DOT/FAA/AR-06/49

Air Traffic Organization
Operations Planning
Office of Aviation Research
and Development
Washington, DC 20591

Laboratory-Scale and Full-Scale Fire Testing of Lightweight Aircraft Seat Cushion Materials

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March 2007

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-06/49		

4. Title and Subtitle	5. Report Date
LABORATORY-SCALE AND FULL-SCALE FIRE TESTING OF LIGHTWEIGHT AIRCRAFT SEAT CUSHION MATERIALS	March 2007
	6. Performing Organization Code ATO-P R&D
7. Author(s) Timothy R. Marker	8. Performing Organization Report No.
9. Performing Organization Name and Address Federal Aviation Administration William J. Hughes Technical Center Airport and Aircraft Safety Research and Development Division Fire Safety Branch Atlantic City International Airport, NJ 08405	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Air Traffic Organization Operations Planning Office of Aviation Research and Development Washington, DC 20591	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code ANM-115

15. Supplementary Notes

16. Abstract

Laboratory- and full-scale fire tests were conducted on a number of different types of aircraft seat cushion materials to determine the applicability of the current weight loss criteria specified in Title 14 Code of Federal Regulations Part 25.853(c) Appendix F Part II (herein referred to as Appendix F Part II) to new, very lightweight cushion designs. Cushion samples were initially tested in accordance with the current standard, and if they exceeded the 10% weight loss criteria, they were evaluated under full-scale fire test conditions. The full-scale tests were conducted with a modified narrow-body fuselage test article exposed to an adjacent fuel pan fire to simulate a severe but survivable postimpact cabin fire. Four triple-seat frames used to mount the cushion samples were installed inside the test article. Aircraft-grade honeycomb sidewall, ceiling panels, and carpet were also installed in the vicinity of the seat frames to simulate a realistic aircraft cabin.

Laboratory-scale tests were completed on one set of standard fire-blocked cushions that met the current Appendix F Part II requirement, in addition to four lightweight materials. The standard fire-blocked cushions were then run under full-scale conditions to provide a baseline of the current level of fire safety, followed by full-scale tests of the four lightweight materials. Results indicated that several of the lightweight seat materials that failed the weight loss criteria specified in Appendix F Part II did not result in greater fire hazards than the baseline materials when tested under realistic full-scale conditions. A conservative adjustment to the current weight loss criteria was developed to allow the use of very lightweight seat cushion materials that exhibit acceptable fire performance.

17. Key Words	18. Distribution Statement
Weight loss criteria, Urethane foam, Lightweight seat, Fractional effective dose, Aircraft fire safety	This document is available to the U.S. public through the National Technical Information Service (NTIS) Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	49	

Form DOT F1700.7 (8-72) Reproduction of completed page authorized

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LIST SYMBOLS OF ACRONYMS

CO	Carbon monoxide
CO_2	Carbon dioxide
O_2	Oxygen
AFFF	Aqueous film forming foam
CAWL	Corrected allowable weight loss
FAA	Federal Aviation Administration
FED	Fractional effective dose
FED_I	Fractional effective dose for incapacitation
FED_L	Fractional effective dose for lethality
PBI	Polybenzimidazole

EXECUTIVE SUMMARY

As technological advancements in materials processing continue to unfold, the commercial aviation industry is finding new ways to improve comfort and reduce weight. Historically, the most cost-effective means of meeting the Federal Aviation Administration (FAA) flammability requirements for aircraft seating, in particular burn length and weight percentage loss, has been to use a polyurethane foam encapsulated in a fire-blocking material and an outer dress cover. However, with the introduction of newer materials and concepts, the aircraft seat manufacturers are capable of achieving the same level of comfort as the traditional polyurethane seat, but with considerable weight savings. Because of the substantial difference in weight between the new materials and traditional materials, the applicability of the FAA performance requirements has been questioned. Although the new foam cushion seating materials are often as fire-resistant as traditional polyurethane foam, these lighter materials may be unfairly judged based on the weight loss criteria, which was originally based on heavier, polyurethane foam in conjunction with fire-blocking materials. For example, at 10% weight loss, a traditional 5-pound seat may lose up to 0.5 pound of mass, while a new generation seat weighing only 3 pounds would far exceed the weight loss criteria by losing the identical 0.5 pound (16.67% weight loss). This study was undertaken to determine if the lighter seat foam materials that do not meet the weight loss criteria are more or less hazardous than traditional seats under realistic cabin fire test conditions.

Tests were conducted using a full-scale, narrow-body test article adjacent to a fuel pan fire, which simulated a realistic postcrash cabin fire scenario. Initial tests using seats comprised of urethane foam encapsulated in a fire-blocking barrier were run to establish baseline results, followed by tests using four types of lightweight seat material. Results indicated that several of the lightweight seat materials that failed the current weight loss criteria specified in Title 14 Code of Federal Regulations Part 25.853(c) Appendix F Part II did not result in greater fire hazards than the baseline materials when tested under realistic full-scale conditions. Consequently, a conservative adjustment to the current weight loss criteria was developed to allow the use of very lightweight seat cushion materials that exhibit acceptable fire performance.

1. INTRODUCTION.

1.1 PURPOSE.

The purpose of this report is to summarize the findings of laboratory- and full-scale flammability tests in which various new seat cushion materials of lightweight construction were compared to traditional fire-blocked urethane foam materials. Three independent seat manufacturers supplied four sets of lightweight seat cushion test samples according to the specification in Title 14 Code of Federal Regulations Part 25.853 (c) Appendix F Part II (herein referred to as Appendix F Part II). The tests were run to determine if seat materials that exceed the current laboratory-scale, weight loss criteria performed better or worse than standard materials under realistic full-scale conditions. In addition, if it was determined that the full-scale fire hazards were less than the levels generated by traditional fire-blocked seats, then new laboratory test criteria would be developed for the lightweight seat cushion materials.

1.2 BACKGROUND.

The current fire test standard for aircraft seating materials described in Appendix F Part II was implemented in 1987, affecting all transport category aircraft having 20 seats or greater. The standard consists of a laboratory test in which a mock-up seat cushion is exposed to an intense 1800^{o}F oil-fired burner flame for a period of 2 minutes. The test method was based on the results of realistic full-scale tests that used a mock-up, wide-body cabin fuselage adjacent to a fuel pan fire, which simulated a postcrash cabin fire [1, 2, and 3]. There are two main criteria for acceptance of the seat material: burn length and percentage weight loss. The burn length requirement specifies a maximum of 17 inches across any face of the 18-inch-wide bottom or back cushion surfaces. In addition, the percentage weight loss of the cushions must not exceed 10%, which is calculated by measuring the before- and after-test weights, and dividing the difference by the before-test weight, expressed as a percentage. Historically, the airframe and seat manufacturers have met these performance requirements by using urethane foam encapsulated in a thin, fire-resistant blocking material that prevents or minimizes the amount of urethane foam that becomes involved during a fire. Many blocking- and outer-dress cover materials are capable of meeting these performance criteria, with final selection depending on other factors such as weight, durability, and expense. In recent years, foam cushions have been developed and employed that meet the weight loss criteria without the need for a fire-blocking layer.

Federal Aviation Administration (FAA) flammability requirements are based on the available materials and technology during the time period in which they are being developed. In the case of aircraft seating, the FAA test method was established using seats composed of urethane foam with a fire-blocking layer, which is still the most widely used seat material combination in the commercial aviation industry today. However, recent technological advancements in materials manufacturing have provided the aircraft seating industry with an array of materials that are much lighter than the traditional combination of urethane foam and fire-blocking layer, yet they can perform similarly in terms of fire resistance. As a result, a number of new, very lightweight seat concepts have emerged, which have the potential to supplant traditional seat materials.

As technological advancements are made in the field of commercial aviation, the FAA is often tasked to conduct research to review the applicability of the regulations to reflect the changing times. The International Aircraft Materials Fire Test Working Group was chartered in 1989 to work jointly with the aerospace community on these types of issues as they relate to the fire testing and certification of commercial transport aircraft interior materials [4]. The working group is chaired and administered by the Fire Safety Branch at the FAA William J. Hughes Technical Center. Among other things, the working group meets three times a year to investigate new problems that exist with current FAA test methods. The subject of the applicability of the current weight loss criteria for seat materials was originally discussed at a working group meeting in June 2002. Under consideration is whether the new generation of very lightweight materials will necessitate an adjustment of the FAA-mandated weight loss acceptance criteria, since they typically exceed the maximum 10% weight loss due to their lightweight construction. Although many of the new lightweight materials are as fire-resistant as traditional ones, the manufacturers claim the lighter materials are unfairly susceptible to the current weight loss criteria, which was originally based on heavier, urethane foam and fire-blocking materials. At 10% weight loss, a traditional 5-pound seat can lose up to 0.5 pound of mass, and a new generation seat weighing only 3 pounds will exceed the weight loss criteria by losing the same 0.5 pound (16.67% weight loss). The seat manufacturers contend that, although the lighter materials do not meet the weight loss criteria, they are no more flammable than a traditional seat under actual cabin fire conditions. As a result of the manufacturers' perspective, the FAA decided to open more formal discussions on the applicability of the original weight loss criteria to very lightweight seat cushions.

During the June 2002 working group meeting in Toulouse, France, the FAA agreed in principle to evaluate the performance of lightweight seat materials under realistic full-scale conditions. This decision was based on one manufacturer's request to review their specific lightweight seating material. The FAA initially advised the prospective applicant and working group meeting participants that a laboratory and accompanying full-scale test could be run on a specific material combination, allowing the possibility of a weight loss exemption based on the full-scale results. However, it was not the intent of the FAA to continually run full-scale tests every time a newer, lighter material became available.

Consequently, during the subsequent October 2002 working group meeting in Ottawa, the interested parties proposed a more general investigation of the suitability of the current weight loss criteria. The FAA agreed to conduct tests to evaluate the applicability of the current weight loss criteria rather than to evaluate a specific manufacturer's exact material configuration, and manufacturers were invited to participate in the research and submit cushion sets (back and bottom) for evaluation. Moreover, manufacturers were encouraged to submit more than one type of design configuration to make the assessment more comprehensive.

2. DISCUSSION.

To substantiate claims that some lightweight seat materials can be as fire-resistant as traditional materials, a series of laboratory tests were conducted in accordance with the fire test standard for seat materials, described in Appendix F Part II. Tests were performed on a traditional urethane foam, fire-blocked set of cushions to establish baseline data and on the various combinations of seat materials that were supplied by the manufacturers and classified as lightweight. Lightweight materials that exceeded the 10% weight loss criteria, but met the burn length requirements, were eligible for a full-scale test evaluation. During the full-scale evaluation, the identical materials were tested under more realistic conditions that were representative of an actual cabin fire during an accident.

Three manufacturers participated in the tests. Each manufacturer supplied 18 complete sets (back and bottom) of test cushions for each particular material configuration. Six sets were randomly chosen for the laboratory-scale (oil burner) test, and the remaining 12 sets were used for the full-scale test, if they met the burn length requirement but exceeded the weight loss criteria. Since one of the manufacturers supplied two complete sets of dissimilar configurations, a total of four lightweight systems were evaluated. The geometry of each test cushion was identical to that specified by the FAA certification test; i.e., the seat cushion back specimen measured 25 by 18 by 2 inches and the bottom specimen measured 20 by 18 by 4 inches.

3. LABORATORY-SCALE TESTS.

During the initial baseline test, a set of fire-blocked urethane foam cushions was fabricated with fire-retardant foam encapsulated in a polybenzimidazole (PBI) felt. The PBI felt had a weight per area of 290 g/m^2, and the assembly was finished with a 90% wool, 10% polyamide (nylon) dress cover. The foam density was calculated at 2.7 pounds per cubic foot, which resulted in a total assembly weight of approximately 5.33 pounds for the completed set of cushions (bottom and back). Six tests were run on this combination, which resulted in an average weight loss of 7.96% (table 1).

Since it was extremely difficult to obtain an accurate measurement of the posttest weight of the individual cushion components, the percent weight loss was not calculated individually for the cushion and the cover, but rather as an assembly only.

Similar tests were conducted on all lightweight cushions submitted, with each configuration tested six times. All lightweight configurations met the burn length requirement, yet failed the weight loss criteria, making them all eligible for full-scale tests (tables 2 through 5). The test results from all lightweight materials are also displayed graphically in figures 1 through 4. None of the lightweight configurations used a blocking layer, and all used wool/polyamide dress covers in the range of 375 to 380 g/m^2.

Table 1. Laboratory Test Results of Baseline Seat Cushion

Test Number	Item	Initial Weight (lb)	Initial Weight (g)	Final Weight (lb)	Final Weight (g)	Weight Loss (%)
Set 1*	Bottom Cushion	2.25	1020.6	NR	NR	NC
	Bottom Dress Cover	0.75	340.2	NR	NR	NC
	Back Cushion	1.48	671.3	NR	NR	NC
	Back Dress Cover	0.78	353.8	NR	NR	NC
	Total	5.26	2385.9	4.94	2242.1	6.03
Set 2*	Bottom Cushion	2.25	1020.6	NR	NR	NC
	Bottom Dress Cover	0.75	340.2	NR	NR	NC
	Back Cushion	1.48	671.3	NR	NR	NC
	Back Dress Cover	0.78	353.8	NR	NR	NC
	Total	5.26	2385.9	4.81	2182.2	8.54
Set 3*	Bottom Cushion	2.25	1020.6	NR	NR	NC
	Bottom Dress Cover	0.75	340.2	NR	NR	NC
	Back Cushion	1.48	671.3	NR	NR	NC
	Back Dress Cover	0.78	353.8	NR	NR	NC
	Total	5.26	2385.9	4.73	2146.4	10.04
Set 4**	Bottom Cushion	2.19	993.4	NR	NR	NC
	Bottom Dress Cover	0.72	326.6	NR	NR	NC
	Back Cushion	1.47	666.8	NR	NR	NC
	Back Dress Cover	0.78	353.8	NR	NR	NC
	Total	5.16	2340.5	4.75	2154.6	7.95
Set 5**	Bottom Cushion	2.19	993.4	NR	NR	NC
	Bottom Dress Cover	0.72	326.6	NR	NR	NC
	Back Cushion	2.08	943.5	NR	NR	NC
	Back Dress Cover	0.78	353.8	NR	NR	NC
	Total	5.77	2617.2	5.35	2426.7	7.28
Set 6**	Bottom Cushion	2.21	1002.4	NR	NR	NC
	Bottom Dress Cover	0.80	362.9	NR	NR	NC
	Back Cushion	1.50	680.4	NR	NR	NC
	Back Dress Cover	0.78	353.8	NR	NR	NC
	Total	5.29	2399.5	4.87	2209.0	7.94
Average	Bottom Cushion % Weight Loss Average					NC
	Bottom Dress Cover % Weight Loss Average					NC
	Back Cushion % Weight Loss Average					NC
	Back Dress Cover % Weight Loss Average					NC
	Total % Weight Loss Average					7.96

* Seam facing towards the fire
**Seam facing away from fire
NR - Not Recorded
NC - Not Calculated

Table 2. Laboratory Test Results of Lightweight Seat Cushion A

Test Number	Item	Initial Weight (lb)	Initial Weight (g)	Final Weight (lb)	Final Weight (g)	Weight Loss (%)
Set 1*	Bottom Cushion 2/18	0.55	250.1	0.49	221.2	11.56
	Bottom Dress Cover 2/18	0.71	323.0	0.54	243.1	24.74
	Back Cushion 3/18	0.42	190.1	0.42	190.1	0.00
	Back Dress Cover 3/18	0.77	349.0	0.63	284.6	18.45
	Total	2.45	1112.2	2.07	939.0	15.54
Set 2*	Bottom Cushion 11/18	0.54	244.1	0.47	211.1	13.52
	Bottom Dress Cover 11/18	0.69	315.0	0.52	235.0	25.40
	Back Cushion 6/18	0.41	184.5	0.41	184.3	0.11
	Back Dress Cover 6/18	0.75	340.4	0.62	281.3	17.36
	Total	2.39	1084.0	2.01	911.7	15.90
Set 3*	Bottom Cushion 10/18	0.54	244.0	0.49	220.0	9.84
	Bottom Dress Cover 10/18	0.69	315.1	0.50	226.7	28.05
	Back Cushion 7/18	0.41	184.5	0.41	184.1	0.22
	Back Dress Cover 7/18	0.75	340.4	0.57	258.3	24.12
	Total	2.39	1084.0	1.96	889.1	17.99
Set 4**	Bottom Cushion 7/18	0.54	245.0	0.44	197.6	19.35
	Bottom Dress Cover 7/18	0.70	316.4	0.42	191.6	39.44
	Back Cushion 5/18	0.41	185.3	0.35	160.4	13.44
	Back Dress Cover 5/18	0.75	341.9	0.59	269.7	21.12
	Total	2.40	1088.6	1.81	819.3	24.71
Set 5**	Bottom Cushion 4/18	0.54	245.9	0.50	228.3	7.16
	Bottom Dress Cover 4/18	0.70	317.5	0.49	223.0	29.76
	Back Cushion 2/18	0.41	185.9	0.40	181.1	2.58
	Back Dress Cover 2/18	0.76	343.0	0.59	265.8	22.51
	Total	2.41	1092.3	1.98	898.2	17.84
Set 6**	Bottom Cushion 6/18	0.54	245.0	0.48	215.8	11.92
	Bottom Dress Cover 6/18	0.70	316.5	0.49	221.2	30.11
	Back Cushion 4/18	0.41	185.5	0.41	185.5	0.00
	Back Dress Cover 4/18	0.75	342.0	0.64	291.0	14.91
	Total	2.40	1089.0	2.02	913.5	16.04
Average	Bottom Cushion % Weight Loss Average					12.22
	Bottom Dress Cover % Weight Loss Average					29.58
	Back Cushion % Weight Loss Average					2.72
	Back Dress Cover % Weight Loss Average					19.75
	Total % Weight Loss Average					18.00

