FUTURE TRENDS IN AIRCRAFT FIRE SAFETY R&D

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ABSTRACT

This paper discusses current and future R&D under the Federal Aviation Administration (FAA) Fire Research and Safety Program. The support for and the direction of R&D is influenced by three factors: accidents (and incidents), emerging technology and new aircraft designs. Past R&D products have resulted in mandated fire safety design improvements in the passenger cabin and cargo compartment. The current program is composed of activities related to thermal acoustical insulation, halon replacement extinguishing agents, cargo smoke detectors, fuselage burnthrough resistance and ultra fire resistant materials (long range research). Future research includes activities related to in-flight fire safety, fuel tank protection, on-board nitrogen/oxygen generation, oxygen systems, cabin water spray, hydraulic systems, and fire safety in very large (double-deck) transports and the high speed civil transport (HSCT).

INTRODUCTION

The purpose of this paper is to describe the future direction of R&D conducted under the FAA's Fire Research and Safety Program. The paper will discuss R&D currently under way and future R&D that is planned or proposed over the next 5-10 years. It should be recognized that the fire research and safety program includes both near term and long range research activities. Near term research addresses specific aircraft applications and/or fire problems. The unique fire test facilities housed at the FAA's William J. Hughes Technical Center are utilized to develop fire safety improvements. Individual projects or activities are completed in the near term because of the availability of dedicated facilities and in-house expertise. The products of this research are utilized by FAA certification officials as regulatory or advisory material to improve aircraft fire safety. Over the years the primary application has been the interior of transport aircraft, mainly the cabin and cargo compartments.

Long range, fundamental research related to aircraft fire safety is mandated by the Aviation Safety Research Act of 1988, which directs the FAA Administrator to undertake or supervise research in a number of areas, including the development of "improved fire and smoke resistant materials for aircraft interiors". Currently, the primary emphasis is on the development of ultra-fire resistant interior materials, i.e., cost effective materials that perform significantly better in an aircraft fire than current fire resistant materials.

PAST ACCOMPLISHMENTS

From 1984 to 1991, an unprecedented series of fire safety regulations were adopted by FAA that were primarily products of the Aircraft Systems Fire Safety Program (Sarkos, 1989). At great cost to the aircraft manufacturers and airlines, the regulations were aimed at improving survivability during postcrash fires and preventing uncontrollable in-flight fires. Moreover, since 1991 rulemaking and certification activities related to cargo compartment fire protection and flight recorder postcrash fire survivability were supported by the fire safety program. A summary of the improvements specifically attributed to or supported by the fire safety program follows.

Postcrash Fire

Seat Cushion Fire Blocking Layers. This rule requires that seat cushions meet a severe flammability test that simulates a postcrash fire. The standard reduces the burning rate and involvement of the flammable (albeit fire retardant) urethane foam during a severe cabin fire. Most US airlines encapsulate the urethane foam with a highly fire resistant fire blocking layer material.

Low Heat/Smoke Release Panels. This rule requires that large surface area panels (sidewalls, ceiling, stowage bins and partitions) meet a stringent heat release test. Airframe manufacturers were required to develop new material designs in order to gain compliance with the standard. In this sense, the standard was considered to be a technology driver.

Floor Proximity Lighting. This rule requires that airplane emergency lighting systems provide escape path (aisle) definition and identify each exit when smoke accumulates in the upper cabin and obscures overhead lights.

Radiant Heat Resistant Slides. This revised Technical Standard Order (TSO) includes a new test requirement that measures the heat resistance of pressurized slide material. Evacuation slides constructed of reflective materials compliant with this test remain inflated much longer when subjected to fuel fire radiative heating during an emergency evacuation.

Flight Recorder Thermal Protection. This revised TSO includes more stringent thermal protection test criteria. The intense fuel fire test exposure duration was doubled. Also, a low temperature, long duration test requirement was added that represents exposure to a smoldering fire comprised of accident debris (Curran, 1993)

In-Flight Fire

Halon 1211 Extinguishers. This rule requires at least two Halon 1211 hand-held extinguishers in every transport airplane. The requirement was based on the demonstrated superior fire knockdown capabilities and low toxicity of Halon 1211.

