



AEROSPACE INFORMATION REPORT

AIR5774™

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Composite Fuel Tanks, Fuel System Design Considerations

RATIONALE

It has been discussed for quite some time that an industry standard is needed to outline the important considerations when developing the fuel system in a composite airplane and/or composite structure that contains the fuel system. After much consideration, an industry working group was formed to develop this AIR. This industry working group consisted of members from major airframers, system suppliers, component manufacturers, and government agencies.

FOREWORD

This report is intended to give guidance for the design of modern fuel systems within the context of composite fuel tanks. It is a compilation of industry references and best practices regarding fuel system design and composite structure.

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1. SCOPE

This SAE Aerospace Information Report (AIR) is a compilation of engineering references and data useful to the technical community that can be used to ensure fuel system compatibility with composite structure. This AIR is not a complete detailed design guide and is not intended to satisfy all potential fuel system applications. Extensive research, design, and development are required for each individual application.

1.1 Purpose

This document is intended to serve as guidance to airframe and equipment manufacturers for the design and installation of fuel systems into composite structure. This document is not intended to be a fully definitive specification, but concentrates on areas where it is felt guidance is needed.

The purpose of this AIR is to compile one definitive source of the references, rules, regulations, and preferred practices for the development of a fuel system in composite structure. This AIR sets forth some useful design considerations for work with composites as it relates to the fuel system.

1.2 Background

The development and installation of a fuel system in composite structure introduces a variety of design situations which are different from aluminum. The differences are related to the properties of the composite material. As an example these may include low electrical and thermal conductivity, greater design sensitivity to penetrations, reduced shielding from electromagnetic radiation, reduced conductivity of lightning, and potential corrosion in graphite aluminum interfaces.

1.3 Field of Application

This AIR applies to the aerospace industry and specifically to aircraft that use common petroleum fuels.

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.

AIR1662	Minimization of Electrostatic Hazards in Aircraft Fuel Systems
AIR5128	Electrical Bonding of Aircraft Fuel System Plumbing Systems
ARP5412	Aircraft Lightning Environment and Related Test Waveforms
ARP5414	Aircraft Lightning Zoning
ARP8615	Fuel System Components: General Specification For

2.1.2 ASTM Publications

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 Standard Specification for Aviation Turbine Fuels

ASTM D6615 Standard Specification for Jet B Wide Cut Aviation Turbine Fuel

2.1.3 FAA Publications

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

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

AC 25.981-2A Advisory Circular, Fuel Tank Flammability

CFR 25.981 Fuel Tank Ignition Prevention

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, <https://assist.daps.dla.mil/quicksearch/>.

MIL-STD-461F Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

MIL-STD-464 Electromagnetic Environmental Effects, Requirements for Systems

MIL-STD-810 Environmental Test Methods and Engineering Guidelines

2.1.5 Other Publications

AC/AMJ 20-53B Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning

CAN/CGSB 3.23 Aviation Turbine Fuel (Grades JET A and Jet A-1)

DEF STAN 91-91 Turbine Fuel, Kerosine Type, Jet A-1 NATO Code: F-35 Joint Service Designation

DERD 2494 Turbine Fuel, Aviation Kerosine Type, Jet A-1 NATO Code: F-35 Joint Service Designation

RTCA DO-160F Environmental Conditions and Test Procedures for Airborne Equipment

STAS5639/88 Romanian Fuels, TH and T-1 Fuel grades

2.2 Related Publications

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

2.2.1 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.

- ARP4043 Flight Line Grounding and Bonding of Aircraft
- AIR4069 Sealing of Integral Fuel Tanks
- ARP5413 Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning
- ARP5416 Aircraft Lightning Test Methods
- ARP5577 Aircraft Lightning Direct Effects Certification
- ARP5583 Guide to Certification of Aircraft in a High-Intensity Radiated Field (HIRF) Environment
- AMS3279 Sealing Compound, Sprayable for Integral Fuel Tanks and Fuel Cell Cavities, For Intermittent Use to 350 °F (177 °C)
- AMS-C-27725 Coating, Corrosion Preventative, for Aircraft Integral Fuel Tanks for Use to 250 °F (121 °C)
- AMS-S-4383 Sealing Compound, Topcoat, Fuel Tank, Buna-N Type
- AMS-S-7124 Sealing Compound, Polysulfide, Accelerator Required, for Aircraft Structures
- AMS-S-29574 Sealing Compound, Polythioether, for Aircraft Structures, Fuel and High Temperature Resistant, Fast Curing at Ambient and Low Temperatures

