CSR 027

An awesome challenge

New FAA Regulations Improve Aircraft Fire Safety

by Constantine P. Sarkos

Constantine P. Sarkos manages the Fire Safety Branch and Aircraft Systems Fire Safety Program at the Federal Aviation Administration (FAA) Technical Ctr. He has been involved in the various activities and topics covered by the program, including materials fire tests, full scale tests, seat cushion blocking layers, fire management, hand fire extinguishers, postcrash fire protection, combustion toxicology, and in-flight fire safety (current emphasis).

The Federal Aviation Administration (FAA) has undertaken an unprecedented series of regulatory actions over the past two years for the purpose of improving aircraft interior fire safety. These initiatives are part of a broad, scheduled program to enhance airliner safety that includes such diverse topics as water survival, child restraints, and crashworthiness.[1] They are a culmination of a number of factors, including advisory committee recommendations,[2] congressional support, product oriented FAA technical programs, accident pressures, and industry cooperation.

The jet airliner presents a unique, if not awesome, fire protection design challenge. A cabin interior is furnished and lined with polymeric materials. Passengers are confined inside a relatively small enclosure. Inaccessible compartments contain potential ignition sources and combustible materials. Wing tanks are laden with thousands of gallons of aviation fuel. After weighing these factors, the aircraft fire accident record appears better than might be imagined, especially when compared against the approximately 6,000 civilian fire deaths per year in the United States.[3] For example, an estimated 32 people per year died from the effects of fire in accidents involving U. S. air carriers from 1965 to 1979.[2] Also, roughly one airliner per year is destroyed by accidental fire. When these fire losses are contrasted against the exposure of people and property, the record is indeed good. For example, in 1984, the U. S. major airline fleet of 2,072 aircraft carried 262,686,000 passengers.[4] Nevertheless, although fatal aircraft fires are rare and the annual losses are relatively small, the potential loss of life and property in one accident is very high. This is undoubtedly the underlying concern behind the movements for improved aircraft fire safety.

At the time of this writing, the regulatory actions resulting from FAA research include three final rules, two proposed standards, two new technical standard orders (TSO), and a revised advisory circular (AC). The subjects addressed by the final rules are as follows: Seat cushion flammability;[5] floor proximity emergency lighting;[6] and smoke detectors and fire extinguishers.[7] The proposed standards cover cargo compartment fire protection[8] and improved flammability test requirements for cabin materials.[9] Emergency evacuation slides[10] and crewmember protective breathing equipment[11] are dealt with in the new TSOs. Hand held extinguishers[12] are addressed in the revised AC.

Seat Cushion Flammability

Aircraft seats are typically constructed of fire retardant polyurethane foam and upholstery fabric, which must pass the Bunsen burner test prescribed in Federal Aviation Regulation (FAR) 25.853.[13] However, under the conditions of a severe cabin fire, the foam core becomes involved and significantly contributes to the spread of fire. The concept of a fire blocking layer material to encapsulate and to protect the polyurethane foam was recommended for evaluation and development by the Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee.[2]

The initial phase of FAA evaluation consisted of a series of full scale tests to determine the effectiveness of the seat cushion fire blocking layer concept under the conditions of an intense postcrash fuel fire. Prior work by others was limited to the evaluation of fire blocking layers under moderate fire conditions for office, theater, institutional, and

