Federal Aviation Administration

2013 Fire Safety Highlights

Contents

Full-Scale Aircraft Fire Tests with Bulk Shipments of Lithium Metal Batteries

A series of fire tests were conducted in the FAA Boeing 727 freighter test article to ascertain the hazards presented by bulk shipments of lithium metal batteries. These tests represent a culmination of research conducted by the FAA to characterize the flammability hazard associated with the use, handling, storage and shipment of lithium metal batteries. Previous small-scale tests have documented the fire hazards of lithium metal cells experiencing thermal runaway, including case temperature, auto ignition temperature, flammable electrolyte ignition sprayed molten lithium and explosive pressure. Also, in a typical bulk shipment cardboard box, it was determined that a single cell in thermal runaway produces enough heat to cause other nearby cells to also go into thermal runaway. This process propagates through all the cells within the box as well as to adjacent boxes, until all cells in the shipment have been consumed. Halon 1301, the fire suppressant used in all passenger aircraft cargo compartments, is ineffective in stopping the propagation of thermal runaway, though it does suppress the ignition of released electrolyte and prevent fire spread to other combustibles.

This research has been the basis for action taken by the Department of Transportation that banned the bulk shipment of lithium metal batteries on passenger aircraft, as well as an FAA Safety Alert for Operators (SAFO): 10017: Risks in Transporting Lithium Batteries in Cargo Aircraft.

The bulk shipment of lithium metal cells is only permitted onboard 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 has instrumented a Boeing 727 freighter aircraft in preparation for running full scale fire tests with lithium batteries. Bulk shipments of lithium batteries can number in the tens of thousands. For the purpose of these tests, a fire size of five thousand cells was chosen.

The aircraft was configured to simulate inflight emergency conditions in terms of interior airflow settings. Two cargo storage locations were chosen, the main deck Class E compartment, and the forward lower Class C compartment. Class E compartments, found on all freighter aircraft, rely on smoke detection, decompression and oxygen starvation to control a fire. Class C compartments, found on all passenger aircraft as well as some freighters, have both detection and active fire suppression (Halon 1301).

Three tests were conducted in each location. For comparison, the first test in each location consisted of 5000 mixed non-lithium cells, including nickel cadmium, nickel metal hydride and alkaline, all AA size. These cells were exposed to an adjacent fire as the ignition source. The second test used 4800 lithium metal 123A cells, again exposed to an adjacent fire source. The last test used 4800 lithium metal 18650 cells with a simulated thermal runaway of a single cell as the ignition source. All cells were in the original shipping cartons and boxes as received.

Class E results:

Mixed non-lithium cells with adjacent fire ignition. The adjacent fire ignited the fiberboard shipping cartons. This was a slowly developing fire that eventually generated enough smoke to obscure the compartment. The cells did not contribute to the fire. There was minimal damage to the aircraft cargo liner, moderate ceiling temperatures. There was no smoke penetration in the flight deck. The fire smoldered for nearly an hour before the test was terminated.

4800 Lithium metal 123A cells with simulated thermal runaway. The cells in thermal runaway ignited the cardboard packaging and rapidly propagated to rest of the cells in the shipping box, and then to adjacent boxes. The fire rapidly escalated, oxygen depletion did not seem to impede the fire growth. Peak ceiling temperatures were significantly higher than experienced with the lithium-ion fires. Smoke was visible in the flight deck almost immediately and quickly caused total obscuration. The fire did significant damage to the cargo liner. Test was terminated after 16 minutes to prevent further damage to the aircraft.

4800 lithium metal 123A cells with adjacent fire ignition. Similar results as the previous test. The adjacent fire ignited the shipping boxes which in turn ignited the lithium metal cells. Very rapid fire escalation despite oxygen depletion; flight deck became fully obscured. Test was terminated after 18 minutes.

Class C results:

Mixed non-lithium cells with adjacent fire ignition. The adjacent fire ignited the fiberboard shipping cartons. The Halon 1301 was discharged at smoke detection, suppressing the fire. The fire smoldered between the cartons, leaving the surfaces scorched. No damage to the aircraft; smoke contained within the compartment.

4800 lithium metal 123A cells with adjacent fire ignition. The adjacent fire again ignited the shipping cartons. Halon 1301 was discharged at smoke detection, suppressing the fire. The fire smoldered between boxes. The smoldering fire, after approximately 30 minutes, provided enough heat to ignite some of the lithium metal cells. Test was terminated with water. Smoke was contained within the compartment.

4800 Lithium metal 123A cells with simulated thermal runaway. The cells in thermal runaway ignited the cardboard packaging and rapidly propagated to rest of the cells in the shipping box, and then to adjacent boxes. Halon 1301 was discharged at smoke detection, suppressing the cardboard and electrolyte fire. Heavy smoke was observed in the adjacent mix bay compartment as well as in the main deck Class E compartment. Some smoke was observed in the flight deck. The lithium metal battery fire continued to escalate despite the presence of Halon and oxygen depletion. The test was terminated with water. Water was applied for five minutes then shut off. Halon concentration at this time was approximately one percent; oxygen had increased to 13 percent. Twenty seconds after the water was shut off, a single cell could be heard exploding. This ignited the unburned hydrocarbon fumes at the ceiling of the cargo compartment. This caused a pressure increase that opened the blow out panel between the cargo compartment and the mix bay. The cargo compartment fire provided an ignition source for the fumes in the mix bay, causing an explosion. The mix bay explosion blew through the main deck floor above into the cargo compartment and into the EE bay forward, and blew the door into the flight deck. The aircraft sustained significant damage from the explosion.

