

Aircraft Fuel Tank Inerting Systems

RATIONALE

This document provides recommended practices for developing a non-aircraft specific commercially certifiable nitrogen based Flammability Reduction Means (FRM) including the applicable design considerations supporting Title 14 Code of Federal Regulations part 25, Appendix M, for Transport Category Airplanes” (Reference 14 CFR 25.981).

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1. SCOPE

The Aerospace Recommended Practices of this document are intended for nitrogen-based Flammability Reduction Means (FRM) implemented on transport category, turbine powered airplanes. The recommended practices herein, therefore, relate only to the transport category aircraft, and focus specifically on contemporary inerting systems equipment. Such systems are referred to as Fuel Tank Inerting Systems (FTIS) in this document. This document does not cover the following:

- Military aircraft applications
- Air separation technologies other than hollow fiber membrane (HFM) and pressure swing adsorption (PSA)
- Inerting of conventional unheated wing tanks or aircraft dry bays
- Expected future technology solutions for the generation of inert gas.

The advice contained in this document is aimed towards providing aircraft manufacturers with guidance on the key issues associated with contemporary aircraft fuel tank inerting systems to supplement the guidance in FAA Advisory Circular AC 25.981-2. This document also provides system and component designers and manufacturers with advice on what aspects must be evaluated and addressed when designing a safe, low risk solution for transport aircraft fuel tank Flammability Reduction Means. As such, the information herein is intended as a guide for some system design aspects, but primarily identifies the issues which must be addressed in designing an inerting system for fuel tank flammability reduction.

1.1 Purpose

This SAE Aerospace Recommended Practice (ARP) provides guidance for the design, development and certification of an aircraft fuel tank inerting system (FTIS) and will provide technical references and data regarding an FTIS. The intent of this ARP is to address issues associated with the requirements of the current regulations for aircraft fuel tank flammability at the time of initial release of this document in 2012. As such, it focuses specifically on the FAA requirements of 14CFR 25.981 and appendices M and N of 14 CFR part 25, and also similar regulations from EASA.

This ARP provides guidance on the two types of fuel tank inerting systems that have been selected by the industry as the potential designs for a fuel tank flammability reduction means. Design guidelines for qualification, installation and system performance of the fuel tank inerting system are addressed in this document.

Further, this ARP attempts to provide guidance to support the use of an FTIS to meet the intent of AC 25.981-2 introduced at amendment 125 (14 CFR 25.981 amendment 25-125) for fuel tank explosion prevention (including a summary and utilization of appendix M and appendix N of the regulation). The ARP documents the process for determining fleet average flammability exposure using the FAA Monte Carlo Analysis tool and how fuel tank system flammability reduction means is used in this analysis.

2. REFERENCES

2.1 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.

2.1.1 SAE Publications

Available from 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.

AIR1539 Environmental Control System Contamination

AIR4766/1 Air Quality for Commercial Aircraft Cabin Particulate Contaminants

2.1.2 EASA Publications:

Available from European Aviation Safety Agency, Postach 10 12 53, D-50452, Koeln, Germany, Tel: +49-221-8999-000, <http://www.easa.eu.int>.

CS-25 Certification Specifications for Large Aeroplanes

2.1.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Ave., SW, Washington, DC 20591, Tel: 866-835- 5322, <http://www.faa.gov/>

14 CFR Part 25 Airworthiness Standards: Transport Category Airplanes

14 CFR Part 26 Continued Airworthiness And Safety Improvements For Transport Category Airplanes

14 CFR Part 121 Operating Requirements: Domestic, Flag, and Supplemental Operations

14 CFR Part 125 Certification And Operations: Airplanes Having A Seating Capacity Of 20 Or More Passengers Or A Maximum Payload Capacity Of 6,000 Pounds Or More

14 CFR Part 129 Operations: Foreign Air Carriers And Foreign Operators Of U.S.-Registered Aircraft Engaged In Common Carriage

AC 25.981-2 Advisory Circular, Fuel Tank Flammability

AC No: 21-16G Advisory Circular, RTCA Document DO-160 versions D, E, F and G, "Environmental Conditions and Test Procedures for Airborne Equipment"

Fuel Tank Flammability Assessment Method User's Manual, dated May 2008, document number DOT/FAA/AR-05/8, Incorporation by reference (IBR) approved for Sec. 25.981 and Appendix N (ref. 14 CFR 25.5). It can be obtained at the following Website: <http://www.fire.tc.faa.gov/systems/fuel tank/FTFAM.stm>.

2.1.4 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/>.

JSSG-2009 Department of Defense Joint Services Specification Guide - Air Vehicles Subsystems

MIL-HDBK-310 Global Climatic Data for Developing Military Products

2.1.5 ASTM Documents

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D1655 Turbine Fuels, Jet A and Jet A1

2.1.6 Transport Canada Documents

Available from Transport Canada Library - National Capital Region, 275 Slater Street, Ottawa, Ontario K1A 0N5; <http://www.tc.gc.ca/eng/publications-menu.htm>

Canadian Aviation Regulations 2011-1 Part V Chapter 525 – Transport Category Aeroplanes

Advisory Circular (AC) No. 500-006 Issue 1 Aircraft Operations after Ground Cold Soak

2.1.7 UK Government Publications

Available from by mail from HSE Books, PO Box 1999, Sudbury, Suffolk CO10 2WA; Also can be can be downloaded from HSE's website: <http://www.hse.gov.uk>

HSE8 Take Care With Oxygen - Fire and Explosion Hazards in the Use of Oxygen

2.1.8 Russian Federation Publications

Published by Federal Agency on Technical Regulating and Metrology; available from Federal State Institution "Consulting and innovation company in the field of international standardization and certification" ("INTERSTANDARD") <http://www.interstandart.ru/homeeng.htm>

GOST 10227-86 Jet Fuel Specification

2.1.9 Radio Technical Commission for Aeronautics Publications

Available from RTCA website <http://www.rtca.org>

DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

2.1.10 Other Publications

The Airliner Cabin Environment, Air Quality and Safety, National Academy Press, Washington, DC, 1986, by the Committee on Airliner Cabin Quality Board on Environmental Studies and Toxicology Commission on Life Sciences

2.2 Related Publications

The following publications are provided for informational purposes only and are not a required part of this SAE Aerospace Technical Report.

