Tests for Aircraft Interior Materials in Fire Accident

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Preface

Although a lot of aircraft are survivably intact after an emergency landing, very often many people die because of the development of fire. Fires not only hinder the passengers to escape from the airplane, but also melt the skin of the airplane and warm up or ignite the airplane interior. Most airplane interior materials will burn rapidly and give off smoke and very toxic gases, which then cause death of a lot of passengers who survived the crash itself.

During the past few years, some 'milestone' aircraft fire accidents occurred, leading to significant reforms in aircraft design, equipment, materials and operation. One of the most important methods of providing larger escape times for passengers after a crash, is the development and use of materials with low toxic gas and smoke production and low flammability properties. In order to be able to test all characteristics on these properties, a lot of test-methods have been developed and some of them are prescribed in airworthiness requirements.

This document is intended to be used by persons, not familiar with fire tests and requirements on flammability of materials. Therefore, this document gives a survey of terms often used in connection with aircraft interior materials flammability tests (chapter II). It is advised to fold out the last page of this document, in order to be quickly able to find an unknown term used in the text. After this, a description has been made of a lot of often-referred-to small-scale test methods (chapter III) and of some full-scale test methods (chapter IV). The effects of inhalation of toxic gases and exposure to radiant heat on human beings have been described in chapter V. A full description of the flammability requirements in FAR Part 25 is given in appendices A and B.

An attempt was made to produce a survey of nowadays used or new developed materials and their flammability characteristics. This almost was impossible, because of differences in test methods and test conditions referred to in materials' properties-tables provided by material suppliers.

I wish to thank Marja Eijkman for skillfully positioning the figures in the text. Furthermore, I wish to thank Mr. E. Feldkirchner (from Airbus Industries, Toulouse) for providing information, Mr. A. Beukers (from the Department of Aerospace Engineering, section 'Production and Materials') for his assistance in general, and the members of the staff of the Department of Aerospace Engineering for the valuable discussions during the work on this subject.
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Summary

A survey of terms often used in connection with aircraft interior materials flammability tests is given. After this, a description is made of a lot of often-referred-to small-scale test methods and of some full-scale test methods. The effects of inhalation of toxic gases and exposure to radiant heat on human beings are described. A full description of the actual flammability requirements in FAR Part 25 is provided.

Notice

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Reference to a company or product name does not imply approval or recommendation of any of the products stated in this paper to the exclusion of others that may be suitable.
The tests described may involve hazardous materials, operations, and equipment. These tests do not purport to address all of the safety problems associated with its use.
It is the responsibility of whoever uses the standard test methods described in this paper to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.
### Abbreviations and symbols used in the text

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<td>Acrylonitrile-butadiene-styrene</td>
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<td>AMK</td>
<td>Antimisting Kerosine</td>
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<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
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<td>ATS</td>
<td>Airbus Test Specification</td>
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<td>CAA</td>
<td>Civil Aviation Authority (United Kingdom)</td>
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<tr>
<td>CFS</td>
<td>Cabin Fire Simulator</td>
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<td>CHI</td>
<td>Combined Hazards Index</td>
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<td>CID</td>
<td>Controlled Impact Demonstration</td>
</tr>
<tr>
<td>$D_m$</td>
<td>Maximum specific optical density attained in a test</td>
</tr>
<tr>
<td>$D_s$</td>
<td>Specific optical density of smoke</td>
</tr>
<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
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<td>FAR</td>
<td>Federal Aviation Regulation</td>
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<td>FBL</td>
<td>Fireblocking Layer</td>
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<td>FR</td>
<td>Flame Retardant</td>
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<td>FRPU</td>
<td>Fire-retarded polyurethane foam</td>
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<td>HRR</td>
<td>Heat Release Rate</td>
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<tr>
<td>$I$</td>
<td>Transmitted flux by a light beam</td>
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<td>$I_0$</td>
<td>Flame spread index</td>
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<td>JAR</td>
<td>Joint Airworthiness Requirements</td>
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<td>JPL</td>
<td>Jet Propulsion Laboratory</td>
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<td>LLL</td>
<td>Lawrence Livermore Laboratory</td>
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<td>LOI</td>
<td>Limiting Oxygen Index</td>
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<td>MBB</td>
<td>Messerschmitt-Bölkow-Blohm</td>
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<td>MSDH</td>
<td>Maximum Smoke Density Hazard</td>
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<tr>
<td>NAFEC</td>
<td>National Aviation Facilities Experimental Center</td>
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<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>NBS</td>
<td>National Bureau of Standards</td>
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<td>NPRM</td>
<td>Notice of Proposed Rulemaking</td>
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<td>NTSB</td>
<td>National Transportation Safety Board</td>
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<td>OSU</td>
<td>Ohio State University</td>
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<td>PAS</td>
<td>Polaryl Sulfone</td>
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<td>PDT</td>
<td>Polymer Decomposition Temperature</td>
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<td>PEEK</td>
<td>Polyetheretherketone</td>
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<td>PES</td>
<td>Poluethersulfone</td>
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<td>PMMA</td>
<td>Polymethylmethacrylate</td>
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<tr>
<td>PPBE</td>
<td>Passenger Protective Breathing Equipment</td>
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<td>PPS</td>
<td>Polyphenylene Sulfide</td>
</tr>
<tr>
<td>RHR</td>
<td>Rate of Heat Release</td>
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<td>$R_m$</td>
<td>Maximum rate of smoke accumulation</td>
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<td>SAFER</td>
<td>Special Aviation Fire and Explosion Reduction (advisory committee)</td>
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<td>SOI</td>
<td>Smoke Obscuration Index</td>
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<td>SRR</td>
<td>Smoke Release Rate</td>
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<td>$t_c$</td>
<td>Time to reach a specific optical density</td>
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<td>TGA</td>
<td>Thermogravimetric Analysis</td>
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<td>TLV</td>
<td>Threshold Limit Value</td>
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<td>USF</td>
<td>University of San Francisco</td>
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1 INTRODUCTION

1.1 Introduction

Although the number of accidents in the airline industry is very low, on rare occasions accidents do occur with grave consequences. Fire is a major concern because of the large quantities of flammable fuel carried by the airplane and because of the cabin design, which consists of a densely populated enclosure lined and furnished with a wide variety of materials.

The large amount of combustible materials in a relatively small vehicle designed for transportation of a large number of passengers implies the necessity to consider the performance of those materials in the case of fire as most important for fire safety.

In the survivable impact crash scenario, the threats to human beings in order of importance are [partly from ref. 5]:

- Inhalation of hot toxic gases
- Direct, initially localised exposure to fire
- Smoke, which degrades visibility
- Flashover within the fuselage due to accumulation of combustible products
- Possibility of sudden eruption of fire or of flashover due to explosion of adjacent fuel tanks
- Exposure to radiant heat

1.2 History

In order to minimize the danger associated with the involvement of interior materials in a cabin fire, the Federal Aviation Administration (FAA) has sought to promulgate standards to limit the selection of materials to those meeting certain fire safety levels. Initially, emphasis was placed on the problem of the in-flight cabin fire.

Flammability regulations were first adopted in 1947 with a requirement that cabin materials burn no greater than 10 cm. in a horizontal orientation when subjected at one end to a Bunsen burner flame. Control of the flame spread rate was intended to provide sufficient time for the extinguishment of an incipient fire. With the availability of new and better fire-resistant materials, the FAA was able to upgrade the materials flammability regulations several times.

The crash of a Boeing 727 at Salt Lake City, Utah, in 1965 perhaps was the first source of concern about fire and toxic gases in the potential fire hazard in an aircraft cabin interior with many sorts of synthetic materials. A fire originating at a ruptured fuel line underneath the cabin floor instantly spread at first impact into the cabin, which remained intact during the entire crash deceleration. The hazard created by the rapid fire involvement of the cabin materials was believed to have
contributed to the enormous loss in life. One important aspect stressed by the survivors was the very heavy smoke that obscured vision and seriously impaired the ability of passengers to evacuate the cabin.

The concern with smoke emissions caused the development of a number of laboratory-type smoke measuring devices. The NBS smoke chamber was considered by the FAA to be the most compromising for characterizing the smoke emission characteristics of aircraft cabin materials.

The first indication in an actual accident of the potential dangers associated with the toxic combustion products emitted by burning cabin materials was also provided by the Salt Lake City crash in 1965. As part of an extensive crashworthiness program by industry and government arising out of this accident, the FAA contracted with the Bureau of Standards to measure the smoke and toxic gas emissions of a large number of aircraft interior materials.

New rules for fireworthy airliner cabins were contemplated by the US Federal Aviation Administration (FAA) in 1978. The new FAA proposals require materials to exhibit low heat release (see 'definitions'); virtually all in that time current production cabin materials would be eliminated by the new proposals [ref. 4]. The FAA originally proposed that materials with a heat release of 65 kw/m² (measured by OSU tests) should be applied by August 1988 to all new or refurbished aircraft carrying more than 19 passengers. The FAA has since amended this to 1990, though requiring 100 kw/m² by 1988. The intent of this regulation is to delay the spread of fire in a post-crash scenario allowing passengers more egress time before the non-survivable flash-fire occurs. The cost of compliance with the 65 kw/m² proposal will be high, because this requires a lot of research to be done in laboratory in order to get more different materials with various properties for specific purposes.

The upgrade of August 25, 1988, establishing refined fire test procedures and apparatus and a new requirement for smoke emission testing, is described in Appendices A and B. In these appendices also a full description of FAR-Part 25 concerning flammability is given.

I.3  Airbus Test specification

The Airbus Test Specification (ATS-1000.001) in fact is an extended version of the FAA regulations. In first instance, the ATS-1000.001 covered smoke and toxicity requirements, unlike the FAA regulations at that time. All Airbus cabin material suppliers must comply with ATS-1000.001. [ref. 16]

Since August 25, 1988, the FAA regulations include new requirements for smoke emission. However, toxicity still is not a part of the FAA regulations. Airbus is now working on a new release (number five) of the ATS-1000.001, which would have much stronger requirements than issue four.
1.4 Reforms in aircraft design

During the last few years, there have been some ‘milestone’ aircraft fires: a Saudia TriStar at Riyadh on August 19, 1980, an Air Canada DC-9 on June 2, 1983, and a British Airways Boeing 737 accident on August 22, 1985 at Manchester. This last accident may well be one of those safety milestones that led to significant reforms in aircraft design, equipment, materials and operation. One of those reforms may be the development of new smokehoods, which perhaps should be mandatory airline passenger safety equipment, like seatbelts, lifejackets and oxygen (see chapter II, ‘Definitions’).

Another new method is the water-mist spray system developed by the British company Save. It is stated [ref. 10,15] that the water mist washes out toxic gases and smoke, absorbs infrared heat, and like any water, wets things, making them fire-retardant. The cabin would require three spray pipes, one along the ceiling centre-line fed by onboard water, and the other two, fed externally, along the bins.

A so called ‘Air screen system’ in combination with Aircraft cabin compartmentation is an other possibility to provide protection for flashover and toxic gases [ref. 35]. Air and smoke from the upper areas in the interior are extracted through grilles near ceiling level. It is then exhausted by the extraction system, provided by a fire vehicle outside. Smoke and products of combustion, which arrive at the airscreen, will be deflected by the flow to a smoke extraction tube and then it is exhausted via the overhead duct.

In 1984, the FAA adopted a new cabin safety rule, effective Nov. 26, establishing new performance standards for floor proximity emergency escape path markings. The rule requires airlines to meet the new standards in two years from the effective date [ref. 32]. With these markings mounted in an airplane, evacuation could proceed when cabin lighting more than 4 ft above the aisle floor (normally used in the interior), would be totally obscured by smoke [ref. 24]. Another new development is the fuel called ‘Anti-Misting Kerosine’ (AMK) [ref. 117]. When a high molecular weight polymer is blended into aviation kerosine, the resulting fuel is able to resist the formation of small droplets under impact-survivable crash conditions, which otherwise could cause a severe fire. This fuel has been tested in a full scale test, described in chapter IV.2.2.

Some disadvantages of AMK are [ref. 23]:

1. Fuelling with AMK of aircraft not equipped for it is possible,
2. It is possible to mix the wrong proportion of the safety ingredient,
3. AMK is expensive,
4. Failure of one or more degraders causing engine malfunction can occur.

1.5 Different sorts of aircraft fires

Aircraft cabin fires may be categorized as follows: ramp, in-flight, and postcrash. The characteristics of each are sufficiently distinct to require separate analysis.
Ramp fires occur when an aircraft is parked at the ramp, usually in an unattended condition, but on less frequent occasions during servicing. The majority of ramp fires is caused by electrical system and servicing errors, during oxygen system changing. Post-ramp fire experience has resulted in loss of property but not in loss of life.

Most in-flight fires occur in accessible areas, such as a galley, and are detected and extinguished promptly. Other causes of in-flight fires are electrical malfunction and cigarette smoking [ref. 38]. On rare occasions in-flight fires become uncontrollable, leading to large loss of life. Of some 'milestone' in-flight cabin fires, uncontrollable in-flight cabin fires developed in three cases, and all three aircraft were survivably intact after an emergency landing. Yet nearly 450 people died in these three accidents [ref. 14,24].

Most fatalities attributable to fire occur in postcrash fire accidents and often are accompanied by a large fuel spill fire. The postcrash fire occurs after an aborted take-off or a crash landing. More in detail, the causes of the accident could be: hard landing, gear-up landing, gear collapse, landing short, over-shooting the runway, and impacting into obstructions or terrain during takeoff or landing. If such a crash occurs, the impact may be survivable. However, frequently a fuel fire occurs because the wing tanks are one of the most vulnerable parts of an aircraft with respect to mechanical damage. Safety of passengers has to be achieved then at least for the period of time necessary for the evacuation.
II DEFINITIONS AND DESCRIPTION OF ITEMS

Airplane interior - Any area or compartment within the pressurized shell of the airplane.

A.S.T.M. - The American Society for Testing Materials (ASTM) is a scientific and technical organization whose prime function is to develop standards on characteristics and performance of materials, products, systems and services. Numerous test methods concerning flammability of plastics have been developed by ASTM. [ref. 79]

Burn length - Burn length is the distance from the original edge to the farthest evidence of damage to the specimen due to flame impingement, including areas of partial or complete consumption, charring, or embrittlement, but not including areas sooted, stained, warped, or discolored, nor areas where material has shrunk or melted away from the heat source. [ref. 36, 16]

Burnthrough resistance - For realistic testing of the burnthrough resistance it is necessary to simulate temperature, intensity and to a certain amount the size, i.e. the quantity of heat of a large fuel fire.

Material temperature, which is essential for material failure under the impact of a flame, is not only determined by the flame temperature but also by:

- heat transfer coefficient between skin and flames
- density and specific heat of the material
- radiative losses on both sides
- thermal conductivity of the material.

The complex interconnections described imply the necessity of using a relatively large fire source and samples which are much larger than those normally used for (small scale) laboratory testing. [ref. 37]

Ceiling Panel - From a fire safety consideration, panels are clearly the most important category because of their large surface area and upper cabin location where peak fire temperatures are expected.

Initial full-scale tests in the Federal Aviation Administration Technical Center’s C-133 test article (described in chapter IV) have demonstrated [ref. 1] two ways ceiling panels contribute to postcrash fire hazards:

1. During the initial stages of the fire, the thin layer of decorative laminate applied to the facing surface of the panel sheets ignites and drops to the floor as flaming debris. This then accelerates the spread of the fire to the seats below that have not already been ignited directly by the pool fire.
2. The remainder of the panel consisting of front and back facesheets and honeycomb core thermally decomposes and adds fuel to the cabin environment. This is presumed to contribute to the onset of flashover. [ref. 1,36]
Char - Carboneous material formed by pyrolysis or incomplete combustion. [ref. 99]

Char yield - The (anaerobic) char yield is measured thermogravimetrically at 800°C C at a fixed applied radiative heating rate [ref. 65]. The hypothesis for seeking higher char yields in synthetic polymers was that retaining carbon in the char would make that carbon unavailable for oxidation to carbon monoxide and carbon dioxide, or for fragmentation into low-molecular-weight combustible organic compounds. Reducing the carbon monoxide and carbon dioxide produced would reduce the heat of combustion, and reducing the combustible organic volatiles would reduce the probability of reaching the lower flammable limit and producing flammable mixtures. Reducing the carbon monoxide evolved would also reduce toxicity due to carbon monoxide. Attaining higher char yields theoretically would reduce both the thermal threat and the toxic threat from plastics in fire situations. [ref. 86]

The advanced materials offer greater values than 35 for the char yield; they are virtually nonflammable in air and produce little or no smoke or toxic gas. [ref. 3]

Combined Hazards Index (CHI) - The CHI for any material is expressed in terms of the number of seconds of escape time available from a ‘theoretical’ fire before conditions become nonsurvivable due to a combination of heat, smoke and toxic gases. Each individual hazard is rated according to its severity, thus for example, Hydrogen Cyanide (HCN) which at 100 parts per million causes incapacitation in five minutes is about thirty times as toxic as Carbon Monoxide (CO), which has a hazard level of 3000 ppm in five minutes.

The prediction of escape time is based on the addition of the various factors each expressed as a ‘fractional dose’ - that is the percentage of the dose needed to incapacitate due to that hazard alone. When the sum of the fractional doses acquired in a test reaches one, the possible time for escape (and hence the CHI) is known. Thus a ‘good’ material is found to have a high value and is ranked accordingly. [ref. 3,7,35]

Note: According to [ref. 5] this method is a valuable technique, which reduces a ‘fairly large number of somewhat abstract measurements into a single, cogent parameter’. In [ref. 7] it is mentioned that this approach would certainly benefit from further refinement to consider, ‘for example synergistic effects of different gases’ (i.e. gases where the combined effect is more serious than the sum of the individual effects). In contrast to this remark, in [ref. 71] it is extensively described that for several reasons synergism of the inhalation toxicity of fire gas is unproved.

Combustible gas evolution - Combustible gas evolution may be defined as the amount of combustible gases evolved from the burning or pyrolysis of a material, and their tendency to produce flashover, under given conditions of exposure. [ref. 38]

Combustion - A chemical process of oxidation that occurs at a rate fast enough to produce heat and usually light either as a glow or flame. [ref. 99]

The combustion of solids occurs in three stages. At first, thermal decomposition causes volatile matter to be driven out of the solid. Secondly, flaming combustion of these products occurs, leading to the generation of heat. After that transport of this heat back to the polymer surface restarts the cycle. The rate at which oxygen of the air diffuses to its surface controls the burning
of the hot solid residue. [ref. 35]

**Decomposition temperature**  - The decomposition temperature ($T_D$) is the temperature range associated with the decomposition of a material in the presence of oxygen. It depends strongly on the chemical nature of the material and, to a lesser extent, on its specific shape. The decomposition temperature marks the beginning of a relatively rapid development of different low-molecular-weight products, most of which are flammable. Most decomposition processes are exothermic in the presence of sufficient oxygen, capable of self-propagation, and can be considered as significant heat sources for attaining flame reproduction. [ref. 96]

**Drip flaming time**  - The drip flaming time is the time that any dripping material continues to flame after dripping to the floor of the chamber. If there is more than one drip, the longest drip flame time has to be recorded. If succeeding drips reignite earlier drips, then the total flame time has to be recorded.

