

AN26



Large Scale PET Mock up Test

A presentation by a member of the International Aircraft Materials Fire Test Working Group at a meeting of that group brought into question the fire safety properties of an insulation material presently installed in many transport aircraft. The insulation film in question (AN26) is a non-metalized polyethylene terephthalate (PET or trade name, Mylar). The Fire Safety Branch obtained numerous samples of the materials from airlines and evaluated the materials flammability properties using a number of small scale test

methods. All of the samples tested performed very poorly in those tests. It was demonstrated that a small ignition source, such as an electrical arc, could easily ignite this material and the fire would propagate on the material until the material was consumed.

Because AN26 is no longer produced and no new AN26 material could be located, only material that had been installed in aircraft for 15 or more years was tested. This brought about the question as to the role of aging and contamination in the flammability of insulation film. The Fire Safety Branch obtained 10 different insulation films from out-of-service aircraft and conducted the same series of tests as previously used to evaluate AN26. All of these materials performed acceptably. Although there does not seem to be a major problem from film aging, contamination has played a role in some incidents of aircraft fires on insulation blankets. For that reason, a task group to help mitigate the problem was formed under the International Aircraft Materials Fire Test Working Group.

Additional testing of AN26 was requested by the Seattle Aircraft Certification Office in order to evaluate its potential fire safety risk. A large-scale mock up test was conducted and it was demonstrated that an arc from a typical aircraft electrical wire could easily ignite the AN26 and that the fire could propagate on the AN26. The flames from the AN26 were capable of igniting other aircraft materials and in a cascading fashion cause a catastrophic fire. As a result of this effort, in early 2005, the Seattle Aircraft Certification Office (SACO) issued a proposed airworthiness directive (AD) for the removal and replacement of all AN26 insulation film (Federal Register, April 4, 2005, pages 16986-16990).



Electrical Arc Ignition



Typical PET Insulation Burn

As a follow on, additional work has been conducted to evaluate alternate means of compliance (AMOC). Because of the large cost of removing AN26 (estimated to be 400 million dollars for the US fleet) alternate means of compliance with the intent of the proposed AD have been and are being developed.

They include a fire blocking cover and a spray on fire retardant. The Fire Safety Branch has conducted and will continue to conduct test in conjunction with SACO in order to insure that any approved AMOC does indeed meet the intent of the proposed AD.

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An Evaluation of the Flammability of Aircraft Electrical Wiring and the Adequacy of Current FAA Flammability Requirements

Life threatening in-flight fires usually originates in hidden areas of the airplane, such as the attic above the cabin ceiling, beneath the floor, in or around the lavatories, or at similar locations that are difficult to access. Because of the incidence of in-flight fires in recent years, the FAA is examining the adequacy of its flammability test requirements for all hidden materials. The focus will primarily be on thermal acoustic insulation, electrical wiring, and heating, ventilation, and air conditioning (HVAC) ducting.

The genesis for the current FAA flammability test requirement for electrical wiring was Amendment 25-32, effective May 1, 1972, which added a new section 25.1359(d), which applied the flammability requirements of Appendix F of Part 25 to wire insulation used in aircraft. Section 25.1359(d) is now Section 25.869 in 14 CFR Part 25. The mandated test specifies that insulation on electrical wire or cable installed in any area of the fuselage must be self-extinguishing when subjected to the 60° test specified in Part I of Appendix F. The requirements state that the average burn length may not exceed 3 inches and the average flame time after removal of the 3-inch Bunsen burner flame source may not exceed 30 seconds. Drippings from the test specimen may not continue to flame for more than an average of 3 seconds after falling. This is the only test the FAA mandates for aircraft wire flammability.

TEST PROGRAM

60° Flammability Testing

The results of the 60° flammability tests performed in this program are shown in table 1.

TABLE 1. 60° FLAMMABILITY TEST RESULTS
(Average of 3 tests)

Wire/Cable	Burn Length (inches)	After Flame (seconds)	Drippings
Polyimide	1.5	0	0
PVC/nylon	14.8	121	0
Tefzel™	2	0	0
X-linked Tefzel™	1.8	0	0

PTFE/polyimide/PTFE	1.2	0	0
Spec 2112	2.1	1.7	0
Plenum cable (A)	2.5	0	0
Riser cable (A)	2.5	0	0
Telecommunication cable zero halogen	3.1	60.3	0
Limited combustible, CMP CAT 6	2	0	0
Riser cable, CMR CAT 5E	2.5	0	0
Plenum cable, CAT 5-E	1.8	0	0

The data in table 1 shows that all wires and cables passed this test except PVC/nylon wire, which exhibited the longest burn length and after flame time and the zero halogen cable. Note that the zero halogen cable had an average after flame of 60.3 seconds and an average burn length of 3.1 inches, which barely exceeded the 3-inch requirement. These samples did not propagate the flame but continuously burned in place (evolving gases) with no drippings. The 60° test does not discriminate very well between the performance of different materials. For those materials that were compliant with the 60° test requirement, the difference in burn length for the best material (PTFE/polyimide/PTFE) and the worst materials (plenum cable A, riser cable A, and riser cable, CMR CAT 5E) was only 1.3 inches. Only one material exhibited after flame (Spec 2112) and the value was very small (1.7 inches) with no drippings.

