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EVALUATION OF MATERIALS AND CONCEPTS FOR AIRCRAFT FIRE PROTECTION

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Final Report

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16. Abstract

Three NASA-defined woven fiberglass fluted-core simulated aircraft interior panels were flame tested and structurally evaluated against the Boeing 747 present baseline interior panels. The NASA-defined panels, though inferior on a strength-to-weight basis, showed better structural integrity after flame testing, due in part to the woven fiberglass structural concept.

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1.0 INTRODUCTION

This report finalizes the results of a National Aeronautics and Space Administration (NASA) contract with The Boeing Company to determine the passenger fire protection capabilities of NASA-identified materials fabricated into panels simulating aircraft interior sidewall and ceiling panels, and to determine the structural characteristics of these materials in (secondary) load-carrying configurations. Using the NASA-identified materials as defined in the Material Description section of this report, the Boeing Materials Technology (BMT) organization tested 234 specimens cut from Hitco-fabricated panels. An additional 12 specimens were prepared for burn-through testing conducted at NASA-Ames. The basic panel consisted of an integrally woven fiberglass-reinforced structure impregnated with a Kerimid 601 resin system cured over Teflon mandrels. The fluted cores of these panels were filled with insulation material for evaluation. These test results are compared to the present baseline interior wall panel of the 747.

2.0 SYMBOLS AND ABBREVIATIONS

a	1/4-span length
avg	average
BMT	Boeing Materials Technology
Btu	British thermal unit
^oC	degrees Celsius (centigrade)
cm	centimeter
cps	cycle per second
EI	flexural rigidity
f	natural frequency
^oF	degree Fahrenheit
FAA	Federal Aviation Agency
FAR	Federal Aviation Requirements
ft	feet
gEI	gravity flexural rigidity
gph	gallons per hour
Hg	mercury
hr	hour
in.	inch
ISU	Isocyanurate foam
kcal	kilogram calories
kg	kilogram
kg/cm	kilogram per centimeter
kg/cm^2	kilogram per square centimeter
kg/m^2	kilogram per square meter
ℓ	span length
lb	pound
lb/ft^2	pounds per square foot
lb/ft^3	pounds per cubic foot
lb/in.	pounds per inch
m	meter
min	minutes
NASA	National Aeronautic and Space Administration
NASA-Ames	National Aeronautic and Space Administration, Ames Research Center
PBI	Polybenzimidazole foam
PQ	Polyquinoxaline
psi	pounds per square inch
P/Y	load over yield
sec	second
T/C	thermocouple
T-3	AMES T-3 thermal test facility
W	load
w	uniform density in weight per unit length
Δ	deflection
π	pi
π^2	pi squared

3.0 PROGRAM DEFINITION

The subject program was structured to be conducted in five phases. This section describes these five phases and the objectives accomplished.

3.1 PHASE I, DESIGN STUDY AND TEST PROGRAM DEFINITION

3.1.1 DESIGN STUDY

Baseline characteristics of current 747 interior fuselage wall panels were defined in terms of standard requirements developed over a number of years. These requirements would also impact any new panel design and include flame resistance, thermal insulation, acoustical insulation, weight, physical size, cosmetic requirements, structural considerations, replaceability, serviceability (cleaning), and commonality.

The specific design requirements identifiable as baseline for current 747 commercial jet aircraft are described in the following paragraphs.

Flame Resistance

The current requirement is defined in Federal Aviation Regulations FAR 25, Amendment 32, paragraph 25.853(a). This requirement is considered to be baseline and was used as a basis for comparison with the improved materials and concepts.

Thermal and Acoustical Insulation

A major portion of thermal insulating and acoustical attenuation is achieved by the installation of fiberglass insulation in the airspace between the fuselage skin and the interior panels (see fig. 1). These cross sections permitted preliminary trade studies of interior panels which might provide a larger portion of the necessary thermal and acoustical insulation and reduce the amount of fiberglass insulation required.

Weight

The current 747 interior sidewall panels display a weight of 0.25 lb/ft^2 (1.22 kg/m^2). The panels evolved from this program exceed this weight, but they exhibited superior flame resistance.

3.1.2 TEST PROGRAM DEFINITION

The test program included burn-through fire testing and mechanical specimen testing. The burn-through tests were conducted by and at NASA-Ames. The mechanical tests were conducted by and at the BMT Laboratory as follows:

1. Long beam flexure

2. Short beam bending

3. Interlaminar shear (beam bending)

4. Flatwise tension

5. Flatwise compression

6. Core shear

3.2 PHASE II, MATERIAL SELECTION

Today's cabin interior panels cover unsightly wire bundles, tubing runs, air-conditioning ducts, etc., and provide easily cleaned and maintained surroundings for passengers. The interior panels also contribute to passenger comfort by forming a double wall with the fuselage skin to separate the passenger from the flight environment and meet both a thermal and an acoustical insulation requirement. Finally, the interior panels provide attachment points and support for lighting fixtures, window reveals, etc., installed between airplane frames. All of these factors must be taken into consideration when evaluating materials for interior panel applications.

3.2.1 DECORATIVE AND SERVICE CRITERIA

The aesthetic and maintenance characteristics of interior panels are given major consideration in ceiling and sidewall panel design.

Aesthetics (color, pattern, texture)

Panel design must allow some flexibility for customer choice in aesthetics.

Maintenance

Interior panels must be highly resistant to stain by tobacco smoke, food, and beverages. They must be cleanable with mild soap and water, and the decorative surface, when damaged, must be repairable.

3.2.2 FUNCTIONAL AND ENVIRONMENTAL REQUIREMENTS

Fire Resistance

Interior sidewall and ceiling panels are the largest continuous surfaces by which a cabin fire could spread, so the applicable flammability requirements are the most demanding set by the FAA. The current FAR 25.853(a) requires that a specified size of interior panel sample be held vertically and subjected for 60 sec to a Bunsen burner flame under specified conditions of flame, ventilation, etc. An acceptable material must self-extinguish within 15 sec after flame removal, drippings must self-extinguish in 3 sec., and there must be a maximum burn length of 6 in. (15.24 cm). The decorative surface of the panel can play a large role in the test results.

Environment

Airplanes are exposed to wide ranges of environmental factors because of worldwide and high-altitude use. The interiors must withstand temperatures from -65°F to 160°F (-54°C to 71°C) without degradation, and must be resistant to moisture, hydraulic fluid, ultra-violet light, cleaning fluids, and ozone.

Abrasion Resistance

Sidewall panels must have good abrasion resistance to withstand the abuse given them in service and have an acceptable life. Ceiling panels are less exposed to damage and the abrasion resistance may be lower.

Impact Resistance

Impact resistance is dependent upon panel stiffness, decorative surface resiliency, skin porosity, and other factors related to panel design, as well as installation factors, such as mounting rigidity, support spacing, etc. The necessary impact resistance can be defined only for a specific design and use.

Configuration and Size

The 747 ceiling panels are flat, and a design size of 52 by 54 in., edge supported, was chosen. The sidewall panels are 40 in. wide, 69 in. high, simple curvature (120-in. radius), and predominantly upper and lower end retained.

Weight

Light weight for interior panels is a paramount goal. Panel weight also determines or affects the flexural strength and stiffness required of the panels. The 747 ceiling and sidewall panels weigh approximately 0.25 lb/ft^2 (1.22 kg/m^2) without trim and stiffeners.

Thermal Resistance

The fuselage wall insulation is mainly provided by the airspace between the fuselage skin and the interior panel and by the thermal/acoustical-fiberglass insulation in this wall space. An advantageous trade of higher interior panel weight for a reduction in thermal insulation does not appear possible for the type and weight panels under consideration. The 747 fiberglass insulation provides a thermal resistance of 17.9 Btu · in./hr · ft^2 · °F (kcal · m/hr · m^2 · °C) for a weight of 0.167 lb/ft^2 (0.815 kg/m^2) (including cover), while the interior panels at 0.25 lb/ft^2 (1.22 kg/m^2 give only about 0.6 Btu · in./hr · ft^2 · °F (kcal · m/hr · m^2 · °C) thermal resistance.

Acoustical Insulation

The amount of fiberglass insulation in the 747 sidewalls and ceilings is governed primarily by a noise reduction rather than a thermal insulation requirement. The primary acoustic insulation function of the interior panel is the forming of the double wall construction. An increase of panel weight to 0.50 lb/ft^2 (2.44 kg/m^2) would be significantly effective in the lower frequency noise range but, as compared to the fiberglass insulation, would not be very effective in reduction of the higher frequency noise levels.

3.2.3 MECHANICAL PROPERTIES

The required mechanical properties of 747 interior panels are not always established by the use. The required strength of the sidewall panel is in part determined by loads placed on the panel by handling during fabrication and installation.

The stiffness and strength of a ceiling panel is very dependent on the panel weight. Large 747 panels are stiffened with aluminum angles. Heavier panels would require more stiffening or greater panel strength and stiffness. The test results of 747 panels in long and short beam flexure and present design allowables for the baseline comparison are shown in table 1.

3.3 PHASE III, SPECIMEN DESIGN AND FABRICATION

The fluted-core structure was optimized within the constraints imposed by NASA. The NASA constraints identified the woven glass structure and the resin matrix system, plus the foam insulation within the flutes (see fig. 2). Three specific configurations were identified as follows:

- Design No. 1: woven structure plus polybenzimidazole (PBI) foam
- Design No. 2: woven structure plus isocyanurate (ISU) foam
- Design No. 3: woven structure without foam

All three designs had a decorative fly screen material bonded to the front surface.

3.4 PHASE IV, SPECIMEN TESTING

Tests were conducted to identify the mechanical capabilities of the candidate fluted-core structures. Mechanical tests were performed by the BMT Laboratory and consisted of the following tests:

- Long beam flexure — 24 specimens
- Short beam bending — 24 specimens
- Interlaminar (core) shear — 12 specimens

- Flatwise tension 6 specimens
- Flatwise compression 6 specimens
- Core shear 6 specimens

Tests to evaluate the fire-protective performance of the fluted-core structures were conducted by and at NASA-Ames. NASA tested two baseline configurations, as well as the three NASA configurations.

