficient amount of "soluble copper" (or "soluble zinc") to meet the stoichiometric ratio for the additive as directed in Phase I. The control fluids containing the approved additives and the required amount of soluble copper (or required zinc) shall be stored at 43 °C for 24 h to ensure the conversion of the metal/additive complex.

(c) Test Fluids—Test fluids shall be prepared by treating 75 mL of each base fuel with four times the recommended treat rate of the candidate additive. Samples of each test fluid shall be prepared in 100 mL clear centrifuge tubes. To the treated fuel is added sufficient amount of "soluble copper" to meet the stoichiometric ratio for the additive as directed in Phase I. The test fluids containing the candidate additive and the required amount of soluble copper shall be stored at 43 °C for 24 h to ensure the conversion of the metal/additive complex. The same process shall be performed for "soluble zinc".

(d) Soluble Metals—The metal complex to be utilized to deliver soluble metals for the control fluids and test fluids can be either a complex of the metal (copper or zinc) with napthenoic acid, or with acetoaceteonate (AcAc) complex.

(5) Testing of Control Fluids and Test Fluids:

(a) Testing Procedure—The control and test fluids shall be cooled to room temperature 23 °C (75 °F), and then cooled to –17.8 °C (0 °F), and then subsequently cooled to –40 °C (–40 °F) and stored for 24 h at each temperature. The clarity and presence of precipitates in each fluid shall be evaluated immediately upon removal from low temperature storage. At the end of the –40 °C (–40 °F) storage and evaluation, control and test tubes shall be allowed to warm to room temperature, and centrifuged in a centrifuge tube readable to 0.005 mL at a relative centrifugal force of 800 r/min for 10 min at 18 °C to 27 °C (65 °F to 80 °F). The clarity and presence of precipitates in each fluid shall be described, and also documented by photographing each tube. The evaluation process shall be separately carried out for each metal (copper and zinc), and repeated using each base fuel. A general description of samples to be prepared and tested is listed in Table A2.8. The clarity and presence of precipitates in each fluid shall be photographed and reported.

TABLE A2.8 Metal Complexes—Visual Evaluation

Storage and Testing Conditions	23 °C (75 °F) for 24 h	–17.8 °C (0 °F) for 24 h	–40 °C (40 °F) for 24 h
Control Fluid—Approved Metal Complex			
Test Fluid—Candidate Metal Complex			

(6) Phase III Remediation of transition metal induced fuel instability—The program shall evaluate the ability of the candidate metal deactivator to enhance the stability of a fuel in the presence of transition metals that can be present in the fuel handling, transport and storage system.

(7) Preparation of Base Fuel, Control Fluids and Test Fluids:

(a) Base Fuel—It is recommended that the fuel test set contain a diversity of fuels; with multiple samples of aviation fuel produced from common refinery processes (including straight run, hydro treated, severely hydro treated and Merox fuels), and a set of samples produced using blending components as listed in Specification D7566. The total aromatic content of each fuel used in the evaluation shall be listed. The preparation of the base fuels is described in A2.1.5.3.

(b) Control Fluid (Metal)—Control fluids shall be prepared by treating each base fuel with 0.5 to 1.5 of the stoichiometric amount of active metal required to be complexed by the maximum treat of an approved MDA. The treat level of the MDA is commonly based on active ingredient (not including weight of solvent) on the MDA.

(c) Control Fluid (Additive)—Control fluids shall be prepared by treating each base fuel with the maximum recommended treat rate as specified in Specification D1655 (commonly 2 mg/L of active ingredient—not including weight of solvent) of the aviation approved MDA.

(d) Control Fluid (Additive and Metal)—Control fluids shall be prepared by treating each base fuel with the maximum recommended treat rate (2 mg/L of active ingredient—not including weight of solvent) of the aviation approved MDA, and 0.5 and 1.5 of stoichiometric amount of soluble copper (and soluble zinc) required to complex 2 mg/L of active ingredient of the aviation approved MDA.

(e) Test Fluid (Additive)—Test fluids shall be prepared by treating each base fuel with the maximum recommended treat rate of the candidate additive.

(f) Test Fluid (Additive and Metal)—Test fluids shall be prepared by treating each base fuel with the maximum recommended treat rate of the candidate additive. Soluble copper (and soluble zinc) shall be added to each test fluid as listed in Table A2.9. The stoichiometric ratio used for the candidate additive and the soluble copper and zinc shall be calculated based on the stoichiometric recommendation made by the candidate additive sponsor as described in Phase I.

(g) Soluble Metals—The common metal complexes utilized to deliver soluble metals to the control fluid and test fluid are napthenate, or acetoacetonate (AcAc) complexes of the specific metal.

(8) Testing of Base Fuel, Control Fluids and Test Fluids:

TABLE A2.9 Break Point (Test Method D3241)

	Break Point
Base Fuel (Fuel Control)	
Base Fuel + 0.50 eq. of active Cu (Metal Control)	
Base Fuel + 1.50 eq. of active Cu (Metal Control)	
Control Fluid – MDA 2 mg/L (Approved Additive Base Control)	
Control Fluid – MDA 2 mg/L + .50 eq. of active Cu (Approved Additive Control)	
Control Fluid – MDA 2 mg/L + 1.0 eq. of active Cu (Approved Additive Control)	
Control Fluid – MDA 2 mg/L + 1.5 eq. of active Cu (Approved Additive Control)	
Test Fluid – Candidate MDA max mg/L (Candidate Additive Base Control)	
Test Fluid – Candidate MDA max mg/L + .50 eq. of active Cu (Candidate Additive Control)	
Test Fluid – Candidate MDA max mg/L + 1.0 eq. of active Cu (Candidate Additive Control)	
Test Fluid – Candidate MDA max mg/L + 1.5 eq. of active Cu (Candidate Additive Control)	

(a) Testing Procedure—The control and test fluids shall be evaluated for the stability enhancement impact by the additive to remediate metal induced instability by measuring the break point of the fluid using Test Method D3241. Each fuel sample shall be prepared and evaluated separately with each copper and zinc complex. Table A2.9 describes a shorthand notation for the experiments to be varied out with copper. Same testing format shall be carried out for zinc. The tubes shall also be rated as per Test Method D3241. The use of modern methods (Interferometer—Annex A2 of Test Method D3241, and Ellipsometer—Annex A3 of Test Method D3241) for determining deposit thickness is also recommended for the comparison of the heater tubes.

A2.4.5.3 *Static Dissipator Additives (SDA)*—Static dissipator performance for aviation applications shall utilize a two Phase evaluation process: I) Basic Performance Characteristics—Conductivity Enhancement (ability of the additive to increase fluid conductivity) and Conductivity Retention (maintenance of fluid conductivity with time and storage conditions), and II) Field Performance Characteristics—enhancement of static dissipation by the additive under field use conditions.

