2012

FAA Fire Safety Highlights

Table of Contents

Preliminary Full-Scale Fire Tests with Bulk Shipments of Lithium Batteries

A considerable amount of research has been conducted by the FAA to characterize the flammability hazard associated with the use, handling, storage, and shipment of lithium-ion (re-chargeable) and lithium metal (non re-chargeable) batteries. The results of a single cell induced into thermal runaway have been well documented, including case temperature, auto ignition temperature, flammable electrolyte ignition, molten lithium, and explosive pressure. The effect a single cell in thermal runaway has on adjacent cells in a bulk shipment shipment cardboard box has been explored. It has been determined that a single cell in thermal runaway produces enough heat to cause other nearby cells within the shipping box to also go into thermal runaway. This process has been shown to propagate to all cells within the box as well as to adjacent boxes of cells, as shown in a test with three 100 cell boxes. Halon 1301, the fire suppressant used in all passenger aircraft cargo compartments is ineffective in stopping the propagation of thermal runaway in lithium-ion and metal cells, though it does suppress the open flame form a lithium ion battery and spread to other combustibles. It is ineffective against a flaming lithium metal battery.

This research has been the basis for banning the bulk shipment of lithium metal batteries on passenger aircraft, as well as two Safety Alerts for Operators (SAF0): 09013: Fighting Fires Caused By Lithium Type Batteries in Portable Electronic Devices and 10017: Risks in Transporting Lithium Batteries in Cargo Aircraft.

The bulk shipment of lithium-ion cells is permitted on passenger aircraft with Halon 1301 cargo compartment fire suppression systems and the bulk shipment of both ion and metal cells is permitted on cargo aircraft. The involvement of lithium batteries is suspected in recent accidents resulting in the loss of two Boeing 747 cargo aircraft. The need to characterize the flammability hazard associated with a large shipment of lithium batteries in a realistic aircraft environment has been identified. To this end, the FAA Fire Safety Branch is instrumenting a Boeing 727 freighter with the intent of running full scale fire tests with lithium batteries. Bulk shipments of lithium batteries can number in the tens of thousands. For the purposes of these tests, a fire size of five thousand cells has been chosen.

Two tests have been conducted in an outdoor setting to determine the severity of the fire prior to conducting similar tests within the Boeing 727. Thermocouple instrumentation was installed to measure the peak temperatures and rate of propagation. The first test consisted of 5000 lithium-ion 18650 cells in fifty, one hundred cell boxes. The second test consisted of 4800 lithium metal SF123A cells in twelve four hundred cell boxes. In each test, a single cell was removed from a centrally located box at the bottom of the stack and replaced with an electric cartridge heater of similar dimensions and whose temperature profile closely matches a cell in thermal runaway. The tests were initiated by energizing the heater.

5000 lithium-ion cell test results: Much like the smaller scale tests, the spread of thermal runaway proceeded to other batteries, gradually speeding up as the fire size increased. Many cells exploded, rocketing as far as one hundred and thirty-three feet from the site of the fire. Peak temperature measured four inches above the battery stack, was 1400 degrees F. The maximum temperature within the battery stack peaked at 1668 degrees F. The duration of the fire from initial smoke observance to final flame out was one hour and five minutes

4800 lithium metal cell test results. Again, much like the smaller scale tests, the spread of thermal runaway propagated from cell to cell and box to box. However, the rate of propagation increased dramatically as the fire size increased. Nearly all of the cells remained in place during the fire, fusing together in the extreme heat. Peak temperature measured four inches above the battery stack was 1993 degrees F and 2009 degrees F within the battery stack. The duration of this test was in stark contrast to the lithium ion battery test, seventeen minutes from first smoke to final flame out.

A third test was conducted to evaluate the effectiveness of water as an extinguishing agent on lithium metal battery fires. The test consisted of a stack of 400 lithium metal SF123A cells, initiated with a cartridge heater. The fire was allowed to progress to a high intensity, at which time water was sprayed from four fifteen gallon per minute nozzles. The water immediately extinguished the open flame and rapidly cooled the battery stack. The water spray continued until all thermocouples indicated the batteries were cooled, about five minutes. The temperature was monitored and showed a gradual increase, water was again applied. After three applications of water, the battery pack remained cool and was considered extinguished.

The results of these tests are being applied to the design of the full scale tests to be conducted in the Boeing 727 freighter.

POC: Harry Webster, (609) 485-4183

Preliminary 5000 lithium-ion cell fire test

The Impact of Discharged Extinguishing Agent in the Flight Deck and Cabin on Human Safety

The safe-use guidance for hand extinguishers in AC 20-42D[1], "Hand Fire extinguishers For Use In Aircraft", provides discharge limits for halocarbon extinguishing agents that are safely below the adverse effect level. Peak arterial blood concentrations predicted for an exposed person should not exceed a target arterial blood concentration, which is considered the threshold for safe use.[2] Human arterial blood concentration histories are determined from the Halon 1211 gas concentration histories using a simple kinetic model, developed by FAA personnel, which has been shown to provide good agreement with Physiologically Based Pharmacokinetic Modeling (PBPK).[2, 3]

The safe use guidance in AC 20-42D is based on the assumption of instantaneous perfect mixing in a ventilated aircraft cabin. Actual halocarbon gas and arterial concentrations may be lower than predicted at the nose level of a seated or standing passenger due to stratification of the heavier-than-air agent and exhaust at the floor-level air return ducts, or higher than predicted at locations in the aircraft near where the agent is discharged.

A stratification/localization multiplication factor, MF, can be applied to the perfect mixing concentration to increase the allowable AC-20-42D safe use weight of agent to account for stratification/localization based on the position that a reasonable mobile person would be located at the time of discharge. This would allow the use of effective extinguishers that might otherwise be prohibited because of safety concerns. For example, higher Halon 1211 extinguisher charge weights than those based on peak arterial perfect mixing concentrations are expected to be safe due to a long history of safe use of Halon 1211 extinguishers in small compartments.