Burnthrough Resistant Cargo Liners. This rule requires a severe burnthrough test for ceiling and sidewall cargo liners in inaccessible cargo compartments. Cargo liners compliant with this test will prevent cargo/baggage fires from spreading outside the cargo compartment, maintaining flight control and protecting passengers and crewmembers.

Cargo Compartment Fire Protection. This rule requires the retrofit of approximately 75% of U.S. commercial transport aircraft with cargo compartment fire detection and suppression systems (FAA, 1998). A major consideration in the issuance of this rule was the potential explosive hazards of aerosol cans carried in passenger luggage and the demonstrated effectiveness of halon fire suppression in controlling cargo fires involving aerosol cans (Marker, 1998).

Combi Aircraft Fire Protection. This airworthiness directive (AD) ensures adequate fire protection in "combi" aircraft, or aircraft containing both passenger and cargo compartments on the main deck (FAA, 1993). Previous requirements relied primarily upon accessibility to the cargo compartment and firefighting by crewmembers. The AD contains provisions based on full-scale fire tests (Blake, 1996).

Blanket Flammability. This new flammability test method measures the ignition resistance of airline blankets subjected to a small source (Cahill, 1996)

R&D DRIVERS

The direction and level of support for fire safety R&D is influenced by a number of factors, most notably accident experience. Additional factors include emerging technology and fire safety considerations in future aircraft. Also, past regulatory activities/interior design changes alter the perception of the need for R&D and impact cost/benefit computations.

The greatest determinant is, understandably, recent accident experience. In times of budget constraint, scarce resources are often devoted to R&D programs addressing a problem area punctuated by recent accident experience. Three recent catastrophic accidents, involving in-flight fire or explosion (ValuJet, May 1996; TWA 800, July 1996; and Swiss Air, September 1998), accounting for 589 fatalities, have heightened interest in aircraft fire safety R&D. Also, fire safety R&D is also driven by the possibility of a bad accident with a large number of fire fatalities, which is a major concern in future, high capacity double-decked transports.

Research may be undertaken to simply advance the state-of-the-art of aircraft fire safety. Because the motivating factor is often new or emerging technology and not accident/incident history, cost effectiveness and practicality are important considerations in selecting this type of R&D. The goal is to make aircraft as fire-safe as is technologically possible.

Another factor which has an important bearing on the fire safety program is past regulatory activity that has lead to the installation of a number of fire safety improvements in the US fleet, as discussed earlier (Sarkos, 1989). For example, 650,000 seats were protected with fire blocking layers at a cost of $75 million to US airlines. The airlines and airframe manufacturers have also invested several $100 million in low heat/smoke release panels. More recently, it is estimated that retrofit of the fleet with cargo compartment fire detection and suppression systems will cost the airlines and manufacturers $300 million. Thus, using these examples, it is clear that the aviation industry has made a significant financial investment toward the improvement of aircraft fire safety; therefore, the cost/benefit ratio of potential new fire safety improvements (e.g., cabin water spray) becomes exceedingly large (unfavorable) when factoring in the effect of calculated lower fire fatalities due to the benefit of past improvements.

Fire Safety considerations in new aircraft designs, including the Very Large Commercial Transport (VLCT) and High Speed Civil Transport (HSCT), will be addressed in future R&D under the fire safety program. The vulnerability of the upper deck in the VLCT and the impact on postcrash survivability is a major concern. Industry and government officials appear in agreement that carrying 800 - 1000 passengers, the VLCT must be designed to higher fire safety standards than contemporary airliners (Aviation Week and Space Technology, 1994). This attitude is not unprecedented. Tougher fire safety and emergency evacuation design criteria were imposed on the wide body jets when they were introduced into service in the early 1970's. With respect to the supersonic HSCT, the possibility of a composite fuselage skin raises a general question. Will the replacement of the non-combustible aluminum skin with an organic composite material impact HSCT postcrash fire survivability? Elevated skin temperatures on the fuselage and wings is a major concern, particulary as it relates to fuel volatility.

