FEDERAL AVIATION ADMINISTRATION

REPORT ON
SYSTEMS AND TECHNIQUES FOR REDUCING THE INCIDENCE OF
POST-CRASH FUEL SYSTEM FIRES AND EXPLOSIONS

LIST OF FIGURES

GLOSSARY OF TERMS

Crash-Resistant Fuel Tank - a fuel tank that has the capability to retain fuel during an impact-survivable accident.

Breakaway, Self-Closing Fitting - a fitting (valve) at a fuel tank outlet or in a fuel line that will separate at a predetermined load and seal at both ends to minimize fuel spillage upon separation.

Engine Ignition Suppression System - a system that is designed to either: (1) surround engine hot surfaces with an inert atmosphere which will not support combustion when fuel contacts the hot surfaces, (2) provide a high-discharge-rate liquid spray for rapid cooling of hot surfaces to temperatures below fuel ignition temperature, (3) release inert gas into the engine air intake to extinguish combustor flames, or (4) provide for rapid fuel shutoff and draining of the fuel manifold to extinguish combustor flames.

Fuel Tank Nitrogen Inerting System - a system that purges the fuel and vapor space above the fuel with nitrogen to reduce the oxygen concentration in the vapor space below combustibility limits.

Fuel Tank Foam Filler Explosion Suppression System - a system in which a reticulated polymeric foam is installed in a fuel tank and acts to extinguish a fire generated within the tank and suppress the development of an explosion.

Fuel Tank Chemical Agent Explosion Suppression System - a system in which infrared or ultraviolet light detectors are installed to sense the flame of an incipient explosion and discharge a fire extinguishing agent to quench the fire and suppress the development of an explosion.

Anti-Misting Kerosene - aviation kerosene fuel with a high molecular weight polymeric additive which acts to physcially bind the fuel as it is sheared in an airstream to form a coarse spray of large droplets through which flames could not propagate.

Fuel Vent Flame Arrestor - a stainless steel web of quenching cells or channels installed in a fuel vent tube which absorbs the heat from a flame front entering the fuel vent at a rate exceeding the rate of heat generation and prevents flame penetration and propagation through the vent system.

Surge Tank Chemical Agent Explosion Suppression System - a system which includes a detector in the vent outlet tube to sense an oncoming flame front and discharge a fire extinguishing agent in the surge tank to quench the fire when it reaches the tank and suppress the development of an explosion.

Section I. INTRODUCTION

The Airport and Airway Safety and Capacity Expansion Act of 1987, Public Law (P.L.) 100-223 was signed by President Reagan on December 30, 1987, and directed the Secretary of Transportation, in Section 303, subsection (e), to conduct a study pertaining to aircraft design and equipment which minimize the incidence of fire or explosion, including fuel tanks (including crash-resistant inner fuel tanks and breakaway, self-closing fittings throughout the fuel system). A report on the results of this study, together with recommendations, is to be transmitted to Congress no later than December 30, 1988.

This report describes the study conducted by the Federal Aviation Administration (FAA) for the Secretary of Transportation in response to P.L. 100-223. The focus of the study is on systems and techniques for reducing the incidence of post-crash fuel system fires and explosions. The study does not address inflight fires and explosions. This is in accordance with the intent of Congress as expressed by Senator Howard M. Metzenbaum in his letter of December 11, 1987, to Mr. T. Allan McArtor, Administrator of the FAA. In his letter, Senator Metzenbaum stated that "...the legislation as agreed to in conference directs the FAA to study possible aircraft designs, including crash-resistant fuel tanks and break-away fuel lines, which could help...to reduce the risk of post-crash fires." Senator Metzenbaum repeated this intent of Congress in his comments published in the Congressional Record of December 17, 1987, wherein he said that "...the conferees agreed to have the FAA study the feasibility of using technologies such as crash-resistant fuel tanks and break-away fuel lines to reduce the incidence of post-crash fires."

The study covers the feasibility of fuel system post-crash fire safety improvements for transport category airplanes, general aviation airplanes, rotorcraft and tiltrotor aircraft. Past and present regulatory initiatives and research and development programs are described and conclusions and recommendations are presented for each type of aircraft.

Section II. TRANSPORT CATEGORY AIRPLANES

A. Background

The following techniques and systems to reduce the post-crash fire/explosion hazard have been suggested for consideration in transport category airplanes:

- Crash-Resistant Fuel Tanks and Breakaway, Self-Closing Fittings
- Engine Ignition Suppression System
- Fuel Tank Nitrogen Inerting System
- Fuel Tank Foam Filler Explosion Suppression System
- Fuel Tank Chemical Agent Explosion Suppression System
- Anti-Misting Kerosene (AMK)
- Fuel Vent Flame Arrestor
- Surge Tank Chemical Agent Explosion Suppression System
- Design to Assure Fuel Tank-to-Engine Shutoff Valve Activation
- Fire-Resistant Fuel Tank Access Panels
- Revised Location of Fuel Tanks and Engines

All of these techniques and systems, with the exception of mandating the location of fuel tanks and engines, have been or are currently being considered in rulemaking by the FAA. Initial consideration of rulemaking with respect to crash-resistant fuel tanks, self-closing breakaway fittings, and engine ignition suppression was reflected in Advance Notice of Proposed Rule Making (ANPRM) No. 64-12 which was issued on February 27, 1964 to solicit the views of all interested persons on the practicability and availability of these various techniques. The FAA concluded after consideration of comments submitted in response to Notice No. 64-12 that technical information was not available at that time to provide a sufficient basis on which to develop regulatory standards. Notice No. 64-12 was withdrawn on July 30, 1965.