Intermediate- Scale Testing

In this phase of testing, 5 of the original 12 types of wire and cable were evaluated. They included PTFE/polyimide/PTFE, Tefzel™, Spec 2112, riser cable (A), and PVC/nylon. These constructions were selected based on the data from the 60° flammability tests and widespread use in commercial and general aviation aircraft. The PTFE/polyimide/PTFE construction was the overall best performer. The Tefzel™ and Spec 2112 constructions were selected because they are widely used. The PVC/nylon construction was included as a worst-case scenario and the riser cable (A) as the only non-aviation grade wire.

Intermediate Scale Testing (Second Configuration)

In order to verify the findings from the first intermediate test, two further tests were run. The PTFE/polyimide /PTFE and the riser (A) cable were chosen because the data showed them as being the best and the worst (disregarding PVC/nylon) in terms of wiring compliance with the 60° test. Also, spacing of the bundles appeared to have a bearing on the degree of flame propagation. In this series of testing, the wire bundle configuration was changed. Instead of intersecting the bundles, they were placed in the lengthwise direction only. Also, the test area was halved. Figure 1 shows stages of the riser (A) cable burn.



Figure: 1 Riser cable (A) Test Progression

Based on the test data, the 60° flammability test may not disqualify wiring that propagates a fire when subjected to a severe ignition source used by the FAA to upgrade the fire test criteria of hidden fires. The test results are documented in Technical Note, DOT/FAA/AR-TN04/32, “An Evaluation of the Flammability of Aircraft Wiring”.

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Development of Advisory Circulars for Thermal Acoustic Insulation Flammability

On September 1, 2003, a new FAA Rule was passed pertaining to the flammability of thermal acoustic insulation used in transport category aircraft. The new Rule established two new tests, the first aimed at measuring the material’s capability of resisting flame spread from a small ignition source, and the second used to determine the ability of the material at resisting penetration, or “burnthrough” from an external fuel fire. A radiant panel is used to conduct the flame spread test, while an oil-fired burner is used to simulate the external fire in the burnthrough test. Both of these tests are significantly more severe than the previous test method used to qualify insulation materials, the vertical Bunsen burner.

Although the new tests have been further developed and refined over the past 2 years, many details still exist with regard to the conduct of these tests and the installation of insulation blankets in an aircraft. In terms of flame propagation, for example, many components of the blanket system such as tape and “hook and loop” fasteners must also be tested, since they are considered part of the blanket system and have been shown to have an influence on whether the material will propagate a fire. In the case of measuring the burnthrough resistance of insulation, although the test is now well established, it is important that a blanket meeting the requirement be properly installed and attached to the aircraft structure in order to recognize the full benefit of its fire resistance. A highly burnthrough resistant blanket will be of no value in a crash accident if it is easily displaced during the fire due to insufficient attachment hardware.

In order to ensure that all of these additional details are properly addressed, Advisory Circulars (ACs) have been developed for both new test methods. The radiant panel AC, 25.856-1 describes the test methodology and pass/fail criteria for evaluating the flammability of insulation blankets containing sub-components, not just the basic elements such as the thin moisture barrier and encapsulated batting material. The most common sub-components or detail materials include thread, tape, and hook and loop. In

addition, damping material that is not part of the traditional insulation blanket assembly must also be tested. Although there is practically an infinite number of possibilities in terms of blanket arrangement, the AC describes a simple plan for reducing the number of tests, while not compromising safety. Tapes, for example, are used during initial production and also in the process of making repairs to aircraft in service. Since it is not practical to test each possible configuration of tape and film/batting material, a simplified process using strips of tape has been developed. As shown in figure 1, four 2-inch strips of tape are installed on the test blanket from right to left, with a one-half inch overlap for successive strips.

In addition to the detail materials integrated into the typical blanket, there are also structural damping materials, which may be considered thermal/acoustic insulation, depending on their specific configuration and use. Although small aluminum sheets bonded directly to the airplane skin would not be considered insulation, materials that include a layer of foam or other material sandwiched between the skin and thin aluminum sheets should be tested. The most important aspect of testing this type of design is to ensure that the interface between the insulating material and the substrate is exposed to the tip of the burner flame.

The burnthrough AC, 25.856-2 describes the appropriate methods of installing the insulation in an aircraft, which is important in fully realizing the benefits of improved materials. To date, numerous thermal/acoustic insulation materials have been successfully tested, and these materials can be classified into three basic categories: batting systems, barrier systems, and encapsulating systems. The AC describes each of the system types, and an appendix lists schematic examples of each.

