



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. Guidance information for these other applications is available in the appendix.

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. However, other units of measurement are included in this standard.

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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 and Liquid Fuels at Atmospheric Pressure
- D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
- 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)
- D613 Test Method for Cetane Number of Diesel Fuel Oil
- 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

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.

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

- 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
- 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 Separometer
- 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
- D4737 Test Method for Calculated Cetane Index by Four Variable Equation
- 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
- D6890 Test Method for Determination of Ignition Delay and Derived Cetane Number (DCN) of Diesel Fuel Oils by Combustion in a Constant Volume Chamber
- 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)
- D7170 Test Method for Determination of Derived Cetane Number (DCN) of Diesel Fuel Oils—Fixed Range Injection Period, Constant Volume Combustion Chamber 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 Chromatography (HPLC) Method

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

- D7566** Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons
- D7619** Test Method for Sizing and Counting Particles in Light and Middle Distillate Fuels, by Automatic Particle Counter
- D7668** Test Method for Determination of Derived Cetane Number (DCN) of Diesel Fuel Oils—Ignition Delay and Combustion Delay Using a Constant Volume Combustion Chamber Method
- 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
- D7872** Test Method for Determining the Concentration of Pipeline Drag Reducer Additive in Aviation Turbine Fuels
- D7945** Test Method for Determination of Dynamic Viscosity and Derived Kinematic Viscosity of Liquids by Constant Pressure Viscometer
- D7959** Test Method for Chloride Content Determination of Aviation Turbine Fuels using Chloride Test Strip
- E29** Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- 2.2 *EI Standards:*⁴
- EI 1550** Handbook on equipment used for the maintenance and delivery of clean aviation fuel
- EI 1583** Laboratory tests and minimum performance levels for aviation fuel filter monitors
- EI/JIG 1530** Quality assurance requirements for the manufacture, storage and distribution of aviation fuels to airports
- 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 method
- 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 564** Determination of the level of cleanliness of aviation turbine fuel—Laboratory automatic particle counter method
- IP 565** Determination of the level of cleanliness of aviation turbine fuel—Portable automatic particle counter method
- IP 577** Determination of the level of cleanliness of aviation turbine fuel—Automatic particle counter method using light extinction
- 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

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

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

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

IATA Guidelines for Sodium Chloride Contamination Troubleshooting and Decontamination of Airframe and Engine Fuel Systems, 2nd Ed., February 1998⁹

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

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.

3.1.2 *metrological method, n*—heater tube deposit rating methods employing an optically-based deposit thickness measurement and mapping technique described in the Test Method D3241 annexes.

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. 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 Specification 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. Where it is necessary to dilute an additive for handling purposes, a refined hydrocarbon stream from a refinery, produced in accordance with Materials and Manufacture requirements of Specification D1655, or a reagent grade (or better) hydrocarbon or hydrocarbon mixture from a chemical supplier shall be used. Reporting does not change when dilution is used; additive package content as received or active ingredient content as described in **Table 2** is the concentration to be reported.

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, 1275 Pennsylvania Ave. NW, Suite 1300, 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>.

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.

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: | | | D86, ^D D2887/IP 406, ^E D7345 ^F , IP 123 ^D |
| 10 % recovered, temperature | max | 205 | |
| 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, D7042, ^K or D7945 |
| 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 A3 ETR, nm average over area of 2.5 mm ² | max | 85 | |
| CONTAMINANTS | | | |
| Existent gum, mg/100 mL | max | 7 | D381, IP 540 |
| Microseparator, ^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. Calculate and report the net heat of combustion corrected for the sulfur content when using Test Method D4529 and D3338 empirical test methods. 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 | Dosage |
|--|---|
| Fuel Performance Enhancing Additives | |
| 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, H} Diethylene Glycol Monomethyl Ether (see Specification D4171 Type III) | 0.07 % by volume, min ^I 0.15 % by volume, max |
| Fuel Handling and Maintenance Additives | |
| Electrical Conductivity Improver ^J <i>One of the following:</i> AvGuard SDA ^{K, L} On initial blending After field reblending, cumulative concentration | 3 mg/L max 5 mg/L max |
| Stadis 450 ^{L, M} On initial blending After field reblending, cumulative concentration | 3 mg/L max 5 mg/L max |
| If the additive concentrations are unknown at time of retreatment, additional concentration is restricted to 2 mg/L max | |
| Leak Detection Additive Tracer A (LDTA-A) ^N | 1 mg/kg max |
| Biocidal Additives ^{E, O, P} Biobor JF ^Q Kathon FP1.5 ^R | |
| Corrosion Inhibitor/Lubricity Improvers ^S <i>One of the following:</i> HiTEC 580 ^T Innospec DCI-4A ^U 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 DIEGME is not suitable for use in systems that will later use EI 1583 filter monitors, which are commonly used at the point of aircraft fueling. Additional guidance is provided in EI 1550 Chapter 9.

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

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

^K AvGuard is a trademark of Afton Chemical Corporation, 500 Spring Street Richmond, VA 23219. Supporting documentation for this additive is found in RR:D02-1861.

^L Electrical conductivity improver content can be analyzed by Test Method **D7524**.

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

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

^O 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.

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

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

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

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

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

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

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

TABLE 3 Identified Incidental Materials

| Material | Permitted Level | Test Methods |
|---|-------------------------|---|
| Fatty Acid Methyl Ester (FAME), ^A max | 50 mg/kg ^{B,C} | D7797 /IP 583, IP 585, ^D IP 590, IP 599 |
| Pipeline Drag Reducing Additive (DRA), ^E max | 72 µg/L ^F | D7872 |

^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.

^E Active polymer ingredient.

^F DRA is not approved as an additive for jet fuel. This level is accepted by approval authorities as the functional definition of “nil addition.”

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, 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 Dxxxx/IP xxx. Where test methods are technically equivalent or related but not officially jointed, this is denoted as Dxxxx 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 freezing 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.

12. Keywords

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

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

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 Specification D1655 to support applications that are not within the stated scope of this specification, such as unique gas turbine engine designs not used in civil applications (for example, military aircraft), diesel engines (either in ground vehicles or aircraft), or other novel engine or vehicle designs, are considered when the proposed changes do not conflict with or further burden the primary purpose of supporting aircraft and engines utilized in civil aviation. Conversely, requests to modify Specification D1655 to better support civil aviation cannot be contingent upon the

requirements of these vehicles, engines, or aircraft that are outside the scope of this specification.

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.

¹⁶ *Manual on Significance of Tests for Petroleum Products*, MNL 1, ASTM International, 2003.

¹⁷ MNL 37, *Fuels and Lubricants Handbook: Technology, Properties, Performance, and Testing*, Eds., Totten, George E., Westbrook, Steven R., and Shah, Rajesh J., ASTM International, W. Conshohocken, PA, 2003.

¹⁸ *Handbook of Aviation Fuel Properties*, Fourth Edition (2014), *CRC Report 663*, Coordinating Research Council, Atlanta, GA, 30022.

