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Superseding ARP1401A

(R) Aircraft Fuel System and Component Icing Test

RATIONALE

This revision of the Aerospace Recommended Practice is intended to address several industry questions pertaining to the method of conducting Icing Tests. Some of those questions pertained to the actual testing setup, others were related to the water content analysis method and finally some were more about the test validity and actual procedural application. This new revision attempts to address those questions as well as provide an improved fuel water analysis methodology.

1. SCOPE

This Aerospace Recommended Practice (ARP) covers a brief discussion of the icing problem in aircraft fuel systems and different means that have been used to test for icing. Fuel preparation procedures and icing tests for aircraft fuel systems and components are proposed herein as a recommended practice to be used in the aircraft industry for fixed wing aircraft and their operational environment only. In the context of this ARP, the engine (and APU) is not considered to be a component of the aircraft fuel system, for the engine fuel system is subjected to icing tests by the engine/APU manufacturer for commercial and specific military applications. This ARP is written mostly to address fuel system level testing. It also provides a means to address the requirements of 14 CFR 23.951(c) and 25.951(c). Some of the methods described in this document can be applied to engine and APU level testing or components of those application domains.

This revision does not completely address new developments in ice accretion resulting from internal flow in tubing. This will be addressed in a future revision when more experimental data is available. Some background information on the topic is planned to be available in AIR790.

1.1 Purpose

The cold temperatures to which jet aircraft are exposed can have a detrimental effect upon the fuel system and its components by causing water that is entrained in the fuel to form ice and clog filter and screens or cause component or system malfunction. As a result, fuel flow to engines can be reduced, restricted or stopped altogether causing flameouts or loss of power which pose a flight safety hazard. Even though many aircraft normally operate with fuels treated with an anti-ice additive, (Reference 2.1.2), fuel without this additive is routinely encountered. Consequently, fuel systems should be tested with fuel that does not contain the anti-icing additive unless the aircraft is specifically restricted from operating without the additive. Because there is great disparity in the requirements and procedures used to perform these icing tests as evidenced in military specifications and aircraft industry reports, it is difficult to determine which testing procedure is the best for a particular fuel system or component.

Therefore, this ARP recommends practices for icing tests for aircraft fuel systems and fuel system components and helps avoid expensive overdesign and overtesting of a component or system while insuring the reliability of a fuel system in icing conditions. In general, system tests are used to assess the overall airframe fuel system tolerance to icing using a representative test setup and test duration. Although system testing has been used in lieu of component testing and vice-versa, in general component level tests are more specific and more severe than system level testing.

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Three icing test procedures are presented herein:

a. Continuous Operation

b. Emergency Operation (Component or System)

c. Filter with Bypass Function Operation

These three procedures fullfill different purposes. The test paradigm used in this ARP is to create a representative ice accumulation test that would simulate a typical aircraft mission. The representative scenario includes a take-off, climb and cruise segment followed by a descent, approach and go around before landing segment.

The Continuous Operation procedure simulates the “cruise” portion of the flight, when the aircraft fuel system is subjected to cold temperatures with water saturated fuel and no excess water. The take-off and climb time segments are typically rolled in the Continuous Operation regime given their relatively short duration when compared to the cruise portion of a typical mission.

The Emergency Operation procedure simulates the effect of excess water being introduced in the system by condensation from lower altitude air and the verification that the fuel system can still supply an adequate amount of fuel in case of engines being powered up for an “emergency”, such as a go around maneuver. This testing can also be used to simulate conditions in which large amounts of water could suddenly be mixed with fuel. For the purpose of the test, this test regime can include the descent, approach and go around segments of the mission.

Although designed with system test in mind, the abovementioned procedures can be applied to individual component testing to verify susceptibility to ice formation during specific aircraft operating conditions.

The Filter Bypass Function Operation test is very specific in that it aims at demonstrating the functional capability of the bypass feature of a filter element (or, alternatively, specific component) when subjected to ice blockage.

If aircraft level flight testing is performed, the recommended practices herein should be applied in the preparation of the flight test demonstration plan. This would include the discussion as applicable on water saturation levels, fuel conditioning, critical icing temperatures and durations of simulated mission profiles.

2. REFERENCES

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

2.1.1 AIR790 Considerations on Ice Formation in Aircraft Fuel Systems

2.1.2 610314 “Jet Fuel Anti-Icing Additives - A New Concept in Safety of Flight,” W. C. French and E. A. Malick SAE Technical Paper, 1961.

2.2 U. S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

2.2.1 MIL-F-17874B Military Specification Fuel Systems: Aircraft, Installation and Test of

2.2.2 MIL-F-38363B Military Specification; Fuel System, Aircraft, General Specification for

2.2.3 MIL-P-5238C Military Specification; Pump Centrifugal, Fuel Booster, Aircraft, General Specification For

2.2.4 MIL-F-8615C Military Specification; Fuel System Components; General Specification For

2.2.5 MIL-E-5272C Military Specification; Environmental Testing, Aeronautical and Associated Equipment, General Specification for

2.2.6 MIL-S-8710B Military Specification; Strainer Airframe Fuel System, General Specification for

2.2.7 MIL-V-38003 Military Specification; Valves, Fuel Level Control, Fuel Tank, Aircraft General Specification for

2.3 Other References

See individual reference publisher for document availability.

