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AEROSPACE RECOMMENDED PRACTICE

ARP 1401

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AIRCRAFT FUEL SYSTEM AND COMPONENT ICING TEST

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 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 manufacturer for commercial and particular military applications.

2. PURPOSE

The cold temperatures to which jet airplanes are exposed can have a detrimental effect upon the fuel system and its components by causing water which 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 slowed down or stopped altogether causing flameouts which pose a flight safety hazard. Even though many aircraft normally operate with fuels treated with an anti-ice additive, (Ref. 1), there are times when fuel without this additive may be encountered. Consequently, fuel systems should be tested with fuel that does not contain the anti-icing additive unless the airplane 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.

3. BRIEF HISTORY

As airplanes operated higher and in colder 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. Many other failures due to icing in the fuel system have been recorded. (Ref. 2)

In aviation fuels, water occurs in two basic forms, dissolved water and free water. Dissolved water is similar to humidity in the atmosphere. The amount of water which a 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 gallons. Fuels may be partly or fully saturated with dissolved water. As with air, the higher the temperature of 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.

3. (Continued)

Free water may be entrained or may be in slugs or pools. Entrained water is water suspended in the fuel in minute globules. 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 as in a pump, throttling valve, or in high velocity transfer operations, by condensation of moisture in the tank atmosphere due to low tank metal temperatures, or by the reduction in temperature of a saturated fuel (Ref. 3, 4).

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 (Ref. 2, 5). This situation is further aggravated as an airplane climbs higher, cold soaks, and then descends to a lower altitude. This causes the fuel system to breathe in and out to adapt to the changing atmospheric pressure. Warm, moist air which is drawn in during descent, condenses when coming into contact with the cold soaked tank and fuel, hence raising the water content.

Early solutions to the icing problem, many 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 of the system.

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 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 (Ref. 6 thru 14).

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 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.

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 temperature of the fuel is lowered, concentration of water droplets in the fuel begins to decrease 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 further. 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 and form of 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 offers a threat to plugging small openings such as screens, filter, and orifices (Ref. 2, 4). The cooling rate and agitation or turbulence due to obstruction of flow have an effect on the type and size of ice formed, so it becomes important to have actual aircraft systems and to cool the fuel during tests at the airplane cooling rate to obtain more accurate results.

5. RECOMMENDATIONS

Research of available information of actual and experimental system tests supports the procedures for aircraft system icing test required in MIL-F-17874B as being the most concise procedures to date. These procedures form the basis of the recommended test of this ARP.

5.1 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 80° +10°, -0° F (27° +5°, -0° C). To obtain this condition, the expected primary fuel, JP-4, JP-5, 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. 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.

5.2 Preparing the Fuel for "Continuous System Operation" Test: The following procedures are recommended for continuous operation tests:

(a) Using Fig. 1, place the fuel in the storage tank and begin circulation from the tank through the heat exchanger and back into the storage tank until the fuel is heated to 80° F +10°, -0° (27° C +5°, -0°).

(b) While maintaining the flow and the required temperature range, use a pneumatic atomizing nozzle to atomize 1 gal (liter) of water per 1000 gal (liters) of fuel at a rate of approximately 55 cc per minute.

(c) After all the water has been atomized into the fuel, continue circulation for approximately 30 min. to help insure complete mixing.

(d) Direct the flow of fuel from the storage tank through the filter/water separator (colester) and into the test tank. (At this point, the fuel should be saturated).

(e) Establish circulation of the fuel in the test tank using either the aircraft engine boost pump(s) or a separate circulating pump. The circulation should be from the tank through a cooling heat exchanger and back into the tank terminating in a spray bar located below the fuel level. If the aircraft fuel boost pump(s) is used to circulate the fuel, provisions should be included for isolating the cooling heat exchanger and its associated plumbing from the aircraft fuel system during the test.

(f) Using the Karl Fischer method (which is included in the Naval Research Laboratory Report #3604), analyze samples from the three points in the bulk of the fuel. The average quantity of water from the three samples shall contain not less than the amount required to saturate the fuel at 80° F (27° C) and not more than this content plus 15 parts per million (PPM) for the continuous operation test. Any excess water should be drained out of the test tank after being allowed to settle. The amount of water to saturate fuel varies for different fuel blends; however, no fuel which is saturated with less than 90 PPM of water should be used. The water content should be tested after the cooling process and after the test.