**Fire blocking layer**  - A fire blocking layer is designed primarily to function as a thermal barrier. It would accomplish the following:

- insulate, to delay the involvement of foam cushion in the fire situation
- provide mechanical enhancement of the tear strength of the foam cushion  [ref. 52]

**Fire endurance**  - A measure of the elapsed time during which a material or assemblage continues to exhibit fire resistance [ref. 99]. Thus, fire endurance may also be defined as the resistance offered by a material to the passage of fire. This characteristic is relevant to fire safety in that a material (considering its related installation, detail, and structure), that will contain a fire, provides more protection than one that will fail to contain the same fire, all other factors being the same in both cases. Some measures of fire endurance are penetration time and resistance time. [ref. 38, 79]

**Fire hazard**  - A fire risk greater than an acceptable level. [ref. 99]

**Fire involvement**  - Fire involvement is largely dependent on material pyrolysis and flammability. It comprises the interaction of a number of factors that contribute to the generalization of lethal cabin conditions: ease of ignition, flame spread rate, heat release, and smoke and toxic gas emission. All of these factors interact cooperatively to reduce the probability of passengers either to escape or to survive. These properties depend on the thermochemical properties of the basic polymer of which the interior component is constructed as well as on the size and intensity of the applied fire source. [ref. 3]

**Fire isolation (= containment)**  - There are two distinct thermochemical mechanisms by which interior materials systems can interact with a given fire source. These mechanisms can be defined as fire isolation (containment) and fire involvement (described before).

In a closed system situation with limited or no egress, the containment of a fire within a compartment is directly relevant to the safety of occupants in adjacent compartments. Fire containment capabilities are generally determined by measuring the time needed for a given heat
flux applied to the exposed face of a material to produce a specified effect at the unexposed face or back side. [ref. 3,51]

Fire load - One of the classic approaches to understand the potential severity of fires in a given space has been to measure the 'fire load' or potential heat release under fire conditions. The fire load on aircraft can be divided into three categories:
1. FAR Part 25 Materials installed by the air frame manufacturer
2. FAR Part 25 Materials installed or FAR Part 121 Materials put on board by the airlines
3. Materials worn or carried on board by passengers [ref. 38]

Flame impingement time - The time in seconds that the flame from the burner is in contact with the specimen. [ref. 97]

Flameproofing agents - Flameproofing agents which interfere in the combustion process at any point can work on a physical or chemical basis, and we can distinguish further as to whether they work in the solid or liquid (that is to say 'condensed') phase or in the gas phase.

The chemical effect consists for example of disturbing radical-chain reactions in the gas phase and thus possibly terminating them. A fire retardant chemical can be a part of the molecular structure, an admixture or an impregnant. [ref. 99]

Purely physical effects are achieved, for example, by absorbing heat, if appropriate by endothermic processes (such as melting or decomposing), or by forming covering layers. [ref. 61]

Flame propagation - The rate at which flames will travel along surfaces depends upon the physical and thermal properties of the material, its method of mounting and orientation, the type and level of fire or heat exposure, the availability of air, and properties of the surrounding enclosure. [ref. 93]

Flame spread - The propagation of a flame away from the source of ignition under given conditions of burning. Thus, it defines the amount of material, or surface area, involved in the fire as a function of time. [ref. 46]

This characteristic provides a measure of fire hazard, in that flame spread can transmit fire to more flammable materials in the vicinity and thus enlarge danger, even though the transmitting material itself contributes little fuel to the fire. Some measures of flame spread are burning rate or combustion rate, flame spread factor, flame height, burning extent or distance of flame travel.

Because flame spread is a surface phenomenon, it is critically affected by whether combustible gases are evolved at the surface, or are evolved in the interior of the material and escape at the surface.

The ignitability characteristics of a material have directly to do with flame spread: flame spread requires that successive sections of surface are brought to the ignition temperature as a result of the heat flux produced by the advancing flame [ref. 114]

Flame time - Flame time is the time interval after removal of the burner to the end of specimen flaming. Since a small, immobile flame that can vary in duration from one test to another is observed on some materials after removal of the burner flame, flame time generally is less
Flammability - Those characteristics of a material that pertain to its relative ease of ignition and relative ability to sustain combustion. [ref. 103]

Flash-fire - The flash fire phenomenon involves several processes of gas-phase combustion reactions of the volatile products of polymer degradation and air. A flash fire will occur if combustible vapors produced by polymeric materials mix with air during thermal decomposition of the material and the mixture is then ignited.

Any combustible vapour mixed with air will propagate flame only within a certain range of concentrations. Below a certain concentration, called the 'lower limit of flammability', the concentration of combustible is not sufficient to support flame propagation. Above a certain concentration, called the 'upper limit of flammability', the concentration of oxygen is not sufficient to support flame propagation. [ref. 49]

Factors such as heating rate, type of heating, heat release, ignition source, and the chemical nature of the polymeric material affect the rate and type of combustibles generated, and thus the material's flash-fire propensity. It is worth noting that materials which tend to evolve combustible gases more rapidly than they can be burned at the site of the parent material are more likely to produce an accumulation of combustibles and therefore have a greater flash fire propensity [ref. 49].

Extreme rapidity of flame propagation seems to be generally considered as characteristic of a flash fire [ref. 84].

See also 'flashover, note'. [ref. 14, 54, 84]

Flash-Ignition-temperature - The lowest initial temperature of air passing around the specimen at which a sufficient amount of combustible gas is evolved to be ignited by a small external pilot flame. [ref. 112]

Flashover - Flashover can be defined as a stage in the development of a contained fire in which all exposed surfaces reach ignition temperature more or less simultaneously and fire spreads throughout the space and flames appear on all surfaces. This fire spread occurs like a fire ball instantly filling the interior, which can be presumed to be completely lethal [Ref. 14, 35, 38, 51, 65, 84, 114].

Note: The difference between flashover and a flash-fire is not always considered. Some authors only mention flashover as a combination of flashover (as defined in this paper) and flashfire. But others, like for example [ref. 14, 51 and 114] emphasize that there exist differences between those two terms.

In short, the differences are: at a flash-fire one looks at the concentrations of combustible gases evolved (as a result of thermal exposure) that can be ignited, and flashover occurs due to the heat released during decomposition, which is as high as the auto-Ignition temperatures of the exposed surfaces. [ref. 14, 35 and 114]
Flash point - The lowest temperature, corrected to 1.0 atmosphere of pressure, of a sample at which application of an ignition source causes the vapour of a sample to ignite momentarily under specified conditions of test. [ref. 99]

Glow time - The glow time is the duration of combustion without visible flame occurring after removal of the external flame or after cessation of the self-perpetuating flaming of the material. [ref. 97,110]

Heat flux - The thermal intensity indicated by the amount of energy transmitted per unit area (W/cm²). Since heat flux is a function of distance from the heat source and is reduced by intervening materials, placement and design of the material in the system can often determine whether or not ignition will occur in a particular fire situation. [ref. 103]

Heat of combustion - The amount of heat released in the oxidation of one mole of a substance at constant pressure or constant volume. Also known as ‘fuel value’ or ‘heat value’. The heat of combustion must be in excess of the ignition point, or the flame will extinguish itself. [ref. 95]

Heat release - Heat release may be defined as the heat produced by the combustion of a given weight or volume of material. This characteristic is relevant to fire safety in that a material that burns with the evolution of little heat per unit quantity burned will contribute appreciably less to a fire than a material that generates large amounts of heat per unit quantity burned.

Heat release is expressed in terms of energy per unit area (kilowatt-minutes per square meter). The amount of heat released depends on the burning environment. [Ref. 38,50,51,54,87,114]

Hydrocarbon equivalent (HC-value) - Chemical analysis of the combustible gases evolved from a material can provide an indication of flash fire propensity. One approach proposed is the calculation of the Hydrocarbon equivalent (HC-value) of each compound relative to its lower limit of flammability. The HC values for all the significant combustibles present are added, and the extend to which the total HC value approaches 1.0 (the theoretical lower limit of a mixture composed of paraffin hydrocarbons) is determined. This approach has limitations in that it is valid only for the particular conditions under which the material was decomposed, and only if the significant combustibles from the particular material are included among the compounds analyzed. [ref. 49,86]

Ignitability - The facility with which a material or its pyrolysis products can be ignited under given conditions of temperature, pressure, and oxygen concentration.

Some measures of ease of ignition are autoignition temperature, flash ignition temperature, and ignition sensitivity.

Almost any material can be made to ignite, given enough heat, enough oxygen, and enough time. Ease of ignition can therefore be determined by keeping two of the three under fixed conditions and measuring the amount of the third one required. [ref. 114]

Ignition - Ignition can be defined as that process by which a rapid exothermic reaction is initiated, which propagates, or is self-sustaining, and causes the material involved to undergo change, reaching temperatures greatly in excess of ambient. [ref. 9]
Limits of flammability - Any combustible vapour mixed with air will propagate flame only within a certain range of concentrations. Below a certain concentration, called the 'lower limit of flammability', the concentration of combustible is not sufficient to support flame propagation. Above a certain concentration, called the 'upper limit of flammability', the concentration of oxygen is not sufficient to support flame propagation. [ref. 49]

Limiting Oxygen Index - The LOI is the minimum concentration of oxygen, expressed as volume percent, to allow for ignition by a small pilot flame [ref. 4 and 94]. If a material has a high LOI, this material will be hard to ignite and easier to extinguish. [ref. 24]

N.B.S. - The National Bureau of Standards (NBS) develops and issues a variety of standards and testing techniques. The NBS smoke test is one of the most widely accepted smoke density tests. [ref. 79]

Optical density of smoke - A measure (D) of the attenuation of a light beam passing through (visible) smoke, expressed as the common logarithm of the ratio of the incident flux, I_o, to the transmitted flux, I. D = \log (I_o/I). [ref. 44,99]

Pyrolysis - Irreversible chemical decomposition caused by heat, usually without oxidation. The thermal decomposition products can ignite spontaneously or be ignited by an igniting source. The pyrolysis gases are burnt in the resulting flame. The temperature of the polymer will be further increased by heat conduction or heat radiation, and the pyrolysis continues. [ref. 61,99]

Sandwich constructions - Generally, interior panels are composite structures composed of a honeycomb core, resinimpregnated cloth facings and a decorative laminate. Over the past 10 years, NASA has developed and evaluated improved panel component materials. The main approach has been to increase the anaerobic char yield in order to improve fire performance. PEEK often is selected as the decorative film in advanced panel design, primarily to eliminate the production of hydrogen fluoride during thermal decomposition of the polyvinyl fluoride film commonly used in the past [ref. 4].

Composites used in interior applications may react to fire in one of two ways. They may function as fire barriers and contain or isolate the fire or they may contribute to flame spread, leading to flashover, smoke, and toxic gas emissions. [ref.65]

It can be seen [ref. 65] that graphite/phenolic and graphite/ polyimide structures with matrix resin char yields between 50 and 60 % and glass temperatures in excess of 350° C show fire endurance thirty times greater than the epoxy-based structures. It may be presumed that the ablation efficiency and high heat distortion temperatures account for this significant improvement in the fireworthiness of these composites. [ref. 3,4,5,37,50,63,64,65]

Self-ignition temperature - The lowest initial temperature of air passing around the specimen at which, in the absence of an ignition source, the self-heating properties of the specimen lead to ignition or ignition occurs of itself, as indicated by an explosion, flame or sustained glow. [ref. 112]
Smoke - Smoke consists of airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion. [ref. 99]

Current methods of measuring smoke are divided into two general classifications: physical, in which instrumentation is used, and biochemical.

Physical methods include:

1. optical or light attenuation;
   - smoke being allowed to flow through a tube, and the attenuation of a light beam focussed across the tube onto a photoelectric device that measures the reduction in light transmission
   - smoke being accumulated in a chamber, and measuring the reduction in light intensity

The NBS smoke test and the ASTM D-2843 test are examples of optical methods.

2. gravimetric or weight; the weight of smoke particles deposited on a filter under specified conditions is determined. Examples of the gravimetric method are the ASTM E-162 test and the Arapahoe smoke test.

3. measuring the gases involved in smoke or analyzing the particles evolved.

In biochemical procedures, animals are exposed to smokes generated under various sets of conditions, and the responses of the animals are observed and measured.

The most striking feature of a cabin fire is the smoke layer. Smoke obscuration may lead to confusion or panic of the passengers, and is thought to be one of the critical factors in delaying or preventing the escape process in otherwise survivable fires [ref. 5]. A hot, smoky layer can nullify the benefit of ceiling-mounted emergency lighting, possibly by causing thermal failure in the units, or by obscuring exit signs or blocking illumination. The smoke layer appears, because of upward pression (warm gases are lighter than cold gases), to cling to the ceiling.

The cabin environment may be approximately described by two zones [ref.63]:

- a hot zone at the ceiling, which thickens as the fire progresses, with a linear temperature profile
- a much cooler zone in the lower cabin with a uniform, but above ambient, temperature

The temperature differential between the ceiling and the lower cabin is very large. In the test described in [ref. 63] at 2½ minutes the differential was higher than 540° C. This has to be realised when doing tests on cabin interior materials: ceiling materials are exposed to higher convective heat fluxes than are carpets, for instance.

It is stated [ref. 4] that significant smoke obscuration can occur without hazardous levels of toxic gases or elevated temperatures, but mostly this is not the case in aircraft fires because of the arise of immense heat produced by fuel fires.

It is shown [ref. 3] that as long as the polymer does not melt or flow (as do, for example epoxides, urethanes and phenolics) all of the significant fire-involvement properties of the bulk polymers, such as flame spread rate, ease of ignition, smoke obscuration, and toxic gas
production, vary in a regular way (usually linearly) with the vapour production rate of the polymer being heated. Moreover, it was also showed that this relative vapor production rate can be accurately determined by the simple thermogravimetric analysis of the anaerobic char yield. [ref. 3,4,5,35,38,51,53,61]

Smoke density - The degree of light or sight obscuration produced by the smoke from the burning material under given conditions of combustion. Some measures of smoke density are degree of light absorption, specific optical density, and smoke development factor.

Smoke hood - Smoke hoods are Passenger Protective Equipment (PPBE) that could be used by passengers during a cabin fire for protection against smoke and toxic gases. Contemporary PPBE designs incorporate either stored oxygen or a filter for removing toxic gases in order to provide the wearer with breathable air. Each of these types has a different way of allowing the wearer to breathe [ref. 35].

The filter type removes the particles and poison gases produced by a typical plastics fire, such as hydrogen cyanide, hydrogen chloride, hydrogen fluoride, nitrogen oxides, sulphur dioxide, and (with a special catalytic filter at extra cost) carbon monoxide. The filter must remove these gases and smoke particles without breakthrough for such a period of time that a physically stressed hard-breathing survivor will be able to escape. A typical commercially available filter gives about five minutes protection [ref. 18].

The breathable gas hood is inevitably bulkier and heavier and more expensive. An integral bottle (cartridge) of oxygen or compressed air is used [ref. 18].

Smoke release - Smoke release is a measure of the quantity of smoke evolved by a material when burned. It is expressed in terms of a dimensionless quantity called Specific Optical Density, which is proportional to the mass of smoke evolved per unit area. [ref. 114]

SMOKE unit - the concentration of smoke particulates in a cubic metre of air that reduces the percent transmission of light through a 1-m path to 10 %. SMOKE = Standard Metric Optical Kinetic Emission. [ref. 91]

Smoldering - Combustion of a solid without flame at a relatively low temperature, often evidenced by visible smoke. Smoldering can be initiated by small sources of ignition, and may persist for an extended period of time after which a flame may be produced [ref. 99].

Smoldering combustion is important in aircraft fires because:

1. It may start in relatively inaccessible locations and go undetected for relatively long periods of time. It may then break out at some critical time such as when the aircraft is in flight or left unattended on the ground.

2. Gases produced are toxic to the occupants and may incapacitate the flight crew.

3. A transition to flaming combustion after a long period of smoldering may produce a very rapid growing fire because of the preheating of fuels and accumulation of combustible gases during the smoldering period. [ref. 38]
Specific optical density - The specific optical density of smoke, noted as $D_s$, is defined as the logarithm of the reciprocal of the light transmitted through the medium. For example, if the light transmitted through a medium is 10% of that incident upon it, the optical density is 1; if the light transmitted is 1%, the optical density is 10, etc. Thus, the smaller the $D_s$ value, the better the material. The specific optical density is a calculated value that reduces the area smoking, the volume involved, and the light path all to unity.

$$\text{Specific optical density} = \frac{V}{A \cdot L} \cdot \log_{10} \frac{100}{T}$$

In which: $V = \text{chamber volume}$, $L = \text{length of light path}$, $A = \text{exposed sample area}$, $T = \text{light transmission (\%)}$.

Other values of interest are $D_m$, the maximum specific optical density obtained in a test and $T_m$, the time that it occurs. [ref. 2,38,61,72]

Synergism - Synergism is the interaction of discrete agencies or agents such that the total effect is greater than the sum of the individual effects. [ref. 35,71]

Toxic gas - Toxic has been defined [ref. 114] as poisonous, or destructive to body tissues and organs or interfering with body functions. The toxic gases evolved from materials involved in fires may lead to incapacitation and death, and are the principle threat to life safety when the thermal threat is minor or insignificant.

Underwriters Laboratories (UL) - UL is an independent nonprofit organization that develops standards and test methods, operates laboratories, and issues certification, all in the interest of public safety. [ref. 79]

Weight loss - Weight loss of a material is an important parameter since it corresponds directly with the amount of visible smoke and other toxic gases produced during the pyrolysis of a sample. A lower rate of weight loss corresponds with a lower rate of pyrolysis products produced.

The percent weight loss is governed by this equation [ref. 72]:

$$\text{Percentage weight loss} = \frac{\text{weight loss at any time interval}}{\text{original weight}} \cdot 100$$
III SMALL SCALE TESTS

III.1 Introduction

Materials intended for aircraft and aerospace applications differ markedly from other materials and other applications in a number of respects: they are highly engineered materials because of the emphasis on maximum strength and minimum weight; they are employed in environments that permit limited or no egress in the event of fire; and they face possible exposure to high levels of heat flux because of the large quantities of fuel in an airplane. The post-crash fire is the most severe and best-known situation.

Materials used in aerospace applications have to be evaluated by means of appropriate fire response test methods. As fire research sophistication increases, so should the degree of systematic approach to test methods.

The basic properties of materials are [partly from ref. 114]:

- Propensity to ignite
- Smoke emission
- Heat release
- Toxic gas emission
- Flame spread velocity
- Burnthrough resistance [ref.37]
- Smolder susceptibility
- Flash fire propensity
- Fire endurance
- Ease of extinguishment

To a person unfamiliar with the details of fire tests, it would appear that the material that exhibits superior performance in one fire test, would exhibit superior performance in any other test. Unfortunately, this is not always the case since relative performance can vary considerably depending upon the test used.

Many variables influence the results [ref. 14,46]:

- specimen orientation
- form of the test specimen
- air velocity (if applicable)
- material thickness and width
- type of fuel
- flame pattern
- chamber temperature
- outside temperature
- humidity
- percentage of oxygen
- elevation

With all these parameters influencing combustion, it is not surprising that little correlation occurs between the various existing tests.
There should be full agreement on type of testing and evaluation criteria all over the world in order to be able to compare different materials. Wool for example is quite an enormous emitter of hydrogen cyanide when really burning, but it has a low heat-release, emits a cool nonsticking ash, and has one of the highest 'limiting oxygen indices', which means that it is hard to ignite and easier to extinguish [ref.24]; thus the passengers will have enough time to evacuate before the emitting of toxic gases or other problems relating to fire will start. In fact, it should be questioned whether this material is to be rejected taking into account the large escape time before being dangerous.

III.2 Some influences on test-results

III.2.1 Influence of Specimen Orientation

Orientation is well known to have a very dramatic effect on burn rate. Burning upward vertically for flame spread rate measuring is usually avoided by investigators because it is so rapid that tracking of the flame front is difficult.

