INTERNATIONAL

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Standard Practice for Aeroplane Turbine Fuel System Hot Weather Operations[1]

This standard is issued under the fixed designation F3397/F3397M; 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 standard practice provides requirements for performing hot weather testing as a means of compliance to Subsection 7.7 of Specification F3063/F3063M for kerosene-type turbine fuels such as Jet A and Jet A-1 (Specification D1655). The appendix provides supplemental information and considerations for turbine fuel system hot weather operation. The material was developed through open consensus of international experts in general aviation.

1.2 An applicant intending to propose this information as Means of Compliance for a design approval must seek guidance from their respective oversight authority (for example, published guidance from applicable civil aviation authorities (CAAs)) concerning the acceptable use and application thereof. For information on which oversight authorities have accepted this standard (in whole or in part) as an acceptable Means of Compliance to their regulatory requirements hereinafter ("the Rules"), refer to the ASTM Committee F44 web page (www.astm.org/COMMITTEE/F44.htm).

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* A specific warning is given in Section 6 on Test Setup.

1.5 *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]
D910 Specification for Leaded Aviation Gasolines
D1655 Specification for Aviation Turbine Fuels
F3063/F3063M Specification for Aircraft Fuel Storage and Delivery
F3064/F3064M Specification for Aircraft Powerplant Control, Operation, and Indication
F3179/F3179M Specification for Performance of Aircraft

2.2 *FAA Standards:*[3]
AC 23-16A Powerplant Guide for Certification of Part 23 Airplanes and Airships
CAR 3 Airplane Airwothiness – Normal, Utility, and Acrobatic Categories

2.3 *CRC Report:*[4]
CRC AV-20-14 Determination of Heat of Vaporization and Creating Enthalpy Diagrams for Several Common Jet Fuels

2.4 *Fuel Standards:*
GOST 10227 Russian Standards and Regulations: Jet Fuel Specification[5]
MIL-DTL-5624 Detail Specification: Turbine Fuel, Aviation, Grades JP-4 and JP-5[6]

3. Terminology

3.1 *Definitions:*

3.1.1 *fuel volatility, n*—the fuel's tendency to evaporate (that is, change to a vapor from a fluid).

3.1.2 *vapor pressure, n*—pressure exerted by its vapor in equilibrium with the liquid at a specific temperature with the absence of air over the fuel.

[1] This practice is under the jurisdiction of ASTM Committee F44 on General Aviation Aircraft and is the direct responsibility of Subcommittee F44.40 on Powerplant.

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

[3] Available from Federal Aviation Administration (FAA), 800 Independence Ave., SW, Washington, DC 20591, http://www.faa.gov.

[4] Available from Coordinating Research Council (CRC), 5755 North Point Parkway, Suite 265, Alpharetta, GA 30022, https://www.crcao.org.

[5] Available from Russian Gost, LLC. P.O. Box 366, Alief, TX 77411, https://www.russiangost.com.

[6] Available from DLA Document Services, Building 4/D, 700 Robbins Ave., Philadelphia, PA 19111-5094, http://quicksearch.dla.mil.

3.1.3 *weathering, v*—reduction of fuel volatility when given sufficient time, agitation, temperature cycles, or pressure changes, or combinations thereof.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *initial boiling point, n*—for the purpose of this standard practice, the temperature and pressure at which a fuel begins vapor formation.

3.2.2 *vapor formation, v*—for the purpose of this standard practice, the transition of a liquid fuel to fuel vapor, which may result in vapor lock or cavitation within the fuel system.

4. Significance and Use

4.1 This specification provides designers of general aviation aeroplanes a process for evaluating and testing a fuel system under hot weather conditions to ensure safety during flight. The specification is applicable to kerosene-type turbine engine fuels and fuel systems for traditional general aviation aeroplanes.

5. Test Prerequisites

5.1 Determine the fuel grade requested for approval that is the most susceptible to vapor formation (that is, the most volatile). This is indicated by the highest fuel vapor pressure. In addition, volatility is supported by distillation data; a higher percentage of fuel recovered at lower temperatures indicates a higher volatility.

5.2 Determine any sources of heat rejection, within or adjacent to the fuel system, into the fuel and what portions of the fuel system are directly affected.

