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FIRE RETARDANT MATERIALS TESTING FOR PRESENT AND FUTURE AIRCRAFT

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Abstract

Due to the increased emphasis on flight safety and crashworthiness of high-capacity transports, an extensive program has been conducted on the flammability resistance and smoke emission characteristics of over 200 aircraft interior materials. Techniques have been developed to compare the flaming resistance of fire retardant materials under ambient and increased temperatures, zero ventilation compared to various airflows, and a combination of both variables. Results indicate the flammability resistance of most fire retardant fibrous materials decreases with an increase in surrounding temperatures, while several fail to be self-extinguishing. The smoke emission characteristics of interior materials subjected to radiation and flaming conditions have been determined on an NBS-type smoke chamber and typical results are presented in specific optical density. The effect of various operational parameters in the NBS-type smoke chamber and an XP-2 smoke chamber are investigated. Participating work is continuing on industry standardization of test procedures.

Introduction

As a result of a flame-resistant aircraft interior materials survey conducted in 1967 by the AIA (Aerospace Industries Association) together with material suppliers and in agreement with the FAA, a need was apparent to improve the flame-resistant properties of aircraft interior materials. Also, in 1967, a parallel effort was conducted by Lockheed-California Company to determine the nature and hazards of inflight and crash fire situations, together with a survey of existing flammability test procedures. The review of test methods revealed many varied and arbitrary methods involving approximately 36 different tests for flammability evaluation. For a comprehensive materials evaluation testing program, Lockheed-California Company decided to use a simple vertical burn test, noted as Method 5902 of Federal Specification CCC-T-191b. This method, revised from the original according to the recommendations of Ref. 1 and concurred with by the FAA, shows compliance with FAR 25.853 (a)(b) of the Federal Airworthiness Standards. In addition to evaluating the flammability resistance of materials and for a further degree of fire safety, the AIA members initiated individual programs to evaluate the smoke emission of burning aircraft materials. These efforts were guided by initial studies at the National Bureau of Standards (NBS). Consequently, in 1968 a fire research facility was fabricated, assembled and calibrated at Lockheed-California Company (see Figure 1), and a crashworthiness program on fire retardant materials testing was initiated. In Figure 1, beginning at the extreme right is located a Setchkin Apparatus, utilized to determine the self-ignition and flash ignition properties of materials. Next to the Setchkin Apparatus is located a Method 5902 vertical burn chamber. To the