Pridham, B., Jaeger, D., and Schreiner, M., "Integral Lightning Strike Protection of CFC Fuel Tanks on Aircraft," SAE Technical Paper 2001-01-2912, 2001, doi:10.4271/2001-01-2912

2.2.2 ASTM Publications

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 D4154 Standard Practice for Evaluating the Compatibility of Additives with Aviation-Turbine Fuels and Aircraft Fuel System Materials
- ASTM D6469 Standard Guide for Microbial Contamination in Fuels and Fuel Systems
- ASTM D910 Standard Specification for Aviation Gasoline

2.2.3 FAA Publications

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

AC 20-136A Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning

FAA-RD-73-98 Guidelines for Lightning Protection of General Aviation Aircraft

2.2.4 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, <https://assist.daps.dla.mil/quicksearch/>.

AFFDL-TR-79-3047 Aircraft Integral Fuel Tank Design Handbook

AFWAL-TR-81-4007 Manufacturing Methods for Adhesively Sealed Integral Fuel tanks

AFWAL-TR-83-3114 Survivable Aircraft Fuel System Engineering Design Guide (SAFE/DG)

JSSG-2009 Air Vehicles Subsystems

JSSG2009 App. E Joint Service Specification Guide, Fuel System

MIL-B-5087 Bonding, electrical and Lightning Protection, Aerospace Systems

MIL-C-27725 Coating, Corrosion Preventive, for Aircraft Integral Fuel Tanks

MIL-DTL-83133 Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8) and NATO F-35

MIL-STD-1568 Materials and Processes for Corrosion Prevention and Control

MIL-STD-882 System Safety Program Requirements

MIL-T-27422 Tank, Fuel, Crash Resistant, Aircraft (Non-Self-Sealing and Self-Sealing)

MIL-T-5578 Tank, Fuel, Aircraft, Self Sealing

MIL-T-5624 Turbine Fuel, Aviation, Grades JP-4 and JP-5

2.2.5 Other Publications

AC/AMJ 20-53B Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning

EUROCAE ED-107 HIRF Users Guide

GB 6537-94 Chinese Fuels, National Technology Supervisory Bureau, August 1994, Updated 1 June 1995

GOST 10227-86 Russian Fuels, Jet Fuel Specifications, Prepared by the State Standards Committee of the USSR, 1987, Updated August 1995. (CMEA Standard 5024 - 85)PRC

Lightning protection of aircraft Franklin Fisher and Anderson Plumer and published by Lightning Technologies

Microbes Hazards to Space Missions from Microbial Biofilms
By: R. Mitchello, and Ji-Dong Gu
DECHMA Monographs Vol. 133 - 1996

RTCA DO-160F Environmental Conditions and Test Procedures for Airborne Equipment

STAS5639/88 Romanian Fuels, TH and T-1 Fuel grades

2.3 Definitions

BONDING SURFACE: The conductive surface of structure, part, or component which is to be electrically bonded to.

CAPACITOR: Capable of accumulating and holding electric charge.

COMPOSITE: A series of layers of filaments/fibers/fabrics of one or more materials bonded or embedded in an essentially homogeneous, resinous matrix, such as an epoxy matrix.

CONDUCTOR: A material capable of carrying an electrical current.

DIELECTRIC: A substance with negligible electrical conductivity.

DIELECTRIC STRENGTH: The maximum electric field strength that a material can withstand intrinsically without experiencing failure of its electrical insulating properties.

DIELECTRIC WITHSTAND VOLTAGE: See dielectric strength.

ELECTRICAL BOND: A fixed union between two objects that results in electrical conductivity between those objects.

ELECTRICAL BONDING: Connecting two or more conductive surfaces to form an electrically conductive joint.

ELECTRICAL GROUND: An electrically conductive return path from equipment to structure.

ELECTRICAL PERMITTIVITY: The ratio of the electric displacement in a medium to the electric field strength. Sometimes referred to as the dielectric constant.

FAULT CURRENT: A higher than normal current flowing in a circuit resulting from an electrical short.

FIRE/EXPLOSION HAZARD AREA: Work area that may contain or be contaminated with combustible material or vapor.