5.2.1 Each source of heat rejection shall be evaluated.

5.2.2 The evaluation shall consider heat rejection from multiple sources in accordance with their duty cycles.

6. Test Setup

6.1 *Ambient Conditions*—The flight test shall be conducted with outside air temperatures at 29 °C [85 °F] or higher measured at 1.2 m to 1.8 m [4 ft to 6 ft] above the runway surface.

6.2 *Fuel:*

6.2.1 Do not allow the fuel to weather by exposing it to the atmosphere for extended periods prior to the test.

6.2.2 The fuel shall be heated such that the fuel temperature at takeoff is at least the maximum temperature for which the cooling requirements of Specification F3064/F3064M have been shown or 43 °C [110 °F], whichever is greater. The fuel temperature is measured within the fuel storage system near the intake of the fuel distribution system.

6.2.2.1 The fuel shall be heated artificially when the fuel cannot be raised to the required temperature by parking the aeroplane in full sun. Artificial heating should be accomplished within 90 min to prevent excessive weathering. Extended fuel heating time may be required for aeroplanes with large fuel storage systems. Fuel heating beyond 90 min should be coordinated with the CAA.

6.2.2.2 Heating fuel beyond the initial boiling point shall be avoided in order to prevent weathering prior to the test.

6.2.2.3 Do not agitate or excessively handle the fuel during any heating process. (**Warning—**Heating and handling fuel at elevated temperatures is hazardous to ground and flight personnel. Safety precautions should be taken.)

6.3 *Aeroplane:*

6.3.1 The aeroplane shall be in a configuration representative of type design, particularly with respect to installations that affect fuel system performance. Instrumentation and other modifications shall not interfere with the test results to be considered representative of type design system performance.

6.3.2 The weight and center of gravity of the aeroplane shall be within the limits prescribed by the aeroplane flight manual (AFM).

6.3.3 Fuel loading shall be in accordance with the following requirements, unless otherwise coordinated with the CAA:

6.3.3.1 The aeroplane shall be loaded with full fuel if the fuel system is not subject to heat rejection described in 5.2 that can heat fuel beyond maximum temperatures required by 6.2.2.

NOTE 1—A full fuel volume results in higher fuel temperatures during the flight due to a larger volume retaining more heat. A fuel system with no heat rejection and a full fuel load, for example, will retain more heat resulting in higher fuel temperatures during flight.

6.3.3.2 The aeroplane shall be loaded with a "low" fuel quantity if the fuel system is subject to heat rejection described in 5.2 that can heat fuel above the maximum ambient temperatures required by 6.2.2.

NOTE 2—The critical test configuration for a fuel system with heat rejection is with a reduced fuel volume, which will be more susceptible to the effects of heat rejection, particularly if the heat rejection is capable of warming the fuel beyond hot weather conditions. Note that "low" fuel quantity is not necessarily the "fuel low level" quantity satisfying Specification F3064/F3064M, but a volume of fuel not more than what is sufficient to safely execute the test.

6.3.3.3 If multiple tanks that directly feed an engine are symmetric, then only testing one of the symmetric tanks is required.

6.3.3.4 If multiple tanks that directly feed an engine are not symmetric, then the testing shall evaluate all such tanks.

6.4 *Data Recording and Instrumentation:*

6.4.1 The following data shall be recorded, either manually or automatically, throughout the test:

6.4.1.1 Fuel temperature in the fuel tank under test that directly feeds the engine.

6.4.1.2 Usable fuel quantity, including at takeoff.

6.4.1.3 Fuel delivery to the engine, either fuel pressure or fuel flow.

6.4.1.4 Main pump operation, as applicable.

6.4.1.5 Emergency pump operation, as applicable.

6.4.1.6 Pressure altitude.

6.4.1.7 Ambient air temperature.

6.4.1.8 Airspeed.

6.4.1.9 Engine power or other representative parameter, engine inlet temperature, exhaust gas temperature, and fuel flow, as appropriate.

7. Test Procedure

7.1 Prepare the test setup as established by Section 6.

7.2 Begin the flight test as quickly as is practical once the fuel temperature within the fuel tank reaches the fuel temperature determined in 6.2.2.

