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Standard Guide for Evaluation of New Aviation Gasolines and New Aviation Gasoline Additives[1]

This standard is issued under the fixed designation D7826; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This guide provides procedures to develop data for use in research reports for new aviation gasolines or new aviation gasoline additives.

1.2 This data is intended to be used by the ASTM subcommittee to make a determination of the suitability of the fuel for use as an aviation fuel in either a fleet-wide or limited capacity, and to make a determination that the proposed properties and criteria in the associated standard specification provide the necessary controls to ensure this fuel maintains this suitability during high-volume production.

1.3 These research reports are intended to support the development and issuance of new specifications or specification revisions for these products. Guidance to develop ASTM International standard specifications for aviation gasoline is provided in Subcommittee J on Aviation Fuels Operating Procedures, Annex A6, "Guidelines for the Development and Acceptance of a New Aviation Fuel Specification for Spark-Ignition Reciprocating Engines."

1.4 The procedures, tests, selection of materials, engines, and aircraft detailed in this guide are based on industry expertise to give appropriate data for review. Because of the diversity of aviation hardware and potential variation in fuel/additive formulations, not every aspect may be encompassed and further work may be required. Therefore, additional data beyond that described in this guide may be requested by the ASTM task force, Subcommittee J, or Committee D02 upon review of the specific composition, performance, or other characteristics of the candidate fuel or additive.

1.5 While it is beyond the scope of this guide, investigation of the future health and environmental impacts of the new aviation gasoline or new aviation gasoline additive and the requirements of environmental agencies is recommended.

1.6 The values stated in SI units are to be regarded as standard.

1.6.1 *Exception*—Some industry standard methodologies utilize imperial units as their primary system (permeability; Table A2.2).

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

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]

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

D97 Test Method for Pour Point of Petroleum Products

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)

D323 Test Method for Vapor Pressure of Petroleum Products (Reid Method)

D381 Test Method for Gum Content in Fuels by Jet Evaporation

D395 Test Methods for Rubber Property—Compression Set

D412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension

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

D471 Test Method for Rubber Property—Effect of Liquids

D664 Test Method for Acid Number of Petroleum Products by Potentiometric Titration

[1] This guide is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.J0.02 on Aviation Piston Engine Fuels.

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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

D873 Test Method for Oxidation Stability of Aviation Fuels (Potential Residue Method)
D892 Test Method for Foaming Characteristics of Lubricating Oils
D909 Test Method for Supercharge Rating of Spark-Ignition Aviation Gasoline
D910 Specification for Leaded Aviation Gasolines
D924 Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids
D943 Test Method for Oxidation Characteristics of Inhibited Mineral Oils
D1002 Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)
D1056 Specification for Flexible Cellular Materials—Sponge or Expanded Rubber
D1094 Test Method for Water Reaction of Aviation Fuels
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D1331 Test Methods for Surface and Interfacial Tension of Solutions of Paints, Solvents, Solutions of Surface-Active Agents, and Related Materials
D1414 Test Methods for Rubber O-Rings
D1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)
D1621 Test Method for Compressive Properties of Rigid Cellular Plastics
D2240 Test Method for Rubber Property—Durometer Hardness
D2344/D2344M Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates
D2386 Test Method for Freezing Point of Aviation Fuels
D2500 Test Method for Cloud Point of Petroleum Products and Liquid Fuels
D2583 Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor (Withdrawn 2022)[3]
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
D2700 Test Method for Motor Octane Number of Spark-Ignition Engine Fuel
D2717 Test Method for Thermal Conductivity of Liquids (Withdrawn 2018)[3]
D2896 Test Method for Base Number of Petroleum Products by Potentiometric Perchloric Acid Titration
D3339 Test Method for Acid Number of Petroleum Products by Semi-Micro Color Indicator Titration
D3359 Test Methods for Rating Adhesion by Tape Test
D3525 Test Method for Gasoline Fuel Dilution in Used Gasoline Engine Oils by Wide-Bore Capillary Gas Chromatography
D3652 Test Method for Thickness of Pressure-Sensitive Tapes
D3762 Test Method for Adhesive-Bonded Surface Durability of Aluminum (Wedge Test) (Withdrawn 2019)[3]
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
D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants
D4294 Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
D4308 Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter
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
D5188 Test Method for Vapor-Liquid Ratio Temperature Determination of Fuels (Evacuated Chamber and Piston Based Method)
D5191 Test Method for Vapor Pressure of Petroleum Products and Liquid Fuels (Mini Method)
D5453 Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
D5762 Test Method for Nitrogen in Liquid Hydrocarbons, Petroleum and Petroleum Products by Boat-Inlet Chemiluminescence
D5972 Test Method for Freezing Point of Aviation Fuels (Automatic Phase Transition Method)
D6053 Test Method for Determination of Volatile Organic Compound (VOC) Content of Electrical Insulating Varnishes
D6227 Specification for Unleaded Aviation Gasoline Containing a Non-hydrocarbon Component
D6304 Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
D6424 Practice for Octane Rating Naturally Aspirated Spark Ignition Aircraft Engines
D6469 Guide for Microbial Contamination in Fuels and Fuel Systems
D6812 Practice for Ground-Based Octane Rating Procedures for Turbocharged/Supercharged Spark Ignition Aircraft Engines
D7042 Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity)
D7096 Test Method for Determination of the Boiling Range Distribution of Gasoline by Wide-Bore Capillary Gas Chromatography
D7220 Test Method for Sulfur in Automotive, Heating, and Jet Fuels by Monochromatic Energy Dispersive X-ray Fluorescence Spectrometry
D7547 Specification for Hydrocarbon Unleaded Aviation Gasoline

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

D7719 Specification for High Aromatic Content Unleaded Hydrocarbon Aviation Gasoline Test Fuel
E659 Test Method for Autoignition Temperature of Chemicals
E1259 Practice for Evaluation of Antimicrobials in Liquid Fuels Boiling Below 390 °C

2.2 *EI Standards:*[4]
EI 1529 Aviation fuelling hose and hose assemblies
EI 1581 Specification and qualification procedures for aviation jet fuel filter/separators
EI 1583 Laboratory tests and minimum performance levels for aviation fuel filter monitors
EI 1590 Specifications and qualification procedures for aviation fuel microfilters

2.3 *MODUK Standard:*[5]
MODUK DEF STAN 80-97 Paint System, for the Interior of Bulk Fuel Tank and Fittings, Multi-Pack

