



Standard Specification for Aviation Turbine Fuels¹

This standard is issued under the fixed designation D1655; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This specification covers the use of purchasing agencies in formulating specifications for purchases of aviation turbine fuel under contract.

1.2 This specification defines the minimum property requirements for Jet A and Jet A-1 aviation turbine fuel and lists acceptable additives for use in civil operated engines and aircrafts. Specification D1655 is directed at civil applications, and maintained as such, but may be adopted for military, government or other specialized uses.

1.3 This specification can be used as a standard in describing the quality of aviation turbine fuel from production to the aircraft. However, this specification does not define the quality assurance testing and procedures necessary to ensure that fuel in the distribution system continues to comply with this specification after batch certification. Such procedures are defined elsewhere, for example in ICAO 9977, EI/JIG Standard 1530, JIG 1, JIG 2, API 1543, API 1595, and ATA-103.

1.4 This specification does not include all fuels satisfactory for aviation turbine engines. Certain equipment or conditions of use may permit a wider, or require a narrower, range of characteristics than is shown by this specification.

1.5 Aviation turbine fuels defined by this specification may be used in other than turbine engines that are specifically designed and certified for this fuel.

1.6 This specification no longer includes wide-cut aviation turbine fuel (Jet B). FAA has issued a Special Airworthiness Information Bulletin which now approves the use of Specification **D6615** to replace Specification D1655 as the specification for Jet B and refers users to this standard for reference.

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

2. Referenced Documents

2.1 ASTM Standards:²

- D56** Test Method for Flash Point by Tag Closed Cup Tester
- D86** Test Method for Distillation of Petroleum Products at Atmospheric Pressure
- D93** Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
- D129** Test Method for Sulfur in Petroleum Products (General High Pressure Decomposition Device Method)
- D130** Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
- D156** Test Method for Saybolt Color of Petroleum Products (Saybolt Chromometer Method)
- D240** Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter
- D323** Test Method for Vapor Pressure of Petroleum Products (Reid Method)
- D381** Test Method for Gum Content in Fuels by Jet Evaporation
- D445** Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
- D1266** Test Method for Sulfur in Petroleum Products (Lamp Method)
- D1298** Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
- D1319** Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
- D1322** Test Method for Smoke Point of Kerosine and Aviation Turbine Fuel
- D1405** Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
- D1660** Method of Test for Thermal Stability of Aviation Turbine Fuels (Withdrawn 1992)³

¹ This specification is under the jurisdiction of ASTM Committee **D02** on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee **D02.J0.01** on Jet Fuel Specifications.

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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.

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

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

- D1840** Test Method for Naphthalene Hydrocarbons in Aviation Turbine Fuels by Ultraviolet Spectrophotometry
- D2276** Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling
- D2386** Test Method for Freezing Point of Aviation Fuels
- D2622** Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
- D2624** Test Methods for Electrical Conductivity of Aviation and Distillate Fuels
- D2887** Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography
- D2892** Test Method for Distillation of Crude Petroleum (15-Theoretical Plate Column)
- D3120** Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry
- D3227** Test Method for (Thiol Mercaptan) Sulfur in Gasoline, Kerosine, Aviation Turbine, and Distillate Fuels (Potentiometric Method)
- D3240** Test Method for Undissolved Water In Aviation Turbine Fuels
- 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
- D3343** Test Method for Estimation of Hydrogen Content of Aviation Fuels
- D3701** Test Method for Hydrogen Content of Aviation Turbine Fuels by Low Resolution Nuclear Magnetic Resonance Spectrometry
- 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 Separator
- D4052** Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
- D4057** Practice for Manual Sampling of Petroleum and Petroleum Products
- D4171** Specification for Fuel System Icing Inhibitors
- D4176** Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedures)
- D4294** Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
- D4306** Practice for Aviation Fuel Sample Containers for Tests Affected by Trace Contamination
- D4529** Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
- D4809** Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)
- D4865** Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems
- D4952** Test Method for Qualitative Analysis for Active Sulfur Species in Fuels and Solvents (Doctor Test)
- D4953** Test Method for Vapor Pressure of Gasoline and Gasoline-Oxygenate Blends (Dry Method)
- D5001** Test Method for Measurement of Lubricity of Aviation Turbine Fuels by the Ball-on-Cylinder Lubricity Evaluator (BOCLE)
- D5006** Test Method for Measurement of Fuel System Icing Inhibitors (Ether Type) in Aviation Fuels
- D5190** Test Method for Vapor Pressure of Petroleum Products (Automatic Method) (Withdrawn 2012)³
- D5191** Test Method for Vapor Pressure of Petroleum Products (Mini Method)
- D5452** Test Method for Particulate Contamination in Aviation Fuels by Laboratory Filtration
- D5453** Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
- D5972** Test Method for Freezing Point of Aviation Fuels (Automatic Phase Transition Method)
- D6045** Test Method for Color of Petroleum Products by the Automatic Tristimulus 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
- D6469** Guide for Microbial Contamination in Fuels and Fuel Systems
- D6615** Specification for Jet B Wide-Cut Aviation Turbine Fuel
- D6751** Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels
- D7042** Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity)
- D7153** Test Method for Freezing Point of Aviation Fuels (Automatic Laser Method)
- D7154** Test Method for Freezing Point of Aviation Fuels (Automatic Fiber Optical Method)
- D7345** Test Method for Distillation of Petroleum Products and Liquid Fuels at Atmospheric Pressure (Micro Distillation Method)
- D7524** Test Method for Determination of Static Dissipater Additives (SDA) in Aviation Turbine Fuel and Middle Distillate Fuels—High Performance Liquid Chromatograph (HPLC) Method
- D7566** Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons
- D7797** Test Method for Determination of the Fatty Acid Methyl Esters Content of Aviation Turbine Fuel Using Flow Analysis by Fourier Transform Infrared Spectroscopy – Rapid Screening Method
- E29** Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- 2.2 *IP Standards*.⁴
- EI/JIG 1530** Quality Assurance Requirements for the Manufacture, Storage and Distribution of Aviation Fuels to Airports

⁴ Available from Energy Institute, 61 New Cavendish St., London, WIG 7AR, U.K., <http://www.energyinst.org.uk>.

