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FIRE TESTS AND CRITERIA FOR AIRCRAFT INTERIORS

by

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I. Introduction

From its inception this research program was based on the concept that aircraft must be analyzed and controlled in a very logical manner. In the initial proposal the concept of having a set of requirements that simply state the fire safety objectives of aircraft interiors was introduced. These statements can be general in nature but they should be divided into logical subject areas that relate to the real world. In a sense, they can be thought of as the spirit of the law rather than the letter of the law. By necessity codes and standards must be more specific, but in the final analysis the detailed criteria and test methods must be related back to a rational framework of requirements. The process of improving fire safety through actual accident experience and laboratory research must continuously be forced by vigorous interchange between all parties concerned with the subject. The fire safety design and regulation system has five essential parts:

A. The Requirements for fire safety in aircraft.

B. The Criteria to meet those requirements.

C. Tests which determine whether a given design meets the criteria.

D. Feedback from all concerned parties, good fire statistics are vital; deficiencies in the system must trigger immediate action.

E. Research applied to forming a rational basis for meeting the requirements, criteria and tests.

This research program was primarily concerned with the development of criteria for large-scale fire tests of aircraft interior materials, components and systems. A series of aircraft fire scenarios were developed to illustrate the meaning of specific criteria and a framework to interpret the large-scale tests. A series of large-scale component tests were undertaken at the University of California. In addition, the University of California staff worked jointly with the NASA Ames staff in designing, conducting, and interpreting large-scale tests conducted at NASA-Houston, the McDonnell Douglas Company, and the Boeing Company.

In the course of this research a self-consistent set of Fire Safety Requirements for Aircraft Interiors has been developed at the University of California at Berkeley which was used as a basis for planning the research carried out on the grant. There are five requirements in this analysis that focus on the essential areas which need to be controlled.

REQUIREMENTS FOR AIRCRAFT INTERIORS

1. Risk of Fire Outbreak:
   The frequency of unwanted fires must be controlled at the ignition or initial phase of the fire. The probability of fire must be kept as low as possible.

2. Fire Propagation within Aircraft Interior Spaces:
   The rate of fire spread through any interior space from a given source of ignition (at a certain fire threat level) should be slow enough to allow extinguishment and/or evacuation.

3. Containment of Fire in Aircraft Interior Spaces:
   A fire should be contained in spaces that do not affect the control and safe operation of the aircraft. Further, any concealed space should have the demonstrated ability to contain any conceivable fire without jeopardizing the passengers and crew.

4. Structural Integrity and Airworthiness:
   The aircraft should retain its structural integrity and airworthiness from an on-board fire and there should be minimum threat to passengers or crew from this point of view.

5. Toxic Threat of Products of Combustion:
   The aircraft construction should be free from any materials that produce excessive amounts of smoke or toxic gases that would threaten the life of passengers and crew under foreseeable fire conditions.

In practice, each of these requirements would be established as a major heading and specific criteria and tests would establish the level of performance of given materials, components and systems. For instance, in the case of the first requirement, Risk of Fire Outbreak, criteria should be established to prevent fire initiation from electrically powered equipment (e.g., the use of hot plates must be carefully controlled). Other criteria should address the ease of ignition of materials.

This work is principally concerned with establishing criteria on the second and third of the requirements above, Fire Propagation and Containment of Fire. A program of research was conducted that began with the development of possible aircraft fire scenarios and continued with the experimental determination of actual fire performance.

II. Inflight Fire Scenarios

The use of scenarios has come to be recognized as one of the best ways to study fire safety of complex systems.[1] Serious aircraft fires occur infrequently, but when they do occur they may result in large loss of life and extensive property damage. Because of this low frequency of occurrence, the statistical methods of analysis that have proved so valuable in dealing with many fire problems are of little use in the case of aircraft fires. The fire scenarios then emerge as a major tool in the analysis of fire hazards associated with the design, construction and operation of aircraft.

In the course of this research project a set of fire scenarios was developed to serve as background for large-scale fire tests of aircraft interiors[2]. Aircraft fire scenarios should be based on real incidents, either major aircraft fires or plausible extrapolations from minor incidents where proper design or timely introduction prevented a major catastrophe[3]. It is recognized that most aircraft fire investigations are handicapped by the absence of trained observers during active stages of the fire and by the extensive destruction of physical evidence. On the other hand, major accidents are thoroughly investigated by skilled investigators, and the probable sequence of events can frequently be reconstructed with a high degree of confidence. A recent ramp fire in the service center of a wide-bodied aircraft was experimentally simulated in order to understand how the actual fire might have spread. This is a good example of how experimental simulation of critical elements in the scenario may be helpful in choosing between alternative paths of fire development or in lending support to speculative deductions.

A practical range of fire scenarios can describe only a small fraction of the possible fire incidents which can occur in aircraft. It is necessary that they threaten the relevant factors which affect fire development in a way that permits generalization. In particular, scenarios based on real incidents will be retrospective in nature and will be incapable of predicting the effects of new design and new materials on fire safety unless the teachings of the scenario can be applied to new situations. Fictitious scenarios can be written in either past tense, and thus sound like a actual accident, or in the present or future tense to make their fictitious nature more apparent. In the five fictitious scenarios given below the first is in present tense and the remaining four are in past tense.

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[1]National Materials Advisory Board, <u>Fire Safety Aspects of Polymeric Materials--Fire Dynamics and Scenarios</u>, <u>4</u>, 1980.

[2]Four Scenarios were prepared for the project by the well known Fire Protection Engineer, Rexford Wilson of Firepro Inc, in a document entitled: "A Selection of Inflight Fire Conditions for Possible Modeling", Firepro File: 6U423, October 28, 1975. These appear below as Scenarios II through V with some minor editorial changes.

[3]The application of scenarios to aircraft is specifically discussed in the companion volume to the previous reference on scenarios, namely: National Materials Advisory Board, <u>Fire Safety Aspects of Polymeric Materials--Aircraft: Civil and Military</u>, <u>6</u>, 1977.

Scenario I -- Fire in Forward Lavatory of Wide-Body Aircraft

Let us assume that a "Wide-Body" passenger aircraft is in a holding pattern over a final destination where local weather conditions have temporarily closed all of the air fields. It is expected that these local conditions are transitory, such as a line of thunder showers that sweeps the midwestern parts of the United States during the summertime. Our flight is in a holding pattern above the weather and the passengers are allowed to freely walk about the cabin and smoking is allowed. On this aircraft there are two lavatories at the front of the forward cabin, (often the first class section occupies this portion of the aircraft), and these lavatories share a wall with the flight deck. We shall assume that a cabin attendant has placed three bags of trash in the left lavatory and has locked it from the outside. The stage is now set for the actors to begin the sequence of events that almost always involve the elements of human error.

A passenger in the smoking section suddenly has what might be delicately called "an attack of diarrhea". It is a failing we have all had at one time or another and a crowded airplane must be one of the worst possible places to have one. This passenger rushes to the left hand lavatory, but does not stop to read the occupied sign that would be displayed with the locked door. Instead, the door is forced open and the passenger springs the lock. Once in the lavatory, however, the passenger finds the trash bags are blocking the toilet as well as making it difficult to reopen the door. Another lunge, however, gets the passenger out of the lavatory, but not before dropping a lighted cigarette on one of the polyethylene bags of trash. The passenger goes to the other lavatory and we need not follow the passenger's actions any further since the ignition phase of the scenario is started as soon as the trash bag begins to burn.

The growth phase of the fire in the lavatory is the next element in the scenario. It is quite probable that without automatic detection, this growth could proceed quite far before it is discovered by someone. It is easy to imagine that the flight attendants are tired and are taking the delay as an opportunity to relax before landing at the end of a long flight. The door is not latched, so there is the possibility that it may be any degree of openness. In general, it is safe to assume that it will assume the worst position at any one instant of time. The growth of the fire will usually be marked by some point where the whole lavatory will be involved in fire and this will make the beginning of the fire that must be contained.

It would seem reasonable that the wall panels and the ceiling panel of the left hand lavatory where the fire has started should contain the fire, and prevent its spread into the flight deck. It is obvious that the flames and smoke could spread with ease through the door but this is really a fire propagation problem rather than one of containment.

The scenario given here was chosen as "Design-Basis" scenario for a series of experiments conducted under this grant. It is obvious that even two or three trash bags do not make a very serious fire if the aircraft materials do not become involved. Furthermore, it is the kind of fire that might be extinguished if one of the flight attendants could don a fire-fighting coat to approach the open door. In any event, it is clearly a situation in which the wall between the lavatory and the flight deck will have to contain the fire, or the flight of the aircraft will be in jeopardy.

Scenario II -- Fire in Lift Closet on Wide-Body Aircraft

In this scenario a wide-body aircraft, carrying a total of 120 passengers is on its way from Denver to New York. The crew consists of 3 flight crew, 1 inflight supervisor and 10 flight attendants. The aircraft is 33,000 ft. over Urbana, Illinois, the closest largest airports being Chicago and Indianapolis. It is 12:23 pm., cst, in November on the day before Thanksgiving.

In the middle of the aircraft, between doors 3L and 3R, there is cross aisle 3, approximately 10 ft. long and 4 ft. wide. The most forward wall houses 2 electric coat racks, which can be raised and lowered with a sliding cover panel to close them. Four small compartments are also in the same wall at floor level. These compartments house 2 bassinets, 2 water extinguishers, an oxygen bottle and a first aid kit. The aft wall is solid except for two small cabinets containing bayonet tray tables. (This is the actual arrangement of one of the common wide-body aircraft.)

Due to the passenger load and time of year, the center coat closets were full of garment bags of all kinds and contents. Although they normally remain in a closed configuration there are times in flight when they are opened. This happens to be one of those times.

Two hours into the flight, cocktails has been served and approximately eight serving carts were being positioned to begin the dinner service to the coach passengers. Four of these were located at cross aisle 3. Most passengers had made themselves comfortable; loose newspapers, books, magazines, pillows and blankets abounded. A number of passengers were stretching themselves in the aisles.

A passenger requested his garment bag. It was retrieved from the rack at cross aisle 3 and the rack was raised back into the wall and the panel door lowered.

Two minutes later, smoke was seen coming from the wall of this coat rack door. The door was hot and one of the attendants opened the door by its normal mechanism. A two foot high flame and large quantities of smoke came out. One flight attendant notified the cockpit while another tried to use the water extinguisher grabbed from the cabinet below. The water didn't completely control the fire. There is little or no fire resistance (i.e., the ability to contain fire) built into the walls or ceiling of these closets and in this scenario we assume flame had reached the space above the center ceiling panels forward of the wall (rows 18-20).