Figure 1 The ignition of unburned electrolyte hydrocarbons in the mix bay caused an explosion that opened a large hole in the main cabin floor.

Conclusions

Bulk shipments of lithium metal batteries pose a severe threat to the aircraft. In the Class E compartment the high temperature fire caused severe damage to the cargo liner and quickly forced smoke into the flight deck. Oxygen starvation did not impede the progress of the fire or limit the severity. In the Class C compartment, the Halon 1301 suppressed the electrolyte fire, but the battery fire still increased rapidly. Smoke and fumes were forced out of the cargo compartment into the mix bay and the main deck Class E compartment above. The danger of the accumulated unburned hydrocarbons from the electrolyte was born out after the test was terminated, resulting in an explosion when a single cell in thermal runaway provided the spark.

POC; Harry Webster, ANG-E211, 609 485 4183

Full-Scale Aircraft Fire Tests with Bulk Shipments of Lithium-ion Batteries

A series of fire tests were conducted in the FAA Boeing 727 freighter test article to ascertain the hazards presented by bulk shipments of lithium-ion batteries. These tests represent a culmination of research conducted by the FAA to characterize the flammability hazard associated with the use, handling, storage and shipment of lithium-ion batteries. Previous small-scale tests have documented the fire hazards of lithium ion cells experiencing thermal runaway, including case temperature, auto ignition temperature, flammable electrolyte ignition and explosive pressure. Also, in a typical bulk shipment cardboard box, it was determined that a single cell in thermal runaway produces enough heat to cause other nearby cells to also go into thermal runaway. This process propagates through all the cells within the box as well as to adjacent boxes, until all cells in the shipment have been consumed. Halon 1301, the fire suppressant used in all passenger aircraft cargo compartments, is ineffective in stopping the propagation of thermal runaway, though it does suppress the ignition of released electrolyte and prevent fire spread to other combustibles.

This research has been the basis for two Safety Alerts for Operators (SAFO): 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 both passenger and 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 instrumented a Boeing 727 freighter aircraft in preparation for running full scale fire tests with lithium batteries. Bulk shipments of lithium batteries can number in the tens of thousands. For the purpose of these tests, a fire size of five thousand cells was chosen.

The aircraft was configured to simulate inflight emergency conditions in terms of interior airflow settings. Two cargo storage locations were chosen, the main deck Class E compartment, and the forward lower Class C compartment. Class E compartments, found on all freighter aircraft, rely on smoke detection, decompression and oxygen starvation to control a fire. Class C compartments, found on all passenger aircraft as well as some freighters, have both detection and active fire suppression (Halon 1301).

Three tests were conducted in each location. For comparison, the first test in each location consisted of 5000 mixed non-lithium cells, including nickel cadmium, nickel metal hydride and alkaline, all AA size. These cells were exposed to an adjacent fire as the ignition source. The second test used 5000 lithium-ion 18650 cells, again exposed to an adjacent fire source. The last test used 5000 lithium-ion 18650 cells with a simulated thermal runaway as the ignition source. All cells were in the original shipping cartons and boxes as received.

Class E results:

Mixed non-lithium cells with adjacent fire ignition. The adjacent fire ignited the fiberboard shipping cartons. This was a slowly developing fire that eventually generated enough smoke to obscure the compartment. The cells did not contribute to the fire. There was minimal damage to the aircraft cargo liner, moderate ceiling temperatures. There was no smoke penetration in the flight deck.

Lithium-ion with simulated thermal runaway. The cells in thermal runaway generated enough heat to ignite the fiberboard cartons, which in turn ignited the released electrolyte. The fire gradually escalated, generating a large amount of smoke that soon penetrated the flight deck. The flight deck became fully obscured. The fire consumed most of the oxygen in the compartment, reducing the intensity. As oxygen infiltrated the compartment, the intensity increased. This cycle would have continued until all cells were consumed. The test was terminated with water. Significant damage was done to the compartment.

Lithium-ion with adjacent fire ignition. The adjacent fire ignited the fiberboard shipping cartons. This in turn heated the lithium-ion cells causing them to go into thermal runaway. The burning cartons ignited the released cell electrolyte. At this point the fire characteristics and aircraft hazards were indistinguishable from the previous test.

Figure 1 5000 lithium-ion cells after the test was terminated; approximately two thirds consumed in the fire.

Class C results:

Mixed non-lithium cells with adjacent fire ignition. The adjacent fire was ignited and began to spread to the cartons containing the mixed cells. Halon 1301 was discharged upon smoke detection. This suppressed the fire preventing further fire spread. No smoke spread into the flight deck or main deck compartment

Lithium-ion with adjacent fire. The adjacent fire again spread to the cartons containing the lithium-ion cells. Halon 1301 suppressed the fire preventing fire spread. No cells became involved. No smoke spread into the flight deck or main deck compartment.

Lithium-ion with simulated thermal runaway. The simulated thermal runaway device caused adjacent cells to also go into thermal runaway. This in turn ignited the cartons and electrolyte. Halon 1301 was discharged upon smoke detection, suppressing the open flames. Thermal runaway continued to propagate throughout the shipping carton and spread to adjacent cartons. The rate of propagation increased with time. The test was terminated with water. There was no smoke penetration into the flight deck or main deck compartment.

Conclusions.

