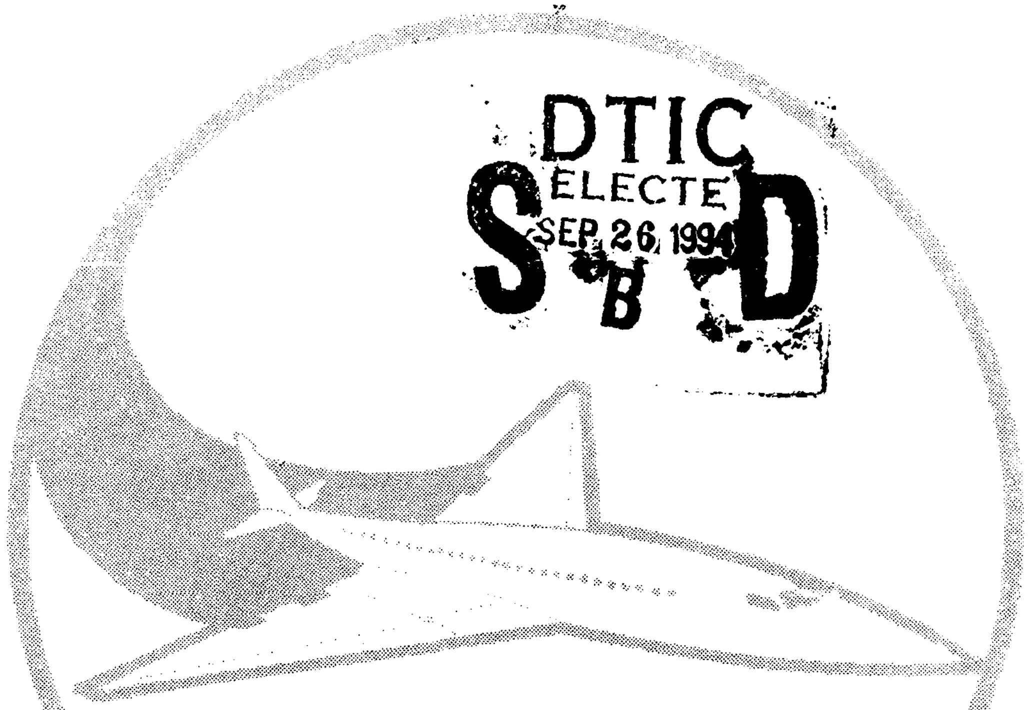
technical note

Fuel Line Study



August 1994

DOT/FAA/CT-TN94/14

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NOTICE

Technical Report Documentation Page

1. Report No.
DOT/FAA/CT-TN94/14

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
FUEL LINE/FITTING TECHNICAL NOTE

5. Report Date
July 1994

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.

9. Performing Organization Name and Address
Atlantic Science and Technology Corp.
1413 Cantillion Blvd., suite 200
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10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DTFA03-92-P-01884

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City International Airport, NJ 08405

13. Type of Report and Period Covered
Technical Note
Sept. 1992 - July 1994

14. Sponsoring Agency Code
ACD-210

15. Supplementary Notes
FAA Program Manager: Gary Frings

16. Abstract
This report is part of an ongoing effort directed toward the complete crash-resistant fuel system (CRFS). It reviews, evaluates, and summarizes the current use of fittings and fuel lines in transport category aircraft. In addition, available aircraft crash data is analyzed and several conclusions are presented regarding fuel/line fitting technology.

17. Key Words
Fuel Line
Fitting
Post-crash Fire
Crash-Resistent Fuel System

18. Distribution Statement
Document is on file at the Technical Center Library, Atlantic City International Airport, New Jersey 08405

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
42

22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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EXECUTIVE SUMMARY

This report is part of an ongoing effort directed toward the complete crash-resistant fuel system (CRFS). It reviews, evaluates, and summarizes the current use of fittings and fuel lines in trasport category aircraft. In addition, available aircraft crash data is analyzed and several conclusions are presented regarding fuel line/fitting technology.