The FAA, subsequently, extended it's fuel system fire safety program to include consideration of means to prevent fires and explosion within the fuel tank and the tank vapor and vent spaces. Based on information developed by FAA-sponsored government-industry conferences on fuel system fire safety in December 1967 and August 1970, and an FAA-industry advisory committee that was established in 1968, it was concluded that three systems are capable of preventing fuel tank and vent system fires and explosions arising from ignition within the fuel system. These are the fuel tank nitrogen inerting, foam filler, and chemical agent explosion suppression systems.

A prototype nitrogen inerting system was certificated and installed in a DC-9 airplane operated by the FAA in 1971. Nitrogen inerting systems are installed in all Air Force C-5 transport airplanes. Foam filler explosion suppression systems are installed in a variety of military airplanes. Chemical agent explosion suppression systems are installed in the surge tanks of several civil transport airplanes. Although these systems are not intended to provide protection against the post-crash external spilled fuel fire hazard, it was believed that these inflight explosion prevention systems might be effective in controlling the post-crash hazard caused by an internal ignition source.

On November 12, 1971, the National Transportation Safety Board issued Recommendation No. A-71-59 which recommended that the FAA initiate action to require "fuel system fire safety devices which will be effective in the prevention and control of both in-flight and post-crash fuel system fires and explosions." The Aviation Consumer Action Project petitioned on September 28, 1972 requesting rulemaking to require nitrogen fuel tank inerting systems on all transport category airplanes. Based on the feasibility of the three explosion prevention systems and in response to the NTSB recommendation and ACAP petition, the FAA issued Notice of Proposed Rulemaking (NPRM) No. 74-16 on March 27, 1974 to propose amendment of Part 25 of the Federal Aviation Regulations to require an explosion prevention system for each fuel tank and fuel vapor and vent space of turbine engine powered transport category airplanes. The majority of comments received opposed this proposal because it was argued that the explosion prevention systems would have little or no effect in reducing the fire and explosion hazards of impact-survivable accidents when a fuel tank is ruptured. In view of these comments, the FAA concluded that a public hearing should be held to obtain information needed to determine whether a requirement should be developed to reduce the fire and explosion hazards of both in-flight and impact-survivable accidents.

The public hearing was held on June 13-16, 1977, and provided additional information which confirmed that the fuel tank nitrogen inerting, foam filler, and explosion suppression systems cited in NPRM 74-16 can prevent internal fires and explosions in undamaged fuel systems, but cannot prevent external fires caused by ignition of fuel released from damaged fuel tanks under post-crash conditions. It was suggested that anti-misting kerosene might reduce the post-crash fire hazard due to fuel spillage from damaged tanks. It was also concluded in the public hearing that application of military crash-resistant fuel system technology for the wing tanks of transport airplanes would result in significant weight and volume penalties. In addition, crash-resistant fuel tanks in the wings might not be effective in view of the severe wing damage, including wing separation, which has occurred in numerous impact-survivable accidents.

The Air Line Pilots Association proposed at this hearing that crash-resistant fuel tank technology should be applied to transport airplane fuselage tanks and the use of breakaway fittings should be made mandatory in the fuel lines between tanks and engines. Other participants at the hearing recommended that the development and full-scale evaluations of crashworthy tanks and breakaway fittings for transport airplane fuselage tanks should be pursued.

As a result of the information from this public hearing, the FAA established the Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee on June 26, 1978,to recommend ways to improve survivability in the post-crash environment. In conjunction with establishment of the SAFER Committee, NPRM 74-16 was withdrawn on August 15, 1978, since it was considered that issuance of final rules would be premature due to the need for additional development and testing of promising systems.

The SAFER Committee and its Technical Support Group on Post-Crash Fire Hazard Reduction, consisting of about 50 experts from government and industry organizations, evaluated several methods for reducing the fire hazard in a post-crash environment including the use of breakaway fittings. The technical support group concluded that the effectiveness of breakaway fittings had not been proven for use in transport airplanes and that testing was required to evaluate the level of reliability. The technical support group also concluded that crash-resistant fuel tanks, fuel tank inerting, explosion suppression systems, and anti-misting kerosene, at their state of development at that time, were not feasible for commercial airplane application or did not offer significant advantages over exisitng methods of protection such as vent flame arrestors and assured cutoff of the fuel supply to the engine in emergencies.

The SAFER Committee offered the following recommendations in its final report dated June 26, 1980, (reference 1) pertaining to systems and techniques for reducing the postcrash fuel system fire and explosion hazard:

Related to Research and Development (In order of priority)

- Expedite the investigation and validation of antimisting kerosene (AMK)
- Continue and expedite FAA/NASA research to establish realistic airplane crash scenarios with increased emphasis on postcrash fuel system failure modes and effects on cabin fire safety.
- From the crash scenarios, develop fuel system design criteria for transport category airplanes in order to minimize postcrash fuel fires.

Related to Regulatory Amendments

- Amend FAR Part 25 to require that each fuel tank vent to atmosphere must be designed to minimize the possibility of external ground fires being propagated through the vent line to the tank vapor space, providing that the tank and vent structure remain intact.

- Amend FAR Part 25 to require design practices that maximize the probability of engine fuel supply shut-off in potential fire situations.