* Wear fabric surface facing away from fire
**Wear fabric surface facing towards fire

Table 3. Laboratory Test Results of Lightweight Seat Cushion B

Test Number	Item	Initial Weight (lb)	Initial Weight (g)	Final Weight (lb)***	Final Weight (g)	Weight Loss (%)
Set 1*	Bottom Cushion	1.86	842.4	1.45	656.2	22.10
	Bottom Dress Cover	0.74	333.4	0.52	236.3	29.12
	Back Cushion	1.19	539.6	0.97	438.3	18.77
	Back Dress Cover	0.78	353.1	0.72	326.8	7.45
	Total	4.56	2068.5	4.06	1657.6	10.96
Set 2*	Bottom Cushion	1.83	829.3	1.43	647.9	21.87
	Bottom Dress Cover	0.74	333.9	0.53	242.0	27.52
	Back Cushion	1.18	534.4	1.02	463.1	13.34
	Back Dress Cover	0.78	355.4	0.72	324.9	8.58
	Total	4.54	2053.0	4.01	1677.9	11.67
Set 3*	Bottom Cushion	1.83	832.1	1.46	662.7	20.36
	Bottom Dress Cover	0.74	334.4	0.50	228.0	31.82
	Back Cushion	1.15	520.5	0.98	443.1	14.87
	Back Dress Cover	0.78	354.5	0.62	279.0	21.30
	Total	4.50	2041.5	3.98	1612.8	11.56
Set 4**	Bottom Cushion	1.86	844.0	1.50	680.6	19.36
	Bottom Dress Cover	0.74	336.2	0.57	259.2	22.90
	Back Cushion	1.15	523.5	0.93	422.9	19.22
	Back Dress Cover	0.78	353.6	0.67	305.3	13.66
	Total	4.55	2057.3	3.98	1668.0	12.53
Set 5**	Bottom Cushion	1.86	842.7	1.48	671.1	20.36
	Bottom Dress Cover	0.74	333.6	0.56	251.9	24.49
	Back Cushion	1.18	535.9	0.94	425.3	20.64
	Back Dress Cover	0.78	354.2	0.68	307.3	13.24
	Total	4.58	2066.4	4.02	1655.6	12.23
Set 6**	Bottom Cushion	1.83	828.9	1.41	640.8	22.69
	Bottom Dress Cover	0.74	333.8	0.52	237.8	28.76
	Back Cushion	1.17	530.5	0.92	417.3	21.34
	Back Dress Cover	0.78	354.7	0.67	303.7	14.38
	Total	4.52	2047.9	3.90	1599.6	13.72
Average	Bottom Cushion % Weight Loss Average					21.13
	Bottom Dress Cover % Weight Loss Average					27.44
	Back Cushion % Weight Loss Average					18.03
	Back Dress Cover % Weight Loss Average					13.10
	Total % Weight Loss Average					12.11

* Wear fabric surface facing away from fire

**Wear fabric surface facing towards fire

***Measured final weight does not typically equal the sum of the individual components, since some of the burned materials fall away prior to measurement.

Table 4. Laboratory Test Results of Lightweight Seat Cushion C

Test Number	Item	Initial Weight (lb)	Initial Weight (g)	Final Weight (lb)	Final Weight (g)	Weight Loss (%)
Set 1*	Bottom Cushion	1.48	670.0	1.14	517.1	22.82
	Bottom Dress Cover	0.56	255.0	0.42	190.5	25.29
	Back Cushion	1.05	475.0	0.96	435.4	8.33
	Back Dress Cover	0.60	270.0	0.55	249.5	7.60
	Total	3.68	1670.0	3.07	1392.5	16.62
Set 2**	Bottom Cushion	1.46	660.0	1.26	571.5	13.41
	Bottom Dress Cover	0.55	250.0	0.43	195.0	21.98
	Back Cushion	1.06	480.0	1.00	453.6	5.50
	Back Dress Cover	0.57	260.0	0.54	244.9	5.79
	Total	3.64	1650.0	3.23	1465.1	11.21
Set 3*	Bottom Cushion	1.46	660.0	1.29	585.1	11.34
	Bottom Dress Cover	0.54	245.0	0.45	204.1	16.69
	Back Cushion	1.06	480.0	0.99	449.1	6.45
	Back Dress Cover	0.60	270.0	0.55	249.5	7.60
	Total	3.65	1655.0	3.28	1487.8	10.10
Set 4*	Bottom Cushion	1.46	660.0	1.25	567.0	14.09
	Bottom Dress Cover	0.54	245.0	0.42	190.5	22.24
	Back Cushion	0.95	430.0	0.90	408.2	5.06
	Back Dress Cover	0.57	260.0	0.53	240.4	7.54
	Total	3.52	1595.0	3.10	1406.1	11.84
Set 5*	Bottom Cushion	1.42	645.0	1.24	562.5	12.80
	Bottom Dress Cover	0.55	250.0	0.42	190.5	23.80
	Back Cushion	1.05	475.0	1.00	453.6	4.51
	Back Dress Cover	0.58	265.0	0.55	249.5	5.86
	Total	3.60	1635.0	3.21	1456.0	10.95
Set 6*	Bottom Cushion	1.44	655.0	1.24	562.5	14.13
	Bottom Dress Cover	0.55	250.0	0.44	199.6	20.17
	Back Cushion	1.03	465.0	1.00	453.6	2.45
	Back Dress Cover	0.58	265.0	0.53	240.4	9.28
	Total	3.60	1635.0	3.21	1456.0	10.95
Average	Bottom Cushion % Weight Loss Average					14.77
	Bottom Dress Cover % Weight Loss Average					21.69
	Back Cushion % Weight Loss Average					5.38
	Back Dress Cover % Weight Loss Average					7.28
	Total % Weight Loss Average					11.94

*Blue cotton fabric surface facing away from fire
**Blue cotton fabric surface facing towards fire on back cushion only

Table 5. Laboratory Test Results of Lightweight Seat Cushion D

Test Number	Item	Initial Weight (lb)	Initial Weight (g)	Final Weight (lb)	Final Weight (g)	Weight Loss (%)
Set 1	Bottom Cushion	1.01	460.0	0.86	390.1	15.20
	Bottom Dress Cover	0.55	250.0	0.42	190.5	23.80
	Back Cushion	0.80	365.0	0.76	344.7	5.55
	Back Dress Cover	0.60	270.0	0.53	240.4	10.96
	Total	2.97	1345.0	2.57	1165.7	13.33
Set 2	Bottom Cushion	0.98	445.0	0.82	371.9	16.42
	Bottom Dress Cover	0.55	250.0	0.41	186.0	25.61
	Back Cushion	0.79	360.0	0.75	340.2	5.50
	Back Dress Cover	0.58	265.0	0.54	244.9	7.57
	Total	2.91	1320.0	2.52	1143.0	13.41
Set 3	Bottom Cushion	0.99	450.0	0.83	376.5	16.34
	Bottom Dress Cover	0.54	245.0	0.40	181.4	25.94
	Back Cushion	0.83	375.0	0.78	353.8	5.65
	Back Dress Cover	0.58	265.0	0.53	240.4	9.28
	Total	2.94	1335.0	2.54	1152.1	13.70
Set 4	Bottom Cushion	0.99	450.0	0.84	381.0	15.33
	Bottom Dress Cover	0.54	245.0	0.40	181.4	25.94
	Back Cushion	0.83	375.0	0.78	353.8	5.65
	Back Dress Cover	0.58	265.0	0.52	235.9	10.99
	Total	2.94	1335.0	2.54	1152.1	13.70
Set 5	Bottom Cushion	1.00	455.0	0.83	376.5	17.26
	Bottom Dress Cover	0.56	255.0	0.40	181.4	28.85
	Back Cushion	0.83	375.0	0.80	362.9	3.23
	Back Dress Cover	0.57	260.0	0.55	249.5	4.05
	Total	2.97	1345.0	2.58	1170.3	12.99
Set 6	Bottom Cushion	0.99	450.0	0.85	385.6	14.32
	Bottom Dress Cover	0.55	250.0	0.41	186.0	25.61
	Back Cushion	0.84	380.0	0.78	353.8	6.89
	Back Dress Cover	0.58	265.0	0.53	240.4	9.28
	Total	2.97	1345.0	2.57	1165.7	13.33
Average	Bottom Cushion % Weight Loss Average					15.81
	Bottom Dress Cover % Weight Loss Average					25.96
	Back Cushion % Weight Loss Average					5.42
	Back Dress Cover % Weight Loss Average					8.69
	Total % Weight Loss Average					13.41

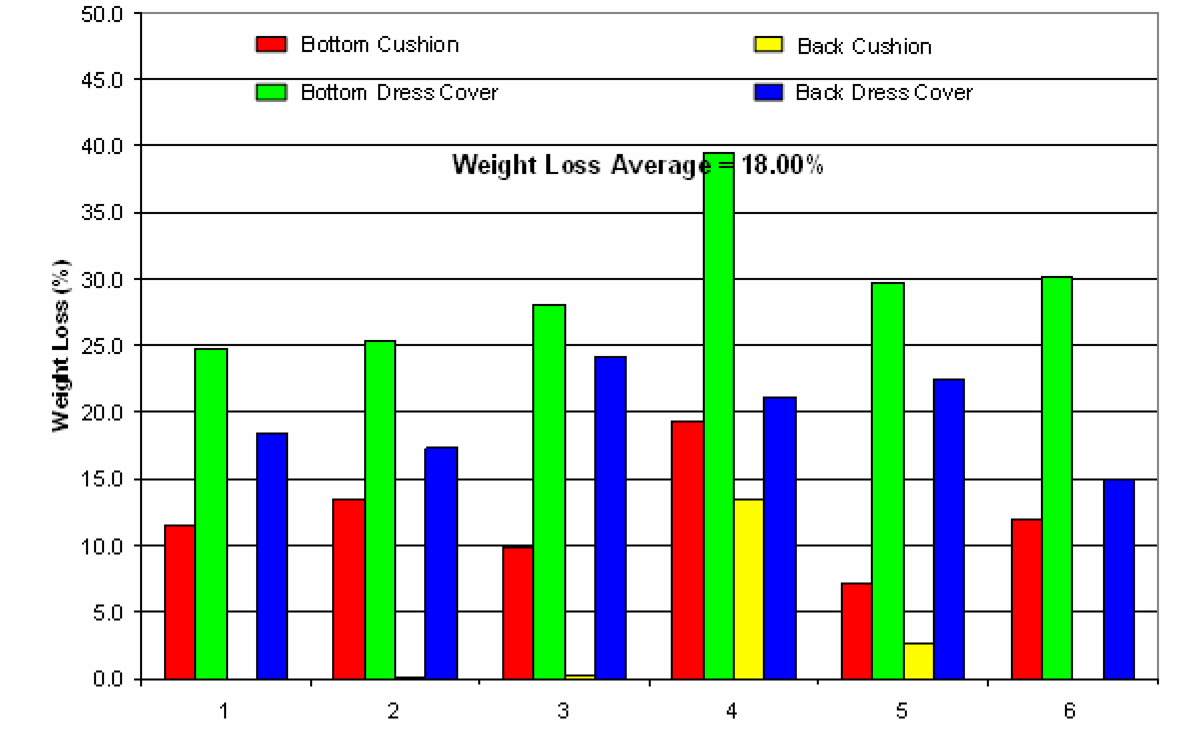

Figure 1. Laboratory Test Results of Lightweight Seat Cushion A

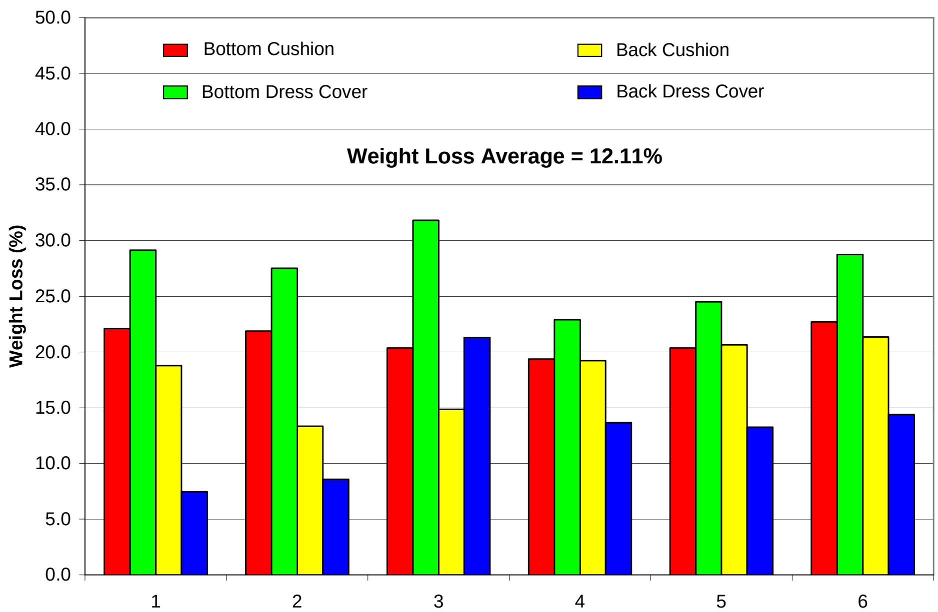

Figure 2. Laboratory Test Results of Lightweight Seat Cushion B

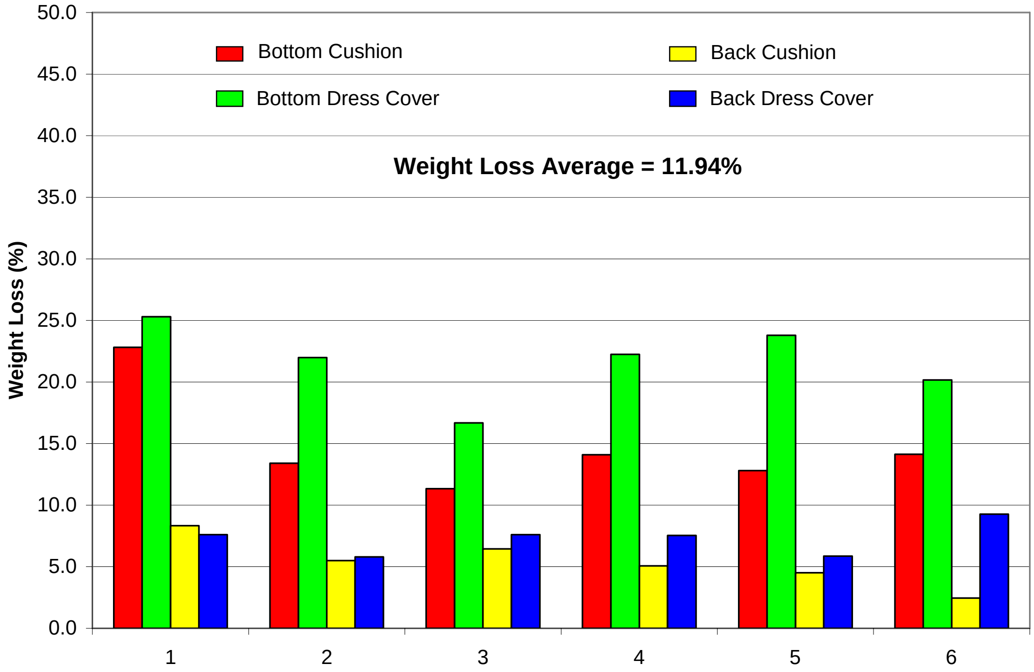

Figure 3. Laboratory Test Results of Lightweight Seat Cushion C

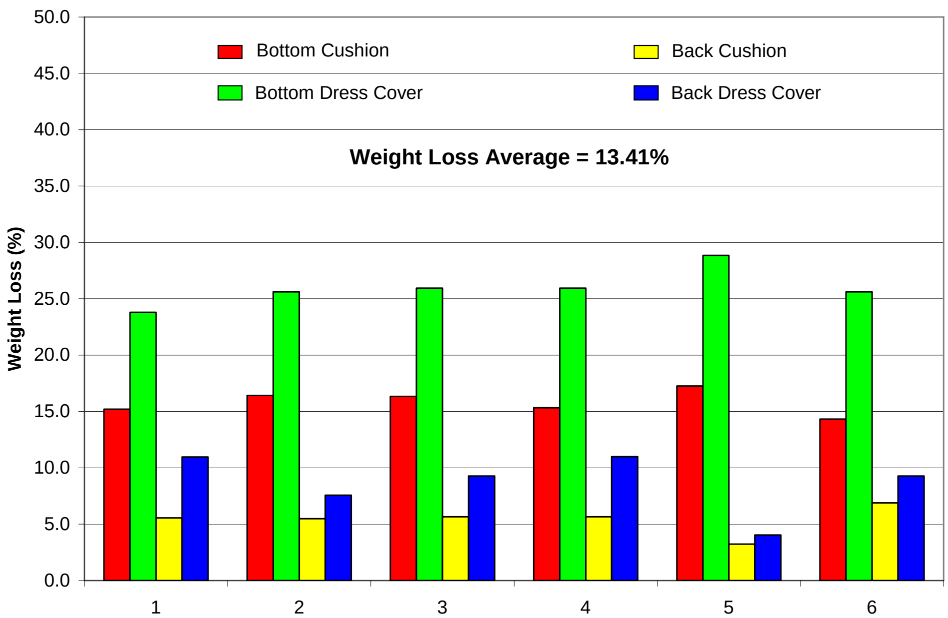

Figure 4. Laboratory Test Results of Lightweight Seat Cushion D

4. ANALYSIS OF LABORATORY-SCALE TESTS.

As shown in tables 2 through 5, all lightweight configurations clearly exceeded the 10% maximum allowable weight loss, with values ranging from 11.94% to 18.00%, compared to the traditional fire-blocked urethane configuration, which produced a weight loss of only 7.96%. Of interest is that the heaviest of the lightweight configurations (lightweight B, 4.55 lb) yielded only 12.11% weight loss, nearly the lowest of the four, and the lightest configuration (lightweight A, 2.4 lb) yielded the highest weight loss of 18.00%. This tends to support the manufacturers' initial claim that the lighter the cushion weight, the more biased the current requirement is.