Lithium-ion batteries in bulk shipments pose a more serious threat to the aircraft than other more common battery chemistries. Lithium-ion fires in the Class E compartment can do significant damage to the aircraft and generate enough heat and pressure to force smoke into the flight deck. Class C compartments equipped Halon 1301 can suppress the open flames from a lithium-ion fire, prevent smoke penetration into the flight deck but cannot stop the propagation of thermal runaway. The buildup of unburned hydrocarbons from the released electrolyte may pose a flash fire or explosion threat when the compartment is opened.

POC: Harry Webster, ANG-E211, 609 485 4183

Development of a Flame Propagation Test Method for Composite Structure

Technological advances in materials science have led to the increased use of composite materials for primary structures in commercial airframes. Carbon fiber composites are favorable for aerospace applications due to their increased strength, lower density, and better corrosion resistance than traditional aircraft aluminum. Nearly every major transport-category aircraft manufacturer is currently using or has plans to use carbon fiber composites for fuselage skins and structures. Current Federal Aviation Regulations do not require flammability testing for aircraft fuselage skins or structural members, as all transport airplanes up until now have been constructed from aluminum, which will not burn or propagate flames when exposed to a fire in an inaccessible area of the cabin. In recent years the Federal Aviation Administration has been working to increase the fire worthiness of materials located in inaccessible areas, including insulation, ducting, and electrical wiring, striving to enhance in-flight cabin safety. Modern transport airplanes constructed from composite materials will inherently have a significant amount of composite material in the inaccessible areas, possibly posing a threat to in-flight cabin safety. In order to certify an aircraft with a composite fuselage, the manufacturer must demonstrate that the composite materials will provide an equivalent level of safety to an aluminum-constructed aircraft when exposed to an in-flight fire. To date, this has been accomplished through Special Conditions imposed by the FAA, where the applicant submitted a test plan to the FAA for review, performed testing and analysis specific to their design and provided the results to the FAA which then determined whether the composite material in fact did not present any increased safety hazard compared to aluminum.

In order to standardize the certification process for composite aircraft, this study has been undertaken to develop a laboratory scale test method for determination of flame propagation of structural composite materials. The test method was designed such that it correlates to an intermediate scale test simulating a (realistic) moderately severe fire impinging on the inboard side of the aircraft skin. An intermediate scale test rig was constructed to simulate an inaccessible area in an aircraft cabin with the ability to interchange the test panels in order to study various composite materials. A variety of materials were evaluated in this research, including aerospace and non-aerospace woven laminates, uni-directional laminates, and carbon/epoxy-honeycomb sandwich panels. Other materials tested included glass-fiber reinforced vinylester, glass-cloth epoxy resin, and a baseline aluminum panel. The standard hidden fire source was a polyurethane foam block spiked with a small amount of heptane to promote uniform, consistent burning. The simulated hidden area was insulated with ceramic fiberboard in order to retain heat produced from the burning foam block and direct it towards the test panel. Panel temperatures were recorded during each test with thermocouples located on the inboard-side of the test panels in an attempt to quantify the progress of the flame along the panel surface. Video was recorded to study the duration and intensity of panel burning, and a post-test measurement of the burn area was recorded. Materials were ranked according to burn length and burn time after foam block extinguishment.

A lab-scale test apparatus was designed, constructed, and tested by the FAA Technical Center's Fire Safety Branch. The apparatus consists of a 710-watt, two and three quarter-inch diameter radiant coil furnace mounted vertically and opposite of a six-inch by twelve-inch composite test sample. A six-flamelet propane-air pilot burner impinges on the lower portion of the test sample for fifty seconds, and then is removed. The sample is then allowed to burn while still exposed to the radiant heat flux emitted by the coil furnace. The burn time beyond pilot flame removal is recorded, as well as post-test measurements of burn length and burn width. Multiple test apparatuses were constructed and validated with machine-to-machine comparative test series. Reproducibility was confirmed by testing all apparatuses in different laboratories. The final phase currently underway is the delivery of apparatuses to the major airframe manufacturers to validate the performance in a different geographic location. The final test parameters and pass/fail criteria will be confirmed through the test method's task group in the International Aircraft Materials Fire Test Working Group.