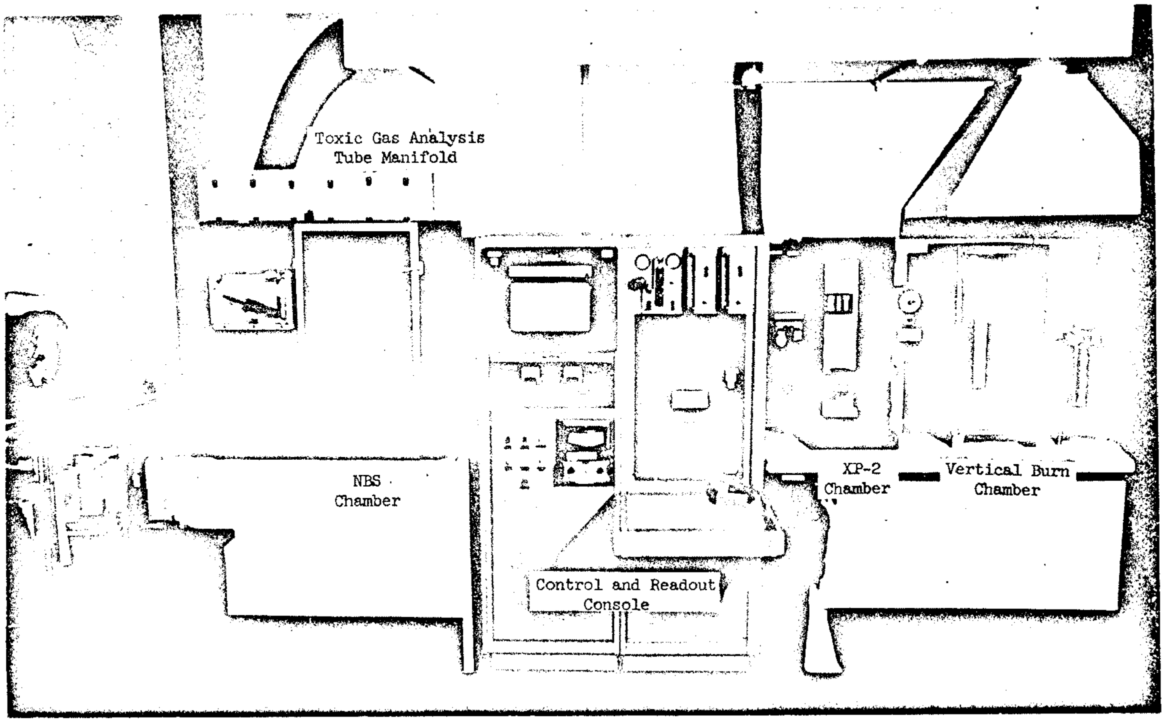

FIGURE 1. FIRE RESEARCH FACILITY

left of the burn chamber is located an XP-2 smoke chamber.(2) Next to the XP-2 chamber is the control and readout console of an NBS type of smoke chamber, (3) and continuing to the left is a specimen humidity conditioning chamber, since enlarged.

Experimental Technique

Flammability Testing

In the overall comprehensive program of materials flammability properties research, the candidate materials are screened for self-extinguishing and burn length/time requirements in the vertical burn chamber ref. Figure 1. Obtaining data on the self-ignition and flash-ignition properties of materials utilizing the Setchkin Apparatus requires more time-consuming tests. Useful analytical techniques for material thermal properties are DTA and TGA studies. However, the tests require an experienced operator and are not universally reproducible due to the character of the test equipment. Another useful tool for materials analysis is gas chromatography, which provides information on the gaseous and volatile constituents of a material undergoing a thermal change. Materials which will definitely be used in substantial quantities are good candidates for this analysis, but for a materials selection program it is a lengthy test method.

In the Method 5902 chamber, the test procedure is to condition three specimens, 3.0 x 12.0 inches and not more than 3/4-in. thick, at 50 ±5% R.H. and 70 ±5°F for at least 4 hours. In the chamber a Bunsen natural gas burner is used and the flame height is adjusted to 1-1/2 inches. A specimen is withdrawn from the conditioning chamber and installed in a suspended vertical holder. At time zero the burner is moved under the specimen and the lower edge of the specimen is immersed in 3/4-in. of the flame. A specimen is subjected to either a 12 or 60 second exposure and then the flame is withdrawn. The guidelines used for various specimens are included in a set of flammability rules, Appendix I. These rules state that, if the candidate materials are to be used next to the fuselage sidewalls, flooring and overhead, the flame exposure will be 60 seconds. All other materials are subjected to a 12-second exposure. The results for 3 specimens are averaged and entered into an aircraft interior category data sheet. The burn lengths of the three tested specimens generally vary within ±5/8-in.

Smoke Emission Testing

Initially, smoke tests on materials passing the flammability requirements were performed on an early smoke chamber designated as an XP-2 chamber, ref. Figure 1. Tests were performed in the XP-2, while another smoke chamber was being constructed at Lockheed-California Company according to guidelines set forth by the NBS. The NBS chamber design was to incorporate features not available on an XP-2 chamber. Principal features of the NBS chamber, cited in ref. 3, are a vertical light beam to prevent stratification effects, measurement of the total smoke emission of a specimen (no openings at the bottom), radiation with or without a pilot flame front, and the use of a larger test specimen. After construction of the NBS type smoke chamber, efforts were made to correlate results with XP-2 chamber data. The results of a smoke study comparing XP-2 and NBS chamber data are shown in Figure 2. The variation shown is not surprising due to the difference in detail test conditions.

For the NBS chamber, two test conditions are available for smoke emission evaluation of materials. The two conditions are flaming and non-flaming. The flaming condition imposes a 2.5 watts/cm^2 radiant heat flux together with a 6 flamelet flame front on the front vertical surface of a 3.0 x 3.0 in. specimen. The nonflaming condition simply imposes the radiant heat flux of 2.5 watts/cm^2. The detail procedure for testing in this chamber involves presetting the heat flux onto a calibrated air-cooled radiometer and setting the photometric system at 100% light transmission. At time zero the specimen is brought into view of the furnace and the light recorder is turned on. For the flaming condition the pilot gas manifold with the six flamelets is rotated 90° to impinge on the lower surface of the specimen. As the specimen undergoes thermal decomposition the smoke evolved interrupts the vertical light beam and a quantitative measure of the light absorption is obtained as a function of time. A smoke test is generally extended to 5 minutes. However, the smoke emission within 1-1/2 minutes is significantly important due to the 90 sec aircraft evacuation time limit specified in FAR 121.291. Although basic guidelines were followed from the NBS in the construction of the smoke chamber, a modification in the photometric system was incorporated in the Lockheed-California Company chamber. A fiber optics light source and a photovoltaic cell were substituted for a film viewer lamp and an IP39 phototube. The photovoltaic cell in the Lockheed-California Company chamber has a Viscor filter to match very closely the eye sensitivity response, while an IP39 phototube has a peak sensitivity shifted to shorter wavelengths than the eye sensitivity peak. However, smoke emission tests of similar materials correlate very closely to the NBS results. Linearity of the photometric system is periodically calibrated with neutral density filters ranging from 0.41 to 91.6% light transmission in the visible region. Data reduction from a smoke emission test is accomplished by using a conversion scale from % light absorption (from the recorder trace) to specific optical density, D_s, subsequently described.