Summer, Steven M: Limiting Oxygen Concentration Required to Inert Jet Fuel Vapors Existing at Reduced Fuel Tank Pressures – Final Phase; DOT/FAA/AR-04/8; 2004

Burns, Michael; Cavage, William M.; Morrison, Robert; and Summer, Steven - Evaluation of Fuel Tank Flammability and the FAA Inerting System on the NASA 747 SCA; DOT/FAA/AR-04/41; 2004

Burns, Michael; Cavage, William M.; Hill, Richard; and Morrison, Robert: Flight-Testing of the FAA Onboard Inert Gas Generation System on an Airbus A320; DOT/FAA/AR-03/58; 2004

AC 25.981-1C Advisory Circular, Fuel Tank Ignition Source Prevention Guidelines

AIR1903 Aircraft Inerting Systems

Aviation Rulemaking Advisory Committee (ARAC) Fuel Tank Harmonization Working Group Final Report; July 1998 (available from FAA website)

Aviation Rulemaking Advisory Committee (ARAC) Fuel Tank Harmonization Working Group Final Report; June 2001 (available from FAA website)

2.3 Definitions

AC	Advisory Circular
AFDX	Avionics Full-Duplex Switched Ethernet
AFM	Airplane Flight Manual
AIR	Aerospace Information Report
AMC	Acceptable Means of Compliance
APU	Auxiliary Power Unit
ARINC	Aeronautical Radio, Incorporated
ARP	Aerospace Recommended Practice
ARAC	Aviation Rulemaking Advisory Committee
ASM	Air Separation Module
ASTM	American Standard Test Method
BITE	Built In Test Equipment
CAR	Canadian Aviation Regulations
CFR	Code of Federal Regulations
CS	Certification Specifications
CV	Check Valve
CWT	Center Wing Tank
EASA	European Aviation Safety Agency
ECS	Environmental Control System
FAA	Federal Aviation Administration
FRM	Flammability Reduction Means

FTFAM	Fuel Tank Flammability Assessment Method
FTHWG	Fuel Tank harmonization Working Group
FTIS	Fuel Tank Inerting System
GBI	Ground Based Inerting
HEPA	High-Efficiency Particulate Air filter
HFM	Hollow Fiber Membrane
Hx	Heat Exchanger
ICAO	International Civil Aviation Organization
IMM	Ignition Mitigation Means
JSSG	Joint Service Specification Guide
LFL	Lower Flammability Limit
LRU	Line Replaceable Unit
M	Mach number
MEL	Minimum Equipment List
MMEL	Master Minimum Equipment List
MTBF	Mean Time Between Failures
NACA	National Advisory Committee for Aeronautics
NEA	Nitrogen Enriched Air
NGS	Nitrogen Generating System
OBIGGS	On Board Inert Gas Generating System
OEA	Oxygen Enriched Air
PRT	Platinum Resistance Thermometry
PSA	Pressure Swing Adsorption
RAM	Random Access Memory
SFAR	Special Federal Aviation Regulation
SOV	Shut Off Valve
UCWT	Unheated Center Wing Tank
UFL	Upper Flammability Limit
WT	Wing Tank

3. REQUIREMENTS

This section contains a set of recommended requirements for a fuel tank inerting system. “Shall” statements indicate requirements that are mandatory. “Should” statements indicate objectives or goals.

3.1 Applicability of Flammability Reduction Means (FRM) Requirements

In order to determine the applicability of requirements which may necessitate the addition of a flammability reduction means (FRM) such as a Fuel Tank Inerting System to a transport category aircraft, it is necessary to perform a review which considers the aircraft age, date of type certificate application, passenger and payload capacity, fuel tank configuration, and fuel tank thermal characteristics. The References section contains a list of documents which provide guidance regarding this review. Figures 1 through 4 provide flowcharts to assist in verifying the applicability of flammability reduction means (FRM) requirements. Since these flowcharts are based on information gathered from published rules and guidance material, those regulatory documents always take precedence in the event of a discrepancy.

3.1.1 Federal Aviation Administration (FAA) Guidance

The FAA certification requirements regarding fuel tank flammability for new transport category applicants may be found in 14 CFR 25.981, and Part 25 Appendices M and N. Figure 1 provides a simplified flowchart which assists in the determination of whether FRM requirements are applicable to new type design applicants.

As defined in 14 CFR 25.981, the following definitions apply to terms used in the flowcharts depicted in Figure 1 through Figure 4:

- Equivalent Conventional Unheated Aluminum Wing Tank is an integral tank in an unheated semi-monocoque aluminum wing of a subsonic airplane that is equivalent in aerodynamic performance, structural capability, fuel tank capacity and tank configuration to the designed wing.
- Fleet Average Flammability Exposure is defined in Appendix N to Part 25 and means the percentage of time the fuel tank ullage is flammable for a fleet of an airplane type operating over the range of flight lengths.
- Main Fuel Tank means a fuel tank that feeds fuel directly into one or more engines and holds required fuel reserves continually throughout each flight.
- Ignition Mitigation Means is defined as a means to mitigate the effects of an ignition of fuel vapors within that fuel tank such that no damage caused by an ignition will prevent continued safe flight and landing.

For existing United States type-certificated transport category aircraft, Figure 2 provides additional steps in the determination of whether FRM requirements are applicable. These considerations may be found in 14 CFR Part 26 and in AC25.981-2A, fuel tank flammability reduction means, including time constraints on incorporation of the requirements and exclusions and applicability for specific aircraft models. Refer to 14 CFR Part 26 for additional requirements regarding supplemental type certificates and auxiliary fuel tank installations. Figure 3 incorporates further considerations in the determination of whether FRM requirements are applicable for existing U.S. type-certificated transport category aircraft which are operated under 14 CFR Parts 121, 125, or 129. These criteria may be found, along with exclusions and applicability for specific aircraft models, in 14 CFR 121.1117, 14 CFR 125.509, and 14 CFR 129.117.