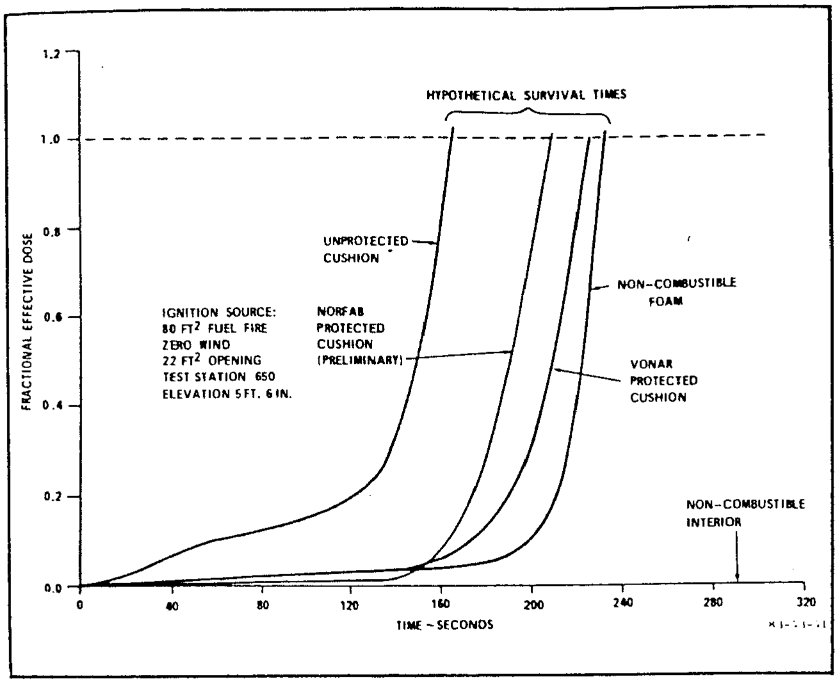


Figure 1—Effect of Seat Cushion Protection on Hypothetical Survival Time

surface transit vehicle settings. The FAA full scale tests were conducted in a new building with the capability of subjecting aircraft test articles to large jet fuel pool fires.[14] A C-133 airplane modified to resemble a wide body interior was employed as the test article. Basically, a section of the C-133 test article was lined and furnished with actual cabin materials and subjected to an external fuel fire placed adjacent to a simulated fuselage rupture. The results of four tests with modified seat cushions,[15] but with all other test aspects identical, are shown in Figure 1. The fractional effective dose accounts for the effect of measured levels of toxic gases and elevated temperature on survival, with a value of unity indicating incapacitation. The additional time available for escape when the seats were protected with Vonar® and Norfab® fire blocking layers was 60 and 43 s, respectively, and was comparable in the case of Vonar to the safety benefits provided by noncombustible foam cushions. Further testing demonstrated that blocking layers could provide even greater improvements against certain types of ramp and in-flight fires, for example, preventing fires that may otherwise become out of control when initiated at an unprotected seat and left unattended.[16] Although these data demonstrate the efficacy of the fire blocking layer concept, extensive additional FAA work was needed to make the concept into a viable product. This additional work covered the subjects of weight optimization and durability,[17] flotation,[18] cost-effectiveness,[19] and certification testing of cushions.[20]

The final rule establishes that transport aircraft seat cushions must meet new and more severe flammability requirements by November 26, 1987.[5] The new test methodology subjects seat back and seat bottom cushion specimens to a burner with temperature and heat flux typical of a cabin fire (Figure 2). Unlike most flammability tests, the test specimens simulate the end use seat configuration and allow for the burning interaction of upholstery cover, fire blocking layer, and foam cushion. Criteria for acceptance consist of 10 percent allowable weight loss, a burn length of 17 in., and a performance essentially matching that attained by the Vonar and Norfab blocking layers.

Aircraft seat manufacturers, airframe manufacturers, and airlines are developing and implementing seat fire blocking layer technology that not only meet FAA flammability requirements, but also have improved weight, durability, comfort, and cost features. The leading blocking layer materials are polybenzimidazole (PBI) fabric, PBI/Kevlar® blends, spun lace aramid, and PBI felt, with all materials weighing between 6 to 10 oz/yd^2. A remaining challenge is to develop practical, lightweight upholstery covers or foam cushions that achieve compliance with FAA seat flammability requirements without the use of a separate blocking layer material.

Floor Proximity Emergency Lighting

Rapid passenger evacuation is the most critical and overriding consideration in postcrash cabin fire safety. Buoyant hot smoke from a fire, however, clings to the cabin ceiling and rapidly obscures conventional ceiling mounted emergency illumination and exit signs, thereby prolonging evacuation time. The resultant reduction in visibility and escape guidance may occur when the lower portion of the cabin is relatively free of combustion products. FAA tests have demonstrated the effectiveness of emergency lighting placed below the smoke layer in the proximity of the cabin floor. In one study, the improved visibility of floor proximity lighting systems, including lights mounted on armrests, floor mounted electroluminescent lights and self powered betalights, was evidenced during full scale postcrash cabin fire tests.[21] Another study translated the improved visibility of low level lighting to faster evacuation rates.[22] People were able to evacuate in approximately 20 percent less time from a cabin simulator filled with stratified theatrical smoke when seat mounted lighting illuminated the main aisle than from the simulator with conventional ceiling lights. In a third study, the degree of merit of 11 improved emergency lighting systems was evaluated on the basis of illumination, reliability, cost, and other parameters.[23]

The final rule, published on October 26, 1984, requires floor proximity emergency escape path marking to enable passengers to visually identify the emergency escape path along the cabin aisle and to readily identify each exit by reference only to markings and visual features not more than 4 ft above the floor.[6] All in-service airplanes, type certificated after 1958, must comply with the new design standards within two years.

