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Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Evaluating the Flammability of Various Magnesium Alloys During Laboratory- and Full-Scale Aircraft Fire Tests

Timothy R. Marker

January 2013

Final Report

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16. Abstract

This report summarizes the research undertaken by the Federal Aviation Administration to investigate the flammability of magnesium alloys under various laboratory- and full-scale aircraft fire test conditions. During the initial investigation, a laboratory-scale test apparatus was constructed to allow flame exposure to various magnesium alloy bars as they were suspended over a small steel pan. An oil-fired burner, configured in accordance with Title 14 Code of Federal Regulations Part 25.853 (c) Appendix F Part II, was used to simulate a jet fuel fire. A variety of magnesium alloy combinations were evaluated, including two prototype alloys containing rare earth elements, when subjected to the burner flame for various durations. In most cases, the alloys melted, depositing pieces of molten material into the catch pan below. Subsequent to the melting event, the materials typically ignited, emitting an intense light during ignition. The flame duration and the amount of material consumed were measured during each test. From the initial tests, it was determined that several rare earth-containing alloys showed greater flammability resistance compared to traditional magnesium alloys, such as AZ-31. Two prototype alloy materials, WE-43 and Elektron 21, self-extinguished shortly after removing the fire source. By comparison, the AZ-31 magnesium alloy configurations did not self-extinguish and continued to burn, sometimes until completely consumed.

Additional tests were conducted to determine the ability of aircraft cabin hand-held fire extinguishers to extinguish the magnesium alloys following ignition. Halon 1211, DuPont™ FE-36™, and water extinguishers were evaluated against several different magnesium alloy fires. The Halon 1211 and FE-36 were ineffective at extinguishing the burning alloy, whereas the water was somewhat effective.

Full-scale tests simulating a survivable postcrash aircraft fire were conducted with a large external fuel fire to determine if an increased hazard resulted with seat frames constructed of magnesium alloy in the primary components. The primary components included the legs, cross tubes, and spreaders. An initial full-scale baseline test was conducted using B/E Aerospace 990 aircraft seats constructed of standard aluminum components. Follow-on tests using B/E 990 seats outfitted with components constructed from both a well-performing magnesium alloy and a poor-performing alloy were conducted to determine any increase in hazard resulting from the use of these materials in the seat frames. The tests indicated no additional hazard resulted for a majority of the test duration when using either of the magnesium alloys. However, portions of two seats constructed of AZ-31 alloy caught fire and were difficult to extinguish following extinguishment of the external fuel fire.

The ultimate goal is to use the results to develop an appropriate laboratory-scale flammability test for structural components used in the aircraft cabin, particularly the seat frames, made of potentially combustible metallic structure or composite materials.

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LIST OF SYMBOLS AND ACRONYMS

CO	Carbon monoxide
CO_2	Carbon dioxide
O_2	Oxygen
AFFF	Aqueous film-forming foam
B/E	B/E Aerospace, Inc.
CFR	Code of Federal Regulations
FAA	Federal Aviation Administration
FED	Fractional effective dose
FED_I	Fractional effective dose for incapacitation
FED_L	Fractional effective dose for lethality
FID	Flame Ionization Detector
FTIR	Fourier Transform Infrared
IAMFTWG	International Aircraft Materials Fire Test Working Group
MAPP	Methylacetylene-propadiene propane
OEM	Original equipment manufacturer
RTV	Room-temperature vulcanizing
SAE	Society of Automotive Engineers
THC	Total hydrocarbon
TSO	Technical Standard Order

EXECUTIVE SUMMARY

In recent years, magnesium alloys have been suggested as substitutes for aluminum alloys in aircraft seat structure, as well as other applications, due to the potential weight savings. The Federal Aviation Administration (FAA) has had several inquiries regarding the policy for using magnesium alloys in airplane cabins. Although magnesium alloys are routinely used in the construction of noncabin aircraft components, they are currently prohibited from use in aircraft seats, according to an FAA Technical Standard Order (TSO) that references a Society of Automotive Engineers (SAE) standard. FAA TSO-C127, "Rotorcraft and Transport Airplane Seating Systems," prescribes the minimum performance standards that rotorcraft and transport airplane seating must meet, including the qualification requirements and minimum documentation set forth in various sections of SAE AS8049, "Performance Standard for Seats in Civil Rotorcraft, Transport Aircraft, and General Aviation Aircraft." Within AS8049, revision A, paragraph 3.3.3 states, "Magnesium alloys shall not be used." These criteria have blocked the use of magnesium alloys in seat structure for decades.

The FAA's central concern regarding the use of magnesium and its many alloys in the cabin is flammability. The current regulations do not address the potential for a flammable metal to be used in large quantities in the cabin. Therefore, if such a material were introduced into the cabin, the FAA must be assured that the level of safety is not reduced. Recent developments in materials technology have shown that different magnesium alloys have different susceptibility to ignition. However, magnesium remains a material that, once ignited, is very challenging to cope with using fire extinguishers currently available on aircraft.

To better evaluate the potential risks of using magnesium alloys in the cabin, a task group was formed under the auspices of the International Aircraft Materials Fire Test Working Group. The FAA agreed to support additional research in this area to the extent industry could supply materials. This included laboratory- and full-scale tests to determine the level of hazard associated with magnesium use in an aircraft cabin under realistic conditions, including postcrash and in-flight fire scenarios.

A preliminary assessment of magnesium alloy flammability was conducted using a laboratory-scale test apparatus. The test apparatus consisted of an oil-fired burner to simulate the fuel fire, and a frame to mount and expose representative test samples. Test samples consisting of several blends of magnesium alloy were evaluated. One sample was a prototype alloy containing rare earth elements to minimize flammability. The laboratory-scale tests indicated a large difference in flammability between the various samples tested. Magnesium alloys WE-43 and Elektron 21 both showed outstanding resistance to ignition compared to the more conventional alloys such as AZ-31.

Subsequent full-scale aircraft fire tests of these alloy systems provided useful information concerning the feasibility of using such materials as the primary components of aircraft coach seating. During the tests, it was determined that the prototype WE-43 material would not impact postcrash fire survivability, producing minimal quantities of toxic and flammable gases during a 5-minute fire exposure. Additional laboratory-scale tests evaluated the performance of hand-held fire extinguishers against these same alloys when ignited. Halon was shown to be largely ineffective while water showed some promise. The technique employed by the operator was also found to be important.

1. INTRODUCTION.

1.1 PURPOSE.

This report describes the research undertaken by the Federal Aviation Administration (FAA) to investigate the feasibility of employing magnesium and magnesium alloys for use in aircraft seat frame construction. A laboratory-scale test was used for initial assessment of the flammability of various magnesium alloys, while subsequent full-scale tests were performed to measure flammability under realistic conditions. Temperature, smoke, and decomposition products were measured inside an intact transport category fuselage during full-scale tests using standard, aluminum-framed aircraft seats. Follow-on tests employed magnesium alloys in the construction of the primary seat components to determine any increase in hazard associated with their use.

1.2 BACKGROUND.

In a majority of survivable accidents accompanied by fire, ignition of the interior of the aircraft is caused by burning jet fuel external to the aircraft as a result of fuel tank damage during impact. One important factor to occupant survivability is the integrity of the fuselage during an accident. Usually, there are two possibilities that exist in a survivable aircraft accident: (1) an intact fuselage and (2) a compromised fuselage from either a crash rupture or an opened emergency exit, which allows direct impingement of external fuel fire flames on the cabin materials. Based on a consideration of past accidents, experimental studies, and fuselage design, it is apparent that the fuselage rupture or opening represents the worst-case condition and provides the most significant opportunity for fire to enter the cabin [1]. Past FAA regulatory actions governing interior material flammability were based on full-scale tests that employed a fuel fire adjacent to a fuselage opening in an otherwise intact fuselage. This scenario, in which the cabin materials were directly exposed to the intense thermal radiation emitted by the fuel fire, represented a severe but survivable fire condition and was used to develop improved material flammability test standards.

To meet these new requirements, aircraft designers had to strike a balance between material performance, weight, and cost. Material performance is not confined to flammability alone; other parameters are equally important, including corrosion, strength-to-weight ratio, water absorption, environmental concerns during manufacture, and others. Designers continuously strive to increase performance, while at the same time, reducing the overall weight of transport category aircraft. The amount of fuel required to operate an aircraft is corollary to the weight of the aircraft; considerable savings in fuel consumption are obtained by reducing the weight of the aircraft. To help save weight, designers review advancements made with new materials, their properties, and the associated costs of using these materials in the fabrication of aircraft.

Magnesium has become popular as a potential replacement or supplement to the standard aluminum alloys used in aircraft construction. Although it is not as strong as aluminum on a weight basis, magnesium is approximately 30% lighter. Creative new designs in specific applications can result in structures of equal strength, at a weight savings of approximately 20% over aluminum.

Although magnesium offers the potential for considerable weight savings, it does not come without some drawbacks, namely corrosion and flammability [2]. In recent years, the corrosion aspect has been addressed and largely solved via electroplating, powder-coating, and other related surface-treating processes. Recent advancements in the area of flammability have increased the appeal of magnesium and magnesium alloys for use in certain aircraft cabin applications. Despite this attractiveness, obstacles still exist that prevent magnesium from being used in the aircraft cabin, specifically, an outright ban on its use in seat construction. This ban on magnesium use in aircraft seats is facilitated by an FAA Technical Standard Order (TSO)-C127, "Rotorcraft and Transport Airplane Seating Systems" [3]. The TSO prescribes the minimum performance standards that rotorcraft and transport airplane seating must meet, including the qualification requirements and minimum documentation set forth in various sections of Society of Automotive Engineers (SAE) AS8049. As stated in the TSO:

> "Seating systems…that are manufactured on or after the date of this TSO (dated 3/30/1992) must meet:
>
> (i) the minimum performance standards, qualification requirements, and minimum documentation requirements set forth in Sections 3.2, 3.3, 3.4, 3.5, 4.1, 4.2, 5, 5.1, 5.2, 5.3, and 5.4 of Society of Automotive Engineers, Inc. (SAE), Aerospace Standard AS8049, "Performance Standard for Seats in Civil Rotorcraft and Transport Airplanes," dated July 1990.

Within SAE AS8049, revision A (revised September 1997), paragraph 3.3.3 states, "Magnesium alloys shall not be used" [4]. As a result, these two standards have effectively blocked the use of magnesium in aircraft seat construction.

The SAE Aircraft Seat Committee is a working group within the SAE that addresses all facets of aircraft seats—design, maintenance, in-service experience, and performance standards development. Participants in the SAE Seat Committee include original equipment manufacturers (OEM), suppliers, aircraft seat equipment companies, consulting firms, government entities, and other interested parties across the aerospace and defense industries. The SAE Aircraft Seat Committee is presently the custodian of AS8049.

Because of the recent interest in using magnesium for weight-saving applications, the FAA has had several inquiries regarding its policy for using magnesium in airplane cabins. Specifically, industry groups have lobbied to have the FAA revisit the current policy (TSO-C127) on banning magnesium use in the cabin. While the FAA's central concern regarding the use of magnesium in the cabin is flammability, the current regulations do not address the potential for a flammable metal to be used in large quantities in the cabin. Therefore, if such a material were introduced into the cabin, the FAA would have to be assured that the level of safety was not reduced. Although different magnesium alloys have different susceptibility to ignition, magnesium remains a material that, once ignited, is very challenging to manage using fire extinguishers currently available on aircraft. An earlier study [5] by the FAA only provided limited information on the ignitability and flammability of a narrow range of magnesium alloys.

Despite initial concerns over the potential use of magnesium in cabin components, there was enough interest to initiate a more formal discussion. As a result, a task group to investigate magnesium flammability was formed under the auspices of the International Aircraft Materials Fire Test Working Group (IAMFTWG), which is chaired and administered by the FAA Fire Safety Team[1]. Although the potential for weight savings is undeniable, the FAA has proceeded with caution to ensure the level of cabin safety is not compromised or that an additional hazard is not introduced.

The task group initially solicited industry on prospective areas within the cabin where magnesium use would be beneficial, and discussed potential hazards associated with these. Industry had identified aircraft seat structure as the single, most likely area of the cabin interior to benefit from the use of magnesium alloy components in place of existing aluminum. Additional discussions led to a more formal testing program undertaken by the FAA Fire Safety Team, located at the FAA William J. Hughes Technical Center in Atlantic City, NJ. The test program included initial investigative laboratory-scale flammability tests, as well as realistic, full-scale tests on magnesium alloy seat structure. The goal of the research was to first determine the feasibility of using magnesium alloys in the construction of seat components from a flammability safety standpoint. If the research indicates no additional hazard would exist within the cabin, the next phase would be to develop an appropriate laboratory-scale flammability test for seat structural components. This flammability test may also be required for structural seat components fabricated from other nonmagnesium materials, such as composites.

2. EXPERIMENTS.

2.1 INITIAL OIL-FIRED BURNER TESTS OF MAGNESIUM ALLOY BARS.

A preliminary assessment of magnesium alloy flammability was conducted using a laboratory-scale test apparatus. The test apparatus consisted of an oil-fired burner to simulate a fuel-fed cabin fire, and a mechanism used to mount rectangular cross-section bar stock test samples. The burner was configured according to Title 14 Code of Federal Regulations (CFR) Part 25.853 (c) Appendix F Part II. This is the test standard for evaluating the flammability of aircraft seat cushion materials. Although there is no current requirement for the flammability resistance of aircraft seat structure, this test was suitable for generating initial test data on the flammability of various magnesium alloys. Test samples consisting of several blends of magnesium alloy bar stock were evaluated. The samples tested were of two different cross sections: approximately 0.4 by 1.6 inches, and 0.6 by 1.6 inches, with bare-metal band-sawn surfaces. Each bar sample measured 19.7 inches in length and was securely mounted in the test fixture at a distance of 4 inches from the end of the burner cone (figures 1 and 2). The center of the bar sample face exposed to the burner was positioned 1 inch above the horizontal centerline of the oil burner cone.

During a typical test, the burner was turned on and allowed to warm for a period of 2 minutes. Following this step, the rolling cart assembly holding the magnesium alloy bar sample was moved in front of the burner (figure 3). The samples were exposed to the burner for 3, 4, or 5 minutes, depending on the thickness of the bar sample being tested. Within this exposure

[1] As defined by the Materials Fire Test Working Group Charter.

period, the bar samples would typically droop or distort just prior to melting, and often, a large center section of the bar sample would fall into a catch pan mounted below (figures 4 and 5). In these instances, the molten pieces in the catch pan continued to burn for varying periods of time. Once the bar sample melted and a portion of it fell into the catch pan, the remaining pieces attached to the sample holder would either ignite and continue to burn (figure 6), or depending on the type of alloy, they would quickly self-extinguish.

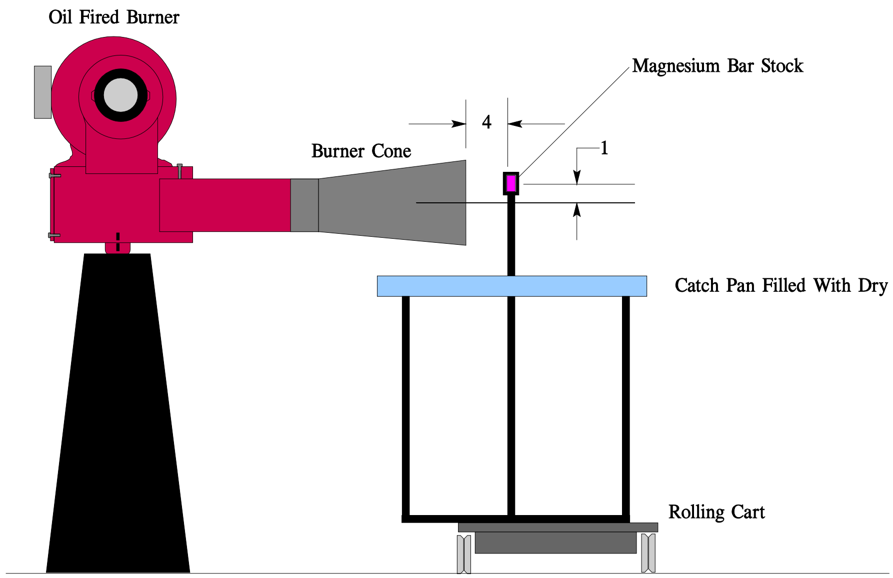

Figure 1. Oil-Fired Burner Test Apparatus Used for Preliminary Study of Magnesium Flammability

Figure 2. Magnesium Alloy Bar Sample Mounted in Test Apparatus Prior to Test

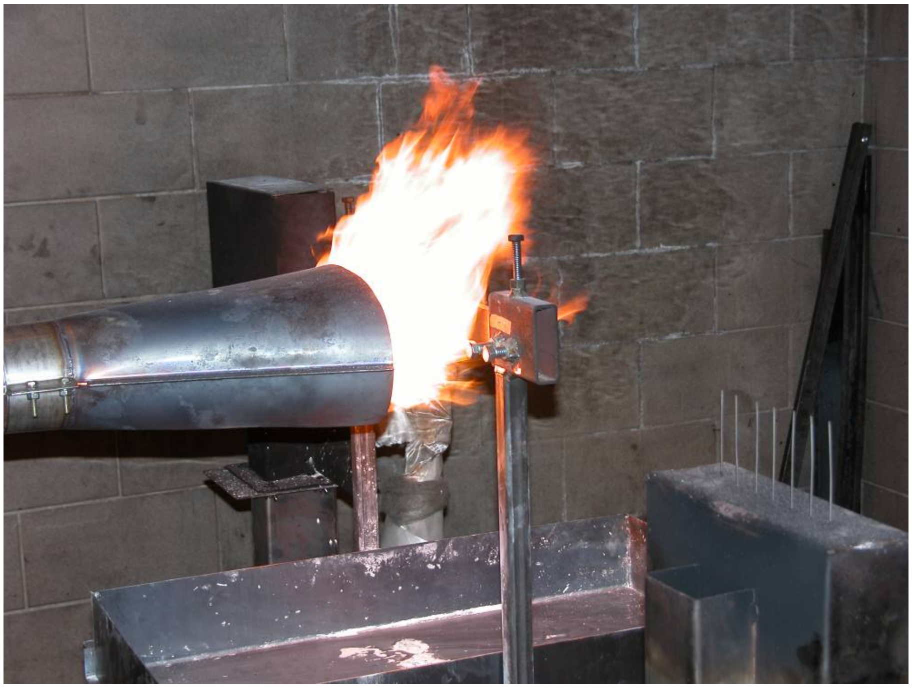

Figure 3. Magnesium Alloy Bar Sample Exposed to Burner Flames

Figure 4. Magnesium Alloy Bar Sample Immersed in Flames, Just Prior to Melting

Figure 5. Center Section of Bar Sample Falling Into Catch Pan After Melting

Figure 6. Ignition of Magnesium Alloy Following Burner Flame Exposure

The catch pan was filled with dry talc to prevent any splattering of molten materials and to aid in the safe extinguishment of burning samples. After the burner was shut off and all burning had subsided, the sample pieces were cooled and removed for inspection (figure 7). Various parameters were measured and recorded during the test, including the sample dimensions, the time the burner flame was turned off, the time the sample melted, the time the sample self-extinguished, and whether or not any melted pieces that fell into the catch pan were still burning.

Figure 7. Posttest Inspection Showing Molten Center Section Removed From Catch Pan

Numerous types of magnesium alloy samples were tested. The designation system used to identify the various elements in the magnesium alloy employs a combination of letters and numbers. The first two letters indicate the major alloying elements, according to the following codes:

- A—Aluminum (Al)
- B—Bismuth (Bi)
- C—Copper (Cu)
- D—Cadmium (Cd)
- E—Rare earth elements
- F—Iron (Fe)
- G—Magnesium (Mg)
- H—Thorium (Th)
- K—Zirconium (Zi)
- L—Lithium (Li)
- M—Manganese (Mn)

- N—Nickel (Ni)
- P—Lead (Pb)
- Q—Silver (Ag)
- R—Chromium (Cr)
- S—Silicon (Si)
- T—Tin (Sn)
- W—Yttrium
- Y—Antimony (Sb)
- Z—Zinc (Zn)

The two letters are followed by two numbers, indicating the percent concentration of the major alloying elements. In some cases, a fifth letter symbol signifies alloy modification (A through Z, excluding I and O), which distinguishes between different alloys with the same percentages of the two principle alloying elements. This alloy code is followed by a designation of temper. The temper designation system is similar to the temper designation system for aluminum alloys, as follows:

- F—As fabricated
- O—Annealed
- H—Cold worked
- T4—Solution treatment
- T5—Artificial aging
- T6—Solution treatment followed by artificial aging

For example, an alloy designated as ZE63A-T6 is a magnesium alloy containing 6% Zinc, 3% rare earth elements, is the first type (A) of a series of similar alloys, and carries a solution treatment followed by artificial aging process (T6).

The magnesium alloys tested in the preliminary evaluation ranged from the conventional types of sand and die casting alloys, such as AZ-31, to the other end of the spectrum containing rare earth elements, including many that have only recently been invented (table 1).

None of the tested sample bars melted prior to 2 minutes, which was not surprising given the relative thickness of the samples tested. When the exposure time was increased beyond 2 minutes, the samples melted, typically between 3 and 4 minutes for the 0.59-inch-thick samples and approximately 2 to 3 minutes for the thinner 0.39-inch-thick samples. The type of alloy also played a role in the time to reach the melting point. As shown in figure 8, the alloys with higher melting points typically required longer periods of time to melt. The chart shows the time required to melt six different alloys at a thickness of 0.59 inch. Also shown are the lower and upper melting ranges of each of the alloys. With the exception of ZE-10, there is a direct correlation with the alloys' upper melting range and the time required to melt the samples.

Table 1. Initial Laboratory-Scale Test Results

Test No.	Alloy	Width (inches)	Height (inches)	Length (inches)	Burner Duration (min:sec)	Sample Melted (min:sec)	Sample Continued to Burn	Sample Self-Extinguished (min:sec)	After Flame Duration (min:sec)	Residue Burning	Comments
1	WE-43	0.6	1.6	19.7	4:00	3:45	No	4:00	0:00	No	Height face exposed to flames
2	AZ-80	0.6	1.6	19.7	3:30	3:07	Yes	9:21	5:51	Yes	Height face exposed to flames
3	Elektron 21	0.6	1.6	19.7	5:00	3:47	Yes	6:07	1:07	No	Height face exposed to flames
4	ZE-41	0.6	1.5	19.7	4:00	3:06	Yes	5:45	1:45	No	Height face exposed to flames
5	ZE-10	0.6	1.6	19.7	4:00	3:35	Yes	7:29	3:29	Yes	Height face exposed to flames
6	AZ-31	0.5	1.6	19.7	4:00	3:19	Yes	Kept burning	n/a	Yes	Height face exposed to flames
7	WE-43	0.6	1.6	19.7	5:00	3:35	No	5:00	0:00	No	Height face exposed to flames
8	Elektron 21	0.6	1.6	19.7	4:00	3:35	No	4:00	0:00	No	Height face exposed to flames
9	AZ-80	0.6	1.6	19.7	5:00	3:00	Yes	6:15	1:15	Yes	Height face exposed to flames
10	AZ-31	0.6	1.6	19.7	5:00	3:01	Yes	6:12	1:12	Yes	Height face exposed to flames
11	WE-43	0.4	1.6	19.7	4:00	2:26	Yes	6:12	2:12	Yes	Height face exposed to flames
12	Elektron 21	0.4	1.6	19.7	4:00	2:08	Yes	6:08	2:08	No	Height face exposed to flames
13	WE-43	0.4	1.6	19.7	4:00	2:30	Yes	5:43	1:43	No	Height face exposed to flames
14	AZ-80	0.4	1.6	19.7	4:00	2:09	Yes	8:10	4:10	Yes	Height face exposed to flames
15	AZ-80	0.4	1.6	19.7	3:00	1:58	Yes	5:00	2:00	Yes	Height face exposed to flames
16	Elektron 21	0.4	1.6	19.7	3:00	2:12	Yes	4:08	1:08	No	Height face exposed to flames
17	WE-43	~0.4	~1.6	19.7	11:45	10:37	Yes	13:42	1:57	No	Intumescent paint coating
18	ZE-41	0.6	1.6	19.7	5:00	3:51	Yes	6:31	1:31	No	Width face exposed to flames
19	ZE-10	0.6	1.6	19.7	4:00	No melting	No	4:00	0:00	n/a	Width face exposed to flames
20	AZ-31	0.4	1.6	19.7	4:00	3:37	Yes	Kept burning	n/a	Yes	Bar orientation vertical
21	Elektron 675	0.4	1.6	19.7	5:20	5:00	Yes	6:35	1:15	No	Height face exposed to flames
22	Elektron 675	0.4	1.6	19.7	5:15	4:50	Yes	6:00	0:45	No	Height face exposed to flames
23	Elektron 675	0.4	1.6	19.7	5:15	5:00	Yes	5:20	0:05	No	Height face exposed to flames

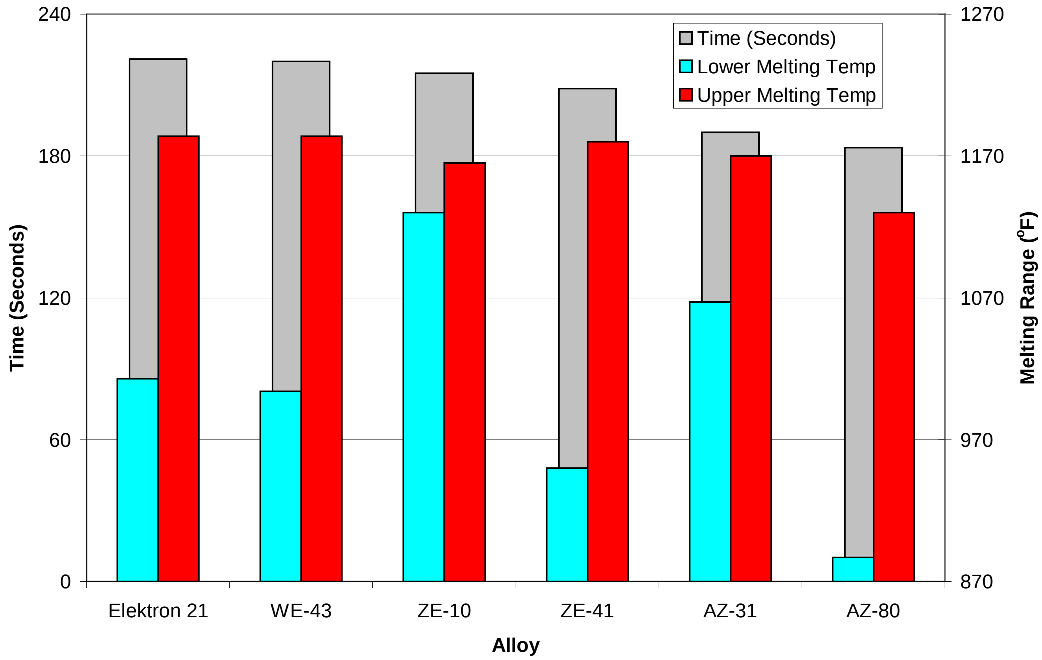

Figure 8. Various 0.59-Inch-Thick Samples and Respective Time to Reach Melting

In many cases, once the samples were subjected to the burner for a time period adequate to cause melting, the alloys would ignite. Several samples were prototype alloys specifically designed to minimize flammability; as a result, there was a large difference in flammability observed between the various samples tested. For example, the alloys WE-43 and Elektron-21 both showed outstanding resistance to ignition compared to the more traditional alloys, such as AZ-31. In two of the three AZ-31 tests, the sample would not self-extinguish, regardless of time, and would burn indefinitely.

Of the 23 tests conducted, 18 resulted in continued burning of the sample, the molten remnants, or both. In 5 of the 23 tests, there was no ignition or the materials self-extinguished within 5 seconds. The sample performance seemed to be largely dependent on the alloy type and, in some cases, the section thickness. For example, WE-43 self-extinguished in tests 1 and 7, in which the section thickness was measured to be close to 0.6 inch. However, in tests 11 and 13, with a section thickness of only 0.4 inch, both WE-43 samples continued to burn for at least 90 seconds after the burner was switched off.

With the exception of two tests (18 and 19), all tests were run such that the wide face of the sample (1.6-inch face) was exposed to the burner flames. In two tests, the orientation of the bar was changed so that the narrow face (0.6-inch face) was exposed to the burner to determine the effect. When considering the ZE-10 alloy, the orientation appears to have made a significant impact on the results. In test 5, the burner was switched off at 4 minutes, and the sample continued to burn for an additional 3 minutes 29 seconds. However, in test 19, with the narrow face exposed, the burner was switched off at 4 minutes; the bar did not melt, and there was no ignition. This indicated less heat from the burner was being transferred to the sample in this orientation. The results confirmed that orientation of the sample plays a critical role in the results.

A slightly different approach was also investigated in test 20, where the sample bar was shortened and oriented vertically rather than horizontally (figure 9). It was difficult to determine the exact impact of orienting the sample in this manner since this test was performed on a sample of AZ-31, which had burned consistently after burner removal. It was clear that this orientation prevented the separation of a large mass of the test sample during the melting process, which was common when mounting the samples horizontally. By mounting vertically, the molten section of sample ran down the unmolten section like a candle; this tendency kept the sample hotter, since the molten mass was still in contact with the sample.

Figure 9. Magnesium Alloy Sample Mounted Vertically

After conducting a number of tests on a variety of alloys, it was suggested that a protective coating or barrier be investigated as a potential method of protection. Intumescent coatings and paints had proven their usefulness in certain fire applications, so a test sample of WE-43 was coated with a 500-micron layer of intumescent paint manufactured by Indestructible Paint Ltd., Sparkhill, Birmingham, UK [6]. The intumescent layer was then top-coated with a 25-micron layer of flame-resistant enamel. This protective layer had a pronounced effect on the test result, as the sample did not melt until 10 minutes 37 seconds. This was approximately four times the typical 2-minute, 30-second melting time of a WE-43 sample of this thickness. The burner was not switched off until 11 minutes and 45 seconds. Although the sample continued to burn for nearly 2 minutes after the burner was switched off, the test demonstrated the effectiveness of the intumescent coating at extending the melting time.

Three final tests were run on Elektron 675, a high-strength wrought alloy designed for elevated temperature applications. The samples melted consistently between 4 minutes 50 seconds and 5 minutes. The molten residue did not ignite during any of the three tests, and the sample self-extinguished immediately upon burner removal during one of the three tests.

2.2 HAND-HELD FIRE EXTINGUISHER TESTS ON BURNING MAGNESIUM ALLOY SAMPLES.

The next test phase was an outgrowth of the initial laboratory-scale tests using the oil burner. In this phase, the effectiveness of several types of aircraft hand-held extinguishers was studied. This was a logical progression, as the initial tests indicated several different types of magnesium alloys did not readily self-extinguish once the ignition source (burner) was removed. Since the purpose of the research was to investigate the feasibility of using magnesium alloys in the construction of aircraft cabin components, it was necessary to also investigate extinguisher performance.

To study their effectiveness against magnesium alloy fires, a separate test stand was constructed to mount a remotely controlled extinguisher, which could be activated once the burning magnesium alloy sample was rolled to a preset location in front of it (figure 10). Several pretest firings were performed to ensure accuracy with the extinguisher discharge plume. Since a limited quantity of magnesium alloy bar stock was available, it was decided to cut the samples in half, yielding twice as many test samples. The samples were then mounted vertically in the sample holder.

