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

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Final Report
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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 result, 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 componentsô 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.