Aviation Committee

of the NATIONAL FIRE PROTECTION ASSOCIATION

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August 1971
Price: $2.00

Aviation Bulletin No. 388

Improvement of Fire Safety in Commercial Aircraft

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Presented at the Aviation Seminar held in conjunction with the 75th Annual Meeting of the National Fire Protection Association, San Francisco, Calif., May 17, 1971.

Editor's Note: Some of the terms used in this paper (e.g. "fireproof," "flameproof") are not those currently employed by fire protection specialists. Ordinary combustible materials treated to reduce their hazard are more commonly called "flame-resistant." For NFPA usage of terms, see NFPA Fire Protection Handbook, 13th Edition, particularly Section 5, Chapter VIII.

Since the inception of the manned space-flight program, NASA has been actively engaged in a search for nonflammable materials to be used within the spacecraft. This NASA search, conducted with the assistance of industry, has led to a progression from the relatively unsophisticated flameproof materials available 10 years ago to the great variety of fibers, cellulosics, elastomers, and composites which can now be fabricated into nonflammable end items. The capability for fabrication, of course, involves the development of technology necessary to evaluate and to use properly the specialized materials now available. It is believed that many of the nonflammable and fire-resistant materials and much of the supporting technology developed for spacecraft usage can, when properly adapted, make a significant contribution toward achieving a fireproof aircraft interior.

Certain physical considerations assume importance when materials for aircraft interiors are selected. Foremost among these considerations is durability, requiring flameproof materials that will withstand competitively the rigors of repetitive usage in functional applications.

Esthetic qualities also are of major importance for airline applications. This is an area that presently commands prime technological attention. Because many of the fibrous materials currently being used in the spacecraft cannot be dyed and are available only in white or in varying shades of brown, other advancements have been made in techniques for spraying, laminating, embossing, and printing to achieve decorative results by using nonflammable and flameproof materials.

Despite differences in end-item usage, however, the applicability of nonflammable spacecraft materials is apparent for many commercial aircraft items such as curtains, upholstery, carpets, decorative panels, cabinets, paper products, oxygen lines (and associated equipment such as masks), and straps. The ensuing discussion of available materials includes specific characteristics, availability, and applicability of these nonflammable materials to specific end usage within the aircraft interior.

FIBROUS MATERIALS

Undoubtedly, the highest degree of nonflammability can be obtained with inorganic fibers such as asbestos and fiber glass. Assemblies containing asbestos exhibit a high degree of resistance to the conductive passage of heat and are used in the spacecraft to fabricate containers for flammable contents.

The fiber glass used most extensively within the spacecraft is called Beta, a fiber characterized by an extremely fine diameter. Textile structures can be fabricated from Beta to provide the maximum in flexibility and performance within the limits of the inherently low abrasion resistance of fiber glass. Various techniques have been used successfully to improve the abrasion resistance of both Beta and a newly developed Alpha fiber glass. These techniques generally have centered around the use of coatings, applied either to the woven fabric itself or to the individual yarns before weaving.

Several modified aromatic polyamide fibers that are nonflammable in air and in moderately enriched-oxygen atmospheres have recently been developed. Two of these fibers, Durette and Fypro, are discussed in detail under specific aircraft applications. Fabrics made from these fibers exhibit excellent physical and fabrication characteristics; in fact, clothing made from one of these fabrics is currently under consideration for use by the NASA Skylab Program mission crews. Natural colors of the fibers are golden, dark brown, and black; however, developmental efforts to dye the fibers with colors of requisite fastness are underway.

A phenolic-type fiber called Kynol, which retains its whole identity when exposed to flame temperatures up to 2500° F, has recently been developed. This fiber was originally used mostly as felts and battings, but spinnability has been improved to the extent that conventional knitted and woven fabrics are now available. Suits made from these fabrics have been demonstrated to be highly protective outer garments for firemen and race drivers.

For purposes of completeness, several materials that are used in the spacecraft but are not presently considered for aircraft applications are discussed briefly. Polybenzimidazole is an excellent fabric from almost every point of view, including nonflammability; but it is presently very expensive. Teflon fabric is nonflammable, but has unsatisfactory hand and low tensile strength. Metallic fibers are expensive and lack durability. A new fabric from German Enka closely simulates cotton and is nonflammable, but is as yet available only in experimental quantities.

A more recent candidate is a fire-retardant wool (treated with a chemical process called Proban) which meets many of the characteristics desirable for aircraft and other vehicle interiors. This material does not burn in air, is available in a wide range of colors, and can be considered for any application in which wool is a potential candidate.