Vertical burning rates are about 10 times as rapid as horizontal rates. This occurs as a result of the extensive preheating of the material ahead of the flame front by hot gases convecting over the surface, whereas the horizontal position only tends to heat the air above the burning location. For test purposes, 45° appears to represent a reasonable compromise between the very rapid vertical burning and the slower horizontal burning. [ref. 5 and 46]

III.2.2 Influence of specimen width

Burn rates tend to increase with specimen width. Presumably, this is caused by less convection inflow of cooling air from the specimen edges as the specimen becomes wider. Also, heat transfer to the material ahead of the flame front is dependent upon the flame size. The larger flame sizes accompanying the wider specimens probably increased the burn rate. [ref. 46]

III.2.3 The influence of sample thickness on smoke density

If the smoke density is plotted against the sample thickness or sample weight, an approximately linear curve region is first obtained, where the smoke density is proportional to the weight or thickness used. The curve then flattens off more and more, until it finally ceases to rise despite an increasing sample thickness. This effect is due to the fact that at relatively large thicknesses the material is no longer completely decomposed, for example because of poorer heat conduction and the formation of coketype covering layers.

The point on the curve where the linear part changes into the non-linear part is called the 'critical thickness'. In order to be able to convert the smoke density to a unit sample weight and then to
obtain identical values, the values of the smoke density must be taken from the region of proportionality; thus the sample thickness must be below the ‘critical thickness’.

III.2.4 Influence of altitude

Subjection of specimens to altitude lowers the partial pressure of oxygen and also reduces the convective heat transfer. Thus the burning rate at higher altitudes will be lower. From full scale tests it can be concluded [ref. 46] that decompression to normal cruise altitudes reduces the severity of the fire and may aid in control. However, it does not extinguish it. Higher altitudes which extinguish the fire are not operationally feasible. Re-ignition is likely with any fire, even if the fire is temporarily extinguished, because descent would soon be necessary in such an emergency. [ref. 61]

III.2.5 The influence of dripping

During tests, many materials tend to drip, and thus part of the material escapes decomposition.

There are several solutions to this problem:
- putting a trough on the bottom edge of the sample holder to catch the material which dripped; some of the igniting flames are directed so as to strike the contents of the trough; disadvantages are the insufficient volume of the trough and the different mode of decomposition of the material in the trough
- preventing the drip of the polymer by adding an inert material; disadvantages are that unmodified test material cannot be used, and that the heat conductivity of the material is changed
- referring the smoke density only to the actually decomposed and volatilised material; this method does not, however, take into account the fact that the residues and the dripped material are present in the unaltered state as well as in the partially or completely decomposed state
- locating the sample not vertically but horizontally; in some tests this is not a good solution because of the very slow burning of a horizontally placed specimen

III.3 Description of small-scale tests

III.3.1 Introduction

A short description of several tests will follow now. Some tests are being approved by the FAA, others are not prescribed but used for laboratory research. A survey of these small-scale tests is given in appendix C.

All small scale test methods described in this chapter are intended to measure and describe the properties of materials, products or assemblies in response to heat and flame under controlled
laboratory conditions. They shall not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of those tests may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use.

III.3.2 Bunsen burner exposure test

This test is requested for airworthiness certification of transport category aircraft (see appendices A and B). All parts used inside the pressurized fuselage have to be subjected to a Bunsen burner flame with a temperature of about 840 °C (except for the sixty-degree test where 955 °C is required).

There are different sorts of tests with the Bunsen burner:
- a vertical test (in compliance with FAR 25.853 (a) and (b)) as shown in fig. 3.1,
- a horizontal test (in compliance with FAR 25.853 (b-2) and (b-3), as shown in fig. 3.2
- a forty-five degree test (in compliance with FAR 25.855 (a-1),
- a sixty-degree test (in compliance with FAR 25.1359(d)).

In the vertical test, for materials covered by FAR 25.853(a), the flame must be applied for 60 seconds and then removed. For materials covered by FAR 25.853(b) this time must be 12 seconds. Flame time, burn length, and flaming time of drippings, if any, are recorded.

![Diagram of Bunsen burner test setup](image)

Figure 3.1 General assembly view chamber for vertical and inclined tests [ref. 18].
In the horizontal test, the exposed surface when installed in the aircraft must be face down. The flame is applied for 15 seconds and then removed. With this test the average burn rate is recorded.

In the forty-five degree test, again, the exposed surface when installed in the aircraft must be face down. Flame time, glow time, and whether the flame penetrates (passes through) the specimen are recorded.

In the sixty-degree test wire or cable including insulation is tested. The specimen must be placed at an angle of 60° with the horizontal in the cabinet, with the door open during the test. Thus, complete combustion is obtained by allowing sufficient flow of air. A flame of 955 °C is applied at a test mark for 30 seconds. The burner is mounted underneath the test mark on the specimen, perpendicular to the specimen and at an angle of 30° to the vertical plane of the specimen. Flame time, burn length, and flaming time of drippings, if any, are recorded.  [ref. 77]

Figure 3.2 Chamber for horizontal tests [ref. 12].

III.3.3 NBS smoke chamber (ASTM E-662)

The NBS smoke chamber (see fig. 3.3) is a closed chamber (914 by 610 by 914 mm) where a specimen is exposed to a radiant heat level of 2.5 W/cm² (in order to obtain pyrolysis) and additionally can be exposed to flames by a propane/air burner (for combustion), see fig. 3.4. Thus flaming and non-flaming (= smoldering) conditions can be simulated. A vertical light beam directed toward a photomultiplier serves for measurement of light extinction i.e. smoke density. Parallel to smoke measurement, gas samples are drawn and analyzed for the toxic components most frequently expected from burning plastic material.

The specimen is exposed to the heat source in the sealed chamber until light transmission reaches a minimum value or the elapsed time reaches 20 minutes, whichever comes first (see fig. 3.5). The maximum specific optical density is calculated from the minimum light transmission. The final data format usually is a plot of specific optical density against time.
Figure 3.3  NBS smoke chamber [ref. 38].

The test specimens, according to ATS 1000.001 76 by 76 mm and which can be in thicknesses up to 25.4 mm, are mounted in the vertical position. The results of the test apply only to the thickness of the specimen as tested. The test method is sensitive to small variations of the position of the specimen relative to the radiant heat source and is sensitive to small variations in sample geometry. [ref. 92]

There are numerous features of the smoke chamber worth summarizing which attest to its wide popularity [ref.36]:

- It can test materials in the thickness used in their application.
- The use of two standard exposure conditions tends to differentiate between flaming and non-flaming (smoldering) smoke emissions.
- The chamber is sealed; this is a favorable feature not often found in other tests which allow undetermined amounts of smoke to escape.
- A continuous smoke concentration recording is more beneficial than the ultimate total weight of smoke obtained by filter deposition methods.
- Only the front surface of the material or composite is exposed to ignition, thus representing a realistic cabin combustion condition: the material will generally be impacted by fire from only one direction [ref.51].
Figure 3.4 NBS smoke density chamber [ref. 16].

The NBS smoke chamber is suitable for spacecraft and military aircraft without significant air recirculation systems, but is less appropriate for wide-body aircraft with significant air recirculation. Furthermore, it should be questioned whether the used radiant heat-level of 2.5 W/cm² is high enough: it has been found [ref. 3] that the combustible vapour production rate at the wall of the material is the controlling rate process for all of the fire involvement factors. A heating rate of 2.5 W/cm² is much too low to characterize materials in the usual fire environment, in which case heating rates are found to vary from as little as 0.5 W/cm² to as much as 14 W/cm².

This test has been proposed in an Notice of proposed rulemaking (NPRM) by the FAA in 1975, but never was rendered mandatory. Nevertheless Airbus started to use it as a requirement for all parts inside the pressurized fuselage and now similar requirements are used by almost all suppliers of airplanes and aircraft equipment and furnishing.

The NBS Smoke Density Chamber was developed in 1966 as a modification and extension of the XP2 Smoke Density Chamber.

At Lawrence Livermore Laboratory (LLL) one takes the view that within the lifetime of a fire, the exposure of any material or materials system of interest can be expressed by a series of bracketing parameters (see fig. 3.6); i.e., the material may be exposed to a low heat or a high heat
Figure 3.5  Test set-up, NBS smoke density chamber [ref. 16].

Figure 3.6  Boundary conditions of a fire [ref. 19, 38].
or something in between. It may be exposed to flame or no flame. It may be subjected to no ventilation, to minor ventilation or to considerable ventilation. The variable in the fire regimen is the kind, thickness, and attitude of the material [ref. 53]. A modification has been made, called the LLL modification. This modification consists of adding a ventilation capability and using a variable heater flux of 0-13 W/cm² [ref.38].

III.3.4 Limiting Oxygen Index Test (LOI, ASTM D-2863)

This method, shown in fig. 3.7, is used to determine the propensity of materials to ignite. It has been found applicable for testing various forms of plastic materials including film and cellular plastic [ref. 94]. The test exposes the specimen to an open flame in a controlled nitrogen/oxygen atmosphere and gives a ranking index that may be used to compare materials. The ratio of nitrogen/oxygen is such that concentrations up to 100% oxygen can be obtained. A higher amount of oxygen necessary to sustain ignition would indicate a greater resistance to ignition, and an index rating of 100 would indicate that the material would only burn in an atmosphere of 100% oxygen. Thus, a higher number of LOI indicates that the material is more resistant.

Figure 3.7 Limiting oxygen index test equipment [ref. 94].
According to [ref. 36], the LOI would offer a better discrimination between advanced polymers than the vertical Bunsen burner test. [ref. 36,50,64,94]

III.3.5 OSU heat release rate apparatus (ASTM E-906)

Heat release rate measurements provide, although they do not show the actual full-scale burning characteristics of a material, a sufficient descriptive index of the thermal response of a material to a specific heat flux and test conditions. The HRR enables one to predict realistically the development rate of a fire in an enclosure in which the materials are used.

The air flowing through the test chamber (see fig. 3.8) is heated by the energy released by the burning sample. The amount of heat released by the burning sample is evidenced by an increase in temperature of the outlet gas. By utilizing a heat and mass balance of the air moving through the test chamber, and including the heat losses from the apparatus walls, the heat released by the burning sample can be measured as a function of time. [ref. 60]

In the OSU chamber the sample can be exposed to different radiant heat levels up to 10 W/cm² and it is an open system. Sufficient oxygen is continuously available for the realistic burning process.

Figure 3.8 OSU heat release rate apparatus [ref. 50].

Continuous monitoring of the heat released by the sample is possible and can be accomplished by the measurement of smoke and toxic gases.
This test method provides for radiant thermal exposure of a specimen both with and without a pilot. Piloted ignition may be effected by direct flame impingement on the specimen (piloted, point ignition) or by placing the pilot to ignite gases evolved by pyrolysis of the specimen. The specimen may be tested so that the exposed surface is horizontal or vertical.

Continuing research on fire the American SAFER Committee (Special Aviation Fire and Explosion Reduction Advisory Committee) in 1980 recommended to use the Ohio State University (OSU) heat release rate (HRR) apparatus for research on fire safety of materials and parts used in aircraft construction. The utilized radiant heat is - according to the SAFER Committee - most representative of the post-crash fire environment.

The ability of the test method to discriminate acceptable from unacceptable materials was verified using several generic materials. These materials covered a range of flammability characteristics and each was tested and ranked using the OSU apparatus. The ranking of materials from the OSU tests was identical to that obtained in the full-scale fire facility. Thus, the OSU apparatus demonstrated that it would properly rank the relative performance of interior materials in typical post-crash fires [ref. 40].

There are several differences between smoke measurements in the NBS chamber and in the OSU release rate calorimeter. The NBS chamber is normally run at only one standard flux. Thus it can not be related to a real fire situation where materials are exposed to a spectrum of fluxes. The NBS chamber measures total smoke by accumulating it within the box whereas the OSU calorimeter operates with an airflow through the combustion chamber and total smoke is determined by integration of the instantaneous smoke values [ref. 101].

This method is prescribed by the FAA in FAR part 25, app. F (see appendix B). [ref. 4,7,50,60,64,80,87,91]

III.3.6 Smoke Density Chamber (ASTM F-814)

This method provides a means for determining the specific optical density of the smoke generated by solid aerospace materials and assemblies, including insulated wire. The maximum thicknesses are: for flat specimens 25.4 mm, for thermoplastic foams 12.7 mm, and for insulated wire specimens 6.35 mm.

The method employs an electrically heated radiant-energy source mounted within an insulated ceramic tube in order to obtain nonflaming pyrolytic decomposition. For the flaming condition, a six-tube burner is used to apply a row of equidistant flamelets across the lower edge of the exposed specimen area and into the specimen holder trough. The specimen has been mounted vertically, facing the radiant heater. See fig. 3.4 and 3.5.

Measurement is made of the attenuation of a light beam by smoke accumulating within a closed chamber, due to nonflaming pyrolytic decomposition and flaming combustion. Results are
expressed in terms of specific optical density which is derived from a geometric factor and the measured optical density, a measurement characteristic of the concentration of smoke.

Values determined by this test are specific to the specimen or assembly in the form and thickness tested and are not to be considered inherent fundamental properties of the material tested. [ref. 2,64]

III.3.7 Underwriter's Laboratory vertical flame test (UL-94)

In this test, mostly referred to as the UL-94 test method, the specimen is clamped vertically and a blue Bunsen burner flame is applied to the bottom end of the specimen for a period of 10 seconds and then removed (see fig. 3.9). The duration of combustion is noted. If combustion ceases within 30 seconds after removal of the burner flame, the burner flame is again placed under the specimen for 10 seconds immediately after the combustion stops. The burner flame is withdrawn again and the duration of combustion noted.

![UL-94 vertical test set-up](fig. 3.9)

Figure 3.9 The UL-94 vertical test set-up [ref. 101].

The rating of test specimens in the UL-94 test are as follows:
- V-O if combustion stops within 5 sec and does not drip flaming particles,
- V-1 if combustion stops within 25 sec and does not drip flaming particles,
- V-2 if combustion stops within 25 sec but releases flaming particles or drips during that time, and
- N.R., which means 'non rated', if the combustion does not stop within 25 sec.

The specimens are 152.4 mm in length by 12.7 mm in width by either 6.35 mm, 3.18 mm or 1.59 mm in thickness. Conditions during the test are more severe with a 1.59 mm thick specimen than with thicker specimens. [ref. 101,115]
A somewhat stringent classification sometimes referred to is the rating 94-5V. In this test, the burner is ignited at a remote location from the specimen and adjusted so that the overall flame height is 12.7 cm and height of the inner blue cone is 3.8 cm. The flame is then applied to one of the lower corners of the specimen at a 20° angle from the vertical so that the tip of the blue cone touches the specimen. The flame is applied for 5 sec. and then removed for 5 sec. This process is repeated four additional times. Duration of flaming plus glowing, the distance the specimen burned, dripping, and deformation of the specimen are observed and recorded.

To achieve this classification, the test specimens must not burn with flaming and/or glowing combustion for more than 60 sec. after the fifth flame. Also, the test specimens must not drip. [ref.79]

Materials are classified 94-HB if the rate of flame spread over the horizontal surface is less than specified maxima. These are: if they burn over a 7.6 cm span in a horizontal bar test at a rate of not more than 3.8 cm/min for specimens 0.3 cm to 1.3 cm thick and not more than 7.6 cm/min for specimens less than 0.3 cm thick, or if the specimens cease to burn before the flame reaches the 10.2 cm reference mark. [ref. 79,101]

The flame is applied so that the front edge of the specimen (see figure 3.10), to a depth of approximately 0.6 cm, is subjected to the test flame for 30 sec without changing the position of the burner, and is then removed from the burner. If the specimen burns to the 2.54 cm mark before 30 sec, the flame is withdrawn. If the specimen continues to burn after removal of the flame, the time for the flame front to travel from the mark 2.54 cm from the free end to the mark 10.2 cm from the free end is determined and the rate of burning is calculated [ref 79]. This test is nearly identical to ASTM D-635, rate of burning and/or extent and time of burning, described in chapter III.3.10.

The previously described UL-94 tests are considered to be very subjective tests [ref. 79]. Identical specimens tested by different operators using the same testing equipment can give different flammability ratings. Such variations are attributed to the differences in interpretation of end points, differences in observation techniques, and differences in operators. Proper care in observing the procedure of flame application has to be taken, otherwise the specimen may preheat, overheat, underheat, or unevenly heat, giving inconsistent results.

![Figure 3.10](image-url)  The UL-94 horizontal test set-up [ref. 101].
III.3.8 Burn-through test

Flame penetration can be measured on the Boeing burn-through apparatus (see figure 3.11). This device measures the resistance of the panel to an open flame condition (8-9 W/cm²). The transfer of heat through the candidate sandwich panels is determined by measurement of the backface temperature increase with exposure time. This test gives an indication of the fire containment properties possessed by a given material. Also, an estimate of heat release can be made by measuring the stack gas temperature change; this is similar to the method used to measure heat release in the Ohio State Heat Release Rate apparatus.

The FAA recently introduced a burn through test for lining materials like the one described. This was because a fire originating in a cargo compartment has to be kept contained inside the cargo compartment, to avoid endangering of aircraft functions and of the health of passengers. [ref.37,50]

Figure 3.11 Burn-through apparatus [ref. 50].

III.3.9 Materials response to flame (vertical test specimen) (ASTM F-501)

This test method is intended for use in determining the resistance of materials to flame and glow propagation. In addition to the vertical position of the test specimen and the flame exposure conditions common to tests of this type, this test method also defines gas composition, burner, cabinet, temperature and humidity, and test conditions since it is designated for interlaboratory
testing of similar materials or constructions. This test is designed for use in air atmosphere at standard temperature and pressure. The burner temperature must be at least 843 °C. The specimen is 69.9 by 305 mm, and is positioned with the long dimension in the vertical position. With this test, the flame time, glow time, drip flaming time, and burn length of the sample unit are determined. [ref. 110]

III.3.10 Ignition properties of plastics (ASTM D-1929-85)

This test method covers a laboratory determination of the self-ignition and flash-ignition temperatures of plastics using a hot-air ignition furnace (see figure 3.12). A 3 gram specimen is exposed to air at successively higher temperatures until ignition is observed.

The test must be conducted in the standard laboratory atmosphere of 23 °C and 50 % relative humidity. Prescribed air velocities have to be used. This test is also known as the Setchkin ignition test. [ref. 101,112]

![Figure 3.12](image)

Figure 3.12 Apparatus for measuring ignition temperatures [ref. 101].

III.3.11 Rate of burning and/or extent and time of burning (ASTM D-635-81)

This method covers a small-scale laboratory screening procedure for comparing the relative rate of burning and/or extent and time of burning of self-supporting plastics in the form of bars, molded or cut from sheets, plates, or panels, and tested in the horizontal position.

A bar of the material to be tested is supported horizontally at one end. The free end is exposed to a specified gas flame for 30 s. The time and extent of burning are measured.
The specimens are 125 mm in length by 12.5 mm in width, and of the thickness of material normally supplied. [ref. 111]

III.3.12 Extinguishing characteristics in a vertical position (ASTM D-3801-80)

This method covers a small-scale laboratory procedure for determining comparative extinguishing characteristics of solid plastic materials, using a small flame of controlled size and intensity applied to the base of specimens held in a vertical position.

The procedure consists of subjecting a set of specimens of identical composition and geometry to a standard test flame for two 10-s flame applications. The burner is placed centrally under the lower end of the vertical mounted test specimen, and remains for a flame impingement time (see 'definitions') of 10 s. The duration of flaming of the specimen after removal of the test flame (in seconds) is recorded. When flaming of the specimen ceases, the test flame is immediately replaced under the specimen. After this additional 10-s flame impingement time, again the test flame is withdrawn. The duration of flaming time and glowing time in seconds is measured. The test specimen must be 13 by 127 mm, and not thicker than 12.7 mm. Temperature and relative humidity are prescribed. [ref. 97]

III.3.13 Resistance of materials to horizontal flame propagation (ASTM F-776-'84)

This test method covers determination of the resistance of materials to horizontal flame propagation when subjected to a small flame. It is used for evaluating materials or constructions used in the interiors of aerospace vehicles. The method defines gas composition, burner, cabinet, temperature, and humidity test conditions since it is designated for interlaboratory testing of similar materials or constructions.