Due to the crowded conditions and the carts' positions, movement was difficult, but two dry chemical extinguishers were brought from doors 2R and 4L. They were also exhausted as they knocked down visible flame, but smoke continued to build. Movement in the cabin was difficult. Passengers were reseated, the 24 nearest the fire moved into empty seats (4 of the 28 empty seats were in the fire area). The cabin was depressurized and the O_2 masks were dropped.

There was an attempt to reach O'Hare field, but the flight crew was overcome. The plane impacted 15 miles south of O'Hare. No survivors. Autopsy indicated all on board dead before impact. Fire apparently spread above the ceiling as well as in the passenger compartment.

<u>Scenario III</u> -- A Fire in Aft Storage Area of A Wide-Body A/C

In this scenario a wide-body aircraft, carrying a total of 200 passengers in on its way from Chicago to Honolulu. The crew consists of 3 flight crew, 1 inflight supervisor, and 12 flight attendants. The aircraft is 35,000 ft. over Sacramento, during March at 11:12 a.m., pst.

The left aft closet behind door 5L is officially designated as storage for life vests. Assorted blankets, pillows, paper lavatory supplies and crew luggage are stored here on occasion. The ceiling panel of the closet can be freely lifted. On looking into the tail area, insulation and some wiring is visible. It is an open area and can be entered and moved around in. This tail area above the closet is an unofficial rest area for crew members on long flights.

This scenario is based on the chance that the ceiling panel had been left slightly ajar. The closet door was closed, and the fire ignited inside the closet.

Upon detection of the fire, the cockpit was notified by phone. Two flight attendants secured 2 water and 2 dry chemical extinguishers to fight the fire. Two other flight attendants relocated 40 passengers forward away from the fire. The flight engineer arrived during this maneuver. Three minutes after detection the 4 extinguishers were exhausted. The closet fire was almost extinguished but insulation above the fire was burning but out of reach. The cockpit was notified.

Three and one-half minutes after detection smoke and fumes had reached a level that prevented further firefighting. The O_2 masks were dropped and the captain notified Oakland to expect an emergency landing with fire on board. The cabin was then rapidly decompressed.

Five minutes after detection the Oakland Fire Department received its alarm at 11:17 am., pdt. On orders from the Battalion Chief, a third alarm support was sounded bringing 10 engines, 4 ladders, 3 rescues. In addition, the hospitals were alerted to stand by for a major emergency. In addition, 12 ambulances were summoned on a stand-by basis.

The crash command post was established at the South end of the major North-South runway.

At eleven minutes after detection a rapid descent had been made, the plane landed at Oakland at Runway 29. The cabin was full of smoke. Seventy-five passengers, 7 flight attendants and 2 flight crew were evacuated using doors 1L, 1R, 2L, 2R, and 3R. Other slides were inoperable because of inside conditions, and, unknown to others, 4 flight attendants were unconscious.

125 passengers, 6 flight attendants and 1 flight crew were killed. 68 passengers, 6 flight attendants and 2 flight crew and injured and hospitalized due to toxic smoke products.

Scenario IV -- A Lavatory Fire in in a Narrow-Body Aircraft

In this scenario a Standard narrow-body aircraft carrying a total of 65 passengers is on its way from Chicago to Toronto. The crew consists of 3 flight crew and 3 flight attendants. The aircraft is 29,000 ft. over Flint, Michigan in November at 8:10 pm., est.

Thirty minutes after takeoff, an intoxicated passenger entered the left aft lavatory, cigarette in hand. He apparently put his cigarette in a full towel disposal bin. Several minutes later he stumbled out, "There's a fire back there!"

Two water extinguished and 1 dry chemical extinguished were used to quell the fire. It appeared to be out.

The O_2 masks were used. Smoke continued to build in the cabin. The plane landed in Lansing on Runway 9 ten minutes after detection of the fire. Burning was located inside the walls and above the lavatory.

Fifty-five passengers and 5 crew were evacuated safely through the front and buffet doors and window exits. Ten passengers and one crew member jammed the narrow aisle at Row 19 and couldn't get out in time.

Scenario V -- A Stretched Narrow-Body Charter Inflight Fire at Seat

In this scenario a "Stretched" Narrow-Body Aircraft, Charter Configuration, carrying a total of 223 passengers is on its way from New York to Las Vegas. The crew consists of 3 flight crew and 6 flight attendants. The aircraft is 35,000 ft. over Pueblo, Colorado about 1-1/2 hours out of Las Vegas. It is 3:45 pm., mst, on April 14.

This aircraft was one long tube, all one class. Four hours out of New York, dinner and cocktails had been served. A second round of cocktails had been started. The aisle was jammed with people visiting, drinking, and smoking. Newspapers, magazines, clothing, blankets and pillows were strewn everywhere. A party mood prevailed with cocktails beginning to cloud judgement.

An unnoticed cigarette missed the ashtry and landed in the folds of a newspaper on the floor of the overwing area (approx. seat 18B).

Approximately two minutes later, an open flame extended from the now burning newspaper to a blanket hung over the seat back. A passenger in the aisle saw the flame in the blanket. The passenger yelled "fire" and smoke was now beginning to be seen. Considerable confusion began.

Flight attendants tried to work up to the area. One passenger attempted to smother the fire. The A steward ordered everyone to his/her seat. The cockpit was notified.

People began to move away, some obviously disturbed. Several tried to fight the fire. The burning newspapers were smothered. The blanket still burned and the underside of the three seats in Row 17 was now burning and the carpet was beginning to contribute to the smoke. The smoke was beginning to make the cabin intolerable. The pilot depressurized the cabin, and the O_2 masks were dropped.

Flight attendants could not reach the area for 4 minutes. When they did, smoke and fumes precluded any firefighting. Two minutes later the wall and overhead bins were ignited.

The fire could not be controlled or fought. An attempted emergency landing in an open field eight minutes south of Denver was unsuccessful.

The preceding scenarios were used during the course of the project as examples of potential inflight fires. All of these fires could have been thwarted by the use of two "Requirements" , namely Nos. 2 and 3, as given in the Introduction:

2. <u>Fire Propagation within Aircraft Interior Spaces</u>:
   The rate of fire spread through any interior space from a given source of ignition (at a certain fire threat level) should be slow enough to allow extinguishment and/or evacuation.

3. <u>Containment of Fire in Aircraft Interior Spaces</u>:
   A fire should be contained in spaces that do not affect the control and safe operation of the aircraft. Further, any concealed space should have the demonstrated ability to contain any conceivable fire without jeopardizing the passengers and crew.

There is further evidence from actual inflight fires which have occurred since the end of the active experimental phase of the project that an improvement in these two areas would prevent major life loss in aircraft fires. For example, the severe inflight fire and subsequent loss of 301 persons on the Saudi Arabian Airlines Lockeed L-1011, HZ-AHK, at Riyadh, Saudi Arabia, on August 19, 1980 would clearly have been avoided if there had been some measure of containment of the aft cargo compartment; or if there had been steps taken to reduce the fire propagation within the passenger compartment[4]. The ignition source in the Riyadh fire was probably some kind of smoking material left in the aft cargo compartment which started a fire after the aircraft was airborne. A summary of the events is similar to the scenarios given above. The sequence of events was as follows:

1. The aircraft was pushed back from the gate at 1750.

2. It was cleared for take off at 1808.

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[4] "Aircraft Accident Report: Saudi Arabian Airlines, Lockeed L-1011, HZ-AHK, Riyadh, Saudi Arabia, August 19, 1980, Submitted by E.D. Dreifus, Director of Civil Aviation Safety to H.E. Sheikh Nassar Al-Assaf, President of Civil Aviation, Jedda, Saudi Arabia, January 16, 1982.

3. At 1814:54 the crew was alerted by both visual and aural warnings that smoke was in the aft cargo compartment (C-3).

4. The next 4 minutes and 26 seconds were spent by the flight crew in confirming the warning.

5. At 1820:16 the flight engineer reported back to the flight deck that there was fire in the cabin.

6. At 1820:17 the first officer contacted Riyadh by radio and said that they had fire in the cabin and that they were returning to Riyadh.

7. At the time they started back they were 78 miles out at 22,400 ft.

8. At 1825:26 they were 40 miles out and reported to Riyadh that there was an "actual fire" in the cabin and that they had shut down their No. 2 engine (the one in the tail) since its throttle was stuck.

9. The aircraft touched down at Riyadh at 1836:24 and came to a stop at 1838:56.

10. During the roll-out the aircraft was in radio contact with the tower.

11. At 1840:33, after being told by the tower that they have fire in the tail, someone on the flight deck stated over the radio, "Affirmative, we are trying to evacuate now". This was the last transmission received from the aircraft.

12. The tower and fire personnel continued to talk over the radio about the need for the engines to be shut down, and they were shut down at 1842:18.

13. The R2 door was opened at 1905 and no sign of life was seen.

14. At 1908 the fuselage interior was engulfed in flames.

It is apparent that if more fire containment had been designed into the cargo compartment and the fire propagation within the cabin had been slower the passengers and crew of this aircraft might have escaped. The approach to fire safety in buildings has been centered on these concepts and it would appear that they would be wise to include them in the evaluation of aircraft as well. The concept of evaluating the "Expected Fire" or Fire Threat Level and then the fire testing to evaluate the fire resistance of aircraft panel or complete assemblies will be discussed below.

III. A Fire Propagation Test for Aircraft Materials

A series of experiments was conducted under this grant to evaluate the fire propagation performance of materials used on the interiors of aircraft. Some of the early experiments were conducted in the relatively confined spaces of a "Lavatory Test Module" and the open environment of a 12 ft. x 12 ft. room[5,6]. Later in the research program a special "A/C Corner Assembly" was used to evaluate the fire propagation potential of aircraft panel materials. Fig. 1 shows the plan view of the A/C Corner Assembly as it is installed within an 8 ft. x 12 ft. compartment, and Fig. 2 shows the section A-A from Fig. 1. The A/C Corner Assembly itself is shown in Fig. 3. Note that the ceiling panel of the assembly is surrounded by a continuous skirt of gypsum wallboard which forms a weir to hold a layer of hot gases at the ceiling of the test specimen as would happen in many actual aircraft configurations. Notice the corner location of a gas burner ignition source in Fig. 1 and 2.

