AEROSPACE INFORMATION REPORT

AIR790™ REV. D

Issued 1964-04
Reaffirmed 1992-08
Revised 2020-09

Superseding AIR790C

(R) Considerations on Ice Formation in Aircraft and Engine Fuel Systems

RATIONALE

The purpose of this revision is to organize and combine the useful information from AIR790C and ARP1401 into AIR790D and to expand the document with additional information on icing, fuel, and water management and testing. This revision includes observations and considerations regarding testing methods to provide a basis for a standardized test methodology.

FOREWORD

This AIR is intended to provide useful information for the consideration of ice formation in aircraft fuel systems, including fuel filters that may be included in either the airframe or engine fuel system. It does not include consideration of ice formation within fuel tank vent systems, nor does it include instructions for the use of anti-icing fuel additives. This document does not include in this revision considerations for non-crude oil derived fuels (generically referred to as alternative fuels, derived from alternate fuels pathways, or synthetic fuels) which do not meet drop-in fuel specifications.

This report was initially based on conclusions reached at a combined Air Force-Navy-Industry conference held in 1959 and subsequently updated to reflect current industry consensus and practice by the SAE Committee AE-5. It represents a summary of contributions, based on personal experience, from aircraft fuel system engineering representatives from the industry. This report also includes information that was previously included in ARP1401, as well as information gathered from the investigation results on the incident involving a Boeing 777-236ER, at London Heathrow Airport on January 17, 2008.

In the past, incidents and accidents occurred in the operation of military and civil aircraft which were attributed to the formation of ice in the fuel supply system resulting in intermittent or complete starvation of fuel flow. Considerable effort was devoted by many airframe companies, engine and accessory manufacturers, fuel system component suppliers, and government agencies to study the problem of ice formation and to develop corrective measures. By its very nature, the problem of ice formation is very complex and difficult to analyze. However, corrective measures were developed which, for many years, have virtually eliminated serious icing problems in aircraft fuel systems.

Successful corrective measures are numerous and include, but are not limited to, the use of anti-icing fuel additives, aircraft fuel heaters, improved in-flight fuel and ambient temperature monitoring, appropriate corrections in route or altitude or air speed, and improved water management and drainage provisions in aircraft fuel tanks, as well as ground storage and delivery systems.

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1. SCOPE

Ice formation in aircraft fuel systems results from the presence of dissolved and undissolved water in the fuel. Dissolved water or water in solution with hydrocarbon fuels constitutes a relatively small part of the total water potential in a particular system with the quantity dissolved being primarily dependent on the fuel temperature and the water solubility characteristics of the fuel. One condition of undissolved water is entrained water, such as water particles suspended in the fuel as a result of mechanical agitation of free water or conversion of dissolved water through temperature reduction. This can be considered as analogous to an emulsion state. Another condition of undissolved water is free water which may be introduced as a result of refueling or the settling of entrained water which collects at the bottom of a fuel tank in easily detectable quantities separated by a continuous interface from the fuel above. Water may also be introduced as a result of condensation from air entering a fuel tank through the vent system. Assuming good quality of uplifted fuel, vapor passing through the aircraft vent system is a significant water introduction mechanism.

Entrained water will settle out in time under static conditions and may or may not be drained, depending on the rate at which it is converted to free water. In general, it is not likely that all entrained water can ever be separated from fuel under field conditions. The settling rate depends on a series of factors including temperature, quiescence, and droplet size. The droplet size will vary depending upon the mechanics of formation. Usually the particles are so small as to be invisible to the naked eye, but in extreme cases can cause a slight haziness in the fuel.

Free water can be drained from a fuel tank if low point drain provisions are adequate and recommended maintenance actions are followed. Water in solution cannot be removed except by dehydration or by converting it, through temperature reduction, to entrained, then to free water.

Water strictly in solution is not a serious problem in aviation fuel so long as it remains in solution. Entrained and free water are the most problematic because of the potential of freezing on the surfaces of the fuel system. Further, entrained water will freeze in cold fuel and tend to stay in solution longer since the specific gravity of ice is approximately the same as that of hydrocarbon fuels.