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 | |
| | Chloride contamination | X1.12.6 | |
| | Fuel lubricity | X1.10 | |
| | Fuel lubricating ability (lubricity) | Additives | X1.15.1 |
| | | Sample containers | X1.15.3 |
| | Miscellaneous | | |

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 1972 and Bert and Painter's SAE paper 730385¹⁹) that concluded Test Method **D3241** at 245 °C gave equivalent results to **D1660** at specified test conditions. Specification D1655 mandated Test Method **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 Test Method **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**,

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.

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.

X1.6 Fuel Atomization

X1.6.1 *Distillation*—The fuel volatility and ease of vaporization at different temperatures are determined by distillation. The 10 % distilled temperatures are limited to ensure easy starting. The Final Boiling Point limit excludes heavier fractions that would be difficult to vaporize.

X1.6.1.1 Test Method **D86** or IP 123 is the referee method for measuring distillation properties; Test Methods **D2887/IP 406** and **D7345** are approved as alternative methods. Results from Test Method **D7345** shall be corrected for relative bias by applying the GRP4 corrections in the Test Method **D7345** Precision and Bias section. Test Method **D86** or IP 123 and Test Method **D2887/IP 406** do not give the same numerical results. Test Method **D2887/IP 406** always starts at a lower temperature and ends at a higher temperature than Test Method **D86** or IP 123 because Test Method **D2887/IP 406** gives true boiling point distribution (similar to Test Method **D2892**), as opposed to Test Method **D86** or IP 123, which is a low efficiency distillation. To avoid confusion, it is required that Test Method **D2887/IP 406** results be reported as estimated **D86** or IP 123 results by applying the correlation in Appendix X4 of Test Method **D2887** or Annex G of IP 406.

X1.6.1.2 Caution should be used when using distillation properties to estimate other fuel properties. A correlation equation giving a quantitative estimate of a fuel property based on Test Method **D86** or IP 123 data should not be used with unconverted Test Method **D2887/IP 406** results without validation. Further, Test Method **D2887/IP 406** results converted into a form compatible with Test Method **D86** or IP 123 might not be suitable for some property correlations because of the accumulation of errors from each correlation step.

X1.6.2 *Viscosity*—The viscosity of a fuel is closely related to pumpability over the temperature range and consistency of fuel nozzle spray patterns. The ability of fuel to lubricate a pump can also be related to the viscosity.

X1.6.2.1 Some engine and auxiliary power unit (APU) manufacturers specify a maximum viscosity of 12 mm²/s to ensure satisfactory low temperature operation. Aviation turbine fuel viscosity can exceed 12 mm²/s as the fuel temperature approaches the specification freezing point maximum when the viscosity at –20 °C exceeds 5.5 mm²/s for Jet A (–40 °C freezing point) or 4.5 mm²/s for Jet A-1 (–47 °C freezing point). Most commercially available jet fuels have viscosities at –20 °C below these values.

X1.6.2.2 Some small propulsion engines and APUs do not have inlet fuel-oil heat exchangers to warm the fuel and lower the viscosity. This can potentially impact certain aircraft operation such as limiting the low temperature start envelope, which could impact Extended Twin Operations (ETOPS). While there are no known field problems at this time, there needs to be further discussion on the need for all the fuel being

delivered to these engines to have a 12 mm²/s maximum viscosity, and on how this could be accomplished (for example, through fuel specification changes, airframe or APU design changes, or operational changes).

X1.6.2.3 Test Method **D7945** includes a procedure for assessing the temperature at which the fuel viscosity reaches 12 cSt.

X1.7 Fluidity at Low Temperatures

X1.7.1 *Freezing Point*—The freezing point is particularly important and must be sufficiently low to preclude interference with flow of fuel through filter screens to the engine at temperatures prevailing at high altitudes. The temperature of fuel in an aircraft tank decreases as the outside temperature decreases. The minimum temperature experienced during a flight depends mostly on the outside air temperature, flight duration, and aircraft speed. For example, long duration flights would require fuel of lower freezing point than would short duration flights.

X1.7.1.1 The manual freezing point method, Test Method **D2386/IP 16**, has a long history of providing results sufficient to support safe aviation operations, so it is designated the referee method. As shown by the results in RR:D02-1572¹⁵, automated methods often provide greater precision in determining freezing point and more sensitivity to cross-product contamination than the manual method, so their use is recommended in certifying and recertifying jet fuel. Recent experience has shown, however, that automated methods sometimes give unreliable freezing points or freezing points significantly warmer than the manual method. In such cases, in the absence of cross-product contamination, the fuel may be certified/recertified by the manual method.

X1.7.1.2 Because of the advantages of automated freezing point methods, many laboratories no longer run the manual freezing point method on a routine basis. It is recommended, when requesting manual freezing point measurements, that requestors ensure that the method is being conducted properly.

NOTE X1.1—Absence of cross-product contamination is intended to set an expectation that the possibility and ramifications of cross-product contamination are considered before the fuel is released, hence this decision should not be made solely on the manual freezing point result.

X1.8 Compatibility with Elastomer and the Metals in the Fuel System and Turbine

X1.8.1 *Mercaptan Sulfur*—Mercaptans are known to be reactive with certain elastomers. A limitation in mercaptan content is specified to preclude such reactions and to minimize the unpleasant mercaptan odor.

X1.8.2 *Sulfur*—Control of sulfur content is significant for jet fuels because the sulfur oxides formed during combustion may be corrosive to turbine metal parts.

X1.8.3 *Copper Strip Corrosion*—A requirement that jet fuel must pass the copper strip test ensures that the fuel will not corrode copper or any copper-base alloys in various parts of the fuel system.

X1.8.4 *Total Acidity*—Some petroleum products are treated with mineral acid or caustic, or both, as part of the refining procedure. Any residual mineral acid or caustic is undesirable.

Neither impurity is likely to be present. However, a determination of acidity confirms this when inspecting new or unused fuel. It also measures organic acids if present.

X1.9 Fuel Storage Stability

X1.9.1 *Existent Gum*—Gum is a nonvolatile residue left on evaporation of fuel. Steam or air is used as an evaporating agent for fuels that are to be used in aircraft equipped with turbine engines. The amount of gum present is an indication of the condition of the fuel at the time of test only. Large quantities of gum are indicative of contamination of fuel by higher boiling oils or particulate matter and generally reflect poor fuel handling practices.

X1.10 Fuel Lubricity

X1.10.1 Aircraft/engine fuel system components and fuel control units rely on the fuel to lubricate their sliding parts. The effectiveness of a jet fuel as a lubricant in such equipment is referred to as its *lubricity*. Differences in fuel system component design and materials result in varying degrees of equipment sensitivity to fuel lubricity. Similarly, jet fuels vary in their level of lubricity. In-service problems experienced have ranged in severity from reductions in pump flow to unexpected mechanical failure leading to in-flight engine shutdown.