POC: Robert Ochs, (609) 495 4651

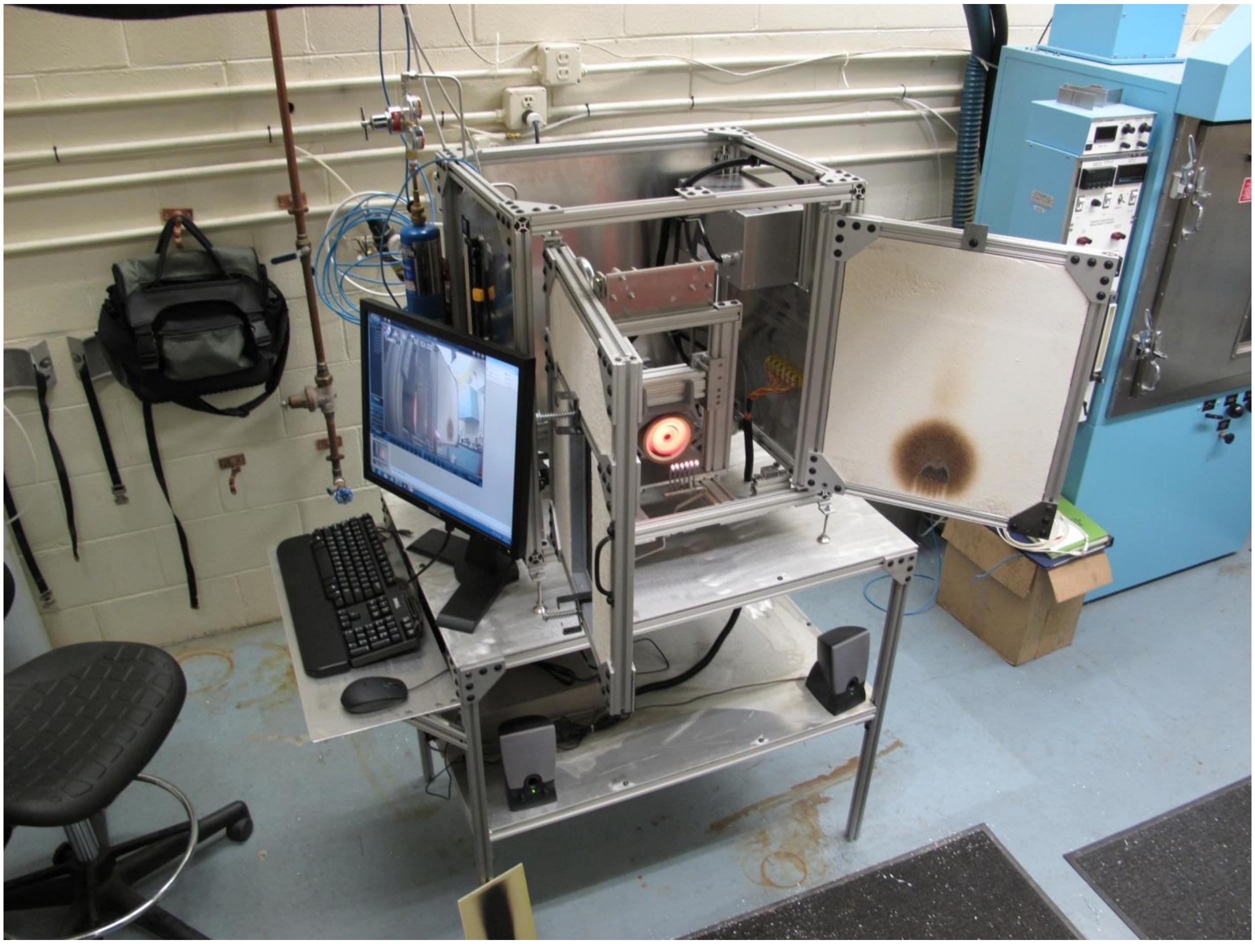

Figure 1. Flame propagation test apparatus

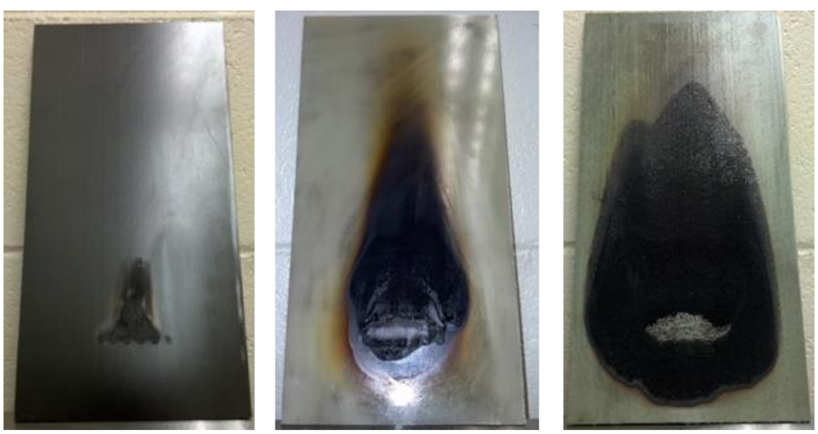

Figure 2. Post-test comparison of burned areas for aerospace carbon/epoxy (L), industrial-grade glass/epoxy (C), and glass/vinylester (R).

Safe Human Exposure Criteria for Halon Discharge in a Small General Aviation Airplane

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. 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 aircraft compartments.

---

[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.

Retrospective studies were conducted of Cessna 210C Halon 1211 discharge tests for an empty aircraft [4] and an aircraft loaded with 4 mannequins and baggage.[5] The aircraft was positioned in a wind tunnel (figure 1). Three ventilation conditions were included in the analysis, all with a 120 mph wind tunnel air speed: overhead vents open, all vents open and all vents closed. The air change time for the Cessna 210C tests were determined to be 1.16 minutes for the empty aircraft with overhead vents open. Cessna 210C test data selected for analysis included 2 discharge targets: under the instrument panel, copilot's side and the copilot's seat.

This retrospective analysis determined the arterial concentration histories from the agent gaseous concentration histories using Halon 1301 kinetics, and determined the stratification/localization multiplication factors for Halon 1211 (figure 2). Figure 2 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, taking into account the measured cabin ventilation rate.

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 3. For example, the multiplication factor for the nose level of a seated pilot was 2.2 when discharged under the instrument panel on the co-pilot's side and 2.1 when the agent was discharged at the copilot's seat.

POC: Louise Speitel, 609 485-4528

[4] Slusher, G.R., Wright, J., Demaree, J.E., and Neese, W.E., " Extinguisher Agent Behavior in a Small Airccraft", FAA Report DOT/FAA/CT-83/30, 1984.

[5] Slusher, G.R., Wright, J., Demaree J., "Halon Extinguisher Agent Behavior in a Ventilated Small Aircraft", FAA Report DOT/FAA/CT-86/5, 1986.