As shown in figure 5, the bottom dress cover yielded a higher percentage of weight loss than the bottom cushion (foam) for all four lightweight configurations. Similarly, lightweight configurations A, C, and D also yielded higher percentages of weight loss for the back dress cover compared to the back cushion. This is noteworthy, indicating that in most cases the cushion material did not burn nearly as much as the dress cover, with the exception of lightweight configuration B. This evidence would also tend to support the manufacturers' claims that the lighter foam cushion has no more impact on the spread of fire than a heavier foam, but the full-scale tests would offer a more accurate assessment of this theory.

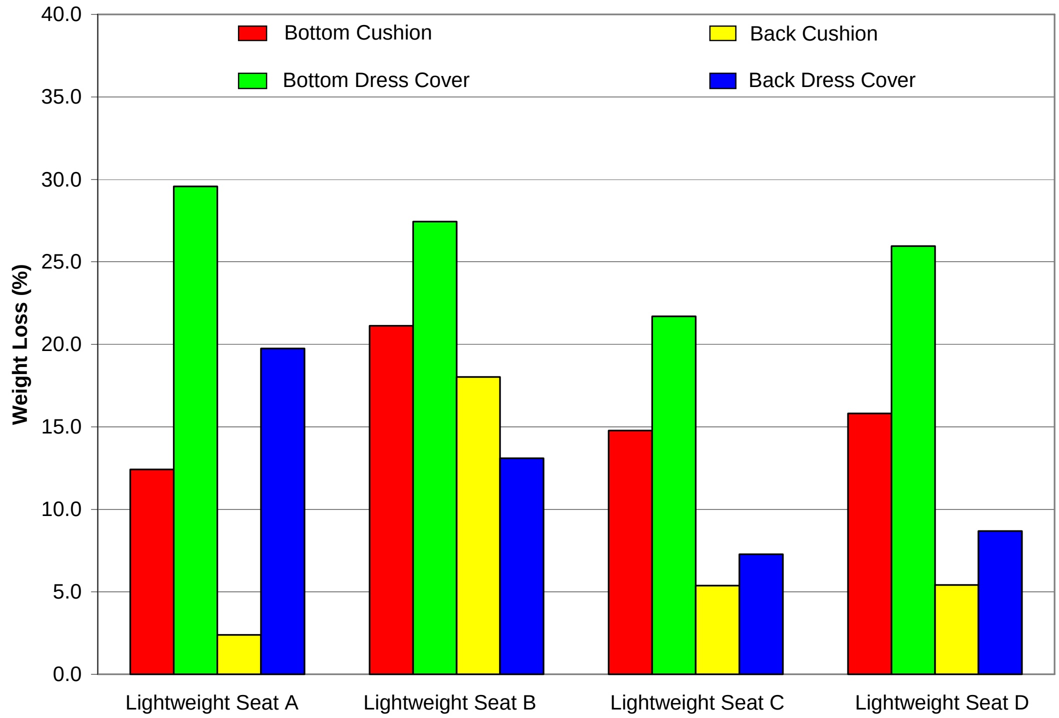

Figure 5. Laboratory Test Comparison of Lightweight Seats (6 Test Average)

5. FULL-SCALE TESTS.

In addition to the baseline fire-blocked cushion, a total of four different lightweight material configurations were tested in the laboratory. Each configuration met the burn length requirement as per Appendix F Part II, but failed for excess weight loss. All five seat configurations were also tested under realistic, full-scale conditions to allow for a more thorough assessment of their performance. This was accomplished by mocking-up the interior of a Boeing 707 test fuselage and igniting a pan of jet fuel that was situated adjacent to an opening, simulating a severe but survivable postcrash fire accident. During the full-scale tests, continuous measurements of the cabin atmosphere were taken to determine the level of hazards that would likely develop in an actual aircraft cabin fire event. The full-scale tests would determine if a material that failed the laboratory test (due to weight loss) exhibited a comparable level of performance to the traditional seating materials that met the weight loss requirement.

The B-707 test article was initially stripped of all interior components and fire-hardened to protect the aluminum structure. A steel barrel section was inserted into the existing fuselage to provide an indestructible test section to allow for repeated fires. The entire fuselage was fully instrumented with thermocouples, gas sampling stations, light transmissometers, and heat flux transducers. The 20-foot test section of the fuselage was mocked-up with interior honeycomb panels, carpeting, and four triple seats. The flat Nomex honeycomb panels were 0.25 inch thick with fiberglass face plies, met current heat release requirements, and were used to form ceiling panels, stow bin areas, and sidewall panels. The carpet used in the testing was typical aircraft grade and met the vertical Bunsen burner test, which is the current FAA requirement for floor coverings. The fire threat was an 8- by 10-foot fuel pan with 50 gallons of burning JP-8 fuel. A 40- by 80-inch opening was installed in the fuselage to simulate a small rupture, with a triple seat positioned directly in front of the opening (figure 6).

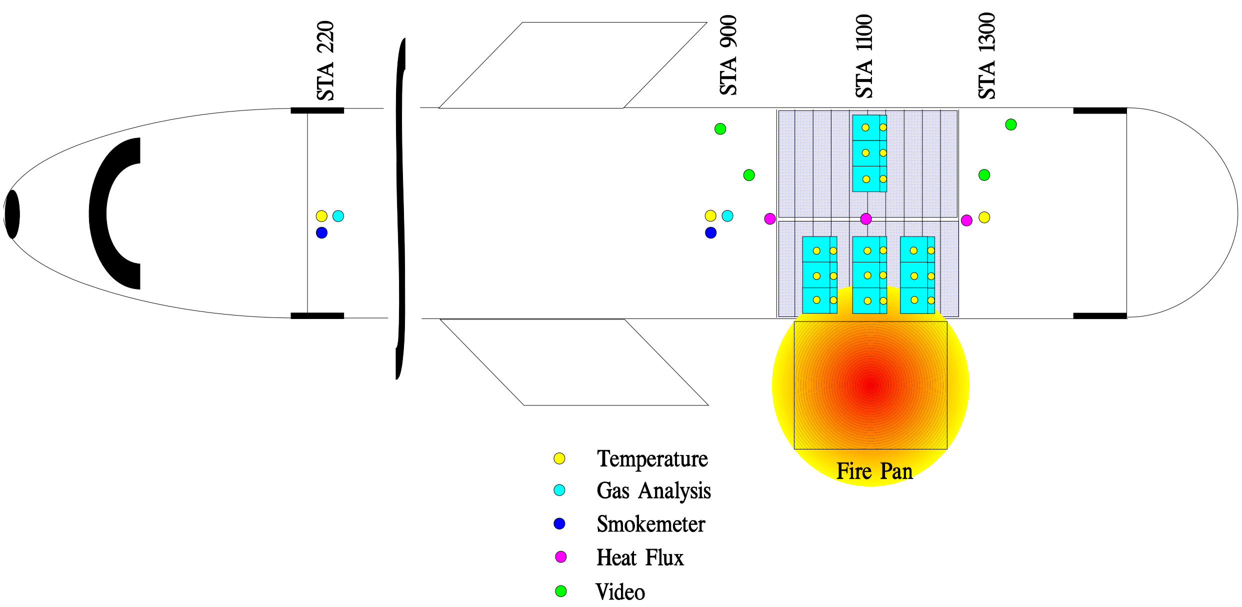

Figure 6. The B-707 Full-Scale Test Article

6. INSTRUMENTATION.

6.1 THERMOCOUPLES.

Three thermocouple trees were installed in the fuselage at station 220 (forward cabin), station 900 (mid cabin), and station 1300 (aft cabin). The station numbers represent approximate distances in inches from the nose of the airplane. Each tree consisted of a rigid steel tube with seven thermocouples placed at 1-foot increments from the floor to the ceiling, beginning with one placed at 1 foot above the floor. In addition, thermocouples were placed on the front surfaces of the bottom and back cushion of each of the 12 seats, for a total of 24 (figure 7). All thermocouples were Type K, chromel-alumel, with an open bead junction.

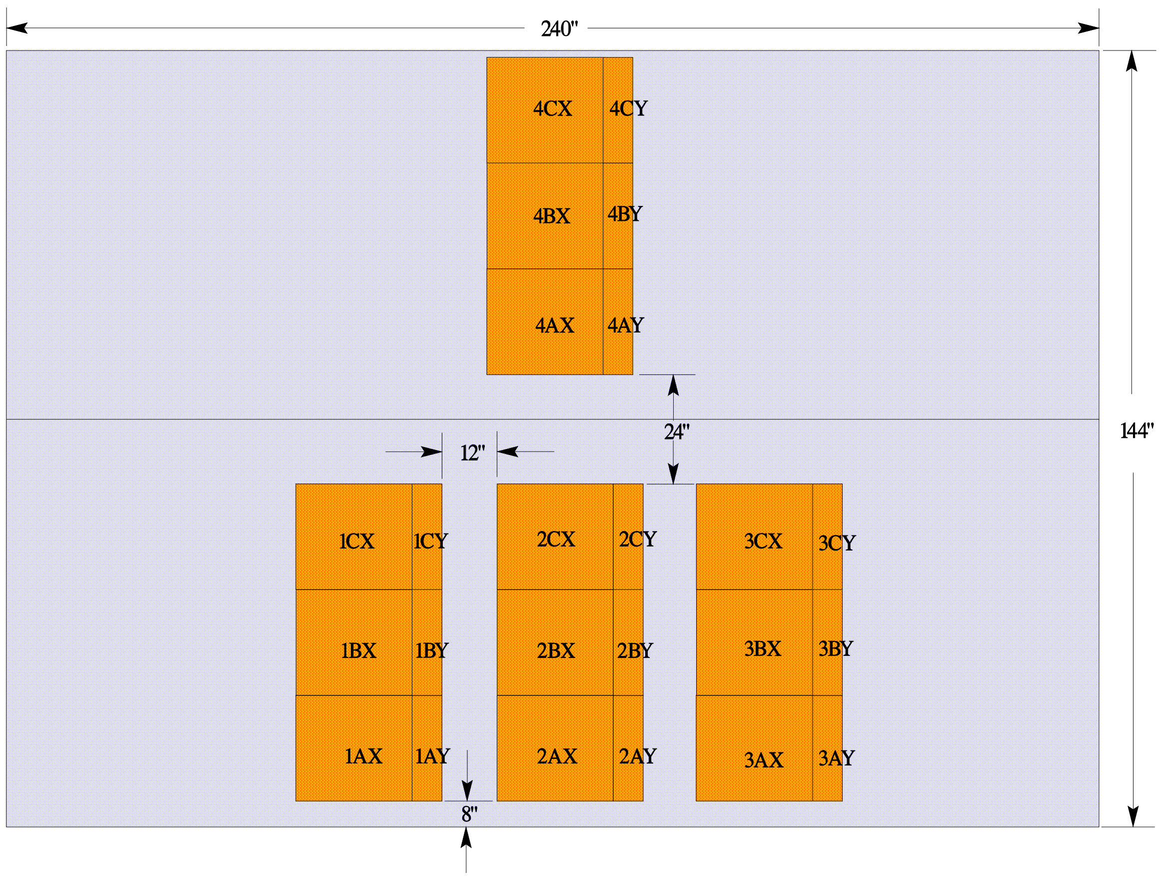

Figure 7. Location of Thermocouples on Seat Cushions

6.2 GAS SAMPLING.

Two gas-sampling stations were used to continuously monitor the cabin atmosphere. Each sampling station consisted of two intake ports, one situated 42 inches above floor level and the other at 66 inches above floor level, for a total of four intake ports. The forward ports were located at station 220, and the aft ports were located at station 900. Each intake stream was drawn through a rack of continuous Beckman-style 880A gas analyzers, which monitored for carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2). In-line filters were used to limit particulate matter from passing through the sensitive analyzers.

6.3 SMOKE METERS.

Smoke-monitoring stations were situated at cabin station 220 and 900 to determine the level of smoke during tests. Each station consisted of three meters situated at 18, 42, and 66 inches above the cabin floor. The meters consisted of a collimated light source in one end and a photocell in the other end. The light source was set at a distance of 12 inches from the photocell. At the beginning of the test, the voltage output of the photocell was recorded as a value of 100% light transmission. As the test progressed, the level of smoke obscured the amount of light traversing from the source to the photocell, and the voltage decreased proportionately. This metering system provided a continuous measurement of the level of smoke (light transmission) during the test.

6.4 HEAT FLUX.

Three heat flux transducers were located in the immediate vicinity of the test section. The transducers were mounted at a height of 42 inches above the floor. Each transducer is a water-cooled, Gardon gauge, total heat flux (radiant and convective) type. For added protection, the transducers are all housed in water-cooled jackets fabricated from copper cylinders. The center transducer was aimed directly out the fire door opening to monitor the intensity of the pan fire. This would ensure that identical fire conditions were generated during each test. The other two transducers were located along the fuselage centerline, one facing forward and the other facing aft, to monitor the growth and intensity of the burning cabin materials.

7. FULL-SCALE TEST RESULTS.

Following ignition of the fuel pan, the external fire would typically require 8 to 10 seconds before it started to penetrate the fuselage opening, thus impinging on the interior materials. The agreed-upon test approach was to allow the fire scenario sufficient time to reach a flashover condition, and then extinguish the external fire after approximately 1 minute. The pan fire was extinguished using aqueous film forming foam (AFFF), which was sprayed onto the pan surface via two pan-mounted nozzles. Gaseous CO_2 was subsequently flooded into the cabin to douse the interior fire and cool the atmosphere. The main objective of the tests was to quantify the severity of the fire for each material configuration based on cabin temperatures, heat flux levels, toxic gas emission, and the degree of flame spread across the seat materials. If the flashover condition was unabated, most of the materials would be consumed, resulting in reduced information available for analysis. By terminating the fire, a more in-depth analysis of the severity could be possible.

7.1 BASELINE CONFIGURATION.

During the initial baseline test, the fire progressed as expected, resulting in the onset of a flashover condition at approximately 270 seconds from test commencement. AFFF was applied to the fire pan at 330 seconds, and additional gaseous CO_2 was introduced at 390 seconds. Figures 8 through 20 contain the measured hazards as a function of time for this baseline test.

The seat-mounted thermocouples indicated an expected flame pattern, with temperatures highest on the surface of seat 2, which was located directly in the center of the fire door opening (figure 9). Seats 1 and 3, forward and aft of the fire door seat, respectively, also showed a predictable flame pattern, with the cushions closest to the fire (left side looking forward) indicating higher temperatures, followed by the middle cushions, and finally the right side cushions (figures 8 and 10). This pattern was anticipated, because the fire initiated on the cushions closest to the fire pan (left side), and propagated left to right across the cabin during the test. The temperatures on seat 4, across the aisle, indicated the fire was not able to traverse this space, illustrating the capability of the blocking layer at impeding the spread of fire (figure 11). This temperature data was useful in determining the degree of flame spread, because the cabin environment often becomes obscured and reduces the ability to observe the conditions from the interior cameras.

