Low False Alarm Cargo Compartment Fire Detector Prototype

Cargo compartments on commercial aircraft are required to have fire detectors that will alarm within one minute of the start of a fire. The aviation industry currently uses particle sensing smoke detectors to comply with this regulation. These sensors readily detect fires but also alarm to other airborne particles not associated with fires. The ratio of false alarms from existing smoke detectors to the detection of actual cargo fires is on the order of 100 to 1. These false alarms lead to unnecessary flight diversions that are both costly and potentially hazardous.

A test project was completed that developed a series of fire detection alarm algorithms that sensed not only smoke particles but also other combustion products including heat, ionized particles, carbon monoxide (CO) and carbon dioxide (CO_2). The algorithms used various combinations of absolute values of these combustion products as well as rate of change of the values. The algorithms were exposed to a variety of types of fires as well as false alarm sources. One of the alarm algorithms was successful in alarming to all of the test fires in less than one minute and displayed complete immunity to alarming to any of the false alarm sources.

This project demonstrated the potential for multi sensor fire detectors, with an appropriate alarm algorithm, to dramatically reduce the current rate of false alarms without a loss in detection sensitivity. This could lead to a safety improvement by significantly reducing the incidents of aircraft diverting from their intended flight paths due to false alarms from cargo compartment fire detectors. A description of this project is contained in FAA Final Report DOT/FAA/AR-07/58, “Aircraft Cargo Compartment Multisensor Smoke Detection Algorithm Development”.

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Cargo Fire Suppression Effectiveness Of A Halon 1301/Nitrogen Enriched Air Mixture

The Federal Aviation Administration (FAA) Halon Replacement Program continues its investigative efforts to eliminate or reduce the amount of Halon 1301 used in aircraft cargo compartments. In the past, the FAA has tested plain water mist, water mist combined with nitrogen, HFC-125, HFC-227, 2-BTP, and FK5-1-12; water mist combined with nitrogen was the only fire suppression system able to meet the FAA minimum performance standard (MPS) acceptance criteria. Since water mist/nitrogen systems are still under development, the FAA Fire Safety Team has been evaluating transitional techniques to reduce the use of Halon 1301 onboard the aircraft cargo compartment. One such technique is the introduction of nitrogen into the cargo compartment, using the aircraft fuel tank's onboard inert gas generation system (OBIGGS), to replace the fire suppression system metering phase (second discharge stage) of Halon 1301. Therefore, of interest is the effectiveness of a mixture of Halon 1301 (first discharge) and nitrogen from an OBIGGS.

The experiments were conducted in the High Pressure Vessel facility at the FAA WJH Technical Center. This facility had a 402.6 ft3 pressure vessel instrumented with thermocouples, pressure transducers, gas analyzers, and a video camera. In the past, it was determined that the exploding aerosol can simulator test requirement in the MPS was the primary determinant of the potential feasibility of a halon replacement agent. Therefore, the FAA aerosol can explosion simulator was installed inside the pressure vessel to conduct the tests. It contained a mixture of propane, alcohol, and water to simulate the contents of a large commercial aerosol can (i.e., hairspray). A wide range of nitrogen (to reduce the oxygen volumetric concentration) and Halon 1301 mixture concentrations were discharged inside the pressure vessel. After achieving the required oxygen and Halon 1301 concentrations, the aerosol can explosion simulator was activated to attempt to create an explosion. Temperature, pressure, and gas volumetric concentrations were recorded with a 1 Hz and a 1kHz analog to digital data acquisition systems.

This research showed that beneficial effects resulted when Halon 1301 and nitrogen were combined to inert a closed pressure vessel (compartment) against an explosion from an aerosol containing propane, alcohol, and water. Less Halon 1301 was needed to inert a compartment having an oxygen-depleted environment. Explosions were prevented when these two gases were combined at concentrations that were below their individual inert concentrations. For example, an explosion was prevented when the volumetric concentration of Halon 1301 was 1% and the oxygen concentration was 17%. Individually, the required inert concentrations would be about 3% Halon 1301 and 12% oxygen. This means that in a typical aircraft cargo compartment fire protection system configuration, with a dual-stage discharge (high-rate/low-rate discharge), it may be more feasible to replace one of the two Halon 1301 fire bottles because of the availability of a nitrogen generator system. This approach would be particularly attractive in an aircraft with an available onboard inert gas generation system to prevent fuel tank explosions. The system integration could reduce the amount of Halon 1301 from the aircraft cargo compartment fire suppression system by approximately 50% or more.