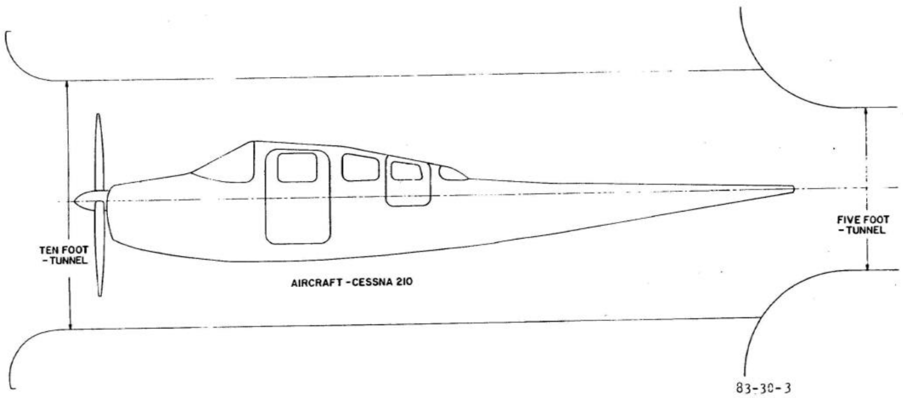

Figure 1. Wind Tunnel Profile with Cessna 210C

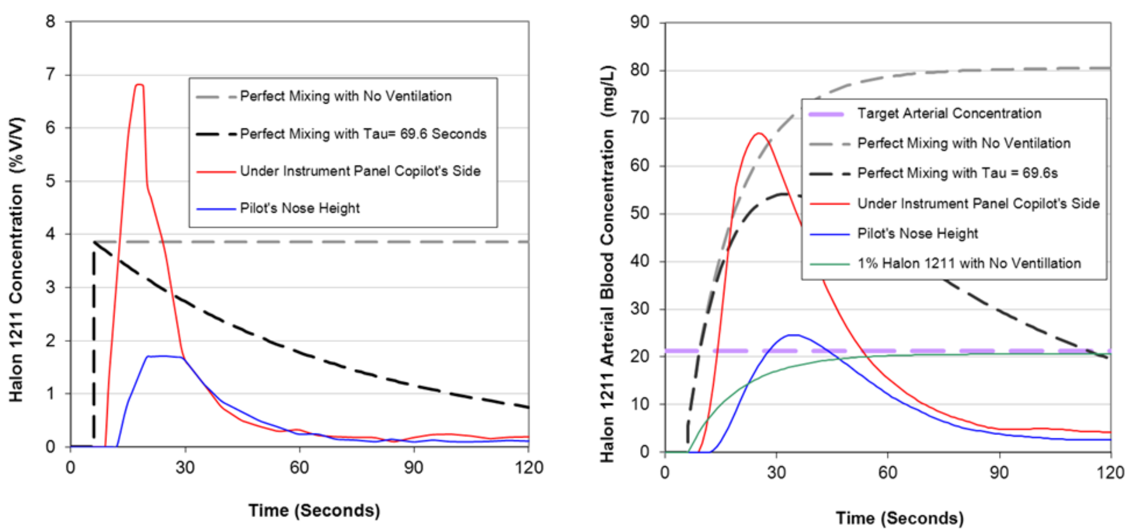

Figure 2. Halon 1211 gaseous and arterial blood concentration histories at pilot's nose level for one Halon 1211 extinguisher discharged under instrument panel on copilot's side into empty fuselage with overhead vents open. Halon 1301 kinetics was used.

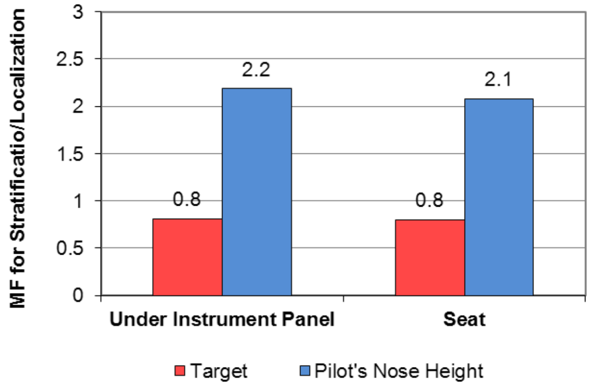

Figure 3. Multiplication factors for stratification/localization at Pilot's Nose Level in an empty aircraft for discharges at copilot's seat and under instrument panel, copilot's side with overhead vents open.

Extinguishment of Lithium-Ion and Lithium-Metal Batteries

Lithium-metal and lithium-ion batteries exist in many consumer portable electronic devices. The batteries sometimes overheat and create a fire and/or explode. When a single cell in a battery pack undergoes a condition of uncontrolled internal heating and rapid temperature rise called thermal runaway its heat output causes other cells to do likewise. The propagation of thermal runaway and the resultant fire may be controlled if the correct extinguishing agent is used.

The objective of this study was to compare the effectiveness of fire extinguishing agents for the extinguishment of lithium-metal and lithium-ion battery fires and the termination of cell-to-cell propagation of thermal runaway.

Tests were performed in a 64 cubic foot test chamber with a sealable door. Quantitative tests were first done to compare the ability of "streaming" extinguishing agents, used primarily in hand-held extinguishers, to cool a hotplate. The effectiveness of the agent's ability to cool was quantified by the average temperature drop measured by 5 surface thermocouples. Water and other aqueous extinguishing agents were the most effective coolants and they increased in effectiveness with increased volumes. The non-aqueous agents were essentially ineffective and showed a smaller increase in effectiveness with increased volumes, as shown in figure 1a.