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

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

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

2.3.4 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.

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

2.3.6 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.

2.3.7 University of Dayton Research Institute (UDRI) Method KFT-1 to determine the total water content in jet fuel, UDRI evaluation report, January 3, 2010

2.3.8 University of Dayton Research Institute (UDRI) Evaluation of UDRI Method KFT-1 to Accurately Measure Total Water Content in Jet Fuel, Rhonda Cook, January 3, 2010

2.3.9 D7566 – 10a Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons, ASTM International, July 1, 2010

3. BRIEF HISTORY

As aircraft were operated at higher altitudes and in colder ambient temperatures, the cooler temperatures had an effect on water which was saturated or entrained in the fuel. If these conditions produced ice, valves, pumps, filters and screens become clogged with resulting failure in the aircraft fuel system. One case of failure through fuel icing occurred in 1958 when a large aircraft crashed short of a runway in South Dakota after power was lost on three engines. An inspection of the wreckage indicated that ice was blocking the engine fuel feed system. However, the cause of high water content was not determined. Many other failures due to icing in the fuel system have been recorded. (Reference 2.3.1)

Water can be present in aviation fuels in two basic forms: dissolved or free water. Dissolved water is completely solubilized within the fuel while free water (i.e., droplets) is that in excess of the solubility limit. Dissolved water is similar to humidity in the atmosphere. The amount of water which a volume of fuel will absorb and hold is dependent on both the temperature and the blend of hydrocarbons making up the fuel. At 60 °F (16 °C) this may vary from less than .003 percent to approximately .010 percent by weight or almost one pint per one thousand US gallons. Fuels may be partly or fully saturated with dissolved water. As with air, the higher the temperature of the fuel, the more dissolved water it can contain. Thus, whenever the temperature of a fuel saturated with dissolved water is lowered, some of the dissolved water will become free water.

Free water may be entrained or may be in slugs or pools. Entrained water is water suspended in the fuel in minute globules (akin to an emulsion). It may not be perceptible to the naked eye, or it may cause the fuel to take on a hazy or milky appearance. Water may become entrained by the breaking up of water slugs through turbulence in a pump, throttling valve, or in high velocity transfer operations, by condensation of moisture in the tank atmosphere due to low tank structure temperatures, or by the reduction in temperature of a saturated fuel volume (Reference 2.3.2, 2.3.3).

Fuel filtration requirements limit the total water content during fueling to dissolved plus a maximum of 10 ppmV free water. Once on-board the aircraft, the primary process for additional water introduction is via fuel tank venting. Fuel systems draw outside air into the fuel tanks through their vents as fuel is consumed and as the aircraft descends in altitude. As an aircraft flies through moist air, the fuel onboard tends to absorb some of this moisture . Some water, which is free, can be drained from tank sumps or separated from the fuel through a filter and then drained; however, some water remains in solution in the fuel. This water, plus excess water which cannot be drained off, as well as that collected in flight, can pose a serious threat to proper functioning of fuel system components (Reference 2.3.1, 2.3.4). This situation is further aggravated as an aircraft climbs higher, cold soaks, and then descends to a lower altitude. Fuel tank vents expel fuel tank ullage vapors during climbs, then draw in outside ambient air during descents. Warm, moist air drawn in during a descent, condenses when it comes in contact with the cold soaked tank and fuel, hence raising the water content.

As ice forms within the fuel system, it may accumulate in certain places such as a pump inlet. Therefore, a slush of ice and fuel may begin to build-up. The turbulence produced by the action of the pump is considered to be the most severe inducement for the crystallization of ice from the water droplets within the fuel at subfreezing temperatures (References 2.3.1, 2.3.4). Under high fuel flows, it is expected that the ice formed will travel through the pump because it would not have an opportunity to accumulate and grow in size. At lower fuel flows, only a portion of the ice formed will travel through the pump with most of the ice accumulating about the pump or on its inlet or inlet screen. The worst flight condition may occur when after sustained low fuel flows under subfreezing conditions, a demand is made for high fuel flow. The slush formed during the low fuel flow is expected to be accumulated at the pump screens with reduced or no flow existing. Therefore, at each test temperature, during the icing tests on the fuel systems, the flow rate should be raised from a sustained low rate to a high rate with the resulting drop in pressure, if any, recorded. The pump and the rest of the system shall function with no deterioration in performance that would result in a flight safety hazard or seriously compromise the mission.

Early solutions to the icing problem, many of which are still used, included enlarged screens, added bypass valves, and lower filter densities. Engine bleed air was used to heat the fuel near the engine, but did not affect the fuel before reaching the engine area. Anti-icing additives were developed and subsequently replaced fuel heaters in many aircraft. Although many fuels have been treated with an anti-ice additive, there is no guarantee this will always be the case. There are occasions when fuel without this additive may be encountered. As a result, specifications for icing tests were issued which covered not only the fuel system as a whole, but also certain components within the system. Most modern commercial aircraft are designed and approved to operate without the need for fuel system icing inhibiter.