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FY 2008 Accomplishments

Acute Human Exposure Limits for Gaseous Halocarbon Extinguishing Agents

Effective environmentally-friendly halon replacement agents are available for aircraft hand-held extinguishers. However, the use of these gaseous halocarbon hand extinguishers in the confined space of an aircraft compartment has raised concerns and stymied their use because they can pose cardiotoxic, anesthetic and hypoxic risks to the occupants of that compartment if excessive agent weights are discharged. Yet, it is of the utmost importance that a sufficient number of halocarbon extinguishers of the proper rating are available to extinguish any in-flight fire that is likely to occur.

The report "Safe Acute Exposure Limits for Gaseous Halocarbon Extinguishing Agents in Ventilated Aircraft" DOT/FAA/AR-08/3 was drafted during this period. A methodology was developed for selecting the maximum safe agent weights for halocarbon hand extinguishers of the required fire rating for use in aircraft compartments based on compartment volume, certificated cabin pressure altitude, and ventilation air change time, τ. The resultant guidance is conservative and protects sensitive populations. A perfect stirrer first order kinetic model was developed which provides a simplified method of using existing human physiologically-based pharmacokinetic (PBPK) modeling results for the inhalation of constant halocarbon concentrations to determine the arterial blood intake in a ventilated compartment where the agent concentration is continuously changing. The PBPK data for constant agent concentration exposure was used to determine the first order kinetic rate constants for arterial blood uptake, k_1 and elimination, k_2. In addition, a separate analysis was developed to provide guidance to minimize exposure to low oxygen partial pressures resulting from the discharge of these agents into small unpressurized aircraft compartments.

Arterial concentration histories obtained using first order kinetics provided a good fit to the arterial concentration histories obtained by PBPK modeling for simulated human exposures to constant concentrations of Halon 1301and the replacement agents HFC-227ea and HFC-236fa. Solving the equation for ventilated compartments for these agents eliminated the need to rerun costly, complex PBPK modeling programs. A good fit was not obtained for the replacement agent HCFC-123 and it was necessary for the manufacturer to run the ventilated PBPK model for this agent. The safe agent weight to compartment volume guidance for halocarbons developed in this report is the basis for the safe-use guidance for halocarbon extinguishing agents in the proposed updated FAA Advisory Circular (AC) 20-42D "Hand Fire Extinguishers for use in Aircraft"

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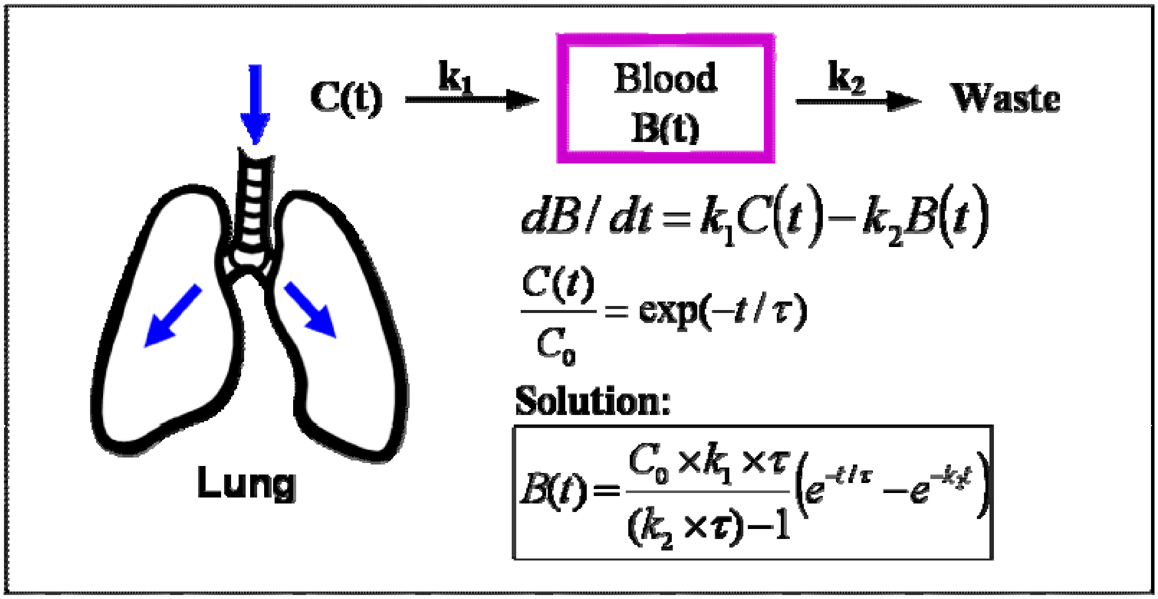