1. INTRODUCTION.

In its persistent effort to improve aircraft safety, particularly in the crashworthiness area, the Federal Aviation Administration (FAA) is continuing to place major emphasis on reducing, if not eliminating, those hazards associated with post-impact fire related to failed aircraft fuel systems. Numerous studies and tests have been conducted over the past few years that examined the scope of the problem and investigated potential solutions including both U.S. military and commercial aircraft. The effort as related to military aircraft, primarily rotary wing aircraft, has been most comprehensive and productive, covering complete aircraft fuel systems. The U.S. Army sponsored an extensive research and development program dealing with the aircraft post-crash environment and proposed design techniques that can be used to reduce post-crash hazards. These studies and tests resulted in the "Aircraft Crash Survival Design Guide" prepared by Simula, Inc. of Tempe, Arizona. Included were the post-crash fire environment, crashworthy fuel systems, ignition source control, and fire behavior. As a result of these studies and recommendations, the Army installed crash-resistant fuel systems in the majority of their helicopters. These systems include bladders, break-away fittings, and fuel lines which have proven to be successful in reducing the number and severity of post-crash fires, fire ignition and spread and, concurrently, in providing increased personnel safety.

Some of these concepts have applicability to other categories of aircraft such as commercial jet transport aircraft. Post-crash fires account for a high percentage of injuries and fatalities in transport category aircraft accidents. Studies and tests on commercial transport aircraft have primarily addressed aircraft fuel tanks, their construction, structural material composition, location in the aircraft, and post-impact structural integrity. Efforts are under way to minimize fuel spillage and reduce the post-crash fire hazard. Fuselage auxiliary fuel tank configurations have been tested under dynamic loading conditions to determine responses in a crash-simulated environment. A somewhat more limited effort has been exerted in the aircraft fuel systems area as related to fuel lines, fittings, routing, design philosophy, and their interface with the aircraft structure, (e.g., wings, bulkheads, engine pylons, etc.). It is this subject area on aircraft fuel systems that the current effort by the FAA Technical Center (FAATC) addresses. This FAATC program is part of an ongoing effort directed toward the complete crash-resistant fuel system (CRFS).

Atlantic Science and Technology Corporation (AS&T), under Contract No. DTFA03-92-P-01884 with the FAA Technical Center, was tasked to undertake this phase of the CRFS program. The initial effort was designed to review, evaluate, and summarize the current use of fittings and fuel lines in transport category airplanes, investigate the available airplane crash data, and make recommendations based on the findings.

1.1 PURPOSE.

The purpose of this study was to review, evaluate, and summarize available crash test data, National Transportation Safety Board (NTSB) crash reports, and aircraft manufacturer design documentation to analyze fuel lines and fittings in transport category aircraft. The goal of this research was to gain greater insight into an improved fuel line system as part of the complete CRFS. The purpose of this report is to summarize the results of this fuel line study.

1.2 APPROACH.

The approach that was followed to implement the fuel line study is outlined in this section. The study was divided into four phases as follows:

Phase 1 - Task Planning
Phase 2 - Data Collection and Initial Review
Phase 3 - Data Analysis
Phase 4 - Reporting of Results

Phase 1 was dedicated to planning and the generation of a task plan, schedule, and milestone charts. Initial contacts with FAA and NTSB information sources were made.

Phase 2 consisted of gathering and reviewing all necessary and relevant documentation to conduct the study. This phase was accomplished by subdividing the documentation into three separate areas, each related to the source of the data. The three literature search subject areas were categorized as follows:

- Aircraft Manufacturers. This area applied to the data that was supplied by the commercial transport category aircraft manufacturers regarding their current fuel line technology. The data requested included: design criteria, current locations, flow rates, routing, sizes of fuel lines and fittings, and aircraft sizes. An attempt was made to obtain a point-of-contact from each of the major aircraft manufacturers to facilitate the data search process. The major aircraft manufacturers for this study included:

    - Boeing, Models 727/737/747/757/767
    - Lockheed, Model L1011
    - McDonnell Douglas, Models DC-9/10, MD-80/90
    - Airbus, Models A300/A310/A320/A330/A340

- National Transportation Safety Board. This area applied to airplane crash data supplied by the NTSB. Several contacts were made to try to procure relevant reports or data regarding airplane crash data. A subset of all crash reports was thoroughly reviewed to eliminate the collection and review of irrelevant or inappropriate data. By narrowing the population of accident reports, the review and analysis process was streamlined. The methodology implemented to accumulate only relevant reports and studies was to first define the population of accidents that are rated as "survivable" or "partially survivable". From this subset, the focus was then placed on accidents that resulted in post-crash fires. Finally, only those accidents related to the major transport aircraft listed above were carefully examined.