(1) Phase I Basic Performance Characteristics—Static dissipator additives are utilized to ensure safety in handling of fuels. Thus there is reliance on the repeatable and continued performance of the additive in the fuel. Parameters used to evaluate additive performance under various industrial end use conditions are: conductivity response with dose rate, conductivity retention with time, and conductivity retention with temperature. The response and retention performance evaluation of the candidate static dissipator additive will be measured as per Test Methods D2624. It is recommended that similar data be collected under the same experimental conditions, with the existing Specification D1655 aviation approved static dissipator additive.

(a) Base Fuel—It is recommended that the fuel test set contain a diversity of fuels; with multiple samples of aviation fuel produced from common refinery processes (including straight run, hydro treated, severely hydro treated and Merox fuels), and a set of samples produced using blending components as listed in Specification D7566. The total aromatic content of each fuel used in the evaluation shall be listed. The base fuels shall be prepared in accordance to procedure described in A2.1.5.3.

(b) Conductivity Response (Dose Rate)—Preparation of Control Fluids and Test Fluids:

(c) Control Fluid—Control fluid shall be prepared by treating each base fuel with the aviation approved static dissipator additive based on its maximum allowable treat rate as specified in Specification D1655 (commonly initial maximum treat rate of 3 mg/L) and at a range of concentrations up to the maximum treat rate (recommended—one-half (½) and one-quarter (¼) of the maximum initial treat rates). The treat rate and the final conductivity shall be noted.

(d) Test fluid—Test fluid shall be prepared by treating each base fuel with the candidate additive as supplied at its maximum initial treat and at a range of concentrations, one-half (½) and one-quarter (¼) of the proposed maximum initial treat rates. The treat rate and the final conductivity shall be noted.

(e) Testing Procedure—The base fuel, control fluids, and test fluids shall be prepared as listed in Table A2.10. The conductivity response of the fluids shall be measured at ambient room temperature (commonly 23 °C (75 °F)) using Test Methods D2624. The study with the control and candidate additive shall be performed using each base fuel and the results reported for each fuel as per Table A2.10. A graph of the treat rate, using an appropriate scale vs. the conductivity response of the approved and candidate SDA may help illustrate the results.

(f) Conductivity Retention (Temperature)—Preparation of Control Fluids and Test Fluids:

(g) Control Fluids—Control fluids shall be prepared by treating each base fuel described in A2.1.5.3 with ⅓ maximum initial treat with the aviation approved static dissipator additive.

(h) Test Fluids—Test fluids shall be prepared by treating each base fuel with ⅓ maximum initial treat of the candidate additive.

(i) Testing Procedure—The base fuel, control fluids, and test fluids shall be prepared as listed in Table A2.10. The fluids shall be stored at the required temperature for 24 h prior to making each measurement. The fluid conductivity at different temperatures shall be measured using Test Method D2624. The measurement shall be made directly after removal from the low

TABLE A2.10 Conductivity Treat Rate Response using Test Methods D2624

Dose Rate	Conductivity; pS/m
Base Fuel	
Approved SDA, ¼ max treat rate mg/L (Control Fluid)	
Approved SDA, ½ max treat rate mg/L (Control Fluid)	
Approved SDA, max treat rate mg/L (Control Fluid)	
Candidate SDA, ¼ max treat rate mg/L (Test Fluid)	
Candidate SDA, ½ max treat rate mg/L (Test Fluid)	
Candidate SDA, max treat rate mg/L (Test Fluid)	

temperature environment. At the conclusion of the measurement cycle a final measurement of the samples shall be made at initial temperature of 23 °C (after allowing the –40 °C (–40 °F) sample to warm to room temperature). The study with the control and candidate additive shall be performed using each base fuel. The results for the evaluation of control and test fluids shall be reported for each fuel as per Table A2.11. A bar graph of temperature using an appropriate scale vs. conductivity of the approved and candidate SDA may help illustrate the results.

(j) Conductivity Retention (Time)—Preparation of Control Fluids and Test Fluids:

(k) Control Fluid—Control fluid shall be prepared by treating each base fuel described in A2.1.5.3 with ¼ initial maximum treat with the aviation approved static dissipator additive.

(l) Test Fluid—Test fluid shall be prepared by treating each base fuel with ¼ initial maximum treat of the candidate additive.

(m) Testing Procedure—The fluids shall be stored in the dark at a temperature of 43 °C for the duration of the study, and fluid conductivity using Test Methods D2624 measured in seven day increments for a total of 14 days (2 weeks). Prior to measurement the fuel is removed from the 43 °C oven, stored in a dark cabinet and allowed to cool to room temperature 23 °C. The study with the control and candidate additive shall be performed using each base fuel. The results for the evaluation of control and test fluids shall be reported for each fuel as per Table A2.12.

(2) Phase II Field Performance Characteristics—Static dissipator additives impact the electrical properties of hydrocarbon fluids. They are known to enhance both the rate of fluid charging, and the rate of fluid charge dissipation. For an additive to be approved as an aviation static dissipator additive, the increase in the rate of charge dissipation under all field use conditions must be greater that the increase in the rate of fluid charging. Antistatic additives have the primary purpose of dissipating charge and preventing charge accumulation in a receiver. Surface voltage in the receiver during fill is, therefore, the parameter of crucial importance for interpreting the effectiveness of static dissipator additives in reducing the risk of electrostatic ignition. A variety of laboratory-scale procedures are available to determine the effect of static dissipator additive on the electrostatic behavior of distillate fuels. However a firm correlation of the small-scale tests with actual field performance does not exist to indicate the effectiveness of the static dissipator additive to dissipate charge during actual field

TABLE A2.11 Conductivity Temperature Response Measurement (Test Methods D2624)

	23 °C (75 °F)	4 °C (40 °F)	–17.8 °C (0 °F)	–40 °C (–40 °F)	23 °C (75 °F)
Base Fuel					
Approved SDA, ⅓ initial maximum treat rate mg/L (Control Fluid)					
Candidate SDA, ⅓ initial maximum treat rate mg/L (Test Fluid)					

TABLE A2.12 Conductivity Retention Measurement using Test Methods D2624

	Start	7 days	14 days
Base Fuel			
Approved SDA, with ¼ initial maximum treat (Control Fluid)			
Candidate SDA, with ¼ initial maximum treat (Test Fluid)			

conditions. In order to ensure the safety of field handling personal, to protect transport equipment and to adequately demonstrate the performance of the additive for its intended purpose (specifically preventing the accumulation of charge during transfer), static dissipator additive historically utilized in the aviation industry were evaluated using a full scale field apparatus to demonstrate performance of an antistatic additive to dissipate charge generated during field transfer of fuel.

(a) Static Dissipation under Field Use Conditions—The testing protocol shall evaluate the charge dissipation performance of the additive in the approved minimum conductivity range, and also the impact on fuel charging after clay filtration of the fuel containing the additive.

(b) Preparation of Base Fuel, Control Fluids and Test Fluids:

(c) Base Fuel—The base fuels shall be prepared in accordance to procedure described in A2.1.5.3.