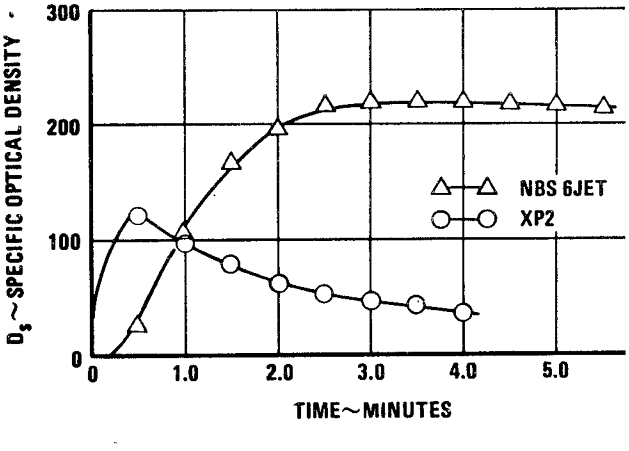

FIGURE 2. SMOKE CHAMBER COMPARISON DATA

If a volume of smoke is considered passing through a parallel beam of light, then the law of light extinction, known as Bouguer's law (sometimes Lambert's or Beer's law) is given by:

$$F = F_o e^{-\sigma L} \quad \text{where:}$$

F = transmitted flux
F_o = incident flux
L = light path length
σ = attenuation coefficient

Optical density is defined as:

$$D = \log_{10} \frac{F_o}{F} = \frac{L\sigma}{2.303} = \log_{10} \frac{100}{T} \quad \text{where:}$$

T = % light transmission

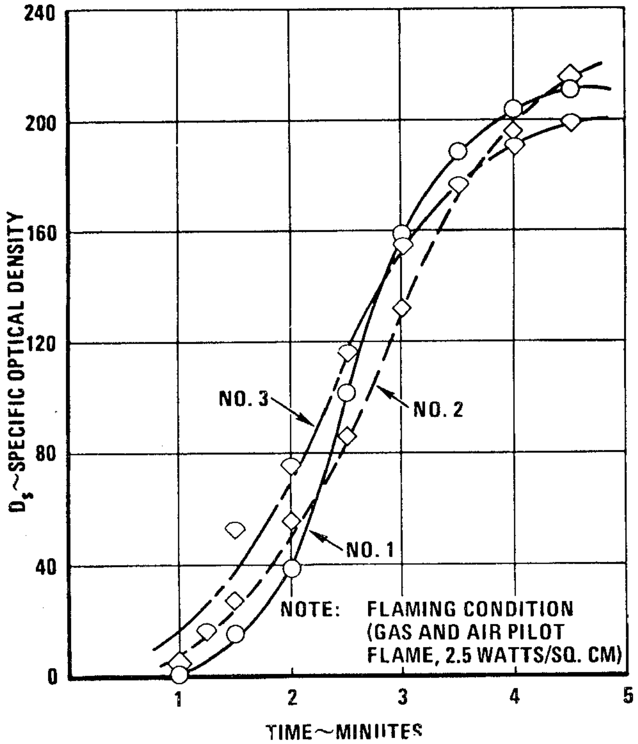

FIGURE 3. VARIABILITY OF THREE TESTS OF A TYPICAL SPECIMEN

For a specimen of unit area, unit light path length and a chamber of unit volume, the specific optical density is:

$$D_s = D \frac{V}{AL} = \frac{V}{AL} \log_{10} \frac{100}{T}$$

Where T = 100% - light absorption. Thus, for any chamber size, any light path length and any specimen size the smoke results of a given thickness of material should be the same within reasonable limitations (ref. 3). For the NBS-type smoke chamber used, the volume, V, is 18 ft^3, the exposed specimen area is 6.56 in.^{2} and the light path length is 36 in. The constant, $\frac{V}{AL}$, is therefore 132. For very smoky materials the D_S may approach 660. For candidate materials smoke testing, three tests are performed and the results are averaged. The variability of three tests for a similar specimen is shown in Figure 3 and the repeatability of three tests on a specimen varies within ±15%.