Figure 1. First-order kinetic approach to solve for human arterial concentration histories of halocarbons discharged into a ventilated compartment

EFFECTS OF IN-FLIGHT FIRE EXPOSURE OF ALUMINUM AND COMPOSITE FUSELAGE MATERIALS

Modern civilian transport aircraft are being constructed with increasingly greater portions of the aluminum fuselage being replaced with composite materials. The Boeing 787 is a nearly all composite aircraft. Composite materials consist of layers of fiber material held together with a resin binder. Composite materials have many benefits for the aircraft

manufacturer in terms of fabrication strength and weight savings. However, the performance of these materials under in-flight and post crash fire conditions is essentially unknown. Aircraft have been constructed with aluminum skin and structure for decades. The performance of this material when exposed to an in-flight or post crash fire is well known. Aluminum is essentially non-flammable, conducts heat very well and has a high thermal radiation coefficient. Aluminum also melts at a relatively low temperature. These properties cause the aluminum hull material to behave very differently during an in-flight fire versus a post crash fire. During in-flight fire exposure of the fuselage, the aluminum skin and structure are cooled by the flow of air around the fuselage. This keeps the metal below its melting point and preserves the structural integrity of the aircraft. There has never been a documented case of hull penetration due to in-flight fire in an aluminum aircraft.

A series of tests were performed in the FAA Technical Centers Airflow Induction Facility to determine the relative performance of both aluminum and composite hull materials when exposed to an internal fire while in flight. A test fixture was designed to simulate in-flight airflow over the test panels. The underside of the fixture was fitted with an enclosed box that housed the heat sources. Two heat sources were utilized to expose the underside of the test panel, an electric heater and a live fire. The electric source was used to determine the relative heat conduction properties of each type of material under ground and in-flight conditions The live fire intensity was sized to expose the test panels to a condition that was severe enough to melt through the aluminum panel under ground conditions, but not in-flight. The aluminum and composite test panels were exposed to each of these heat sources under airflows that simulated both ground and in-flight conditions. The heat transfer and conduction properties were measured with both thermocouples and FLIR infrared cameras.