This study characterized Halon 1211 distribution in time and space, determined the arterial concentration histories from the agent gaseous concentration histories, and determined the stratification/localization multiplication factors for cabin and flight deck Halon 1211 discharges for a particular B-737 configuration. The test targets were selected after considering the most probable fire sources based on a history of fire occurrences. Cabin discharges were directed at an overhead exit light at the aft end of the cabin seating area. Discharging the extinguisher near the far end of the cabin should provide the highest localized concentrations. Flight deck discharges were directed at the copilot's window heater and lower instrument panel (figure 1).

---

[1] FAA AC 20-42D *Hand Fire Extinguishers for use in Aircraft*, January 2011.

[2] Speitel, L.C., Lyon R.E. (August 2009.) *Guidelines for Safe Use of Gaseous Halocarbon Extinguishing Agents in Aircraft*, FAA Report DOT/FAA/AR-08/3.

[3] Lyon, R.E. and Speitel, L.C. (December 2010.) A kinetic model for human blood concentrations of gaseous halocarbon fire extinguishing agents, *Inhalation Toxicology, 22*(12–14), pp. 1151–1161.

The measured concentrations of Halon 1211 in the cockpit at different heights and the calculated resultant arterial blood levels are shown in figure 1. Figure 1 also shows the theoretical perfect mixing concentration histories with and without ventilation, which were calculated based on the weight of agent discharged and the air change time of the compartment, and taken into account the cabin air leakage rate which was determined experimentally.

The ratio of the predicted peak arterial blood concentration, obtained from assuming perfect mixing in a ventilated compartment to the test-based predicted peak arterial blood concentrations, provides a stratification/localization multiplication factor for each test and each gas sampling position. Considering this data, one can select a multiplication factor that can be applied to the currently recommended maximum Halon 1211 concentrations to provide higher safe concentrations of Halon 1211. The resultant multiplication factors are shown in figure 2. For example, the multiplication factor for a seated pilot (41”) was 1.6 when the agent was discharged at a window heater.

POC: Louise Speitel, 609 485 4528

Firefighter directing extinguisher at copilot’s window heater in FAA B-737 test aircraft

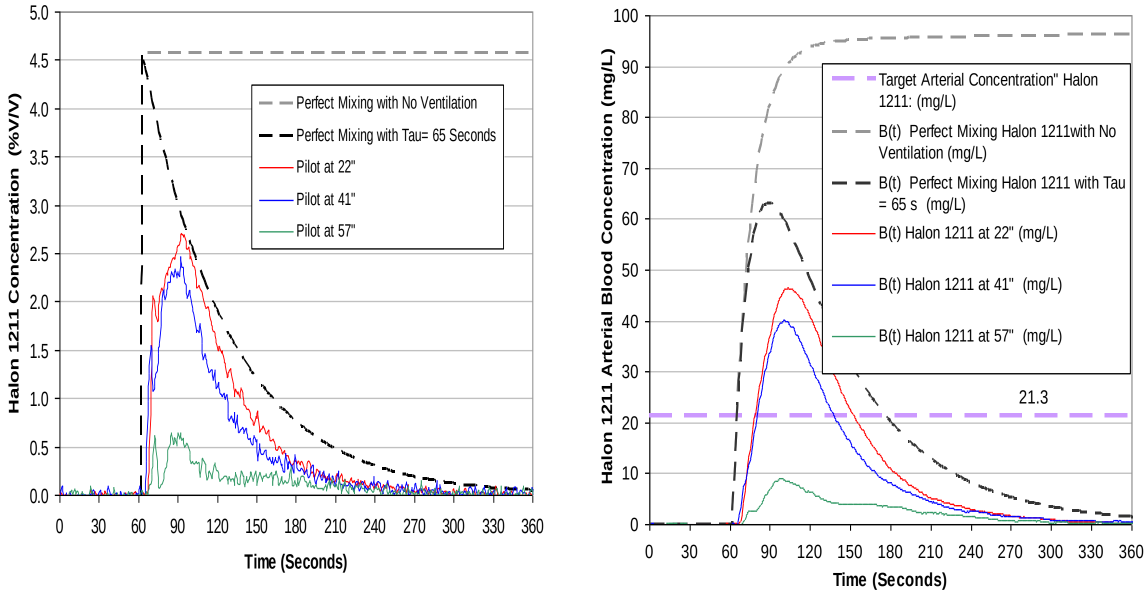


Figure 1. Halon 1211 gaseous and arterial blood concentration histories for one Halon 1211 extinguisher discharged at copilot's window heater. Agent discharged at 60 Seconds. Halon 1301 kinetics was used.

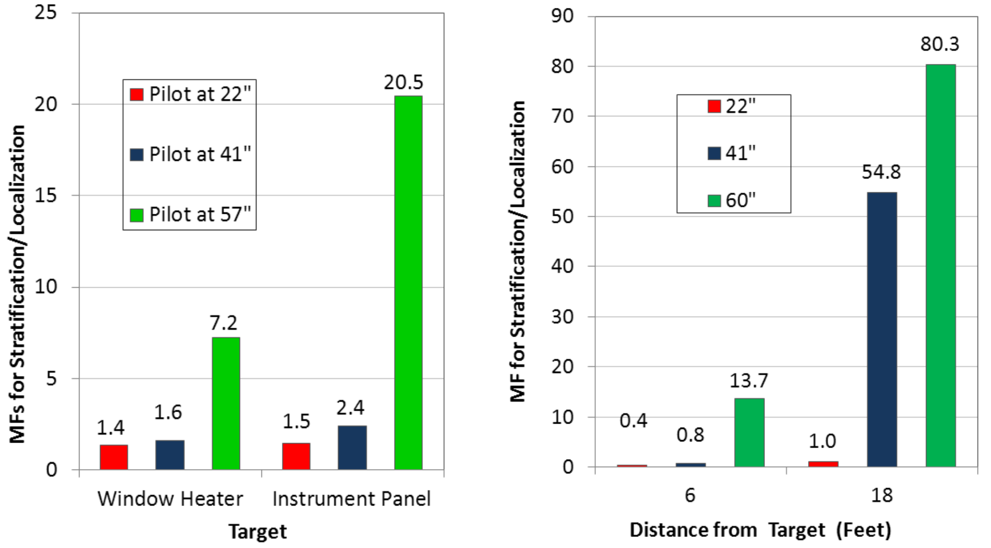


Figure 2. Multiplication factors for stratification/localizationfor flight deck and cabin tests