NONFLAMMABLE PAPER

A cellulosic material, developed by the Scheufelen Paper Company of Germany and processed primarily as a paper, carbonizes in the presence of a flame but does not propagate the flame. This nonflammable characteristic is evident in both air and oxygen-enriched atmospheres. This paper lends itself well to printing and, with some minor exceptions, has physical properties that are comparable to conventional paper.

This paper can be processed into a continuous roll of 0.5-inch-thick foam, similar to papier-mache. When placed on a ceiling, for example, the foam has both the appearance and function of conventional acoustic tile and offers the additional advantage of nonflammability.

In addition to the paper, a process called Laminite which treats cellulose-base fiberboard with ammonium aluminum sulfate has been evolved. The resultant material is minimally flammable in oxygen and nonflammable in air. It can be formed wet, coated, cemented, and joined like a composite; yet it is lightweight and inexpensive.

ELASTOMERS

Elastomers developed for the space program are fluorocarbons, basically copolymers of hexafluoropropene and vinylidene fluoride. Although the elastomers are themselves flammable, through the judicious use of compounding ingredients and plasticizers, nonflammability concomitant with a wide range of physical properties has been achieved. Notable among these elastomers are Fluorel (developed by the Minnesota Mining and Manufacturing Company and available from the Mosites Rubber Company and Raybestos-Manhattan Incorporated) and Viton [developed by E. I. du Pont de Nemours and Company (Du Pont)]. The compounded elastomers can be foamed, cast, molded, or extruded. The materials can be controlled as a paste, a coating, or a spray solution.

Mineral pigments in a wide variety of colors can be formulated into fluorocarbon-based paints. Panels fashioned of elastomer-backed nonflammable paper, to which decorative patterns have been applied, have been manufactured. The inclusion of asbestos in the backing provides insulating properties. Such a lightweight, fireproof sandwich affords much flexibility in decorative panel design. Elastomeric coatings can be applied to polyurethane foams and to cellulosic materials such as paper, wood, and sponge, thereby effectively fireproofing the materials for structural and insulative applications. The extensive uses of these elastomers are discussed further under specific aircraft applications.

There are the more promising materials, but are by no means all of the materials that can be used for fireproofing aircraft interiors. Additional materials with new and advanced technology become available every day. As a stimulus to the effective fireproofing of commercial aircraft, some of the methods and the materials combinations which have been evaluated by the NASA Manned Spacecraft Center in conjunction with a few of the major airlines are discussed. This effort is a part of the overall NASA commitment of making space technology available and practical for commercial uses.

SPECIFIC AIRCRAFT APPLICATIONS

As a first step, four nonflammable ceiling panels were installed into the United Airlines 727 Quick-Change Aircraft no. N7423U. Personnel of NASA, working at the United facility, refurbished and installed these panels during a scheduled aircraft maintenance check, matching the interior decor well enough that the panels still remain in place after 3 months and are not discernible from the rest of the ceiling.

Existing panels were of resin-impregnated board coated with vinyl. The front surfaces of two of these panels were stripped of vinyl and coated with Fluorel-impregnated fiber glass. An overlay coating of transparent Kel-F was applied for soil and stain resistance. The front surfaces of the two remaining panels were coated with 3M adhesive and sprayed with white-pigmented Fluorel. The backs of all panels were coated with a mixture of 75-percent Fluorel/25-percent asbestos to prevent heat transfer as well as to provide fire protection.

This same technique is applicable to ceiling panels of all types; although, in the interests of expediency, it is believed to be more practical in the future to supply the Fluorel/fiber-glass/Kel-F combination for direct adhesive application to the panels. These nonflammable composites can be furnished in decorator designs and colors and will be a less expensive method of fireproofing aircraft ceilings than the direct coating method which was used.

Another approach, one particularly favored from the standpoint of low toxic offgassing, is the replacement of existing ceiling panel materials with a recently developed lightweight board treated for rigidity, durability, and nonflammability. When coated with Fluorel, these panels give off none of the toxic products associated with burning vinyl.

Three curved panels of Laminite board are presently being converted into aircraft paneling to demonstrate the capability for supplying panels with decorative and textured finishes. The backs and edges of the panels have been coated with the Fluorel as a mositure sealant. The Owens-Corning Fiberglas Corporation is working with NASA on approaches for surface-finishing two of these panels. For one panel, a United Airlines pattern is being duplicated on Fluorel-impregnated fiber glass with a clear Kel-F finish. For the second panel, a textured glass fabric, which will be impregnated with Fluorel and coated with Kel-F, is being prepared. This glass fiber will then be stretched across the ceiling arc, and the intervening space will be filled with Durette or Fypro batting. The latter panel concept is intended for use on a Gulfstream aircraft.