FRICTIONAL CHARGING: Whenever a hydrocarbon liquid, such as jet fuel, flows with respect to another surface, like the surface of a tube, charge separation will occur. Fluid shear along the surface of the tube will cause a transfer of electrons between the fuel and the tube. This results in a net charge of one polarity on the tube and a charge of the opposite polarity in the fuel.

FLASH POINT: The minimum temperature, where sufficient vapor evolves, in the presence of an ignition source, where combustion (flash over) will occur.

FUEL TANK: Volume in an aircraft designated for carrying fuel. Can be integral, bladder or self-sealing, external droppable, or portable tanks.

GAS TIGHT: No leakage when pneumatically pressurized to the maximum differential pressure expected in service, or no less than 5 psi, throughout the life of the part.

HYDROPHILIC: A material with an affinity for water.

HYDROPHOBIC: A material with a strong aversion to water.

INCENDIVE/INCENDIARY: Capable of causing ignition of a flammable atmosphere

INDUCED CHARGING: Charge separation, results in a net charge to the bulk fuel loaded into fuel tanks during refueling. The charged fuel can provide (or induce) a charge on any isolated part contacting the fuel surface (or residing in the vapor space above the fuel surface).

INSULATOR: A material of such low conductivity that the flow of current through it is negligible. Sometimes referred to as a dielectric.

OPERATING PRESSURE: The pressure within the fuel system during normal system operation.

PRIMARY STRUCTURE: For bonding and grounding purposes, this is the major portion of an aircraft which carries primary structural loads.

SURFACE FINISH: Finishes which have been applied on top of a surface and which are required to be removed prior to electrical bonding.

SURFACE FLASHOVER: Electrostatic discharge characterized by gaseous breakdown along the surface of a material.

ULTIMATE PRESSURE: The ultimate pressure is usually three times the operating pressure, but depending on the system architecture, it can be different. The system shall be capable of structural stability when exposed to ultimate pressure, but not functionally as defined in the specification.

2.4 Acronyms and Abbreviations

APU	Auxiliary Power Unit
ARAC	Aviation Rulemaking Advisory Committee
ASTM	American Society for Testing and Materials
BCAR	British Civil Aviation Requirement
BTL	Liquid Fuels from Bio-Mass
CAD	Computer Aided Design
CIS	Commonwealth of Independent States
CATIA	Computer Aided Three-dimensional Interactive Application
CFC	Carbon Fiber Composite
CG	Center of Gravity
CRN	Current Return Network
CWT	Center Wing Tank
EASA	European Aviation Safety Agency
ECS	Environmental Control System
EMI	Electro-Magnetic Interference
EMH	Electro Magnetic Hazard
ETOPS	Extended Twin-Engine Operations
FAA	Federal Aviation Administration
FAA/AC	Federal Aviation Administration Advisory Circular
FAR	Federal Aviation Regulation
FMEA	Failure Mode Effects Analysis
FOD	Foreign Object Debris/Foreign Object Damage
FQIS	Fuel Quantity Indicating System
GFI	Ground Fault Interrupter
GTL	Liquid Fuels from Gas
HIRF	High Intensity Radiated Field
HYTRAN	Hydraulic Transients
IATA	International Air Transport Association
JAR	Joint Aviation Regulation
LRU	Line Replaceable Unit
MTBF	Mean Time Before Failure
MTBUR	Mean Time Between Unscheduled Replacement
NFPA	National Fire Protection Association
NGS	Nitrogen Generation System
STC	Supplemental Type Certificate

3. DISCUSSION AND PREFERRED PRACTICES

3.1 Fuel Types

Today's kerosene jet fuels have been developed from the illuminating kerosene used in the early gas turbine engines. These engines needed a fuel with good combustion characteristics and high energy content. Current Jet fuels are refined and chemically processed from crude oil or oil sands to produce a mixture of hydrocarbon materials generally in the range of C8 to C16. Future fuels are in development that will utilize alternative feedstocks such as coal and biomass to produce a similar mixture of hydrocarbons in the same range as the current petroleum feedstocks. The Jet A and Jet A-1 kerosene type fuels are the primary fuels used in civil aviation. The former has a higher freezing point (maximum -40 °C instead of maximum -47 °C) and is available primarily in North America. The military utilizes a fuel similar to Jet A-1 with additives designated as JP-8 or NATO F-35.