Figure 10. Hand-Held Extinguisher Test Configuration

During the first test series, a Halon 1211 extinguisher was mounted into position, and an AZ-31 sample was mounted to the rolling cart assembly. The burner was warmed for 2 minutes, and then the cart was rolled directly in front of the burner, allowing flame impingement. The cart was kept in this position until the sample had melted sufficiently, and there was evidence of fire (figure 11). At this point (approximately 4 minutes), the burner was shut off, and the cart was immediately rolled in front of the fire extinguisher stand.

Figure 11. Vertically Mounted Sample Just Prior to Extinguisher Discharge

Once the cart abutted its prepositioned stop, the extinguisher was activated, producing a directed stream across the burning test sample (figure 12).

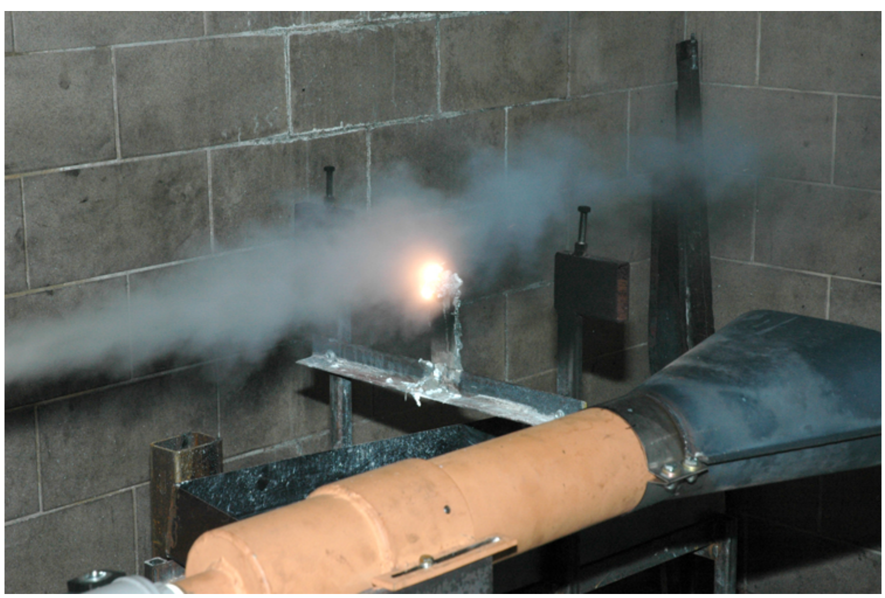

Figure 12. Extinguisher Stream Being Directed Across Burning Magnesium Alloy Sample

The extinguisher activation typically caused a large piece of the burning test sample to fall into the catch pan (figure 13). This was problematic, as the extinguishing agent stream was initially aimed at the upper section of the test sample where the burning was taking place. Once this upper section fell into the catch pan, the agent was no longer directed at any burning material, so it was difficult to determine the impact of the extinguishing agent on the sample.

Figure 13. Section of Molten Test Sample in the Catch Pan After Extinguisher Discharge

To obtain a more accurate assessment of the extinguisher capability, a burning piece of the ZE-10 alloy was removed from the catch pan during the second test and positioned on a sheet of aluminum on the floor of the test area. This allowed a stream of agent to be manually directed into the burning mass of material (figure 14).

Figure 14. Molten Mass of ZE-10 Alloy Removed From the Catch Pan and Placed on the Floor

A Halon 1211 extinguisher was discharged directly at the burning material, which flashed violently upon contact (figure 15). This confirmed that the Halon 1211 extinguishing agent had no effect on the burning material, and perhaps, exacerbated it.

Figure 15. Molten ZE-10 Reacting to Stream of Halon 1211

Two additional tests were conducted using a standard water extinguisher, one test with AZ-31 and one test with ZE-10. In both instances, the initial application of water caused a substantial reaction similar to what occurred when the Halon 1211 was applied. During the second water extinguisher test using ZE-10, the water was purposely directed at the base of the material, away from the burning section. This appeared to produce the best result, as the water was able to cool the material without increasing the burning, eventually cooling it enough that the flaming diminished completely.

Three final tests were conducted using extinguishing agent DuPont™ FE-36™. This agent was designed as a potential replacement to the ozone-depleting Halon 1211, which is being be phased out of use. During the first test, a small mass of burning material fell into the catch pan upon extinguisher discharge. The fire on the vertical sample was initially extinguished, while the piece in the catch pan continued to burn. A second FE-36 extinguisher was discharged into the catch pan, which extinguished the burning material. Almost simultaneously, the vertical sample then began to burn on its own. The fire was allowed to progress for 1 minute, when an additional burst of agent from the mounted extinguisher was directed at the vertical sample, extinguishing it. A second test was run with similar results. A third test was conducted using the remnant sample piece from the previous test. The sample was reheated with the burner, and when melting was observed, the burner was switched off, even though no burning was observed. This caused the sample to ignite, which was not the first time this sequence had occurred during the tests. It was theorized that the burner produced an atmosphere deplete of oxygen in the immediate vicinity of the sample and flames. When the burner was turned off, the oxygen returned to normal, causing the sample to immediately ignite. During the third test, the extinguishing agent was discharged directly at the burning section of material, which caused intensification of the burning. However, when the discharge of agent was stopped, the flames diminished, and eventually subsided completely.

During the final three tests with the FE-36 extinguishing agent, a peculiar oxidation formed on the vertical sample following agent discharge (figure 16). The formation occurred quickly, as the flames subsided and the sample cooled.

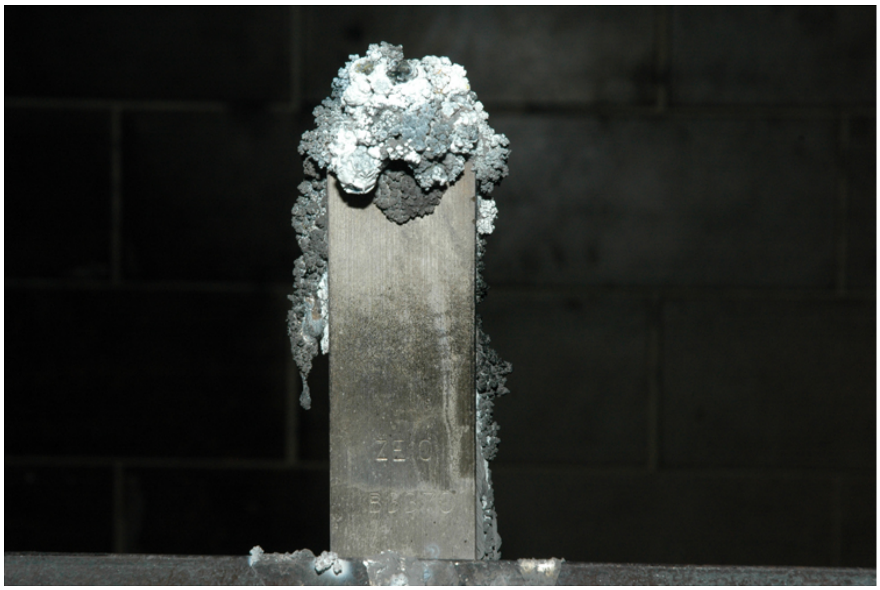

Figure 16. Strange Oxidation on ZE-10 Sample Following Agent Application

Table 2 provides a summary of all extinguisher tests conducted, including the type of alloy tested and the type of extinguishing agent used. The three extinguishing agents tested were largely ineffective at extinguishing the flames on the samples. In most instances, directing the stream of agent across the burning sample caused intensification of the fire. The agents were more effective, particularly the water, when the stream was directed near the burning section, rather than directly at it. This appeared to cool the sample, lowering the temperature enough to suppress the surface burning.

Table 2. Summary of Extinguisher Tests on Various Burning Magnesium Alloys

Test	Sample Material	Extinguishing Agent	Results
1	AZ-31	Halon 1211	A large mass of burning material fell into the catch pan upon agent discharge. The fire was extinguished on the vertical sample. Additional extinguisher agent was discharged at the sample. The residue in the catch pan still burned.
2	ZE-10	Halon 1211	A small piece of ZE-10 was used from the previous test. Following sample ignition, the extinguisher was discharged at the burning material, with no effect on extinguishment of flames.

Table 2. Summary of Extinguisher Tests on Various Burning Magnesium Alloys (Continued)

Test	Sample Material	Extinguishing Agent	Results
3	ZE-10	Halon 1211	The burning pieces in the catch pan from the previous test were retrieved and placed on the floor. The extinguisher was discharged manually at the burning material, with no effect on extinguishment of flames.
4	ZE-41	Halon 1211	A small piece of ZE-41 was used from the previous test. Following sample ignition, the extinguisher was discharged, largely extinguishing the sample.
5	AZ-31	Water	Following sample ignition, the initial extinguisher discharge produced a pencil stream that only contacted the very top of the burning sample. The extinguisher was repositioned and discharged again. The discharge excites the burning material, causing an intense reaction. The sample continued to burn, and the extinguisher stream was repositioned again. Several additional bursts of water were applied to the burning sample. Eventually, the water application cooled the sample enough to eliminate the burning. The residue in the catch pan continued to burn.
6	ZE-10	Water	Following sample ignition, the initial agent discharge excites the burning material, causing an intense reaction. The sample continued to burn, and the extinguisher stream was repositioned. Several additional bursts of water were applied to the burning sample. As the water stream hit the sample, the burning was excited. The extinguisher stream was directed at the base of the sample, away from the burning area. Eventually, the water application cooled the sample enough to eliminate the burning. No residue was burning in the catch pan.
7	ZE-10	FE-36	A small mass of burning material fell into the catch pan upon extinguisher discharge. The fire was initially extinguished on the vertical sample, while the piece in catch pan continued to burn. The extinguisher was discharged into catch pan, and the residue was extinguished. The vertical sample began to burn on its own. The fire was allowed to progress for 1 minute, and then an additional burst of agent extinguished the fire on the vertical sample.
8	ZE-10	FE-36	A sample from a previous test was reheated until it ignited. The initial discharge of agent extinguished the fire, but the sample eventually re-ignited on its own. A second discharge of agent did not extinguish the fire, but appeared to cool the sample. The fire slowly diminished and self-extinguished. Unique oxidation formed on the sample as it cooled.
9	ZE-10	FE-36	Following burner shut-down, the sample began to ignite. The agent discharge caused the fire to intensify, but upon termination of the agent discharge, the sample fire diminished and slowly self-extinguished. Unique oxidation formed on the sample as it cooled.

2.3 ADDITIONAL LABORATORY-SCALE FLAMMABILITY TESTS USING VARIOUS IGNITION SOURCES.

Following the initial laboratory-scale tests using the oil burner, a better understanding of the flammability performance of the various magnesium alloys was achieved. It was clear that melting the material was required before any burning would take place. The ability to get the samples to melt was largely a function of sample thickness; the thicker samples required more time to heat to reach the melting point. Although the initial tests using the solid, rectangular cross-section bar samples was a good starting point to assess material flammability, the sample thickness and shape did not represent a typical seat frame member. Informal discussions with airframe manufacturers and seat suppliers indicated the primary components of a typical aircraft seat would be the target of future magnesium alloy substitution. The primary components included the leg assemblies, the spreaders, and the cross tubes. The leg assemblies and spreaders were typically machined from plates, and the cross tubes were hollow, circular extrusions. In each of these three component designs, thin sections of material existed that could potentially heat up and melt more readily.

To create a more realistic test condition mimicking a machined leg or spreader, one of the thinner WE-43 test sample bars was modified using a milling machine. Two 10-inch-long longitudinal channels were milled into the test sample bar to create a thinner cross-sectional area where the heat from the burner was concentrated (figures 17 and 18). The longitudinal channels were square in shape, approximately 0.25 inch wide by 0.25 inch deep.

Figure 17. Magnesium Alloy Test Sample Bar With a Milled Cross Section

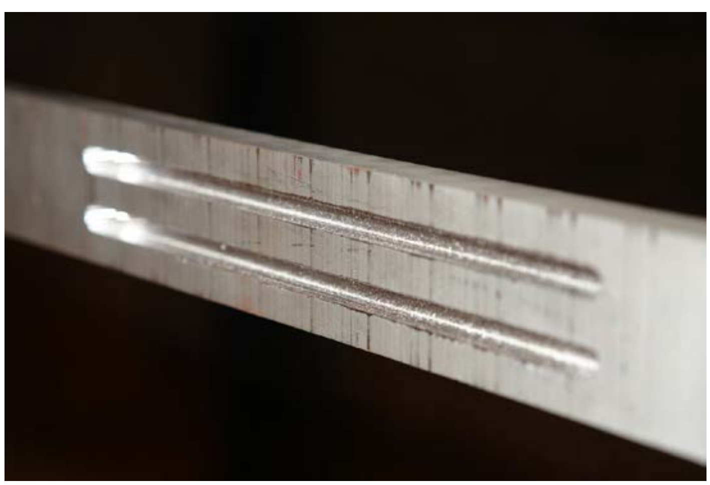

Figure 18. Close-Up of Test Sample Bar With a Milled Cross Section

Following burner warm-up, the test samples were exposed for a period of 4 minutes, at which point the burner was switched off. Melting occurred at approximately 2 minutes 30 seconds. The machining did not appear to cause the test sample to become more flammable, as the melting process was similar to previous tests of nonmilled samples (figure 19).

Figure 19. Posttest Photograph of Milled Bar Test Sample

One additional test was conducted using a vertically mounted, milled test bar sample (figure 20). A remnant piece from the previously milled sample was used for this test. The milled sample was clamped into place and exposed to the burner until melting was observed. The orientation had no effect on the flammability of the sample, as the burning subsided within 10 seconds of removing the burner.

Figure 20. Posttest Photograph of Milled Sample Mounted Vertically

To supplement the laboratory-scale flammability tests using the oil burner, several additional small-scale tests were conducted. These were simple, investigative tests intended to develop a better understanding of the overall flammability of the magnesium alloys.

During the first test, the magnesium alloy millings captured from the milling process in the previous test were piled into a small mound in the catch pan (figure 21). A hand-held methylacetylene-propadiene propane (MAPP) gas torch was used to ignite the pile of material. The millings were relatively easy to ignite with the torch, due to their high surface-area-to-volume ratio (figure 22). This high ratio allowed the millings to heat quickly and melt rapidly, providing the proper conditions for ignition. A second test was run in which a pile of millings was placed on top of a piece of aircraft-grade carpeting in the catch pan. The millings were ignited with the torch as in the previous test. Despite the intense light given off by the material, the resulting fire did not spread beyond the diameter of the pile of millings.

Figure 21. Torch Used to Ignite a Small Pile of Magnesium Alloy Millings

Figure 22. Small Pile of Magnesium Alloy Millings on Fire

Another series of tests were run using small slivers of magnesium alloy sawn from a bar sample. An industrial band saw was used to produce the thin slivers, in both crosswise and lengthwise fashion. It was difficult to obtain uniformly sawn samples, as they measured approximately 0.0625 to 0.125 inch in thickness. The slivers were held using a pair of pliers, and heated using the MAPP gas torch (figure 23). Similar to the pile of millings, the sliced samples had high surface-area-to-volume ratios, making them easy to ignite. Once ignited, the samples would continue to burn until nearly or completely consumed (figure 24).

Figure 23. Thin Sliver of Magnesium Alloy Being Heated With Torch

Figure 24. Thin Sliver of Magnesium Alloy on Fire After Being Heated With Torch

A longitudinal slice of the magnesium alloy was sawn from the length of a sample bar and clamped vertically in front of the oil burner (figure 25). Following burner warm-up, the sample was exposed until melting began (approximately 1 minute). The melting caused the sample to slump downward at which point the burner was turned off (figure 26). Although a significant percentage of the sample had melted during exposure, it did not ignite.

Figure 25. Longitudinal Slice of Magnesium Alloy Positioned Vertically in Front of the Burner

Figure 26. Vertically Mounted Slice After Self-Extinguishment

A final laboratory test was conducted on a modified bar sample. The sample was sliced lengthwise and sectioned, removing approximately 25% (figure 27). The sample was clamped in place horizontally, with the sectioned area positioned in front of the burner. The sectioned area was approximately 0.125 to 0.1875 inch in thickness. Following burner warm-up, the sample was exposed for approximately 2 minutes, at which point it melted and ignited (figure 28). The burner was subsequently turned off.

Figure 27. Sectioned Bar Sample Positioned Horizontally in Front of the Burner

Figure 28. Sectioned Magnesium Alloy Bar Sample Ignited Using Oil Burner

The sample continued to burn for several minutes, with molten pieces of the sample falling into the catch pan. This was an unexpected result, as the previous test series using the vertically mounted slice did not ignite following melting.

2.4 FULL-SCALE TESTS OF SEATS CONSTRUCTED OF MAGNESIUM ALLOY COMPONENTS.

To evaluate potential hazards associated with the ignition of magnesium alloy components under more realistic conditions, a series of full-scale tests were conducted. Based on input from industry regarding the potential use of magnesium alloy inside a passenger cabin, it was clear that the seat structure was a primary target area. In particular, the large, machined primary components, such as the legs, spreaders, and cross tubes, were ideal. These aluminum components were substantial in mass and would benefit the most from substitution using a magnesium alloy. Other less massive seat components, such as the seat bottom and back pans, would not be ideal for magnesium alloy substitution and, therefore, were not considered in the full-scale study. To conduct the tests, a narrow-body test fuselage was used. Using this test fuselage was the most practical approach for repetitive testing and systematic evaluation of the various magnesium alloys. The test fuselage consisted of a 20-foot-long steel cylinder fabricated from curved steel channels, which was then inserted between two halves of a Boeing 707 fuselage (figures 29 and 30). This test fuselage was configured with a standard-sized opening, 40 by 80 inches, representing a break in the fuselage. In this configuration, flames from an external fuel fire impinged directly on one of the seats positioned in the opening. An 8- by 10-foot fuel pan was situated adjacent to the test fuselage. The fire was produced from 55 gallons of JP-8 fuel ignited in the fuel pan. The mocked up section of the test fuselage included seats and other cabin materials, such as paneling and carpet.

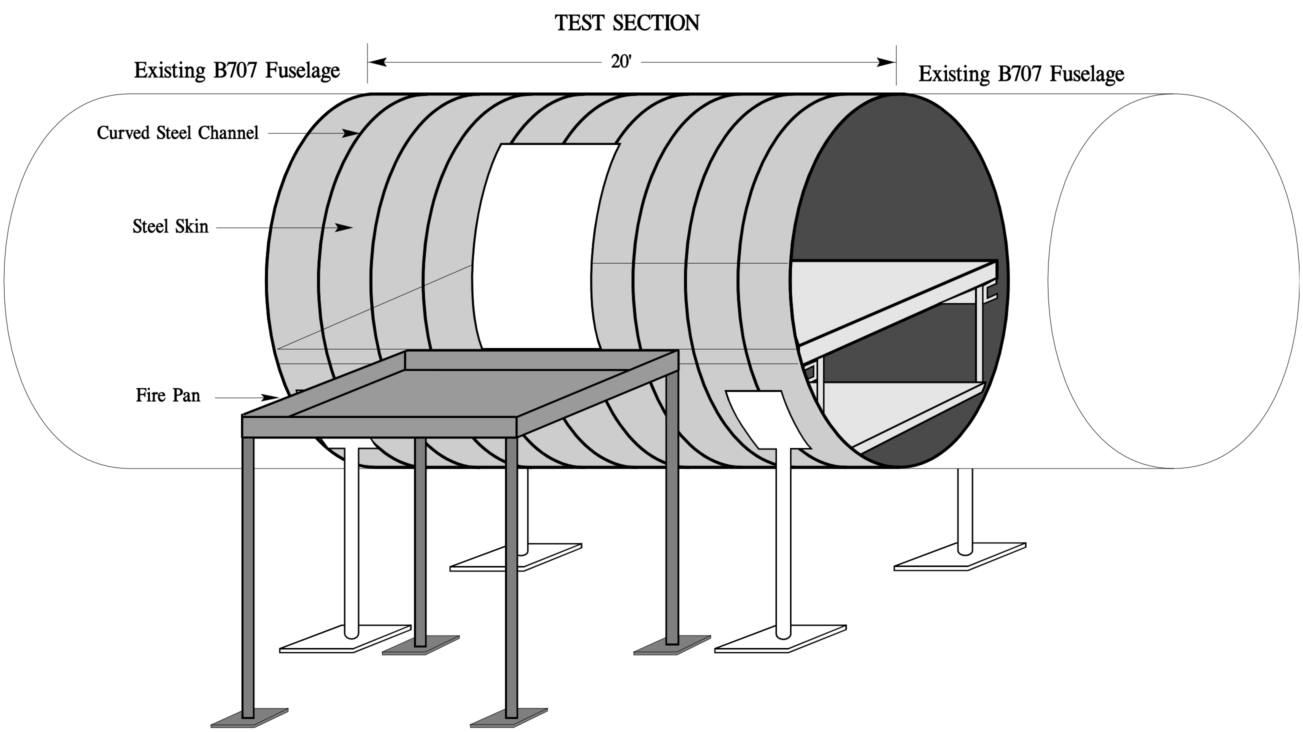

Figure 29. Full-Scale Test Fuselage

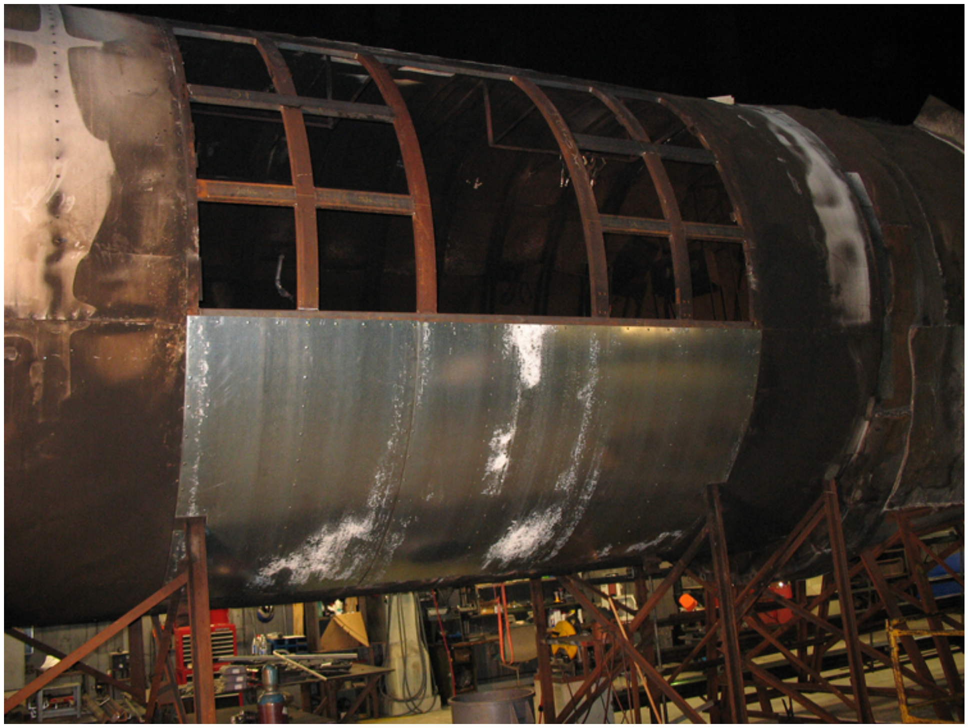

Figure 30. Construction of Steel Test Fuselage Showing Curved Steel Channels

The main objective of the full-scale tests was to determine if an additional hazard existed during a cabin fire when magnesium alloy was used in the primary seat components. To establish a basis by which any increased hazards could be measured, it was necessary to conduct a baseline test. The baseline test used standard aircraft, triple coach seats with aluminum primary components. Following the baseline test, the agreed upon plan between the FAA and industry was to conduct a test using seat components machined from a well-performing magnesium alloy, such as WE-43. If the results of this test indicated no obvious increase in hazard, a third test would be conducted using seat components machined from a poor-performing magnesium alloy, AZ-31, for contrast. A fourth optional test was discussed in which the primary and additional secondary seat components would be machined using the well-performing magnesium alloy. This would provide another data point to help determine the overall performance of the magnesium alloy in increased quantities during realistic conditions. To maintain control, all other materials would remain identical throughout the tests, thus enabling an accurate assessment of only the magnesium alloys' impact on the test outcome.

2.5 INSTRUMENTATION USED IN FULL-SCALE TESTS.

Measurements of temperature and smoke levels were taken inside the test rig along with video coverage at several locations to monitor the progress of the interior fire. In addition, extensive measurements of gas decomposition products were taken using four sets of continuous gas analyzers, a Fourier Transform Infrared (FTIR) analyzer, and a flame ionization detection (FID) total hydrocarbon (THC) analyzer. There were two hazard-monitoring stations, one in the forward-most section of the cabin and one in the mid cabin area, in closer proximity to the installed cabin materials and seats. The forward station was approximately 53 feet from the centerline of the fuel pan, while the mid-station was approximately 18 feet away. The continuous gas sampling ports were located at two heights at each monitoring station, one at 3 feet 6 inches above the floor and one at 5 feet 6 inches above the floor. Only two FTIR ports were used at each station, both at 5 feet 6 inches. Thermocouple trees at these stations measured temperature at 1-foot increments from the floor to the ceiling. An additional thermocouple tree was installed in the aft section of the fuselage. There were three smoke meters at each station, mounted at 1 foot 6 inches, 3 feet 6 inches, and 5 feet 6 inches above the floor. Three heat flux transducers were mounted in the immediate test section, along the fuselage centerline, at 3 feet 6 inches; one transducer facing aft, another facing forward, and a third facing out the fuselage opening centered on the fuel pan (figure 31).

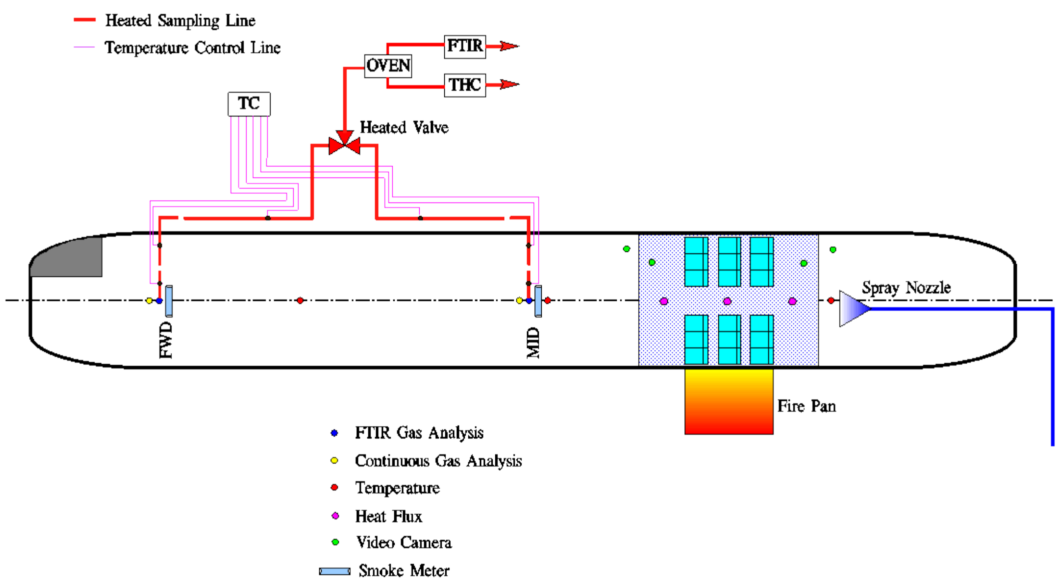

Figure 31. Instrumentation Used in Full-Scale Test Fuselage

2.6 GAS-SAMPLING METHODOLOGY FOR THE FTIR AND THC ANALYZERS DURING FULL-SCALE TESTS.

Figure 32 is a schematic of the FTIR/THC sampling system used during the full-scale tests. Each of the two identical sampling paths leading to the oven was heated to minimize absorption and condensation of analytes in the sampling system. The flexible, heated, Teflon®-lined, 1/4-inch- (0.64-cm) diameter sample lines ran from the test fuselage to a three-way selector valve leading to the oven. Each of the heated sample lines were composed of one 3-foot section, one 6-foot section, and one 40-foot section, each separately thermostatted to 160°C. The oven was also thermostatted to 160°C. The path from the oven to the FID/THC analyzer was thermostatted to the working temperature of the THC analyzer, 160°C. The FTIR sample cell and the heated Teflon-lined, 1/4-inch- (0.64-cm) diamter line running from the oven to that heated cell were independently thermostatted to 170°C, the temperature at which most of the FTIR calibration standard library was developed.

As mentioned previously, the sample line intakes were located at two stations inside the test fuselage, one at a forward location, in closer proximity to the exit door, and the other approximately in the middle of the fuselage, closer to the installed materials and fuel pan. Both stations were located 5 feet 6 inches from the floor. The three-way valve was manually switched during the test so that measurements could be obtained at both locations (although this sampling method covered more of the test fuselage, it created gaps in the data when the valve was switched to the opposite station).

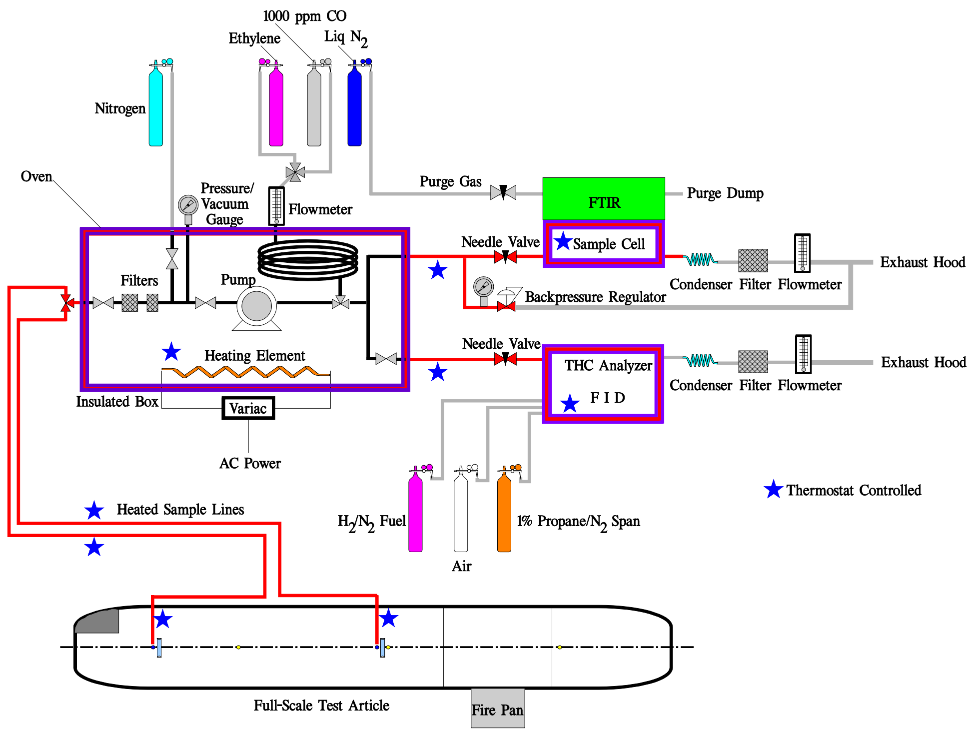

Figure 32. The FTIR Gas-Sampling System

The gas sample was continuously drawn through the heated sample line, at a flow rate of approximately 11 liters per minute, and passed through a series of filters into the bellows pump. A high system flow rate (constant flow rate) through the 160-ml, 4-meter optical path length sample FTIR cell and the FID-based THC cell were used. This ensured a constant system response time throughout the fire test and from test to test, as particulates build up in the filters and the filter backpressure increases. The backpressure regulator output bypasses the analyzer. A needle valve at the inlet to each analyzer was set to provide a flow rate of 2.0 liters/min. A cooling coil (1/4-inch- (0.064-cm) diameter copper tubing) and a high-capacity filter protected the flow meter downstream of the sample cells.

