Designation: D4054 – 09

AnAmerican 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 at Atmospheric Pressure
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
D1002 Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)

[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 D02.03 on Elemental Analysis.

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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.

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 Surface-Active Agents
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
D3241 Test Method for Thermal Oxidation Stability of Aviation Turbine 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)
D4629 Test Method for Trace Nitrogen in Liquid Petroleum Hydrocarbons by Syringe/Inlet Oxidative Combustion and Chemiluminescence Detection
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
D7111 Test Method for Determination of Trace Elements in Middle Distillate Fuels by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
E411 Test Method for Trace Quantities of Carbonyl Compounds with 2,4-Dinitrophenylhydrazine
E659 Test Method for Autoignition Temperature of Liquid 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:*[3]

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

2.3 *Department of Defense Specifications:*[3]

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
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
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-H-17902 Hose, End Fittings and Hose Assemblies, Synthetic Rubber, Aircraft Fuels
MIL-HDBK-510-1 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

[3] Copies of these documents are available from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 1911-5094 or online at http://assist.daps.dla.mil/quicksearch/

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-81733 Sealing and Coating Compound, Corrosion Inhibitive
MIL-PRF-87260 Foam Material, Explosion Suppression, Inherently Electrostatically Conductive, for Aircraft Fuel Tanks
MIL-R-46082 Retaining Compounds, Single Component, Anaerobic
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)

2.4 *SAE International:*[4]

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 400 °F (204 °C)
SAE-AMS-3278 Sealing and Coating Compound: Polyurethane (PUR) Fuel Resistant High Tensile Strength/Elongation for Integral Fuel Tanks/Fuel Cavities/General Purpos
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
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)

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

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):*[5]

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:*[6]

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):*[7]

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):*[8]

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):*[9]

Defence Standard 91-91 Turbine Fuel, Aviation Kerosine Type, Jet A-1, NATO Code: F-35 Joint Service Designation: AVTUR

2.10 *Environmental Protection Agency (EPA):*[10]

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)

2.11 *American Petroleum Institute (API)*[11]

API 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.

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.

[5] Available from American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126; http://www.aws.org/

[6] Available from IPC, 3000 Lakeside Drive, Suite 309S, Bannockburn, Illinois 60015; http://www.ipc.org

[7] Available from Boeing.

[8] Available from ISO, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland; http://www.iso.org/

[9] Available from Defence Equipment and Support, UK Defence Standardization, Kentigern House, 65 Brown Street, Glasgow, G2 8EX; http://www.dstan.mod.uk

[10] Available from US EPA, Office of Resource Conservation and Recovery (5305P), 1200 Pennsylvania Avenue, NW, Washington, DC 20460; http://www.epa.gov/

[11] Available from API, 1220 L Street, NW, Washington, DC 20005; http://www.api.org/