An experiment utilizing the A/C Corner Assembly was conducted on "Baseline" panels on Feb. 9, 1978 in which many measurements were made of the fire behavior of what was considered to be a representative panel in use at that time. The panel ignited within seconds after the ignition source was started and the temperatures at the ceiling near the ignition source reached over 750^{o}C within the first minute and remained above 550^{o}C for almost two minutes. In addition flames were seen to spread across the ceiling during the first minute of the experiment and flaming pieces of the surface film were observed to fall off the ceiling. The experiment was repeated on June 9, 1978 with a panel with substantially the same surface film as in the Feb. 9 panel, although there were some differences in the materials within the panel; the results were essentially the same. Further experiments were conducted on "Hardened" panels and the experimental apparatus appeared to give reliable results. The concept of using a "corner/compartment" fire test appeared to be the best available way to evaluate the fire propagation characteristics of aircraft interior panels.

In the period of time following the end of active experiments on this project a formal "test method" has been prepared to describe in detail how to evaluate the fire propagation of aircraft materials, and this is given in Appendix A to this report. This incorporates the experience of using the A/C Corner Assembly, but simplifies the construction of the test specimen. The 8 ft. x 12 ft. compartment is utilized in the test, but the test specimen is mounted directly on the walls of

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[5]Williamson, R.B. and Hasegawa, H., "Large Scale Fire Testing of Aircraft Interior Construction and the Development of Criteria to Represent the Level of Threat", Quarterly Progress Report, Nov. 1974 - January 1975, NASA-NSG 2026.

[6]Williamson, R.B. and Hasegawa, H., "Summary of Recent Work on Nasa Grant NSG 2026", Progress Report for Period Feb. - June 1975, NASA-NSG 2026.

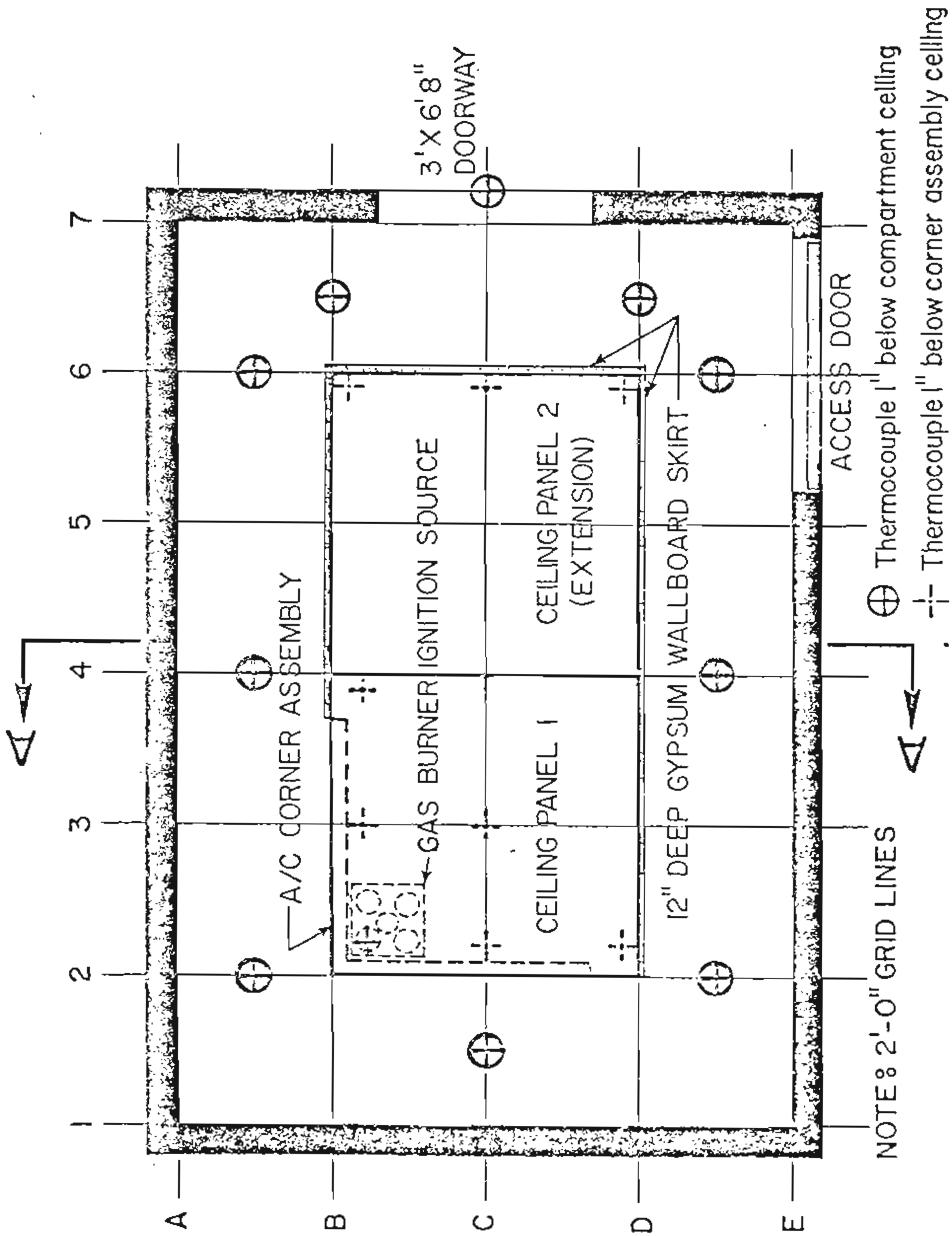

FIGURE 1: Plan View of an A/C Corner Assembly in an 8' X 12' Compartment.

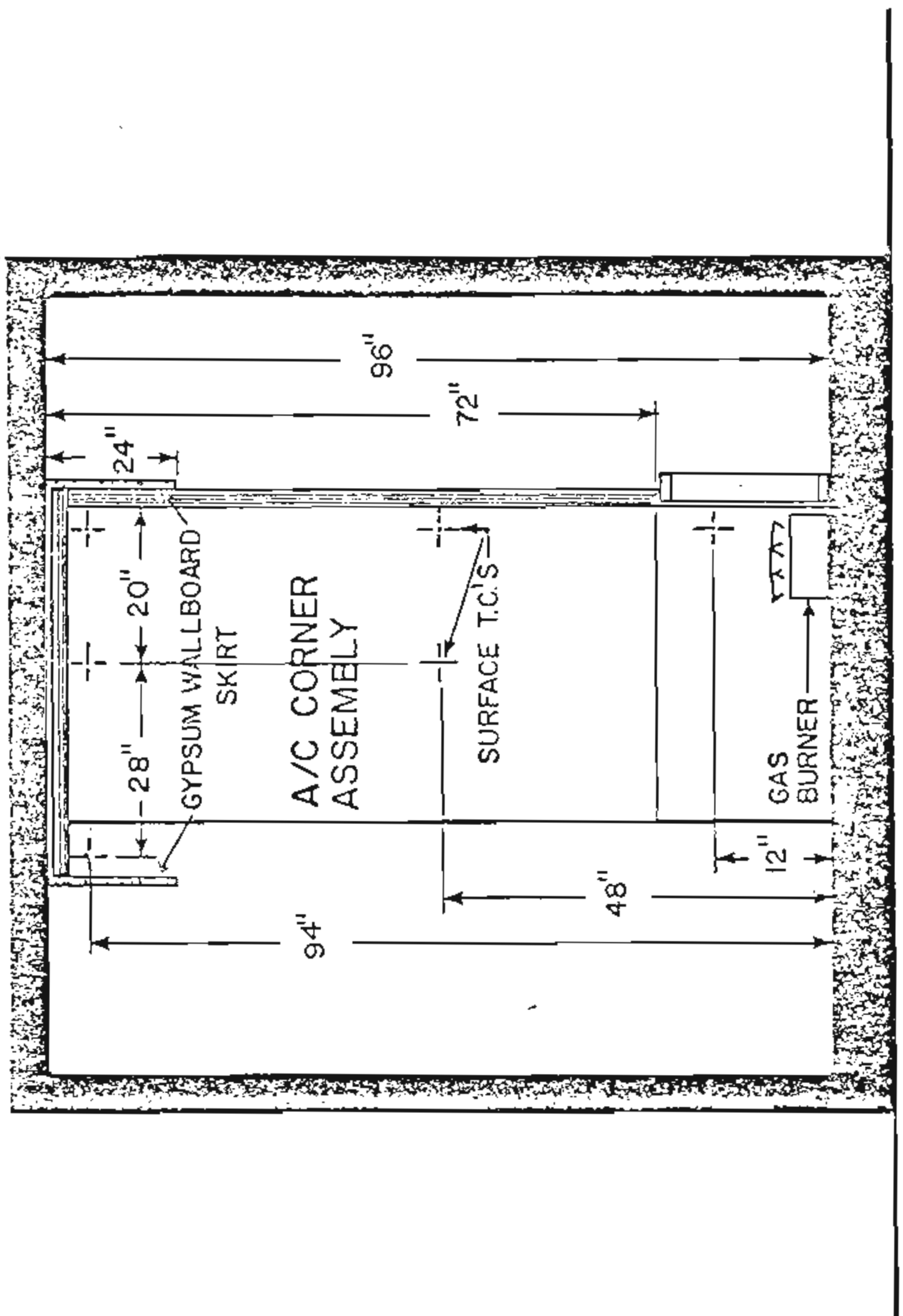

FIGURE 2: A Sectional View A-A Through the Drawing of the A/C Corner Assembly shown in Figure 1.