3.5 PHASE V, DATA REDUCTION AND PRELIMINARY COST COMPARISON

Concepts, designs, and composite structures were evaluated, but a realistic cost analysis was not possible at this time. All the NASA-defined interior panels were fabricated as flat developmental test specimens. These test panels do not reflect possible production fabrication methods or costs, which are necessary for a comparative cost analysis to the present 747 production of interior wall panels.

4.0 RESULTS AND DISCUSSION

4.1 MATERIAL DESCRIPTION

All materials for the NASA-defined designs were purchased from HITCO, Woven Structures Division, Gardena, California, and are defined as follows: Hitcore 406, 1/4- by 3/4-in., cured fluted-core panels consisting of an integrally woven reinforcing structure impregnated with a Kerimid (Rhodia) 601 bismaleimide resin cured over Teflon mandrels. The panels displayed flutes 3/4 in. wide and 1/4 in. high, with an additional ply of 181 style Volan A glass cloth added to each panel face. An additional ply of UM 203 Leno glass cloth fly screen was added to one side only as an aesthetics consideration.

A total of six panels 36 by 54 in. were purchased. The six panels consisted of two each of NASA-defined designs No. 1, No. 2, and No. 3. The three design configurations differ only with respect to use of foam, or absence of foam, in the flutes of the panels. Design No. 1 has a low-density PBI foam in its flutes, design No. 2 has its flutes filled with ISU foam, and design No. 3 has no foam at all.

4.2 CURE CYCLE

The 36- by 54-in. panels were cured by the fabricator (Hitco) in an oven under a minimum of 25 in. (63.5 cm) of Hg vacuum. The cure cycle consisted of 4 hr at 350°F (176.7°C) followed by 2 hr at 400°F (204.4°C). A single panel was postcured 20 hr at 480°F (248.9°C). The 20-hr postcure was subsequently deleted from the remaining panels because of the fabricator's claim that this postcure cycle was causing excessive warpage and a polymer degradation resulting in reduced strengths. All mechanical tests were conducted on non-postcured panels. The postcured panel, identifiable by the very dark appearance, was cut into burn-through specimens and forwarded to NASA for burn testing.

4.3 SPECIMEN FABRICATION

The fabrication procedures used to produce the mechanical test specimens and the burn-through test specimens are as follows: fluted-core panels were fabricated by Hitco and shipped completely cured to Boeing, where they were cut into individual test specimens. The materials and cure cycle used to produce the test panels are described in paragraphs 4.1 and 4.2.

4.4 TEST PROCEDURE AND RESULTS

The following is a description of the fire-resistance tests, performed by and at NASA-Ames, and the mechanical test procedures used by the BMT organization during this program.

4.4.1 FIRE RESISTANCE TEST

A series of 12- by 12-in. fluted-core (both filled and unfilled) interior panel materials were fire tested at the Ames T-3 thermal test facility. Since the testing technique was substantially different than those normally used on the T-3, a brief description follows (see fig. 3).

A panel support fixture was built up of asbestos millboard. The specific panel for testing was placed into the fixture on a gasket of Fiberfrax, and additional Fiberfrax was placed around the edges to seal the edges against smoke and flames. An asbestos millboard frame was placed on top of the Fiberfrax gasket to hold the panel in place. A 16-in. (40.64 cm)-to-a-side stainless steel box was placed on the lower fixture and clamped in place. Windows in the box allowed for passing a light beam through for monitoring light transmission. A thermocouple measured the panel backface temperature, and a gas thermocouple measured inside box air temperature. The ratio of the area of exposed panel to the volume of the box equals 0.3/ft (1.16/m). Prior to testing at NASA-Ames, the fluted-core panels were subjected at Boeing to the current flame resistance requirements (self-extinguishing) as defined in FAR 25, Amendment 32, paragraph 25.853(a) and were found to pass this test. Results of the NASA-Ames T-3 flame tests are shown in figures 4 through 8. The following is a discussion of the results.

The initial run included an aluminum sheet, painted, 0.040 in. thick, to simulate the aircraft skin. The panel was placed 1 in. (2.54 cm) away and the edges sealed between the panel and aluminum sheet. Since the melting and dropping away of the aluminum was a variable, and since each panel-skin configuration was identical, it was felt that removal of the aluminum on subsequent runs would be a truer picture of the individual panel performance. Therefore, figure 4 shows the effect of an unfilled woven structure, tested with and without the aluminum skin. Each subsequent run can be considered to have performed slightly better if the aluminum had been present. Therefore, in each of the other figures, the data shown are taken from panels that were directly exposed to the fire, the worst case.

Figure 5 is a composite of both backface panel temperature and box or cabin air temperature. The flux was adjusted to 10.5 Btu/ft^2 · sec (26.56 x 10^{-4} kcal/cm^2 · sec) for each run, and each run had an ending flux of approximately 12 Btu/ft^2 · sec (32.64 x 10^{-4} kcal/cm^2 · sec).

Since the separation distance for data on each panel is not well shown on figure 5, figure 6 is a plot of cabin air temperature for each material on an expanded scale for temperature. The runs were each terminated at 10 min so that panel inspection of postfire damage would be more significant. It was also obvious (from the color) that the panels of woven structure and bismaleimide resin were cured at different temperatures; these are noted in the legend. At 10 min, no panels had burned through, although the 747 state-of-the-art panel was close, with no structural integrity remaining. All the woven fluted-core panels were quite rigid and appeared to have retained significant structural integrity (see pictures in figs. 9, 10, and 11).

Since additional panels were available, tests of both the high-temperature and low-temperature cure bismaleimide resin panels were conducted. These are plotted in figure 7. In each case, the lower cure temperature panels performed as better thermal barriers.

During each of the tests, the interior of the box filled rapidly with smoke. This is shown in figure 8. The difference between the panels tested is hardly significant. It is anticipated that with aircraft skin in place and full-depth fuselage panels, the smoke data would have been more significant.

4.4.3 MECHANICAL TESTS

All mechanical tests were conducted per the applicable requirements of MIL-STD-401B unless otherwise stated. The long beam and short beam flexural tests had the loads applied through 1/4-in. (0.635 cm) thick by 1-in. (2.54 cm) wide steel plates to prevent local failures. A load-deflection curve was obtained for each specimen configuration tested. All tests were conducted at room temperature.

Long Beam Flexural

Specimens were cut 4 in. (10.16 cm) wide by 20 in. (50.80 cm) long (in the flute direction) and tested over an 18-in. (45.72 cm) span with two-point load application at 1/4 span points. Eight specimens from each of the three design configurations were tested, a total of 24 tests. All panels failed in compressive face stress, and the heavier PBI foam-filled panels exhibited the highest face stresses. Test results showing total load at failure and calculated face stresses are shown in table 2.

Short Beam Bending

Specimens were cut 4 in. (10.16 cm) wide by 14 in. (35.56 cm) long (in the flute direction) and tested over a 12-in. (30.48 cm) span with a single-point center load application. Eight specimens from each of the three design configurations were tested, a total of 24 tests. All panels failed in compressive face stress, and the heavier PBI foam-filled panels exhibited the highest face stresses. The results showing total load at failure and calculated face stresses are shown in table 3.

Interlaminar (Core) Shear

The interlaminar shear tests were also conducted as a beam in bending. However, in the case of these core shear tests, the load was applied directly from the round steel bar without the use of a flat steel plate. The specimens were cut 4 in. (10.16 cm) wide by 10 in. (25.40 cm) long (in the flute direction) and tested over an 8-in. (20.32 cm) span with a single-point center load application. Four specimens from each of the three design configurations were tested, a total of 12 tests. None of the panels failed in core shear. All exhibited compression failures and the loads at failure were calculated to face stresses. Note that there is good correlation between the three beam tests when the total load at failure is calculated to face stress. In all cases, the PBI foam-filled panels had the highest face stresses. Test results are shown in table 4.

Flatwise Tension

Test specimens were cut 2 by 2 in. (5.08 by 5.08 cm). The specimens were tested after being bonded between two steel cubes measuring 2 by 2 by 2 in. (5.08 by 5.08 by 5.08 cm). The bonding was effected with a polyamide modified epoxy adhesive cured at room temperature under contact pressure. Two specimens from each of the three design configurations were tested, a total of six tests. Tests show that there is probably no contribution of the foams to the flatwise tensile properties. The average of all six specimens is 84.29 psi (5.93 kg/cm^2), which is lower than either specimen tested without the foam. One might conclude from these meager data that the foam had a negative impact on the flatwise tension. The results of the six panels tested are shown in table 5.

Flatwise Compression

Test specimens were cut 4 by 4 in. (10.16 by 10.16 cm). Two specimens from each of the three design configurations were tested, a total of six tests. As in the flatwise tension tests, there is little evidence to indicate any contribution of the foam to the flatwise compressive strength. The wide spread in results can possibly be attributed to the specific number of flutes per specimen at the time of testing. Test results are shown in table 6.

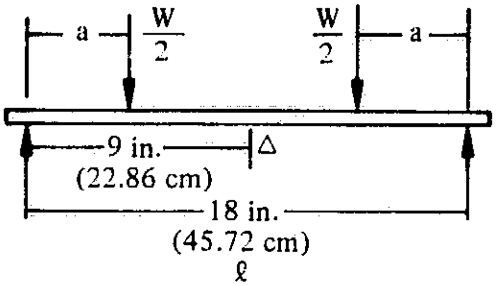
Core Shear

Test specimens were cut 2 in. (5.08 cm) wide by 6 in. (15.24 cm) long (in the flute direction) and tested with the load applied parallel to the 6-in. (15.24 cm) dimension. The specimens were tested after being bonded between two steel plates measuring 2 by 6 by 1 in. (5.08 by 15.24 x 2.54 cm) thick. The bonding was effected with a polyamide modified epoxy adhesive cured at room temperature under contact pressure. Two specimens from each of the three design configurations were tested, a total of six tests. The core shear test results were scattered and, again, this may be attributed to the specific number of flutes per specimen. Again, the foam filling does not appear to contribute to the strength of the flutes as tested. See table 7 for actual test results.