2.4 *ISO Standards:*[6]
ISO 1825 Rubber hoses and hose assemblies for aircraft ground fuelling and defuelling—Specification
ISO 20823 Determination of the flammability characteristics of fluids in contact with hot surfaces—Manifold ignition test

2.5 *UL Standard:*[7]
UL 94 Standard for Safety of Flammability of Plastic Materials for Parts in Devices and Appliances Testing

2.6 *Federal Standards:*[8]
DOT/FAA/AR-03/21 Characterization of In-Plane, Shear-Loaded Adhesive Lap Joints: Experiments and Analysis
DOT/FAA/AR-06/10 Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Fabric Prepregs
14 CFR Part 33:49 Block Tests; Reciprocating Aircraft Engines—Endurance Test
Fed-Std-791 Testing Method of Lubricants, Liquid Fuels, and Related Products
MIL-S-8802 Sealing Compound, Temperature-Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High-Adhesion
MIL-DTL-6000 Hose, Rubber, Aircraft, Fuel, Oil, Coolant, Water, and Alcohol
Federal Aviation Administration, TSO-C80 Flexible and Oil Cell Material[9]

2.7 *SAE Standards:*[10]
SAE AMS 3276 Sealing Compound, Integral Fuel Tanks and General Purpose, Intermittent Use to 360 °F (182 °C)
SAE AMS 3277 Sealing Compound, Polythioether Rubber Fast Curing for Integral Fuel Tanks and General Purpose, Intermittent Use to 360 °F (182 °C)
SAE AMS 3281 Sealing Compound, Polysulfide (T) Synthetic Rubber for Integral Fuel Tank and Fuel Cell Cavities Low Density for Intermittent Use to 360 °F (182 °C)
SAE AS4842 Fittings and Bosses, Pipe Threaded, Fluid Connection
SAE AS5127 Aerospace Standard Test Methods for Aerospace Sealants Two-Component Synthetic Rubber Compounds
SAE AMS-P-5315 Acrylonitrile-butadiene (NBR) Rubber For Fuel-Resistant Seals 60 to 70
SAE AMS-C-6183 Cork and Rubber Composition Sheet; for Aromatic Fuel and Oil Resistant Gaskets
SAE AMS 7276 Rubber: Fluorocarbon (FKM) High-Temperature-Fluid Resistant Low Compression Set for Seals in Fuel Systems and Specific Engine Oil Systems
SAE AMS-S-8802 Sealing Compound, Fuel Resistant, Integral Fuel Tanks and Fuel Cell Cavities

2.8 *IP Standards:*[11]
IP 12 Determination of Specific Energy
IP 15 Determination of Pour Point
IP 16 Determination of Freezing Point of Aviation fuels—Manual Method
IP 69 Determination of Vapour Pressure—Reid Method
IP 71 Transparent and Opaque Liquids—Determination of Kinematic Viscosity and Calculation of Dynamic Viscosity
IP 119 Knock Characteristics of Aviation Gasolines by the Supercharged Method
IP 123 Determination of Distillation Characteristics at Atmospheric Pressure
IP 138 Determination of Oxidation Stability of Aviation Fuel Potential Residue Method
IP 160 Crude Petroleum and Liquid Petroleum Products—Laboratory Determination of Density— Hydrometer Method
IP 196 Determination of Colour (ASTM scale)
IP 219 Determination of Cloud Point
IP 236 Determination of Knock Characteristics of Motor and Aviation Fuels—Motor Method
IP 274 Determination of Electrical Conductivity of Aviation and Distillate Fuels
IP 365 Crude Petroleum and Petroleum Products—Determination of Density—Oscillating U-tube Method
IP 394 Liquid Petroleum Products—Vapour Pressure—Part 1: Determination of Air Saturated Vapour Pressure (ASVP) and Calculated Dry Vapour Pressure Equivalent (DVPE)
IP 435 Determination of the Freezing Point of Aviation Turbine Fuels by the Automatic Phase Transition Method

3. Terminology

3.1 *Definitions:*

[4] Available from Publications Team, Energy Institute, 61 New Cavendish St., London W1G 7AR, UK, http://www.energyinst.org.
[5] Available from UK Defence Standardization, Kentigern House, Rm. 1138, 65 Brown St., Glasgow G2 8EX.
[6] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.
[7] Available from Underwriters Laboratories (UL), 2600 N.W. Lake Rd., Camas, WA 98607-8542, http://www.ul.com.
[8] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.
[9] Available from Federal Aviation Administration (FAA), 800 Independence Ave., SW, Washington, DC 20591, http://www.faa.gov.
[10] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, http://www.sae.org.
[11] Available from Energy Institute, 61 New Cavendish St., London, W1G 7AR, U.K., http://www.energyinst.org.

3.1.1 For definitions of terms used in this guide, refer to Terminology D4175.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *additive, n—in aviation gasoline,* substance added to a base aviation gasoline in relatively small amounts that either enables that base aviation gasoline to meet the applicable specification properties or does not alter the applicable specification properties of that base aviation gasoline beyond allowable limits.

3.2.2 *aviation gasoline, n*—fuel derived from petroleum or non-petroleum materials possessing specific properties suitable for operating aircraft powered by spark-ignition piston engines.

3.2.2.1 *Discussion*—Principal properties include combustion, fluidity, volatility corrosion, stability, water shedding, and detonation-free performance in the engine (or engines) for which it is intended. In the context of this guide, the terms "fuel" and "gasoline" are interchangeable.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *critical altitude, n*—maximum altitude at which, in standard atmosphere, it is possible to maintain at a specific engine revolutions per minute (RPM), a specified power, or a specified manifold pressure.

3.3.1.1 *Discussion*—Unless otherwise stated, the critical altitude is the maximum altitude at which it is possible to maintain, at the maximum engine RPM, one of the following:

(1) The maximum continuous power, in the case of engines for which this power rating is the same, at sea level and at the rated altitude, or

(2) The maximum continuous rated manifold pressure, in the case of engines, the maximum continuous power of which is governed by a constant manifold pressure.

3.3.2 *fit-for-purpose (FFP), adj—in aviation gasoline*, describes a condition of acceptance of an aviation fuel or aviation fuel additive that signifies acceptable performance in existing and future aircraft and aircraft engines, but not necessarily all existing or future aircraft and engines.