4. NEED FOR TEST STANDARDIZATION

Many reports and specifications have widely varying test temperatures and test durations or no clear statement of duration. There is a lack of agreement on the use of anti-icing additive in the fuel during the test. Most reports show no schedule of temperature decrease. Fuel conditioning was accomplished by similar but still varying means (References 2.2.1 through 2.2.7, 2.3.5).

Present-day icing tests vary so greatly that it is difficult and sometimes impossible to accurately compare results from one test to another and to assess which one more realistically represents an actual aircraft environment. A realistic standard icing test could eliminate or minimize this problem and give both manufacturer and customer more confidence in component and system integrity.

The purpose of the recommended testing methodologies discussed herein is not to account for specific types of ice particle size nor accretion rate. Those will partly be dependent on the conditioning system. As stated the interest lies in the macroscopic effect of possible ice formed in the aircraft fuel system or components through a standardized test procedure. Research of available information of actual and experimental system tests supports the procedures for aircraft system icing tests required in MIL-F-17874B as being the most concise procedures to date. These procedures form the basis of the recommended tests of this ARP.

5. 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.

It is known that, for a fuel sample saturated with water at room temperature, water will come out of solution as the temperature of the sample is lowered. It is also known that, as the fuel temperature is lowered, the concentration of water droplets in the fuel begins to decrease when the fuel sample reaches temperatures in the vicinity of 40 to 50 °F (4 to 10 °C). Therefore, to achieve a reliable conditioning of fuel prior to an icing test, mixing of fuel and water should be accomplished before lowering the temperature below 40 to 50 °F (4 to 10 °C). In the same manner, fuel samples taken to measure the fuel water content prior to test should be taken at the same time.

Ice crystals will begin to form as the fuel temperature nears the freezing 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 and form ice. This is known as the critical icing temperature and occurs at about 12 to 15 °F (-11 to -9 °C). At temperatures below 0 °F (-18 °C), ice crystals tend to become larger and offer a threat to plugging small openings such as screens, filter, and orifices (References 2.3.1, 2.3.3). Below -5 °F (-20 °C), ice tends to be less “sticky” and does not have high rates of accretion. The density of the ice is approximately the same as the fuel medium. Consequently, the ice will generally stay in suspension and drift within the fuel. As stated before, several references mention that the critical temperature is the point at which ice has the highest potential for accumulation.

The cooling rate and agitation or turbulence due to obstruction of flow have an effect on the type and size of ice formed. Consequently, it becomes important when designing a test setup, to have a close representation of the actual aircraft systems to be tested and, if possible, to cool the fuel during tests at a typical aircraft cooling rate to obtain more accurate results.

6. RECOMMENDATIONS

6.1 Test Setup

Figure 1 presents a recommended, but not mandatory, single pass test setup for conditioning fuel and performing system and component icing tests. The intent for using this type of test setup is to only condition enough fuel for the intended test and then circulate this entire quantity through the system or component in a single pass. In other words, all the fuel in the conditioning tank will flow through the system or component and return to the dump tank. Water is introduced in the system via an atomizing spray in the conditioning tank and/or a discrete water injection point. Prevention of water accumulation and settling in the condition system is critical to insure that all water is transferred to the test article during evaluation.

Figure 2 is an alternate test setup which allows for a “recirculation” method. A batch of fuel is conditioned then used in the test setup after which additional water can be injected. This setup is preferred when it is is not practical to use a single pass method given the amount of fuel that would be required to perform such a test (see Note 8.3).

Whichever test setup is used, low points and quiescent areas where water can settle should be avoided and the fuel cooling heat exchanger should be regulated. In addition, the conditioning and dump tanks should have minimun venting to atmosphere to avoid changes in fuel water content although this not generally an issue for short duration tests.