- IP 12** Determination of Specific Energy
- IP 16** Determination of Freezing Point of Aviation Fuels—Manual Method
- IP 71 Section 1** Petroleum Products—Transparent and Opaque Liquids—Determination of Kinematic Viscosity and Calculation of Dynamic Viscosity
- IP 123** Petroleum Products—Determination of Distillation Characteristics at Atmospheric Pressure
- IP 154** Petroleum Products—Corrosiveness to Copper—Copper Strip Test
- IP 156** Petroleum Products and Related Materials—Determination of Hydrocarbon Types—Fluorescent Indicator Adsorption Method
- IP 160** Crude Petroleum and Liquid Petroleum Products—Laboratory Determination of Density—Hydrometer Method
- IP 170** Determination of Flash Point—Abel Closed-Cup Method
- IP 216** Particulate Contaminant in Aviation Fuel
- IP 225** Copper Content of Aviation Turbine Fuel
- IP 227** Silver Corrosion of Aviation Turbine Fuel
- IP 274** Determination of Electrical Conductivity of Aviation and Distillate Fuels
- IP 323** Determination of Thermal Oxidation Stability of Gas Turbine Fuels
- IP 336** Petroleum Products—Determination of Sulfur Content—Energy-Dispersive X-ray Fluorescence Spectrometry
- IP 342** Petroleum Products—Determination of Thiol (Mercaptan) Sulfur in Light and Middle Distillate Fuels—Potentiometric Method
- IP 354** Determination of the Acid Number of Aviation Fuels—Colour-Indicator Titration Method
- IP 365** Crude Petroleum and Petroleum Products—Determination of Density—Oscillating U-tube Method
- IP 406** Petroleum Products—Determination of Boiling Range Distribution by Gas Chromatography
- IP 423** Determination of Particulate Contamination in Aviation Turbine Fuels by Laboratory Filtration
- IP 435** Determination of the Freezing Point of Aviation Turbine Fuels by the Automatic Phase Transition Method
- IP 436** Determination of Aromatic Hydrocarbon Types in Aviation Fuels and Petroleum Distillates—High Performance Liquid Chromatography Method with Refractive Index Detection
- IP 523** Determination of Flash Point—Rapid Equilibrium Closed Cup Method
- IP 528** Determination for the Freezing Point of Aviation Turbine Fuels—Automatic Fibre Optic Method
- IP 529** Determination of the Freezing Point of Aviation Turbine Fuels—Automatic Laser Method
- IP 540** Determination of the Existent Gum Content of Aviation Turbine Fuel—Jet Evaporation Method
- IP 583** Determination of the Fatty Acid Methyl Esters Content of Aviation Turbine Fuel Using Flow Analysis by Fourier Transform Infrared Spectroscopy—Rapid Screening Method
- IP 585** Determination of Fatty Acid Methyl Esters (FAME), Derived from Bio-diesel Fuel, in Aviation Turbine Fuel—GC-MS with Selective Ion Monitoring/Scan Detection Method
- IP 590** Determination of Fatty Acid Methyl Esters (FAME) in Aviation Fuel—HPLC Evaporative Light Scattering Detector Method
- IP 598** Petroleum Products—Determination of the Smoke Point of Kerosine, Manual and Automated Method
- IP 599** Determination of Fatty Acid Methyl Esters (FAME) in Aviation Turbine Fuel by Gas Chromatography using Heart-cut and Refocusing
- 2.3 *API Standards:*⁵
- API 1543** Documentation, Monitoring and Laboratory Testing of Aviation Fuel During Shipment from Refinery to Airport
- API 1595** Design, Construction, Operation, Maintenance, and Inspection of Aviation Pre-Airfield Storage Terminals
- 2.4 *Joint Inspection Group Standards:*⁶
- JIG 1** Aviation Fuel Quality Control & Operating Standards for Into-Plane Fuelling Services
- JIG 2** Aviation Fuel Quality Control & Operating Standards for Airport Depots & Hydrants
- 2.5 *ANSI Standard:*⁷
- ANSI 863** Report of Test Results
- 2.6 *Other Standards:*
- Defence Standard (Def Stan) 91-91** Turbine Fuel, Aviation Kerosine Type, Jet A-1⁸
- IATA Guidance Material on Microbiological Contamination in Aircraft Fuel Tanks** Ref. No: 9680-02⁹
- EN14214** Automotive Fuels—Fatty Acid Methyl Esters (FAME) for Diesel Engines—Requirements and Test Methods¹⁰
- Bulletin Number 65** MSEP Protocol¹¹
- ATA-103** Standard for Jet Fuel Quality Control at Airports¹²
- ICAO 9977** Manual on Civil Aviation Jet Fuel Supply¹³

⁵ Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, <http://www.api.org>.

⁶ Available from Joint Inspection Group (JIG), <http://www.jigonline.com>.

⁷ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

⁸ Available from Procurement Executive DFS (Air), Ministry of Defence, St. Giles Court 1, St. Giles High St., London WC2H 8LD.

⁹ Available from International Air Transport Association (IATA), (Head Office) 800 Place Victoria, PO Box 113, Montreal, H4Z 1M1, Quebec, Canada. www.iata-online.com.

¹⁰ Available from European Committee for Standardization (CEN), 36 rue de Stassart, B-1050, Brussels, Belgium, <http://www.cenorm.be>.

¹¹ Available from Joint Inspection Group (JIG), <http://www.jigonline.com>.

¹² Available from Air Transport Association of America, Inc. (ATA) d/b/a Airlines for America, 1301 Pennsylvania Ave. NW, Suite 1100, Washington, D.C. 20004, <http://www.airlines.org>.