From a fire retardant materials testing program conducted for approximately 1-1/2 years, over 310 materials have been evaluated for flammability resistance and over 200 materials have been evaluated for smoke emission characteristics. A typical summary flammability/smoke data sheet for a particular category is shown in Figure 4.

Results and Conclusions

Results of this program indicate that fire retardant wools, cotton-rayon blends, high temperature nylons, polycarbonates, polysulfones, polyvinyl fluoride covered aluminum and some fiberglass laminates meeting the flammability requirements are among the low smoking candidates for aircraft interiors. Most materials generate more smoke under a flaming exposure. However, the cellulosic materials and polyurethanes foams exhibit more smoke under a nonflaming condition.

Advanced Fire Safety Test Techniques

In addition to testing materials for flammability resistance and smoke emission according to the flammability rules, it was deemed desirable to investigate further aspects of in-flight and crash fires and develop advanced techniques contributing to aircraft fire safety.

Films and Decorative Panels

MATERIAL DESCRIPTION	60 SEC. VERTICAL IGNITION	12 SEC. VERTICAL IGNITION	SPECIFIC OPTICAL DENSITY @ 2 MIN.	SPECIFIC OPTICAL DENSITY @ 3 MIN.
#37 ML653 Coated Fabric	Pass	Pass	D_S = 43	D_S = 46
#38 ML490 Coated Fabric	Pass	Pass	D_S = 52	D_S = 55
#66 Asbestos-Vinyl Panel	Fail	Pass	D_S = 450	D_S = 500

FIGURE 4. TYPICAL FLAMMABILITY/SMOKE DATA SHEET

Increased temperature tests were performed on fire retardant fabrics, carpeting, RFP laminates, thermoplastics and thermoplastic/thermosetting-inorganic combinations. These tests consisted of preconditioning the specimens to elevated ambient temperatures (80 to 250°F) in the 5902 vertical-burn chamber prior to ignition. Results of these tests on fabrics and carpeting materials indicate that the burn times and burn lengths increase with an increase in temperature, e.g., FRT (Fire Retardant Treated) Rayon and Cotton and FRT Wool. Several materials which are self-extinguishing at room temperature continue to burn at increased temperatures, e.g., 100% wool rug and 60% cotton 40% rayon. Results on fire retardant thermoplastics and thermosetting fire retardant materials indicate that increased temperature tests up to 250°F do not significantly affect their self-extinguishing characteristics. Continued current efforts are directed toward determining the reaction of fire retardant materials at increased temperatures. Techniques have been developed to determine the flammability resistance of materials under simulated cabin ventilation flows. Results of these tests indicate little change in burn times and burn lengths under various airflows up to 6.5 ft^3/min. A technique was developed to simultaneously test materials at increased temperatures and simulated ventilation air flows. This combined preheat-ventilation condition increased the burn length from the preheat condition alone. This indicates that the flammability resistance is lowered if a material undergoes convection heating. A typical preheat/ventilation flammability test on a fire retardant fabric is shown in Figure 5. As shown in the figure, radient heat lamps have been installed on the sides of a Method 5902 burn chamber with black plates installed between the lamps and the specimen. A circulating fan at the top of the chamber prevents temperature stratification while preconditioning for an increased temperature test.

FIGURE 5. PREHEAT/VENTILATION FLAMMABILITY TEST

Advanced Smoke Testing Techniques

In addition to testing materials under a constant condition, namely a flaming exposure, it was also deemed desirable to determine the smoke emission of a material such as open cell urethane foam as a function of irradiation. Results of such a study are shown in Figure 6. For this material and for cellulosic materials such as rayon or cotton, it was determined that the smoke emission was approximately proportional to the irradiation level.