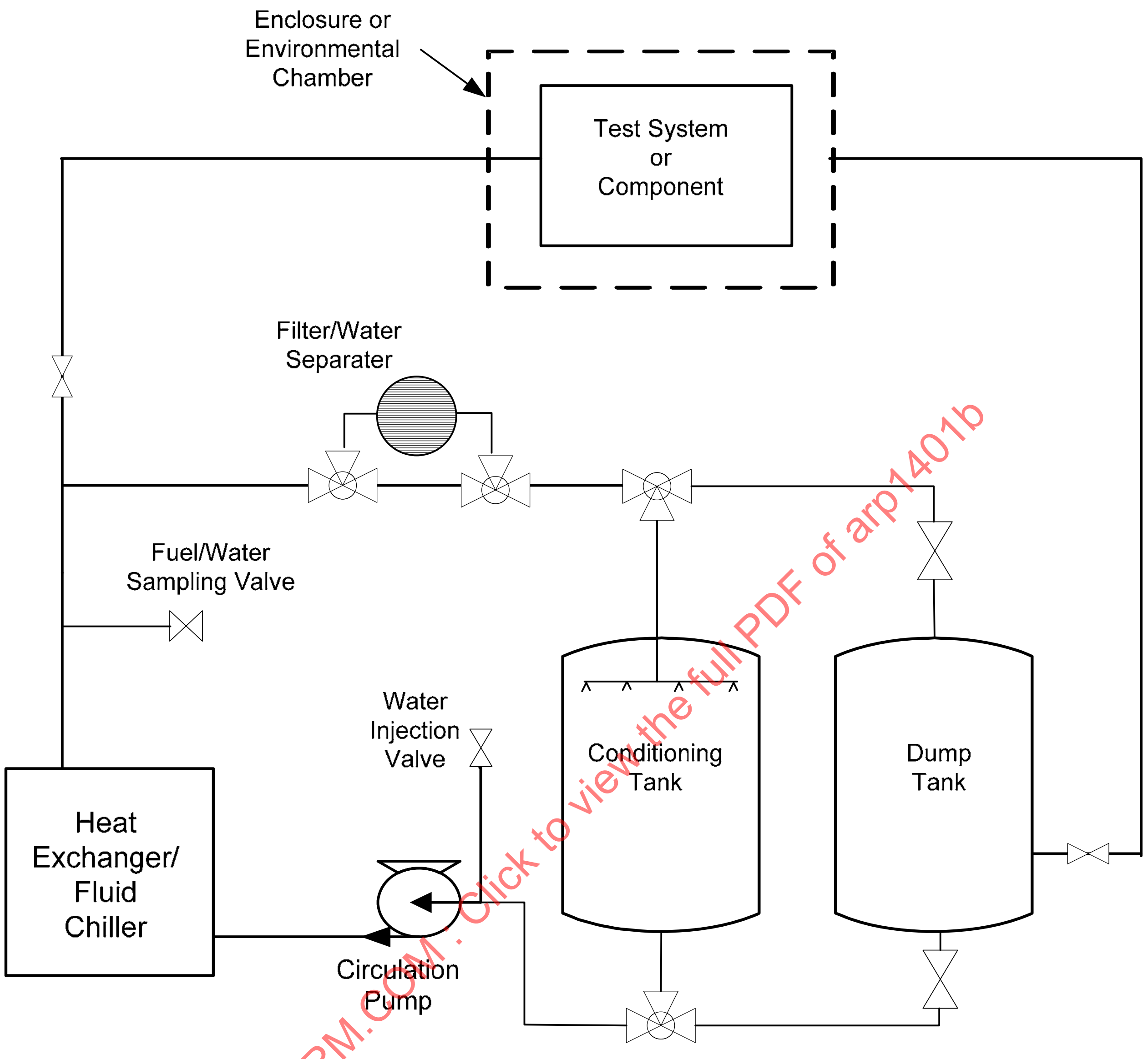

FIGURE 1 - TEST SETUP FOR SYSTEM ICING TEST

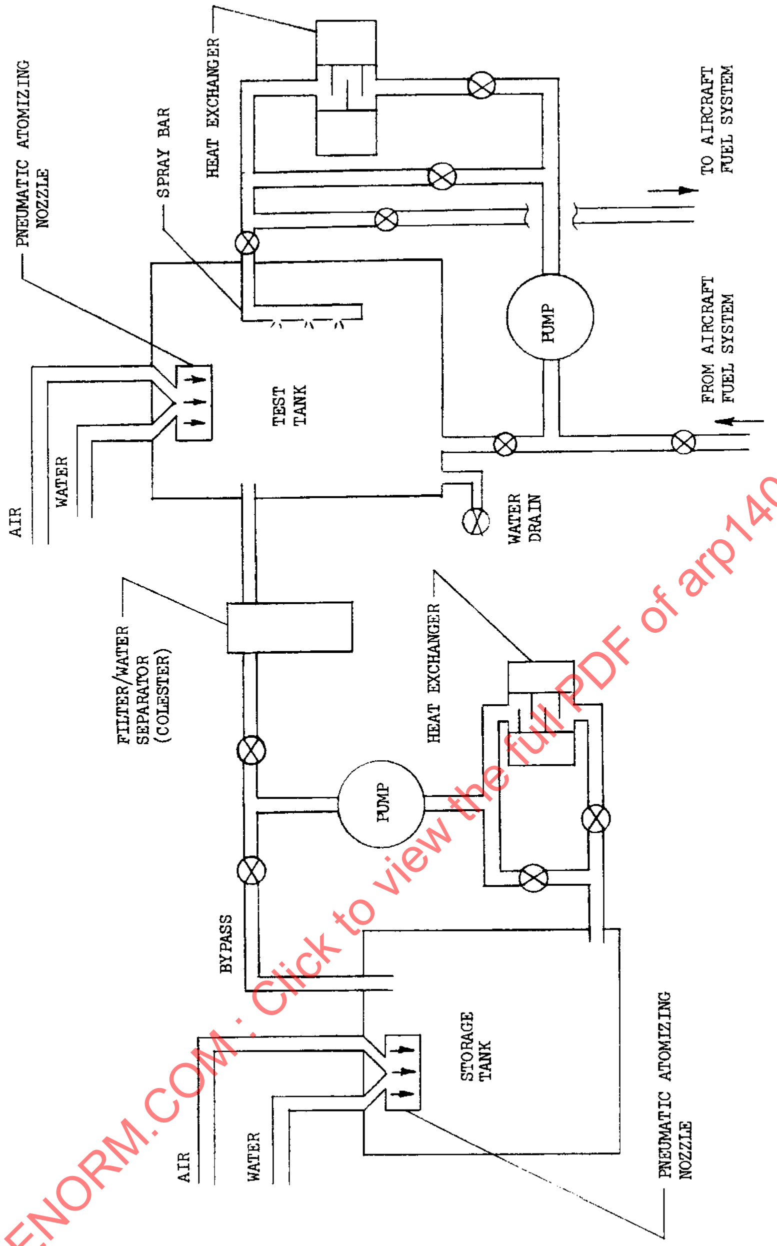

FIGURE 2 – ALTERNATE FUEL SETUP FOR SYSTEM ICING TEST

6.2 Recommended Preparation of the Fuel

Proper conditioning of the fuel prior to test should be accomplished to establish a standard baseline so that valid results of the tests can be obtained and compared. A standard to start with is fuel that is saturated with water at 85 ± 5 °F (29 °C ±3 °C). To obtain this condition, the expected primary fuel, JP-4, JP-5, JP-8, Jet A or Jet A-1 with 10% +15%, -0% aromatics should be procured in sufficient quantity for the total fuel capacity required for the aircraft system test. If the fuel is commercially purchased aromatics content for “as delivered” is acceptable, including fuels containing synthesized hydrocarbons as per reference 2.3.9.

Anti-icing additives should be left out of the fuel so that a worst case situation will be simulated, and more repeatable results obtained, unless the aircraft is restricted to using anti-icing additives even under emergency conditions.

It is recommended to procure fuel from a typical aerospace industry supplier The fuel should not be filtered (cleaned) beyond what is normally accomplished by a typical ground infrastructure distribution system (hydrant, truck filtering medium).

6.3 Preparing for Fuel for “Continuous System Operation” Test

The following procedure is recommended for continuous operation tests with fuel at its saturation level of 90 ppm at 85 ± 5 °F. This has been used as an industry standard, but historically saturation level tests have been conducted with water content between 90 and 130 ppm, but not less than 90 ppm.

a. Place the fuel in the conditioning tank, isolate the coalescer filter and begin circulation from the conditioning tank through the heat exchanger and back into the conditioning tank until the fuel is heated to 85 ± 5 °F (29 °C ±3 °C). Circulation should be sufficient to agitate the fuel/water mixture and not allow water to settle in the bottom of the tank or in quiescent areas. A mechanical stirrer can be used to ensure this. A spray bar in the bottom of the conditioning tank is recommended to assist in agitation and to keep water from settling on the tank bottom. Alternatives to a spray bar are acceptable as long as they provide for agitation and preventing water from settling on the tank bottom.