¹³ Available from International Civil Aviation Organization (ICAO), 999 University St., Montreal, Quebec H3C 5H7, Canada, <http://www.icao.int>.

AFRL-RQ-WP-TR-2013-0271 Determination of the Minimum Use Level of Fuel System Icing Inhibitor (FSII) in JP-8 that will Provide Adequate Icing Inhibition and Biostatic Protection for Air Force Aircraft¹⁴

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *identified incidental materials, n*—chemicals and compositions that have defined upper content limits in an aviation fuel specification but are not approved additives.

4. General

4.1 This specification, unless otherwise provided, prescribes the required properties of aviation turbine fuel at the time and place of delivery.

5. Classification

5.1 Two types of aviation turbine fuels are provided, as follows:

5.1.1 *Jet A and Jet A-1*—Relatively high flash point distillates of the kerosine type.

5.2 Jet A and Jet A-1 represent two grades of kerosine fuel that differ in freezing point. Other grades would be suitably identified.

5.3 This specification previously cited the requirements for Jet B. Requirements for Jet B fuel now appear in Specification **D6615**.

6. Materials and Manufacture

6.1 Aviation turbine fuel is a complex mixture predominantly composed of hydrocarbons and varies depending on crude source and manufacturing process. Consequently, it is impossible to define the exact composition of Jet A/A-1. This specification has therefore evolved primarily as a performance specification rather than a compositional specification. It is acknowledged that this largely relies on accumulated experience; therefore the specification limits aviation turbine fuels to those made from conventional sources or by specifically approved processes.

6.1.1 Aviation turbine fuel, except as otherwise specified in this specification, shall consist predominantly of refined hydrocarbons (see **Note 1**) derived from conventional sources including crude oil, natural gas liquid condensates, heavy oil, shale oil, and oil sands. The use of jet fuel blends containing components from other sources is permitted only in accordance with **Annex A1**.

NOTE 1—Conventionally refined jet fuel contains trace levels of materials that are not hydrocarbons, including oxygenates, organosulfur, and nitrogenous compounds.

6.1.2 Fuels used in certified engines and aircraft are ultimately approved by the certifying authority subsequent to formal submission of evidence to the authority as part of the type certification program for that aircraft and engine model.

¹⁴ Available from Defense Technical Information Center (DTIC), 8725 John J. Kingman Rd., Ft. Belvoir, VA 22060-6218, <http://www.dtic.mil/dtic>, accession number ADA595127.

Additives to be used as supplements to an approved fuel must also be similarly approved on an individual basis (see **X1.2.4** and **X1.15.1**).

6.2 *Additives*—Only additives approved by the aviation industry (including the aircraft certifying authority) are permitted in the fuel on which an aircraft is operated. The additives approved for use in D1655 jet fuel are shown in **Table 2** and may be used within the concentration limits shown in the table subject to any restrictions described in the table footnotes.

6.3 *Identified Incidental Materials*—**Table 3** lists specific materials that have an agreed limit, known as Identified Incidental Materials. Specification D1655 does not require that each batch of fuel be analyzed for identified incidental materials where there is essentially no risk of contamination exceeding **Table 3** limits. Where a supplier risk assessment suggests that identified incidental materials could exceed **Table 3** limits, jet fuel should be confirmed to comply with **Table 3** limits prior to airport supply because airports generally are not equipped to mitigate identified incidental material content that exceeds specification limits. Further guidance concerning these materials is presented in **X1.16**.

6.4 Guidance material is presented in **Appendix X2** concerning the need to control processing additives in jet fuel production.

7. Detailed Requirements

7.1 The aviation turbine fuel shall conform to the requirements prescribed in **Table 1**.

7.2 Test results shall not exceed the maximum or be less than the minimum values specified in **Table 1**. No allowance shall be made for the precision of the test methods. To determine conformance to the specification requirement, a test result may be rounded to the same number of significant figures as in **Table 1** using Practice **E29**. Where multiple determinations are made, the average result, rounded in accordance with Practice **E29**, shall be used.

8. Workmanship, Finish, and Appearance

8.1 The aviation turbine fuel specified in this specification shall be visually free of undissolved water, sediment, and suspended matter. The odor of the fuel shall not be nauseating or irritating. If the fuel has an odor similar to that of “rotten egg,” please refer to **X1.12.5** for further discussion. No substance of known dangerous toxicity under usual conditions of handling and use shall be present, except as permitted in this specification.

9. Sampling

9.1 Because of the importance of proper sampling procedures in establishing fuel quality, use the appropriate procedures in Practice **D4057** to obtain a representative sample from the batch of fuel for specification compliance testing. This requirement is met by producing fuel as a discrete batch then testing it for specification compliance. This requirement is not satisfied by averaging online analysis results.