Smoke Detectors and Fire Extinguishers

As the result of investigations of in-flight fires, including the Air Canada DC9 on June 2, 1983, that resulted in 23 fatalities, and an inspection survey of the U. S. air carrier fleet, FAA amended the FARs with the following requirements: a smoke detector in each lavoratory, an automatic fire extinguisher in each lavatory trash receptacle, increased number of hand fire extinguishers, and the use of Halon 1211, or equivalent, as the extinguishing agent in at least two of the hand fire extinguishers.[7] A separate time period is specified for implementation of each requirement, with the longest period extending to April 29, 1986.

FAA supportive experimental and analytical studies for these amended regulations have concentrated on the effectiveness and safety of Halon 1211 (bromochlorodifluoromethane) hand extinguishers. Initial tests showed the superiority of Halon 1211 in knockdown and extinguishment capability against fuel drenched seat fires in comparison to water, dry chemical, and carbon dioxide extinguishers. However, opposition to the usage of Halon 1211 centered on the toxicity associated with the agent and, in particular, its decomposition products. Subsequent tests by the FAA clearly showed that virgin agent and decomposition gas concentrations peaked at levels significantly below values considered dangerous, and rapidly dissipated due to the effect of dilution and ventilation.[24] Typical gas profiles measured near an extinguished seat fire are shown in Figure 3. Most importantly, it became evident that the hazards associated with an uncontrolled seat fire would quickly surpass those transient hazards resulting from Halon 1211 decomposition,[24] and would result in cabin flashover within 3 to 4 min if left unchecked.[15] To place a conservative upper limit on the quantity of agent that could safely be discharged inside a compartment, a perfect stirrer model was used to analyze the decay of agent concentration due to ventilation.[25] Nomographs developed from this analysis predict maximum safe agent weight for a given compartment volume and ventilation rate, and are incorporated in a revised AC on hand fire extinguishers.[12] In a related study, testing under simulated flight conditions demonstrated that a 2 ½ lb Halon 1211 extinguisher could be safely discharged inside a small general aviation airplane.[26]

Cargo Compartment Fire Protection

Lower cargo compartments in large transport aircraft are categorized as either class C or class D types.[13] The latter are small compartments designed for fire containment by oxygen starvation, while the former are larger