(d) Control Fluid—The control fluid shall be prepared by treating each base fuel with the aviation approved static dissipator additive to achieve a fluid conductivity in the range of 25 pS⁄m to 50 pS⁄m. The treat rate and the final conductivity shall be noted.

(e) Test Fluid—The test fluid shall be prepared by treating each base fuel with candidate SDA to achieve a fluid conductivity in the range of 25 pS⁄m to 50 pS⁄m. The treat rate and the final conductivity shall be noted.

(f) Testing Procedure—The specific protocol for the field evaluation maybe different from prior additive qualification studies provided the evaluation incorporates current field handling parameters (flow rates, filtration etc.) and, the surface voltage is measured with and without the additive. Comparison with aviation approved static dissipator additive is recommended. The specific design of the testing equipment is the responsibility of the proponent of the candidate additive. A proposal of the equipment design and procedure for conducting the study shall be presented to the task force prior to commencing with the evaluation. As guidance, Appendix X1 describes the specific procedure carried out prior to approval of SDA for use in aviation fuels.

(g) Results—The base, the treated fuel conductivity and the charging tendency of each fluid (base, control and test) shall be reported.

(h) Charging Propensity of Clay Filtered Fuels that Contained Static Dissipator Additive—Aviation fuels containing static dissipator additive, are at times processed by clay filtration. One of the effects of filtration is the removal of polar materials from the fuel. Static dissipator additives are generally formulated products containing multi components and chemistries, where some of the components can be polar materials. It is critical that when fuels containing static

dissipator additives are filtered through clay, that either all of additive components are completely removed by clay filtration or that if one or more of the component elute at different rates through the clay, that these individual components do not increase the charging tendency of the fuel. Increasing the charging tendency of the fluid without increasing fluid conductivity can result in an increased risk of static discharge ignition. The evaluation protocol is designed to evaluate the impact on charging by the candidate additive or its components, after a fuel containing the additive has been clay filtered.

(i) Preparation of Base Fuel, Control Fluids and Test Fluids—It is recommended that performance testing shall be conducted using at least two fluids, wherein one of the fluids shall be a purely paraffinic synthetic fuel as listed in Specification D7566 or Isopar M (trademarked), and the other fluid shall be non-hydro processed Jet A/Jet A1.

(j) Base Fuel—The base fuels shall be prepared in accordance to procedure described in A2.1.5.3.

(k) Control Fluid—The control fluid shall be prepared by treating each base fuel with aviation approved static dissipator additive to achieve a fluid conductivity in the range of 500 pS/m to 600 pS/m as measured by Test Methods D2624. The treat rate and the final conductivity shall be noted. The treated fluid shall be clay filtered to achieve fuel conductivity below 25 pS/m and above 5 pS/m in accordance with guidance provided in Test Method D3948.

(l) Test Fluid—The test fluid shall be prepared by treating each base fuel with candidate SDA to achieve a fluid conductivity in the range of 500 pS/m to 600 pS/m. The treat rate and the final conductivity shall be noted. The treated fluid shall be clay filtered to achieve a fuel conductivity below 25 pS/m and above 5 pS/m in accordance with guidance provided in Test Method D3948.

(m) Testing Procedure—The testing procedure will incorporate the testing equipment and method developed for evaluating charging propensity of fuels treated with SDA. The fluids (control and test) after being prepared as described shall be evaluated for charging propensity.

(n) Results—The base, the treated and the clay filtered fluids conductivity, and the charging tendency of each fluid (base, control and test) shall be reported.

A2.4.5.4 *Corrosion Inhibitor/Lubricity Improvers*—The evaluation protocol for CI/LI's performance for its intended function and other required attributes of CI/LI additives are adequately described in the Military Specification MIL-PRF-25017. The proponent of a candidate additive is directed to form an ASTM task force and collaborate directly with the U.S. Military to develop a testing protocol to evaluate the performance of the additive for its intended function. Note that the specification requires compositional analysis "3.2 Materials. The composition of the finished additive is not limited but is subject to review by the Qualifying Activity to ensure service compatibility with previously qualified products" to be conducted by the U.S. Military. This review, of additive chemistry, is only available for companies from the U.S., NATO, or ASIC treaty countries. Foreign national companies seeking CI/LI additive approval are directed to request specific chemical review through the TF. The applicable review can be conducted under confidentiality with selected industry stakeholders (OEMs). The evaluation protocol for the remaining sections (Compatibility and No-interaction) shall follow evaluation process described in the respective sections of Practice D4054.

A2.4.5.5 *Fuel System Icing Inhibitor*—Additives performing this function in the fuel industry are commonly evaluated by the U.S. military. The proponents of a candidate additive to perform this function were directed to form an ASTM task force and collaborate directly with the U.S. Military to develop a testing protocol to evaluate the performance of the additive for its intended function. The remaining sections (Compatibility and Non-Interaction) shall follow evaluation process described in the respective sections of Practice D4054.

A2.4.5.6 *Leak Detection Additive*—Additives performing this function are not extensively utilized in commercial aviation industry; however, the U.S. Military has used these additives in their fuel handling operations. Due to lack of Industry demand for this type of additive, no specific protocol has been drafted to evaluate function for its intended purpose. However U.S. Military Specification MIL-PRF-81298 may provide guidance in developing a protocol for evaluation of the additive. The proponents of a candidate additive are directed to form a task force to develop a testing protocol to evaluate the performance of the additive for its intended function. The remaining sections (Compatibility and Non-Interaction) shall follow evaluation process described in the respective sections of Practice D4054.

A2.4.5.7 *Thermal Stability Additive*—Thermal stability additive is not utilized in commercial fuel application. The following section is included to give general guidance to address the possibility that in the future commercial operations will require such additives. The protocol used in the past for evaluation of thermal stability additives is described in the U.S. Air Force Research Laboratory (AFRL) for evaluation of high heat sink fuel additives. The candidate additives maybe subject to a two-phase approval process. Phase I being composed of laboratory testing to include; ICOT (Isothermal Corrosion Oxidation Test), QCM (Quartz Crystal Microbalance), EDTST (Extended Duration Thermal Stability Test) and ARSFSS (Advanced Reduced Scale Fuels System Simulator) tests. Also possibly required during Phase I are various filtration testing (AFRL ICE test, NAVAIR, and SwRI), additive compatibility studies (interactions among between selected additives) and a dosage study (over-dosing effects). The specifics of each test listed in the evaluation protocol are available through AFRL. Phase II of the approval to follow required testing listed in Practice D4054 not already covered in the military protocol.

A2.4.5.8 *Biocide*—Additives performing this function require non common fuel testing methodologies, thus no specific protocol has been drafted to evaluate biocides function for its intended purpose. The proponent of a candidate additive is directed to form a task force to develop a testing protocol to evaluate the performance of the additive for its intended function. The remaining sections (Compatibility and No-interaction) shall follow evaluation process described in the respective sections of Practice D4054.