7.3 Conduct the flight test as follows:

7.3.1 Throughout the test:

7.3.1.1 The fuel system shall be operated normally in accordance with the AFM;

7.3.1.2 Maintain the speed and performance limits in accordance with the AFM and in accordance with the requirements specified in Specification F3179/F3179M;

7.3.1.3 Do not operate the emergency fuel pumps if they are being considered for use as "backup" pumps, as this test may be used to establish the maximum pressure altitude for operation with the emergency pumps off; and

7.3.1.4 The pilot shall note any unusual or unexpected engine or fuel system fluctuations at the point in the flight at which they occur.

7.3.2 Perform a takeoff using takeoff power.

7.3.3 Climb to the maximum approved altitude using maximum continuous power at the maximum vertical climb rate (*Vy*).

7.3.4 Establish maximum continuous cruise power and maintain until engine speed, airspeed, and fuel flow stabilize.

7.3.5 Reduce power to a low to moderate cruise power setting and maintain altitude for 5 min.

7.4 Perform a normal descent and landing.

7.5 *Pass/fail Criteria:*

7.5.1 The fuel pressure or flow, as applicable, remains at or above the minimum prescribed by the engine manufacturer throughout the test;

7.5.2 The fuel temperature remains at or below the maximum prescribed by the engine manufacturer throughout the test;

7.5.3 The fuel pressure or flow does not fluctuate excessively throughout the test; and

7.5.4 No engine malfunctions occur due to fuel flow or pressure interruption throughout the test.

7.5.5 The operation of the emergency fuel pump, manually or automatically, during the test due to excessive fuel pressure or fuel flow fluctuations is considered a test failure and will require a retest.

NOTE 3—Emergency fuel pump operation might be required for the continued safety of the flight.

8. Post-Test

8.1 Evaluate the test results data and determine if the pass/fail criteria in 7.5 was met.

8.1.1 Consider additional testing to evaluate any test points that exhibited fuel flow, fuel pressure, or engine power fluctuations to determine if additional testing is required.

8.2 Determine any AFM procedures, such as fuel pump usage, required for hot weather operation.

8.3 Determine any limitations, such as outside air temperature, fuel temperature, or reduced service ceiling, or combinations thereof, required for hot weather operation.

8.4 Document any procedures or limitations required for hot weather operation in the AFM.

9. Applicability of Results

9.1 Successful test results for one grade of fuel may be considered to envelope less volatile fuel grades requested for approval.

9.1.1 Any procedures or limitations for hot weather operation with the most volatile fuel shall be applied to all less volatile fuel grades unless additional testing in accordance with 9.1.1 is performed for those less volatile fuels. The test may be repeated as desired for fuel grades that are less volatile than a tested fuel grade. This is typically done to minimize or remove procedures or limitations resulting from testing of the more volatile fuel.

9.1.2 Any differing procedures or limitations for specific fuel grades shall be specified in the AFM.

10. Keywords

10.1 cavitation; fuel system testing; heat rejection; hot fuel; hot weather operation; hot weather testing; turbine fuel hot weather; turbine fuel testing; vapor formation; vapor lock

APPENDIXES

(Nonmandatory Information)

X1. REGULATORY DISCUSSION

X1.1 The initial regulatory requirement for fuel system hot weather testing with fuel at 43 °C [110 °F] appeared in the Civil Airworthiness Regulation (CAR) 3 in 1949. The most common fuels at the time were fuels similar to AvGas (Specification D910) for reciprocating engines and wide-cut jet fuels similar to JP-4 (MIL-DTL-5624) for turbine engines. The initial boiling point of these fuels is in the temperature and pressure regime of hot weather conditions.

X1.2 In previous CAA regulations and guidance, a fuel temperature of 43 °C [110 °F] has been established as a baseline for fuel temperature prior to commencement of the test. This limit is discussed within FAA AC 23-16A with the following explanation: "… autogas heated to 110°F in a vented vessel (i.e., an airplane fuel tank) will boil off approximately 18 percent of its mass in the form of non-recoverable vapors. These lost constituents are primarily the highly volatile fractions, mainly pentane and butane, the fuel constituents that can cause vapor lock problems. In contrast, aviation gasoline will boil off approximately 1 percent of its mass when heated to 110°F."