The elimination of undissolved water, to the extent it is practical, in fuel storage, handling, and delivery systems, as well as in aircraft fuel systems, can reduce or eliminate the potential for icing problems. Appropriate testing of fuel systems, subsystems, and components under controlled icing conditions can establish confidence in the safe operation of the aircraft fuel system in such icing conditions. The objective of testing is not necessarily to demonstrate that no icing will occur but rather that the effects of the icing will not create a hazardous condition. Considerations for these measures to control potential icing problems are addressed herein.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP1401 Aircraft Fuel System and Component Icing Test

ARP5794 Centrifugal Aircraft Fuel Pump Requirements, Design and Testing, Aerospace Standard

ARP8615 Fuel System Components: General Specification for

French, W. and Malick, E., "Jet Fuel Anti-Icing Additives - A New Concept in Safety of Flight," SAE Technical Paper 610314, 1961, https://doi.org/10.4271/610314.

2.2 U.S. Government Publications

Copies of these documents are available online at https://quicksearch.dla.mil.

MIL-F-17874 Fuel Systems: Aircraft, Installation and Test of

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

Department of Defense Joint Services Specification Guide: JSSG-2009.

2.3 Other Publications

AAIB Report on the accident to Boeing 777-236ER, G-YMMM, at London Heathrow Airport on 17 January 2008.

Aviation Fuels, Maxwell Smith, G. T. Forlis and Company Ltd., Henley-On-Thames, Oxfordshire, 1970.

Fuel Icing and Contamination Testing of the A4D-2 and 2-N Fuel System Including the J65 Engine Fuel Control, Part No. 330541-1, T. J. Baginski, R. R. Wickwire, Douglas Aircraft Company, Inc., Report 40586, December 5, 1961.

Fuel System Icing Susceptibility Test Model A3D-2 Tanker/Receiver, R. R. Wickwire, Douglas Aircraft Company, Inc., Report 20094, July 17, 1961.

JP-4 Fuel System Icing, Gerhard Langer, Armor Research Foundation, WADD Technical Report 60-826, October 1960.

The Behavior of Water in Jet Fuels and the Clogging of Micronic Filters at Low Temperatures, John A. Krynitshy, John W. Crellin, and Homer W. Carhart, NRL Report 3604, January 11, 1950.

The Filtration of and Water Removal From Aviation Fuels, API Bulletin November 1965.

3. STORAGE, GROUND HANDLING, AND DELIVERY SYSTEMS

The following are recommendationsto reduce the likelihood of icing in aircraft fuel system.

3.1 Undissolved Water

The fuel should be maintained with no detectable undissolved water at fuel ambient temperature. If free water is observed, it is likely that the fuel is already saturated with water.

3.2 Control Techniques

Procedures should be used to ensure continuous compliance with the recommendations of 3.1 at point of delivery to aircraft. Filtration to control the contamination level of the fuel, and water coalescing type equipment to separate and remove undissolved water from the fuel should be employed in storage, handling and delivery systems to accomplish this. Even so, it is recommended to follow the airframer and engine manufacturer maintenance procedures when testing for water presence in fuel.

4. AIRCRAFT FUEL SYSTEMS

4.1 Anti-Icing Fuel Additive

Icing inhibitor is included by specification requirement in some military aviation fuels. It is not included in commercial aviation fuels; however, it may be added by operators. The additive effectively lowers the freezing temperature of entrained and free water, depending upon its percentage of concentration in the fuel. The additive is water soluble; therefore, its concentration and effectiveness may be reduced by properly removing settled free water from low point drains. Use of the additive may allow low point drainage of free water in cold ground operations which might otherwise be frozen.

It should be noted that in some instances (primarily due to higher than recommended concentrations and/or poor fuel tank drainage practices), anti-icing inhibitors have been known to create other issues in terms of handling and corrosion because of their toxicity. Furthermore, the additive is only effective if it is properly mixed with the fuel, it should never be assumed that the anti-icing agent will spontaneously diffuse in fuel without any mechanical mixing.

4.2 Fuel Heating

Fuel can be heated by the use of circulation and transfer pumps and heat exchangers making maximum use of available heat. Fuel can be heated by integrating hydraulic and environmental control systems (ECS) with the fuel system, specifically using fuel oil and fuel coolant (e.g., polyalphaolefin or PAO) heat exchangers to heat fuel. This integration of fuel thermal management can have beneficial impacts to the overall air vehicle by minimizing waste heat and maximizing cooling of other subsystems.