In the third approach, Fluorel (into which a decorative finish has been incorporated) is being sprayed directly onto the front on the panel and a Kel-F finish applied. These panels will all be available for evaluation in the near future.

In an effort to improve the basic board, the Hexcel Corporation is evaluating the use of Scheufelen paper to develop a honeycombed, nonflammable board that can be fabricated into aircraft ceiling panels. Corrugating and honeycombing processes also are being developed for the Laminite board. These boards will have physical characteristics that are comparable to the boards presently used in addition to the advantages of lower cost and nonflammability. By imprinting designs onto the Fluorel/textured fiber-glass surface (or directly onto the board) with a silk-screen process, all of these boards can also be fabricated as side panels for aircraft. This process has been satisfactorily accomplished at NASA.

In another forward step in the development and application of nonflammable technology, the Monsanto Company has refurbished an Aero Commander aircraft with golden Durette fabric. This material is completely nonflammable in air environments and was used to replace upholstery, curtains, and baggage-compartment liners. Durette is available in plushes, brocades, and sculptured patterns as well as in conventional knits and weaves.

Fabric replacement within the T-39 aircraft with Durette or with like fabrics is presently under consideration by the U.S. Air Force. One of these similar fabrics is Fypro, developed by Travis Mills and somewhat cheaper than Durette. Both fabrics are currently supplied in a limited range of colors.

To serve their upholstery needs, several European airlines (such as Swissair and KLM) have switched to Proban-treated woolens. This treatment imparts fire-retardant qualities based on the use of tetrakis-(hydrozymethyl)phosphonium chloride (THPC), a chemical which apparently does not adversely affect the wool but enables the treated woolens to meet Federal Aviation Agency (FAA) flammability regulations. This material is available in a wide gamut of decorator colors and weaves.

A 20-mil Fluorel sheet has been backed with Durette knit to simulate a polyvinyl chloride on textile leatherlike finish. This material can be made porous by a special process called poralating to impart "breathe" qualities to the material. This material is completely nonflammable, durable, and available in any desired color. It is intended for use in fabricating armrests, headers, magazine covers, or in any other area in which leather or leatherlike materials are used.

Seat cushions can be made fireproof by using polyurethane foam sprayed with Fluorel. This process is relatively inexpensive, costing only about a dollar a seat for processing. Such an airline seat, further protected with nonflammable upholstery, armrests, and headers, will go a long way toward protecting passengers from fire until resuce can be accomplished. Even seat belts can be fabricated of nonflammable Durette or Fypro webbing.

Nonflammable carpet material has presented somewhat a challenge. The best developed to date is 100-percent wool with a fire-retardant latex backing. Methods of spraying the carpet back with Fluorel are presently being investigated, but this will be a relatively expensive process. American Enka has developed a fire-retardant rayon which can be fabricated into carpet materials and backed with Fluorel spray. Among the more promising efforts underway is an attempt to adapt the Proban treatment to wool carpets. This has been done successfully with wool shag rugs, but so far, sufficient penetration of the THPC into the carpet pile to achieve nonflammability has not been accomplished.

Because approximately 85 per cent of aircraft fires are externally caused, a great deal of effort has been concentrated toward flameproofing the aircraft itself. During flame-impingement testing in a 3400° F environment, the following increases in burn-through times have been achieved by spraying Fluorel on an aluminum surface. While uncoated 20-mil aluminum burns through in 30 seconds, a threefold increase to 90 seconds is obtained when the aluminum is coated on one side with a 10-mil coating of Fluorel. A 7-mil coating of Fluorel on both sides of the aluminum increases the burn-through time to 180 seconds. This is an important factor when evacuation of passengers from a burning airplane is involved.

Time to flame breakthrough into the aircraft cabin can of course be increased dramatically by the use of nonflammable insulation between the hull and the aircraft interior. Several definite possibilities exist in this area, all of which use nonflammable materials that vary in composition and in method of application.

Asbestos foam has been developed by the Rex Asbestos Works of Germany. This material is marketed in batting and sheets and should be useful for general insulation applications. This materials is available in limited quantities ranging from 0.5-inch-thick sheet at $1.98/sq m to 2-inch-thick sheet at $7.38/sq m. Large-scale production is expected in 1972. The Monsanto Corporation has developed a polyimide foam, also available as batting or sheets, but considerably more expensive than asbestos.

A definite need exists for an insulative material which can be foamed in place. To fill this need, the Avco Corporation has developed (under NASA contract) an isocyanurate foam which is nonflammable in air atmospheres. Although easy to apply, the material is at present time expensive. The Owens-Corning Fiberglas Corporation has a lightweight organic and organic/fiber glass, which can also be foamed in place, under development. In addition to being nonflammable, these materials are inexpensive and are available at this time in limited quantities.