In addition to these examples, the AC focuses on specific installation aspects, highlighting key areas that include blanket overlap at frame members, horizontal blanket overlap, penetrations, and types of installation hardware. Previous testing has shown that a certain level of blanket overlap at the frame member is essential in maintaining a continuous burnthrough barrier, as shown in figure 2. A detailed test methodology for evaluating the burnthrough resistance of two horizontally overlapped blankets is also included in the AC.

Although schematic descriptions of acceptable installation techniques are included, the AC also describes the appropriate test methodology for evaluating system performance in the event that an alternative approach is desired. This methodology includes a description of the test apparatus modifications necessary to fully evaluate any unconventional approach.

In the case of both AC's, this guidance material is primarily aimed at airframe manufacturers, modifiers, foreign regulatory authorities, and FAA type certification engineers and their designees. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations.

An electronic version of the radiant panel AC can be found at <http://www.airweb.faa.gov/rgl> Although an electronic version of the burnthrough AC is not yet available, it will also be posted on this site in the near future.

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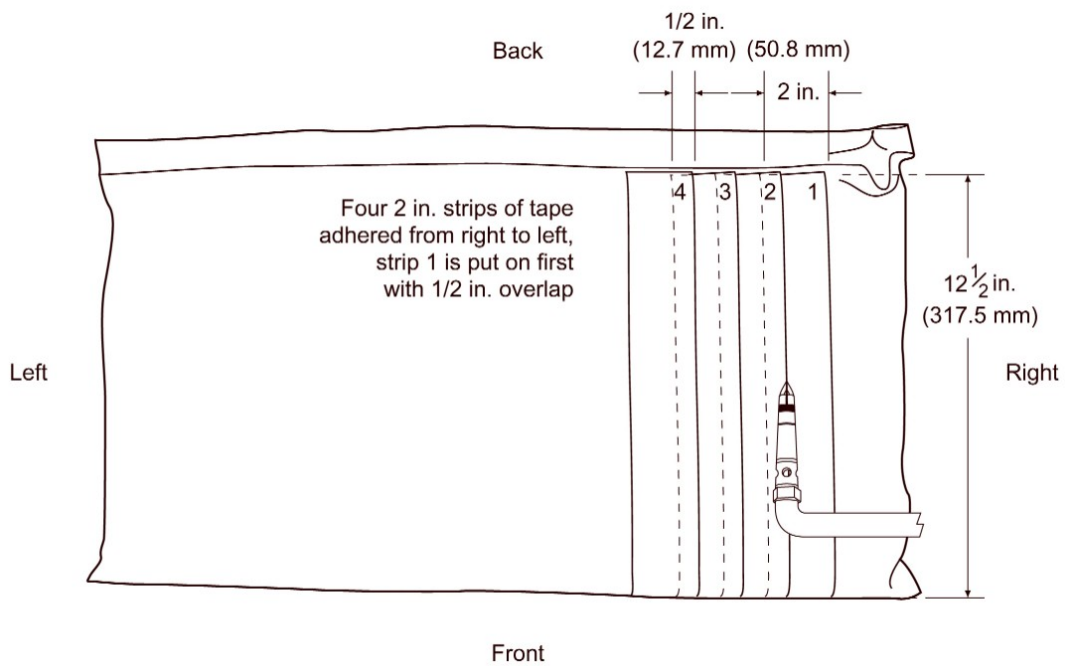


Figure 1. Method of Testing Tapes in Radiant Panel Test Apparatus

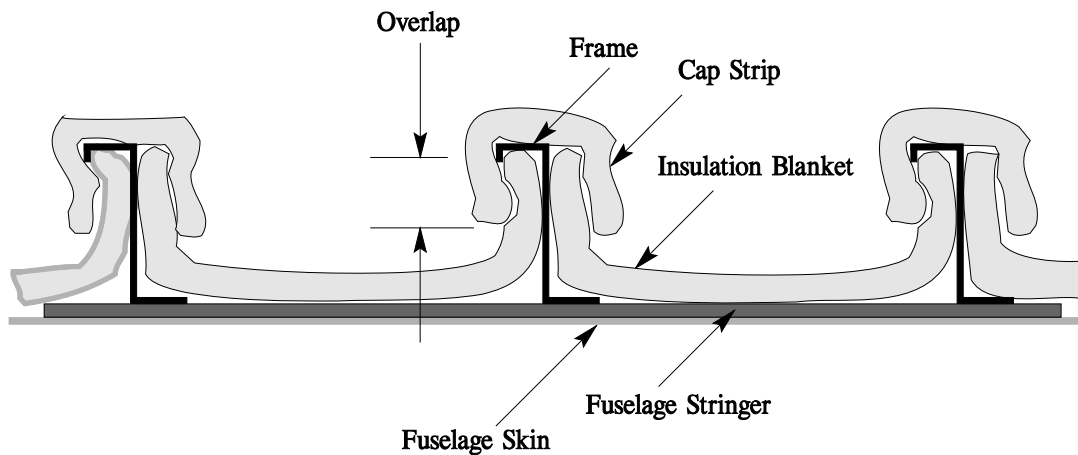


Figure 2. Description of Blanket Overlap to Ensure Continuous Burnthrough Barrier