In-flight corrections in route, altitude, and air speed may be employed to control fuel temperature and avoid icing problems associated with water in the fuel.

4.3 Water Management and Drainage

Minimization of free water can be achieved with proper design considerations and drainage provisions and procedures. The tank bottom surfaces, and associated ribs, stringers, and features should provide passages for free water to migrate to low point drains in water sumps of adequate capacity. Drainage provisions should be located for maximum free water removal, accessibility, and ease of operation, and should display prominent clearly defined markings.

Free water may also be routed to circulation or inter-tank transfer pump inlets or to engine feed pumps providing provisions exist for adequate mixing with fuel to prevent slugs of free water from entering the engine feed system.

Adequate drainage provisions and water management systems are especially important to prevent accumulation of water that comes out of solution as temperature falls. This is especially important considering cases when the aircraft is stored for prolonged periods (e.g., overnight) or during long flights.

Ejector pumps are often used to scavenge free water from trapped areas in fuel tanks to sumps or pump inlets.

4.4 System Components

Filters and screens which are not necessary for safety of flight should be eliminated if possible, to prevent possible ice accretion locations. Use of a reliable by-pass design around filters or screens which, if clogged, could result in engine flameout or other safety of flight hazard should be mandatory.

By-pass elements should be located to prevent backwashing of sediment. Multiple by-pass elements in a principal filter may be considered. An impending by-pass or by-pass activation warning device on principal filters or screens may be considered as an indication to the flight crew and/or maintenance crew that such bypass has happened. This information would be useful for post-flight evaluation and to trigger flight crew corrective action.

Generally, empirical evidence has shown that No. 4 mesh screen or coarser is considered not subject to critical icing; however, this would depend on and should be demonstrated for the critical operating conditions such as mission profile, water content, and environment. Filters and screens should be selected for adequate filtration and capacity based on engine requirements and should be subject to maintenance inspections per aircraft and engine maintenance manuals.

System components should be located, as practicable, in favorable environmental locations to best utilize available heat. Insulation provisions may be considered where appropriate and practical.

Components should be designed to be tolerant to water and ice with provisions for water run-off and drainage of water traps. Materials and coatings which are non-ice adhering should be used where appropriate.

Low points in fuel lines where water can collect should be avoided wherever possible. In situations where they cannot be avoided, it is recommended that drainage provisions such as float drain valves are provided. Multiple vent system openings to atmosphere should be located such that no pressure differential exists between them to preclude continuous circulation of outside air which can introduce considerable quantities of water in some operating conditions. It is recommended that both normal ground attitudes and normal flight attitudes are considered to evaluate possible water traps.

5. FUEL SYSTEM OR COMPONENT TESTING CONSIDERATIONS

5.1 Water to Ice Evolution

Several things happen to moisture-laden fuel as the temperature is lowered, and an understanding of this helps to arrive at proper fuel conditioning procedures and subsequent testing for icing conditions. As the temperature of fuel is lowered, the concentration of water droplets in the fuel begins to decrease when the fuel temperature in the vicinity of 40 to 50 °F (4 to 10 °C). Therefore, to get a reliable conditioning of fuel, samples should be taken and mixing of fuel and water should be accomplished before lowering the temperature below 40 to 50 °F (4 to 10 °C). Ice crystals begin to form as the temperature nears the freeze point of water; however, due to impurities in the water, this normally takes place at slightly lower temperatures (27 to 31 °F) (-3 to -1 °C). As the temperature is lowered further, the ice crystals begin to adhere to their surroundings in the form of ice. This is known as the critical icing temperature and occurs at about 12 to 15 °F (-11 to -9 °C). The density of the ice is approximately the same as the fuel, so any loose, floating ice will generally stay in suspension and drift within the fuel.

At temperatures below 0 °F (-18 °C), ice crystals tend to become larger and offer a threat to plugging small openings such as screens, filters, and orifices. They do not however carry the same accretion risk as crystals at the critical temperature. The cooling rate, heat transfer due to local flow features, and turbulence due to obstruction of flow have an effect on the type and size of ice formed, so it becomes important to test actual or closely simulated aircraft systems and to cool the fuel during tests at the aircraft cooling rate or practical simulation to obtain more accurate results.

