AEROSPACE INFORMATION REPORT

AIR4170™ **REV. C**

Issued 1991-12
Reaffirmed 2007-12
Revised 2016-08
Stabilized 2021-12

Superseding AIR4170B

Reticulated Polyurethane Foam
Explosion Suppression Material for
Fuel Systems and Dry Bays

RATIONALE

This document has been determined to contain basic and stable technology which is not dynamic in nature.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE AE-5D Fuel Tank Flammability Reduction Systems Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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1. SCOPE

This document describes the initial development, evolution, and use of reticulated polyurethane foam as an explosion suppression material in fuel tanks and dry bays. It provides historical data, design practice guidelines, references, laboratory test data, and service data gained from past experience.

The products discussed in this document may be referred to as "Safety Foam," "Reticulated Polyurethane Foam," "Baffle and Inerting Material," or "Electrostatic Suppression Material." These generic terms for the products discussed in this document are not meant to imply any safety warranty. Each individual design application should be thoroughly proof tested prior to production installation.

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.

NOTE: In this Applicable Documents Section, not all publications listed are referenced in this document. The intent of this expanded list of documents is to maintain a composite listing of all known documents that are pertinent to the subject discussed in this document. Therefore, all documents in this section preceded by an asterisk (*) indicates that the specific document in the reference section is not referenced within this document, but is technical information to assist those using the document for the design, fabrication, testing, installation and maintenance of foam for inerting fuel tanks.

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.

*AIR1662 Minimization of Electrostatic Hazards in Aircraft Fuel Systems

*AIR1664 Aircraft Flexible Tanks - General Design and Installation Recommendations

*AIR 5691 Guidance for the Design and Installation of Fuel Quantity Indicating Systems

2.1.2 Air Force Publications

Available from Defense Technical Information Center, 8725 John J Kingman Road, Fort Belvoir, VA 22060. NOTE: Some of these documents may be available for download from www.dtic.mil/dtic/

Report No. 1819 (20 May 1966)	Development and Testing of Cellular Packing Material, written by Firestone Coated Fabrics Co. under Air Force Contract No. AF33(615)-3423
*ASJ-TM-66-1 (November 1966)	Investigation of Polyurethane Foam for Aircraft Fuel System Applications
*RPL-TDR-64-25 (November 1968)	Aerospace Fluid Component Designers Handbook
*ASNJI-70-2 (May 1970)	USAF Experience with Polyurethane Foam Inerting Material
*ENJI-70-10 (November 1970)	Effects of Polyurethane Foam on Fuel System Contamination

*ENJPF-TM-72-1 (March 1972)	The Use of Polyurethane Foam for Fuel System Inerting (Unpublished Report)
*AFAPL-TR-72-12 (March 1972)	Advanced Flame Arrestor Materials and Techniques for Fuel Tank Protection
*AFAPL-TR-73-50 (July 1973)	Incendiary Gunfire Simulation Techniques for Fuel Tank Explosion Protection Testing
*AFML-TR-73-283 (December 1973)	Environmental Aging of Candidate for Suppressant Dry Bay Area Materials for Aircraft
*AFAPL-TR-73-76 (December 1973)	Vulnerability Assessment of JP-4 and JP-8 Under Verticle Gunfire Impact Conditions
*AFML-TR-73-278 (January 1974)	A Method to Predict the Service Life of Internal Fuel Cell Baffle Materials
AFAPL-TR-73-124 (February 1974)	Gross Voided Flame Arrestors for Fuel Tank Explosion Protection
*ASD-TR-74-34 (September 1974)	Gunfire Effectiveness and Environmental Suitability of Void Filler Materials
AFAPL-TR-74-126 (July 1975)	Void Filler Ballistic Fire Protection for Aircraft Fuel System Dry Bays
AFAPL-TR-75-93 (July 1975)	Integrated Aircraft Fuel Tank Fire and Explosion Protection Systems Phase I and II
*AFFDL-TR-76-98 (January 1978)	Ballistic Evaluation of Aircraft Explosion Suppression Materials
*AFAPL-TR-78-89 (December 1978)	Factors Affecting Electrostatic Hazards
ENFEF-TM-78-08 (June 1979)	Guidelines for Use in Design, Fabrication, Installation and Testing of Reticulated Foam Kits
*Bulletin 4-9 Part 1 (September 1979)	The Shock and Vibration Bulletin. A publication of The Shock and Vibration Information Center, Naval Research Laboratory, Washington, D.C.
*ENFEF-TM-79-08 (December 1979)	Qualification Test Results for Scott Paper Co., Blue Hybrid Polyether Foam
AFWAL-TR-80-4135 (September 1980)	Compatibility of Reticulated Foams in Typical Turbine Fuels with Currently Approved Additives
*Memorandum Report (February 1983)	Hydrodynamic Ram AttenuationARBRL-MR-03246
*Letter report (14 June 1983)	C-130 Fuel Tank Shroud Electrostatic Evaluation, Summary of Results(POSH) Dept. of the Air Force Wright-Patterson AFB
*Final Report (September 30, 1981)	A-10A Fuel Tank Vent System, Vapor Ignition Investigation
AFWAL-TR-83-3114 (September 1983)	Survivable Aircraft Fuel System Engineering Design Guide (SAFE/DG)
AFWAL-TM-84-237-FIESL (December 1984)	A Comparison of White Reticulated Foam to Rigid Foam as Fire Protection for Aircraft Dry Bays
*AFWAL-TR-84-2048 (December 1984)	Damage Caused to Polyurethane Foams by Aging, Simulated Sunlight Exposure, Heat and Fire

*AFWAL-TM-85-237-FIESL (September 1985)	A Comparison of Electric Field Measurements on Conductive and Nonconductive ExplosionSuppressant Foams in C-130 External Fuel Tanks
*AFWAL-TR-85-2060 (January 1986)	Vulnerability Methodology and Protective Measures for Aircraft Fire and Explosion Hazards
*AFWAL-TR-82-2022 (March 1986)	Electrostatic Hazards of Urethane Packed Fuel Tanks
*86-MMSRE-011 (12 May 1986)	Baffle and Inerting, Conductive, Aircraft Fuel Tank
*AFWAL-TR-86-2077 (November 1986)	Study of Aeropropulsion Lab Pressure Drop Rig and Recommended Test Procedure
ESL-TR-84-63 (January 1987)	Effective Disposal of Fuel Cell Polyurethane Foam
TE-ENFE-86-1 (1 Nov. 1987)	Electrically Conductive Explosion Suppression Material, General Exhibit for
*MS-MMSR-87-100 (12 Sept. 1988)	A-10 Aircraft Electrically Conductive Explosion Suppression Material, Material Specification for
*USAAVSCOM TR 89-D-16 (February 1990)	Aircraft Fuel System Fire and Explosion Suppression Design Guide
WRDC-TR-90-4074 (28 Sept. 1990)	Foam, Explosion Suppressant, Thermal Resistance Electrical Conductivity, High Temperature
AFRL-PR-WP-TR-2000-2015 (October 2001)	Fuel and Fuel System Materials Compatibility Test Program for a JP-8 +100 Fuel Additive

2.1.3 FAA Publications

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

ARAC FTHWG Final Report (July 1998)	Aviation Rulemaking Advisory Committee – Fuel Tank Harmonization Working Group Final Report
FAA-1999-6411, SFAR 88 (09 Dec. 2002)	Fuel Tank System Fault Tolerance Evaluation Requirements
AC 25.981-1C (19 Sept. 2008)	Fuel Tank Ignition Source Prevention Guidelines
AC 25.981-2A (19 Sept. 2008)	Fuel Tank Flammability Reduction Means
AC 120-98A (22 June 2012)	Operator Information for Incorporating Fuel Tank Flammability Reduction Requirements into a Maintenance or Inspection Program

2.1.4 Military Publications

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

A-A-3174	Plastic Sheet, Polyolefin
A-A-208	Ink, Marking, Stencil, Opaque
MIL-PRF-81705	Barrier Materials, Flexible, Electrostatic - Free, Heat Sealable
*MIL-DTL-27422F (6 Feb. 2014)	Tank, Fuel, Crash Resistant, Aircraft (Non-Self-Sealing and Self-Sealing)

MIL-DTL-83054 C (20 October 2003)	Baffle and Inerting Material, Aircraft Fuel Tank
*JSSG-2009	Air Vehicle Subsystems
MIL-PRF-87260 B (2 November 2006)	Foam Material, Explosion Suppression, Inherently Electrically Conductive, for Aircraft Fuel Tank and Dry Bay Areas
MIL-DTL-5578	Tank, Fuel, Aircraft, Self-sealing
MIL-DTL-5624	Turbine Fuel, Aviation, Grades JP-4 and JP-5
MIL-DTL-6396	Tank Aircraft Propulsion Fluid Systems, Internal, Removable, Nonsealing
MIL-DTL-83133	Turbine Fuel, Aviation, Grade JP-8
MIL-STD-129	Markings for Shipment and Storage

2.1.5 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 D2276-73	Test Methods for Particulate Contamination in Aviation Turbine Fuels
ASTM D910	Gasolines, Aviation
*ASTM D1655	Specification for Aviation Turbine Fuels
*ASTM D3574	Standard Test Methods for Flexible Cellular Materials—Slab, Bonded, and Molded Urethane Foams

2.1.6 ASME Publications

Available from ASME, P.O. Box 2900, 22 Law Drive, Fairfield, NJ 07007-2900, Tel: 800-843-2763 (U.S./Canada), 001-800-843-2763 (Mexico), 973-882-1170 (outside North America), www.asme.org.

*71-GT-54 Effects of Polyurethane Foam on Fuel System Contamination

2.2 Applicable Films

Ounces of Protection, Firestone, circa 1960	Firestone accepted the challenge from the auto racing industry to develop safer fuel systems for racing cars. Adaption of flexible bladder used in aircraft to racing cars using foam as the baffling system to attenuate slosh.
Polyurethane Foam for Explosion Suppression Air Force - Color/Sound 7 min	Explains use of reticulated polyurethane foam and how it is installed: making, cutting, and stuffing. Shows C-123, RB-57 “Canberra,” F-105 "Thunderchief," C-130 and AC-130 “Gunship 2.” Shows stuffing wet wing in C-130, toughest type of installation due to intricacy of plumbing in C-130.
Crashworthy Integral Fuel Cells, Photographic Instrumentation Data Film, Color/No Sound 12 min	Compares fuel spread of dropped (ruptured) tip tank with fuel only and then with fuel and foam inside.