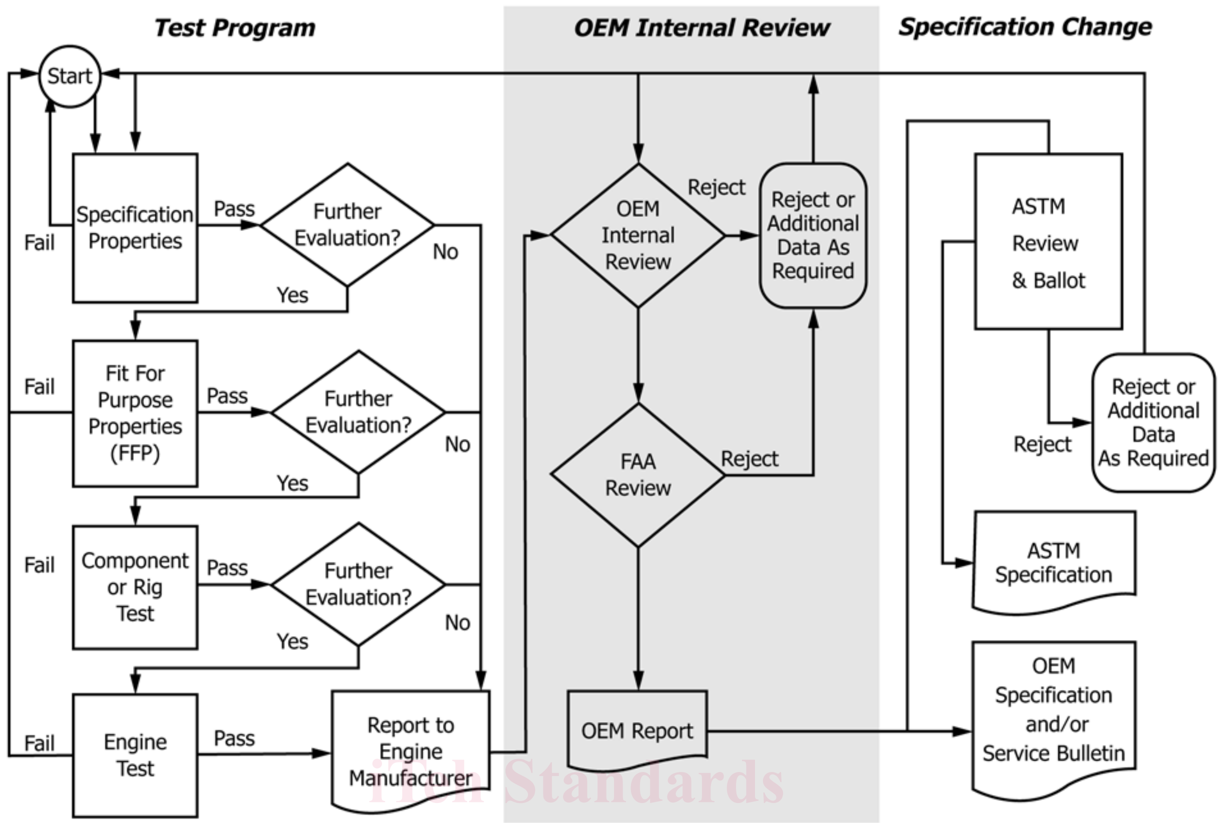
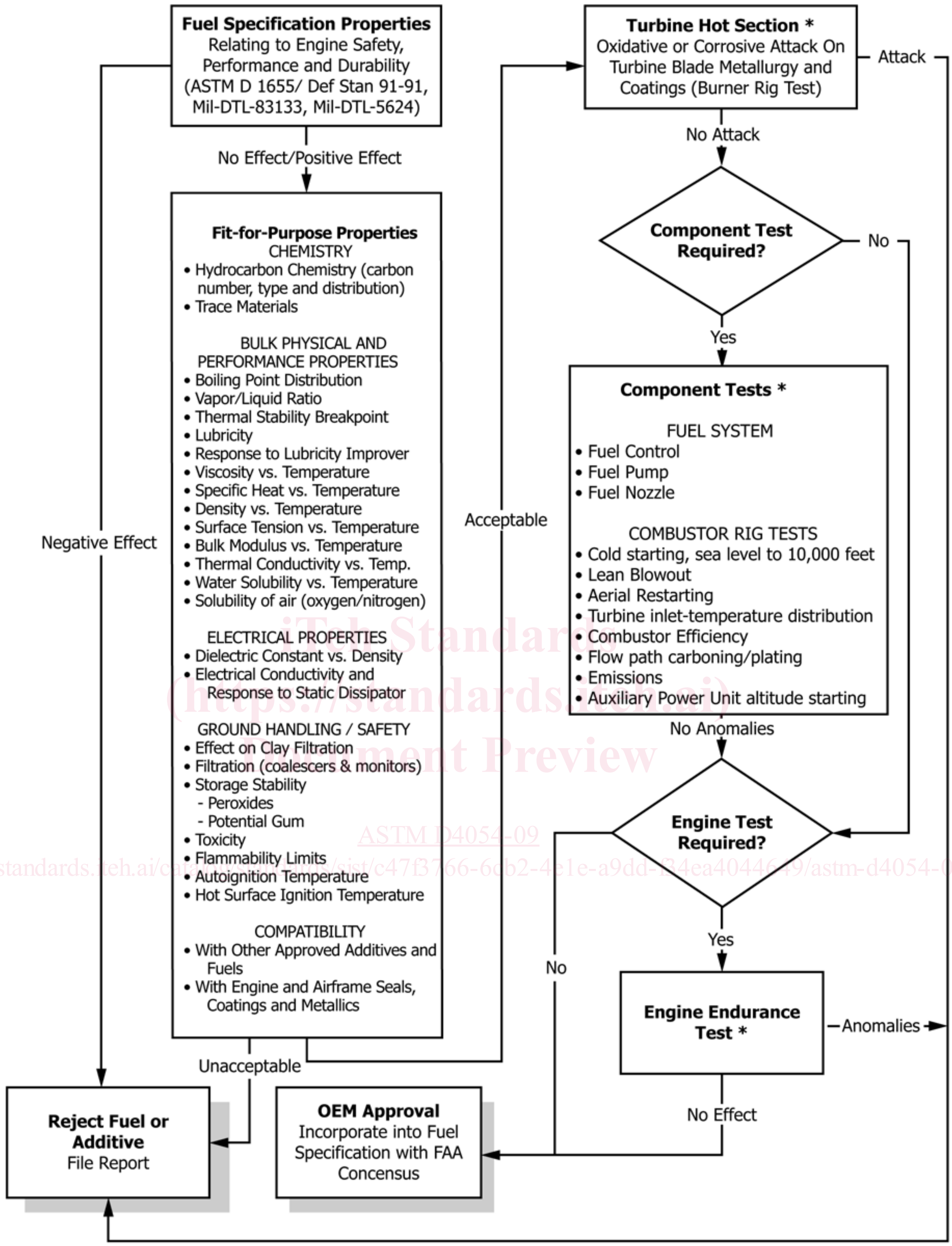