The Effect of Pressure and Oxygen Concentration on the Burning Rate of Materials

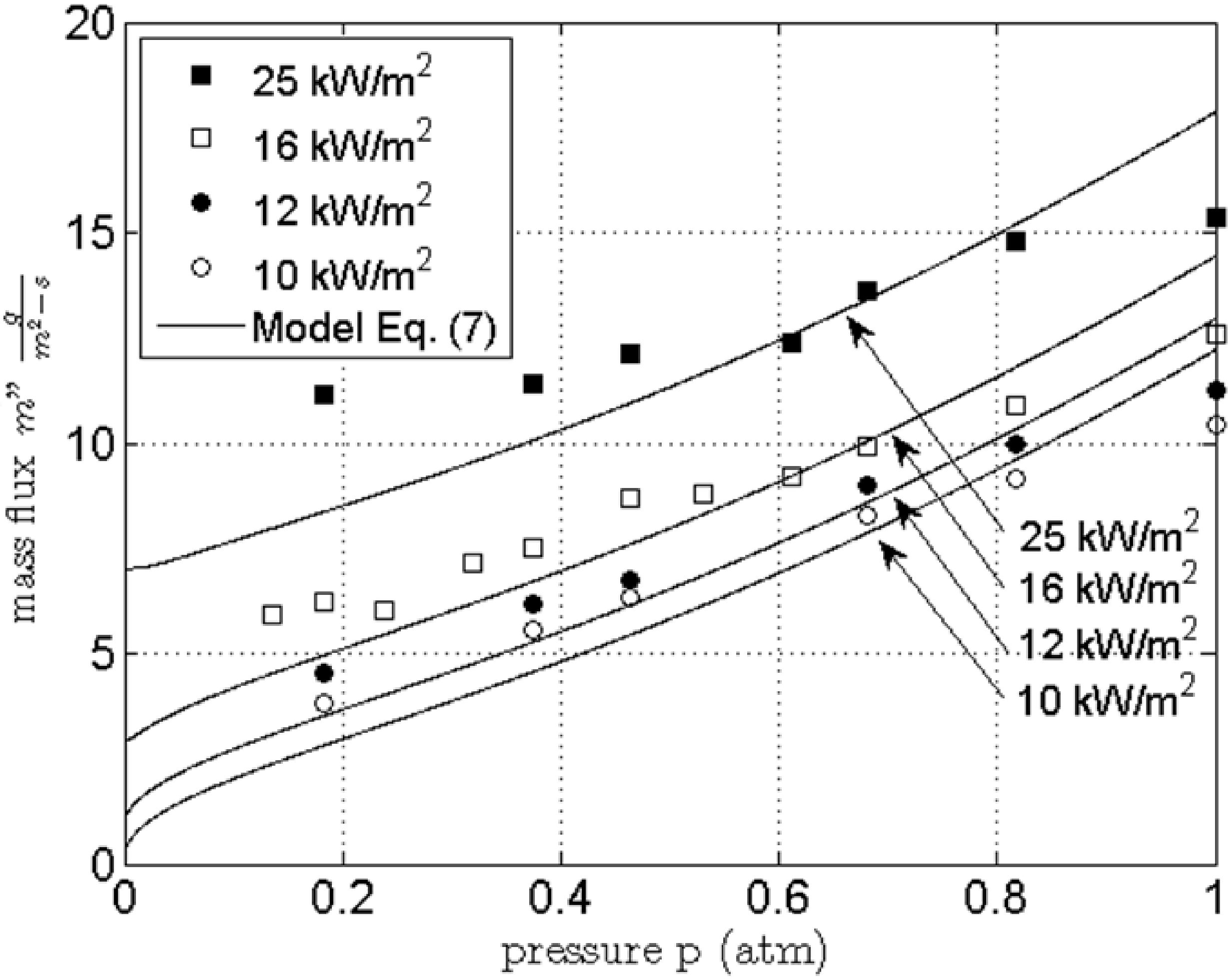
Understanding the behavior of burning materials at reduced pressure is important because aircraft depressurization is an approved procedure employed in freighter aircraft to suppress an in-flight cargo compartment fire. Also, during an enclosure fire the concentration of oxygen may become depleted, affecting the characteristics of the fire. Thus, a study was undertaken to examine and attempt to quantify the effect of pressure (altitude) and oxygen concentration on the burning rate of a material.

The material selected for the study was polymethylmethacrylate (PMMA), because it is readily combustible and burns relatively uniformly. Experiments were conducted in a 10-cubic-meter pressure vessel, capable of reaching pressures as low as 0.1 atmosphere (atm). The PMMA flammability was characterized by the burning rate and the time to ignition. Tests were conducted at pressures from 0.18 to 1.0 atm, oxygen concentrations from 12 to 21 %, and applied external heat fluxes from 10 to 72 kW/m2. A simple analytical model was developed to compare with the experimental results.

The experimental measurements and observations revealed the effect of pressure and oxygen concentration on the burning characteristics of PMMA. As the pressure decreased, the height of the flame diminished and the color of the flame changed from bright yellow at atmospheric pressure to a dim blue at lower pressures. The results also showed that the steady burning rate decreased with pressure, which was more pronounced at lower values of the external heat flux. On the other hand, a reduction in pressure causes the sample to ignite earlier, apparently because the convective heat losses decrease as the pressure was lowered, causing higher PMMA surface temperatures. For all pressures tested, the burning rate decreased when the oxygen concentration was decreased.

The experimental results were compared with the simple analytical model predictions. It was shown that the model predicts the dependency of the burning rate on pressure reasonably well at low external heat fluxes up to about 25 kW/m2. The model clearly under-predicts the burning rate at higher external heat fluxes where the experimental data show little effect of pressure. The model indicated that the burning rate was proportional to the product of the square root of pressure and oxygen concentration. Using this product a simple relationship was derived for the measurements made with all PMMA samples burned at different pressures, oxygen concentrations and external heat fluxes, except at the higher heat fluxes that dominate the burning rate.