The Unseen Storm, Firestone Tire & Rubber Co., circa 1970 16MM/10 min/Color/ Sound	Deals with suppressing surge and slosh in fuel tanks, specifically in competitive racing speed boats.
Survivability, Enhancement Through Aircraft Design T.O. Reed ASD/ENFEF May 1979 Copy #6 Unclassified, 16MM/20 min/Color/ Sound	Approximately middle of film deals with fuel tank protection with foam and dry bay protection with foam.
Fairchild A-10 Gunfire Film, Air Force Flight Dynamics Laboratory, 1973/16MM/Color/Sound/ 10 min	Deals with survivability testing of A-9 and A-10 by the Air Force after the GOA determined that the craft had a low level of survivability. Foam was not designed into the fuel cells because the Air Force had no test results supporting it. So the Air Force conducted a 20-month evaluation of evaluation of the fuel system survivability using external dry bay rigid foam and internal Safety Foam.
Firestone, US News Release, circa 1965 16MM/Color/No Sound/ 2 min	Firestone brochure and intro to reticulated polyurethane foam with surge demo and explosion suppression demo.
Wing Foam Test, circa 1989	VHS Tape, 10 min John F. Barnes, Engineering Branch Naval Weapons Center China Lake, CA 93555

2.3 Definitions

RETICULATED POLYURETHANE FOAM: Low density flexible urethane foams characterized by a three-dimensional skeletal structure of interconnected strands with few or no membranes between the strands, containing up to 97% or more of void space.

IN SITU: In natural order - a foam that has a conductive additive included in the chemical foam formulation prior to blowing and curing.

HYDROLYTIC STABILITY: The foam's ability to resist a chemical process of decomposition involving splitting of a bond and the addition of the elements of water. In the case of polyurethane foam, the decomposition is usually caused by a cycling of temperature, heat, and humidity.

COALESCE: To unite into a whole, to grow together. In the case of reticulated foam, the geometric structure catches the minuscule droplets of fuel, not permitting them to vaporize and combine with oxygen into an explosive mixture.

STOICHIOMETRIC MIXTURE: The optimum ratio of air and fuel required to provide a maximum possible combustion pressure.

SWITCH LOADING - SWITCH REFUELING: Refueling with a grade of fuel different than the residual fuel occupying the tank.

ULLAGE: Vapor space above the fuel surface at any fuel level.

HEI: High Explosive Incendiary

COMBUSTION PRESSURE: Increase in pressure within the fuel tank due to combustion of a flammable mixture (ΔP in PSID). Sometimes defined or referred as combustion overpressure.

COMBUSTION VOLUME: Percent of ullage space which is ignited by a projectile or some other ignition source.

COMPONENT VOID: Cutout in the foam which provides clearance between the foam and an internal element of the fuel tank (e.g., pump, quantity probe, or fuel inlet). Void Volume = cutout volume - component volume.

DRY BAY: Space (cavity) within the mold line of an aircraft that is normally dry but may contain an explosive gas mixture in the event of combustible fluid leakage due to combat damage or natural causes.

FOAM POROSITY: Numerous, small openings in the foam structure; coarse and fine classifications are indicative of the size of the openings and are based upon air pressure drop tests.

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

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

OPTIMUM VOID LEVEL/FOAM KIT CONFIGURATION: Foam kit which contains sufficient foam to protect the tank, but no more than is necessary.

PLAN VOID: Cutout intentionally designed into the foam for weight reduction and to aid fuel flow through the foam. Void volume = cutout volume.

PSID: Pounds per square inch differential; unit of pressure measurement.

PSIG: Pounds per square inch gage; unit of pressure measurement.

PSIA: Pounds per square inch absolute; unit of pressure measurement.

SINGLE VOID COMBUSTION: Combustion occurs only in the void which is initially ignited, i.e., no propagation.

TOTAL VOID: Sum of designed voids and component voids.

VOID: Absence of foam in a given volume or space (cutout).

EXPLOSION SUPPRESSION MATERIAL (ESM): A general term used to define materials used in fuel tanks to prevent fuel tank overpressures, i.e., reticulated polyurethane foam, one such material.

3. DISCUSSION OF FUEL SYSTEM EXPLOSION SUPPRESSION

3.1 History of Reticulated Polyurethane Foam

In the early 1960s, the USAC (United States Automobile Club) was concerned with the rising number of accidents involving fuel explosions and fires. The primary contributing factors were increasing speeds, and the use of lighter weight materials and structures, which contributed to fuel tanks being ruptured on impact. At this time, USAC approached industry to investigate the cause and to provide a feasible solution that would help suppress explosions and fires. As a result of this development program, a successful crashworthy fuel cell tank system was designed by private industry and implemented by automotive racing associations.

In 1965, as the initial development of reticulated polyurethane foam was completed, and the Vietnam conflict was escalating, the U.S. Air Force sustained an increasing number of aircraft losses and pilot fatalities due to fuel tank explosions caused by small arms gunfire.

During this period the U.S. Air Force began searching for a solution to reduce vulnerability of the fuel tanks and improve survivability. They approached industry, (airframe manufacturers, bladder manufacturers and a foam manufacturer who had developed the reticulated polyurethane foam system) to determine if this same concept could be applied as an Explosion Suppressant Material (ESM) in aircraft fuel tanks. Additional research ascertained that reticulated polyurethane foam was an excellent explosion suppressant for aircraft wet wing and bladder fuel tanks. Type I orange reticulated foam gained widespread acceptance by the military for use in F-105s, AC-47s, A-37s, O2s, B-57s, C-123s, C-130s, helicopters, and other aircraft.

Although weight and fuel penalties accompanied use of foam they were considered small in relation to the benefits. The military was made aware from the onset that the usable life was estimated to be 5 years for reticulated polyester polyurethane foam (Type I orange).

With Type I orange reticulated polyurethane foam acceptance regarded as a significant advancement in survivability, the U.S. Air Force came back to the foam industry with a request to reduce the weight penalty. As a result of this request, and with additional development effort during the 1970 through 1972 time frame, Type II yellow reticulated polyurethane foam was developed. It exhibited a lower density, with the equivalent explosion suppression protection of Type I orange. Lower density reduced the foam kit weight by 25%. This resulted in additional allowable fuel and munitions to be carried, thus extending the aircraft mission capabilities. The kit designs using Type I and II are considered fully packed systems, but inherently contain up to a 15% void volume.

Paralleling the development program for Type II, yellow reticulated polyurethane foam, a major airframe designer/manufacturer was developing an aircraft fuel system utilizing reticulated foam for a new fighter aircraft design. Their ultimate goal was to provide explosion suppression using a grossly voided reticulated polyurethane foam kit, with up to 70% void volume. The revolutionary design would greatly reduce the weight, and fuel retention penalties compared to traditional fully packed systems. Laboratory testing determined that a finer foam cell structure was required to equal the flame arrestor and explosion suppression capabilities of a fully packed design. A joint research effort between the aircraft manufacturer and the foam producer successfully resulted in Type III, red reticulated polyester polyurethane foam for use in grossly voided explosion suppression systems. This new system greatly enhanced the life cycle costs of aircraft employing this new concept.

In the early 1970s as the Vietnam conflict was coming to an end, the U.S. Air Force was experiencing degradation of the reticulated polyester polyurethane foam (Type I, orange). As originally anticipated, due to environmental conditions encountered in Southeast Asia, the combination of extreme temperatures, high humidity, and cool evenings accelerated the problem of foam hydrolysis. (See Lesson Learned Section for a detailed discussion on the effects of foam degradation, and resulting contamination of the fuel system.) Again, the U.S. Air Force approached the foam industry to solve the degradation problem. All reticulated polyurethane foams up to this time were of a polyester type, which has inherent limitations with hydrolytic stability. In 1974, a major development breakthrough by the resin chemical producer/suppliers, namely a polymer-polyol resin, became available enabling production of a hybrid polyether type polyurethane foam. Development of Types IV and V reticulated polyether polyurethane foams was accomplished by the original manufacturer of reticulated polyurethane foam and the USAF; installations of Type IV and Type V kits were being used in military systems by 1978.

Types IV and V provided the equivalent explosion suppression capabilities of the original polyester reticulated polyurethane foam products. At the same time, they offered an expectant life 5 to 10 times greater than the earlier polyester reticulated polyurethane foams. All foams were produced in accordance with MIL-DTL-83054C.

In the late 1970s the U.S. Air Force undertook major retrofit programs, with the installation of blue polyether reticulated polyurethane foam ESM kits in A-10 and, in the early 1980s in the C-130 aircraft. Widespread implementation of both Types IV and V also took place in newly designed aircraft such as the F-15 and F-18.

Beginning in the mid-1970s, the U.S. Air Force began experiencing numerous electrostatic ignitions. The problem was confined only to two types of aircraft, the A-10 and C-130. Electrostatic ignitions were reported mostly during cold weather operations. The ignitions occurred during ground refueling operations, in-flight fuel/air purging and during special operating missions being performed. The problem occurred as a result of charge separation due to fuel passing through the foam. Electrostatic charge generation related to aircraft, fuel handling, and electrical storms has always been a major concern. Limited information existed pertaining to electrostatic generation and the associated behavioral relationship between reticulated polyurethane foam installed in fuel cells in combination with the usage of hydrocarbon fuels.

During the 1980s comprehensive research programs were undertaken by the U.S. Air Force, airframe manufacturers, foam manufacturers, and academic research people to investigate the electrostatic phenomenon. Extensive laboratory test programs were conducted to better understand the complex mechanism of electrostatic generation/ignition. The programs included inspection of aircraft, and stationary simulation on actual fuel tankage sections. Once a basic understanding of the mechanics of the electrostatic generation/ignition problem was ascertained, the reticulated foam manufacturers entered into various research and development programs. This work ultimately produced a conductive reticulated polyether type polyurethane foam that would reduce the hazard of electrostatic generation and minimize foam related ignitions in aircraft fuel systems.

Two types of conductive reticulated polyurethane foams were developed by the mid to late 1980s. The initial approach utilized the basic Type IV and Type V foam products, subjecting the base foam to a post-reticulation treatment to make it conductive per the requirements of TE-ENFE-86-1. These materials became known as Type VI Dark Beige and Type VII Light Beige, reflecting the differences between coarse and fine pore sizes, respectively. The USAF utilized post-reticulation treated Type VI and VII starting in 1986 and ending in the early 1990s.

A second alternative development, also started in 1986, provided inherently conductive reticulated polyether type polyurethane foam, also known as in situ conductive reticulated polyether polyurethane foam. The USAF has been utilizing the in situ conductive reticulated foam approach supplied by the foam industry in sufficient quantities for in-flight service testing and evaluation in C-130 and A-10 aircraft.