- Related Documentation. This area applied to general research efforts and any related data, documentation, or information that could be useful in accomplishing the objectives of the study. Past U.S. Army studies, past FAA sponsored studies, recent auxiliary fuselage fuel tank reports, aircraft crash survival design guides, advisory circulars, test reports, and technical studies were collected. Many of the reports were provided by FAATC personnel. Others were found through literature research. The remaining were gathered by contacting information sources throughout the aviation community. Often the literature contained information which led to additional sources of data.

Phase 3 consisted of data review and analysis for each document or report collected from the three literature search areas of phase 2.

Phase 4, the final phase of this effort, was the compilation of all data gathered from the study. The product of phase 4 is this technical note.

2. RESEARCH SUMMARY.

This section of the report is divided into each of the three literature search subject areas. A brief review and analysis of the data collected is presented.

2.1 GENERAL INFORMATION.

The following paragraphs summarize general information regarding fuel lines. This data was obtained from Aircraft Crash Survival Design Guide, Volume V - Aircraft Post-Crash Survival, USARTL-TR-79-22E, January 1980, paragraphs 4.2.2 and 4.2.3, Fuel Lines and Supportive Components, pp. 57 - 76, and Fuel Containment Concepts - Transport Category Airplanes, DOT/FAA/CT-87/18, November 1987.

Flexible lines are used in transport category airplanes in locations where there is a high stretch potential. Hoses are required where relative displacement is anticipated. Flexible lines may be more prone to leakage and less fire retardent than steel tubing. Damaged fuel lines frequently cause spillage in aircraft accidents. Lines often are cut by surrounding structure or worn through by rubbing against rough surfaces. The use of flexible hose armored with a steel-braided harness is strongly suggested in areas of anticipated dragging or structural impingement. In systems where breakaway valves are not provided, hoses twenty to thirty percent longer than the minimum required hose length are desirable. This will allow the hose to shift and displace with collapsing structure, rather than be forced to carry tensile loads. For this reason, it is equally important that couplings and fittings be used sparingly because of their propensity to snag and restrict the natural ability of the hose to shift.

All fuel lines should be secured with breakaway (frangible) attachment clips in areas where structural deformation is anticipated. When fuel lines pass through areas where extensive displacement or complete separation is anticipated, self-sealing breakaway valves should be used. The valves may be specifically designed for this purpose, or quick-disconnect valves may be modified for use.

Routing of hoses should be carefully considered during the design stage. Fuel lines should be routed along the heavier structural members, since those members are less likely to deform or separate in an accident. Also, it is important that hoses have a space into which they can deform when necessary. For example, when hoses pass through large flat-plate areas, such as bulkheads or firewalls, the hole allowing line passage should be considerably larger than the outside diameter of the line. Hose stabilization as well as liquid-tight, fire-tight seals still can be maintained if a frangible structure is used.

2.2 RELATED DOCUMENTATION.

The following list outlines the results of the general research efforts conducted during the study. Each report, article, or document was reviewed and is summarized below.

- FAA Aircraft Fuel Systems Survey prepared by Simmonds Precision - This report summarized the aircraft fuel systems in various aircraft and commented on the use of antimisting kerosene in terms of degradation, component performance, and safety for each aircraft. Some of the data found in section 2.4 were obtained from this source.

- Commercial Aircraft Airframe Fuel Systems Survey and Analysis, DOT/FAA/CT-82/80, February 1982 - This study was performed as part of the FAA Antimisting Fuel Engineering Development Plan to study the fuel systems of a representative sample of commercial aircraft to determine the range of conditions to which the antimisting kerosene fuel (AMK) would be exposed. This is the interim report. The bulk of the data in section 2.4 was obtained from this source.

- Commercial Aircraft Airframe Fuel Systems Survey and Analysis, DOT/FAA/CT-82/12, July 1982 - This is the final report of the above listed document.

- Boeing Specification Control Drawings, 81205, #6OB92407 - This specification control drawing covered the design, fabrication, performance, and testing requirements for the hose assembly used in the fuel system to supply fuel to the auxiliary power unit (APU).

- FAA Safety Recommendation 92.136 - This document from the Los Angeles Aircraft Certification Office, ANM-100L, summarizes the Douglas pylon mock-up review and lists recommendations.

