



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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Documents

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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 recommendations to 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.