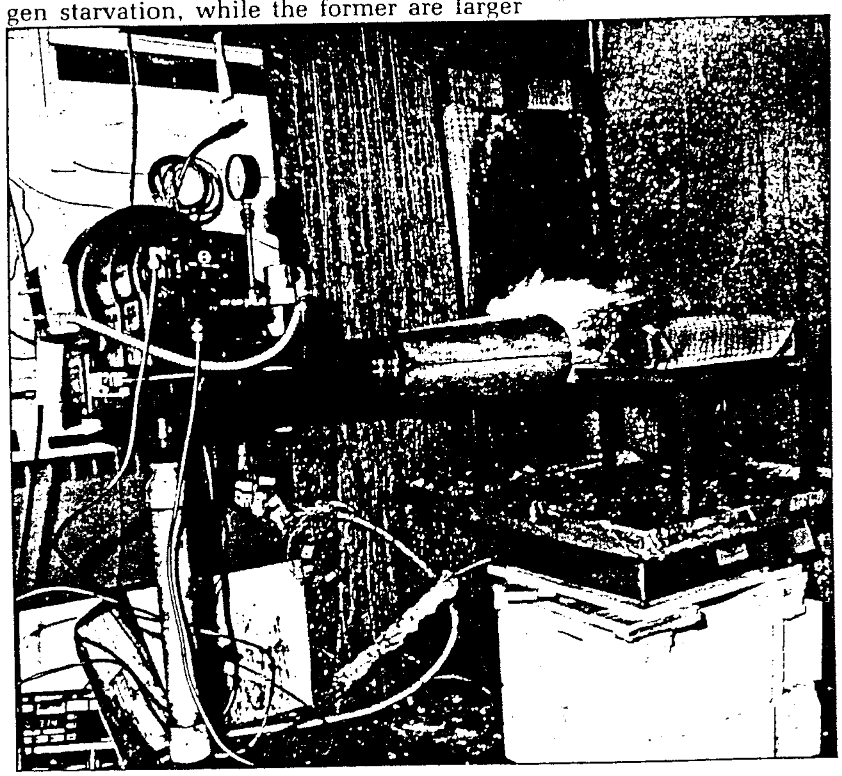
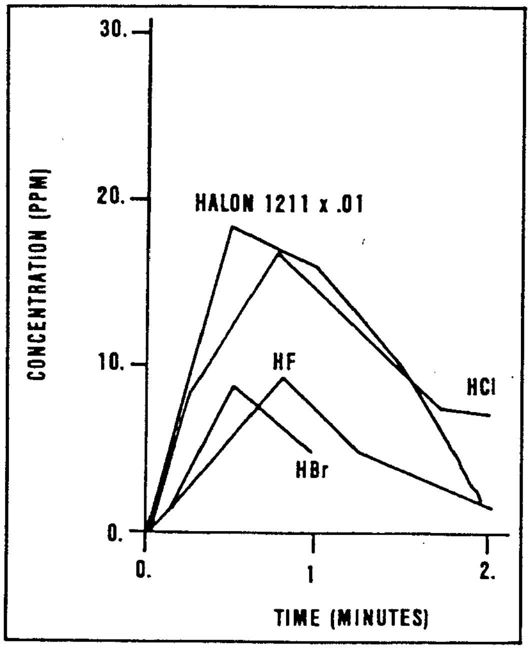


Figure 2— Seat Cushion Flammability Test Apparatus

Figure 3—Cabin Gas Profiles During Halon 1211 Extinguishment of a Seat Fire



compartments that are required to have a fire detection and suppression system. FAA conducted full scale fire tests to investigate the resistance of cargo liners to flame penetration for both compartment classifications. In a class D compartment, where it is critical that liners not be breached in order to allow oxygen starvation to take place, it was found that some types of liners failed.[27] Fiberglass liners resisted burnthrough, whereas, Nomex liners were penetrated by the flames (Figure 4). It was concluded that a class D cargo fire was controllable if fiberglass or equivalent were the liner materials, but, if Nomex were used, the fire would continue to burn because of the availability of oxygen due to liner failure. In tests conducted inside a class C cargo compartment, even with a detection/suppression system, liner burnthrough resistance equivalent to fiberglass was required to ensure fire suppression under all scenarios.[28] For example, Kevlar liner burnthrough occurred when sudden, intense flaming fires were employed and when a time lapse was allowed between the points of detection and discharge of suppression agent. The main conclusion from the testing was that a more realistic and severe test requirement was needed for cargo liners used in both class C and class D cargo compartments.

A new fire test method that measures the burnthrough resistance of cargo liners was developed with the features of severe liner exposure, matching the maximum heat flux and temperature measured during full scale tests, and realistic ceiling and sidewall liner orientation.[29] This test method is the basis of a proposal to upgrade the fire safety standards for cargo or baggage compartments.[8] Criteria for acceptance are that there must be no flame penetration of ceiling and sidewall specimens and that the temperature measured above the ceiling specimen must not exceed 400°F. The flame penetration criterion can be met by fiberglass liners but not by Nomex or Kevlar liners.[29] However, many fiberglass liners cannot meet the peak temperature criterion because of the type or weight of resin and type of cloth weave.[30] It currently appears that fiberglass suitably tailored to meet the peak temperature criterion will be the material of choice for future requirements although several new materials or combinations are being touted.

Improved Flammability Test Requirements

In addition to the new rule for seat cushion flammability, the FAA has proposed improved flammability test requirements for the larger interior surface materials above the cabin floor, such as sidewalls, ceilings, stowage bins, and partitions, to further enhance postcrash fire survivability.[9] This proposed standard is the result of experimental studies conducted by FAA that demonstrated the potential for improved safety under certain fire scenarios, leading to the development of appropriate fire test requirements.