3.1.1 Summary of Jet Fuel Grades

3.1.1.1 American and European Jet Fuels

The basic civil jet fuel specification used in the United States of America is ASTM Specification for Aviation Turbine Fuels D 1655, which defines the requirements for three grades of fuel.

3.1.1.1.1 Jet A-1

Jet A-1 is a kerosene grade of fuel suitable for most turbine engines. It has a flash point minimum of 38 °C (100 °F) and a freeze point maximum of -47 °C. It is widely available throughout the world. The main specifications for Jet A-1 grade fuel are the UK specification DEF STAN 91-91 (Jet A-1) NATO code F-35, (formerly DERD 2494) and the ASTM Specification D1655 (Jet A-1).

3.1.1.1.2 Jet A

Jet A is a kerosene grade fuel, normally only available in the USA. It has the same flash point as Jet A-1 but a higher freeze point maximum (-40 °C). It is supplied against the ASTM D1655 (Jet A) specification. Jet A is used within the United States by domestic and international airlines.

3.1.1.1.3 Jet B

Jet B is a wide-cut type fuel distillate covering the naphtha and kerosene fractions. It can be used as an alternative to Jet A-1 but because it is more difficult to handle (higher flammability). There is only significant demand in very cold climates where its better cold weather performance is important. ASTM has a specification, D6615, for Jet B but in Canada it is supplied against the Canadian Specification CAN/CGSB 3.23.

Jet B is rarely available except in parts of northern Canada where its lower freeze point and higher volatility is an advantage for handling and cold starting.

3.1.1.2 Military Fuel Grades

- JP-4 "Wide Cut", similar to Jet B, NATO F-40
- JP-8 "Kerosene Type", similar to Jet A-1 but has several additives, NATO F-34/F-35
- JP-8 +100 "Kerosene Type", similar to JP-8 but has a thermal stability and other additives
- JP-5 "Kerosene Type", higher flash point for carrier operations, NATO F-44
- JP-7, JP-9, and JP-10 are specialty fuels

3.1.1.3 UK Jet Fuels

Although developed basically as a military jet fuel, DERD 2494, issued by the Ministry of Defence, was adopted as the standard UK civil jet fuel. It is now renamed as DEF STAN 91-91 and defines the requirements for a kerosene type fuel (Jet A-1 grade) having a maximum freeze point of -47 °C.

Jet A-1 according to the DEF STAN 91-91 specification is very similar to Jet A-1 defined by ASTM D1655 except for a small number of areas where DEF STAN 91-91 is more stringent.

3.1.1.4 Former Soviet Union and East European Jet Fuels

Soviet kerosene type jet fuels are covered by a wide range of specification grades reflecting different crude sources and processing treatments used. The grade designation is T-1 to T-8, TS-1 or RT. The grades are covered either by a State Standard (GOST) number, or a Technical Condition (TU) number. The limiting property values, detailed fuel composition and test methods differ quite considerably in some cases from the Western equivalents.

3.1.1.4.1 TS-1

TS-1 is the main jet fuel grade available in Russian and CIS states. It is a kerosene type fuel with slightly higher volatility (flash point is 28°C minimum) and lower freeze point (<-50°C) compared to Jet A-1.

The main differences in characteristics are that Soviet fuels have a low freeze point (equivalent to about -57 °C by Western test methods) but also a low flash point (a minimum of 28 °C compared with 38 °C for Western fuel). RT fuel (written as PT in Russian script) is the superior grade (a hydro treated product) but is not produced widely. TS-1 (regular grade) is considered to be on a par with Western Jet A-1 and is approved by most aircraft manufacturers.

Eastern European countries have their own national standards with their own nomenclature. Many are very similar to the Russian standards but others reflect the requirements of visiting international airlines and are similar to Western Jet A-1 in properties and test methods.

3.1.1.5 Chinese Jet Fuels

Five types of jet fuel are covered by current Chinese specifications. Previously, each grade was numbered with a prefix RP, they are now renamed No 1 Jet Fuel, No 2 Jet Fuel, etc. RP-1 and RP-2 are kerosene which are similar to Soviet TS-1. They both have low flash point (minimum 28 °C). RP-1 freeze point is -60 °C and RP-2 is -50 °C. RP-3 is basically as Western Jet A-1, produced as an export grade. RP-4 is a wide-cut type fuel similar to Western Jet B and Soviet T-2. RP-5 is a high flash point kerosene similar to that used in the West by naval aircraft operating on aircraft carriers. Virtually all jet fuel produced in China is now RP-3 (renamed No 3 Jet Fuel).