Values determined by this test are - like most other small-scale test methods - specific to the specimen or assembly material in the form and thickness tested and are not to be considered inherent, fundamental properties.

The flame temperature must be 843 °C minimum. The test specimen is 102 by 305 mm and is mounted in a metal frame so that the two long edges are held securely. It is inserted in the specimen holder with the exposed surface, as installed in the vehicle, face down. The exposed area of the specimen is 51 by 304 mm.

The flame is applied to the specimen for a period of time as required by the applicable specification. After the burner has been moved away the time required for the flame to travel 254 mm length of the specimen is recorded. The flame time and burn length is determined for materials that extinguish before the length of 254 mm is burned. [ref. 78]
III.3.14 Radiant panel (ASTM E-162)

This test method of measuring surface flammability of materials uses a radiant heat source in front of which an inclined specimen of the material is placed. The orientation of the specimen (size: 150 by 460 mm) is such that ignition is forced near its upper edge and the flame front progresses downward. [ref. 64,93]

A flame spread index ($I_f$) is provided by the combination of a factor derived from the rate of progress of the flame front ($F_f$) and another relating to the rate of heat evolution by the material ($Q$). $I_f = F_f \times Q$. Like for the Steiner Tunnel, this test is not considered to be appropriate for aerospace materials because of differences in geometry and heat flux [ref. 51,72].

III.3.15 The XP2 Smoke Density Chamber (ASTM-D 2843)

Figure 3.13 shows the XP2 Chamber, used for measuring smoke density from burning plastics. It has been criticized both because of the small size of the sample involved and the fact that it represents a single set of fire conditions [ref. 38].

The measurements are made in terms of loss of light transmission through a collected volume of smoke produced under controlled, standardized conditions. A 25 by 25 by 6 mm specimen is placed on a supporting metal screen and burned in a laboratory test chamber under active flame conditions using a propane burner. The size of the test chamber is 300 by 300 by 790 mm. [ref. 38,90]

III.3.16 Arapahoe smoke chamber

This a gravimetric method. The Arapahoe chamber consists of a vertical cylindrical combustion chamber 125 mm in diameter and 175 mm high, a cylindrical chamber stack 75 mm in diameter and 450 mm high, and a filter assembly at the top of the stack. A propane burner mounted at an angle of 10° from the horizontal is mounted in the base of the combustion chamber, and is fed with approximately 90 ml/min of propane to produce a well defined blue flame about 25 mm long. A specimen 38 by 13 by 3 mm is exposed to the burner flame, and the smoke particles are collected on the surface of the glassfiber filter paper at the top of the stack by drawing air through the filter at an initial rate of 127 l/min. The specimen is exposed to the burner flame for 30 seconds with air flowing through the filter. The gas is then turned off to extinguish the burner, and air flow is continued for an additional 30 seconds to give a total collection time of 60 seconds. The air flow is then turned off and the specimen is extinguished if still burning. The filter is weighed before and after the test to determine the loss of material. Smoke is reported as per cent of initial sample or as per cent of material burnt. [ref. 51,85]
III.3.17 The Steiner Tunnel (ASTM E-84) [ref. 12,38,51]

The Steiner Tunnel as prescribed by ASTM E-84, was originally designed to measure the spread of flame across a ceiling surface of building materials. It has been adapted to measure the obscuration of smoke as it passes through the exit flue.

The test requires a specimen 7.62 by 0.496 m., mounted face down so as to form the roof of a tunnel of the same length. The fire source consists of two gas burners, and is adjusted so that a test sample of select-grade red oak flooring would spread flame 5.94 m. from the end of the igniting fire in 5.5 min. ± 15 sec. The end of the igniting fire is considered as being 1.37 m from the burners, this flame length being due to an average prescribed air velocity.

This test method has been subject to criticism both because the location of the sample (some think that wall mounting or floor mounting would be preferable in some cases) and because it represents a limited set of fire parameters. Because aircraft differ substantially from buildings in configuration (which for example leads to differences in heat flux) this test is not considered to be appropriate for aerospace materials. [ref. 38,51]
III.3.18 USF flash-fire screening test

This test uses a vertical combustion tube 45 mm in diameter and 660 mm high, into which pyrolysis gases from a horizontal tube furnace at 800° C are introduced. These gases are permitted to mix with air, and ignited when the volume of flammable gas mixture reaches the hot pyrolysing surfaces. A 0.10 g sample of material is used. The time interval between introduction of the sample and the occurrence of the flash fire, and the height of the flash fire observed, are recorded. [ref. 84,114]

III.3.19 USF Ignitability test

The University of San Francisco ignitability test employs a 50/50 platinum/ rhodium wire heater to provide heat flux up to 13 W/cm². A specimen of 76.2 mm² is supported vertically in a frame such that an area 65.1 mm² is exposed to a specified level of heat flux; time to ignition is recorded. The advantages of this test are the high heat flux and the one-dimensional heat flux needed for engineering evaluation of composite materials. [ref. 51]

III.3.20 USF/NASA toxicity test

This test method involves the exposure of four Swiss albino male mice in a 4.2 liter hemispherical chamber in order to provide an indication of relative toxicity (see fig. 3.14). The routine screening procedure involves pyrolysing a 1.00 g sample at a heating rate of 40° C/min from 200° C to 800° C without forced air flow. Materials are ranked on the basis of time to incapacitation and time to death. The animals used in this sort of tests should show similar behaviour like human beings with respect to toxic gases in order to be able to relate the test results to a real fire situation. [ref. 45,48,49,51]

Figure 3.14 Pyrolysis toxicity apparatus [ref. 45].

III.3.21 NASA Ames T-8 thermal test

This test method is used to determine the fire endurance or fire containment capability of materials (for example for composite panels). In this test (see fig. 3.15), specimens measuring 25 by 25 by 2.54 cm thick are mounted in the chamber and thermocoupled on the backface of the specimen.
The flames from an oil burner provide heat flux to the front face of the sample in the range of 10 - 12 W/cm². The average furnace temperature is about 1000° C. [ref. 45,65]

Figure 3.15 NASA Ames T-3 thermal test [ref. 45].

III.3.22 Thermogravimetric Analyzer (TGA)

Thermogravimetric analysis is a test procedure in which changes in weight of the specimens are recorded as the temperature is increased at a constant rate. Components of a material that volatilize or decompose at different temperatures are quantitatively measured.

Thermal analyses of composite materials can be conducted on a Thermogravimetric Analyzer (TGA) using both nitrogen and air atmospheres with a sample size of 10 mg. A heating rate of 10° C/min is applied.

Pyrolysis in air atmosphere is intended to approximate the environment at the start of a toxicity test, and the pyrolysis in a nitrogen atmosphere is intended to approximate the environment during the test after the original air has been essentially displaced by pyrolysis effluent. [ref. 45]

This test can be used to determine:
1. the decomposition rate (for example of films)
2. the exotherm/endotherm of the materials when decomposing
3. their weight loss

Materials with high exotherms are considered [ref. 64] to be undesirable because of their potential contribution to a fire. Materials with a high weight loss at temperatures below 260° C are undesirable because the gases given off at these low temperatures would contribute like ignitable fuel to a fire.
III.3.23 Extinquishing characteristics

This method covers a small-scale laboratory procedure for determining comparative extinguishing characteristics of solid plastic materials. A small flame of controlled size and intensity is applied two times during 10 seconds to the base of the specimens in a vertical position.

The test results represent flaming and glowing time in seconds for a material of specified shape, under the conditions of the test.
[ref. 97]
IV. FULL-SCALE TESTING

IV.1 Introduction

Fire performance of polymeric materials is usually gauged on the basis of small-scale laboratory tests. A large number of fire tests with a variety of types of measurements is available. It is generally recognized [ref. 4, 47, 63, 85, 96] that these small-scale test results, a priori, cannot predict the performance of a material in a real fire. They do not treat the dynamic range of conditions and important parameters present in such a real cabin fire. Therefore, full-scale fire tests are necessary to determine the potential safety in real fires and to check the trends indicated by small-scale test results. During full-scale tests, important real-world conditions such as fire source, geometry, and scale are reasonably simulated.

Another important application of full-scale fire tests is the analysis of the hazards affecting survivability during a cabin fire. Usually, the hazards of an enclosure fire, such as a fire inside an aircraft cabin, are grouped into three categories: heat, smoke (visibility) and toxic gases. Realistic full-scale tests can provide information which give insight in the relative importance of each of these hazards, and in the effects of different types of fire scenarios on the significance of each hazard category.

There are some different sorts of full-scale testing:

- Full-scale modified C-133 aircraft
- Controlled Impact Demonstration (CID) test with a Boeing 720
- Cabin Fire Simulator (CFS)
- One-third scale simulated aircraft cabin interior

Based on past accidents, experimental studies and knowledge of the design of an aircraft fuselage, it is proposed [ref. 59] that a small opening, perhaps a crash rupture or an inadvertently opened emergency exit, provides the most significant opportunity for fire to enter the cabin.

Ignition and significant involvement of the cabin interior materials by burnthrough of the fuselage structure will be much later in time than when direct fire penetration through an opening occurs. Burnthrough is prevented by thermal and acoustical insulation and by composite honeycomb interior panels. Radiative heat damage to seats adjacent to melted windows (as found in past accidents and tests), however, suggested that this may be an earlier mechanism for burnthrough than fire penetration through skin, insulation and honeycomb paneling.

Whether an interior hazard will develop from an external pool fire is greatly affected by wind, door opening configuration, and fuselage orientation.

The worst case is when the fire is upwind of the fuselage and there is an opening exposed to the fire as well as if there are openings on the downwind side of the fuselage. The pressure distribution over the fuselage can result in significant axial velocity components along the length of the fuselage interior. Thus, an externally initiated fire may be blown through an opening and its spread
will then be increased by the induced flow along the interior of the fuselage. [ref. 27] Rapid development of nonsurvivable thermal conditions within the fuselage will occur.

On the other hand, if no downwind doors are open, but instead there are additional upwind doors open but not exposed to fire, the hazard development in the cabin will be greatly retarded. [ref. 58,59]

It was found [ref.58] that when the wind results in flame penetration into the cabin, the accumulation of heat is primarily by convection, and increases monotonically with wind velocity.

IV.2 Description of full-scale tests

IV.2.1 Full-scale modified C-133 aircraft

The full-scale cabin test article was constructed from a surplus C-133 aircraft modified into a wide-body configuration. A drawing of the test article is shown in figure 4.1 and 4.2. The fuselage diameter of a C-133 is 200 inches, which is slightly smaller than that of a DC-10, which is 216 inches.

![Diagram of C-133 wide body cabin fire test article](image)

Figure 4.1 Schematic of C-133 wide body cabin fire test article [ref. 4,13].

The test article is designed for fire durability to allow for the conduct of numerous tests. For example, a CO₂ total flooding system allows for the selective termination of the test.

The test article is extensively instrumented to measure the major hazards produced by a cabin fire as a function of time at various cabin locations. The following measurements are routinely taken: temperature, heat flux, smoke density, carbon dioxide, carbon monoxide, oxygen, acid gases like hydrogen fluoride and hydrogen chloride, and organic gases like hydrogen cyanide.
Figure 4.2 Installation of wide-body materials inside C-133 test article [ref. 13].

Under the postcrash scenarios, the interior is subjected to an external fuel fire adjacent to an opening (door or fuselage rupture) in the forward part of the fuselage. An additional door opening exists in the rear of the fuselage to simulate an opened exit for passenger evacuation. The main role of the fuel fire is to subject the interior materials to intense radiant heat.

For the inflight scenario, the fuselage openings are covered and a simulated cabin air ventilation is employed. The fire scenario consists of the ignition of a passenger seat doused with gasoline. The tests are performed outdoors, with the primary variables being (uncontrolled) ambient wind velocity and fuel fire size. In order to obtain adequate test repeatability, it is possible to simulate the wind with a large blower at zero ambient wind. [ref. 4,5,13,58,63]

IV.2.2 Controlled Impact Demonstration (CID) test

On December 1, 1984, the FAA and NASA conducted the first remotely piloted air-to-ground full-scale crash test of a transport aircraft. The aircraft used was a Boeing 720. Some photographs of the test sequence are shown in fig. 4.3.

One of the primary objectives of this experiment was to demonstrate a fuel additive called antimisting kerosine (AMK), intended to suppress crash-related fires. After a planned symmetric impact to the ground, a slide through wing cutters and obstructions required for the AMK experiment was followed. Although the aircraft deviated from the planned impact profile, the impact was judged to be survivable and the desired impact data was obtained. The cabin maintained a habitable space, all but one row of seats located at a rupture in the cabin remained in place, all emergency exits were operable. The seat fire blocking layers provided significant protection. [ref. 78]

This sort of experiment is a relatively expensive solution in order to obtain information about the fire characteristics of an airplane. Like in all other tests, also in this situation it has to be realized
that the test provides information about only one sort of aircraft fire. However, much can be learned from this test, for example insight in the crash dynamics of an aircraft structure and the behaviour of fuel wing tanks in a crash can be obtained. [ref. 12,20]

Figure 4.3 CID impact sequence [ref. 20].

IV.2.3 Cabin Fire Simulator (CFS)

To facilitate full-scale testing, McDonnell Douglas developed a Cabin Fire Simulator (CFS) as illustrated by figure 4.4. The CFS is a cylindrical, double walled, steel pressure vessel 3.66 m

Figure 4.4 Cabin fire simulator [ref. 47].
diameter and 12.20 m long with a double door entry airlock at one end and a full-diameter door at the other. The CFS is equipped with a cabin ventilation system. A gaseous and liquid nitrogen drench system is employed to determine fire quickly upon command so that physical test evidence can be preserved for post-test evaluation. According to ref. 47, post-test inspection of the CFS revealed that an aircraft fire scenario is being accurately simulated.

The Douglas cabin fire simulator has been utilized for full-scale testing of lavatory configurations and passenger seat materials and for the development of a combined hazard index (CHI) to be used in the evaluation of relative hazards associated with different interior materials. [ref. 47]

IV.2.4 One-third scale simulated aircraft cabin interior

Obviously, the large-scale tests described above are expensive to conduct. Thus, reduced-scale experiments that incorporate some of the essential elements of the full-scale situation are required.

Figure 4.5 One-third scale simulated aircraft cabin [ref. 27].

The reason why this test is mentioned in this chapter for full-scale tests is, that this test method is a relatively good representation of a real fire, whereas small-scale tests in fact are not.

As part of NASA and FAA efforts to study the postcrash fire scenario, a pool fire and flame spread test facility was built at the Jet Propulsion Laboratory (JPL) to study fire dynamics and flame spread under controlled conditions that simulate actual fire situations.

The pool fire and flame spread test facility (see figure 4.5) was designed to simulate a fuel fire that has penetrated an opening in an aircraft fuselage and spread across the width of the interior. The test section is 0.76 m high by 1.52 m wide, which is approximately one-third scale of a wide-body transport interior. The total test section length is 3.4 m. There is a fuel source of kerosine and ventilating airflow is provided by a centrifugal blower in such a way that possible flow conditions
occurring in a postcrash fire are simulated. These conditions assume that in the real postcrash fire case other doors along the fuselage length have been opened for passenger egress. Pressure differences over the fuselage cylinder due to wind then produce an axial ventilation flow along the fuselage. [ref. 21,27]
V THE EFFECTS OF TOXICITY OF FIRE GAS.

V.1 Introduction

Thermal decomposition caused by overheating or a fire frequently converts a relatively inert, non-toxic material into toxic gases or vapours. Such toxic substances are absorbed into the body mainly via the lungs. Absorption through the skin rarely occurs. Also the eyes can be irritated. When thermal oxidation is incomplete, intermediate breakdown substances like aldehydes and carbon monoxide can be formed. Examples of sources of toxic gases are given in table 5.1.

V.2 The terms MAC and TLV

The term Maximum Allowable Concentration (MAC) is often used for allowable concentrations. It should be stressed, however, that MAC values are developed for industrial use, taking into account that the concentrations occur during a long period of time. These levels are much lower than the levels used for short periods of exposure to toxic gases with which we are dealing in aircraft fires.

In fact the Threshold Limit Values (TLV) are the same as MAC-values. Some lists of TLV-values, however, are extended with ceiling values for some gases, indicated with 'C'; these C-values indicate maximum acceptable concentrations for a short period of exposure. [ref. 107]

V.3 Human response to gases produced in aircraft fires

[ref. 82,89,107]

Nitrogen dioxide - It is possible to be exposed to lethal concentrations of Nitrogen dioxide without feeling discomfort directly. Even a short exposure to 50 ppm results (after some time) in lung-oedema. This means that a person can not breath because the lungs get wet. This syndrome is also called A.R.D.S. (Adult Respiratory Distress Syndrome, or also 'wet lung syndrome'). A dose of 100 ppm is rapidly fatal.

Hydrogen fluoride - Inhalation causes coughing and choking. Lungoedema can develop. A brief exposure of 50-250 ppm already is dangerous.

Hydrogen Sulfide - Causes problems with eyes, headache, and lung-oedema will develop. At high concentrations (some 1000 ppm) instantly fatal. \( \text{H}_2\text{S} \) causes paralysis of breathing at high concentrations.

Hydrogen chloride - Hydrogen chloride gives (like \( \text{NO}_x \)) rise to lung-oedema, by disturbing the surface of the lungs. Also oedema or spasm of larynx (lower part of the throat) and upper respiratory tract can occur.
Carbon monoxide - Carbon monoxide is a major product of combustion and is invariably produced by fire in an aircraft. CO is a colorless, odorless gas, which is absorbed via the lungs. Carbon monoxide has a greater affinity (some 210 times stronger!) to Haemoglobin than Oxygen. It combines with Haemoglobin in the blood instead of oxygen (see figure 5.1). Thus it causes a reduction of the transport of oxygen in the body. Clinical symptoms are: collapse, coma (affecting the brains) and death. If CO, instead of O₂, has been combined with haemoglobin, it can be replaced by O₂ by giving large quantities of O₂ to the person involved. This is because we have to do with equilibrium reactions. [ref. 113]

Carbon dioxide - The threshold limit value for Carbon dioxide is 0.5 %;
- at 1% - 2.5 % increased air-hunger occurs (you feel breathless),
- at 3% - 7% impair of vision and hearing occurs,
- at 7% and higher epileptic fits, loss of consciousness and death are the result.
Unconsciousness may occur within one minute at a concentration above 10 %.

Hydrogen cyanide - Inhalation of hydrogen cyanide may cause death within a minute (by inhibiting cell function); CN combines, like CO, with Haemoglobin in the blood instead of oxygen. It also has a greater affinity to haemoglobin than oxygen. HCN may also penetrate through the skin. Both inhalation and penetration through the skin can cause paralysis of breathing. Therefore, smokehoods will only be useful for short periods of time.

Figure 5.1 The haemoglobin molecule [ref.113].
<table>
<thead>
<tr>
<th>Toxic gas or vapour</th>
<th>Source material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide and carbon monoxide</td>
<td>many organic materials including fuel, and plastics such as polymethylmethacrylate (windows); epoxy; polyester; polycarbonate; and PPL (Noryl)</td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td>CSP (chlorosulphated polyethylene insulation materials); polysulphide (sealants)</td>
</tr>
<tr>
<td>Hydrogen cyanide and nitrogen oxide</td>
<td>wool (carpets, seatcovers); polyurethane foam (seat cushions); polyamides (nylon); ABS; modacrylics; aramids; leather; cheese</td>
</tr>
<tr>
<td>Hydrogen chlorides</td>
<td>PVC; some fire retardants; CSP (insulation) modacrylics; polychloroprene (Neoprene)</td>
</tr>
<tr>
<td>Hydrogen Fluoride</td>
<td>PVF (Tedlar decorative coverings); PTFE (Teflon)</td>
</tr>
<tr>
<td>Smoke</td>
<td>all organic materials, plastics, and fuel</td>
</tr>
</tbody>
</table>

Table 5.1 Examples of gases releasing from materials [ref. 18,25,89].