5.2 (Continued)

(g) The fuel should be cooled at the rate which is the fuel cooling rate for the particular aircraft system being tested. The fuel should be cooled by circulation through the heat exchanger. To prevent water in the fuel from freezing on the walls of the heat exchanger, the difference in temperature between the fuel in the heat exchanger and the refrigerant should not be allowed to exceed 24° F (13° C). Once the test temperature is reached, the water content should be analyzed again.

(h) After recording the water content, terminate the circulation and begin the test for "continuous system operation." At the end of the test, the fuel should not contain less than 90 PPM of water.

5.3 Preparing the Fuel for "Emergency System Operation" Test:

(a) Prepare the fuel using the same procedures as for the "continuous system operation" fuel conditioning down through step (f).

(b) The fuel should be cooled at the rate which is the fuel cooling rate in the particular aricraft system being tested. While the saturated fuel is still being circulated in the test tank, 0.75 cc of water per gal (.198 cc of water per L) of fuel should be atomized through two pneumatic atomizing nozzles located approximately 1 in. (2.54 cm) below the surface of the fuel in the test tank. Approximately 100 cc of water should be added at a time and then allowed to distribute evenly for about 5 minutes. However, all water should be atomized before fuel temperature in the test tank decreases below 45° F (7° C).

(c) Once the test temperature has been reached, the test run should begin. Upon completion of the test, the fuel should not contain less than 0.60 cc of water per gallon of fuel over the quantity required to saturate the fuel at 80° F (27° C).

5.4 Test Procedures: The complete fuel system should function continuously for the expected duration of the flight plus as many in-flight refuelings as applicable, and the duration of the tests should be capable of emergency operation with an excess of water in the fuel system. The emergency operation tests should last for 30 min. each, during which the engine should be capable of maintaining at least minimum flight power. The engine 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 close 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 $\pm$ 2 (-2° C $\pm$ 1) at the lowest fuel temperature experienced in flight (or on the ground), and at 13° F $\pm$ 2 (-11° C $\pm$ 1) which is approximately the critical icing temperature. A continuous and an emergency operation test should be run at each test temperature for a total of six tests to be performed. For continuous operation, the duration of the test should be approximately 25% at 28° F $\pm$ 2 (-2° C $\pm$ 1), 50% at 13° F $\pm$ 2 (-11° C $\pm$ 1), and 25% at the lowest fuel temperature experience in flight or on the ground. For emergency operation, the duration of the test should be 30 min. at each test temperature. Since ice will build up on components from flight to flight under winter operating conditions, the environment of the apparatus should be such that ice from previous tests is not destroyed between test runs. 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 severest inducement for the crystallization of ice from the water droplets within the fuel at subfreezing temperatures (Ref. 2, 4). Under high fuel flows, it is expected that

5.4 (Continued)

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. 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 packed against 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.

5.5 Preparation of the Fuel for Component Testing: Inherently, individual components within a given system can experience different environments relative to water content in the aircraft fuel. This can be caused by several factors such as quiescent areas in a tank that allow more free water to settle to the bottom, high or low location of components in a tank, turbulent areas, and temperature gradients in the system. Thus, components in a system are recommended to be tested individually at a higher free water content than in the completed system to help insure high reliability. Since turbulent areas are conducive to ice formation, sharp-edged orifices should be considered as a fuel system component during icing tests. Many factors affect a component in a system that are not taken into consideration during component testing due to the complexity and cost. Therefore, a component should not be considered fully qualified under icing conditions until successfully tested in a system or a good simulation.

Using Fig. 2, prepare the fuel for component testing as follows:

(a) Prepare the fuel using the same procedures as for the "continuous system operation" fuel conditioning down through step (f).

(b) The fuel should be cooled at the rate which is the fuel cooling rate in the particular aircraft being tested. While the saturated fuel is still being circulated in the test tank, 2 cc of water per gal (.53 cc of water per L) of fuel should be atomized through two pneumatic atomizing nozzles located approximately 1 in. (2.5 cm) below the surface of the fuel in the test tank. Approximately 100 cc of water should be added at a time and then allowed to distribute evenly for about 5 minutes. However, all water should be atomized before fuel temperature in the test tank decreases below 45° F (7° C).

(c) Once the test temperature has been reached, the test run should begin. Upon completion of the test, the fuel should not contain less than 1.60 cc of water per gal (.42 cc of water per L) of fuel over the quantity required to saturate the fuel at 80° F (27° C).