9.2 A number of jet fuel properties, including thermal stability, water separation, electrical conductivity, and others,

TABLE 1 Detailed Requirements of Aviation Turbine Fuels^A

| Property | | Jet A or Jet A-1 | Test Methods ^B |
|--|-----------|--------------------------|---|
| COMPOSITION | | | |
| Acidity, total mg KOH/g | max | 0.10 | D3242/IP 354 |
| 1. Aromatics, percent by volume | max | 25 | D1319 or IP 156 |
| 2. Aromatics, percent by volume | max | 26.5 | D6379/IP 436 |
| Sulfur, mercaptan, ^C percent by mass | max | 0.003 | D3227/IP 342 |
| Sulfur, total percent by mass | max | 0.30 | D1266, D2622, D4294, D5453, or IP 336 |
| VOLATILITY | | | |
| Distillation temperature, °C: | | | |
| 10 % recovered, temperature | max | 205 | D86, ^D D2887/IP 406, ^E D7345 ^F , IP 123 ^D |
| 50 % recovered, temperature | | report | |
| 90 % recovered, temperature | | report | |
| Final boiling point, temperature | max | 300 | |
| Distillation residue, % | max | 1.5 | |
| Distillation loss, % | max | 1.5 | |
| Flash point, °C | min | 38 ^G | D56, D93, ^H D3828, ^H IP 170 ^H or IP 523 ^H |
| Density at 15 °C, kg/m ³ | | 775 to 840 | D1298/IP 160 or D4052 or IP 365 |
| FLUIDITY | | | |
| Freezing point, °C | max | -40 Jet A ^I | D5972/IP 435, D7153/IP 529, D7154/IP 528, or D2386/IP 16 |
| | | -47 Jet A-1 ^I | |
| Viscosity -20 °C, mm ² /s ^J | max | 8.0 | D445/IP 71, Section 1 or D7042 ^K |
| COMBUSTION | | | |
| Net heat of combustion, MJ/kg | min | 42.8 ^L | D4529, D3338, D4809, or IP 12 |
| One of the following requirements shall be met: | | | |
| (1) Smoke point, mm, or | min | 25.0 | D1322/IP 598 |
| (2) Smoke point, mm, and | min | 18.0 | D1322/IP 598 |
| Naphthalenes, vol, % | max | 3.0 | D1840 |
| CORROSION | | | |
| Copper strip, 2 h at 100 °C | max | No. 1 | D130/IP 154 |
| THERMAL STABILITY | | | |
| (2.5 h at control temperature of 260 °C min) | | | |
| Filter pressure drop, mm Hg | max | 25 | D3241 ^M /IP 323 ^M |
| Tube rating: One of the following requirements shall be met: ^N | | | |
| (1) Annex A1 VTR, VTR Color Code | Less than | 3 | No peacock or abnormal color deposits |
| (2) Annex A2 ITR or Annex 3 ETR, nm average over area of 2.5 mm ² | max | 85 | |
| CONTAMINANTS | | | |
| Existent gum, mg/100 mL | max | 7 | D381, IP 540 |
| Microseparometer, ^O Rating | | | D3948 |
| Without electrical conductivity additive | min | 85 | |
| With electrical conductivity additive | min | 70 | |
| ADDITIVES | | | |
| Electrical conductivity, pS/m | | See 6.2 ^P | D2624/IP 274 |

^A For compliance of test results against the requirements of Table 1, see 7.2.

^B The test methods indicated in this table are referred to in Section 11.

^C The mercaptan sulfur determination may be waived if the fuel is considered sweet by the doctor test described in Test Method D4952.

^D D86 and IP 123 distillation of jet fuel is run at Group 4 conditions, except Group 3 condenser temperature is used.

^E D2887/IP 406 results shall be converted to estimated D86 or IP 123 results by application of the correlation in Appendix X4 on Correlation for Jet and Diesel Fuel in Test Method D2887 or Annex G of IP 406. Distillation residue and loss limits provide control of the distillation process during the use of Test Method D86, and they do not apply to Test Method D2887/IP 406. Distillation residue and loss shall be reported as "not applicable" (N/A) when reporting D2887 results.

^F Results from Test Method D7345 shall be corrected for relative bias as described in Test Method D7345.

^G A higher minimum flash point specification can be agreed upon between purchaser and supplier.

^H Aviation turbine fuel results obtained by Test Method D93 can be up to 1 °C higher than those obtained by Test Method D56. Results obtained by Test Methods D3828, IP 170, and IP 523 can be up to 2 °C lower than those obtained by Test Method D56, which is the preferred method. In case of dispute, Test Method D56 shall apply.

^I Other freezing points can be agreed upon between supplier and purchaser.

^J 1 mm²/s = 1 cSt.

^K Test Method D7042 results shall be converted to bias-corrected kinematic viscosity results by the application of the correction described in Test Method D7042 for jet fuel at -20 °C (currently subsection 15.4.4).

^L For all grades use either Eq 1 or Table 1 in Test Method D4529 or Eq 2 in Test Method D3338. Test Method D4809 can be used as an alternative. In case of dispute, Test Method D4809 shall be used.

^M D3241/IP 323 Thermal Stability is a critical aviation fuel test, the results of which are used to assess the suitability of jet fuel for aviation operational safety and regulatory compliance. The integrity of D3241/IP 323 testing requires that heater tubes (test coupons) meet the requirements of D3241 Table 2 and give equivalent D3241 results to the heater tubes supplied by the original equipment manufacturer (OEM). A test protocol to demonstrate equivalence of heater tubes from other suppliers is on file at ASTM International Headquarters and can be obtained by requesting Research Report RR:D02-1550. Heater tubes and filter kits, manufactured by the OEM (PAC, 8824 Fallbrook Drive, Houston, TX 77064) were used in the development of the D3241/IP 323 test method. Heater tube and filter kits, manufactured by Falex (Falex Corporation, 1020 Airpark Dr., Sugar Grove, IL, 60554-9585) were demonstrated to give equivalent results (see D3241 for research report references). These historical facts should not be construed as an endorsement or certification by ASTM International.

^N Tube deposit ratings shall be measured by D3241 Annex A2 ITR or Annex A3 ETR, when available. If the Annex A2 ITR device reports "N/A" for a tube's volume measurement, the test shall be a failure and the value reported as >85 nm. Visual rating of the heater tube by the method in D3241 Annex A1 is not required when Annex A2 ITR or Annex A3 ETR deposit thickness measurements are reported. In case of dispute between results from visual and metrological methods, the referee shall be considered the Annex A3 ETR method if available, otherwise Annex A2 ITR.

^O At point of manufacture. See X1.13 for guidance concerning the application of microseparometer results in fuel distribution.