POC: Gus Sarkos
Fire Research and Safety

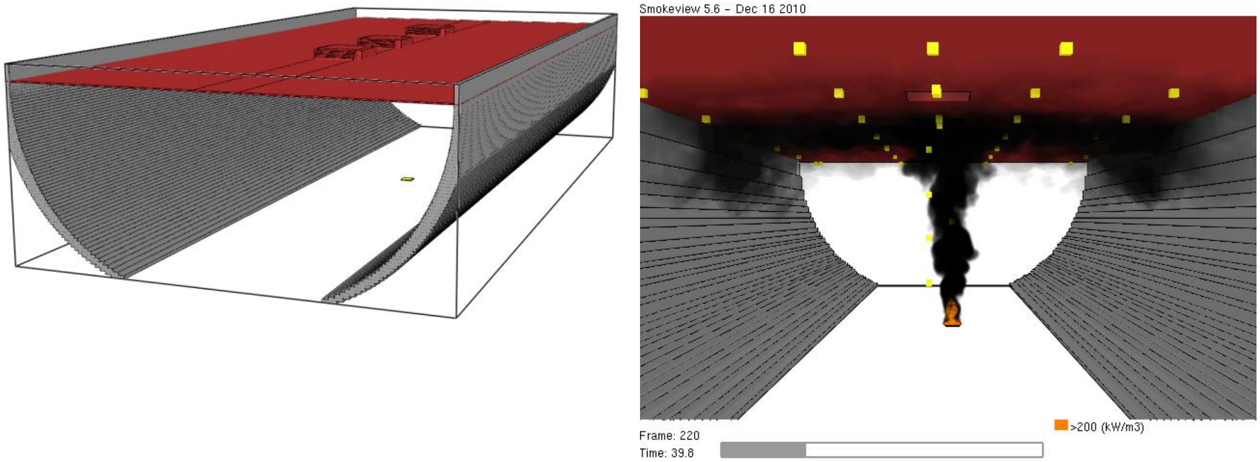


Steady Burning Mass Flux vs Pressure at Different Heat Fluxes – Experiment and Theory

Evaluation of CFD models for smoke movement in cargo compartments

To ensure aircraft fire safety, Federal Aviation Regulations[1] mandates the use of certified smoke and fire detection devices in aircraft cargo compartments. These systems, although successful at fire detection, are prone to detect airborne particles not associated with the fire, hence, have high false alarm rates. It is reported that only one in every hundred alarms is due to a real fire source[2]. False alarms lead to unnecessary evacuations, flight delays, and diversions from intended flight paths, and bring additional safety and cost concerns. Moreover, the certification process requires not only ground tests but also in-flight tests that are both expensive and time consuming. Therefore, cost considerations limit the number of fire scenarios that can be employed to demonstrate that the detector response time is compliant with regulatory requirements. In order to improve the reliability of the detection systems and to reduce the number of necessary tests for certification, it is critical to have a better understanding of fire/smoke behavior in cargo compartments. Although experimental research efforts are ongoing for this purpose, because of the scenario-specific nature and complexity of the problem it is also important to utilize available numerical modeling methods.

The focus of this study is to assess the predictive abilities of computational fluid dynamics (CFD) tools for the transport of smoke and hot gases due to a possible fire source in a cargo compartment. Fire Dynamics Simulator (FDS)[3] developed by National Institute of Standards and Technology (NIST) is chosen among many other open-source solver candidates particularly for its fast turnaround time and robustness. FDS simulations are compared with an extensive set of data collected from FAA fire tests that span four test cases in two cargo compartments, namely, a Boeing 707 and a McDonnell Douglas DC-10. The selected metrics for the comparison are the predictions of temperature, light transmission and concentrations of carbon monoxide and carbon dioxide in the first three minutes of the test initiation.