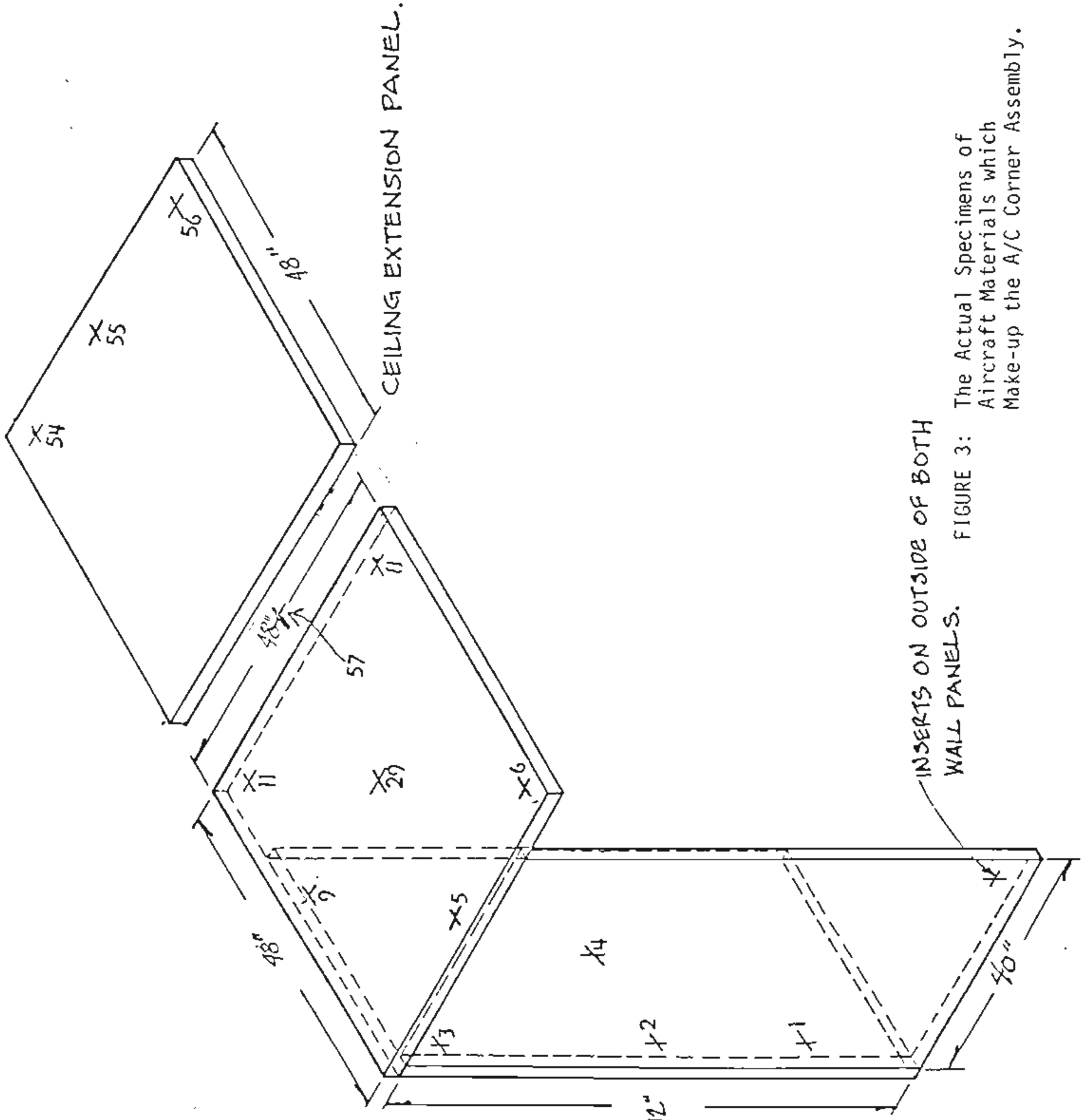

FIGURE 3: The Actual Specimens of Aircraft Materials which Make-up the A/C Corner Assembly.

the compartment. This test is intended to evaluate, under a specified fire exposure condition, the contribution to room fire growth provided by wall and/or ceiling materials or assemblies. The test is not intended to evaluate the fire endurance of assemblies. The test can be used to evaluate the effectiveness of thermal barriers in restricting the contribution of combustible materials in the wall assembly to fire growth in an aircraft. The test simulates a fire in the corner of a 8 ft. x 12 ft. (2.4 m x 3.7 m) compartment containing a single open doorway; this can be used to evaluate the relative performance of specific wall and ceiling materials or assemblies when they are used together in the same relationship within an enclosure, in addition to simulating the manner in which they will be used.

This fire test is applicable to a description of certain fire performance characteristics in appraising wall and ceiling materials, products, or systems under specified fire exposure conditions in an enclosure. The test indicates the maximum extent of fire growth in aircraft interiors, the rate of heat release, and if they occur, the time to flashover and the time to flame extension beyond the doorway following flashover. It determines both the extent to which the wall and ceiling materials or assemblies may contribute to fire growth in a compartment and the potential for fire spread beyond the compartment under the particular conditions simulated. It does not measure the contribution of the furnishing materials such as seats or other items of contents.

The potential for the spread of fire to other objects in the aircraft interior, remote from the ignition source, is evaluated by measurements of: (a) the total heat flux incident at the center of the floor, and (b) a characteristic upper level gas temperature in the test compartment. The potential for the spread of fire to objects outside the compartment of origin is evaluated by the measurement of the total rate of heat release of the fire.

Measurements of the rate of production of carbon monoxide and visible smoke are taken. The overall performance of the test specimen is visually documented by full color photographic records. Video taping of the complete fire test may be done as an alternate to the continuous photographic record. Such records may show when each area of the test specimen becomes involved in the fire.

The test method has two types of protocols. One is the "Screening Test" protocol and the second is the "Final Design Evaluation" (FDE) protocol. The "screening test" protocol utilizes two separate cover test exposure of relatively small specimens mounted on the walls and ceiling of a test compartment. The "FDE" protocol involves a single type of ignition source exposure of the wall and ceiling lining materials or assemblies as they would be incorporated in an aircraft. The FDE exposure could be in the same compartment as the screening test protocol or in a special configuration such as a prototype section of the aircraft.

This method uses a gas burner to produce a diffusion flame in contact with the walls and ceiling in the corner of a 8 ft. x 12 ft. x 8 ft. (2.4 m x 3.7 m x 2.4 m) high compartment[7]. The burner produces a prescribed rate of heat output

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[7]It is recognized that most aircraft do not have 8 ft. ceiling heights or square covers, but this test compartment has been chosen to be compatible with other laboratory test methods and the results will not be adversely effected.

of 10,000 Btu per minute (176 kW). The contribution of the wall and ceiling materials or assemblies to fire growth is measured in terms of the time history of the incident heat flux at the center of the floor, the time history of the temperature of the gases in the upper part of the compartment, the time to flashover, and the rate of heat release. The test is conducted with natural ventilation to the test compartment provided through a single doorway 30 in. x 80 in. (0.76 m x 2.03 m) in width and height. The combustion products are collected in a hood feeding into a plenum connected to an exhaust duct in which measurements are made of the gas velocity, temperature, and concentrations.

In the "Screening Test" protocol the test specimens are 1 ft. x 8 ft. on both walls for the test cover and there is a 2 ft. square piece of the same material on the ceiling.

The ignition source for the test shall be a gas burner[8] with a nominal 12 in. x 12 in. (0.31 m x 0.31 m) porous top surface of a refractory material. The top surface of the burner through which the gas is supplied shall be located horizontally, 12 in. (0.3 m) off the floor, and the burner enclosure shall be in contact with both walls in a corner of the room opposite from the door. The edge of the diffusion surface shall be within 1 in. of the wall.

The gas supply to the burner shall be of natural grade propane (96% purity) and shall produce a maximum gross heat output of 10,000 Btu/min ± 250 Btu/min (176 kW ± 4 kW), to be reached in 90 seconds.[9] The flow rate shall be metered throughout the test. The burner shall be so designed that it can be set at 0.25, 0.50 and 0.75 of its maximum heating rate value with fixed hardware such as a multi-valved manifold which as been calibrated to produce to produce the specified fractions of the maximum heating value.

In the screening test protocol one of the fire exposures is at at 2500 Btu/min ± 100 Btu/min (44 ± 1.8 kW) to be reached in one second. The fire exposure for the FDE protocol and the second screening test fire exposures is 10,000 Btu/min ± 250 Btu/min (176 kW ± 4 kW) to be reached in the following fashion: It is set at 0.25 of its maximum value at the start of the test and be increased to 0.50 of its maximum at 30 seconds, to 0.75 of its maximum at 60 seconds; and to its maximum value in 90 seconds.

The screening test procedure simulates important aspects of the FDE but requires less than 4 m^2 (40 ft^2) of sample material. The purpose of the screening test procedure is to allow manufacturers to eliminate from consideration those material formulations which are likely to perform poorly when subjected to the FDE. In this way the manufacturer is able to evaluate large numbers of possible product formulations without incurring the costs associated with conducting the full scale room fire test.

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[8] A burner may be constructed with a 1 in. thick (2.5 cm) porous ceramic-fiber board over a 6 in. (20 cm) plenum; or alternately a minimum 4 in. (10 cm) layer of Ottowa sand can be used to provide the horizontal surface through which the gas is supplied. The sand burner may be preferable for dripping materials.

[9] This corresponds to a flow rate of approximately 4.0 scfm (0.13 m^3/s) for propane whose gross heat of combustion is 2480 Btu/ft^3 (92.5 MJ/m^3) at 68° (20°C) and 14.70 Psia (100 kPa).

The screening test procedure utilizes the same equipment and instrumentation as the FDE. Two test exposures are conducted for each material under evaluation. The first test exposes the material to a gas fired ignition source burner that produces a flame height of approximately -0.3 - 0.4 m and a gross rate-of-heat-release of 44 kW. This exposure evaluates the ignition and flame spread characteristics of the test material. The second test exposes the material to an ignition source which bathes nearly the entire sample in flame and produces a gross rate-of-heat-release of 176 kW. This exposure provides a measure of the rate-of-heat-release per unit area (i.e., kW/m^2) produced by the test material.

Each of the two screening test exposures required 1.82 m^2 (20 ft^2) of test material. This material consists of two wall panels, each measuring 0.3 m (1 ft.) in width and 2.44 m in height, and a ceiling panel, measuring 0.6 m x 0.6 m (2 ft. x 2 ft.). The test material is applied to the corner of the room that contains the ignition source.

The flowchart presented in Fig. 4 provides a conceptual framework for use of the screening test procedure. The first step of the chart indicates exposure of the test material to the 44 kW ignition source. If, under these conditions, the material causes flame spread to the ceiling it is removed from further consideration since under the conditions imposed by the FDE the material would likely cause room flashover.

If the material does not cause flame spread to the ceiling then it is advanced to the next step in the flowchart; exposure to the 176 kW ignition source. The 176 kW level represents the rate-of-heat-release reached by the ignition source used in the FDE after an elapsed time of 90 seconds. The first three diamonds following the 176 kW step are criteria used to denote room flashover. If any of these criteria are reached during the screening test then the material can obviously be retired from further considerations. The last diamond in the flowchart, RHR$\geq$ 300 kW, is an estimate of the maximum rate-of-heat-release that a test material can produce during the screening test and still have a reasonable probability of not causing room flashover when subjected to the FDE.