- World Aviation Directory, Buyer's Guide, Summer 1992 - This source was used to obtain the information regarding aircraft manufacturers.

- World Aviation Directory, Winter 1992 - This source was used to obtain the information regarding aircraft manufacturers.

- Crashworthiness Design Handbook, July 1971 - This book discussed essential principles of crashworthiness design, some of the problems encountered related to safety design and various ways of handling these problems. Prepared by FAA Airframe Section, Engineering and Manufacturing Branch, Flight Standards Technical Division, Aeronautical Center, Oklahoma City, Oklahoma.

- Aircraft Crash Survival Design Guide, Volume I - Design Criteria and Checklists, USARTL-TR-79-22A, December 1980 - Part 1 of 5. Volume 1 is a compilation of criteria and checklists for the design of crashworthy aircraft. It is the summary of volumes 2 through 5.

- Aircraft Crash Survival Design Guide, Volume II - Aircraft Crash Environment and Human Tolerance, USARTL-TR-79-22B, January 1980

- Aircraft Crash Survival Design Guide, Volume III - Aircraft Structural Crashworthiness, USARTL-TR-79-22C, August 1980. This volume contains information on the design of aircraft structures and structural elements for improved crash survivability. Current requirements for structural design of U. S. Army aircraft pertaining to crashworthiness are discussed.

- Aircraft Crash Survival Design Guide, Volume IV - Aircraft Seats, Restraints, Litters, and Padding, USARTL-TR-79-22D, June 1980 - This volume contains information of aircraft seats, litters, personal restraint systems, and hazards in the occupant's immediate environment.

- Aircraft Crash Survival Design Guide, Volume V - Aircraft Post Crash Survival, USARTL-TR-79-22E, January 1980 - This volume contains information on the aircraft post-crash environment and design techniques that can be used to reduce post-crash hazards. Topics include post-crash fire environment, crashworthy fuel systems, ignition source control, fire behavior of interior materials, ditching survival, emergency escape, and crash locator beacons. It is from this source that the recommended design for fuel lines and fittings contained in appendix D was obtained.

- Fuel Containment Concepts - Transport Category Airplanes, DOT/FAA/CT-87/18, November 1987 - This study includes a review and evaluation of accident crash test and analyses data, design guidelines, specification and criteria, design procedures, state-of-the-art technology, and design studies and conclusions. Excerpts from this report are contained in appendix E.

- NASA Technical Memorandum 85654, Structural Response of Transport Airplanes in Crash Situations - This report highlights the results of contractual studies of transport accident data undertaken in a joint research program sponsored by the FAA and NASA. From these accident studies it was concluded that the greatest potential for improved transport crashworthiness is in the reduction of fire related fatalities. Accident data pertaining to fuselage integrity, main landing gear collapse, fuel tank rupture, wing breaks, tearing of tank lower surfaces, and engine pod scrubbing are discussed.

- Transport Aircraft Crashworthiness Program Review, NASI-16076, August 19/20, 1981 - This report summarizes areas of research that might lead to improved structural crashworthiness by reviewing accident data and assessing current technology. The conclusions of this study are that (1) advancements in crash avoidance techniques would have significantly reduced fatalities, (2) current jet transport design methods are continually being improved based on knowledge gained form accident experience and has resulted in the present high degree of structural crashworthiness, (3) greatest potential for improved crashworthiness is the reduction of fire related studies, (4) structural integrity of the fuel systems and fuselage are leading candidates for improved crashworthiness, and (5) a research and development program would lead to improved crashworthiness technology.

- Desk Reference Guide Crashworthiness, Chapter 37, February 15, 1991 - This report summarizes the investigation of the survival aspects of general aviation aircraft. Prepared by Aviation Safety Division Transportation Safety Institute, NTSB, and FAA Civil Aeromedical Institute for the Office of Accident Investigation, FAA HQ/AAI-1.

- Investigation of Transport Airplane Fuselage Fuel Tank Installations Under Crash Conditions, DOT/FAA/CT-88/24, July 1989 - This is the follow-on effort to the study Fuel Containment Concepts - Transport Category Airplanes, DOT/FAA/CT-87/18, November 1987 (No. 16). This report reviewed existing crash design criteria and investigated three fuel tank installation configurations.

- Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee, Final Report Volume IIB, FAA-ASF-80-4, June 26, 1978 through June 26, 1980 - The SAFER Committee examined the factors affecting the ability of the aircraft cabin occupant to survive in the post-crash fire environment and the range of solutions available. This report contains the summary of the proceedings of the SAFER Committee, FAA responses to the recommendations, pertinent correspondence and information on crew protection and passenger evacuation.

- Report to Congress - Systems and Techniques for Reducing the Incidence of Post-Crash Fuel System Fires and Explosions, December 1988 - This report describes the study conducted by the FAA for the Secretary of Transportation on the feasibility of fuel system post-crash fire safety improvements for transport category airplanes, general aviation aircraft, and rotorcraft. Crash-resistant fuel tanks and breakaway fuel line fitting technologies were evaluated for each type of aircraft and for transport category airplanes; consideration was given to other technologies including explosion prevention systems and anti-misting fuel. The report concludes that crash-resistant fuel tanks have the potential for improved fuel containment of transport airplane inboard wing and fuselage-mounted auxiliary fuel systems. Crash-resistant fuel tank technology is not recommended for the wing tanks of transport aircraft because of the significant reduction in fuel capacity and the severe wing damage which has occurred in numerous accidents.

- Crashworthy Fuel System Design Criteria and Analyses, AS-723 988, March 1971 - This study investigated eight aircraft fuel systems in the U.S. Army inventory. Unsatisfactory areas in regard to crashworthiness were determined and recommendations for improving the crash resistance of these hazardous areas were proposed.

- The Development of Aircraft Crash-Resistant Fuel Cells, Safety Valves, and Breakaway Accessories, 517D - This paper discusses the development of concepts and components for an aircraft crash-resistant fuel system. A description of the first aircraft crash-resistant fuel cell installation, complete with safety valves and frangible breakaway components, is included. The authors of this report (John Sommers, Jr. and John H. Clark, FAA) felt that safety cells and valves meeting military specifications and when properly installed with breakaway attachments would provide the desired crashworthiness integrity for aircraft crash-resistant fuel cells. It was presented at the National Aeronautic Meeting, New York, NY, April 3-6, 1962 by the Society of Automative Engineers.

- Impact Tests of Flexible Nonmetallic Aircraft Fuel Tanks Installed in Two Categories of Simulated Wing Structures, PB 121788, January 1957 - This report presents the results of tests conducted at the Technical Development Center of Civil Aeronautics Administration to correlate the ability of a nonmetallic aircraft fuel tank to resist rupture under impact loads with material strength and/or energy-absorbing properties. The results of the tests indicated that impact resistance of the test unit varied linearly with fuel cell material strength and energy-absorbing properties for materials of similar basic construction.

2.3 NATIONAL TRANSPORTATION SAFETY BOARD.

The NTSB provided a composite listing of all continental U.S. aircraft accidents that resulted in fires from years 1983-1989. Appendix A contains these charts. These charts depict 15 transport category aircraft accidents which occurred during the period 1983 - 1990, where a post-impact fire occurred, and the accident was identified as a "survivable" accident. To determine the completeness of this set, four sources were used for additional information:

- NTSB Aircraft Accident Briefs (Received on March 5, 1993 from NTSB, Washington, DC).

- NTSB Annual Review of Aircraft Accident Data, U.S. Carrier Operations, Calendar Years 1985, 1986, 1987

- NTSB Individual Aircraft Accident Reports

- Flight Safety Foundation - Flight Safety Digests

2.3.1 NTSB Aircraft Accident Briefs.

The results of the analysis of these briefs are summarized as follows:

- Thirty-four accident briefs were reviewed. After review and filtering out those accidents which were not applicable, the data was reduced to 15 potentially useable accidents. One additional accident was added to the data set from the chart provided by NTSB. This accident was a ground-collision accident between a B-727 and DC-9 on 12/13/90 in Detroit in which the DC-9 caught fire. Thus, the preliminary data set consisted of 16 potentially useable accidents where a post-impact fire occurred.

- Of these 16 potentially useable accidents, none of the NTSB reports analyzed to date revealed any useful data on fuel ignition sources, fuel fire propagation histories, or fuel line/fitting effectiveness.