A pressure/vacuum gauge located between the pump and the filter monitored the filter for excessive vacuum, indicating a restriction in flow and the need to replace the filter. The gauge can also be used to check for air leaks after filter replacement by pressurizing the filters with nitrogen, shutting adjacent valves, and checking if the pressure drops with time. This sampling system is not appropriate for quantitative sampling of hydrogen fluoride, as the large particulate filter contains glass wool, which reacts with hydrogen fluoride [7].

2.7 DESCRIPTION OF MATERIALS USED IN TEST FUSELAGE.

Aircraft-grade wool/nylon carpet was used in all tests. The carpet covered approximately 20 feet of the length of the cabin, centered at the fuselage opening. Aircraft-grade, fiberglass-faced, Nomex crushed-core honeycomb panels were used to mock-up the cabin in the immediate area of the fuselage fire opening. The honeycomb panels were used in the sidewall area, the ceiling, and overhead stowage bin areas, and met the current FAA flammability requirements (figure 33).

Figure 33. Typical Full-Scale Test Configuration With Seats, Panels, and Carpet Installed

As mentioned previously, four full-scale tests were originally planned for the study: a baseline test, a good-performing magnesium alloy test, a poor-performing magnesium alloy test, and a test in which the primary and additional secondary components would be machined from a good-performing magnesium alloy. The test configuration would consist of three rows of aircraft triple seats situated inside the fuselage, centered around the fire opening. A total of 24 triple seats were purchased from an aircraft interior spares dealer, The Avianor Group, of Mirabel, Montreal, Canada (6 triple seats were used for each of the four tests). The purchased seats were B/E model 990, m anufactured by B/E Aerospace of Wellington, Florida. Although the purchased seats contained the necessary structural components, they arrived without the bottom seat cushions (figure 34).

Figure 34. Original B/E 990 Seats

Since the bottom seat cushions were an integral part of the overall test program, it was necessary to obtain these components from an aircraft spares dealer. However, the bottom cushions obtained from the dealer did not match the existing seatback design (figure 35). The supplied bottom cushions and accompanying seatback dress covers (figure 36) were an olive-colored pattern used by Air Canada, while the blue dress cover pattern on the supplied seat frames appeared to be Continental Airlines livery.

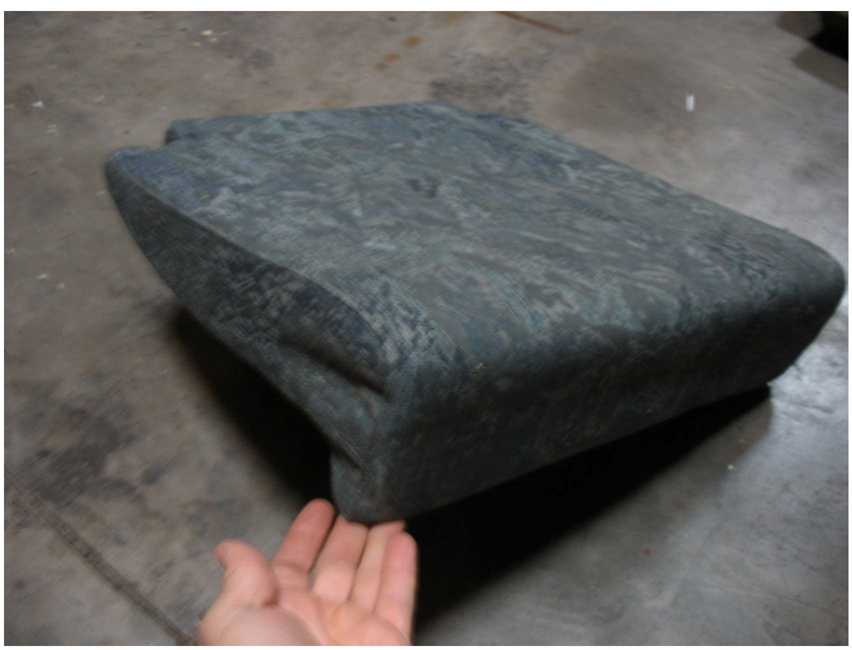

Figure 35. Bottom Seat Cushions With Olive-Colored Air Canada Dress Cover Pattern

Figure 36. Seatback Dress Covers With Olive-Colored Air Canada Pattern

The supplied blue dress covers were removed, and the olive dress covers and bottom seat cushions were installed on the B/E 990 seats in preparation for the full-scale test (figure 37).

Figure 37. Completed B/E 990 Assemblies With Olive-Colored Cushion Materials

During assembly of the seats, it was discovered that the B/E 990 seatback component was not typical of a conventional seatback, which usually contained a substantial urethane foam cushion mounted to an aluminum back frame. The B/E 990 seatbacks consisted of a carbon/epoxy frame hoop, with a stretched fabric acting as a suspension system. The seatback cushioning contained no urethane foam, and consisted only of a dress cover, cotton muslin, and fiberfill. A close-up of the inspection tag on the seatback materials indicates compliance with FAR 25.853 (c), the seat cushion flammability standard (figure 38). The suspension system was likely for additional cushioning not offered by the very thin fiberfill used. The seatback frame also contained numerous plastic parts, including bolsters in the headrest area (figure 39). The high percentage of plastic parts in the seatback structure, in combination with the carbon/epoxy frame and limited fire-retardant foam, was not typical of conventional aircraft seat construction and had not been previously evaluated in full-scale tests.

The aircraft seats were installed in the test fuselage in three rows of two triple seats, one on either side of the aisle, which is a typical configuration for a narrow-body fuselage (figure 40). The middle row of seats was centered in the fire opening.

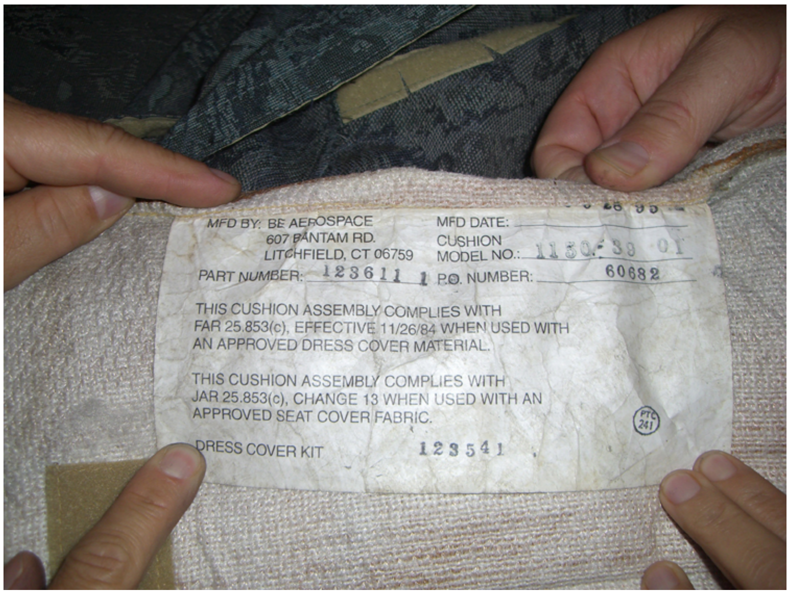

Figure 38. B/E 990 Triple Seatback Cushion Inspection Tag

Figure 39. B/E 990 Triple Seat With Cushions and Covering Removed Revealing Bolsters

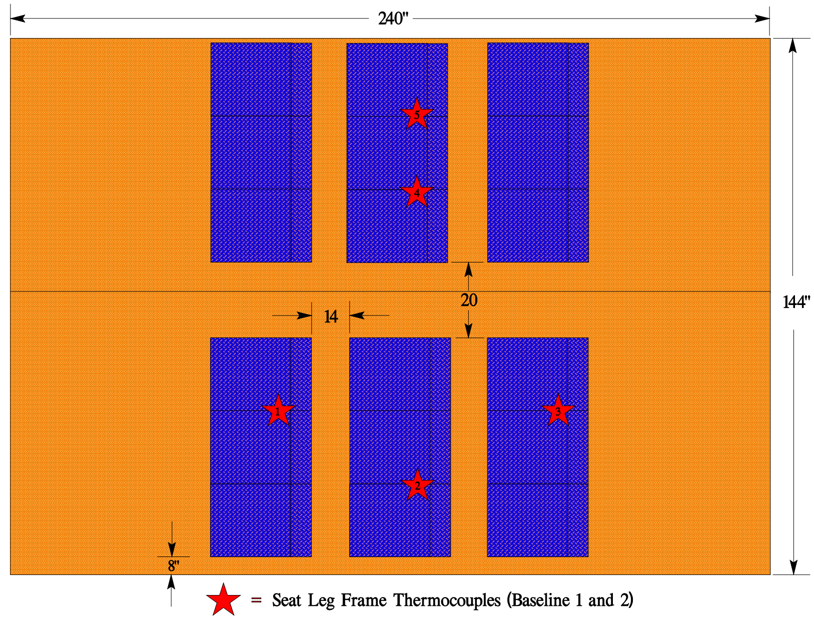

Figure 40. Seat Layout Inside Full-Scale Test Fuselage

3. TEST RESULTS AND DISCUSSION.

3.1 BASELINE TEST 1 (ALUMINUM SEAT COMPONENTS).

After all three rows of triple seats were installed in the test fuselage, thermocouples were mounted on the top surface of each of the bottom seat cushions (figure 41). The thermocouples were used to track the fire spread, in the event the internal cameras became obscured during the test. The thermocouples were held in place with steel safety wire.

Figure 41. Baseline Test 1 Cabin Configuration

To create the desired threat from the external fire and burning cabin materials, a small exhaust fan was mounted in the forward section of the fuselage, exhausting cabin air to the exterior. This purging action had the effect of pulling the fuel fire into the cabin. A rotary-type anemometer placed in the fire opening measured a 1- to 2-mile per hour wind speed. Although this seemed very low, experience with full-scale testing had shown that even a small wind current was capable of significantly impacting the intensity of the fire entering the fuselage. The exhaust fan created a slightly lower pressure inside the cabin, effectively drawing the fire in through the fire opening.

The plan was to ignite the pan of jet fuel and allow the fire to progress until noticeable flashover conditions were reached, which was estimated to be in the 4- to 5-minute range. After the desired conditions were reached, the external fuel fire would be extinguished using aqueous film-forming foam (AFFF). An aft-mounted water spray nozzle was installed in the cabin interior to control the cabin fire if necessary.

One drum (55 U.S. gallons) of JP-8 fuel was emptied into the pan over a thin layer of water, which was used to provide a level surface for the fuel since the pan bottom was warped from repeated fire testing. After a final instrumentation check, the fire was lit, and all data collection systems were initiated simultaneously.

Upon ignition, the fire entered the fire opening quickly and spread rapidly along the seat materials. The cabin fire became intense and reached flashover conditions within 2 minutes, considerably sooner than was expected. The internal cameras were completely obscured shortly after 2 minutes. To protect the test fuselage and instrumentation from significant damage, a decision was made to extinguish the external fuel fire at 3 minutes. The aft-mounted cabin water spray nozzle was activated to cool the cabin atmosphere.

A posttest inspection revealed significant damage to the interior materials (figure 42). A majority of the honeycomb sidewall and ceiling panels were consumed, and significant damage to the seat assemblies was evident, particularly in the seatbacks. The damage clearly showed the fire was able to jump the aisle and involve the seat materials farthest from the fire entry point.

A closer inspection of the seating materials revealed that the seatback assemblies played a significant role in the spread of fire. The stretched nylon suspension system and miscellaneous thermoplastic parts were completely consumed in all seat places. The cushioning materials on the seatback assemblies were largely consumed, with remnants indicating the materials had collapsed onto the surface of the bottom cushion (figure 43). A large percentage of the bottom seat cushions were consumed on the seat assemblies closest to the fire opening; the bottom cushions on the far side of the fuselage were burned on the top, but remained intact. In general, it appeared the bottom seat cushions were not the cause of the rapid fire spread, but had burned more out of consequence from the seatbacks igniting quickly and collapsing onto the bottom cushions.

Figure 42. Baseline Test 1 Cabin Materials Following Test Fire

Figure 43. Seatback Materials Consumed and Cushioning Remnants Displaced

Despite the large amount of seating materials consumed during the fire, it was interesting to note that only a very small amount of the primary aluminum components had melted. The outboard spreader on the port side, row 2 seat sustained the most melting (figure 44). The forward half of the spreader component was still attached to the forward cross tube, which had warped from the heat, but did not melt through. The aft cross tube on this seat had clearly melted through, with an end piece still connected to part of the melted spreader.

Figure 44. Portside Row 2 Seat Primary Spreader Component

Although the outboard spreader was a fairly massive component, the cross tubes were very thin-walled by comparison and were anticipated to melt during the test. Most surprisingly, the leg assembly experienced no melting (figures 45 and 46). This indicated that the test was not run for a sufficient duration, which would be a concern for subsequent tests involving an evaluation of magnesium alloys. Laboratory-scale tests showed conclusively that the alloys were required to be in a molten state before any ignition would occur. Since the amount of melting in this Baseline 1 test was minimal overall, it was questionable whether this would be a good basis for evaluating the magnesium alloys.

Figure 45. Close-Up View of Outboard Leg Assembly of the Portside Row 2 Seat

Figure 46. Close-Up of Portside Row 2 Seat Assembly

A review of the data corroborated the video monitoring of the test, as temperatures in the forward cabin climbed quickly, starting at 90 seconds (figure 47). Ceiling temperatures at this station reached 700°F at the point of external fire extinguishment. At the mid cabin station closer to the fire, the temperatures reached nearly 1400°F at the same point (figure 48).

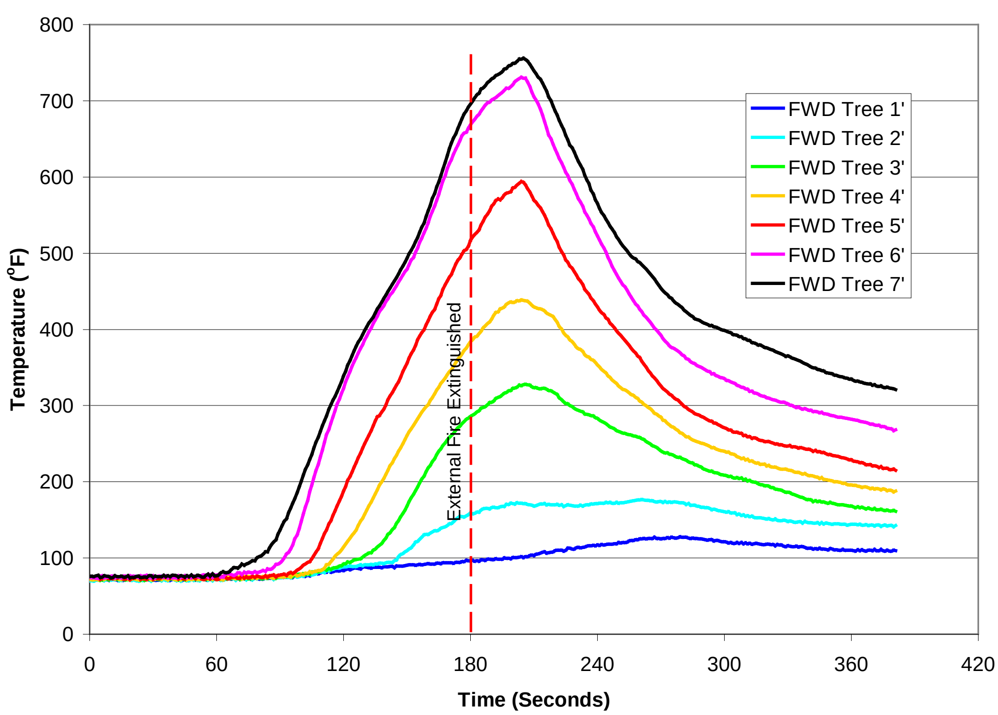

Figure 47. Forward Cabin Temperatures vs Time for Baseline Test

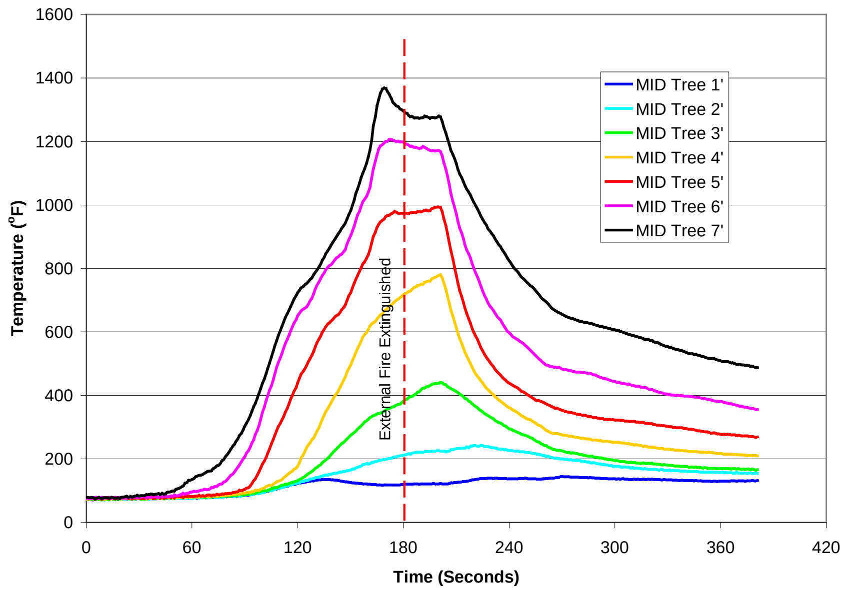

Figure 48. Mid Cabin Temperatures vs Time for Baseline Test

The continuous gas analyzers also recorded elevated levels of carbon monoxide (CO) and carbon dioxide (CO_2), along with oxygen depletion. The CO levels clipped at the maximum 2% recording limits at approximately 3 minutes (figure 49). These are high levels of CO, indicative of a flashover condition. A closer look at the CO traces reveals the timing of events, with the mid cabin station (upper) first experiencing the rise in gas measured, followed by the forward cabin station (upper). The gases then appeared to collect at the forward end, as the next rise is indicated at the forward cabin station (lower). The final rise is shown at the mid cabin station (lower). These traces corroborate the observed smoke plume in the cabin prior to video camera obscuration.

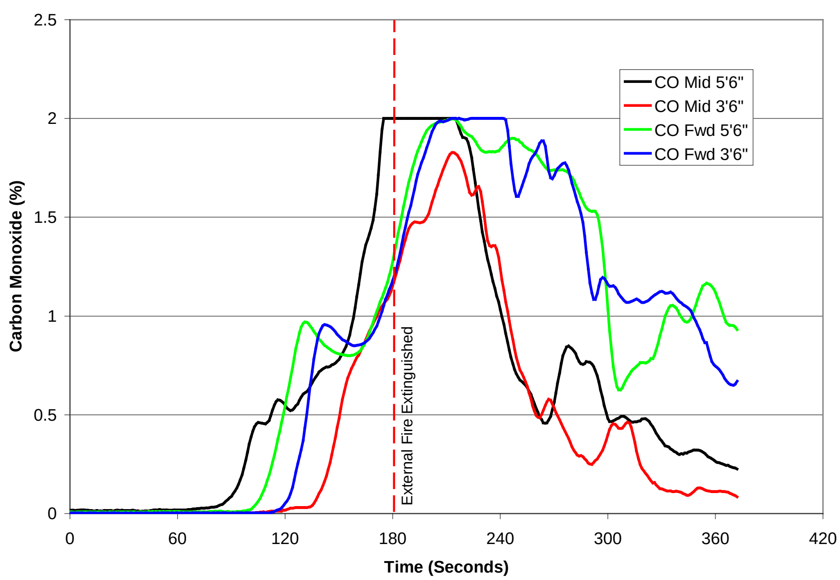

Figure 49. Carbon Monoxide Levels vs Time for Baseline Test

3.2 DESCRIPTION OF SEAT CUSHION MATERIALS USED IN BASELINE TEST 1.

Because the test resulted in flashover conditions being reached so quickly, there was concern over the test configuration and materials used. Since the panels and carpet had been used in previous full-scale tests with no adverse affect, they were ruled out. This focused the attention on the seating materials and the use of the exhaust fan to draw the fire into the test fuselage. Upon removing the burned materials from the test fuselage, the bottom seat cushions were inspected with greater scrutiny, revealing inconsistent construction. In some cases, the bottom cushions included a felt-type, fire-blocking layer, while others appeared to lack a fire-blocking layer, indicating they were fire-hardened foam (blocking layer not used). Since there was some concern over the performance of the seat materials, the untested cushions were removed from the remaining seat assemblies in storage. The inspection revealed a number of different types of bottom cushions, including the (presumably) original units manufactured by B/E Aerospace (figures 50 and 51). A close-up photograph of the inspection tag on the bottom side reveals the manufacturing details, including the statement that it complies with FAR 25.853 (c), which is the flammability test using the oil burner (figure 52). Other units were manufactured by Franklin Products (figures 53 and 54). The Franklin Products inspection tag revealed a similar statement of compliance with FAR 25.853 (c) (figure 55).

Figure 50. Bottom View of Bottom Seat Cushion Used in Baseline Test 1 With B/E Aerospace Markings

Figure 51. Side View of Bottom Seat Cushion Used in Baseline Test 1 With B/E Aerospace Markings

Figure 52. B/E Aerospace Manufacturer's Plate on Bottom Seat Cushion Used in Baseline Test 1

Figure 53. Bottom View of Bottom Seat Cushion Used in Baseline Test 1 With Franklin Products Markings

Figure 54. Side View of Bottom Seat Cushion Used in Baseline Test 1 With Franklin Products Markings

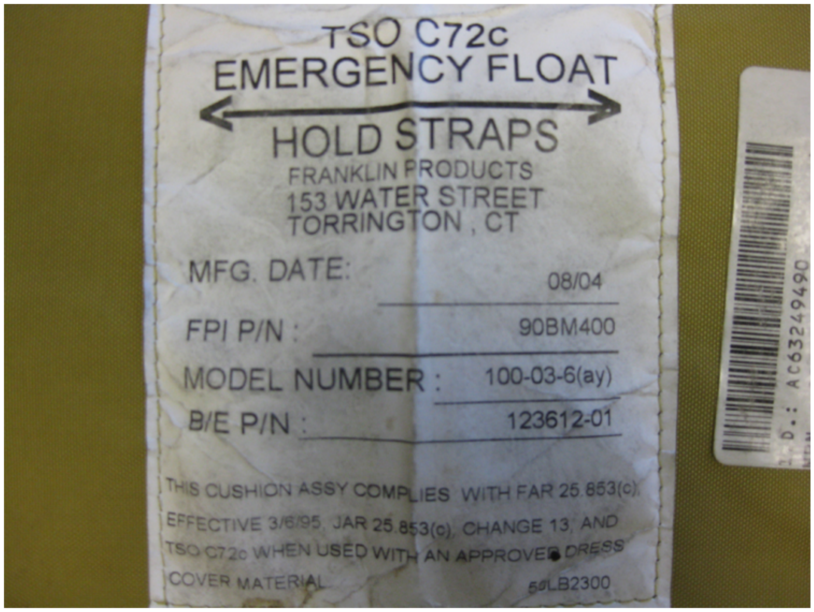

Figure 55. Franklin Products Manufacturer's Plate on Bottom Seat Cushion Used in Baseline Test 1

Although these two types of bottom seat cushions appeared to meet the current flammability requirements, a third cushion type was found that did not include any fire-blocking layer (figure 56). Furthermore, this particular unit had no i nspection tag or other information identifying it or its compliance level (figure 57). It can only be assumed that this unit was a fire-hardened foam cushion, but this information could not be confirmed, since the seats were purchased from an aircraft spares dealer who did not keep any compliance records.

Figure 56. Side Angle View of Bottom Seat Cushion Used in Baseline Test 1 With no Fire-Blocking Layer or Inspection Tag

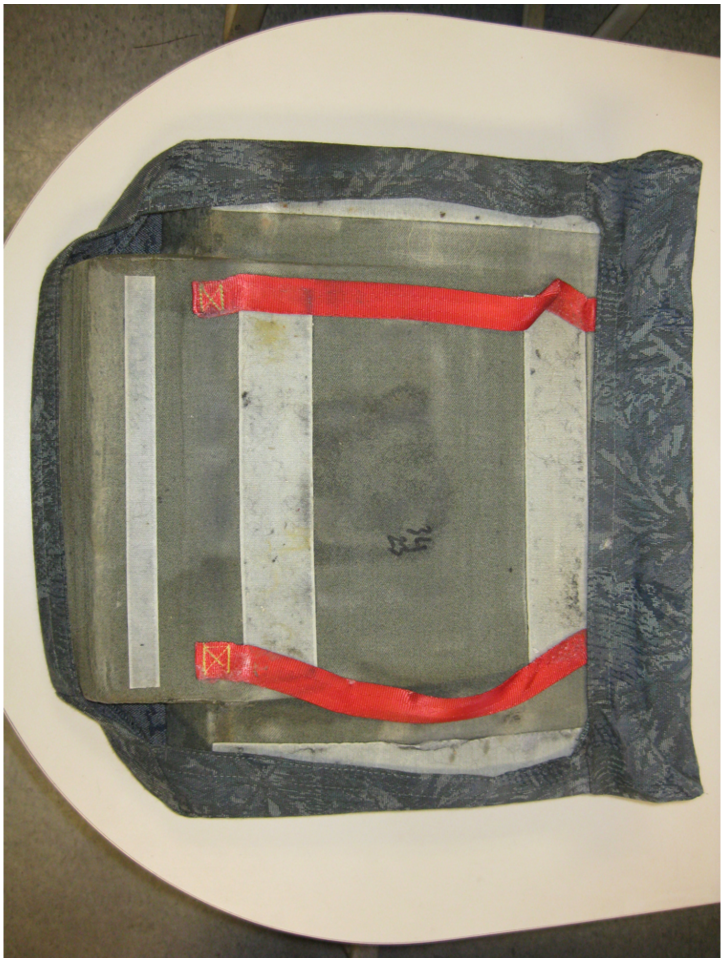

Figure 57. Bottom View of Bottom Seat Cushion Used in Baseline Test 1 With no Fire-Blocking Layer or Inspection Tag

Baseline test 1 provided an unexpected result, with a flashover condition developing very rapidly. Because of the short period of time before conditions inside the cabin became nonsurvivable, the test was shortened to approximately 3 minutes. This short test duration did not allow sufficient time for the primary seat structure to melt, which was a prerequisite for properly evaluating the magnesium alloy components in subsequent tests.

The posttest inspection of cabin materials focused attention on the performance of the seat cushion materials, which led to the discovery of three different types of bottom seat cushions on the B/E 990 seats purchased from the spares dealer. The seatback assembly was also a concern, as the fiberfill and suspension system were completely consumed during the test. The flammability of the carbon fiber-based seatback frame was also questioned, as this structure contained flammable epoxy resin used to impregnate the carbon fiber tape. The inspection revealed considerable delamination of this structure, indicating the resin was also consumed in the fire.

3.3 BASELINE TEST 2.

Because of these uncertainties, a donated set of used seat bottom and back cushions was substituted for a repeat test, Baseline Test 2. The donated set of cushions (supplied by Accufleet of Houston, Texas) was constructed of known materials with the desired flammability characteristics. The cushion dress coverings were Continental Airline livery, and the bottom units included the necessary fire-blocking layer, a felted type manufactured by Franklin Products (figure 58).

Figure 58. Bottom Seat Cushion Used in Baseline Test 2, Showing Inspection Tag

Because of the poor performance of the seatback configuration in Baseline Test 1, a change was also made to the fiberfill cushion material for Baseline Test 2. The seat cushion backs were cut open in the back, and the original fiberfill was removed. The material was replaced with DAX Foam™, a flexible, closed-cell polymeric foam that contains expandable graphite as a fire retardant[2]. The foam material is the U.S. version of a Kay-Metzeler foam produced in the United Kingdom. Reports from industry indicate the combination of DAX Foam and upholstery fabric meets FAR 25.853 (c), with a resulting weight loss of approximately 6% (10% is the maximum allowable per the requirement). All other B/E 990 seat structures and hardware remained identical to those used in Baseline Test 1. The completed B/E 990 seats with backs containing DAX Foam were installed in the test fuselage identical to Baseline Test 1 (figure 59).

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[2] DAX Foam is a flexible, closed-cell polymeric foam that contains expandable graphite as a fire retardant. The foam is prepared by mixing a polymer, a curing agent, at least one blowing agent, and an expandable graphite at a temperature of at least 100°C (but below a temperature causing activation of the blowing agent to form a foamable mixture) and thereafter heating the foamable mixture to activate the blowing agent and cause foaming. The method of preparation may additionally include a curing step in which the foamable mixture is heated under pressure to simultaneously activate each curing agent, which is preferably a free radical curing agent, and a foaming agent. The foams are capable of meeting the U.S. Federal Aviation Authority Standards, especially the oil burner test of 14 CFR Part 25 Appendix F, Part II.

Figure 59. Baseline Test 2 Configuration

The other possible factor that may have caused the fire to enter the cabin so quickly in Baseline Test 1 was using an exhaust fan to draw the fire in through the door. Because of the relatively short time required to reach flashover conditions, it was decided that an exhaust fan would not be used for Baseline Test 2. It was anticipated that without the exhaust fan, flashover conditions would not be reached until 4 to 5 minutes.

The fuel pan was loaded with 55 gallons of JP-8, and a final check of the instrumentation was performed. The data collection system was initiated just prior to fuel pan ignition. As with Baseline Test 1, the fire appeared to spread into the cabin and involve the materials quickly. Within 1 minute, the tops of all seatbacks on the port side of the fuselage were on fire. By 1 minute 30 seconds, the fire on the seatbacks was intense and had progressed downward to the bottom seat cushion area. By 1 minute 40 seconds, the tops of the seatbacks on the starboard side of the fuselage were on fire, and the ceiling panels were falling down onto the seats while on fire. By 1 minute 50 seconds, all seating materials on the port side were fully involved, and the cabin contents were starting to ignite, indicative of flashover beginning. Flashover conditions were fully reached at 2 minutes, and the cameras were completely obscured by the smoke layer by 2 minutes 20 seconds. Despite these conditions, it was agreed that the test should continue unabated in an effort to cause more extensive melting. The extended test time and component melting would be necessary during subsequent magnesium alloy tests. As the previous laboratory-scale results indicated, the materials had to melt first before ignition would occur.

The pan fire was extinguished at 5 minutes 30 seconds with AFFF, and the interior fire self-extinguished a few minutes later. A posttest inspection of the fuselage revealed significant fire damage to the materials, similar to the previous baseline test. A majority of the honeycomb sidewall and ceiling panels were consumed with remnant pieces suspended from steel safety wire at various places in the ceiling and stowage bin areas (figure 60). Again, substantial damage to the seat assemblies was evident, particularly the seatbacks. The damage clearly showed the fire was able to jump the aisle and involve the seat materials farthest from the fire entry point.