The capability for coating or replacing electrical components with Fluorel has been developed and has been used to some extent in the space program. The material can be molded to form wire ties, conduits, circuit breakers, and electrical connectors. When mixed with asbestos, the Fluorel can be applied as a conformal coating over electrical parts, presenting a firebreak in case of ignition from electrical sources.

Numerous other areas within an aircraft can be effectively fireproofed. Developmental efforts to perfect a nonflammable emergency slide are progressing. The Monsanto Corporation has been requested by NASA to develop a continuous-filament Durette fabric which will in turn be coated with Fluorel by Raybestos-Manhattan Incorporated to meet air-retention specifications. Coated on one side, the material can be fabricated into bladder material, notably useful for aircraft lifevests. Coated on both sides with Fluorel, the fabric will be used to fabricate emergency slides that meet the stringent specifications which apply. Because developmental problems to date have centered around the selection of a supporting fabric which retains its fiber integrity under intense heat, it is hoped that the continuous-filament Durette will solve these problems and make available slides which are reasonable in cost, which meet FAA specifications, and which are nonflammable when tested under deployment conditions.

Although another spinoff from space research does not fall into the area of fire safety, it should have general safety applications for aircraft windows. When applied to polycarbonate, special coatings (under development for protection of the space-suit helmet) improve the scratch resistance of the surface. This coating material, called Astrocoat, has potential for application to a plexiglass surface. For further information on this material, interested parties may contact Mr. Myron E. Lippman, AstroResearch Corporation, Santa Barbara, California.

Rubber matting used within an aircraft can present a hazard during a fire situation. Nonflammable Fluorel fabricated by the Mosites Rubber Company can be calendered into mats of varying thicknesses and supplied in a variety of colors. Fiber glass laminated onto the back of the mat decreases the cost and provides better tear strength and durability. These mats are available in production quantities at approximately $30/sq yd for a 40-mil thickness. The quantity of Fluorel used can be reduced to lower this price. Such mats are not only nonflammable but protection the aircraft floor against flame propagation.

Paper is used aboard an aircraft in many more places than are apparent. Nonflammable paper developed by the Scheufelen Paper Company of Germany can substitute for a large majority of these applications. Available in a wide variety of thicknesses and colors, this paper can replace flammable writing materials, maps, tray covers, doilies, headrests, napkins, and (because it is receptive to printing) even booklets, brochures, and magazines.

Nonflammable blankets can be made from Kynol, Fypro, or Durette batting quilted to covers of Fypro or Durette. Pillows can also be fabricated of Kynol, Durette, or Fypro battings, or from treated polyurethane foam. Pillow cases can be made from THPC-tris(1-aziridinyl)phosphine oxide treated cotton, thereby eliminating another fire-hazard category on board the aircraft.

For replacements in areas where molded plastics are used, NASA (in conjunction with industrial sources) has developed a number of nonflammable substitutes. The Whittaker Corporation has developed a nonflammable polyquinoxalate, and North American Rockwell has developed a polyimide with Du Pont. All of these materials can be molded into nonflammable trays, panels, seats, light fixtures, and overhead racks, as well as into cabinets and countertops.

Another major development in nonflammable composites can be cited as a definite advance toward fireproofing the aircraft cabin interior. A nonflammable fabric layup which, when used as a curtain, provides a fire-break against flame propagation from one interior area to another has been fabricated. This curtain material is composed of three layers: a Fluorel-coated Durette fabric layer, a resinated-Fypro inner layer, and a woven Fypro layer. These fabrics are either quilted together or edge sewn, weigh approximately 1 lb/sq yd, and drape beautifully. Use of this layup as galley and compartment curtains, and as a firebreak between the pilot's cabin and passenger compartments can easily be envisioned.

The capability for manufacture of an emergency rescue suit to be worn by ground-support crews associated with an aircraft fire also has been demonstrated. This suit is designed to withstand temperatures of 3400° F for short periods of time. Under such conditions, the materials will not burn nor will the heat penetrate to the wearer. These suits will be given to the City of Houston Fire Department for further evaluation.

It is believed that NASA has reached the technological development point at which the capability for completely fireproofing an aircraft can be demonstrated. To this end, NASA is negotiating for an aircraft fuselage to be used to conduct an aircraft flammability test program. Regions within compartments will be furnished according to a predetermined test plan so that comparisons may be made between the variety of new fire-resistant materials. Flammability test sequences will involve the use of realistic, electrically initiated ignitors, located in predetermined areas, with full television and motion picture coverage. Results of this testing will be made available to the aircraft industry as a part of the overall NASA effort to apply space technology toward increased survivability in the event of aircraft fires.