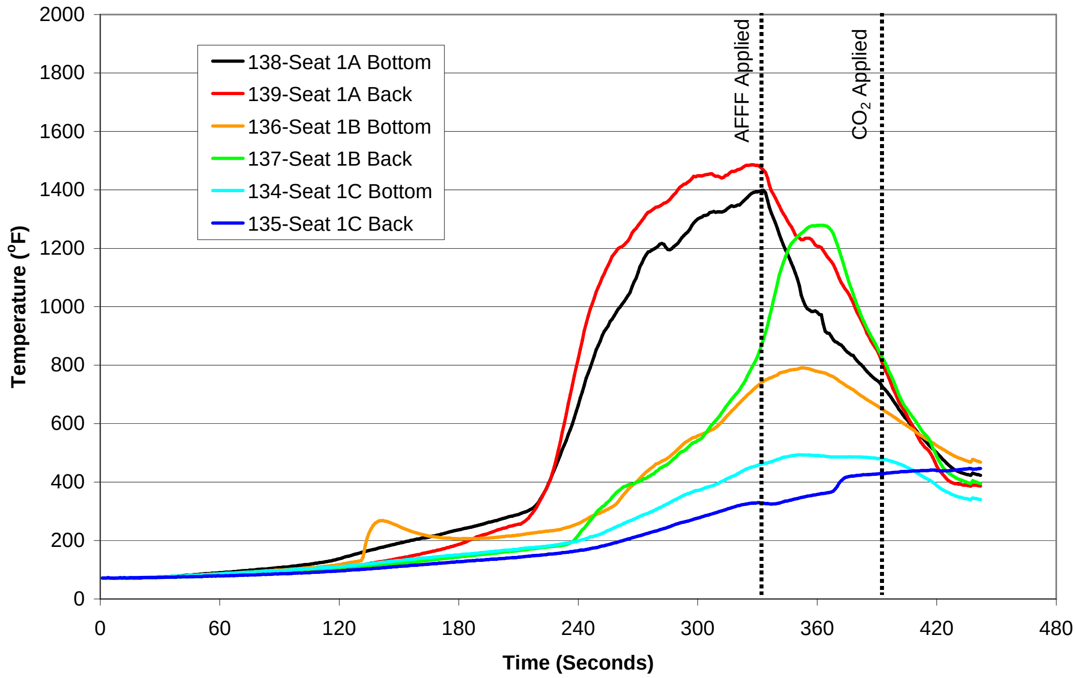

Figure 8. Baseline Configuration, Seat 1 Temperatures

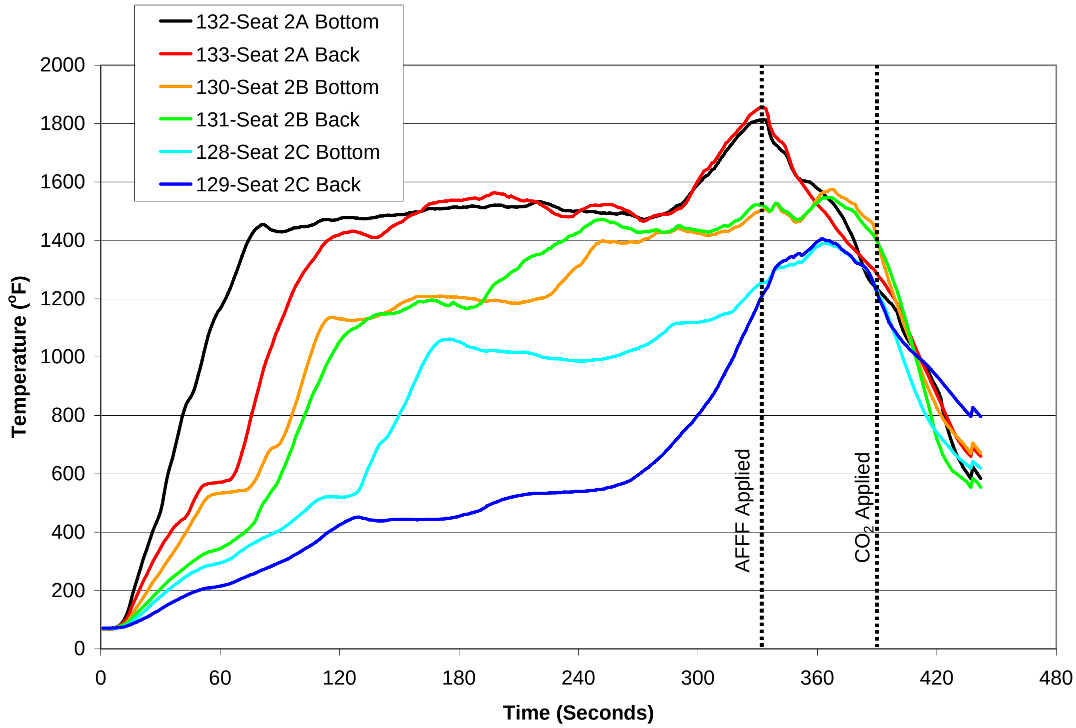

Figure 9. Baseline Configuration, Seat 2 Temperatures

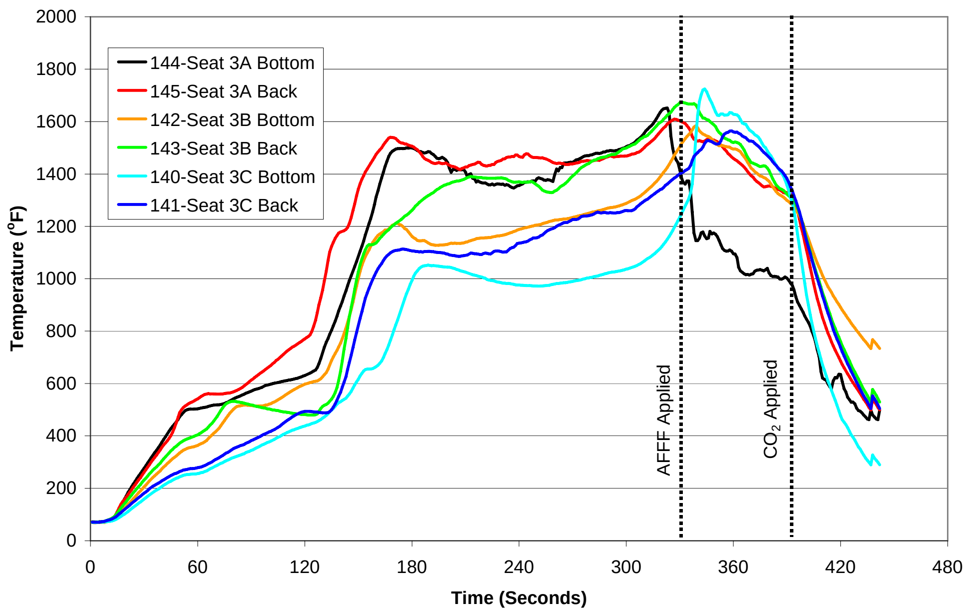

Figure 10. Baseline Configuration, Seat 3 Temperatures

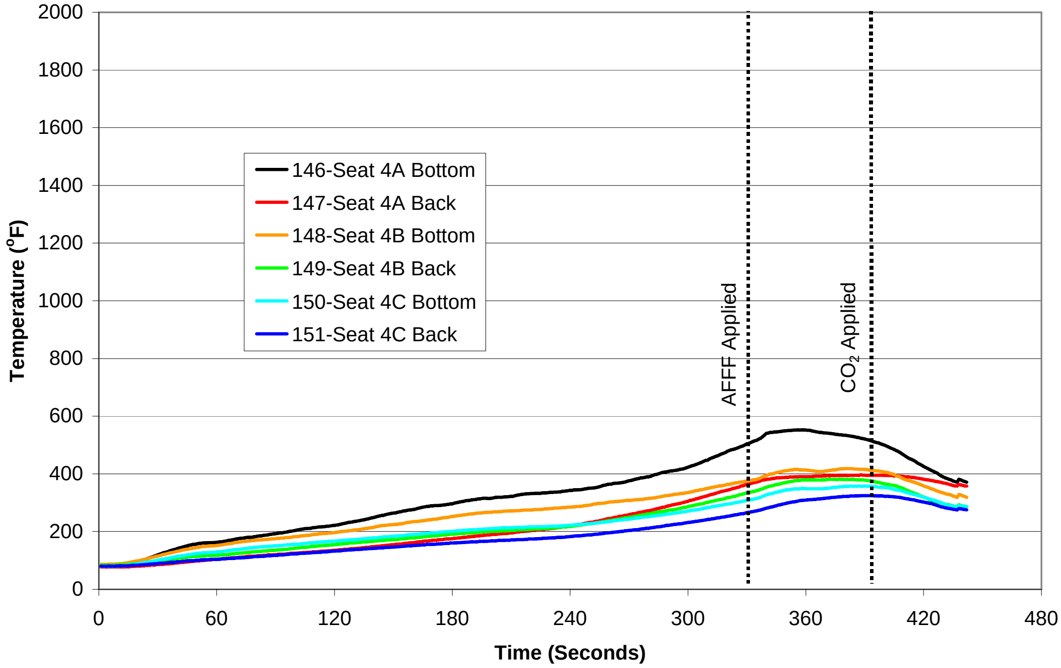

Figure 11. Baseline Configuration, Seat 4 Temperatures

The cabin temperatures at the forward thermocouple tree remained close to ambient conditions until approximately 120 seconds, at which time they increased steadily until the termination of the test (figure 12). The temperatures at the ceiling height just approached a level that would cause a passenger to become incapacitated (400°F) at the termination of the test. Temperatures at all other heights at the forward location were survivable for the duration of the test. Temperatures at the mid and aft thermocouple trees were predictably higher due to their closer proximity to the fire door. Although the temperatures at the 5-foot level and above were significantly higher at this location, the conditions remained survivable at the 4-foot height and below until test termination (figures 13 and 14). All temperature data indicated a very pronounced stratification of the cabin air for the duration of the test, with each location sustaining a higher temperature than the location below it.

The heat flux levels were typical of a fire of this magnitude, with the highest level obtained from the transducer aimed through the door directly at the pan fire (figure 15). The forward- and aft-facing heat flux transducers indicated a fairly symmetric fire, because both produced relatively similar traces.

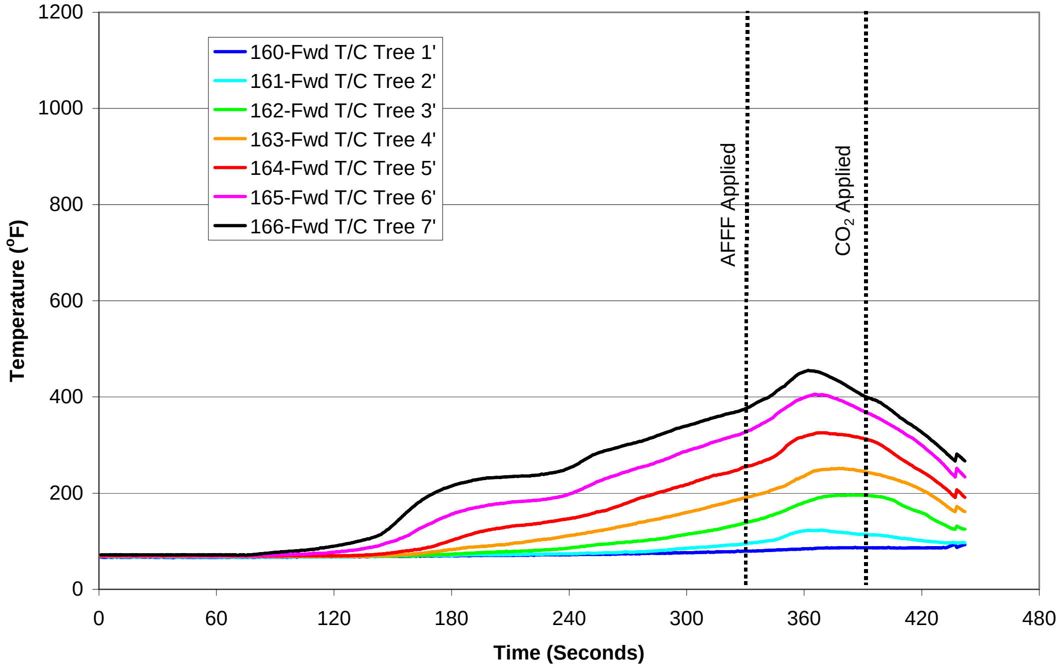

Figure 12. Baseline Configuration, Forward Cabin Temperatures

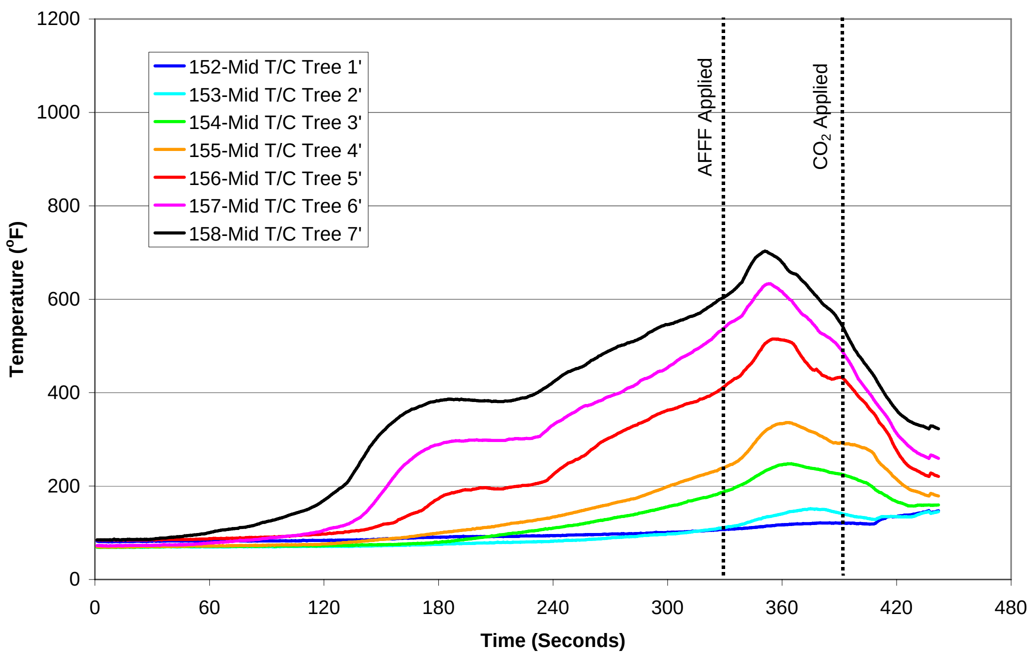

Figure 13. Baseline Configuration, Mid Cabin Temperatures

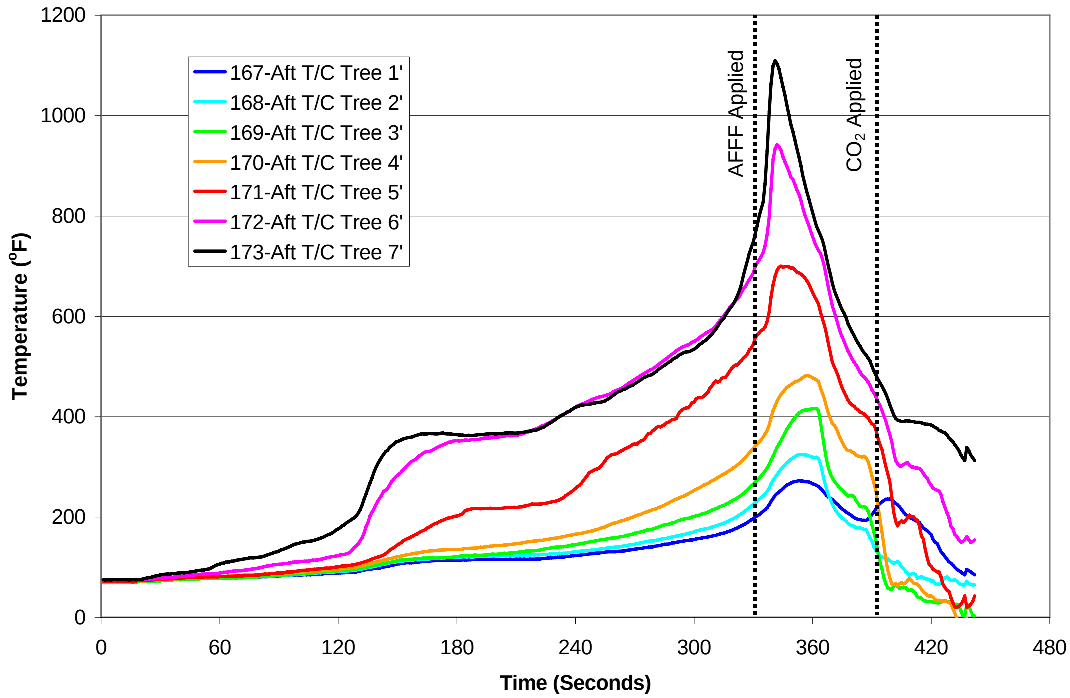

Figure 14. Baseline Configuration, Aft Cabin Temperatures

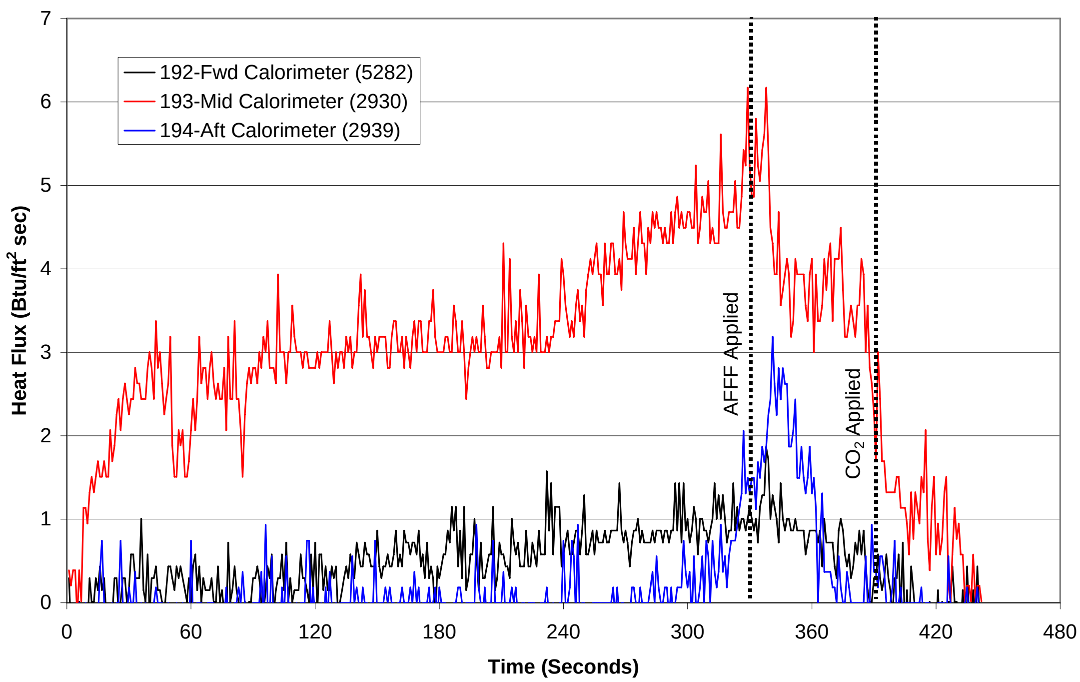

Figure 15. Baseline Configuration, Heat Flux Levels

The light transmissometers indicated a stratified cabin atmosphere with increasing levels of smoke at higher measuring locations. This concurred with the temperature data and suggested that hot smoke was present throughout the cabin at the higher locations, while a cooler and relatively smokeless environment existed during a majority of the test (figures 16 and 17). A comparison of the smoke levels at the two stations (forward and mid cabin) indicated slightly more smoke at the mid height, forward location. This suggests that the hot smoke layer initially rose over the light sensor located in close proximity to the fire, and then descended slightly as it progressed away from the immediate fire area toward the light sensor located in the forward cabin.