Figure 60. Baseline Test 2 Cabin Materials Following Test Fire

A closer inspection of the seating materials revealed that the seatback assemblies, including the stretched nylon suspension system and miscellaneous thermoplastic parts, were completely consumed in all of the portside seats (figure 61). The seatback cushion materials were largely consumed, with remnants collapsed and piled onto the upper surface of the bottom cushion. The portside row 2 and 3 bottom seat cushions were largely consumed, while the portside row 1 seats did not appear as damaged. However, upon examination of these cushions, it was discovered that they were deplete of foam, as if the inside had burned and the fire-blocking layer did not. Also of note were the thermoplastic life vest boxes, which were largely intact and unburned, except in the direct impingement areas. This result indicated the materials near the floor (seat cushion and lower) were in a zone of lesser severity than the materials higher up in the cabin during this particular postcrash scenario.

Figure 61. Close-Up View of Portside Triple Seat in the Baseline 2 Test

The seatback cushions on the starboard side were noticeably less fire damaged than the portside materials (figure 62). Only the starboard-side aisle seats showed similar slumping of the seatback materials onto the bottom seat cushions. Although heavily fire damaged, the materials were still in place on the seatbacks, in contrast to the portside seatbacks, which were largely void of materials. The bottom seat cushions on the starboard side also exhibited signs of being hollow, where the interior foam was consumed, leaving a shell of fire-blocking layer and charred dress cover.

Figure 62. Close-Up View of Starboard-Side Triple Seat in the Baseline 2 Test

A view from the aft cabin revealed a noticeable dividing line between the portside and starboard-side damage (figure 63). Although the fire had crossed the aisle at some point during the test, there was a noticeable difference in the level of damage on either side. The portside seatback assemblies were extensively damaged, with all cushion materials consumed. The carbon frame was also heavily damaged on all portside seats, and in some cases, it had collapsed. In contrast, the seatbacks on the starboard side were relatively intact, with the dress cover still visible from the aft view of the triple seat in row 3.

Figure 63. Aft Cabin View, Showing Portside and Starboard Seat Damage

A closer view of the portside seats revealed several of the carbon seatback frames had collapsed, as the frame appeared to lose structural integrity once the epoxy resin was consumed in the fire (figure 64). The collapse of the structure likely aided in the spread of fire, as the seatbacks were observed igniting early in the fire sequence via fuselage-mounted cameras. Once the structure collapsed, it could have fallen into an adjacent material, causing it to ignite and spread the fire. The seatback structure collapse also impacted the performance of the DAX Foam used there. This foam is a polyurethane with graphite added, and when hit by a flame, the polyurethane burns down until the outer layer is predominantly graphite. In a laboratory setting, a static performance state is quickly reached, since there is no structural collapse of the steel test frame. However, occasional failures of this material can occur during a laboratory test, when the dress cover (typically leather) contracts and breaks apart the foam. This progression exposes new polyurethane foam, which then has to burn down to form a new graphite barrier. In the Baseline Test 2, the burning and failure of the seatback structure would have broken apart the DAX Foam in the cushion as it fell. This likely caused substantially more of the DAX Foam to burn than if it were held in a static position[3]. Also of note were the thermoplastic tray tables, which were almost completely consumed on the portside seats.

[3] Conversation with Jim Davis of Accufleet International, Incorporated, of Benmar, Texas.

Figure 64. Aft Cabin View of Portside Seats Showing Back Assembly Structure Collapse

As mentioned previously, an inspection of the seat structure following Baseline Test 1 revealed limited damage to the primary components. Based on this finding, one of the key elements of the second baseline test was to run it for a sufficient length of time to cause more widespread melting of the primary components. The primary components, in particular the leg assemblies and spreaders, were fairly massive in construction and would require considerable heat to cause melting. Previous laboratory-scale tests on magnesium alloy bar samples clearly showed that melting conditions must exist before any type of ignition can occur. The difficulty with ensuring adequate melting of the primary components during a test was that there was no practical method for viewing or monitoring these conditions. Cameras could not be placed in the proximity of the melting components without impacting the test, nor was this practical. The installation of thermocouples on the primary components was also not a simple solution, since there was no guarantee accurate data could be extracted using this method. As a result of these difficulties, it was decided to simply run the test as long as practical without destroying vital data collection systems. As a result, Baseline Test 2 was extended for a full 2 minutes 30 seconds longer than Baseline Test 1, which should have been adequate for primary component melting to take place.

Following a thorough inspection of the materials in the cabin, the seats were removed and placed on the test facility floor for further examination (figure 65). With the exception of the triple seat located adjacent to the fire opening, there was no melting of the primary components on any of the other seats. The portside row 2 seat assembly sustained the majority of the fuel fire heat and experienced rear cross tube and left-side leg melting (figure 66). Although this melting was not considered widespread, it was similar to the extent of melting experienced on the magnesium alloy bar samples tested in the laboratory and, therefore, had the potential to allow the magnesium components to ignite in subsequent full-scale tests.

Figure 65. Seats Placed on Test Facility Floor for Inspection

Figure 66. Close-Up View of Melted Leg and Cross Tube Structure on Entry Door Seat

A review of the data corroborated the video recording of the test, as temperatures at the forward cabin station climbed quickly, starting shortly after 60 seconds (figure 67). Ceiling temperatures at this station reached 570°F at the point of external fire extinguishment. At the mid cabin station closer to the fire, the temperatures reached approximately 900°F at this point in time (figure 68). A quick comparison revealed that these temperatures were much lower than the temperatures observed during Baseline Test 1, despite the test being 2 minutes 30 seconds longer. This indicates that the DAX Foam substituted for the fiberfill used in the seatback cushions had a positive impact on the test and resulting fire growth. The temperature profiles also show a plateau effect, in which the temperatures initially rose at a steep rate, but leveled off and remained fairly constant for several minutes prior to the external fire being extinguished.

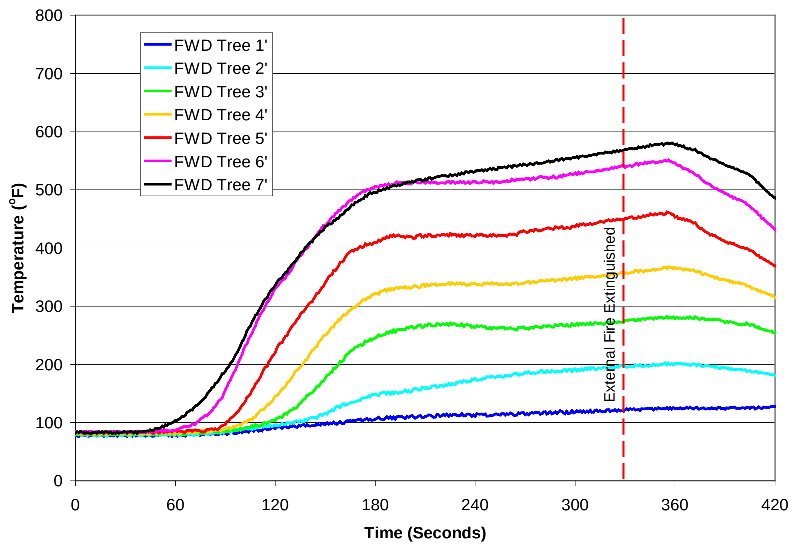

Figure 67. Plot of Forward Cabin Temperature vs Time for Baseline 2 Test

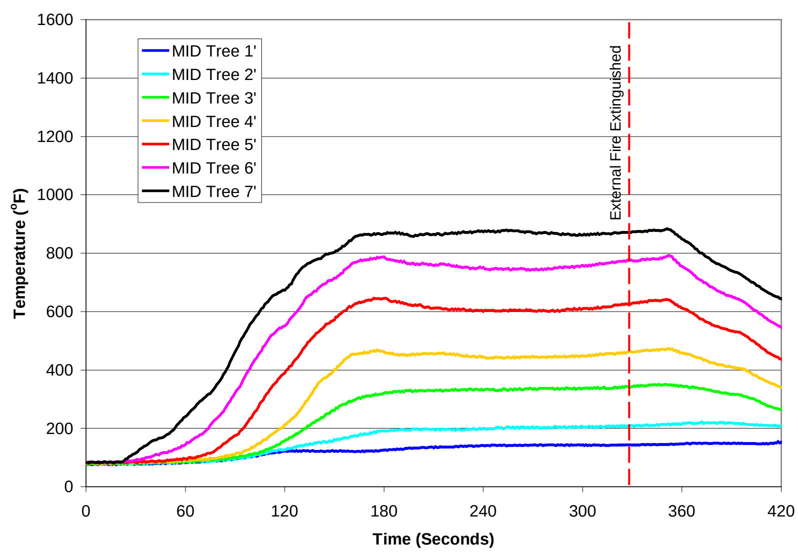

Figure 68. Plot of Mid Cabin Temperatures vs Time for Baseline 2 Test

A review of the CO data also indicates a reduced rate compared to the previous baseline test. Although substantial, the CO levels never reached the maximum 2% recording limit and were less than half the amount achieved at the 3-minute point during Baseline Test 1. Similar to the temperature profiles, the CO traces also show an initial steep rise after 60 seconds, followed by a steady but lower rate of rise from the 3-minute period until the end of the test (figure 69). The traces also reveal the same timing of events, with the mid cabin station (upper) first experiencing the rise in gas measured, followed by the forward cabin station (upper), the forward cabin (lower), and finally the mid cabin (lower). This indicated the test progressed in a similar manner as Baseline Test 1, but at a slightly slower rate.

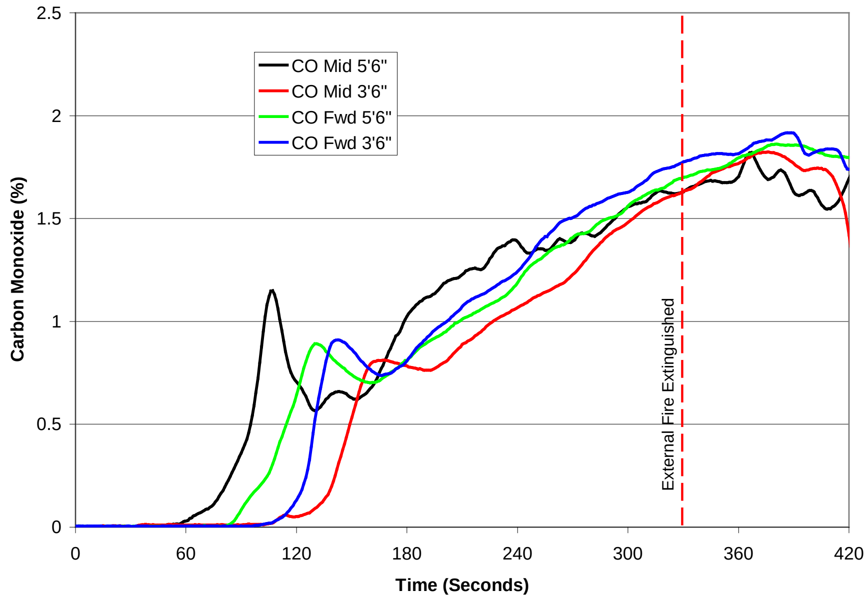

Figure 69. Plot of Carbon Monoxide Levels vs Time for Baseline 2 Test

The lack of an exhaust fan drawing the fire in through the fire opening was another consideration in the observed growth of fire, which was slightly lower during Baseline Test 2. Although flashover conditions were again reached prematurely, the temperatures and gas levels did not reach those obtained during Baseline Test 1. It is possible, and perhaps likely, that the lack of forced ventilation aided in slowing the progress of fire during Baseline Test 2. For this reason, exhaust ventilation would be eliminated for subsequent tests.

To compare the two baseline test results, a survivability model was used to predict the theoretical time at which a person would become incapacitated, based on the levels of temperature and gases measured during the test. A fractional effective dose (FED) model developed by Speitel [8] predicts the amount of time a human has to escape an aircraft fire, using regression equations based on numerous sources for many animal species over a wide exposure concentration range. The effect of carbon dioxide increasing the uptake of other gases is included in this referenced model. This survival 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 unity determines the exposure time available to escape from an aircraft cabin fire and to survive postexposure. Speitel showed that the primary toxic contribution of CO_2 in aircraft cabin fires is the increased uptake of other gases induced by the inhalation of CO_2.

Using the temperature and gas data obtained in the two baseline tests, the survivability model calculated similar results for each (figure 70). Not surprising was the nearly 3-minute time to reach incapacitation at the forward location in the cabin for both tests, with the second baseline showing a marginally better result. This result corroborated the video obtained during each test, in which a rapid burning of the materials culminated in complete camera obscuration by 2 minutes 30 seconds. Most notable was the relatively short period of time required to reach incapacitation at the mid cabin station for both tests, with the initial baseline test yielding a slightly more favorable result. Although the two test results were close, a cursory review of the data indicated more favorable conditions existed at all locations inside the cabin during Baseline Test 2.

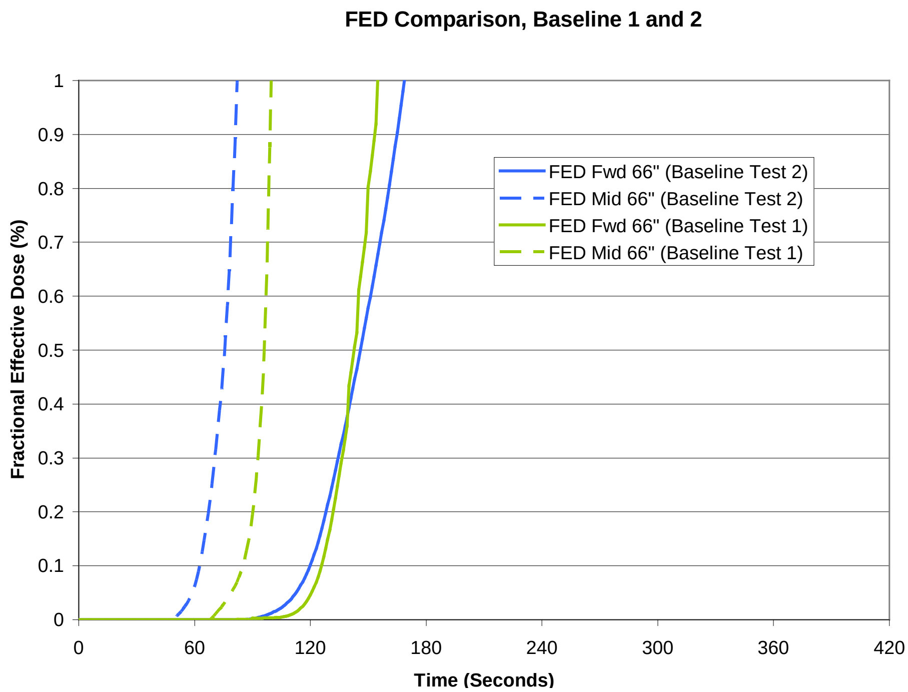

Figure 70. Survivability Calculations for Baseline Tests 1 and 2

Considering the fact that Baseline Test 2 was not terminated until 5 minutes 30 seconds, the seatback area again performed very poorly despite the use of DAX Foam in place of the fiberfill in the back cushions. Another factor that may have contributed to the flame spread in this area during Baseline Tests 1 and 2 was the seat frame structure, which was constructed of carbon fiber tape and epoxy resin. It is possible that the flammable seatback structure contributed to the fire load, and allowed the burning seatback to collapse onto the bottom cushion and the floor, promoting additional fire spread. The many thermoplastic parts in the seatback headrest area must also be considered, given the rapid ignition and spread of fire along the seatback assemblies. Considering these elements, and the relatively short time periods to reach incapacitation, a decision was made to conduct a third baseline test with the intent of obtaining a more favorable result. By extending the time to reach incapacitation, a more complete and accurate assessment of the magnesium alloy performance could be made during subsequent tests.

The topic of conducting a third baseline test was discussed during the March 2009 IAMFTWG meeting. The participants agreed that the seatback assembly played a key role in the rapid spread of fire and short survival times during the first two baseline tests. To prevent this occurrence during a third baseline test, it was necessary to use a completely new seatback assembly. The simplest approach was to design and construct an assembly using known materials with good fire-resistant qualities. This would include replacing the epoxy-impregnated carbon tape frames with simple box aluminum. A prototype assembly was designed and circulated to key task group participants for review.

3.4 REDESIGNED SEATBACK ASSEMBLY.

The new seatback concept was simple, yet retained the original shape and size of the B/E 990 seatback. Chestnut Ridge Foam, Inc. had previously retrofitted a shipset of B/E 990 seatbacks for a business-jet customer, and as a result, they had a back cushion available, which simplified the selection process. This eliminated the need for a costly design and development process. A sample of this cushion was sent to the FAA, and an aluminum box frame was developed to fit the pattern (figure 71). To bend the aluminum tubing to the correct pattern, a special hydraulic tube-bending machine was purchased.

Figure 71. Fire-Hardened Foam and Fabricated Aluminum Frame

The aluminum used for the frame was Al 2024-T3, and measured 0.75 by 1.5 inches. Chestnut Ridge also had available a dress cover for this particular assembly that was supplied for test fitting the prototype assembly (figure 72).

Figure 72. Dress Cover Being Test Fitted to Prototype Cushion Assembly

The frame was adjusted slightly and the prototype was finalized. The assembly was simple, consisting of only six components: the aluminum frame, the fire-hardened foam, the fabric wear protector (slip) glued to the cushion, the dress cover, the tray table, and the fabric literature pocket. This new design eliminated the carbon/epoxy frame, the stretched fabric suspension system, and numerous thermoplastic parts in the headrest assembly area. An aluminum seatback pan was used in place of the fabric suspension system, which extended down to the tray table area (figure 73). The aluminum seatback pans were installed on both the back and front of the newly designed aluminum frames (figure 74). The bottom seat cushions remained as is, stock Continental Airlines livery units, with Franklin Products felt-type fire blocker.

A total of 90 cushion assemblies were ordered from Chestnut Ridge, which was sufficient for five complete full-scale tests (18 seat cushions for each test). This would enable execution of the original four tests (baseline plus three magnesium alloy tests) and would provide extra materials in the event that a test malfunctioned or additional tests needed to be conducted. In addition, 90 dress covers were ordered from Preferred Aviation, Inc. of Miami, Florida, to fit each cushion. Preferred Aviation had supplied the dress cover that was used in the prototype development. By coincidence, the dress covers were supplied in Continental Airlines livery and matched the bottoms supplied with the B/E 990 seats. All additional materials were ordered, and fabrication began as the materials were received.

Figure 73. Seatback Assemblies Being Fabricated and Mounted on B/E 990 Seats

Figure 74. Partially Fabricated Seatbacks Showing Front Aluminum Pan

Aside from the materials purchased for the seatback fabrication, additional B/E 990 seats needed to be purchased, since the original order contained only enough to conduct four tests. Since two additional baseline tests were conducted, at least 12 additional triple seats were needed. An order was placed with a different aircraft spares dealer. Universal Asset Management, Inc. of Memphis, Tennessee, supplied 24 additional B/E 990 seats. The seats received were in very good condition and contained all the necessary cushion materials, including the fire-blocked bottom seat cushions. The seats were outfitted with Continental Airlines livery (figure 75).

Figure 75. Additional B/E 990 Seats

3.5 ADDITIONAL FULL-SCALE TEST DETAILS.

After carefully reviewing the data from the initial two baseline tests, there was considerable debate over the optimum length of the full-scale tests and the most appropriate point to extinguish the external fuel fire. During the first two baseline tests, the external fire was allowed to burn beyond the flashover point, with the pan fire extinguished at 3 minutes and ~5 minutes 30 seconds, respectively. In both tests, flashover and incapacitation were reached prior to 3 minutes. In proposed Baseline Test 3, it was anticipated that flashover would occur at roughly 4 minutes to 4 minutes 30 seconds from initiation of the external fire. Incapacitation would occur in roughly the same time frame. If this estimate was accurate, the external fuel fire would be extinguished at approximately 5 minutes. Reaching an incapacitation state was a desired criterion of this test; however, since the model used to calculate incapacitation is not a real-time model (i.e., data is obtained from the test after completion and subsequently input into the model to determine incapacitation), one suggestion was to perform a real-time approximation of cabin survivability. This could be done by monitoring the CO and temperature at the two measuring stations in the cabin at 30-second increments. For example, at 4 minutes, if the levels were such that incapacitation had not been reached, the test would continue to 4 minutes 30 seconds, and the levels rechecked. Once flashover and incapacitation were reached, it would be permissible to extinguish the external fuel fire. Although this approximation could be performed, it was agreed that, for simplicity, the test would simply be terminated at 5 minutes by extinguishing the external fuel fire instead.

In addition to the test duration, the application of water on the seating materials was also investigated and discussed prior to conducting Baseline Test 3. For the purposes of comparison between the baseline test and subsequent magnesium alloy tests, it was planned that water would be used in all subsequent tests, not just in the magnesium alloy tests. This would be accomplished using both a deluge nozzle positioned to knock down the cabin fire, and an additional side-mounted stream nozzle aimed directly at the seat in the fire door (figure 76). After discussing this plan at IAMFTWG meetings in March and June 2009, it was determined that more useful information would be gained by allowing a 5-minute observation period following fuel pan fire extinguishment. During Baseline Test 3, this would not likely be a concern. During subsequent magnesium alloy tests, there were several possibilities that could exist during this 5-minute observation period. For example, considering extremes, the fire could either be self-extinguishing/diminishing without intervention or conversely, it could be increasing in intensity. Another possibility was a condition that fell somewhere between these two extremes. The IAMFTWG task group members agreed that it might be useful to not apply water initially to the cabin interior immediately following fuel pan fire extinguishment. Water application could be performed during the 5-minute observation period in the event the fire was obviously increasing in intensity, or if there were visible signs of magnesium alloy ignition. If it became difficult to determine if the fire was increasing in intensity or decreasing, water could be applied after certain parameters were met, for example increasing cabin temperature or seat frame temperatures. These details would be finalized prior to the execution of the third magnesium alloy full-scale test.

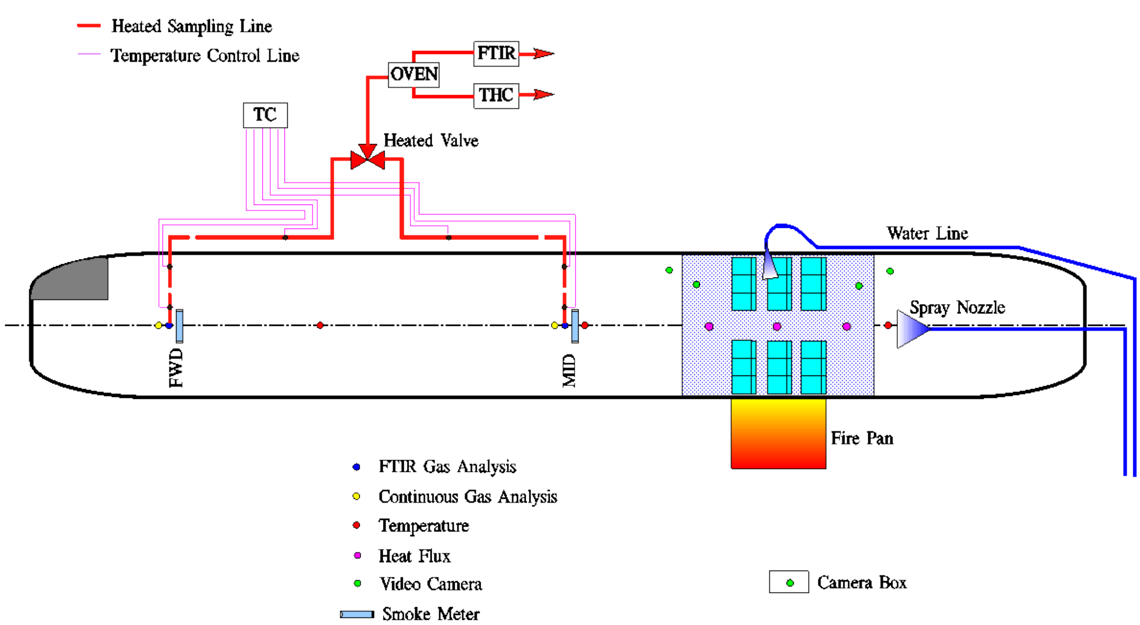

Figure 76. Test Fuselage Schematic Showing Water Nozzles and Additional External Camera

An additional problem encountered in both of the two initial baseline tests was the inability to see the test progression due to smoke obscuration. In both tests, the stratified smoke layer descended to the camera level at approximately 2 minutes 30 seconds, making it impossible to determine the extent of burning/melting of the components. To alleviate this problem an external camera was mounted adjacent to the fuel pan, approximately 50 feet from the seat positioned in the fire door (figure 76). The camera could be zoomed in to capture the burning seat once the fuel pan was extinguished. This would allow a close-up view of the seat during water application and would not be impacted by the high levels of smoke inside the cabin.

The IAMFTWG task group members also agreed that laboratory-scale tests in accordance with 14 CFR 25.853 (c) should be conducted on the finalized seat configuration, which uses a fire-blocked bottom seat cushion and fire-hardened foam in the newly fabricated seatback. This would involve a minimum of six oil burner tests, since the requirement calls for the bottom and back seat cushions to be run independently. Chestnut Ridge supplied three sets of samples representing the seatback cushion fire-hardened foam for the laboratory-scale flammability tests (appendix A). Since it was not possible to obtain three additional sets of block samples to represent the bottom seat cushion, these tests were not conducted. Although it was preferable to conduct these tests for completeness, industry experts familiar with this cushion material system indicated that it performed acceptably, exhibiting consistent passing results over time. As a comparison, an alternative set of laboratory tests were conducted using the actual contoured seat cushions from Baseline Tests 1 and 2 (appendix B). Although using actual seat cushions was not the desired methodology, it did provide a rough estimate of the poor performance of these seating materials used in the first two baseline tests, for comparison.

3.6 SEAT FRAME TEMPERATURE MEASUREMENT.

As shown in the earlier laboratory-scale tests, it was necessary for the magnesium alloy materials to melt before any ignition would occur. To determine if the magnesium alloy seat components reached their melting temperatures during the full-scale tests, thermocouples were embedded into the seat leg components. The most practical method for doing this was to drill a small-diameter hole and insert a metal-sheathed thermocouple into the borehole. As a safety measure, the thermocouples were held in place using high-temperature, room-temperature vulcanizing (RTV) silicone (figure 77). The RTV silicone also prevented the thermocouple from inadvertently measuring air temperature from the surrounding area by sealing the sensor in the borehole, thereby measuring only the core metallic temperature. This measurement technique was not perfected until Baseline Test 3. The lead wires from the thermocouples were also wrapped in a heat-resistant sheath to protect them from fire damage.

Figure 77. Typical Embedded Thermocouple Arrangement in Seat Leg

During Baseline Tests 1 and 2, only five thermocouples were used to monitor the leg frame temperatures: one in each of the three portside seats and two in the starboard-side seat in row 2. It was agreed that additional thermocouples should be mounted in the legs of the seats for all subsequent tests, as this information is useful in determining the extent of component melting. During Baseline Test 3, three additional thermocouples were added to the leg frames, for a total of eight (figure 78).

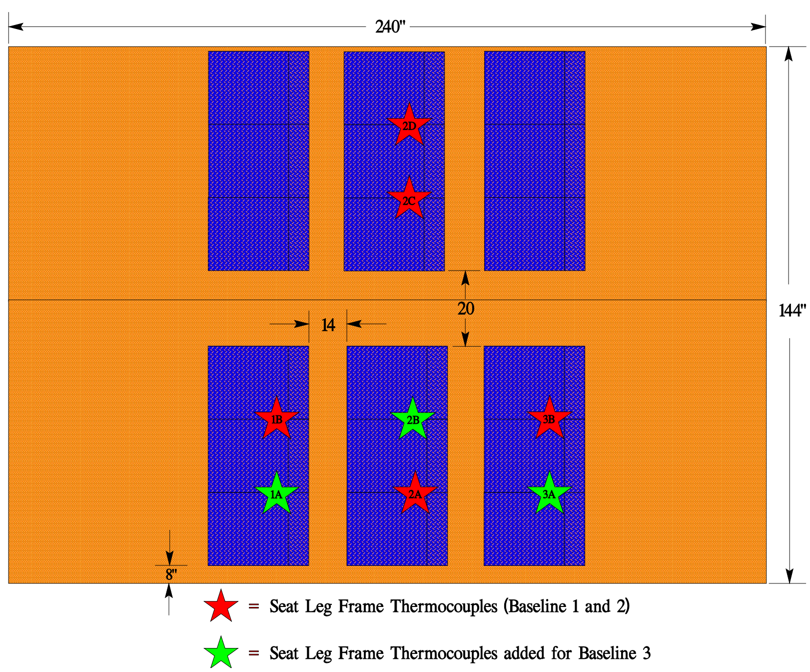

Figure 78. Location of Leg-Mounted Thermocouples

3.7 BASELINE TEST 3.

All seatback construction was completed, and the fully dressed seats were installed in the test fuselage, which had been previously outfitted with honeycomb sidewalls, ceiling panels, and stowage bins, and carpeting (figures 79 and 80). The fuel pan was loaded with 55 gallons of JP-8 fuel, and a final check of the instrumentation was performed. All cabin doors were checked to ensure there were no other openings except the aft L3 door, which was partially open as in previous tests, to allow the entrance of make-up air for combustion. The data collection system was initiated just prior to fuel pan ignition, and the fire was started. In contrast to the previous two baseline tests, the fire did not appear to spread into the cabin as quickly. There was excellent visibility from all cameras at the 1-minute point, with only localized burning on the seat directly in the fire opening. The visibility remained clear at the 2-minute point, as the fire began to spread on the sidewall panels around the periphery of the fire opening and progressed forward and aft on the stowage bin panel surfaces. The aft upper camera clearly showed less visibility and greater quantities of smoke compared with the aft lower camera. At 3 minutes, the aft lower camera was moderately clear, with smoke density beginning to rise. Forward cameras showed the seatbacks on all portside seats were on fire near the tops, but there was no evidence of involvement on the starboard-side seats at this point. By 3 minutes 40 seconds, flashover conditions began to develop, with increased turbulence in the smoke at the ceiling, and visible flames on much of the ceiling surface. Flashover continued, with complete obscuration of the cameras at 4 minutes 15 seconds. The test continued unabated for another 45 seconds after camera obscuration in an effort to cause more extensive melting. The extended test time and component melting would be necessary during subsequent magnesium alloy tests, as the previous laboratory-scale results indicated the materials had to melt first before ignition would occur.

Figure 79. Baseline Test 3 Configuration

Figure 80. Aft View of New Seatback Assemblies Used in Baseline Test 3

The extinguishment of the pan fire began at 5 minutes with AFFF, and the interior fire was allowed to continue without intervention for 5 additional minutes. The pan fire was completely extinguished by 6 minutes 10 seconds, at which point the internal fire was observed burning vigorously on the row 2 seat assembly in the fire opening. The burning appeared to be confined to this seat assembly. The newly installed external camera was used to monitor the interior fire during the 5-minute observation period. In addition, the previously obscured view from the aft lower camera began to clear at 9 minutes 15 seconds, offering some additional observation of the burning seat materials. The fire near the row 2 seat assembly continued to burn until the 10-minute mark when the internal water nozzles were activated. This immediately obscured the aft lower camera again, so the only view of the fire was from the external camera. A small, localized fire just inside the fire opening continued to burn for several more minutes. It appeared the water spray was not reaching this small fire, and it was discovered later that the side-mounted nozzle malfunctioned and never activated. The small fire was not extinguished by the aft-mounted water spray because it could not reach that area of the cabin. The aft water nozzle continued to spray until 13 minutes, at which point, it was shut off. A firefighter climbed a ladder and used a hand-held CO_2 extinguisher to address the small remaining fire. He discharged the CO_2 agent from 14 minutes 50 seconds until 15 minutes, and again at 15 minutes 45 seconds, completely extinguishing the small fire. There were no observed flashes or indications of any metallic fire, which was the anticipated result.