Panel Natural Frequency

An approximate value for the natural frequency of ceiling panels of the construction studied in this contract was calculated as follows. Considering the panels to be 70 in. (177.8 cm) long, simply supported at the ends and unsupported on both sides, and using the deflection obtained during beam tests on the three fluted-core configurations (unfilled, ISU (isocyanurate) foam-filled, and PBI (polybenzimidazole) foam-filled, and following three tests were conducted on each configuration:

1. Long beam flexure, two-point loading (ref. 1)



$$\Delta = \frac{Wa}{48\,EI}(3\ell^2 - 4a^2)$$

where

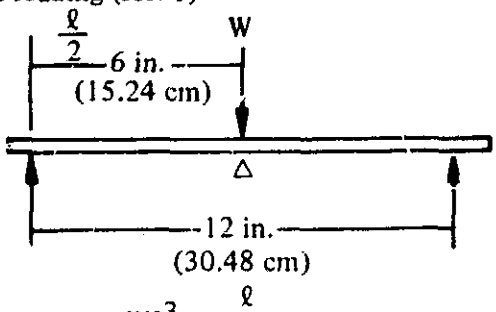
Δ = deflection

W = load

ℓ = span length

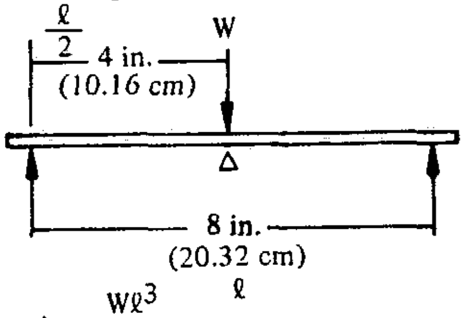
a = 1/4-span length

2. Short beam flexure, single-point loading (ref. 1)



$$\Delta = \frac{W\ell^3}{48\ EI}$$

3. Short beam core shear, single-point loading



$$\Delta = \frac{W\ell^3}{48\ EI}$$

Solution: From the deflections (Δ) measured during the beam tests, the slope of the deflection curves (W/Δ) can be determined.

Equations (1) and (2) can be solved for EI as a function of W/Δ and test dimensions,

$$EI = (W/\Delta)\ a\ (3\ell^2 - 4a^2)/48 \qquad (1')$$

$$EI \approx (W/\Delta)\ (\ell^3/48) \qquad (2')$$

The natural frequency of a beam (or panel) unsupported on the edges (ref. 2) can then be determined by Rayleigh's Method using

$$f = \pi^2 \ \frac{gEI}{w\ell^4} \qquad (3)$$

where

f = natural frequency

ℓ = distance between the supported ends

w = the uniform density of the panel (beam) in weight per unit length

The results are shown in table 8.

All calculations were based on properties for the 4-in. (10.16 cm) wide samples; however, since E is unaffected by specimen width and both I and w vary directly as the width, the results would be the same for any panel width that might reasonably be used in an aircraft ceiling. It is therefore concluded that the three panels studied would have a natural frequency of approximately 35 to 40 cps in 70-in. (177.8 cm) end-supported lengths. This is well above the minimum requirements of 15 cps to prevent visible panel vibrations. The calculated natural frequency of the tested 747 baseline interior sidewall panel is 38 cps.

In actual use, such panels are normally stiffened by edge treatment and stiffeners on the back side to eliminate unacceptable sag. Then the parts would have higher natural frequency values.

The calculated EI (flexural rigidity) of the samples, while not in exact agreement, establishes the magnitude as being correct for each configuration. In calculating the approximate natural frequency for each configuration, the EI established for the long beam flexure test is considered to be most nearly representative, since in the short beam tests the value tends to be lowered by more core deformation and bond loading than would occur in limited deflections of a longer panel (beam).

Therefore, using equation (3),

$$f = \pi^2 \frac{gEI}{w\ell^4}$$

the results are as shown in table 9.

5.0 SUMMARY AND CONCLUSIONS

Initially, a preliminary design study was conducted to define requirements and to establish baseline characteristics for a typical jet transport fuselage wall. The characteristics of the current Model 747 were selected as the baseline standard for comparison.

The NASA-defined improved panels were designed and fabricated to meet baseline requirements of the current 747 interior panels, plus structural requirements set forth in the subject contract. The NASA-defined fluted-core panels, with and without the foam-filled cores, were found to be significantly heavier than the current 747 sidewall and ceiling interior panels. The panel weights, as tested, were:

Panel Identification	Weight lb/ft^2	Weight (kg/m^2)
747 Baseline interior wall panel	0.250	(1.22)
NASA–unfilled fluted core	0.405	(1.98)
NASA–PBI foam-filled core	0.509	(2.49)
NASA–ISU foam-filled core	0.474	(2.31)

Thermal and acoustical insulation is currently achieved by an airspace plus fiberglass insulation between the fuselage skin and the interior panel. The heavier foam-filled fluted-core panels do not offer any improvement in this area, since the acoustical insulation is primarily achieved via the fiberglass insulation.

Flame tests and mechaincal property tests were conducted on these three NASA-defined improved interior panels and compared to the 747 baseline interior panels.

5.1 FLAME TESTS

The flame tests conducted by NASA-Ames showed no burn-through of any of the panels tested, but the state-of-the-art (747) panel was very close and had no structural integrity remaining. The woven fluted-core panels were quite stiff and retained structural integrity. No tests were conducted to determine actual panel strength after flame testing. See pictures of tested panels in figures 9 through 11.

In both the backface temperature and cabin air temperature, the best performing material was the PBI foam-filled fluted-core panel.

5.2 MECHANICAL PROPERTY TESTS

The face compressive stresses of the NASA-defined woven fluted-core panel with PBI compares favorably with the design allowables for the baseline 747 interior wall panel. Since there was no core failure in the NASA-defined panels as tested for long beam flexure, short beam flexure, and short beam shear, the results are comparable for each of the three NASA-defined panels.

In flatwise tension and compression, the NASA-defined fluted-core panels weighed about twice as much as the 747 baseline panel; therefore, on a strength-to-weight basis, the present 747 baseline panel is twice as strong.

5.3 COST ANALYSIS

The cost of the development panels tested in this program could not be equated to cost of the current 747 production interior sidewall panels.

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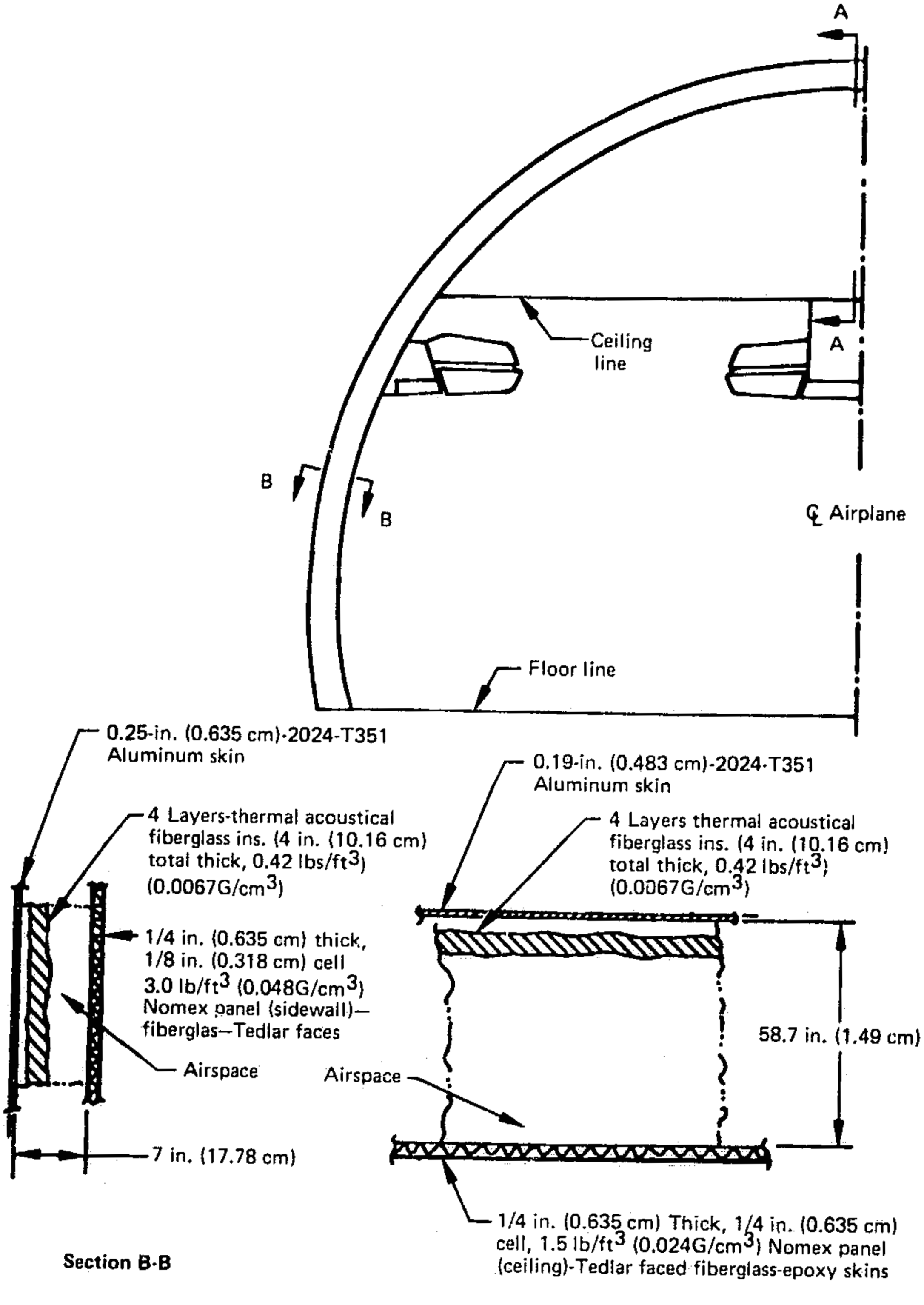
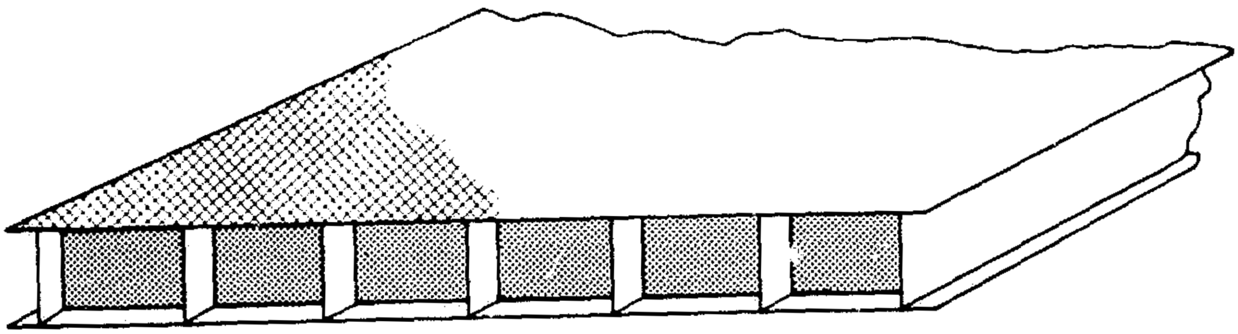


Figure 1.—747 Section



1/4-in. (0.635 cm) thick fluted core with
flutes spaced 3/4 in. (1.905 cm) apart.
ISU or PBI foam in flutes with a decorative
fly screen surface on one side.

