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# A Study of the Continued Fire Worthiness of Aircraft Seat Cushion Fire-Blocking Layers

Doug Ingerson

Federal Aviation Administration
Airport and Aircraft Safety
Research and Development Division
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

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Final Report

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16. Abstract

The continued fire endurance of fire-blocked aircraft seat cushions after service wear and tear was evaluated based on in-service examinations performed on commercial aircraft and sample testing of donated cushions per the oil burner test contained in Part 25, Appendix F, Part II of the Federal Aviation Regulations. A total of 176 examinations took place onboard aircraft to evaluate the condition of the in-service aircraft seats. A comparison was made between the observed conditions of the in-service seat cushions and the 38 used seat cushion sets that were donated for this project. The comparison indicated that the donated used aircraft cushion sets were representative of actual in-service conditions. The donated cushion sets were then evaluated for continued fire worthiness with the aircraft cushion oil burner test. Eight pairs were retained in stock condition and the remaining 30 pairs were altered to a "modified" test configuration. The test results included the weight loss profile for each cushion set burnt. The test results indicated that there were no significant fire endurance problems with the fire-blocking materials that were composed of Kevlar, Nomex, and/or polybenzimidazole (PBI) components.

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TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

# EXECUTIVE SUMMARY

A 1993 China Eastern Airline MD-11 accident led the National Transportation Safety Board (NTSB) investigators to discover several conditions within the aircraft cabin which raised fire safety concerns. Throughout the aircraft the seat cushion's dress covers and fire-blocking layers were worn so heavily that the inner polyurethane cushion had become exposed in many places. Questions developed regarding fire endurance performance of cabin components deteriorating over the course of time. Considering the potential hazard presented by the deterioration of the seat cushion's fire-blocking layer and the resultant exposed polyurethane foam, the NTSB recommended that the Federal Aviation Administration examine effects of deterioration of aircraft seat cushions. This report addresses the fire safety concerns of continued compliance of cushion encapsulating fire-blocking materials on aircraft seats. Through in-service seat examinations and used seat cushion fire testing, the fire-blocking materials found on major U.S. air carriers were evaluated for continued compliance with Part 25, Appendix F, Part II of the Federal Aviation Regulations. Thirty-eight seat tests were performed on donated cushion sets protected by fire-blocking layers manufactured between 1985 and 1993. The test results indicated no significant deterioration of fire endurance related to time in-service for the cushion fire-blocking materials which were composed of Kevlar, Nomex, and/or polybenzimidazole (PBI) components.

# INTRODUCTION

## PURPOSE.

The work described here covers the methodology used to evaluate the continued effectiveness of the fire-blocking scheme commonly found on board narrow- and wide-body aircraft in the U.S. civil fleet. The evaluation was performed on a sampling of cushions to determine if the fire-blocking scheme effectiveness had degraded over time. The test results are treated as an indication of the condition of fire-blocking scheme fleet wide.

## BACKGROUND.

PERTINENT AIRCRAFT ACCIDENT. A China Eastern Airline MD-11 diverted to Shemya, Alaska, on April 6, 1993, due to flight control problems resulting in altitude loss and severe interior structural damage [1, p. 1]. Soon after the accident, the National Transportation Safety Board (NTSB) began its investigation into the incident. As a result, the NTSB generated a list of recommendations identifying concerns regarding the accident. The Federal Aviation Administration responded to the NTSB recommendations indicating actions which will be pursued to remedy the noted concerns [3].

The NTSB investigators noted that the aircraft seat cushion fire-blocking layers (FBLs) were visibly damaged [1, p. 38]. The damage indicated extreme mechanical wear and contamination. The fire-blocking material was further identified as a foreign manufactured, carbon fiber-based material. Based on the degraded fire-blocking material observed in the China Eastern Airline accident [1, p. 52], NTSB recommendations A-93-148 through A-93-152 dealt exclusively with FBL issues [2, p. 6]. The work described by this report explicitly addresses recommendation A-93-150 and indirectly addresses A-93-149, A-93-151, and A-93-152.

Recommendation A-93-150 states:

A-93-150. Conduct research upon the effects of actual in-service wear on the continued airworthiness of fire-blocking materials. Based on the findings, require periodic actual in-service tests of fire-blocking materials to verify compliance with the requirements of 14CFR 25.853 [2, p. 6].

AIRCRAFT SEAT CUSHION CONSTRUCTION. Aircraft seat cushions were the major component tested for this project. The fire-blocked cushion consists of a polyurethane foam cushion encapsulated by an FBL and finished with an outer, decorative dress cover. From a cabin fire safety standpoint, the polyurethane is a major threat due to its presence in large quantities and its relatively high flammability (even when treated with flame retardants). The FBL is in place to prevent or retard the polyurethane from burning by keeping sufficient oxygen needed for combustion away from the polyurethane and ultimately preventing flaming combustion.

FAA AIRCRAFT SEAT CUSHION TEST. FAR 25.853 prescribes the fire endurance standard for aircraft seat cushions used on transport category aircraft. Part 25, Appendix F, Part II of the

FAR describes an acceptable test method and the required performance criteria [4, ch. 7]. The following is an overview of the test method.

The accepted test requires the specimens to be conditioned in an environmental chamber and then exposed to a continuous, 3-segmented, 9-minute-long test. The test apparatus consists of a modified oil burner, similar to a unit possibly found in a home heating system, weighing instrumentation, a seat fixture, and calibration instrumentation. The oil burner is capable of being pointed away from and directed at the seat fixture as needed. The weighing instrumentation is used to record pre- and posttest cushion weights. The seat fixture is a steel frame which holds two seat cushions, a vertical one and a horizontal one. Two seat cushions form one test specimen. A complete test consists of results from three test specimens of like construction. Calibration instrumentation is used to ensure a specified energy profile for the burner flame.

The test criteria are the test specimen weight loss and the burn lengths across cushion surfaces. The burn lengths, four per test specimen, are the measured lengths of damage due to combustion across each face of the cushions forming the test specimen. The weight loss is measured as a percent as given by the following equation:

$$Percent\ weight\ loss = \left(\frac{W_i - W_f}{W_i}\right) \times 100$$

where

$W_i$ = initial weight of the test specimen (both cushions)
$W_f$ = final weight of the test specimen.

The specimen test runs according to the following timeline:

1. Pretest
    a. Burner is pointed away from test specimen
    b. Pretest specimen weight is taken
2. 0 - 2 minutes, burner warm-up
    a. Burner is ignited and issuing a flame from its burner cone
    b. Test cell conditions stabilize
3. 2 - 4 minutes, specimen burner flame exposure
    a. Burner is still operating
    b. Burner is directed at test specimen for the duration
4. 4 - 9 minutes, specimen free burning period
    a. Burner is turned off and directed away from test specimen
    b. Test specimen is allowed to freely burn for the duration
    c. At 9 minutes, any remaining fire is manually suppressed and
        - Posttest specimen weight is taken
        - Burn lengths across specimen faces are measured

The pass/fail criteria for the test, based on a complete test, are:

1. Two-thirds of the specimens must have a weight loss less than 10 percent.

2. Average weight loss for complete test must be less than 10 percent.
3. Two-thirds of the specimens must have a burn length not exceeding 17 inches (43.2 cm).

EXPECTED CUSHION FIRE ENDURANCE PERFORMANCE. Some deterioration of the FBL fire endurance is expected over time, based on some function describing the wear, contamination, and cleaning exposures. The time required for the fire endurance of a particular FBL material to degrade to a marginal condition is indeterminate and would be difficult, if not virtually impossible to predict, based on the wide variability of in-service conditions cushions are exposed to.

## DISCUSSION

TEST DESCRIPTION.

INITIAL APPROACH. The initial approach considered involved mechanically wearing new fire-blocking material with an existing wear apparatus employed by airframe or seat manufacturers. Seat cushion assemblies would then be constructed with the "worn" fire-blocking material, polyurethane foam, and dress cover materials representing deteriorated in-service seat cushions. The assemblies would then be tested according to Part 25, Appendix F, Part II. However, each of the different apparatuses considered for wearing the material had shortcomings that did not provide realistic and feasible conditions to generate mechanically worn materials. Three problems prevented this approach from being pursued.

1. The mechanically worn fire-blocking material generated by a smaller apparatus, like the Wyzenbeck and Martindale apparatus, produce such small samples that oil burner testing would not be expected to yield reasonable results to base later decision making upon.

2. The larger wear apparatus, in particular the "Squirmin' Herman/Erma," was not expected to produce mechanically worn fire-blocking materials comparable to truly worn in-service materials. Additionally, current rules-of-thumb, relating test time to service time, are based on an original "Herman" configuration, which cannot be reproduced today because some original materials are no longer available. Therefore, the validity of the rules of thumb are questionable. Moreover, the Squirmin' Herman/Erma was originally developed to examine dress cover deterioration and its relevance to fire-blocking layers is uncertain [7].

3. The contaminated condition of actual seat cushions could not be reasonably produced. The contamination would be expected to affect the material wear and fire endurance behaviors.

DECIDED APPROACH. A modified approach resulted in a more realistic method for resolving this concern. The initial action, when aircraft were available, was the in-service examination of aircraft seat cushions to determine deterioration conditions. These investigations took place at the Atlantic City International Airport in Pomona, New Jersey, the Newark International Airport in Newark, New Jersey, and the Stewart International Airport in Newburgh, New York. One hundred and seventy-six in-service seats were examined. The seats examined were located on eight Shorts 360s, four ATR 42s, six Embraer EMB 120RTs, nine McDonnell Douglas DC9/MD80s, one Boeing 727, one Boeing 737, and one Airbus A300.