A posttest inspection revealed a number of the portside seatbacks were consumed, including the aluminum frames (figures 81 and 82). The starboard-side seatbacks were largely intact, with only surface burning and charring of the fabric dress cover (figures 83 and 84).

Figure 81. Baseline Test 3 Damage to Portside Seats

Figure 82. Close-Up of Portside Triple Seats Showing Melted Aluminum Seatbacks

Figure 83. Posttest Starboard-Side Seats in Baseline Test 3

Figure 84. Aft View of Starboard-Side Seats

To facilitate a closer inspection of the burned materials, the seat structures were carefully removed from the fuselage and put on the floor of the test facility, positioned in the same orientation as in the test (figure 85). The damage clearly indicated the newly designed seatbacks had prevented extensive flame spread, as the starboard-side seats were heavily charred but the seatback materials were still intact. The 5-minute test duration appeared sufficient, as there was thorough melting of the seat frame near the fire opening, which was the desired result (figure 86). The close-up photographs show that both cross tubes were melted, along with the outboard leg component and outermost spreader assembly. The next inboard spreader assembly had partially melted and was lying on the fuselage floor. Although they were not primary components, the seatback frames and most of the lower baggage bar on this triple seat were also completely melted. These results indicated a successful test condition had been established. The conditions resulted in thorough melting of the primary components, but the overall atmospheric conditions were not so severe that subsequent magnesium alloy materials could not be effectively evaluated.

Figure 85. Seats Removed From Fuselage Following Baseline 3 Test

Figure 86. Close-Up of Melted Seat Structure Primary Components

3.8 COMPARISON OF BASELINE TEST RESULTS (ALUMINUM SEAT COMPONENTS).

The data from all three baseline tests were compared to confirm the observed results. Temperature data from the tests indicated a much earlier rise during the initial two baseline tests with the carbon/epoxy seatback structure. For clarity, only the 4- and 5-foot temperature data is shown (figure 87). In the forward cabin, there is an approximate 2-minute lag in temperature when comparing Baseline Test 3 to the previous two tests. This data gives a very rough estimate that the newly designed seatback provided approximately 2 more minutes before nonsurvivable conditions were reached. A similar trend was observed in the aft cabin (figure 88).

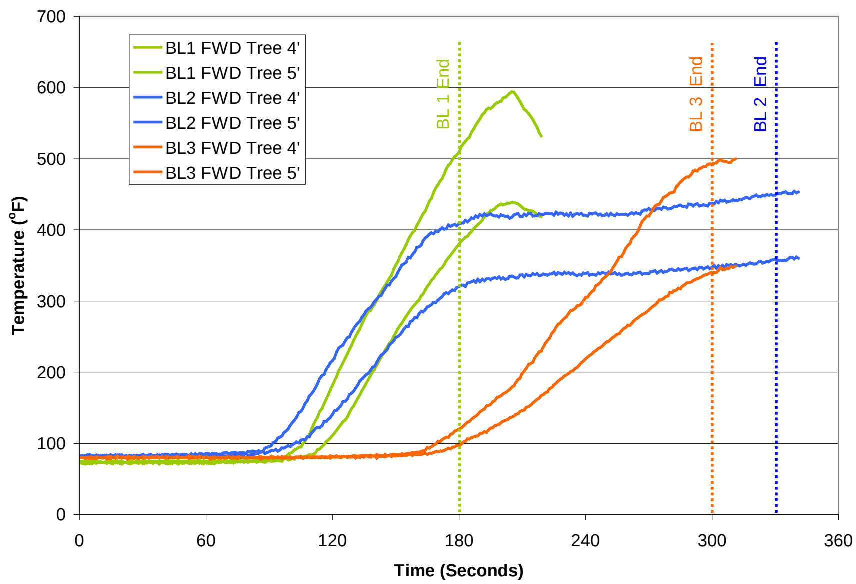

Figure 87. Baseline Temperature Comparison in Forward Cabin Area

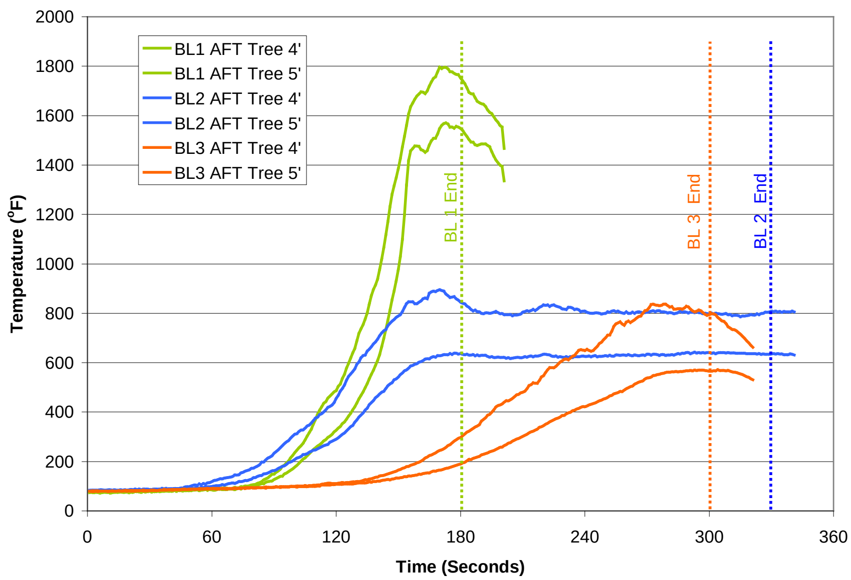

Figure 88. Baseline Temperature Comparison in the Aft Cabin Area

The data obtained for the CO levels followed the same trend as the temperature data. During Baseline Tests 1 and 2, the forward gas-monitoring station (3 feet 6 inches to 5 feet 6 inches) indicated a nearly identical result, with both tests reaching a level of approximately 0.8% at the 2-minute mark (figure 89). Baseline Test 3 reached a level of approximately 0.8% at the 4-minute mark. Similar results were obtained at the mid cabin station, closer to the fire opening (figure 90). Oxygen depletion was also recorded and showed much the same result of delay between Baseline Tests 1 and 2 and Baseline Test 3 (figures 91 and 92).

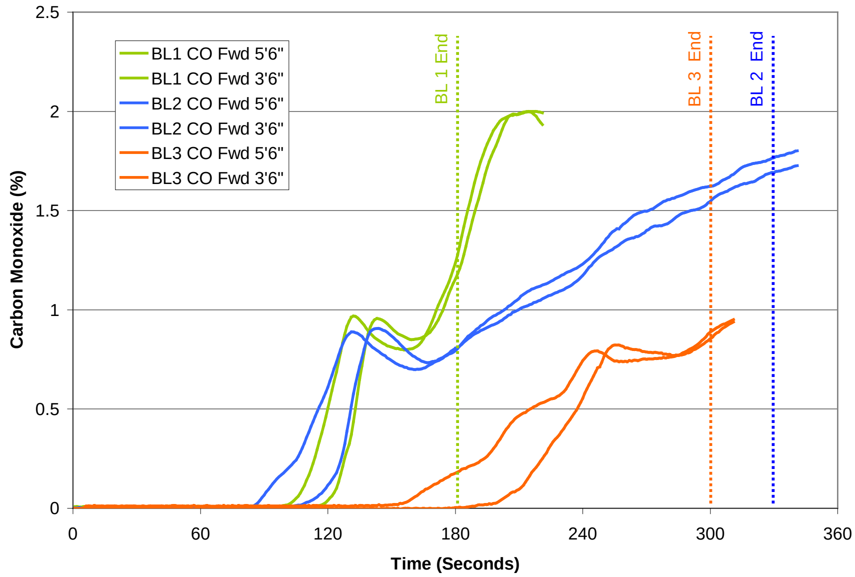

Figure 89. Baseline CO Comparison in the Forward Cabin Area

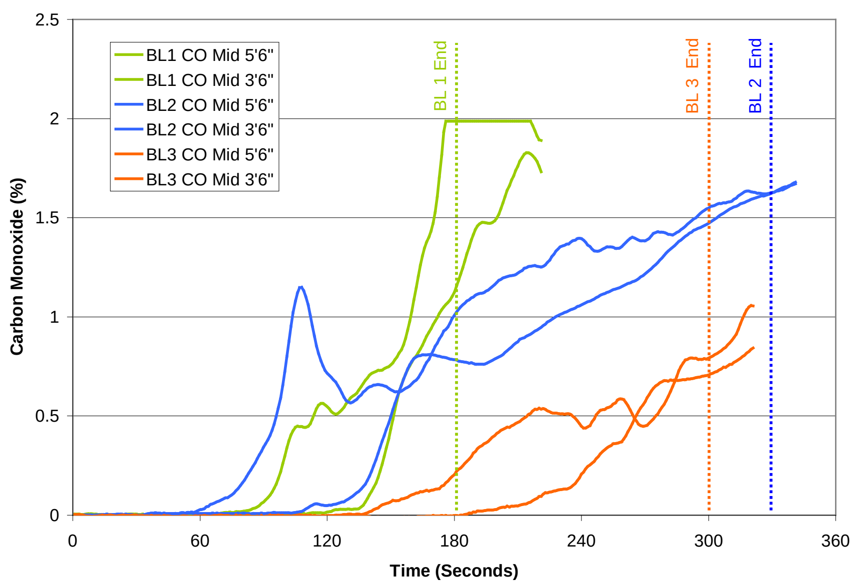

Figure 90. Baseline CO Comparison in the Mid Cabin Area

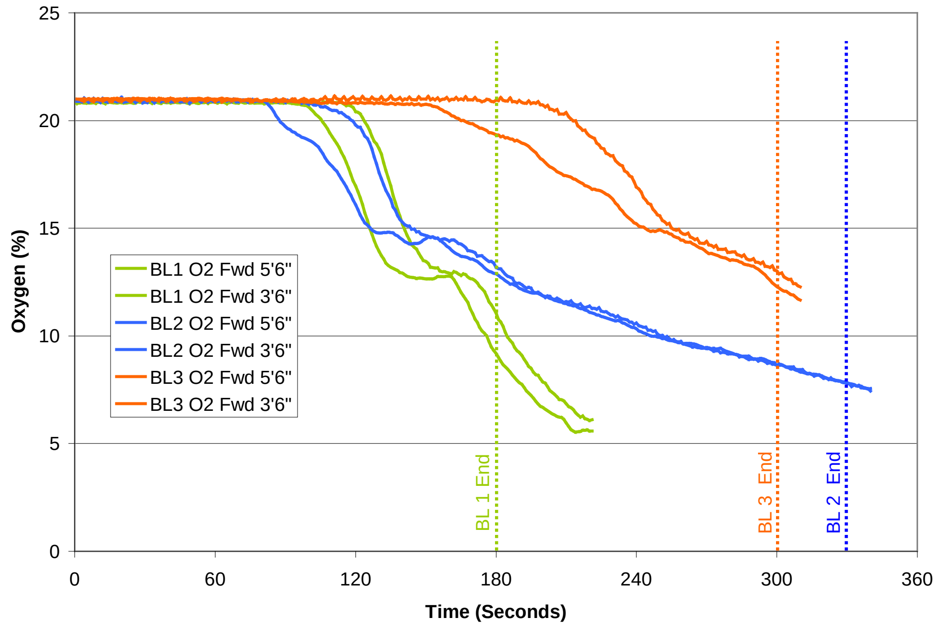

Figure 91. Baseline Oxygen Comparison in the Forward Cabin Area

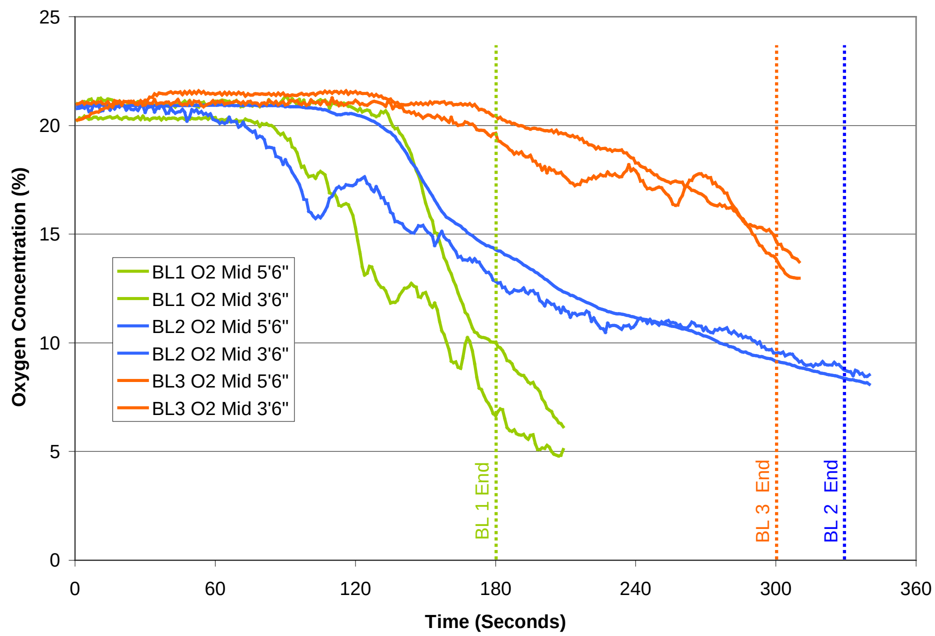

Figure 92. Baseline Oxygen Comparison in the Mid Cabin Area

Heat flux measurements were taken as an indicator of the fire spread within the cabin. Heat flux transducers were situated in the immediate area of the seats and other cabin materials, facing forward and aft toward the materials, and also facing out toward the fire opening. The transducer traces from the center of the fire opening mimic the temperature and gas measurement traces, with a steep rise in level at approximately 2 minutes into the test for Baseline Tests 1 and 2. Baseline Test 3 required approximately 2 additional minutes to achieve the same heat flux level (figure 93).

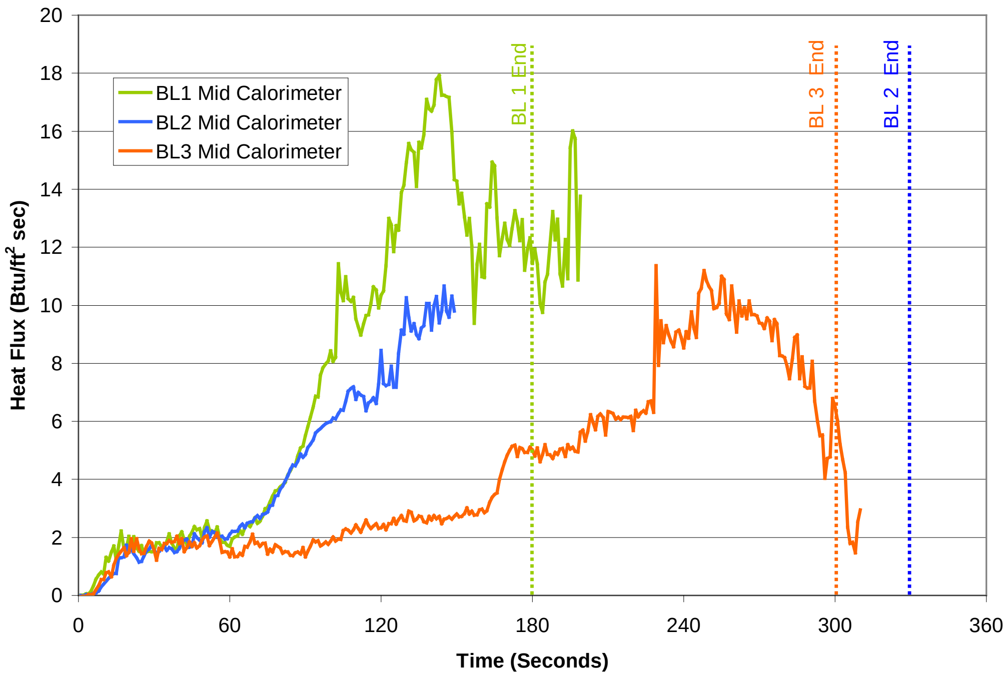

Figure 93. Baseline Heat Flux Comparison in Center of Fire Opening Area

As in Baseline Tests 1 and 2, a survivability model was used to predict the theoretical time at which a person would become incapacitated, based on the levels of temperature and gases measured during the test. As expected, Baseline Test 3 yielded close to 2 additional minutes before incapacitating conditions were reached in the forward cabin, compared to Baseline Tests 1 and 2 (figure 94). This result was expected based on the delay in buildup of temperature and toxic gases, as shown in figures 87-93. Incapacitation for Baseline Test 3 was reached at 250 seconds at this location, which was the initial desired result of the test series, prior to the discovery of the poorly performing materials in the seatback assembly. The model was also used for predicting incapacitation at the mid cabin station, which was closer to the fire opening. Although incapacitation was reached much sooner due to the closer proximity to the fire and burning materials, there was still an increase of 70 and 88 seconds beyond the first two baseline tests, respectively (figure 95).

During Baseline Test 3, the leg frame temperatures increased the most on the row 2 seat assembly, which was expected, as this seat was positioned directly in front of the fire opening. The outer leg thermocouple, which was nearest to the fire, climbed into the melting range of aluminum by the time the external fire was extinguished. The melting range of Al 2024-T3, which was used to fabricate the leg assemblies, is 935° to 1180°F. This data was corroborated by a posttest inspection of the leg frame, which showed it had melted and fractured during the test. It was noteworthy that no other leg components reached temperatures high enough to cause melting, including the inner leg component in the row 2 seat assembly (figure 96). These were the largest of the primary components, so it was expected that the other lower-mass assemblies (spreaders and cross tubes) would sustain more melting, which they did.

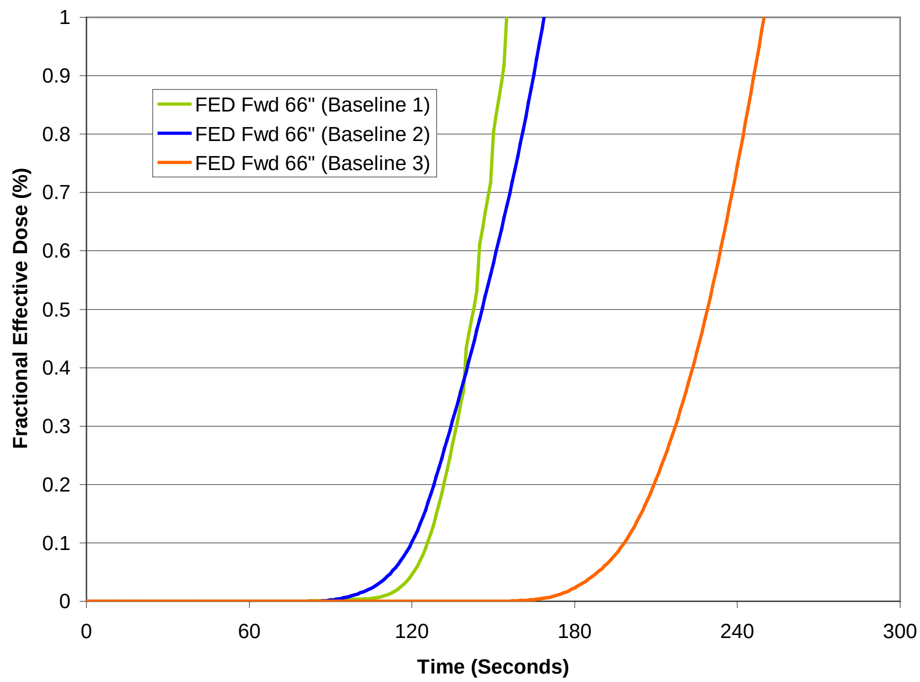

Figure 94. Comparison of Baseline Tests FED for the Forward Cabin

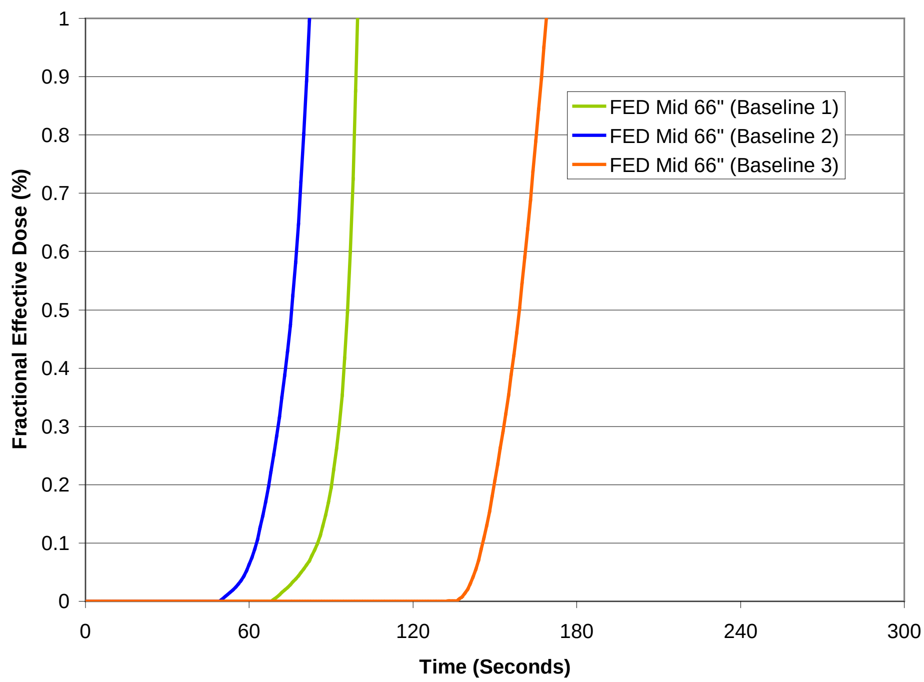

Figure 95. Comparison of Baseline Tests FED for the Aft Cabin

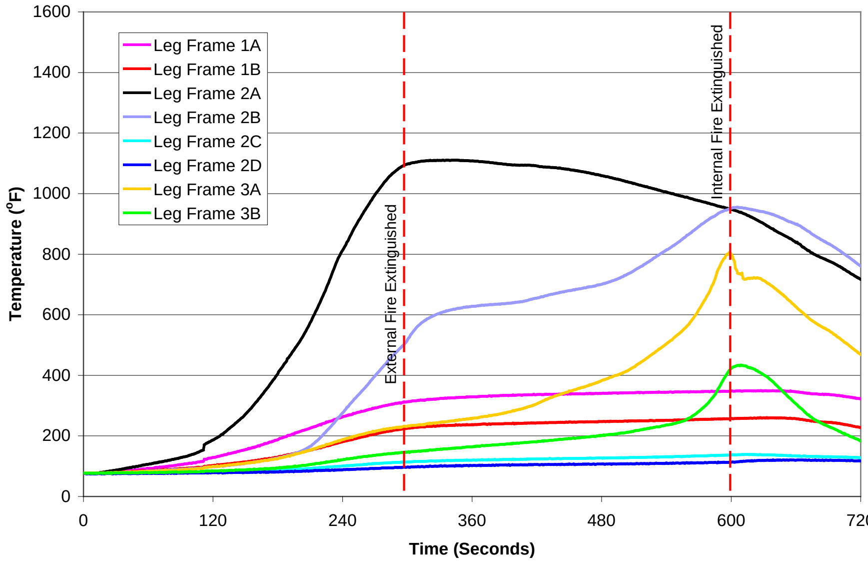

Figure 96. Leg Frame Temperatures During Baseline Test 3

3.9 TESTS USING MAGNESIUM ALLOY IN THE PRIMARY SEAT COMPONENTS.

After establishing an acceptable baseline test condition by which to evaluate the performance of magnesium alloy, the primary seat components were machined in two alloy types. The machining was performed by Wonder Machine Services, Inc. of Avon, Ohio, which performs precision computer numerically controlled machining for the aerospace, medical, and automation industries. The magnesium alloy raw materials WE-43 and AZ-31 were supplied by Magnesium Elektron, LLC.

3.9.1 The WE-43 Test.

The WE-43 alloy had shown excellent resistance to ignition during the laboratory-scale tests. For this reason, it was selected as the good-performing material for the full-scale test evaluation. The good-performing WE-43 alloy was chosen for the first test, since it would be pointless to continue with the study if this material did not perform well under full-scale, realistic conditions. The machined WE-43 parts were received, and the seats were assembled. This was a difficult task, as it was necessary to first disassemble each B/E 990 triple seat, and then reconstruct it using the WE-43 alloy components (legs, spreaders, and cross tubes). Since no assembly diagrams were available, the process was slow, with technicians continually referring to a fully assembled B/E 990 triple seat. The newly designed seatback assembly, identical to that used in Baseline Test 3, was added to each leg frame assembly. The completed assemblies were installed in the furnished test fuselage, and the thermocouples were installed on the leg frames as in the previous test. All other instrumentation was checked prior to the test (figures 97 and 98).

Figure 97. Pretest Configuration for WE-43 Magnesium Alloy Test

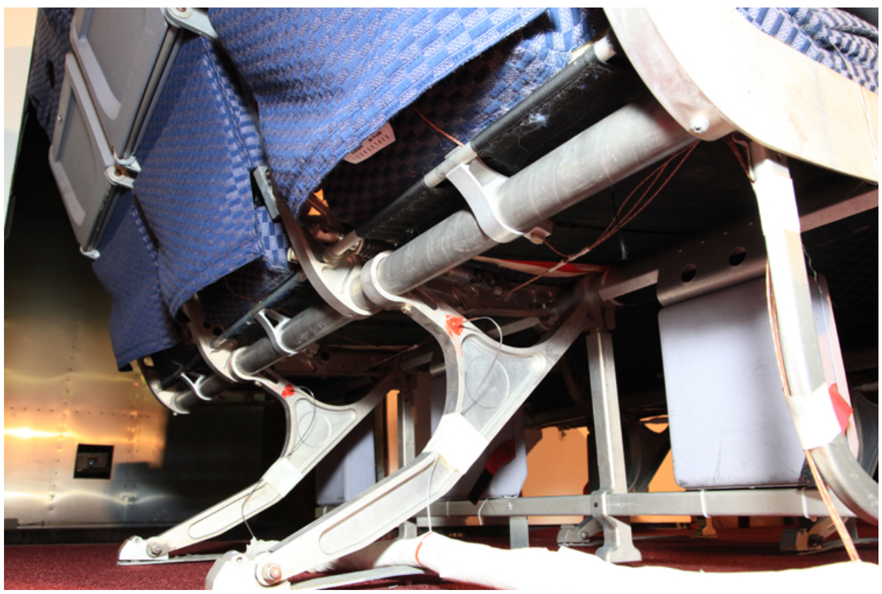

Figure 98. The WE-43 Primary Components With Thermocouples Embedded in the Legs

The fuel pan was loaded with 55 gallons of JP-8 fuel, and a final check of the instrumentation was performed. All cabin doors were set as they were in previous tests, to create identical pretest conditions. The data collection system was initiated just prior to fuel pan ignition, and the fire was started (figure 99). As in Baseline Test 3, the fire did not appear to spread into the cabin as quickly, with excellent visibility from all cameras at the 1-minute point, and only localized burning on the seat directly in the fire opening. The visibility remained clear at the 2-minute point, as the fire began to spread on the sidewall panels around the periphery of the fire opening and progressed forward and aft on the lower surface of the stowage bins. By 2 minutes 30 seconds, the fire started to involve the ceiling panel in the fire opening, while the visibility of the forward and aft upper cameras began to diminish. At 3 minutes, the aft lower camera was moderately clear as the smoke density began to increase. The forward lower camera showed two of the seatbacks on the row 1 portside seat assembly were on fire near the tops, but there was no evidence of involvement on the starboard-side seats at this point. By 3 minutes 30 seconds, the aft lower camera showed the portside seatbacks were fully involved. By 3 minutes 45 seconds, flashover conditions began to develop, with increased turbulence in the smoke at the ceiling and visible flames on much of the ceiling surface. From 4 minutes onward, flashover continued, with complete obscuration of the cameras at 4 minutes 35 seconds. The test continued unabated for 25 additional seconds after camera obscuration, identical to Baseline Test 3, to expose the materials for the same period of time.

Figure 99. External Pan Fire During WE-43 Magnesium Alloy Test

AFFF was applied to the fuel fire beginning at 5 minutes. Within 15 seconds, the fire had been sufficiently abated, allowing the externally mounted camera to view the burning row 2 seat and other materials inside the fire opening. The AFFF continued to address the external fire, which was completely extinguished by 6 minutes 30 seconds. The interior fire continued without interruption (as agreed pretest) until the 10-minute mark. During this observation period, the row 2 seat assembly was observed to continue burning, with brief periods of seat structure collapse as the fire melted the various components. At 7 minutes 25 seconds, a brief period of intense blue-white light was observed among the burning seat materials, near the floor of the fuselage, indicative of burning magnesium alloy. The light burst was short in duration, and no other bursts were observed during this period.

At 10 minutes, the interior water nozzles were activated, which resulted in some initial sparking in the fire opening area from the burning magnesium alloy. Although as intense localized area of light was observed during the application of water, the spray was able to extinguish the fire in 25 seconds. The water spray remained active until 11 minutes, when it was shut off. At

11 minutes 15 seconds, the smoke and steam layer inside the fuselage lifted, revealing that the fire was still burning in a localized cluster near the fuselage floor. This cluster of burning materials was permitted to burn without intervention and self-extinguished at 12 minutes 20 seconds. No additional water spray was used, and no evidence of additional sparking was observed.

A posttest inspection revealed that a number of the portside seatbacks were consumed, including the aluminum frames (figure 100). The fire had also caused the hold-down straps on the portside row 3 seat to melt, allowing the seat to tip over backwards (figure 101). It is not clear at what point during the fire sequence this occurred, but it does not appear to have impacted the test results in any way. It is also possible that this occurred much later in the test, perhaps as a result of the water nozzle stream, which was concentrated in the row 2 seat area. Although it was directed at the row 2 seat, the stream could have deflected off the remaining seat structure, causing the row 3 seat to become unstable. The starboard-side seatbacks were largely intact, with only surface burning and charring of the fabric dress cover (figure 102).

Figure 100. The WE-43 Magnesium Alloy Posttest Results

Figure 101. The WE-43 Magnesium Alloy Test Showing Portside Row 3 Seat Tipped Over

Figure 102. Starboard-Side Seats Showing Minimal Damage

A closer look at the portside seats indicated there was considerable melting of the row 2 seat assembly's primary components (figure 103). The two outer spreaders, both cross tubes, and the outer leg experienced melting during the test. This result was similar to Baseline Test 3, in which several primary seat components had also melted. This and the results from Baseline Test 3 confirmed that the test conditions were ideal, with thorough melting of the primary components while survivable conditions remained for approximately 4 minutes.

Figure 103. View Through Fire Opening Showing Row 2 Frame Remnants

The seats were carefully removed from the test fuselage and placed on the test area floor for further inspection. After removing some of the melted cushioning and dress cover, it was clear that the magnesium alloy was involved in the fire, as several pieces showed signs of ignition (figure 104).

