



AEROSPACE STANDARD

AS6858™

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Installation of Fuel Cell Systems in Large Civil Aircraft

RATIONALE

This document defines the technical guidelines for the safe development, testing, integration, validation and certification of proton exchange membrane fuel cell systems, including fuel storage, fuel distribution, and the integration of electrical systems into the aircraft.

AS6858 has been reaffirmed to comply with the SAE Five-Year Review policy.

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1. SCOPE

This is a joint SAE/EUROCAE development. This document will be released as both an SAE Aerospace Specification (AS) and a EUROCAE Minimum Aviation System Performance Standard (MASPS).

This document defines the technical requirements for the safe integration of gaseous hydrogen fueled Proton Exchange Membrane (PEM) Fuel Cell Systems (FCS) within the aircraft.

Most of the technical concepts and approaches covered by this document represent current industry "best practice". Others require specific approval from the procuring activity before use. This requirement for approval is not intended to prohibit their use; but rather to ensure that the prime contractor has fully investigated their capability to perform reliably and to be sufficiently durable under the required conditions and that the prime contractor can present substantiating evidence for approval before the design is committed to.

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 +1 724-776-4970 (outside USA), www.sae.org.

AIR64C	Electrical and Electronic Equipment Cooling in Commercial Transports
AIR825/13	Guide for Evaluating Combustion Hazards in Aircraft Oxygen Systems
AS861B	Minimum General Standards for Oxygen Systems
AIR1059	Oxygen Cylinder Quality, Serviceability, Maintenance Transfilling and Marking
AIR1168	Aircraft Fuel Weight Penalty Due to Air Conditioning
AIR1277	Cooling of Military Avionic Equipment
ARP1532A	Aircraft Oxygen System Lines, Fabrication, Test and Installation
ARP1870	Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety
AIR1957	Heat Sinks for Airborne Vehicles
ARP4418	Procedure for Sampling and Measurement of Engine and APU Generated Containments in Bleed Air Supplies from Aircraft Engines
ARP4754	Guidelines for Development of Civil Aircraft and Systems
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
ARP5021A	Oxygen Cylinder Installation Guide
AIR6464	EUROCAE/SAE WG80/AE-7AFC Hydrogen Fuel Cells Aircraft Fuel Cell Safety Guidelines

- AS8010 Aviator's Breathing Oxygen Purity Standard
- SAE J2579 Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles
- SAE J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles

2.1.2 EASA Publications

Available from European Aviation Safety Agency, Ottoplatz, 1, D-50679 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu

- AC 25.1309 Advisory Circular, System Design and Analysis
- AMC 25.1309 Acceptable Means of Compliance, System Design and Analysis
- AMC 25.1435 Hydraulic Systems
- AMC 25.1453 Protection of Oxygen Equipment from Rupture
- CS 25.561 Emergency Landing Conditions - General
- CS 25.795 Security Considerations
- CS 25.869 Fire Protection: Systems
- CS 25.1181 Designated Fire Zones
- CS 25.1309 System Design and Analysis
- CS 25.1453 Protection of Oxygen Equipment from Rupture
- CS 25.1461 Equipment Containing High Energy Rotors
- CS 25.1541 Markings and Placards: General
- ETSO-C97 Lithium Sulfur Dioxide Batteries
- ETSO-C142a Non-Rechargeable Lithium Cells and Batteries
- ETSO-C173a Nickel-Cadmium, Nickel Metal-Hydride, and Lead-Acid Batteries
- ETSO-C179a Permanently Installed Rechargeable Lithium Cells, Batteries and Battery System

2.1.3 EUROCAE Publications

Available from EUROCAE Secretariat, 102 rue Etienne Dolet, 92240 Malakoff, France, Tel: +33 1 40 92 79 30, www.eurocae.net.

ED-14	Environmental Conditions for Airborne Equipment
ED-12	Software Considerations in Airborne Systems and Equipment Certification
ED-80	Design Assurance Guidance for Airborne Electronic Hardware
ED-219	Aircraft Fuel Cell Safety Guidelines

2.1.4 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

AC 20.184	Advisory Circular, Guidance on Testing and Installation of Rechargeable Lithium Battery and Battery Systems on Aircraft
14 CFR 25.561	Emergency Landing Conditions - General
14 CFR 25.795	Security Considerations
14 CFR 25.869	Fire Protection: Systems
14 CFR 25.1181	Designated Fire Zones
14 CFR 25.1309	System Design and Analysis
14 CFR 25.1435	Hydraulic Systems
14 CFR 25.1461	Equipment Containing High Energy Rotors
14 CFR 25.1541	Markings and Placards: General
PS-ANM-25.1441-01-Rn	Mitigating Fire Hazards in Gaseous Oxygen Systems
TSO-C97	Lithium Sulfur Dioxide Batteries
TSO-C142a	Non-Rechargeable Lithium Cells and Batteries
TSO-C173a	Nickel-Cadmium, Nickel Metal-Hydride, and Lead-Acid Batteries
TSO-C179a	Permanently Installed Rechargeable Lithium Cells, Batteries and Battery System