3.3.3 *fit-for-purpose properties, n*—characteristics of an aviation fuel or aviation fuel additive in the fuel that are not controlled by the fuel specification or specification properties but that are specified for evaluation in addition to the specification properties to provide a comprehensive assessment of the suitability of an aviation fuel for use on existing or future aircraft and aircraft engines, but not necessarily all existing or future aircraft and engines.

3.3.4 *sponsor, n*—entity submitting a new fuel or new fuel additive for review.

4. Summary of Practice

4.1 This guide gives sponsors of a new aviation gasoline or aviation gasoline additive guidance on evaluation procedures using both laboratory and aircraft equipment. This guide includes requirements that address the following subjects:

4.1.1 Basic specification properties;

4.1.2 Fit-for-purpose properties, including compatibility with other aviation gasolines and aviation piston-engine lubricants;

4.1.3 Materials compatibility;

4.1.4 Aircraft component bench or rig testing;

4.1.5 Engine test cell evaluation; and

4.1.6 Aircraft flight test evaluation.

4.2 The procedure for new aviation gasolines is organized into Phase 1 and Phase 2. Details of the two phases are described below:

4.2.1 Phase 1 is intended to provide data and information sufficient to provide an initial understanding of the performance and properties of the candidate new aviation gasoline and to help guide the subsequent Phase 2 testing. A preliminary data package produced in accordance with 6.2 of this guide and an associated draft specification should be prepared to support the initial ASTM task force and subcommittee review. The preliminary data package and the draft specification should be submitted for subcommittee review in an initial ballot.

4.2.2 Phase 2 consists of the development of the final data set and the balloting of the ASTM Research Report and proposed specification to the subcommittee and/or committee. Based on feedback from the subcommittee in response to the initial ballot, the preliminary data should be supplemented with data developed in accordance with 6.3 of this guide. The entire data set should then be compiled in an ASTM Research Report and balloted along with the proposed specification to the subcommittee and/or committee.

4.3 The procedure to evaluate new aviation gasolines or aviation gasoline additives is progressive and iterative in nature with the extent of continued testing determined by the fuel properties, characteristics, and test results revealed at each successive stage. The extent of testing can be expected to grow with increasing degree of divergence from the properties, performance, and experience with existing aviation gasolines. This degree of divergence and its consequences are evaluated during the analysis of data provided in the preliminary data package or the research report.

4.4 The procedure for new aviation gasoline additives consists of test specification, Fit For Purpose 1 (FFP-1) and, where appropriate, Fit for Purpose 2 (FFP-2) testing.

5. Significance and Use

5.1 This guide is intended for the developers or sponsors of new aviation gasolines or additives to describe the data requirements necessary to support the development of specifications for these new products by ASTM members. The ultimate goal of the data generated in accordance with this guide is to provide an understanding of the performance of the new fuel or additive within the property constraints and compositional bounds of the proposed specification criteria.

5.2 This guide is not an approval process. It is intended to describe test and analysis requirements necessary to generate data to support specification development. This guide does not address the approval process for ASTM International standards.

5.3 This guide will reduce the uncertainty and risk to developers or sponsors of new aviation gasolines or additives by describing the test and analysis requirements necessary to proceed with the development of an ASTM International specification for aviation gasoline or specification revision for an aviation gasoline additive. There are certain sections within this guide that do not specify an exact number of data points required. For example, 6.2.4.3 requires viscosity to be measured from freezing point to room temperature; 6.2.4.4, 6.2.4.5, and 6.3.2.3 require measurements over the operating temperature range; 6.3.2.4 and 6.3.2.5 require measurements versus temperature. In these cases, the developers or sponsors of new aviation gasolines or additives should attempt to generate data close to the upper and lower boundaries indicated. If no boundary is specified (for example, generate data versus temperature), then data at the widest practical test limits should be generated. A minimum of three data points is required in all cases (for example, upper, middle, lower), while five or more data points are preferred.

5.4 This guide does not purport to specify an all-inclusive listing of test and analysis requirements to achieve ASTM International approval of a specification or specification revision. The final requirements will be dependent upon the specific formulation and performance of the candidate fuel and be determined by the ASTM International task forces and committees charged with overseeing the specification development.

5.5 This guide is intended to describe data to be used to make a determination of the suitability of the proposed fuel or additive for use in existing or future aircraft and engines, but not necessarily for use in all existing or future aircraft and engines.

5.6 This guide does not describe data requirements of other approving authorities, such as national aviation regulatory authorities, or of other organizations or industry associations. However, the data generated in the conduct of the procedure may be useful for other purposes or other organizations.

5.7 Over 200 000 piston-engine aircraft rely on Specification D910 lead-containing aviation gasoline (avgas) for safe operation. There has been an increase in the research and development of alternatives to Specification D910 gasolines as a result of environmental and economic concerns.

6. Procedure

6.1 *Special Considerations for Additives*—The following procedure is applicable to both aviation gasolines and aviation gasoline additives. Therefore, the terms "aviation gasoline," "gasoline," and "fuel" will only be used to describe the test product unless special considerations exist for additives. When these special considerations for additives exist, they will be specified in the appropriate section of the procedure.

6.1.1 The additive's final chemistry, carrier solvent, recommended treatment level, location in the production or supply chain for treatment, and conditions for retreatment should be identified.

6.1.2 Complete information on the base fuel into which the additive is to be added should be provided. If the base fuel is fuel approved to current major aviation gasoline specifications such as Specifications D910, D7547, D6227, or D7719, this shall be noted and all further testing shall be done on fuel samples blended with locally available fuel.

6.1.3 All testing of additives, unless otherwise noted, should be conducted with base fuel containing 400 % (4×) of the maximum additive dosage.

6.2 *Phase 1: Draft Specification and Preliminary Data Package*—The tests and analysis in Table 1 should be conducted and the resulting data should be compiled for review by the task force and subcommittee.

6.2.1 *Pilot Production Report*—A report describing the simulated production, pilot plant ramp up, and/or production capability to confirm that adequate production capacity is available to support the test and analyses of this procedure. Ideally, several batches of fuel should be produced to reflect a range of specification properties to support "worst-case" testing of fuel for the below requirements.