The seat examinations involved the removal of the dress covers and the inspection of the underlying fire-blocking layers. A subjective rating based on a five point scale, one being the best condition and five being the worst, was used to describe the deterioration of the fire-blocking layer regarding wear and contamination. Additionally, when possible, an entire overview of aircraft seat cushions within a cabin was undertaken. In several instances, the seat examinations occurred while evening cleaning crews were on board performing their duties. This allowed a broad overview of the cushion conditions. The overview was not performed to the detail that the individual seat examinations were but helped develop a general sense of the condition. The general overview was based on observed cleanliness, appearance, and the mechanical state of the cushions.

In addition, through the cooperation of several air carriers, 38 sets of used aircraft cushions were donated for destructive testing. The donated cushions were assessed for deterioration in the same manner as the in-service seat cushions. After the in-service and donated material deterioration assessments were completed, the levels of deterioration for each were compared.

The final step in the testing sequence was the actual seat cushion test. The cushion sets were subject, as circumstances warranted, to the requirements of Part 25, Appendix F, Part II.

The main focus for the fire testing sequence of this project was the donated seat cushions. The donated material was difficult to acquire. The condition of the material acquired also suggested the wide variation of deterioration potentially found on any given seat cushion set. As a preliminary step to gage test behavior, eight used cushion sets were left in an unmodified condition and tested. The results of these eight cushion sets, which were grouped in three of one design and five of another, ranged widely. Additionally, the unmodified, donated materials presented compliance difficulties with Part 25, Appendix F, Part II regarding the geometry of the test specimens. Several problems were evident: these being regulatory compliance with respect to test specimen geometry, widely varying deterioration, and widely varying preliminary test results. Based on unique circumstances and observed or expected fire behavior, decisions were made to allow three major deviations from Part 25, Appendix F, Part II.

First, the cushion's geometry and composition were altered. Based on the data scatter in the first eight unmodified cushion tests and with deviation of the cushion geometry with respect to the requirement of Part 25, Appendix F, Part II, the remaining 30 cushion sets were altered to a modified state to ease the evaluation of the fire-blocking layers.

Two cushion construction styles were used. The stock cushion refers to the shape of the cushion as it is found in-service. The modified cushion was made to a shape approaching, but not identical to, what is required by Part 25, Appendix F, Part II. The four major differences between the stock and modified configurations are:

1. The geometric shapes are different. The stock shapes varied widely, fitting whichever seat design that was prescribed. The modified shape is fixed and of consistent rectilinear geometry.

2. The dress cover for the stock cushion covered five of the six cushion faces, leaving the bottom surface exposed. The modified cushion was fully encapsulated by the dress cover.

3. In the stock configuration, the fire-blocking and dress cover layers were adorned with strapping and Velcro. In the modified configuration, these materials were removed.

4. The cushions were different when considering their constituent material degradation. The stock cushion materials were left in their original condition for testing. The modified cushions were altered from the stock condition.

The alteration from a stock to a modified cushion involved removing the fire-blocking layer from each of the remaining stock cushions. The handhold nylon strapping, located on the bottom of the horizontal cushion for flotation purposes, was removed in approximately 50 percent of the modified cushion sets. The used fire-blocking layer was then placed over polyurethane foam block and encapsulated with a wool/nylon dress cover material. These replacement materials were all Technical Center stock, therefore providing some additional uniformity for the remaining cushion sets. The polyurethane foam had a density of 1.8 $lbf/ft^3$ (282.8 $N/m^3$) and the dress cover material was a 90 percent wool and 10 percent nylon blend. The worn fire-blocking layer and the replacement dress cover material were sewn closed with common nylon thread. The seams were located away from the burner flame impingement. The desire was to evaluate the fire-blocking layer behavior, not the nylon thread seams. The resulting standardized cushions closely approximated the standard shapes required per Part 25, Appendix F, Part II.

Second, the orientation of the horizontal cushion did not include flame exposure of the FBL enclosure. Again, this is contrary to Part 25, Appendix F, Part II, which requires all seams and closures on the test specimen be exposed to the flame. When the cushions for this project were modified to fit the seat fixture, excess FBL material resulted. In the process of modification, the enclosure on the FBL was altered sufficiently that the original enclosure was no longer represented. To preclude any difficulty regarding penetration of an altered enclosure, the enclosure was cut out to fit the replacement foam cushion and stitched closed with common nylon thread. The orientation for the modified horizontal cushion was such that the edge located behind the knees when sitting in an actual aircraft seat received the oil burner flame impingement. There were no closure evaluations for any of these tested cushions.

Third, each cushion set was treated as a unique data point. Again, this is contrary to Part 25, Appendix F, Part II which requires three cushion sets and test data averaging to generate the results of one seat cushion evaluation. This three-sample requirement was not followed for this testing program because of the extreme variation in the test specimens when considering material ages, wear profiles, contamination levels, and different FBL blends available. With regard to the

There is one other note regarding unusual procedures used for this project. For the donated material, the number of horizontal (bottom) cushions exceeded the number of vertical (back) cushions by four. Therefore, the cushion sets of the final four seat tests each included the reuse of a previously tested vertical cushion.

## TEST RESULTS.

IN-SERVICE EXAMINATION RESULTS. The in-service seat inspections resulted in a wide array of deterioration data. Wear and contamination are collectively referred to as deterioration. The deterioration was subjectively rated on the five-point rating system, evaluating wear and contamination. As discussed previously, one was the best condition and five was the worst condition. The statistical values are found in table 1. The existing conditions ranged from light to extreme deterioration. The majority of the material conditions were found to be in the intermediate deterioration ranges.

TABLE 1. IN-SERVICE AND DONATED MATERIAL DETERIORATION EVALUATION

| | In-Service Cushions | | Donated Cushions | |
|---|---|---|---|---|
| Number of Samples | 176 | | 38 | |
| Deterioration Mode | Wear | Stain | Wear | Stain |
| Mean | 3.10 | 2.93 | 3.21 | 3.74 |
| Standard Deviation | 1.14 | 1.29 | 0.61 | 0.94 |

The seat cushion designs found during the in-service examinations included FBL encapsulated cushions and fire retardant foam cushions. The FBLs consisted of polybenzimidazole (PBI), Kevlar, Nomex, and other foreign manufactured material, as shown in table 2. The foreign fire-blocking materials were found prominently on the commuter type aircraft. These materials were not tested for this project, but were found mechanically intact and did not exhibit any extreme deterioration conditions.

Initially, seat manufacturers indicated that no FBL cleaning occurred. However, in the time span of this work, some aircraft seat refit projects had been undertaken. During refitting, contaminated fire-blocking layers are not usually cleaned but are instead replaced. In rare instances, seat refit may incorporate the cleaning and repair of the FBL. The resultant work must meet existing regulatory mandates when returned to service. For the materials examined in-service and tested for this project, no repaired seats were found. Based on the rarity noted, the investigation of repaired FBL was not included in this project.

TABLE 2. FIRE-BLOCKING LAYER MATERIAL BREAKDOWN BY AIRPORT

| Atlantic City International Airport | | Stewart International Airport | |
|---|---|---|---|
| Total Seats Examined | 109 | Total Seats Examined | 30 |
| PBI Blends | 48 | PBI Blends | 21 |
| Kevlar/Nomex Blends | 11 | Kevlar/Nomex Blends | 9 |
| Fire Retardant Foams | 9 | Fire Retardant Foams | 0 |
| Other: | 41 | Other: | 0 |
| Newark International Airport | | Totals | |
| Total Seats Examined | 37 | Total Seats Examined | 176 |
| PBI Blends | 19 | PBI Blends | 88 |
| Kevlar/Nomex Blends | 18 | Kevlar/Nomex Blends | 38 |
| Fire Retardant Foams | 0 | Fire Retardant Foams | 9 |
| Other | 0 | Other | 41 |

FIRE TESTING. The fire test specimens are grouped for analysis and identified as a lettered series A through E. Table 3 lists the pertinent statistics. Six tests were excluded for extenuating circumstances. Four of the six excluded tests, numbers 35, 36, 37, and 38, reused previously tested components and the remaining two tests, numbers 17 and 24, had horizontal cushions that could not be dated.

TABLE 3. SEAT CUSHION TEST SERIES IDENTIFICATION

| | Series A | Series B | Series C | Series D | Series E |
|---|---|---|---|---|---|
| Test Configuration | Stock | Stock | Modified | Modified | Modified |
| Horizontal FBL Material | PBI | PBI | Kevlar | PBI | PBI |
| Vertical FBL Material | Kevlar-Nomex | PBI | Kevlar | Kevlar-Nomex | PBI |
| Number of Samples | 3 | 5 | 4 | 9 | 11 |
| Tests Forming the Series | 1-3 | 4-8 | 27-30 | 16, 18-23, 25, 26 | 9-15, 31-34 |

Donated and In-Service Material Deterioration Comparison. The donated fire-blocking materials consisted primarily of varying blends of PBI, Nomex, and Kevlar, and these were the focus of the testing sequence. The manufacture date, fire-blocking material, wear, and contamination ratings are found in tables 4 and 5. Overall, the mechanical integrity of the FBLs was acceptable. Except the specimen used in test number five, no unusually large penetrations were found. Most penetrations were wear generated, circular in nature, and one inch (2.54 cm) or less in diameter. Based on values given in table 1, the condition of the donated cushions represented the average level of deterioration found during the in-service cushion examinations. Therefore, the oil burner test results are considered a reasonable, relative measure of the fire endurance performance of typical in-service fire-blocking layers.