5.6 Test Procedures for Component Testing (See Fig. 2): The duration of the tests should be the expected duration of the flight plus as many inflight refuelings as applicable. 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 the lowest fuel temperature experienced inflight (or on the ground), and at 13° F ± 2 (-11° C ± 1) which is approximately the critical icing temperature. 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 flowrate (if applicable) should be raised from a sustained low rate to a high rate with resulting drop in pressure, if any, recorded. The test component shall function with no deterioration in performance that would result in a flight safety hazard or seriously compromise the mission.

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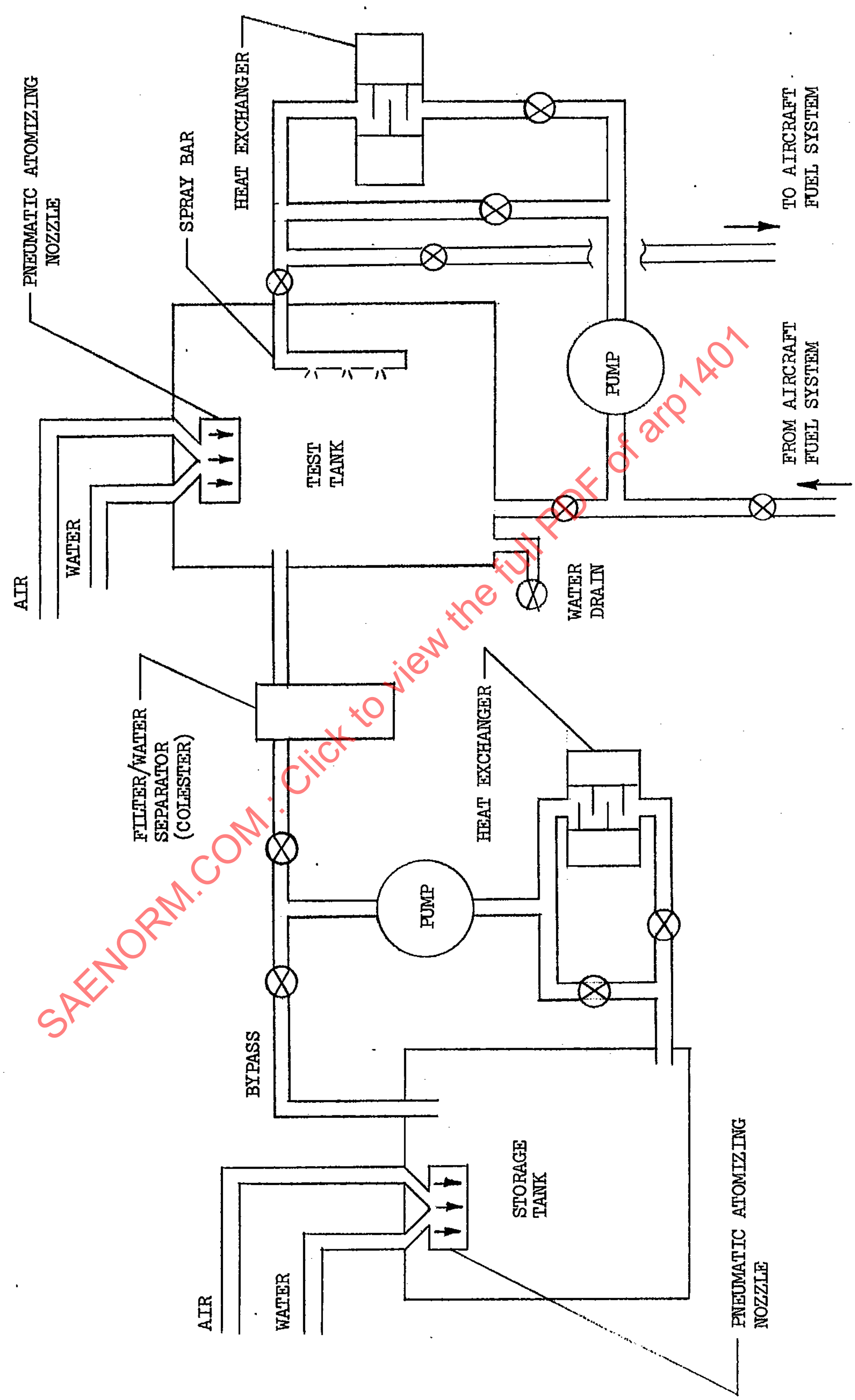

FUEL SETUP FOR SYSTEM ICING TEST

FIGURE 1