^P If electrical conductivity additive is used, the conductivity shall not exceed 600 pS/m at the point of use of the fuel. When electrical conductivity additive is specified by the purchaser, the conductivity shall be 50 to 600 pS/m under the conditions at point of delivery.

$$1 \text{ pS/m} = 1 \times 10^{-12} \Omega^{-1} \text{ m}^{-1}$$

TABLE 2 Detailed Information for Additives for Aviation Turbine Fuels

| Additive | Fuel Performance Enhancing Additives | Dosage |
|---|--------------------------------------|---|
| Antioxidants ^{A,B} <i>One of the following:</i> 2,6 ditertiary-butyl phenol 2,6 ditertiary-butyl-4-methyl phenol 2,4 dimethyl-6-tertiary-butyl-phenol 75 % minimum, 2,6 ditertiary-butyl phenol plus 25 % maximum mixed tertiary and tritertiary butyl-phenols 55 % minimum 2,4 dimethyl-6-tertiary-butyl phenol plus 15 % minimum 2,6 ditertiary-butyl-4-methyl phenol, remainder as monomethyl and dimethyl tertiary-butyl phenols 72 % minimum 2,4 dimethyl-6-tertiary-butyl phenol plus 28 % maximum monomethyl and dimethyl-tertiary-butyl-phenols | | 24.0 mg/L max ^C |
| Metal Deactivator (MDA) ^A N,N-disalicylidene-1,2-propane diamine On initial blending After field reblending cumulative concentration | | 2.0 mg/L max ^{C,D} 5.7 mg/L max |
| Fuel System Icing Inhibitor ^{E,F,G} Diethylene Glycol Monomethyl Ether (see Specification D4171 Type III) | | 0.07 % by volume, min ^H 0.15 % by volume, max |
| Fuel Handling and Maintenance Additives | | |
| Electrical Conductivity Improver ^I Stadis 450 ^{J,K} On initial blending After field reblending, cumulative concentration If the additive concentration is unknown at time of retreatment, additional concentration is restricted to 2 mg/L max | | 3 mg/L max 5 mg/L max |
| Leak Detection Additive Tracer A (LDTA-A) ^L | | 1 mg/kg max |
| Biocidal Additives ^{E,M,N} Biobor JF ^O Kathon FP1.5 ^P | | |
| Corrosion Inhibitor/Lubricity Improvers ^Q <i>One of the following:</i> HiTEC 580 ^R Innospec DCI-4A ^S Nalco 5403 | | 23 mg/L max 23 mg/L max 23 mg/L max |

^A The active ingredient of the additive must meet the composition specified.

^B Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1125.

^C Active ingredient (not including weight of solvent).

^D At the point of manufacture, Metal Deactivator Additive (MDA) may be added to improve thermal oxidative stability subject to the following limitations:

(1) No more than 5 % of the jet fuel batches produced in a 12 month period may be treated with MDA to meet **Table 1** thermal oxidative stability requirements (260 °C test temperature).

(2) The batch of fuel shall pass **Table 1** thermal oxidative stability requirements at a test temperature of 245 °C prior to any MDA addition.

(3) The fuel batch after MDA addition (2.0 mg/L maximum MDA) shall pass **Table 1** thermal oxidative stability requirements at a test temperature of 275 °C.

(4) The thermal oxidative stability test result at 245 °C prior to MDA addition, the original test result at 260 °C and the test result at 275 °C (post MDA addition) and the concentration of MDA added shall be reported on the Refinery Certificate of Quality.

Initial addition of more than 2.0 mg/L MDA to jet fuel that meets **Table 1** thermal oxidative stability requirements (260 °C test temperature) prior to MDA addition is permitted when fuel will be transported in supply chains where copper contamination can occur: the maximum cumulative addition in this table still applies.

MDA may be added to jet fuel in the distribution system to recover thermal oxidative stability performance lost during distribution (after refinery release). The Certificate of Quality shall show the initial thermal oxidative stability test result, the result after the addition of the MDA and the concentration of MDA added.

^E The quantity shall be declared by the fuel supplier and agreed to by the purchaser.

^F The lower FSII concentration limit allowable in Jet Fuel is based on research by the U.S. Air Force as documented in report AFRL-RQ-WP-TR-2013-0271. Some engines and aircraft as certified require higher minimum concentrations of icing inhibitor than the lower limit in this jet fuel specification. When fueling an aircraft, the fuel should be added to the concentration levels specified in the appropriate engine and aircraft manual.

^G DiEGME content can be analyzed by Test Method **D5006**.

^H Some aircraft require higher levels than 0.07 % by volume.

^I If electrical conductivity improver is used, the conductivity shall not exceed 600 pS/m at the point of use of the fuel. When electrical conductivity additive is specified by the purchaser, the conductivity shall be 50 pS/m to 600 pS/m under the conditions at point of delivery.

$$1 \text{ pS/m} = 1 \times 10^{-12} \Omega^{-1} \text{ m}^{-1}$$

^J Stadis 450 is a registered trademark marketed by Innospec Inc., Innospec Manufacturing Park, Oil Sites Road, Ellesmere Port, Cheshire, CH65 4EY, UK.

^K Stadis 450 content can be analyzed by Test Method **D7524**.

^L Tracer A (LDTA-A) is a registered trademark of Tracer Research Corp., 3755 N. Business Center Dr., Tucson, AZ 85705.

^M Biocidal additives are available for controlled usage. Where such an additive is used in the fuel, the approval status of the additive and associated conditions must be checked for the specific aircraft and engines to be operated.

^N Refer to the Aircraft Maintenance Manual (AMM) to determined if either biocide is approved for use and for their appropriate use and dosage.

^O Biobor JF is a registered trademark of Hammonds Technical Services, Inc. 910 Rankin Rd., Houston, TX 77073.

^P KATHON is a trademark of The Dow Chemical Company ("Dow") or an affiliated company of Dow, 2030 Dow Center, Midland, MI 48674.

^Q More information concerning minimum treat rates of corrosion inhibitor/lubricity improver additives is contained in **X1.10.2**.

^R HiTEC 580 is a trademark of Afton Chemical Corp., 500 Spring St., Richmond, VA 23219.