## TABLE 4. AIRCRAFT SEAT CUSHION FIRE TESTING RESULTS

| Continued Compliance Test Number and Series | Date Test Performed | Initial Test Weight (lbf) | Final Test Weight (lbf) | Percent Weight loss (%) | Horizontal Top Surface Burn Length (inch) | Horizontal Bottom Surface Burn Length (inch) | Vertical Front Surface Burn Length (inch) | Vertical Back Surface Burn Length (inch) |
|---|---|---|---|---|---|---|---|---|
| A 3 | 10/18/94 | 5.44 | 4.94 | 9.19 | 10.25 | 13.00 | 15.00 | 0.00 |
| 1 | 10/18/94 | 5.50 | 5.10 | 7.27 | 7.25 | 15.50 | 10.50 | 0.00 |
| 2 | 10/18/94 | 5.18 | 4.66 | 10.04 | 9.75 | 10.75 | 17.75 | 0.00 |
| B 4 | 10/20/94 | 5.99 | 5.14 | 14.19 | 10.00 | 11.75 | 17.50 | 9.50 |
| 5 | 10/20/94 | 6.37 | 4.62 | 27.47 | 15.50 | 17.00 | 17.50 | 13.50 |
| 6 | 10/20/94 | 6.01 | 5.33 | 11.31 | 8.00 | 15.00 | 14.75 | 2.25 |
| 7 | 10/24/94 | 6.41 | 5.83 | 9.05 | 9.25 | 11.25 | 15.75 | 0.00 |
| 8 | 10/24/94 | 6.39 | 5.66 | 11.42 | 13.00 | 6.00 | 18.00 | 0.00 |
| C 29 | 11/30/94 | 5.93 | 5.62 | 5.23 | 5.25 | 5.50 | 7.75 | 0.00 |
| 30 | 11/30/94 | 5.48 | 5.06 | 7.66 | 5.00 | 10.00 | 10.00 | 0.00 |
| 27 | 11/30/94 | 5.69 | 5.42 | 4.75 | 3.50 | 6.00 | 7.00 | 0.00 |
| 28 | 11/30/94 | 5.78 | 5.51 | 4.67 | 5.00 | 6.00 | 7.50 | 0.00 |
| D 16 | 11/10/94 | 5.49 | 5.20 | 5.28 | 7.00 | 1.50 | 11.00 | 0.00 |
| 18 | 11/10/94 | 5.53 | 5.25 | 5.06 | 6.00 | 1.75 | 9.50 | 0.00 |
| 19 | 11/14/94 | 5.65 | 5.35 | 5.31 | 6.25 | 2.00 | 9.50 | 0.00 |
| 20 | 11/14/94 | 5.61 | 5.30 | 5.53 | 7.00 | 4.00 | 10.00 | 0.00 |
| 21 | 11/14/94 | 5.34 | 5.00 | 6.37 | 8.50 | 3.75 | 12.25 | 0.00 |
| 22 | 11/14/94 | 5.58 | 5.31 | 4.84 | 6.00 | 1.50 | 9.50 | 0.00 |
| 25 | 11/14/94 | 5.43 | 5.12 | 5.71 | 7.00 | 1.25 | 10.00 | 0.00 |
| 26 | 11/14/94 | 5.39 | 5.03 | 6.68 | 7.00 | 5.25 | 9.00 | 0.00 |
| 23 | 11/14/94 | 5.68 | 5.38 | 5.28 | 7.25 | 1.25 | 9.00 | 0.00 |
| E 31 | 12/1/94 | 5.21 | 4.88 | 6.33 | 5.00 | 5.50 | 9.50 | 0.00 |
| 32 | 12/1/94 | 5.33 | 4.95 | 7.13 | 6.00 | 8.50 | 9.25 | 0.00 |
| 34 | 12/1/94 | 5.60 | 5.24 | 6.43 | 4.00 | 9.50 | 7.00 | 0.00 |
| 10 | 10/27/94 | 5.20 | 4.79 | 7.88 | 7.00 | 5.50 | 9.25 | 0.00 |
| 11 | 11/9/94 | 5.31 | 4.78 | 9.98 | 10.00 | 6.25 | 10.50 | 0.00 |
| 14 | 11/10/94 | 5.24 | 4.77 | 8.97 | 6.50 | 9.75 | 9.25 | 0.00 |
| 33 | 12/1/94 | 5.54 | 5.19 | 6.32 | 5.50 | 5.25 | 9.00 | 0.00 |
| 9 | 10/27/94 | 5.14 | 4.82 | 6.23 | 5.50 | 5.50 | 8.25 | 0.00 |
| 15 | 11/10/94 | 5.17 | 4.72 | 8.70 | 7.50 | 5.50 | 11.00 | 0.00 |
| 12 | 11/9/94 | 5.02 | 4.74 | 5.58 | 7.50 | 4.50 | 10.50 | 0.00 |
| 13 | 11/10/94 | 5.30 | 4.80 | 9.43 | 10.00 | 10.50 | 11.00 | 0.00 |
| n/a 17 | 11/10/94 | 5.43 | 5.10 | 6.08 | 7.50 | 2.00 | 11.50 | 0.00 |
| 24 | 11/14/94 | 5.68 | 5.33 | 6.16 | 7.00 | 3.50 | 12.00 | 0.00 |
| 37@ | 12/1/94 | 5.47 | 5.09 | 6.95 | 8.25 | 5.50 | 7.50 | 0.00 |
| 35@ | 12/1/94 | 5.34 | 4.93 | 7.68 | 5.50 | 8.50 | 7.00 | 0.00 |
| 36@ | 12/1/94 | 5.06 | 4.51 | 10.87 | 11.00 | 10.50 | 10.25 | 0.00 |
| 38@ | 12/1/94 | 5.57 | 5.12 | 8.08 | 6.50 | 6.25 | 8.25 | 0.00 |

@ - Tests involved reused vertical cushions
n/a - Not applicable

a - PBI derivative
b - Kevlar derivative
c - Nomex/Kevlar derivative

TABLE 5. AIRCRAFT SEAT CUSHION WEAR AND MANUFACTURE INFORMATION

| Continued Compliance Test Number and Series | Horizontal Cushion | | | | Vertical Cushion | | | |
|---|---|---|---|---|---|---|---|---|
| | Mfr. Date | Wear Rating | Stain Rating | FBL Material | Mfr. Date | Wear Rating | Stain Rating | FBL Material |
| A 3 | 9/88 | 2 | 4 | a | 10/87 | 3 | 3 | c |
| 1 | 8/89 | 2 | 3 | a | 4/91 | 3 | 3 | c |
| 2 | 12/90 | 3 | 3 | a | 4/86 | 3 | 2 | c |
| B 4 | 8/85 | 4 | 5 | a | 1/88 | 4 | 2 | a |
| 5 | 9/86 | 3 | 5 | a | 8/86 | 3 | 3 | a |
| 6 | 7/88 | 2 | 2 | a | 1/88 | 2 | 2 | a |
| 7 | 6/92 | 4 | 4 | a | 1/88 | 3 | 2 | a |
| 8 | 8/93 | 3 | 1 | a | 1/88 | 3 | 2 | a |
| C 29 | 12/86 | 4 | 4 | b | no tag | 4 | 4 | b |
| 30 | 1/87 | 3 | 4 | b | no tag | 4 | 3 | b |
| 27 | 1/87 | 4 | 3 | b | no tag | 3 | 4 | b |
| 28 | 1/87 | 3 | 3 | b | no tag | 4 | 3 | b |
| D 16 | 9/88 | 4 | 4 | a | 1/92 | 3 | 2 | c |
| 18 | 9/88 | 3 | 4 | a | 1/92 | 3 | 4 | c |
| 19 | 9/88 | 3 | 4 | a | 3/87 | 3 | 4 | c |
| 20 | 9/88 | 3 | 4 | a | 1/92 | 3 | 3 | c |
| 21 | 9/88 | 3 | 4 | a | 9/85 | 3 | 4 | c |
| 22 | 9/88 | 3 | 4 | a | 4/91 | 3 | 4 | c |
| 25 | 9/88 | 3 | 3 | a | 11/85 | 4 | 4 | c |
| 26 | 9/88 | 3 | 4 | a | 2/86 | 3 | 4 | c |
| 23 | 11/88 | 3 | 4 | a | 9/85 | 4 | 5 | c |
| E 31 | 6/86 | 4 | 4 | a | 10/86 | 3 | 4 | a |
| 32 | 6/86 | 4 | 4 | a | 10/86 | 3 | 4 | a |
| 34 | 7/86 | 4 | 4 | a | 6/86 | 4 | 4 | a |
| 10 | 7/86 | 3 | 5 | a | 11/91 | 2 | 3 | a |
| 11 | 7/86 | 3 | 4 | a | 7/88 | 3 | 2 | a |
| 14 | 7/86 | 3 | 4 | a | 1/87 | 3 | 3 | a |
| 33 | 6/87 | 4 | 3 | a | 10/86 | 4 | 4 | a |
| 9 | 1/88 | 3 | 2 | a | 1/88 | 4 | 1 | a |
| 15 | 1/88 | 4 | 3 | a | 1/88 | 3 | 2 | a |
| 12 | 1/88 | 3 | 2 | a | 1/88 | 3 | 2 | a |
| 13 | 1/88 | 4 | 3 | a | 1/88 | 3 | 2 | a |
| n/a 17 | not found | 3 | 4 | a | 2/91 | 3 | 3 | c |
| 24 | not found | 3 | 4 | a | 2/86 | 4 | 4 | c |
| 37@ | 3/85 | 4 | 5 | a | n/a | n/a | n/a | n/a |
| 35@ | 4/86 | 2 | 5 | a | n/a | n/a | n/a | n/a |
| 36@ | 12/87 | 3 | 5 | a | n/a | n/a | n/a | n/a |
| 38@ | 3/88 | 3 | 5 | a | n/a | n/a | n/a | n/a |

@ - Tests involved reused vertical cushions
n/a - Not applicable

a - PBI derivative
b - Kevlar derivative
c - Nomex/Kevlar derivative

Stock Test Results. The weight loss profiles of the stock tests are shown in figures 1 and 2. The eight stock tests resulted in five tests exceeding 10 percent weight loss. The stock cushion tests did result in several instances where burn lengths exceeded the 17 inch (43.2 cm) requirement. In either case, the standard pass/fail criteria has no relevance in the stock configuration tests, which are expected to have higher test values. The data scatter was wide for both stock test series A and B, as seen in tables 4 and 5. Excluding test number five, no unusual fire behavior was observed during the testing.