6.2.2 *Basic Specification Properties*—These should be based on, but not be limited to, Specification D910 Table 1 or Specification D7547 Table 1 properties. The basic specification property results for evaluation of additives should be compared to the corresponding data for the base fuel. Special focus should be provided for the following properties:

6.2.2.1 *Octane*—This requirement should consider the variations in the correlation between the motor octane test (Test Method D2700) and the rich rating test (Test Method D909) with actual engine anti-knock capability for unleaded fuels.

6.2.2.2 *Freezing Point*—Critical for flight safety (Test Method D2386).

6.2.2.3 *Total Sulfur Content*—Total sulfur content of aviation fuels is significant because the products of combustion of sulfur-containing compounds can cause corrosive wear of engine parts.

(1) There are multiple available test methods for measuring total sulfur in petroleum products: D2622, D4294, D5453, and D7220. The test method chosen should be based on the product type as specified in the method's scope, as well as a consideration of the limitations and interferences of each method as compared to the composition of the fuel or additive blend being tested. See Appendix X1 for further discussion.

6.2.2.4 *Distillation Curve*—Critical for adequate engine performance throughout the entire operability range, including engine starting. Provide distillation points of Specification D910, Table 1 or D7547, Table 1 (Test Method D86).

6.2.2.5 *Vapor Pressure*—Important for vapor lock and engine starting. Test at 38 °C (Test Method D5191).

6.2.2.6 *Net Heat of Combustion*—Determines aircraft range (Test Method D4809).

6.2.2.7 *Density*—Determines aircraft range, possible impact on structure, weight, and balance and its impact under different flight attitudes. Note that traditional density/range relationships are based on traditional hydrocarbon fuels. The relationships may change with different base compositions. Test at 15 °C (Test Method D4052).

6.2.2.8 *Water Reaction and Separation*—Important for control of water in fuel and confirm the absence of significant quantities of alcohol (Test Method D1094).

6.2.2.9 *Electrical Conductivity*—Fire safety (Test Methods D2624).

6.2.3 *Fuel Composition*—Detailed chemical analysis of hydrocarbons and trace materials. The composition of additives

TABLE 1 Phase 1—Summary of the Testing Required for the Preliminary Data Package and Draft Specification

Manufacturing Documentation		
Documentation covering manufacture, pilot plant or full scale, quality control, typical and "worst case" analysis.		
Laboratory Tests – Basic Specification Properties		
Test	Premise	ASTM Test Method
MON	Combustion anti-detonation quality	D2700/IP 236
Supercharge	Combustion anti-detonation quality	D909/IP 119
Freeze Point	Fluidity at low temperature/altitude	D2386/IP 16
Sulfur, % by Mass	Avoidance of fuel system and engine part corrosion	D2622, D4294, D5453, or D7220
Distillation	Engine starting and operability	D86/IP 123
Vapor Pressure	Combustion performance	D5191/IP 394
Net Heat of Combustion	Determines aircraft range	D4809/IP 12
Density	Aircraft range and structural considerations	D4052/IP 365
Water Reaction	Control of water in fuel	D1094
Electrical Conductivity	Fire safety	D2624/IP 274
Fuel Composition	Describes fuel composition	GC X GC
Laboratory Tests – Fit For Purpose Properties – Part 1		
Test	Premise	ASTM Test Method
Distillation Curve	Engine operability	D86/IP 123 and D7096
Liquid/Vapor Ratio	Fuel vaporization characteristics	D5188
Vapor Pressure	Fuel vaporization characteristics	D323/IP 69, or D5191
Viscosity	Fluidity at low temperature experienced at altitude	D445/IP 71 or D7042[B]
Density	Aircraft range and structural considerations	D1298 or D4052
Water Solubility	Control of water in fuel	D6304/IP 160
Cloud Point	Fluidity at low temperature/altitude	D2500/IP 219
Pour Point	Fluidity at low temperature/altitude	D97/IP 15
Copper Strip Test	Avoidance of fuel system and engine part corrosion	D130
Additional Tests		
Test	Premise	Refer to Sections
Preliminary Materials Compatibility	To ensure compatibility with aviation fuel handling, aircraft and engine components.	6.2.5
Optional Tests[A]		
Engine test[A]	To support laboratory data and demonstrate fuel performance in full size engine.	6.2.6
Flight test[A]	To support operational performance.	6.2.7

[A] These tests are not mandatory but may offer useful supporting data.
[B] See 6.2.4.3 of this standard.

should be defined to the extent necessary to establish conformance of the products used for testing (GC X GC).

6.2.4 *Fit-For-Purpose Properties, Part 1 (FFP-1)*—The following FFP-1 tests should be performed to evaluate the fuel properties. The test results should be compared to the corresponding data for Specification D910 100LL or D7547 unleaded fuels. The FFP-1 results for evaluation of additives should be compared to the corresponding data for the base fuel.

6.2.4.1 *Distillation Characteristics*—A complete boiling point distribution and comparison of the distillation curve, residue, and loss with Specification D910 100LL per Test Method D86. Include simulated distillation to Test Method D7096.

6.2.4.2 *Fuel Vaporization Properties*—Liquid/vapor ratio per Test Methods D5188 and vapor pressure per Test Methods D323 or D5191. Temperature for a vapor-liquid ratio of 20 should be reported. Temperatures of other vapor-liquid ratios may be requested.

6.2.4.3 *Viscosity*—Measure from freezing point to room temperature per Test Method D445 or D7042. Because of a lack of a precision statement with aviation gasoline and a lack of information regarding correspondence between test results from the D445 and D7042, the test method used shall be reported. No statement overt or implied of equivalence between method results should be made. Offerors may choose to use either method; however, both the test fuel and a baseline reference should be tested using the same method.

6.2.4.4 *Density*—Measure over operating temperature range per Test Methods D1298 or D4052.

6.2.4.5 *Water Solubility*—Measure over operating temperature range per Test Method D6304.

6.2.4.6 *Low-Temperature Fuel Characterization*—Phase transition to freezing as compared to Specification D910 100LL freeze point per Test Method D2386/IP 16 or Test Method D5972/IP 435, cloud point per Test Method D2500 (IP 219), and pour point per Test Method D97 (IP 15).

6.2.4.7 *Corrosion, Copper Strip*—The requirement that gasoline must pass the copper strip corrosion test provides assurance that the product will not corrode the metal parts of fuel systems. Exposure testing should be performed for two hours at 100 °C.