b. While maintaining the flow and the required temperature range, 1 gallon (liter) of water per 1000 gallons (liters) of fuel should be added at a recommended rate of approximately 55 cc per minute. Water can be added by either using the pneumatic atomization method or by injecting the water at the inlet of the circulation pump.

c. After all the water has been added into the fuel, continue circulation for approximately 30 minutes to help insure complete mixing.

d. While maintaining 85 ± 5 °F (29 °C ±3 °C) direct the flow of fuel from the conditioning tank through the filter/water separator (coalescer) and into the dump tank and then back again through the coalescer filter into the conditioning tank. Isolate the coalescer filter. It is acceptable to bypass this filtering step and adjust directly the water concentration as long as the final results match the 90 to 130 ppm target. If the water concentration is less than 90 ppm, refer to step g.

e. While still maintaining circulation at 85 ± 5 °F (29 °C ±3 °C) take three fuel/water samples from the sampling valve at time spaced intervals to capture representative samples of the entire fuel volume as it passes through the system. Sample should be taken in 100 ml sampling bottles with air tight lids (plastic is recommended. See notes 8.4 and 8.5). Sample bottles should be filled and drained and then filled and immediately capped for analysis (See note 8.4).

f. Using the Karl Fischer method (documented in the Naval Research Laboratory Report #3604, Reference 2.3.4) or a “Modified” Karl Fischer method (refer to Appendix A), analyze samples from the three time spaced intervals collection from the bulk of the fuel. The modified version of the method is recommended to allow for more reliable measurement of total water content (see Note 8.6). The average quantity of water from the three samples shall contain not less than 90 ppm and not more than 130 ppm. It should be noted that a total water content analysis of > 90 ppm only ensures that the fuel is completely saturated with water and does not verify that excess free water is not present. If precise control of the total water content is mandatory, an alternative method for fuel conditioning should be employed as per note 8.9.