X1.3 The critical point of 43 °C [110 °F] has been consistently applied to all aviation reciprocating and turbine engines since 1949. However, distillation data has shown that kerosene-type turbine fuels have initial boiling points well beyond hot weather conditions. For example, Russian TS-1 (GOST 10227), which is the most volatile kerosene-type turbine fuel, has an initial boiling point of 133 °C [271 °F] at sea level. Therefore, the value of 43 °C [110 °F] is not a critical point for kerosene-type turbine fuels.

X1.4 The maximum approved ambient operating temperature for each aeroplane using kerosene-type turbine fuels is the correct critical point for evaluation with respect to ambient temperatures.

X2. CONSIDERATIONS FOR FUEL SYSTEM HOT WEATHER TESTING

X2.1 The primary concern of fuel systems hot weather operation is vapor formation resulting in the interruption of engine power. Aviation fuels contain hydrocarbon compounds that evaporate from the fuel liquid mixture under conditions of increased temperature or decreased pressures, or both. These vaporized components can cause vapor formation within the aeroplane engine or fuel system leading to interruption of engine power due to vapor lock or pump cavitation.

X2.2 Vapor formation is a function of temperature and pressure. The initial boiling points of the fuels evaluated within CRC AV-20-14 are reproduced in Table X2.1. The equivalent International Standard Atmosphere (ISA) pressure altitudes (PA) are shown for reference. Note that the Jet A data is also applicable to Jet A-1.

X2.2.1 Fig. X2.1 shows the approximate initial boiling points (vapor formation of most volatile components) for typical kerosene-type turbine fuels based on CRC AV-20-14.

NOTE X2.1—These data are not directly applicable to fuel under pressure and flow conditions such as within the fuel distribution system, though the relationship between boiling point, temperature and pressure remains true.

X2.2.2 For the purposes of this practice, it is assumed that maximum approved ambient operating temperatures do not exceed 60 °C [140 °F]. Therefore, based on the data within Table X2.1 and illustrated within Fig. X2.1, kerosene-type turbine fuel at the maximum approved ambient operating temperatures and atmospheric pressures is not considered to release gaseous volatile compounds that lead to vapor formation.

X2.2.3 As the fuel transfers from the fuel storage system into the fuel distribution system, the pressure of the fuel can increase or decrease rapidly. Particular points within the fuel distribution system reduce the pressure of the fuel, such as within ejector pumps, at the impeller of centrifugal pumps, and within distribution lines of suction lift systems. Therefore, a fuel that is near the initial boiling point within the fuel storage system may be then exposed to conditions in the fuel distribution system that are conducive to vapor formation due to a reduction in pressure.

X2.2.3.1 For example, consider an aeroplane with a fuel storage system pressure of 0.19 atm (40 000 ft ISA PA [12 192 m ISA PA]) using TS-1 at a fuel temperature of 85 °C [185 °F] at the distribution system pickup point. If temperature remains constant and the distribution system reduces the pressure by 0.05 atm (5 kPa [0.7 psi]), then the fuel is exposed to conditions that are conducive to vapor formation.

TABLE X2.1 Initial Boiling Point of Various Aviation Turbine Fuels

Fuel Grade	Initial Boiling Point							
	1 atm		0.5 atm		0.25 atm		0.1 atm	
	0 m PA		5508 m PA		10 252 m PA		16 141 m PA	
	0 ft PA		18 070 ft PA		33 634 ft PA		52 956 ft PA	
Jet A	170 °C	[338 °F]	145 °C	[293 °F]	100 °C	[212 °F]	90 °C	[194 °F]
JP-8	152 °C	[306 °F]	119 °C	[246 °F]	104 °C	[219 °F]	87 °C	[189 °F]
TS-1	144 °C	[291 °F]	133 °C	[271 °F]	97 °C	[207 °F]	75 °C	[167 °F]
JP-5	195 °C	[383 °F]	160 °C	[320 °F]	128 °C	[262 °F]	99 °C	[210 °F]
JP-4[A]	84 °C	[183 °F]	71 °C	[160 °F]	63 °C	[145 °F]	34 °C	[93 °F]

[A] JP-4 is a wide-cut turbine fuel, while the remainder of the fuels within Table X2.1 are kerosene-type turbine fuels.