B. Research and Development Programs

1. Antimisting Kerosene (AMK)

In 1978, the FAA initiated a program to establish the feasibility of AMK for reducing the post-crash fire hazard resulting from ignition of the fuel mist when fuel is spilled from damaged tanks while the aircraft is in motion during an impact-survivable accident. In view of the SAFER Committee recommendation to expedite the program, a high priority was established for the program and the major portion of FAA aircraft safety R&D funding was applied from 1980 through 1984 to the AMK program. Following intensive investigations with AMK, including full-scale ground and flight tests, a B-720 transport aircraft operating on AMK was flown remotely in a controlled impact demonstration on December 1, 1984, to demonstrate the effectiveness of AMK in an impact survivable accident. The actual impact conditions exceeded the planned test parameters creating conditions beyond those for which the AMK was designed to provide post-crash fire protection and a post-crash fire occurred.

In view of the failure mode highlighted by the controlled impact demonstration, the FAA concluded in 1985 that justification did not exist to issue a NPRM to require the use of AMK in airline operations. At an FAA-sponsored Fuel Safety Research Workshop that was held on October 29 through November 1, 1985, the AMK controlled impact demonstration and the state-of-the-art in fuel safety research were reviewed, potential approaches to preventing post-crash fires were explored, and recommendations for future research were made, including continuation of fuel safety research. In response to this recommendation, the FAA is monitoring safety fuel development activities of the petrochemical industry and has signed agreements with five companies to protect proprietary information and materials associated with the development of safety fuels. The FAA is prepared to support such development by conducting flammability and physical characterization tests on promising fuels, but activity under the agreements has been limited during the past two years.

2. Crash-Resistant Fuel Systems

The SAFER Committee recommendation to continue and expedite FAA/NASA research to establish realistic airplane crash scenarios referred to joint FAA/NASA sponsored studies of transport airplane accidents that occurred between 1959 and 1979. These studies were conducted by the three major domestic transport airplane manufacturers under contracts awarded in February 1980. The results of the studies are contained in final reports that were published in March 1982 (references 2, 3, and 4). Candidate impact-survivable accident scenarios were developed in these studies for use in future crashworthiness R&D efforts including the B-720 controlled impact demonstration.

When the AMK program was scaled down in 1985, funds were made available to continue the crash-resistant fuel system R&D program. The structural impact data from the 1984 B-720 controlled impact demonstration and other full-scale fuselage section tests were used in conducting this program. In December 1985, the FAA awarded a contract to a major domestic airplane manufacturer to identify potential fuel containment concepts for reducing the post-crash fire hazard in the overall crash environment described in the previous studies. The final report of this study was published in November 1987 (reference 5), and included a review of the state-of-the-art in crashworthy fuel tank systems for transport airplanes. This review identified the following alternative concepts of improved wing and fuselage fuel containment to be appropriate for a detailed cost/benefit analysis:

- Wing Inboard Fuel Tank Modification to Incorporate Crash-Resistant Bladder Cells with and without Crash-Resistant Bladder-Cells in Wing Center Section Tanks

- Wing Span Structural Modifications Including Leading Edge Protection, Front Spar Protection, and Crash-Resistant Bladder Cells and Components

- Crash-Resistant Fuselage Auxiliary Fuel Tank System

A cost/benefit analysis of each concept suggested that wing span structural modifications including a crash-resistant fuel system would be the least effective approach while a crash-resistant fuel system for the fuselage auxiliary fuel tanks and wing inboard tank structural modifications would provide potentially the most effectiveness. The study concluded that the application of crash-resistant bladder cells to integral wing tanks would require a complete redesign of the wing structure because of its multicellular construction. It was also concluded that fuselage fuel containment concepts are more state-of-the-art and are more practically attainable than inboard wing fuel containment concepts. It was estimated that the development and validation of design standards for crash-resistant fuselage auxiliary fuel tanks could be accomplished in a short-term R&D program of 1-3 years contingent upon available funding, while a long-term program of 3-10 years would be required for inboard wing fuel tank modifications.

In June 1987, the short-term program was initiated with a follow-on contractual effort to establish the crash design and test criteria for the following fuselage mounted auxiliary fuel tank installation configurations:

- Conformable tank containing a bladder and supported within a dedicated structure (Figure 1)

- Double wall cylindrical strap-in auxiliary tank (Figure 2)

- Bladder cells fitted in the lower fuselage (Figure 3)

These three fuselage fuel tank arrangements were analyzed for a range of impact conditions with regard to their crash-resistant features, design philosophies, and loading paths. Anticipated structural responses were determined in the form of floor and fuel tank accelerations and attachment loads, fuel tank displacement, and fuselage underfloor crush characteristics. These results were evaluated against current crash design criteria and available test data and it was concluded that two fuselage section tests should be performed; a longitudinal-direction pulse excitation and a vertical-direction impact. The purpose of these tests is to obtain dynamic responses, measured loads, accelerations, and displacements to assess the need for new or revised design standards. The analyses and preliminary test plan for the two tests are described in the report dated November 1988 (reference 6).