Figure 2.—Test Panel Cross Section

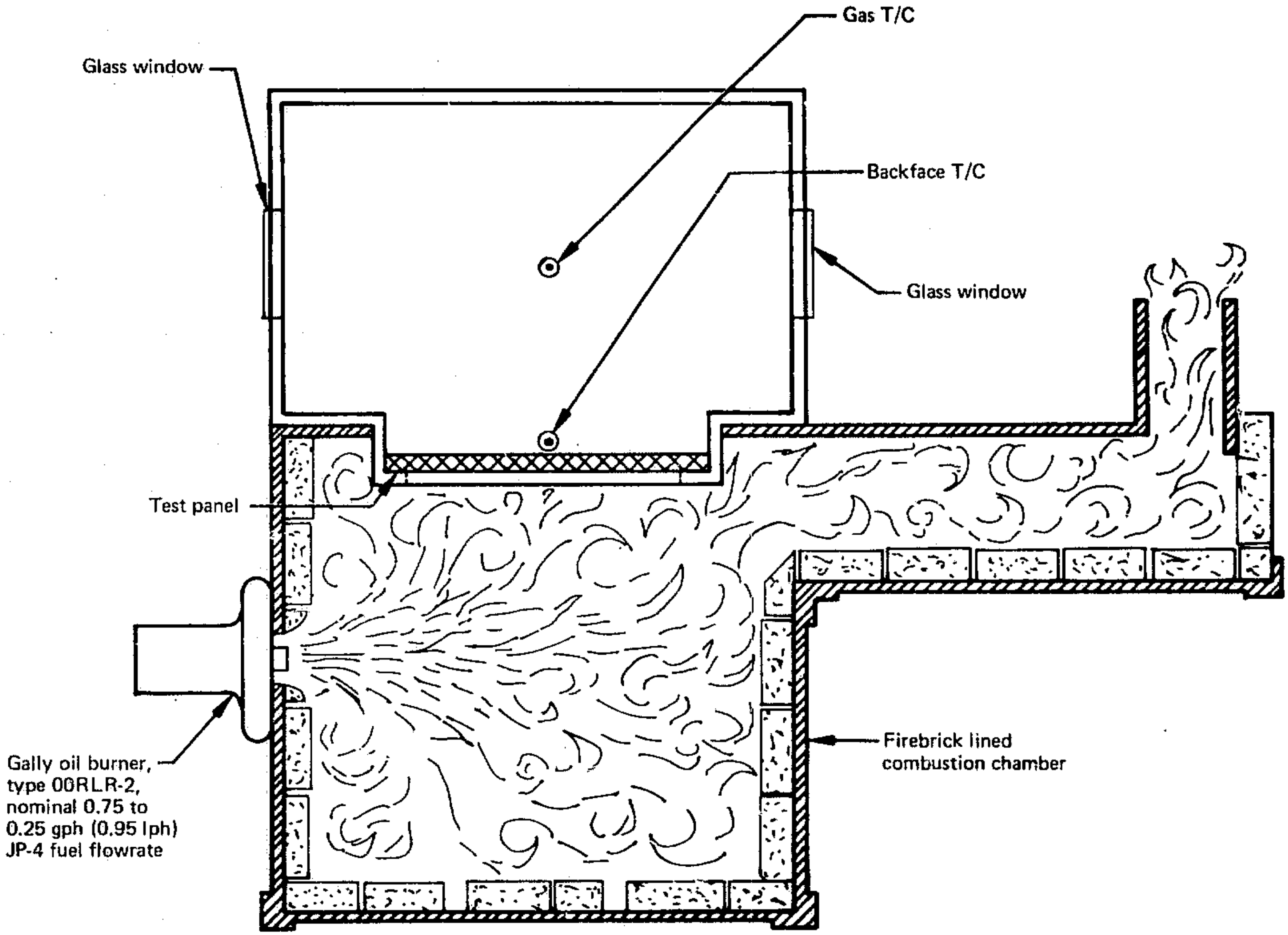


Figure 3.—Schematic of Fire Resistance Test Arrangement

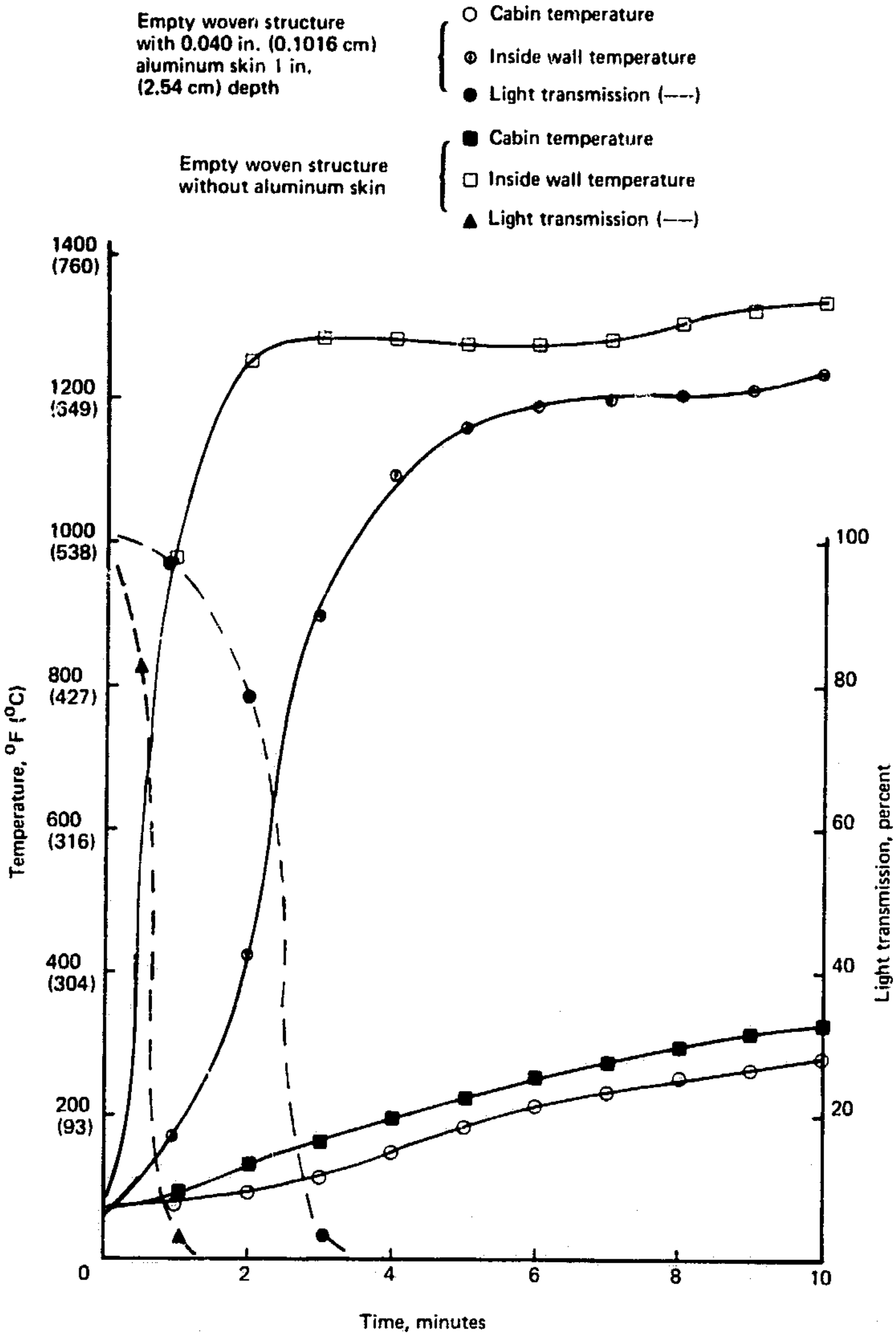
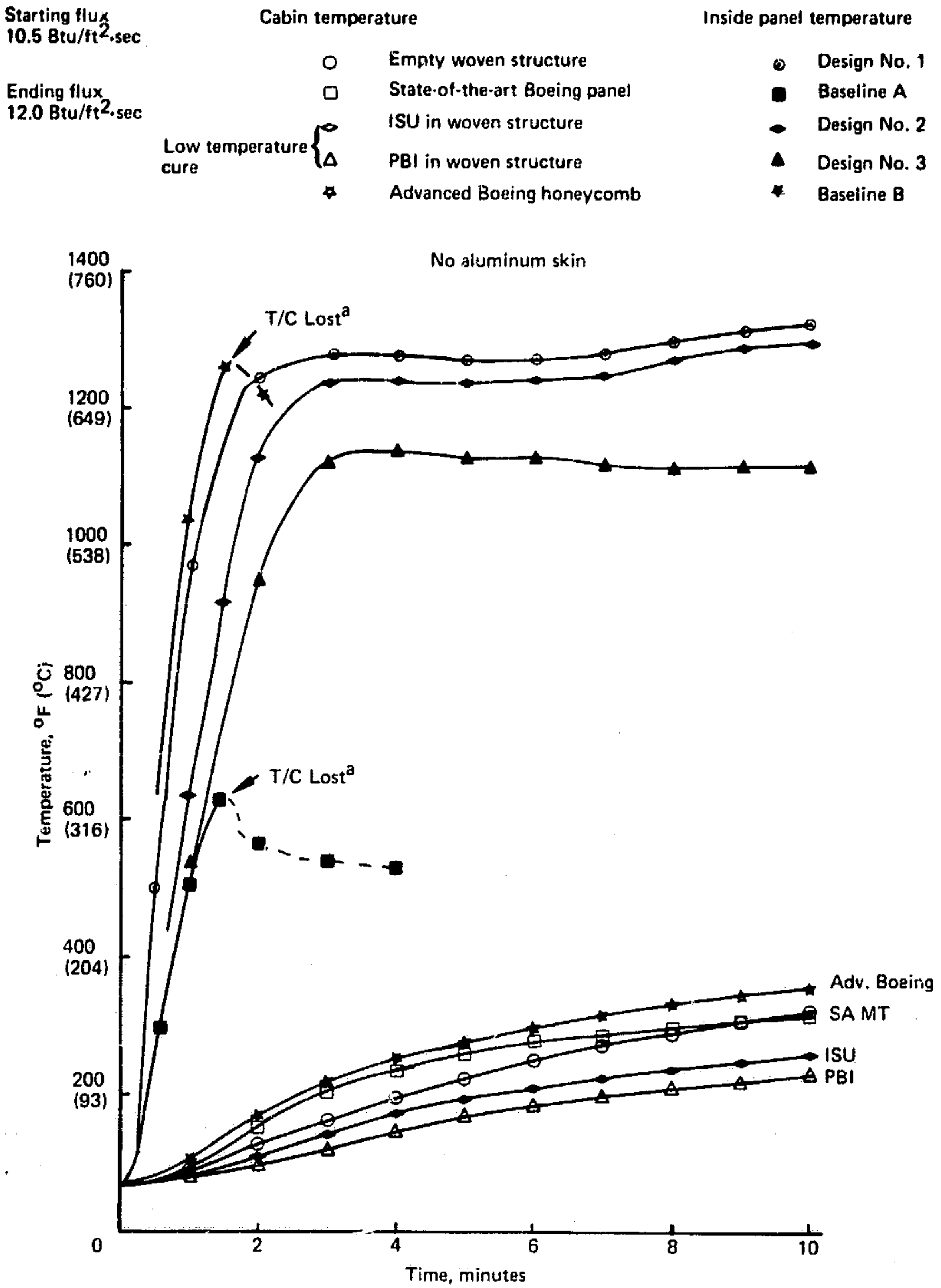