<table>
<thead>
<tr>
<th>Cumbustion gas</th>
<th>Hazardous levels (ppm) for times indicated</th>
<th>MAC (/TLV) ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minutes</td>
<td>0.5 hour</td>
</tr>
<tr>
<td>CO</td>
<td>3 000</td>
<td>1 600</td>
</tr>
<tr>
<td>CO₂</td>
<td>50 000</td>
<td>40 000</td>
</tr>
<tr>
<td>SO₂</td>
<td>400</td>
<td>150</td>
</tr>
<tr>
<td>NO₂</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>HCl</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>HCN</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>HF</td>
<td>50-100</td>
<td>50</td>
</tr>
<tr>
<td>H₂S</td>
<td>1000</td>
<td>300</td>
</tr>
</tbody>
</table>

Table 5.2 Human tolerance to selected combustion gases [ref. 25,35,38,114,107]

**Note:** There is considerable variation among investigators as to what level of a particular gas does constitute a life hazard; the table is a combination of the references mentioned, taking into account [ref. 89].
V.4 Heat produced in aircraft fires

Hot air and gases from a fire, ignoring any effects of oxygen depletion or toxicity, can cause burns, heat exhaustion, dehydration and blockage of the respiratory tract (oedema).

A breathing level temperature of 150 °C is considered to be the maximum value for survival. Breathing level, the distance above the floor, is considered to be about 1.5 meters. In table 5.3 the human heat thresholds are being summarized.

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Exposure time min.</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>25</td>
<td>Maximum that can be tolerated</td>
</tr>
<tr>
<td>120</td>
<td>15</td>
<td>Maximum that can be tolerated</td>
</tr>
<tr>
<td>140</td>
<td>5</td>
<td>Maximum that can be tolerated</td>
</tr>
<tr>
<td>150</td>
<td>-</td>
<td>Limit for escape, mouth breathing difficult</td>
</tr>
<tr>
<td>160</td>
<td>-</td>
<td>Rapid unbearable pain (dry skin)</td>
</tr>
<tr>
<td>180</td>
<td>0.5</td>
<td>Irreversible injury (dry skin)</td>
</tr>
<tr>
<td>200</td>
<td>4</td>
<td>Maximum tolerated (wet skin)</td>
</tr>
<tr>
<td>200</td>
<td>4</td>
<td>Max. tolerated by respiratory tract</td>
</tr>
</tbody>
</table>

Table 5.3 Human heat thresholds [ref. 35,100]
VI  CONCLUSIONS

A lot of test methods have been developed to test materials for use in aircraft interiors. The OSU rate of heat release apparatus and the NBS smoke chamber are the best test methods nowadays available. However, these tests do not provide all information one should get before using materials in aircraft interiors. Unfortunately, little correlation seems to exist between the different sorts of test methods. It is also of importance to realize that small-scale test results can not really predict the performance of a material in an aircraft fire. Perhaps there should not be only small-scale tests on two dimensional test-specimens, but also on some standard small 'real' components of aircraft interiors. Even a full-scale test can not precisely predict the behaviour in a real fire: for example, the influence of wind direction, door opening configuration, fuselage orientation and of the way of fuel spillage seems to be high.

In my opinion, there should be full agreement about a little number of uniform test-methods, using some different precisely defined burner temperatures and heat fluxes, with standardized conditions and standard test specimens. This would possibly be the only way of being able to compare materials for use in aircraft interiors. Material suppliers will then be able to provide standardized test results on flammability characteristics of their materials. This is in contrast to the situation nowadays, where every supplier provides test results of different test methods or results of the same test method but under different conditions. In order to obtain such standard tests, showing more correlation with real fires, much more research should be done.

Other subjects of importance are the clothes of passengers and their hand-bags with frightful fire-characteristics brought into the airplane. Perhaps one should require the handbags and coats to be put in overhead storage racks. Thus it would take more time before a fire can cause these clothes and hand-bags to burn and give off toxic gases. Sometimes smoking by passengers in the aircraft is the cause of a fire. At this moment it would be difficult for some people not to smoke, in particular during flight. It is because of this that the airliners will not appreciate requirements of 'no smoking' during flight.

Many lives could be saved by the use of new materials, showing good fire, smoke and toxicity behaviour. This will cost a lot of money. One should come to a well-balanced situation of spending money on preventing aircraft crashes in common, preventing materials to burn quickly and give off too much smoke and toxic gases, and on fire extinguishing methods.

Perhaps in a few decades, when using total different less flammable sources for propulsion, we will not have the problems with post-crash fires anymore!
References


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   c. H.W.G. Wyeth, Fuel system protection methods
   e. C.P. Sarkos, R.G. Hill and W.D. Howell, The Development and Application of a Full-Scale wide body Test Article to study the behaviour of interior materials during a Postcrash Fuel Fire.
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29. FAA Orders Smoke Detector Installations, *Aviation Week & Space Technology*, April 1, 1985


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APPENDIX A  FAR Part 25

In this appendix a full description of FAR Part 25, 1-1-1987 edition, concerning flammability is given. In appendix B, the amendments from August, 25, 1988, upgrading the fire safety standards for cabin interior materials in transport category airplanes have been added.

FIRE PROTECTION

§ 25.551 Fire extinguishers.

(a) Hand fire extinguishers. For hand fire extinguishers the following apply:
(1) Each hand fire extinguisher must be approved.
(2) The types and quantities of each extinguishing agent used must be appropriate to the kinds of fires likely to occur where used.
(3) Each extinguisher for use in a personnel compartment must be designed to minimize the hazard of toxic gas concentrations.
(4) A readily accessible hand fire extinguisher must be available for use in each Class A or Class B cargo compartment.
(5) There must be at least the following number of hand fire extinguishers conveniently located in passenger compartments:

**MINIMUM NUMBER OF HAND FIRE EXTINGUISHERS**

Passenger capacity:
- 7 through 20: .................................................. 1
- 21 through 50: ............................................... 2
- 51 or more: .................................................. 3

(6) There must be at least one hand fire extinguisher conveniently located in the pilot compartment.

(b) Built-in fire extinguishers. If a built-in fire extinguishing system is required—
(1) The capacity of each system, in relation to the volume of the compartment where used and the ventilation rate, must be adequate for any fire likely to occur in that compartment; and
(2) Each system must be installed so that—
   (i) No extinguishing agent likely to enter personnel compartments will be hazardous to the occupants; and
   (ii) No discharge of the extinguisher can cause structural damage.


§ 25.553 Compartment interiors.

Materials (including finishes or decorative surfaces applied to the materials) used in each compartment occupied by the crew or passengers must meet the following test criteria as applicable:

(a) Interior ceiling panels, interior wall panels, partitions, galley structure, large cabinet walls, structural flooring, and materials used in the construction of stowage compartments (other than stowage compartments and compartments for stowing small items such as magazines and maps) must be self-extinguishing when tested vertically in accordance with the applicable portions of Appendix F of this part, or other approved equivalent methods. The average burn length may not exceed 6 inches and the average flame time after removal of the flame source may not exceed 15 seconds. Drippings from the test specimen may not continue to flame for more than an average of 3 seconds after failing.

(a-1) For airplanes with passenger capacity of 20 or more, interior ceiling and wall panels (other than lighting lenses), partitions, and the outer surfaces of galleys, large cabinets and stowage compartments (other than stowage compartments and compartments for stowing small items, such as magazines and maps) must also meet the test requirements of Part IV of Appendix F of this part, or other approved equivalent methods. In addition to the flammability requirements prescribed in paragraph (a) of this section.

(b) Floor covering, textiles (including draperies and upholstery), seat cushions, padding, decorative and non-decorative coated fabrics, leather, trays and galley furnishings, electrical conduit, thermal and acoustical insulation and insulation covering, air ducting, joint and edge covering, liners of Class B and E cargo or baggage compartments, floor panels of Class C or D cargo and baggage compartments, insulation blankets, cargo covers, and transparencies, molded and thermo-formed parts, air ducting joints, and trim strips (decorative and chafing), that are constructed of materials not covered in paragraph (b-2) of this section, must be self-extinguishing when tested vertically in accordance with the applicable portions of Part I of Appendix F of this part, or other approved equivalent methods. The average burn length may not exceed 8 inches, and the average flame time after removal of the flame source may not exceed 15 seconds. Drippings from the test specimen may not continue to flame for more than an average of 5 seconds after failing.

(b-1) Motion picture film must be safety film meeting the Standard Specifications for Safety Photographic Film PH 1.25 (available from the United States of America Standards Institute, 10 East 40th Street, New...
Appendix A

§ 25.853 Cargo and baggage compartments.

(a) Thermal and acoustic insulation (including coverings) and liners, used in each cargo and baggage compartment not occupied by passengers or crew, must be constructed of materials that at least meet the requirements set forth in § 25.853(b).

(a-1) Class B through Class E cargo or baggage compartments, as defined in § 25.857, must have a liner and the liner must be separate from (but may be attached to) the airplane structure, and must be tested as follows:

(1) Ceiling and sidewall liner panels of Class C and D compartments must meet the test requirements of Part III of Appendix F of this part or other approved equivalent methods.

(2) Floor panels of all compartments and ceiling and sidewall liner panels of Class B and E compartments must be constructed of materials that meet at least the requirements set forth in § 25.853(b). Also, these liner panels must be tested at a 45 degree angle in accordance with the applicable portions of Part I of Appendix F of this part or other approved equivalent methods. The flame may not penetrate (pass through) the material during application of the flame or subsequent to its removal. The average flame time after removal of the flame source may not exceed 15 seconds, and the average glow may not exceed 10 seconds.

(a-2) Insulation blankets and cargo covers used to protect cargo in compartments not occupied by passengers or crew must be constructed of materials that at least meet the requirements of § 25.853(b), and tiedown equipment (including containers, bins, and pallets) used in each cargo and baggage compartment not occupied by passengers or crew must be constructed of materials that at least meet the requirements set forth in § 25.853(b-3).

(b) No compartment may contain any controls, wiring, lines, equipment, or accessories whose damage or failure would affect safe operation, unless those items are protected so that—

York, NY 10018), or an FAA-approved equivalent. If the film travels through ducts, the ducts must meet the requirements of paragraph (b) of this section.

(b-2) Acrylic windows and signs, parts constructed in whole or in part of elastomeric materials, edge lighted instrument assemblies consisting of two or more instruments in a common housing, seat belts, shoulder harnesses, and cargo and baggage tiedown equipment, including containers, bins, pallets, etc., used in passenger or crew compartments, may not have an average burn rate greater than 2.5 inches per minute when tested horizontally in accordance with the applicable portions of Appendix F of this part, or other approved equivalent methods.

(b-3) Except for electrical wire and cable insulation, and for small parts (such as knobs, handles, rollers, fasteners, clips, grommets, rub strips, pulleys, and small electrical parts) that the Administrator finds would not contribute significantly to the propagation of a fire, materials in items not specified in paragraphs (a), (b), (b-1), or (b-2) of this section may not have a burn rate greater than 4 inches per minute when tested horizontally in accordance with the applicable portions of Appendix F of this part or other approved equivalent methods.

(c) In addition to meeting the requirements of paragraph (b), seat cushions, except those on flight crewmember seats, must meet the test requirements of Part II of Appendix F of this part, or equivalent.

(d) If smoking is to be prohibited, there must be a placard so stating, and if smoking is to be allowed—

(1) There must be an adequate number of self-contained, removable ashtrays; and

(2) Where the crew compartment is separated from the passenger compartment, there must be at least one sign meeting the "No Smoking" sign requirements of § 25.791 notifying all passengers when smoking is prohibited.

(e) Each disposal receptacle for towels, paper, or waste must be fully enclosed and constructed of at least fire resistant materials, and must contain fires likely to occur in it under normal use. The ability of the disposal receptacle to contain those fires under all probable conditions of wear, misalignment, and ventilation expected in service must be demonstrated by test. A placard containing the legible words "No Cigarette Disposal" must be located on or near each disposal receptacle door.

(f) Lavatories must have "No Smoking" or "No Smoking in Lavatory" placards located conspicuously on each side of the entry door, and self-removable ashtrays located conspicuously on or near the entry side of each lavatory door, except that one ashtray may serve more than one lavatory door if the ashtray can be seen readily from the cabin side of each lavatory door served. The placards must have red letters at least one-half inch high on a white background of at least one inch high. (A "No Smoking" symbol may be included on the placard.)

(Sec. 604, 72 Stat. 778 (49 U.S.C. 1424))

(1) They cannot be damaged by the movement of cargo in the compartment; and
(2) Their breakage or failure will not create a fire hazard.
(c) There must be means to prevent cargo or baggage from interfering with the functioning of the fire-protective features of the compartment.
(d) Sources of heat within the compartment must be shielded and insulated to prevent igniting the cargo.
(e) Cargo compartments must meet one of the class requirements of § 25.857. In addition, flight tests must be conducted to show compliance with the provisions of § 25.857 concerning—
(1) Compartment accessibility;
(2) The entry of hazardous quantities of smoke or extinguishing agent into compartments occupied by the crew or passengers; and
(3) The dissipation of the extinguishing agent in Class C compartments.
During these tests, it must be shown that no inadvertent operation of smoke or fire detectors in any compartment would occur as a result of fire contained in any one compartment, either during or after extinguishment, unless the extinguishing system floods each such compartment simultaneously.
(Sec. 604, 72 Stat. 778, 49 U.S.C. 1424)
§ 25.857 Cargo compartment classification.
(a) Class A. A Class A cargo or baggage compartment is one in which—
(1) The presence of a fire would be easily discovered by a crewmember while at his station; and
(2) Each part of the compartment is easily accessible in flight.
(b) Class B. A Class B cargo or baggage compartment is one in which—
(1) There is sufficient access in flight to enable a crewmember to effectively reach any part of the compartment with the contents of a hand fire extinguisher;
(2) When the access provisions are being used, no hazardous quantity of smoke, flames, or extinguishing agent, will enter any compartment occupied by the crew or passengers;
(3) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station.
(c) Class C. A Class C cargo or baggage compartment is one not meeting the requirements for either a Class A or B compartment but in which—
(1) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station;
(2) There is an approved built-in fire-extinguishing system controllable from the pilot or flight engineer stations;
(3) There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent, from any compartment occupied by the crew or passengers;
(4) There are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.
(d) Class D. A Class D cargo or baggage compartment is one in which—
(1) A fire occurring in it will be completely confined without endangering the safety of the airplane or the occupants;
(2) There are means to exclude hazardous quantities of smoke, flames, or other noxious gases, from any compartment occupied by the crew or passengers;
(3) Ventilation and drafts are controlled within each compartment so that any fire likely to occur in the compartment will not progress beyond safe limits; and
(4) (Reserved)
(5) Consideration is given to the effect of heat within the compartment on adjacent critical parts of the airplane. For compartments of 500 cu. ft. or less, an airflow of 1500 cu. ft. per hour is acceptable.
(6) The compartment volume does not exceed 1,000 cubic feet.
(e) Class E. A Class E cargo compartment is one on airplanes used only for the carriage of cargo and in which—
(1) (Reserved)
(2) There is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station.
(3) There are means to shut off the ventilating airflow to, or within, the compartment, and the controls for these means are accessible to the flight crew in the crew compartment.
(4) There are means to exclude hazardous quantities of smoke, flames, or noxious gases, from the flight crew compartment; and
(5) The required crew emergency exits are accessible under any cargo loading condition.
§ 25.858 Cargo compartment fire detection systems.
If certification with cargo compartment fire detection provisions is requested, the following must be met for each cargo compartment with those provisions:
(a) The detection system must provide a visual indication to the flight crew within one minute after the start of a fire.
(b) The system must be capable of detecting a fire at a temperature significantly below that at which the structural integrity of the airplane is substantially decreased.

(c) There must be means to allow the crew to check in flight, the functioning of each fire detector circuit.

(d) The effectiveness of the detection system must be shown for all approved operating configurations and conditions.

[Amdt. 25-54, 45 FR 60173, Sept. 11, 1980]

§ 25.859 Combustion heater fire protection.

(a) Combustion heater fire zones. The following combustion heater fire zones must be protected from fire in accordance with the applicable provisions of §§ 25.1181 through 25.1191 and §§ 25.1195 through 25.1203:

(1) The region surrounding the heater, if this region contains any flammable fluid system components (excluding the heater fuel system), that could—

(i) Be damaged by heater malfunctioning; or

(ii) Allow flammable fluids or vapors to reach the heater in case of leakage.

(2) The region surrounding the heater, if the heater fuel system has fittings that, if they leaked, would allow fuel or vapors to enter this region.

(3) The part of the ventilating air passage that surrounds the combustion chamber. However, no fire extinguishment is required in cabin ventilating air passages.

(b) Ventilating air ducts. Each ventilating air duct passing through any fire zone must be fireproof. In addition—

(1) Unless isolation is provided by fireproof valves or by equally effective means, the ventilating air duct downstream of each heater must be fireproof for a distance great enough to ensure that any fire originating in the heater can be contained in the duct; and

(2) Each part of any ventilating duct passing through any region having a flammable fluid system must be constructed or isolated from that system so that the malfunctioning of any component of that system cannot introduce flammable fluids or vapors into the ventilating airstream.

(c) Combustion air ducts. Each combustion air duct must be fireproof for a distance great enough to prevent damage from backfiring or reverse flame propagation. In addition—

(1) No combustion air duct may have a common opening with the ventilating airstream unless flames from backfires or reverse burning cannot enter the ventilating airstream under any operating condition, including reverse flow or malfunctioning of the heater or its associated components; and

(2) No combustion air duct may restrict the prompt relief of any backfire that, if so restricted, could cause heater failure.

(d) Heater controls; general. Provision must be made to prevent the hazardous accumulation of water or ice on or in any heater control component, control system tubing, or safety control.

(e) Heater safety controls. For each combustion heater there must be the following safety control means:

(1) Means independent of the components provided for the normal continuous control of air temperature, airflow, and fuel flow must be provided, for each heater, to automatically shut off the ignition and fuel supply to that heater at a point remote from that heater when any of the following occur:

(i) The heat exchanger temperature exceeds safe limits.

(ii) The ventilating air temperature exceeds safe limits.

(iii) The combustion airflow becomes inadequate for safe operation.

(iv) The ventilating airflow becomes inadequate for safe operation.

(2) The means of complying with paragraph (e)(1) of this section for any individual heater must—

(i) Be independent of components serving any other heater whose heat output is essential for safe operation; and

(ii) Keep the heater off until restarted by the crew.

(3) There must be means to warn the crew when any heater whose heat output is essential for safe operation has been shut off by the automatic means prescribed in paragraph (e)(1) of this section.

(f) Air intakes. Each combustion and ventilating air intake must be located so that no flammable fluids or vapors can enter the heater system under any operating condition—

(1) During normal operation; or

(2) As a result of the malfunctioning of any other component.

(g) Heater exhaust. Heater exhaust systems must meet the provisions of §§ 25.1121 and 25.1123. In addition, there must be provisions in the design of the heater exhaust system to safely expel the products of combustion to prevent the occurrence of—

(1) Fuel leakage from the exhaust to surrounding compartments;

(2) Exhaust gas impingement on surrounding equipment or structure;

(3) Ignition of flammable fluids by the exhaust, if the exhaust is in a compartment containing flammable fluid lines; and

(4) Restriction by the exhaust of the prompt relief of backfires that, if so restricted, could cause heater failure.