The potential for improved safety was examined in the C-133 wide body test article used earlier for evaluation of the effectiveness of seat cushion fire blocking layers. A section of the test article was fitted with sidewalls, stowage bins, ceiling, and a partition, each constructed of an advanced composite panel selected by the National Aeronautics and Space Administration (NASA), as well as fire blocked seats and carpet, and subjected to three types of full-scale fire conditions. The same tests were repeated with a panel design used extensively in early wide body interiors and still retained for some interior applications. The safety improvement associated with the advanced panel when compared to the in-service panel was significant. With the advanced panel, flashover was actually prevented when the external fuel fire was adjacent to a door opening or when an in-flight fire was started from a gasoline drenched seat. In the more severe ruptured fuselage scenario, wherein seats are more directly exposed to the external fuel fire, use of advanced panels resulted in a 2 min delay to the onset of flashover.[31]

A complex and controversial aspect of the development of appropriate test requirements is the need to address the three most commonly stated concerns associated with burning materials: flammability, smoke, and toxicity. Earlier, the FAA had sponsored research to develop a combined hazard index (CHI) test methodology, a means of weighing the importance of each factor, but later abandoned this approach for lack of valid models for postcrash cabin fire and human escape impairment.[32] Moreover, subsequent full-scale postcrash cabin fire tests demonstrated that hazardous levels of smoke and toxic gases resulted from flashover, defined here as the sudden and rapid uncontrolled growth of fire from a relatively small area surrounding the ignition source to the remainder of the cabin.[14,15,16,31] Typical C-133 test data exhibiting this behavior is shown in Figure 5. Before the onset of flashover, which occurred at about 150 s, the smoke and toxic gas levels were minimal and survival was clearly possible. After the onset of flashover, smoke and toxic gas levels and temperature very suddenly increased to a level that would have made survival highly unlikely. Thus, since flashover is related to flammability considerations, an appropriate improved flammability test requirement will also implicitly reduce smoke and toxic gases under postcrash conditions; that is, intense, open fires of short duration.

The selection of an improved flammability test method was made from correlation studies of data from candidate test methods and data from aircraft model[33] and large-scale[34] fire tests. A modified version of the Ohio State Univ. (OSU) rate of heat release apparatus used in ASTM E 906, Test Method for Heat and Visible Smoke Release Rates for Materials and Products, was determined to be the most suitable test method for material qualification. A schematic of the modified OSU apparatus is shown in Figure 6. The equipment is basically a flow through device that measures the heat release rate produced as a function of time by a material subjected to a preset level of radiant heat flux. Criteria for acceptance was based primarily on demonstrated safety improvement, performance of in-service materials, and availability of advanced materials. Both newly manufactured transports, type certificated after January 1, 1958, and such in-service transports undergoing cabin interior replacement, would be required to comply with the new standard two years after its effective date.[9]