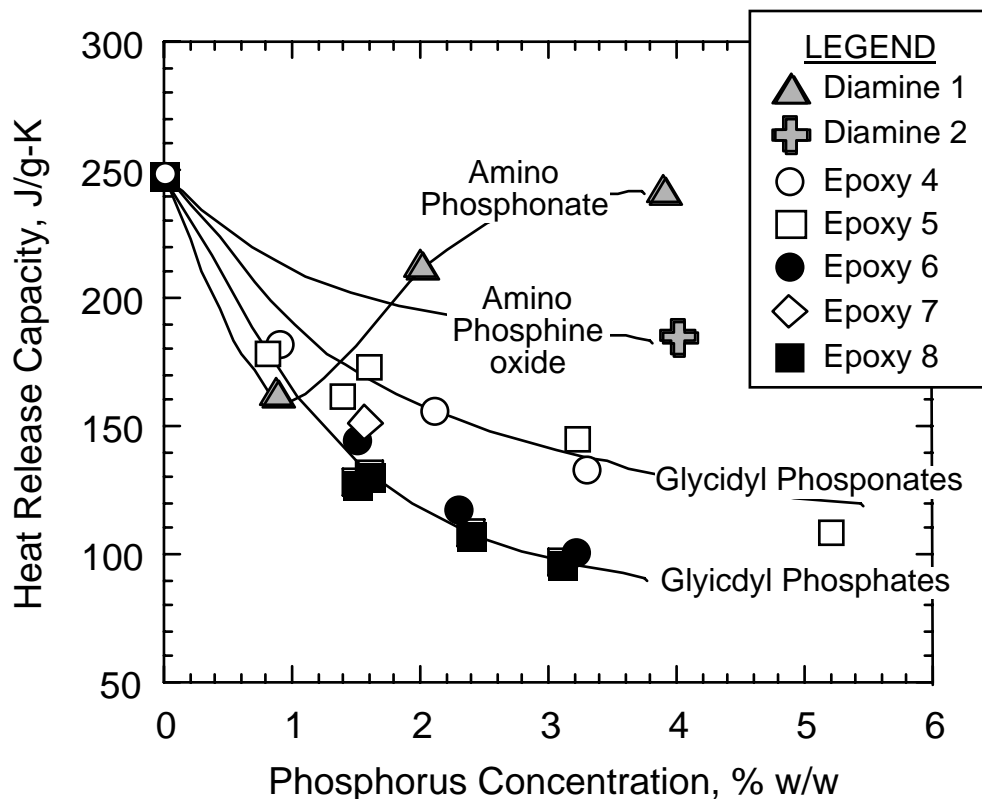
FLAME RETARDANT EPOXY RESINS CONTAINING PHOSPHORUS FOR AIRCRAFT STRUCTURAL APPLICATIONS

The use of composite structures in both commercial and general aviation aircraft has been increasing primarily because of the advantages composites offer over metal (e.g. lower weight, better fatigue performance, no corrosion, better design flexibility, etc.). The new Airbus A380 is expected to have about 22% of the structural weight in composites and about 50% of the structural weight of the new Boeing 787 is proposed to be composites-including for the first time a composite fuselage and wings in a large commercial airliner. Currently no fire resistance requirements exist for exterior polymer composite structures on airplanes. However, the aircraft manufacturer will be required to demonstrate that polymer structural composites provide equivalent safety to the current material system (aluminum alloy). The primary hazards during aircraft fires are heat, smoke, and toxic gas. In a severe aircraft fire, life-threatening levels of these hazards are produced by cabin flashover- the time to which is largely governed by the rate of heat release of the materials in the fire.

Phosphorus is a flame retardant for epoxy resins that is known to impart fire retardation by condensed phase and gas phase mechanisms. In the condensed phase phosphorus catalyzes formation of a carbonaceous char that protects the underlying material from heat and acts a barrier to the release of fuel gases from the surface. When acting in the condensed phase as a char catalyst, phosphorus retards the spread of fire with minimal release of toxic gases. In the gas phase phosphorus acts as a flame poison with PO

species participating in a kinetic mechanism that is analogous to that of halogens in flames. Gas phase activity is indicated by one or more of the following as a consequence of incomplete combustion: low heats of flaming combustion, high levels of visible smoke, and high yields of carbon monoxide. Phosphorus has been incorporated into polymeric materials as an additive and as part of the polymeric chain. Additives are normally more economical to use but tend to leach out and have a negative impact on processing characteristics and mechanical properties. Epoxy resins and curing agents that contain phosphorus as part of the chemical structure are more expensive but the phosphorus is permanently incorporated into the polymer and the effect on physical and mechanical properties is minimal. The intent of this work was to identify an epoxy resin and/or curing agent containing phosphorus that could be incorporated into existing aerospace epoxy formulations at low levels to provide fire resistant structural composites with little or no compromise in processing, handling, and mechanical properties.