3.1.1.6 International Specifications - AFQRJOS Checklist

As jet fuel supply arrangements have become more complex, involving co-mingling of product in joint storage facilities, a number of fuel suppliers developed a document which became known as the Aviation Fuel Quality Requirements for Jointly Operated Systems, or AFQRJOS, Check List. The Check List represents the most stringent requirements of the DEF STAN and ASTM specifications for JET A-1. By definition, any product meeting Check List requirements will also meet either DEF STAN or ASTM specifications.

Fuel delivered to the Check List embodies the most stringent requirements of the following specifications:

- a. DEF STAN 91-91
- b. ASTM D1655 Kerosene Type Jet A-1

The Check List is recognized by eight of the major aviation fuel suppliers - Agip, BP, ChevronTexaco, ExxonMobil, Kuwait Petroleum, Shell, Statoil and Total - as the basis of their international supply of virtually all civil aviation fuels outside North America and former Soviet Union.

There are many individual national specifications. Typically, these are based on the U.S., UK or former Soviet specifications with minor differences. There are increasing moves to harmonize the small differences between the ASTM and DEF STAN specifications. This process of harmonization is also in progress with many national specifications.

3.1.2 Fuel Additives

Additives are included in fuel when required by the airline, U.S. military, or certifying authority. The following are the most commonly used additives.

3.1.2.1 Lubricity Additives

Lubricity additives may be added to lessen wear on moving parts. Currently some corrosion inhibitors provide increased fuel lubricity (military fuels).

3.1.2.2 Antistatic Additives

Antistatic additives may be added to dissipate static electrical build up by increasing the conductivity of the fuel. In Europe the DEF Stan fuel specification requires an antistatic additive.

3.1.2.3 Anti-Icing Additives

Anti-icing additives may be added to prevent ice crystal formation in the fuel by increasing the solubility of water in the fuel and lowering the freezing point of water. Some U.S. military fuels require an anti-icing additive which has been linked to thick deposit contamination and paint peeling; therefore, special design features may be required.

3.1.2.4 Biocide Additives

Biocide additives may be added to kill microorganisms in the fuel that deposit corrosive by-products. Special periodic Biocide treatment procedures may be required.

3.1.2.5 Fire Retardant Additives

Not yet developed for use.

NOTE: A fire retardant additive was developed and tested in the late 1980s. It was an anti-misting kerosene designed to slow the atomization of fuel in a crash. The full scale airplane flight and ground crash test showed it had little benefit and further development seems to have halted.

3.1.3 Future Fuels

Aviation fuels are being developed that make use of hydrogen and carbon sources other than those currently based on petroleum crude oil and oil sands. Strategic oil supplies, increasing oil prices, and environmental concerns are leading to the utilization of these alternative fuels wherever practical. The fuels being pursued for aviation are being classed as drop in replacements for current jet fuels. For all intents and purposes these fuels are the same as petroleum based fuels and can be dropped into the existing fuel infrastructure with little or no effects. Extensive testing is being conducted to assure these fuels meet the specification requirements as well as the fit for purpose properties that have been assumed to be present in petroleum derived aviation fuel. A coal to liquid (CTL) fuel is in production that utilizes the Fischer-Tropsch (F-T) process to convert CO and H₂ gases to liquids, which are then chemically processed to produce hydrocarbons in the range of jet fuels. This aviation fuel was developed and approved by DEF STAN 91-91 and accepted by ASTM D1655 as a blend material with jet fuel at up to 50% and has been in limited use since 1999. Another CTL process was approved by DEF STAN 91-91 in 2008 which produces fully synthetic iso-paraffinic kerosene that meets all specification and fit for purpose evaluations and is, therefore, designated as Jet A-1. Similar processes can also produce liquid fuels from natural gas (GTL) and biomass (BTL). The ASTM and UK MoD are evaluating these jet fuel production processes and may approve these additional feedstocks.