6.2.5 *Preliminary Materials Compatibility*—Perform soak testing of two metallic materials from Table A2.1 (5052-0 aluminum, tube and AMS 4505 brass), and five categories of nonmetallic materials from Table A2.2; (Buna – N (nitrile), fluorosilicone, and SAE AMS 7276 Viton), and five integral fuel tank sealants (SAE AMS-S-8802, Type 1, Class B2; SAE AMS-S-8802, Type 2, Class B2; AMS-3276 Type 2, Class B2; AMS-3277 Type 2, Class B-2; and AMS-3281 Type 1, Class B-1/2) in accordance with the procedures described in Annex

A2 to measure property changes such as percent volume change, hardness, tensile strength, and so forth. Perform tests of two additional groups of nonmetallic materials, MIL-DTL-6000 hose, and two types of materials as o-rings (AMS-P-5315 Nitrile, and AMS-7276 fluorocarbon).

6.2.6 *Engine Testing*—The basic specification property data and FFP-1 data should be compared to similar data for known aviation gasolines such as Specification D910 100LL. This analysis should be used to determine the engine model to be used for these tests.

6.2.6.1 New production or newly overhauled engines that have not been operated on any fuel other than the test fuel should be used for this testing. The engine should be broken in and exclusively operated on only the test fuel. Limited operation with other fuels may be permitted under controlled conditions if accompanied by purging run periods of acceptable duration.

6.2.6.2 *Performance and Operability Testing*—Engine-rated power, steady-state performance, transient performance, and starting should be evaluated on a dynamometer-equipped engine test stand that meets industry standards for facility configuration and instrumentation calibration. Performance data should be compared to the engine manufacturer's published performance data.

6.2.6.3 *Engine Detonation Testing*—Detonation testing should be conducted in accordance with the procedures described in ASTM International Specifications D6424 and D6812. A detonation measurement system that uses piezoelectric sensors that are flush mounted in the combustion chamber, or a system found to be equivalent, should be used for this testing. Detonation threshold levels and measurement accuracy and sensitivity should be correlated to known systems.

(1) Users of this guide are advised to sufficiently understand the purpose of the testing being conducted and the interpretation of the results obtained when measuring "detonation." Detonation testing is a complex concept with different considerations depending on the goal of the testing. Detonation testing is conducted to measure data as a property of the fuel (that is, MON, single cylinder testing in a CFR engine), as a performance characteristic of the engine (that is, full-scale engine mounted in a test cell), and as a characteristic of the aircraft system (that is, flight test). Offerors are advised to clearly understand the goal of the testing and, if necessary, to obtain expert advice in the nuances of testing and interpretation of the results. Individual aircraft make/model/Serial Number installation effects may result in an installed octane requirement that differs from that of the controlled ground engine test.

(2) The effects of detonation on the MON D2700 CFR engine have correlated implications to what occurs in a high speed, highly loaded, turbo/supercharged aircraft engine. While such correlations have successfully been developed for traditional aviation gasoline formulations such as 100LL, they should not be taken at face value for suitability of the octane number requirement of new formulations. The relationship between individual aircraft make/model serial number installation effects and the octane ground engine test may not be completely understood and the difference in installed octane requirement may be affected.

(3) While these relationships can be developed over time, one cannot take a numerical value from a MON test and necessarily apply it in practice, especially if the fuel formulation being tested contains no lead. An unleaded fuel with a given MON value may not be directly equivalent in resisting knock to a 100LL fuel of the same MON value. While fuel enrichment of air/fuel ratio is commonly used as knock mitigation on SI piston aircraft engines, the mitigation for unleaded fuel that has the same MON may not be equivalent to a standard 100LL fuel. It is possible in an extreme case, where the formulation of the unleaded fuel includes an increase in aromatics content, that knock mitigation may be much worse during enrichment, or may not be able to mitigate detonation at all.

6.2.7 The preliminary data package should provide data and summarize results of above fuel and engine testing. It should include the draft specification properties that are sufficient to control the performance of the fuel for testing in the next phase of this procedure. Both the draft specification and preliminary data package should be submitted as an initial ballot for determination of the additional testing required to support the eventual balloting of the new specification.

6.3 *Phase 2*—Upon completion of Phase 1, the following tests and analysis should be conducted and the resulting data should be compiled in an ASTM Research Report (see Table 2).

6.3.1 *Production Report*—A report describing the pilot plant or, preferably, a refinery/chemical plant production process. The fuel used in the following testing should be produced from representative production processes, including the fuel's blending components. Fuel produced for this phase should be derived from an integrated process from feedstock to finished fuel. Chemical facsimiles of production fuel or fuel produced in a manner not representative of finished production routes are not acceptable for development of an ASTM production specification.

6.3.2 *Fit-For-Purpose Properties, Part 2 (FFP-2)*—FFP-2 includes additional properties relating to engine and aircraft operability and performance and also includes properties relating to fuel handling and distribution. The data generated during this testing should be compared to corresponding data for Specification D910 100LL fuel properties. Differences from Specification D910 FFPs should be reconciled in the research report. The FFP-2 results for evaluation of additives should be compared to the corresponding data for the base fuel.

6.3.2.1 *Carburetor Icing*—A simulated or actual flight test evaluation of carburetor icing propensity of the candidate fuel. An example of carburetor testing may be seen in Coordinating Report No. AV-17-13.[12]

6.3.2.2 *Fuel Gauging and Capacitance*—Comparative analysis to 100LL per Test Methods D2624 or D4308.

6.3.2.3 *Conductivity and Static Charge Dissipation*—Comparative analysis to 100LL over the operating temperature range per Guide D4865.

[12] Available from Coordinating Research Council, 5755 North Point Parkway, Suite 265, Alpharetta, GA 30022, www.crcao.org.