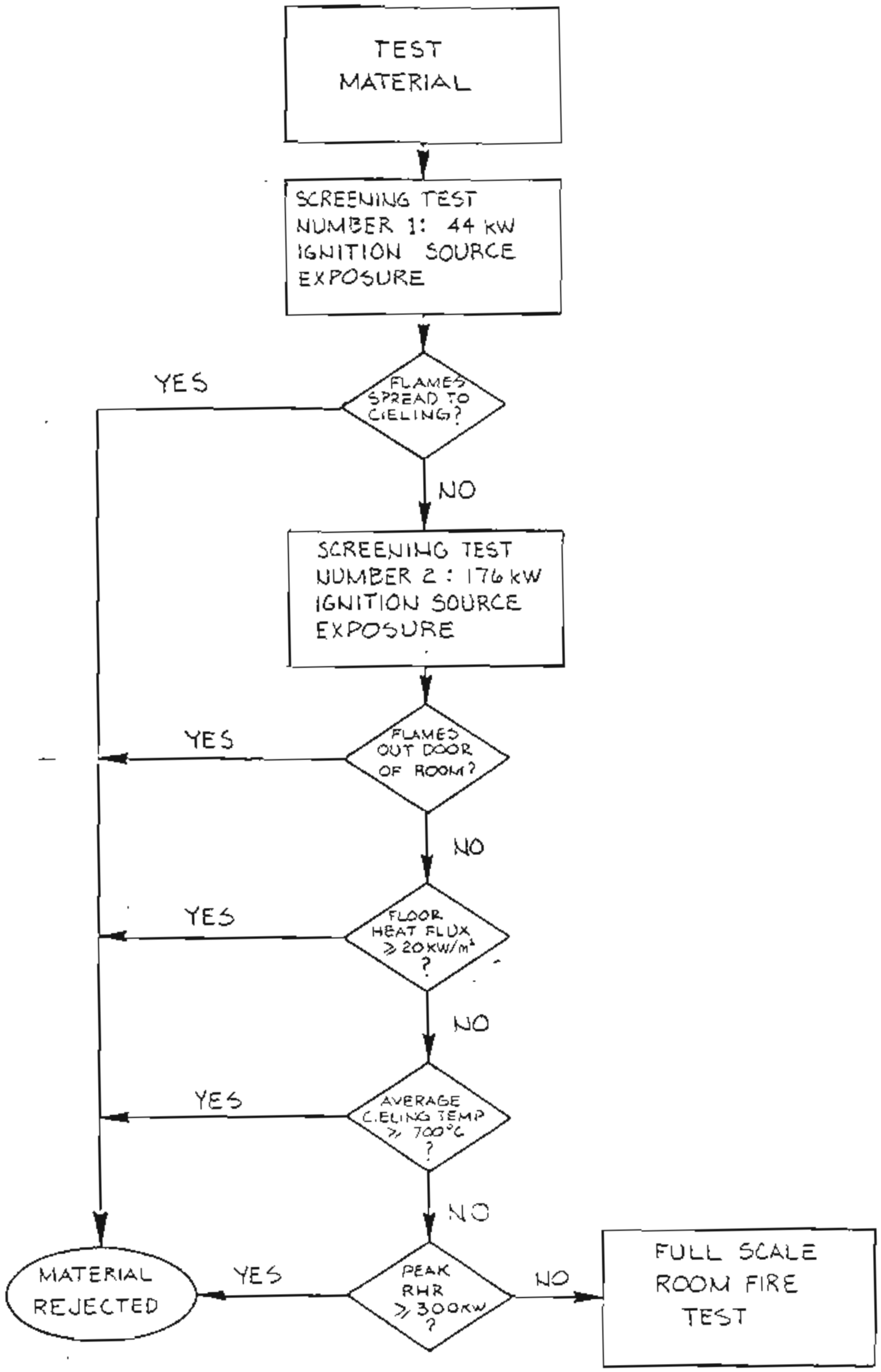

FIG. 4: Flowchart for Use of the Screening Test Procedure for Materials Evaluation

IV. A Fire Containment Test for Aircraft Panels and Assemblies

The concept of providing compartmentation in order to limit fire damage has been widely employed in buildings, ships, transit vehicles and other applications for many years. The general goal, of course, is to limit the amount of damage sustained by a structure in a given fire event. In order to achieve this goal, physical barriers are erected which will contain fire of a given severity for a specified period of time. Given the present inability to theoretically predict the fire resistance of a complex building element, it is necessary to conduct large scale fire tests for this purpose. As such, the ultimate success of the fire resistive element to fulfill its fire protection function is dependent, to a large degree, upon the accuracy with which the test method models the "real" fire event and upon the criteria used to evaluate the resultant test performance. The fire containment test falls in the more general class of fire resistance test.

The context of a fire resistance test of aircraft panels or assemblies is similar to that for walls or other elements used buildings. The test is performed to certify that elements identical to the test specimen can be expected to resist a fire for a period of time. It is well recognized that a "two hour" assembly may not last for two hours under actual fire conditions but the fire resistance test is a laboratory method of comparing different assemblies under the same conditions. A framework to consider the fire test of aircraft panels and assemblies is shown in Fig. 5. It is first necessary to choose a fire exposure which has been labelled "EXPECTED FIRE" in Fig. 5. and then the arrow directed toward the "AIRCRAFT PANEL OR ASSEMBLY" represents the testing process. The "RESPONSE OF PANEL OR ASSEMBLY" is the basis of "EVALUATION" but that process depends heavily on the "CRITERIA". This framework was used in the development of a fire test for containment for aircraft panels.

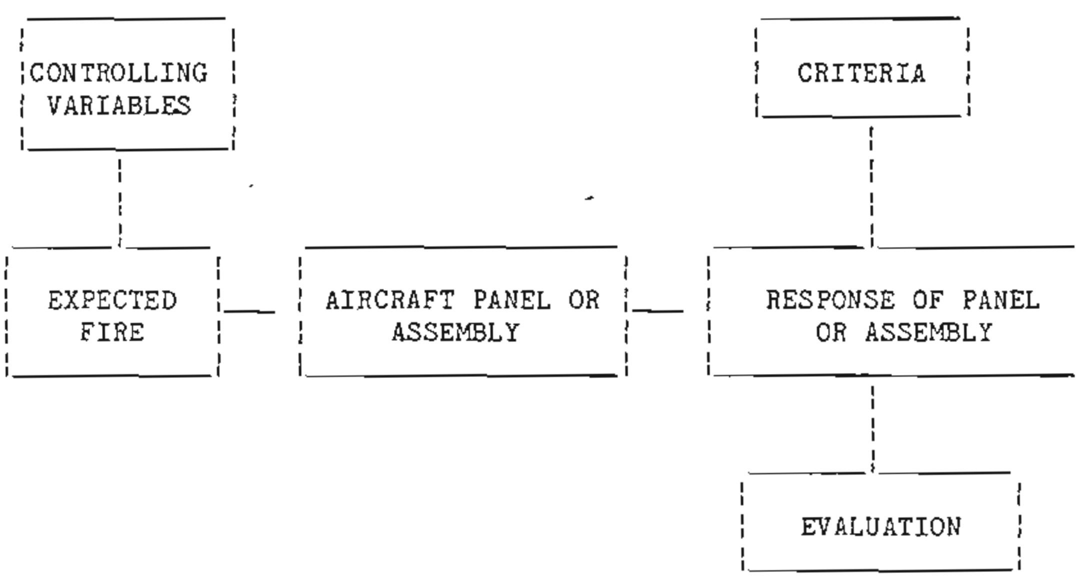

FIGURE 5: Framework for Evaluating the Fire Resistance of Aircraft Panels and Assemblies.

Since we are developing a completely new test, a first step is to identify the major controlling variables and develop the expected Fire Threat Level (FTL) or design basis fire. In this discussion the general FTL is assumed to be that of a fully developed fire which completely fills the compartment of origin. The severity of such a fire can be described in terms of its potential for spreading beyond the compartment of origin. The severity will be a function of the quantity of fuel in the typical compartment, the burning characteristics of the fuel, the ventilation of the compartment, and the thermal properties of the walls and ceiling of the compartment. At the present time, the time temperature history and the principal characteristics of a fully developed fire can be predicted by performing a heat balance calculation[10,11]. This requires, however, that controlling variables listed above for fire severity be fixed. Thus the current state-of-the-art would allow a deterministic calculation of the expected FTL for a given compartment, and then fire test could be performed with a specific fire exposure which duplicates the expected fire.

Even though it is possible to calculate the expected fire under specific conditions the larger task of solving the stochastic problem of analyzing all possible fires and determining the most probable and possibly the worst fire with a given probability of occurring has not been satisfactorily treated. Thus the common practice today, as reflected in the building codes and other regulations for buildings, is that the FTL is represented by one, two, three, or four hours of the time-temperature relationship delineated by the ASTM E-119[12] fire "resistance" test method, "Fire Tests of Building Construction and Materials". Approximately the same time-temperature history is used by most countries for evaluating the containment of fire by walls and floor/ceiling assemblies as well as the structural integrity of columns, beams and other elements under the action of fire. The ASTM E-119 test method is generally regarded as producing a reasonable representation of the time-temperature characteristics of postflashover fires for buildings, but there is no reason to believe it to be valid for aircraft.

During the course of this research project a series of full scale containment experiments were conducted on the lavatory module. These were

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[10] Babrauskas, V. and Williamson, R.B.,"Post-Flashover Compartment Fires: Basis of a Theoretical Model", Fire and Materials, 2, 2: pp. 39-53 (1978).

[11] Babrauskas, V. and Williamson, R.B., "Post-Flashover Compartment Fires - Application of a Theoretical Model", Fire and Materials, 3, 1: pp. 1-7 (1979).

[12] American Society for Testing and Materials, Book of Standards, Part 18, Philadelphia, PA.

described in two papers[13,14] which are reproduced in Appendix B and Appendix C to this report. Note in Appendix B that Figs. 3, 4, and 5 show the calculated surface temperatures with trash bag fuel sources in the lavatory module with the door either closed or partially open. This is an example of calculating the "Expected Fire" or the FTL for the first scenario given above. Then in Fig. 8 the gas burner program is shown to simulate that FTL. If the same procedure had been used to model the FTL in the cargo compartment of the L-1011, the accident at Riyadh might have been avoided.

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[13]Kourtides, D., Parker, J.A., Leon, H.A., Williamson, R.B., Hasegawa, H., Fisher, F., Draemel, R., Marcussen, W.H., and Hilado, C.J.,"Fire Containment Tests of Aircraft Interior Panels", J. Fire & Flammability, 7,(1976), pp.257-278.