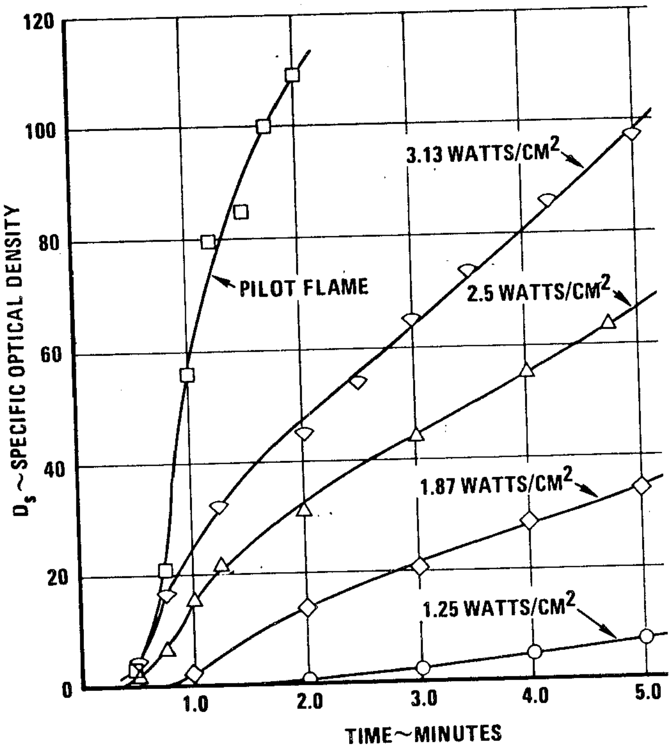

FIGURE 6. EFFECT OF IRRADIATION ON POLYURETHANE FOAM

Additionally, it was desired to determine the smoke emission of varying thicknesses of materials for a constant heat flux or irradiation. Figure 7 illustrates the smoke emission characteristics of various thicknesses for a thermoplastic material. Another aspect of smoke testing evolved from the question of whether the smoke emission of several components in a sandwich material equaled the total composite. Figure 8 illustrates the smoke emission of individual components in a sandwich structure in relation to the total. As can be seen the sum of the individual components does not equal the total, indicating that a particular type of surface layer may insulate the remaining components.

Another aspect of smoke emission testing involved the determination of the effect of backing used when testing clear plastics for comparison purposes. The difference between an aluminum foil and a flat black backing on a transparent material is shown in Figure 9. It is apparent the aluminum foil causes an increase in temperature in the plastic, thereby causing more smoke emission in the nonflaming condition.