X1.10.2 The chemical and physical properties of jet fuel cause it to be a relatively poor lubricating material under high temperature and high load conditions. Severe hydroprocessing removes trace components resulting in fuels that tend to have lower lubricity than straight-run or wet-treated fuels. Corrosion inhibitor/lubricity improver additives (see [Table 2](#)) are routinely used to improve the lubricity of military fuels and may be used in civil fuels. These additives vary in efficacy and may be depleted by adsorption on tank and pipe surfaces, so treat rates should be set with care. Because of their polar nature, these additives can have adverse effects on fuel filtration systems and on fuel water separation characteristics. For this reason, it is preferable to avoid adding more of these additives than needed. When adequate jet fuel lubricity performance is achieved solely by additive use (without BOCLE testing or commingling with higher lubricity fuels), the additive concentration should be used at no less than its Minimum Effective Concentration (MEC) from the military Qualified Products List (QPL-25017). These levels are:

| CI/LI Additive | MEC |
|-----------------|---------------------|
| HITEC 580 | 15 g/m ³ |
| Innospec DCI-4A | 9 g/m ³ |
| Nalco 5403 | 12 g/m ³ |

X1.10.3 Most modern aircraft fuel system components have been designed to operate on low lubricity fuel (Test Method [D5001](#) (BOCLE) wear scar diameter up to 0.85 mm). Other aircraft may have fuel system components that are more sensitive to fuel lubricity. Because low lubricity fuels are commingled with high lubricity fuels in most distribution systems, the resultant fuels no longer have low lubricity. However, problems have occurred when severely hydroprocessed fuel from a single source was the primary supply for sensitive aircraft. Where there are concerns about fuel lubricity,

the air frame manufacturer can advise precautionary measures, such as the use of an approved lubricity additive to enhance the lubricity of the fuel.

X1.10.4 Test Method [D5001](#) (BOCLE) is a test for assessing fuel lubricity where lower lubricity fuels give larger BOCLE wear scar diameters. BOCLE is used for in-service trouble shooting, lubricity additive evaluation, and in the monitoring of low lubricity test fluid during endurance testing of equipment. However, because the BOCLE may not accurately model all types of wear that cause in-service problems, other methods may be developed to better simulate the type of wear most commonly found in the field.

X1.10.5 Regulations are requiring increased production and distribution of ultralow sulfur diesel fuel (15 ppm maximum sulfur content). Diesel fuels are desulfurized to these low levels by severe hydroprocessing, sometimes resulting in very low lubricity fuels. Jet fuel lubricity may be impacted by the increased use of low sulfur diesel fuel, because batches of jet fuel may be made to these ultralow sulfur levels to maintain efficient production and distribution.

X1.11 Fuel Handling

X1.11.1 *Flash Point*—The flash point is an indication of the maximum temperature for fuel handling and storage without serious fire hazard. The shipment, storage, and handling precautions regulated by municipal, state, or federal laws and insurance requirements are a function of the flash point for the particular fuel being utilized.

X1.11.2 *Static Electricity*—The generation and dissipation of static electricity can create problems in the handling of aviation fuels. Electrical conductivity additives can be added to dissipate charge more rapidly. This is most effective when the fuel conductivity is in the range from 50 to 600 pS/m. Studies have shown that when fuels treated with conductivity additive are commingled with non-additized fuel resulting in a low conductivity fuel, that fuel blend does not exhibit unusual static behavior. For more information on this subject, see [Guide D4865](#).

X1.12 Fuel Cleanliness and Contamination

X1.12.1 Introduction:

X1.12.1.1 Unlike most other fuel properties, fuel cleanliness is dynamic; constantly changing during transportation and distribution. Jet fuel should be maintained in as clean a condition as possible right up to and in airport storage to ensure that possible failures of individual filtration components will not result in an unsafe condition. Airport control of cleanliness should be such as to ensure that only fuel relatively absent of free water and solid particulates is delivered into aircraft.

X1.12.1.2 The cleanliness of aviation turbine fuel is an essential performance requirement. Cleanliness requires the relative absence of free water and solid particulates. Water or dirt contamination, or both, in fuel onboard an aircraft represents a threat to flight safety and can cause long-term problems in areas such as wear, corrosion, and plugging of filters and other narrow tolerance parts.

X1.12.1.3 The cleanliness of aviation turbine fuel is protected in part by allowing time for dirt and water to settle

during fuel distribution and by the routine use of effective filtration that removes both dirt and water. Generally the fuel handling system filters the fuel several times between manufacture and use with the final filtration occurring as the fuel is loaded onto an aircraft.

X1.12.2 *Undissolved Water*—The test method for undissolved water provides a quantitative means for measuring the amount of undissolved or free water in flowing fuel streams without exposing the sample to the atmosphere or to a sample container. It also provides a means for checking the performance of fuel filter-separators. Test Method **D3240** describes this test method.

X1.12.3 *Free Water and Particulate Contamination in Distillate Fuels (Clear and Bright Pass/Fail Procedures)*—The procedures in Test Method **D4176** provide rapid but nonquantitative methods for detecting contamination in a distillate fuel. Other following methods permit quantitative determinations.

X1.12.4 *Particulate Matter*—The presence of adventitious solid particulate contaminants such as dirt and rust may be detected by filtration of the jet fuel through membrane filters under prescribed conditions. Test Methods **D2276/IP 216** and **D5452/IP 423** describe a suitable technique.

X1.12.4.1 *Membrane Color Ratings*—Filtering the fuel through a membrane and rating the color of the deposits against a standard color scale offers a qualitative assessment of particulate contaminant levels in fuels or of changes in fuel contaminant levels at a particular location. Appendix XI on Filter Membrane Color Ratings for Fuels of Test Method **D2276** or Annex B of IP 216 describes a suitable technique.

X1.12.4.2 *Automatic Particle Counter*—The test methods provide a means for measuring the quantity and size distribution of solid particulate and free water droplet contaminants in jet fuel. Chemical additives can be used to eliminate free water droplets from being counted as particulates. Test Methods **D7619**, IP 564, IP 565, and IP 577 describe suitable techniques.

X1.12.5 *Microbial Contamination*—Uncontrolled microbial contamination in fuel systems can cause or contribute to a variety of problems including corrosion, odor, filter plugging, decreased stability, and deterioration of fuel/water separation characteristics. In addition to system component damage, off-specification fuel can result.

X1.12.5.1 *Microorganisms* (that is, bacteria, yeast, and mold) that have become established in a fuel system can present the fuel manufacturer, distributor, or user with a unique set of operational and maintenance challenges. Unlike inanimate material such as dirt, rust, or chemicals, microorganisms are living organisms that are ubiquitous in the environment, can reproduce from a single cell into a great number ($>10^9$) of cells, are transported during fuel movement, need only small amounts of water to remain viable and utilize aviation fuel as a food source. Gross evidence of the presence of microbial contamination can include suspended matter in the fuel or at the fuel water interface and/or the smell of “rotten egg” which is due to the presence of hydrogen sulfide a typical metabolite of sulfate reducing bacteria. There are a number of semi-quantitative and quantitative techniques available when gross observation proves inconclusive to rule out the presence of

microorganisms. These techniques include nutrient/growth media, bioluminescence and immunoassay. As a result of uncontrolled microbial growth, structural components that make up the aviation fuel storage and distribution network such as product pipeline, tankers, storage tanks and airport fueling hydrant systems can experience accelerated forms of corrosion thereby compromising the integrity and operation of the fuel network as well as acting as a conduit to introduce microorganisms into aircraft fuel systems.