(h) Heater fuel systems. Each heater fuel system must meet each powerplant fuel system requirement affecting safe heater operation. Each heater
fuel system component within the ventilating airstream must be protected by shrouds so that no leakage from those components can enter the ventilating airstream.

(i) Drains. There must be means to safely drain fuel that might accumulate within the combustion chamber or the heat exchanger. In addition—

(1) Each part of any drain that operates at high temperatures must be protected in the same manner as heater exhausts; and

(2) Each drain must be protected from hazardous ice accumulation under any operating condition.


§ 25.863 Flammable fluid fire protection.

(a) In each area where flammable fluids or vapors might escape by leakage of a fluid system, there must be means to minimize the probability of ignition of the fluids and vapors, and the resultant hazards if ignition does occur.

(b) Compliance with paragraph (a) of this section must be shown by analysis or test, and the following factors must be considered:

(1) Possible sources and paths of fluid leakage, and means of detecting leakage.

(2) Flammability characteristics of fluids, including effects of any combustible or absorbing materials.

(3) Possible ignition sources, including electrical faults, overheating of equipment, and malfunctioning of protective devices.

(4) Means available for controlling or extinguishing a fire, such as stopping flow of fluids, shutting down equipment, fireproof containment, or use of extinguishing agents.

(5) Ability of airplane components that are critical to safety of flight to withstand fire and heat.

(c) If action by the flight crew is required to prevent or counteract a fluid fire (e.g., equipment shutdown or actuation of a fire extinguisher) quick acting means must be provided to alert the crew.

(d) Each area where flammable fluids or vapors might escape by leakage of a fluid system must be identified and defined.

[Secs. 313(a) 601, 603, 604, Federal Aviation Act of 1958 (49 U.S.C. 1354(a), 1421, 1423, 1424), sect. 6(c), Dept. of Transportation Act (49 U.S.C. 1653(c))]


§ 25.865 Fire protection of flight controls, engine mounts, and other flight structure.

Essential flight controls, engine mounts, and other flight structures located in designated fire zones or in adjacent areas which would be subjected to the effects of fire in the fire zone must be constructed of fireproof material or shielded so that they are capable of withstanding the effects of fire.

[Amtd. 25-23, 35 FR 5676, Apr. 8, 1970]

§ 25.867 Fire protection: other components.

(a) Surfaces to the rear of the nacelles, within one nacelle diameter of the nacelle centerline, must be at least fire-resistant.

(b) Paragraph (a) of this section does not apply to tail surfaces to the rear of the nacelles that could not be readily affected by heat, flames, or sparks coming from a designated fire zone or engine compartment of any nacelle.

[Amtd. 25-23, 35 FR 5676, Apr. 8, 1970]

POWERPLANT FIRE PROTECTION

§ 25.1181 Designated fire zones: regions included.

(a) Designated fire zones are—

(1) The engine power section;

(2) The engine accessory section;

(3) Except for reciprocating engines, any complete powerplant compartment in which no isolation is provided between the engine power section and the engine accessory section;

(4) Any auxiliary power unit compartment;

(5) Any fuel-burning heater and other combustion equipment installation described in §25.859;

(6) The compressor and accessory sections of turbine engines; and

(7) Compressor, turbine, and tailpipe sections of turbine engine installations that contain lines or components carrying flammable fluids or gases.

(b) Each designated fire zone must meet the requirements of §25.1185 through 25.1205.


§ 25.1182 Nacelle areas behind firewall, and engine pod attaching structures containing flammable fluid lines.

(a) Each nacelle area immediately behind the firewall, and each portion of any engine pod attaching structure containing flammable fluid lines, must meet each requirement of §§25.1103(d), 25.1165 (d) and (e), 25.1183, 25.1185(c), 25.1187, 25.1189,
and 25.1195 through 25.1203, including those concerning designated fire zones. However, engine pod attaching structures need not contain fire detection or extinguishing means.

(b) For each area covered by paragraph (a) of this section that contains a retractable landing gear, compliance with that paragraph need only be shown with the landing gear retracted.

(Amdt. 25-11, 32 FR 6913, May 5, 1967)

§ 25.1183 Flammable fluid-carrying components.

(a) Except as provided in paragraph (b) of this section, each line, fitting, and other component carrying flammable fluid in any area subject to engine fire conditions, and each component which conveys or contains flammable fluid in a designated fire zone must be fire resistant, except that flammable fluid tanks and supports in a designated fire zone must be fireproof or be enclosed by a fireproof shield unless damage by fire to any non-fireproof part will not cause leakage or spillage of flammable fluid. Components must be shielded or located to safeguard against the ignition of leaking flammable fluid. An integral oil sump of less than 25-quart capacity on a reciprocating engine need not be fireproof nor be enclosed by a fireproof shield.

(b) Paragraph (a) of this section does not apply to—

(1) Lines, fittings, and components which are already approved as part of a type certificated engine; and

(2) Vent and drain lines, and their fittings, whose failure will not result in, or add to, a fire hazard.


§ 25.1185 Flammable fluids.

(a) Except for the integral oil sumps specified in § 25.1013 (a), no tank or reservoir that is a part of a system containing flammable fluids or gases may be in a designated fire zone unless the fluid contained, the design of the system, the materials used in the tank, the shut-off means, and all connections, lines, and control provide a degree of safety equal to that which would exist if the tank or reservoir were outside such a zone.

(b) There must be at least one-half inch of clear airspace between each tank or reservoir and each firewall or shroud isolating a designated fire zone.

(c) Absorbent materials close to flammable fluid system components that might leak must be covered or treated to prevent the absorption of hazardous quantities of fluids.


§ 25.1187 Drainage and ventilation of fire zones.

(a) There must be complete drainage of each part of each designated fire zone to minimize the hazards resulting from failure or malfunctioning of any component containing flammable fluids. The drainage means must be—

(1) Effective under conditions expected to prevail when drainage is needed; and

(2) Arranged so that no discharged fluid will cause an additional fire hazard.

(b) Each designated fire zone must be ventilated to prevent the accumulation of flammable vapors.

(c) No ventilation opening may be where it would allow the entry of flammable fluids, vapors, or flame from other zones.

(d) Each ventilation means must be arranged so that no discharged vapors will cause an additional fire hazard.

(e) Unless the extinguishing agent capacity and rate of discharge are based on maximum air flow through a zone, there must be means to allow the crew to shut off sources of forced ventilation to any fire zone except the engine power section of the nacelle and the combustion heater ventilating air ducts.

§ 25.1189 Shutoff means.

(a) Each engine installation and each fire zone specified in § 25.1181(a) (4) and (5) must have a means to shut off or otherwise prevent hazardous quantities of fuel, oil, deicer, and other flammable fluids, from flowing into, within, or through any designated fire zone, except that shutoff means are not required for—

(1) Lines, fittings, and components forming an integral part of an engine; and

(2) Oil systems for turbine engine installations in which all components of the system in a designated fire zone, including oil tanks, are fireproof or located in areas not subject to engine fire conditions.

(b) The closing of any fuel shutoff valve for any engine may not make fuel unavailable to the remaining engines.

(c) Operation of any shutoff may not interfere with the later emergency operation of other equipment, such as the means for feathering the propeller.

(d) Each flammable fluid shutoff means and control must be fireproof or must be located and protected so that any fire in a fire zone will not affect its operation.

(e) No hazardous quantity of flammable fluid may drain into any designated fire zone after shutoff.

(f) There must be means to guard against inadvertent operation of the shutoff means and to make it possible for the crew to reopen the shutoff
means in flight after it has been closed.

(g) Each tank-to-engine shutoff valve must be located so that the operation of the valve will not be affected by powerplant or engine mount structural failure.

(h) Each shutoff valve must have a means to relieve excessive pressure accumulation unless a means for pressure relief is otherwise provided in the system.


§ 25.1191 Firewalls.

(a) Each engine, auxiliary power unit, fuel-burning heater, other combustion equipment intended for operation in flight, and the combustion, turbine, and tailpipe sections of turbine engines, must be isolated from the rest of the airplane by firewalls, shrouds, or equivalent means.

(b) Each firewall and shroud must be—

(1) Fireproof;

(2) Constructed so that no hazardous quantity of air, fluid, or flame can pass from the compartment to other parts of the airplane;

(3) Constructed so that each opening is sealed with close fitting fireproof grommets, bushings, or firewall fittings; and

(4) Protected against corrosion.

§ 25.1192 Engine accessory section diaphragm.

For reciprocating engines, the engine power section and all portions of the exhaust system must be isolated from the engine accessory compartment by a diaphragm that complies with the firewall requirements of § 25.1191.

(Amdt. 25-23, 35 FR 5678, Apr. 8, 1970)

§ 25.1193 Cowling and nacelle skin.

(a) Each cowling must be constructed and supported so that it can resist any vibration, inertia, and air load to which it may be subjected in operation.

(b) Cowling must meet the drainage and ventilation requirements of § 25.1187.

(c) On airplanes with a diaphragm isolating the engine power section from the engine accessory section, each part of the accessory section cowling subject to flame in case of fire in the engine power section of the powerplant must—

(1) Be fireproof; and

(2) Meet the requirements of § 25.1191.

(d) Each part of the cowling subject to high temperatures due to its nearness to exhaust system parts or exhaust gas impingement must be fireproof.

(e) Each airplane must—

(1) Be designed and constructed so that no fire originating in any fire zone can enter, either through openings or by burning through external skin, any other zone or region where it would create additional hazards.

(2) Meet paragraph (e)(1) of this section with the landing gear retracted (if applicable); and

(3) Have fireproof skin in areas subject to flame if a fire starts in the engine power or accessory sections.

§ 25.1195 Fire extinguishing systems.

(a) Except for combustor, turbine, and tailplane sections of turbine engine installations that contain lines or components carrying flammable fluids or gases for which it is shown that a fire originating in these sections can be controlled, there must be a fire extinguishing system serving each designated fire zone.

(b) The fire extinguishing system, the quantity of the extinguishing agent, the rate of discharge, and the discharge distribution must be adequate to extinguish fires. It must be shown by either actual or simulated flight tests that under critical airflow conditions in flight the discharge of the extinguishing agent in each designated fire zone specified in paragraph (a) of this section will provide an agent concentration capable of extinguishing fires in that zone and of minimizing the probability of reignition. An individual "one-shot" system may be used for auxiliary power units, fuel burning heaters, and other combustion equipment. For each other designated fire zone, two discharges must be provided each of which produces adequate agent concentration.

(c) The fire extinguishing system for a nacelle must be able to simultaneously protect each zone of the nacelle for which protection is provided.

(Secs. 313(a), 601, 603, 604, Federal Aviation Act of 1958 (49 U.S.C. 1354(a), 1421, 1423, 1424), sec. 6(c), Dept. of Transportation Act (49 U.S.C. 1855(e)))


§ 25.1197 Fire extinguishing agents.

(a) Fire extinguishing agents must—

(1) Be capable of extinguishing flames emanating from any burning of fluids or other combustible materials in the area protected by the fire extinguishing system; and

(2) Have thermal stability over the temperature range likely to be experienced in the compartment in which they are stored.

(b) If any toxic extinguishing agent is used, provisions must be made to prevent harmful concentrations of fluid or fluid vapor from leakage during normal operation of the airplane or as a result of discharging the fire extinguisher on the ground or in
flight) from entering any personnel compartment, even though a defect may exist in the extinguishing system. This must be shown by test except for built-in carbon dioxide fuselage compartment fire extinguishing systems for which—

(1) Five pounds or less of carbon dioxide will be discharged, under established fire control procedures, into any fuselage compartment; or

(2) There is protective breathing equipment for each flight crew member on flight deck duty.

(Secs. 313(a), 601, and 603, 49 U.S.C. 1354(a), 1421, and 1423; sec. 6(c), 49 U.S.C. 1635(c));


§ 25.1199 Extinguishing agent containers.

(a) Each extinguishing agent container must have a pressure relief to prevent bursting of the container by excessive internal pressures.

(b) The discharge end of each discharge line from a pressure relief connection must be located so that discharge of the fire extinguishing agent would not damage the airplane. The line must also be located or protected to prevent clogging caused by ice or other foreign matter.

(c) There must be a means for each fire extinguishing agent container to indicate that the container has discharged or that the charging pressure is below the established minimum necessary for proper functioning.

(d) The temperature of each container must be maintained, under intended operating conditions, to prevent the pressure in the container from—

(1) Falling below that necessary to provide an adequate rate of discharge; or

(2) Rising high enough to cause premature discharge.

(e) If a pyrotechnic capsule is used to discharge the extinguishing agent, each container must be installed so that temperature conditions will not cause hazardous deterioration of the pyrotechnic capsule.

(Secs. 313(a), 601, and 603, 72 Stat. 752, 775, 49 U.S.C. 1354(a), 1421, and 1423; sec. 6(c), 49 U.S.C. 1635(c));


§ 25.1201 Fire extinguishing system materials.

(a) No material in any fire extinguishing system may react chemically with any extinguishing agent so as to create a hazard.

(b) Each system component in an engine compartment must be fireproof.

§ 25.1203 Fire detector system.

(a) There must be approved, quick acting fire or overheat detectors in each designated fire zone, and in the combustion, turbine, and tailpipe sections of turbine engine installations, in numbers and locations ensuring prompt detection of fire in those zones.

(b) Each fire detector system must be constructed and installed so that—

(1) It will withstand the vibration, inertia, and other loads to which it may be subjected in operation;

(2) There is a means to warn the crew in the event that the sensor or associated wiring within a designated fire zone is severed at one point, unless the system continues to function as a satisfactory detection system after the severing;

(3) There is a means to warn the crew in the event of a short circuit in the sensor or associated wiring within a designated fire zone, unless the system continues to function as a satisfactory detection system after the short circuit;

(c) No fire or overheat detector may be affected by any oil, water, other fluid or fumes that might be present.

(d) There must be means to allow the crew to check, in flight, the functioning of each fire or overheat detector electric circuit.

(e) Wiring and other components of each fire or overheat detector system in a fire zone must be at least fire-resistant.

(f) No fire or overheat detector system component for any fire zone may pass through another fire zone, unless—

(1) It is protected against the possibility of false warnings resulting from fires in zones through which it passes; or

(2) Each zone involved is simultaneously protected by the same detector and extinguishing system.

(g) Each fire detector system must be constructed so that when it is in the configuration for installation it will not exceed the alarm activation time approved for the detectors using the response time criteria specified in the appropriate Technical Standard Order for the detector.


§ 25.1207 Compliance.

Unless otherwise specified, compliance with the requirements of §§ 25.1181 through 25.1203 must be shown by a full scale fire test or by one or more of the following methods:

(a) Tests of similar powerplant configurations;

(b) Tests of components;

(c) Service experience of aircraft
§ 25.1359 Electrical system fire and smoke protection.

(a) Components of the electrical system must meet the applicable fire and smoke protection requirements of §§ 25.831(c), 25.863, and 25.867.

(b) Electrical cables, terminals, and equipment in designated fire zones, that are used during emergency procedures, must be at least fire-resistant.

(c) Main power cables (including generator cables) in the fuselage must be designed to allow a reasonable degree of deformation and stretching without failure and must:

(1) Be isolated from flammable fluid lines; or

(2) Be shrouded by means of electrically insulated flexible conduit, or equivalent, which is in addition to the normal cable insulation.

(d) Insulation on electrical wire and electrical cable installed in any area of the fuselage must be self-extinguishing when tested at an angle of 60° in accordance with the applicable portions of Appendix F of this part, or other approved equivalent methods. The average burn length may not exceed 3 inches and the average flame time after removal of the 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.

(Sec. 604, 72 Stat. 778, 49 U.S.C. 1424)


§ 25.1439 Protective breathing equipment.

(a) If there is a class A, B, or C cargo compartment, protective breathing equipment must be installed for the use of appropriate crewmembers. In addition, protective breathing equipment must be installed in each isolated compartment in the airplane, including upper and lower lobe galleys, in which crewmember occupancy is permitted during flight for the maximum number of crewmembers expected to be in the area during any operation.

(b) For protective breathing equipment required by paragraph (a) of this section or by any operating rule of this chapter, the following apply:

(1) The equipment must be designed to protect the flight crew from smoke, carbon dioxide, and other harmful gases while on flight deck duty and while combating fires in cargo compartments.

(2) The equipment must include—

(i) Masks covering the eyes, nose, and mouth; or

(ii) Masks covering the nose and mouth, plus accessory equipment to cover the eyes.

(3) The equipment, while in use, must allow the flight crew to use the radio equipment and to communicate with each other, while at their assigned duty stations.

(4) The part of the equipment, protecting the eyes may not cause any appreciable adverse effect on vision and must allow corrective glasses to be worn.

(5) The equipment must supply protective oxygen of 15 minutes duration per crewmember at a pressure altitude of 8,000 feet with a respiratory minute volume of 30 liters per minute BTPD. If a demand oxygen system is used, a supply of 300 liters of free oxygen at 70° F. and 760 mm. Hg pressure is considered to be of 15-minute duration at the prescribed altitude and minute volume. If a continuous flow protective breathing system is used (including a mask with a standard rebreather bag) a flow rate of 80 liters per minute at 8,000 feet (45 liters per minute at sea level) and a supply of 600 liters of free oxygen at 70° F. and 760 mm. Hg pressure is considered to be of 15-minute duration at the prescribed altitude and minute volume. BTPD refers to body temperature conditions (that is, 37° C., at ambient pressure, dry).

(6) The equipment must meet the requirements of paragraphs (b) and (c) of § 25.1441.

APPENDIX F TO PART 25


(a) Conditioning. Specimens must be conditioned to 70°F, plus or minus 5°F, and at 50 percent plus or minus 5 percent relative humidity until moisture equilibrium is reached or for 24 hours. Only one specimen at a time may be removed from the conditioning environment immediately before subjecting it to the flame.

(b) Specimen configuration. Except as provided for materials used in electrical wire and cable insulation and in small parts, materials must be tested either as a section cut from a fabricated part as installed in the airplane or as a specimen simulating a cut section, such as a specimen cut from a flat sheet of the material or a model of the fabricated part. The specimen may be cut from any location in a fabricated part; however, fabricated units, such as sandwich panels, may not be separated for test. The specimen thickness must be no thicker than the minimum thickness to be qualified for use in the airplane, except that: (1) Thick foam parts, such as seat cushions, must be tested in ¼-inch thickness; (2) when showing compliance with § 25.853(b), the flame must be applied for 12 seconds and then removed. Flame time, burn length, and flaming time of drippings, if any, must be recorded. The burn length determined in accordance with paragraph (h) of this appendix must be measured to the nearest one-tenth inch.

(c) Apparatus. Except as provided in paragraphs (a) and (b) of this appendix, tests must be conducted in a draft-free cabinet in accordance with Federal Test method Standard 191 Method 5903 (revised Method 5903) for the vertical test, or Method 5906 for horizontal test (available from the General Services Administration, Business Service Center, Region 3, Seventh and D Streets SW., Washington, DC 20407) or other approved equivalent methods. Specimens which are too large for the cabinet must be tested in similar draft-free conditions.

(d) Vertical test in compliance with § 25.853(c) and (d). A minimum of three specimens must be tested and the results averaged. For fabrics, the direction of weave corresponding to the test orientation flammability conditions must be parallel to the longest dimension. Each specimen must be supported vertically. The specimen must be exposed to a Bunsen or Turull burner with a nominal ½-inch L.D. tube adjusted to give a flame of 1 ½ inches in height. The minimum flame temperature measured by a calibrated thermocouple pyrometer in the center of the flame must be 1,550°F. The lower edge of the specimen must be three-fourths inch above the top edge of the burner. The flame must be applied to the center line of the lower edge of the specimen. For materials covered by § 25.853(a), the flame must be applied for 50 seconds and then removed. For materials covered by § 25.853(b), the flame must be applied for 12 seconds and then removed. Flame time, burn length, and flaming time of drippings, if any, must be recorded. The burn length determined in accordance with paragraph (h) of this appendix must be measured to the nearest one-tenth inch.