A2.4.6 *Candidate Additive of the New Additive Class currently NOT included in Specification D1655:*

A2.4.6.1 As described in A2.1.4.2, a new candidate additive is a material that is based on a different chemistry, or imparts a different function in the fuel than the existing approved additives listed in Specification D1655.

A2.4.6.2 The sponsor of a candidate additive is directed to form a task force, and in collaboration with the task force to draft a proposed testing protocol for evaluation of the candidate additive performance for its intended function. The testing protocol for Compatibility and No-interaction shall be followed in a similar manner as described for additives in an existing class.

A2.4.6.3 The proposed protocol to evaluate performance for its intended function may include custom tests and ASTM test methods to evaluate additive performance. The task force, the OEMs or committee (sub J) given technical justification may modify, change or add other tests to the performance evaluation protocol.

A3. EVALUATING COMPATIBILITY OF ADDITIVES OR FUELS WITH FUEL SYSTEM MATERIALS

A3.1 Scope

A3.1.1 The following procedure is required to determine compatibility of a new fuel or new fuel additive with fuel-wetted nonmetallic materials and metals present in gas turbine engine and aircraft fuel systems.

A3.2 Test Program

A3.2.1 *Entrance Criteria*—A complete chemical description of the candidate fuel or additive is required for defining the test program. If the new material is an additive, its carrier solvent and recommended concentration must also be provided. The chemical nature of the fuel or additive is important for determining the necessity and types of material tests to be performed.

A3.2.2 *Blend Concentration if Evaluating a New Fuel Additive*—Fuel additive concentration for the material compatibility tests shall be tested at 4× the concentration being sought for qualification. The additive shall be blended at 4× into at least one of the two baseline reference fluids described in A3.2.3. Back-to-back tests shall be performed on the additive blend and a control sample consisting of the baseline reference fuel without the additive. The purpose of the control sample is to provide a baseline for comparison.

A3.2.3 *Baseline Test Fluids:*

A3.2.3.1 Two baseline test fluids are approved for use for 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 to 25 % may be used. Alternatively, a Jet Reference Fuel (JRF) as formulated in Table A3.1 may be used. JRF is a blend developed by the Air Force Research Laboratory (AFRL) to be representative of, or a surrogate for, kerosine-type fuels. JRF is formulated by blending the following technical grade constituents in the volumes shown in Table A3.1.

A3.2.3.2 The JRF blend shown in Table A3.1 is designated JRF-3 by AFRL to designate that it is the third iteration of their formulation. The formulation was established by AFRL assuming zero aromatics and zero sulfur in Exxsol D-40 and Exxsol D-80. Also assumed was zero sulfur in the Aromatic 100, 150, and 200 constituents. As indicated in the aromatics and total sulfur analyses, some adjustment of the formulation may be required to correct for these assumptions.

A3.2.4 *Test Materials:*

A3.2.4.1 Table A3.4 is a complete list of fuel-wetted nonmetallic materials and metals used in P&W, GEAE, RR, and Honeywell gas-turbine engine fuel systems. The list also includes materials found in aircraft fuel tanks and ground-supply vehicles. The list is comprised of 255 materials.

A3.2.4.2 Tables A3.2 and A3.3, collectively, are referred to as the "short list" by the engine and aircraft OEMs and the U.S. Military. Table A3.2 is a list of representative nonmetallic materials used in gas turbine engine and airframe fuel systems.

TABLE A3.1 Jet Reference Fuel

Formulation			Property Analyses		
	Component	Volume %	Property	Test Results	Jet A-1 Specification
Paraffins	Exxsol D40	37.1	Aromatics	25.8 vol %	25 vol % max
	Exxsol D80	37.1	Olefins	0.9 vol %	No Requirement.
Aromatics	Aromatic 100	7.5	Flash Point	55 °C	38 °C min
	Aromatic 150	15	Freezing Point	–55 °C	–47 °C max
	Aromatic 200	2.5	Naphthalenes	2.3 volume %	3.0 volume %
Sulfur	tert-Butyl Disulfide	0.73	API gravity	42.2	37 min to 51 max
Mercaptan	Decanethiol	0.01	Total Sulfur	0.31 mass %	0.30 mass % max
Fuel System Icing Inhibitor	DiEGME	0.15	Mercaptan	0.002 mass %	0.003 mass % max
Lubricity Improver/ Corrosion Inhibitor	Air Force QPL-25017	0.0017			

TABLE A3.2 Nonmetallic Materials, Tests, and Test Temperatures

NOTE 1—All sealant peel strength test panels shall be aluminum AMS 4045 panels, sulfuric acid anodized per AMS 2471, and coated with AMS-C-27725 II, Class B corrosion preventive coating. For the duration of the aging process of specimens, a fuel change-out shall occur after each 14-day period.