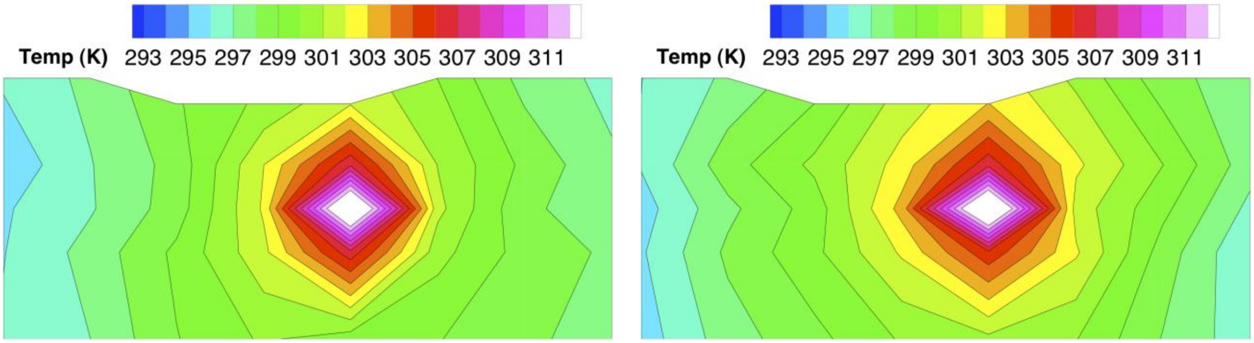


(a) Model geometry *(b) Smoke predictions at 40 s*

Figure 1. B707 cargo compartment simulations

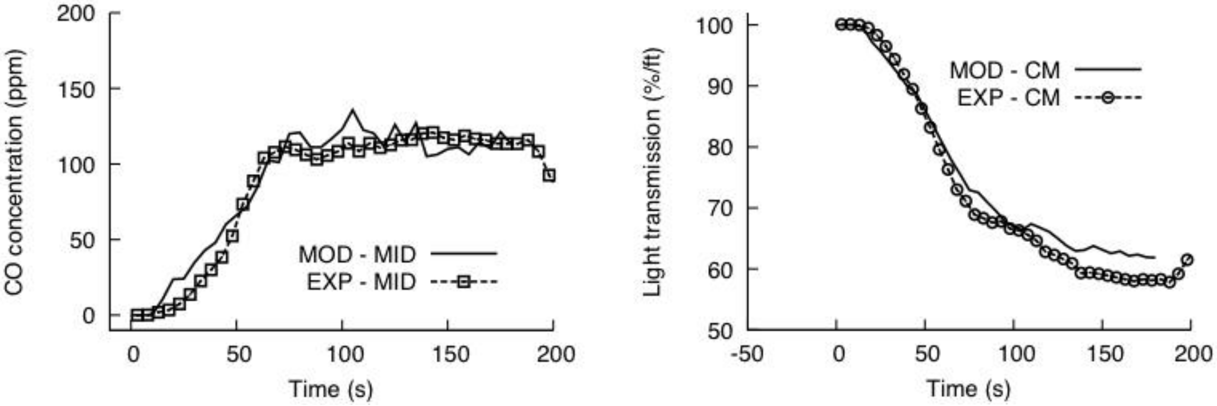
The schematic of the model geometry and the predicted smoke behavior in the B707 cargo compartment are shown in fig. 1. For the test cases studied, CFD is proven to be a powerful tool producing results that are fairly in good agreement with the available test data. For one of the fire scenarios studied, figs. 2(a) and (b) display the contour plot comparisons of measured and predicted ceiling gas temperatures, while figs. 2(c) and (d) show the time variation comparisons of carbon monoxide (CO) concentrations and light transmissions due to visible smoke obscuration, respectively. A detailed description of the model and the results obtained for the other fire scenarios can be found in the given reference[4].

The agreement between the model predictions and the experimental data demonstrates the potential of CFD fire modeling, and encourages its use, as a tool to complement experimental research efforts in developing enhanced detection algorithms and optimal location of detectors. The significant research findings of the current study are as follows: first, the main areas of model limitations are established, and second, the possible improvements to the experimental set-ups are identified. The overreaching benefits include the use of fire modeling as a means to analyze risk and vulnerability of the existing systems in addition to the effectiveness of future modifications dictated by the aircraft fire safety requirements.



(a) Measured ceiling gas temperature at 90 s

(b) Predicted ceiling gas temperature at 90 s



(c) CO concentration

(d) Light transmission

Figure 2: ***B707 cargo compartment simulations:*** *contour plots of (a) measured and (b) predicted ceiling gas temperatures at 90s, history of (c) CO concentration at mid-gas analyzer (MID), and (d) light transmission at mid-ceiling beam detector (CM)*

References

[1] Federal Aviation Regulation (FAR), Part 25, Section 858 - Cargo or Baggage Compartment Smoke or Fire Detection, FAR 25, Federal Aviation Administration, Sept. 1980.

[2] Blake, D., Aircraft Cargo Compartment Smoke Detector Alarm Incident on US-registered Aircraft, 1974-1999, DOT/FAA/AR-TN00/29, Federal Aviation Administration, June 2000.

[3] McGrattan, K.B., Hostikka, S., Floyd, J., Baum, H.R., Rehm, R.G., Mell, W., and McDermott, R., Fire Dynamics Simulator - Technical Reference Guide, NIST Special Publication 1018-5, National Institute of Standards and Technology, Oct. 2010, http://www.fire.nist.gov/fds/.

[4] Oztekin, E.S., Blake, D., and Lyon, R.E., Flow Induced by a Small Fire in an Aircraft Cargo Compartment, 50th AIAA Applied Aerospace Sciences Meeting and Exhibit, AIAA, Nashville, Tennessee, 2011.

Cockpit Visibility Impairment from an EFB with Lithium Batteries in Thermal Runaway

Tests were conducted on board a fully operational Boeing 737 aircraft to evaluate the potential safety hazard resulting from the thermal runaway failure of the lithium batteries in an Electronic Flight Bag (EFB). EFBs are electronic devices used to replace the paper materials typically found in the pilot's flight bag, and are divided into three classes:

- **Class I** – Portable electronic device (PED), Commercial off the Shelf (COTS) equipment that is used as loose equipment and stowed during portions of flight. There is no active charging on board the aircraft.
- **Class II** – PED, can be COTS equipment, and is mounted and connected to aircraft power during flight for use and charging.
- **Class III** – Considered installed equipment, these are not PED or COTS equipment, but rather are pieces of equipment built and tested specifically for aircraft EFB use. They are connected to aircraft power during flight for use and charging.

Class I and II EFBs are considered PEDs that are not subject to airworthiness standards, however the mounting/charging connection hardware used for the installation of a class II EFB is required to be airworthy. Class III EFBs are subject to airworthiness standards, as they are considered installed equipment. The primary concern is the resulting fire/smoke hazards should one of the lithium-ion (Li-ion) batteries installed in these units fail and experience thermal runaway, a failure causing rapid increases in temperature, significant smoke production and at times, explosion and/or rocketing of the battery cell.

To examine this potential safety hazard, one or two (depending on the test criteria) individual battery cells in a COTS laptop was replaced with a small cartridge heater. This small heater was utilized to replicate a single battery cell going into thermal runaway, causing adjacent cells within the 9 cell, 7.2 Ah Li-ion battery pack to subsequently go into thermal runaway. This laptop was installed in the cockpit of the Fire Safety Branch's Boeing 737 test aircraft, which was instrumented with thermocouples, gas sampling probes, smoke meters and video cameras to examine the results of the battery failure. In order to protect the 737 test article, the cockpit was fire-hardened. In addition, at any sign of fire, Halon 1211 was immediately disbursed into the cockpit in order to extinguish the flames, which occurred a number of times. Therefore,, the focus of these tests was the smoke hazard resulting from the propagation of thermal runaway in the lithium batteries inside an EFB, during fire extinguishment..

The testing showed that even with a very high ventilation rate of one air exchange per minute within the cockpit, a typical COTS Li-ion battery could pose a significant smoke hazard within the flight deck environment. . The initial battery event occurred, at times, without warning (i.e. no visible smoke or audible event prior to failure). The battery cells failed in a very vigorous manner, at one point with enough pressure to forcefully push open the unlatched cockpit door. The most striking safety hazard however, was the volume and density of smoke that emanated from the failed battery cells. During one test in which only four of the nine battery cells went into thermal runaway, the installed smoke meter recorded greater than 10% light obscuration/ft for a period of greater than 5 minutes and a peak value of greater than 50% light obscuration/ft, resulting in severe lack of visibility within the flight deck.