2.1.5 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

DO-160	Environmental Conditions for Airborne Equipment
DO-178B	Software Considerations in Airborne Systems and Equipment Certification
DO-254	Design Assurance Guidance for Airborne Electronic Hardware
DO-227	Minimum Operating Performance Standards for Lithium Batteries
DO-293	Minimum Operating Performance Standards for Nickel-Cadmium, Nickel Metal-Hydride, and Lead Acid Batteries
DO-311	Minimum Operating Performance Standards for Rechargeable Lithium Battery Systems
DO-347	Certification Test Guidance for Small and Medium Sized Rechargeable Lithium Batteries and Battery Systems

2.1.6 ANSI Accredited Publications

Copies of these documents are available online at <http://webstore.ansi.org/>

ANSI/AIAA G-095-2004 Guide to Safety of Hydrogen and Hydrogen Systems

2.1.7 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 60079	Electrical Apparatus for Explosive Gas Atmospheres
IEC 60952	Aircraft Batteries

2.1.8 ISO Publications

Copies of these documents are available online at <http://webstore.ansi.org/>

ISO 11119-1	Refillable Composite Gas Cylinders and Tubes – Design, Construction and Testing – Hoop Wrapped Fibre Reinforced Composite Gas Cylinders and Tubes up to 250 Litres
ISO 11119-2	Refillable Composite Gas Cylinders and Tubes – Design, Construction and Testing – Fully Wrapped Fibre Reinforced Composite Gas Cylinders and Tubes up to 250 Litres with Load-Sharing Metal Liners
ISO 11119-3	Refillable Composite Gas Cylinders and Tubes – Design, Construction and Testing – Fully Wrapped Fibre Reinforced Composite Gas Cylinders and Tubes up to 250 Litres with Non-Load-Sharing Metallic or Non-Metallic Liners

2.1.9 Military Standards

Copies of these documents are available online at <http://quicksearch.dla.mil>.

MIL-DTL-7891G	Detail Specification: Filler Valve, Aircraft Oxygen
MIL-STD-704	Military Standard: Electric Power Aircraft Characteristics

2.1.10 Other Publications

ASTM G128	Standard Guide for Control of Hazards and Risks in Oxygen Enriched Systems
EN 2282	Characteristics of Aircraft Electrical Supplies
EN 2570	Nickel-Cadmium Batteries. Technical Specification
UL 1642	Standard for Lithium Batteries

2.2 Abbreviations and Definitions

2.2.1 Abbreviations

AC Advisory Circular

A/C Aircraft

AIAA American Institute of Aeronautics and Astronautics

AIR Aerospace Information Report

ANSI American National Standards Institute

AMC Acceptable Means of Compliance

ASTM American Society for Testing and Materials

ARP Aerospace Recommended Practice

AS Aerospace Specification

ATA Air Transport Association

BoP Balance of Plant

CFR Code of Federal Regulations

CS Certification Specification

DC Direct Current

DOP Design Operating Pressure

EASA European Aviation Safety Agency

ECS Environmental Control System

ECU Electronic Control Unit

EUROCAE European Organization for Civil Aviation Equipment

FAA Federal Aviation Administration

FCA Fuel Cell Aircraft

FCS Fuel Cell System

H₂ Hydrogen

HSSS Hydrogen Storage and Supply System

IEC International Electro-Technical Commission

ISO International Organization for Standardization

LEL Lower Explosive Limit

LFL Lower Flammability Limit

MASPS Minimum Aviation System Performance Standard

MAWP Maximum Allowable Working Pressure

Medevac Medical Evacuation

O₂ Oxygen

ODA Oxygen Depleted Air

PEM Proton Exchange Membrane

psia pounds per square inch

PRA Particular Risks Analysis

RAT Ram Air Turbine

RTCA Radio Technical Commission for Aeronautics

TPRD Thermal Pressure Relief Device

2.2.2 Definitions

Standard terminology for the Fuel Cell Aircraft (FCA) is provided below:

AMBIENT AIR: Air outside the pressurized fuselage.

BALANCE OF PLANT: The assembly of equipment used in the control of the reactants and products supporting the operation of the fuel cell stack. The equipment may consist of valves, sensors, pumps, compressors, humidification devices and water separator.

BLEED AIR: Air from outside the plane entering the cabin after having been processed through an engine compressor, turbo compressor and/or air conditioning units (ARP 4418).