Simplified Assessment Process for Determining Applicability of Requirements New 14 CFR Part 25 Transport Category Applicants

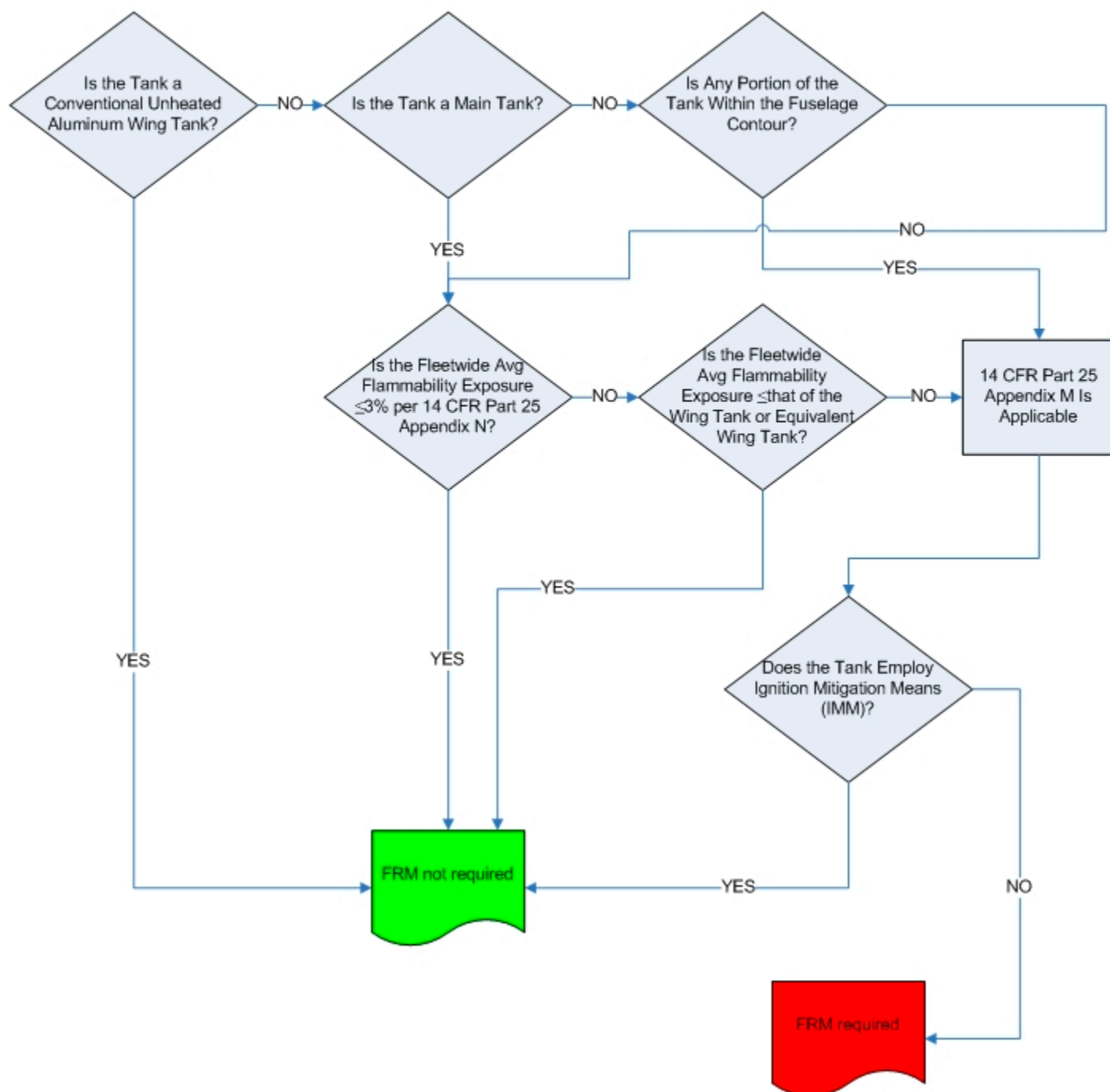


FIGURE 1 - APPLICABILITY OF FRM REQUIREMENTS FOR NEW 14 CFR PART 25 APPLICANTS

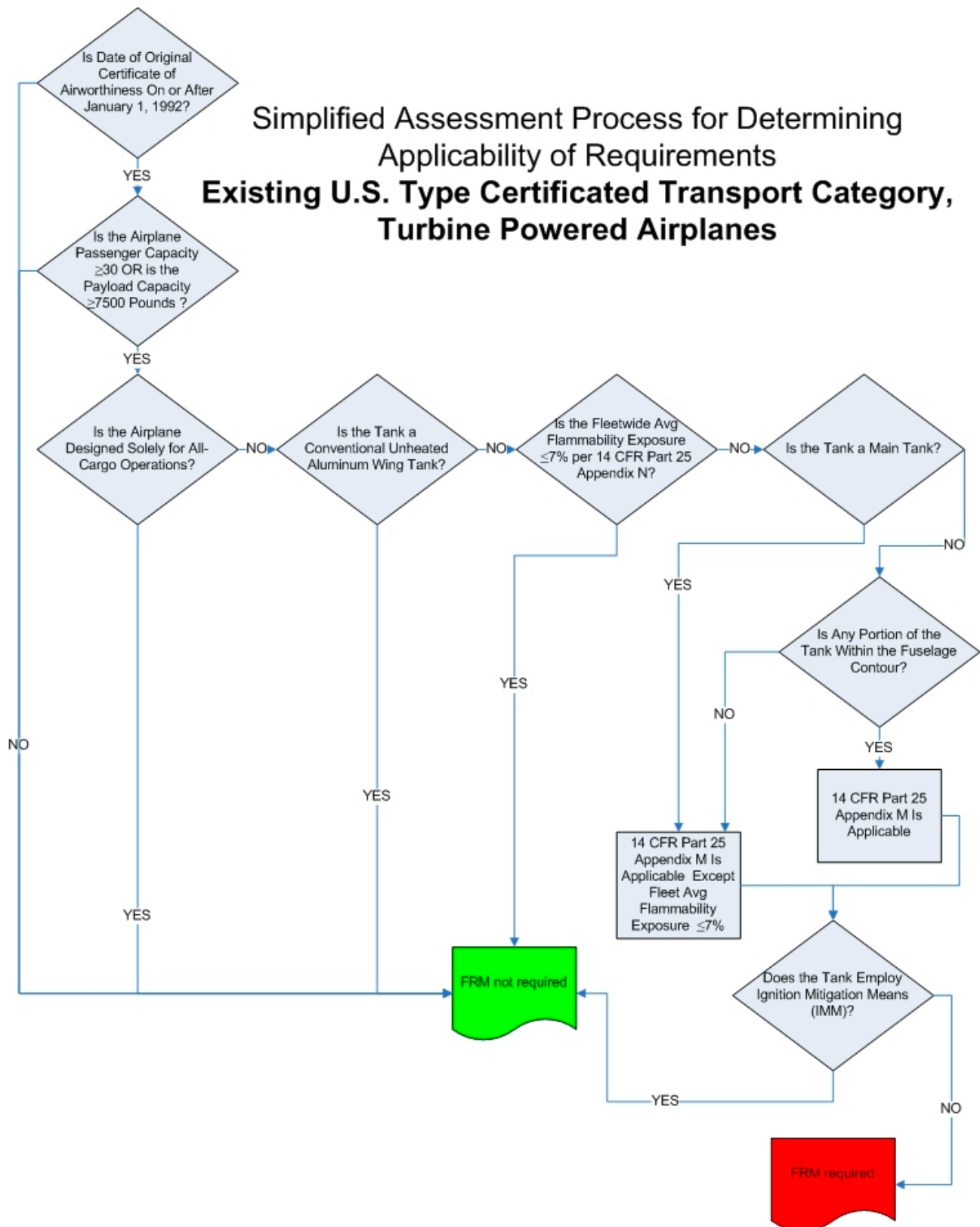


FIGURE 2 - APPLICABILITY OF FRM REQUIREMENTS FOR EXISTING U.S. TYPE CERTIFICATED AIRCRAFT

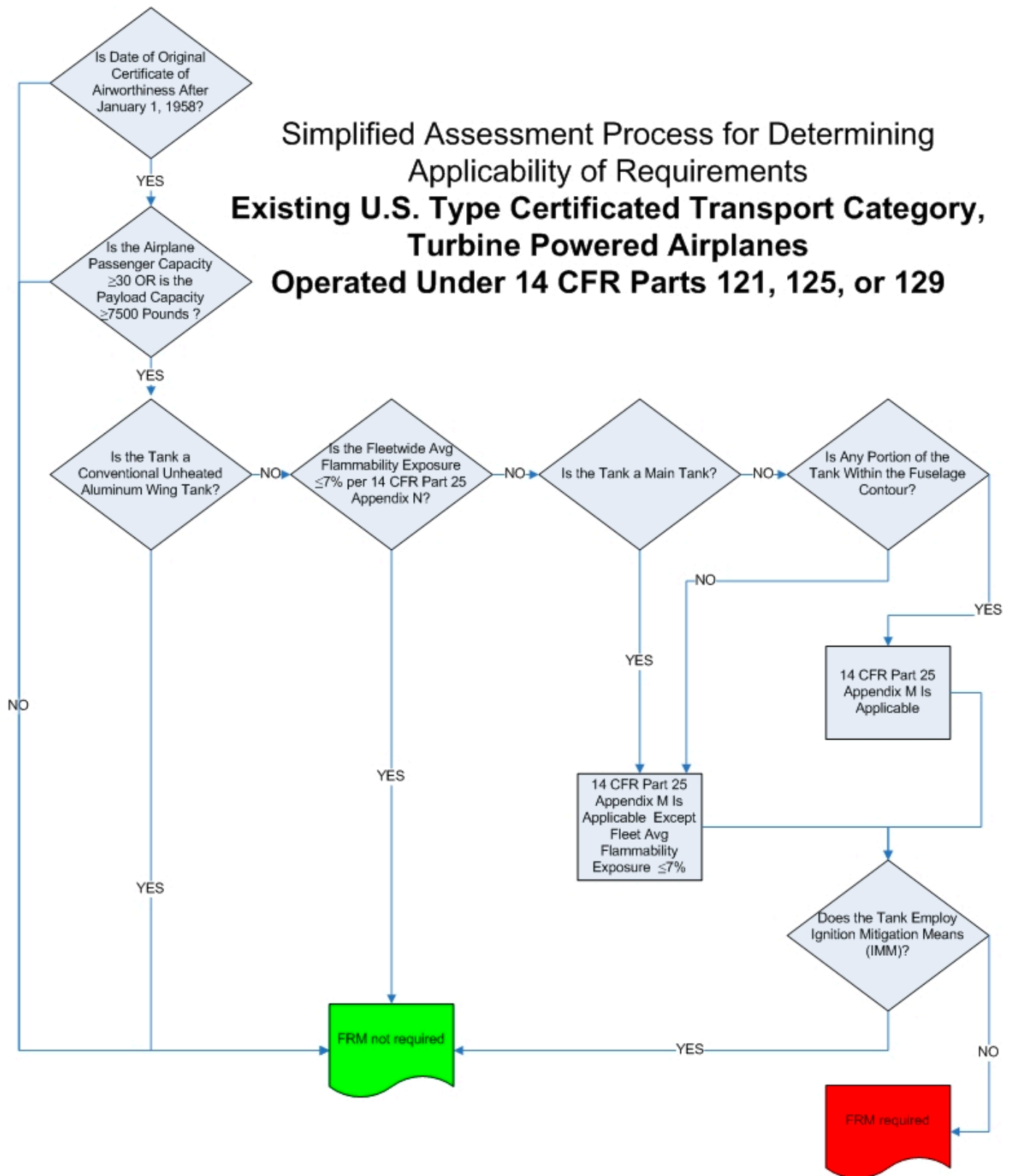


FIGURE 3 - APPLICABILITY OF FRM REQUIREMENTS FOR EXISTING U.S. TYPE CERTIFICATED AIRCRAFT OPERATED UNDER 14 CFR PARTS 121, 125, OR 129

3.1.2 European Aviation Safety Agency (EASA) Guidance

EASA certification requirements for fuel tank flammability for new transport category type design applicants may be found in CS-25 Book 1, 25.981 and Appendices M and N, as well as in CS-25 Book 2, AMC 25.981(b)(1), AMC 25.981(b)(2), and AMC to Appendix N. Figure 4 provides a simplified flowchart to assess the applicability of these FRM requirements. It should be noted that there are two significant distinctions between the EASA requirements and those of the FAA:

- EASA requires limiting tank heat and energy input to the extent practicable, including limiting warm day ground operation tank temperature rise.
- EASA does not require meeting the requirements of Appendix M for Normally Emptied Tanks which intersect any portion of the fuselage contour.