FUTURE FIRE SAFETY R&D

It is useful to partition the discussion of future fire safety R&D in terms of three major areas - Materials, Fire Management and Systems. Materials consist of the development of improved or new fire test methods and criteria for aircraft materials. Fire Management refers to rapid and reliable detection of aircraft fires and effective fire extinguishment or suppression. Systems addresses the need for the protection of vital aircraft systems from the effects of fire or preventing malfunction of these systems from causing or accelerating the spread of a fire.

Materials

There is general agreement that significant gains in postcrash fire survivability were achieved by seat cushion fire blocking layers and low heat/smoke release panels. Seat cushions, particularly urethane foam, and large surface area panels (sidewalls, ceiling, stowage bins and partitions) are clearly the most important interior material categories with respect to the generation of postcrash cabin fire hazards. The FAA standards mandating these material upgrades were developed for a cabin fire scenario consisting of an external fuel fire adjacent to a fuselage opening; i.e., interior materials are directly exposed to the fuel fire. Further improvements in postcrash fire safety would be expected to be minimal from additional small incremental gains in seat cushion or panel fire test performance. At this time, in terms of postcrash cabin fire material performance, FAA R&D consists of near term improvements in fuselage burnthrough resistance and long range research aimed at the development of ultra-fire resistant (practically fire proof) interior materials.

Fuselage Burnthrough. In survivable postcrash fire accidents, the fuselage may remain intact and the cabin is ignited by the external fuel fire burning through the fuselage shell. The most catastrophic example of this type of postcrash fire scenario was the 737 accident in

Manchester, England (Aircraft Accidents Investigation Branch, 1988). Investigators concluded that the fuel fire penetrated the fuselage in approximately 60 seconds. Although there was no impact trauma, 55 people died from the effects of the cabin fire. The Air Accidents Investigation Branch recommended "increased effort directed towards fire hardening of the hull, the limitation of fire transmission through the structure" ....leading to "fire criteria should form a part of international airworthiness requirements". FAA has conducted full-scale fire tests to determine the mechanism and time framework for fuselage burnthrough (Webster, 1994). It appears that the lower quadrant or cheek area is most vulnerable to burnthrough due at least to the lesser thickness of thermal insulation in this area. Fire and smoke penetration into the cabin is initially via air return grilles and sidewall panel edging. FAA has a cooperative program with the U.K. Civil Aviation Authority to evaluate new materials and concepts for hardening a fuselage against burnthrough. To date this research had focused on the thermal acoustical insulation. Full-scale tests have identified replacement materials or fire barriers for the current fiberglas insulation which prevent fuel fire penetration for more than 5 minutes (the aluminum skin and fiberglas insulation currently fail in 1.5-2 minutes) (Marker and Sarkos, 1997). In order to ensure burnthrough protection, it is critical that the insulation blankets completely cover the fuselage skin and structure and that they remain in place during fire exposure. Currently, a small-scale fire test is being developed to evaluate the burnthrough resistance of insulation materials and the effectiveness of fasteners or methods of attachment. Although the cheek area appears most vulnerable to burnthrough, the cabin windows could provide an entry point under some scenarios. Research is also needed to develop a burnthrough resistant cabin window system.

The planned use of composite material for the fuselage skin in the high speed civil transport (HSCT) is another concern. Conventional aluminum skin conducts heat away and melts rather quickly when exposed to a fuel fire, whereas a composite skin will char and probably be an effective fire barrier. The concern is whether pyrolysis products in the form of smoke and toxic/combustible gases percolate through the composite, creating hazardous conditions within the cabin. This issue needs to be addressed during the early stage of the HSCT design.

Fire Resistant Materials. The objective of the FAA long range fire resistant materials program is "to discover the fundamental relationship between the composition and structure of materials and their behavior in fires to enable the design of a totally fire resistant cabin for future commercial aircraft. Research will be basic in nature and will focus on synthesis, characterization, modeling, and processing of new materials and materials combinations to improve the fire performance, increase the functionality, and reduce the cost of next-generation cabin materials" (Lyon, 1994). FAA performance guidelines for ultra fire resistant aircraft materials set stringent criteria and lofty goals; e.g., reduction in heat release measured by regulatory test criteria of 50% and 100% for near term and long term, respectively. Considerable progress has been made over the past two years in the development of new polymers for use in aircraft as composites, molded thermoplastics, elastomers and fibers, modeling of polymer thermal degradation and the development of a microcalorimeter for screening of laboratory samples available in only milligram quantities (Lyon, 1997).