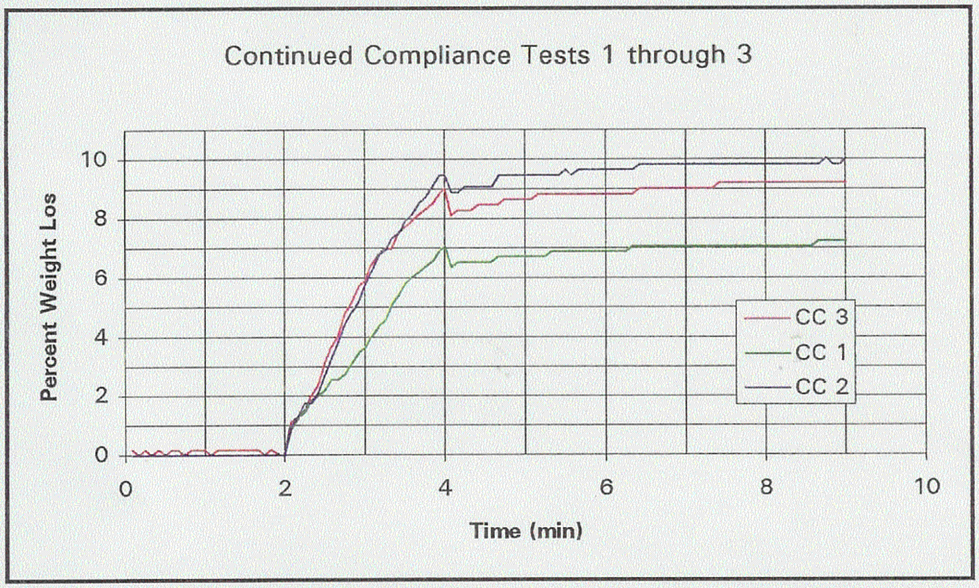


FIGURE 1. PERCENT WEIGHT LOSS PROFILES, TESTS 1 THROUGH 3

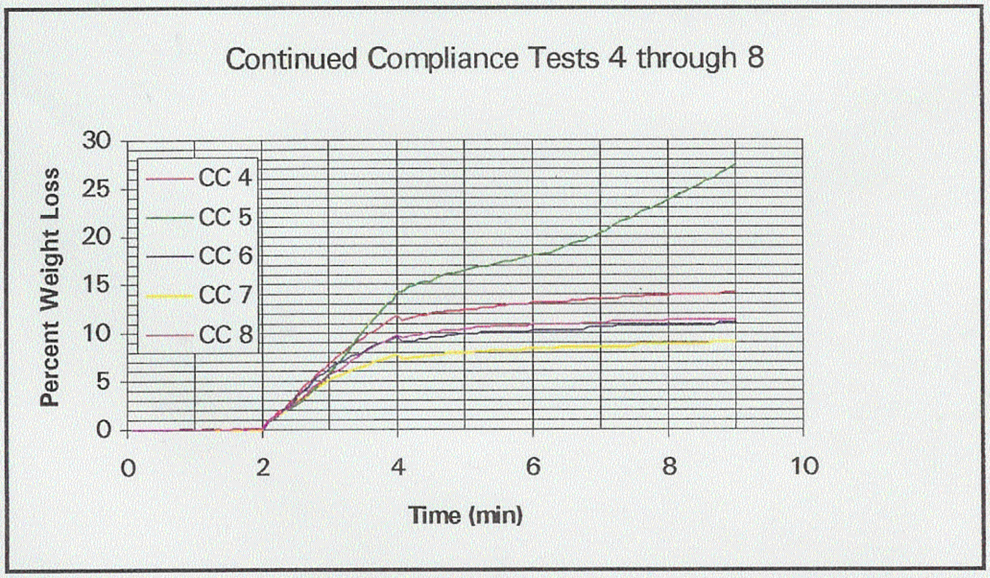


FIGURE 2. PERCENT WEIGHT LOSS PROFILES, TESTS 4 THROUGH 8

Test number five resulted in a weight loss of 27.47 percent. Excessive damage resulted from penetrations in the vertical cushion FBL. The three penetrations were located on the back side bottom corner closest to the burner (see figure 3). They consisted of two, four-inch by one-half-inch (10.2-cm by 1.27-cm) vertical, parallel slashes with a separation of one inch (2.54-cm); and a one-inch (2.54-cm) -diameter hole located approximately two inches (5.08 cm) below and one inch (2.54 cm) to the side, opposing the burner, from the vertical slashes. During the portion of the test when the oil burner was turned off, burning originated from the backside of the cushion. This behavior was solely due to the FBL penetrations.

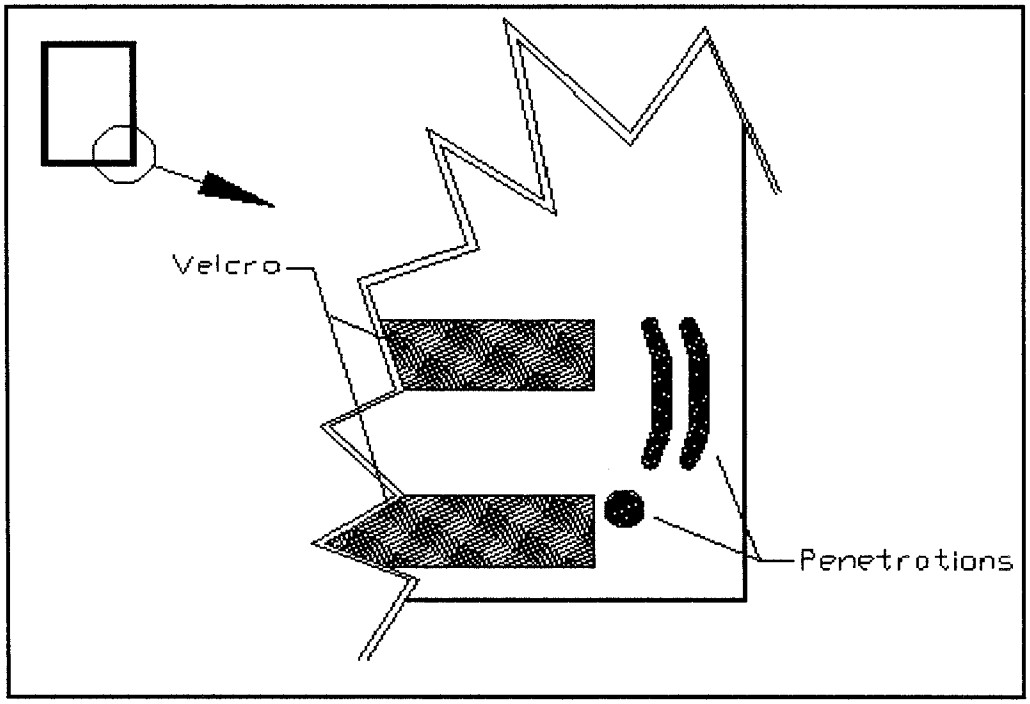


FIGURE 3. TEST NUMBER FIVE FIRE-BLOCKING LAYER PENETRATIONS
(vertical cushion, cutaway view of rear facing corner closest to burner cone)

Modified Test Results. The weight loss profiles of the modified tests are shown in figures 4 through 9. The 30 modified shaped cushion tests yielded one failure and that was for a weight loss greater than 10 percent (see table 4). There were no differences noted in the test performance based on the lack of or the presence of the strapping affixed to the horizontal cushions for flotation purposes.

The percent weight loss was 10.87 for test number 36. This test was one of the final four tests performed which had reused vertical cushions. In review of this test, the final weight loss was mainly affected by the involvement of the reused vertical cushion. Had the vertical cushion been in an untested condition, the entire cushion set would have been expected to pass in the same manner as the other 29 tests.