Material	Description	Specification	Soak Temperature/ Duration	Test	Test Procedure	Evaluation Criteria	
						Test Requirements	Allowable Variation from Baseline
Adhesive	Vinyl Phenolic	MMM-A-132 Type 1, Class 3	93 °C/28 days	Lap Shear	ASTM D1002	>1500 psi	250 psi decrease
Adhesive	Epoxy Resin	~	93 °C/28 days	Lap Shear	ASTM D1002	>1500 psi	250 psi decrease
Adhesive	Nitrile Phenolic	MMM-A-132 Type 1, Class 2	93 °C/28 days	Lap Shear	ASTM D1002	>1500 psi	250 psi decrease
Adhesive	Epoxy Paste	MMM-A-132 Type 1, Class 3	93 °C/28 days	Lap Shear	ASTM D1002	>1500 psi	250 psi decrease
Adhesive	Nitrile Epoxy Film	MMM-A-132 Type 1, Class 2	93 °C/28 days	Lap Shear	ASTM D1002	>1500 psi	250 psi decrease
Adhesive	Methacrylate	ASTM D5363 Group 4, Class 1, Grade 1	93 °C/28 days	Static Shear	ASTM D5363	>1200 psi	250 psi decrease
Bladder (Inner Liner)	Nitrile	~	71 °C/28 days	Tensile Strength Elongation Volume Swell	ASTM D412 ASTM D412 ASTM D471	>1500 psi >300 % < 25 %	200 psi decrease 40 % decrease ±5 %
Bladder (Inner Liner)	Polyurethane	~	93 °C/28 days	Tensile Strength Elongation Volume Swell	ASTM D412 ASTM D412 ASTM D471	>1500 psi >300 % < 25 %	200 psi decrease 40 % decrease ±5 %
Bladder (Self Sealing)	Nitrile	MIL-DTL-5578	RT/30 min	Volume Swell	ASTM D471	~	±5 %
Coating	Nitrile	SAE-AMS-S-4383	93 °C / 28 days	Hardness (Pencil) Tape Adhesion	ASTM D3363;D3359, Test Method A	≥ unaged Pass.	1 pt decrease
Coating	Polyurethane	SAE-AMS-C-27725 Type II	93 °C/28 days	Hardness (Pencil) Tape Adhesion	ASTM D3363;D3359, Test Method A	≥ unaged Pass	1 pt decrease
Coating	Epoxy	BMS 10-39	93 °C/28 days	Hardness (Pencil) Tape Adhesion	ASTM D3363;D3359, Test Method A	≥ unaged Pass	1 pt decrease
Bulk Tank Coating	Epoxy-Polyamide	MIL-DTL-24441	49 °C/28 days	Hardness (Pencil)	ASTM D3363	>unaged	1 pt decrease
Sealant	Polysulfide Dichromate Cured	SAE-AMS-S-8802 Type I, Class B-2	93 °C/28 days	Peel Strength Hardness, Shore A Tensile Strength Elongation Volume Swell	SAE AS5127/1 ASTM D2240 ASTM D412 ASTM D412 ASTM D471	>20 lb/in./100 % cohes. >35 pts >200 psi >150 % 0 % – 20 %	8 lb/in. decrease ±5 pts 35 psi decrease 25 % decrease 5 % increase
Sealant	Polysulfide Manganese Cured	SAE-AMS-S-8802 Type II, Class B-2	93 °C/28 days	Peel Strength Hardness, Shore A Tensile Strength Elongation Volume Swell	SAE AS5127/1 ASTM D2240 ASTM D412 ASTM D412 ASTM D471	>20 lb/in./100% cohes. >35 pts >200 psi >150 % 0 % – 20 %	8 lb/in. decrease ±5 pts 35 psi decrease 25 % decrease 5 % increase
Sealant	Fluorosilicone	SAE-AMS-3375	93 °C/28 days	Peel Strength Hardness, Shore A Tensile Strength Elongation Volume Swell	SAE AS5127/1 ASTM D2240 ASTM D412 ASTM D412 ASTM D471	>10 lb/in./100 % cohes. >35 pts >200 psi >150 % 0 % – 20 %	8 lb/in. decrease ±5 pts 35 psi decrease 25 % decrease 5 % increase
Sealant	Polyurethane	SAE-AMS-3279	93 °C/28 days	Peel Strength Hardness, Shore A Tensile Strength Elongation Volume Swell	SAE AS5127/1 ASTM D2240 ASTM D412 ASTM D412 ASTM D471	>20 lb/in./100 % cohes. >35 pts >200 psi >150 % 0 % – 30 %	8 lb/in. decrease ±5 pts 35 psi decrease 25 % decrease 5 % increase
Sealant	Polythioether	SAE-AMS-3277 Class B-2	93 °C/28 days	Peel Strength Hardness, Shore A Tensile Strength Elongation Volume Swell	SAE AS5127/1 ASTM D2240 ASTM D412 ASTM D412 ASTM D471	>20 lb/in./100 % cohes. >35 pts >200 psi >150 % 0 % – 25 %	8 lb/in. decrease ±5 pts 35 psi decrease 25 % decrease 5 % increase
Sealant	Polysulfide Lightweight	SAE-AMS-3281	93 °C/28 days	Peel Strength Hardness, Shore A Tensile Strength Elongation Volume Swell	SAE AS5127/1 ASTM D2240 ASTM D412 ASTM D412 ASTM D471	>20 lb/in./100 % cohes. >35 pts >200 psi >150 % 0 % – 20 %	8 lb/in. decrease ±5 pts 35 psi decrease 25 % decrease 5 % increase
Sealant (Groove Injection)	Polysulfide	SAE-AMS-3283	71 °C/28 days	Volume Swell	ASTM D471	1 % to 12 %	±5 %
Sealant (Groove Injection)	Fluorosilicone	MIL-S-85334	71 °C/28 days	Volume Swell	ASTM D471	1 % to 12 %	±5 %
Composite, Epoxy Graphite	AS4/3501-6	~	93 °C/28 days	Laminar Shear	ASTM D790	>5000 psi	500 psi decrease
Composite, Epoxy Graphite	IM7/977-3	~	93 °C/28 days	Laminar Shear	ASTM D790	>5000 psi	500 psi decrease
Composite, Epoxy Graphite	IM7/8552	~	93 °C/28 days	Laminar Shear	ASTM D790	>5000 psi	500 psi decrease

TABLE A3.2 *Continued*

Material	Description	Specification	Soak Temperature/ Duration	Test	Test Procedure	Evaluation Criteria	
						Test Requirements	Allowable Variation from Baseline
Composite, Graphite Bismaliemide	IM7/5250-4	~	93 °C/28 days	Laminar Shear	ASTM D790	>5000 psi	500 psi decrease
Foam	Polyurethane	MIL-PRF-87260	93 °C/28 days	Tensile Strength	ASTM D412	>10 psi	5 psi decrease
				Elongation	ASTM D412	>100 %	15 % decrease
				Resistivity	ASTM D257	< 1.0E12 Ohm-cm	
Gasket, O-Ring	Nitrile	SAE-AMS-P-5315	71 °C/28 days	Hardness,	ASTM D2240	±5 pts from unaged	±5 pts
				Shore M	ASTM D1414	>1000 psi	125 psi decrease
				Tensile Strength	ASTM D1414	>200 %	35 % decrease
				Elongation	ASTM D395	< 50 %	5 % increase
				Compression Set	ASTM D471	0 % to 25 %	±10 %
				Volume Swell			
Gasket, O-Ring	Fluorosilicone	SAE-AMS-R-25988, Type I, Class 1, Grade 70	107 °C/28 days	Hardness,	ASTM D2240	–20 pts from unaged	±5 pts
				Shore M	ASTM D1414	>500 psi	125 psi decrease
				Tensile Strength	ASTM D1414	>125 %	35 % decrease
				Elongation	ASTM D395	< 65 %	5 % increase
				Compression Set	ASTM D471	0 % to 25 %	±10 %
				Volume Swell			
Gasket, O-Ring	Fluorocarbon	SAE-AMS-7276	153 °C/28 days	Hardness,	ASTM D2240	± 5 pts from unaged	± 5 pts
				Shore M	ASTM D1414	>1000 psi	125 psi decrease
				Tensile Strength	ASTM D1414	>150%	35% decrease
				Elongation	ASTM D395	< 60%	5% increase
				Compression Set	ASTM D471	0% to 10%	± 10%
				Volume Swell			
Gasket	Low Temperature Fluorocarbon	SAE-AMS-R-83485 Type I	163 °C/28 days	Hardness,	ASTM D2240	±5 pts from unaged	±5 pts
				Shore M	ASTM D1414	>1000 psi	125 psi decrease
				Tensile Strength	ASTM D1414	>150 %	35 % decrease
				Elongation	ASTM D395	<60 %	5 % increase
				Compression Set	ASTM D471	0 % to 10 %	±10 %
				Volume Swell			
Hose (Ground Refueling)	Epichloro-hydrin	MIL-DTL-26521	71 °C/28 days	Tensile Strength	ASTM D412	>1500 psi	125 psi decrease
				Elongation	ASTM D412	>300 %	25 % decrease
				Hardness, Shore A	ASTM D2240	±5 pts from unaged	±5 pts
				Volume Swell	ASTM D471	<8 %	±5 %
Teflon (Film)[A]	Teflon[A]	~	71 °C/28 days	Tensile Strength	ASTM D412	>500 psi	150 psi decrease
				Elongation	ASTM D412	>25 %	15 % decrease
Nylon (Film)	Nylon	~	71 °C/28 days	Tensile Strength	ASTM D412	>500 psi	850 psi decrease
				Elongation	ASTM D412	>25 %	5 % decrease
Polyethylene (Film)	Polyethylene	~	71 °C/28 days	Tensile Strength	ASTM D412	>500 psi	250 psi decrease
				Elongation	ASTM D412	>25 %	50 % decrease
Kapton (Film)	Kapton	~	93 °C/28 days	Tensile Strength	ASTM D412	>500 psi	1800 psi decrease
				Elongation	ASTM D412	>25 %	5 % decrease
Potting Compound	Polysulfide	MIL-PRF-8516, Cure B	71 °C/28 days	Hardness, Shore A	ASTM D2240	>20 pts	±5 pts
				Tensile Strength	ASTM D412	>100 psi	35 psi decrease
				Elongation	ASTM D412	>150 %	25 % decrease
				Peel Strength	SAE AS5127/1	>10 lb/in./100 % cohes.	8 lb/in. decrease
				Volume Swell	ASTM D471	>–20 %	±10 %