[14]Williamson, R.B. and Hasegawa, H., "Criteria for Large Scale Fire Testing of Aircraft Interiors", NFPA Seminar on Aircraft Rescue and Firefighting, Geneva, Switzerland, September 1976.

V. Conclusions and Recommendations

We live in a rapidly changing world and the scope and complexity of fire dangers has changed over the last twenty years. This report has addressed the risk of a cabin fire in an airborne passenger aircraft, and the use of specific fire tests to evaluate the fire propagation and containment of interior panels and assemblies. Most of the major airframe manufacturers participated in the FIREMAN Program, of which this project was a part, and they have incorporated the results of our research in their current design procedures. There are other organizations, however, such as "retrofit" companies and some air carriers, which may not be aware of the potential for inflight fires. There needs to be more review of the fire problems in aircraft, and it is our opinion that the fire safety design and regulation system needs to move out of the back rooms of the major aircraft manufacturers and air carriers and into the open arena of the aircraft industry. If a small airline is shopping around for a new interior for some of its airplanes, the less knowledgeable retrofit company can deliver a less expensive package than a company which would feel obligated to use more fire resistant materials and install fire stops in hidden spaces to prevent fire spread. It is in everybody's interest to revise the way in which the fire safety of aircraft is regulated.

One of the sources of fresh ideas in the regulation of aircraft fire safety is to look at how other fire hazards have been treated. There have been a number of tragic fires in the last ten years which have helped professional Fire Protection Engineers and Scientists focus on solutions for specific occupancies and types of structures. One of the most important of these earthbound fires took place on March 22, 1975 at the Brown's Ferry Nuclear Reactor. This fire initiated a complete re-evaluation of the risk of fires in nuclear plants. As part of the re-evaluation the Nuclear Regulatory Commission (NRC) has published[15] the following regulation:

II. General Requirements

A. Fire Protection Program

> A fire protection program shall be established at each nuclear power plant. The program shall establish the fire protection policy of structures, systems, and components important to safety at each plant and the procedures, equipment and personnel required to implement the program at the plant site.

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[15] Federal Register, Sept. 25, 1981, Part 50:Domestic Licensing of Production and Utilization Facilities, Page 50-53.

B. Fire Hazards Analysis

A fire hazards analysis shall be performed by qualified fire protection and reactor systems engineers to (1) potential in situ and transient fire hazards; (2) determine the consequences of fire in any location in the plant on the ability to safely shutdown the reactor or on the ability to minimize and control the release of radio-activity to the environment; and, (3) specify measures for fire prevention, fire detection, fire suppression, and fire containment and alternative shutdown capability as required for each fire area containing structures, systems, and components important to safety in accordance with NRC guidelines and regulations.

The fire protection program shall be under the direction of an individual who has been delgated authority commensurate with the responsibilities of the position and who has available staff personnel knowledgeable in both fire protection and nuclear safety.

The fire protection program shall extend the concept of defense-in-depth[16] to fire protection in fire areas important to safety, with the following objectives:

a) to prevent fires from starting;

b) to detect rapidly, control, and extinguish promptly those fires that do occur;

c) to provide protection for structures, systems, and components important to safety so that a fire that is not promptly extinguished by the fire suppression activities will not prevent the safe shutdown of the plant.

C. Fire Prevention Features

Fire protection features shall meet the following general requirements for all fire areas that contain or present a fire hazard to structures, systems, or components important to safety.

1. In situ fire hazards shall be identified and protection provided.

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[16] Correction 46 FR 44734

2. Transient fire hazards associated with normal operation, maintenance, repair, or modification activities shall be identified and eliminated where possible. Those transient fire hazards that can not be eliminated shall be controlled and suitable protection provided.

3. Fire detection systems, portable extinguishers, and standpipe and hose stations shall be installed.

4. Fire barriers or automatic suppression systems or both shall be installed as necessary to protect redundant systems or components necessary for safe shutdown.

5. A site fire brigade shall be established, trained and equipped and shall be on site at all times.

6. Fire detection and suppression systems shall be designed, installed, maintained, and tested by personnel properly qualified by experience and training in fire protection systems.

7. Surveillance procedures shall be established to ensure that fire barriers are in place and that fire suppression systems and components are operable.

D. Alternative or Dedicated Shutdown Capability

In areas where the fire protection features cannot ensure safe shutdown capability in the event of a fire in that area, alternative or dedicated safe shutdown capability shall be provided.

This is only one section of a very detailed set of regulations which also address many specific topics other than the fire problems. The quoted section, however, is particularly important since it could be adopted by the FAA, or any other organization, as part of their treatment of inflight fire safety with only minor changes, such as "aircraft" for "nuclear power plant" or "safe landing of the aircraft" for "safe shutdown of the plant".

The concept of defense-in-depth supported by a formal Fire Hazards Analysis would make an effective way to implement the Requirements for design and regulation of aircraft fire safety given in the introduction. We feel that the fire tests for Fire Propagation and Containment described in this report would make an important component in a new attack on the fire safety of aircraft.

A TEST FOR FIRE PROPAGATION OF WALL AND CEILING MATERIALS AND ASSEMBLIES FOR USE IN AIRCRAFT

1. Scope

1.1 This test is intended to evaluate, under a specified fire exposure condition, the contribution to room fire growth provided by wall and/or ceiling materials or assemblies. The test is not intended to evaluate the fire endurance of assemblies. The test can be used to evaluate the effectiveness of thermal barriers in restricting the contribution of combustible materials in the wall assembly to fire growth in an aircraft.

1.2 The test simulates a fire in the corner of a 8 ft. x 12. ft. (2.4 m x 3.6 m) compartment containing a single open doorway; this can be used to evaluate the relative performance of specific wall and ceiling materials or assemblies when they are used together in the same relationship within an enclosure, in addition to simulating the manner in which they will be used.

1.3 The test may be used for evaluating wall and ceiling finish materials and assemblies; including panels, tiles, boards, sprayed or brushed coatings, etc. The test is not intended to evaluate flooring materials or furnishings.

(Note 1) This standard shall be used in conjunction with ASTM E 603-77, Standard Guide for Room Fire Experiments, which covers instrumentation, safety precautions, and the general effect of various parameters. See Annex D for specific information on safety.

... fire test is applicable to a description of the fire propagation characteristics of wall and ceiling materials, products, or systems under specified fire exposure conditions in an enclosure . The test indicates the maximum extent of fire growth in aircraft interiors, the rate of heat release, and if they occur, the time* to flashover and the time to flame extension beyond the doorway following flashover. It determines both the extent to which the wall and ceiling materials or assemblies may contribute to fire growth in a ...ompartment and the potential for fire spread beyond the compartment under the ...articular conditions simulated. It does not measure the contribution of the ...nishing materials.

... The potential for the spread of fire to other objects in the aircraft ...ior, remote from the ignition source, is evaluated by measurements of: (a) ...tal heat flux incident at the center of the floor, and (b) a ...eristic upper level gas temperature in the test compartment.

...e potential for the spread of fire to objects outside the compartment ...is evaluated by the measurement of the total rate of heat release of

...ashover is defined herein, as either the time when the radiant flux ...r reaches 20 kW/m^2 or the temperature of the upper air reaches 600C ...umpled up single sheet of newspaper may be placed on the floor 3 ...ut from the center of the rear wall. The spontaneous ignition of ... will provide a visual indication of flashover.

2.1.3 Measurements of the rate of production of carbon monoxide and visible smoke are taken.

2.1.4 The overall performance of the test specimen is visually documented by full color photographic records. Video taping of the complete fire test may be done as an alternative to the continuous photographic record. Such records may show when each area of the test specimen becomes involved in the fire.

3. Summary of Method

3.1 The test method has two types of protocols. One is the "Screening Test" protocol and the second is the "Final Design Evaluation" (FDE) protocol. The "screening test" protocol utilizes two separate cover test exposures of relatively small specimens mounted on the walls and ceiling of a test compartment. The "FDE" protocol involves a single type of ignition source exposure of the wall and ceiling lining materials or assemblies as they would be incorporated in a aircraft. The FDE exposure could be in the same compartment as the screening test protocol or in it could be applied to a specific configuration such as used by a prototype section of a particular aircraft.

3.2 This method uses a gas burner to produce a diffusion flame in contact with the walls and ceiling in the corner of a 8 ft. x 12 ft. x 8 ft. (2.4 m x 3.6 m x 2.4 m) high compartment(2). The burner produces a prescribed rate of heat

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(Note 2) It is recognized that most aircrafts do not have 8 ft. ceiling heights or square corners, but this test compartment has been chosen because it is compatible with other laboratory test methods and the results will not be adversely effected. The first of the two Screening Test exposures is with a 2500 Btu/min (44 kW) propane burner and the second is with 10,000 Btu/min (176 kW) flame produced by the same burner. In the FDE protocol the compartment is fully lined; the ignition source operates at 10,000 Btu/min (176 kW).

output of 10,000 Btu per minute (176 kW). The contribution of the wall and ceiling materials or assemblies to fire growth is measured in terms of the time history of the incident heat flux at the center of the floor, the time history of the temperature of the gases in the upper part of the compartment, the time to flashover, and the rate of heat release. The test is conducted with natural ventilation to the test compartment provided through a single doorway 30 in. x 80 in. (0.76 m x 2.03 m) in width and height. The combustion products are collected in a hood feeding into a plenum connected to an exhaust duct in which their velocity, temperature, and composition are measured.

3.3 In the "Screening Test" protocol the test specimens are 1 ft. x 8 ft. on both walls for the test cover and there is a 2 ft. square piece of the same material on the ceiling.

4. Ignition Source

4.1 The ignition source for the test shall be a gas burner[3] with a nominal 12 in. x 12 in. (0.31 m x 0.31 m) porous top surface of a refractory material.

4.2 The top surface of the burner through which the gas is supplied shall be located horizontally, 12 in. (0.3 m) off the floor, and the burner enclosure shall be in contact with both walls in a corner of the room opposite from the door. The edge of the diffusion surface shall touch the wall.

(Note 3) A burner may be constructed with a 1 in. thick (2.5 cm) porous ceramic-fiber board over a 6 in. (15 cm) plenum; or alternately a minimum 4 in. (10 cm) layer of Ottowa sand can be used to provide the horizontal surface through which the gas is supplied.