X1.12.5.2 Once microorganisms have established a presence in an aircraft fuel system a variety of operational and maintenance issues can occur that could affect the safe and economic operation of the aircraft. For example, uncontrolled microbial contamination can lead to the corrosion of metallic structures such as wing tanks; degradation of protective coatings, alloys, and electrical insulation; erratic readings in the Fuel Quantity Indication System (FQIS); blocking of the scavenge systems; and blocking of engine fuel filters. The two biocide additives that are generally approved for use by the airframe and engine manufacturers are Biobor JF²¹ and KATHON.²² These biocide additives may be used in aviation fuel only in accordance with local regulations, aircraft engine guidelines and airframe manufacturer guidelines. The ultimate user shall be informed and agree to the presence of biocide additive in their jet fuel supply. Consult with the appropriate Aircraft Maintenance Manual (AMM) for instructions.

X1.12.5.3 Guide **D6469** provides individuals with a limited background in microbiology an understanding of the occurrence, symptoms, and consequences of chronic microbial contamination. The guide also suggests means for detection and remediation of microbial contamination in fuels and fuel systems. IATA Guidance Material on Microbiological Contamination in Aircraft Fuel Tanks also provides guidance for determining the potential source, detection and remediation of the potential microbial contamination.

X1.12.6 *Chloride Contamination*—Chloride present in aviation turbine fuel can originate from refinery salt drier carryover or seawater contamination (for example, product transferred by marine vessel). Elevated chloride levels (for example, 11 900 ppm to 21 900 ppm in the form of NaCl) in wing tank water bottoms have caused corrosive wear of aircraft fuel control systems leading to engine failure as documented in IATA Guidelines for Sodium Chloride Contamination Troubleshooting and Decontamination of Airframe and Engine Fuel Systems. The IATA report states that jet fuel with water bottoms containing less than 500 ppm NaCl “...appears to have no detrimental operating effects to the systems.” (Units of “ppm” are used in the IATA report with no indication as to whether this concentration was determined on a mass or volume basis.) Due to the rigorous housekeeping procedures utilized by petroleum distribution systems, a water bottom sample is often not available for analysis. Australian Defence Standard Def (Aust) 5240B, Amendment 1, April 1990 (now

²¹ Biobor JF is a registered trademark of Hammonds Technical Services, Inc. 910 Rankin Rd., Houston, TX 77073.

²² KATHON is a trademark of The Dow Chemical Company (“Dow”) or an affiliated company of Dow, 2030 Dow Center, Midland, MI 48674.

withdrawn) specified that jet fuel have less than 0.15 mg/L chloride calculated as NaCl. When calculated as chloride alone this value becomes 0.09 mg/L. However the background for this Def (Aust) requirement has been lost. Test Method **D7959** provides a rapid means of determining chloride content in aviation turbine fuel. The test method is a relatively inexpensive methodology to determine chloride content using widely available laboratory equipment. As jet fuel cools at altitude, free water will separate, which will promote the settling of any emulsified brine and most likely solubilize any inorganic chloride crystals present in the fuel. The amount of free water that separates and resulting chloride concentration of that water depends on several factors (for example, water content of the jet fuel, chloride present in the jet fuel, and temperature). The maximum permissible chloride content in jet fuel is under investigation within industry. If elevated chloride content is detected in the fuel, subsequent trace metals analysis could help identify the chloride origin (that is, refinery salt drier carryover or seawater contamination). Salt driers predominately use NaCl or a combination of NaCl and CaCl₂. MgCl₂ is prominent in seawater but rarely (if ever) used in salt driers.

X1.13 Surfactants

X1.13.1 A key element in preventing contamination is to minimize or eliminate surfactants, which can compromise the ability of fuel handling systems to remove dirt and water. For example, surfactants can reduce the particle size of suspended solid and water droplets, which slows removal by settling. Surfactants can disperse dirt and water so finely that they pass through filters. Surfactants can adsorb on the surfaces of filter/coalescers interfering with water removal. Surfactants can also lift rust from surfaces, thus increasing the solids level in the fuel.

X1.13.2 *Water Separation Characteristics*—The ease of coalescence of water from fuels as influenced by surface active agents (surfactants) is assessed by Test Methods **D3948** and is designed to be used as a field or laboratory method. A high rating suggests a fuel free of surfactants; a low rating indicates that surfactants are present. Surfactants, which may be contaminants or deliberately added materials, may gradually disarm filter coalescers, allowing fine water droplets and particulate contaminants to pass separators in ground handling equipment. High microseparator rating results support the expectation that filters/coalescers will remove dirt and water. (The water removal performance of filter monitors is believed to be insensitive to surfactants.)

X1.13.2.1 *Water Separation Characteristics at Point of Manufacture*—The presence of surfactants in aviation turbine fuel specified by Specification D1655 is controlled at the point of manufacture by the Test Method **D3948** performance requirement listed in **Table 1**. To determine if surfactant contamination occurs during transportation the fuel should also be tested downstream of the point of manufacture as appropriate.

X1.13.2.2 *Water Separation Characteristics at Points Downstream*—Results of downstream Test Method **D3948** testing are not to be used as the sole reason for rejection of fuel, but they can indicate a mandatory need for further diligent

investigation or remedial action, or both, such as passing the fuel through a clay adsorption unit to remove surfactants. (A protocol giving guidelines on possible actions to be taken following failed microseparator testing can be found in the Joint Inspection Group’s Bulletin Number 65 under “product specifications.”) However, the fuel may be rejected in the absence of satisfactory Test Method **D3948** testing results if no documented evidence is presented that a detailed investigation was carried out or if it is uncertain that the fuel will be free of excess water and dirt when delivered into aircraft.

X1.13.2.3 *Water Separation Assessment*—Because distribution systems can be complex and employ a variety of methods of transporting the fuel, sampling points and methodologies should be established as a result of a technical assessment designed to ensure that fuel cleanliness is maintained throughout the system to the point of delivery into aircraft. Since transport systems vary in their basic nature, for example, a multi-product pipeline versus a dedicated pipeline, and also in their detailed operating conditions, the parties assuming custody of the fuel should evaluate their particular systems and establish suitable testing requirements.

X1.14 Cleanliness at Time of Fuel Custody Transfer at Airport

X1.14.1 Airport fueling is the most critical location for controlling dirt and water cleanliness. Into-airport storage is thus an important point for controlling surfactant contamination so as to protect out-of-storage and into-plane dirt and water filtration.

X1.15 Miscellaneous

X1.15.1 *Additives*—Antioxidants and metal deactivator additive (MDA) are used to prevent the formation of oxidation deposits in aircraft engine fuel systems, to counteract the catalytic effects of active metals (see **X1.3.3**) in fuel systems, and to improve the oxidation stability of fuels in storage. Note that fuel containing MDA has been shown to promote the dissolution of copper and can exacerbate thermal stability problems. Other additives are available to inhibit the corrosion of steel in fuel systems, to improve the fuel lubricity, to increase the electrical conductivity of fuel, to combat micro-biological organisms, to prevent the formation of ice in fuel systems containing water, and to assist in detecting leaks in fuel storage, delivery, and dispensing systems. The chemical names or registered trade names of approved additives and the maximum quantities permitted are shown in the specifications.

X1.15.1.1 *Fuel System Icing Inhibitor*, diethylene glycol monomethyl ether (DiEGME) conforming to the requirements shown in Specification **D4171**, Type III, may be used in concentrations of 0.07 % to 0.15 % by volume. Test Method **D5006** can be used to determine the concentration of DiEGME in aviation fuels.