[A] Registered trademark of E. I. du Pont de Nemours and Company.

Table A3.3 is a list of representative metals used in gas turbine engine and airframe fuel systems. Tables A3.2 and A3.3 are comprised of materials that have been selected as representative, or worst case, for each class of material listed in Table A3.4. For example, many different polysulfide sealants are used in fuel tanks. Rather than test them all, a representative manganese dioxide cured product and a representative chromate cured product were selected for the short list. The engine manufacturers, airplane manufacturers, and the U.S. Military have agreed to these generic classes of materials for the purpose of evaluating compatibility with fuels and fuel additives. Testing material classes significantly reduces the burden from that of testing all 255 materials listed in Table A3.4 that are present in engine and airplane fuel systems. The list of materials to be tested in Tables A3.2 and A3.3 include 37 non-metallics and 31 metals, respectively. Materials known to be sensitive to a specific fuel or additive chemistry should be tested first.

A3.2.5 *Test Temperatures:*

A3.2.5.1 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 reduces test sensitivity. The appropriate test temperature for each material is shown in Tables A3.2 and A3.3 along with the standard test procedure and pass/fail criteria.

A3.2.6 *Screening Tests:*

TABLE A3.3 Metals, Material Specifications, 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	93 °C
7075-T6 Sulfuric Acid Anodize Type IIB	SAE-AMS-QQ-A-250/12	MIL-A-8625, Type II B	93 °C
7075-T6 Chromate Conversion Coated Class IA	SAE-AMS-QQ-A-250/12	MIL-DTL-5541, Class 1A	93 °C
7050-T74	SAE-AMS-4107	N/A	93 °C
2024-T3 Bare	SAE-AMS-4037	N/A	93 °C
6061-T6 Bare	SAE-AMS-4027	N/A	93 °C
5052-H34 Bare	SAE-AMS-4017	N/A	93 °C
356 T6 Cast Aluminum	SAE-AMS-4260	N/A	93 °C
AZ91 T6	ASTM B93/B93M	N/A	93 °C
CU/NI 90/10		N/A	93 °C
Sn 60 Pb 40 Solder		N/A	93 °C
304 SS	ASTM A240/A240M	N/A	163 °C
17-4 pH	SAE-AMS-5604	N/A	163 °C
440 SS	ASTM A240/A240M	N/A	163 °C
TI 8A1 -IV -1MO	SAE-AMS-4915 SAE-AMS-4901	N/A	163 °C
TI CP 70	SAE-AMS-4915 SAE-AMS-4901	N/A	163 °C
TI 3AL - 2.5V	SAE-AMS-4915 SAE-AMS-4901	N/A	163 °C
4130 IVD Coating	SAE-AMS-6345	SAE-AMS-2427	163 °C
Alloy Steel Fastener MS24694 HL21PN20-16	SAE-AMS-6415	SAE-AMS-QQ-P-416, Type II, Class 2	163 °C
A286 Fastener MS24694 HL49GU20-16	SAE-AMS-5737	Sliver Plate SAE-AMS-2410	163 °C
CPM 10V		N/A	163 °C
INCO 625		N/A	163 °C
INC0 718		N/A	163 °C
Nitralloy 135	SAE-AMS-5330 SAE-AMS-5338	N/A	163 °C
IN 200 Ni		N/A	163 °C
Monel 400		N/A	163 °C
Waspaloy		N/A	163 °C
Lead	SAE-AMS-4751	N/A	163 °C
268 Brass Sheet	ASTM B36/B36M	N/A	163 °C
TAP MS 285		N/A	163 °C
Mag Wire Type I		N/A	163 °C

A3.2.6.1 If the OEMs determine that material compatibility testing is required, laboratory-scale soak tests shall be performed on the short list of materials compiled in Tables A3.2 and A3.3. Soak temperatures, test methods, and acceptance criteria are called out in the respective tables. The soak period is 28 days. The test fluid shall be changed out every 14 days with fresh test fluid.

A3.2.6.2 The tests called out in Tables A3.2 and A3.3 compare changes in properties, for example, tensile strength, of materials soaked in the new fuel (or new fuel additive blend) to that of materials soaked in a baseline reference fuel(s). The tests are intended to be a first level screening to identify potential compatibility problems. If tests results are within allowable variation as defined in the evaluation criteria for each material, then the risk level of the new fuel or fuel additive is considered minimal.

A3.2.7 *Procedure for Soaking (Aging) Test Materials in Fuel:*

A3.2.7.1 *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-preg, 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 (75 °F and 50 % 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 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 dog-bone shaped cookie cutter is used to obtain dog-bone specimens for tensile and elongation testing.

(4) O-rings are also obtained directly from the vendors which 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. These specimens are roughly one inch by two inches. Thickness is not relevant as we are only looking at surface effects.