CABIN AIR: Air that has been conditioned by the aircraft Environmental Control System (ECS).

COOLING AIR: Air that is used for cooling up to the point that the fuel cell stack ceases to add heat energy to the cooling air.

COOLING AIR EXHAUST: Air used for cooling after the fuel cell stack has added heat energy to the cooling air.

COMMON MODE FAILURE: The result of a failure event which, because of dependencies, causes multiple failures within a system, resulting in the system failing to perform its intended function.

COMPARTMENT: A space that is enclosed (by barriers) except for openings necessary for interconnection, controls, fuel supply and ventilation.

CROSSOVER: Unintentional cross-over of reactant gas, resulting in local chemical reaction(s) with a consequent temperature increase.

DESIGNATED FIRE ZONE: A region in the aircraft which is designed to cope with a fire likely to occur (e.g., by means of fire resistant/proof materials and fire detection). Areas that have been designated as Designated Fire Zones are listed in CS 25.1181 and 14 CFR 25.1181.

EXHAUST: Fluids and gases leaving the FCS during normal operation.

EXHAUST CONDITIONING: The conditioning of exhaust products, such as the collection of fluids or dehumidification of gases.

EXTERNAL HYDROGEN LEAKAGE: Leakage rates, per ANSI/AIAA G-095-2004, are defined in relation to the Lower Flammability Limit (LFL) of Hydrogen (H₂) as follows:

- **LOW LEAKAGE:** An amount of leaking fuel which leads to a fuel concentration in a fuel/air mixture below 25% of the LFL (1% volumetric H₂ concentration).
- **MEDIUM LEAKAGE:** An amount of leaking fuel which leads to a fuel concentration in a fuel/air mixture between 25% and 50% of the LFL (1 to 2% volumetric H₂ concentration).
- **HIGH LEAKAGE:** An amount of leaking fuel which leads to a fuel concentration above 50% of the LFL (>2% volumetric H₂ concentration).

FIRE ZONE: A potential flammable fluid leakage zone that contains a nominal ignition source. Note: This is not a Designated Fire Zone per CS 25.1181 and 14 CFR § 25.1181 as defined above. It is a zone where means to protect the airplane from the hazardous effects of fire may be required, but these means may differ from the fire protection means for designated fire zones.

FUEL CELL STACK: That portion of the FCS achieving electrochemical conversion of fuel and oxidant into electrical energy, thermal energy and exhaust gas. This includes the fuel cell housing, fittings, wiring and all devices allowing the connection to other subsystems.

FUEL CELL SYSTEM: Those units and components using an electrochemical conversion process to produce electricity from a fuel (on the anode side) and an oxidant (on the cathode side). This includes reactants and reaction products, supply/exhaust devices, fuel cell stacks, electric power output devices, cooling or/and heating devices and a centralized control and monitoring subsystem.

FUEL SUPPLY: Compressed H₂ gas.

IGNITION SOURCE: Any process or event that is capable of causing a fire or an explosion. Open flames, sparks, static electricity and hot surfaces are possible ignition sources.

LOWER EXPLOSIVE LIMIT: The lowest concentration at which an exothermic chemical reaction releases a supersonic shock wave that compresses the unreacted fuel/air mixture to sustain the reaction.

LOWER FLAMMABILITY LIMIT: The lowest concentration at which a flame can move through a fuel/air mixture in the form of a subsonic wave (with respect to the unburned mixture). For H₂ the lower flammability limit is 4.1% volumetric concentration in dry air (or oxygen) at 14.7 psia and ambient temperature, per ANSI/AIAA G-095-2004.

NORMAL DISCHARGES: Discharges expected during normal operation and not associated with failure conditions.

NORMAL OPERATION: All transient and steady state operating conditions, according to the flight envelope of the aircraft, which occurs during start, intended operation and shut down, which does not involve a component or system failure.

OXIDANT SUPPLY: Compressed Oxygen (O₂) or air (ambient, bleed or cabin).

POTENTIALLY UNSAFE CONDITION: A potentially unsafe condition is a one that could lead to a hazardous or catastrophic condition, per CS 25.1309 and 14 CFR § 25.1309. Among these are conditions caused by fluids and electrical voltages which have the potential to cause a hazard as follows:

- Flammability and explosiveness - Sufficient quantities of fuel/air mixtures at or above the LFL are by definition flammable as well as sufficient quantities of fuel/air mixtures at or above the Lower Explosive Limit (LEL) are by definition explosive.
- High Pressure - High pressure fluids that can transfer kinetic energy causing personal injury and damage to critical systems and structure.

PURGES: Normal discharges associated with the time limited removal of fluids from fuel cell systems.