POC: Steve Summer, (609) 485 4138

A view from within the Boeing 737 cockpit (a) prior to first battery cell failure, (b) at initial event of battery cell failure, (c) 27 seconds after initial event and (d) 1 minute, 45 seconds after initial event.

Development of a Fire Test for Magnesium Seat Structure

In recent years, magnesium alloys have been proposed as a substitute for aluminum alloys in aircraft seat structure, as well as other applications, due to the potential for weight savings. Although magnesium alloys are routinely used in the construction of non-cabin aircraft components, FAA policy described in Technical Standard Order TSO-C127, "Rotorcraft and Transport Airplane Seat Systems", has prohibited the use of magnesium alloys in aircraft seats for decades. The FAA's central concern regarding the use of magnesium and its many alloys in the cabin is flammability. The current flammability regulations do not address the potential for a flammable metal to be used in large quantities in the cabin, such as in seat structure. However, recent developments in materials technology have shown that different magnesium alloys have different susceptibility to ignition. Yet,, magnesium remains a material that, once ignited, is very challenging to cope with using fire extinguishers currently available on commercial aircraft. Therefore, a research activity was undertaken to determine if magnesium alloys could be safely used in aircraft seat structure and, if shown to be safe, to develop an appropriate flammability test method to ensure fire-safe seat structure.

A preliminary initial assessment of magnesium alloy flammability was conducted using a laboratory-scale test rig. The test rig consisted of an oil-fired burner to simulate a postcrash jet fuel fire, and a mounting mechanism used to secure and expose representative test samples. Test samples consisting of several blends of magnesium alloy were evaluated. One of the samples was a prototype alloy containing rare earth elements to minimize flammability. Tests indicated a large difference in flammability between the various samples evaluated. Magnesium alloys WE-43 and Elektron-21 both showed outstanding resistance to ignition when compared to the more conventional alloys such as AZ-31. Additional laboratory-scale tests evaluated the performance of handheld fire extinguishers against these same alloys when ignited.

Realistic full-scale testing of these alloys also provided useful information into the feasibility of using such materials in the primary components of aircraft coach seating. During the testing, it was determined that the prototype WE-43 material produced minimal quantities of toxic and flammable gases during a 5-minute fire exposure. The full-scale tests confirmed that certain new magnesium alloys were capable of being used in the aircraft's cabin without producing additional hazards during a simulated postcrash fire event. These tests paved the way for the development of a laboratory-scale flammability test for magnesium alloys used in the construction of aircraft seats.

An oil-fired burner, configured according to the current test parameters for seat cushion flammability testing, was used as the basis for the new flammability test. During initial trials, bar-shaped test samples were mounted horizontally in front of the burner flames, and exposed until melting occurred. It was necessary to bring the magnesium alloy samples to their melting point in order to induce any ignition. Various thicknesses and alloys were tested, yielding an array of data on the melting times, time to ignition, and duration of burning following burner removal. These were determined to be the most important flammability factors during the tests. The goal was to devise a condition in which the alloy WE-43 would ignite at approximately 2 to 3 minutes of exposure, and subsequently self-extinguish within 90 seconds of the burner flame being removed. This behavior would mimic the full-scale fire test results obtained using this particular alloy. Although this result was initially achieved with a truncated cone sample, additional tests proved the inconsistency of this configuration. Subsequent trials were conducted on upright hollow cylinders, and numerous other shapes and sizes of samples, in an effort to produce a repeatable and representative test condition. The sample configurations were ultimately narrowed down to a horizontal bar and an upright hollow cylinder. Additional testing led to the selection of the horizontal bar as the configuration of choice, based on its relative ease of fabrication and having similar characteristics witnessed during full-scale fire tests.. Follow-on tests are underway to perfect the test procedure, and finalize test conditions and pass/fail criteria.

POC: Tim Marker (609) 485-6469

Laboratory-Scale Flammability Test on a Magnesium Alloy Bar Sample

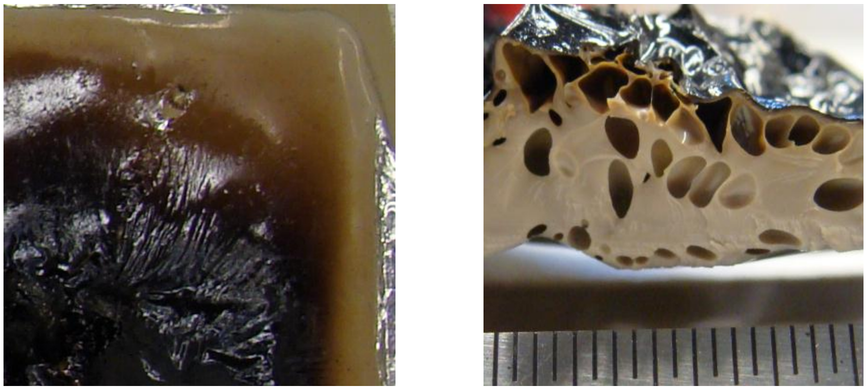
Sources of variability in fire test data: a case study on poly(aryl ether ether ketone)(PEEK)

Having superior mechanical properties (toughness, strength and rigidity), and exceptional chemical and radiation resistance at elevated temperatures, high performance polymers have wide application areas including the aerospace industry. PEEK (poly(aryl ether ether ketone)) is one such thermoplastic that is used as an aircraft structural material in the exterior and as a cabin material in the interior for its notable mechanical properties, low flammability and low smoke emission levels.