5.2 Ice Accumulation

It is known that ice might form on the walls of transport elements, screens, and filters. Extensive testing to generate such ice has been conducted to understand further the mechanisms that led to the Heathrow incident. The general conclusion was that ice accumulation on the transport element walls occurred but that it did not lead to flow restrictions in the piping. As stated before, small ice crystals are usually entrained with fuel. In order for ice to accumulate, an anchor point or seed is required, for example a screen inlet. As ice particules randomly attach to the subject anchor point, it creates a node for more ice to be captured. This accretion will continue until mechanical constraints (e.g., fuel flow) detach or break the accreted lump.

Most icing tests will result in ice formation somewhere in the test setup. Direct observation of ice in the fuel system is difficult: transport elements are generally not made of transparent material and manipulation of the test setup or parts of the setup after the icing test will often result in ice melting away or more ice being generated from ambient air humidity condensing on the setup. It has been suggested that transparent transport elements or cameras are used, or that the melted ice content of transport element post test is measured to understand how much ice is accumulated in the fuel system. However, the means of observation must not impact the results of the testing being performed to measure flow and pressure within the fuel system. There is no standard method to conduct those observations and in general they will produce results that may be difficult to interpret.

During test development planning, consideration should be given to fuel type and condition as water retention is directly affected by the aromatic content of the fuel. Generally, the higher the aromatic content of the fuel, the more water will be held in suspension.

Ice formed outside the fuel system in the fuel tanks is generaly not a threat to the fuel system unless it blocks existing inlets, fuel components, or water drain valves, but this ice can melt, leading to increased free water.

5.3 Ice Release

Ice release is a random and not well understood phenomenon due to the number of variables involved in the fuel system. ARP1401 does not contain a standard method for ice release testing at this time. Tests performed as part of the Heathrow investigation showed that fuel pumps, isolation valves, and other airframe fuel system components had no problem handling released ice accretion as long at they were small enough to pass through inlet screens.

5.4 Testing Considerations

This section provides discussion and information to consider in performing testing of fuel systems, subsystems, and components and applies to all fuel flowing components and plumbing from fuel tank to engine, excluding engines.

The basic test considerations presented herein were derived from previously published methods recorded in MIL-F-17874. The information provided in this AIR is intended to supplement recommended practices provided in ARP1401 which have served the industry as a baseline from which specific test procedures have been developed for specific systems and components. It should be noted that icing test procedures must be tailored for the system, subsystem, or component being tested. In addition, consideration should be given to the ambient conditions (such as humidity and temperature) around the test chamber. As such, it is important to consider the location and time of year when conducting the test in order to limit the impacts of the environment on test results. For example, a high humidity environment could result in the unintentional introduction of excess water into the test chamber. Care should be taken to cool the test fluid and chamber prior to testing to minimize unintentional affects such as premature water precipitation. Continuous or intermittent operation, flow rate, and temperature schedules should be developed to simulate actual aircraft operating conditions as closely as practical.

Icing tests conducted in the industry have varied widely in the requirements and procedures used. There has been a lack of agreement on certain aspects of conducting tests including but not limited to general test setups, fuel conditioning, single pass test versus recirculating, use of anti-icing additive, test temperatures, test duration, water content analysis, and post-test requirements. By virtue of the reduced number of parts, fuel volume, and plumbing complexity, component testing is easier to conduct, and may result in greater repeatability and comparison to other tests results. However, component testing does not provide comprehensive system level testing; therefore, the evaluation of potential ice accumulation in the fuel system plumbing and conveyance components. With wide variations in test methods it is often difficult and sometimes impossible to accurately compare test results from different sources and assess which most realistically represents actual aircraft environment or demonstrates acceptable performance. Most reports show no schedule of temperature decrease. Fuel conditioning was accomplished by similar but still varying means (References 6 through 14). There is no optimum universal test setup or detailed procedure to cover all systems and components; however, certain guidelines can be established, based on industry knowledge and experience, to minimize overdesign or over-testing while providing confidence in safe operation of a fuel system in realistic icing conditions. It is the intent of this report to provide such guidelines.

Although the investigation following the incident involving a Boeing 777-236ER at London Heathrow Airport could not reproduce the events that led to the extensive restriction of fuel feed to the engines, it is very likely that ice blockage of a heat exchanger led to restricted flow and the inability for the engine to provide the required power. This is relevant in that most of the testing guidance contained in ARP1401 has focused on the airframe mounted fuel system. At the same time, engine manufacturers have focused on icing protection for the engine build unit. This observation does not invalidate the results of previous tests or design features but rather provide further areas for which research might need to be conducted to better understand coupling effects between airframe and engine fuel systems.