2.3.2 NTSB "Annual Review of Aircraft Accident Data".

This publication presents the record of aviation accidents involving revenue operations of U.S. Air Carriers including "Commuter Air Carriers" and "On-Demand Air Taxis" for one calendar year. Three reports were available for the years 1985, 1986, and 1987. Although primarily statistical in nature, these reports included a table in each which is a "List of Accidents, CFR Part 121, 125, 127 Operations." The accidents listed were then compared with the NTSB Aircraft Accident Briefs involving post-impact fire to insure completeness in the data set. Unfortunately, CFR Part 121, 125, and 127 operations accidents are not broken out and categorized separately. Accordingly, some degree of knowledgeable interpretation of the table was made, CFR Part 121 air carrier operations were filtered out and a positive correlation between the two separate NTSB aircraft accident data sources was obtained.

2.3.3 NTSB Aircraft Accident Reports.

Review of several available NTSB reports determined that the contents do not contain useable information on ignition source(s), fuel system deformation/failure during impact, integrity or adequacy of aircraft fuel systems, etc. Additional field investigators data acquired during an aircraft accident might provide such detail. Attempts to obtain the data were unsuccessful.

2.3.4 Flight Safety Foundation - Flight Safety Digest.

The Flight Safety Foundation (FSF) is a well-recognized and respected international membership organization dedicated to improving aviation safety. One of its publications is the Flight Safety Digest (FSD), a monthly publication which primarily addresses real or potential aviation safety issues and periodically provides aviation statistics, briefs, and related information on aircraft accidents and incidents, both domestically and worldwide. Review of the digests published over the past five years (60 issues) revealed good correlation between their tabulation of aircraft accidents with post-impact fire and the briefs received from the NTSB cited earlier. Additional candidate accidents were identified in the Digest that were not in the NTSB briefs. This was due to the fact that there were either foreign aircraft involved, or non-Part 121 operations, and therefore did not meet our designated criteria.

2.4 AIRCRAFT MANUFACTURERS.

The information obtained from aircraft manufacturers was analyzed and summarized as follows:

2.4.1 Boeing 747.

General - The hose assemblies are installed within a tubular aluminum shroud and carry the fuel through the fuselage to the APU. Flexible hose is used as the fuel carrying medium to obtain the maximum fuel line integrity in the event of damage to the surrounding structure.

Fuel System Discussion - The fuel in this aircraft is contained in a center wing tank, tip reserve tanks, and 4 main wing tanks. Auxiliary tanks are added between the reserve tank and the outboard main tank in some models. The maximum fuel capacity is 51,100 gallons.

- Pressure refueling and defueling is performed with two 2 1/2 inch MIL-S-25896D fueling adapters.
- Fuel is pumped from the center wing tank first until it is empty then from the main wing tanks. Fuel can be pumped and cross-fed between all tanks and engines.
- A fuel scavenge pump in the center wing tank transfers fuel that is unavailable to the center wing tank boost pumps to the no. 2 main tank.
- A water scavenge system scavenges water from low points in the main tanks and pumps it to a point near the boost pump inlet.
- A schematic of the basic fuel system is shown in appendix B.

Fuel System Components and Features.

- Line Sizes - The main fuel system uses 1.5-in to 2.5-in pipe, and the scavenge system uses 3/4-in pipe.
- Boost Pumps - Electrically driven, 7200 rpm centrifugal pumps with a 20,000 lb/hr rating at 13 psig are used. Four run continuously, 8 are supplied. Cruise flow is approximately 8000 pph, zero flow pressure is approximately 20 psig.
- Transfer & Jettison - Four additional pumps identical to the boost pumps are supplied.
- Fuel Scavenge and APU - These are vane pumps. The APU pump is battery powered and is used to supply fuel to the APU when 115/200 VAC power is not available.
- Water Scavenge - Eight small jet pumps with 0.064-in nozzles are used which run continuously.
- Filters - The boost pumps, override pump, APU pumps, and fuel scavenge pump have 4 mesh screens on the inlets. No other filters are supplied with the airframe fuel system.

- Vent System - The vent system utilizes small honeycomb mesh flame arrestors.

- Suction Feed - The suction feed condition during flight would occur only as a result of major pump and/or electrical failure. The aircraft can operate in the suction feed condition.

- Pressure Refueling - Normal pressure refueling is performed with 2 hoses from the left side of the aircraft. The 2 1/2-in MIL-25896D adapter is used. This system utilizes a refueling valve which contains pilot float valves and small bleed lines of approximately 0.125 inch diameter.

- Refuel Distribution Lines - Several 4 to 5 foot lengths of 2-in pipe with 1/8-in holes are used to bleed off static charge and distribute the fuel.