Arrangements are underway to procure two cylindrical strap-in auxiliary fuel tank test specimens for installation in fuselage sections for the longitudinal and vertical impact tests. These tests are planned to be conducted in FY-89 and FY-90. The short-term program test plan proposes that similar dynamic impact tests for conformable tank installations be conducted in FY-90 and FY-91 to obtain data for comparison with cylindrical

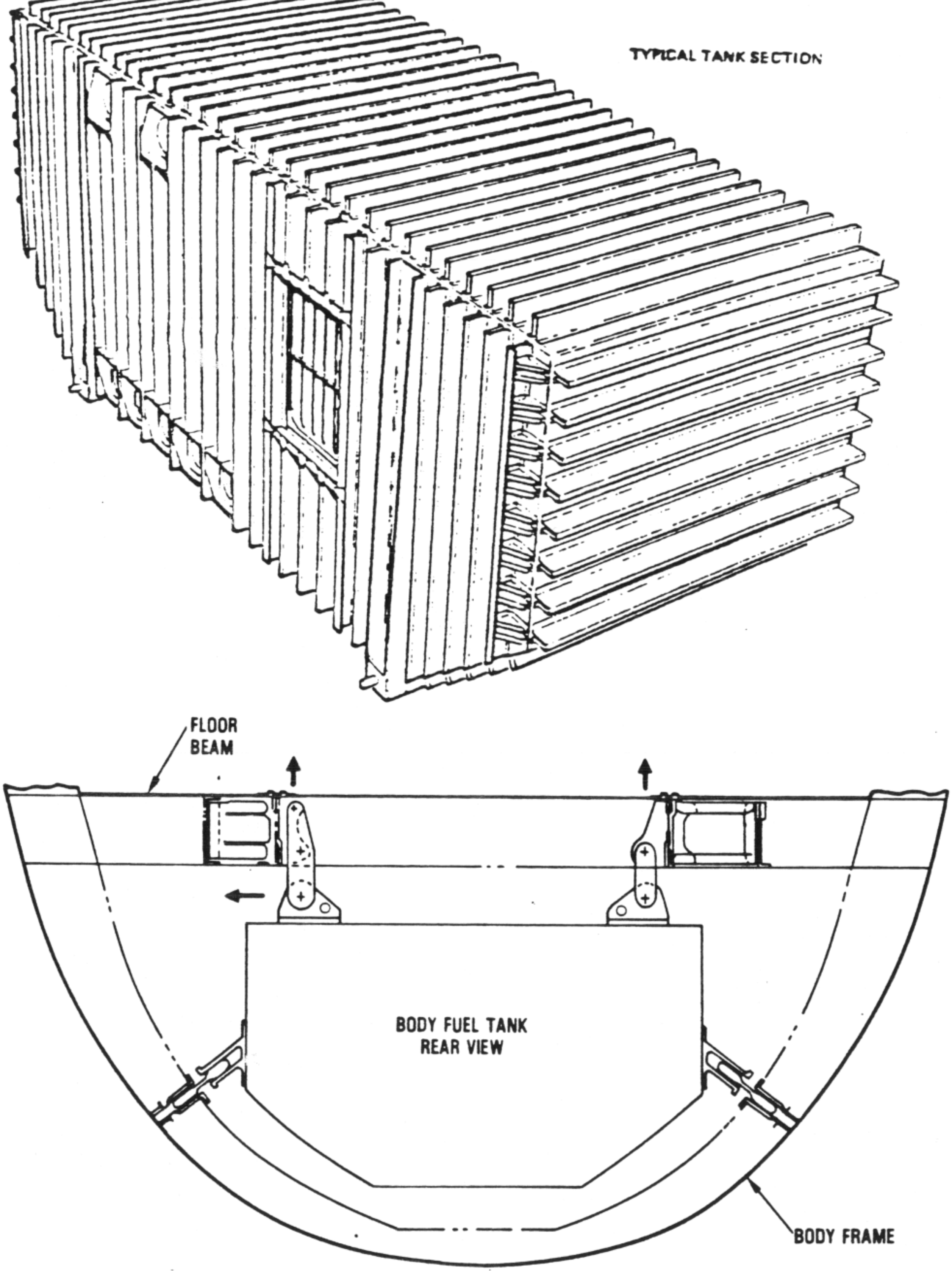

FIGURE 1. Conformable Tank Containing a Bladder and Supported Within a Dedicated Structural Box