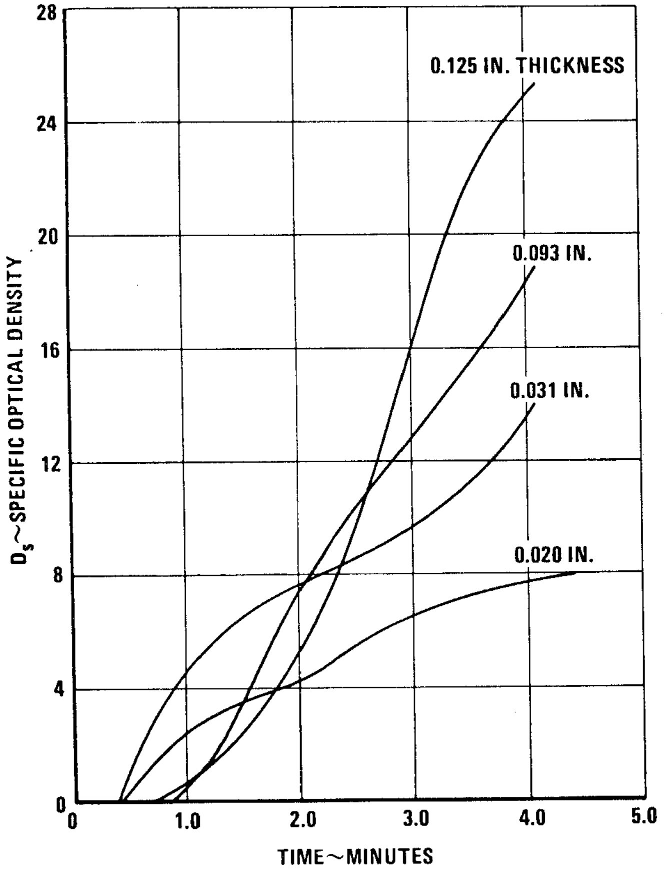

FIGURE 7. EFFECT OF SPECIMEN THICKNESS ON SMOKE EMISSION

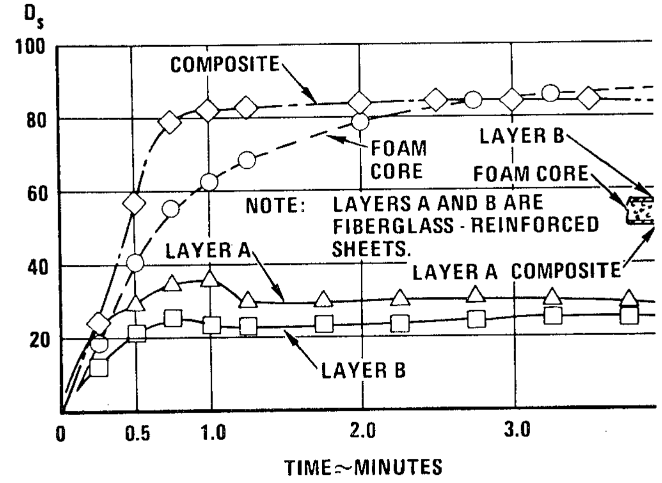

FIGURE 8. SMOKE GENERATION OF COMPONENTS VERSUS THE COMPOSITE STRUCTURE

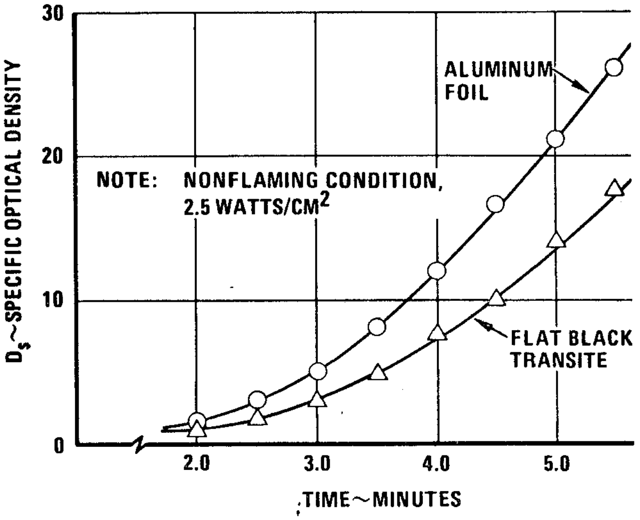

FIGURE 9. EFFECT OF BACKING ON A TRANSPARENT PLASTIC

A technique was investigated to determine the smoke emission of a fabric with an air gap behind it, where the application or use may be as a drapery or curtain material. The effect of an air gap for a fabric is shown in Figure 10.

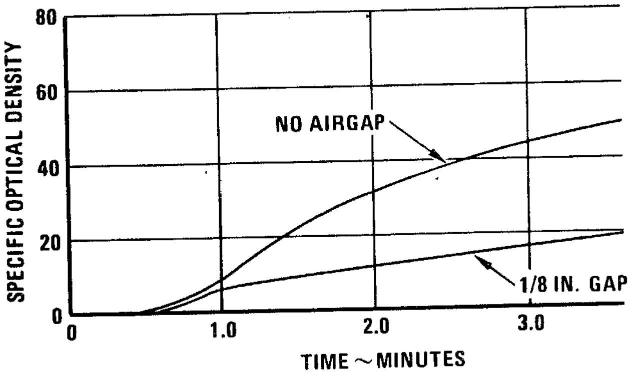

FIGURE 10. SMOKE EMISSION OF A FABRIC WITH AND WITHOUT AN AIRGAP

An important aspect of smoke emission testing was the consideration of ventilation air flows simulating cabin air-conditioning flow rates on the smoke emission characteristics of materials. The effect of various ventilation air flows on the smoke emission of a wool carpeting is shown in Figure 11. As shown in the Figure, the smoke emission varies inversely as the ventilation rate. Thus, tests with zero ventilation yield the most conservative results.

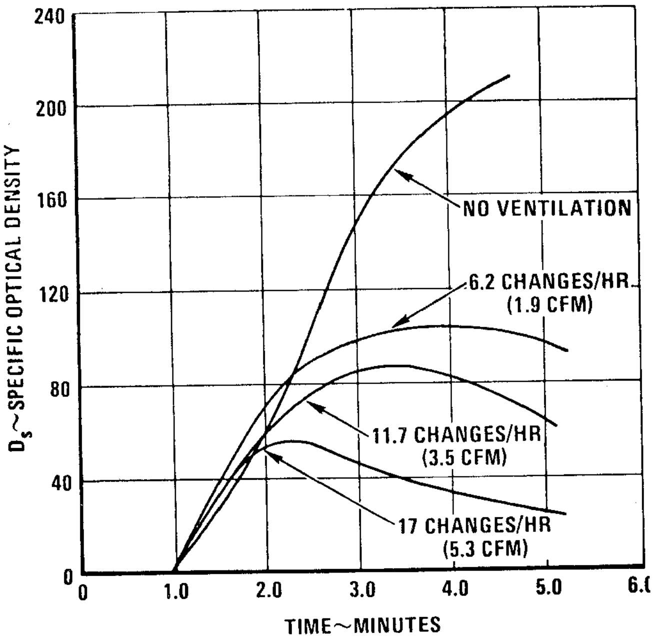

FIGURE 11. EFFECT OF VENTILATION RATE ON THE SMOKE EMISSION OF A RUG

Due to the lack of quantitative data on the smoke emission of aircraft electrical wiring, a technique was developed to evaluate the smoke emission at different wire insulations for various current overload conditions. The technique involved coiling a 10 ft length of wire onto an electrical insulator in the NBS chamber and subjecting this wire to various current carrying conditions. These conditions were controlled through a rheostat and power supply outside of the chamber. The wire test setup is shown in Figure 12.