Simplified Assessment Process for Determining Applicability of Requirements New EASA CS-25 Transport Category Applicants

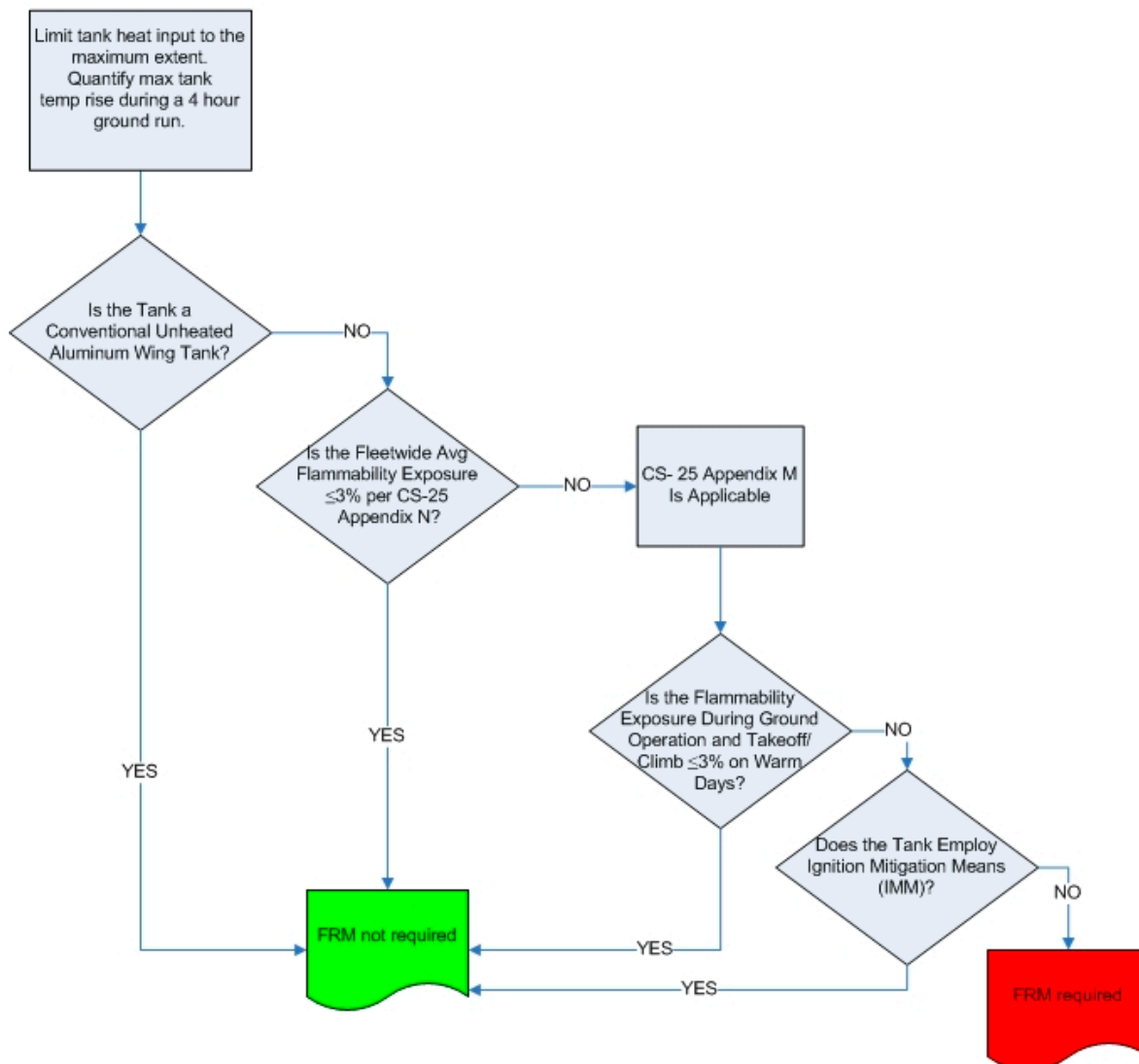


FIGURE 4 - APPLICABILITY OF FRM REQUIREMENTS FOR NEW EASA CS-25 APPLICANTS

3.2 Functional Requirements

The system shall meet the functional requirements contained herein.

3.2.1 Inerting Function

The fuel tank inerting system shall supply and distribute Nitrogen Enriched Air (NEA) within the fuel tank system.

3.2.2 Inerting Performance and Flammability Exposure

The inerting system is a significant aid in reducing the flammability exposure of the airplane's fuel tanks. The definition of inert for commercial aircraft fuel tanks is found in paragraph N25.2(h) of appendix N to part 25. It states "the tank is considered inert when the bulk average oxygen concentration within each compartment of the tank is 12% or less from sea level up to 10 000 ft altitude, then linearly increasing from 12% at 10 000 ft to 14.5% at 40 000 ft altitude, and extrapolated linearly above that altitude."

The fuel tank inerting system shall, therefore, provide sufficient performance such that the oxygen content of the ullage (vapor space) is less than the required percentage for the inert threshold (as defined above) by volume for a high percentage of the operational time of the aircraft. The actual requirement is for flammability exposure which is the percentage of the airplane's operational time in which the airplane fuel tanks are not inert and are flammable per the flammability curve for the fuel in question. This time is illustrated in Figure 5. The method of certifying the flammability exposure is by a Monte Carlo analysis which is described in 4.13.5.