FIG. 1 Overview Fuel and Additive Approval Process

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 manufacturer experience. Departure from engine 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 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*—Results of the test program are carefully reviewed 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 shows 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



* Testing must be performed at P&W, GEAE, 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

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), Rolls Royce (RR), Honeywell, and Hamilton Sundstrand. 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. The airlines must submit 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 as major compositional changes cannot be accommodated during the review process. 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)[12] 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 the mission to promote and to be an advocate for aviation fuels, agencies, and associated industries 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. The CRC can be viewed as the investigative arm of Subcommittee D02.J0. CRC typically will respond to a request

[12] Coordinating Research Council, Inc., 3650 Mansell Road, Suite 140, Alphaetta, GA 30022. www.crcao.org

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 investigate the fuel or candidate additive in more detail. Involvement of CRC 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.

6. Funding the Investigation and Qualification Process

6.1 The organization (for example, the additive manufacturer or refiner) seeking the qualification 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. Defining and Performing 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, other approved additives, and engine operability. "Fit-for-purpose properties" refers to properties inherent in a petroleum-derived fuel that are not controlled by specification. 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. 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, military and OEM past efforts directed at investigating fuels and fuel additives. Additive investigations have included biocides, leak-detectors, thermal oxidative stability improvers and pipeline drag reducers 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. 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 base test fuel. The base test fuel shall be Jet A or Jet A-1 conforming to ASTM D1655 or Defence Standard 91-91. The same batch of fuel should be used for the entire test program.

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. Properties

8.1 *Fuel Specification Properties*—All property tests as required in Specification D1655, Defence Standard 91-91, MIL-DTL-83133, and MIL-DTL-5624.

8.2 *Fit-for-Purpose Properties :*

8.2.1 *Accepted Test Methods and Limits*—Fit-for-Purpose Properties as agreed upon by the engine manufacturers are shown in Table 1. 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