Figure 104. Seat Frames on the Floor of the Test Facility Showing Evidence of Magnesium Burning

As with the previous baseline tests, a large volume of data was collected on the temperatures, smoke, and gas levels inside the test fuselage. To condense this data and use it effectively in this report, this data will be compared to the third baseline test and two magnesium alloy tests followed by a description of each test.

3.9.2 The AZ-31 Test.

The AZ-31 alloy had shown poor resistance to ignition during the laboratory-scale tests. For this reason, it was selected as the poor-performing material for the full-scale test evaluation. The good-performing WE-43 alloy chosen for the first full-scale test performed well and gave the desired result, similar to what was observed during the laboratory-scale tests (difficult to ignite and self-extinguishing). It was envisioned that the AZ-31 alloy, based on its poor laboratory performance (more easily ignited and non-self-extinguishing), would yield predictable full-scale results, thus contrasting with the WE-43 results.

The machined AZ-31 parts were received and the seat assemblies were constructed. This process was much easier the second time, as the technicians were more familiar with the seat construction and the required disassembly/reassembly. As in the WE-43 test, it was necessary to first disassemble six standard B/E 990 seats, and then reconstruct them using the AZ-31 alloy components supplied by Magnesium Elektron and Wonder Machine. The newly designed seatback assemblies (identical to those used in Baseline Test 3 and the WE-43 magnesium alloy test) were added to each leg frame assembly. The completed assemblies were installed in the furnished test fuselage, and the thermocouples were installed on the leg frames as in the previous tests. All other instrumentation was checked prior to the test (figures 105 and 106).

Figure 105. Pretest Configuration for AZ-31 Magnesium Alloy Test

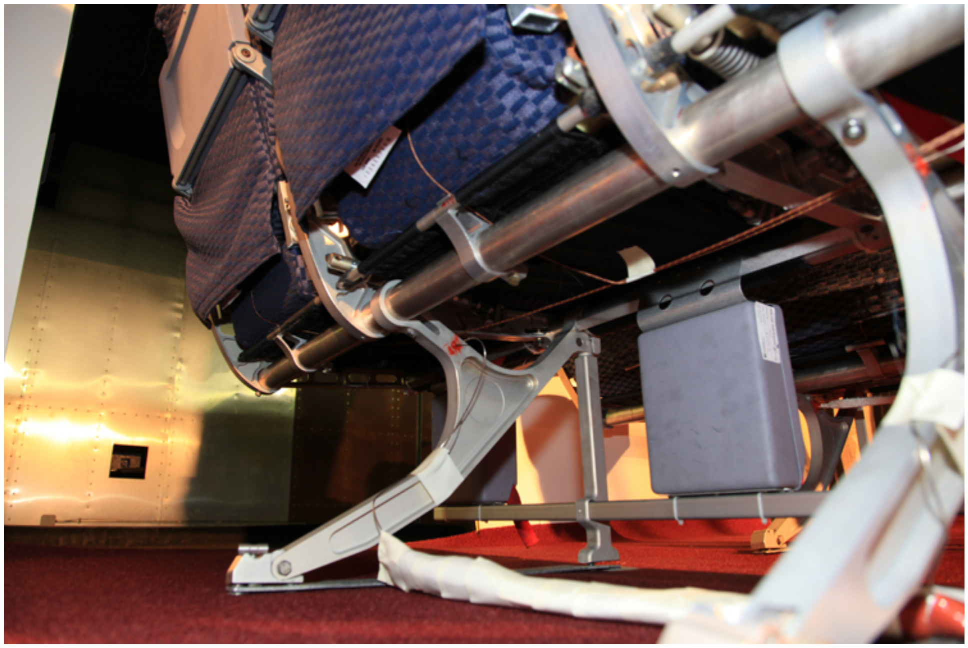

Figure 106. The AZ-31 Components Showing Thermocouple Installed on the Leg Component

Following fuel pan fire ignition, the test proceeded according to plan, with excellent visibility from all cameras at the 1-minute mark and only localized burning on the seat directly in the fire opening. By 1 minute 50 seconds, the portside row 1 seat began burning on the top of the seatback. Additional seatbacks began to burn on the portside row 2 seat assembly in the fire opening. The visibility remained clear at the 2-minute point, but the fire began to spread on the sidewall panels around the periphery of the fire opening and progressed forward and aft on the lower surface of the stowage bins. By 2 minutes 40 seconds, the visibility of the aft upper camera was completely obscured, and the fire started to involve the ceiling panel in the fire opening. From the aft lower camera, there was heavy burning of all portside seatbacks at the 3-minute mark. The forward upper camera displayed the beginning of flashover conditions at 3 minutes 15 seconds, as large sections of the ceiling panels were shown falling down while on fire. Between 3 minutes 15 seconds and 3 minutes 30 seconds the flashover condition grew in intensity. By 3 minutes 55 seconds, all cameras were completely obscured. The test continued unabated for an additional 1 minute 5 seconds after camera obscuration to expose the materials for the same period of time as in the previous tests.

Fuel pan fire extinguishment began at 5 minutes with AFFF and appeared to be complete by 5 minutes 25 seconds. During this initial extinguishment period, there were clear indications of a magnesium alloy fire inside the fuselage, as viewed from the externally mounted camera, beginning at 5 minutes 15 seconds. The external fuel fire re-ignited and was not fully extinguished until 6 minutes 20 seconds. The interior fire was allowed to continue without interruption once the external fire was fully extinguished. During this observation period, there was a large mass of burning magnesium alloy on the row 2 seat assembly, just inside the fire opening. This mass of material burned intensely, emitting the telltale blue-white intense light indicative of a magnesium fire. There were other brief periods of intense light emitted from other areas viewed by the external camera, indicating other small magnesium alloy fires were also occurring. The interior fire continued to consume the row 2 seat structure, and collapsing was observed as the structure melted and burned. Other more remote sections within the viewing area of the camera showed brief bursts of intense light. As pieces of the seat structure collapsed, minor sparking was observed from the burning sections of magnesium alloy. The fire continued to consume the seat structure, causing a mass of molten and burning magnesium to begin to form near the floor under the seat structure. By 10 minutes, this mass of burning magnesium was significant.

At 10 minutes, the interior water nozzles were activated, which caused a violent intensification of the burning mass of magnesium alloy. Significant sparking was also observed during the application of water. The water application eventually caused the external camera to become temporarily obscured from the turbulent conditions, allowing only brief periods of light inside, indicating the fire was not extinguished. By 11 minutes, the fire diminished in size, but there was still clear evidence of burning magnesium. By 12 minutes, the camera was completely obscured, but the water spray continued. Between 12 and 14 minutes, periodic flashes of light were observed, indicating the fire was still active, which required the water nozzles to remain activated. Between 14 minutes 30 seconds and 15 minutes, there was a steady flickering of light from the active magnesium fire. Because the fuel pan was overflowing with water, the water nozzles were shut off at 15 minutes. By 15 minutes 15 seconds, the smoke and steam layer had lifted, revealing flashing from a small localized area of burning magnesium, located aft of the fire opening and not in direct view of the camera. This indicated it was in the row 3 seat area. By 16 minutes, the camera view was clear, revealing the floor of the fuselage to be completely flooded with water. The flashing from the row 3 seat area had also ceased. A precautionary spray of water was released at 19 minutes 45 seconds for 1 minute, at which point the test was deemed successfully completed, with no additional signs of fire in the fuselage.

A posttest inspection revealed that a number of the portside seatbacks were totally consumed, including the aluminum frames (figure 107). The portside row 2 seat assembly sustained the most damage, as expected, with no visible evidence of any remaining seatback frames. Although the fire had severely impacted this seat assembly, the portside row 1 seat assembly still contained a visible seatback, as well as a partial seatback frame in the middle seat position (figure 108). It was difficult to determine how much of the row 2 seat assembly damage was from the initial fuel fire or from the subsequent magnesium fire during the observation period.

The starboard-side seatbacks were largely intact, with only surface burning and charring of the fabric dress cover and aisle-side arm rests. The thermoplastic tray table assemblies from all starboard-side seats were still intact, with no other damage observed (figure 109).

Figure 107. Posttest Conditions for AZ-31 Magnesium Alloy

Figure 108. Portside Row 1 Seat Assembly Posttest for the AZ-31 Magnesium Alloy Test

Figure 109. Aft View of Fire Damage for AZ-31 Magnesium Alloy Test

A closer inspection of the portside row 2 seat showed the extent of the damage (figures 110 and 111). The cross tubes and three of the four spreaders sustained heavy damage, with only small remnants of these components remaining on a small section of the unconsumed seat structure. The more massive leg assemblies also showed signs of fire involvement, with patches of whitish, magnesium oxide remaining on certain areas near the leg components. The magnesium oxide resulted from the reaction of the burning magnesium alloy with the water spray. The portside row 3 seat also exhibited fire damage, with the outboard spreader plate and part of the forward cross tube melted, leaving similar patches of magnesium oxide on the fuselage floor.

Figure 110. Portside Row 2 Seat Frame Damage Following AZ-31 Magnesium Alloy Test

Figure 111. Portside Row 2 Seat Frame Remnants

The seats were carefully removed from the test fuselage and placed on the test facility floor for further inspection. After removing some of the melted cushioning and dress cover, it was clear that a significant amount of AZ-31 magnesium alloy from the portside row 2 seat was involved in the fire because the remaining structure showed signs of ignition (figure 112). Additional pieces of magnesium alloy recovered from the vicinity of this seat assembly also showed signs of burning. A tedious inspection of the remaining parts revealed signs of burning magnesium alloy, which corroborated the video coverage during the observation period, in which several pockets of intense light were observed.

Figure 112. The AZ-31 Magnesium Alloy Seats on the Test Facility Floor

3.10 COMPARISON OF BASELINE TEST 3 TO MAGNESIUM ALLOY TESTS.

To effectively evaluate the performance of the two magnesium alloys, several comparative charts are presented. These charts compare the fuselage interior conditions for the Baseline 3 Test, the good-performing WE-43, and the poor-performing AZ-31 magnesium alloy tests.

The forward cabin temperatures, measured at heights of between 4 and 5 feet above the floor, showed similar results for the three tests. The baseline test reached the highest temperature at this station, and WE-43 maintained the lowest temperature (figure 113). While there were subtle differences in the peak temperatures, the data indicated that all three tests progressed similarly, with the temperature rise beginning between 150 and 180 seconds into the test. A similar trend was observed at the mid cabin temperature tree, which was located close to the burning materials (figure 114). The temperature ranking was the same at this location compared to the forward cabin station, with Baseline Test 3 reaching the highest temperatures and WE-43 producing the lowest temperatures.

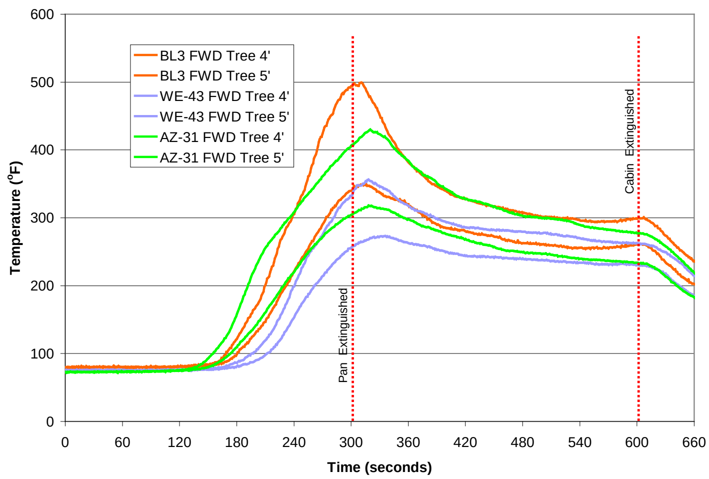

Figure 113. Temperature Comparison at the Forward Cabin Area

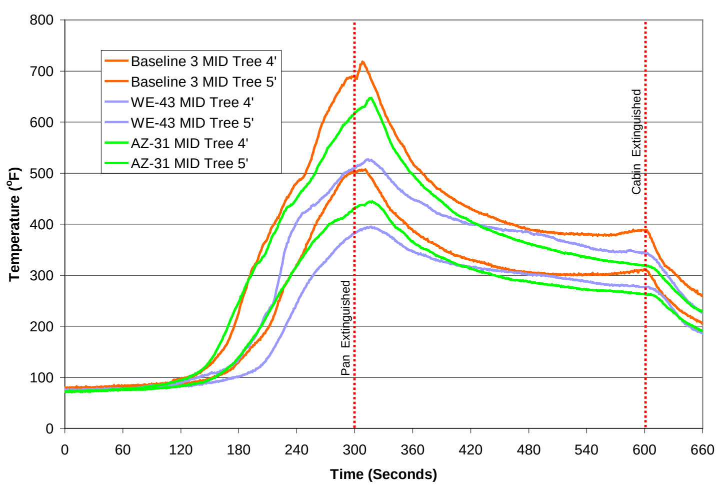

Figure 114. Temperature Comparison at the Mid Cabin Area

The data obtained for the CO levels followed the same trend as the temperature data. The forward cabin area CO levels (measured at 3 feet 6 inches and 5 feet 6 inches) began to increase above trace levels between 140 and 200 seconds into the test, with Baseline 3 and AZ-31 test levels rising slightly before the WE-43 test level (figure 115). Although there was a slight delay shown with the WE-43 test, all test levels were nearly identical at the point of external fuel fire extinguishment, approximately 0.8% to 0.9%. During the 5-minute observation period, the Baseline 3 and AZ-31 test levels continued to climb for a short period, peaking at 1.2% before diminishing. All test levels were again similar at the 10-minute mark when the water spray was activated, reaching approximately 0.4% to 0.5%. The mid cabin area CO levels (measured at 3 feet 6 inches to 5 feet 6 inches) showed a much more erratic behavior, indicating greater turbulence in the cabin air at this location (figure 116). This was not unexpected, as there is typically more air movement closer to the fire. Although less clear than the forward cabin station, the CO levels obtained for all tests were relatively similar, with the AZ-31 test levels rising before the Baseline 3 or WE-43 test levels. At the 10-minute mark when the water spray was activated, all levels diminished to 0.3% to 0.5%.

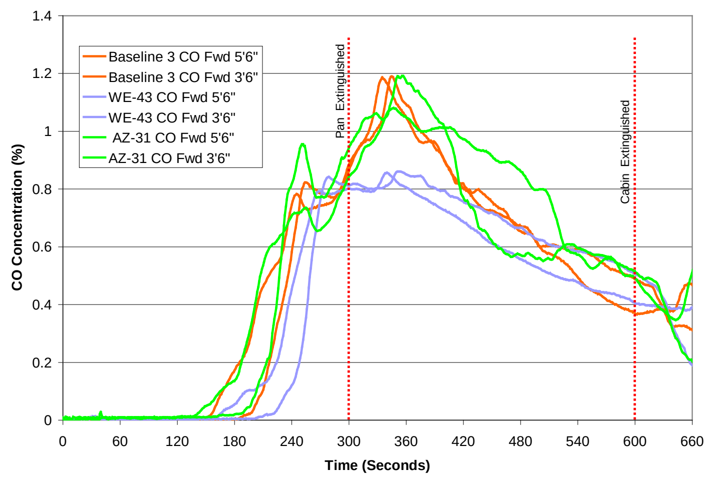

Figure 115. The CO Level Comparison at Forward Cabin Area

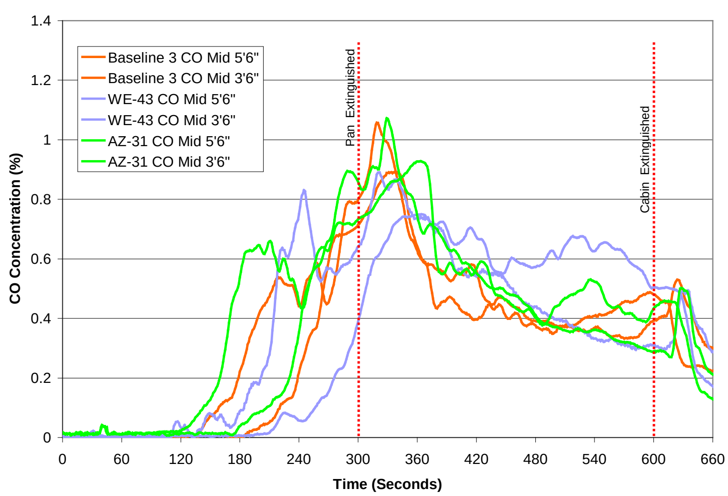

Figure 116. The CO Level Comparison at Mid Cabin Area

Oxygen depletion was also recorded and showed much the same delay and trending between the three tests compared (figures 117 and 118). At the forward cabin area, the oxygen levels dropped to between 13% and 14% at the point where the external fuel fire was being extinguished (figure 117). The levels all began to rise from their lowest point, which occurred at approximately 330 seconds into the test, increasing fairly linearly until the 10-minute mark, in which all levels were nearly the same at 16% to 17%. The mid cabin oxygen levels, although not as uniform as the forward cabin levels, also showed a similar trend (figure 118).

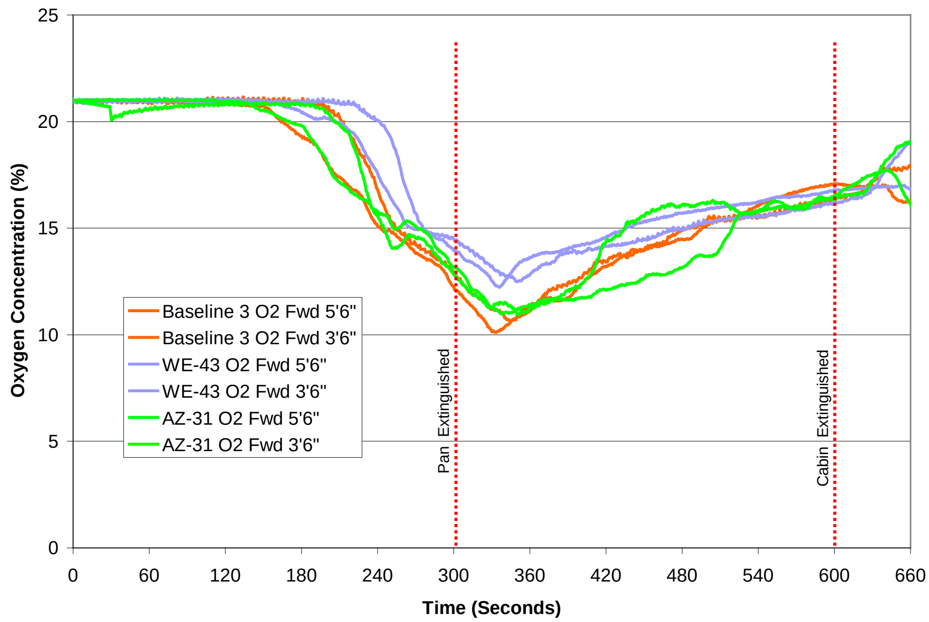

Figure 117. Oxygen Level Comparison at Forward Cabin Area

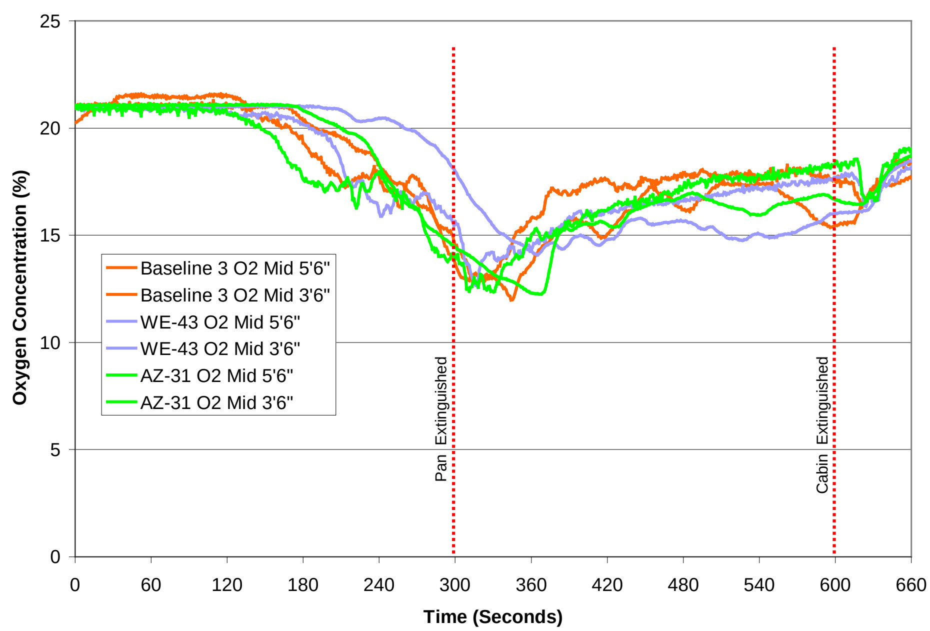

Figure 118. Oxygen Level Comparison at Mid Cabin Area

As in the baseline tests, a survivability model was used to predict the theoretical time at which a person would become incapacitated, based on the levels of temperature and gases measured during the test. After inputting all the temperature and gas measurement data from the tests, the model generated the FED survivability curves. The results from this three-test comparison were very similar; the test results showed very comparable levels of temperature and gases measured. At the forward cabin area, the time to reach incapacitation for the three tests was all within 28 seconds of each other (figure 119). This separation was likely within normal experimental errors for a test of this nature and scale. Likewise, the incapacitation results were within 21 seconds of each other at the mid cabin area (figure 120). The results also showed that while the WE-43 magnesium alloy material provided marginally better results at the forward cabin area, the baseline test provided a better result at the mid cabin area. This highlighted the close similarity in performance from these materials during this study.

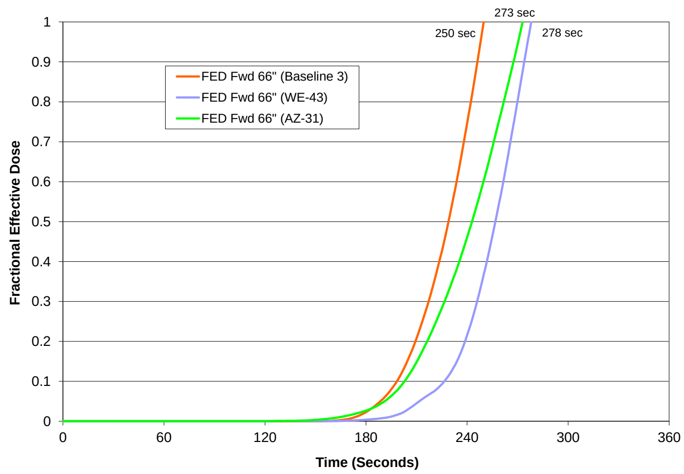

Figure 119. Survivability Comparison for Baseline and Magnesium Alloy Tests at the Forward Cabin Area

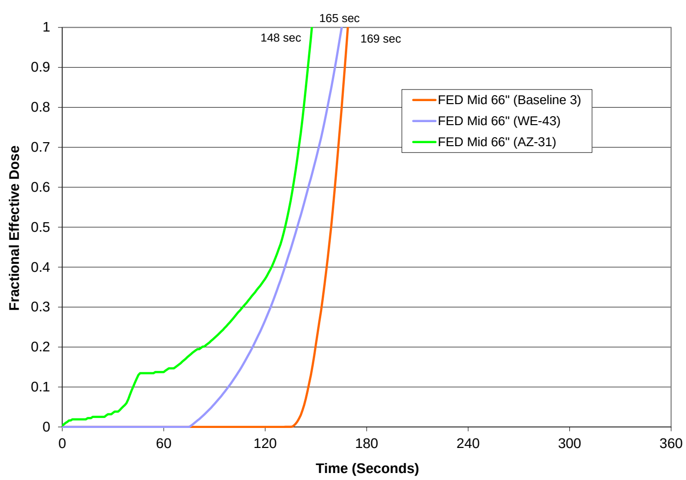

Figure 120. Survivability Comparison for Baseline and Magnesium Alloy Tests at the Mid Cabin Area

3.11 ADDITIONAL TESTS USING MAGNESIUM ALLOY IN THE PRIMARY AND SECONDARY SEAT COMPONENTS.

One final test was planned in which additional magnesium alloy components would be used in the seat structure. Aside from the primary leg, spreader, and cross tube components, the magnesium alloy would also be used to fabricate the box section seatback frames and lower box section baggage bar (both composed of aluminum in the preceding tests). Because of the relatively good performance displayed by the WE-43 alloy, it was chosen for this final evaluation. The purpose of the test was to determine if additional quantities of magnesium alloy used in the fabrication of less massive seat frame components would have an influence on the overall test results during realistic cabin fire conditions.

3.11.1 The WE-43 Test Using Additional Magnesium Alloy Components.

Since rectangular WE-43 box section extrusions had not been previously produced by Magnesium Elektron, they were given 3 months to produce the unbent extrusions for the seatback and baggage bar components. This allowed the supplier adequate time to refine their extrusion process with this particular profile. Once the extrusions were received, the FAA formed the straight extrusions into the baggage bar and seatback frame shapes. This was difficult, as the magnesium alloy material was softer than the aluminum used in the previous seatbacks, so extra precautions were taken to prevent the extrusions from collapsing during the bending process. This also held true for the baggage bars, since this particular component had not been previously fabricated by the FAA and no extra extrusions were available in the event one of them became damaged during the initial bending process. The added precautions were effective, and all shapes were formed without issue.

Once the machined WE-43 primary components were received and the fabricated seatback frame and baggage bars were completed, the seat structures were assembled. The newly fabricated WE-43 seatback assemblies were identical in size to those used in Baseline Test 3 and previous magnesium alloy tests. The completed assemblies were then installed in the test fuselage, and the thermocouples were installed on the leg frames, as in the previous tests. All other instrumentation was checked prior to conducting the test (figures 121 and 122).

Following pan fire ignition, it became apparent that the fire was entering the cabin more aggressively than in the previous three tests. Although this was noted by the test director and other witnesses, no immediate explanation could be offered for this perceived difference, as all pretest conditions and settings had been repeatedly checked prior to ignition of the fuel fire. Within 1 minute, there was considerably more burning of the ceiling panels, sidewall panels, and seatbacks in the immediate vicinity of the fire opening compared to the previous tests. The fire quickly traversed the surface of the ceiling panel, which had not occurred during the previous three tests. By 1 minute 40 seconds, the tops of the seatbacks on all portside seat assemblies were on fire. Despite this early fire on the tops of the seats, by 2 minutes, the fire had burned a majority of the dress cover on the row 1 seat, and the burning rate on this seat appeared to be diminishing somewhat. By 2 minutes 20 seconds, the forward lower camera was completely obscured. This was not typical, as this particular camera generally maintained visibility for the longest period in all previous tests. Between 2 minutes 40 seconds and 3 minutes 10 seconds, the aft lower camera showed a partially obscured view of the seatbacks burning intensely on the portside of the fuselage. This camera became completely obscured by 3 minutes 10 seconds. The test continued for nearly 2 more minutes until the 5-minute mark, even though all internal cameras were completely obscured, and there was no visible means of determining the severity of the conditions inside the test fuselage. Pan fire extinguishment began at 5 minutes with AFFF, lasting approximately 30 seconds. After the majority of the fuel fire was extinguished, the AFFF was deactivated. This allowed the fire to reflame, requiring a final application of AFFF, which completely extinguished the fire by 6 minutes.

Figure 121. The WE-43 Test Configuration With Additional Magnesium Alloy Components

Figure 122. The WE-43 Test Configuration With Additional Magnesium Alloy Components Viewed Through the Fire Opening

Once the external fire was extinguished, the interior fire could be seen clearly via the externally mounted camera. The row 2 seating materials burned vigorously at 5 minutes 15 seconds, and the fire continued to grow over the next several minutes. During this period, an area of intermittent intense light was observed near the floor of the test fuselage, at times becoming very intense and then subsiding completely. This area was clearly a pocket of burning magnesium, which emitted the characteristic blue-white light. At 7 minutes 40 seconds, the light became very intense and then subsided. The nonmetallic seating materials continued to burn, with the pocket of magnesium emitting light and then diminishing several times until the 10-minute mark. The water spray nozzles were activated at 10 minutes, which exacerbated the burning materials and the pocket of magnesium; this caused significant turbulence and smoke/steam, which obscured visibility. The intensified fire caused the fuel in the fuel pan to re-ignite within 10 seconds. Sparking pieces of burning magnesium appeared to be propelled into the now-burning pan of fuel. The fuel fire was fully developed by 10 minutes 40 seconds. The AFFF was activated at 10 minutes 45 seconds and appeared to have the fuel fire under control by 11 minutes. However, the interior fire was still burning intensely, and the side-mounted water spray nozzle continued to carry burning pieces of magnesium into the fuel pan, making it impossible to fully extinguish it. At 11 minutes 20 seconds, the fuel fire and interior fire were simultaneously and completely extinguished. The interior water spray nozzles remained activated and were turned off at approximately 17 minutes. The externally mounted camera showed the interior smoke layer beginning to clear at 20 minutes, confirming that all combustion had ceased.

A posttest inspection revealed a number of the portside seatbacks were totally consumed, including the magnesium frames (figure 123). As in the previous test, the portside row 2 seat assembly sustained extensive fire damage, with evidence of substantial melting of the magnesium alloy seatback frames. The remaining portions of these components fell aftward onto the row 3 seat (figures 124 and 125). Although the fire had severely impacted this seat assembly, the portside row 1 seat assembly still contained a visible seatback, as well as a partial seatback frame at the middle seat place. This result was nearly identical to the previous test. It was again difficult to determine how much of the row 2 seat assembly damage was from the initial fuel fire or from the subsequent fire during the observation period.

Figure 123. The WE-43 Test With Additional Magnesium Alloy Components, Posttest

Figure 124. The WE-43 Test With Additional Magnesium Alloy Components, Row 2 Seat

Figure 125. Close-Up of Portside Row 2 Seat (Ceiling Panel Removed)

Several additional photographs were taken of the portside seat frames through the fire opening. It appears the fire entered the opening and caused the majority of the damage to the row 2 and row 3 seats, and left the seat structure from row 1 largely intact (figures 126 and 127).

Figure 126. View of Row 1 and Row 2 Seat Assemblies Through Fire Opening

Figure 127. View of Row 2 and Row 3 Seat Assemblies Through Fire Opening

Although the damage to the portside seat assemblies was extensive, the starboard-side seats were relatively intact, with charring of the fabric dress covers on all aisle-side seats (figure 128).

Figure 128. Forward View of Starboard-Side Seat Assemblies

An aft view of the starboard-side seats (figure 129) shows that all thermoplastic tray tables were still in place, although the aisle seat tray tables showed signs of melting.

Figure 129. Aft View of Starboard-Side Seat Assemblies

The seats were carefully removed from the test fuselage and placed on the test facility floor for further inspection (figure 130). After removing most of the remaining melted cushioning and dress cover, it was clear that a significant amount of WE-43 magnesium alloy from the portside row 2 seat was involved in the fire. The primary component damage from the row 2 seat included both cross tubes, the outermost spreaders (2), and portions of the outer leg assembly. For the row 3 seat, the damage included both cross tubes and two outermost spreaders. In addition, all but one of the seatback frames from the row 2 and 3 seat assemblies were completely melted. Additional pieces of magnesium alloy recovered from the vicinity of these two seat assemblies also showed signs of burning. An inspection of the remaining parts attached to the seat assemblies revealed characteristic signs of minor magnesium alloy burning, which corroborated the video coverage of several light bursts during the observation period.