g. If the fuel samples are less than 90 ppm additional water shall be added. Adding 0.00378 cc of water per gallon of test fuel should raise the water concentration by 1 ppm. Calculate and add the amount of water required to bring the fuel to the desired water concentration level. The fluid mixture shall be circulated for 30 minutes prior to re-analyzing.

h. If the water content is greater than the desired quantity, repeat the coalescing process (See Note 8.7 on usage of old or weathered fuel).

i. Once the proper water quantity has been verified and the fuel properly conditioned, the fuel should be cooled by circulation through the heat exchanger/fluid chiller. To prevent water in the fuel from freezing on the walls of the heat exchanger, it is recommended that the difference in temperature between the fuel in the heat exchanger and the refrigerant should not be allowed to exceed 24 °F (13 °C). A higher temperature difference is acceptable as long as it can be demonstrated that water in the fuel will not freeze in the heat exchanger (See Note 8.10). After recording the water content, continue the circulation and begin the test for “Continuous System Operation.”

j. Once the test temperature is reached, the water content may be analyzed again but it is recommended that the results be used for information only (See Note 8.11).

6.4 Preparing the Fuel for "Emergency System Operation" Test

The following procedure is recommended for Emergency Operation testing with fuel at its saturation level of 90 ppm at 85 ± 5 °F (29 °C ±3 °C) plus 0.75 cc of water per gallon of fuel, for a total water content of 288 ppm. This has been used as an industry standard to satisfy 14CFR 23.951(c) and 25.951(c). This section is applicable for both engine feed system and component testing.

a. Prepare the fuel using the same procedure as for the "Continuous System Operation" fuel conditioning down through step (h).

b. Once the saturation level has been verified, use a pneumatic atomizing nozzle (Reference Figure 2), or inject into the inlet of the circulation pump (Reference Figure 1), add 0.75 cc of water per gallon of fuel at approximately 55 cc/min. Approximately 100 cc of water should be added at a time and then allowed to distribute evenly for approximately 5 minutes. Allow the mixture to circulate for approximately 60 minutes to ensure adequate mixing and then analyze for "total" water content. Take three fuel/water samples from the sampling valve at time spaced intervals to capture representative samples of the entire fuel volume as it passes through the system. Sample should be taken in 100 ml sampling bottles with air tight lids (plastic is recommended. See notes 8.4 and 8.5). Sample bottles should be filled and drained and then filled and immediately capped for analysis (See note 8.4). If additional water is required based on the water sample results, all water should be added before the fuel temperature in the test tank decreases below 45 °F (7 °C).

c. Once the proper water content has been verified, proceed to the test section (See Note 8.12 on test results interpretation).

6.5 Preparation of Fuel for "Filters with Bypass Function Operation" Testing

This section was originally intended to test fuel system components but research into MIL-F-17874B and other documents provided insight that testing with 2.0 cc per gallon was only intended for testing filter elements with bypass features. The higher than normal water content was used to intentionally plug the filter element so that the bypass operation could be verified. Therefore, to meet the intent of 14CFR 23.951(c) and FAR 25.951(c), fuel system components shall be tested per paragraph 6.4 "Emergency Operation" water concentrations levels. Filter elements with a bypass feature shall be tested at 2.0cc of water per gallon of fuel greater than required to saturate the fuel at 85 ± 5 °F (29 °C ±3 °C).

Using Figure 1 or 2, prepare the fuel for Filters Elements with Bypass Valves testing as follows:

a. Prepare the fuel using the same procedures as for the "Continuous System Operation" fuel conditioning down through step (h).

b. Once the saturation level has been verified, use a pneumatic atomizing nozzle (Reference Figure 2), or inject into the inlet of the circulation pump (Reference Figure 1), add 2.0 cc of water per gallon of fuel at approximately 55 cc/min. Approximately 100 cc of water should be added at a time and then allowed to distribute evenly for approximately 5 minutes. Allow the mixture to circulate for approximately 60 minutes and then analyze for "total" water content. Take three fuel/water samples from the sampling valve at time spaced intervals to capture representative samples of the entire fuel volume as it passes through the system. Sample should be taken in 100 ml sampling bottles with air tight lids (plastic is recommended. See notes 8.4 and 8.5). Sample bottles should be filled and drained at least three times and then filled and immediately capped for analysis. All water should be added before fuel temperature in the test tank decreases below 45 °F (7 °C).

c. Once the fuel is properly conditioned proceed to the test section.

7. TEST PROCEDURES

This section describes the particular recommendation for testing both components and fuel systems.

7.1 Test Procedures for System and Component Testing

The complete fuel system or component should function continuously for the expected duration of the flight plus as many in-flight refuelings, as applicable. Determining the appropriate test time should take into account long missions, not only average mission time. The emergency operation tests should last for 30 minutes each, during which the engine should be capable of maintaining at least minimum flight power The engine/APU does not need to be connected and running for these tests.