Four types of in situ conductive reticulated foam have been developed, in accordance with MIL-PRF-87260B. Class 1 performance per the military specification identifies foam with in situ conductive properties over a temperature range from 0 to 160 °F (-17.7 to 71.1 °C). Class 2 performance per the military specification identifies foam with in situ conductive properties over a temperature range from -25 to 160 °F (-31.7 to 71.1 °C). Within the two class designations, the pore size difference between coarse and fine is determined by Grade IC and Grade IIC, respectively. Regardless of Class designation, Grade IC is now also known as Type VI Black and Grade IIC is now also known as Type VII Grey. The use of in situ conductive reticulated polyether polyurethane foam materials have proven to be completely successful in the elimination of the foam electrostatic generation/ignition problem in aircraft fuel tanks.

In 1987 a new program was initiated by the U.S. Air Force to develop and evaluate a high temperature reticulated foam for use in advanced aircraft. The new material developed as a result of this program can sustain temperatures of 300 °F for an extended period. The new foam material will also meet the USAF's requirements for improved hydrolytic stability and electrical conductivity. The program was successfully completed in 1990 and samples of the material were submitted to the Project Director at the Materials Laboratory, Wright Patterson AFB. The program demonstrated that this product can be produced commercially if there is an existing need. This program was completed September 28, 1990 Report No. GJ-0928-90, WRDC-TR-90-4074.

In 1996 TWA Flight 800 exploded over Long Island, NY shortly after take-off from John F. Kennedy International Airport. The most likely cause of this explosion was a spark in the center fuel tank which ignited heated fuel vapor. This event prompted an industry-wide review of aircraft fuel tank safety, culminating in a series of recommendations from the Fuel Tank Harmonization Working Group (FTHWG) in 1999. Various industry-expert led teams under FTHWG produced reports outlining improvements that should be made to prevent fuel tank explosions. Reticulated polyurethane foam as an ESM was reviewed under Chapter 8 of FTHWG and found to support all of the conclusions shown in Section 3.3 of this document. In addition, the use of reticulated polyurethane foam as an ESM was estimated to improve the mean-time between a fuel tank explosive event from one every five years to one approximately every fifty years – a ten-fold increase in safety performance.

Since the FTHWG report, the Federal Aviation Authority (FAA) enacted Special Federal Aviation Regulation (SFAR) 88, which requires operators of type certificated aircraft of a certain size and passenger load to mitigation fuel tank explosions in their aircraft fleet. The FAA also enacted rulemaking changes for 14 CFR 25.981 addressing fuel tank explosion prevention. Subsequent aviation Advisory Circulars have noted reticulated polyurethane foam as a mitigation technology for prevention of fuel tank explosions (AC25.981-1C, AC25.981-2A and AC120-98A). This guidance has led to industry use of reticulated polyurethane foam for commercial aircraft applications through engineering designs.

3.2 Special Note Regarding Export Classifications for ESM

Export requirements for reticulated polyurethane foam as an ESM have changed following the classification of certain Grades and Classes of the technology as Defense Articles by the Department of State following September 11, 2001. The technology is capable of being exported under license from either the Department of State or the Department of Commerce depending on the application of the foam in a military or commercial fuel tank, respectively. This paragraph is offered as guidance to non-US users of reticulated polyurethane foam as an ESM for purposes of planning when designing the product into a new application. The manufacturer of the reticulated polyurethane foam has the responsibility to control the export of the technology when applicable by obtaining an export license or release from the appropriate authority.

3.3 History of Dry Bay Reticulated Polyurethane Foam

Since the early to mid-1970s, the U.S. Air Force and private industry have been actively engaged in the engineering, development and installation of reticulated polyurethane foam as a dry bay suppressant material. The earliest known technical report on this subject is Air Force Document Number AFAPL-TR-74-126. The basic concept was to use 25 and 29 pores per inch reticulated polyurethane foams that had been developed for fuel tank explosion suppression.

The use of flexible reticulated polyurethane foam in a dry bay will inhibit the mixing of air and the spray of fuel from leaking tanks or lines, thus minimizing explosion and possible sustained fires. The open pores permit any fuel escaping from the tank to drain to the low points of the aircraft where it can be exhausted overboard. The foam acts as an explosion and fire suppressor in much the same manner as it does inside the tank. Current testing indicates that the support provided to a fuel tank by the external installation of foam reduces the severity of hydrodynamic ram effects.

The application of dry bay foam requires minimum logistic support and provides multi-hit capability. Foam pieces should be designed for installation under 3 to 5% compression. The dry bay foam can be cut to the shape of the bay using the same techniques used for reticulated polyurethane foam.

After the initial acceptance and implementation of reticulated polyurethane dry bay foams as an explosion suppression material for aircraft dry bay protection, further development and testing resulted in use of finer pore foams. Gunfire testing and evaluation in the mid-1980s for the F-15 aircraft proved that a 45 pores per inch white reticulated polyether polyurethane dry bay foam provides maximum protection. The results for this series of gunfire testing may be found in Air Force Document Number AFWAL-TM-84-237-FIESL.

Just as the finer pore (45 ppi) dry bay foam development was completed, the U.S. Navy became interested in the use of this product for the A-6D/E aircraft. They stipulated that it must be a flame retardant-type foam. The fire retardant requirement had a dual purpose. First, the A-6 is a carrier-based aircraft and may be exposed to enemy gunfire while on the carrier deck. The U.S. Navy did not want the risk of dry bay explosion suppressant material contributing to a deck fire as a result of combat damage. Secondly, spare dry bay foam components/kit(s), or bulk replacement reticulated polyurethane dry bay foam is stored on shipboard, and the flame retardant precaution was taken in the unlikely event of a shipboard fire. Ultimately, implementation of the Magenta, 45 ppi, fire retardant, reticulated polyurethane dry bay foam began in 1987.

The most recent development of dry bay foam was provided as the result of a helicopter aircraft manufacturer requiring a stiff dry bay explosion suppressant material offering maximum drainability. The desired stiffness provided sufficient support for a bladder type fuel cell. To satisfy this request, a gold, 30 ppi, fire retardant, reticulated polyurethane dry bay foam was qualified for their application.

Currently, there are two dry bay foam products in production that are not specified under either MIL-DTL-83054C or MIL- F- 7260B. All the products for dry bay applications are noted in Tables 4 and 5.

Other applications utilizing reticulated polyurethane foam explosion suppression technology:

3.3.1 Military

a. Round ball spheres of reticulated polyurethane foam kits for single port entry of limited access composite tanks. CAUTION: Protection effectiveness using round ball spheres must be verified by testing of the specific application.

b. Aircraft and tracked vehicle refuelers

c. Armored tracked vehicles

d. Marine target boats

e. Hovercraft/landing craft

f. High speed turbine-powered boats

g. Unmanned flight platforms

h. Military wheeled vehicles

3.3.2 Nonmilitary

a. Automobile racing

b. Agricultural aircraft

c. Boat racing

d. Commercial aircraft

e. Gas cans

3.4 Functional Description of Reticulated Polyurethane Foam

The material is a lightweight reticulated flexible polyurethane foam composed of a skeletal matrix of tiny interconnecting strands which act as a three-dimensional fire screen. Reticulated polyurethane foam used as an explosion suppressor is a combat-proven system refined from experience that will minimize fuel tank overpressure caused by: gunfire; electrical ignition; lightning strikes; and electrostatic discharges. It functions as a multiple hit, passive defense system to reduce vulnerability and increase survivability. The system is always available to protect an aircraft or vehicle operating on a mission or parked in a nonoperating mode, requiring no crew or maintenance action.

Foam has the following inherent benefits:

a. Nothing to turn on

b. No pilot monitoring

c. No moving parts

d. No pressure lines

e. No pressure relief valves

f. No explosion sensing devices

g. No functional components to fail, maintain or monitor other than periodic inspection

h. No failure modes if properly installed and maintained

i. No need to handle the logistics of large quantities of LN_2, or the special safety requirements during refueling

j. No onboard high pressure storage vessels to protect

k. Self-healing characteristics

l. Compatible with most standard fuels

m. Only explosion suppression protection system that is effective for multiple hits to the same tank

n. Reduced airframe structural damage when hit by a round, due to its energy absorbing characteristics

Foam has the following inherent disadvantages:

a. The weight of the foam (even with gross voiding) may be heavier than other protection systems.

b. The foam reduces usable fuel by the volume it occupies and the fuel retained in the foam, however, normal aircraft operation vibration will reduce fuel retention below published data.

c. Routine and unscheduled maintenance and inspection of fuel tank interiors are more complicated since the foam must be removed and then re-installed. In the kit, each block of foam is carefully shaped for its unique position in the fuel tank. Residual fuel in the foam causes an increase in the time required for the fuel tank to be air purged and to safely enter the fuel tank as the foam pieces are removed. The foam pieces must be properly stored until tank maintenance/component replacement has been completed. The foam pieces must then be replaced with the same care as the initial foam installation. In some cases, foam pieces may be damaged on removal due to the low strength when wet, and will need to be replaced with new pieces.

3.5 Reticulated Polyurethane Foam Effectiveness

3.5.1 Explosion Suppression

Explosion within a fuel tank containing gasoline or kerosene-type fuels can only occur by having a flammable mixture in the ullage with an ignition source: for example, incendiary ammunition penetrating the fuel tank as might occur under combat conditions, static discharges, lightning strikes, switch refueling, and electrical shorts.

Reticulated polyurethane foam is in effect a three-dimensional fire screen, which minimizes the possibility of gasoline and kerosene-type (aircraft type) fuel explosions under one or several of the following theories:

a. It acts as a heat sink, i.e., it removes energy from the combustion process by absorbing heat.

b. It mechanically interferes with the compression wave that precedes the flame front in an explosion.

c. The high surface-to-volume of reticulated polyurethane foam enables the strands to collect or coalesce the droplets of fuel, thus changing the vaporous mixture above the fuel level (ullage), in the tank. Coalescing causes the vaporous mixture to become lean, which minimizes possible explosion.

At the time of initial development and testing of Type I, orange reticulated polyurethane foam by the Air Force, the product's explosion suppression characteristics and effectiveness were tested and evaluated under Air Force contract. Firestone's Report No. 1819, dated 20 May 1966, discusses gunfire testing performed on 55-gallon drums, with and without reticulated polyurethane foam. The movie film titled "Ounces of Prevention" provides visual gunfire testing comparison of 55 gallon drums and actual aircraft fuel tanks with and without ESM, demonstrating the material's effectiveness.

All types of reticulated polyurethane foam products listed for internal fuel tanks in this document have been subjected to testing per MIL-DTL-83054C and MIL-PRF-87260B. The flame arrestor (explosion suppression) characteristics were tested as per MIL-DTL-83054C utilizing the flame tube test described in 4.6.19 and MIL-PRF-87260B utilizing the flame tube test described in 4.5.18.

3.5.2 Slosh Attenuation

As a surge mitigator, reticulated polyurethane foam attenuates sloshing of fuel and in some cases eliminates the need for structural baffles within a tank. Foam gives the fuel a smooth sine wave motion and reduces rapid redistribution of mass. The two films "Ounces of Prevention" and the "Unseen Storm" contain visual demonstration of the slosh control attained with the use of reticulated polyurethane foam.