TABLE 2 Phase 2—Summary of Testing Required for the ASTM Research Report

Preliminary Data Package		
Include all test data from Table 1 in the final ASTM Research Report.		
Manufacturing Documentation		
Documentation covering manufacture, pilot plant or full scale, quality control, typical and "worst case" analysis.		
Laboratory Tests – Fit For Purpose Properties – Part 2		
Test	Premise	ASTM Test Method
Carburetor Icing	Cold weather fuel system operation	Refer to 6.3.2.1
Fuel Gauging and Capacitance	Aircraft range measurement	D2624/IP 274 or D4308
Conductivity and Static Charge Dissipation	Fire safety	D4865
Surface Tension	Fuel system operation	D1331
Thermal Conductivity	Engine cooling	D2717
Dielectric Constant	Aircraft range measurement	D924
Hot Surface Ignition Temp	Engine durability	FED-STD-791 or ISO 20823
Gum Formation	Storage stability	D873/IP 138
Potential Gums	Storage stability	D873/IP 138
Water Reaction	Water control	D1094
Microbial Contamination	Contamination control	D6469
Electrical Conductivity	Fire safety	D2624
Fuel Weathering	Long-term fuel performance	User defined
Test Method Validation	Fuel performance control	Refer to 6.3.2.14
Additive Response and Compatibility	Fuel property control	Refer to 6.1 and Annex A1
100LL Fuel Compatibility	Fuel property control	Refer to 6.3.2.16
Lube Oil Compatibility	Engine durability	Refer to 6.3.2.17
Fuel Coloration	Mis-fueling control	D156 or D1500/IP 196
Health, Safety, and Environmental	Personnel health	Refer to 6.3.2.19
Toxicity		Refer to 6.3.2.20
Long-Term Fuel Storage Stability	Storage stability	D873/IP 138
Laboratory Tests	Fuel property control	Refer to 6.3.2.22
Fuel Distribution System	Fuel quality control	Refer to 6.3.2.23
Component Compatibility		User defined
Emissions	Environmental impact	Refer to 6.3.2.24
Additional Tests		
Test	Premise	Refer to Sections
Final Materials Compatibility	To ensure compatibility with aviation fuel handling, aircraft and engine components.	6.3.3
Component Testing		6.3.4
Aircraft Operation and Safety Tests		
Engine Test	To support laboratory data and demonstrate fuel performance in full size engine.	6.3.5
Flight Test	To support operational performance.	6.3.6

6.3.2.4 Surface tension versus temperature compared to baseline test fluid per Test Method D1331.

6.3.2.5 Thermal conductivity versus temperature compared to baseline test fluid per Test Method D2717.

6.3.2.6 Dielectric constant versus density compared to baseline test fluid per Test Method D924. Users should be aware this test method includes the capacitance of the air which may contribute to variability in resulting test values.

6.3.2.7 Hot surface ignition temperature compared to baseline test fluid using FED-STD-791, Test Method D6053 Manifold Ignition Test, or ISO 20823.

6.3.2.8 Gum formation per Test Method D873.

6.3.2.9 *Potential Gums*—Test Method D873.

6.3.2.10 Water reaction per Test Method D1094.

6.3.2.11 *Microbial Contamination Susceptibility per Guide D6469 and Test Method E1259*—Since alkyl lead compounds are biocides, microbial growth has not generally been an issue in aviation gasoline containing lead compounds. However, microbial growth in lead-free aviation gasoline could become a concern. Microbial growth should be compared with Specification D910 fuels or suitably identified test fluid over ambient operating range and fuel compositional range.

6.3.2.12 Electrical conductivity per Test Methods D2624.

6.3.2.13 *Fuel Stability Over Time (Weathering)*—Evaluate for impact on fuel performance over long-duration storage, include anti-knock capability, cold starting, and so forth. The method for weathering the fuel and selection of data collected is user defined. The offeror is encouraged to obtain industry input on the weathering plan prior to execution.

6.3.2.14 *Test Method Validation*—Test methods and associated criteria are based on Specification D910. They need to be validated for applicability and accuracy with the new fuel. Additional and/or replacement methods should be provided.

6.3.2.15 *Additive Response and Compatibility*—The new fuel should respond to currently approved additives in the same manner as existing fuels, such as Specification D910 100LL fuel. Typical additives are antioxidants, fuel system icing inhibitor (FSII), electrical conductivity, and corrosion inhibitor. Refer to Annex A1.

(1) New additives should be evaluated for compatibility with additives approved for the base fuel in accordance with Annex A1 and Annex A2.

6.3.2.16 *100LL Fuel Compatibility*—Data indicates that MON and other fuel properties may not vary linearly when mixing 100LL with other liquid fuels. Fuel blends need to be prepared representing the range of blend ratios with 100LL of 20:80, 30:70, 50:50, 70:30, and 80:20. Table 1 properties from Specifications D910, D7547, D6227, or D7719 as appropriate shall be confirmed at each blend ratio.

6.3.2.17 *Lubricating Oil Compatibility*—Assessment of the fuel's compatibility with lubricating oils approved for use with aviation piston engines. It is recommended the assessment be accomplished by evaluating the oil from the engine Durability and Operability test (see 6.3.2*(1)*).

(1) Data from engine durability testing may be used to support this analysis. Sample the oil before (virgin sample for baseline), every 25 h during testing, and after the engine test using industry standard practices (Practice D4057). Execute a standard oil analysis including a spectrometric oil analysis program (SOAP) test for wear materials, physical properties changes including acid number (Test Methods D664 or D3339), base number (Test Method D2896), viscosity (Test Method D445), density (Test Methods D1298 or D4052), oil dilution with fuel (Test Method D3525), nitrogen (Test Method D5762), foaming (Test Method D892), oxidation (Test Method D943), and moisture content (Test Method D6304).

6.3.2.18 *Fuel Coloration*—Dyes need to be specified to produce fuel color. Variations in color need to be evaluated. If, by choice or availability, none of the current approved Specification D910 dyes is to be used, any proposed new dye should be evaluated in both Phase 1 and Phase 2.

6.3.2.19 *Health, Safety, and Environmental*—The fuel should meet health, safety, and environmental (HSE) criteria for sale to the general public. Examples include vapor exposure, skin exposure cancer risk, and spill/water table contamination (that is, methyl tertiary butyl ether (MTBE) issue). Additional information may be available from the Environmental Protection Agency (EPA). Other HSE requirements include the following:

(1) Flammability—Acceptable flammability range. Products with very broad range (for example, hydrogen) represent additional handling risk/explosive atmosphere. Visible flame on combustion, for example, alcohol fire may not be visible.

(2) Ignition Energy—Appropriate ignition energy. Very low ignition energy represents additional hazard from friction and so forth, for example, hydrogen.

(3) Autoignition Temperature—Suitable autoignition temperature and not unstable in storage (for example, peroxide risk). Compare to Specification D910 fuel, Test Method E659.

(4) Firefighting Media—Current firefighting media need to be effective.