Figure 130. The WE-43 Test With Additional Magnesium Alloy Components, Seats Placed on the Test Facility Floor

After reviewing the collected data and video recordings, it was clear that the external fire had entered the cabin more aggressively during this test than in previous tests. Since the magnesium alloys typically did not melt until several minutes into the test, it was concluded that the poor conditions observed during the beginning of the test were not a result of the magnesium alloy components' performance but, rather, were attributed to the test fuselage configuration. A thorough examination of the test fuselage arrangement was made, including the position of all internal and external doors. While all external cabin doors were confirmed to be closed as normal, the internal cockpit door was found to be open, which may have allowed the fuel fire to enter the cabin more easily, since the backpressure inside the cabin would be reduced. Additionally, the forward cargo compartment door was found to be unlatched and open approximately 1 foot, which would also have reduced the backpressure in the cabin. It was possible that the combination of these two factors allowed the external fire to enter the fire opening more easily, thus spreading more quickly onto the cabin materials.

Based on these findings, a decision was made to repeat the test, since it was agreed that the fire conditions did not allow for an accurate assessment of the WE-43 performance when used in the primary and other seat component areas. The difficulty with conducting a repeat test was that the portside seats were destroyed in the test, and no additional WE-43 components were available. To overcome this, an alternate test configuration was conceived. The alternate configuration used the starboard-side magnesium alloy seat frame assemblies, which were essentially undamaged, and placed them on the port side of the test fuselage. Damaged or unusable bottom cushions on these assemblies were replaced with identical units from extra seats on hand. Similarly, the additional seatback cushions originally purchased were used in place of the damaged back cushions. On the starboard side, standard OEM aluminum frame B/E 990 seat assemblies were used, since the seat structures on this side of the aisle were not involved in the fire during any of the previous three tests. As in previous tests, the carbon/epoxy seatback frames on the original B/E 990 seats were removed and replaced with the aluminum frame units fabricated at the FAA.

There were several minor issues created by switching the starboard magnesium alloy seats to the port side. For example, the aisle side spreaders were slightly different than the fuselage side: the aisle-side components were flat and the fuselage-side components were contoured to fit the curvature of the aircraft body. A similar situation resulted with the baggage bars, as the aisle-side bars were rounded, while the fuselage-side bars had a butted end. Although these problems could not be rectified, they were viewed as insignificant in the overall evaluation of the magnesium alloy materials.

Note: The data compiled from this test will be used in a three-test comparison, contrasting the original WE-43 test, the WE-43 with additional magnesium alloy components, and the following repeat test.

3.11.2 Repeat of WE-43 Test Using Additional Magnesium Alloy Components.

All starboard-side seats containing WE-43 components from the previous test were stripped of their cushion materials, thoroughly cleaned, inspected, and outfitted with new cushion and dress cover materials. These seats were then positioned in the port side of the test fuselage, which contained the typical arrangement of honeycomb sidewall and ceiling panels, honeycomb stowage bins, and carpeting. The seat frames were outfitted with the typical array of thermocouples installed in the seat leg components. Following this, the original B/E 990 seats with FAA-fabricated aluminum seatback assemblies were installed on the starboard side of the test fuselage. All other instrumentation was checked prior to the test (figure 131).

Figure 131. Starboard Seats on Port Side of Test Fuselage (Repeat Test)

Although the seats positioned in the port side of the test fuselage contained flat spreaders on the outboard side of the seat, the seats were able to be positioned up against the sidewall fairly close with no significant issues. The seat positioned in the fire opening now had the curved portion of the baggage bar exposed to the fire, thus exposing an additional, small and likely insignificant, amount of magnesium alloy (figure 132).

Figure 132. Starboard-Side Seat Assembly in Fire Opening, With Curved Baggage Bar (Repeat Test)

Following pan fire ignition, it became apparent that the fire was again entering the cabin more aggressively, similar to the previous test. Although this was observed by those witnessing the test, there was no option other than to allow the test to progress as it had during the previous test. The pretest conditions and settings were again discussed as the test proceeded, but all parties agreed these parameters had been repeatedly checked prior to ignition of the fuel fire.

Within 20 seconds, the fire was rolling into the upper area of the fire opening and along the ceiling panel in 1-second pulses, which typically did not happen until approximately 90 seconds during the baseline and two magnesium alloy tests. By 1 minute, there was a thick, heat-filled layer of smoke from the fuselage ceiling down to approximately 5 feet above floor level. The aft upper camera became obscured in 1 minute 40 seconds. Visibility on the aft lower camera was still good at this point and showed vigorous burning of all portside seatbacks. This burning continued, growing in intensity until 2 minutes 10 seconds, at which point the camera was largely obscured. The fire had not progressed across the aisle and involved the starboard-side seats at this point. By 3 minutes, the forward lower camera was completely obscured. Throughout the 3 minutes of visible conditions inside the fuselage, at no point was localized intense light (indicative of burning magnesium alloy) observed.

As planned prior to the start of the test, the external fuel fire continued for 2 additional minutes up to the 5-minute mark, even though all internal cameras were completely obscured, and there was no visible means of determining the severity of the conditions inside the test fuselage. Pan fire extinguishment began at 5 minutes with AFFF, lasting approximately 30 seconds. Minor pan flare-ups were addressed with short bursts of AFFF, and the pan fire was completely extinguished by 6 minutes. The interior fire could be seen clearly from the externally mounted camera. The row 2 seat assembly and the panels that had fallen on top of the seats were observed burning vigorously from 6 minutes until 8 minutes into the test. At 8 minutes, the increased burning re-ignited the fuel in the pan, which was quickly extinguished within 20 seconds. The interior materials continued to burn, with a noticeable collapse of the row 2 seat structure at approximately 9 minutes. Between 9 and 10 minutes, two small, barely noticeable areas of higher-intensity light were observed at the floor level just inside the fire opening, most likely small magnesium alloy fires. The water spray nozzles were activated at 10 minutes, and the interior fire appeared to be extinguished instantly, but this was not the case. The water spray caused significant turbulence and smoke/steam, which obscured visibility. Following a brief period, the fire was visible again at 10 minutes 30 seconds. The water spray continued, and by 11 minutes 30 seconds, all visible signs of the internal fire were extinguished; water spray was deactivated at 12 minutes 30 seconds. The smoke lifted, and visibility returned at 13 minutes, confirming that all burning had ceased.

A posttest inspection revealed a number of the portside seatbacks were totally consumed, including the magnesium frames (figure 133). As in the AZ-31 test, the portside row 2 seat assembly sustained extensive fire damage, with evidence of substantial melting of the row 2 and row 3 magnesium alloy seatback frames. The remaining portions of these assemblies had fallen aftward onto the row 3 seat (figures 134 and 135). It appeared that the cross tubes on both the row 2 and row 3 seats had melted, allowing a collapse of a majority of the seat structure (figure 136). Although the fire had severely impacted these seat assemblies, the portside row 1 seat assembly still contained a visible seatback, as well as a partial seatback frame in the middle seat place. This result was nearly identical to the AZ-31 test. It was again difficult to determine how much of the row 2 and row 3 seat assembly damage was from the initial fuel fire or from the subsequent interior fire during the observation period.

Figure 133. The WE-43 Repeat Test With Additional Magnesium Alloy Components, Posttest

Figure 134. The WE-43 Repeat Test With Additional Magnesium Alloy Components, Aft View

Figure 135. The WE-43 Repeat Test With Additional Magnesium Alloy Components, View of Portside Seats

Figure 136. The WE-43 Repeat Test With Additional Magnesium Alloy Components, Close-Up of Portside Row 2 Seat Structure

As standard practice, the seats were carefully removed from the test fuselage and placed on the test facility floor for further observation and documentation (figure 137). Once the seats were repositioned as they had been in the cabin, the damage pattern was observed to be similar to the previous test in which the portside row 2 and row 3 seat assemblies sustained the majority of the fire damage.

Figure 137. The WE-43 Repeat Test With Additional Magnesium Alloy Components, Seats on the Test Facility Floor

An inspection of the portside row 2 and row 3 seats revealed extensive melting and burning of the cross tubes and spreaders (figure 138). The damage indicated the possibility that the row 2 seat assembly collapsed rearward following melting/burning of the cross tube component, thereby igniting the row 3 seat assembly from below, and perhaps aiding in the melting of the row 3 seat cross tube components.

Figure 138. The WE-43 Repeat Test With Additional Magnesium Alloy Components, Damage to Portside Seat Assemblies

A three-test comparison of the data was conducted to better assess the performance of the WE-43 magnesium alloy when used in the primary and secondary seat components. The forward cabin temperatures illustrate how the fire entered the cabin more quickly for the two tests in which the additional magnesium was used in the seatback and baggage bar frames, compared to the original WE-43 magnesium alloy test in which the material was used only in the primary components (figure 139). The temperatures began to rise nearly 2 minutes sooner during the tests using magnesium in the seatback frame and baggage bar frames. This corroborates video coverage observed during the test, which clearly showed a more aggressive fire entering the cabin sooner. As discussed, this occurrence could not have been the result of the additional magnesium alloy being used, as the components had not yet melted at this point during the test; therefore, the additional magnesium alloy played no role in the fire spread. The more aggressive test conditions could not be explained, which made it difficult to accurately evaluate the role of the magnesium alloy when used in additional areas of the seat frame. Similar to the forward cabin temperatures, the mid cabin station also showed a much earlier temperature rise during the two tests using additional magnesium alloy (figure 140). The temperature rise at this location was approximately 90 seconds earlier. A similar temperature trend was also found at the aft cabin location (figure 141).

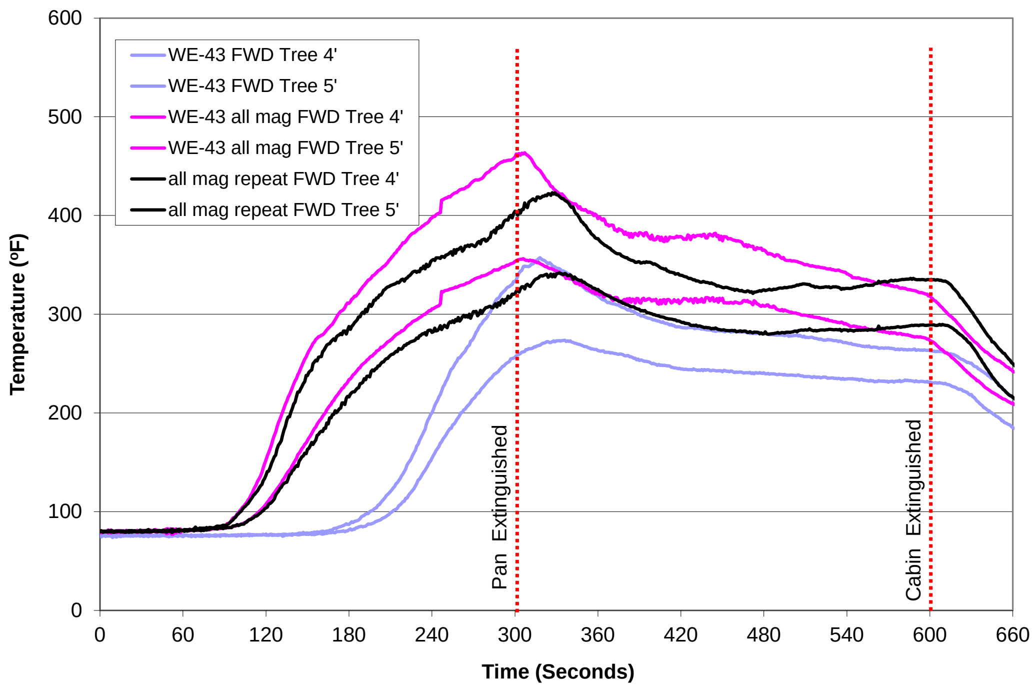

Figure 139. Temperature Comparison at Forward Cabin

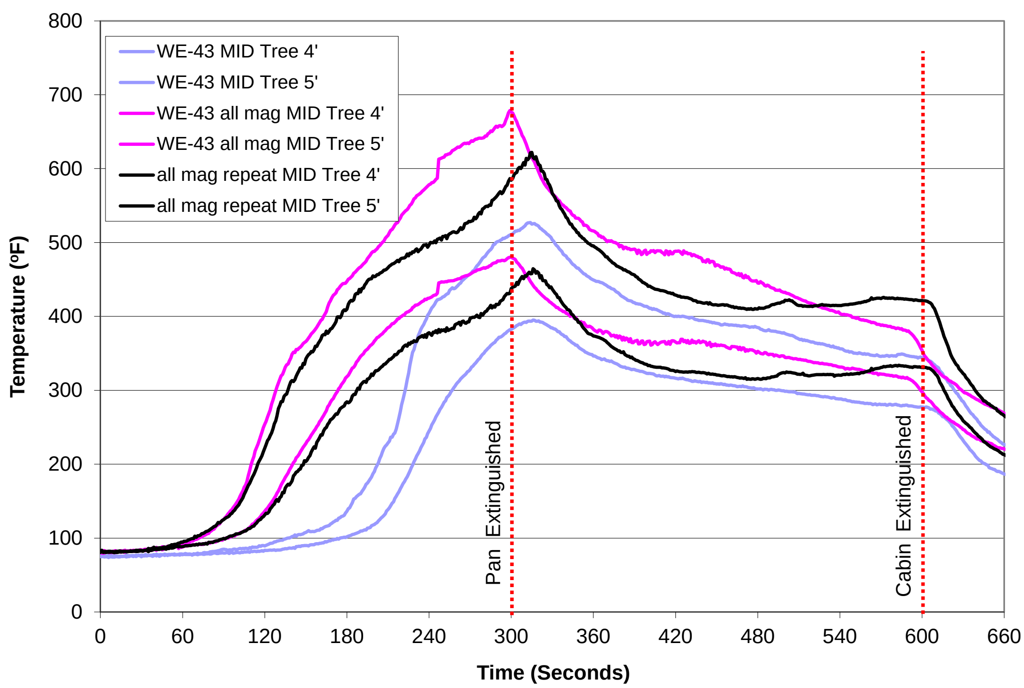

Figure 140. Temperature Comparison at Mid Cabin

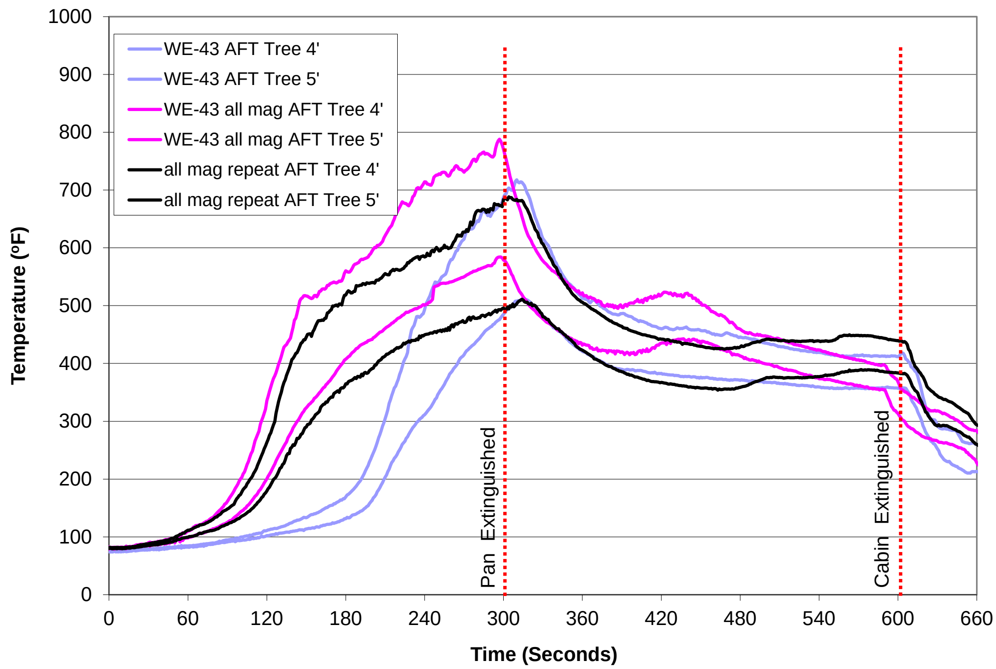

Figure 141. Temperature Comparison at Aft Cabin

Gas level measurements were compared for the three tests. They also showed a similar trend of earlier rise during the two tests using additional magnesium alloy components (figures 142 through 145). This further confirmed the observed conditions and was not unexpected once the temperature profiles were studied. Despite the approximate 2-minute earlier onset of the fire conditions during the beginning of the tests using additional magnesium alloy components, the data showed a limited improvement in conditions during the repeat test. In all gas measurement plots there is a slight, but noticeable, delay (improvement) of the levels during the repeat test compared to the first test with the additional magnesium alloy components. This at least suggests that the corrections to the cabin configuration (closing internal cockpit door and external cargo door) had some impact on the test outcome.

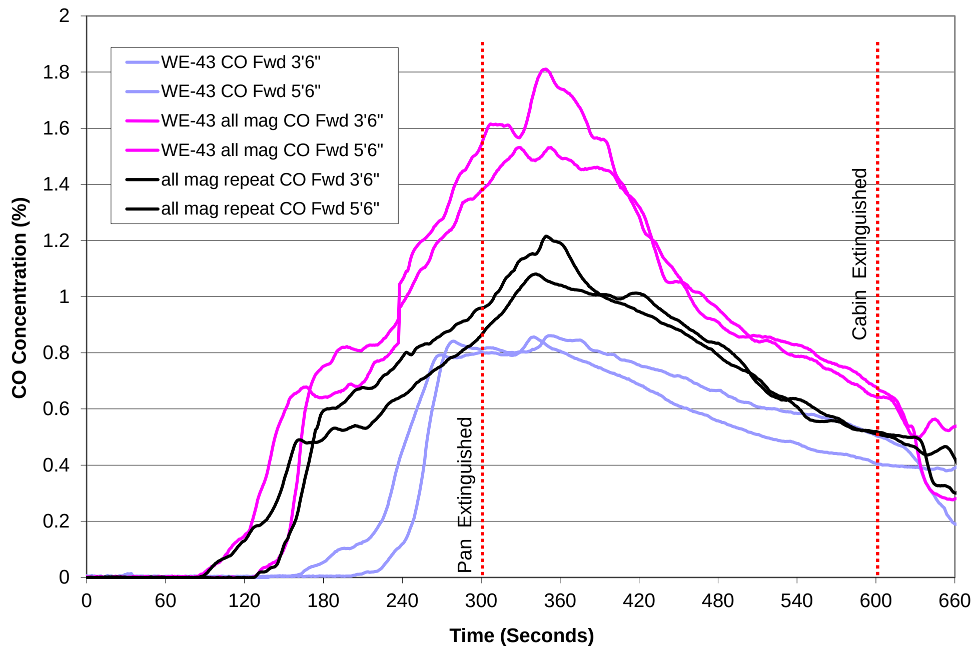

Figure 142. Carbon Monoxide Comparison at Forward Cabin

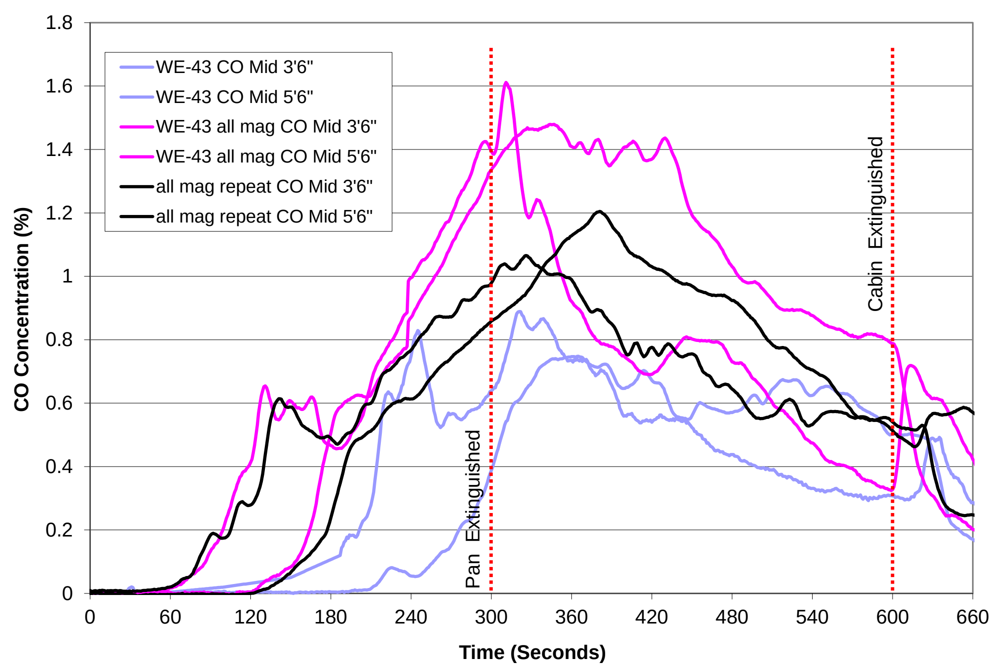

Figure 143. Carbon Monoxide Comparison at Mid Cabin

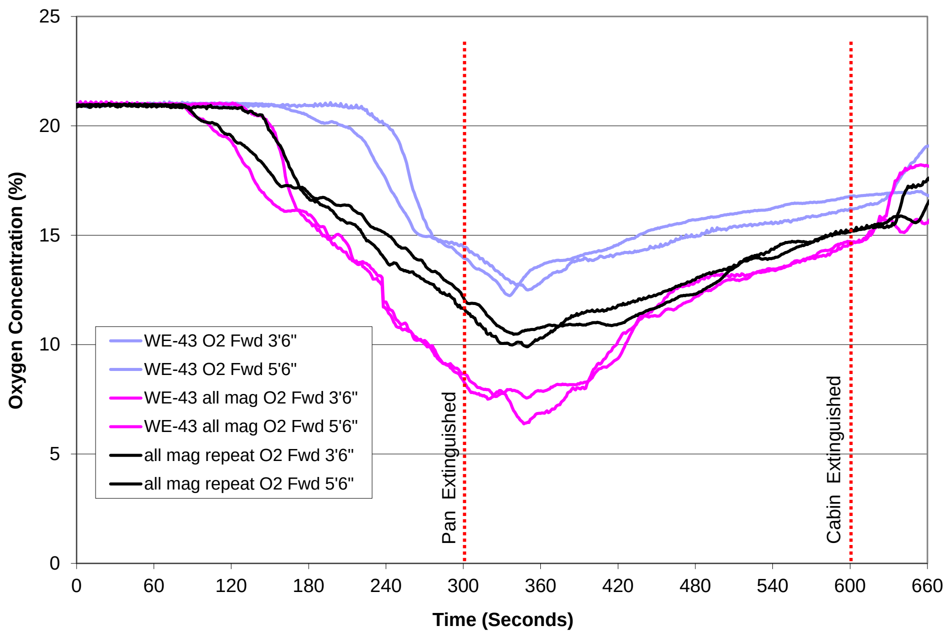

Figure 144. Oxygen Comparison at Forward Cabin

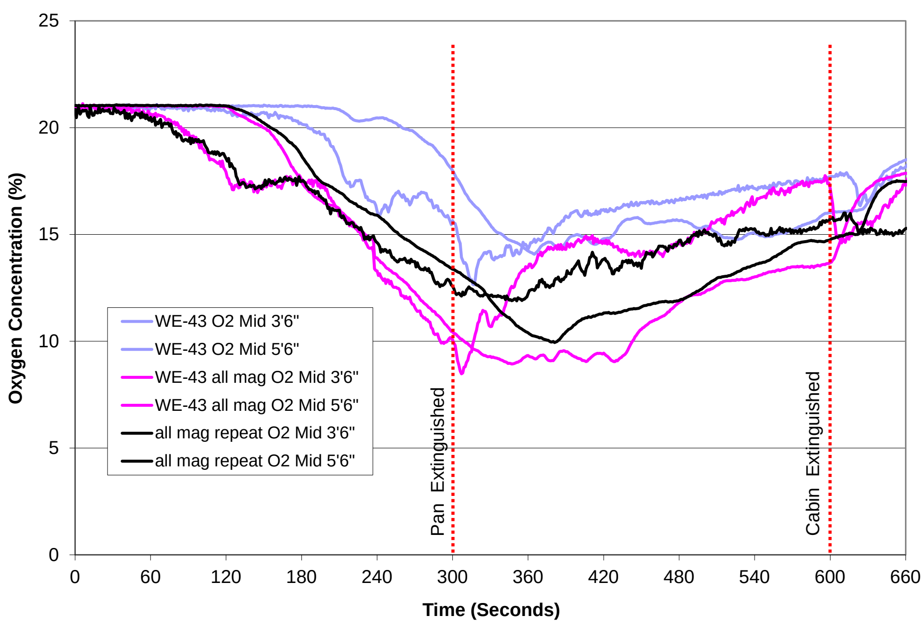

Figure 145. Oxygen Comparison at Mid Cabin

As with previous tests, a survivability model was used to predict the theoretical time at which a person would become incapacitated, based on the levels of temperature and gases measured during the test. After inputting all the temperature and gas measurements data from the tests, the model generated the FED survivability curves. The results from the more recent tests using additional magnesium alloy in the seatbacks and baggage bars corroborates video coverage observed during the tests, along with temperature and gas levels data plotted previously. The results indicated a more aggressive fire entering the cabin, which translated into earlier times to reach incapacitation (figures 146 and 147). At the forward cabin area, the time to reach incapacitation for the additional magnesium tests was 40 to 56 seconds earlier than during the test in which WE-43 was used only in the primary components (238 and 212 seconds versus 278 seconds). This result was not unexpected, given the temperature and gas levels data indicating a more aggressive fire condition from the outset of the tests, with associated rises occurring approximately 90 seconds to 2 minutes earlier during the more recent tests. Similarly, incapacitation was reached 71 to 75 seconds earlier at the mid cabin location during the more recent tests using additional magnesium in the seatback and baggage bar components (94 and 90 seconds versus 165 seconds). The incapacitation results followed the earlier rises in hazards shown previously.

Although the data suggest a more aggressive fire scenario during the tests in which additional quantities of magnesium alloy were used in the seats, it does not appear the increased hazards were the result of the magnesium alloy burning. A review of the video recordings did not indicate the telltale high-intensity light (evidence of magnesium burning) occurring any time prior to the pan fire extinguishment segment of the test, but rather after that activity was complete. This suggests that the increased hazard level was a product of the non-metallic materials igniting more quickly, as a consequence of the fire entering the cabin more aggressively.

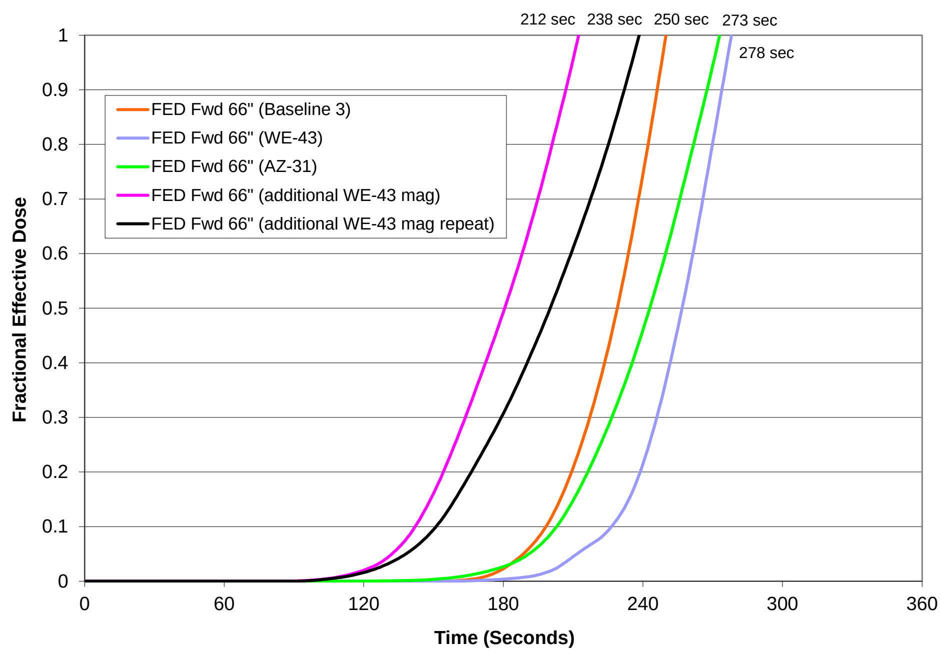

Figure 146. Survivability Comparison for All Tests at the Forward Cabin Area

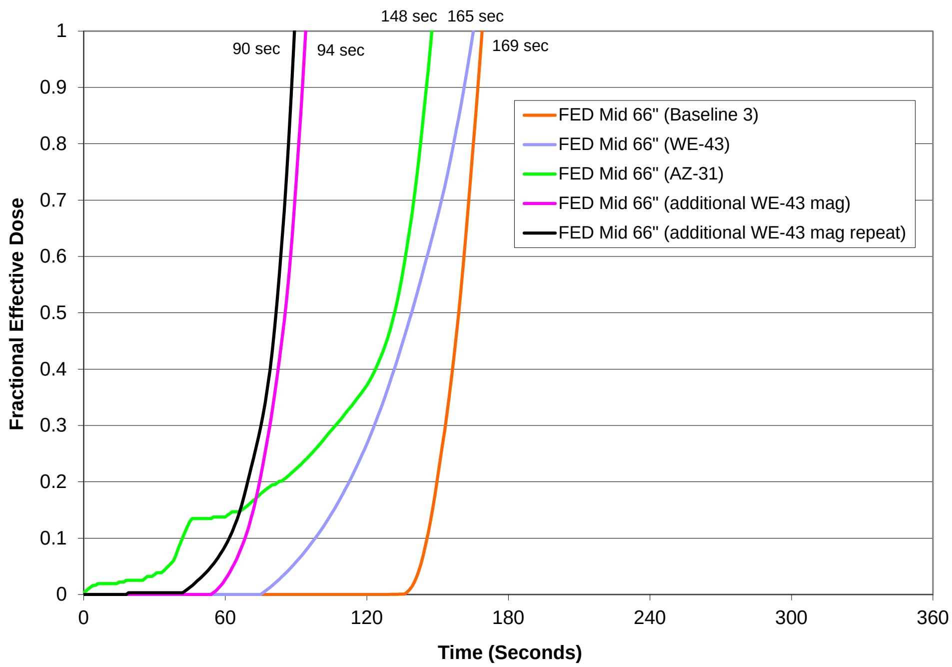

Figure 147. Survivability Comparison for All Tests at the Mid Cabin Area

Another possible explanation for the difference in results between the initial WE-43 test (conducted September 10, 2009) and the more recent WE-43 tests (conducted April 20, 2010 and May 13, 2010) was the atmospheric conditions that existed prior to and during the tests. During the initial test, the ambient conditions were damp and cool. Since the test facility environment is only marginally controlled (partially heated in winter months, no air conditioning or humidity control), it was not possible to condition the cabin materials prior to testing. As a result, the materials were subject to the relative humidity and temperature that existed inside the test facility. With routine openings of the large roll-up doors at both ends of the test facility, it is conceivable that the cushioning materials and fabric dress cover were exposed to much higher levels of relative humidity in the days preceding the test. This could have played a role in the fire's slower growth during the initial WE-43 test. By comparison, both the April and May 2010 tests, in which additional quantities of magnesium were used, were conducted during dryer periods of weather.