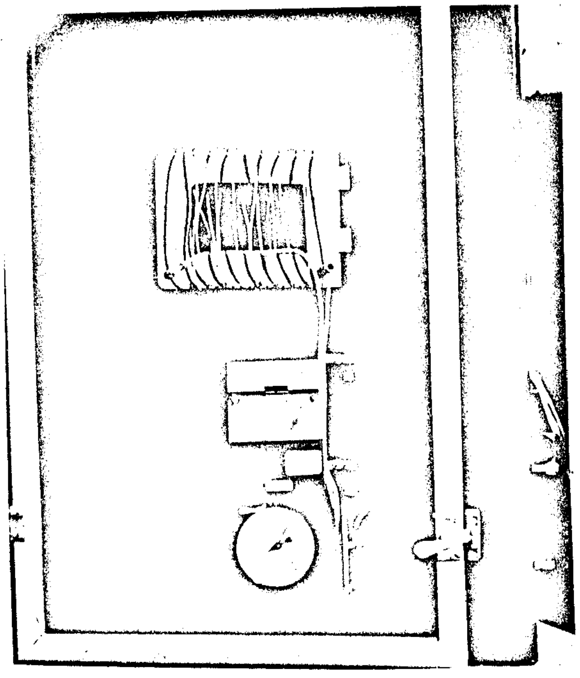

FIGURE 12. ELECTRICAL WIRE SMOKE TEST

A light absorption versus D_s scale was specifically developed for this study based on the wire surface area. A considerable amount of data was obtained on the smoke emission of different insulation configurations under various overload conditions. As far as is known, this is the first technique to provide quantitative data on aircraft wire smoke emission. A total of 13 specimens were evaluated and typical data are shown in Figure 13.

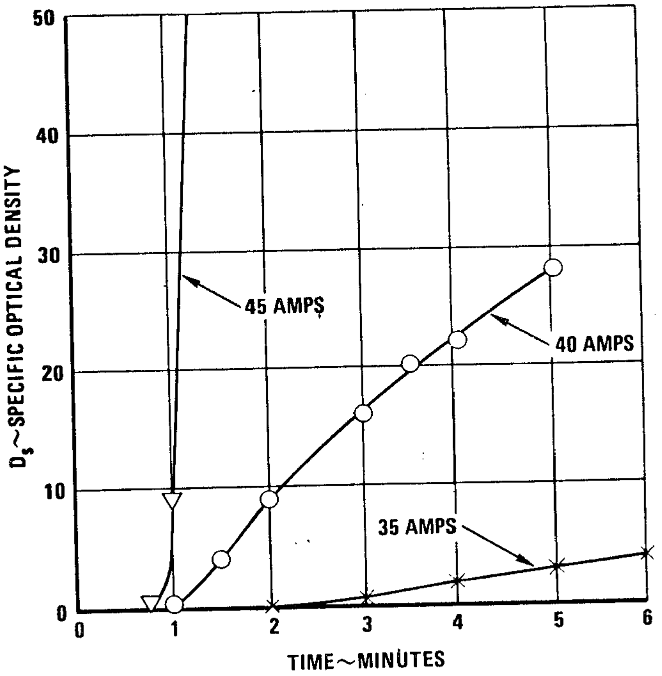

FIGURE 13. TYPICAL ELECTRICAL WIRE SMOKE DATA SHEET

The information obtained from these wire studies can be used to approximate the amount of smoke generated from a given length of wire in a closed compartment whenever circuit breaker switches fail. From these studies the most promising low smoking candidates for aircraft electrical wiring insulations are high temperature thermoplastic alloys.

With the increasing recognition of the importance of materials smoke emission in a fire situation, a need has evolved for standardized test procedures. Thus, close association has been maintained by Lockheed with NBS and other industry investigators to standardize on procedures and correlate data from comparable materials.

A final aspect of materials investigation has been the analysis of the products of thermal decomposition. A technique has been developed to automatically sample for six different gases while performing the smoke emission test. To perform such an analysis, the use of commercial colorimetric detector tubes, sensitive to different gases is utilized as shown in Figure 14. Although this method is simple, inexpensive and gives a rapid analysis of by-products generated, the accuracy is limited. Results from these tests provide information on materials which may indicate the need for a more sophisticated study into the gases evolved during combustion.