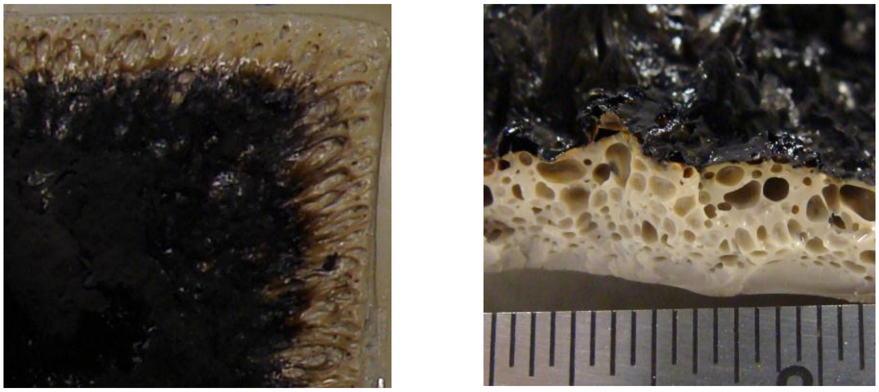
A recent study reported a wide scatter in bench scale fire test results for this material[1]. Both the ignition times and the average heat release rates were found to be sensitive to the moisture absorption of the tested specimen. Although the effect of moisture on the burning behavior has long been recognized, the maximum water desorption of PEEK is negligibly small (0.26% when heated to 125 C for 24 h[2]). Yet, under the same test conditions, approximately 2 min variation was found in ignition times between specimens of varying moisture uptakes.

Time to ignition, which is important as it is a measure of not only fire initiation but also of fire growth, is the main focus of the present study. The cone calorimetry tests of PEEK were analyzed in an attempt to understand the variability in ignition delays observed in bench scale fire tests. The effect of moisture absorption was studied by repeating the experiments for samples with varying moisture content in two groups, namely, dry and wet. The first group, dry samples, was kept in a vacuum oven at 100 °C, while the second group, wet samples, was immersed in distilled water close to the boiling temperature for several weeks prior to the fire tests.

A remarkable difference between the morphologies of dry and wet specimens was observed (see fig. 1). While the surface of the dry sample was glossy and smooth throughout the test duration, that of the wet sample started to bubble early on. These bubbles increased in size and number as the ignition temperature was approached. Although the surface of the dry polymer was smooth, its cross-section revealed bubbles of uniform size accumulated under the charred skin. A similar observation was also seen in the wet sample cross-section, however, the size and number density of the bubbles were noticeably different. Two separate bubble formation mechanisms are identified, one that is due to the thermal decomposition, and another one that is the result of water evaporation. The lower ignition times and heat release rates of the wet specimens are the direct consequences of different bubble nucleation and growth mechanisms in dry and wet samples. Not only do bubble dynamics play an important role in the transport of gaseous decomposition products, but also they alter the optical and thermal properties of the polymer. These findings confirm the significance of environmental conditions (more specifically humidity) and the standardization procedure for test specimens.



(a) Dry sample



(b) Wet sample

Figure 1. Photographs of the specimen surfaces (left) and cross-sections (right): Specimens from each conditioning category were exposed to an external heat flux in the cone calorimeter. Upon ignition they were removed from the sample post and fractured to examine possible morphological changes in the interior[3].

References

[1] P. Patel, Investigation of fire behavior of PEEK-based polymers and compounds, Ph.D. Thesis, University of Central Lancashire, UK, 2011.

[2] Material properties guide, www.victrex.com.

[3] Oztekin, E.S., Crowley, S.B., Lyon, R.E., Stoliarov, S.I., Patel, P., and Hull, T.R., ”Sources of variability in fire test data: A case study on poly(aryl ether ether ketone) (PEEK)”, Combustion and Flame, Vol. 159, Issue 4, pp. 1720-1731, Apr 2012.

A Statistical Model of Fire Test Results

Aircraft cabin materials must meet regulatory requirements established by the Federal Aviation Administration (FAA) for fire safety. The tests used by the FAA to determine the fire safety of materials and products used in aircraft measure, either directly or indirectly, the spread of flame over a solid combustible surface under standardized conditions. These conditions may include a particular sample orientation with respect to gravity, air velocity, ignition source or imposed heat flux to force the sample to burn. What is measured in the bench-scale fire test is the duration, extent, or velocity of burning, or the rate at which heat is released during burning, and a pass/fail rating is assigned to the material based on performance criteria derived from full-scale aircraft fire tests. In principle, the flame spread or burning rate of the sample, and hence the outcome of the bench-scale fire test, is determined by the test conditions and the fire properties of the specimen. In practice, fire test results also depend on the skill of the operator, the condition and calibration of the equipment, and anomalous physical behaviors of samples such as melting, dripping, swelling, deformation, incomplete combustion, edge effects, thickness variations, off-gassing, etc. Consequently, numerous fire tests requiring many kilograms of cabin material must be conducted to establish compliance with the regulations. The uncertainty in the outcome of pass/fail fire tests, and the relative importance of a material fire property to this outcome, make it difficult or impossible to establish a particular (threshold) value of a fire property that can be accurately measured in a small scale test and subsequently used to screen new fire safe materials for development or used for quality control of production cabin materials.

To this end a statistical methodology was developed using a well-known model for surface flame-spread on a vertical sample that was re-written in terms of thermal combustion (fire) properties of the material that are measured in the FAA Microscale Combustion Calorimeter (MCC) using milligram samples. This allowed the pass/fail criterion (maximum flame spread rate or extent or burning) for the regulatory tests to be expressed as a flame spread criterion in terms of properties easily measured in MCC tests. Several thermal combustion properties were evaluated as explanatory variables for two pass/fail fire tests. The fire tests were a heat release (burning) rate test used by the Federal Aviation Administration for large area cabin materials (FAR 25 HRR) and an upward flame spread test used by Underwriters Laboratories as a voluntary standard for flammability of plastics (UL 94 V-0) used in electrical and electronic applications. Fire tests were conducted on hundreds of research and commercial polymers, flame retardant plastics, composites and adhesives used in aircraft. Several thermal combustion properties were measured for each sample in the MCC before fire testing.