^S Innospec DCI-4A is available from Innospec Inc., Innospec Manufacturing Park, Oil Sites Road, Ellesmere Port, Cheshire, CH65 4EY, UK.

TABLE 3 Identified Incidental Materials

| Material | Permitted Level | Test Methods |
|---|-----------------------------|--|
| Fatty Acid Methyl Ester (FAME) ^A | 50 mg/kg max ^{B,C} | D7797/IP 583, IP 585, ^D IP 590, IP 599 |

^A For the purpose of meeting this requirement FAME is defined as material meeting the limits of EN14214 or Specification D6751. Fatty acid methyl esters that fail to meet the biodiesel quality standards are not permitted in aviation turbine fuel.

^B On an emergency basis, up to 100 mg/kg FAME is permitted in jet fuel when authorized by the airframe and engine manufacturers and managed in compliance with airframe and engine manufacturer requirements.

^C Subcommittee J intends to evaluate field experience in December 2016 to determine if a ballot to increase the FAME content limit to 100 mg/kg is supported by the absence of significant FAME-related problems.

^D Test Method IP 585 shall be the referee method.

are very sensitive to trace contamination, which can originate from sample containers. For recommended sample containers, refer to Practice D4306.

10. Report

10.1 The type and number of reports to ensure conformance with the requirements of this specification shall be mutually agreed upon by the seller and the purchaser of the aviation turbine fuel.

10.2 A suggested form for reporting inspection data on aviation turbine fuels is given in Appendix X3 as Fig. X3.1. This form is optimized for electronic data entry.

10.3 When Table 1 test results and Table 2 additive additions are reported at the point of batch origination or at full certification in a form commonly known as a “Certificate of Quality” or “Certificate of Analysis,” at least the following should be included:

10.3.1 The designation of each test method used,

10.3.2 The limits from Table 1 and Table 2 for each item reported with units converted as appropriate to those measured and reported, and

10.3.3 The designation of the quality system used by the reporting test laboratory. If no quality system is used then this shall be reported as “None.”

10.4 A suggested, nonmandatory form for reporting inspection data in a Certificate of Quality or Analysis format is given in Appendix X3 as Fig. X3.2.

NOTE 2—This form is appropriate for reporting complete certification results. A different form (not reproduced here) showing original and retest results is more appropriate for reporting test results intended to assess if a specific batch of fuel has changed as it moves through the distribution system.

11. Test Methods

NOTE 3—Where IP test methods are referenced in this specification as alternatives to ASTM test methods, the following nomenclature is used. Where test methods are officially jointed, this is denoted as Dxxx/IP xxx. Where test methods are technically equivalent or related but not officially jointed, this is denoted as Dxxx or IP xxx.

11.1 Determine the requirements enumerated in this specification in accordance with the following ASTM test methods.

11.1.1 *Density*—Test Method D1298/IP 160 or D4052 or IP 365.

11.1.2 *Distillation*—Test Method D86 or IP 123. For Jet A and Jet A-1, Test Methods D2887/IP 406 and D7345 may be used as an alternative. Results from Test Method D2887 shall be reported as estimated D86 results by application of the correlation in Appendix X4 on Correlation for Jet and Diesel Fuel in Test Method D2887/IP 406. Results from Test Method D7345 shall be corrected for bias by applying the GRP4 corrections in the Test Method D7345 Precision and Bias section. In case of dispute, Test Method D86 shall be the referee method (see X1.6.1.1).

11.1.3 *Flash Point*—Test Method D56, D93, D3828, IP 170, or IP 523. Test Method D56 is the referee method.

11.1.4 *Freezing Point*—Test Method D5972/IP 435, D7153/IP 529, D7154/IP 528, or D2386/IP 16. Any of these test methods can be used to certify and recertify jet fuel. However, Test Method D2386/IP 16 is the referee method. An interlaboratory study (RR: D02-1572¹⁵) that evaluated the ability of freezing point methods to detect jet fuel contamination by diesel fuel determined that Test Methods D5972/IP 435 and D7153/IP 529 provided significantly more consistent detection of freeze point changes caused by contamination than Test Methods D2386/IP 16 and D7154/IP 528. It is recommended to certify and recertify jet fuel using either Test Method D5972/IP 435 or Test Method D7153/IP 529, or both, on the basis of the reproducibility and cross-contamination detection reported in RR:D02-1572.¹⁵ The cause of freezing point results outside specification limits by automated methods should be investigated, but such results do not disqualify the fuel from aviation use if the results from the referee method (Test Method D2386/IP 16) are within the specification limit.

11.1.5 *Viscosity*—Test Method D445/IP 71 Section 1, or D7042. Results from Test Method D7042 shall be reported as bias-corrected kinematic viscosity results by application of the correction in Test Method D7042, relative bias for jet fuel at –20 °C (currently subsection 15.4.4). In case of dispute, Test Method D445 shall be the referee method.

11.1.6 *Net Heat of Combustion*—Test Method D4529, D3338, D4809, or IP 12.

11.1.7 *Corrosion (Copper Strip)*—Test Method D130/IP 154.

11.1.8 *Total Acidity*—Test Method D3242/IP 354.

11.1.9 *Sulfur*—Test Method D1266, D2622, D4294, D5453, or IP 336.

11.1.10 *Mercaptan Sulfur*—Test Method D3227/IP 342.

11.1.11 *Water Separation*—Test Method D3948.

11.1.12 *Existent Gum*—Test Method D381 or IP 540. Test Method D381, using steam jet operating conditions, shall be the referee test method.

11.1.13 *Thermal Stability*—Test Method D3241/IP 323.

11.1.14 *Aromatics*—Test Method D1319, IP 156, or D6379/IP 436. Test Method D1319 shall be the referee test method.

11.1.15 *Smoke Point*—Test Method D1322/IP 598.

11.1.16 *Naphthalene Content*—Test Method D1840.

11.1.17 *Electrical Conductivity*—Test Method D2624/IP 274.