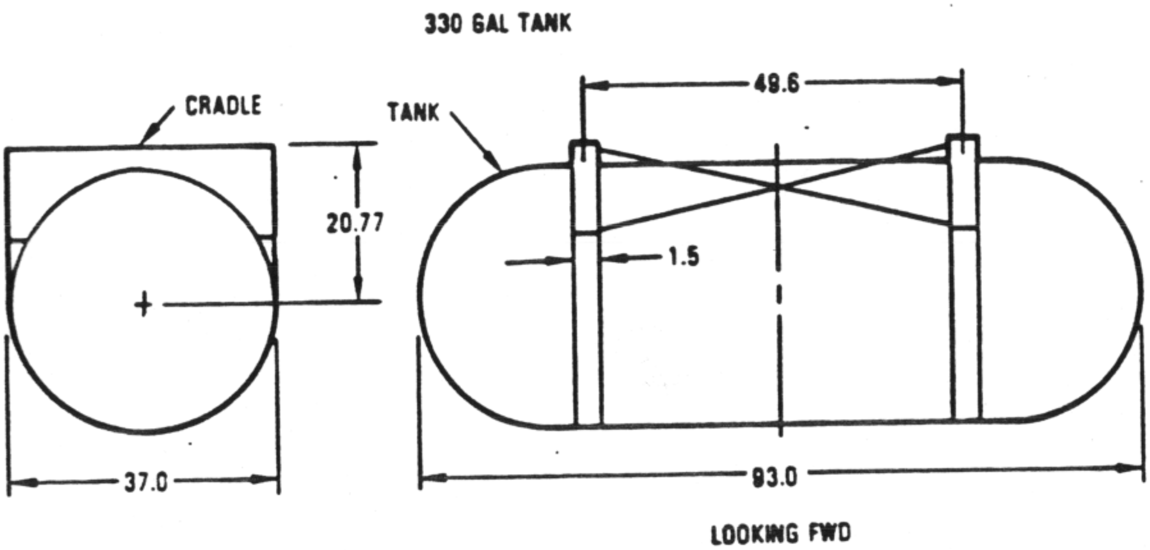

FIGURE 2. Double Wall Cylindrical Strap-In Auxiliary Tank

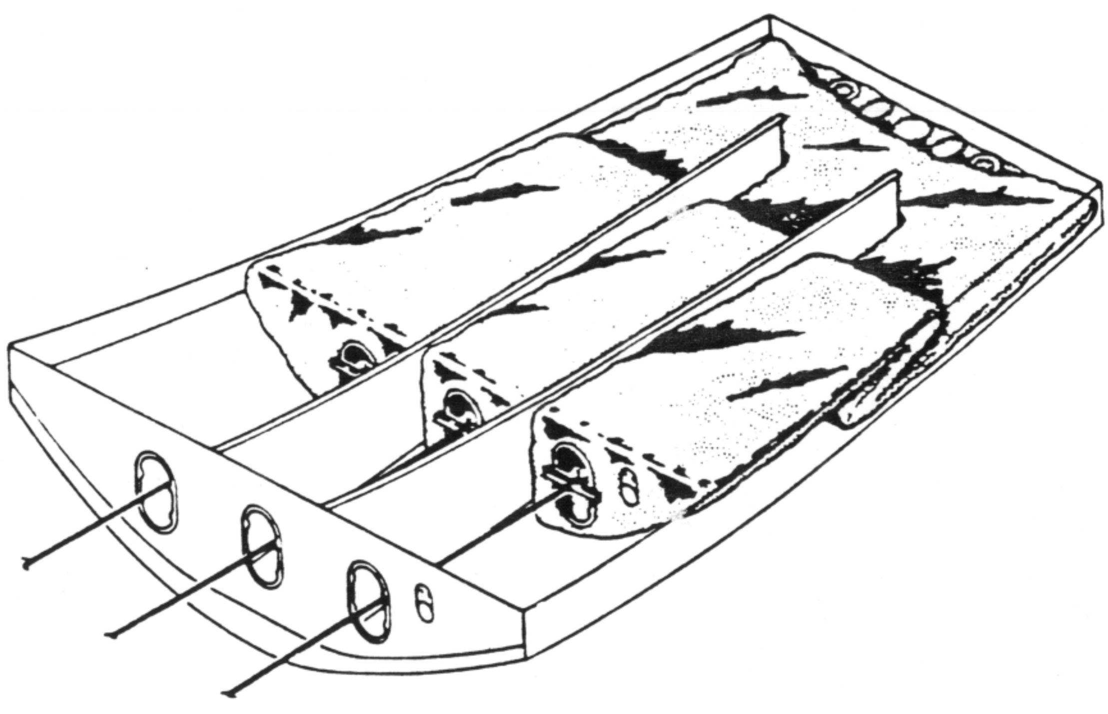

FIGURE 3. Bladder Cells Fitted in the Lower Fuselage

tank installations. The conformable tank installations may be passenger floor mounted, passenger and cargo floor mounted, or passenger and fuselage frame mounted. If shown to be necessary, these tests will be followed by tests of cylindrical or conformable tanks with crash-resistant features such as breakaway fittings and/or penetration resistant bladders. Testing at this level may require additional component tests and development. Loads, line displacement and crush performance are important parameters to evaluate and may require these component tests prior to the fuselage section impact tests. Tests may also be conducted in FY-91 and FY-92 on wing center section fuel tanks with current bladders and, if shown to be necessary, with improved crash-resistant materials. These tests will also require realistic loading to provide meaningful data. Additional analysis will be required to develop the optimum tests conditions. Program costs will have to be increased several times over current funding levels to conduct these additional tests on conformable tanks and wing center section tanks. Funding support to conduct this additional testing is under FAA management consideration.

The short-term R&D program will include an evaluation of the effects of any fires in fuselage auxiliary tank and wing center section tank installations on the cabin floor and ventilation vents. Full-scale fire tests are being planned to characterize the size and growth rate of fuselage fuel tank fires. If the fuselage section longitudinal and vertical impact tests show a specific structural failure mode for a fuselage tank, that failure mode will be simulated for the fire tests. If the initial fire characterization tests indicate that cabin floor and floor vent improvements are warranted, promising concepts will be investigated and tested. Other fire test conditions will be developed to examine the effects of post-crash external fuel fires that burn through the fuselage in the vicinity of fuselage tanks. Concepts for protection of fuselage tanks against burn-through fires will be also investigated as part of the overall study of means to protect against the entry of fires into the passenger cabin.

The long-term R&D program on inboard wing fuel tanks near the wing root will focus on concerns related to wing bending loads and penetration of leading edge structure. Crash-resistant features from previous fuselage section fuel tank tests can be used as initial indications of potential approaches for improved inboard wing fuel containment.

C. <u>Regulatory Programs</u>

1. Current Federal Aviation Regulations

The airworthiness standards contained in Part 25 of the Federal Aviation Regulations for certification of transport category airplanes include the following design rules to minimize fuel spillage:

o 25.963 Fuel tanks: general.

(d) Fuel tanks within the fuselage contour must be able to resist rupture and to retain fuel, under the interia forces prescribed for the emergency landing conditions in § 25.561. In addition, these tanks must be in a protected position so that exposure of the tanks to scraping action with the ground is unlikely.