- Heat Exchangers - Hydraulic fluid/fuel heat exchangers are used in this aircraft. Hydraulic fluid is on the tube side and fuel is on the shell side. The fuel is used as a static heat sink.

- Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is used on this aircraft. No thermistor type point level sensors are used.

- The APU is supplied by Garrett Airesearch; their part no. is GTCP660-4. This unit has 10- and 25-micron paper filters and a 4000 rpm gear pump that has 4000 pph flow at 600 psig. The max bypass ratio is 3.6:1. There are 8 primary nozzles with a diameter of 0.014 inch. The fuel control bypass flow metering system uses a 0.020-in to 0.060-in flow passage.

2.4.2 McDonnell Douglas DC-10-40.

Fuel System Discussion - The DC-10-30 and -40 are the long range versions of this aircraft, which have a fuel capacity of 36,200 gallons (gal). There are three main tanks, one for each engine, plus auxiliary tanks in the center wing box.

Aircraft refueling can be accomplished through either two or four standard 2 1/2-in MIL-A-25896D adapters, two of which are installed on each wing. The maximum initial flow rate through each adapter at 50 pounds per square inch gauge (psig) supply pressure is approximately 600 gal/min. This system utilizes refueling flow. This system can also be used to defuel the aircraft.

The fuel transfer philosophy during flight is as follows. Fuel is transferred from the auxiliary tanks to the main wing tanks for use. The main wing tank fuel is used in three segments consisting of the inboard, outboard, and wing root areas. The inboard compartment fuel is used first, with the outboard compartment held full for wing structural considerations. Late in the flight the outboard fuel is transferred inboard for use and then fuel in the wing root area is used last. Float switches and indicator lights are used to indicate the fuel usage scheduling and status to the flight engineer. A water scavenging system employing jet pumps is used to remove water from the tank low points and mix it with the fuel near the boost pump inlets. The motive flow comes from the engine feed lines and the secondary flow of water and fuel is drawn up through tubing rakes whose inlets are located in the tank low points.

A schematic of the basic fuel system is shown in appendix B.

Fuel System Components and Features.

- Line Sizes - The main fuel system uses 2.0-in to 3.0-in outside diameter pipe.

- The scavenge and transfer system, uses 1/2-in to 5/8-in pipe.

- Boost Pumps - Electrically driven, 8000 revolutions per minute (rpm) centrifugal pumps rated at 46,000 lb/hr at 17 psig are used. Twelve are supplied for boost and transfer and at least 4 run continuously. Five are in each inboard wing tank and two are in the auxiliary tank. Fuel serves as a coolant for the electrical winding of these pumps. Nominal cruise flow is approximately 5000 lb/hr, and pump dead head pressure is 30 psi.

- Ejector Pumps - Fourteen ejector pumps are supplied, 4 for transfer and 10 for scavenging. Five are located in each wing and 4 in the auxiliary center section tank. The scavenge pumps run continuously.

- Filters - The boost pump inlets have 5 mesh screens, and no other filters are supplied.

- Suction Feed - The suction feed condition during aircraft flight would occur only as a result of major pump and/or electrical failure. The fuel system design, however, provides for continuous operation under suction feed conditions.

- Vent System - The vent system provides for equalization of tank pressure with ambient pressure. This system incorporates vent float valves and fine honeycomb mesh flame arrestors to prevent the possibility of lightning-ignited fuel vapor causing flames to travel into the tank space. Bypass valves are provided to avoid tank over pressure in the event of arrestor plugging.

- Jettison System - A jettison system is provided which utilizes the centrifugal pumps to dump fuel overboard. The maximum rate obtainable is 6000 lbs/minute.

- Pressure Refueling - Normal pressure refueling is performed with two hoses from one side of the aircraft; four hoses and both sides can be used. The 2 1/2-in MIL-A-25896D adapter is used. This system utilizes a refueling valve which contains pilot float valves and small bleed lines of 0.125 inch maximum.The maximum initial fueling rate is 2170 gal/min. using four adapters and 50 psig supply pressure while filling all tanks.

- Refuel Distribution Manifold - A distribution line in each wing containing 1/4-in holes is used to reduce static charge build-up and distribute fuel evenly.

- Heat Exchangers - There are no airframe supplied heat exchangers using fuel as a heat sink on this aircraft.