5.5 Test Setups

Test setups should represent actual aircraft conditions as closely as practicable. The component or system installation should be representative of that in the aircraft in configuration and location relative to aircraft features which might influence the performance. For instance, for fuel pumps having inlets near the bottom of a tank, the tank bottom should represent the aircraft tank in size, geometry, and contour, and should include ribs and stringers which might collect water. Actual aircraft fuel tanks have been used, as well as fabricated equivalents.

The test system as well as the test fuel should have the capability of being cooled at controlled rates and maintained at specified temperatures. Maintaining specified cooling rates and steady state test temperatures can be difficult and reasonable tolerances are advised considering wide variations in actual aircraft operations. Closed circuit refrigeration units with heat exchangers are commonly used for the fuel. Insulated enclosures cooled by cold nitrogen from a liquid supply have been used to cool systems as large as a full scale wing. Care must be taken to ensure the cooling methods do not result in accretion of ice on cooling surfaces that result in water content of the test fuel being outside the required range. Figures 1 and 2 provide examples of how a test setup could be prepared for mixing fuel and water and chilling to the defined test temperatures. It should be noted that these figures are for reference purposes only and are not intended to provide a recommendation of design or assembly of the setup.

5.6 Test Facility

The test facility supplying fuel to the test system should be designed to provide and maintain specified fuel flow rates at specified temperatures and water concentrations. The facility and fuel delivery lines should be free of water traps and unnecessary restrictions. Insulation on lines will help control fuel temperatures. Line sizing should be considered to maintain fuel velocities sufficient to keep undissolved water in suspension and prevent settling in lower elevations.

Fuel conditioning and water content control can be accomplished in a number of ways, the merits of which have been widely debated. The proof lies in accurate and consistent laboratory fuel sample water content analysis. Common water injection methods are by atomizing water over the surface of the fuel and by simply feeding water into the suction side of a circulation pump. The test fuel should be kept agitated by circulation to keep undissolved water in suspension and uniformly distributed throughout the test system. One means of accomplishing this would be use of a spray bar to agitate the fuel as shown in Figures 1 and 2.

Single pass tests, where conditioned fuel is passed through the test system once, are preferred; however, the quantity of conditioned fuel required for a simulated mission of a large transport, cargo, or tanker aircraft can be prohibitive for most facilities. In this case, delivery systems which return fuel from the test system outlet to the conditioned fuel supply are commonly used. When such a recirculating system is used, the conditioned fuel supply should be as large as possible to minimize the quantity of recirculated fuel. Consideration should also be given to minimizing flow disturbances between the conditioning tank and test article by minimizing the number of pipe bends, connections, and elevation changes. Starting the test within a short time period (e.g., 1 hour maximum) after reaching the test temperature of the conditioned fuel should minimize variation in water concentration and mixing due to ice accretion in the tank or precipitation of the water from the fuel.

For such recirculation tests, care should be taken in the method and quantity by which water is added to the system. Excessive amounts of water introduced in the test setup could lead to erroneous results and non-representative icing of the test setup (e.g., during the Heathrow incident investigation tests, when pump inlets became significantly covered with ice). In addition, care must be taken regarding the method of water introduction to accurately simulate water introduction via the refuel process and/or vent system as it occurs on the aircraft. For example, injecting water directly into the feed system may not be an accurate representation of water entering the aircraft fuel tanks through refueling or venting.

5.7 Laboratory Analysis

Fuel samples for laboratory water content analysis should be taken from points easily accessible during test. Assuming that samples are taken from valves, the valves should be opened and purged prior to collecting samples. Sample containers should then be rinsed with fuel and emptied prior to being filled with the laboratory sample. Laboratory sample containers should be kept sealed until analysis is performed. Laboratory water content analysis methods may vary, some reportedly more accurate with oversaturated fuel. The laboratory should be consulted and advised of the purpose of the analysis, the condition of the fuel samples, and the predicted water content based on previous fuel conditioning. Consistent results in the expected range of water concentration establishes confidence in methods and procedures.