(e) Horizontal test in compliance with § 25.853(b) and (b–3). A minimum of three specimens must be tested and the results averaged. Each specimen must be supported horizontally. The exposed surface when installed in the aircraft must be face down for the test. The specimen must be exposed to a Bunsen burner or Turull burner with a nominal ½-inch L.D. tube adjusted to give a flame of 1 ½ inches in height. The minimum flame temperature measured by a calibrated thermocouple pyrometer in the center of the flame must be 1,550°F. The specimen must be positioned so that the edge being tested is three-fourths of an inch above the top of, and on the center line of, the burner. The flame must be applied for 15 seconds and then removed. A minimum of 10 inches of the specimen must be used for timing purposes, approximately 1 ½ inches must burn before the burning front reaches the timing zone, and the average burn rate must be recorded.

(1) Forty-five-degree test, in compliance with § 25.855(e–2). A minimum of three specimens must be tested and the results averaged. The specimens must be supported at an angle of 45° to a horizontal surface. The exposed surface when installed in the aircraft must be face down for the test. The specimen must be exposed to a Bunsen or Turull burner with a nominal ½-inch L.D. tube adjusted to give a flame of 1 ½ inches in height. The minimum flame temperature measured by a calibrated thermocouple pyrometer in the center of the flame must be 1,550°F. Suitable precautions must be taken to avoid drafts. One-third of the flame must contact the material at the center of the specimen and must be applied for 30 seconds and then removed. Flame time, burn time, and whether the flame penetrates...
(passes through) the specimen must be re-
corded.
(g) Static-degree test in compliance with § 25.135(k). A minimum of three specimens of
each wire specification (make and size) must be tested. The specimen wire (or cable (including insulation)) must be placed at
an angle of 60° with the horizontal in the
cabinet specified in paragraph (c) of this ap-
pendix with the cabinet door open during
the test or must be placed within a chamber
approximately 2 feet high x 1 foot x 1 foot,
open at the top and at one vertical side
(front), and which allows sufficient flow of
air for complete combustion, but which is
free from drafts. The specimen must be par-
allel to and approximately 6 inches from
the front of the cabinet. The lower end of
the specimen must be held rigidly clamped.
The upper end of the specimen must pass
over a pulley or rod and must have an
appropriate weight attached to it so that the
specimen is held tautly throughout the
flammability test. The test specimen span
between lower clamp and upper pulley or
rod must be 24 inches and must be marked
8 inches from the lower end to indicate the
center of flame application. A flame from a
Bunsen or Turritt burner must be applied
for 30 seconds at the test mark. The
burner must be mounted underneath the
test mark on the specimen, perpendicular
to the specimen and at an angle of 30° to
the vertical plane of the specimen. The burner
must have a nominal bore of three-eighths
inch, and must be adjusted to provide a 3-
inch-high flame with an inner cone approxi-
amately one-third of the flame height, if the
minimum temperature of the hottest por-
tion of the flame, as measured with a cal-
ibrated thermocouple pyrometer, may not be
less than 1,750°F. The burner must be posi-
tioned so that the hottest portion of the
flame is applied to the test mark on the
wire. Flame time, burn length, and flaming
time of drippings, if any, must be recorded.
The burn length determined in accordance
with paragraph (h) Part I of this appendix
must be measured to the nearest one-tenth
inch. Breaking of the wire specimen is not
considered a failure.
(h) Burn Length. Burn length is the dis-
tance from the original edge to the farthest
evidence of damage to the test specimen
due to flame impingement, including areas of
partial or complete consumption, charring,
or embrittlement, but not including areas
sooted, stained, warped, or discolored, nor
areas where material has shrunk or melted
away from the heat source.

Part II—Flammability of Seat Cushions

(a) Criteria for Acceptance. Each seat
cushion must meet the following criteria:
(1) At least three sets of seat bottom and
seat back cushion specimens must be tested.
(2) If the cushion is constructed with
a fire blocking material, the fire blocking ma-
terial must completely enclose the cushion
foam core.
(3) Each specimen tested must be fabricat-
ed using the principal components (i.e.,
foam core, flotation material, fire blocking
material, if used, and dress covering) and as-
sembly processes (representative seams and
closures) intended for use in the production
articles. If a different material combination
is used for the back cushion than for the
bottom cushion, both material combinations
must be tested as complete specimen sets,
each set consisting of a back cushion speci-
men and a bottom cushion specimen. If a
bottom cushion, including outer dress covering,
is demonstrated to meet the requirements of
this appendix using the oil burner test, the
covering of that cushion may be re-
placed with a similar dress covering provid-
ed the burn length of the replacement cov-
ering, as determined by the test specified in
§ 25.85(k), does not exceed the correspond-
ing burn length of the dress covering used
on the cushion subjected to the oil burner
test.
(4) For at least two-thirds of the total
number of specimen sets tested, the burn
length from the burner must not reach
the side of the cushion opposite the burner. The
burn length must not exceed 17 inches.
Burn length is the perpendicular distance
from the inside edge of the seat frame clos-
est to the burner to the farthest evidence
of damage to the test specimen due to flame
impingement, including areas of partial or
complete consumption, charring, or embrit-
tlement, but not including areas sooted,
warped, or discolored, or areas
where material has shrunk or melted away
from the heat source.
(5) The average percentage weight loss
must not exceed 10 percent. Also, at least
two-thirds of the total number of specimen
sets tested must not exceed 5 percent
weight loss. All droppings from flame
on the cushions and mounting stand are to be
discarded before the after-test weight is deter-
mined. The percentage weight loss for a
specimen set is the weight of the specimen
set before testing less the weight of the
specimen set after testing expressed as the
percentage of the weight of the specimen set.
(b) Test Conditions. Vertical air velocity
should average 25 fpm to 10 fpm at the top of
the back seat cushion. Horizontal air veloc-
ity should be below 10 fpm just above the
bottom seat cushion. Air velocities should
be measured with the ventilation hood oper-
aing and the burner motor off.
(c) Test Specimens. (1) For each test, one
set of cushion specimens representing a seat
bottom and seat back cushion must be used.
(2) The seat bottom cushion specimen
must be 18 1/4 inches (462.3 mm) wide by
20 1/4 inches (508.3 mm) deep by 4 1/4
inches (102.3 mm) thick, exclusive of fabric
 closures and seam overlap.
(3) The seat back cushion specimen
must be 18 1/4 inches (462.3 mm) wide by
25 1/4 inches (635.3 mm) high by 2 1/4
inches (51.3 mm) thick, exclusive of fabric
 closures and seam overlap.
(4) The specimens must be conditioned at
72±5 °F (21±2 °C) 55±10% relative hu-
midity for at least 24 hours before testing.
(d) Test Apparatus. The arrangement
of the test apparatus is shown in Figures 1
through 5 and must include the components
described in this section. Minor details of the
apparatus may vary, depending on the model
burner used.
(1) Specimen Mounting Stand. The
mounting stand for the test specimens con-
sists of steel angles, as shown in Figure 1.
The length of the mounting stand legs is
12±1/4 inches (305±3 mm). The mounting
stand must be used for mounting the test
specimen seat bottom and seat back, as
shown in Figure 2. The mounting stand
should also include a suitable drip pan lined
with aluminum foil, dull side up.
(2) Test Burner. The burner to be used in
testing must:
(i) Be a modified gun type;
(ii) Have an 80-degree spray angle nozzle
nominally rated for 2.25 gallons/hour at 100
psig;
(iii) Have a 12-inch (305 mm) burner cone
installed at the end of the draft tube, with
an opening 6 inches (152.4 mm) high and 11
inches (280 mm) wide, as shown in Figure 3.
and
(iv) Have a burner fuel pressure regulator that is adjusted to deliver a nominal 2.0 gallon/hour of a 2 Grade kerosene or equivalent required for the test.

Burner models which have been successfully tested in the test are the Lennox Model CR-2, Carlin Model 200 GRD, and Park Model DPL 3400. FAA published reports pertinent to this type of burner are: (1) Powerplant Engineering Report No. 34, Standard Fire Test Apparatus and Procedure for Flexible Hose Assemblies, dated March 1978; and (2) Report No. DOT/FAA/ RD/76/213, Reevaluation of Burner Characteristics for Fire Resistance Tests, dated January 1977.

(3) Calorimeter.
(i) The calorimeter to be used in testing must be a 0-150 BTU/t/sec. 0.170 w/cm² calorimeter, accurate ±9%, mounted in a 6-inch by 12-inch (152 by 305 mm) by 4-inch (19 mm) thick calcium silicate insulating board which is attached to a steel angle bracket for placement in the position during burner calibration, as shown in Figure 4.
(ii) Because crumbling of the insulating board with service can result in malposition of the calorimeter, the calorimeter must be monitored and the mounting shimmed, as necessary, to ensure that the calorimeter face is flush with the exposed plane of the insulating board in a plane parallel to the exit of the test burner cone.

(4) Thermocouples. The seven thermocouples to be used for testing must be 4½ to 6-inch metal sheathed, ceramic packed, type K, grounded thermocouples with a nominal 22 to 30 American wire gage (AWG)-size conductor. The seven thermocouples must be attached to a steel angle bracket to form a thermocouple rake for placement in the test stand during burner calibration, as shown in Figure 5.

(5) Apparatus Arrangement. The test burner must be mounted on a suitable stand to position the exit of the burner cone at a distance of 4½ inches (102÷3 mm) from one side of the specimen mounting stand. The burner stand should have the capability of allowing the burner to be swung away from the specimen mounting stand during warmup periods.

(6) Data Recording. A recording potentiometer or other suitable calibrated instrument with an appropriate range must be used to measure and record the outputs of the calorimeter and the thermocouples.

(7) Weight Scale. Weighing Device—A device must be used that with proper procedures may determine the before and after test weights of each set of seat cushion specimens within 0.02 pound (0 grams). A continuous weighing system is preferred.

(8) Timing Device. A stopwatch or other device calibrated to ±1 second must be used to time the application of the burner flame and self-extinguishing time or test duration.

(9) Preparation of Apparatus. Before calibration, all equipment must be turned on and the burner fuel must be adjusted as specified in paragraph (d)(2).

(1) Calibration. To ensure the proper thermal output of the burner, the following test must be made:
(i) Place the calorimeter on the test stand as shown in Figure 4 at a distance of 4½ inches (102÷3 mm) from the exit of the burner cone.
(ii) Turn on the burner, allow it to run for 2 minutes for warmup, and adjust the burner air intake damper to produce a reading of 10.5±0.5 BTU/t/sec (11.8±0.6 w/cm²) on the calorimeter to ensure steady state conditions have been achieved. Turn off the burner.
(3) Replace the calorimeter with the thermocouple rake (Figure 5).
(4) Turn on the burner and ensure that the thermocouples are reading 1900±100 °F (1038±55 °C) to ensure steady state conditions have been achieved.
(5) If the calorimeter and thermocouples do not read within range, repeat steps in paragraphs 1 through 4 and adjust the burner air intake damper until the proper readings are obtained. The thermocouple rake and the calorimeter should be used frequently to maintain and record calibrated test parameters. Until the specific apparatus has demonstrated consistency, each test should be calibrated. After consistency has been confirmed, several tests may be conducted with the pre-test calibration before and a calibration check after the series.

(2) Test Procedure. The flammability of each set of specimens must be tested as follows:
(i) Record the weight of each set of seat bottom and seat back cushion specimens to be tested to the nearest 0.02 pound (0 grams).
(ii) Mount the seat bottom and seat back cushion test specimens on the test stand as shown in Figure 2, securing the seat back cushion specimen to the test stand at the top.
(iii) Swing the burner into position and ensure that the distance from the exit of the burner cone to the side of the seat bottom cushion specimen is 4 to 4½ inches (102÷3 mm).
(iv) Swing the burner away from the test position. Turn on the burner and allow it to run for 2 minutes to provide adequate warmup of the burner cone and flame stabilization.
(v) To begin the test, swing the burner into the test position and simultaneously start the timing device.
(vi) Expose the seat bottom cushion specimen to the burner flame for 2 minutes and then turn off the burner. Immediately swing the burner away from the test position. Terminate test 7 minutes after initiating cushion exposure to the flame by use of a gaseous extinguishing agent (i.e., Halon or CO₂).
(vii) Determine the weight of the remains of the seat cushion specimen set left on the mounting stand to the nearest 0.02 pound (0 grams) excluding all droppings.

(3) Test Report. With respect to all specimens tested for a particular seat cushion for which testing of compliance is performed, the following information must be recorded:
(1) An identification and description of the specimens being tested.
(2) The number of specimen sets tested.
(3) The initial weight of each set, the calculated percentage weight loss of each set, and the calculated average percentage weight loss for the total number of sets tested.
(4) The burn length for each set tested.

Part III—Test Method to Determine Flame Penetration Resistance of Cargo Compartment Liners.

(a) Criteria for Acceptance. (1) At least three specimens of cargo compartment sidewall or ceiling liner panels must be tested.
(2) Each specimen tested must simulate...
the cargo compartment, sidewall or ceiling liner panel, including any design features, such as joints, l.,n.assemblies, etc., the failure of which would affect the capability of the liner to 1ay contain a fire.

(3) There must be no flame penetration of any specimen within 5 minutes after application of the flame source, and the temperature measured at 4 inches above the upper surface of the horizontal test sample must not exceed 160°F.

(b) Summary of Method. This method provides a laboratory test procedure for measuring the capability of cargo compartment lining materials to resist flame penetration with a 2 gallon per hour (GPH) #2 Grade kerosene or equivalent burner fire source. Ceiling and sidewall liner panels tested individually provided a baffie is used to simulate the missing panel. Any specimen that passes the test as a ceiling liner panel may be used as a sidewall liner panel.

(c) Test Specimens. (1) The specimen to be tested must measure 18 x 1/4 inches (406 x 3 mm) x 2 x 1/4 inches (610 x 3 mm).

(2) The specimens must be conditioned at 70°F ± 5°F. (21°C ± 2°C) and 55% ± 5% humidity for at least 24 hours before testing.

(d) Test Apparatus. The arrangement of the test apparatus, which is shown in Figure 3 of Part II and Figures 1 through 3 of this part of the appendices, must include the components described in this section. Minor details of the apparatus may vary, depending on the model of the burner used.

(1) Specimen Mounting Stand. The mounting stand for the test specimen consists of steel angles as shown In Figure 1.

(2) Test Burner. The burner to be used in testing must—

(i) Be a modified gun type.

(ii) Use a suitable nozzle and maintain fuel pressure to yield a 2 GPH fuel flow. For example, an 80 degree nozzle nominally rated 0.22 GPH and operated at 85 pounds per square inch (PSI) gage to deliver 2.03 GPH.

(iii) Have a 12 inch (305 mm) burner extension installed at the end of the draft tube with an opening 6 inches (152 mm) high and 11 inches (280 mm) wide as shown in Figure 3 of Part II of this appendix.

(iv) Have a burner fuel pressure regulator that is adjusted to deliver a nominal 2.0 GPH of #2 Grade kerosene or equivalent. Burner models which have been used successfully in testing are the Lenox Model OB-35, Carlins Model 200 CRD and Port Model DPL. The basic burner is described in FAA Powerplant Engineering Report No. 3A. Standard Fire Test Apparatus and Procedure for Flexible hose Assemblies, dated March 1978; however, the test settings specified in this appendix differ in some instances from those specified in the report.

(3) Calorimeter. (1) The calorimeter to be used in testing must be a total heat flux Foam Type Gordon Gage of an appropriate range (approximately 0 to 15.0 British thermal unit (BTU) per ft.² sec. 0-17.0 watts/cm²). The calorimeter must be mounted in a 6 inch by 12 inch (152 x 305 mm) by 6 inch (19 mm) thick insulating block which is attached to a steel angle bracket for placement in the test stand during burner calibration as shown in Figure 2 of this part of this appendix.

(ii) The insulating block must be monitored for deterioration and the mounting shimmed as necessary to ensure that the calorimeter face is parallel to the exit plane of the test burner cone.

(4) Thermocouples. The seven thermocouples to be used for testing must be ½ inch ceramic sheathed, type K, grounded thermocouples with a nominal 30 American wire gauge (AWG) size conductor. The seven thermocouples must be attached to a steel angle bracket to form a thermocouple rake for placement in the test stand during burner calibration as shown in Figure 3 of this part of this appendix.

(5) Apparatus Arrangement. The test burner must be mounted on a suitable stand to position the exit of the burner cone a distance of 8 inches from the ceiling liner panel and 2 inches from the sidewall liner panel. The burner stand should have the capability of allowing the burner to be swung away from the test specimen during warm-up periods.

(6) Instrumentation. A recording potentiometer or other suitable instrument with an appropriate range must be used to measure and record the outputs of the calorimeter and the thermocouples.

(7) Timing Device. A stopwatch or other device must be used to measure the time of flame application and the length of time of flame penetration, if it occurs.

(e) Preparation of Apparatus. Before calibration, all equipment must be turned on and allowed to stabilize, and the burner fuel flow must be adjusted as specified in paragraph (d)(2).

(f) Calibration. To ensure the proper thermal output of the burner the following test must be made:

(1) Remove the burner extension from the end of the draft tube. Turn on the blower portion of the burner without turning the fuel or igniters on. Measure the air velocity using a hot wire anemometer in the center of the draft tube across the face of the opening. Adjust the damper such that the air velocity is in the range of 1500 to 1800 ft./min. If tabs are being used at the exit of the draft tube, they must be removed prior to this measurement. Reinstall the draft tube extension cone.

(2) Place the calorimeter on the test stand as shown in Figure 2 at a distance of 8 inches (203 mm) from the exit of the burner cone to simulate the position of the horizontal test specimen.

(3) Turn on the burner, allow it to run for 2 minutes for warm-up, and adjust the damper to produce a flow of 8.0 ± 0.5 BTU per ft.² sec. (9.1 ± 0.6 Watts/cm²).

(4) Replace the calorimeter with the thermocouple rake (see Figure 3).

(5) Turn on the burner and ensure that each of the seven thermocouples reads 1700 °F ± 100 °F. (927 °C ± 53 °C) to ensure steady state conditions have been achieved. If the temperature is out of this range, repeat steps 2 through 5 until proper readings are obtained.

(6) Turn off the burner and remove the thermocouple rake.

(7) Repeat (1) to ensure that the burner is in the correct range.

(g) Test Procedure. (1) Mount a thermocouple of the same type as that used for calibration at a distance of 4 inches (102 mm) above the horizontal (ceiling) test specimen. The thermocouple should be centered over the burner cone.

(2) Mount the test specimen on the test stand shown in Figure 1 in either the horizontal or vertical position. Mount the insulating material in the other position.

(3) Position the burner so that flames will not impinge on the specimen, turn the burner on, and allow it to run for 2 minutes.
Rotate the burner to apply the flame to the specimen and simultaneously start the timing device.

(4) Expose the test specimen to the flame for 5 minutes and then turn off the burner. The test may be terminated earlier if flame penetration is observed.

(5) When testing ceiling liner panels, record the peak temperature measured 4 inches above the sample.

(6) Record the time at which flame penetration occurs, if applicable.

(h) Test Report. The test report must include the following:

(1) A complete description of the materials tested including type, manufacturer, thickness, and other appropriate data.

(2) Observations of the behavior of the test specimens during flame exposure such as delamination, resin ignition, smoke, etc., including the time of such occurrence.

(3) The time at which flame penetration occurs, if applicable, for each of the three specimens tested.