The types of in-flight fire that can become a problem are those that originate in hidden or inaccessible areas. Upgraded seat cushion and panel fire test standards to enhance postcrash fire survivability were not developed to address the hidden in-flight fire scenario. Hidden fires involve materials such as thermal acoustical insulation, and wiring and cable, installed behind the cabin sidewall, above the ceiling and beneath the floor.

Thermal Acoustical Insulation. Aircraft thermal acoustical insulation batting usually consists of fiberglas bagged inside a thermoplastic film. Polyester and polyvinylfluoride are the predominatingly used bagging materials, although polyimide was used in the L1011. From 1993-1995, fire service incidents have occurred with flame propagation across the former types of batting films. This prompted the creation of an FAA-industry task group to examine the adequacy of the current Bunsen burner test requirement and the suitability of an industry test called the "cotton swab" test (Cahill, 1997). Results from tests by eight laboratories indicated considerable variability with the Bunsen burner test. In particular, a metalized polyester film previously used by one aircraft manufacturer failed in some laboratory tests, depending on how the test was conducted. The "cotton swab" test indicated that the metalized polyester was flammable and, generally, produced more consistent test results. However, the "cotton swab" test failed to identify two other flammable insulation materials. Moreover, during full-scale burnthrough tests, flame propagation observed in tests with polyvinylfluoride film did not occur when polimide film was tested. Work is underway to determine the relative performance of a full range of thermal acoustical insulation batting materials against an in-flight fire challenge and to develop an improved laboratory fire test method for thermal acoustical insulation. The test method will evaluate both burnthrough resistance and flame spread.

Contamination is a part of the problem. Past full-scale tests have shown that thermal acoustical insulation, when it is new and uncontaminated, will not propagate a fire initiated by a small ignition source (Blake, 1991). However, a number of hidden fires have occurred in-flight or on the ground which, in some cases, have gutted the aircraft. Investigations of these fires have revealed extensive contamination in hidden areas, for example, thick greasy dust on cable, stained insulation batt, grease, etc. Work is needed to address the contamination problem in hidden areas.

Aircraft Wiring. Most aircraft in-flight fires are electrical in nature and are usually controlled before having any effect on flight safety. At present, the only standard for aircraft wiring is a Bunsen burner flammability test. However, arc tracking failures have occurred in civilian and military aircraft. Also, electrical fires may cause high cockpit smoke levels; yet wiring selection in civil transports is not based on smoke emission. Finally, electrical faults from frayed wires have occurred in service because of failed or improper securing of wiring and cable. Therefore, more comprehensive test methods may be required for electrical wiring as well as improved methods for securing and protecting cable and wiring. Another aspect of the problem that needs to be investigated is the effects of aging or time in service.

Fire Management

Although more fireworthy interior materials have improved aircraft fire safety, risk of fire is also posed by other contents of the airplane. These include fuel, freight and luggage in the cargo compartments, passenger carry-ons, hydraulic fluid, and emergency oxygen systems. Fire management employs active systems to counter these potential fire hazards.

Halon Replacement Guidelines. For the past 35 years, the agent of choice in aircraft fire extinguishing systems has been Halon 1301. Unfortunately, on December 31, 1993, the manufacture of halons ceased by international agreement because of their contribution to the depletion of the ozone layer. The uncertain future availability of halons for aircraft fire extinguishment systems is being addressed by the FAA's fire safety R&D program. A description of the halon replacement project is contained in the Public Notice published in the Federal Register (FAA, 1993b). The FAA has been working closely with the aviation industry to evaluate promising new agents under full-scale fire test conditions and to develop the basis for demonstrating equivalent fire protection with halon for aircraft applications; viz., cargo compartments, engine nacelles, hand-held extinguishers and lavatory trash receptacles. To date, a minimum performance standard has been developed for lavatory trash receptacles (Marker, 1997). Performance standards for cargo compartments, engine nacelles and hand-held extinguishers are scheduled for completion in 1999.