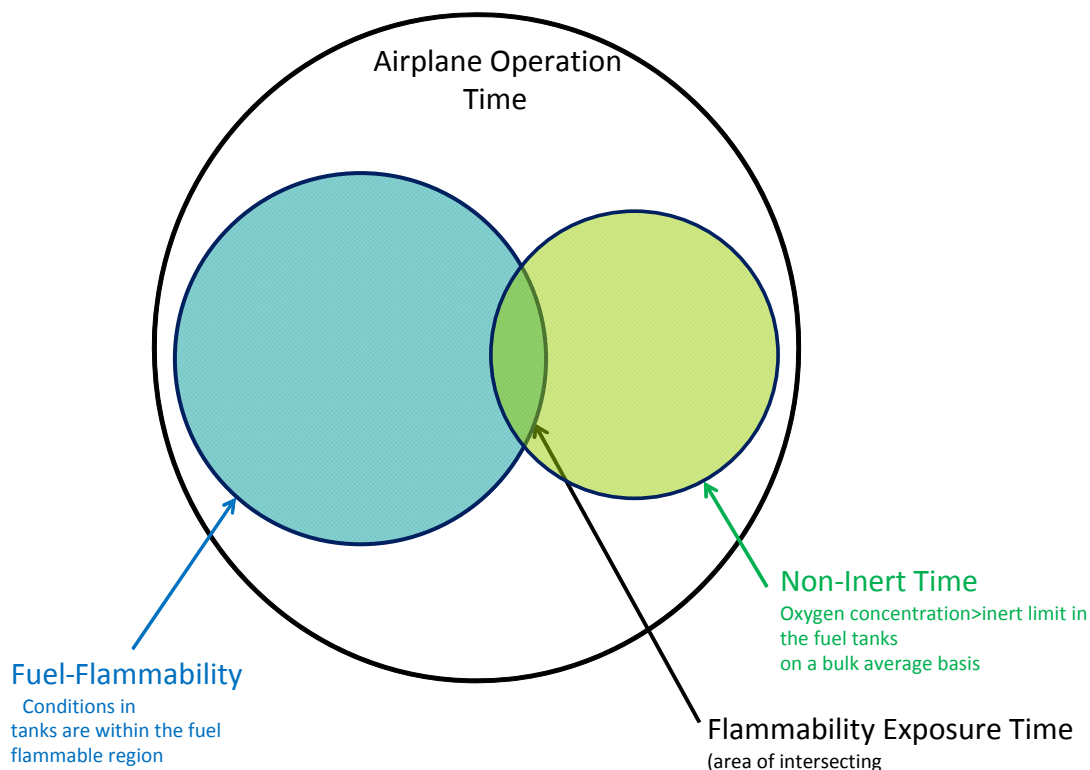


FIGURE 5 - FLAMMABILITY EXPOSURE DIAGRAM

3.2.3 Fuel Types; Inerting Consideration and Needs

The Inerting system shall meet all functional requirements using the fuel type specified by the aircraft manufacturer. Different fuels are approved for use in turbine powered airplanes. The most widely used fuel types are JET-A/JET-A1 per ASTM Specification D1655-99, "Standard Specification for Aviation Turbine Fuels". Other fuel types include JET-B (JP-4), which is uncommon, and TS-1 per GOST 10227-86 "Jet Fuel Specification". The approved fuel types for a given airplane type are listed in the Airplane Flight Manual (AFM). Each fuel type has its own properties; those directly related to flammability are "flash point" and "distillation" characteristics. Property differences can occur in a given fuel type as a result of variations in the source crude oil properties and the refining process used to produce the fuel.

The fuel properties provided in the FAA Monte Carlo model are based upon fuel samples from both Domestic US and some foreign flights that utilized fuel from both Russia and China. The fuel properties used in the flammability assessment should be adjusted to include consideration of expected operation with fuels with flammability characteristics that are not consistent with the FAA nominal values used in the Monte Carlo model.

3.2.4 Tank Venting

The FTIS shall be compatible with the aircraft fuel system venting scheme. Venting system architectures are discussed in 4.6.2.3.

3.2.5 Noise

The FTIS is a potential noise source that should be considered in the overall aircraft design. Reducing the FTIS contribution to this can be done by reducing the inherent noise emission of the equipment, adding noise treatment or a combination of both.

3.2.5.1 Interior Noise

Noise transmitted to the cabin due to operation of the fuel tank inerting system shall not be significant for ground and flight conditions.

3.2.5.2 Ramp Noise

During ground operation, the contribution of the fuel tank inerting system to aircraft external noise sources shall not cause the airplane to exceed ICAO ramp noise standards.

3.2.6 Safety

3.2.6.1 Hazard Assessment

Aircraft-level and system-level hazard assessments shall be conducted and the FTIS shall be designed to be in accordance with the assessments.

3.2.6.2 Proof and Burst Pressure

Elements of the fuel tank inerting system that are pressurized with air or NEA (including ducting) that are outside the fuel tank shall be structurally adequate in accordance with 14 CFR Part 25.1438 and EASA CS 25.1438.

Elements of the FTIS that reside inside the fuel tank shall be structurally adequate in accordance with aircraft manufacturer's requirements.

3.2.6.3 Smoke Toxicity and Density

If any parts of the fuel tank inerting system are within or connected by ducting to the aircraft cabin or cargo compartments, these parts must meet smoke and toxicity requirements of the applicable FAA or EASA regulation.

3.2.6.4 Flammability

Fuel tank inerting system equipment installed in the pressurized volume of the aircraft shall meet the flammability requirements of the equipment in the aircraft bay in which it is mounted.

3.2.6.5 Ignition Source

Fuel tank inerting system equipment installed in a flammable fluid leakage zone shall not produce any unmitigated ignition risks.

3.2.6.6 Excessive Air Temperature

The fuel tank inerting system shall prevent air from entering the fuel tank that has excessively high temperature that could cause tank over temperature.

There shall be provisions such that hot gas leakage from FTIS does not damage susceptible adjacent structure or equipment.

3.2.6.7 Fuel Ingress

The design of the NEA distribution system shall minimize fuel ingress during operation and periods during which the FTIS is not being operated.

3.2.6.8 High Energy Rotors

Failure of any high energy rotors contained within the fuel tank inerting system shall be contained in accordance with 14 CFR 25.1461.

3.2.6.9 Air Exhaust Temperature

The temperature of any cooling air discharging the airplane should be considered:

- a. The design and material selection of any adjacent equipment should be considered in any area on which exhaust air impinges.
- b. For ground operation, the proximity of maintenance personnel should be considered; appropriate safeguards shall be taken.

In some cases, it may be required to limit overboard exhaust air temperature, which may impact design of the fuel tank inerting system.

3.2.7 System Operation and Indication

AC25.981-2A states "Since inerting systems are considered a safety enhancing system, similar to a flight data recorder, no indication to the flightcrew of the flammability of the fuel tank and associated flightcrew procedures for fuel tank flammability or oxygen concentration are specifically required by the regulation."

A fuel tank inerting system is introduced to enhance aircraft safety and, therefore, a design which minimizes additional work load in the flight deck is recommended.

If the inerting system fails and the subject tank(s) are no longer inert the actual impact on flight safety is negligible. At worst it could be considered that the result of temporary non-inert tanks is a slight reduction in safety margins. A flight deck annunciation is not required as failure of this system would require no immediate crew action. This assumes the other consequences of the failure do not impinge on flight safety.