The fire test and MCC data were analyzed by calculating the fraction of passing results for each fire test over a small range of MCC properties. This gives the likelihood (probability) of passing a fire test for an average value of the thermal combustion property, i.e., it gives a probability distribution with the thermal combustion property as the explanatory variable. This empirical probability distribution, shown in Figures 1 and 2 as solid circles, could be fit with the flame-spread criterion, shown as solid lines, using two adjustable parameters. It was found that the flame-spread criterion could describe the empirical probability distribution using some, but not all, of the thermal combustion properties as explanatory variables. The MCC thermal combustion properties that showed the best predictive capability were the heat of combustion of the sample (Figure 1) and the heat release capacity (Figure 2). The resulting parametric equation, shown as solid lines in Figures 1 and 2, can then be used to calculate the likelihood of passing the UL 94 vertical flame test or FAR 25 HRR test for any material for which thermal combustion properties can be measured in the MCC.

POC: Rich Lyon, (609) 485 6076

Milligram-Scale Fire Test in the FAA Microscale Combustion Calorimeter

Underwriters Laboratories Vertical Flame Test for Flammability of Plastics

FAA Part 25 Heat Release Rate Test for Cabin Materials

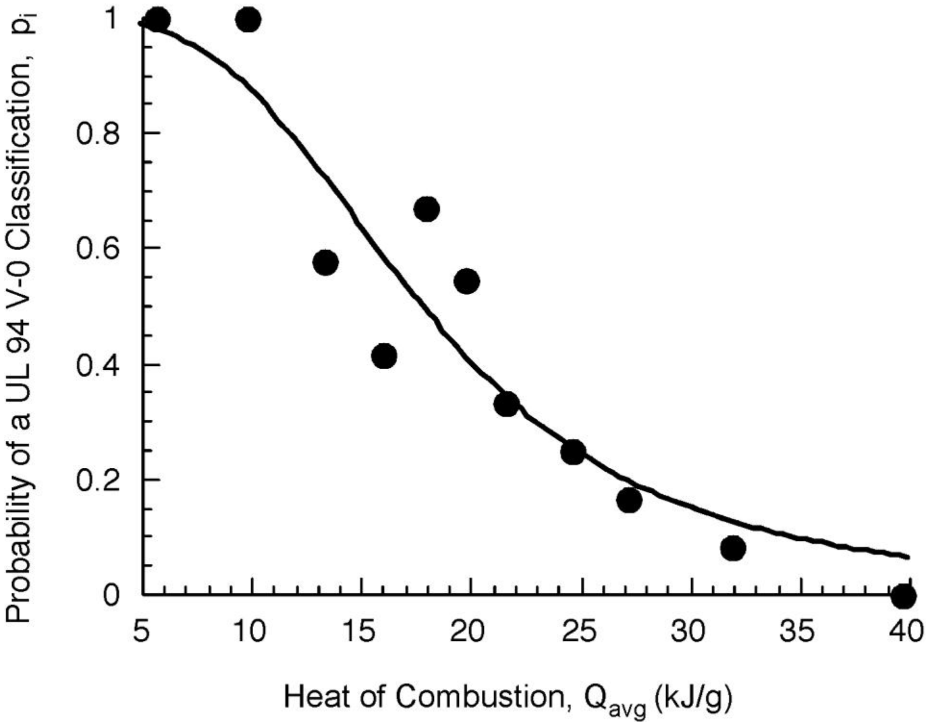


Figure 1. Plot of the Probability of Obtaining a V-0 Rating in UL 94 Vertical Flame Test Versus the Heat of Combustion of the Material Measured in the FAA Microscale Combustion Calorimeter. Circles are Experimental Data. Solid Line is a Fit of the Flame Spread Criterion to the Experimental Data.

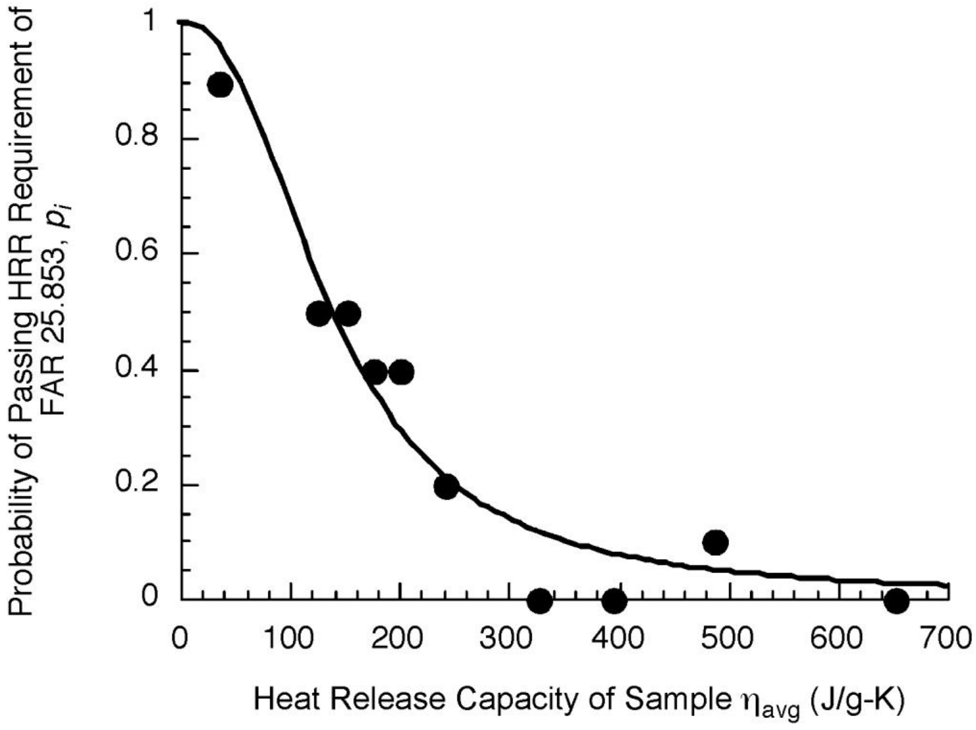


Figure 2. Plot of the Probability of Passing the FAR 25 Requirement for the Heat Release Rate of Cabin Materials Versus the Heat Release Capacity of the Material Measured in the FAA Microscale Combustion Calorimeter. Circles are Experimental Data. Solid Line is a Fit of the Flame Spread Criterion to the Experimental Data.