Figure 4.—Flame Test—Aluminum Skin Versus No Skin



[a]Lost T/C decomp. of Tedlar inner liner.

Figure 5.—Flame Test—Baseline and Test Panels

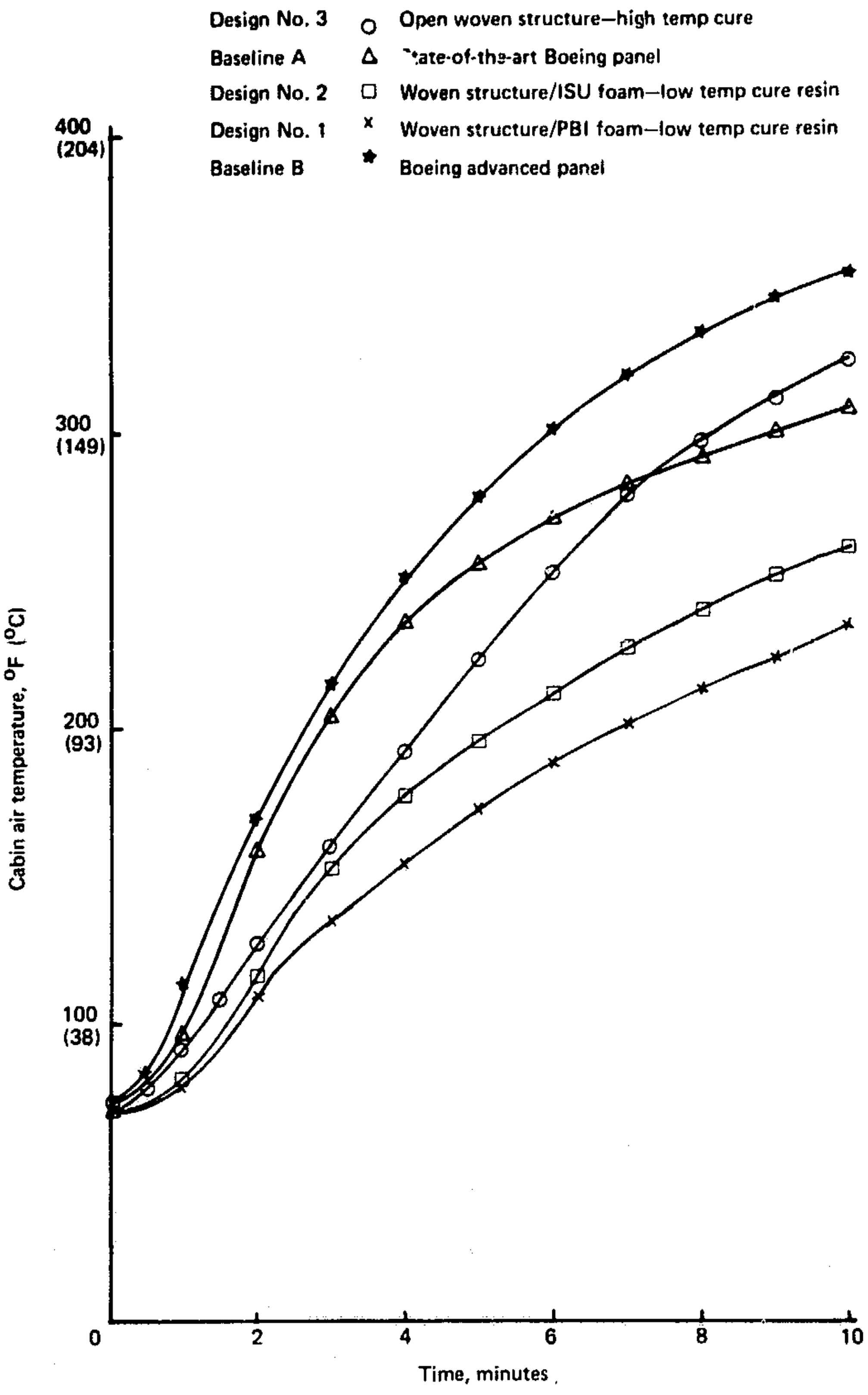


Figure 6.—Flame Test—Cabin Temperature Rise Versus Time