3.5.3 Hydrodynamic Ram Attenuation

Hydrodynamic ram within a fuel tank or bladder cell is caused when a projectile impacts the exterior structure of a fuel tank. Ram force can be intensified when the tank is penetrated by an HEI delayed detonating-type projectile. The matrix-type structure of reticulated polyurethane foam absorbs a portion of the shock wave as a projectile penetrates a fuel tank. Attenuation of hydrodynamic ram minimizes damage to the fuel tank structure by reducing the overpressure associated with the shock wave and helps to orient the round to prevent tumbling. Reduction of fuel tank structural damage can effectively reduce fuel discharge through the projectile entrance and exit points. The effectiveness of reticulated polyurethane foam in attenuating hydrodynamic ram may be seen in an actual demonstration in the Wright-Patterson AFB film clip titled "Crashworthy Integral Fuel Cells".

3.5.4 Foreign Object Debris Barrier

FOD capability of reticulated polyurethane foam materials is not a product specification requirement, but rather an inherent beneficial effect. Reticulated foam is a natural filter. The finer the pore size of the material the greater entrapment of foreign objects and loose debris. The finer pore size foam materials entrap loose debris within a fuel tank and minimizes the amount of debris entering the engine fuel system.

3.5.5 Additional Benefits

Experience and testing with reticulated polyurethane foam has demonstrated that the material can provide a number of added benefits beyond that of internal fire and explosion protection. These added benefits include: reduction in slosh and vibration effects; enhancement of the performance of self-sealing fuel tanks; reduction of the effects of hydrodynamic ram; and a significant reduction in the "blast damage" that results from high explosive incendiary (HEI) ballistic threat. It is important to note that these added benefits are a function of the amount of foam present in the tank. In other words, to take maximum advantage of any or all of these benefits, one would be led to the use of lower voiding levels, resulting in a maximum foam penalty factor for the aircraft. Therefore, the choice of foam and void level becomes a tradeoff between optimum benefits and system penalty. For this reason, the designer should consider both sides of the issue and select the foam porosity and void level which best meets the needs of the aircraft (expected usage). Optimized benefits occur with the use of a coarse pore foam with only component voids. However, the associated weight and fuel retention penalties are also maximized.

3.6 General System Design Guidelines

3.6.1 Material Selection Guide and Cautions

See Tables 1, 2, and 3 for the available types of reticulated polyurethane foams used as inerting materials in fuel systems. MIL-DTL-83054C governs all types of non-conductive safety foam Types I through V. MIL-PRF-87260B governs all conductive safety foam types under the nomenclature of Class 1 and 2 (to designate temperature range) and Grades IC and IIC (to designate pore sizes). Conductive safety foam may also be referred to generically as Type VI course pore and Type VII fine pore.

Two proven concepts exist for inerting aircraft fuel tanks with reticulated polyurethane foam:

a. Fully Packed - utilizing a choice of Type IV or Class 1 and 2, Grade IC coarse pore foams

b. Grossly Voided - utilizing a choice of Type V or Class 1 and 2, Grade IIC fine pore foams

The fully packed concept offers maximum protection and baffling at the expense of weight and fuel retention.

The grossly voided system trades off weight, baffling, and possibly some protection for additional fuel and munition stores.

Both concepts have their merits and a compromise, or a hybrid system can be used employing different concepts for each tank depending on aircraft design, vulnerability, and the ultimate mission of the aircraft.

3.6.2 Fully Packed Design Concept

A fully packed system is defined as one where all potential fuel tank ullage is filled with reticulated polyurethane foam with cutouts for components only. This system is most desirable where minimal or no tank over-pressure can be tolerated. See Figure 1, flame tube data that shows the effect on operating pressure versus combustion pressure, for Type IV, (data should be similar for all coarse pore type products), blue polyether reticulated polyurethane foam. The coarse pore types of reticulated polyurethane foams, (Types I, II, IV, and Class 1 and 2, Grade IC), are intended for fully packed applications. However, it is strongly recommended that one of the conductive coarse pore products be used: see Table 1. The basic design guidelines referenced in this section have been taken from the following available documents.

a. ENFEF-TM-78-08

b. AFAPL-TR-75-93

c. AFWAL-TR-83-3114, Vol. I and Vol. II

The suggested guidelines listed below are intended to assist the designer in the development of a fully packed system, and should not be limited to this list:

Table 1 - Product classifications

Foam Type	Specification	Type	Class	Grade	Color	Target Density		Nominal ppi		Target Electrical Resisitivity	Fuel Tank	Slosh Attenuation	Conductive
						(lb_m/ft^3)	(kg/m^3)	(pore/in)	(pore/cm)	(Ω-cm)	Explosion Suppression	(Baffling)	
Polyester	Mil-DTL-83054C	I			Orange	1.8	28.8	10	4	1×10^{13}	X	X	No
Polyester	Mil-DTL-83054C	II			Yellow	1.3	20.8	15	6	8×10^{13}	X	X	No
Polyester	Mil-DTL-83054C	III			Red	1.3	20.8	25	10	8×10^{13}	X	X	No
Polyether	Mil-DTL-83054C	IV			Dark Blue	1.3	20.8	15	6	1×10^{15}	X	X	No
Polyether	Mil-DTL-83054C	V			Lt. Blue	1.3	20.8	29	11	1×10^{15}	X	X	No
Polyether	MIL-PRF-87260B		1 or 2	IC	Dk.Black	1.45	23.2	15	6	3×10^{11}	X	X	Yes
Polyether	MIL-PRF-87260B		1 or 2	IIC	Lt. Grey	1.5	24.0	29	11	3×10^{11}	X	X	Yes

Table 2 - Typical product specifications
Physical properties and characteristics of Type I through Type V per MIL-DTL-83054C

Property	Type I				Type II				Type III				Type IV				Type V			
Units	English		SI		English		SI		English		SI		English		SI		English		SI	
Color	Orange				Yellow				Red				Dark Blue				Light Blue			
Polyol Type	Polyester				Polyester				Polyester				Polyether				Polyether			
Density Range, Min. and Max. in lb_m/ft^3 (kg/m^3)	1.70	2.00	27.23	32.04	1.20	1.45	19.22	23.23	1.20	1.45	19.22	23.23	1.20	1.45	19.22	23.23	1.20	1.45	19.22	23.23
Porosity, Min. and Max. pore size in pore/in (pore/cm)	7	15	3	6	8	18	3	7	20	30	8	12	8	18	3	7	24	34	9	13
Air Pressure Drop, Min. and Max. in in of H_2O (cm of H_2O)	0.190	0.285	0.483	0.724	0.140	0.230	0.356	0.584	0.250	0.330	0.635	0.838	0.140	0.230	0.356	0.584	0.270	0.370	0.686	0.940
Tensile Strength, minimum, in psi (kPa)	15		103		15		103		15		103		10		69		15		103	
Tensile Strength at 200% Elongation, minimum, in psi (kPa)	10		69		10		69		10		69		--				--			
Ultimate Elongation, minimum in %	220				220				220				100				100			
Tear Resistance, minimum, in lb_f/in (N/cm)	5		9		5		9		5		9		3		5		3		5	
Constant Deflection Compression Set, maximum, in %	30				35				35				30				30			
Compression Load Deflection at:																				
25% Deflection, minimum, in psi (kPa)	0.40		2.76		0.30		2.07		0.30		2.07		0.35		2.41		0.35		2.41	
65% Deflection, minimum, in psi (kPa)	0.60		4.14		0.50		3.45		0.50		3.45		0.60		4.14		0.60		4.14	
Fuel Displacement, maximum, Vol. %	3.0				2.5				2.5				2.5				2.5			
Fuel Retention, maximum, Vol. %	2.5				2.5				4.5				2.5				5			
Flammability, maximum, in in/min (cm/min)	10		25		15		38		15		38		15		38		15		38	
Extractable Materials, maximum, Wt. %	3.0				3.0				3.0				3.0				3.0			
Low Temperature Flexibility at -55 °F	/1/				/1/				/1/				/1/				/1/			
Entrained Solid Contamination, maximum, in mg/ft^3	11.0				11.0				11.0				11.0				11.0			
Steam Autoclave Exposure, maximum % tensile loss, in %																				
Type I, II, III for 5 hours @ 250 °F	40				40				40				--				--			
Type IV and V for 10 hours @ 250 °F	--				--				--				30				30			
Typical Electrical Resistivity in Ω-cm	1×10^{13}				8×10^{13}				8×10^{13}				1×10^{15}				1×10^{15}			
Projected Life Expectancy in Years /2/	2 to 10				2.5 to 10				2.5 to 10				10 to 50				10 to 50			
Recommended for New Aircraft Design Applications	No				No				No				No				No			

Notes:

/1/ No cracking or braking of strands.
/2/ For information only (Not for procurement certification).

Table 3 - Typical product specifications
Physical properties and characteristics of Grade IC and Grade IIC per MIL-PRF-87260B

Property	**Grade IC**								**Grade IIC**							
Specification Type	Class 1				Class 2				Class 1				Class 2			
Units	English		SI		English		SI		English		SI		English		SI	
Color	Black				Black				Grey				Grey			
Polyol Type	Polyether				Polyether				Polyether				Polyether			
Density Range, Min. and Max. in lb_m/ft^3 (kg/m^3)	1.20	1.55	19.22	24.83	1.20	1.55	19.22	24.83	1.20	1.55	19.22	24.83	1.20	1.55	19.22	24.83
Porosity, Min. and Max. pore size in pore/in (pore/cm) /3/	7.5	21.0	3.0	8.3	7.5	21.0	3.0	8.3	21.5	33.0	8.5	13.0	24	34	9	13
Air Pressure Drop, Min. and Max. in in of H_2O (cm of H_2O)	0.150	0.250	0.381	0.635	0.150	0.250	0.381	0.635	0.260	0.360	0.660	0.914	0.270	0.370	0.686	0.940
Tensile Strength, minimum, in psi (kPa)	10.0		68.9		10.0		68.9		15.0		103.4		15		103	
Ultimate Elongation, minimum in %	100.0				100.0				100.0				100			
Tear Resistance, minimum, in lb_f/in (N/cm)	3.0		5.3		3.0		5.3		3.0		5.3		3		5	
Constant Deflection Compression Set, maximum, in %	45				45				45				45			
Compression Load Deflection at:																
25% Deflection, minimum, in psi (kPa)	0.35		2.41		0.35		2.41		0.35		2.41		0.35		2.41	
65% Deflection, minimum, in psi (kPa)	0.60		4.14		0.60		4.14		0.60		4.14		0.60		4.14	
Fuel Displacement, maximum, Vol. %	2.5				2.5				2.5				2.5			
Fuel Retention, maximum, Vol. % /4/	2.5				2.5				5.0				5.0			
Flammability, maximum, in in/min (cm/min)	15		38		15		38		15		38		15		38	
Extractable Materials, maximum, Wt. %	3.0				3.0				3.0				3.0			
Volume Increase, Min. and Max. in Volume %																
in Type I Fluid	0		15.0		0		15.0		0		15.0		0		15.0	
in Type III Fluid	0		40.0		0		40.0		0		40.0		0		40.0	
in JP-4 Turbine Fuel	0		25.0		0		25.0		0		25.0		0		25.0	
Low Temperature Flexibility at -55 °F	/1/				/1/				/1/				/1/			
Entrained Solid Contamination, maximum, in mg/ft^3	11.0				11.0				11.0				11.0			
Steam Autoclave Exposure, maximum % tensile loss, in %	30				30				30				30			
Typical Electrical Resistivity in Ω-cm at 75 °F	1×10^7 to 5×10^{11}				1×10^7 to 5×10^{11}				1×10^7 to 5×10^{11}				1×10^7 to 5×10^{11}			
Resistivity Uniformity at 75 °F	/2/				/2/				/2/				/2/			
Projected Life Expectancy in Years /3/	10 to 50				10 to 50				10 to 50				10 to 50			
Temperature Range, Min. and Max. in °F (°C)	10	160	-12.2	71.1	-25	160	-31.7	71.1	10	160	-12.2	71.11	-25	160	-31.7	71.11
Recommended for New Aircraft Design Applications	Yes				Yes				Yes				Yes			