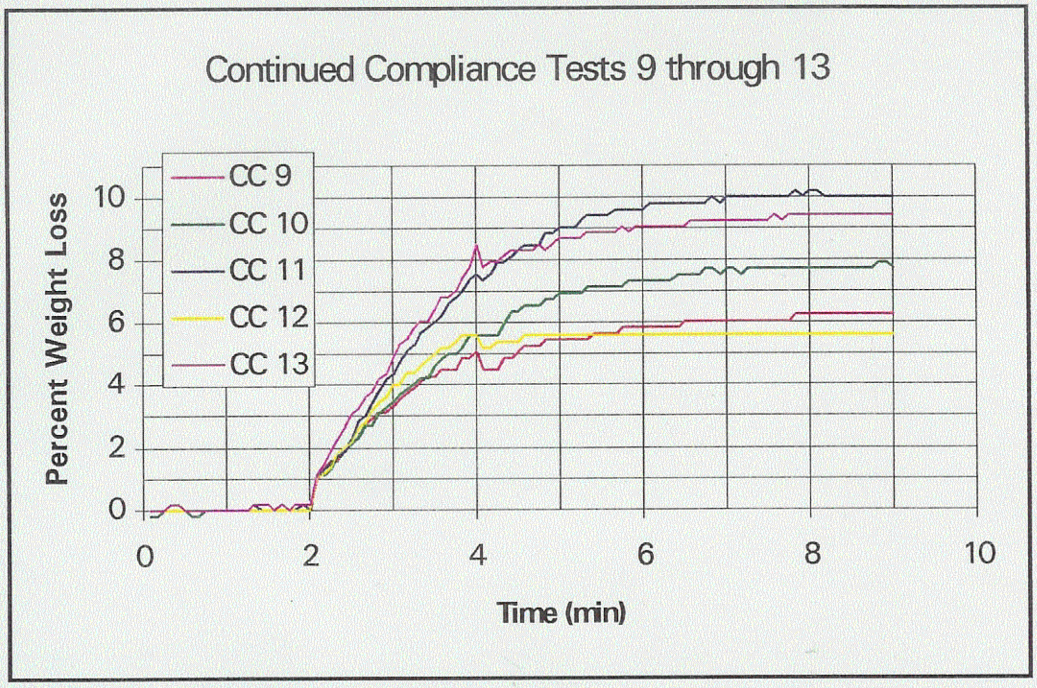


FIGURE 4. PERCENT WEIGHT LOSS PROFILES, TESTS 9 THROUGH 13

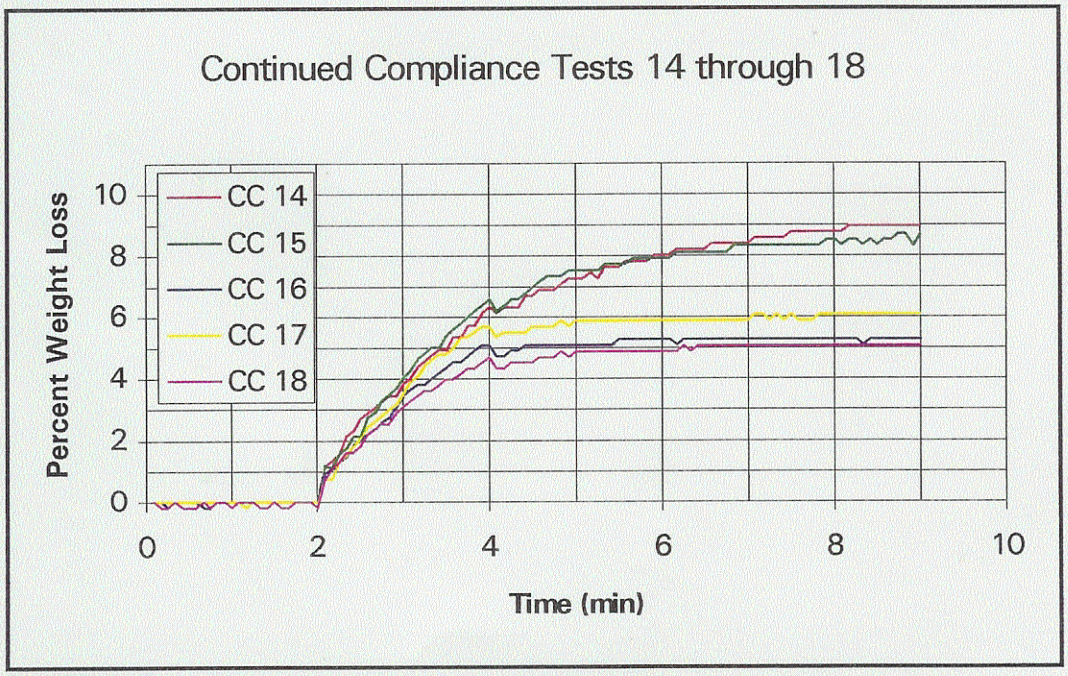


FIGURE 5. PERCENT WEIGHT LOSS PROFILES, TESTS 14 THROUGH 18

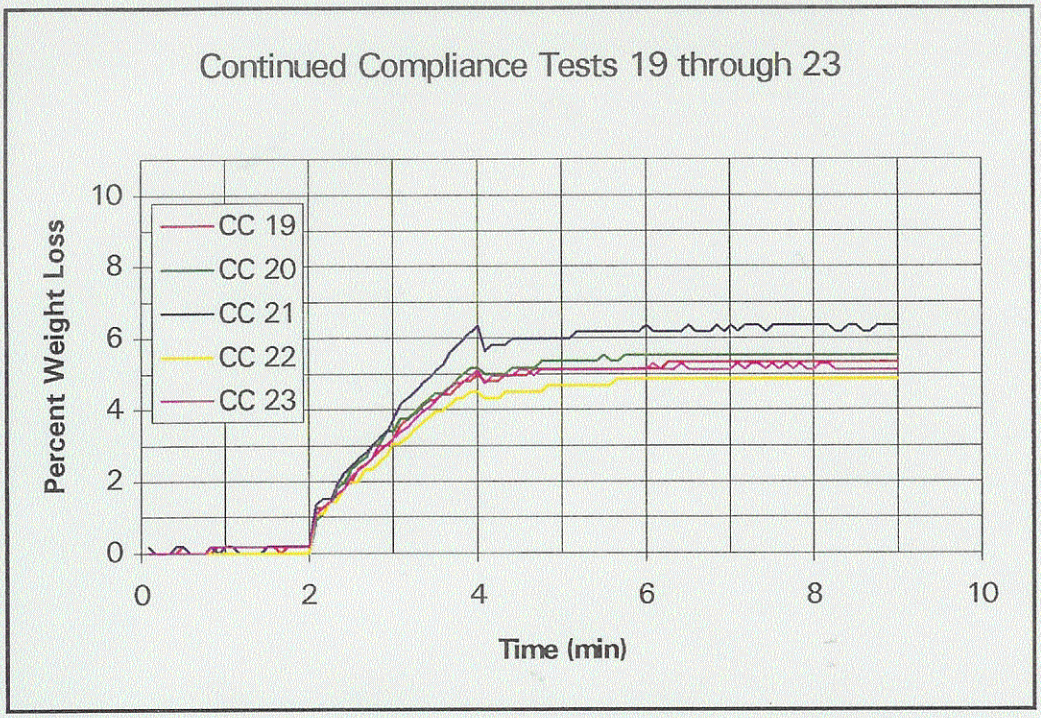


FIGURE 6. PERCENT WEIGHT LOSS PROFILES, TESTS 19 THROUGH 23

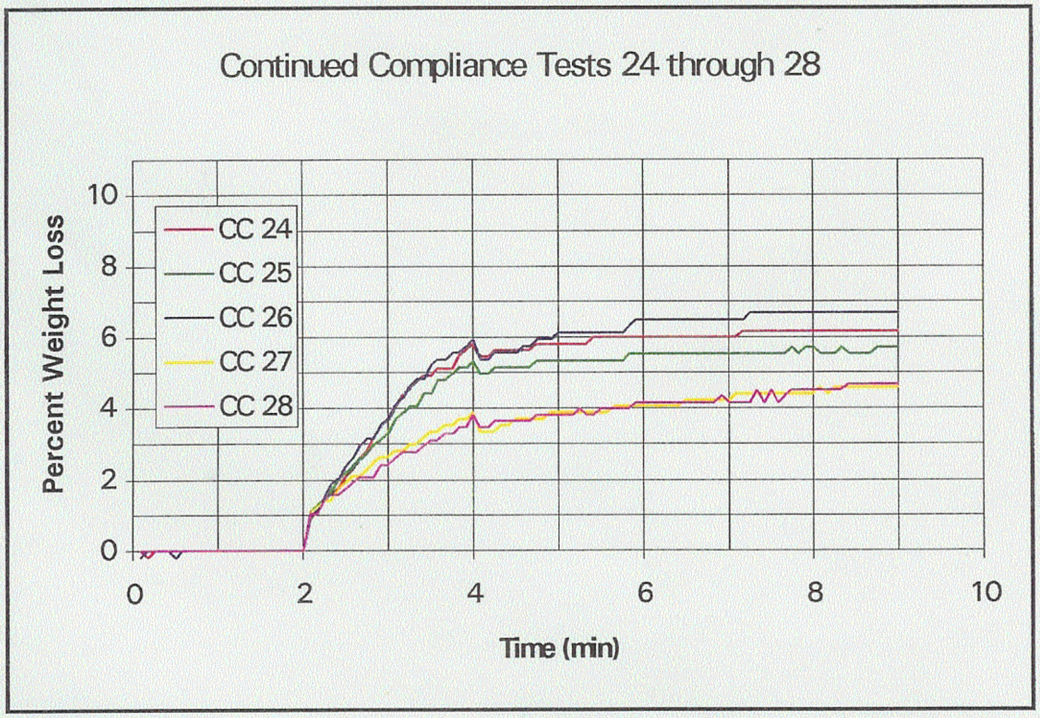


FIGURE 7. PERCENT WEIGHT LOSS PROFILES, TESTS 24 THROUGH 28

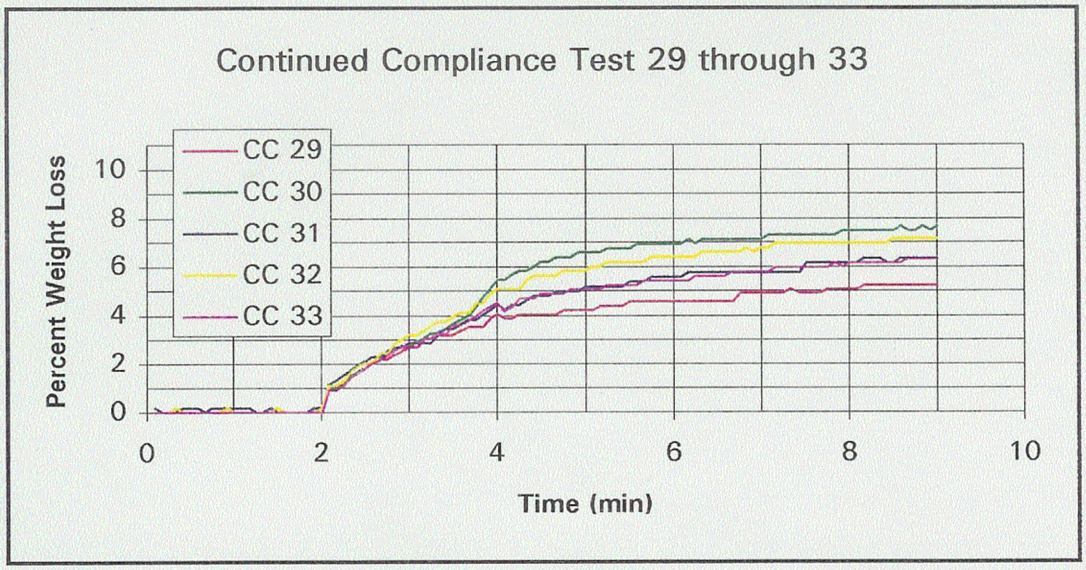


FIGURE 8. PERCENT WEIGHT LOSS PROFILES, TESTS 29 THROUGH 33

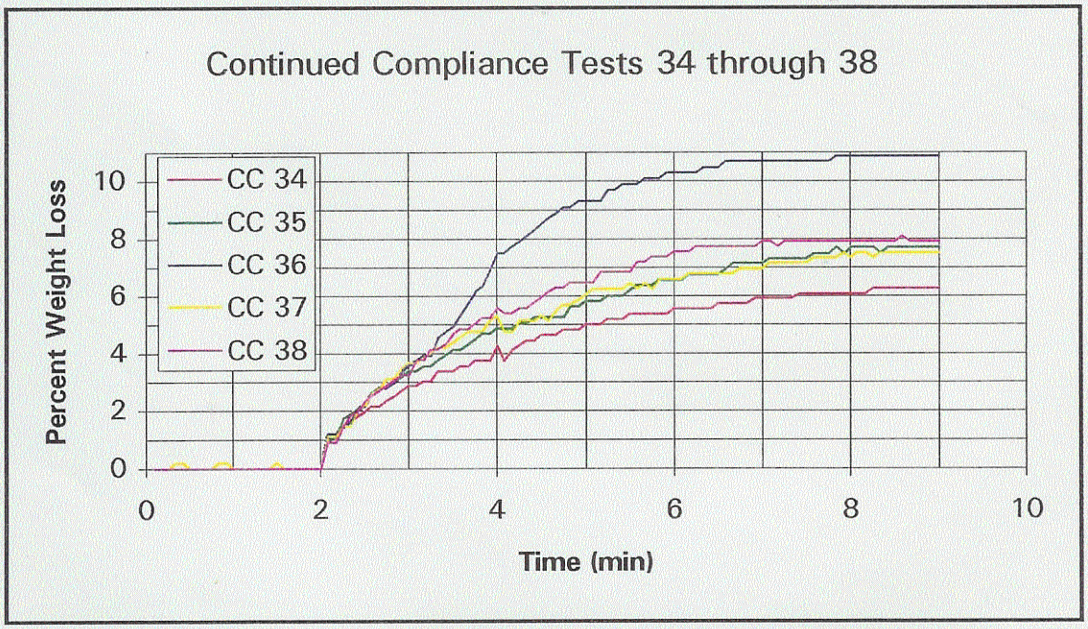


FIGURE 9. PERCENT WEIGHT LOSS PROFILES, TESTS 34 THROUGH 38

Overall Test Results Comparison. The overall breakdown of all tests based on percent weight loss is given in table 6. Figures 10 through 15 illustrate the test results comparatively.

TABLE 6. TEST RESULTS BREAKDOWN FOR ALL SHAPES, PERCENT WEIGHT LOSS

| Percent Weight Loss | >10% | 9%-10% | 8%-9% | 7%-8% | 6%-7% | 5%-6% | <5% |
|---|---|---|---|---|---|---|---|
| Number of Samples | 6 | 4 | 3 | 5 | 9 | 8 | 3 |