NOTE: The emergency landing ultimate inertia force requirements prescribed in FAR 25.561 are:

(i) Upward - 2.0 g.
(ii) Forward - 9.0 g.
(iii) Sideward - 1.5 g.
(iv) Downward - 4.5 g, or any lesser force that will not be exceeded when the airplane absorbs the landing loads resulting from impact with an ultimate descent velocity of five f.p.s. at design landing weight.

o 25.721 Landing gear: general.

(a) The main landing gear system must be designed so that if it fails due to overloads during takeoff and landing (assuming the overloads to act in the upward and aft directions), the failure mode is not likely to cause-

(1) For airplanes that have passenger seating configuration, excluding pilots seats, of nine seats or less, the spillage of enough fuel from any fuel system in the fuselage to constitute a fire hazard; and

(2) For airplanes that have a passenger seating configuration, excluding pilots seats, of 10 seats or more, the spillage of enough fuel from any part of the fuel system to constitute a fire hazard.

(b) Each airplane that has a passenger seating configuration excluding pilots seats, of 10 seats or more must be designed so that with the airplane under control it can be landed on a paved runway with any one or more landing gear legs not extended without sustaining a structural component failure that is likely to cause the spillage of enough fuel to constitute a fire hazard.

(c) Compliance with the provisions of this section may be shown by analysis or tests, or both.

- 25.993 Fuel system lines and fittings.

  (f) Each fuel line within the fuselage must be designed and installed to allow a reasonable degree of deformation and stretching without leakage.

- 25.994 Fuel system components.

  Fuel system components in an engine nacelle or in the fuselage must be protected from damage which could result in spillage of enough fuel to constitute a fire hazard as a result of a wheels-up landing on a paved runway.

2. Advisory Circulars (AC)

a. AC No. 25-8

Advisory Circular No. 25-8, "Auxiliary Fuel System Installations," was issued on May 2, 1986, and describes acceptable methods by which fuselage mounted auxiliary fuel tank installations may be shown to comply with FAR 25.963, 25.721, 25.993, 25.994, and related FAR sections. In order to prevent fuel tank fittings from being torn out of the tank wall in an impact survivable accident, the advisory circular suggests that breakaway fittings be mounted on the external surface of the tank. If breakaway fittings are used, a failure analysis must show that inadvertent closure of these fittings will not interfere with continued safe flight. The advisory circular also requests that a crashworthiness evaluation report of the auxiliary fuel system installation be submitted during certification which shows, by analysis or test, that precautions have been taken to minimize the hazards of an impact-survivable accident. It may be noted that breakaway fittings are used in the fuselage auxiliary fuel system installations of some current transport airplanes.

b. AC 25.994-1

Advisory Circular No. 25.994-1, "Design Considerations to Protect Fuel Systems During A Wheels-Up Landing," was issued on July 24, 1986, and presents guidelines and methods for complying with FAR 25.994. These guidelines pertain to protecting fuel system components located in the engine nacelle and the fuselage from damage which could result in spillage of enough fuel to constitute a fire hazard following a wheels-up landing on a paved runway. The advisory circular suggests that fuel line and fuel system components should be located and routed as far as practicable from likely impact areas during a wheels-up landing where structural deformation may cause crushing, severing, punctures or high tensile loads in the lines. It also suggests that flexible and stretchable fuel lines should be used or the fuel line should be designed to allow stretching or movement to prevent failure under high tensile or shear loading. As noted in reference 5, some current transport category aircraft use flexible fuel lines which provide 50% stretch capability in areas where relative displacement is possible.

3. Proposed Regulatory Amendments

a. NPRM No.

To implement the SAFER Committee fuel system regulatory recommendations listed on page 5, preliminary rulemaking action was initiated. ANPRM No. 84-17 was issued on September 4, 1984, to solicit public comments and any information regarding proposed regulatory amendments to require: (1) fuel tank vent protection during post-crash ground fires to delay propagation of ground fires and resulting explosions in undamaged fuel systems, and (2) design practices that maximize the probability of engine fuel supply shutoff to reduce the fire hazard from spilled fuel. While an FAA preliminary regulatory evaluation completed in November 1985 showed that the cost-to-benefit ratio was less than positive to justify on a cost/benefit basis, it was noted that analysis cannot properly account for the potential magnitude of a hazardous situation created by a post-crash ground fire and a fuel tank explosion. Therefore, the FAA concluded that the proposed regulatory amendments are in the interest of public safety and should be promulgated.

NPRM No.   was issued on   and proposes to amend FAR 25.975 by adding a new paragraph (a)(7) and amend FAR 25.1189 by adding a new paragraph (i) as follows:

o 25.975 Fuel Tank vents and carburetor vapor vents.

(a) * * *

(7) Each fuel system must be designed to minimize external ground fires from propagating through the vent system and any other openings to fuel vapor spaces for a minimum of five minutes, when the tank and vent system components and airplane structure remain intact after a survivable crash landing.

o 25.1189 Shutoff means.

(i) The engine and auxiliary power unit (APU) fuel supply and fuel crossfeed systems design shall provide for isolation and shutoff capability of fuel flow from the fuel tanks to the engine to prevent spillage following a survivable crash landing.

NPRM No. also proposes to amend the air carrier operating rules of FAR Part 121 and the air taxi operating rules of Part 135 to require that the proposed changes to Part 25 be incorporated into all newly manufactured transport category airplanes used in air carrier and air taxi service on or after a date years after the effective date of the amendments.

b. NPRM No. 88-10

In a recent accident, the failure of an access panel on a wing fuel tank resulted in the loss of hazardous quantities of fuel which subsequently ignited and destroyed the airplane. Other fuel tank access panels have failed in service due to impact with high speed objects such as failed tire tread material and engine debris following engine failures. In order to reduce the hazards associated with the loss of fuel tank access panels, the FAA issued NPRM No. 88-10 on May 10, 1988 which proposes to amend FAR 25.963 by revising paragraph (e) as follows to require that fuel tank access panels of transport category airplanes be fire resistant and designed to minimize penetration by likely foreign objects:

- o 25.963 Fuel tanks: general.