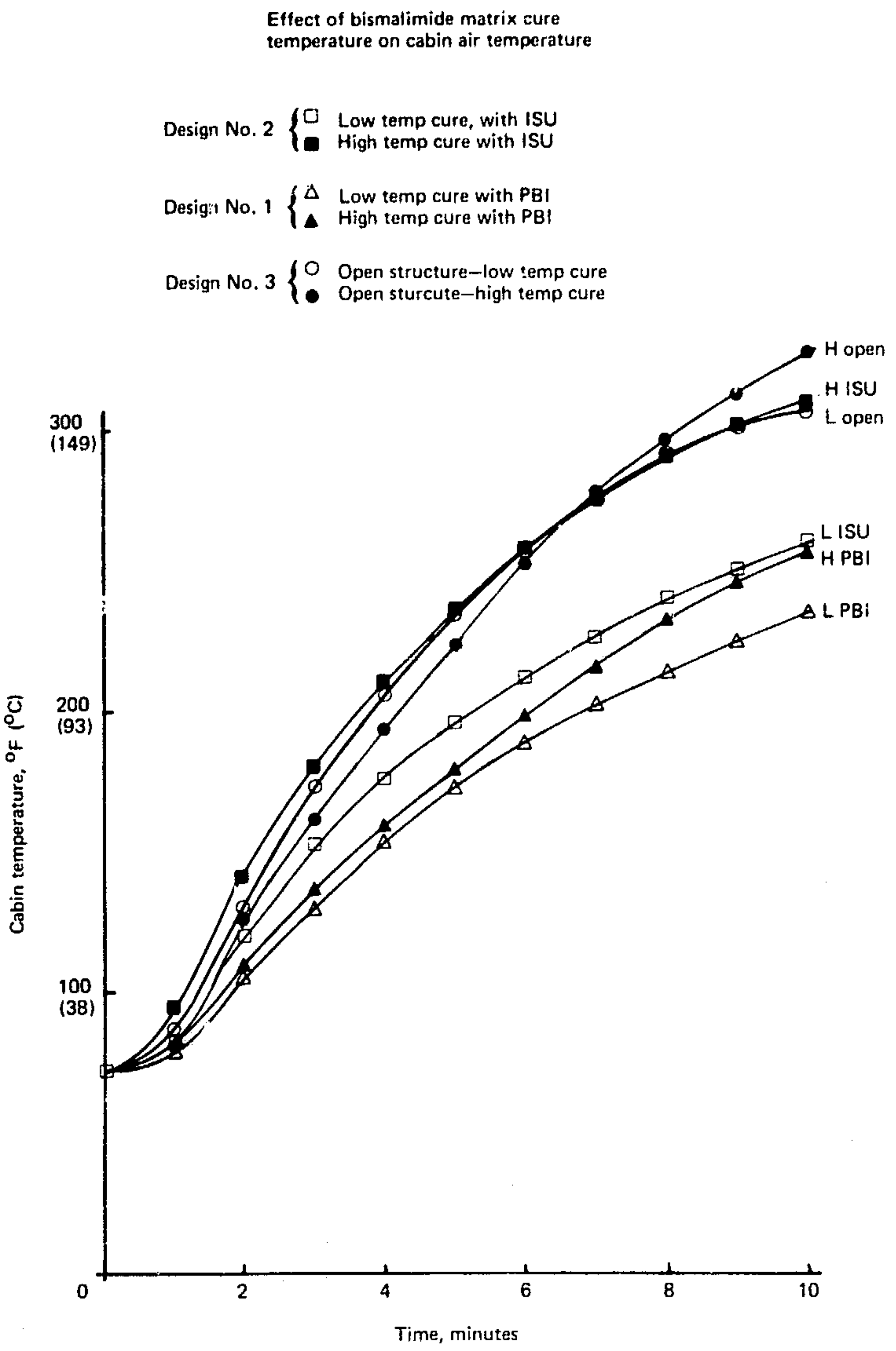


Figure 7.—Cabin Temperature Rise—High and Low Temperature Cured Resin Systems

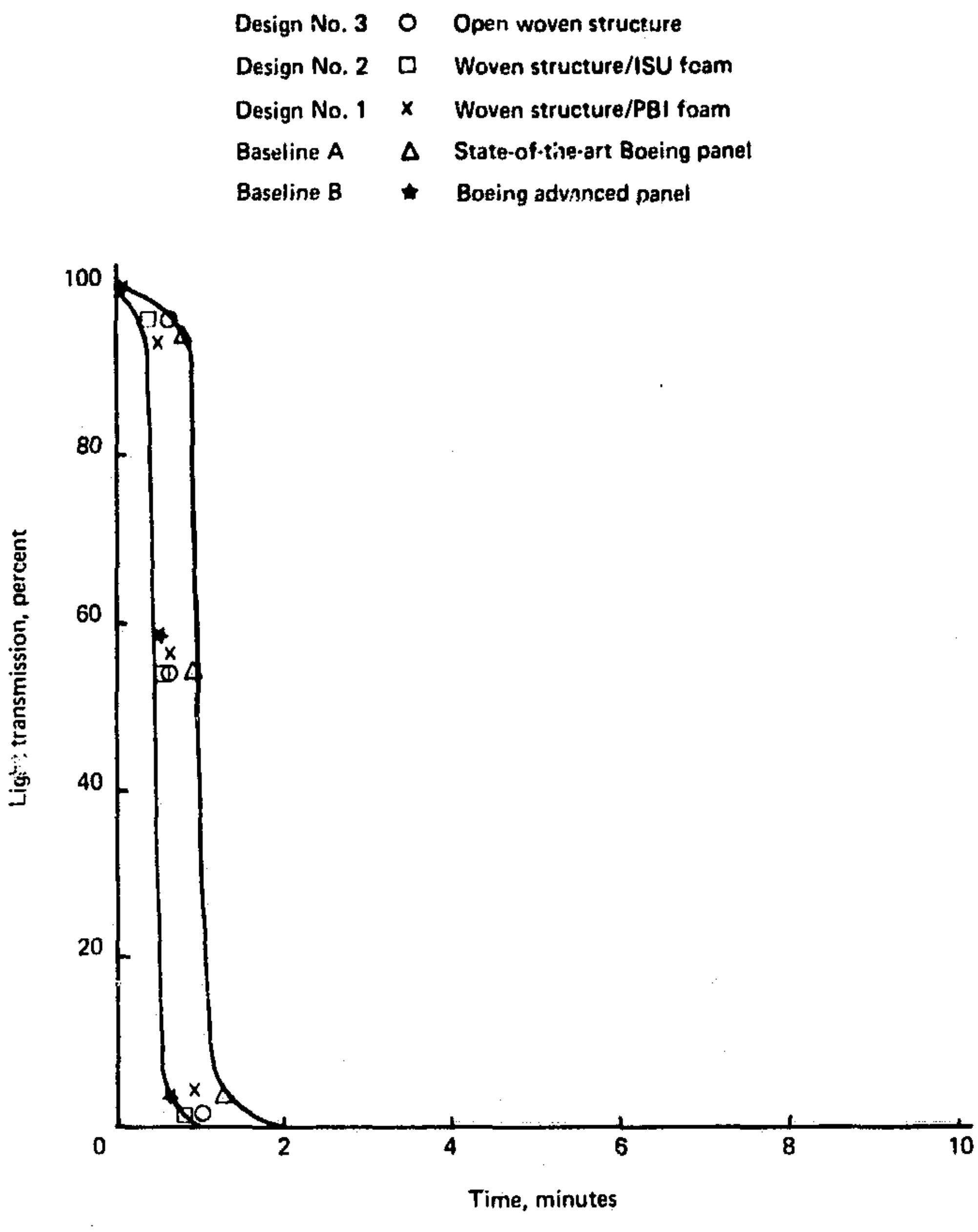
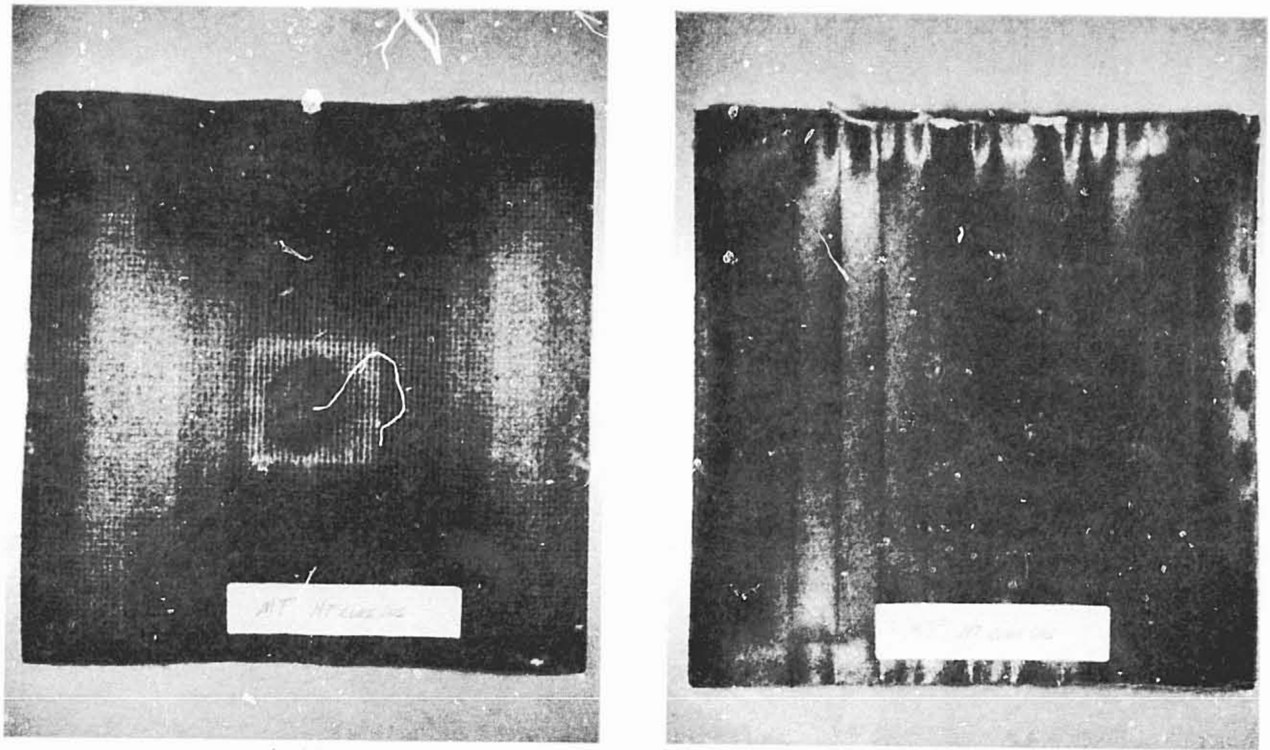
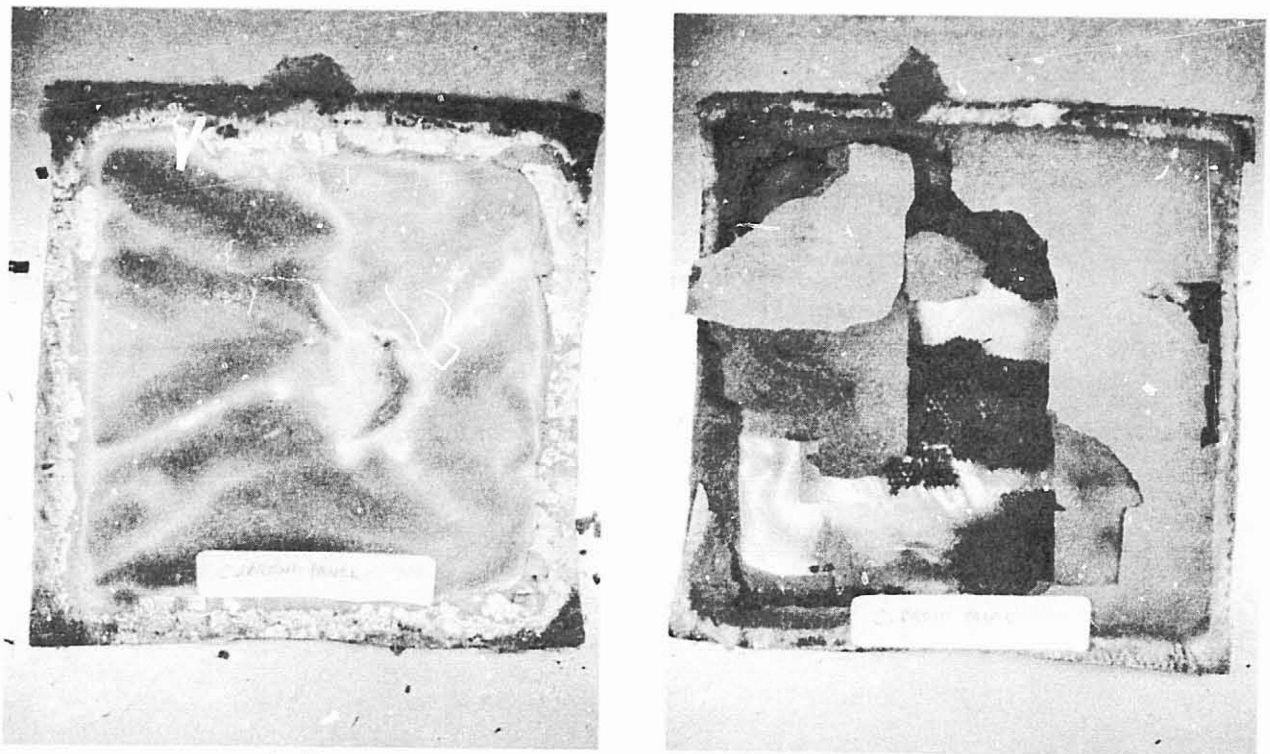