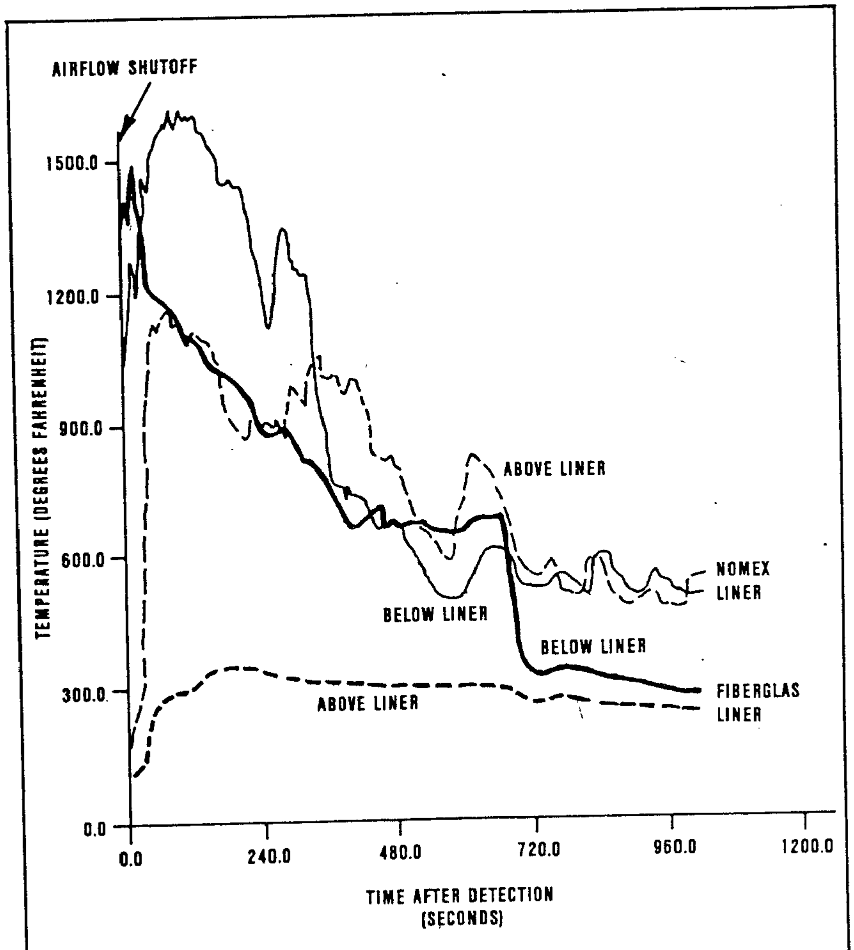


Figure 4—Cargo Liner Resistance to Burnthrough

At this time, it is difficult to predict whether the proposed standards, if enacted, would result in the introduction of new types of cabin materials. The aircraft manufacturers can be expected, at least initially, to attempt to utilize production materials to redesign panels that cannot meet new standards. Meanwhile, resin suppliers are evaluating the feasibility of and gauging the market for commercialization of advanced resins developed by NASA.[35]

Crewmember Protective Breathing Equipment

Criteria for design of flight crewmember protective breathing equipment (PBE) is contained in TSO-C99, issued by the FAA on June 27, 1983.[11] The FAA has also prepared a notice of proposed rulemaking, presently undergoing Executive Branch coordination, that would require the following: flight crewmember PBE meet the otherwise optional standards of TSO-C99; equivalent portable PBE for flight attendants; and hands on training for all crewmembers in fighting typical cabin fires.[1]

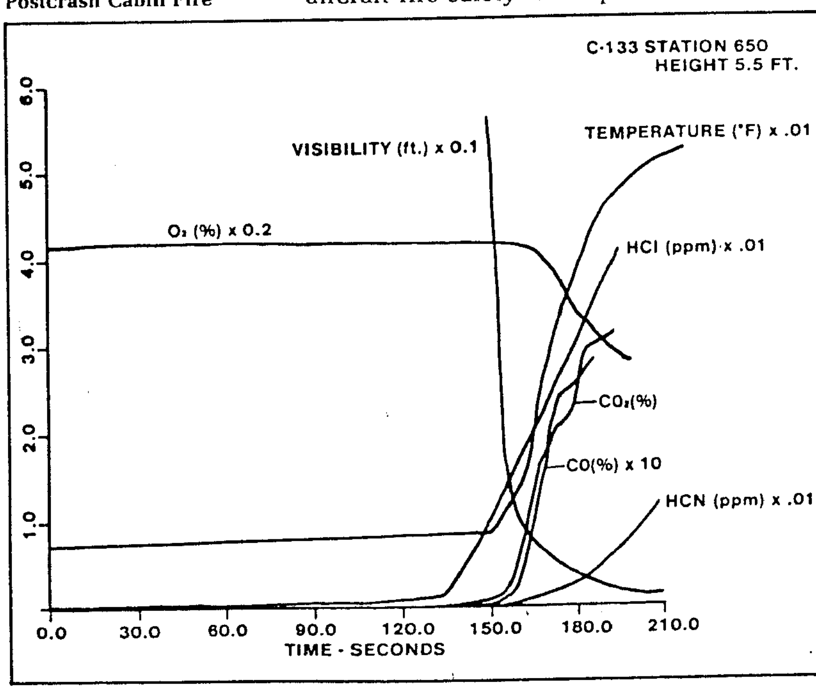
Emergency Evacuation Slides

On June 3, 1983, the FAA issued TSO-C69a, Emergency Evacuation Slides, Ramps, and Slide/Raft Combinations, which made general improvements to the equipment requirements and contained new requirements for radiant heat resistance.[10] The latter was a product of FAA experimental studies, which demonstrated that evacuation slides may collapse from radiant heat damage caused by a reasonably close fuel fire and developed an objective small scale test method for measuring the radiant heat resistance of pressurized slide specimens.[36] Pressure holding members of inflatable evacuation devices are now constructed of aluminized materials in order to provide radiant heat resistance.[37] The impact of TSO-C69a is to require that all evacuation slides purchased after December 3, 1984, meet the new standards.