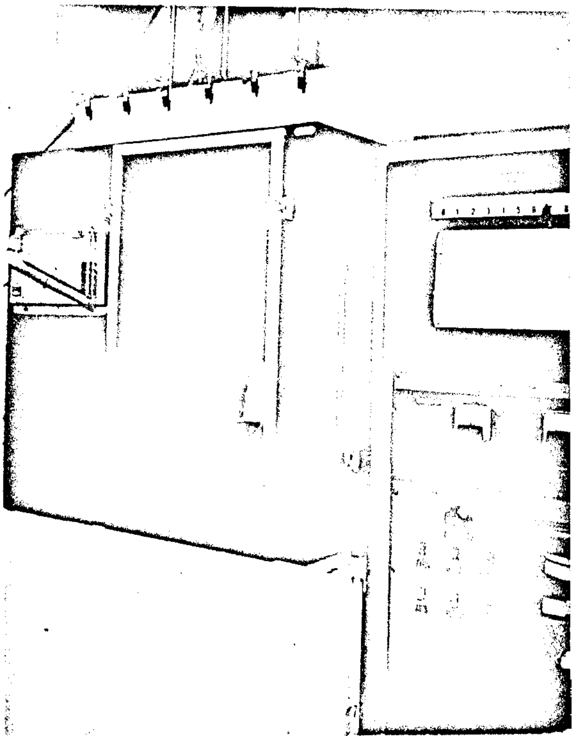

FIGURE 14. GAS ANALYSIS TESTS

Summary and Conclusions

As new and improved fire retardant material candidates become available, they are subsequently evaluated. Advanced fire safety test techniques continue to be investigated and developed in a continuing program. Active participation in several cooperative programs continues on standardization of test procedures. These research and development studies into the reactions and characteristics of aircraft interior materials under pyrolytic and flaming conditions will result in safer airplanes for the '70s.

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3. Gross, D., Loftus, J. J., and Robertson, A. F., "Method for Measuring Smoke from Burning Materials," Symposium on Fire Test Methods - Restraint and Smoke 1966, ASTM STP 422, Am. Soc. Testing Matls., 1967, p. 166.

APPENDIX I
FLAMMABILITY TEST PROCEDURES USED BY LOCKHEED*

	Requirement
A. *Upper Surfaces and Side Panels, and Flooring of Passenger Compartments 1. Interior ceiling panels 2. Interior wall panels 3. Partitions (including galleys and other large cabinet walls) 4. Carry-on hat racks 5. Luggage bins 6. Cargo liners 7. Wall panels below top of windows 8. Structural flooring 9. Draperies and curtains 10. Thermal and acoustical insulation and its covering *NOTE: Do not separate layers for testing	Test Method 5902 of CCC-T-191b with 60 sec. exposure to flame (1550°F min). Must self-extinguish. Burn length: 6" or less. Extinguishing time: 5 secs. or less. Drip extinguishing time: 3 secs. or less. (Vertical Test)
B. Large Area Materials in Crew and Passenger Compartments 1. Decorative floor covering 2. Trays and galley furnishings 3. Upholstery 4. Seat cushions and padding 5. Decorative and non-decorative coated fabrics 6. Leather 7. Transparencies not in (c) 8. Electrical conduit 9. Air ducting 10. Molded and thermoformed parts 11. Joint and edge trim strips (decor. and chafing)	Test Method 5902 of CCC-T-191b with 12 sec. exposure to flame (1550°F min). Must self-extinguish. Burn length: 8" or less. Extinguishing time: 15 secs. or less. Drip extinguishing time: 5 sec. or less. Thick foam: Use 1/2" thick specimen. (Vertical Test)
C. Specialty Materials 1. Acrylic cabin and cockpit windows 2. Edge-lighted instrument assemblies 3. Seat belts 4. Small items (isolated or protected) knobs, handles, rollers, elastomeric seals, hose and parts, wire bundle clips, grommets, rub strips, pulleys, materials in metal containers, other small non-metals	Horizontal burn rate: 2.5"/min. or less per Test Method 5906 of CCC-T-191b. Use 1/8" thick flat specimens from the generic material.
D. Cargo Compartments 1. Cargo liners (for cargo only) 2. Liners (for convertible passenger/cargo)	1. Materials meet 25.853(a) as applicable. 2. Meet 30 sec. flame test at 45° 8" x 8" panels (AMS 3851A). Panel must self-extinguish. No flame penetration. Extinguishing time 15 secs. or less. Glow time 10 secs. or less.
3. Insulation blankets and covering	3. Meet A above.
4. Cargo tie down equipment	4. Horizontal burn test: 2.5"/min. or less

*These procedures satisfy requirements of FAR Part 25.853, 25.855. In some cases they are more stringent.