A3.2.7.2 *Fuel Soak:*

TABLE A3.4 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
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
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
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	Epoxy Graphite
I.E.2	Composite	Composite, IM 7/5250-4	Graphite Bismaliemide
I.E.3	Composite	Composite, AS7/8551-7A	Epoxy Graphite
I.E.4	Composite	Composite, IM7/977-3	Epoxy Graphite
I.E.5	Composite	Composite, IM7/8552	Epoxy Graphite
I.E.6	Vent Lines	Composite	Fiberglass
I.E.7	Isolator Tube	Composite	Epoxy Resin

TABLE A3.4 *Continued*

I.D. No.	Aircraft Use	Material Designation	Material Type
I.F.1	Fuel Filter	AC-B683F-2435	F-100 Eng.
I.F.1.1	11/18/97	AC-B253F-2435Y1, 1/4	F-110 Eng.
I.F.1.2	11/18/97		
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)
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.l)	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
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.3 (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
II.G.14	Plumbing Gasket	O-Ring, Stillman P/N TH-1384 MIL-DTL-25988	Fluorosilicone (Teflon[A])
II.G.15	Plumbing Gasket	O-Ring, Parker P/N L 1186-80 MIL-DTL-25988	Fluorosilicone (Teflon[A])

TABLE A3.4 *Continued*

I.D. No.	Aircraft Use	Material Designation	Material Type
I.H.I	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-DTL-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[A]	TFE (Teflon[A]) (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.	SAE AMS-I-7444 “Insulation Sleeving, Electrical, Flexible”	Vinyl Plastic
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, 14	Nylon Cloth
I.I.11	Engine Fuel Control Stepper Motor	Magnetic Wire Insulation, Type I	HML Varnish
I.I.12	Wire Insulation	Teflon[A] /Kapton	Hybrid Teflon[A] /Kapton (Wire)
I.I.13	Wire Bundle Wrap	Shrink Wrap	
I.I.14	Wire Insulation	Teflon Insulation[A] , 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	Waspaloy (Ni), Brazed	AMS 4786 Au
I.J.10	Joining Material	321 SS, Brazed	B Ag (5 or 6)
I.J.11	Joining Material	J-STD-004 “Requirements for Soldering Fluxes” J-STD-005 “Requirements for Soldering Pastes” J-STD-006 “Requirements for Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders for Electronic Soldering Applications”	Tin & Lead (Solder Spots)
I.J.12	Joining Material	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”	4145 or 4147 fill
I.J.13	Joining Material	Ti, Cu, Ni Braze P & W	Ti, Cu, Ni
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	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”	(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

TABLE A3.4 *Continued*

I.D. No.	Aircraft Use	Material Designation	Material Type
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
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, ASTM D5363	Cyanoacrylate
I.L.2	Locking Devices	Threadlock ASTM D5363	Cyanoacrylate
I.L.3	Locking Devices	Threadlock, ASTM D5363	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
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
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

TABLE A3.4 *Continued*

I.D. No.	Aircraft Use	Material Designation	Material Type
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
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	Waspaloy	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
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 Ste el
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	SAE AMS 6470 “Steel, Nitriding, Bars, Forgings; Tubing 1.6Cr-0.35Mo-1.1Al (0.38-0.43C) - UNSK24065” SAE AMS 6472 “Steel Bars and Forgings, Nitriding 1.6Cr-0.35Mo-1.1 Al (0.38-0.43C) Hardened and Tempered, 112 ksi (772 MPa) Tensile Strength - UNS K24065”	Nitralloy

TABLE A3.4 *Continued*

I.D. No.	Aircraft Use	Material Designation	Material Type
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
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	SAE-AMS-7902 AlBeMet 162 Reactive Material Sheet & Plate, Beryllium Alloy	.2) investment cast high strength alloy with machined surfaces (157)
II.M.30.3	Eng. Fuel lines & Components	SAE-AMS-7902 AlBeMet 162 Reactive Material Sheet & Plate, Beryllium Alloy	.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
1.O.1	Float	HR Textron Inc.	Unicellular Buna-N
1.O.2	Float	HR Textron Inc., Foam Molders Inc.	Polyurethane Unicellular
1.O.3	Float	HR Textron Inc.	Polyurethane
1.O.4	Float	XAR Industries Inc.	
1.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, Electrical Connector Application
I.P.3	Potting Compound	SAE-AMS-3361, Fluorosilicone	Fluorosilicone
I.P.4	Potting Compound	Urethane	Urethane

[A] Registered trademark of E. I. du Pont de Nemours and Company.

(1) Materials are typically exposed to the fuel in separate glass mason jars (quart-size). 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 example, the tensile and elongation 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 elongation and volume swell specimens.

(2) Tensile and elongation; volume swell; and hardness specimens must be 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 must be 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, must be 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.

A3.2.8 *Root Cause Evaluation:*

A3.2.8.1 Additional testing is required if in the screening tests a material property falls outside of the allowable variation as a result of exposure to the new fuel or new fuel additive. This second- level testing is referred to as root cause evaluation. The root cause evaluation is meant to further investigate material families that yielded dubious results in the screening tests. Root cause evaluation involves testing all the materials in the family of materials that failed. For example, if one polysulfide sealant failed, then all polysulfide sealants shown in Table A3.4 shall be tested. The results of these tests are be used to evaluate the extent of incompatibility and the root cause of the failure, for example, the chemical constituent causing the failure. Some common failure modes are lack of swell; hardening; loss of flexibility; reversion due to polymer chain scission; acid attack; mercaptan sulfur attack; and corrosion.

A3.2.8.2 Root cause evaluation may also include functional testing that would address the specific failure mode. For example, if lack of swell was the cause of failure in an o-ring material, functional tests may be required to determine if the lack of swell is likely to cause fuel leaks. Functional tests can be designed to evaluate the impact on fuel couplings, static seals, pump seals, and fuel control valves. Root cause evaluation may also include component or system-level tests. Examples of component or system-level testing include dynamic cycling tests; large-scale integral fuel tank testing; thermal cycling; and lifetime stress/strain tests.

A3.2.8.3 The same concentration of additive used in the screening tests shall be used in the root cause evaluation. The same batch of fuel used in the screening tests shall be used in the root cause investigation.

A3.2.9 *Types of Tests to be Performed after 28 Day Soak Period:*

A3.2.9.1 *Non-Metallic Materials*—Examples of the tests to be performed on the non-metallic materials listed in Table A3.2 include the following:

(1) Lap Shear
(2) Cohesion
(3) Volume Swell
(4) Tensile
(5) Elongation
(6) Tape Adhesion
(7) Hardness
(8) Peel Strength
(9) Laminar Shear
(10) Compression Set
(11) Resistivity

A3.2.9.2 *Metals*—Tests to be performed on the metals listed in Table A3.3 are described in A3.2.9.3 and A3.2.9.4.

A3.2.9.3 *Surface Evaluation*—At the conclusion of the 28 day soak, the metal test specimens shall be removed from the test fluid, air dried, and examined visually and under low power (<50×) optical magnification. The objective is to inspect for evidence of staining, deposits, surface pits, or gross corrosion. Staining is considered a benign surface phenomenon. Staining results in no appreciable weight loss or gain and indicates the formation of a passive layer that inhibits corrosion. Subsequent to the initial examination, the metal surfaces shall be cleaned using acetone or alcohol and reexamined for surface pits. If desired, deposits can be preserved by evaporating the solvents and then storing in a desiccator for future analysis.