  (e) In order to prevent the loss of hazardous quantities of fuel, all fuel tank access covers must be shown by analysis or tests to:

  (1) Be designed to minimize penetration and deformation by tire fragments, low energy engine debris, or other likely debris, if the access panel is located in an area where service experience indicates a strike is likely; and

  (2) Be fire resistant.

NPRM No. 88-10 also proposes to amend FAR Part 121 to require that the panels of all turbine powered airplanes operated in air carrier service meet these standards after two years after the effective date of this amendment.

The closing date for receipt of comments on NPRM No. 88-10 was September 17, 1988. All comments received are being considered before taking action on this proposed rulemaking.

D. Discussion

The FAA, with the assistance of public hearings and the SAFER Advisory Committee, has evaluated a variety of transport airplane design concepts and systems which have been suggested as having the potential for reducing the post-crash fire and explosion hazard. The systems included those which are intended to provide protection of undamaged fuel systems against fuel tank fires and explosions caused by internal ignition sources such as sparks from lighting strikes or, in the case of military aircraft, from ballistic penetrations. These are the fuel tank nitrogen inerting, foam filler, and chemical agent explosion suppression systems. In view of the severe wing damage, including wing separation, which has occurred in numerous impact-survivable accidents, the FAA has concluded that these systems primarily intended for inflight protection would have little or no effect in reducing the post-crash fire and explosion hazard. It has been concluded for the same reason that crash-resistant bladder cells in the integral wing tanks would also not be effective.

The FAA had considered that the use of antimisting kerosene (AMK) might be able to protect against ignition of the fuel mist when fuel is spilled from damaged tanks during an impact-survivable accident. Ground tests had shown that the high molecular weight polymeric additive in AMK serves to physically bind the fuel as it is released at ground impact speeds to form a coarse spray of large droplets through which flames could not propagate and create a large post-crash fire. However, in a full-scale transport airplane controlled impact demonstration, degraded AMK was ignited in liquid form by a severely damaged engine before the large droplets were formed and a post-crash fire occurred. In view of this AMK failure mode, the FAA concluded that justification did not exist to require the use of AMK in airline operations. It has also been concluded that an engine hot surface or combustor flame ignition suppression system probably would not have been able to prevent ignition of the AMK in this demonstration due to the multiple ignition sources in the severely damaged engine.

A comprehensive study of improved wing and fuselage fuel containment concepts showed that a crash-resistant fuel system for fuselage auxiliary fuel tanks would provide the most effectiveness, followed by wing inboard fuel tank modifications to incorporate crash-resistant bladder cells. The study also showed that fuselage fuel containment concepts are more state-of-the art and are more practically attainable than inboard wing fuel containment concepts. In addition, the study suggested from a crashworthiness viewpoint that breakaway fittings might have a potential benefit in: (1) fuel tank to engine fuel supply lines to prevent release of fuel and maintain tank wall integrity in the event the engine separates from the wing, (2) if compartments are added along the span of integral wing tanks to isolate fuel spillage, in crossover fuel lines from each tank compartment to shut off fuel flow from one compartment to another in the event of a tank compartment rupture, and (3) fuel systems of crash-resistant fuselage auxiliary bladder cells supported in a dedicated structural box to assure that fuel spillage is minimized in the event of a large displacement.

It is to be emphasized that the installation of breakaway fittings in transport airplane fuel systems must address the concern for inadvertent closure caused by fatigue stress or some other causes other than a fuel line break. The inflight failure of a breakaway fitting in a tank-to-engine fuel supply line would shutdown the engine due to loss of the use of fuel from the tank. If breakaway fittings are used to isolate additional integral wing tank compartments, moderate weight, volume, and cost penalties would be added as a result of extra fittings, plumbing, controls and fuel management procedures. For this concept, analyses of the operational aspects (e.g., flow pressure, volume, cross-feed, and fitting closures) would be required. In evaluating the feasibility of using breakaway fittings in transport airplane fuel systems, the fatigue life and strength and operational characteristics will have to be demonstrated to assure that inadvertent closure will not interfere with continued safe flight. Breakaway fittings have not been used in tank-to-engine fuel lines due to this concern, but they have been found acceptable for use in auxiliary fuel system installations.

The FAA initiated a short-term R&D program in June 1987 to establish crash design and test criteria for three fuselage auxiliary fuel tank installation configurations based upon consideration of current crash design criteria and available test data. These crash design and test criteria have been developed and consist of longitudinal and vertical impacts of auxiliary fuel tanks installed in a narrow-body fuselage section. The purpose of these tests is to determine if current regulatory standards are adequate for fuselage auxiliary fuel systems or if crash-resistant features and new or revised standards are needed.