Ideally, the entire fuel system with the saturated fuel should be cooled down to the test temperature together to provide a relevant simulation to what actually happens in an aircraft. A large test chamber, such as a climatic chamber, capable of producing low temperatures would be suitable for this. The fuel conditioning and test procedures mentioned here could be adapted quite easily to this type of environmental test. Another method that may be used is to insulate and cool the aircraft fuel system with cooling coils, dry ice, etc., although controlling the temperature is more difficult under these conditions.

While the tests are running, all surfaces of fuel system components in contact with the fuel should be at, or below the test temperatures. Tests on fuel systems should be conducted at 28 °F ± 2 °F (-2 °C ± 1 °C), at 13 °F ± 2 °F (-11 °C ±1 °C), which is approximately the critical icing temperature, and at the lowest fuel temperature experienced in flight (or on the ground). The continuous and an emergency operation tests may be performed concurrently where the fuel is conditioned with water to emergency operation levels.

For continuous operation and for combining Continuous and Emergency Operation, the duration of the test should be approximately 25% at 28 °F ± 2 °F (-2 °C ± 1 °C), 50% at 13 °F ± 2 °F (-11 °C ± 1 °C), and 25% at the lowest fuel temperature that will be experienced in flight or on the ground. For emergency operation only, the duration of the test should be 30 minutes at each test temperature.

Note that the testing is usually planned to be “cumulative”. In other words, the most adverse condition would be when ice is allowed to accumulate in the system during all the operating conditions. Depending upon the conditioning system design and operation, it is not possible to insure that the fuel/water will be completely homogeneous during the entire test fuel usage (much less of an issue for the continuous system operation). When using a single batch of test fuel for icing evaluations, it may be possible that fuel with an artificially ‘high’ or ‘low’ total water content may pass through the component during a specific portion of the test cycle (e.g., a large quantity of water passes through component during the 25% at +28F, which results in lower concentrations at the other two test conditions).

7.2 Test Procedures for Filter Testing

The duration of the tests should be the expected duration of the flight, including inflight refuelings for aircraft with such operational capability. By controlling ambient and fluid temperatures, the test component and the fuel should be cooled down to the test temperature at the same time. While the tests are running, all surfaces of the test component should be at, or below, the test temperature. Test on the component should be conducted at 28 °F ± 2 (-2 °C ± 1), at 13 °F ± 2 (-11 °C ± 1) which is approximately the critical icing temperature, and at the lowest fuel temperature experienced inflight (or on the ground). The duration of the test should be approximately 25% at 28 °F ± 2 (-2 °C ± 1), 50% at 13 °F ± 2 (-11 °C ± 1), and 25% at the lowest fuel temperature experienced in flight or on the ground. At each test temperature, the flow rate (if applicable) should be raised from a sustained low rate to a high rate with resulting drop in pressure recorded. The test component shall function with no deterioration in performance that would result in a flight safety hazard or seriously compromise the mission.

8. ADDITIONAL NOTES ON TEST CONSIDERATIONS

8.1 Method for Maintaining Water Droplets in Solution

Water will only settle in quiescent areas, hence there is a need for the test setup to have no quiescent areas and have adequate circulation. Under conditions with significant excess water (e.g. Emergency and Filter Testing), water droplets will coalesce and agglomerate, most likely resulting in settling. It is possible that the fuel transferred to the test article will be extremely inhomogeneous with respect to water content. Conceptually, a homogenous mixture is not required. In fact, reality probably provides for such inhomogeneous mixture. The important thing is to ensure that water will not settle, hence circulation in the conditioning tank is important. Also, the test tank shape is important. A funnel shaped tank for which fuel is drawn from the bottom works well to avoid pooling of water

8.2 Transferring Water from Test Tank to Component/Fuel System

Fuel can be taken from the bottom of the conditioning tank. An alternate option is to transfer the fuel by tapping off of the circulation pump. The circulation/agitation process is one of the most important factors in a proper icing test setup. There must be no quiescent areas in the circulation path and the circulation/agitation rate must be adequate. Adequate is defined as resulting in repeatable and consistent fuel/water samples. With a proper circulation system is in place, taking three samples from the circulation path, at different times (for example 5, 10 or 15 minutes apart) should yield results that are within a small percentage of being the same.

8.3 Operating Tank Sizing

If a single pass test is the method being employed, the conditioning tank volume will be as large as required to meet the flow rates and time required to complete the test.

In some cases, a single pass method is not practical due to test duration or volume of fuel involved. A re-circulation method can be used but should take into account a few factors described below.

If a re-circulation method is used, the amount of water in the fuel should equal the total amount that would normally flow through the component over a given time and flow rate. For example, if 100 gallons of test fuel is used for a component test at emergency level water content (288 ppm), the total amount of water in the system would only be 109 cc. If the component is to operate in the aircraft at 5 gpm for 2 hours, the total water the component should be subjected to in the aircraft is 5 gpm X 120 minutes X 0.000288 X 3785.4 = 654 cc. Therefore, if a recirculation system is selected, the proper water content must be calculated. As can be seen, the 109cc of water would expose the component to a smaller amount of water in the laboratory than what would be expected in the air vehicle over the selected mission.