Notes:

/1/ No cracking or braking of strands.
/2/ Two orders of magnitude from top of foam bun to bottom of foam bun.
/3/ For information only (Not for procurement certification).
/4/ To be determined at the maximum air pressure drop limit.

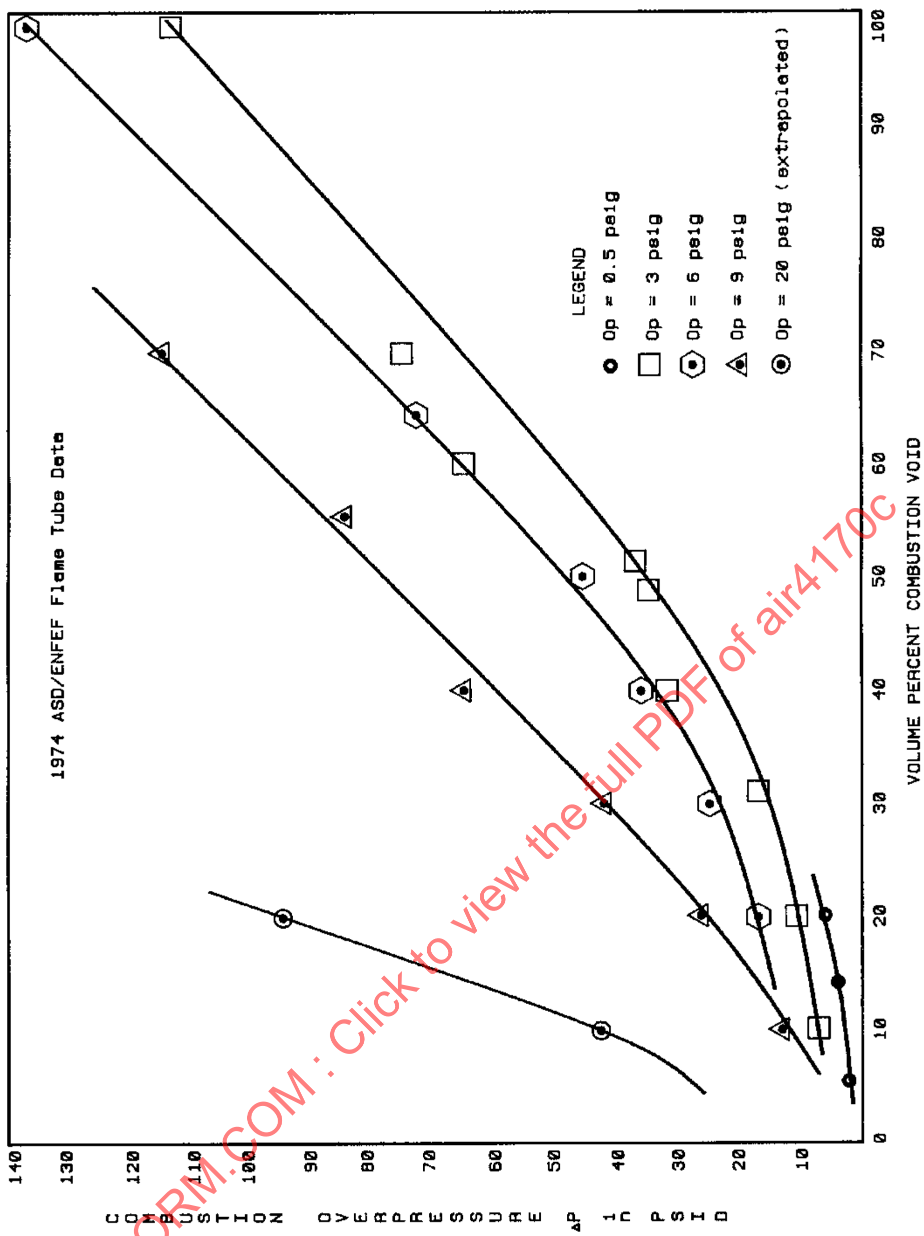


Figure 1 - Effect of operating pressure on combustion pressure blue polyether: coarse pore

3.6.2.1 Basic Layout

a. Determine tank access openings and sizes.

b. Foam component sizes must be consistent with the access opening. Foam has a memory and can be compressed if absolutely necessary. Not keeping this in mind may make installation and removal more difficult, thereby increasing maintenance cost.

c. Configure and arrange foam components to minimize installation time, maintainability, and accessibility to fuel tank components.

d. Minimize the number of foam components.

e. Standard bulk sizes for foam buns as supplied by the reticulated polyurethane foam manufacturers are as follows: 4 x 44 x 110 inches (10.2 x 111.8 x 279.4 cm), 8 x 44 x 110 inches (20.3 x 111.8 x 279.4 cm), and 12 x 44 x 110 inches (30.5 x 111.8 x 279.4 cm).

f. The minimum fabricated thickness for a foam component should be 2 inches (5.1 cm).

g. The maximum thickness for a fabricated foam component should be 12 inches (30.5 cm).

h. Minimum/maximum and configurations of foam components must be consistent with tank access openings to facilitate installation positioning within the tank.

i. Undersizing of foam components/system should not exceed 10% of the actual linear dimensions with consideration given to the type of fuel used, and its effect of swell on the foam, see Figure 2. At time of aircraft fuel system design, verification of foam component swell should be tested.

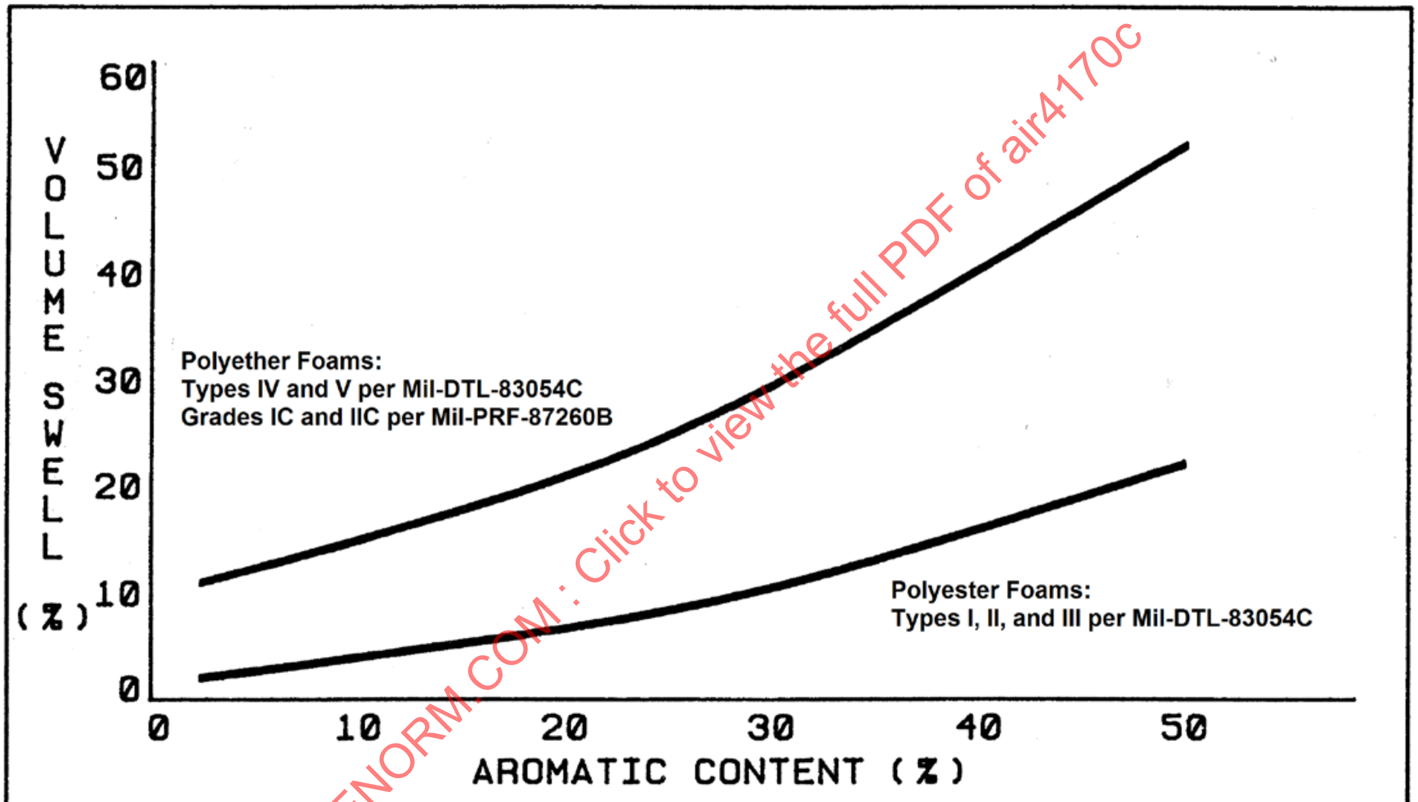


Figure 2 - Foam volume swell

3.6.2.2 Planned Noncomponent Voiding

a. Voids should not be connected, or provide a common flame propagation path from one tank bay to another.

b. Locate selected voids, where possible, to facilitate fuel flow to pumps, interconnects, and vent openings.

c. Calculate void percentage versus combustion overpressure.