Cabin Water Spray. An approach for increasing postcrash fire survivability against all fire sources, including burning jet fuel, is an on-board water spray system. FAA worked with CAA and Transport Canada to test and develop a cabin water spray system. The initial system tested, developed in England by a company named SAVE, continually sprayed water throughout the cabin for about 3 minutes. In numerous full-scale fire tests employing wide body, standard body and commuter aircraft test articles, and over a range of fire scenarios it was shown that water spray increased survival time by 2-3 minutes for all but the most unusually severe fire condition. Moreover, a zoned system was developed and optimized that actually provided more protection than the original system, but only used 10% of the water (Sarkos, et al., 1995). Poor cost-effectiveness of water spray, due largely to the relatively small number of postcrash fire fatalities in recent years, made it unacceptable for service consideration. FAA is now evaluating the effectiveness of water spray against cargo fires, as a halon alternative and as a possible means of offsetting the weight penalty of the cabin water spray system. Cabin water spray may also be evaluated for future aircraft designs, such as the Very Large Commercial Transport (VLCT), where the cost/benefit may be more favorable.

Fire Detection. Reliable and rapid detection of fire and smoke is critical to the effectiveness of intervention systems and procedures. Although FAR 25.858 states a cargo compartment fire detection system "must provide a visual indication to the flight crew within one minute after the start of a fire", there are currently no standardized test procedures to demonstrate compliance with this rule. It is possible that the responsiveness to realistic fires varies for different FAA-approved smoke detection systems. For example, past FAA fire tests demonstrated that artificial smoke, used to certify smoke detectors, indicated a more rapid response time than real smoke in detector systems employing vacuum sampling lines (Blake 1985). Also, manufacturers and airlines may be reluctant to propose new detector designs for

FAA approval because of the absence of approval standards. Thus, a project was initiated in 1998 to develop a standardized test procedures for the certification of aircraft smoke detectors.

Another concern with cargo compartment smoke detectors is the high incidence of false alarms. An analysis of Service Difficulty Reports by the Airline Pilots Association indicates that there are 190 false alarms for every real fire detection (Phillips, 1998). This raises safety concerns since pilots may make emergency landings at unfamiliar airports, perhaps with less than optimal firefighting equipment. Also, frequent false alarms may cause pilots to question the validity of an alarm indication in the flight deck, although there is no evidence that this has happened (Phillips, 1998). Since similar problems exist with residential and industrial fire detectors, in recent years detector manufacturers have developed and introduced new detector designs aimed at reducing (or eliminating) false alarms. Basically, the dectors incorporate multiple sensors with computerized analysis of signals to differentiate between real and false alarms. FAA has initiated a test program to characterize real cargo fires. By working with the National Aeronautics and Space Administration (NASA) and the National Institute of Standards and Technology (NIST), the aim is to also understand what conditions cause false alarms in order to guide the development of new aircraft detectors.

Lavatory Fire Protection. Lavatories have been the source of several fatal in-flight fires (Varig, 1973; Air Canada, 1983), accounting for 146 fire fatalities. These accidents were the impetus for important improvements in lavatory fire protection, such as a cigarette smoking ban, fire hardening of trash receptacles, halon extinguishers ("potty bottles") and smoke detectors. Nevertheless, serious lavatory fires continue to occur. In 1993, an in-flight fire in the aft lavatory of a Domincana 727 forced an emergency landing. All occupants escaped but the fire spread out of control and destroyed the aircraft. The accident highlighted deficiencies in crew procedures in locating and extinguishing an in-flight fire; e.g., hand-held extinguishers were readied but never discharged. In 1995, an International Airlines DC-9 was gutted by fire while parked at a ramp in Barranquilla, Columbia. Investigators noted similarities between this unattended ramp fire and the Air Canada in-flight fire in 1983. These fires raise concerns about the adequacy of lavatory fire protection. The presence of potential ignition sources such as flushing motors, hot water heaters, lighting ballasts, and razor outlets, reported instances of improper passenger activity (detector tampering, smoking, etc.), and certain design features, such as high ventilation rates that may circumvent early fire detection, all point to the need for R&D to enhance fire protection design and crew firefighting procedures in aircraft lavatories.