4.3 The gas supply to the burner shall be of natural grade propane (96% purity) and shall produce a maximum gross heat output of 10,000 Btu/min ± 250 Btu/min (176 kW ± 4 kW), to be reached in 90 seconds.(4) The flow rate shall be metered throughout the test. The burner shall be so designed that it can be set at 0.25, 0.50 and 0.75 of its maximum heating rate value with fixed hardware such as a multi-valved manifold which as been calibrated to produce to produce the specified fractions of the maximum heating value.

4.4 The burner may be ignited by a pilot burner or a remote controlled spark igniter.(5)

4.5 In the screening test protocol one of the fire exposures shall be at 2500 Btu/min ± 100 Btu/min (44 ± 1.8 kW) to be reached within one second. The other screening test fire exposure shall be the same as the FDE exposure defined in the next paragraph.

4.6 The fire exposure for the FDE protocol and the second screening test shall be 10,000 Btu/min ± 250 Btu/min (176 kW ± 4 kW) to be reached in the following fashion: it shall be set at 0.25 of its máximum value at the start of the test and increased to 0.50 at 30 seconds, to 0.75 at 60 seconds; and to its maximum value at 90 seconds.

(Note 4) This corresponds to a flow rate of approximately 4.0 scfm (0.13 m^3/s) for propane whose gross heat of combustion is 2480 Btu/ft^3 (92.5 MJ/m^3) at 68° (20°C) and 14.70 Psia (100 kPa).

(Note 5) This does not preclude the use of a hand-held ignitor.

5. <u>Compartment Geometry and Construction</u>[6]

5.1 The interior dimensions of the floor of the fire room when the specimens are in place, shall measure 8 ft. ± 1 in. x 12 ft. ± 1 in. (2.44 m ± 25 mm x 3.66 m ± 25 mm). The finished ceiling shall be 8 ft. ± 0.5 in. (2.55 m ± 13 mm) above the floor. There shall be four walls at right angles defining the compartment.

5.2 There shall be a 30 in. ± 0.25 in. x 80 in. ± 0.25 in. (0.76 x 2.03 m) doorway in the center of one of the 8 ft. x 8 ft. walls, with no other wall or ceiling openings that allow ventilation.

5.3 The wall containing the door shall be of calcium silicate board of 46 pcf (736 kg/m^3) density and 0.5 in. (12.7 mm) nominal thickness. The door frame shall be constructed to remain unchanged during the test period to a tolerance of ± 1% in height and width.

5.4 The test compartment may be a framed structure, or a concrete block structure. If self-supporting panels are tested a separate exterior frame or block compartment may not be required.

5.5 The floor of the test compartment shall be noncombustible as defined by ASTM E 136.

(Note 6) The experimental choices for the sizes of compartment fire experiments are discussed in section 5 of ASTM E 603. The compartment size defined in this section has been chosen to make it convenient to utilize standard size (4 ft. x 8 ft.) (1.22 m x 2.44 m) building materials or panels.

6. Specimen Mounting

6.1 The specimens, (e.g. the ceiling and wall materials being tested), shall be mounted on a framing or support system comparable to that intended for their field use, using backing materials, insulation, or air gaps, as appropriate to the intended application and representing a typical value of thermal resistance for the wall system.

6.2 For the Screening Test protocol there shall be two wall specimens 1 ft. x 8 ft. mounted on either side of one of the corners of the test compartment away from the door. There shall be a 2 ft. x 2 ft. specimen fixed to the ceiling in the corner above the wall mounted specimens.

6.3 In the FDE protocol the ceiling material shall cover the entire ceiling and the wall material shall cover the three side walls not containing the door. The wall and ceiling materials shall be mounted in the same wall-ceiling relationship in which they are intended to be used, It may thus be necessary to actually construct a section of the prototype aircraft.

7. Fire Compartment Environment

7.1 The test building in which the fire compartment is located shall have vents for the discharge of combustion products and have provisions for fresh air intake, so that no oxygen deficient air shall be introduced into the fire compartment during the test. Prior to initiation of the test the ambient air at the midheight entrance to the compartment shall have a velocity in any direction of less than 100 ft/min (0.5 m/sec.). The building shall be of adequate size so that there shall be no smoke accumulation in the building below the level of the top of the fire compartment.

7.2 Ambient Conditions in Test Building:

7.2.1 The ambient temperature in the test building at any location outside the fire compartment shall be above 40°F (5°C); and the relative humidity shall be less than 75% for the duration of the test.

7.3 Ambient Conditions in Fire Compartment:

7.3.1 The ambient temperature in the fire compartment as measured by one of the thermocouples described in section 8.24 shall be within the range of 65°F to 75°F (18°C to 24°C) for at least 16 hours prior to the test.

7.3.2 The ambient relative humidity in the fire compartment for 16 hours prior to the test shall be within the range of 50 ± 5%. (This may require the use of a humidifier or dehumidifier.)

7.4 Specimen Conditioning

7.4.1 The specimens shall be conditioned prior to mounting at a temperature of 70 ± 5°F (21 ± 3°C), and at a relative humidity of 50 ± 5% until they reach a rate of weight change of less than 0.1% per day.

8. Instrumentation

The minimum requirements for instrumentation for this test are: (Added instrumentation may be desirable for further information.)

8.1 Total Heat Flux Gauges:

8.1.1 Location: Two gauges shall be mounted within 5 in. (130 mm) of each other and within a distance of 2 in. (50 mm) above the floor surface facing upward in the geometric center of the floor. (See Figure 1). One additional gauge shall be mounted in the wall adjacent to the ignition burner during calibration tests only (see 9.2). It shall be 6 ft. (1.83 m) above the floor, and 6 in. (150 mm) from the corner where the burner is located, along the wall opposite the doorway. The front surface of the calibration gauge shall be flush with the wall surface, within .04 in. (± 1 mm).

8.1.2 Specification: The gauges shall be of the Gardon type[7], with a flat black surface, and a 180 degree view angle, and shall be maintained at a constant temperature (within ± 1°C) above the dew point by water supplied at a temperature of 120°F to 150°F (50°C to 65°C). This will normally require a flow rate of at least 0.1 GPM (6 ml/s). The full-scale output range shall be 50 kW/m^2 for the floor gauge and 100 kW/m^2 for the wall gauge (5 and 10 $Btu/ft^2 \cdot s$, respectively).

8.2 **Gas Temperature Thermocouples:**

8.2.1 Specification: Twenty mil diameter bare chromel-alumel thermocouple wire within 0.5 in. (12.5 mm) of the bead should be run along expected isotherms to minimize conduction errors. The insulation between the chromel and alumel wires must be stable to at least 2000°F (1100°C) or the wires must be separated.[8]

(Note 7) A suitable Gardon type heat flux gauge, manufactured by the Medtherm Corporation in Huntsville, Alabama, is listed under model 64-5-18 for the 5 Btu/ft^2 sec (50 kW/m^2) range and under model 64-10-18 for the 10 Btu/ft^2 sec (100 kW/m^2) range for further information see "An Instrument for the Direct Measurement of Intense Thermal Radiation" by R. Gardon, Review of Scientific Instruments, Vol. 24, No. 5, May 1953, pp 366-370.

(Note 8) Metal clad ceramic powder will work satisfactorily. The commonly used silicone impregnated glass insulation will break down above 1500°F (800°C).
top surface of the room. The face dimensions of the hood shall be minimum 8 ft.

8.2.2 Location for doorway: A thermocouple shall be located in the interior plane of the door opening on the door centerline, 1 in. (25 mm) down from the top. (See Figure 2).

8.2.3 Locations for Room: Thermocouples shall be located 4 in. (100 mm) down from the center of the ceiling and from the center of each of the four ceiling quadrants, and one shall be directly over the center of the ignition burner, 4 in. (100 mm) below the ceiling. The thermocouples shall be mounted on supports, with their junctions at least 4 in. (100 mm) away from a solid surface. There shall be no attachments to the test specimens. (See Figure 2).

8.2.4 Location in Canopy Hood and Duct System: One pair of thermocouples shall be placed 11 ft. (3.36 m) downstream to the entrance to the horizontal duct. The pair of T/C's shall straddle the center of the duct and be separated by 2 in. (50 mm) from each other. (See Figure 3).

8.3 Canopy Hood and Exhaust Duct

A hood shall be installed immediately adjacent to the door of the fire room. The bottom of the hood shall be level with the x 8 ft. (2.44 m x 2.44 m) and the depth shall be 3.5 ft. (1.07 m). The hood shall feed into a plenum having a 3 ft. x 3 ft. (0.92 m x 0.92 m) cross section. (See Figure 3). The plenum shall have a minimum height of 3 ft. (0.91 m). The height can be increased up to a maximum of 6 ft. (1.83 m) to satisfy building constraints. The exhaust duct connected horizontally to the plenum shall be 16 in. (400 mm) in diameter, and shall have a circular aperture of 12 in. (300 mm) at its entrance, see Figures 3 and 4.

The hood shall have sufficient draft to collect all of the combustion products leaving the room. (This draft should be capable of moving up to 5000 scfm (2.4 m^3/s) during the test). Provisions shall be made to vary the draft so that it can operate at either 1000 or 5000 scfm (0.47 or 2.4 m^3/s). Mixing vanes may also be required in the duct if concentration gradients are found to exist.

An alternate exhaust system design may be used if it has been shown to produce equivalent results. (Equivalency may be shown by meeting the requirements of Section 9.5)

8.4 Duct Gas Velocity:

A bi-directional probe(9) or equivalent measuring system shall be used to measure gas velocity in the duct. The probe shown in Figure 5 consists of a short stainless steel cylinder 1.75 in. (44 mm) long and 0.975 in. (22 mm) inside diameter with a solid diaphragm in the center. The pressure taps on either side of the diaphragm support the probe. The axis of the probe shall be along the centerline of the duct 11 ft. (3.35 m) downstream from the entrance. The taps shall be connected to a pressure transducer (10) which shall be able to resolve pressure differences of 0.0001 in. of water (0.25 Pa). (The bi-directional probe was chosen rather than the pitot-static tube in order to avoid problems of clogging with soot.)

(Note 9) See B.J. McCaffrey and G. Heskestad, Combustion and Flame, 26, 125-127 (1976).

(Note 10) Capacitance type transducers have been found to be most stable for this application.