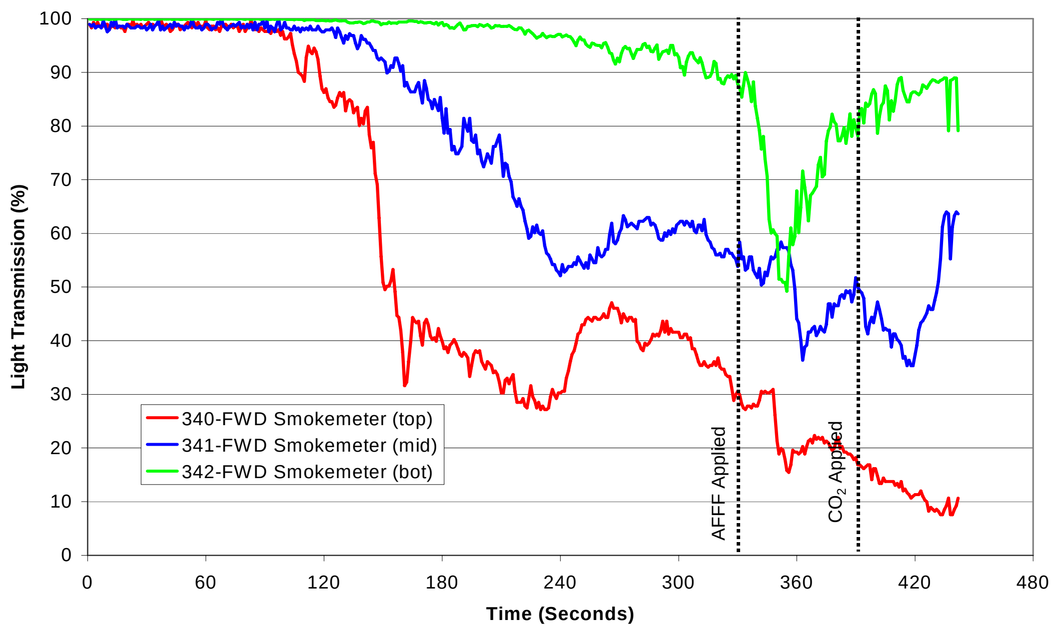

Figure 16. Baseline Configuration, Forward Cabin Smoke Levels

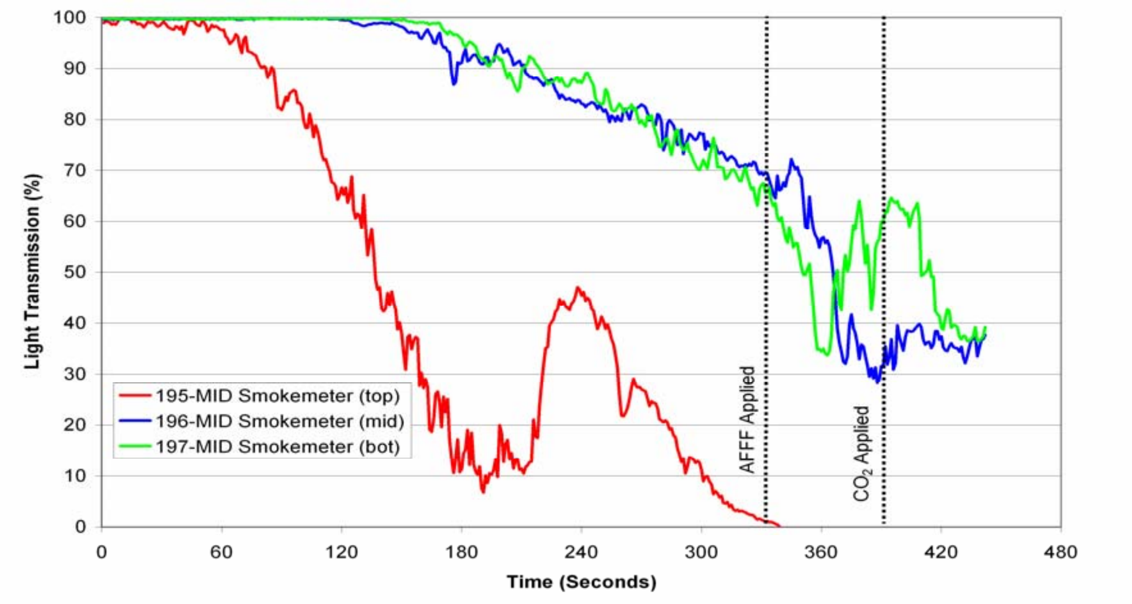

Figure 17. Baseline Configuration, Mid Cabin Smoke Levels

Continuous measurements of CO, CO_2, and O_2 are shown in figures 18, 19, and 20, respectively. CO, generally considered the most hazardous toxic gas produced by a fire, was relatively low for the duration of the test [5]. As shown in figure 18, the maximum level reached 0.38% at the termination of the test at 330 seconds. Considering a continuous level of 0.40% CO (4000 ppm) would not cause incapacitation until approximately 480 seconds, these values were not considered severe [6].

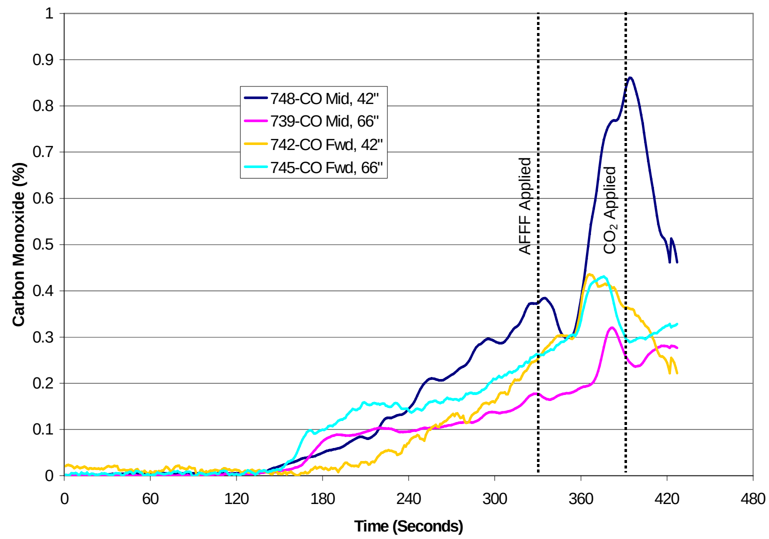

Figure 18. Baseline Configuration, CO Levels

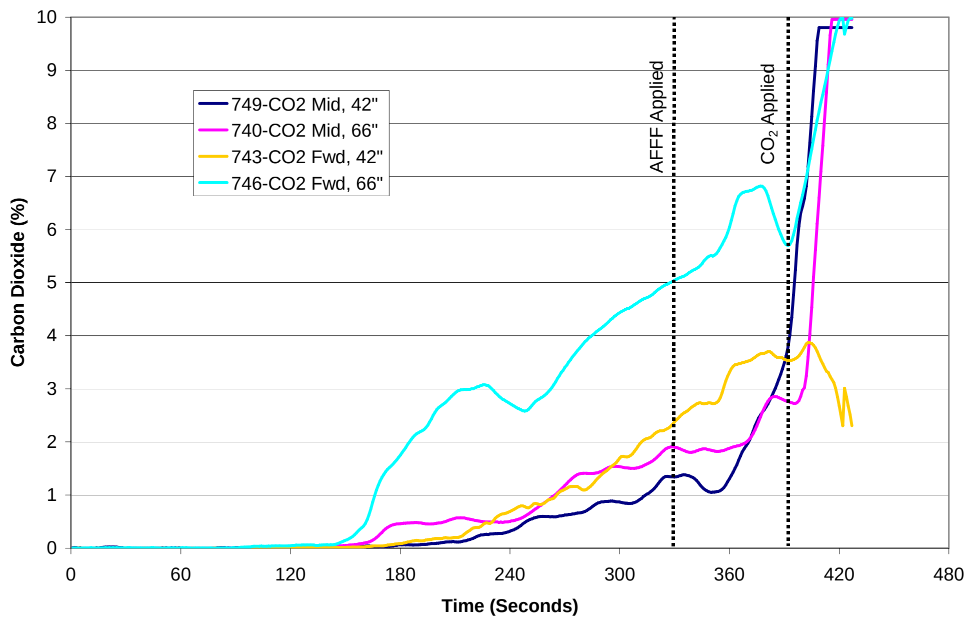

Figure 19. Baseline Configuration, CO_2 Levels

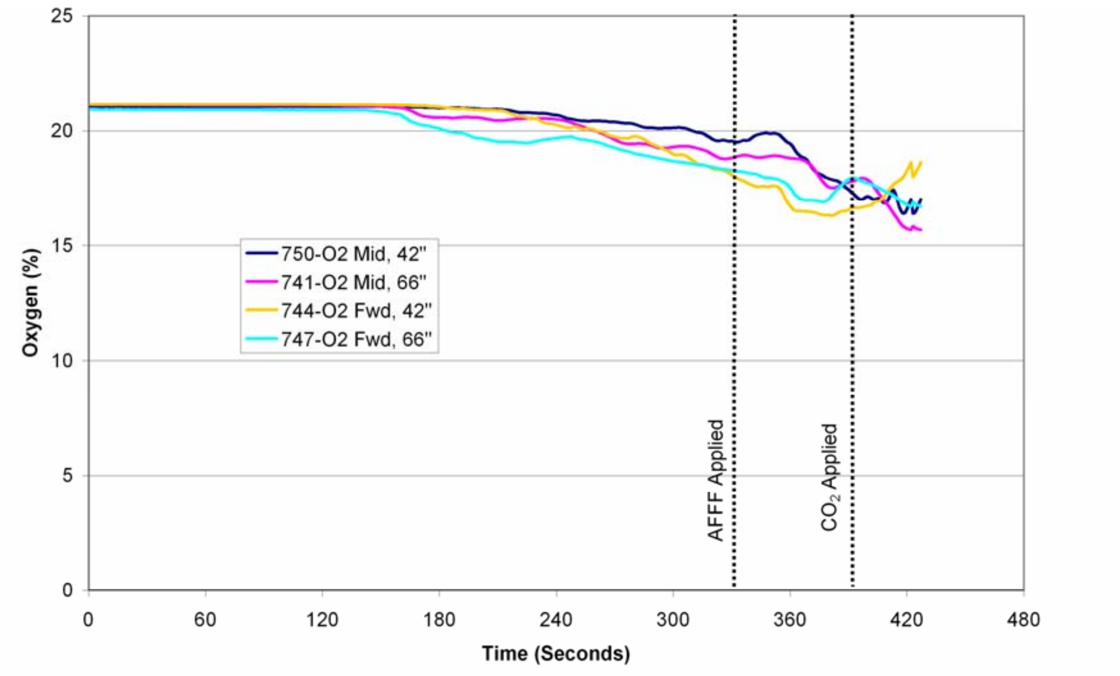

Figure 20. Baseline Configuration, O_2 Levels

Similarly, the levels of CO_2 were not extremely high during the 330 second test. A maximum value of 5% CO_2 (5000 ppm) was recorded at the termination of the test. By comparison, current survival models predict that a continuous level of 5% CO_2 would not incapacitate a person, regardless of exposure time. Toxic effects are not realized until the concentration reaches 6%. However, the inhalation of CO_2 has the effect of increasing the respiratory rate, and as a result, increasing the uptake of other toxic gases, namely, CO [6]. As expected, the CO_2 levels increased dramatically at approximately 390 seconds, the point at which gaseous CO_2 extinguishing agent was discharged into the cabin in an effort to extinguish the burning materials.

Figure 20 shows the levels of O_2 within the cabin. Again, the amount of O_2 depletion was considered minimal, because the lowest recorded value was close to 18% at the termination of the test. The effect of O_2 depletion on passenger incapacitation is not a factor in levels above 11%. It would seem logical that higher levels of CO and CO_2 (as well as greater O_2 depletion) would occur at the mid station than the forward station. However, since the mid station is much closer to the burning materials, this is generally not the case. As discussed previously with the smoke readings, it appears that the buoyant, gas-filled layer of combustion products initially rises above the sensors at the mid-cabin station, eventually descending slightly as it cools, while progressing toward the forward section of the fuselage. This is why the levels of gases are more pronounced at the forward station (66-inch height) than the mid station (66-inch height).

7.2 LIGHTWEIGHT CONFIGURATIONS A, C, AND D.

The conditions progressed as expected during all tests of the lightweight seat materials, although a noticeable flashover condition was only observed during the test of lightweight material B. During all tests, the AFFF was applied to the fire pan no later than 330 seconds (270 seconds during lightweight material A). Additional gaseous CO_2 was applied to the fire pan and introduced into the cabin area between 30 seconds and 1 minute following AFFF discharge. Due to a data acquisition problem, the data for lightweight material B test was lost. However, visual information obtained during the test indicated this material configuration resulted in a much more severe condition than any of the other lightweight combinations tested (noticeable flashover at approximately 3 minutes).

In an effort to consolidate and compare the data, the measurements of temperature, heat flux, smoke, and toxic gases were averaged for the four lightweight seat material tests. As shown in figures 21 through 33, the averaged data is displayed for each of the three lightweight materials, A, C, and D, along with the baseline fire-blocked material for comparison.

Figures 21 through 24 display the average surface temperatures of seats 1 through 4, respectively. The average temperature was calculated from the six thermocouples mounted on the three individual cushion sets (back and bottom). The thermocouples indicated the expected outcome with temperatures highest on the surface of seat 2, which was located directly in the center of the fire opening (figure 22). A fairly similar result occurred on seat 3 (figure 23). The temperatures on seat 3 more closely resemble those of seat 2 than did seat 1, since the front portion of the seat where the temperatures were being recorded was physically closer to the fire than the front of seat 1. Seat 1 resulted in lower temperatures on the front surfaces of that seat because this area was shielded by the seat back (figure 21). The data recorded for seats 2 and 3 also indicate that lightweight materials C and D did not burn as vigorously as material A or the baseline material. The average temperatures of lightweight materials C and D were 400^o to 600^oF lower during a majority of the test on these seats. The temperature on seat 4, which was located across the aisle from the other three seats, rose steadily but gradually during the test for all materials, and was only between 200^o and 300^oF at the end of the test (figure 24). These low temperatures represent the atmospheric temperature in the cabin at those locations, indicating that the fire was not able to traverse this aisle space, and illustrated the relatively good performance of all the seat materials at impeding the spread of fire.

Temperature measurements of the cabin atmosphere were recorded at various locations to determine when the conditions become nonsurvivable (figures 25, 26, and 27). To consolidate the data, the profiles represent an average of the temperatures between 1 and 7 feet above floor level. Starting at the forward cabin area, shown in figure 25, the average temperature was historically somewhat similar, with the baseline test slightly higher and lightweight material D somewhat lower. This trend was repeated at both the mid cabin and aft cabin locations, shown in figures 26 and 27. Lightweight material A exhibited slightly elevated temperatures from approximately 180 to 240 seconds into the test, although these temperatures subsided beyond 240 seconds. Again, this trend was indicated at all three locations, forward, mid, and aft cabin.