X1.15.2 *Leak Detection Additive*—Addition of leak detection additive, Tracer A approved in **Table 2**, should be added to the fuel in accordance with the Tracer Tight²³ methodology.

²³ Tracer Tight is a registered trademark of Tracer Research Corp., 3755 N. Business Center Dr., Tucson, AZ 85705.

X1.15.3 *Sample Containers*—A practice for sampling aviation fuel for tests affected by trace contamination can be found in Practice **D4306**.

X1.15.4 *Color*—While this specification does not have a color requirement, color can be a useful indicator of fuel quality. Normally fuel color ranges from water white (colorless) to a straw/pale yellow. Other fuel colors may be the result of crude oil characteristics or refining processes. Darkening of fuel or a change in fuel color may be the result of product contamination and may be an indicator that the fuel is off-specification, which could render it unfit and not acceptable for aircraft/engine use. Fuel having various shades of color, that is, pink, red, green, blue, or a change in color from the supply source should be investigated to determine the cause of color change to ensure suitability for aircraft/engine use and should be documented prior to final delivery to airport storage.

X1.16 Identified Incidental Materials

X1.16.1 Identified incidental materials are chemicals and compositions that have defined upper content limits in aviation

fuel but are not approved additives (see **Table 2**). Identified incidental materials can occur in turbine fuel as a result of production, processing, distribution or storage (see **Table 3**). Identified incidental materials are unavoidable from a practical view point. **Table 3** lists specific materials and their mandatory limits for compliance with this specification. **Table 3** does not include dirt and water, which are identified incidental materials controlled by aviation fuel handling standards. Turbine fuel containing an identified incidental material in excess of the limit listed in **Table 3** may not comply with the operating limitations approved by aircraft regulatory authorities for use on commercial aircraft.

X1.16.2 It is not necessary to test each batch of turbine fuel for compliance with **Table 3**. The implementation of control or management of change schemes that satisfy the expectation that **Table 3** limits are not exceeded is adequate to meet the requirements of this specification.

X1.16.3 Additional test methods for FAME content analysis are being developed by the Energy Institute and will be cited when complete.

X2. CONTROL OF PROCESSING ADDITIVES, DISTRIBUTION, AND OTHER USES

X2.1 Experience has shown that refinery processing additives, such as corrosion inhibitors, might be carried over in trace quantities into aviation fuel during refinery production. In some cases, this has resulted in operational problems in aircraft fuel systems. Moreover, these additives can cause problems at levels which may not be detected by the standard specification testing detailed in **Table 1**. While the specification (**6.1.2**) requires that only approved additives are used, confirming that non-approved additives are absent is difficult, because it is unclear what analytical method to apply, given that:

X2.1.1 The analytical target may be uncertain, since there is a wide range of (often proprietary) materials involved.

X2.1.2 There is no industry-agreed basis for determining the required analysis sensitivity.

X2.1.3 There usually are no available data, relating to processing additive concentration to aircraft system performance, to set no-harm levels (to define analysis sensitivity).

X2.2 It is therefore not practical for this specification to require detailed chemical analysis of each production batch of aviation fuel beyond the requirements listed in **Table 1**. Instead, each manufacturing location should ensure that procedures are in place to control processing additive use and impact on product performance. One acceptable approach to do this is to

implement a management of change procedure that evaluates the impact of processing changes (including process additives) on finished product quality. Other approaches may also be acceptable.

X2.3 Distribution Control

X2.3.1 Although the application of Specification D1655 extends from jet fuel manufacture to the wing tip, Specification D1655 does not define quality assurance testing and handling procedures appropriate for maintaining the quality of the fuel through the distribution system. Standards for such procedures were originally developed and maintained by fuel suppliers/handlers. Recent initiatives in response to field incidents have resulted in the industry publishing ICAO 9977 to provide guidance for jet fuel handling. ICAO 9977 calls out EI/JIG 1530, JIG 1, JIG 2, API 1543, API 1595, and other standards for producing, handling, and supplying aviation fuels. Changes in the fuel handling systems should be subject to a formal risk and management of change assessment to ensure product quality is maintained.

X2.4 Information on Other Uses of Specification D1655 Aviation Turbine Fuel

X2.4.1 Specification D1655 fuel is used in other applications besides aviation turbines. This section covers some important guidance information for these other applications.

X2.4.2 Compression-ignition Aircraft Engines:

X2.4.2.1 Some compression-ignition aircraft engines are designed to operate with jet fuel meeting Specification D1655. These engines require jet fuel within a certain cetane number range to ensure stable operation, but cetane number (Test Method D613) or derived cetane number (Test Methods D6890/D7170/D7668) is not listed as a required property in Table 1 of Specification D1655. Jet fuel properties that are specified in Table 1 of Specification D1655 do allow for the

calculation of cetane index, which can be used as an approximation for cetane number. Cetane index is derived from distillation and density using Test Method D4737 (Procedure A). However, it should be noted that the Test Method D4737 correlation was not developed with consideration of synthetic kerosenes such as those identified in Specification D7566, and therefore, its accuracy may be suspect should these blend components be present.

X3. FORM FOR REPORTING INSPECTION DATA ON AVIATION TURBINE FUELS

X3.1 Introduction

X3.1.1 Many airlines, government agencies, and petroleum companies make detailed studies of inspection data provided on production aviation turbine fuels. Because a large number of inspections or inspection locations, or both, is generally involved, these studies are frequently made with the aid of a computer. Without a standardized form for reporting data from different sources, transcribing the reported data for computer programming is laborious. An individual must search each different data sheet for desired information because of the random ordering of results by different reporting laboratories. One objective, therefore, of a standard reporting form is to provide a precise ordering of inspection test data being reported.

X3.1.2 The inspection form shown in Fig. X3.1 incorporates the requirements of the most commonly used international fuel specifications, including Specification D1655, British specification Defence Standard (DERD 2494), and IATA Guidance Material on Microbiological Contamination in Aircraft Fuel Tanks.

X3.1.3 A suggested, nonmandatory form for reporting inspection data in a Certificate of Quality or Analysis format is given as Fig. X3.2.

X3.1.4 Specific users of aviation turbine fuels sometimes find it necessary to specify properties that are not included in Specification D1655, which are provided as a basis for formulating their own specifications. Another objective of a standard form is to list all tests that might be included in the large number of individual aviation turbine fuel specifications. The fact that a particular test is listed in the standard reporting form does not in itself indicate that there is a universal need for a specification limit. For example, a high-performance military aircraft might have fuel requirements not applicable to subsonic commercial aircraft.

X3.1.5 The third objective in meeting future electronic commerce needs is to establish the industry standard to be used to electronically transmit aviation turbine fuel quality data from one location to another. This form will serve as the template for mapping to ANSI 863 for aviation fuels.

X3.2 Dimensions of Standard Form

X3.2.1 A standard reporting form for aviation turbine fuels is shown in Fig. X3.1.

X3.2.2 Earlier versions of this form were available from ASTM as Adjunct 12-416552-00 and were sized so that the forms could be used in a standard typewriter. Because of decreased use, the form is now presented only as an example of a suitable data reporting sheet and is no longer available from ASTM as an adjunct.