8.5 Duct Oxygen Concentration:

8.5.1 Specification: A stainless steel gas sampling tube shall be located 13 ft. (3.97 m) downstream from the entrance to the duct, to obtain a continuously flowing sample for determining the oxygen concentration of the exhaust gas as a function of time. A suitable filter and cold trap shall be placed in the line to remove particulates and water. The oxygen analyzer shall be of the paramagnetic or polarographic type and shall be capable of measuring with an accuracy of ± 2 % the reduction in oxygen concentration over the range of 0.21 down to 0.15. After 30 seconds of introducing a step change in composition of the gas stream flowing past the inlet to the sampling tube, the oxygen analyzer must read within 5% of its final value.

8.6 Duct Carbon Dioxide Concentration:

The gas sampling tube defined in 8.5.1 or an alternate tube in the same location, shall provide a continuous sample for the measurement of the carbon dioxide concentration with an analyzer with a range of 0 to 20%, with a maximum error of 2% of full-scale. The total system response time between the sampling inlet and the meter shall be no greater than 30 seconds.

8.7 Duct Carbon Monoxide Concentration:

The gas sampling tube defined in 8.5, or an alternate tube in the same location, shall provide a continuous sample for the measurement of the carbon monoxide concentration with an analyzer with a range of 0 to 10% with a maximum error of 2% of full-scale.

8.8 **Optical Density of Smoke in Duct: (Supplementary Measurement)**

A meter(11) shall be installed to measure the optical density of the exhaust gases in a vertical path across the width of a horizontal duct, 1 ft. (300 mm) downstream of the duct velocity probe. (A horizontal path should be used with a vertical duct.) The optical density shall be continuously recorded over the duration of the test. After completion of the test the optical density reading must be less than 0.02 (Transmission higher than 95%).

(Note 11) A suitable design for the meter is as follows:

Use as a light source a number 1810 lamp which is rated at 6.3 volts, 0.40 amps, and 1.5 candela and is operated at 5 volts d.c. The lamp is mounted at the focal point of a +20 diopter and 50 mm diameter double convex collimating lens. At the other side of the duct the collimated beam is intercepted by a +10 diopter 50 mm diameter plane convex lens and concentrated onto the cathode of a 1P39 phototube. A Corning CS3-132 type 3304 filter (available from the Swift Glass Company, Box 890, Elmira Heights, N.Y. 14903) is used in front of the phototube to correct its spectral response to the standard photoptic curve of the human eye. The lens, filter, and phototube are mounted inside of a light tight housing which is blackened inside to minimize internal reflections. The phototube is connected to a linear operational power amplifier with an adjustable gain of 10^6 which in turn is connected to a commercially available log ratio amplifier to produce an output voltage proportional to the optical density. A smoke meter meeting the above requirements is described in a report by R.W. Bukowski, Smoke Measurements in Large and Small-Scale Fire Testing, NBSIR 78-1502, October 1978.

Alternate system can be used but the color temperature of the light source must match that of the 1810 lamp under the specified operating conditions and the light receiver, including the photo detector, must match the standard photoptic curve of the eye.

8.9 Photographic Records:

Photographic equipment shall be used to continuously record the fire spread in the room and the fire projection from the door of the room. The location of the camera must avoid interference with the air inflow. The interior wall surfaces of the test room, adjacent to the corner in which the burner is located, shall be clearly marked with a 12 in. (30 mm) grid. A clock shall appear in all photographic records, giving time to the nearest second or 0.01 minutes from the start of the test. This clock shall be accurately synchronized with all other measurements; or other provisions shall be made to correlate the photo record with time. Color slides shall also be taken at 15 second intervals for the first 3 minutes of the test and at least at 30 second intervals thereafter for the duration of the test.(12)

9. Calibration and Documentation of Ignition Source and Test Equipment

A calibration test shall have been performed prior to and within 30 days of any fire test. The calibration test, to last for five minutes, shall use the standard ignition source with inert wall and ceiling materials (calcium silicate board of 46 pcf density, (736 Kg/m^3) 0.50 in (13 mm) thickness. The following quantities shall be reported:

9.1 Once the burner is activated the output of all instruments normally used in the test are to measured and data recorded as a function of time.

(Note 12) A window, cut 2 ft.-0 in. above the floor in the front wall facing the gas burner, fitted with heat resistant impact resistant glazing provides useful photographic access. Flood lights should not raise the ambient temperature in the room above that specified in section 7.

9.2 The time history of the total heat flux incident on the calibration gauge (see Section 8.1). This flux level must be at least 3.5 Btu/ft^2·s (40 kW/m^2) for the last 4 minutes of the test. (If criterion in not me, check for spurious drafts, check instruments, check propane flow rate and repeat test.)

9.3 The maximum extention of the burner flame, as recorded by still color color photographs of 0.1 second exposure time taken at least at 30 second intervals or more often if there are rapid changes. These shall be taken with a camera operating in the "operative mode" with the camera set to the standard ASA ratings of the film.

9.4 The temperature and velocity profiles across the duct cross section at the location of the bi-directional probe if one is used. These profiles shall be used to determine the factor, k, in equation 12 Annex Z.

9.5 The total rate of heat production as determined both by the oxygen consumption calculation and by the metered gas input. These must agree within 5%. (The following value should be used in the calculation: the net heat of combustion is 2283 Btu/ft^3 (85 MJ/m^3) for propane at 68°F (20°C) and 14.70 Psia (100 KPa)).

10. Test Procedure

10.1 The Screening Test protocol and the FDE protocol have essentially the same test procedure. In the following paragraphs assume that the descriptions of the procedure is the same for both protocals unless it is specifically stated otherwise.

10.2 If a forced ventilation system is used, establish an initial volumetric flow rate of 1000 cfm (0.47 m^3/s) through the duct and increase the volume flow rate through the duct to 5000 cfm (2.36 m^3/s) when the oxygen content falls below 14%.

10.3 Turn on all sampling and recording devices and establish steady state baseline readings for at least one minute.

10.4 Ignite the gas burner and start the clock simultaneously. Increase gas flow rate in steps as indicated in section 4.3

10.5 Take 35 mm color slides at 15 second intervals during the first 3 minutes and at 30 second intervals thereafter to photographically document the growth of the fire.

10.6 Provide a continuous voice or written record of the fire, which will give times of all significant events such as flame attachment to the wall, flames out of the doorway, flashover, etc.

10.7 Shut off the ignition burner at 15 minutes after initiation of the test and terminate the test at that time unless safety considerations dictate an earlier termination.

10.8 Photograph and verbally describe the damage after the test.

11. Criteria

11.1 The criteria for acceptable performance in the 2500 Btu/min fire exposure in the screening test shall be that the flames do not reach the ceiling mounted specimen. This shall be confirmed by thermocouple measurements, photographic records, inspection of the ceiling mounted specimen and visual observations by trained observers.

11.2 The criteria for acceptable performance in the 10,000 Btu/min exposure in the screening test shall be that the rate of heat released by the specimen will not cause flashover in the test compartment if the specimen was completely lining the compartment. This shall be confirmed by the testing agency based on accepted scientific and engineering principles.

11.3 One of the criteria for acceptable performance in the FDE protocol shall be that no flashover occurs in the compartment during the fifteen minute period that the ignition source flame is burning. Furthermore, the production of CO and smoke shall be shown fall below levels which would endanger occupants in the spaces adjacent to the compartment exposed to the ignition source. The testing agency is obligated to develop an analysis to satisfy this criterion.

12. Report

The report shall include the following items:

12.1 Materials = A description including the name, thickness, density, and size of the material, along with other identifying characteristics or labels.

12.1.2 Mounting and conditioning.

12.1.3 Layout of specimens and attachments in test room.

12.2 Ambient Conditions: Relative humidity and temperature of the room and the test building prior to and during the test.

12.3 Burner Gas Flow = The fuel gas flow to the ignition burner and its calculated rate of gross heat output.

12.4 Time History of teh Total Heat Flux to Floor: The total incident heat flux at the center of the floor for each heat flux gauge as a function of time starting one minute prior to the test.

12.5 Time History of the Gas Temperature = The temperature of gases in the room, the doorway, and in the exhaust duct for each thermocouple as a function of time starting one minute prior to the test. The temperatures recorded by the thermocouple in the duct will be used in the calculations below.

12.6 Volumetric Flow Rate of the Duct Gas = The volumetric flow rate of the gas in the duct shall be calculated from equation 12 in Annex A and reported as a function of time starting one minute prior to the test.

12.6 Oxygen Concentration: The oxygen concentration in the analyzer as a function of time starting one minute prior to the test.

12.7 Carbon Dioxide Concentration: The carbon dioxide concentration in the analyzer as a function of time starting one minute prior to the test. (Separate reporting of the volume flow rate, temperature, oxygen and carbon dioxide concentrations provide diagnostic information on the performance of the exhaust gas collection system and provide a check on the heat production calculations.)

12.8 Time History of the Total Rate of Heat Production of the Fire: The total The total rate of heat production shall be calculated from the measured oxygen and carbon dioxide concentrations and the temperature and volumetric flow rate of the gas in the duct.

12.9 Time History of the Rate of Carbon Monoxide Production: The product of the volumetric flow rate of the gas in the duct and the carbon monoxide concentration at the specified location in the combustion hood system as a function of time after the start of the test.

12.10 Time History of the Rate of Smoke Production: The product of the volumetric flow rate of the gas in the duct at the duct gas temperature and the optical density per ft. at the specified smoke meter location in the duct as a function of time after the start of the test. (If this product is multiplied by 1.55×10^{-3}, for English units, it gives the smoke units produced per second, where a smoke unit is defined as the quantity of smoke which, when distributed uniformly over a cubic meter, would have an optical density of unity over a path length of one meter. This is the definition used in the Proposed ASTM Test for Heat and Visible Smoke Release Rates for Materials and Products.)

12.11 Time History of the Fire Growth: A transcription of the visual, photographic, audio, and written records of the fire test. The records shall indicate the time of ignition of the wall and ceiling finishes, the approximate location of the flame front most distant from the ignition source, at intervals not exceeding 15 seconds during the fire test, the time of flashover, and the time at which flames extend outside the doorway. In addition, still photographs taken at intervals not exceeding 15 seconds for the first 3 minutes, beginning at the start of the test and at every 30 seconds for the remainder of the test shall be supplied. Photographs showing the extent of the damage of the materials after the test shall also be supplied. The camera settings, film speed, and lighting used shall be described.

12.12 Calibration Test: A report on the pre-test calibration (see Section 9).

12.13 Report on Barometric Pressure at Time of Test.

12.14 Complete discussion of the criteria. This shall include all calculations and references to other data used to satisfy the criteria presented in Section 11.