The results from these tests show that there is no significant loss in fuselage structural integrity during an in-flight fire due to the use of composite construction verses aluminum construction. The materials conduct and transmit heat very differently; however the resistance to burn through is similar. The aluminum panels behaved as observed from experience in full scale aircraft fire tests. The aluminum transmits heat in a radial direction very effectively. Aluminum is also very effective at convective transfer of heat to air, more so in a moving air stream. If sufficient heat is applied to overwhelm these characteristics, the panels become plastic and deform when nearing the melting temperature of 1220 DegF. Once this temperature is reached, the metal turns to liquid, leaving a hole in the panel. Burn through under our test conditions occurred in 12-15 minutes. Burn-through is not an issue during in-flight conditions. The air stream is sufficient, even at the relatively low 200 mph in these tests, to cool the top surface of the metal and prevent it from reaching the melting point. This has been demonstrated in real world aircraft fires; burn through occurs on the ground once the relative airflow has stopped. Although omposite panels do not appear to effectively transmit heat in a radial direction, they do transmit heat normal to the surface. The panels are effective at preventing burn through, even though the resin is flammable because they have some insulating effect. Topside temperatures in the static tests were roughly half of the underside temperatures. The fire does damage the exposed face of the panel, burning the resin away and exposing the fiber. Once the outer layer of resin is burned away, however, the exposed fiber material acts like a fire blocking layer, limiting further damage. Burn through did not occur within the time frame of these tests, up to 25 minutes. Airflow over the panel during in-flight conditions is very effective at cooling the top surface of the composite material. The top surface temperature was lowered by more than 200 DegF in a 200 mph airflow. Off gassing from the heated composite panel did produce a flammable mixture in the box resulting in a flash fire. Further work in this area is necessary to determine the magnitude of this hazard and the implications on safety.

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Thermal Acoustic Insulation Burnthrough Resistance Certification and Installation Guidance Material (AC 25.856A)

On September 1, 2003, an important FAA fire safety regulation was adopted pertaining to the flammability of thermal/acoustic insulation used in transport category aircraft. The new regulation established two new flammability test methods that were products of FAA R&D. The first test method measured the resistance of insulation to flame spread from an in-flight fire ignition source and was more realistic and severe than the Bunsen burner test method it replaced. The second test method was a new requirement that measured the ability of insulation to resist penetration, or "burnthrough", from a postcrash external fuel fire. Although the FAA required compliance with the new burnthrough standard in 4 years, industry proposed and was granted a 24-month extension to account for unforeseen test equipment issues that had delayed certification testing. It should be noted that thermal/acoustic insulation is installed very early in the airplane assembly process, so new installations must be implemented well in advance of the actual compliance date, and new designs must be defined well in advance of the installation date. The new compliance date is September 2, 2009.

Although the new burnthrough test method was further developed and refined to maximize its repeatability, many non-test details existed with regard to the installation of insulation blankets in an aircraft. It is important that a blanket meeting the burnthrough requirement be properly installed and attached to the aircraft structure in order to achieve the full benefit of its fire resistance. A highly burnthrough resistant blanket will be of no value in a crash accident if it is easily displaced during the fire due to insufficient attachment hardware. In order to ensure that all of these additional details were properly addressed, an Advisory Circular (AC) was developed (AC 25.856-2). To date, numerous thermal/acoustic insulation materials have been successfully tested, and these materials can be classified into three basic categories: batting systems, barrier systems, and encapsulating systems. The AC described each of the system types, and an appendix listed schematic examples of each. In addition to these examples, the AC focused on specific installation aspects, highlighting key areas that include blanket overlap at frame members, horizontal blanket overlap, penetrations, and types of installation hardware. A detailed test methodology for evaluating the burnthrough resistance of two horizontally overlapped blankets was also included in the AC. The AC also described the appropriate test methodology for evaluating system performance in the event that an alternative approach is desired, including a description of the test apparatus modifications necessary to fully evaluate any unconventional approach.

An updated Advisory Circular, based on the original AC, was published (AC 25.856-2A) on July 29, 2008. In addition to the schematic descriptions detailing the proper installation techniques, a detailed description of the new alternative "sonic" burner is included in this AC. The new "Next Generation" burner was also developed by the FAA, and has distinct advantages over the existing electric-motor-driven burner equipment in terms of output control and repeatability. Although conceptually simple, the new burner equipment requires a fairly robust air compressor as the air source, along with additional heat exchangers and monitoring devices, all of which requires a greater level of description. The new AC contains numerous diagrams and schematics to ensure proper set-up and operation of this equipment. Figure 1 is a schematic representation of the sonic burner test equipment.