X3.3 Description of Standard Form

X3.3.1 The top of the form (Header Section) provides a method for entering pertinent information regarding description and identity of the fuel being tested and the laboratory performing the tests. Items in italic print are mandatory items. Fill in only those data elements necessary to cover the individual testing situation. Explanation of non-self-explanatory Entries is provided below:

X3.3.1.1 *Manufacturer/Supplier*—Agency or activity who has possession of the fuel to be tested.

X3.3.1.2 *Product Code/Grade*—Accepted code for product being tested.

X3.3.1.3 *Sampling Location*—Place where sample was collected, as specific as possible.

X3.3.1.4 *Batch Number*—If sample was taken from the storage tank, this number should be the batch number of the product in the tank. If the sample is a composite of a shipment, this number should be the batch number or cargo number that represents the shipment.

X3.3.1.5 *Destination*—Location to which the product will be shipped. If more than one location, write *Multiple* in this block and list locations in the *Comments* block at the bottom of the form.

X3.3.1.6 *Crude Source*—If required by contract or other agreement, list the crude(s) and percentages used to refine the product. This is done in an attempt to correlate fuel properties with types of crudes.

X3.3.1.7 *Processing Method*—If required by contract or other agreement, list the crude processing technique(s) used to refine the product. Examples are hydrotreating, caustic wash, hydrocracking, merox, and so forth. (All assume atmospheric distillation.) Used in conjunction with the crude source, this information can be used to correlate fuel properties with crude processing technique.

X3.3.2 The body of the form provides for entering test results. There are four columns provided for each test.

INSPECTION DATA ON AVIATION TURBINE FUEL
(Items in **bold** type are referenced in the specification)

MANUFACTURER/SUPPLIER _____
 PRODUCT CODE/GRADE _____
 SPECIFICATION _____
 SAMPLE NUMBER _____
 DATE SAMPLED _____
 SAMPLING LOCATION _____
 BATCH NO. _____
 QUANTITY LITRES @ 15°C _____
 QUANTITY U.S. GALLONS @ 60°F _____
 LABORATORY _____

DATE SAMPLED _____
 DATE RECEIVED AT LAB _____
 CONTRACT NO. _____
 ORDER NO. _____
 TANK NO. _____
 DESTINATION _____
 CRUDE SOURCE _____
 PROCESSING METHOD _____
 REMARKS _____

| <u>Method</u> | | <u>Result</u> | <u>Method</u> | | <u>Result</u> |
|-----------------------------|---|---------------|--------------------------|--|---------------|
| | APPEARANCE | | | COMBUSTION | |
| 010 | D156 Color (Saybolt) | ◇◇◇ | 400A | D240 or IP 12 Net Heat of Combustion (MJ/kg) | ◇◇●◇◇◇ |
| 020 | D6045 Color (Saybolt) | ◇◇◇ | 400B | D1405 Net Heat of Combustion (MJ/kg) | ◇◇●◇◇◇ |
| 030 | D4176 Visual ("Pass" or "Fail") | ◇◇◇◇ | 400C D3338 | Net Heat of Combustion (MJ/kg) | ◇◇●◇◇◇ |
| | COMPOSITION | | 400D D4529 | Net Heat of Combustion (MJ/kg) | ◇◇●◇◇◇ |
| 100C D3242/IP 354 | Acidity, Total (mgKOH/g) | ◇●●◇◇ | 400E D4809 | Net Heat of Combustion (MJ/kg) | ◇◇●◇◇◇ |
| 110 | D1319 or IP 156 Aromatics (vol %) | ◇◇●◇◇ | 410 D1740 | Luminometer No. | ◇◇ |
| 112 D6379/IP 436 | Aromatics (vol %) | ◇◇●◇◇ | 420 D1322/IP 598 | Smoke Point (mm) | ◇◇●◇ |
| 115 | D1319 or IP 156 Olefins (vol %) | ◇◇●◇◇ | | CORROSION | |
| 120 D1840 | Naphthalene (vol %) | ◇◇●◇◇ | 500 D130/IP 154 | Copper Strip | ◇◇ |
| 130 D3227/IP 342 | Sulfur, Mercaptan (mass %) | ◇●●◇◇◇ | 510 | IP 227 Silver Strip | ◇ |
| 140 | D4952 or IP 30 Doctor Test (P = pos, N = neg) | ◇ | | STABILITY | |
| 150A | D129 Sulfur, Total (mass %) | ◇●◇◇◇ | 601A D3241/IP 323 | Filter ΔP (mm Hg) @ other temp | ◇◇●◇ |
| 150B D1266 | Sulfur, Total (mass %) | ◇●◇◇◇ | 602A D3241/IP 323 | Tube Deposit @ other temp | ◇◇◇◇ |
| 150D D2622 | Sulfur, Total (mass %) | ◇●◇◇◇ | 603A D3241/IP 323 | TDR Spun Rating @ other temp | ◇◇ |
| 150E | D3120 Sulfur, Total (ppm) | ◇◇◇◇◇ | 604A | Temperature (°C) of above | ◇◇◇◇ |
| 150F D4294 or IP 336 | Sulfur, Total (mass %) | ◇●◇◇◇ | 601B D3241/IP 323 | Filter ΔP (mm Hg) @ 260°C | ◇◇●◇ |
| 150G D5453 | Sulfur, Total (ppm) | ◇●◇◇◇ | 602B D3241/IP 323 | Tube Deposit Rating @ 260°C | ◇◇◇◇ |
| 160A | D3343 Hydrogen Content (mass %) | ◇◇●◇◇ | 603B D3241/IP 323 | TDR Spun Rating @ 260°C | ◇◇ |
| 160B | D3701 Hydrogen Content (mass %) | ◇◇●◇◇ | | CONTAMINANTS | |
| | VOLATILITY | | 700 | IP 225 Copper Content (mg/kg) | ◇●◇◇ |
| 200A D86 or IP 123 | Distillation by Auto/Manual (°C) | ◇ | 710 D381 | Existent Gum (mg/100 mL) | ◇◇◇ |
| 200B | D2887 or IP 406 Distillation by GC (°C) | ◇ | 710A IP 540 | Existent Gum (mg/100 mL) | ◇◇◇ |
| 200C | D7345 Distillation by Micro Distillation Method | ◇ | 720A | D2276/IP 216 Particulate (mg/L) | ◇●◇◇ |
| 201 | Distillation by Initial BP (°C) | ◇◇◇●◇ | 720B | D5452/IP 423 Particulate (mg/L) | ◇●◇◇ |
| 202 | Distillation by 10 % Rec (°C) | ◇◇◇●◇ | 730 | Filtration time (minutes) | ◇◇ |
| 203 | Distillation by 20 % Rec (°C) | ◇◇◇●◇ | 740 D1094 | Water Reaction Interference Rating | ◇◇ |
| 204 | Distillation by 50 % Rec (°C) | ◇◇◇●◇ | 750 | D3948 MSEP (With SDA) | ◇◇◇ |
| 205 | Distillation by 90 % Rec (°C) | ◇◇◇●◇ | 751 | D3948 MSEP (Without SDA) | ◇◇◇ |
| 206 | Distillation by 95 % Rec (°C) | ◇◇◇●◇ | | ADDITIVES | |
| 211 | Distillation by Final BP (°C) | ◇◇◇●◇ | 800 | Antioxidant (mg/L) | [] ◇◇●◇ |
| 213 | Residue (vol %) | ◇●◇ | 810 | Metal Deactivator (mg/L) | [] ◇●◇ |
| 214 | Loss (vol %) | ◇●◇ | 820 | Static Dissipator Additive (mg/L) | [] ◇●◇ |
| 220A D56 | Flash Point, Tag Closed (°C) | ◇◇●◇ | 830A (D5006) | FSII (vol%) | [] ◇●◇◇◇ |
| 220B | D93/IP 34 Flash Point, PM Closed (°C) | ◇◇●◇ | 830B (FTM5327) | FSII (vol%) | [] ◇●◇◇◇ |
| 220C D3828 or IP 523 | Flash Point, Setaflash (°C), Meth A | ◇◇●◇ | 830C (FTM5340) | FSII (vol%) | [] ◇●◇◇◇ |
| 220D | D3828 or IP 523 Flash Point, Setaflash (°C), Meth B | ◇◇●◇ | 840 | Corrosion Inhibitor (mg/L) | [] ◇◇●◇ |
| 221 | D3828 or IP 524 Flash Point, Setaflash (Flash/No Flash) | ◇ | | OTHER TESTS | |
| 230A D1298/IP 160 | Density @ 15°C (kg/m³) | ◇◇◇●◇ | 900 D2624/IP 274 | Conductivity (pS/m) | ◇◇◇◇ |
| 230B D4052/IP 365 | Density @ 15°C (kg/m³) | ◇◇◇●◇ | 901 D2624/IP 274 | Conductivity Test Temperature (°C) | ◇◇◇ |
| 231A | D1298/IP 160 API Gravity @ 60°F | ◇◇●◇ | | Comments and/or Additional Tests: | |
| 240A | D323 or IP 69 Vapor Pressure, Reid (kPa) | ◇◇●◇ | | _____ | |
| 240B | D4953 Vapor Pressure, Dry Method (kPa) | ◇◇●◇ | | _____ | |
| 240C | D5190 Vapor Pressure, Automatic Method (kPa) | ◇◇●◇ | | _____ | |
| 240D | D5191 or IP 394 Vapor Pressure, Mini Method (kPa) | ◇◇●◇ | | _____ | |
| | FLUIDITY | | | _____ | |
| 300A D2386/IP 16 | Freezing Point (°C) | -◇◇●◇◇ | | _____ | |
| 300B D5901 | Freezing Point (°C) | -◇◇●◇◇ | | _____ | |
| 300C D5972/IP 435 | Freezing Point (°C) | -◇◇●◇◇ | | _____ | |
| 300D D4305 | Freezing Point (°C) | -◇◇●◇◇ | | _____ | |
| 300F D7154/IP 528 | Freezing Point (°C) | -◇◇●◇◇ | | _____ | |
| 310A D445/IP 71 | Viscosity @ -20°C (mm²/s) | ◇◇●◇◇◇ | | _____ | |
| 310B | D7042 Viscosity @ -20°C (mm ² /s) | ◇◇●◇◇◇ | | _____ | |
| 311A | D445/IP 71 Viscosity @ other temperature (mm ² /s) | ◇◇●◇◇◇ | | _____ | |
| 311B | D7042 Viscosity @ other temperature (mm ² /s) | ◇◇●◇◇◇ | | _____ | |
| 312 | D445/Temp (°C) of Item 311 | ◇◇◇◇ | | _____ | |
| | | | | CERTIFIED BY _____ | |