Very Large Commercial Transport. The vulnerability of the upper deck to postcrash fire in future double-decked aircraft carrying 800-1000 passengers such as the VLCT is a major concern of aircraft manufacturers and regulatory authorities. The anticipated difficulty of exercising an emergency evacuation from high elevations would become even more life threatening if a chimney-like effect created an unusually hazardous fire on the upper deck. Enhanced fire protection of the VLCT upper deck would tentatively encompass a number of R&D activities.

A primary concern is the development of in-flight fires in hidden areas. Tougher fire test standards are required for thermal acoustical insulation, which may need to be supplemented with fire stops to limit upward flame spread. What, if any, measures need to be taken to prevent fire spread via open stairway or elevators needs to be determined. Another concern is the protection of the upper deck floor from the effects of a fire below. This includes the strength of flooring and floor beams to prevent floor collapse as well as the flammability of covering materials. The large quantities of stored oxygen for passengers and crewmembers needs to be addressed in order to minimize the likelihood of fires caused or intensified by oxygen system malfunction or failure. Finally, a cabin water spray – a technology which has been shown by full-scale fire tests to significantly improve postcrash fire survivability – may prove to be cost-effective for high passenger capacity aircraft.

Systems

The objective of the systems area of the fire safety program is to minimize or eliminate fire hazards associated with aircraft systems. Past accidents and full-scale tests indicate that improvements in oxygen and hydraulic systems and fuel tank protection could improve both postcrash and in-flight fire safety.

Oxygen Systems. There is an abundance of "pure" oxygen carried on-board commercial airliners. Oxygen systems include oxygen for use in the event of depressurization, oxygen for the flight deck crew, medical oxygen, and crew protective breathing devices for in-flight fire. Preventing fires caused by oxygen system malfunctions during servicing and maintenance will eliminate a significant number of hull losses alone. For example, inadvertent activation of an oxygen mask canister caused a fire that gutted a DC-10 in Chicago 1n 1986. Also, in Salt Lake City in 1989, replacement of an oxygen bottle during preboarding of a 727 caused an extremely intense fire that rapidly spread throughout the cabin. Fortunately, there were only a few occupants on board at the time and they were barely able to escape the fire that reached untenable conditions in an estimated 45 seconds. Also, in New Delhi in 1991, deployment of the passenger oxygen system during a maintenance check in a 737 caused an oxygen-fed fire in the vicinity of the pressure controller (Hill, 1994). The potential large loss of life due to an in-flight fire caused by oxygen system malfunction, similar to the above examples which occurred on the ground, or by a postcrash fire intensified by the release of oxygen is a great concern. NTSB concluded that the ValuJet accident (1996, 110 fatalities), was caused by improperly shipped oxygen canisters in the cargo compartment. Many of the 20 postcrash fire fatalities in the 737 accident at Los Angeles in 1991 may be attributed to the severed crew emergency oxygen system. FAA full-scale fire tests demonstrated a 3 minute loss of survival time due to the release of oxygen into the postcrash fire (Marker and Downie, 1991). In the near term, methods of reducing the quantity of oxygen accidentally released should be explored; e.g., flow restrictors, fuses or solid oxygen generators. The ultimate answer may be an oxygen generation system utilizing gas separation membrane technology, which would probably require a long term R&D program (see below).