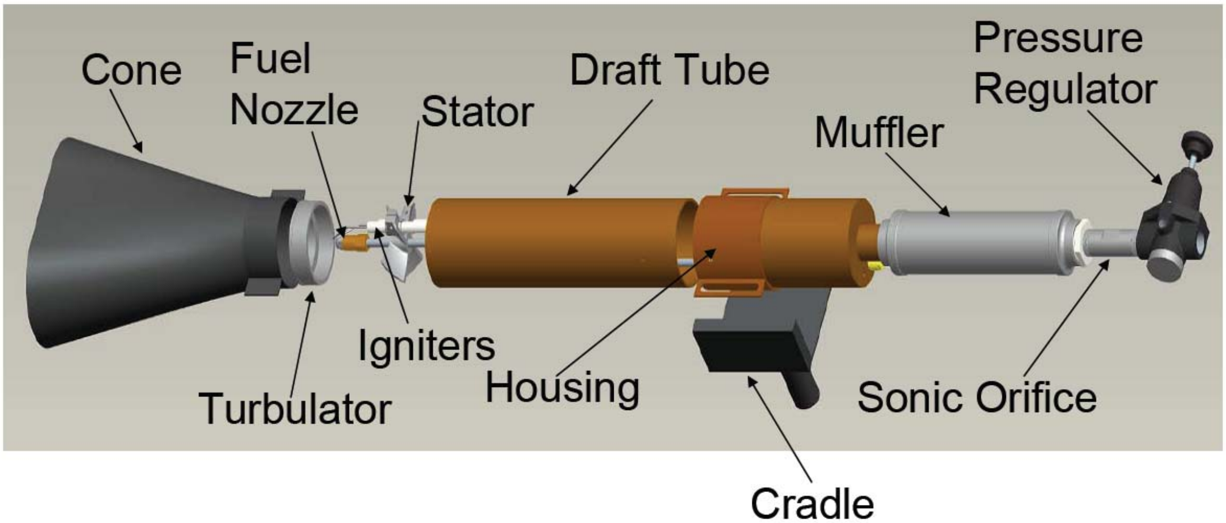

Figure 1

This guidance material is primarily aimed at airframe manufacturers, modifiers, foreign regulatory authorities, and FAA type certification engineers and their designees. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations. An electronic version of the burnthrough AC, 25.856-2A can be found at http://www.airweb.faa.gov/rgl

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Computational Modeling of the Burning Behavior of Cabin Materials

One of the main obstacles to developing ultra fire resistant materials that impart passive fire protection to transport category airplanes is the lack of understanding of the relationships between the bench-scale fire tests used to characterize the material flammability and the development of a full-scale fire.

To address this problem, we have developed a thermal-kinetic numerical model called ThermaKin that simulates the pyrolysis and combustion of aircraft cabin materials in fire situations quickly and easily using only a personal computer. ThermaKin includes transient energy transport, chemical reactions, and mass transport in the calculation of the one-dimensional burning rate of an object. To calibrate ThermaKin we measured the chemical and physical properties of several plastics using laboratory (milligram) scale tests and used only these properties to calculate the burning rates of the plastics in a standard bench-scale fire test (ASTM E 1354). Then we measured the burning rates of the same plastics in the bench-scale fire test and compared the results. Figure 1 shows the calculated mass loss rate and heat release rate of high impact polystyrene (HIPS) as a solid line and the measured values as open circles. The comparison between the calculated and measured values is excellent, showing that ThermaKin captures the complex and coupled processes of flaming combustion without any adjustable parameters.

ThermaKin is the first step in the development of a general fire simulation methodology for aircraft cabins under a broad range of fire conditions. Future research will focus on calibrating ThermaKin for charring and composite materials and extending the simulations to 2-dimensions (flame spread) and 3-dimensions (fire growth in an aircraft cabin and fuselage burn-through). The fire simulation methodology will be calibrated at full-scale and, if successful, will provide a tool to assess the impact of ultra fire resistant materials and material substitutions on the likelihood of an in-flight fire and the severity of a post-crash fire, and will be useful for accident investigation. A description of the model is contained in FAA Report DOT/FAA/AR-TN08/17, “Thermo-Kinetic Model of Burning”.

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Comparison of the mass loss rate (MLR) and heat release rate (HRR) histories obtained from gasification and cone calorimetry experiments (open circles) with ThermaKin predictions (blue lines).