FIG. X3.1 Standard Form for Reporting Inspection Data on Aviation Turbine Fuels

CERTIFICATE OF ANALYSIS TEST REPORT

For fuel supplied to ASTM D1655-XX

Date Sampled: _____ **Product:** _____ **Tank No.:** _____
Batch No.: _____ **Sample No.:** _____ **Quantity:** _____
Location: _____ **Vessel:** _____ **Pipeline:** _____

| Property | Test Method ^A | Specification Limit | Test Result | Remarks (e.g. Pass/Fail) |
|---|-----------------------------------|--|--|--------------------------|
| Appearance | | Visually free of undissolved water, sediment, and suspended matter | | |
| Composition | | | | |
| Acidity, total, mg KOH/g | D3242 | 0.10 max | | |
| Aromatics, vol% | | 25 max D1319; 26.5 max D6379 | | |
| Sulfur, total mass% | | 0.30 max | | |
| Sulfur, mercaptan mass% OR | D3227 | 0.003 max | | |
| Doctor Test | D4952 | Negative | | |
| Volatility & Density | | | | |
| Distillation | | | | |
| Initial Boiling Point, °C | | Report | | |
| 10% recovered at °C | | 205 max | | |
| 50% recovered at °C | | Report | | |
| 90% recovered at °C | | Report | | |
| End Point, °C | | 300 max | | |
| Residue, vol % | | 1.5 | | |
| Loss, vol % | | 1.5 | | |
| Flash Point, °C | | 38 min | | |
| Density at 15°C, kg/m ³ or | | 775 min to 840 max | | |
| API Gravity at 15°C | D4052 | 37 min to 51 max | | |
| | Upper | | | |
| | Middle | | | |
| | Lower | | | |
| Fluidity | | | | |
| Freezing Point, °C | | -40 max | | |
| Viscosity at -20°C, mm ² /s | | 8.0 max | | |
| Combustion | | | | |
| Specific Energy, net, MJ/kg | | 42.8 min | | |
| Smoke Point, mm OR | D1322 | 25 mm | | |
| Smoke Point, mm AND | D1322 | 18 min | | |
| Naphthalenes, vol% | D1840 | 3.0 max | | |
| Corrosion | | | | |
| Copper corrosion, classification | D130 | No. 1 max | | |
| Stability | | | | |
| Thermal Oxidative Stability | D3241 | Control Temp: 260 or 275°C | | |
| Differential Pressure, Torr | | 25 max | | |
| Tube Deposit Rating | | < 3 max, NO Peacock or Abnormal | | |
| Contaminants | | | | |
| Existent Gum, mg/100 ml | | 7 max | | |
| Microseparator (MSEP) Rating ^B | D3948 | 85 min | | |
| MSEP with Electrical Cond. Add ^C | D3948 | 70 min | | |
| Conductivity | | | | |
| Electrical Conductivity, pS/m | D2624 | 50 min to 600 max if required | | |
| Additives | Supplier & Designation | Amount Added | Comments | |
| Antioxidant | | | 24.0 mg/L max | |
| Metal deactivator (MDA) | | | 2.0 mg/L max initial blending, 5.7 mg/L max cumulative | |
| Electrical Conductivity Additive | Innospec Stadis 450 | | 3 mg/L max initial blending, 5 mg/L max cumulative | |
| FSII (DiEGME) | | | 0.10% min when required 0.15% max | |
| Corrosion Inhibitor/Lubricity Improver | | | 23 mg/L max | |

^A Blank spaces in this column indicates that the specification permits a choice of test method. Enter the method number for the test used.

^B MSEP at point of manufacture without Electrical Conductivity Additive.

^C MSEP at point of manufacture with Electrical Conductivity Add.