Fuel Tank Protection. Although not yet able to identify the on-board ignition source, the NTSB has determined that the cause of the TWA 800 accident (1996, 240 fatalities) was a center wing tank explosion. Regulatory requirements for fuel tank explosion prevention have focused primarily, but not entirely, on the elimination of ignition sources below a minimum energy threshold for fuel vapor ignition. Additionally, FAA's goal now is to eliminate flammable jet fuel vapors from aircraft fuel tanks. In early 1998, FAA commissioned the Fuel Tank Harmonization Working Group, under the auspices of the Aviation Rulemaking Advisory Committee, to recommend new regulations related to fuel tank explosion protection, particularly with regard to the elimination of flammable fuel vapors. The working group analyzed numerous explosion protection concepts and systems over a relatively short time period allocated to do its work (Aviation Rulemaking Advisory Committee, 1998). Generally, all on-board systems and concepts were determined to be impractical and/or very poor in terms of cost/benefit, although research to develop <u>practical</u> on-board systems was recommended. It was also concluded that the most cost-effective system by far was a ground-based inerting system.

To examine ground-based inerting, near-term research is needed to more accurately compute costs than the working group was able to do over a short time frame. Moreover, sensitivity of costs to various conditions, for example, the minimum air temperature required to initiate ground inerting, type of aircraft or fuel tank (center wing tank only ?), etc., needs to be determined. The additional benefit of providing protection against ground fire explosions must also be examined and quantified. Also, it would be very useful in terms of feasibility and costs to design, install, evaluate and refine the fuel tank plumbing associated with a ground-based system, preferably in a contemporary airliner. The final product would be more accurate analysis of the cost-benefit and feasibility of ground-based inerting of aircraft fuel tanks.

Longer range research is needed related to the prediction (or better understanding) of flammable fuel tank vapor hazards and the development of an on-board fuel tank inerting system. The former would include, for example, the effect of fuel pump fuel sprays on the fuel vapor explosion envelope, or the transient creation/elimination of flammable fuel vapors in the ullage during heating/cooling of liquid fuel. The latter would focus on on-board generation of nitrogen, as discussed below.

<u>Onboard Nitrogen/Oxygen Generation</u>. The last 15 years have lead to major advances in the technology of gas separation membranes. Polymer systems have been designed and developed that permit manufacture of efficient and compact membrane devices that can separate an incoming air stream into two existing streams with the composition of one of them being a nitrogen enriched air mixture that is approximately 95 percent nitrogen and 5 percent oxygen. These devices are in use in trucks and ships to blanket fresh fruits and vegetables for extended service life. The devices are also in production for fuel tank inerting of a limited member of military aircraft.

The aircraft nomenclature for these systems include on-board inert gas generating systems (OBIGGS) and on-board oxygen generating systems (OBOGS). In commercial aircraft, both would be new technology applications. An OBIGGS installation would have two potential inerting applications. The first is a fuel tank inerting in contemporary commercial transports as well as HSCT. The second is cargo compartment inerting after a fire is knocked down by a separate system. On OBOGS installation, if it had the capacity for continuous on-demand supply for aircraft passengers, would eliminate fire hazards posed by current systems employing bottle oxygen or solid oxygen generating canisters. At this time, NASA has committed funding to work with the FAA to at least initially examine the feasibility (and later develop if feasible) an on-board OBIGGS/OBOGS system that would develop both nitrogen for inerting and oxygen for emergencies, in both cases, on an <u>on-demand</u> basis; i.e., without storage tanks as is done in some military aircraft.

<u>Hydraulic Systems</u>. Aircraft hydraulic fluid has been the source of both in-flight and postcrash fires. In 1989 a 737 experienced a hydraulic fluid fire in the wheel well that resulted in an emergency landing and evacuation. Although there were no fatalities, the ingredients of a catastrophic accident were present; i.e., the fire caused loss of hydraulic pressure and breaking action, causing the airplane to overrun the end of the runway. FAA tests showed that hydraulic fluid spray contained in a enclosure such as a wheel well, may burn intensely if ignited (Blake, 1990). In 1980, a 747 experienced a crash fire following a hard landing that caused sparking ignition of hydraulic fluid released by damaged struts. Fifteen people died from the postcrash fire in which there was no jet fuel spillage. There is sometimes a misconception that fire resistant aviation hydraulic fluid is noncombustible, but this is obviously not the case. R&D is required to determine what improvements are feasible to prevent or minimize hydraulic fluid fires.

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