Epoxy resins and their curing agents (aromatic diamines) containing phosphorus were synthesized by the National Aeronautics and Space Administration (NASA) Langley Research Center, Hampton, VA. The phosphorus-containing epoxy formulations (resin + curing agent) were characterized by thermogravimetric analysis, propane torch test, elemental analysis, microscale combustion calorimetry, and fire calorimetry. The figure shows results for flammability (heat release capacity) of epoxy formulations versus the weight percent phosphorus incorporated into the polymer as either a phosphorus-containing curing agent (diamine) or epoxy resin. A three-fold reduction in flammability is observed for the phosphate epoxies (Epoxy 6 and 8).



Flaming combustion efficiency was used as a global measure of gas phase activity but did not indicate that phosphorus had any significant effect on flame chemistry for the compounds studied. Instead, flammability reduction was attributed to the promotion of charring by phosphorus. Phosphorus appears to act in the condensed phase as a catalyst for char formation, i.e., phosphorus promotes char but is not consumed in the chemical reactions that form char. Catalytic activity is indicated by- 1) the several-fold increase in char mass per unit mass of incorporated phosphorus; 2) lowering of the temperature and activation energy for thermal decomposition; 3) saturation of charring at higher P loadings, typically > 3%. The activity of phosphorus as a char catalyst is in the same order as the oxidation state of phosphorus in the diamine or epoxide, i.e., organophosphate (PO_4) > organophosphite ($:\text{PO}_3$) \approx organophosphonate (RPO_3) > organophosphine oxide (R_3PO). This hierarchy of activity could indicate that the catalyst for char formation is a phosphorus oxide or phosphorus acid. The fracture toughness and compressive strength of several cured formulations showed no detrimental effect due to phosphorus content. The chemistry and properties of these new epoxy formulations are discussed.

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FAA LICENSES MICROSCALE COMBUSTION CALORIMETER

In a fire, the temperature at which a combustible material ignites (the ignition temperature), the rate of mass loss as the material subsequently burns (the burning rate), the rate at which the material releases heat in flaming combustion (heat release rate), and the maximum amount of heat that can be released by burning (heat of combustion) are the primary indicators of the material's hazard to life and property. The time available for passengers to escape from a fire in an enclosure such as an airplane cabin or a room is determined by the growth rate of the fire. The fire growth rate increases with the ignitability and the heat release rate HRR of the materials in the enclosure. Resistance to ignition can be defined as the minimum (critical) heat flux/fire size below which the material will not burn. The critical heat flux CHF is related to the ignition temperature of the material (T_{ign})

$$\text{CHF} = \sigma T_{\text{ign}}^4$$

where, $\sigma = 5.7 \text{ W/m}^2\text{-K}^4$ is the Boltzmann constant. The heat release rate (HRR) is the product of the mass loss rate (MLR) or burning rate and the heat of combustion of the material (HOC):

$$\text{HRR} = \text{MLR} \times \text{HOC}$$

In practice (i.e., in fire calorimeters) mass loss rate and heat release rate are measured continuously during the test by weighing the sample and measuring the amount of oxygen consumed by combustion, respectively. At the present time these fire hazard indicators: ignition temperature, heat release rate, and heat of combustion are measured using procedures published by the American Society for Testing and Materials (ASTM) in at least three separate devices requiring at least 1 kilogram of material to complete all of the tests. Consequently, an instrument and method that measures ignition temperature, burning rate, heat release rate, and heat of combustion in a single, rapid, and quantitative test under fire-like conditions using a small amount (milligrams) of substance is of theoretical and practical importance to fire protection engineers and materials scientists.

The Federal Aviation Administration filed an application for a new patent with the Patent and Trademark Office (PTO) in December, 2005, for a Flammability Tester. The Flammability Tester combines methods of thermal analysis and fire calorimetry in a single device that simultaneously measures multiple flammability parameters: HRR, HOC, and T_{ign} of combustible materials using small samples. The method and apparatus is useful for quickly and accurately testing milligram and larger samples of combustible materials. Figure 1 is data from the Flammability Tester for a 5 milligram sample of acrylic (Plexiglass) illustrating how the burning/heat release rate (500 J/g-°C), ignition temperature (400 °C), and heat of combustion (25 kJ/g) are all determined from a single, 15-minute test.