Figure 8.—Cabin Smoke—Light Transmission Versus Time

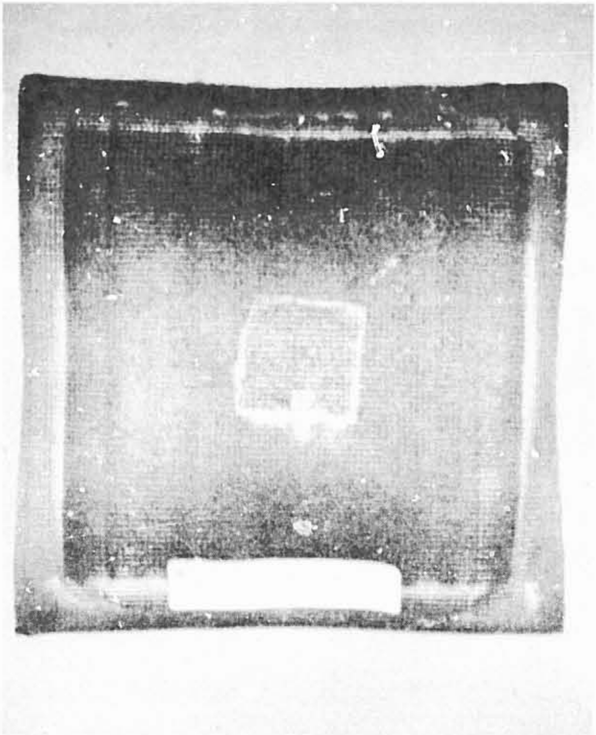


Inside **Unfilled Fluted Core** Outside

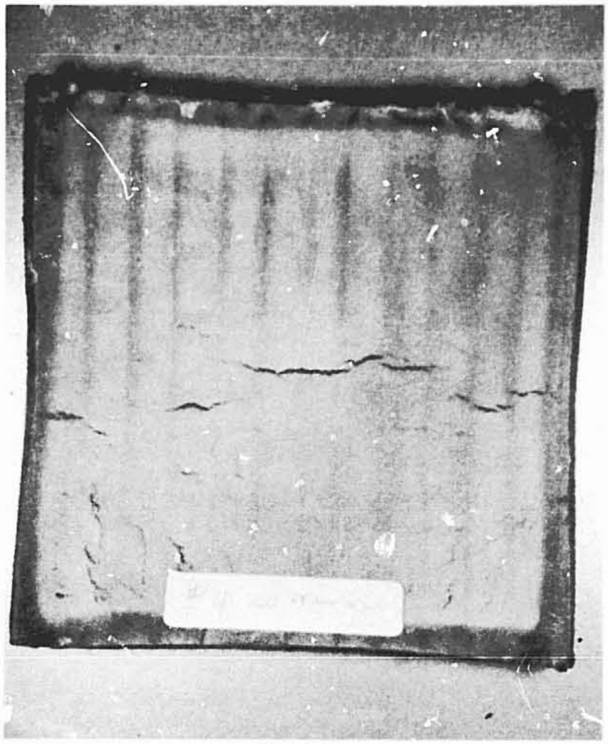


Inside **Boeing State of the Art** Outside

Figure 9.—Pictures—Flame Test Results

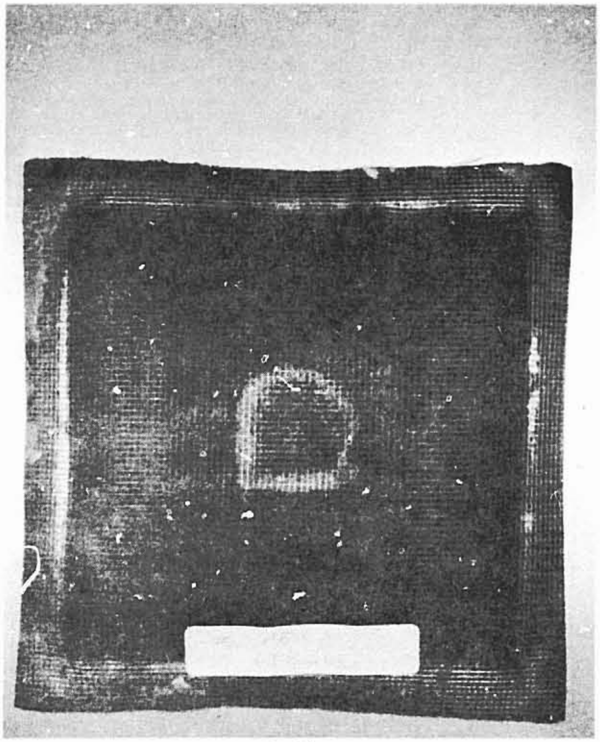


Inside

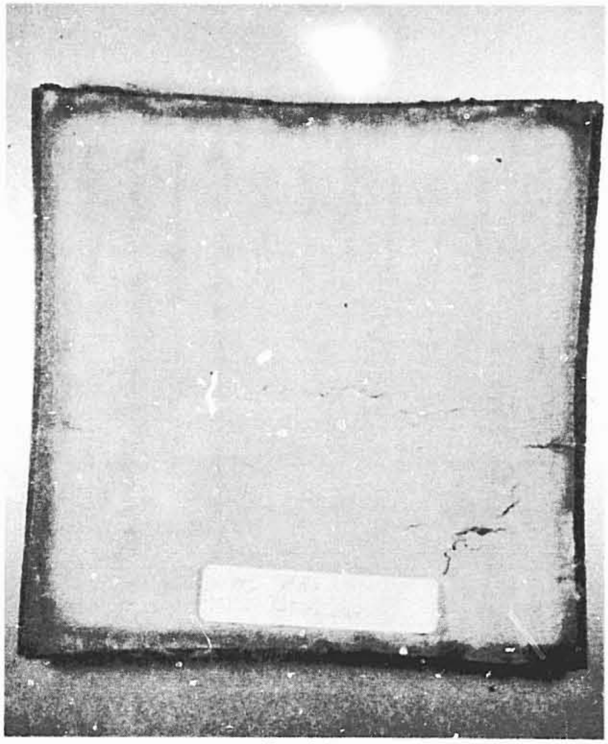


Outside

ISU Foam Filled



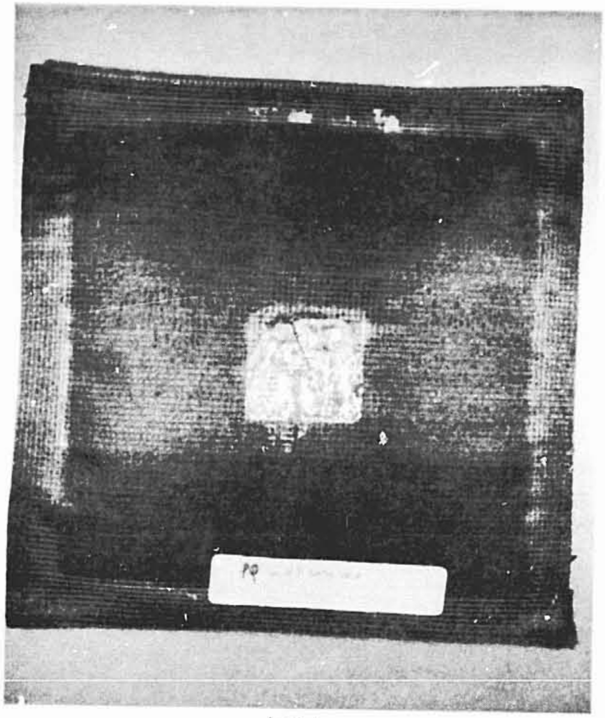
Inside



Outside

PBI Foam Filled

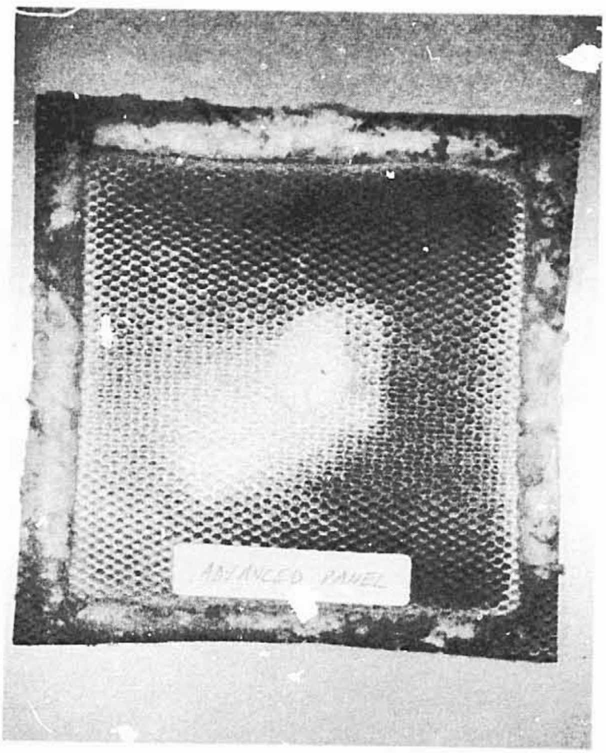
Figure 10.—Pictures—Flame Test Results



Inside

Outside

PQ Filled High Temp Cure Flame Tested for Information Only



Inside

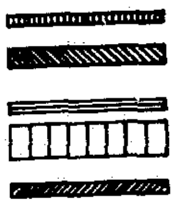
Outside

Boeing Advanced Concept

Figure 11.—Pictures—Flame Test Results

Table 1.—Boeing 747 Baseline

Tests	Results psi (kg/cm^2)	Allowables psi (kg/cm^2)
Interior Sidewall Panel		
Long beam flexure[a]	16 057 (1129)	13 400 (942)
Short beam flexure[a]	16 001 (1125)	13 400 (942)
Flatwise tension		100 (7.0)
Flatwise compression		92 (6.5)
Core shear		65 (4.6)
Typical Sidewall Panel Construction		



Decorative Tedlar sheet
Skin, epoxy, type 181 fiberglass
Bond ply, epoxy, type 120 fiberglass
Nomex honeycomb core, 1/8 cell, 1/4 in. thick
Skin, epoxy, type 128 fiberglass