1. Locate selected voids uniformly throughout the tank; avoid concentration of voids in the upper half of the tank.

2. Suggested maximum size of the void is a 4.5 inch (11.5 cm) diameter cylindrical cutout or a 4 x 4 inch (10.2 x 10.2 cm) square cutout. If possible, extend the cutout completely through the thickness of the foam, for ease of fabrication. No single void volume should exceed 10% of the fuel tank volume.

3. Minimum distance between voids should be 3 inches (7.6 cm) for zero '0' psig operating pressure, and 5 inches (12.7 cm) for 3 psig pressure.

d. Minimize the number and size of voids which are adjacent to the fuel tank boundaries. No void should be longer than 2.5 feet (76.2 cm).

e. Careful attention should be given to the critical components located around fuel inlet points to minimize direct fuel impingement.

f. Eliminate direct fuel stream impingement onto reticulated foam (non-conductive) components. Reduce direct fuel stream impingement onto conductive ESM (foam) components. This is to minimize both static charging of foam pieces and damage.

g. Consider the use of piccolo tubes (perforated tubes) for fuel inlet nozzles.

h. If it is a new aircraft design, consider fuel flow entry at the bottom of the fuel tank.

3.6.2.3 Fuel Tank Component Voiding

a. See Figure 3 for recommended voiding around fuel tank components.

b. Mechanically moving components, such as a surge box flapper valve, should have a screen or perforated plate across the opening to prevent any large piece of foam from entering the opening and interfering with the valve operation.

c. Slits connecting voids should be avoided if possible.

3.6.2.4 Fabrication/Installation Engineering Data

a. Foam component engineering drawings should provide adequate information for fabrication/production.

b. Foam component dimensioning and tolerances should be consistent with the standard fabrication practices of the industry.

c. Installation sequence for a foam kit must be provided for installers.

d. Provide simplistic, understandable individual foam component identification.

3.6.2.5 Fuel Quantity Gaging

a. Determine volume loss due fuel retention of the reticulated polyurethane foam kit based on foam type and foam air pressure drop, see Figure 4.

b. Determine the weight of the reticulated polyurethane foam kit for operating manual information.

c. Fuel Quantity Indicating Systems may be impacted by the installation of polyurethane foam into the aircraft fuel tanks. For further information on possible effects, please refer to AIR 5691

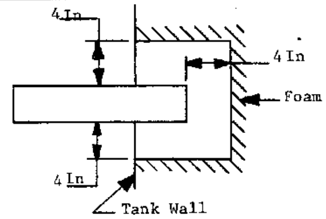
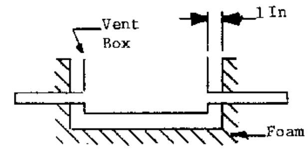
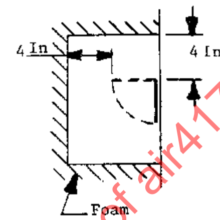
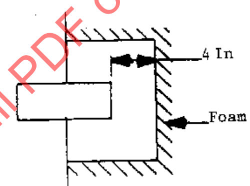
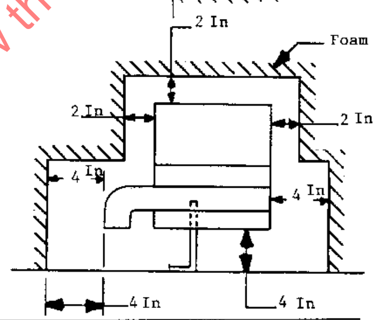
Component	Minimum Clearance	
Vent	4 in in all directions	
Vent Box	1 in around box	
Flapper Valve	4 in in all directions	
Interconnects	4 in in all directions	
Pump/Ejectors	2 in in all directions 4 in at inlet	

Figure 3 - Minimum clearance criteria (examples) - dry, installed condition

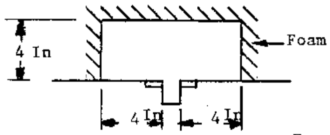
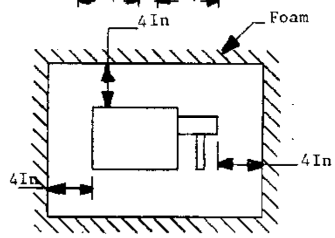
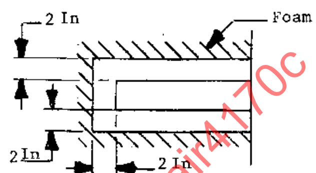
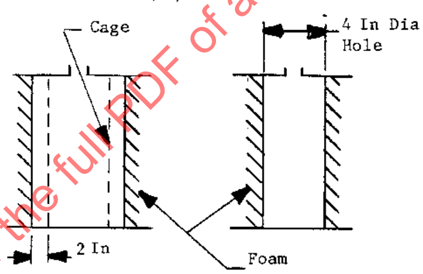
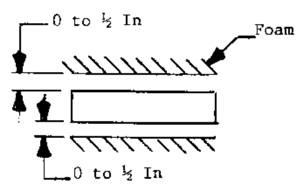
Component	Minimum Clearance	
Sump Drain	4 in in all directions	
Pilot Value	4 in in all directions	
Quantity Gage Probe	2 in greater than probe radius	
Filler Void At Gravity Filler Port	2 in greater than cage radius or 4 in diameter hole to bottom of tank	
Plumbing	Loose Fit: Maximum hole diameter outside diameter of tube plus 1/2 in	

Figure 3 - Minimum clearance criteria (examples) dry, installed condition (continued)

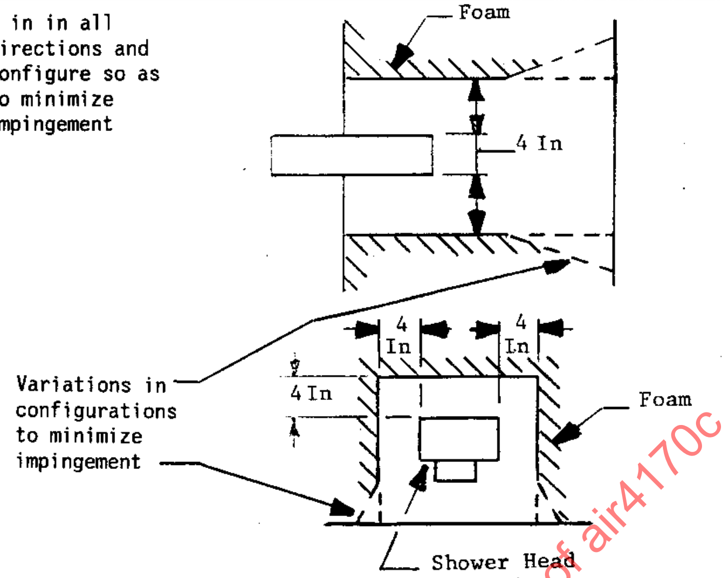
Component	Minimum Clearance	
Fuel Inlets	4 in in all directions and configure so as to minimize impingement	

Figure 3 - Minimum clearance criteria (examples) dry, installed condition (continued)

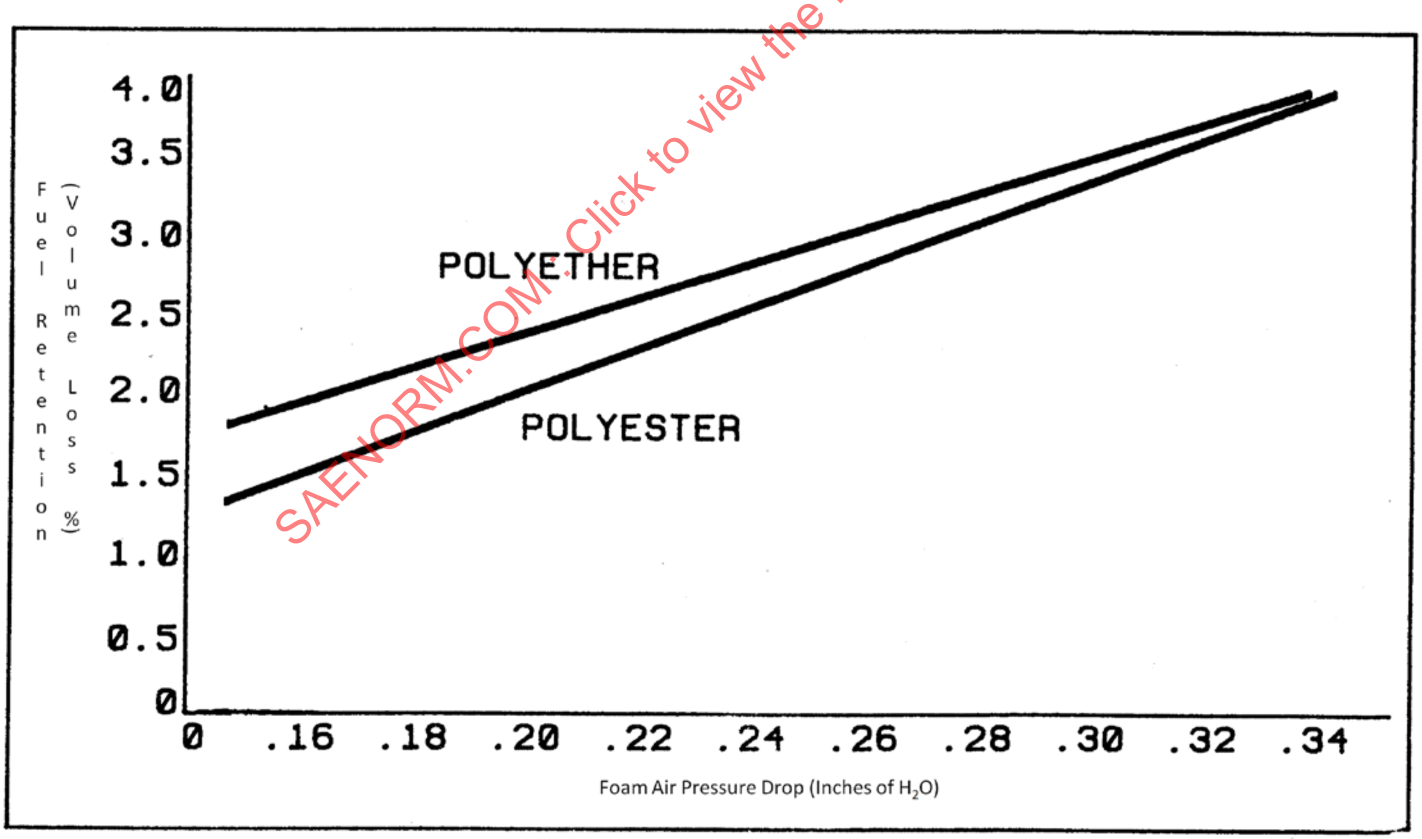


Figure 4 - Fuel retention of foam types

3.6.2.6 Trial Installation

a. A trial installation or prototyping of the reticulated polyurethane foam kit design should be conducted to verify the fit of the foam pieces. Determine if all component voids and installation procedures are adequate, and that the installation and removal times are reasonable.