¹⁵ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1572.

12. Keywords

12.1 aviation turbine fuel; avtur; Jet A; Jet A-1; jet fuel; turbine fuel

ANNEX

(Mandatory Information)

A1. FUELS FROM NON-CONVENTIONAL SOURCES

A1.1 Introduction

A1.1.1 Jet fuel has contained synthesized hydrocarbons since the inception of Specification D1655. However, these synthesized materials are generated from petroleum, oil sand or shale derived feedstocks in the refinery and exhibit properties substantially similar to historically refined kerosine. The fuel property requirements defined in Specification D1655, **Table 1** are batch-to-batch quality control tests which historically have provided fit-for-purpose jet fuel but assume that the jet fuel has a composition that is substantially similar to historical compositions. There is no basis to assume that fuels having novel compositions provide fit-for-purpose performance in current aviation hardware even if they appear to satisfy Specification D1655, **Table 1** requirements. While the use of synthesized hydrocarbons is known and an acceptable practice, the use of synthesized hydrocarbons from new sources requires specific guidance that is currently outside the scope of Specification D1655. This guidance is found in Specification **D7566**.

A1.1.2 Specification **D7566** was developed by Subcommittee D02.J0 to provide control for jet fuel produced with non-petroleum, non-shale, non-oil sands derived synthesized components. This specification guides the preparation of fuel

blends that are compositionally similar to the refined fuels generated to Specification D1655 and can be controlled thereby in the distribution system. Aviation turbine fuels with synthetic components produced in accordance with Specification **D7566** meet the requirements of Specification D1655. Specification **D7566** does not yet include all fuels from non-conventional sources, so as an interim solution, it has been deemed necessary to recognize, on an individual basis, fuels from non-conventional sources whose performance complies with the intent of this specification and that have been approved by a coordinated specification authority.

A1.2 Acceptable Fuels from Non-Conventional Sources

A1.2.1 The SASOL semi-synthetic fuel, a blend of conventionally produced kerosine and a synthetic Iso-Paraffinic Kerosine by itself or as combined with SASOL heavy naphtha #1 and specified in Defence Standard (Def Stan) 91-91, is recognized as meeting the requirements of Specification D1655.

A1.2.2 The SASOL fully synthetic fuel, a blend of up to five synthetic streams, specified in D.4.3 of Defence Standard (Def Stan) 91-91, is recognized as meeting the requirements of Specification D1655.

APPENDIXES
(Nonmandatory Information)
X1. PERFORMANCE CHARACTERISTICS OF AVIATION TURBINE FUELS
X1.1 Introduction

X1.1.1 This appendix describes the performance characteristics of aviation turbine fuels. A more detailed discussion of the individual test methods and their significance is found in ASTM Manual No. 1.¹⁶ Additional information on aviation turbine fuel and its properties is found in ASTM’s MNL 37, *Fuels and Lubricants Handbook: Technology, Properties, Performance, and Testing*¹⁷ and the *Handbook of Aviation Fuel Properties*.¹⁸

X1.2 Significance and Use

X1.2.1 Requests to modify D1655 to better support applications of military, governmental or other specialized agencies are considered when the proposed changes do not conflict with or further burden the primary purpose of supporting civil aviation. Conversely, requests to modify D1655 to better support civil aviation cannot be contingent upon the requirements of military, governmental or other specialized agencies.

X1.2.2 The safe and economical operation of aircraft requires fuel that is essentially clean and dry and free of any

contamination prior to use. It is possible to measure a number of jet fuel characteristics related to quality.

X1.2.3 The significance of standard tests for fuel properties may be summarized for convenience in terms of the technical relationships with performance characteristics as shown in **Table X1.1**.

X1.2.4 The acceptability of additives for use must ultimately be determined by the engine and aircraft type certificate holder and must be approved by his certifying authority. In the United States of America, the certifying authority is the Federal Aviation Administration.

X1.3 Thermal Stability

X1.3.1 Stability to oxidation and polymerization at the operating temperatures encountered in certain jet aircraft is an important performance requirement. The thermal stability measurements are related to the amount of deposits formed in the engine fuel system on heating the fuel in a jet aircraft. Commercial jet fuels should be thermally stable at a fuel temperature as high as 163 °C (325 °F). Such fuels have been demonstrated to have inherent storage stability with respect to gum formation.

X1.3.2 In 1973, Test Method **D3241/IP 323** replaced Method of Test **D1660**, known as the ASTM Coker, for the determination of oxidative thermal stability on the basis of a correlation study (see CRC Report 450, dated 1969 as revised

TABLE X1.1 Performance Characteristics of Aviation Turbine Fuels

| Performance Characteristics | Test Method | Sections | |
|--|--|------------------|--|
| Engine fuel system deposits and coke | Thermal stability | X1.3 | |
| Combustion properties | Smoke point | X1.4.2.1 | |
| | Aromatics | X1.4.2.2 | |
| | Percent naphthalenes | X1.4.2.3 | |
| Fuel metering and aircraft range | Density | X1.5.1 | |
| | Net heat of combustion | X1.5.2 | |
| Fuel atomization | Distillation | X1.6.1 | |
| | Viscosity | X1.6.2 | |
| | Freezing point | X1.7.1 | |
| Fluidity at low temperature | Mercaptan sulfur | X1.8.1 | |
| | Sulfur | X1.8.2 | |
| | Copper strip corrosion | X1.8.3 | |
| | Acidity | X1.8.4 | |
| | Existent gum | X1.9.1 | |
| Compatibility with elastomer and the metals in the fuel system and turbine | Flash point | X1.11.1 | |
| | Static Electricity | X1.11.2 | |
| | Water separation characteristics | X1.13.2 | |
| | Free water and particulate contamination | X1.12.3 | |
| | Particulate matter | X1.12.4 | |
| | Membrane color ratings | X1.12.4.1 | |
| | Undissolved water | X1.12.2 | |
| | Fuel lubricity | X1.10 | |
| | Additives | X1.15.1 | |
| | Sample containers | X1.15.3 | |
| | Fuel lubricating ability (lubricity) | | |
| | Miscellaneous | | |