The standard Karl Fischer Method (per ASTM D323) is only accurate for measuring water up to the fuel saturation level (dissolved water). Free water, when present, must also be extracted from fuel samples. In general though, free water is rarely distributed homogenously, so multiple samples should be considered and a means of reconciling results established.

Lower concentrations can be expected with low temperature samples as some water will freeze on internal surfaces of the system. Post-test water content analysis should be considered for information only unless the entire system is such that all free water can be collected and measured.

Identifiying adequate sampling points and location is important to more accurately determine water concentration. It is recommended to draw samples from a number of locations at both the inlet and outlet lines near the unit under test. The sampling ports should be located at the bottom of these lines to capture water.

Consideration should be given to acceptable criteria whether all samples must be within limits or the average of all samples must be within limits as differences in sample concentrations is likely.

5.8 Test Fuel

The test fuel should be certified as the primary fuel expected to be used on the aircraft. Anti-icing additives should be left out of the fuel so that a worst-case situation will be simulated unless the aircraft is restricted to using anti-icing additives even under emergency conditions.

Test fuel may be procured from a refinery, an airport, or a specialty hydrocarbon blender. Sample analysis at the source and at delivery should be considered since fuel contamination can occur during transit in multi-purpose tank trucks. Traces of anti-icing additives have been detected in commercial fuels processed at facilities which also process military fuels due to multi-purpose piping systems and tankage. If a significant quantity of anti-icing agent is present, it is recommended to procure a batch of fuel that does not contain such additive. There are anecdotal reports of fuel washing where water is added to attempt to remove the anti-icing additive however, experimental evidence that would allow recommendation of this methodology has not been found. Based on available data of anti-icing additive partitioning between the aqueous and fuel phases, relatively high ratios of water/fuel combined with high contacting efficiency would be necessary to completely extract the additive with a fuel washing process.

The amount of water required to saturate fuel at a given temperature varies with different fuel blends and with different batches of the same blend. This is due largely to the vast hydrocarbon variations of the crude oil, natural and introduced surfactants, aromatic content, and additives. For icing tests, fuel which is saturated with 90 ppm minimum at 80 °F (27 °C) is preferred. Fuel with a lower saturation following initial conditioning is considered rare and simply adding more water for a total water content of 90 ppm has been practiced.

5.9 Fuel Flow Rates

Continuous and intermittent duty systems operating at one steady state flow rate should be tested at their specified conditions. Systems operating at various flow rates such as those associated with engine feed can be more susceptible to ice accumulation and need further consideration.

The turbulence produced by the action of a fuel pump is considered to be the most severe inducement for crystallization of ice from water droplets within the fuel at sub-freezing temperatures. At high flow rates it is expected that more of the ice formed will travel through the pump because it would have less opportunity to accumulate and grow in size. At lower flow rates more ice is expected to accumulate within the pump, particularly on inlet screens. The worst flight condition may occur when a high flow rate is initiated following a sustained low flow rate at sub-freezing conditions that would occur on descent. Unfortunately, this represents a typical fuel usage scenario for which an aircraft uses high fuel flow for take-off and climb then throttle back during cruise and descent. Ice packed on a pump inlet screen may prevent the required fuel flow to an engine.

In general, icing test flow rates and durations for engine feed systems should simulate those expected during a typical flight. Following each test temperature phase, a high flow rate setting is recommended for long enough to evaluate system pressure drop characteristics which may be attributable to icing.

5.10 Test Method Considerations

Three test methods are addressed for (1) continuous system operation, (2) emergency system operation, and (3) component operation. Each test includes three test phase temperatures. A system should be subjected to the continuous and emergency system operation tests. The emergency system operation test is a short duration test at each temperature with a higher water content, representative of conditions that would only exist for limited periods (e.g., 30 minutes). Individual components may be required to be tested at a still higher water content, depending on their function and installation, if they may be exposed to more severe icing conditions.

Caution is advised in developing icing test requirements, as overtesting often leads to invalid failures. The real aircraft operating conditions and environment must be considered. Some test operators have chosen to combine the continuous system operation and emergency system operation tests at the emergency operation test water concentrations. This practice establishes a higher level of confidence in system operation in icing conditions.

The fuel system or component should be operated as intended on the aircraft for the expected duration of a typical flight plus in-flight refuelings, if applicable. The system or component shall function throughout the test with no deterioration in performance that would result in a flight safety hazard or compromise a mission.