Only if the specific system architecture exhibits a failure case(s) which requires immediate crew action will flight deck annunciation be necessary.

The aim when designing an inerting system should be to accomplish a fully automated system throughout normal and abnormal modes of operation as well as failures. An inerting system should be designed to minimize, if not eliminate flight deck interface.

System health and functionality shall be confirmed periodically to support the Monte Carlo reliability requirements and must, therefore, be indicated. It is logical to provide this indication at a location accessible to maintenance and flight personnel when the aircraft is on the ground.

Examples of conditions that could be annunciated may include:

- Warning – Immediate corrective action required
- Caution – Future compensating action required
- Advisory – Provides awareness of general system condition

Such annunciations may be required to give only a high level assessment of the system's condition. They should be readily available and utilize intuitive signals such as red, orange and green or hatched warning flags for example.

NOTE: The operator's Minimum Equipment List (MEL) or Master Minimum Equipment List (MMEL) must provide the determination of dispatchability with degraded or inoperable FRM.

In addition to this first line system appraisal indication it may be necessary to provide a more detailed system condition communication elsewhere to aid fault diagnosis. This may take the form of a display screen using alpha-numeric characters or digital interface such as a laptop port.

3.3 General System Requirements

The FTIS shall be designed and constructed to meet the general system requirements specified herein. In addition to consideration of day type conditions specified in 3.3.1, localized effects of other equipment installed in the vicinity of the FTIS must be also considered.

The FTIS component qualification levels shall be based on the component location, installation method and the aircraft operational environment. Guidance for the test methods and levels can be found in RTCA DO-160.

3.3.1 Operational Conditions

The FTIS should demonstrate performance and be qualified for the intended non-operating and operating environment. Performance should be based on operation within the hot and cold temperature and humidity extremes defined in MIL-HDBK-310 as appropriate for the acceptable frequency of occurrence percentile. JSSG-2009, pages 50-52 has recommended occurrence percentile values, which are noted as suitable for world-wide operation. Equipment qualification should be performed using procedures similar to RTCA/DO-160 as recommended in FAA Advisory Circular AC No: 21-16G. These operating conditions are defined as follows:

3.3.1.1 Ground Operations

This sub-section defines operating conditions for ground operation.

- a. The ground atmospheric high temperature extremes are given in Paragraph 5.3.1.1.2 and Table XIX of MIL-HDBK-310. Local effects should be accounted for in determining the high temperature extreme conditions performance for the actual equipment operating environment. The effect of equipment heat loads should be considered in establishing the high temperature environment in enclosed compartments. These local effects should be combined with the extreme ambient environment in MIL-HDBK-310. The qualification extremes for ground operating high temperature are given in Category A of Table 4-1 in RTCA/DO-160 based on installation in the aircraft as defined in paragraph 4.3 of DO-160. As an example, 160 °F (70 °C) is generally used for the temperature inside an enclosure exposed to solar radiation at high ground operating temperature extremes could be used for testing purposes.
- b. The ground atmospheric high humidity extremes for ground operations are given in Paragraph 5.3.1.3.2 and Table XXI of MIL-HDBK-310.
- c. The ground atmospheric low temperature extremes are given in Paragraph 5.3.1.2.2 and Table XX of MIL-HDBK-310. Local effects should be accounted for in determining the low temperature extreme conditions performance for the actual equipment operating environment. The effect of equipment heat loads should be considered in establishing the environment in enclosed compartments. These local effects should be combined with the extreme ambient environment in MIL-HDBK-310. The qualification extremes for ground operating low temperature are given in Category A of Table 4-1 in RTCA/DO-160 based on installation in the aircraft as defined in paragraph 4.3 of DO-160. A ground operating low temperature extreme -67 °F (-55 °C) could be used for testing purposes. This should be considered a cold soak temperature. The system should be capable of operating after a 10-h cold soak per CAR Part V Chapter 525.1301.1.
- d. The ground atmospheric low humidity extremes for ground operations are given in Paragraph 5.3.1.4.2 and Table XXII of MIL-HDBK-310.

3.3.1.2 In-Flight Operations

This sub-section defines operating conditions for flight operation.

- a. The in-flight atmospheric high temperature extremes are given in Paragraph 5.3.1.1.2 and Table XIX of MIL-HDBK-310. Local effects including air speed should be accounted for in determining the extreme conditions performance for the actual equipment operating environment. The effect of equipment heat loads should be considered in establishing the environment in enclosed compartments. These local effects should be combined with the extreme ambient environment in MIL-HDBK-310. The qualification extremes for in-flight operating high temperature are given in Table 4-1 in RTCA/DO-160 based on the ceiling altitude of the aircraft as defined in paragraph 4.3 of DO-160. As an example, 131 °F (55 °C) is generally used for the temperature inside an enclosure at high temperature extremes and could be used for testing purposes.
- b. The in-flight atmospheric high humidity extremes, for flight operations are given in Paragraph 5.3.1.3.2 and Table XXI of MIL-HDBK-310.
- c. The in-flight atmospheric low temperature extremes are given in Paragraph 5.3.1.2.2 and Table XX of MIL-HDBK-310. Local effects including air speed should be accounted for in determining the extreme conditions performance for the actual equipment operating environment. The effect of equipment heat loads should be considered in establishing the environment in enclosed compartments. These local effects should be combined with the extreme ambient environment in MIL-HDBK-310. The qualification extremes for in-flight operating low temperature are given in Table 4-1 in RTCA/DO-160 based on the ceiling altitude of the aircraft as defined in paragraph 4.3 of DO-160. As an example, an in-flight operating low temperature extreme -67 °F (-55 °C) and could be used for testing purposes.
- d. The in-flight atmospheric low humidity extremes, for flight operations are given in Paragraph 5.3.1.4.2 and Table XXII of MIL-HDBK-310.

3.3.1.3 Ground Non-Operating

This sub-section defines conditions for ground non-operating (storage) conditions.