3.6.2.7 Aircraft or Vehicle Technical Manual Data

The designer should provide as a minimum the following engineering technical information:

a. Fuel retention

b. Calculated usable fuel quantities

c. Installation/removal procedures for the reticulated polyurethane foam kit

d. Fuel Quantity Indicating Systems may be impacted by the installation of polyurethane foam into the aircraft fuel tanks. For further information on possible effects, please refer to AIR 5691

e. Inspection procedures for the reticulated polyurethane foam kit and maintenance procedures

3.6.3 Grossly Voided Design Concept

A grossly voided system is defined as one where the fuel tank contains strategically positioned reticulated polyurethane foam for explosion suppression. This system provides for minimal weight penalty and fuel retention, and is best suited for a fuel system that can withstand substantial overpressures. The flame tube data in Figure 5 shows the effect of operating pressure on combustion pressure for Type V. Blue polyether reticulated polyurethane foam data should be similar for all fine pore type products. The fine pore types of foams (Types III, V, and Class 1 and Class 2, Grade IIC) are intended for grossly voided applications. However, for all new applications, it is highly recommended that state-of-the-art conductive ESM (foam) products, either Class 1 or Class 2 be used to minimize static charge buildup. The choice between Class 1 or Class 2 will depend on low temperature range of the operating environment of the air/ground vehicles. The suggested design guidelines referenced in this section have been taken from the following:

a. ENFEF-TM-78-08

b. AFAPL-TR-75-93

c. AFWAL-TR-83-3114, Volume I and Volume II

The suggested guidelines listed below are intended to assist the designer in the development of a grossly voided system, and should not be limited to this list:

a. Determine tank access openings and sizes.

b. Determine fuel tank configuration(s) and ullage void space at various fuel levels.

c. Select a reticulated polyurethane foam gross voiding method in accordance with the previously referenced documents or other applicable sources of information.

d. Perform ignition analysis per paragraph 2.4.1.1.2 of AFAPL-TR-75-93 technical report at various fuel levels to determine percentage of gross voiding.

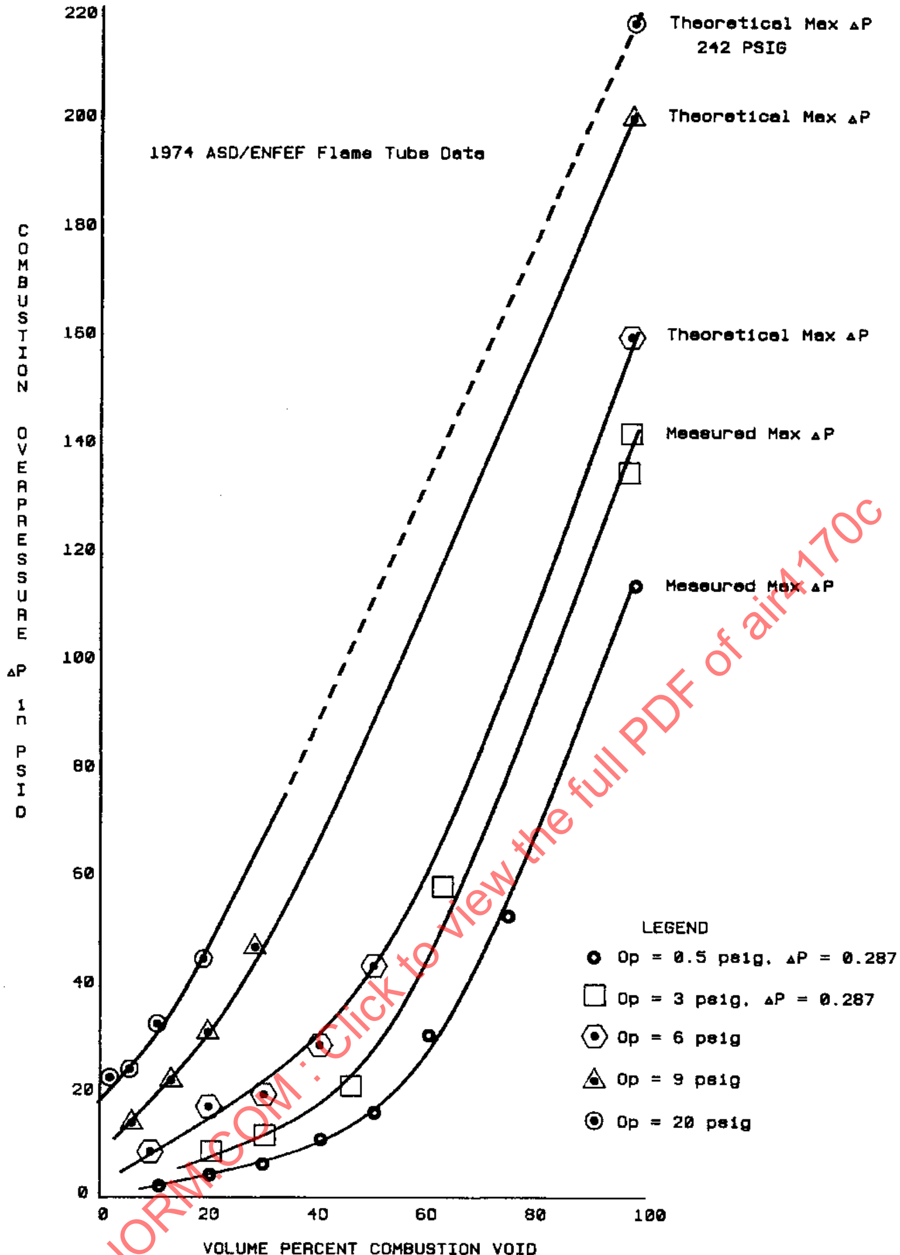


Figure 5 - Effect of operating pressure on combustion pressure blue polyether: fine pore

e. Select foam configuration, sizes, and determine strategic positioning.

f. Perform verification analysis of kit design to insure adequate explosion suppression protection.

g. Determine overpressures.

NOTE: If designing a foam inerting system in an existing fuel tank design, it is important to evaluate the expanding gas flow area ratio change caused by installation of foam inerting components being positioned at tank baffles between fuel tank compartments. The foam may change the gas flow rate sufficiently in one compartment to cause overpressure. These expanding gases would be the result of an ignition created in the fuel tank by a combat type projectile, or some other ignition source. It may be necessary to increase the size of the holes through the compartment baffles to maintain the proper gas flow area ratio. Refer to AFAPL-TR-73-124 pertaining to this issue.

h. If at all possible, scale model gunfire tests should be required for verification of the design concept.

i. Maintain proper clearances between fuel tank components and the foam components as shown in Figure 3.

j. Provide minimal or eliminate direct incoming fuel stream impingement onto foam.

k. Consider the use of piccolo tubes to eliminate direct incoming fuel impingement.

l. In the case of a new aircraft design, consideration of single point bottom fuel entry into a tank should be investigated.

m. Depending upon the positioning of the foam components, and the method selected for obtaining gross voiding, it may be necessary to select and use adhesive, sealant, or special compounds to secure these components in position (sloshing fuel during flight conditions must be considered). If an adhesive, sealant, or special compound is used, it must be proven to be compatible with the foam, fuels, and metal surfaces with which it comes in contact. It must also demonstrate a life expectancy that equals or exceeds the reticulated polyurethane foam. Compatible solvents for glue cleanup should be evaluated and specified by the aircraft manufacturer.

n. Foam component engineering drawings should provide adequate information for fabrication/production.

o. Foam component dimensioning and tolerances should be consistent with standard practices of the foam fabrication industry. Aircraft designers designing a foam kit should work with foam component fabricators to establish reasonable tolerances.

p. Installation sequence for the foam kit must be provided for installers.

q. Provide simplistic, understandable foam numerical identification system.

r. Recalibration or verification of the fuel quantity gauging system is required.

s. Determine fuel retention and volume loss due to reticulated polyurethane foam kit, see Figure 4.

t. Calculate the weight of the reticulated polyurethane foam kit.

u. A trial installation or prototyping of the foam kit design should be conducted to verify the fit of components. Check to determine that component voids and installation procedures are adequate, and that the installation time is reasonable. Check to determine that removal procedures are adequate, including removal of adhesives, sealants, or other special components used to secure the foam components.

v. The designer should provide the following minimum engineering technical data:

   1. Fuel retention

   2. Calculate useable fuel quantities

   3. Installation/removal procedures for the reticulated polyurethane foam kit

   4. Fuel quantity system calibration data for reticulated polyurethane foam use

   5. Inspection procedures for reticulated polyurethane foam kit and maintenance procedures

w. No voids should exceed a maximum length of 2.5 feet.

3.6.4 Foam/Fuel Compatibility

The issue of foam/fuel compatibility has been properly addressed in the military specifications MIL-DTL-83054C and MIL-PRF-87260B and other military procurement specifications for the qualification of reticulated polyurethane foam. However, in the event that a fuel or fuel additive is selected for use other than those specified in the military specifications referenced, adequate testing must be performed to insure compatibility.

A program undertaken by the U.S. Air Force to determine the compatibility of reticulated polyurethane foams in typical turbine fuels with currently approved additives was completed in September 1980. The results of this program may be found in reference document number AFWAL-TR-80-4135. In addition, JP-8+100 was investigated by the Air Force and found compatible with reticulated polyurethane foams. The results of this program may be found in referenced document number AFRL-PR-WP-TR-2000-2015.

Results of fuel compatibility tests with reticulated polyurethane foams may be found in the foam manufacturer's qualification reports.

3.6.5 Gunfire Testing and Electrostatic Compatibility

3.6.5.1 Gunfire Testing

The explosion suppression characteristics of all reticulated polyurethane foam systems should be demonstrated. This is especially important for the fine pore/grossly voided systems which have fuel tank operating pressures over 3 psig. A development test rig or replica fuel tank which simulates the actual tank design in size, shape, and internal configuration should be used to demonstrate the effectiveness of the reticulated polyurethane foam protection system. A minimum of four tests should be conducted to prove system effectiveness. The optimum flammable fuel/air mixture, verified by bomb sample or gas analyzer, should be used for these tests. At least one test should be done at the most critical fuel level (i.e., greatest amount of void volume in the vapor space). The maximum combustion pressure should not exceed 80% of the ultimate pressure capability of the tank.

A detailed test plan should be prepared by the testing organization and approved by the aircraft system program office. If gunfire is used for the ignition source, the test tank must be repaired prior to each test.