On January 18, 2005, the Federal Aviation Administration licensed The Govmark Organization, Inc., 96D Allen Blvd., Farmingdale, NY 11735-5626 USA to manufacture and sell the Flammability Tester. On March 11, 2005, the FAA also licensed Fire Testing Technology, Ltd., Charlwoods Road, East Grinstead, West Sussex, RH19 2HL, UK to manufacture and sell the Flammability Tester.

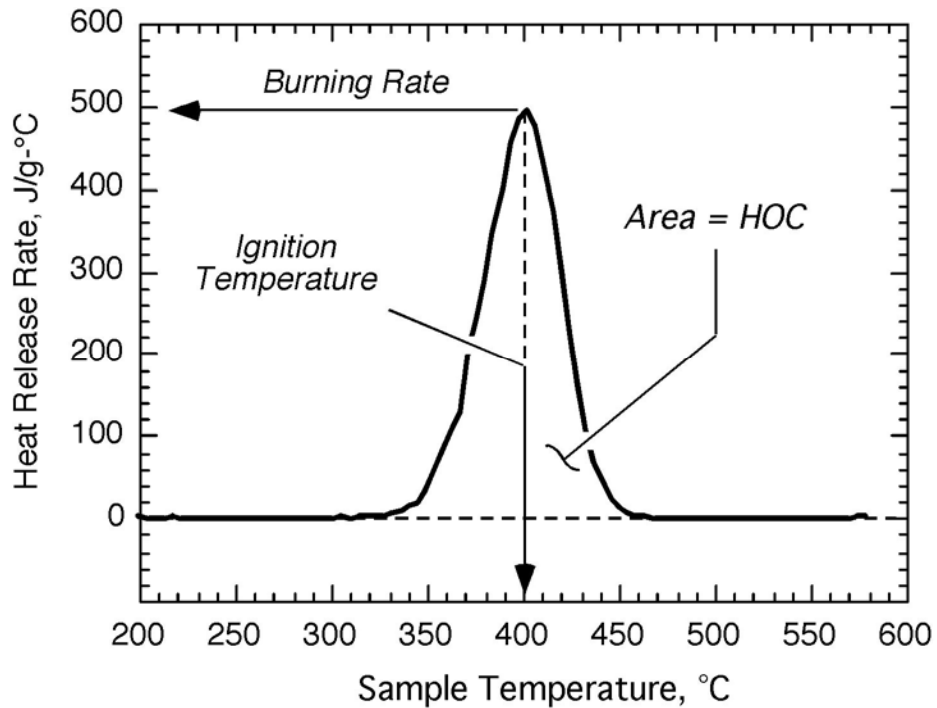


FIGURE 1. FLAMMABILITY DATA FOR ACRYLIC (PLEXIGLASS) FROM TESTER.

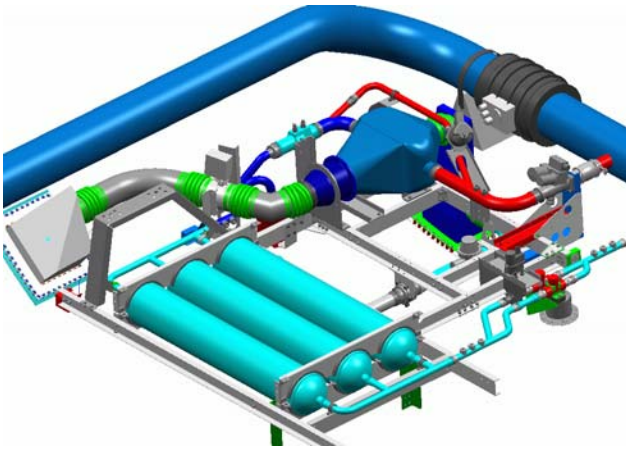


FIGURE 2. PROTOTYPE FLAMMABILITY TESTERS SHIPPED TO LICENSEES.
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Study of In-Flight Flammability and Inerting on the NASA 747 SCA

Significant emphasis has been placed on fuel tank safety since the TWA Flight 800 accident in July 1996. This prompted the Federal Aviation Administration (FAA) to study methods that could limit the flammability exposure of fuel tanks in the commercial transport fleet. The effort was focused on high-flammability exposure fuel tanks, which are center wing and body-style fuel tanks. Extensive development and analysis by the FAA Fire Safety Branch has illustrated that fuel tank inerting during aircraft operation could be cost-effective if air separation modules (ASM) could be integrated into an inert gas generation system in an effective manner. Also, the study of center wing fuel tank ullage flammability through the use of scale experiments and analytical models has been pursued by the FAA extensively. This research allows for a more complete

understanding of both the inerting requirements and the factors that affect the flammability exposure for a commercial transport airplane fuel tank.