- a. The ground atmospheric high temperature extremes are given in Paragraph 5.3.1.1.2 and Table XIX of MIL-HDBK-310. Local effects should be accounted for in determining the high temperature extreme conditions for the actual equipment. The effect of equipment heat loads should be considered in establishing the high temperature environment in enclosed compartments. These local effects should be combined with the extreme ambient environment in the MIL HDBK 310. The qualification extremes for ground survival high temperature are given in Category A of Table 4-1 in RTCA/DO-160 based on installation in the aircraft as defined in paragraph 4.3 of DO-160. As an example, 185 °F (85 °C) is generally used for the temperature inside an enclosure exposed to solar radiation at high ground temperature extremes could be used for testing purposes.
- b. The ground atmospheric low temperature extremes are given in Paragraph 5.3.1.2.2 and Table XX of MIL-HDBK-310. Local effects should be accounted for in determining the low temperature extreme conditions for the actual equipment. These local effects should be combined with the extreme ambient environment in MIL-HDBK-310. The qualification extremes for ground survival low temperature are given in Category A of Table 4-1 in RTCA/DO-160 based on installation in the aircraft as defined in paragraph 4.3 of DO-160. As an example, a ground survival low temperature extreme of -67 °F (-55 °C) could be used for testing purposes.

3.3.2 Environmental Considerations

The main impact to the environment from an inerting system is the small increase in fuel vapors being forced overboard as the nitrogen flows into the fuel tank ullage. The amount of fuel vapor that is vented depends on the fuel air mixture and ullage volume, at the time of inerting, as well as other variables. Testing has shown that presently designed cross-vented fuel tanks, under certain wind conditions, can vent fuel vapors into the atmosphere. A redesign of the inerting system to minimize cross-venting, would help to offset some of the fuel vapor lost during the inerting process.

In addition to the fuel vapor the FTIS is potentially an additional source of ramp noise generated by the airplane during ground operation.

4. PREFERRED PRACTICES

This section provides recommended methods of implementation for a Fuel Tank Inerting System intended to meet FAA requirements for fuel tank flammability reduction.

4.1 Inert Gas Generating Technologies

Two air separation methods are used in Fuel Tank Inerting Systems for aerospace applications. These are the pressure swing adsorption (PSA) and hollow fiber membrane (HFM) methods. PSA was the first to be applied for aircraft on-board fuel tank inerting, being applied in 1982 on the AH-64 Apache helicopter. Since then, PSA has been applied to several other helicopter applications, where time-to-inert is a valued performance parameter. HFM was first applied on the F-22 fighter and then to the C-17 transport in 2004. HFM air separation is now being implemented on a variety of commercial airplanes for fuel tank inerting. HFM is the more air-efficient method that is well-suited for aircraft with large fuel tanks. The following sections describe the HFM and PSA methods of generating inert gas, followed by the advantages and disadvantages of each.

4.1.1 HFM Description

Figure 6 provides a schematic of a typical HFM air separator. Figure 7 shows a cutaway of an HFM air separator. Referring to Figure 6, key components as labeled in the figure are:

1. Feed-side pressure vessel: A thick-walled vessel, usually aluminum, which contains compressed air on the inlet side of the separator.
2. Feed-side tubesheet: An epoxy “plug” or bulkhead which secures each of thousands of hollow fibers. The plug is molded around each fiber and then milled to open each fiber end so that compressed air freely passes into the fiber.
3. Permeable membrane fiber: A small diameter hollow fiber. The walls of the fiber are porous polymer which permeates the components of air (nitrogen, oxygen, argon, carbon dioxide and water vapor), at different permeabilities, from a high pressure region (in this case, in the interior of the fiber) to a lower pressure region, the exterior of the fiber. In the figure, the HFM fiber bundle of thousands of fibers is represented by one hollow fiber.
4. Shell: A thin-wall container which separates the fiber bundle from the equipment bay where it is located. In applications where the separator is in an unpressurized area, the shell sees essentially no pressure difference. In applications where the separator is in a pressurized equipment bay, the shell interior operates at aircraft-ambient pressure, less than the equipment bay. Consequently the shell interior must withstand a relative vacuum. As indicated by the flow arrow, the permeate gas (oxygen rich waste gas) is ducted away from the separator. The HFM method operates more efficiently when the permeate exits to a low absolute pressure and so the permeate is routed overboard.
5. Product side tubesheet: This tubesheet may be identical to item 2, the feed side tubesheet. Like that tubesheet, item 5 is a bulkhead between a low pressure region in the shell and a high pressure region in the pressure vessel.
6. Product gas side pressure vessel: The product gas is generally called “nitrogen enriched air” (“NEA” in the figure) because much of the oxygen has been removed. NEA which is lower in content than nominally 12% oxygen by volume is considered inert, or safe from propagating a fire. At altitude, the oxygen limit may be relaxed slightly due to flammability reasons.

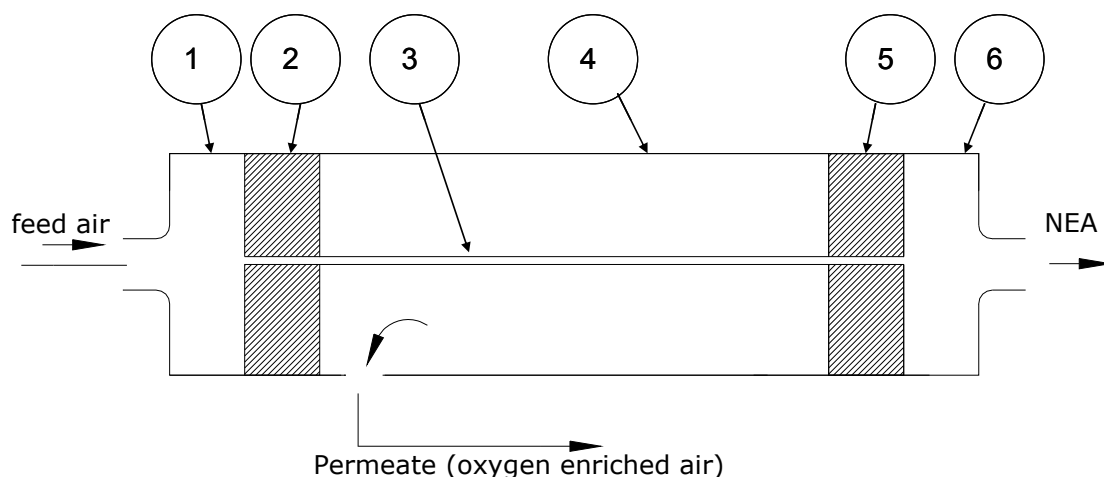


FIGURE 6 - SCHEMATIC OF A HOLLOW FIBER MEMBRANE SEPARATOR