[a]Tested with decorative face skin in compression

Table 2.—Long Beam Flexure

18-in. Span, Two-Point, 1/4-Span Loading

Specimen number	Unit load,[a] lb (kg)	P/Y,[b] lb/in. (kg/cm)	Face compressive stress, psi (kg/cm²)
Design No. 1, PBI Foam-Filled Flutes			
1	140.5 (63.73)	146.3 (26.1)	13 022.7 (915.5)
2	156.0 (70.76)	146.3 (26.1)	14 459.3 (1 016.5)
3	144.5 (65.55)	142.5 (25.5)	13 393.4 (941.6)
4	144.5 (65.55)	147.5 (26.3)	13 393.4 (941.6)
5	150.5 (68.27)	147.5 (26.3)	13 949.5 (980.6)
6	151.0 (68.49)	153.8 (27.5)	13 995.9 (983.9)
7	158.0 (71.67)	142.5 (25.5)	14 644.7 (1 029.5)
8	147.0 (66.68)	140.0 (25.0)	13 625.1 (957.8)
Avg	149.0 (67.59)	145.8 (26.0)	13 810.5 (970.9)
Design No. 2, ISU Foam-Filled Flutes			
1	131.5 (59.65)	130 (23.2)	12 188.5 (856.9)
2	129.5 (58.74)	123 (22.0)	12 003.1 (843.8)
3	115.5 (52.39)	123 (22.0)	10 705.5 (752.6)
4	143.0 (64.86)	125 (22.3)	13 254.4 (931.8)
5	123.0 (55.79)	123 (22.0)	11 400.6 (801.5)
6	125.0 (56.70)	123 (22.0)	11 586.0 (814.5)
7	128.0 (58.06)	121 (21.6)	11 864.1 (834.0)
8	115.5 (52.39)	120 (21.4)	10 705.5 (752.6)
Avg	126.4 (57.32)	123 (22.0)	11 713.5 (823.5)
Design No. 3, No Foam in Flutes			
1	110.2 (49.99)	123 (22.0)	10 214.2 (718.1)
2	105.5 (47.85)	120 (21.4)	9 778.6 (687.4)
3	103.3 (46.86)	115 (20.5)	9 574.4 (673.1)
4	104.7 (47.49)	116 (20.7)	9 704.4 (682.2)
5	96.6 (43.82)	116 (20.7)	8 953.7 (629.4)
6	95.6 (43.36)	114 (20.4)	8 861.0 (622.9)
7	99.0 (44.91)	112 (20.0)	9 176.1 (645.1)
8	106.5 (48.31)	113 (20.2)	9 871.3 (693.9)
Avg	102.7 (46.58)	116 (20.7)	9 516.8 (669.0)

[a]Unit load is listed in pounds (kilograms) at failure.

[b]P/Y is the slope of the tangent drawn to the initial portion of the load deflection (stress-strain) curve in pounds/inch (kilograms/centimeter).

Table 3.—Short Beam Flexure

12-in. Span, Single-Point Loading

Specimen number	Unit load,[a] lb (kg)	P/Y,[b] lb/in. (kg/cm)	Face compressive stress, psi (kg/cm^2)
Design No. 1, PBI Foam-Filled Flutes			
1	115.0 (52.16)	300 (53.6)	14 213.6 (999.2)
2	117.5 (53.30)	284 (50.7)	14 522.6 (1,020.9)
3	95.5 (43.32)	292 (52.1)	11 803.5 (829.8)
4	101.5 (46.04)	288 (51.4)	12 545.1 (881.9)
5	112.5 (51.03)	300 (53.6)	13 904.6 (977.5)
6	109.5 (49.67)	304 (54.3)	13 533.8 (951.4)
7	118.0 (53.52)	300 (53.6)	14 584.4 (1 025.3)
8	110.0 (49.90)	300 (53.6)	13 595.6 (955.8)
Avg	109.94 (49.87)	296 (52.9)	13 587.9 (955.2)
Design No. 2, ISU Foam-Filled Flutes			
1	86.6 (39.28)	236 (42.1)	10 703.5 (752.5)
2	84.2 (38.19)	240 (42.9)	10 406.8 (731.6)
3	85.1 (38.60)	236 (42.1)	10 518.1 (739.4)
4	89.0 (40.37)	232 (41.4)	11 000.1 (773.3)
5	80.9 (36.70)	232 (41.4)	9 999.0 (702.9)
6	80.2 (36.38)	236 (42.1)	9 912.5 (696.8)
7	87.6 (39.74)	240 (42.9)	10 827.1 (761.1)
8	87.5 (39.69)	228 (40.7)	10 814.7 (760.3)
Avg	85.14 (38.60)	235 (42.0)	10 522.7 (739.7)
Design No. 3, No Foam in Flutes			
1	89.0 (40.37)	258 (46.1)	11 000.1 (773.3)
2	85.0 (38.55)	252 (45.0)	10 505.7 (738.6)
3	70.9 (32.16)	240 (42.9)	8 763.0 (616.0)
4	90.8 (41.19)	256 (45.7)	11 222.6 (788.9)
5	66.0 (29.94)	236 (42.1)	8 157.4 (573.5)
6	79.1 (35.88)	240 (42.9)	9 776.5 (687.3)
7	69.5 (31.52)	240 (42.9)	8 590.0 (603.9)
8	65.3 (29.62)	236 (42.1)	8 070.9 (567.4)
Avg	76.95 (34.90)	245 (43.7)	9 510.8 (668.6)

[a]Unit load is listed in pounds (kilograms) at failure.

[b]P/Y is the slope of the tangent drawn to the initial portion of the load deflection (stress-strain) curve in pounds/inch (kilograms/centimeter).

Table 4.—Short Beam (Core) Shear

8-in. Span, Single-Point Loading

Specimen number	Unit load,[a] lb (kg)	P/Y,[b] lb/in. (kg/cm)	Face compressive stress, psi (kg/cm^2)
Design No. 1, PBI Foam-Filled Flutes			
1	146.5 (66.45)	870 (155.4)	12 071.3 (848.6)
2	142.0 (64.41)	860 (153.6)	11 700.5 (822.5)
3	117.0 (53.07)	874 (156.1)	9,640.5 (677.7)
4	139.0 (63.05)	920 (164.3)	11 453.3 (805.2)
Avg	136.12 (61.74)	881 (157.3)	11 216.4 (788.5)
Design No. 2, ISU Foam-Filled Flutes			
1	125.0 (56.70)	693 (123.7)	10 299.7 (724.1)
2	112.5 (51.03)	680 (121.4)	9 269.7 (651.7)
3	115.0 (52.16)	680 (121.4)	9 475.7 (666.1)
4	113.5 (51.48)	700 (125.0)	9 352.1 (657.5)
Avg	116.50 (52.84)	688 (122.9)	9 599.3 (674.8)
Design No. 3, No Foam in Flutes			
1	105.5 (47.85)	726 (129.6)	8,693.0 (611.1)
2	110.5 (50.12)	726 (129.6)	9 105.0 (640.1)
3	120.5 (54 66)	733 (130.9)	9 928.9 (698.0)
4	119.0 (53.98)	746 (133.2)	9 805.3 (689.3)
Avg	113.87 (51.66)	733 (130.9)	9 383.0 (659.6)

[a]Unit load is listed in pounds (kilograms) at failure.

[b]P/Y is the slope of the tangent drawn to the initial portion of the load deflection (stress-strain) curve in pounds/inch (kilograms/centimeter).

Table 5.—Flatwise Tension

Specimen number	Unit load at failure	
	lb (kg)	psi (kg/cm^2)
Design No. 1, PBI Foam-Filled Flutes		
1	265 (120.20)	66.25 (4.66)
2	330 (149.68)	82.50 (5.80)
Design No. 2, ISU Foam-Filled Flutes		
1	233 (105.69)	58.25 (4.09)
2	430 (195.04)	107.50 (7.56)
Design No. 3, No Foam in Flutes		
1	385 (174.63)	96.25 (6.77)
2	380 (172.36)	95.00 (6.68)

Table 6.—Flatwise Compression

Specimen number	Unit load at failure	
	lb (kg)	psi (kg/cm^2)
Design No. 1, PBI Foam-Filled Flutes		
1	1 910 (866.36)	119.38 (8.39)
2	1 620 (734.82)	101.25 (7.12)
Design No. 2, ISU Foam-Filled Flutes		
1	2 270 (1 029.65)	141.88 (9.97)
2	2 160 (979.75)	135.00 (9.49)
Design No. 3, No Foam in Flutes		
1	1 160 (526.16)	71.88 (5.05)
2	2 660 (1 206.55)	141.25 (9.93)

Table 7.—Core Shear

Specimen number	Unit load at failure	
	lb (kg)	psi (kg/cm^2)
Design No. 1, PBI Foam-Filled Flutes		
1	2 340 (1 061.40)	195.00 (13.71)
2	1 235 (560.18)	102.92 (7.24)
Design No. 2, ISU Foam-Filled Flutes		
1	1 380 (625.95)	115.00 (8.08)
2	1 580 (716.67)	131.66 (9.26)
Design No. 3, No Foam in Flutes		
1	1 340 (607.81)	111.66 (7.85)
2	1 535 (696.26)	127.92 (8.99)

Table 8.—Panel Flexural Rigidity

Configuration	Test	(W/Δ) avg,[a] lb/in. (kg/cm)	EI,[a] lb/in.^{2} (kg/cm^2)
Unfilled	Long beam flexure	116 (20.7)	9 700 (681.9)
	Short beam flexure	245 (43.7)	8 800 (618.6)
	Short beam core shear	733 (130.9)	7 800 (548.3)
ISU filled	Long beam flexure	123 (22.0)	10 300 (724.1)
	Short beam flexure	235 (42.0)	8 500 (597.6)
	Short beam core shear	688 (122.9)	7 300 (513.2)
PBI filled	Long beam flexure	146 (26.1)	12 200 (857.7)
	Short beam flexure	296 (52.9)	10 700 (752.2)
	Short beam core shear	881 (157.3)	9 400 (660.8)

[a]For 4-in.-wide test sample (beam) from test data

Table 9.—Panel Natural Frequency

Configuration	EI, lb/in.^{2} (kg/cm^2)	w,[a] lb/in. (kg/cm)	ℓ, in. (cm)	f, Hz
Unfilled	9 700 (681.9)	0.0112 (0.0020)	70 (178)	36.8
ISU filled	10 300 (724.1)	0.0131 (0.0023)	70 (178)	35.1
PBI filled	12 200 (857.7)	0.0141 (0.0025)	70 (178)	36.8

[a]For 4-in.-wide sample

REFERENCES

1. PoPov, E.P.: *Introduction to Mechanics of Solids.* Prentice Hall, 1968, p. 564.

2. Thomson, W. T.: *Mechanical Vibrations, Second Edition,* 1956, p. 163.