To demonstrate the use of hollow-fiber membrane ASMs for inerting commercial transport airplane fuel tanks, the FAA, with the assistance of several aerospace companies, developed a prototype onboard inert gas generation system, with ASMs, that uses aircraft bleed air to generate nitrogen-enriched air (NEA) at varying flows and purities (NEA oxygen concentration) during a commercial airplane flight cycle. Additionally the

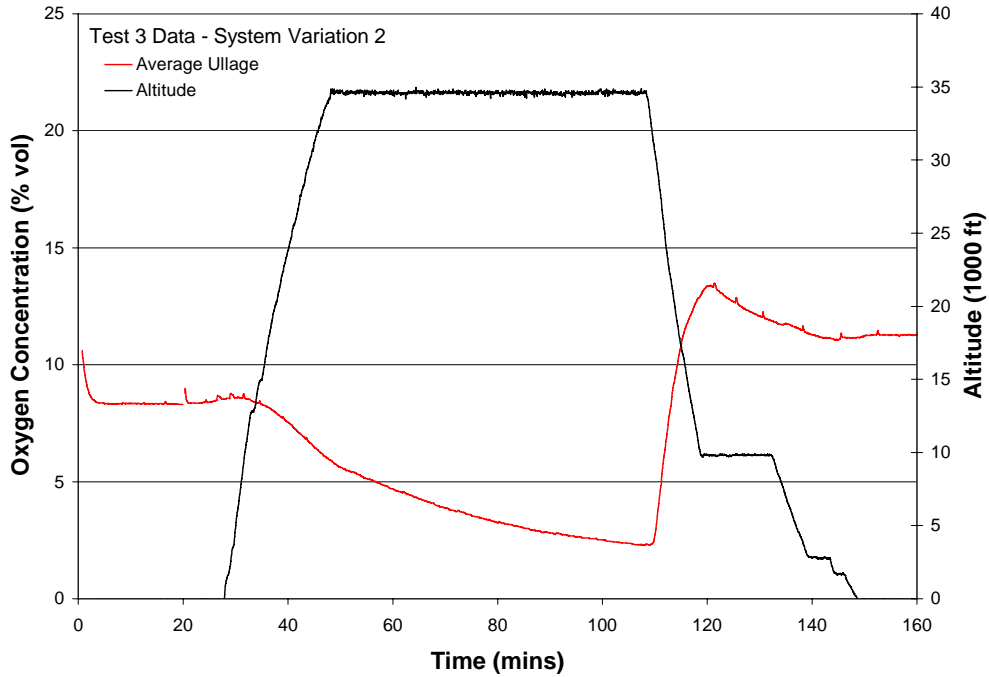
FAA developed models and experimental methods to study the progression of flammability of an aircraft fuel tank throughout a typical flight cycle.

A series of ground and flight tests were performed, in conjunction with National Aeronautics and Space Administration (NASA) aircraft operations personnel, designed to evaluate the simplified inerting system and examine the flammability of both the center wing and one inboard wing fuel tank. The FAA inerting system was mounted in the pack bay of a NASA 747 SCA, which is used for transporting the Space Shuttle Orbiter. During testing the inerting system was operated while fuel tank oxygen concentration and flammability was measured using special instrumentation developed by the FAA. This gave a complete picture of the ability of the inerting system to reduce the flammability exposure of a commercial airplane CWT.