Next, fire tests were performed with exposed lithium-ion and lithium-metal cells to determine the capability of different agents to extinguish a small battery fire and prevent thermal runaway propagation. Five cells were placed side-by-side in an insulated holder and thermal runaway was initiated in a single cell with a cartridge heater. Tests were performed 4 times with lithium-ion cells and 7 times with lithium-metal cells to verify that thermal runaway would consistently propagate without the presence of an extinguishing agent. Once this was verified, streaming agents were applied with a handheld extinguisher from the distance suggested on the extinguisher bottle and liquid agents were poured on the battery fire using a 500mL water bottle. These results also showed that aqueous extinguishing agents were most effective at halting thermal runaway propagation (figure 1b). The gaseous agents were effective at extinguishing the electrolyte fires.

There was a significant variation in the behavior of thermal runaway among various identical lithium-metal cells. The cells would usually do one of the following: (1) vent from melted holes in the cell, (2) leak plastic and lithium and (3) eject their contents. The contents that leaked and ejected were usually burning but on some occasions were not burning, if an ignition source had not materialized.

On occasion, cells would explode and terminate thermal runaway propagation. The propagation would terminate because hot internal battery components would eject away from the exploded cell and reduce the available heat to be transferred to the next cell.

In summary, the tests showed that the extinguishing agents that contained water were most effective at preventing thermal runaway propagation for small numbers of lithium-ion and lithium metal cells and that the effectiveness increased with increased volumes. The streamed agents showed less effectiveness at preventing propagation and a smaller increase in effectiveness with an increased volume.

POC: Thomas Maloney, ANG-E21 (TAMI), 609 485 7542

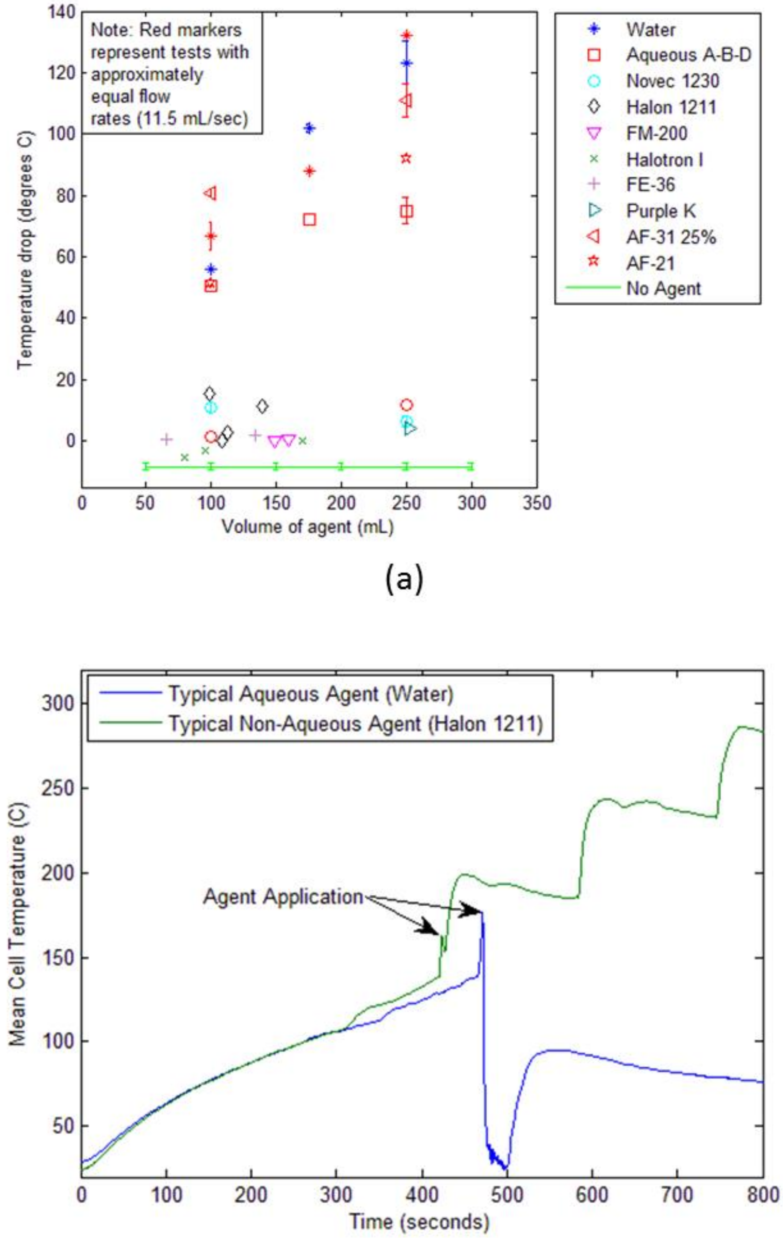

Figure 1: (a) Temperature Drop of a Hot Plate from Extinguishing Agents. (b) Temperature Plot of the Extinguishment of Lithium-Ion Batteries in Thermal Runaway for Verification of Hot Plate Tests.

Fire Extinguishing Agent Distribution & Fire Extinguishment Tests in an FAA-owned Boeing 747SP Aircraft Engine.

A multi-year project investigated the ability of a particular solid aerosol fire extinguishing agent to perform comparably to halon 1301, as used in an aircraft engine fire extinguishment system. The final aspect of this project, the subject of this description, is a collection of 8 tests conducted to demonstrate the acceptable performance of the solid aerosol fire extinguishing agent, its proposed design criteria, and its associated concentration analyzer. This activity's outcome indicated the proposed design criteria specifying this solid aerosol fire extinguishing agent's use for this application would likely not result with performance comparable to halon 1301.