In addition, the ambient temperature during the more recent tests was also slightly higher than the initial test. As a result, the cabin interior temperatures at the start of the test were slightly different, since this reflects the temperature in the marginally conditioned test facility. For example, the average floor-to-ceiling temperature (measured between 1 foot and 7 feet above the floor) was between 75° and 76°F during the initial test (figure 148). These values were obtained by averaging the seven temperature values at the forward, mid, and aft cabin locations. These measurements were recorded at the very start of the test, when the fuel pan was lit. Clearly, the temperatures inside the test fuselage were higher during the April and May 2010 tests than the initial test. A cooler volume of air is denser and could have delayed the fire entering the cabin for a short period of time, compared to the April and May 2010 tests. Although the measurements clearly show a difference, it is difficult to quantify how much the cabin air temperature impacted the severity of the fire and subsequent conditions inside the test fuselage.

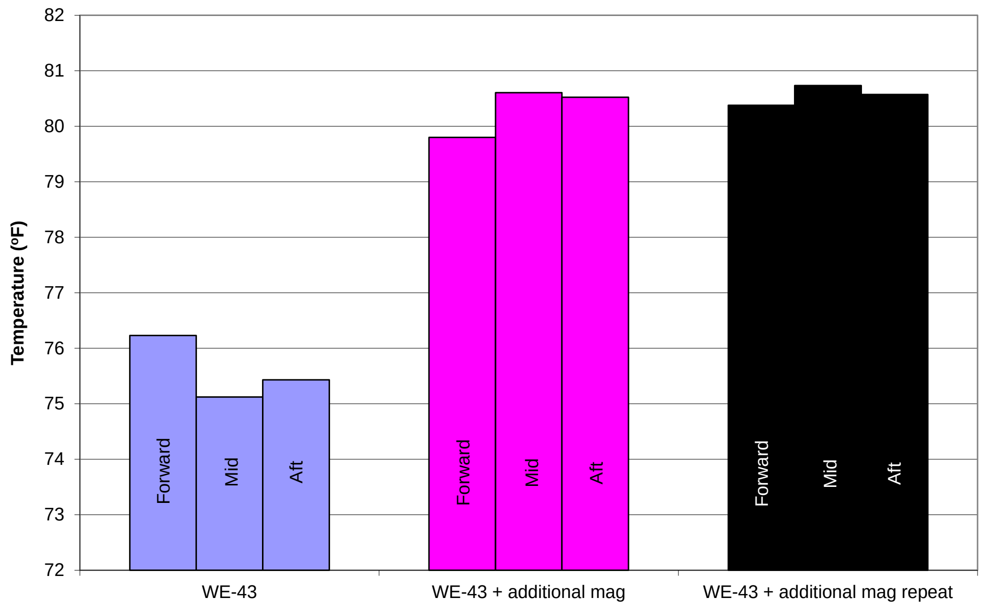

Figure 148. Average Starting Temperature Inside Cabin for Three WE-43 Tests

Similar to the air temperatures inside the test fuselage, the actual temperature of the fuel used for the fire should be noted. The JP-8 fuel was drawn from an outdoor, vaulted 2000-gallon capacity storage tank. The fuel was transferred into a 55-gallon steel drum, which was then emptied into the fuel pan just prior to the start of the test. It is conceivable that the cooler ambient conditions and resulting test facility temperatures encountered during the initial WE-43 test impacted the temperature of the fuel. The cooler fuel would produce a fire that spread less quickly, causing a delay in the time required to reach fully developed fire conditions. Although the ambient conditions were agreeably lower during the initial WE-43 test, it is difficult to quantify how much the cooler fuel impacted the severity of the fire and subsequent conditions inside the test fuselage.

4. SUMMARY.

A laboratory-scale test apparatus was used to perform an initial assessment of the flammability of various magnesium alloy materials. The test apparatus consisted of an oil-fired burner to simulate a fuel-fed cabin fire and a frame to mount and expose rectangular cross-section bar stock test samples. Parameters, such as required melt time, time to ignition, and total burn time, were recorded. The tests revealed that while some of the magnesium alloys ignited and burned very easily (poor-performing), other alloys, in particular those containing rare earth elements, were difficult to ignite (good-performing). Easily ignited alloys had a tendency to burn indefinitely, whereas the more ignition-resistant alloys self-extinguished in many cases.

Subsequent laboratory tests investigated the ability of typical passenger aircraft hand-held extinguishers to extinguish magnesium alloy fires. The oil-fired burner was used again to ignite several types of magnesium alloys to determine the effectiveness of the extinguishers against this type of fire. An aircraft extinguisher containing Halon 1211 and FE-36 (replacement for Halon 1211) proved largely ineffective at extinguishing the magnesium alloy fires. These agents exacerbated the burning magnesium rather than suppressing or extinguishing it. Water extinguishers were also tested. Although it did not completely extinguish the fire, the water was shown to combat the burning magnesium samples by cooling them to the point where ignition ceased.

Additional laboratory-scale tests were conducted with several magnesium alloys exposed to various ignition sources. During one test, a bar sample section was milled in an effort to create a component that melted more easily. This test sample was also rotated from the horizontal position to a vertical position to determine the influence of orientation. Other tests measured the ability to ignite small millings and thin slices of magnesium alloy using a hand-held torch. A final test was run in which a sliced bar section was exposed to the oil burner flames. Similar to the initial laboratory-scale tests, the rare earth-containing alloys showed very good resistance to ignition during these experiments.

This study was conducted in response to growing industry interest in potentially using magnesium alloys to replace specific primary seat components. Primary seat components consist of the leg assemblies, spreaders, and cross tubes, which are the three components common to most types of aircraft coach seat structures. These aluminum primary components are generally robust and would benefit most from substitution using lightweight magnesium alloys, according to airframe and seat manufacturing experts. A full-scale evaluation was conducted as a final phase of the performance assessment of magnesium alloys under realistic postcrash fire conditions. To effectively evaluate their performance in a fire scenario, a baseline test was first conducted using standard aluminum-containing coach seats. Subsequent tests using magnesium alloy components in place of the aluminum components were also performed to determine any increase in hazard level inside the test fuselage. A good-performing alloy and a poor-performing alloy were chosen for the study to provide a contrast in results. The scenario used for all tests employed a large fuel pan fire situated adjacent to an opening that simulated a rupture or break in a fuselage. The fire would enter the cabin and ignite the interior panels, carpet, and seat materials, which were confined to three rows of seats affixed in a single-aisle configuration. The external fire was generally extinguished in 5 minutes, followed by a 5-minute observation period in which the interior materials were permitted to continue burning without intervention. Following this observation period, water spray nozzles were activated to determine the reaction of the magnesium alloy and to determine the difficulty in extinguishing this type of fire in a postevent scenario. These tests were conducted as a proof-of-concept to obtain an overall idea of how well or poorly these alloys performed under realistic conditions and to determine if an additional hazard existed when magnesium alloy components were used.

The tests indicated melting of the primary components was confined to the portside, row 2 seat assembly, which was situated directly in front of the fire opening. The ends of the cross tubes and several spreaders usually melted during a typical 5-minute external fuel fire test. Although the melting generally afflicted the row 2 seat assembly, in some cases, the row 3 seat assembly components also melted. The laboratory-scale tests showed that it was necessary for the magnesium alloy to melt first in order to burn, so it was anticipated that any magnesium alloy fires would be confined to this immediate area during the full-scale evaluation. Although more melting and burning occurred than with aluminum, the rare earth magnesium alloy, WE-43, performed very similarly to aluminum, yielding survivability results comparable to the baseline test.

5. CONCLUSIONS.

The numerous laboratory-scale tests showed a greater fire resistance between the magnesium alloys that contained rare earth elements and those that did not. However, in the full-scale tests, none of the magnesium alloys produced a measurable adverse or hazardous environment compared to the standard aluminum-containing coach seats used in the control (baseline) test. During these tests, any visible difference between the three materials was negligible: aluminum baseline, good-performing magnesium alloy, and poor-performing magnesium alloy. The baseline seats with aluminum components resulted in the best visibility by a small margin. All the theoretical survivability results (obtained using the Fractional Effective Dose model) were comparable for the two types of magnesium alloys in comparison to the standard aluminum component baseline test. Results at the forward station indicated slightly favorable performance from the magnesium alloys compared to the baseline test, while results at the mid station were more favorable for the baseline test. It became apparent that the magnesium alloy was not a significant factor while the external fuel fire existed. The fire only melted components in the immediate vicinity of the fire opening; as a r esult, any burning of magnesium alloys was confined to this immediate area. It was found that the laboratory-scale test, which was largely experimental and not previously correlated to full-scale tests, provided greater discrimination between magnesium alloys than did the full-scale tests.

Both alloy types continued to burn after the external fire was extinguished. The burning magnesium alloy fire that developed during the observation period was more of a concern than the performance of the magnesium during the initial 5-minute fuel fire exposure. The poor-performing AZ-31 alloy was a challenge to extinguish, even with large quantities of water. The initial water application at the end of the observation period caused a violent reaction, with fragments of burning magnesium alloy being displaced by the water stream. Although the good-performing WE-43 alloy resulted in some flashing and sparking during water application, it was relatively easy to extinguish within a reasonable amount of time. A posttest inspection revealed that only a minimal amount of the magnesium alloy material had actually ignited, despite the intense light observed during the test.

Additional full-scale tests conducted to gauge the influence of additional magnesium alloy components used in the construction of the triple seats were inconclusive, as the fire conditions were visibly more intense at the beginning of the test compared to the baseline and previous magnesium alloy tests. Since the magnesium alloys typically did not melt until several minutes into the test, it was concluded that the poor conditions observed during the beginning of these tests were not a result of the magnesium alloy components' performance, but rather attributed to the test fuselage configuration, the influence of atmospheric conditions that existed prior to testing, and the greater fire penetration into the test fuselage. The ingress of the more aggressive fire ignited the nonmetallic components much sooner than in previous tests. The increased intensity of the fire and subsequent burning of cabin materials could not be explained, but was clearly observed by those witnessing the test. As expected, the more aggressive fire condition influenced the survivability results in a negative manner. The two additional tests using WE-43 components in the seatback frame and lower baggage bar frame yielded 12 to 38 seconds less time before incapacitation resulted at the forward location; at the mid location, the tests yielded 75 to 79 seconds less time to reach incapacitation compared to the baseline test. It was concluded that the poorer performance was not due to the use of additional quantities of magnesium alloy, but due to the more severe fire conditions at the start of the tests.

During the extinguishing process, the molten magnesium alloy fragments displaced by the water spray ignited the previously extinguished fuel fire, which was both an unexpected and undesirable result. Although it is impossible to predict the ramifications of this result in an actual fuel fire accident, it is clear that the molten and burning magnesium alloy components and remnants have the potential to spread fire and create a dangerous condition in the presence of spilled fuel during such an accident.

Despite the difficulties experienced during the extinguishment process for these two additional tests, the posttest inspections revealed that a comparable amount of magnesium alloy was consumed when compared to the previous three tests, as the fire damage was confined to the primary components in the row 2 and row 3 portside seat assemblies. The seatback frames in the row 2 and row 3 portside seat assemblies were largely consumed, while the row 1 seatback frames were partially consumed. This result was consistent with previous tests. Similarly, the primary seat structure from row 1 was largely intact, along with all of the starboard-side seat frames, which was again consistent with previous test results. Of note was the condition of the lower baggage bars, which were mostly intact with the exception of the outboard end of the row 2 seat closest to the fire. Overall, these additional tests corroborated previous test results in which only a fraction of the magnesium components actually became involved in the fire, despite the difficulties with extinguishment following the observation period.

Although the postobservation period highlighted the difficulties with extinguishment, the performance of the rare earth-containing magnesium alloy material during the initial 5-minute fuel fire exposure did not indicate a more hazardous condition when compared to standard aluminum materials. The extinguishment difficulties would typically not be encountered during the escape of passengers in a survivable accident, but rather after all nonincapacitated passengers had deplaned. It should be noted, however, that these results are based on (and limited to) the seat structure tested, and that other applications involving different thicknesses or quantities of magnesium alloy components in different cabin locations would likely yield different results.

The next phase of the program will involve the development of a laboratory-scale test that is based on the results of the full-scale tests. The laboratory-scale test will determine the amount of time required to melt a standard sample, whether ignition then occurs, and the amount of time the sample continues to burn. The goal is to develop a test method that will be capable of ranking various magnesium alloy materials based on these parameters, and an appropriate pass/fail condition will be selected to ensure the use of safe magnesium alloys.

<u>6. REFERENCES</u>.

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APPENDIX A—LABORATORY TEST RESULTS ON SEAT CUSHIONS USED IN FULL-SCALE BASELINE TEST 3

The two initial full-scale baseline tests determined the flammability of the seatback assembly of the B/E Aerospace (B/E) 990 seats was poor. The seatback assembly was an atypical design, using a frame constructed of an epoxy-impregnated carbon fiber unidirectional tape with thermoplastic components in the headrest area. In addition, there was no metallic or aluminum support pan, but rather a nylon fabric that stretched across the frame to act as a suspension (figure A-1). The back cushion was very thin with minimal foam and appeared to contain a fiberfill material in place of the typical urethane foam.

Figure A-1. The B/E 990 Standard Seat Components

During the two baseline tests, the seatback assembly became involved in the fire very early in the test sequence, contributing to a rapid flashover event in which the conditions became nonsurvivable very quickly. It was agreed that under these conditions, it would be difficult to accurately measure the contribution of the magnesium components used in the seatframe during subsequent tests. For this reason, an alternate seatback was designed to fit the B/E 990 seat assembly. The alternate design used an aluminum frame and a fire-hardened foam cushion in place of the existing materials (figures A-2 through A-5).

Figure A-2. Aluminum Seatframe Used in Alternate Seatback Assembly

Figure A-3. Fire-Hardened Foam Used in Alternate Seatback Assembly

Figure A-4. Front View of Fire-Hardened Foam Used in Alternate Seatback Assembly

Figure A-5. Front View of Dress Cover Used in Alternate Seatback Assembly

Additional details were designed and fabricated for use in the alternate seatback assembly, including front and back pan structures used to strengthen the frame. The completed seatback frames were then mass-produced and mounted to the B/E 990 triple coach seat lower frames (figure A-6). Components such as the tray tables and arms, as well as the map pockets were all retained from the original B/E 990 seatback frames and incorporated into the alternate assemblies.

Figure A-6. Fabrication of Seat Assemblies Using Alternate Seatbacks

The forward pan structure was then fabricated and installed on the back frames, and the final assembly involved mounting the foam cushioning and dress cover materials (figure A-7).

The fully completed units were installed in the aircraft for the third full-scale baseline test. Test results indicated a clear improvement in cabin conditions when compared to the previous two baseline tests. Survivable conditions were extended approximately 2 additional minutes, which was a significant increase. It was concluded that the resulting conditions were adequate to serve as a basis for evaluating the potential increase in hazard from magnesium frame components during subsequent tests.

Figure A-7. Partially Completed Seat Assemblies Showing Front Pan Structure

To determine the relative performance of the seat cushioning material used in the third full-scale baseline test, it was agreed that laboratory-scale flammability tests should be conducted using an oil-burner configured according to Title 14 Code of Federal Regulations (CFR) 25.853c Appendix F, Part II. The test exposes representative samples of the seat cushion to an oil-fired burner flame for a period of 2 minutes. Standard-size cushion samples were fabricated and supplied by Chestnut Ridge Foam, manufacturers of the cushion materials used during the third baseline test. According to the regulation detailed in 14 CFR 25.853c, Appendix F, Part II, representative cushions must be constructed to a specific shape and size and must contain correctly proportioned amounts of all materials contained in the actual seat. If the bottom and back cushions are of a different construction, a separate series of three tests must be conducted for each design. The three sets of samples supplied by Chestnut Ridge Foam were fabricated in accordance with the regulation and represented the actual back cushion construction used in the full-scale test. Normally, an additional three-test series would need to be conducted based on the bottom cushion design. However, it was decided that these tests would not be conducted, as the previously certified cushion design was known to give consistent, passing results. It would also be difficult and costly to obtain the proper test samples based on this bottom cushion, which would involve a custom fabricator and the acquisition of the correct foam materials that were used in the original construction.

Prior to conducting the tests, the burner equipment was calibrated to ensure the output was within acceptable limits. Following the required 2-minute burner warm-up, the Baseline Test 3 sample cushions were rolled in front of the burner flames. The test requirement calls for a 2-minute exposure of the seat cushion materials to the burner flame. During the test, the burner flames were largely confined to the surface of the bottom cushion and did not rapidly spread to the back cushion (figure A-8). This result confirmed the superior performance of this cushion system used in the seatbacks during the third full-scale test. At the 2-minute mark, the burner flames were turned off, and the burning cushion was required to remain undisturbed for an additional 5 minutes, as per regulation. At the end of this additional 5-minute observation period, if the cushion was still burning, a gaseous extinguisher was required to extinguish all remaining flames. During the laboratory-scale tests of the Baseline Test 3 materials, a gaseous extinguisher was not needed, as the materials self-extinguished within the 5-minute observation period.

Figure A-8. Baseline Test 3 Cushion Sample During Laboratory Test (typical)

The tested samples were removed from the test apparatus and placed on the test facility floor for photographs (figures A-9 through A-11).

Figure A-9. Baseline Test 3 Standard Cushion Sample 1

Figure A-10. Baseline Test 3 Standard Cushion Sample 2

Figure A-11. Baseline Test 3 Standard Cushion Sample 3

The tabulated results, including weight percentage losses, are included in table A-1. The results clearly indicate acceptable weight losses associated with the cushion system, ranging from 6.3% to 8% weight loss for the bottom specimen, and 0.58% to 1.3% weight loss for the seatback specimen. The total percentage weight loss for the cushion set ranged from 4.27% to 5.14%, well below the maximum 10% acceptance criteria.

Table A-1. Laboratory-Scale Test Results on Baseline 3 Seat Cushion Materials

Test	Description	Pretest Weight (grams)			Posttest Weight (grams)			% Weight Loss		
		Bottom Cushion	Back Cushion	Total	Bottom Cushion	Back Cushion	Total	Bottom	Back	Total
1	Airflex + blue-colored dress cover	2041	1388	3429	1886	1380	3266	7.59	0.58	4.75
2	Airflex + blue-colored dress cover	2010	1383	3393	1883	1365	3248	6.32	1.30	4.27
3	Airflex + blue-colored dress cover	1952	1414	3366	1795	1398	3193	8.04	1.13	5.14

APPENDIX B—LABORATORY TEST RESULTS ON SEAT CUSHIONS USED IN FULL-SCALE BASELINE TESTS 1 AND 2

Surplus triple coach seats were purchased for conducting full-scale tests (figure B-1). The initial full-scale baseline test determined the flammability performance of the seats, which were constructed of standard, aluminum alloy primary seat components. Subsequent full-scale tests determined the performance of the seats when magnesium alloy was substituted in place of the aluminum alloy used in the primary components.

To determine the relative performance of the seat cushioning material used in the initial full-scale baseline test, several laboratory-scale flammability tests were conducted using an oil burner configured according to Title 14 Code of Federal Regulations (CFR) 25.853c Appendix F, Part II.

Figure B-1. Baseline Test 1 Triple Coach Seat With Olive-Colored Dress Cover

An inspection of the triple coach seat cushion materials used in the Baseline 1 full-scale test revealed that three different styles of bottom cushions were supplied. One style contained no obvious fire-blocking layer material (figures B-2 and B-3). Although no fire-blocking layer was observed, it was assumed that this particular seat cushion foam was a fire-hardened type, precluding the need for an additional fire-blocking layer. Another style used a fire-blocking layer with original B/E Aerospace labeling on the material (figures B-4 through B-6). A third style of seat cushion was also discovered, which used a fire-blocking layer manufactured by Franklin Products (figures B-7 through B-9).

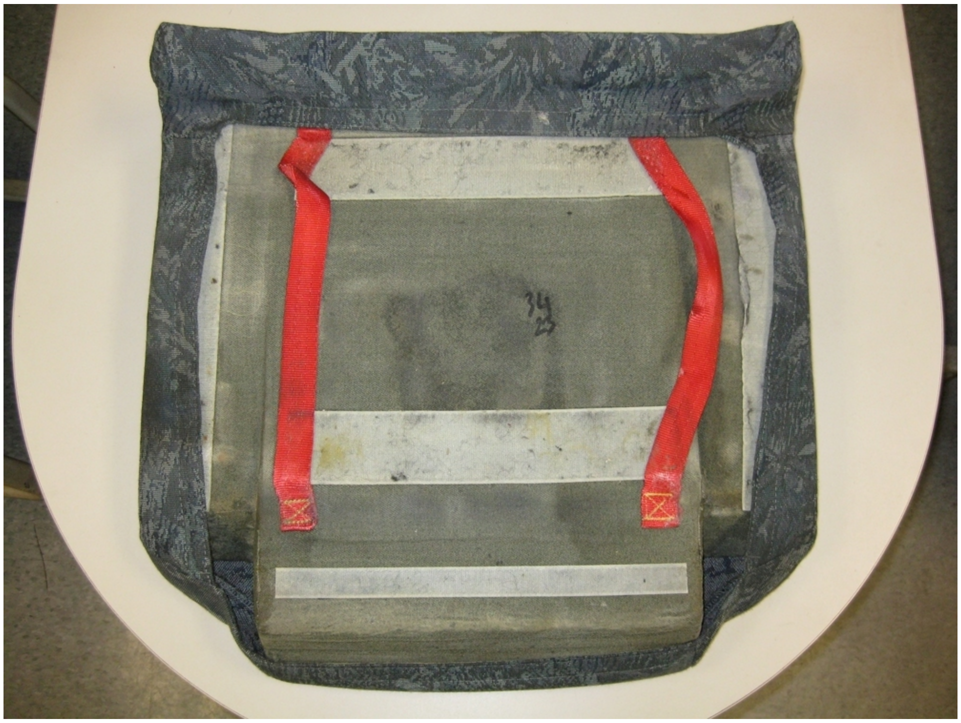

Figure B-2. Baseline Test 1 Bottom Seat Cushion (style 1)

Figure B-3. Baseline Test 1 Bottom Seat Cushion (style 1) Revealing
No Fire-Blocking Layer

Figure B-4. Bottom View of Baseline Test 1 Bottom Seat Cushion With B/E Aerospace Fire-Blocking Layer

Figure B-5. Side View of Baseline Test 1 Bottom Seat Cushion With B/E Aerospace Fire-Blocking Layer

Figure B-6. Close-Up of Baseline Test 1 Bottom Seat Cushion With B/E Aerospace Fire-Blocking Layer

Figure B-7. Baseline Test 1 Bottom Seat Cushion With Franklin Products Fire-Blocking Layer

Figure B-8. Side View of Baseline Test 1 Bottom Seat Cushion With Franklin Products Fire-Blocking Layer

Figure B-9. Close-Up of Baseline Test 1 Bottom Seat Cushion With Franklin Products Fire-Blocking Layer and Label

The cushion back materials used in the Baseline 1 full-scale test were also inspected, revealing the entire seatback system was not a typical design. The frame was constructed of an epoxy-impregnated carbon fiber unidirectional tape with a nylon fabric suspension system (no metallic pan component). The back cushion was very thin with minimal foam (figure B-10). The cushion appeared to contain a fiberfill material in place of the typical urethane foam.

Figure B-10. Baseline Test 1 Back Cushion Containing Fiberfill Material

The test method for determining seat cushion flammability is detailed in 14 CFR 25.853c Appendix F, Part II. The test exposes representative samples of the seat cushion to an oil-fired burner flame for 2 minutes. Representative cushions are constructed to a specific shape and size and must contain correctly proportioned amounts of all materials contained in the actual seat. Since it was not possible to obtain these properly proportioned test samples, it was necessary to use the actual contoured bottom and back cushions for these laboratory-scale tests. Although this was not the desired methodology, it was agreed the tests would provide a general idea of the flammability performance of the cushion materials used in the first full-scale baseline test. Two laboratory-scale oil burner tests would be conducted for each type of Baseline Test 1 seat cushion fire-blocking layer system, for a total of six tests. Prior to conducting the tests, the burner equipment was calibrated to ensure the output was within acceptable limits.

A decision was made to rotate the bottom cushion 90° for all tests, so that the flat surface of the front of the cushion would face the test burner flames (figure B-11). This would prevent the burner flames from protruding under the contoured cushion, which would not typically occur if the samples were the proper shape and size. The back cushions were clamped to the vertical test frame to prevent collapse during the test.

Figure B-11. Baseline Test 1 Cushions Attached to Laboratory-Scale Test Rig

Following the required 2-minute burner warm-up, the Baseline Test 1 sample cushions were rolled in front of the burner flames. The burner flames quickly spread onto the surface of the cushion bottom and back materials (figures B-12 through B-14). Although there were three different types of bottom cushions being tested, they all appeared to burn similarly.

Figure B-12. Baseline Test 1 Bottom Seat Cushion During Laboratory-Scale Test (typical), First Frame

Figure B-13. Baseline Test 1 Bottom Seat Cushion During Laboratory-Scale Test (typical), Second Frame

Figure B-14. Baseline Test 1 Bottom Seat Cushion During Laboratory-Scale Test (typical), Third Frame

The test requirement calls for a 2-minute exposure of the seat cushion materials to the burner flame. At the 2-minute mark, the burner flames were turned off, and the burning cushion is required to remain undisturbed for an additional 5 minutes. At the end of the additional 5-minute observation period, if the cushion was still on fire, a gaseous extinguisher was used to extinguish all remaining flames. During the testing of the Baseline 1 materials, a gaseous carbon dioxide extinguisher was used in all cases to extinguish the remaining flames on the bottom and back cushions.

During the tests, the seatback cushion was largely consumed, regardless of bottom cushion type, with remnant material slumped onto the remaining bottom cushion. Figures B-15 and B-16 show the remnants of two of the tests. The tabulated results, including weight percentage losses, are included in table B-1. The results clearly indicate high weight losses associated with the seatback cushion system, ranging from 55% to 66% of the initial weight. Although the bottom cushions performed much better when compared to the seatback cushions, only the style using the Franklin Products fire-blocking layer came close to the 14 CFR pass-fail requirement, which required 10% or less weight percentage loss. Although these tests were not run in accordance with the seat cushion flammability test specified in 14 CFR 25.853c Appendix F, Part II, due to the lack of standardized test samples, they were a representation of the general fire performance of the materials and confirmed the poor performance of the seatback cushion.

Figure B-15. Close-Up View of Baseline Test 1 Cushion Following Laboratory-Scale Test (typical)

Figure B-16. Baseline Test 1 Cushion Following Laboratory-Scale Test (typical)

Table B-1. Laboratory-Scale Test Results on Baseline 1 Seat Cushion Materials

Test	Description	Pretest Weight (grams)			Posttest Weight (grams)			% Weight Loss		
		Bottom Cushion	Back Cushion	Total	Bottom Cushion	Back Cushion	Total	Bottom	Back	Total
1	Olive-colored dress cover + unblocked	1320	1420	2740	1040	480	1520	21.21	66.20	44.53
2	Olive-colored dress cover + unblocked	1260	1420	2680	840	560	1400	33.33	60.56	47.76
3	Olive-colored dress cover + BE Aero fire-blocker	1220	1340	2560	960	560	1520	21.31	58.21	40.63
4	Olive-colored dress cover + BE Aero fire-blocker	1260	1360	2620	1040	600	1640	17.46	55.88	37.40
5	Olive-colored dress cover + Franklin Products fire-blocker	1300	1400	2700	1140	560	1700	12.31	60.00	37.04
6	Olive-colored dress cover + Franklin Products fire-blocker	1320	1420	2740	1180	580	1760	10.61	59.15	35.77

Following a review of the full-scale Baseline Test 1 results, it was agreed that the seating materials, in particular the seatbacks, performed very poorly. It was theorized that the adverse conditions generated inside the test fuselage during the Baseline 1 full-scale test were mostly due to the overall poor flammability performance of the seat cushion materials. A baseline test result in which nonsurvivable conditions were reached so quickly would make it difficult to evaluate the magnesium contribution during subsequent tests. For this reason, a repeat full-scale test was proposed using cushions constructed of known materials with desirable flammability characteristics in an effort to produce a more favorable baseline result for subsequent comparisons. To accomplish this, a donated set of cushions was obtained in which all of the bottom units included one style of fire-blocking layer, a felted type manufactured by Franklin Products (figures B-17 and B-18). The uniformity in bottom cushion type was in contrast to those used in the full-scale Baseline Test 1, which consisted of an array of cushion types.

Figure B-17. Baseline Test 2 Triple Coach Seat With Blue-Colored Dress Cover

Figure B-18. Baseline Test 2 Bottom Seat and Seatback Cushions

To determine the relative performance of the seat cushion materials used in this full-scale Baseline Test 2, several laboratory-scale flammability tests were again conducted in the same manner as the previous laboratory-scale tests (i.e., tests were conducted on the actual contoured bottom and back cushions since the properly proportioned test samples were not available). Three laboratory-scale oil burner tests would be conducted for this cushion construction. Prior to conducting the tests, the burner equipment was recalibrated to ensure the output was within acceptable limits.

Similar to the Baseline Test 1 full-scale seat cushion materials, a decision was made to rotate the bottom cushion 90°, so that the flat surface of the front of the cushion would face the test burner flames (figure B-19). This would prevent the burner flames from protruding under the contoured cushion, which would not typically occur if the samples were the proper shape and size. The back cushions were clamped to the vertical test frame to prevent collapse during the test (figures B-20 through B-22).

Figure B-19. Front View of Baseline Test 2 Cushions Prepared for Testing in Laboratory-Scale Test Rig

Figure B-20. Side View of Baseline Test 2 Cushions Prepared for Testing in Laboratory-Scale Test Rig

Figure B-21. Rear View of Baseline Test 2 Cushions Prepared for Testing in Laboratory-Scale Test Rig

Figure B-22. Side View of Baseline Test 2 Cushions Prepared for Testing in Laboratory-Scale Test Rig

Following the 2-minute burner warm-up, the seat cushion test assembly was rolled in front of the burner flames to begin the test. As in the Baseline Test 1 oil burner test, the back cushion was largely consumed, with remnant material slumped onto the remaining bottom cushion. Figure B-23 shows the cushion remnants of one of the tests. The tabulated results, including weight percentage losses are included in table B-2. The results again indicated high weight losses associated with the back cushion system, ranging from 30% to 42% of the initial weight. Although the bottom cushions performed much better when compared to the seatback cushions, the results still far exceeded the 14 CFR 25.853c Appendix F, Part II pass-fail requirement, which required 10% or less weight percentage loss. It should be noted again that these tests were not run in accordance with the seat cushion flammability test specified in 14 CFR 25.853c Appendix F, Part II, due to the lack of standardized test samples. However, the tests were at least an indication of the general fire performance of the materials and confirmed the poor performance of the back cushion.

Figure B-23. Baseline Test 2 Cushion Samples Following Laboratory-Scale Test

Table B-2. Laboratory-Scale Test Results on Baseline 2 Seat Cushion Materials

Test	Description	Pretest Weight (grams)			Posttest Weight (grams)			% Weight Loss		
		Bottom Cushion	Back Cushion	Total	Bottom Cushion	Back Cushion	Total	Bottom	Back	Total
1	Blue-colored dress cover + felt fire-blocker	1380	1120	2500	1080	660	1740	21.74	41.07	30.40
2	Blue-colored dress cover + felt fire-blocker	1380	1060	2440	1120	740	1860	18.84	30.19	23.77
3	Blue-colored dress cover + felt fire-blocker	1360	1100	2460	1060	640	1700	22.06	41.82	30.89