(5) Static/Conductivity—Similar/better than current product. Risk of excessive static being generated/charge dissipation rate—hazard for over-wing refueling.

6.3.2.20 *Toxicity*—Does the fuel possesses mutagenic properties, is it classified as an irritant, and so forth? See MIL-HNDBK-510-1.[13]

(1) Combustion Products—Should be analyzed and compared to existing fuels such as Specification D910 100LL.

6.3.2.21 *Long-Term Fuel Storage Stability:*

(1) Long-term storage stability is covered by Test Method D873 tested as part of Specification D910 Table 1 and D7547 Table 1 properties.

(2) Dirt/Water Dropout—Allows dirt/water to partition from fuel at a similar rate to current product.

(3) Density—Density appropriate for storage/manual handling (drums).

6.3.2.22 *Laboratory Tests*—The fuel properties and quality should be controlled by laboratory tests, which are readily available. Currently available personal protective equipment (for example, flame-resistant meta-aramid material coats, gloves) should be appropriate for conducting specified laboratory tests.

6.3.2.23 *Fuel Distribution System Component Compatibility*—In addition to the fuel-wetted components in the aircraft (6.2.5), the fuel sponsor shall also consider the compatibility and impact of the fuel on the fuel-wetted components present in the aviation gasoline supply distribution system. The new fuel should not negatively impact the fuel-wetted materials or their intended operation. Negative effects include, but are not limited to, unacceptable swelling/shrinkage, unacceptable hardening or softening of components, corrosion or unacceptable impact on fuel delivery rates, damage to pumps/refuelling nozzles, and failure to remove water on filtration.

(1) A typical tank lining system such as the three-coat epoxy/amine adduct system should be tested.

(2) Filtration Compatibility—The performance of coalescer filters should be compared to performance with existing fuels such as Specification D910 100LL (see Annex A4).

(3) Operational Compatibility—The operation of other fuel wetted components such as pumps and refueling nozzles should be compared to performance with existing fuels such as Specification D910 100LL (see Annex A4).

6.3.2.24 *Emissions*—CO_2, CO, NOX, PM, benzene, polyaromatic hydrocarbons, total hydrocarbons (THC), vapor emissions, and combustion products, by comparison with existing fuels such as D910 100LL under similar test conditions.

6.3.3 *Final Materials Compatibility*—Engine and aircraft fuel system polymer and metallic materials that are exposed to fuel should be evaluated for compatibility with the new fuel. The results of the compatibility testing should be compared to corresponding results or service experience of existing fuels, and any deviations from current material behavior should be reconciled.

6.3.3.1 Incompatibility may be indicated by unacceptable swelling or shrinkage, delamination, unacceptable hardening or softening, corrosion, or embrittlement.

6.3.3.2 Procedures for materials compatibility testing of aviation gasolines and aviation gasoline additives are provided in Annex A2.

6.3.3.3 A representative listing of piston engine aircraft materials is provided in Annex A3. Those materials tested for the preliminary materials compatibility requirement need not be retested for final materials compatibility.

6.3.3.4 An example procedure for compatibility testing of aircraft composite fuel tank materials may be found in Annex A5.

6.3.3.5 An example procedure for permeability testing of aircraft fuel tank bladder materials may be found in Annex A6.

6.3.4 *Component Testing:*

[13] Available from the U.S. Government Printing Office, Superintendent of Documents, 732 N. Capital St., NW, Washington, DC 20402-0001.

6.3.4.1 *Flame Speed*—Flame speed effects should be evaluated with a representative engine cylinder assembly. Particular attention shall be given to exhaust valve temperature, turbocharger inlet temperature, and exhaust valve seat condition in a worst-case engine or cylinder assembly. A determination of exhaust valve creep life response shall be made. In addition, changes in engine cooling demands, fuel consumption, effective ignition timing, performance, power train stresses, and vibration shall be determined in worst-case engine(s).

6.3.4.2 *Fuel-Gauging Equipment:*

(1) Modern aircraft use capacitance fuel gauges for reporting the fuel quantity. The gauge operates by using a low-voltage capacitor probe where the fuel acts as the dielectric. A low voltage current is applied to the sensing capacitor and the resulting charge is compared to a reference probe. As the fuel level increases, the charge on the senor probe increases. The difference between the sensing probe and the reference probe is measured using a voltmeter. The voltages are calibrated to fuel load, which is reported on the gauge.

(2) If the dielectric properties of the fuel are different, then the measured voltages will be different, resulting in an incorrect fuel load reading. It is known, for example, that the presence of ethanol in the fuel load results in an incorrect fuel reading because the dielectric behavior of the fuel has been changed. Test fuel dielectric constant using Test Method D924 and compare to 100LL baseline.

6.3.5 *Fuel Performance Evaluation on Aircraft and Engines:*

6.3.5.1 A recommended portfolio of tests to be conducted on specific engine and aircraft models has been developed to evaluate the performance of the candidate fuel under actual operating conditions.

6.3.5.2 Each test is designed to evaluate specific performance characteristics of the candidate fuel, but not all tests will necessarily be required for all candidate fuels. The tests to be conducted will be determined based on the properties of the candidate fuel under evaluation. In Table 3, a summary of these tests and the associated fuel performance characteristics the test is intended to address are provided. In the table, the E-series reference engine tests, and the A-series reference aircraft tests. A description of each of these tests and test articles to be used for the tests is provided in the following sections.

6.3.6 *Engine Testing*—Acceptable engine performance, durability, and operability, when operating with the new aviation gasoline, should be demonstrated on the aircraft piston engines identified in this section.

6.3.6.1 *General:*

(1) The testing should be performed on a dynamometer-equipped engine test stand that meets industry standards for facility configuration and instrumentation calibration unless otherwise noted.

(2) New production or newly overhauled engines that have not been operated on any fuel other than the test fuel should be used for Test E-1. Test E-2 should be performed with a new engine or an engine remanufactured to new engine specifications. For both tests, the engine should be broken in and exclusively operated on only the test fuel. Limited operation with other fuels may be permitted under controlled conditions if accompanied by purging run periods of acceptable duration.

(3) Each test engine should undergo a performance calibration before conducting the tests specified in the following.

6.3.6.2 *Engine Tests and Test Articles*—Engine models and the engine tests to be conducted on those models are shown in Table 4.