Arrangements are underway to conduct the first series of longitudinal and vertical impact tests on 330 gallon cylindrical strap-in auxiliary fuel tanks mounted in B-707 aft fuselage sections. The longitudinal impact test will be conducted at the Transportation Research Center of Ohio and the vertical impact test at the FAA Technical Center in New Jersey. These tests are scheduled to be conducted in FY-89 and FY-90. Similar dynamic impact tests for conformable tank installations are proposed in FY-90 and FY-91 to obtain data for comparison with the cylindrical tank test results. If the results of these tests on standard auxiliary tank installations show that fuel containment improvements are needed, the tests will be repeated on cylindrical or conformable tanks with crash-resistant features such as breakaway fittings and/or penetration resistant bladders. Tests may also be conducted in FY-91 and FY-92 on wing center section fuel tanks with current bladders and/or improved crash-resistant materials. Any crash-resistant features found to be necessary from these auxiliary fuel tank tests will be used as initial indications of potential approaches to be considered in a follow-on long-term R&D program on inboard wing fuel tanks near the wing root.

The FAA considers that the short-term R&D program should be completed to determine whether rulemaking action should be taken to propose new or revised regulatory standards relating to crash-resistant fuselage auxiliary fuel systems, including the use of breakaway fittings. It is possible that the R&D program will substantiate the adequacy of the current Federal Aviation Regulations, or it may show where changes are appropriate to policy and advisory guidance material which are used in demonstrating compliance with the regulations. The FAA has placed a high priority on the fuselage auxiliary fuel system R&D program and will strive to assure that the required funding is provided to complete the program in FY-92.

The FAA has initiated two proposed rulemaking actions which are directed toward reduction of the post-crash fuel system fire and explosion hazard. NPRM   was issued on   and proposes to require: (1) fuel tank vent protection during post-crash ground fires to delay propagation of ground fires and resulting explosions in undamaged fuel systems, and (2) design practices that maximize the probability of engine fuel supply shutoff to reduce the fire hazard from spilled fuel. NPRM No. 88-10 was issued on May 10, 1988 and proposes to require that fuel tank access panels be fire resistant and designed to minimize penetration by foreign objects in order to prevent the loss of hazardous quantities of fuel. Final action on this proposed rulemaking is scheduled for completion in   after consideration of public comments.

It is necessary in most current large transport airplanes to incorporate fuselage auxiliary fuel systems to achieve the desired range. However, it is envisioned that advances in airplane and engine design technologies may permit some future airplanes to have the same range as current airplanes without the need for fuselage fuel systems. Prop-fan engines are under development which will reduce fuel consumption by about 30 percent compared to current turbofan engines of comparable thrust. The application of super-critical aerodynamics results in thicker wings which provides for a greater fuel capacity for the same size airplane. In addition to these two technology advances, which may enable the deletion of fuselage fuel systems, other design features pertaining to fuel tank and engine locations, such as horizontal stabilizer fuel tanks and rear fuselage mounted engines, may further reduce the post-crash fire and explosion hazard. While the FAA cannot mandate the location of fuel tanks and engines, the FAA believes that the current and proposed regulatory standards pertaining to fuel tank access panels, fuel vent protection, and engine fuel supply shutoff, the ongoing R&D program on fuselage auxiliary fuel systems, and anticipated technology advances will provide for a substantial reduction in the transport airplane post-crash fire and explosion hazard.

E. Conclusions

1. In view of the severe wing damage, including wing separation, which has occurred in numerous impact-survivable accidents, fuel tank nitrogen inerting, foam filler and chemical agent explosion suppression systems intended for inflight protection and crash-resistant bladder cells in integral wing tanks would have little or no effect in reducing the post-crash fire and explosion hazard.

2. It is not justified to require that antimisting kerosene (AMK) fuel be used in airline operations to protect against fuel mist flame propagation during an impact-survivable accident due to the experimental failure in the controlled impact demonstration.

3. Engine hot surface on combustor flame ignition suppression systems probably would not have been able to prevent ignition of the AMK in the controlled impact demonstration.

4. Of concepts having the potential for improved fuel containment, a crash-resistant fuel system for fuselage auxiliary fuel tanks would provide the most effectiveness, is more state-of-the-art, and is more practically attainable than wing inboard fuel tank modifications to incorporate crash-resistant bladder cells.

5. A research and development program should be conducted to determine if current regulatory standards are adequate for fuselage auxiliary fuel tank and wing inboard fuel tank installations or if crash-resistant features and new or revised standards are needed.

6. Amendments to the Federal Aviation Regulations are warranted to require fuel tank vent protection against propagation of flames from post-crash ground fires, assurance of engine fuel supply shutoff at the fuel tanks to stop fuel spillage from ruptured engine fuel supply lines downstream of the shutoff valves, and fuel tank access panels to be fire-resistant and designed to minimize penetration by foreign objects to prevent the loss of hazardous quantities of fuel.

7. The regulatory amendment which would assure engine fuel supply shutoff at the fuel tanks when the crew is able to activate the shutoff valves will provide for the same function as breakaway, self-closing fittings in the tank-to-engine fuel lines. A regulatory amendment to require the use of breakaway fittings in tank-to-engine fuel lines is not warranted because inadvertent closure would shutdown the engine and could interfere with continued safe flight.

F. Recommendations

1. Expedite the completion of a short-term research and development program on longitudinal and vertical dynamic testing of fuselage auxiliary fuel tank installations to determine whether rulemaking action should be taken to propose new or revised regulatory standards relating to crash-resistant fuselage auxiliary fuel systems.

2. Initiate a longer-term research and development program on inboard wing fuel tank installations following completion of the short-term program to determine whether rulemaking action should be taken relating to inboard wing fuel systems.

3. Expedite the completion of current rulemaking action pertaining to fuel tank vent protection against post-crash ground fires, assurance of engine fuel supply shutoff at the fuel tank to stop fuel spillage from ruptured engine fuel lines, and improved fuel tank access panels.

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