Any fuel produced from fossil carbon will affect the present environment by burning and releasing CO₂ into the atmosphere. As a result a number of biological based fuels are being pursued to reduce the environmental impact of air travel. These biomass fuels utilize the sun, atmospheric CO₂ and water to create hydrocarbon compounds which can then be processed into jet fuel. Burning the jet fuel then re-releases the CO₂ and water back into the atmosphere where it can be re-cycled back into biomass and used again to produce jet fuel, essentially running aircraft on indirect solar power. The processes used to grow and convert the biomass into jet fuel include inefficiencies which result in more CO₂ produced than the CO₂ that will eventually be released when the jet fuel is burned. To prevent this additional CO₂ from being released into the atmosphere some of it can be collected and sequestered by various methods such that it will not re-enter the atmosphere. Due to this removal and sequestration of CO₂ from the atmosphere over the life cycle of these fuels the process can actually reduce the atmospheric levels of CO₂ gases. This is a very complex and controversial topic which is beyond the scope of this document.

Nondrop in alternative fuels are also being pursued such as H₂ and methane which can have benefits for the environment, fuel economies, etc. The technologies to produce, transport, and store these fuels competitively against jet fuels is believed to be in the more distant future and would require considerable shifts in the design and operation of aviation fuel and propulsion systems.

3.2 Materials

The composite materials that have contact with fuel in the fuel system can vary in their material composition; ratio of the contents of the material constituents; material stiffness and effective modulus; absorption capabilities; thermal properties; material directional strata lay-up and strength characteristics (whether primary or secondary structure). These principal parameters can significantly change the effects that the fuel system can have on the composite structure, and how the fuel system conditions vary through flight operations. Many system operation and performance parameters will be different for a fuel system that has composite tank structure when compared to traditional metallic structures.

Many fuel system aircraft applications of composite fuel tanks will have fuel containment as a secondary function, whereas the primary function is often for primary and secondary aircraft structure. This means that the fuel tank structure is not necessarily designed to be a fuel tank, but a structural element of the aircraft that also serves a secondary function to contain fuel. The material type, composition and lay-up may therefore not be optimized to contain fuel, or facilitate the operation of the fuel system equipment within the composite tanks. Material compatibility with fuel system equipment inside the tank is therefore a major consideration, whereas possibilities for tank material changes in the event of incompatibility is often not an option because the material is selected based on nonfuel system considerations.

Fuel system components and component materials which are compatible with metallic tanks should therefore be assessed for their material compatibility with composite tank structures to ensure that materials are compatible, but also that the operation of the component or system is not significantly changed or degraded for a composite tank installation.

3.2.1 Characteristics

Composite materials have been used in prior aircraft design. However there are increasing uses of specific applications of composites to commercial airplane structural applications. The following characteristics are known to require evaluation when designing an airplane fuel system comprising a composite fuel tank.

- **Material strength:** The ability of the installation(s) to support the loads derived from component weight and hydrostatic forces.
- **Material modulus/stiffness:** Composites material stiffness typically varies between axial directions due to fiber orientation. Although the supporting composite material may be of very high strength capability, a modulus incompatibility with fuel system components can result in unexpected high load points.
- **Materials selected for the tank material** can vary not only in the selection of the binder resins (including whether thermo-set or thermo-plastic), but also the matrix material can vary for different layers of material.
- **Composite lay-up:** For multiple layered composites, the various layers for the material are usually oriented at included angles up to 90 degrees. The resulting strength and directional modulus of the composite structure will vary significantly with different lay-ups.

- Temperature effects: Thermal effects can change material properties, resulting in differential thermal expansions. Due to the insulating properties of composite materials, fuel temperatures within a fuel tank will be different than a comparable metallic tank at the same conditions.
- Water/Ice: The enhanced thermal insulation properties of the composite material change the onset of freezing of trapped water in the fuel system. Composite material will absorb free and/or entrained water in the fuel system.
- High temperature with high humidity: The combined effect of high temperature and humidity results in composite material properties which can be significantly degraded compared to ambient temperature/low humidity conditions.
- Impact resistance: The ability of composite material to absorb or attenuate impacts varies depending on material composition, lay-up and thickness. Unlike most metallic monolithic structures, impact damage in composite materials may not be obvious by surface inspection, and can have sub-surface damage which must be inspected and evaluated using purpose-built test and evaluation equipment and techniques.
- Fluid and chemical resistance: Degradation of the composite material may occur due to chemical and/or fluid exposure. It is important to ensure that fluids and chemicals interfacing with the fuel system will not cause material degradation.
- Electrical conductivity: Electrical properties of the composite material will vary depending on the material selection, lay-up and substrate selection. The ability of the material to conduct either high or low voltage electricity may significantly affect fuel system operation and airplane safety. The specific electrical properties of the composite should be used in defining appropriate electrical protection architecture.
- Surface finish: When compared to machined metallic surfaces, composite surface finish can be very different. In some cases, strands of the substrate can be evident at the surface of a machined surface. The surface finish can affect sealing performance, chemical and fluid resistance, and electrical considerations among others.