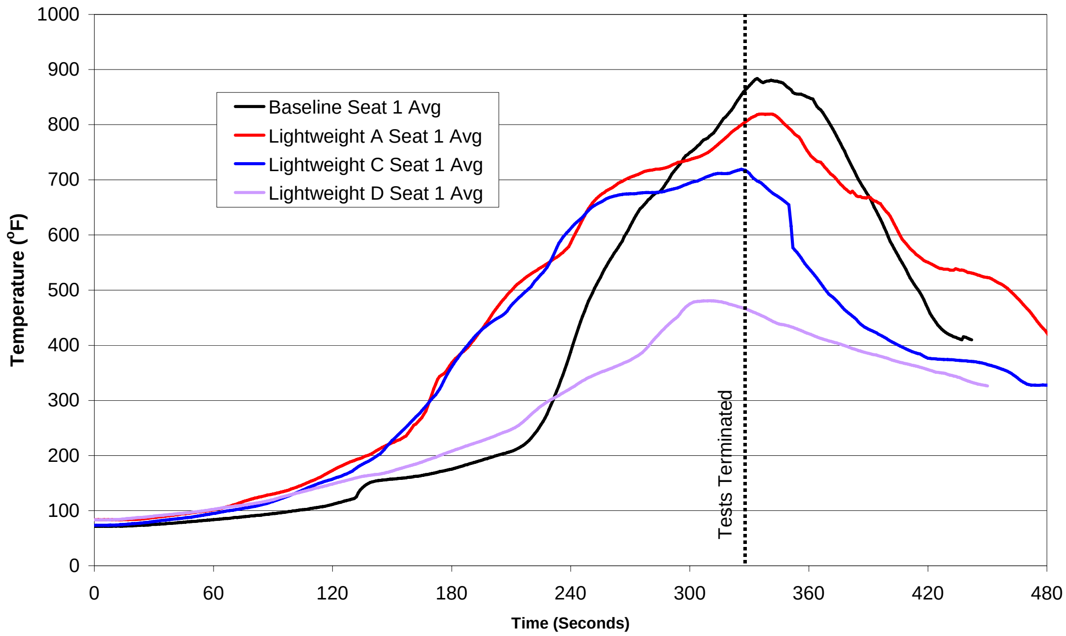

Figure 21. Comparison of Average Temperatures of Seat 1

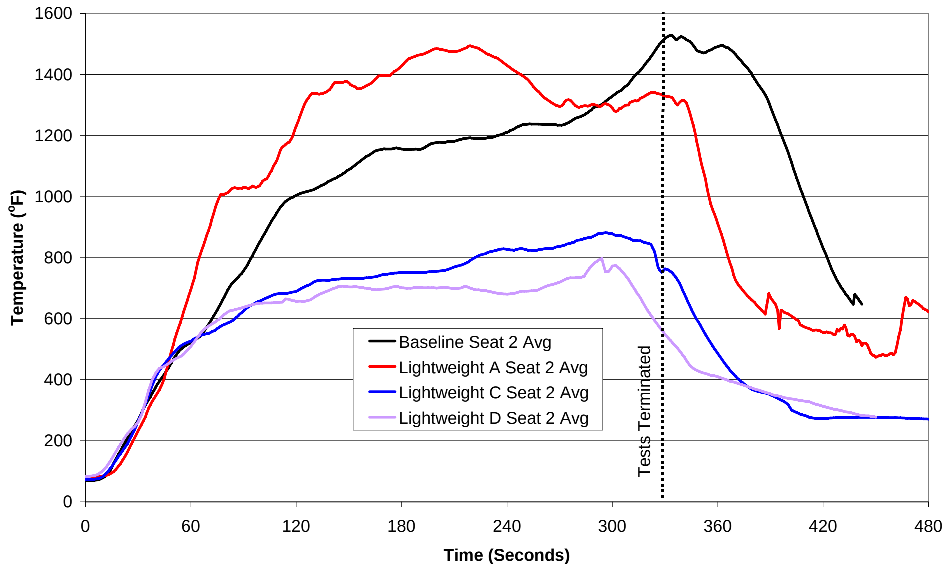

Figure 22. Comparison of Average Temperatures of Seat 2

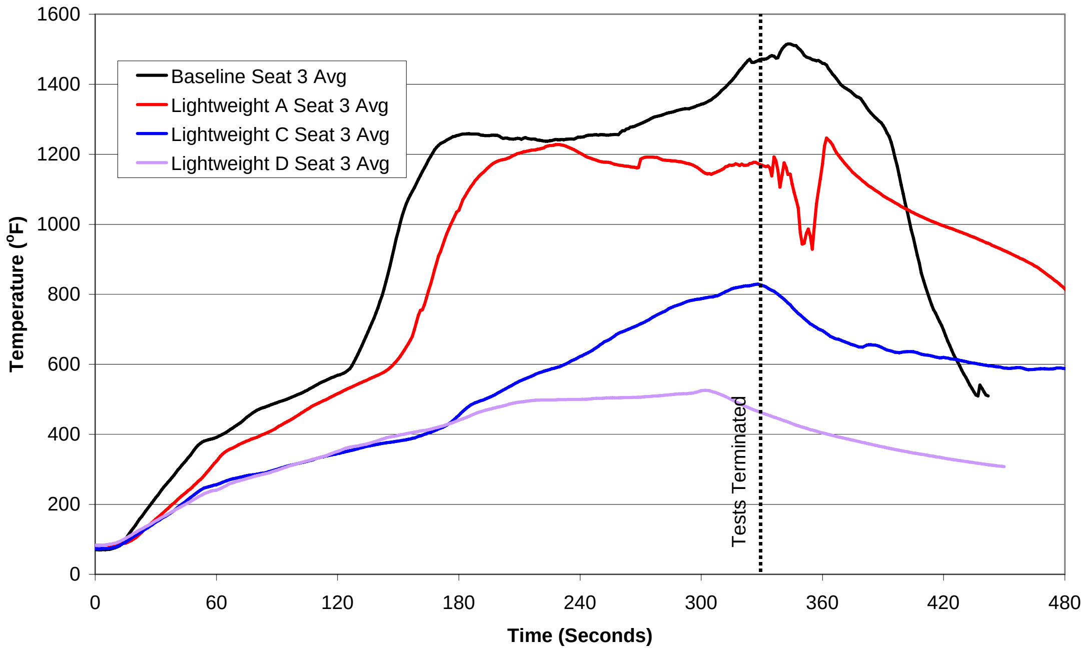

Figure 23. Comparison of Average Temperatures of Seat 3

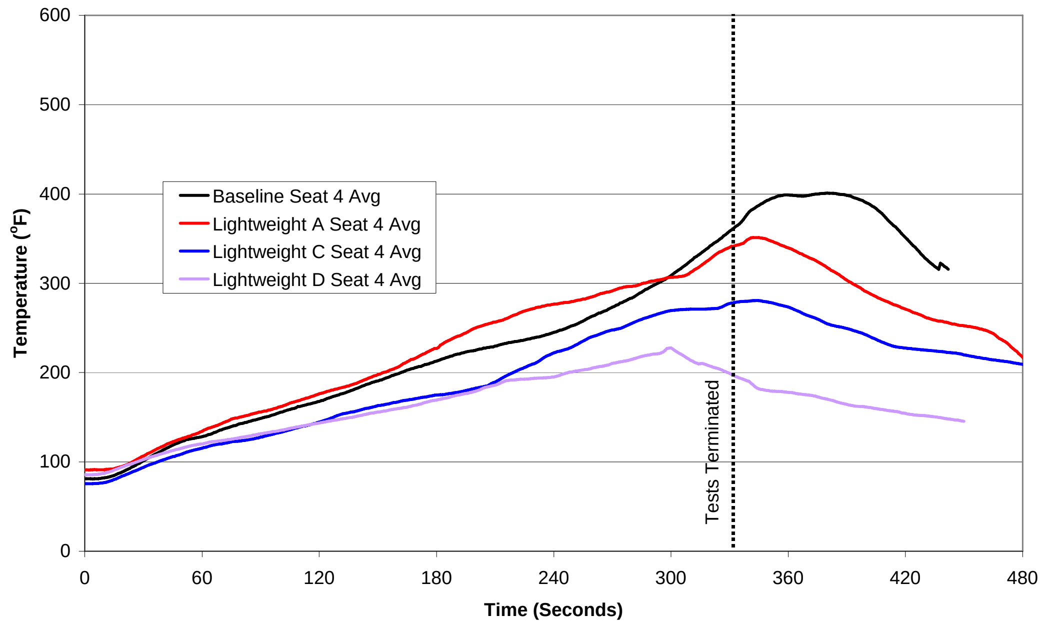

Figure 24. Comparison of Average Temperatures of Seat 4

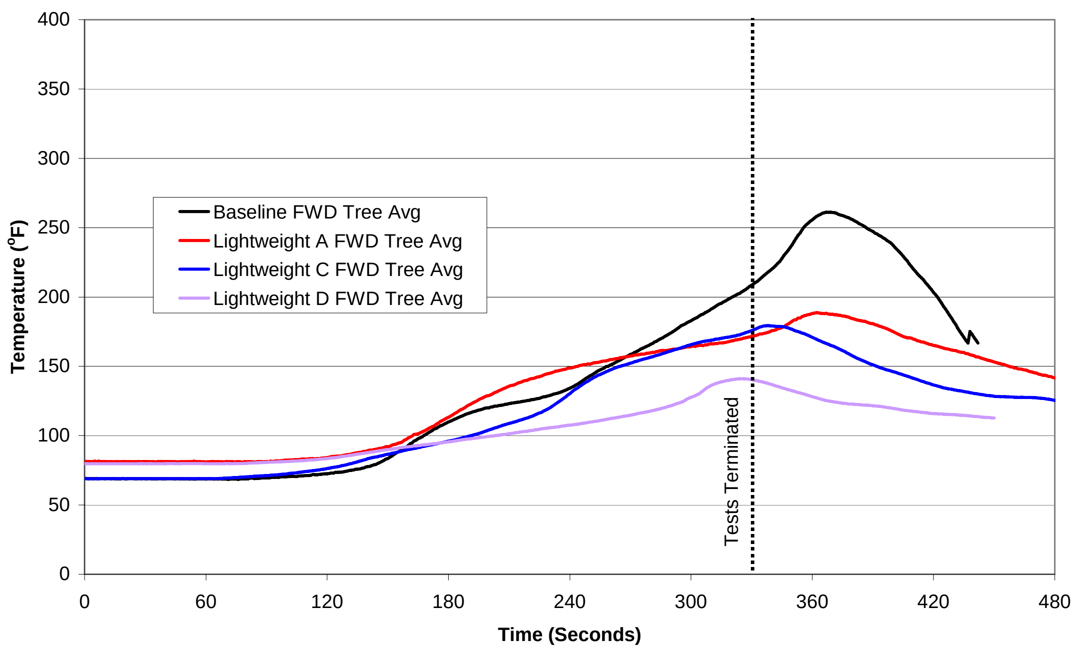

Figure 25. Comparison of Average Temperatures at Forward Tree

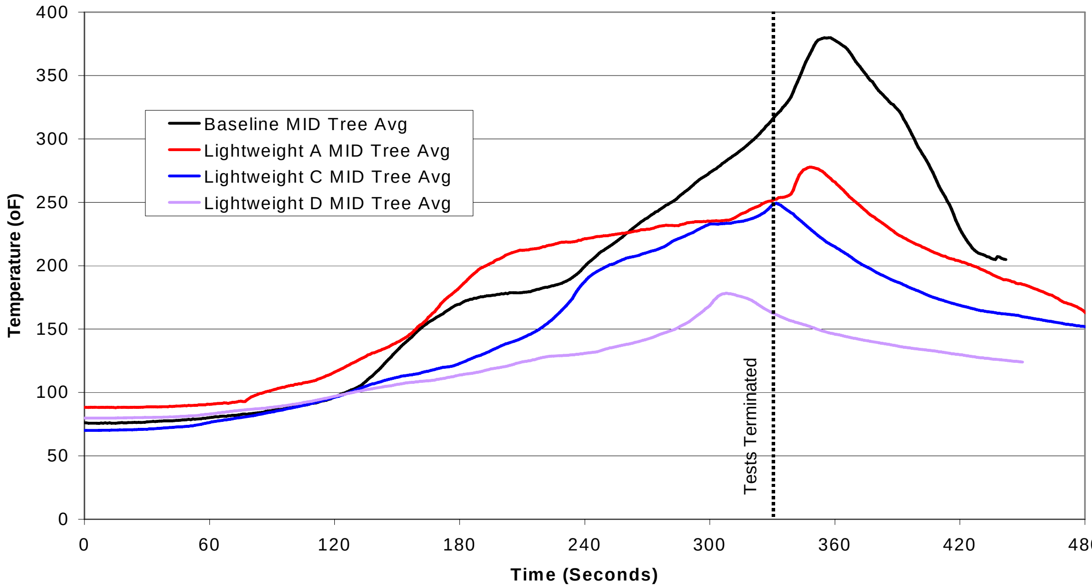

Figure 26. Comparison of Average Temperatures at Mid Tree

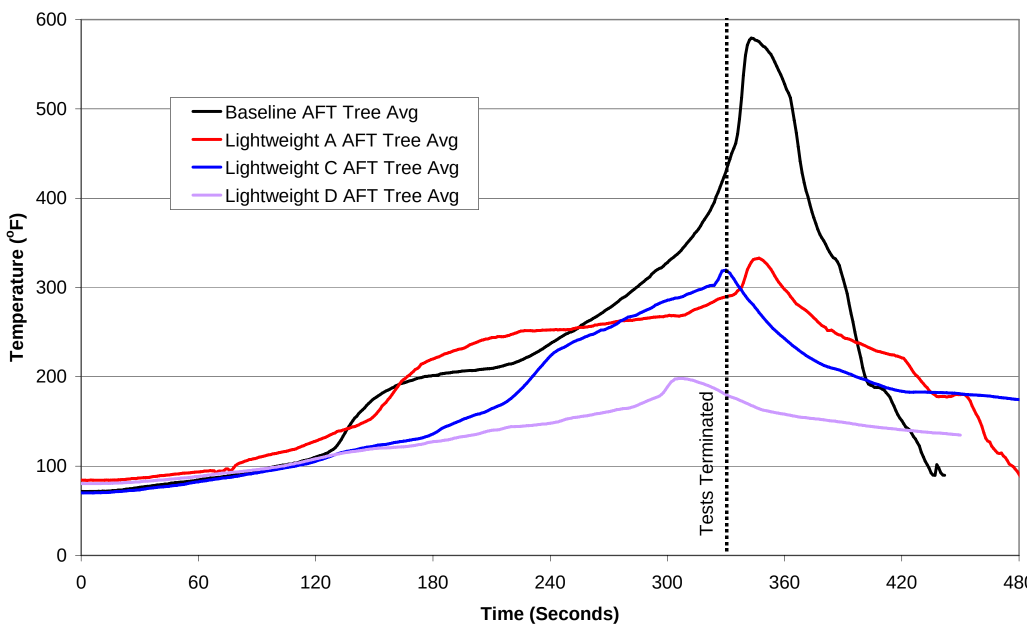

Figure 27. Comparison of Average Temperatures at Aft Tree

Figure 28 shows the averaged cabin area heat flux for each of the four tests. The averaged profiles were produced from the input of three cabin area heat flux transducers: the first transducer faced out through the fire door directly at the fuel pan. The remaining two transducers were mounted along the fuselage centerline and faced the test area. All transducers were positioned 42 inches above the cabin floor. All tests generated traces that were similar for the first 120 seconds, which indicated that the initial fire intensity was the same for all tests. There was a noticeable rise in the heat flux for lightweight material A at approximately 150 seconds, which lasted about 90 seconds and then subsided. This rise was consistent with the elevated cabin temperatures recorded for this material, as discussed previously in this section. Lightweight material C also exhibited a similar occurrence from approximately 210 seconds until 300 seconds, which was also consistent with the rise in temperatures shown in figures 26 and 27. As with the temperature profiles recorded on the seats and in the cabin, lightweight material D produced the lowest heat flux levels, which indicated a reduced level of burning in the cabin.

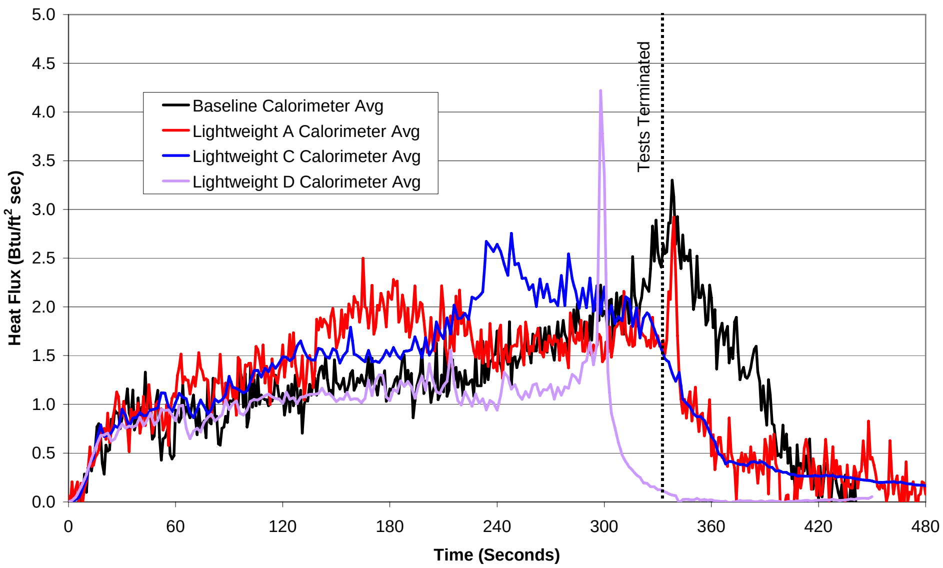

Figure 28. Comparison of Average Heat Flux in Cabin Test Area

The light transmissometers measured the amount of smoke in the cabin at three heights: 18, 42, and 66 inches above the floor. Figures 29 and 30 show an averaged trace of these three heights. The results indicated that the levels of smoke were similar for the first 120 to 180 seconds of the tests when the baseline material seemed to produce slightly more smoke (i.e., less light transmission). At 240 seconds into the test, lightweight material C showed a rapid increase in the amount of smoke until test termination. Lightweight material D produced the least amount of smoke for the majority of the test at both locations.