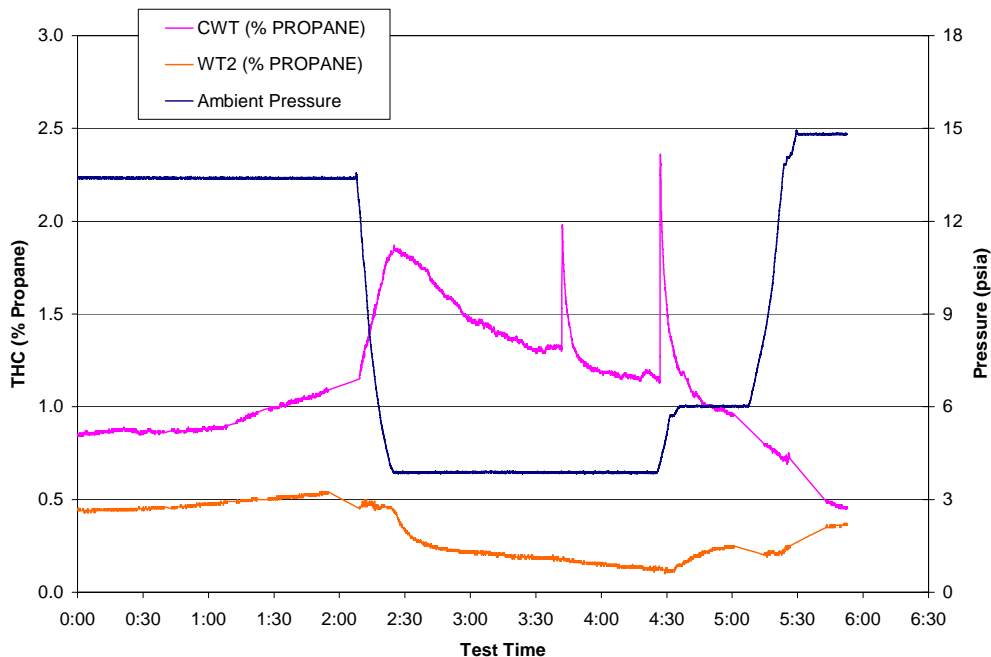


The results of the testing indicated that the FAA inerting system operated as expected. Inerting system warm-up times had no measurable effect on the ability of the system to keep the ullage inert during typical commercial transport flight conditions. Using a variable flow methodology allowed for a greater amount of NEA to be generated on descent at a higher oxygen concentration (lower purity) as intended and allowed for improved inert gas distribution by decreasing the worst bay oxygen concentration. All assumptions concerning ground operations and aircraft turn-around with and inert ullage were validated. Flammability measurements from both the CWT and the wing tank showed trends were consistent with experimental and computational analysis previously performed and allowed for the potential improvement of ullage flammability models.

A description of the flight test program and findings are contained in FAA technical report DOT/FAA/AR-04/41, "Evaluation of Fuel Tank Flammability and the FAA inerting system on the NASA 747 SCA," authored by Mike Burns, William Cavage, Robert Morrison, and Steven Summer.



Average CWT Ullage Oxygen Concentration Measured During SCA Flight Testing



Flammability in Both the CWT and Wing Tank Measured During SCA Flight Testing

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The Fourth Triennial International Aircraft Fire and Cabin Safety Research Conference

The Fourth Triennial International Aircraft Fire and Cabin Safety Research Conference was held in Lisbon, Portugal on November 15-18, 2004. The conference was the fourth in a series of triennial conferences to inform the aviation community about recent, ongoing and planned research activities in aircraft fire and cabin safety. It is the only technical conference devoted exclusively to fire and cabin safety R&D in civil transport aircraft. Approximately 350 people attended the sessions on materials fire safety, systems fire safety, evacuation, crash dynamics, and operational issues.

The conference was organized and sponsored by the Cabin Safety Research Technical Group. Comprised of representatives from the major aviation authorities throughout the world, this group strives to cooperate in fire and cabin safety research. The research conference is one of its major undertakings.

This was the first triennial conference held in Europe. The three prior conferences were hosted by the FAA's Fire Safety Branch and held in Atlantic City which is near the FAA William J. Hughes Technical Center. Information on the Cabin Safety Research

Technical Group and the proceedings of all four conferences is available on the Fire Safety Branch's web site at www.fire.tc.faa.gov

The fire safety sessions were dominated by papers on fuel tank inerting, fuel flammability, thermal acoustic insulation flammability and hidden fire safety. This research is driven by past accidents, such as TWA 800 in 1996 and Swiss Air MD-11 in 1998, incidents and subsequent recommendations issued by the accident investigation boards. Additional presentations included halon replacement (halon production was banned because it is an ozone depleting agent), smoke/fire detectors (current cargo detectors exhibit very high false alarm rates), and ultra-fire resistant materials (Congressional mandate to conduct long range research to create a "fireproof" cabin).

The evacuation sessions covered a broad range of research activities. A major concern is evacuation from the high capacity, new A380, which will have an equal number of passengers on the upper and lower decks. A large number of papers employed computer simulation and modeling. A common theme was the management of an emergency evacuation by the cabin crew, including crew/passenger interaction, crew cooperation and workload.

Under the operational issues session, a full morning was devoted to passenger performance and awareness. It is generally believed that the vast majority of passengers are totally unprepared for an emergency evacuation. A panel discussion delved into how to improve passenger awareness and preparedness for an event as unlikely as winning a lottery. Additional topic examples included in-flight turbulence, direct view for cabin crewmembers, and cabin simulators for research and testing.

The crash dynamics session was a mix of modeling and crash testing. Passenger protection was a common topic, for example, the development of neck injury criteria for occupants in side facing seats, and simplifying the aircraft seat dynamic test requirements. Models were employed for special applications, such as the crashworthiness of comfortable auxiliary fuel tanks and hot air balloon landing and protection. There were several papers on the dynamic testing of commuter aircraft and helicopters.

In order to make further improvements in aircraft fire and cabin safety, it is essential that stakeholders work together to seek practical and cost effective solutions. One must be informed of the issues and technology in order to be able to participate and make meaningful contributions. This conference provided the opportunity to gain some of that essential knowledge.

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The Fourth Triennial International Aircraft Fire & Cabin Safety Research Conference Proceedings



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