PROTON EXCHANGE MEMBRANE: A fuel cell that employs proton exchange membrane as the electrolyte, also referred to as Polymer Electrolyte or Membrane (PEM) fuel cells.

UNCONTROLLED LEAK: An uncontrolled leak is defined as a leak that cannot be maintained below a high leakage level.

VENTILATION: The flow of air to dilute and remove potential hazardous gases from a controlled volume. Ventilation may be active or passive.

3. GENERAL

This specification was developed using a generic PEM FCS functional diagram (Figure 1), as a guide.

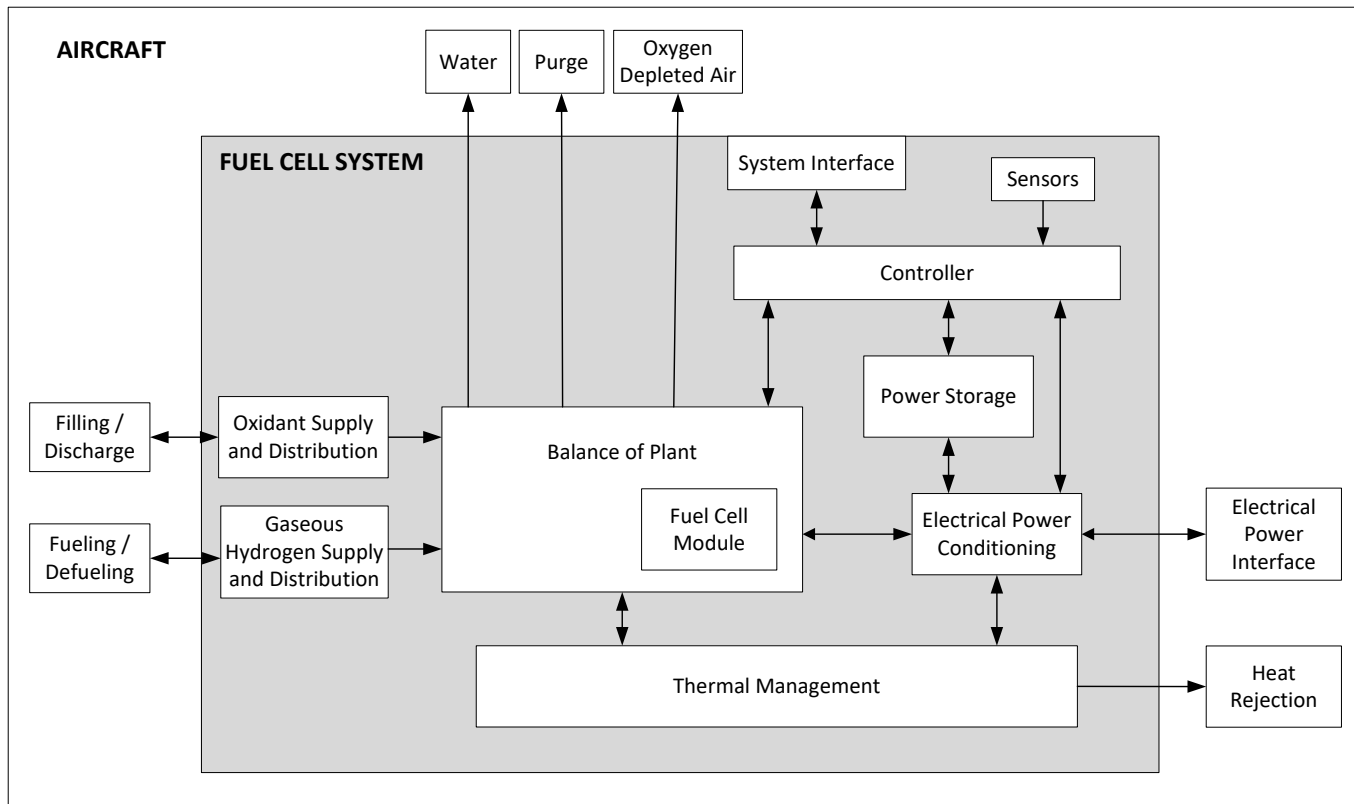


Figure 1 - Functional diagram of generic PEM fuel cell system

3.1 Operating Modes

The FCS generic system operating modes are considered to be: Standby; Startup; Operation; Fueling; Defueling; Maintenance; Shutdown and Off (Figure 2). These modes are defined as follows:

a. Standby

- Apply power to the system controller.
- Controller runs FCS power up tests.
- Controller communicates with aircraft, ready for next mode.

b. Fueling

- Controller receives fueling or filling command.
- Controller initiates communication to the fueling station.
- Controller is ready for fueling procedure, or transitions to standby mode in case of fault condition.
- Controller receives fueling finished command and returns to standby mode.