Summary

Many of the new and proposed FAA regulations for aircraft fire safety evolved from recommendations by the SAFER advisory committee, which dealt with postcrash fire safety. The main thrust of future FAA work in aircraft fire safety is the problem of hidden in-flight fires. Standardization of the improved fire tests methods referenced in this paper is undertaken by ASTM Subcommittee F07.06 on Flammability, a part of Committee F-7 on Aerospace Industry Methods and Aircraft. ●

Figure 5—Typical Hazard Profiles During a Postcrash Cabin Fire



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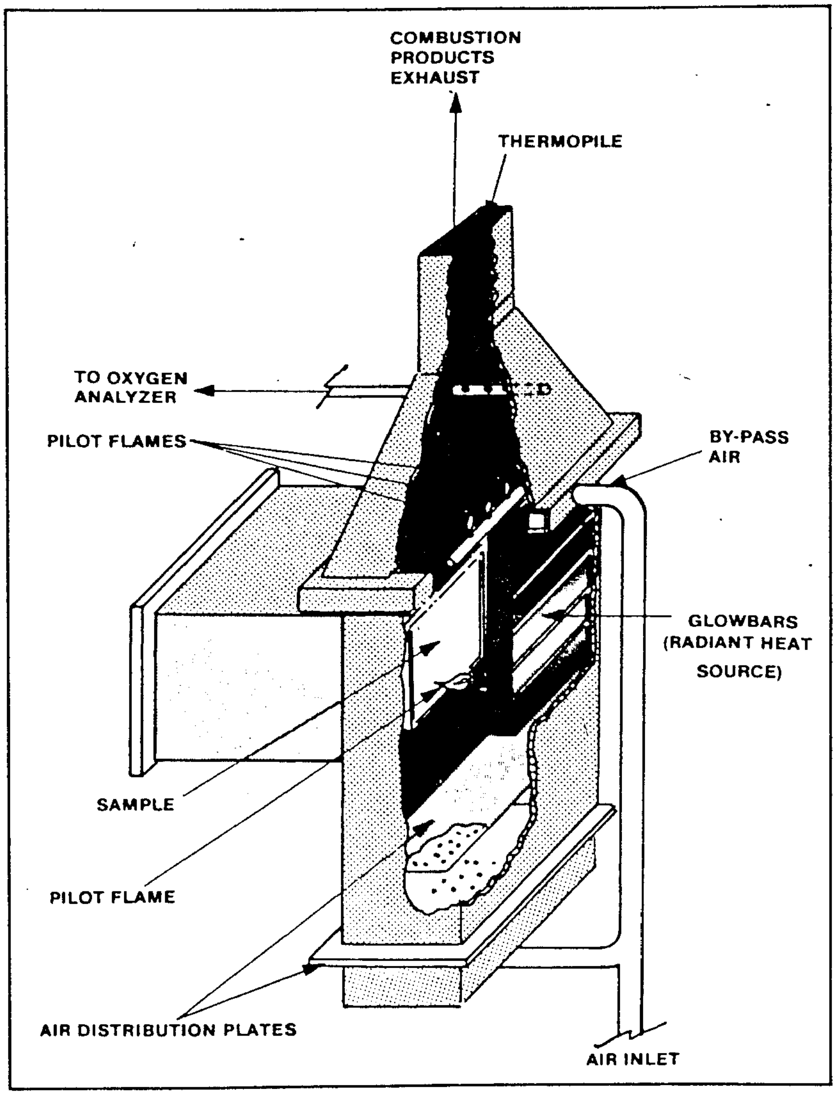

Figure 6—Modified Ohio State University Heat Release Rate Apparatus