Certified that this sample meets the relevant specification with respect to the above tests and complies with ASTM D1655 for Jet A.

Signed: _____ **Title:** _____

Date: _____ **Lab Quality System:** _____

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Comments: _____

FIG. X3.2 Nonmandatory Form for Certificate of Analysis Test Report

X3.3.2.1 The first column shows the item number or code assigned to each specific test result. The number assignment for each grouping of fuel characteristics is as follows:

| | |
|---------|-------------|
| 10-99 | Appearance |
| 100-199 | Composition |
| 200-299 | Volatility |

| |
|---------|
| 300-399 |
| 400-499 |
| 500-599 |
| 600-699 |
| 700-799 |
| 800-899 |
| 900-999 |

| |
|--------------|
| Fluidity |
| Combustion |
| Corrosion |
| Stability |
| Contaminants |
| Additives |
| Other Tests |

The code designations are derived from a master list of codes assigned to tests performed for all products. Under these general categories, item numbers or codes increase either by one unit, five units, ten units, or an alpha character. For each property to be measured under a category, the code increases by five or ten units, depending on the number of characteristics that fall under that general category. The alpha codes represent the various methods allowed by specification to measure that characteristic. This may be a change of test method (see total sulfur as an example) or a change in test conditions (see Test Method **D3241** as an example). When the code varies by one unit, this is intended to indicate more than one reported measurement or evaluation for that particular test method (see distillation and water reaction as examples). This system allows for the coding of test methods with their equivalents and for the introduction of newly approved methods systematically into the standardization data sheet.

X3.3.2.2 The second column lists the applicable ASTM method number. Where there is no ASTM method number, the applicable IP number (Institute of Petroleum) is shown.

X3.3.2.3 The third column presents word descriptors for each test.

X3.3.2.4 The fourth column presents diamonds for entering the results of each test with location of the decimal point shown where applicable.

X3.3.3 The lower right-hand part of the form provides space for comments or for entering other test results that are not listed in the main body of the form.

X3.4 Instructions for Executing Column 4

X3.4.1 General Instructions:

X3.4.1.1 This form is intended for use with both naphtha- and kerosine-based aviation fuels and provides choice of test methods. Individual laboratory analysis reports should cite only the required or relevant data for the top of the form and reference the assigned item number or code for each characteristic analyzed. Number of decimal places or significant figures, or both, is meant to reflect that which is appropriate for the test method. When determining compliance of the data reported with the requirements of the cited specification, however, the specification values (and rules cited for rounding, if any) shall prevail. If a characteristic is determined by a method not cited in the standard form, enter the method identification and result in *Comments and/or Additional Tests* section.

X3.4.2 Detailed Instructions:

X3.4.2.1 *Items 10 and 20, Color (Saybolt)*—Enter either a (+) or a (–) sign in the first square. *Example:* +15.

X3.4.2.2 *Item 30, Visual*—According to Test Method **D4176**, report result as *Pass* or *Fail*, using the criteria outlined in the test method.

X3.4.2.3 *Item 200, Distillation*—This analysis has both a choice of methods and more than one measurement to be made per run. Selection of *A*, *B*, or *C* for item 200 selects which method is used. All of the subsequent measurements are referenced to Test Method **D86**. When Test Method **D2887** is used, the results shall be reported as estimated **D86** results by application of the correlation in Appendix X4 of Test Method **D2887**. Select, using an *x* in the appropriate *A*, *B*, or *C* item, which test method is used, and whichever items or codes apply to the particular situation or specification being reported.

X3.4.2.4 *Items 230 and 231*—For those contracts or instances that require reporting in units of API Gravity, Item 231A reports of API Gravity using Test Method **D1298**, and Item 230A reports density by the same method, either as an alternate or concurrent measurement. Item 230B reports density by using Test Method **D4052**, which only provides for density as currently written.

X3.4.2.5 *Item 310 and 311, Viscosity*—For aviation turbine fuels, viscosity is measured at –20 °C; therefore, the value for item 311 will always be –20. If the test is performed at some other temperature, use item number 311 to report this temperature.

X3.4.2.6 *Items 601–603, D3241*—Select the temperature at which the test was performed. The letter suffix refers to one temperature. Items 601 - 603, as appropriate, refer to the data for that specific test temperature. If results for runs at different temperatures are reported, then use the data with the appropriate suffix consistent for the temperature. In this manner, results for tests at 245 °C and 275 °C, for example, can be kept separate and reported simultaneously on the same report. For colors that match the Color Standards, report the color code number. If the color falls somewhere between two colors, report an L for *less than* followed by the higher code number of the two between which the color falls. If there are only abnormal or peacock deposits as defined in Test Method **D3241**, report an A or P, respectively. If there are both peacock and abnormal deposits, report both an A and P. If the darkest deposit on a tube matches a color code number but there is also an abnormal or peacock deposit, report the code number followed by an A or P, respectively. If the darkest deposit on a tube falls between two color code numbers and there are also abnormal or peacock deposits, or both, record the color as L, followed by the higher of the two code numbers, followed by A, P, or AP, as applicable.

X3.4.2.7 *Items 800, 810, 820, 830, and 840*—Enter the manufacturer’s brand name in the square provided. If there is insufficient room in the square provided, indicate by entering asterisks and provide the information on brand name in the REMARKS section.

SUMMARY OF CHANGES

Subcommittee D02.J0 has identified the location of selected changes to this standard since the last issue (D1655 – 16c) that may impact the use of this standard. (Approved Aug. 1, 2017.)

- (1) Revised **Table 2**.
- (2) Revised **1.2, 6.2, X1.2.1, X1.6.2.1, and X1.6.2.2**.
- (3) Added Test Methods **D613, D4737, D6890, D7170, D7619, D7668**, and IP 564, IP 565, and IP 577 to Referenced Documents.
- (4) Added new subsection **X1.12.4.2**.
- (5) Added new subsection **X2.4**.

Subcommittee D02.J0 has identified the location of selected changes to this standard since the last issue (D1655 – 16b) that may impact the use of this standard. (Approved Dec. 1, 2016.)

- (1) Revised subsection **X1.12.6**.

Subcommittee D02.J0 has identified the location of selected changes to this standard since the last issue (D1655 – 16a) that may impact the use of this standard. (Approved Sept. 1, 2016.)

- (1) Added Test Method **D7959** to Referenced Documents.
- (2) Revised **Table X1.1** and added new subsections **X1.12.6** and **X1.6.2.3**.

Subcommittee D02.J0 has identified the location of selected changes to this standard since the last issue (D1655 – 16) that may impact the use of this standard. (Approved Aug. 1, 2016.)

- (1) Added Test Method **D7945**, EI 1550, and EI 1583 to Referenced Documents.
- (2) Revised **Table 2**, adding new footnote H and relabeling subsequent footnotes.
- (3) Revised **Table 1**.
- (4) Revised subsection **X1.6.2**, adding new subsections **X1.6.2.1** and **X1.6.2.2**.

Subcommittee D02.J0 has identified the location of selected changes to this standard since the last issue (D1655 – 15d¹) that may impact the use of this standard. (Approved June 1, 2016.)

- (1) Revised **Table 3**; added Test Method **D7872** to Referenced Documents.
- (2) Added new term *metrological method* as subsection **3.1.2**.

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