The tests occurred in the number 2 Pratt & Whitney JT-9D engine on an FAA-owned Boeing 747SP, located at the FAA Technical Center, which also included external ancillary equipment necessary for this testing. A team composed of FAA personnel & contractors from the Fire Safety Branch, FAA staff from the Transport Airplane Directorate and the Seattle Aircraft Certification Office, the Boeing Commercial Airplane Company, and Kidde Aerospace and Defense accomplished the build-up, testing, reviews, and attendant decision making as progress occurred. The Fire Safety Branch maintained and operated the 747SP aircraft engine and ancillary systems, excluding all associated with the fire extinguishment system. Kidde Aerospace and Defense provided and serviced the complete fire extinguishment system and maintained and operated the associated concentration analyzer.

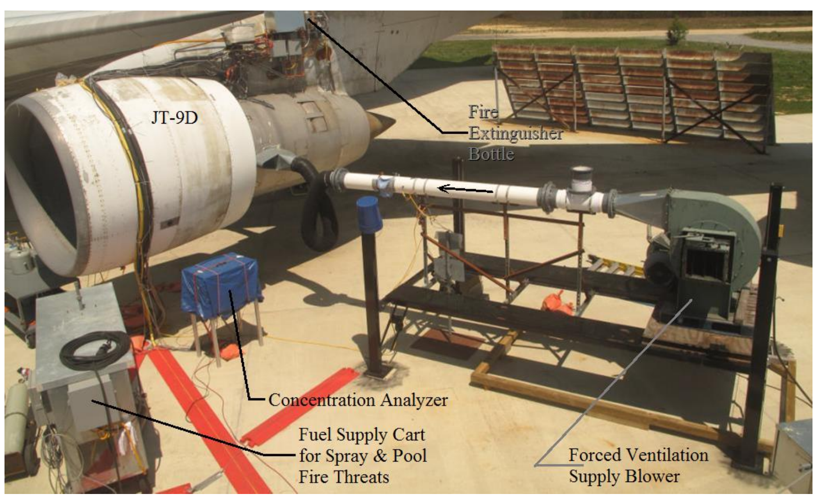

Figure 1. The FAA-owned Boeing 747SP Engine Fire Test Site.

During the test article build up, systems external to the aircraft engine were designed, fabricated, and installed. They provided the engine fire zone with a forced ventilation flow, simultaneous spray and pool fire threats based on turbine fuel, fire extinguishing agent storage and delivery, and numerical and optical telemetry that monitored and recorded the local environment during test. Additional electrical circuits were installed that allowed remote control of these systems during test completion. Minor modifications were made to the engine compartment which minimized differences between tests conducted with the engine running and those without, which promulgated an assessment of a requisite new concentration analyzer associated with the solid aerosol's use. With the completion of the test article, personnel operated the aircraft engine for a desired duration from the aircraft flight deck, while other personnel in the adjacent site control room on the ground operated the forced ventilation supply equipment, prepared and ignited simultaneous spray and pool fires as needed, and prepared and discharged the engine fire extinguishment system.

A series of tests were conducted that provided information for subsequent review and decision-making. Six tests were fire extinguishing agent distribution tests that captured the performance of the agent injection system and the concentration analyzer. Three

Figure 2. Pool Fire Imagery in the Engine Fire Zone during the Solid Aerosol Injection and Migration.

tests were accomplished during an engine run and 3 were accomplished without, but immediately followed an engine run. The team considered the collected information and decided to continue forward, as the performance of the concentration analyzer did not solely discriminate according to engine operating status, that being a main concern. The final 2 tests were fire extinguishment tests conducted in a thermally "hot" engine fire zone with a static engine. The intensity of the fire threats were first assessed with the discharge of a pressurized quantity of nitrogen stored in the fire extinguishing agent bottle. The injected nitrogen did not extinguish the fires, thus the fire threats were considered sufficiently intense. Knowing an acceptable challenge existed, the second test occurred to assess the performance of the solid aerosol fire extinguishing agent and its proposed design criteria. The injected solid aerosol did not extinguish the fire threats.

During a number of meetings with the team, several postulates were offered to better understand the undesired outcome of the real engine fire extinguishment test with the solid aerosol fire extinguishing agent. All were plausible, but segregated between either needing to better understand the behavior of the solid aerosol fire extinguishing agent or of the fire threats through the use of halon 1301. Testing concluded as the industry component of the team desired to further investigate the behavior of the solid aerosol fire extinguishing agent.

POC:
Doug Ingerson, ANG-E21, 609 485 4945

Two-dimensional Model for Burning Materials

Fire safe aircraft materials are critical for ensuring safety of air travel. An important aspect of the fire safety or flammability of materials is flame growth and fire propagation, which in multifaceted engineered environments such as aircraft is highly complex. Therefore, flammability of materials and components is assessed through a broad spectrum of experimental tests, each of which is tailored to represent a specific fire development scenario of high likelihood. This situation creates significant challenges for aircraft material and component developers. These challenges arise from a lack of quantitative relations between physical and chemical characteristics of a given material and its performance in each flammability test. Establishment of such relationships would not only help to bring about a capability to intelligently manipulate material structure to achieve better fire performance but would also streamline and optimize material safety certification process (by providing accurate relationships between various test outcomes and, thereby, reducing the need for testing).