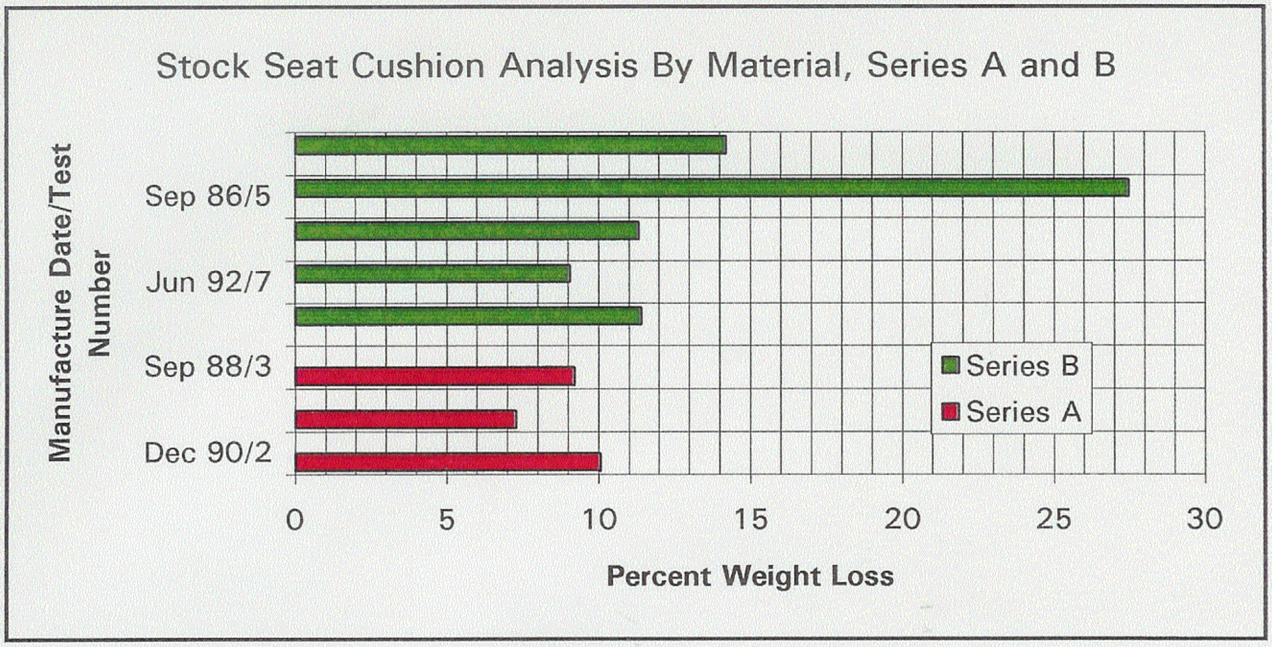


FIGURE 10. TEST RESULTS BY MATERIAL, SERIES A AND B

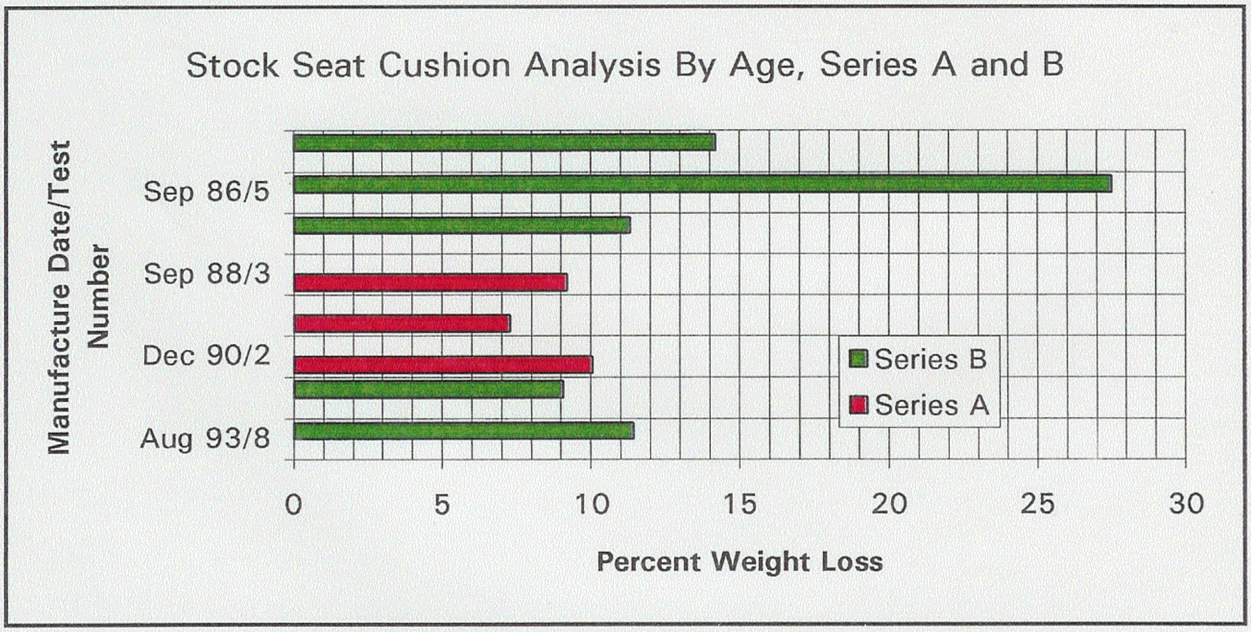


FIGURE 11. TEST RESULTS BY AGE, SERIES A AND B


FIGURE 12. TEST RESULTS BY MATERIAL, SERIES C, D, AND E

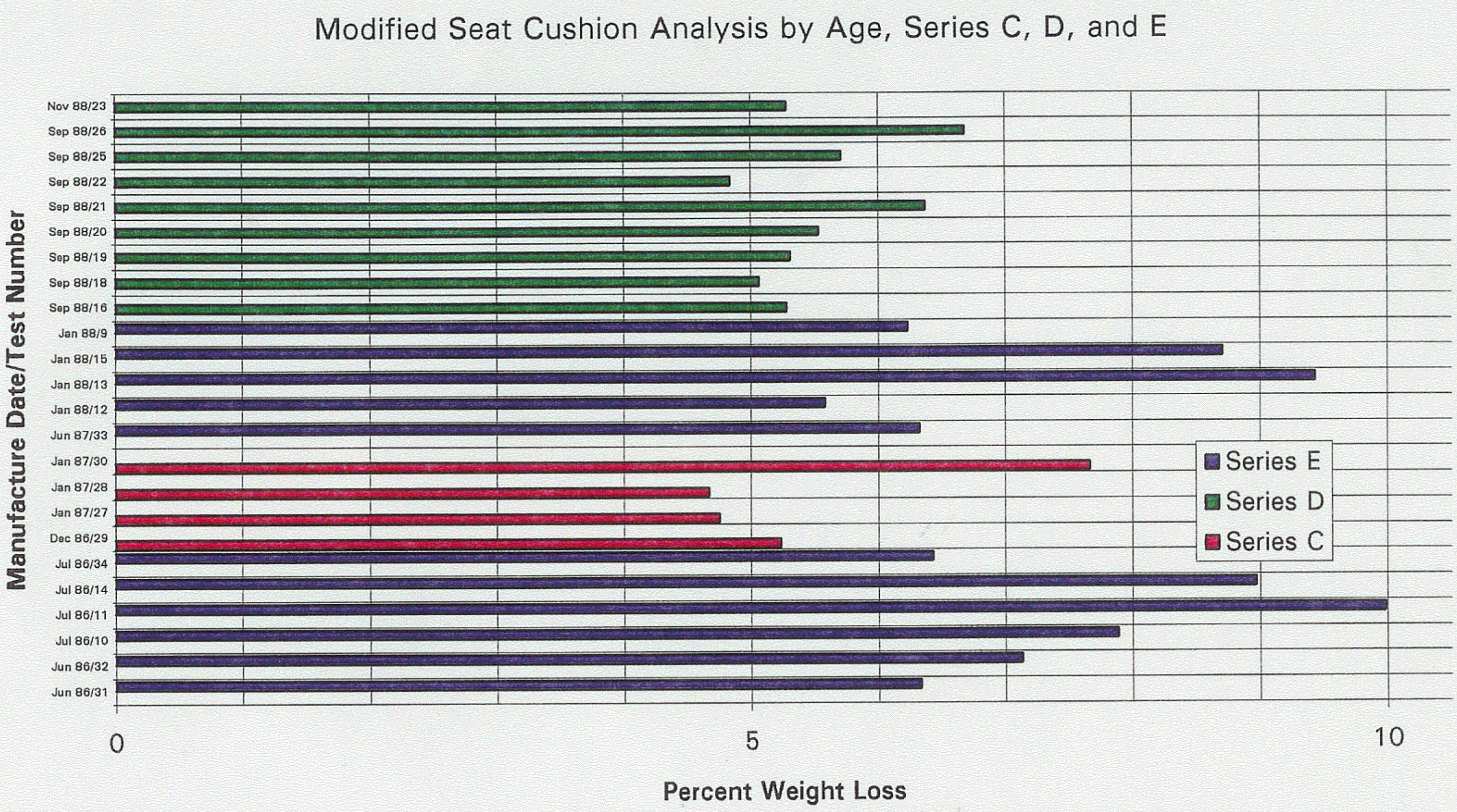


FIGURE 13. TEST RESULTS BY AGE, SERIES C, D, AND E

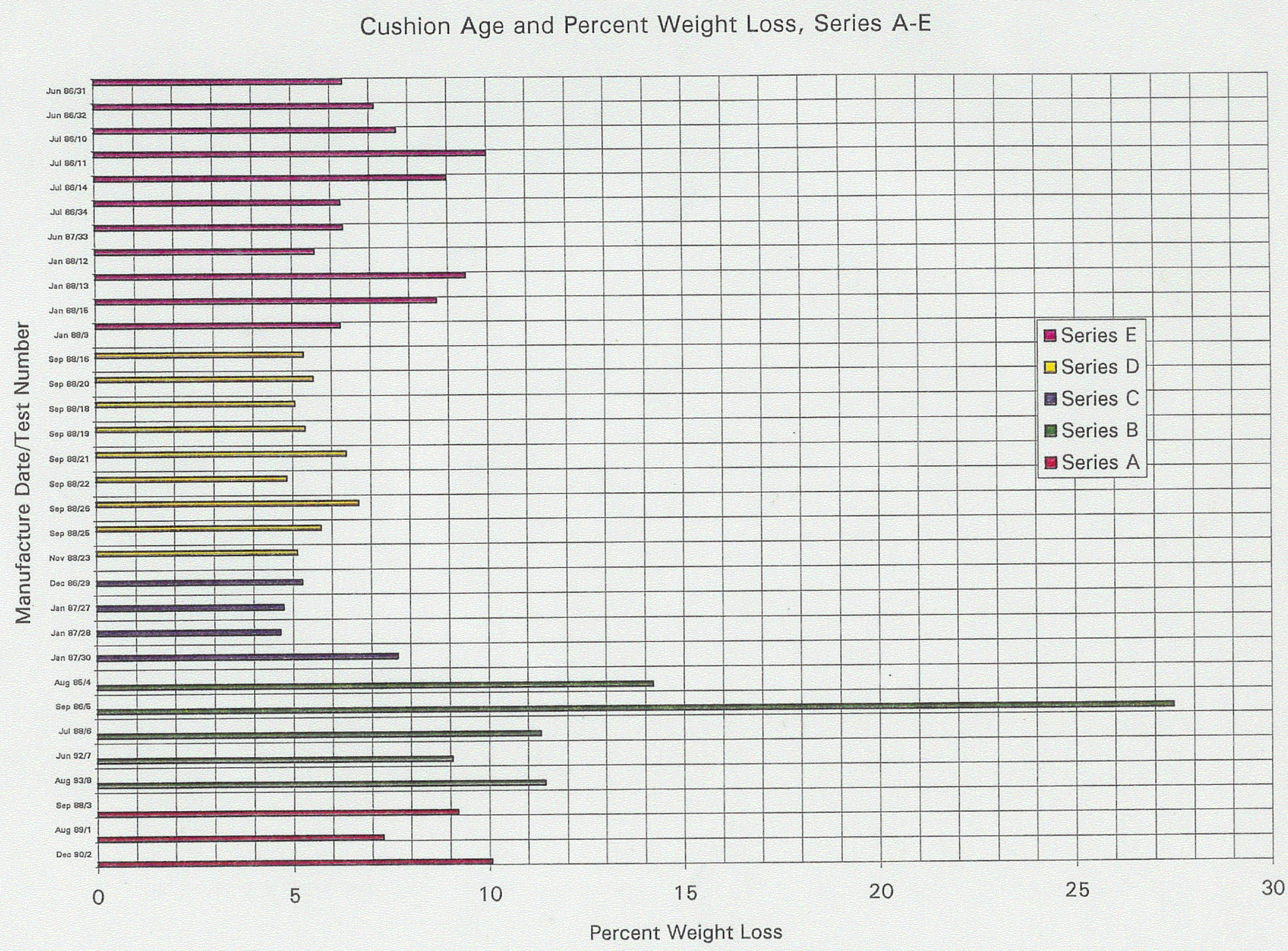


FIGURE 14. OVERALL TEST RESULTS

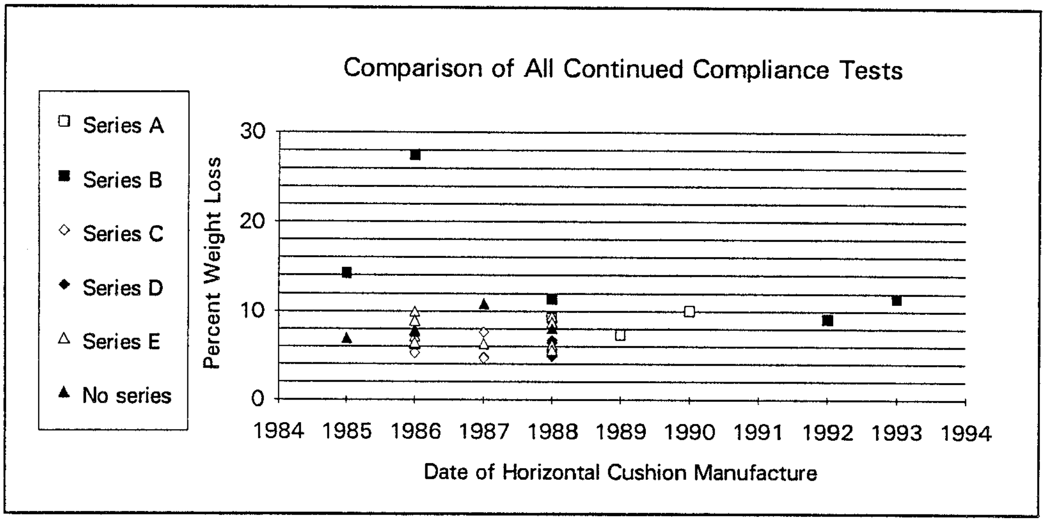


FIGURE 15. COMPARISON OF ALL CONTINUED COMPLIANCE TESTS

## SUMMARY

What appears to be poor fire endurance was evident in the stock cushion group tests. The apparent failures were largely weight loss infractions. The stock test performance must be addressed with caution. The requirements of Part 25, Appendix F, Part II cannot be explicitly applied to the stock tests. The primary requirement for a standard shaped cushion was not met. However, the eight cushion sets were tested in the stock configuration to see if any meaningful trend relating to age would be observed. After the testing, no discernible pattern was readily noticed (see figures 10 and 11). The scattered results from these eight tests illustrated the need to alter the remaining cushions to a modified condition to facilitate data interpretation.

The recognizable variations in the stock and standard test results were attributed to seat cushion construction differences, physical properties of the different cushion materials, the age and the deterioration profiles of the dress covers, the polyurethane foam cushions, and the fire-blocking layers. The construction and material differences between the stock and modified cushions are considered the largest factors affecting the fire endurance of the different shapes. The standard seat test fixture is an angle iron assembly which exposes approximately 300 square inches (0.194 square meters) of the bottom of the horizontal cushion. The modified cushion was fully encapsulated by the FBL and the dress cover. Both the dress cover and seat foam used in the modified cushions were new material, not service worn. The stock cushion had no dress cover on the bottom surface of the horizontal cushion. Further, the materials composing the stock shapes were all worn. The large difference in test performance between the stock and modified shapes can be accounted for by the dynamics related to the exposed bottom portion of the stock fire-blocking layer, left largely exposed by the standard test fixture and the deterioration of the dress cover and polyurethane foam stock materials.