3.2.2 Considerations

As composite fuel tank material selection is often based on factors other than those that optimize the fuel system operation, factors which are peculiar to composite structures must be considered when designing a fuel system for composite tank applications. Although many composite tank applications will feature fuel system equipment which is common to metallic tank installations

Mechanical properties, particularly at the interface of the fuel system components and the tank structures are critical for their compatibility at the interface. Such factors which are important at this interface include such issues as material strength and stiffness, thermal expansion characteristics, surface finish, electrical bonding continuity, and relative motion of the various mount points due to flight load systems.

Although composite fuel system components may be inherently more compatible with composite tank structures, the necessity to use composites in these components should be a secondary consideration, and the effects are often of second-order advantage.

The compatibility of the fuel, and other fluids and chemicals contained in the fuel must be fully evaluated for their effects on the composite fuel tank structure, for the complete expected environment in which the system will operate. Some chemicals may be relatively inert in terms of their effect on the composite material at ambient temperatures, but may be aggressive at other conditions such as elevated temperatures; the effects of these interactions must be fully evaluated. Similarly, any chemicals used in the composite structure itself that are evident at surfaces that are in contact with the fuel, should be fully evaluated in terms of the effect on fuel properties. This is the case for both short and long term exposure at these interfaces.

Wear properties for composite structures are potentially very different than those for metallic structures and components. This may be a consideration at interfaces, particularly for sealing surfaces which may be subject to relative motion.

3.2.3 Obsolescence

The selection of the composite materials for the fuel tank has evolved and changed significantly over the last 35 years. These developments and changes will no doubt continue in the future. The compatibility of the material composition to the fuels in use and under development at the time of airplane configuration must be investigated. Specifically, the material should be evaluated against the fuels intended to be approved for use within the airplane encompassing the complete airplane operating envelope.

Additionally, recent developments in alternative fuel feed stocks will also no doubt continue in the future. Although many of the current evaluations are for 'drop-in' fuels which simulate the properties and performance of traditional aviation fuels, there may also be a divergence in fuel properties in the future. The effects of the alternative fuels must be properly evaluated when approving those fuels for use within an airplane having composite fuel tanks.

3.3 Corrosion

Corrosion of composite and metallic components comes in several forms.

3.3.1 Weathering

Weathering is typically caused by the exposure of materials to abrasive materials which impinge the material surface with great energy. Each impact site removes a microscopic amount of material, thus due to exposure for an extended period of time can cause severe pitting, erosion of the resin in composites or delamination. This type of corrosion is commonly found in leading edges of wing or fuselages, turbine blades or other surfaces exposed to the elements. Other causes of this type of corrosion are exposure to wind, sand, water, hail or FOD strike.

3.3.2 Cavitation

Cavitation damage in general can be defined as damage of a material associated with collapse of cavities in the liquid at a solid/liquid interface under conditions of severe turbulent flow. Whilst high flow velocities and the entrainment of solid particles are the main causes of erosion-corrosion, bubble implosions are responsible for the breakthrough of the passive film in cavitation-corrosion.

These bubbles may, for example, result from boiling phenomena or may arise because of the release of dissolved gases from the fluid as a result of (local) pressure drops (e.g., due to abrupt changes in channel diameters).

Attack is mostly observed on fast-moving parts or elements subject to high-velocity flows. Such parts may be pump casings, pump shafts and impellers, nozzles and valve seats, tubes, etc. Cavitation is also observed at surfaces where boiling occurs.

3.3.3 Galvanic and Dissimilar Materials

Galvanic and dissimilar material corrosion is created when two materials create galvanic currents when in contact with each other. Three conditions must exist for this type of corrosion to occur:

1. Two or more electrically dissimilar materials must be in contact with each other.
2. There must be an electrical path between each of the dissimilar materials.
3. The metal ions to move from the anodic material to the cathodic material.