To achieve this goal, the FAA, in collaboration with the Fire Protection Engineering Department of the University of Maryland (UMD), has developed a computer-based model, ThermaKin2D. ThermaKin2D is a numerical solver of two-dimensional, transient mass and energy conservation equations. This solver computes the rate of gaseous fuel production (or material burning rate) by a solid of specified initial shape, structure, and composition using fundamental physical and chemical properties of this solid as an input. This model also resolves key features of the surface flame and possesses a capability to simulate a wide range of burning assessment scenarios. The model has been recently demonstrated to predict flame growth dynamics on non-charring plastics such as poly(methyl methacrylate) (PMMA) with the accuracy comparable to reproducibility of actual experiments. Two snapshots of the simulation of upward flame spread including in-depth solid temperature profiles and flame-to-surface heat flux distribution are compared in figure 1 to the corresponding experimental images. The top and bottom images were obtained at 15 and 150 s after igniter application, respectively.

Research continues to improve the ThermaKin2D model. The part of the model that represents the gas phase flame requires further refinement and extensive experiment-based validation. Effective use of this model also requires availability of fast and accurate techniques for the measurement of fundamental material properties. Development of such techniques is a focus of the current and future research efforts of the scientists at the FAA and UMD.

POC: Richard Lyon, ANG-E21 609 485 6076

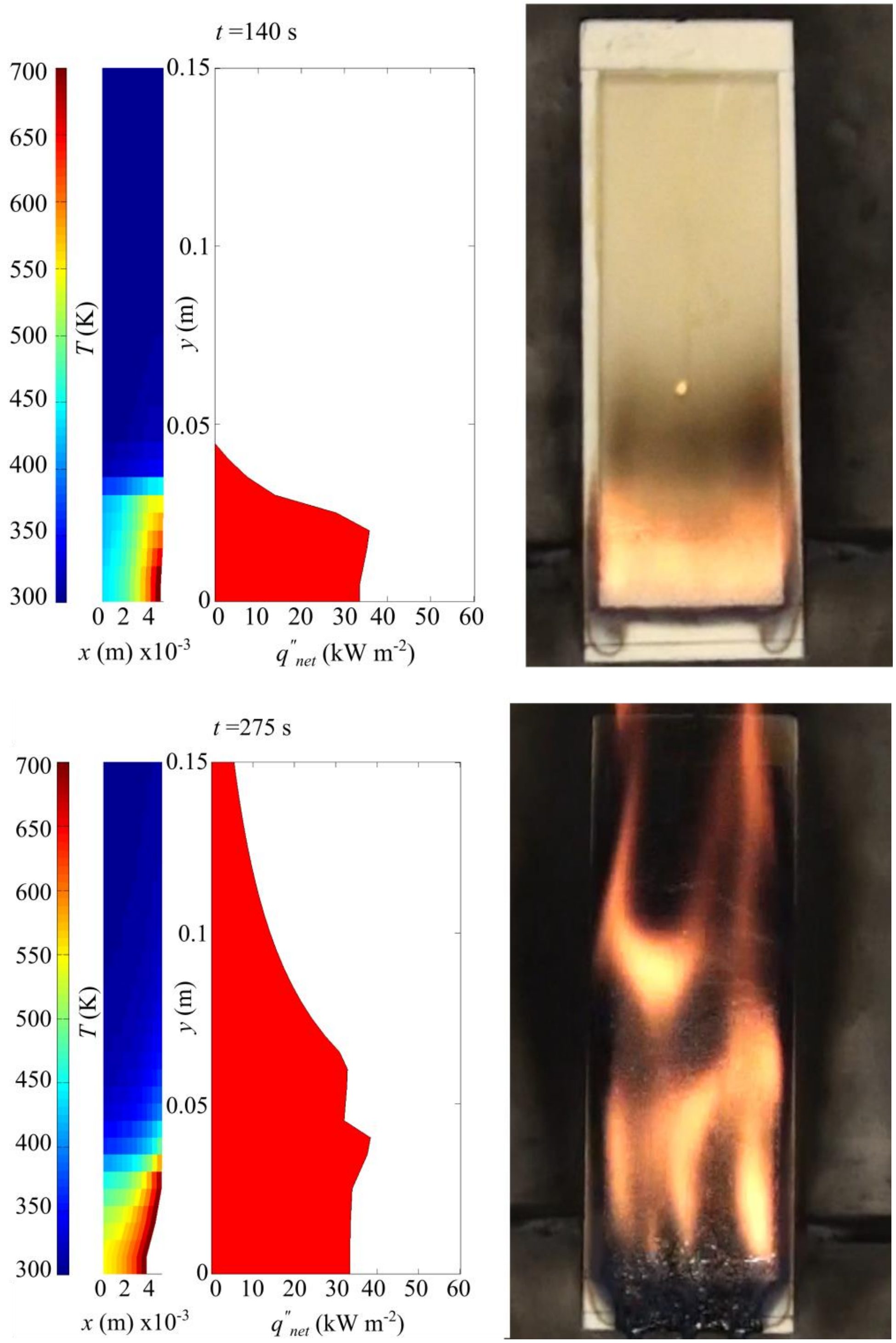

Figure 1. In-depth temperature profile (left) and surface heat flux profile (center) compared to photograph of surface flame for upward flame spread on Plexiglass (right). Top figures obtained at 15 seconds after ignition. Bottom figures obtained at 150 seconds after ignition. The two dimensions are the depth (left) and height (center) of heat transfer from the surface flame.