Consequently, if a re-circulation method is used, it should ensure that the correct amount of water is passed in the system based on the volume of fuel that can be used and the test duration. It is recommended to calculate the amount of water required prior to the test.

If water is added to the re-circulated fuel, it should be done as to ensure that proper mixing occurs prior to re-injecting the conditioned fuel in the test setup. This creates an issue in that the conditioning time for the fuel can be significantly longer than the test time. During the time in which the fuel is re-conditionned the test setup must be maintained at the right temperature and condition in order to continue the test when fuel is available anew.

8.4 Sampling

A fluid sampling valve should be installed between the circulation pump and the tank. It is recommended to use plastic bottles (since water adheres to glass) and should be approximately 100cc. Sample bottles should be clean and dry prior to sampling. If glass bottles are used, note that the sampling bottles are also to be used in the sample preparation and the procedure must effectively capture all water present in the sample during preparation for titration.

When taking a sample the container should be rinsed at least three times by filling and dumping and then the sample taken to minimize the probability of sample contamination. The sampling containers should be capped with an airtight seal as quickly as possible since water in the fuel in excess of saturation will escape into the atmosphere over time. It is recommended to take a minimum of three samples for analysis with a minimum time between samples of 5 minutes.

Assuming that samples are taken from valves, the valves should be opened and purged prior to collecting samples. It is recommended not to use sampling probes in the flow direction of the test fluid since the potential exists for ice accumulation and blockage of the sampling path.

8.5 Setup Contamination with Ambient Air Humidity

The conditioning tank should preferably be closed to atmosphere to avoid condensation. Although open vents are common in conditioning and test tanks, they should be small and breathing of outside ambient air should be limited to the displacement of consumed fuel only. It is suggested to use Nitrogen overhead unless unavailable. For facilities which do not have a Nitrogen capability, a vent with an in-line dessicator can be used instead. Ambient humidity is unlikely to be a big factor when testing with 288ppm or 618ppm, but could introduce error at the 90ppm level.

8.6 Total Water Content Analysis

Simple Karl-Fischer methods do not appropriately address total water content analysis for oversaturated fuel samples. Total water content, even for oversaturated fuel, can be analyzed using a modified Karl-Fischer analysis as explained in Appendix A. In brief, the procedure puts the total content of water into suspension prior to extracting the sample to be injected into the Karl-Fischer analyzer. The method has been shown to provide consistent results, as documented in reference material. This information is provided as reference material and should be customized for each individual laboratory based on the available analysis equipment and specific chemical handling procedures.

8.7 Used, Old or Weathered Fuel

Old or used fuel may be water saturated at a higher level than 90 ppm to 130 ppm. Since the intent of the test is to start with 90 ppm minimum, this excess water (above 130 ppm) may be removed by lowering the fuel temperature slightly and then re-coalescing followed by raising the temperature back to 85 °F (29 °C) and re-sampling to verify that the fuel meets the specified water concentration interval.

8.8 Water Injected through Pneumatic Atomizer

When using a pneumatic atomizing system to inject water in the fuel, air injection occurs at the same time. That should be taken into account in test planning as highly aerated fuel could generate pump cavitation in the test setup.

8.9 Tight Water Concentration Control Requirement

In instances where this procedure is used for other purpose than system testing in experiments where tight water content control is required, it is suggested that following saturation with excess water at 85 ± 5 °F, to decrease the test fuel temperature to 35-40 °F and then pass the test fuel through the coalescer element to remove excess water. Following coalescing, the fuel temperature should be increased to 85 ± 5 °F and three fuel samples obtained and analyzed as described in section 6.3. Quantitation of the total water content below the saturation limit (~80-90 ppmV) will verify that only dissolved water is present and provide an accurate measure of the total water content. The target total water content can then be achieved via addition of the water based on volumetric calculations.

8.10 Heat Exchanger Temperature Control

The refrigerant temperature limit is given as guideline and will depend on the specific heat exchanger characteristics used in a particular test setup. This guideline is there to minimize the risk of ice being formed in the heat exchanger.

8.11 Post Test Water Concentration Analysis

Post test water sampling results can be misleading. It is very difficult to determine where the water/ice has accumulated in the system once it leaves the conditioning tank. As an example, if all the ice were to accumulate within the system or component and the system and/or component has met all of its performance specification, there will be no water in the fuel, therefore sampling to a specific quantity would cause an unnecessary failure and retest.

8.12 Oversaturated Fuel Sample Results

For Section 6.4,the three sample average should be 288 ppm minimum (1.090 cc's/gallon total water content). Large variations in sample water content are common with over-saturated fuel, and are attributed to the inconsistent distribution of suspended discrete water particles migrating through the system resulting in a non-homogeneous fuel water mixture. Therefore, testing may be commenced provided at least one sample is over 288 ppm.

9. NOTES

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