TABLE 1 Fit-for-Purpose Properties

Fuel Property	Test Method	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 or D3701	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	mg/kg (ppm by mass)	Report		
BULK PHYSICAL AND PERFORMANCE PROPERTIES					
Boiling point distribution	ASTM D86	°C			Based on CRC World Survey and Defense Energy Support Center (DESC) 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 Energy Support Center 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		
True Vapor Pressure vs. Temperature	ASTM D6378	kPa or psi	Report -28, 12, 25, 38, 78, and 200°C		
Thermal Stability, JFTOT Breakpoint	ASTM D3241, Appendix X2	°C	See Comment		Additives cannot degrade breakpoint.
Deposit Thickness at Breakpoint	Ellipsometer	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[A]		See Fig. A1.2 for typical response.
Viscosity vs. Temperature	ASTM D445	mm^2/s	Conform[A]		Plot viscosity at -40°C (or freezing point plus 5°C, which ever 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[A]		See Fig. A1.3 for temperature ranges, typical values and temperature variations.
Density vs. Temperature	ASTM D4052	kg/m3	Conform[A]		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[A]		See Fig. A1.5 for minimum values and typical variation.
Bulk Modulus vs. Temperature & Pressure	ASTM D6793	MPa	Conform[A]		Limits not known; see Fig. A1.6 for typical values and variation.
Thermal Conductivity vs. Temperature	ASTM D2717	watts/m/K	Conform[A]		Limits not known; see Fig. A1.7 for typical values and variation.
Water Solubility vs. Temperature	ASTM D6304	mg/kg (ppm by mass)	Conform[A]		See CRC Handbook of Aviation Fuel Properties for typical values
Flash Point	ASTM D56/D3828	°C		68	
Freezing Point Test Methods -Response to manual vs. Automatic Phase Transition	ASTM D2386 and ASTM D5972	°C	Conform[A]		
ELECTRICAL PROPERTIES					
Dielectric Constant vs. Density	ASTM D924	N/A	Conform[A]		See Fig. A1.8 for typical values.
Conductivity & response to SDA	ASTM D2624	pS/m	Conform[A]		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 & Monitors (water fuses)	API 1581	ppm by volume	See Comment		No impact when compared to Jet A
Storage Stability					
Peroxides	ASTM D3703	mg/kg (ppm by mass)	—	8.0	Store for 6 weeks @ 65°C.
Potential gums	ASTM D5304	mg/100mL	—	7.0	Store for 16 h @ 100°C.
Toxicity	MIL-HDBK-510-1, Appendix E				

TABLE 1 *Continued*

Fuel Property	Test Method	Units	Min	Max	Comments
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 Other Approved Fuels	ASTM D4054, Annex A2	N/A	See Comment		No visible separation, cloudiness, solids, or darkening of color.
With Engine and Airframe Seals, Coatings and Metallics	ASTM D4054, Annex A3				

[A] Conform = conform to typical response or values within engine manufacturers' experience. See Comment.

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 1.

8.2.2 *Compatibility with Additives Currently Permitted in Specification D1655*—The procedure required to determine the compatibility of a new additive with additives previously approved for use in aviation fuels is shown in Annex A2.

8.2.3 *Compatibility with Fuel System Materials*—A list of generic materials used in P&W, GEAE, RR, Honeywell, Hamilton Sundstrand, 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 for each material. Examples of the tests to be performed include the following:

8.2.3.1 Lap Shear.
8.2.3.2 Cohesion.
8.2.3.3 Volume Swell.
8.2.3.4 Tensile.
8.2.3.5 Elongation.
8.2.3.6 Tape Adhesion.
8.2.3.7 Hardness.
8.2.3.8 Peel Strength.
8.2.3.9 Laminar Shear.
8.2.3.10 Compression Set.
8.2.3.11 Resistivity.

8.2.3.12 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.

8.3 *Turbine Hot-Section Erosion and Corrosion:*
8.3.1 Metallurgy.
8.3.2 Coatings.

8.3.3 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 *Component Testing:*
8.4.1 *Fuel System:*
8.4.1.1 Fuel Pump.
8.4.1.2 Fuel Control.
8.4.1.3 Fuel Nozzle.
8.4.2 *Combustor Rig Testing:*
8.4.2.1 Cold starting at sea level to 10 000 ft.
8.4.2.2 Lean blowout.
8.4.2.3 Aerial restarting after a flame-out event.
8.4.2.4 Turbine inlet-temperature distribution.
8.4.2.5 Combustor efficiency.
8.4.2.6 Flow path carboning/plating.
8.4.2.7 Emissions.
8.4.2.8 Auxiliary Power Unit (APU) altitude starting.

8.5 *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 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