No test failures resulted solely from excessive burn length. The stock cushions that performed poorly when considering burn length also performed poorly in the weight loss realm. The weight loss parameter was taken as the more significant of the two conditions for the stock tests. The modified cushions did not fail due to burn length because new dress cover material was used. For the five stock tests exceeding 10 percent weight loss, burn lengths on the vertical cushions were measured on the back side in three instances and exceeded 17 inches (43.2 cm) on the forward surface in four tests.

The seat cushion tests, for the most part, followed a generic sequence of events. Upon flame impingement, the vertical edge of the horizontal cushion facing the burner lost its dress cover due to combustion. The flame also contacted the upper and lower horizontal cushion surfaces of the horizontal cushion near the burner cone. The burner flame also tracked in an upward arc across the front, vertical face of the vertical cushion. The arc started from the intersection of the horizontal and vertical cushions, close to the burner, and swept upward further away from the flame source. A typical burn pattern is shown in figure 16.

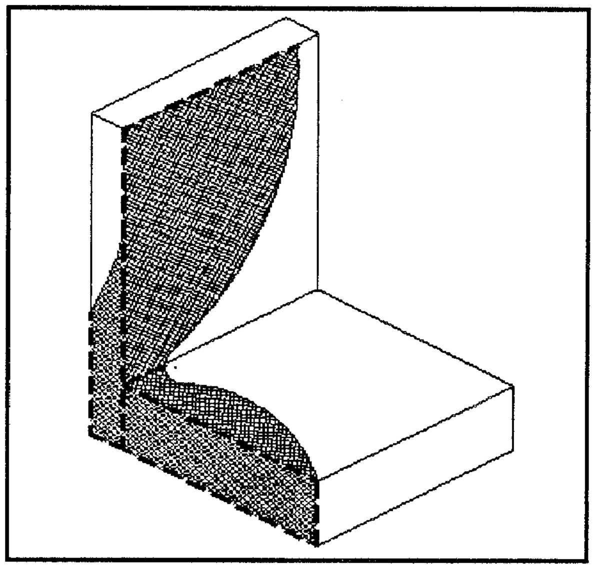

FIGURE 16. TYPICAL BURN PATTERN RESULTING FROM SEAT TEST
(typically damaged areas are cross-hatched)

The dress cover material was consumed in these areas as well. The fire-blocking materials subjected to the oil burner flame were only affected in the flame contact zone and the immediate vicinity of the burner jet. The FBLs underwent a thermal degradation which resulted in a black, charred, brittle state. In many instances, a crack formed on the vertical cushion edge which received the direct flame contact. This crack had no further negative effect in the combustion of the cushion. Excluding the vertical edge facing the burner cone, the mechanical integrity of the FBL materials were never compromised due to flame impingement.

Test number five demonstrated the effect of FBL penetrations. The two, four-inch by one-half-inch (10.2-cm by 1.27-cm) slashes plus the one-inch (2.54 cm) -diameter circle, provide a total penetration area of 4.78 square inches (30.8 square centimeters). Several other cushions also had penetrations in differing spatial orientations which negated propagational behavior as seen in test number five. These penetrations, found in cushions tests 9, 11, and 33, were characterized as one-inch (2.54-cm) or less diameter holes being mechanically created by vibration and friction from contacting rivet heads or other such features in the stock seat frame. The orientation of the burner flame to the penetration played the obvious factor regarding fire development.

Penetrations to the FBL must be considered very carefully beyond the scope of a standardized test. During this work, some threshold phenomena is evident when considering the successful or failed combustion of a seat cushion. The penetration orientation with respect to a flame, the surface area of the penetration, the seat cushion material(s) and construction, and the dynamics of the flame exposure impact this threshold behavior. In the case of test number five, the penetrations were not subject to direct flame contact. However, the size of the penetrations allowed acceptable ventilation inside the fire-blocking layer resulting in combustion of the foam cushion. The danger of penetrations is demonstrated by test number five. Yet, tests 9, 11, and 33 demonstrated smaller insignificant penetrations.

Successful fire development requires the presence of fuel, oxygen, heat, and the initiation and the continuation of a chemical reaction. The mechanical integrity of the FBL is necessary to prevent/retard the polyurethane from burning. During the intense flame exposure of the test, the inner cushion volume is filled with fuel vapors resulting from thermally degraded polyurethane. Significant heat is provided to the cushion interior by the burner flame. The encapsulating effect provided by the FBL prevents sufficient oxygen from entering the volume, prohibiting combustion. Therefore, any properly oriented penetration in the FBL may defeat the desired suppressive effect.

When examining figures 1, 2, and 4 through 9, the percent weight loss values at the oil burner initial and final impingement times exhibit discontinuities. The discontinuities allude to instantaneous decreases or increases in the cushion mass. Physically, this is not possible. These discontinuities are a result of the fluid dynamics of the burner jet impacting the seat test fixture on the scale. Analyzing the initial and final impingement, the associated drop and gain in the weight of the cushion set is nearly offset. By canceling these discontinuities, since the direction and magnitude of the discontinuities are opposing, then adjusting for the differences, the percent weight loss trend portrays a more realistic behavior.

Table 7 illustrates the statistics associated with the test series for this project. For specific test specimen data see table 4. The similar standard deviations for the initial weights indicate the cushion fabrication was reasonably consistent for all series. Examining the results of the percent weight loss for the stock and modified series demonstrates a significant difference. The statistics for the stock series cushions clearly support the basis for standardizing the final 30 cushion sets. For the three modified series, C, D, and E, the mean value percent weight losses indicate the fire-blocking materials performed acceptably. There were no outlying failures in any of the modified cushion series tests.

The work performed addresses questions regarding the continued fire endurance of aircraft seat cushions. The main component in the cushion fire endurance is the fire-blocking layer. The accident which presented conditions leading investigators to question the current level of safety

TABLE 7. STATISTICAL OVERVIEW OF THE PROJECT

| Series | A | B | C | D | E | Stock | Modified |
|---|---|---|---|---|---|---|---|
| Number of Samples | 3 | 5 | 4 | 9 | 11 | 8 | 24 |
| Percent Weight Loss | | | | | | | |
| Mean | 8.83 | 14.69 | 5.58 | 5.56 | 7.54 | 12.49 | 6.71 |
| Median | 9.19 | 11.42 | 4.95 | 5.31 | 7.13 | 10.68 | 6.38 |
| Standard Deviation | 1.16 | 6.60 | 1.22 | 0.57 | 1.44 | 5.98 | 2.63 |
| Range | 2.77 | 18.42 | 3.09 | 1.84 | 4.40 | 20.20 | 6.30 |
| Initial Weight | | | | | | | |
| Mean | 5.37 | 6.23 | 5.72 | 5.52 | 5.28 | 5.91 | 5.44 |
| Median | 5.44 | 6.37 | 5.74 | 5.53 | 5.24 | 6.00 | 5.45 |
| Standard Deviation | 0.14 | 0.19 | 0.16 | 0.11 | 0.16 | 0.45 | 0.22 |
| Range | 0.32 | 0.42 | 0.45 | 0.34 | 0.58 | 1.23 | 0.91 |

for seat cushions was operated by a foreign air carrier [1, p. 1]. The FBL material in that cabin, intended as a shorter life span material than actually in service, was also of foreign manufacture and based on graphitic material [5, 6]. In reviewing the materials found on the U.S. transport category aircraft examined, FBL materials were prominently blends of PBI, Nomex, and Kevlar. No graphite-based FBLs were found.

The fire-blocking materials PBI, Nomex, and Kevlar blends were evaluated through 38 tests. Each cushion set tested presented a data point uniquely associated with time and some quantity of deterioration. With the donated FBL material comparing well with in-service cushions regarding deterioration, the modified cushions, when tested, demonstrated continued fire endurance regardless of age, routine wear, or routine contamination.

One factor arising from this test sequence requiring caution is the concern of FBL penetration. Although highly situation dependent, the testing has shown the mechanical integrity of the FBL does have some finite bound, yet undetermined.

## CONCLUSIONS

1. The donated seat cushions used for testing were comparable to the in-service material examined in active transport category aircraft when considering deterioration. This determination was based on inspections of the donated and in-service cushions.

2. The modified cushion test results, as seen in table 4 and figures 14 and 15, show that the worn fire-blocking layers maintained fire endurance with respect to Part 25, Appendix F, Part II.

3. Penetrations in fire-blocking layers may or may not have an effect on the fire endurance of the seat cushions. There is a threshold phenomena, not evaluated during this work, which determines the success or failure of seat cushion combustion.

# REFERENCES


1. "Aircraft Accident Report NTSB/AAR-93/07, Inadvertent In-Flight Slat Deployment, China Eastern Airlines Flight 583, McDonnell Douglas MD-11, B-2171, 950 Nautical Miles South of Shemya, Alaska, April 6, 1993," National Transportation Safety Board, Washington, D.C., 27 October 1993.

2. National Transportation Safety Board (NTSB) letter to Administrator David R. Hinson (Federal Aviation Administration), Washington, D.C., 10 November 1993.

3. Hall-Daschle, Linda (Deputy Administrator, Federal Aviation Administration), letter to Chairman Carl W. Vogt (National Transportation Safety Board), Washington, D.C., 7 February 1994.

4. Aircraft Materials Fire Test Handbook DOT/FAA/CT-89/15, U.S. Department of Transportation, Federal Aviation Administration, Atlantic City International Airport, NJ, Chap. 7, "Oil Burner Test for Seat Cushions," September 1990.

5. Barrientos, J. Michael, "The Effect of Wear on Fire Blocking Layer Material Effectiveness," DOT/FAA/CT-TN94/16, U.S. Department of Transportation, Federal Aviation Administration, Atlantic City International Airport, NJ, January 1995.

6. Poletti, P. and Testori, P., response to National Transportation Safety Board Aircraft Accident Report NTSB/AAR-93/07, Manifattura A. Testori Di G. S.p.A., Milano, Italy, 11 April 1994.

7. Sarkos, Constantine, personal communication, 4 May 1995.