(4) Panel orientation (ceiling or sidewall).

Part IV—Test Method to Determine the Heat Release Rate From Cabin Materials Exposed to Radiant Heat.

(a) Summary of Method. The specimen to be tested is injected into an environmental chamber through which a constant flow of air passes. The specimen's exposure is determined by a radiant heat source adjusted to produce the desired total heat flux on the specimen of 3.5 W/cm², using a calibrated calorimeter. The specimen is tested so that the exposed surface is vertical. Combustion is initiated by piloted ignition. The combustion products leaving the chamber are monitored in order to calculate the release rate of heat.

(b) Apparatus. The Ohio State University (OSU) rate of heat release apparatus, as described below, is used. This is a modified version of the rate of heat release apparatus standardized by the American Society of Testing and Materials (ASTM). ASTM E-906.

(1) This apparatus is shown in Figure 1. All exterior surfaces of the apparatus, except the holding chamber, shall be insulated with 25 mm thick, low density, high-temperature fiberglass board insulation. A gasketed door through which the sample injection rod slides forms an airtight closure on the specimen holding chamber.

(2) The temperature difference between the air entering the environmental chamber and that leaving is monitored by a thermocouple having three hot and three cold, 32 gauge Chromel-Alumel junctions. The hot junctions are spaced across the top of the exhaust stack. Two hot junctions are located 25 mm from each side on diagonally opposite corners, and the third in the center of the chimney's cross-section 10 mm below the top of the chimney. The cold junctions are located in the pan below the lower air distribution plate (see paragraph B(4)(i)).

(3) Thermal Inertia Compensator. A compensator tab is made from 0.05 mm stainless steel sheet, 10 by 20 mm. An 800 mm length of 24 gauge Chromel-Alumel, glass insulated, duplex thermocouple wire is welded or silver soldered to the tab as shown in Figure 2, and the wire bent back so that it is flush against the metal surface.

(4) The compensator tab must be mounted on the exhaust stack as shown in Figure 3 using a 6-32 round head machine screw, 12 mm long. Add small (approximately 4.3 mm O.D., 9 mm O.D.) washers between the head of the machine screw and the compensator tab to give the best response to a square wave input. (One or two washers should be adequate.) The "sharpness" of the square wave can be increased by changing the ratio of the output from the thermopile and compensator thermocouple which is fed to the recorder. The ratio is changed by adjusting the 1-K ohm variable resistor (R.) of the thermopile bleeder shown in Figure 4. When adjusting compensation, keep R. as small as possible. Adjustment of the compensator must be made during calibration (see paragraph E(11)) at a heat release rate of 7.0 plus or minus 0.5 kW.

(iii) Adjust the washers and the variable resistor (R.) so that 90 percent of full scale response is obtained in 4 to 12 seconds. There must be no overshoot, as shown in Figure 5A. If an insufficient number of washers is added, or R. is too small, the output with square wave input will look like Figure 5B. If too many washers are added and R. is too large, the output will look like Figure 5A.

(iv) Subtract the output of the compensator from the thermopile. The junctions enclosed in the dotted circle of Figure 4 are kept at the same constant temperature by electrically insulating the junctions and placing them on the pipe carrying air to the manifold, then covering them and the pipe with thermal insulation.

(v) Thermopile hot junctions must be cleaned at least once a day on a daily basis during periods of testing.

(3) Radiation Source. A radiant heat source for generating a flux of 10 ± 0.1 kW/m², using four silicon carbide elements. Type LL, 20 inches (50.8 cm) long by ¾ inch (1.94 cm) O.D., nominal resistance 1.4 ohms, is shown in Figures 6A and 6B. The silicon carbide elements are mounted in the stainless steel panel box by inserting them through 16 holes in 0.8 mm thick ceramic fiber board. Location of the holes in the pylon and stainless steel cover plates are shown in Figure 6B. The diamond shaped mask of 24 gauge stainless steel is added to provide uniform heat flux over the area occupied by the 150 by 150 mm vertical sample. A power supply of 121 V, adjustable from 0 to 270 volts, is required.

(4) Air Distribution System. The air entering the environmental chamber is distributed by a 6.3 mm thick aluminum plate having eight, No. 4 drill holes, 51 mm from sides on 102 mm centers, mounted at the base of the environmental chamber. A second plate of 18 gauge steel having 120, evenly spaced, No. 28 drill holes is mounted 150 mm above the aluminum plate. A well-regulated air supply is required. The air supply manifold at the base of the pyramidal section has 48, evenly spaced, No. 28 drill holes located 10 mm from the inner edge of the manifold so that 0.03 m/s/second of air flows between the pyramidal sections and 0.01 m/s/second flows through the environmental chamber when total air flow to apparatus is controlled at 0.04 m/s/second.

(5) Exhaust Stack. An exhaust stack, 133 mm by 70 mm in cross section, and 254 mm long, fabricated from 28 gauge stainless steel, is mounted on the outlet of the pyramidal section. A 20 mm by 76 mm plate of 3 gauge stainless steel is centered inside the stack, perpendicular to the air flow, 75 mm above the base of the stack.

(6) Specimen Holders. The 150 mm x 150 mm specimen is tested in a vertical orientation. The holder (Figure 7) is provided with a specimen holder frame, which touches the specimen (which is wrapped with aluminum
foil as required by paragraph (d)(3) of this Part) along only the 10 mm perimeter, and a "V"-shaped spring to hold the specimen together. A detachable 12 mm x 12 mm x 150 mm drip pan is also provided for testing of materials prone to melting and dripping. The positioning of the spine and frame may be changed to accommodate different specimen thicknesses by inserting the retaining rod in different holes on the specimen holder.

Since the radiation shield described in ASTM E-906 is not used, a guide pin is added to the injection mechanism. This fits into a slotted metal plate on the injection mechanism outside of the holding chamber and can be used to provide accurate positioning of the specimen face after injection. The front surface of the specimen shall be 100 mm from the closed radiation doors after injection.

The specimen holder clips onto the mounting bracket (Figure 7). The mounting bracket is attached to the injection rod by three screws which pass through a wide area which is welded onto a ½ inch nut. The end of the injection rod is threaded to screw into the nut and a .020 inch thick wide area washer is placed between two ¼ inch nuts which are adjusted to tightly cover the hole in the radiation doors through which the injection rod or calibration calorimeter passes.

(7) Pilot Flame Positions. Pilot ignition of the specimen must be accomplished by simultaneously exposing the specimen to a lower pilot burner and an upper pilot burner, as described in paragraph (b)(8)(i) and (b)(8)(ii), respectively.

(i) Lower Pilot Burner. The pilot-flame tubing must be 6.3 mm O.D., 0.8 mm wall, stainless steel tubing. A mixture of 120 cm³/min. of methane and 850 cm³/min. of air must be fed to the lower pilot flame burner. The normal position of the end of the pilot burner tubing is 10 mm from and perpendicular to the exposed vertical surface of the specimen at the outlet of the burner tubing must intersect the vertical centerline of the sample at a point 5 mm above the lower edge of the specimen.

(ii) Upper Pilot Burner. The pilot burner must be a straight length of 6.3 mm O.D., 0.8 mm wall, stainless steel tubing that is 360 mm long. One end of the tubing shall be closed, and three No. 40 drill holes shall be drilled into the tubing, 60 mm apart, for gas ports, all radiating in the same direction. The first hole must be 5 mm from the closed end of the tubing. The tube is inserted into the environmental chamber through a 6.6 mm x 10 mm drilled hole above the upper edge of the window frame. The tube is supported and positioned by an adjustable "V" shaped support mounted inside the environmental chamber, above the viewing window. The tube is positioned above and 20 mm behind the exposed upper edge of the specimen. The middle hole must be in the vertical plane perpendicular to the exposed surface of the specimen which passes through its vertical centerline and must be pointed toward the radiation source. The gas supplied to the burner must be methane adjusted to produce flame lengths of 25 mm.

(c) Calibration of Equipment. (1) Heat Release Rate. A burner as shown in Figure 8 must be placed over the end of the lower pilot flame tubing using a gas tight connection. The flow of gas to the pilot burner must be at least 99 percent methane and must be accurately metered. Prior to usage, the wet test meter is properly leveled and filled with distilled water to the top of the internal pointer while no gas is flowing. Ambient temperature and pressure of the water, are based on the internal wet test meter temperature. A baseline flow rate of approximately 1 liter/min is set and increased to higher preset flows of 3, 4, 6 and 8 liters/min. The rate is determined by using a stop-watch to time a complete revolution of the wet test meter for both the baseline and higher flow, with the flow returned to baseline before changing to the next higher flow. The thermopile baseline voltage is measured. The gas flow to the burner must be increased to the higher preset flow and allowed to burn for 4.0 minutes, and the thermopile voltage must be measured. The sequence is repeated until all four values have been determined. The average of the four values must be used as the calibration factor. The procedure is held between two ¼ inch nuts which are adjusted to tightly cover the hole in the radiation doors through which the injection rod or calibration calorimeter passes.

(2) Flux Uniformity. Uniformity of flux over the specimen must be checked periodically and after each heating element change to determine if it is within acceptable limits of plus or minus 5 percent. Calculations are shown in paragraph (1).

(3) Procedure. (1) The power supply to the radiant panel is set to produce a radiant flux of 3.5 W/cm². The flux is measured at the point which the center of the specimen surface will occupy when positioned for test. The radiant flux is measured after the air flow through the equipment is adjusted to the desired rate. The sample should be tested in its use end thickness.

(2) The pilot flames are lighted and their position, as described in paragraph (b)(8), is checked.

(3) The air flow to the equipment is set at 0.04 plus or minus 0.001 m³/s at atmospheric pressure. Proper air flow may be set and monitored by either (1) An orifice meter designed to produce a pressure drop of at least 200 mm of the manometric fluid, or by (2) A rotometer (variable orifice meter) with a scale capable of being read to plus or minus 0.0004 m³/s. The stop watch is used to measure the time that the specimen holder rod is adjusted so that the exposed surface of the specimen is positioned 100 mm from the entrance slit when injected into the environmental chamber.

(4) The specimen is placed in the hold chamber with the radiation doors closed. The air inlet and outlet doors are opened, and the recording devices are started. The specimen must be retained in the hold chamber for 60 seconds, plus or minus 10 seconds, before injection. The thermopile "zero" value is determined during the last 20 seconds of the hold period.
(5) When the specimen is to be injected, the radiation doors are opened, the specimen is injected into the environmental chamber, and the radiation doors are closed behind the specimen.

(6) A negative heat release will occur due to heat absorption by the cold specimen holder. Data-acquisition devices must have the capability of following these negative outputs and correcting the sample burn with a “blank” test result.

(7) Injection of the specimen marks time zero. A continuous record of the thermopile output must be made during the time the specimen is in the environmental chamber.

(8) The test duration time is five minutes.

(9) A minimum of three specimens must be tested.

(10) Calculations: (1) The calibration factor is calculated as follows:

\[
K_h = \frac{(F_1 - F_0) \times (210.8 - 22) \text{kcal}}{(V_1 - V_0)} \times \frac{273}{T_a} \times \frac{\text{mole} \text{CH}_4 \text{STP}}{760} \times \frac{22.41 \times 0.01433 \text{kcal}}{1000 \text{w}}
\]

\[P_f = \text{flow of methane at baseline (lpm)}\]
\[P_I = \text{higher preset flow of methane (lpm)}\]
\[V_m = \text{thermopile voltage at baseline (mv)}\]
\[V_I = \text{thermopile voltage at higher flow (mv)}\]
\[T_a = \text{ambient temperature (K)}\]
\[P = \text{ambient pressure (mm Hg)}\]
\[P_v = \text{water vapor pressure (mm Hg)}\]

(2) Heat release rates may be calculated from the reading of the thermopile output voltage at any instant of time as

\[\text{HRR} = \frac{(V_m - V_b)}{0.0233 \text{ m}^2} \times K_h\]

HRR = Heat release rate \(\text{kw/m}^2\)

\[V_b = \text{measured thermopile voltage (mv)}\]
\[V_b = \text{“blank” thermopile voltage}\]

(3) The integral of the heat release rate is the total heat release as a function of time and is calculated by multiplying the rate by

the data sampling frequency in minutes and summing the time from zero to two minutes.

(4) Criteria. The total positive heat release over the first two minutes of exposure for each of the three or more samples tested must be averaged, and the peak heat release rate for each of the samples must be averaged. The average total heat release must not exceed 65 kilowatt-minutes per square meter, and the average peak heat release rate must not exceed 65 kilowatts per square meter.

(b) Report. The test report must include the following for each specimen tested:

(1) Description of the specimen.

(2) Radiant heat flux to the specimen, expressed in W/cm².

(3) Data giving release rates of heat (in kW/m²) as a function of time, either graphically or tabulated at intervals no greater than 10 seconds. The calibration factor \(K_h\) must be recorded.

(4) If melting, sagging, delaminating, or other behavior that affects the exposed surface area or the mode of burning occurs, these behaviors must be reported, together with the time at which such behaviors were observed.

(5) The peak heat release and the 2-minute integrated heat release rate must be reported.
Figure 1. Release Rate Apparatus

Figure 2. Compensator Tab

Figure 3. Compensator Tab Mount

Figure 4. Wiring Diagram

(Unless denoted otherwise, all dimensions are in millimeters.)

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Figure 6A. "Globar" Radiant Panel

Figure 6B. "Globar" Radiant Panel

Figure 7
Upgrade of the fire safety standards

These amendments upgrade the fire safety standards for cabin interior materials in transport category airplanes by establishing refined fire test procedures and apparatus and a new requirement for smoke emission testing. The refined test procedures and apparatus are the result of additional research and fire testing and are intended to improve the reproducibility of test results. The refinement for smoke emission testing is intended to minimize the possibility that emergency egress will be hampered by smoke obscuration [ref. 39].

PART 25—AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

1. The authority citation for Part 25 continues to read as follows:


2. By amending § 25.853 by revising paragraph (a)(1) to read as follows:

(a)(1) For airplanes with passenger capacity of 20 or more, interior ceiling and wall panels other than lighting lenses, partitions, and the outer surfaces of galleys, large cabinets, and stowage compartments (other than underseat stowage compartments and compartments for stowing small items, such as magazine and maps) must also meet the test requirements of Parts IV and V of Appendix F of this Part, or other approved equivalent method, in addition to the flammable requirements prescribed in paragraph (a) of this Section.

3. By amending Appendix F by removing paragraph (e)(6) of Part IV and marking it "reserved:" removing Figures 2 through 5 of Part IV; redesignating Figures 6A, 6B, 7, and 8 of Part IV as Figures 2A, 2B, 3, and 4, respectively; revising Figures 1, 2A, 2B, 3 and 4 of Part IV; and revising paragraphs (b)(2), (3), (6), (7), (8) and (8)(i), (c)(1), (d)(1), (e)(7), and (f)(2) of Part IV inserting a new Figure 5 of Part IV; and adding a new Part V to read as follows:

Appendix F

Part IV.—Test Method to Determine the Heat Release Rate From Cabin Materials Exposed to Radiant Heat.

(2) Thermocouple. The temperature difference between the air entering the environmental chamber and that leaving is monitored by a thermocouple having five hot and five cold, 24-gauge Chromel-Alumel junctions. The hot junctions are spaced across the top of the exhaust stack 10 mm below the top of the

chimney. One thermocouple is located in the geometric center, with the other four located 10 mm from the center along the diagonal toward each of the corners [Figure 8]. The cold junctions are located in the pan below the lower air distribution plate (see paragraph (b)(4)). Thermocouple hot junctions must be cleared of soot deposits as needed to maintain the calibrated sensitivity.

(3) Radiation Source. A radiant heat source for generating a flux up to 10 kW/m², using four silicon carbide elements, Type LL, 20 inches (50.8 cm) long by 5/8 inch (1.54 cm) O.D., nominal resistance 1.14 ohms, is shown in Figures 2A and 2B. The silicon carbide elements are mounted in the stainless steel panel box by inserting them through 15.9-mm holes in 0.8 mm thick ceramic fiber board. Location of the holes in the pads and stainless steel cover plates are shown in Figure 2B. The diamond shaped mask of 24-gauge stainless steel is added to provide uniform heat flux over the area occupied by the 100- by 150-mm vertical sample.

(6) Specimen Holders. The 150-mm x 150-mm specimen is tested in a vertical orientation. The holder [Figure 3] is provided with a specimen holder frame, which touches the specimen (which is wrapped with aluminum foil as required by paragraph (d)(3) of this Part) along only the 8-mm perimeter, and a "V"-shaped spring to hold the assembly together. A detachable 12-mm x 12-mm x 150-mm drip pan and two 0.20-inch stainless steel wires (as shown in Figure 3) should be used for testing of materials prone to melting and dripping. The positioning of the spring and frame may be changed to accommodate different specimen thicknesses by inserting the retaining rod in different holes on the specimen holder.

Since the radiation shield described in ASTM E-606 is not used, a guide pin is added to the injection mechanism. This fits into a slotted metal plate on the injection mechanism outside of the holding chamber and can be used to provide accurate positioning of the specimen face after injection. The front surface of the specimen shall be 100 mm from the closed radiation doors after injection.

The specimen holder clips onto the mounted bracket [Figure 3]. The mounting bracket is attached to the injection rod by three screws which pass through a wide area washer welded onto a 1/4-inch nut. The end of the injection rod is threaded to screw into the nut and a 0.020-inch thick wide area washer is held between two 1/4-inch nuts which are adjusted to tightly cover the hole in the radiation doors through which the injection rod or calibration calorimeter pass.
(7) Calorimeter. A total-flux type calorimeter must be mounted in the center of a 4'-inch kaowool "M" board inserted in the sample holder to measure the total heat flux.

The calorimeter must have a view angle of 180 degrees and be calibrated for incident flux. The calorimeter calibration must be acceptable to the Administrator.

(d) Sample Preparation.
(1) The test specimen for vertically mounted specimens is 150 × 150 mm with thicknesses up to 45 mm.

(e) Procedure.

(6) [Reserved]

(7) Injection of the specimen and closure of the inner door marks time zero. A record of the thermocouple output with at least one data point per second must be made during the time the specimen is in the environmental chamber.

(1) * * *

(2) Heat release rates may be calculated from the readings of the thermocouple output voltage at any instant of time as

\[ HRR = \frac{V_m \times K_s}{0.02323} \]

where

- \( V_m \): measured thermocouple voltage (mv)
- \( K_s \): calibration factor (Kw/mv)

Part V. Test Method to Determine the Smoke Emission Characteristics of Cabin Materials

(a) Summary of Method. The specimens must be constructed, conditioned, and tested in the flaming mode in accordance with American Society of Testing and Materials (ASTM) Standard Test Method ASTM F814-83.

(b) Acceptance Criteria. The specific optical smoke density (D), which is obtained by averaging the reading obtained after 4 minutes with each of the three specimens, shall not exceed 200.
### Explanations

1. **A**. Ort mit Punktmarkierung! (°)
2. **B**: 1 = Flammen über (°) (°)

|   | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 80° | 90° | 100° | 110° | 120° | 130° | 140° | 150° | 160° | 170° | 180° |
|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

### Chapter

Appendix C

**Survey of small scale test methods**

-or this section may be omitted or be condensed by the interested reader in their own manner.

Note: This section not be considered to be complete. Its more details see chapter II.
### Appendix D

#### Material flammability properties.

Note: This table only gives an indication of the results of the tests. There exists considerable variation among the values given in literature.
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<th>ASTM E 906</th>
<th>FFA 28.654 (1)</th>
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**DFM specifications:**
- DFM-Chamber
- ASTM E 906
- FFA 28.654 (1)

**Smoke Density (O.45 m/s):**

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**Remarks:**
- Applicable Test Methods
- Subject to
- Requirements