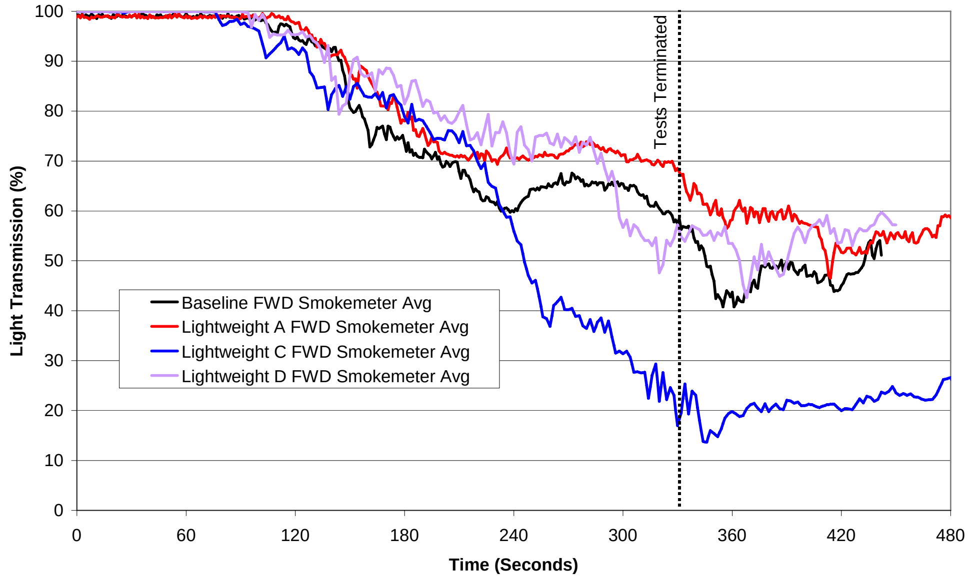

Figure 29. Comparison of Averaged Light Transmission in Forward Cabin

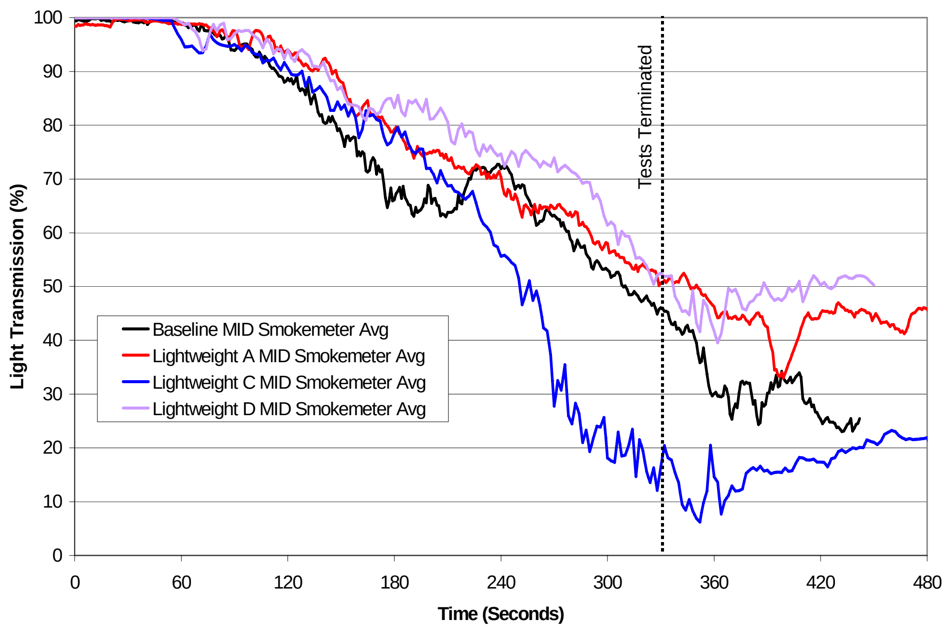

Figure 30. Comparison of Averaged Light Transmission in Mid Cabin

Averaged measurements of CO, CO_2, and O_2 are shown in figures 31, 32, and 33, respectively. Four intake ports were located in the cabin, two in the forward area and two in the mid area closer to the fire door. The intake ports were mounted at heights of 42 and 66 inches above the floor at each location for a total of four ports. The following traces represent an average of the four locations. CO, generally considered the most hazardous toxic gas produced by a fire, was relatively low for the baseline material and lightweight materials A and D for the duration of the tests. At test termination, the levels ranged between 0.13% (lightweight D) and 0.27% (baseline material). Since a continuous level of 0.40% CO (4000 ppm) would not cause incapacitation until approximately 480 seconds, these values were not considered severe [6]. Slightly elevated levels of CO were recorded during the test of lightweight material C, relative to the other three tests. As shown in figure 31, the maximum level exceeded 0.5% at the termination of the test. Although this level would not be considered extreme, it would have an impact on survivability. It is also significant in that it is roughly twice the amount of the next highest level, which was recorded during the baseline test.

Similarly, the levels of CO_2 were not extremely high during any of the 330 second tests (figure 32). A maximum value of 4.5% CO_2 (4500 ppm) was recorded at the termination of the lightweight material C test. By comparison, current survival models predict that a continuous level of 4.5% CO_2 would not incapacitate a person, regardless of exposure time. Toxic effects are not realized until the concentration reaches 6%. However, the inhalation of CO_2 has the effect of increasing the respiratory rate, and as a result, increasing the uptake of other toxic gases, namely, CO [6]. As expected, the CO_2 levels increased dramatically between 60 and 120 seconds after the test was terminated, the point at which gaseous CO_2 extinguishing agent was discharged into the cabin in an effort to extinguish the burning materials.

Figure 33 shows the levels of O_2 within the cabin. Again, the amount of O_2 depletion was considered minimal for all materials except lightweight material C, which dropped off to approximately 15% at the 330 second test termination point. Although this level of oxygen depletion was significantly greater than in the other tests, it was not hazardous, because the effect of O_2 depletion on passenger incapacitation is not a factor in levels above 11% [6].

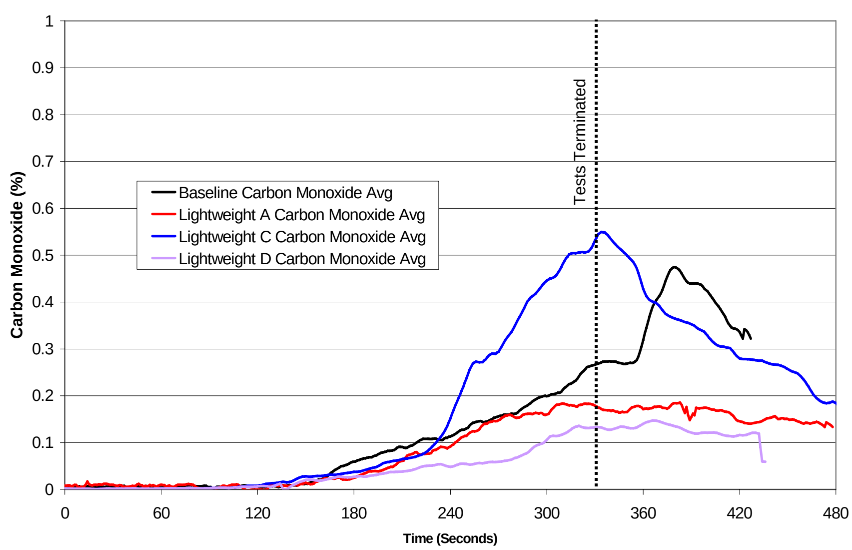

Figure 31. Comparison of Averaged CO Levels in Cabin Area

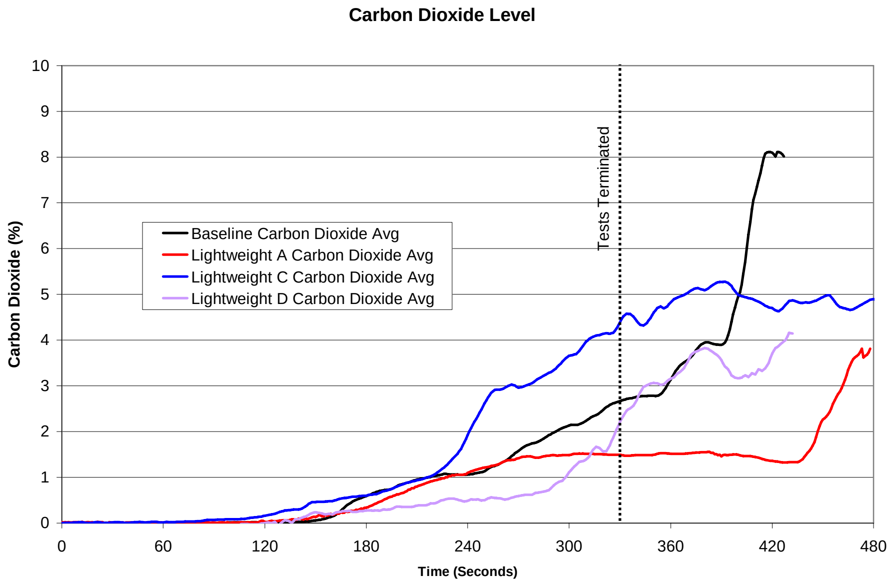

Figure 32. Comparison of Averaged CO_2 Levels in Cabin Area

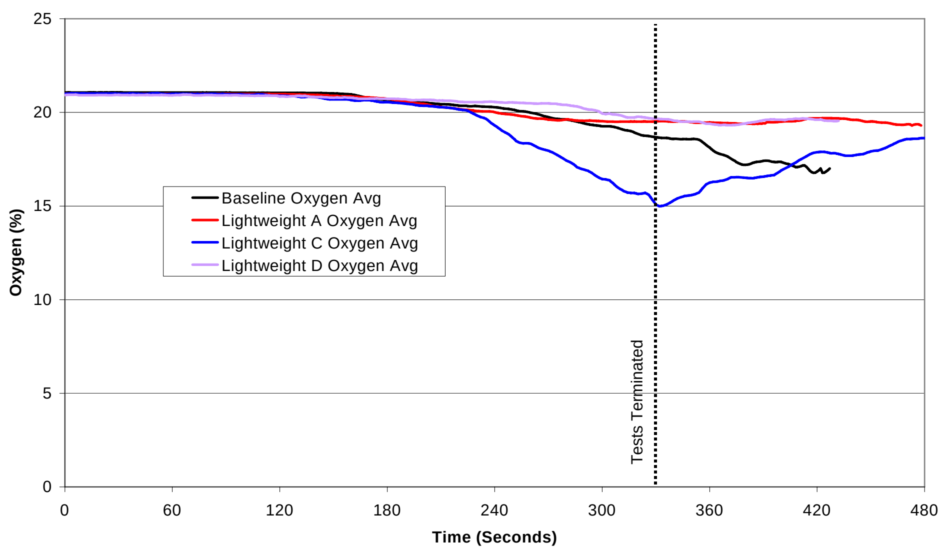

Figure 33. Comparison of Averaged O_2 Levels in Cabin Area

8. USE OF SURVIVAL MODEL TO RANK TEST RESULTS.

A large amount of data is generated during the conduct of a full-scale test. Since the primary purpose of these tests was to determine if the newer, lightweight materials produced more or less hazardous conditions inside the cabin than traditional materials, the data and subsequent analysis needed to clearly illustrate any differences in the results. Due to the large amount of data generated during these tests, averaged data was initially used to compare each test. Although it presented a clearer overall picture, the averaged data could not accurately determine, at a particular location, if one material configuration was more or less hazardous than another. To best determine the outcome of the tests, the use of a hazard survival model was employed, which could predict the survivability at a particular location inside the cabin. This hazard survival model was created using selected regression equations to be used as a predictive tool to gauge human survivability in full-scale aircraft cabin fire tests. The model uses incapacitation data to obtain a fractional effective dose for incapacitation (FED_I) and lethality data to obtain a fractional effective dose for lethality (FED_L). The time when either FED reaches 1 determines the exposure time available to escape from an aircraft cabin fire and survive postexposure [6]. For the purposes of this study, only the FED_I was used.

To generate the fractional effective dose charts, the model was used to individually calculate the effect of temperature and various cabin gases. The cabin gases used in the model were limited to CO, CO_2, and O_2. Each hazard equation was incorporated into a Microsoft Excel® spreadsheet, enabling a calculation of the fractional effective dose for every data point recorded during the tests (every 2 seconds). Once the individual hazards were calculated, a final column was used to tally the individual columns, which produced the total fractional effective dose for a particular location. These results were plotted in figures 34 through 37.

As shown in figure 34, the fractional effective dose at the forward cabin location, 42 inches from the floor, did not approach 1. The highest level was slightly greater than 0.2 at the test termination for lightweight material C. All test materials exhibit similar hazard characteristics for a majority of the test and diverged after the test was terminated, with lightweight material C showing the most dramatic rise.

In figure 35, the FED_I results are shown for the forward cabin location at a height of 66 inches above floor level. The curves indicate a more severe environment than at the lower location because of the higher temperatures and gas concentrations. Despite the increased hazards, the worst-case FED_I test (lightweight material C) was still only at 0.75 at the termination of the test. Of note is that lightweight material D remained well below the other tests in terms of hazard level, reaching only 0.05 (5%), at test termination.

At the mid cabin location, closer to the fire and burning materials, it was expected that the hazard level would be significantly greater during all tests. However, at 42 inches above the floor, the hazards and resulting FED_Is were comparable to the forward location at 42 inches above floor level before the test was terminated (figure 36). As was the case with the forward location, all FED_I calculations were almost nil until approximately 240 seconds into the test, when the curves began to segregate. Although the baseline test and lightweight materials A and C all yield similar results before the termination of the test (FED_I between 0.15 and 0.18), lightweight material D clearly exhibited a lower FED_I.

At a height of 66 inches above the floor at the mid cabin location, the hazards were significantly higher than at the lower height (figure 37). This trend was similar to the forward location, mainly due to the increased gas concentrations and temperature. As was the case at all other measuring locations, the FED_I did not reach 1 for any of the materials before the test was terminated. The worst case was the baseline material, which was 0.55 at test termination.

Lightweight materials A and C were the next highest, at 0.5 and 0.3, respectively, at test termination. Lightweight material D clearly produced the least hazardous cabin conditions, reaching only 0.05 (5%) at test termination.