A3.2.9.4 *Microstructural Evaluation*—Following surface evaluation, metal test specimens shall be cross-sectioned, mounted, and polished to reveal a profile of the surface and interior. Polishing shall be conducted in accordance with procedures established by the evaluating laboratory. The procedures shall be consistent with those specified by the polishing apparatus manufacturer, and appropriate for use on the metallic alloys being evaluated as described by metallographic procedures outline in the ASM Metals Handbook. Mounted and polished specimens shall be examined at optical magnification levels between 100× and 1000× for evidence of microstructural changes, corrosion, or other effects of exposure on the surface or bulk material. A good edge retention mounting compound should be used for cross-section metallographic examination. If there is an evidence of corrosion, then further characterization should be sought using scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDAX) to analyze the corrosion products.

A3.2.10 *Evaluation Criteria*—The evaluation criterion for non-metallic materials is shown in Table A3.2. The approach is to look for significant variations in test values between the baseline fuel and the candidate fuel or additive/baseline fuel blend. The allowable variations from the baseline fuel for nonmetallic materials are based on the precision and bias of the test method. Most of the materials have test requirements expressed as maximum or minimum values. These values are drawn from the material specification when applicable. If there is no material specification or the specification does not have a fuel-soak requirement, then pass/fail criteria is gleaned from experience gained in previous investigations performed on similar materials.

APPENDIX

(Nonmandatory Information)

X1. FULL-SCALE TESTING

INTRODUCTION

Full-scale testing was performed to demonstrate the effect of SDA additive on electrostatic hazards during distillate fuel transfer. Other work in full-scale truck loading equipment has shown that results obtained using top-fill at 700 gal/min were indicative of the consequences using other fill rates and configurations. As an additional check on performance, identical trials were carried out using an existing aviation approved additive, which was known to have given satisfactory results in field use.

X1.1 Equipment and Detailed Procedures

X1.1.1 The schematic of full-scale equipment is shown in Fig. X1.1. The fuel reservoir was charged with 4600 gal of No. 2 fuel oil. Batch size for all runs was 2000 gal. Surface voltage was obtained by a field meter installed in the top of the tank 59 in. above the bottom. This meter was calibrated using a grid in the tank, which was charged with up to 60 000 V dc at various distances from the meter. Response was linear over most of the 0 V to 60 000 V range and linearity was assumed thereafter.

X1.1.2 An A. O. Smith charge density meter was located on the transfer line close to the receiving tank, as shown in Fig. X1.1, and recorded in-line charge density. Another charge density meter was installed in the bottom of the tank. Incoming fuel was directed toward the meter. The charge density recorded at this meter was not, therefore, the average charge density of the fuel in the receiver. Conductivity of the fuel was measured externally by the Test Method D3114 method. Fuel temperature was measured in the receiver after each run, and averaged about 80 °F. The surface voltage recorder was equipped with a device which indicated the amount of fuel in the receiver at various points during the run, allowing calculation of surface voltage and charge density at specific fill points. The fuel was pumped from the reservoir with one or two centrifugal pumps. At 700 gal⁄min, both pumps were required. For all runs, the initial rate was 100 gal⁄min for the

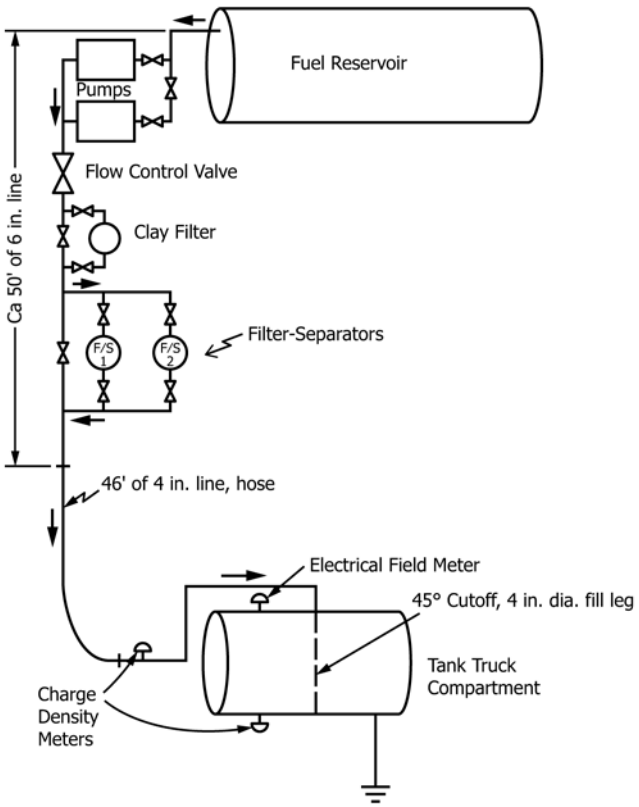


FIG. X1.1 Schematic of Full-Scale Equipment

first 75 gal, 700 gal/min up to about 1950 gal, followed by top off with 75 gal at 100 gal/min. The fuel could be run through a clay filtration unit having a capacity of 300 gal/min. Clay filtration was not used during runs. Clay filtration was used to reduce the conductivity of the fuel to a low level before the trials, and was used to remove SDA. Two filter-separator units were employed; each had a rated capacity of 600 gal/min. Both filter-separator (F/S) units were used at 700 gal/min. These specific units generated high charge densities in fuels. Runs were also made by passing the filter-separators. Six-inch pipe was employed for part of the lines which were then constricted to 4 in. pipe and a length of 4 in. hose which could be switched from top to bottom fill. For top fill, about 21 ft of 4 in. pipe extended from the hose connection to the bottom of the fill pipe. The top fill configuration used a 45° cut-off 4 in. fill pipe resting on the compartment bottom with the outlet directed toward the in-receiver charge density meter and the field meter locations. The top of the fill pipe inlet was about two feet from the field meter. The receiver wall was fitted with a window of poly(methyl methacrylate) (PMMA) acrylic resin for visual observation. The additive to be tested was added to the reservoir as required, and the treated fuel was circulated to obtain good mixing. A nitrogen atmosphere was maintained in the fuel reservoir and receiver during the runs. Surface voltages were calculated for the points at which 12, 24, 36, and 48 in. of fuel had been pumped into the receiver. These levels corresponded to 260 gal, 765 gal, 1365 gal, and 1945 gal of fuel, respectively. Charge densities were similarly calculated at these same fuel levels. After obtaining results for clay filtered fuel having low conductivity, increments of SDA were added, and after addition of each increment, runs were made with and without filter-separators. After completion of trials with SDA, the additive was removed by clay filtration, returning the fuel to its original condition. Runs were then made in the same way using a previously approved SDA.

SUMMARY OF CHANGES

Subcommittee D02.J0 has identified the location of selected changes to this standard since the last issue (D4054 – 14) that may impact the use of this standard. (Approved April 1, 2016.)

(1) Revised Fig. 2, Fig. A1.1, Fig. A1.3, and Fig. A1.5; added new Fig. A1.10 and Fig. A1.11.
(2) Revised Table 2 and Table A3.2; added new Table 1.
(3) Revised Section 2, 7, and 8; revised subsections 4.1.2, 5.3, 5.5.3, 5.6, 6.1, and A3.2.7.2(*1*).
(4) Added new subsection 3.3 and 8.1 (and subsequent subsections).