1972 and Bert and Painter's SAE paper 730385¹⁹) that concluded **D3241** at 245 °C gave equivalent results to **D1660** at specified test conditions. **D1655** mandated **D3241** testing at 260 °C (versus 245 °C) to incorporate a safety margin to cover the scatter around the best-fit correlation of the methods. Today, a single pass/fail run with the tube temperature controlled at 260 °C is used to ensure compliance with the specification minimum requirements. (Passing performance in **D3241** testing at 260 °C is the engineering design basis for current commercial engines.) For a more complete characterization of a fuel's thermal stability, a *breakpoint* can be obtained. The breakpoint is the highest tube temperature at which the fuel still passes the specification requirements of tube deposit color and pressure differential. Normally, obtaining a breakpoint requires two or more runs at differing tube temperatures. Breakpoints are therefore not used for quality control, but they serve mostly for research purposes.

X1.3.3 Metal deactivator additive (MDA) may be added to fuel to counteract the effects of metals known to be deleterious to thermal stability, such as copper, cadmium, iron, cobalt, and zinc. Where metallic contamination is unproven, such as in recovery from processing upsets, MDA may be used to improve thermal stability. Thermal oxidative stability testing at time of manufacture is required to pass at 245 °C prior to MDA addition to ensure a base level of fuel quality. This is consistent with the results from a nozzle fouling study conducted by the CRC (see CRC Report AV-6-06, "Metal Deactivator Additive (MDA) Impacts on Thermal Stability") that concluded with the recommendation: "Based on these results the CRC MDA Task Group recommends a modest allowance of 15 °C for the use of MDA where copper is not detected." See also **X1.15.1** for guidance concerning MDA.

X1.4 Combustion

X1.4.1 Jet fuels are continuously burned in a combustion chamber by injection of liquid fuel into the rapidly flowing stream of hot air. The fuel is vaporized and burned at near stoichiometric conditions in a primary zone. The hot gases produced are continuously diluted with excess air to lower their temperature to a safe operating level for the turbine. Fuel combustion characteristics relating to soot formation are emphasized by current specification test methods. Other fuel combustion characteristics not covered in current specifications are burning efficiency and flame-out.

X1.4.2 In general, paraffin hydrocarbons offer the most desirable combustion cleanliness characteristics for jet fuels. Naphthenes are the next most desirable hydrocarbons for this use. Although olefins generally have good combustion characteristics, their poor gum stability usually limits their use in aircraft turbine fuels to about 1 % or less. Aromatics generally have the least desirable combustion characteristics for aircraft turbine fuel. In aircraft turbines they tend to burn with a smoky flame and release a greater proportion of their chemical energy as undesirable thermal radiation than the other

hydrocarbons. Naphthalenes or bicyclic aromatics produce more soot, smoke, and thermal radiation than monocyclic aromatics and are, therefore, the least desirable hydrocarbon class for aircraft jet fuel use. All of the following measurements are influenced by the hydrocarbon composition of the fuel and, therefore, pertain to combustion quality: smoke point, percent naphthalenes, and percent aromatics.²⁰

X1.4.2.1 *Smoke Point*—This method provides an indication of the relative smoke-producing properties of jet fuels and is related to the hydrocarbon-type composition of such fuels. Generally, the more highly aromatic the jet fuel, the more smoky the flame. A high smoke point indicates a fuel of low smoke-producing tendency.

X1.4.2.2 *Aromatics*—The combustion of highly aromatic jet fuels generally results in smoke and carbon or soot deposition, and it is therefore desirable to limit the total aromatic content as well as the naphthalenes in jet fuels.

X1.4.2.3 *Percent Naphthalenes*—This method covers measurement of the total concentration of naphthalene, acenaphthene, and alkylated derivatives of these hydrocarbons in jet fuels containing no more than 5 % of such compounds and having boiling points below 600 °F (316 °C).

X1.5 Fuel Metering and Aircraft Range

X1.5.1 *Density*—Density is a property of a fluid and is of significance in metering flow and in mass-volume relationships for most commercial transactions. It is particularly useful in empirical assessments of heating value when used with other parameters, such as aniline point or distillation. A low density may indicate low heating value per unit volume.

X1.5.2 *Net Heat of Combustion*—The design of aircraft and engines is based on the convertibility of heat into mechanical energy. The net heat of combustion provides a knowledge of the amount of energy obtainable from a given fuel for the performance of useful work; in this instance, power. Aircraft design and operation are dependent upon the availability of a certain predetermined minimum amount of energy as heat. Consequently, a reduction in heat energy below this minimum is accompanied by an increase in fuel consumption with corresponding loss of range. Therefore, a minimum net heat of combustion requirement is incorporated in this specification. The determination of net heat of combustion is time consuming and difficult to conduct accurately. This led to the development and use of the aniline point and density relationship to estimate the heat of combustion of the fuel. This relationship is used along with the sulfur content of the fuel to obtain the net heat of combustion by Test Method **D4529** for the purposes of this specification. An alternative calculation, Test Method **D3338**, is based on correlations of aromatics content, gravity, volatility, and sulfur content. This method may be preferred at refineries where all these values are normally obtained and the necessity to obtain the aniline point is avoided. The direct measurement method, Test Method **D4809** or IP 12, is normally used only as a referee method in cases of dispute.

¹⁹ Bert, J. A., and Painter, L., "A New Fuel Thermal Stability Test (A Summary of Coordinating Research Council Activity)," SAE Paper 730385, Society of Automotive Engineers, Warrendale, PA, 1973.

²⁰ A task force studied the possible use of hydrogen content as an alternative to aromatics content. Supporting data (a report of these studies completed in 1989) have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1258.