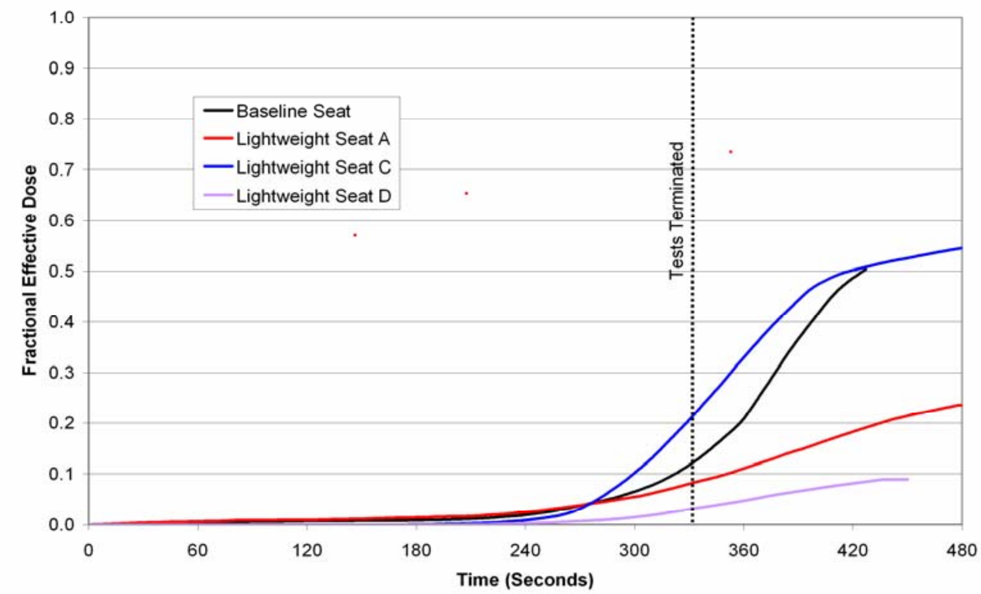

Figure 34. Fractional Effective Dose at Forward Cabin, 42-Inch Height

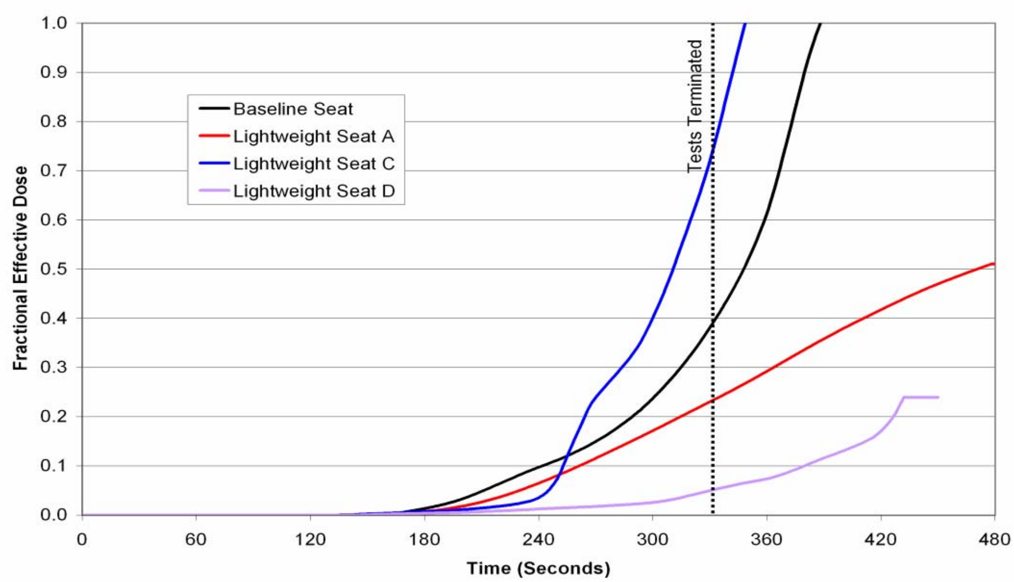

Figure 35. Fractional Effective Dose at Forward Cabin, 66-Inch Height

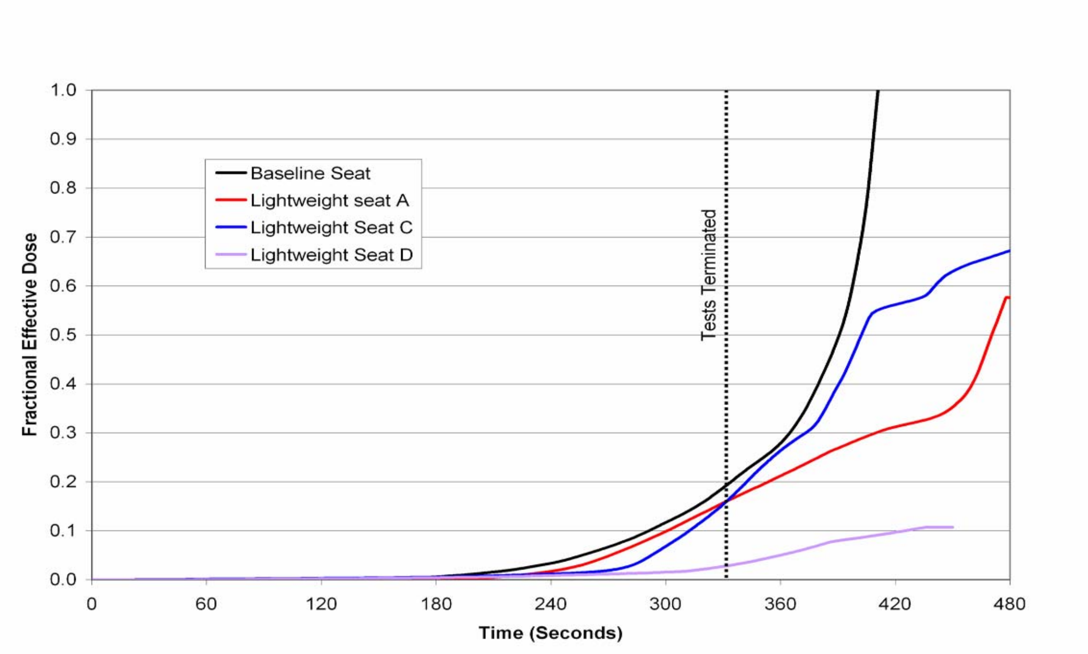

Figure 36. Fractional Effective Dose at Mid Cabin, 42-Inch Height

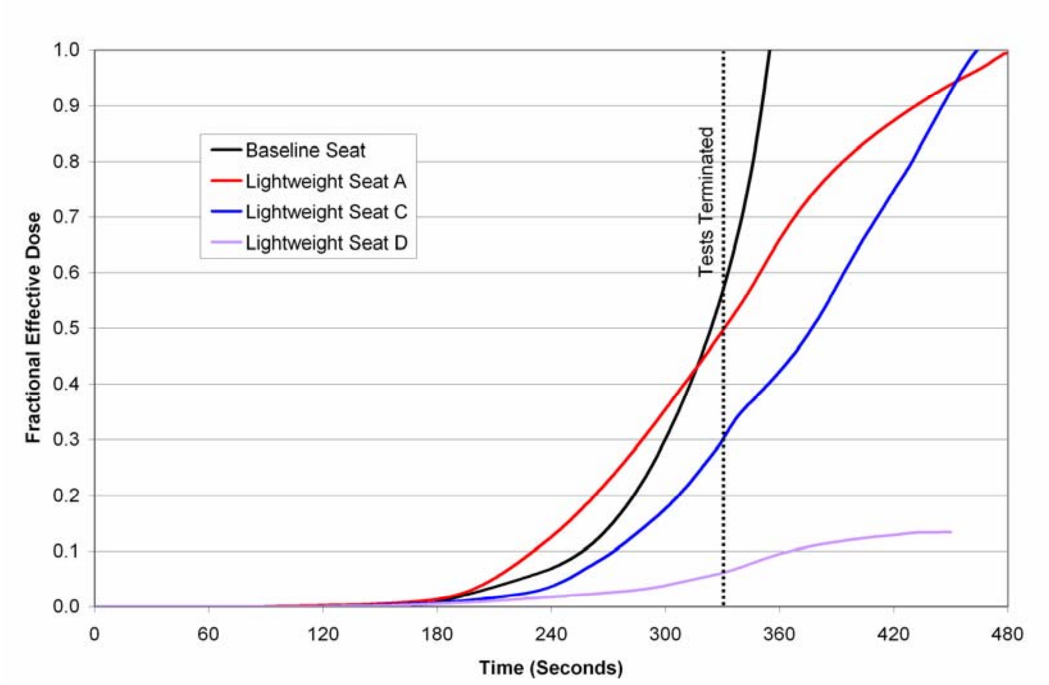

Figure 37. Fractional Effective Dose at Mid Cabin, 66-Inch Height

9. ANALYSIS OF FULL-SCALE RESULTS.

Considering the measurements taken at all four locations and the theoretical survivability (FED_I) calculations for all tests, it is clear that lightweight material D produced the most favorable conditions within the cabin. The fractional effective dose calculations ranged from 0.03 to 0.06 (3% to 6%), and indicated that very minor toxicity resulted from this material combination. Lightweight material A showed only slightly higher toxicity, with FED_I calculations that ranged from 0.08 to 0.5. Although the toxicity level was slightly higher than the baseline material before 300 seconds at the mid cabin 66-inch height, it was less toxic in all other instances within the cabin. Lightweight material C produced toxicity levels higher than the baseline material at the forward sampling areas, but slightly lower toxicity in the areas closer to the burning materials.

10. ANALYSIS.

All four lightweight material configurations clearly exceeded the 10% maximum allowable weight loss for the laboratory-scale test, with values ranging from 11.94% to 18.00%. By comparison, the traditional fire-blocked urethane configuration produced a weight loss of only 7.96%. Of interest is that the heaviest of the lightweight configurations (material B, 4.55 lb) yielded only 12.11% weight loss, nearly the lowest of the four, and the lightest configuration (material A, 2.40 lb) yielded the highest weight loss of 18.00%. This trend supported an inverse relationship between the specimen set weight and the specimen set percentage weight loss (i.e., the higher the specimen set weight, the lower the percent weight loss, and vise versa). The laboratory-scale results also supported the manufacturers' concern that the lighter the cushion weight, the more biased the current 10% weight loss requirement.

In addition, it was discovered that the bottom dress cover yielded a higher percentage of weight loss than the bottom cushion for all four lightweight configurations. Similarly, lightweight configurations A, C, and D also yielded higher percentages of weight loss for the back dress cover compared to the back cushion. This is noteworthy, indicating that in most cases the cushion material did not burn nearly as much as the dress cover, with the exception of lightweight configuration B. This evidence would also tend to support the manufacturers' claims that the lighter foam cushion had no more impact on the spread of fire than a heavier foam.

The full-scale tests were conducted to determine if this theory was true under more realistic conditions. Of the four lightweight materials tested, only the heaviest combination, material B, produced the most hazardous cabin conditions. Although the data was lost for this test, it was evident that a flashover resulted after approximately 180 seconds, which only occurred with the baseline material at a later time. All other materials resulted in toxicity levels at or below the baseline material, which indicated a lightweight cushion that exceeded the laboratory-scale requirements did not necessarily result in worse conditions when tested full-scale.

11. SUMMARY.

From the laboratory and full-scale tests, it became clear that, under certain circumstances, the present weight loss criteria specified in Appendix F Part II is not a completely accurate method of predicting the fire performance of a seat under realistic conditions. The regulations and performance standards specified in Appendix F Part II were developed in the mid 1980s and were based on materials available at that time, i.e., cushion flammability standard, primarily urethane foam with various fire-blocking layers. However, since that time, new extremely lightweight melamine foam-based materials have been developed, and their full-scale fire performance surpasses that of the urethane foam. Although the 10% maximum weight loss criteria was an effective means of evaluating seat performance in the past, it may not be completely applicable for the materials available today.

One of the most difficult tasks is to modify the present pass/fail criteria in such a way as to allow the acceptance of these new lightweight materials, without also granting acceptance of poor performing materials. Simply increasing the maximum allowable weight loss from 10% to a higher number would allow the lighter materials to pass, but would also allow poor performing materials to pass as well. One of the key aspects of the laboratory testing was the weight ratio between the foam used in the cushion and the dress cover material. This cushion-to-cover weight ratio varied between 0 and approximately 2 for the four lightweight materials tested. In general, the lighter the cushion material, the lower the ratio, since the weight of the dress cover does not change significantly. The baseline material configuration resulted in a ratio of approximately 2.4, since the cushion material used was the traditional urethane foam (the fire-blocking layer was considered part of the cushion weight). To better evaluate a seat's performance, a corrected allowable weight loss (CAWL) was devised, based on the cushion-to-cover ratio. As the cushion-to-cover ratio decreases, the corrected (allowable) weight loss increases. A further stipulation was that the complete test specimen set, bottom and back samples combined, could not exceed 3 pounds. This would eliminate any slippage in the allowable percent weight loss for a traditional type of seat that somehow met the ratio (i.e., use of an extremely heavy dress cover), but performed poorly. In addition, a conservative-minded, corrected allowable burn length was also imposed, to further limit the latitude given to the lightweight seats that could be granted a higher allowable weight loss.

The results of table 6 are also represented graphically in figure 38. As shown, the CAWL and the corrected allowable burn length form an inverse relation (i.e., as the allowable weight loss increases, the allowable burn length decreases).

Table 6. Proposed CAWL Based on Cushion-to-Cover Ratio

Total Seat Weight (lb)	Average Ratio of Cushion Weight to Cover Weight	CAWL (%)	Corrected Allowable Burn Length (inches)
Less than 3	1.8 to 2.0	12	16
	1.5 to 1.79	14	15
	1.1 to 1.49	16	14
	0.60 to 1.09	18	13
	0 to 0.59	20	12

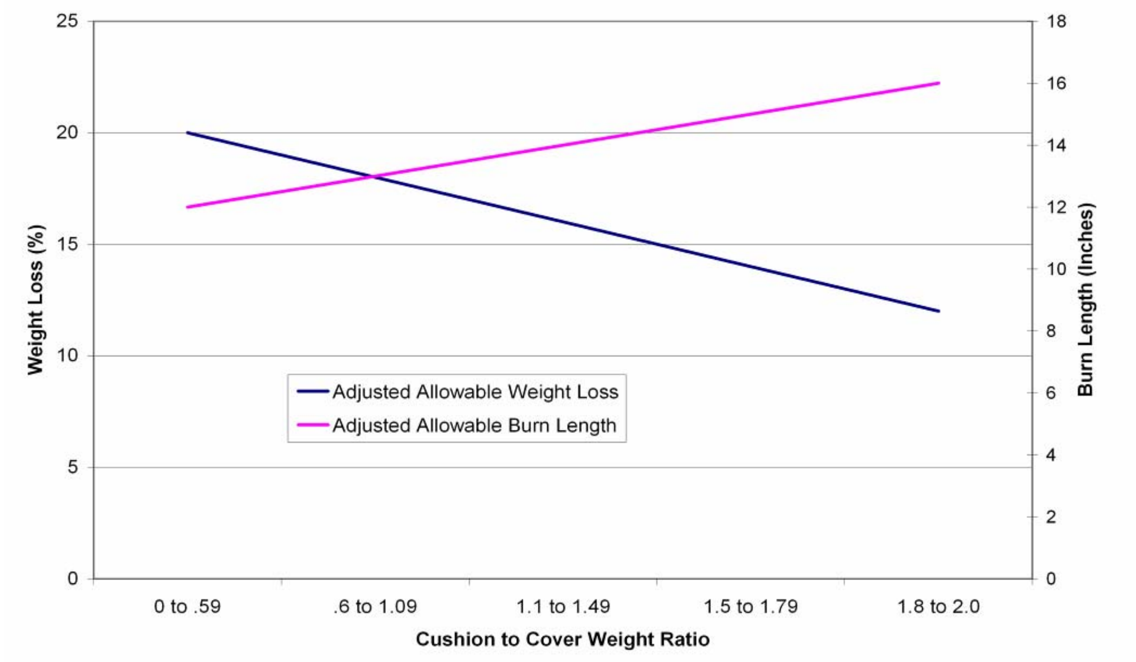

Figure 38. Corrected Allowable Weight Loss and Burn Length as a Function of Cushion-to-Cover Ratio

In table 7, the initial and final weights of the cushion bottoms and backs are given, along with the weight loss and the cushion-to-cover ratios for each material combination tested. Using the proposed criteria, two of the four lightweight materials tested, materials A and D, would pass, while materials B and C would fail. Although lightweight material C did not perform poorly in the full-scale evaluation, the weight of the combined bottom and back test specimens was greater than 3 pounds, excluding it from the proposed allowable weight loss criteria. As such, the 11.94% average would exceed the current 10% standard, causing a failure. This case illustrates the conservative nature of the proposed criteria, in that several conditions must be met before acceptance can be granted, thus assuring only appropriate material combinations are permitted.

Table 7. Laboratory Test Results Using Proposed CAWL Criteria

Seat	Initial Weight Bottom Cushion (lb)	Initial Weight Bottom Cover (lb)	Initial Weight Back Cushion (lb)	Initial Weight Back Cover (lb)	Initial Weight Total (lb)	Final Total (lb)	Weight Loss (%)	Average Weight Loss (%)	Ratio Cushion Weight to Cover Weight	Average Ratio	CAWL (%)	Pass/Fail
Baseline 1	2.25	0.75	1.48	0.78	5.26	4.94	6.03	7.96	2.44	2.49	10	Pass
	2.25	0.75	1.48	0.78	5.26	4.81	8.54		2.44			
	2.25	0.75	1.48	0.78	5.26	4.73	10.04		2.44			
	2.19	0.72	1.47	0.78	5.16	4.75	7.95		2.44			
	2.19	0.72	2.08	0.78	5.77	5.35	7.28		2.85			
	2.21	0.80	1.5	0.78	5.29	4.87	7.94		2.35			
Baseline 2	2.21	0.72	1.5	0.78	5.21	4.790	8.06	6.65	2.47	2.46	10	Pass
	2.22	0.74	1.52	0.79	5.27	4.970	5.69		2.44			
	2.22	0.75	1.56	0.79	5.32	4.990	6.20		2.45			
Lightweight A	0.55	0.71	0.42	0.77	2.45	2.07	15.50	18.00	0.65	0.65	18	Pass
	0.54	0.69	0.41	0.75	2.39	2.01	15.89		0.65			
	0.54	0.69	0.41	0.75	2.39	1.96	17.99		0.65			
	0.54	0.70	0.41	0.75	2.40	1.80	25.00		0.65			
	0.54	0.70	0.41	0.76	2.41	1.98	17.78		0.65			
	0.54	0.70	0.41	0.75	2.40	2.02	15.86		0.65			
Lightweight B	1.86	0.74	1.19	0.78	4.56	4.06	10.96	12.11	2.01	1.99	10	Fail
	1.83	0.74	1.18	0.78	4.54	4.01	11.67		1.98			
	1.83	0.74	1.15	0.78	4.50	3.98	11.56		1.96			
	1.86	0.74	1.15	0.78	4.55	3.98	12.53		1.98			
	1.86	0.74	1.18	0.78	4.58	4.02	12.23		2.00			
	1.83	0.74	1.17	0.78	4.52	3.90	13.72		1.97			
Lightweight C	1.48	0.56	1.05	0.60	3.68	3.07	16.62	11.94	2.18	2.19	10	Fail
	1.46	0.55	1.06	0.57	3.64	3.23	11.21		2.24			
	1.46	0.54	1.06	0.60	3.65	3.28	10.10		2.21			
	1.46	0.54	0.95	0.57	3.52	3.10	11.84		2.16			
	1.42	0.55	1.05	0.58	3.60	3.21	10.95		2.17			
	1.44	0.55	10.3	0.58	3.60	3.21	10.95		2.17			
Lightweight D	1.01	0.55	0.80	0.60	2.97	2.57	13.33	13.41	1.59	1.60	14	Pass
	0.98	0.55	0.79	0.58	2.91	2.52	13.41		1.56			
	0.99	0.54	0.83	0.58	2.94	2.54	13.70		1.62			
	0.99	0.54	0.83	0.58	2.94	2.54	13.70		1.62			
	1.00	0.56	0.83	0.57	2.97	2.58	12.99		1.61			
	0.99	0.55	0.84	0.58	2.97	2.57	13.33		1.61			

12. REFERENCES.

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