3.6.5.2 Electrostatic Compatibility

The reticulated polyurethane foam system design should also be evaluated for electrostatic compatibility, to determine if the kit design is conducive to the generation/accumulation of electrostatic charges to hazardous levels within the fuel tank during normal fuel system operations. Both single point pressure refueling and gravity refueling should be evaluated. Carefully review the entire fuel tank and vent system (fuel tanks, vent tanks and fuel vent lines) to insure that it does not provide severe fuel agitation (slosh/pressure impingement) or fuel system fuel/air impingement on the foam. Tank shape to be evaluated: such as long cylindrical external/conformal fuel tanks in which the fuel can accelerate rapidly through the non-conductive foam thereby building up static charge during abrupt air vehicle in flight/assault landings/takeoffs/maneuvers. Fuel system vent tanks containing foam to be evaluated for rapid fuel discharge through the vent tank foam due to vent line designs which may contain fuel resulting from design, single failures, fuel leakage, level control valve failures, etc.

The electrostatic test procedures should be prepared by the test organization and approved by the aircraft system program office. The test procedures should indicate the required foam/fuel system conductivity, instrumentation, and success criteria for the test.

3.7 Foam Component/Kit Fabrication Methods

This section is intended to provide a foam fabricator with basic guidelines for the fabrication, quality control, cleaning, identification, and packaging of components/kits for use in fuel systems. Due to the critical applications these components/kits are used in, particular attention must be given to the following list, but not limited to (see ENFEF-TM-78-08, guidelines for use in design, fabrication, installation, and testing of reticulated polyurethane foam kits):

a. Select proper storage facilities for reticulated polyurethane foam as received from the manufacturer

b. Establish a manufacturing plan

c. Establish a quality control plan

d. Establish contamination control

e. Maximize fabrication yields

f. Review proper handling methods

g. Construct manufacturing layout templets

h. Review methods of fabrication

i. Establish component identification

j. Provide final component cleaning procedures and equipment

k. Establish a check system for packing/packaging of components/kits

l. Provide clean proper storage areas for fabricated components/kits

3.7.1 Packaging and Storage of Bulk Material as Received from the Manufacturer

Packing/packaging of received reticulated polyurethane foam may vary slightly from one contract to another depending upon the specified level of protection. However, as a minimal requirement, bulk foam (all types) should be packaged as follows:

a. Bulk material should be received in a multipacked configuration with an approximate overall package size of 44 inches (111.8 cm) wide x 110 inches (279.4 cm) long x 24 inches (61.0 cm) high, with a gross weight of 100 pounds (45.4 kg) and an estimated volume of 68 cubic feet (2.0 m^3).

b. Each multipack will contain either two buns of 12 x 44 x 110 inches (30.5 x 111.8 x 279.4 cm), or three buns of 8 x 44 x 110 inches (20.3 x 111.8 x 279.4 cm) (these are standard size buns). Each bun shall be individually packaged.

c. The exterior package shall be an 8-mil, black, polyethylene bag per A-A-3174, Type I, Class 1, Grade B. This polyethylene bag shall be taped closed. The exterior shall be marked in accordance with MIL-STD-129.

d. The individual packaged sheets shall be in a sealed 4-mil, black, polyethylene bag per A-A-3174, Type I, Class 1, Grade B. The exterior shall be marked in accordance with MIL-STD-129.

e. Each sheet shall contain a product ticket indicating run number, dimension, type, and date of manufacture. The ticket should be retained by quality assurance as the material is used.

Upon receipt of the bulk reticulated polyurethane foam, it is suggested that the packages be inspected for shipping damage, such as:

a. Torn or punctured polyethylene bags

b. Foam that has been punctured by forklift truck handling

c. Exposed, dirty, or wet foam from torn packaging

It is suggested that after inspecting torn packaging, if the foam is undamaged the torn areas should be taped closed, or covered with black or opaque polyethylene sheeting taped over the torn area. This will prevent additional contamination, possible exposure to ultraviolet light deterioration, and discoloration of the foam.

WARNING: POLYURETHANE FOAM IS NOT ULTRAVIOLET LIGHT STABLE. Bulk foam and foam components should be ultraviolet light protected per the packaging requirements in accordance with this document.

The bulk reticulated polyurethane foam, as received, must be stored in a storage area that will protect it from the outdoor weather environment.

3.7.2 Product Data Sheets and MSD Sheets

It is recommended that the fabricator obtain current product data and MSD sheets for this material from the specific manufacturer/supplier.

3.7.2.1 Flammability of Cellular Plastics

WARNING: RETICULATED POLYURETHANE FOAM IS A FLAMMABLE ORGANIC URETHANE FOAM. Once burning, it can give off the same smoke and toxic gas as any petrochemical product.

Store flexible reticulated polyurethane foam indoors, protected by an approved fire protection system and away from all heat sparks or ignition sources, such as welding, naked lights, smoking materials, space heaters, open flames, or exposed heating elements. Make certain there are adequate aisle ways to permit quick access from all storage areas. All storage areas should be kept clean and promptly dispose of scraps, cuttings, or waste foam. Allow a minimum of 10 feet clearance between tops of foam stacks and sprinkler heads. Make certain approved fire extinguishers and a substantial source of water are available for use in the event of fire.

3.7.3 Fabrication

The fabricator's manufacturing area should meet required cleanliness to control contaminants that would adversely affect the material or its functionality. It is extremely important to control such contaminants as foreign particles, metal particles, dust, sunlight, water, water vapor steam, harmful liquids, and harmful gases. Manufacturing management should address the following aspects of fabrication:

a. Storage areas

b. Templet storage

c. Proper handling equipment

d. Layout tables

e. Good housekeeping practices

f. Fabricating equipment

g. Personnel clothing

h. Disposal of scrap material or rejected parts (see Section 5 of this document)

Layout marking of reticulated polyurethane foam may be accomplished with use of Blaisdell 1173F, Berol Liquid Tip 600 black marker, or refillable ink pens containing ink per Federal Specification A-A-208. Ink color should provide maximum contrast for easy visibility.

Cutting and shaping of individual foam components can be accomplished by the following methods:

a. Hot wire cutting

b. Mechanical blade type cutting (band saw, electric knife)

c. Specially designed/manufactured smooth blade type cutting tools

3.7.3.1 Hot Wire Cutting

Extreme caution must be taken when hot wire cutting of reticulated polyurethane foams. Adequate ventilation must be provided as the vapors generated by the melting foam may be carcinogenic, extremely toxic, and irritating to the eyes and lungs. The proper ventilated facility must be provided when hot wire cutting is performed on a large scale.

The hot wire cutting method permits the fabrication of intricate irregularly shaped components that are difficult or impossible to achieve with mechanical cutting. This method also reduces the amount of loose foam debris generated during fabrication. Hot wire cutting may cause yellowing of the foam surface. This discoloration does not affect the quality of the foam and is acceptable for use in fuel tanks. However, a charred surface is not acceptable.

3.7.3.2 Mechanical Blade Type Cutting

The most common and preferred method for cutting and shaping of reticulated polyurethane foam is with band saws, electric knives, hand held knives, and special designed/manufactured mechanical blade cutting and boring tools. The types of blades used most successfully are as follows:

a. Smooth blade (no teeth)

b. Serrated or scalloped type blade

c. Extremely fine-toothed band saw-type blade

Cutting blades should be kept clean at all times. Blades may be cleaned with a suitable liquid cleaner that does not leave a residue or oily film. Cutting edges on these blades must be kept sharp. Dull blades can cause a tearing action rather than a clean-cut surface. Lubrication should not normally be required, however, if used, minimal application of a silicon mold release agent spray is acceptable.

3.7.3.3 Handling

Handling of reticulated polyurethane foam should not result in the transfer of foreign materials onto, or into the foam structure. Abusive handling and stressing of the foam buns or components may result in tearing or distortion and should be avoided. The clothing worn by personnel fabricating the components/kits should not be a source of contamination to the fuel cell baffle material.

3.7.4 Cleaning of Fabricated Components

Upon completion of fabrication and before final inspection, components will require a final cleaning to remove any foam debris or contaminants left from the fabricating process. All components must be bounced and thoroughly scrubbed on a screen or hardware cloth to remove loose particles of foam and/or beads of melted foam as a result of fabrication. Consideration may also be given to the use of an industrial type vacuum cleaner for cleaning loose debris as a result of fabrication.

3.7.5 Identification of Components

Component identification numbers/letters must be applied to each component after fabrication. Identification numbers must be in accordance with the instructions on the engineering drawings. Location and position should be specified on the engineering drawings. Identification markings must be in black on all components, except when installing grey or black type foam. Use a Blaisdell, 1175F, Blaisdell Co., Bethayres, PA or Berol Liquid Tip 600, black markers, Berol Corp., Danbury, CT, or refillable ink pens containing ink per Federal Specification A-A-208. Ink colors for the grey and black type materials shall be of a contrasting color for maximum visibility. If other markers or inks are used, they must first be qualified as to their permanency when subjected to fuel immersion.

3.7.6 Component Packaging Storage Recommendations

Immediately upon completing the cleaning and identification marking of a component it shall be packaged to prevent possible contamination. Component/kit packaging should be specified to a fabricator in the contract or purchase order for this product. However, in the event it is not specified, the following minimum level of protection shall be taken:

a. Each individual component shall be wrapped in a 4-mil, black polyethylene film, taped or sealed closed, and properly identified

b. Individually wrapped components shall then be multipacked into commercial grade corrugated cartons, and sealed closed with tape. Markings on the exterior carton shall identify the contents.

The packaged components/kits shall be stored in an area to protect them from the outdoor environment.

3.8 Installation/Removal and Initial Fueling Recommendations

The information provided in this section is intended to assist design engineers, airframe, and/or vehicle manufacturers and maintenance installers/mechanics. There are three categories of installations addressed in this section:

a. Prototype Reticulated Polyurethane Foam Kit Design Verification Installations (both fully packed and grossly voided systems)

b. Manufacturing/Maintenance Fully Packed Production Type Installations

c. Manufacturing/Maintenance Grossly Voided Production Type Installations

The data in this section pertaining to installation, removal, aircraft, and/or vehicle purging, fueling, and specific operational checks are guidelines based on experience gained from previous installations and "lessons learned". See technical memorandum ENFEF-TM-78-08 for additional data. Specific detailed instructions pertaining to a particular design must be developed and maintained by the design engineering activity.

NOTE: For purpose of this document only, all discussions assume that the fuel tank(s) and fuel system have been properly prepared for foam kit installation. It is also assumed that all required tools, lighting, special equipment, and special personnel clothing are available and at the installation site. It is also understood that all safety equipment and procedures are approved and have been provided.

Tank Preparation Considerations:

a. Complete drainage

b. Access hatches opened or wing skin removed where necessary

c. Tanks air purged for safe entry

d. Aircraft structure and/or components removed where applicable