(1) Test E-1: Performance and Detonation

(a) A complete performance characterization of each engine should be performed on a dynamometer-equipped engine test stand to measure brake horsepower, exhaust gas temperature, RPM, and mixture strength relative to the performance charts published in the engine operating instructions.

(b) Detonation testing should be conducted in accordance with the procedures described in Specifications D6424 and D6812. A detonation measurement system that uses piezoelectric sensors that are flush mounted in the combustion chamber, or a system found to be equivalent, should be used for this testing. Detonation threshold levels and measurement accuracy and sensitivity should be correlated to known systems.

(c) Sea level detonation tests should be performed at rated engine power and engine settings defined by the manufacturer such as recommended climb power, maximum best cruise power, and maximum best economy power. Sea level detonation should be performed on naturally aspirated and turbocharged/supercharged engines.

(d) Detonation tests should be performed at critical altitude for 100 %, 75 % power for turbocharged or supercharged engines.

NOTE 1—Testing is performed based on where the engine is most likely to detonate. For normally aspirated engines, this is at sea level at which the highest manifold air pressure is achieved. For turbo/supercharged engines,

TABLE 3 Fuel Tests and Associated Test Characteristics

	Test E-1 Performance and Detonation	Test E-2 Operability and Durability	Test A-1 Performance, Operability, and Durability	Test A-2 Hot Weather Operation	Test A-2b Cold Weather Operation	Test A-3 Detonation and Range
Volatility		X	X	X	X	
Fluidity		X	X		X	
Combustion	X	X		X	X	X
Corrosion		X	X			
Stability		X				
Lubricity		X	X			
Fuel/oil interaction (fuel dilution, CRC sludge rating)		X				

TABLE 4 Engine Tests and Test Articles

Test	Description	Lycoming TIO-540-J2BD Engine	Continental O-470-U Engine	Lycoming IO-540-K Engine	Rotax 912S
	Engine Model Key Characteristics	Turbocharged, nonintercooled, fuel injected, large displacement	Normally aspirated, carbureted, high compression, large displacement	Normally aspirated, fuel injected, high compression, large displacement	Normally aspirated, small displacement, High RPM, High compression, autogas approved
E-1	Performance and detonation	X	X	X	
E-2	Durability and operability		X		X

this may be a critical altitude. The critical altitude is the highest altitude at which the stated power is attained. This is where the turbo/supercharger works the hardest and therefore produces the highest manifold air temperature. Sea level testing is required for both normally aspirated and turbo/supercharged engines.

(2) Test E-2: Durability and Operability Test—This is a long-duration engine test to evaluate the candidate fuel relative to durability, operability, deposit formation, starting, cooling, mixture distribution, and valve-train operation. The test should evaluate the fuel over the complete range of temperature and altitude conditions specified in the manufacturer's operating instructions. The following requirements apply to this test:

(a) This test may be performed in a propeller test stand only if evidence of acceptable performance calibration is provided.

(b) The test duration should be at least 300 h and include throttle transients, cruise conditions, and cold and hot starts. The specific duty cycle should be defined by the fuel sponsor and reviewed with the task force members for acceptability.

(c) Do not switch between unleaded and leaded fuels during the test.

(d) The test should address the ability of the fuel to form a combustible mixture under all operating conditions.

(e) The impact of the candidate fuel on engine cooling should be evaluated during the test.

(f) The test should evaluate the impact of fuel deposits from the new fuel on the octane demand of the engine and pre-ignition tendency of the engine. Periodic detonation measurements with a leaded reference or baseline fuel at 50 h intervals should be included.

(g) Combustion (including peak cylinder pressure) may impact structural loading of critical engine components. If combustion pressure is different or ignition timing shall be adjusted or both, the resulting effect on both crankshaft torsional vibration and bottom end loading (crankcase, main bearings, and crankshaft) shall be addressed to document resulting loads and stresses are within allowable engine limits.

(h) Upon completion of the test, a comparison of pre- and post-test engine hardware condition and measurements should be conducted. Recommended measurements are shown in Table 5. For locations and direction of measurements, refer to the original equipment manufacturer (OEM) engine overhaul manual. The engine should be examined for evidence of discoloration of fuel- and oil-wetted parts, valve sticking, combustion chamber deposits, fuel system deposits, oil system deposits, exhaust system deposits, turbocharger deposits, carburetor deposits, and induction system.

TABLE 5 Engine Durability Measurements

Part/System/Component	Recommended Measurements/Inspections
Valve Train (exhaust and intake)	Stems, guides, stem-to-guide clearance, valve face runout, valve stem height, tappets, tappet bores, tappet-to-bore clearance, tappet hydraulic leak down. Inspect cam lobes, pushrods, rocker surfaces, rocker shaft to bearing clearance, and deposits.
Camshaft	Journals, bearings, journal-to-bearing clearances, and lobes.
Crankshaft	Main and crankpin journals, bearings, and journal-to-bearing clearances.
Piston and Cylinder	Bores, ring-side clearance and end gap, piston-to-cylinder clearance, pin hole, bushing, connecting rod, and deposits.
Fuel System	Nozzle, manifold, intake, carburetor deposits or coatings, and pumps.
Oil System	Deposits, sludge, and gear-driven pumps.

6.3.7 *Aircraft Flight Testing*—Aircraft performance, operability, and range when operating with the new aviation gasoline should be demonstrated on the aircraft identified in this section.

6.3.7.1 *General*—The aircraft fuel system should be flushed with a solvent-acting solution or fuel before initiation of flight testing. When operating with two fuels, the new fuel should be kept segregated from the reference fuel.

6.3.7.2 *Aircraft Tests and Test Articles*—Aircraft models and the flight tests to be conducted on those models are shown in Table 6.

6.3.7.3 *A-1 Performance, Operability, and Durability Test*—Aircraft flight testing should be conducted to evaluate the impact of the new fuel on aircraft performance, operability, and durability. The aircraft should be operated at conditions representing the extreme corners of the operational envelope specified by the OEM in the aircraft flight manual or pilot's operating handbook. The aircraft should be tested for a duration long enough to address the following items in a wide range of temperature conditions, including sufficient operation to identify trends in engine performance with accumulated operating time:

(1) Evaluate impact on fuel system materials;

Note 2—Non-operating time may be more important to evaluate compatibility than operating time.

(2) Demonstrate starting with hot fuel and demonstrate cold fuel altitude relights;