- **Fuel Quantity Gauging System** - A capacitance-type fuel quantity gauging system is used on this aircraft. No thermistor-type point level sensors are used.

- Auxiliary Power Unit (APU) - The APU is supplied by Garrett Airesearch; their part no. is TCSP-700-4. This unit has 10- and 40-micron paper filters, and a 6655 rpm gear pump which supplies 2000 pph at 750 psig. There are 18 nozzles, 9 with a diameter of 0.0125 inch and 9 with a diameter of 0.014 inch. The fuel control bypass metering system uses a flow passage which varies from 0.020 inch to 0.060 inch. This unit can be used either on the ground or in flight. The bypass system recirculates fuel back to the gear pump inlet, not to the bulk fuel.

- The pylons for all Douglas airplanes have undergone a Pylon Mock Review to address all fire protection criteria including a first Article Inspection. The items of review are as follows: all pylon fuel lines and hydraulic lines are steel, not aluminum; all connections are eliminated if possible; if not, all connections are shrouded and drained overboard; proximity and location of electrical lines to fuel lines are evaluated; clipping of electrical feeder cables insure a separation will not impact on a fuel line to arc and penetrate.

2.4.3 Lockheed L1011-500.

Fuel System Discussion - The fuel in this aircraft is contained in six tanks - (two tanks in each wing and two center section tanks) with a total capacity of 32,000 gallons.

Pressure refueling and defueling is accomplished with the standard 2 1/2-in MIL-A-25896 adapters, two of which are located on each wing. Automatic shutoff valves are used to control the fueling operation.

The cross feed system permits any engine feed tank to supply fuel to any engine, but does not allow tank to tank transfer. This is accomplished with ejector pumps and fuel transfer valves in the fuel transfer system. During takeoff and climb each engine is fed from its own tank. When cruise altitude is reached, the left and right no. 2 wing tanks are shut off and the center tanks are used until empty. Each engine is then fed from its own wing tank until the end of the flight.

A water scavenging system using compound jet pumps with inlet rakes draws water and fuel from various low points in the various tanks and deposits it in the boost pump collector boxes.

A basic schematic of the fuel system is shown in appendix B.

Fuel System Components and Features.

- Line Sizes - The main fuel system uses 1.5-in to 2.5-in pipe, and the scavenge system uses 5/8-in lines.

- Boost Pumps - Electrically driven, 10,000 rpm centrifugal pumps with a 45,000 lb/hr rating are used. Four dual-element pumps are provided, one in each wing tank. Three elements run continuously, six run during landing and takeoff. Cruise flow is approximately 5500 pph, dead head pressure is 40 psi.

- Ejector Pumps - Thirty-four jet pumps are used in the scavenge and transfer system. Eighteen of these are compound pumps with a single motive flow stream and multiple secondary flow streams. They are used to scavenge water and transfer fuel. The wing scavenge system operates continuously, and the center tank system operates under manual control.

- Filters - Fourteen mesh screens are used in the boost pump inlets and in the jet pump motive flow lines.

- Suction Feed - The suction feed condition during aircraft flight would occur only as a result of major pump and/or electrical failure.

- Vent System - The vent system contains honeycomb mesh flame arrestors with less then 0.01 inch openings.

- Pressure Refueling - Pressure refueling is performed using the 2 1/2-in MIL-A-25896D adapters, four are supplied, two on each wing. Automatic shutoff valves with pilot valves are used in this system which contain small lines 0.060 inch or greater.

- Heat Exchangers - No heat exchangers are used in the fuel system of this aircraft.

- Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is used on this aircraft.

- Thermistor bead point level sensors are used for low-level jettison pump shutoff and low-level transfer shutoff functions.

- Auxiliary Power Unit (APU) - The APU is supplied by Hamilton Standard, part No. ST-6L-73. The engine portion of this unit consists of a Pratt & Whitney Canada ST6L-73 engine and a fuel control supplied by Aviation Electric.

- The fuel control internal bypass metering valve utilizes a piston in a sleeve with 1/8-in holes.

- The engine utilizes a 6500 rpm, 1400 pph, 100 psi gear pump with a bypass system that returns bypassed fuel to the pump inlet. The pump outlet has a 1-micron paper filter.

2.4.4 Airbus Industrie A-310.

Fuel System Discussion - The fuel in this aircraft is contained in five tanks - center wing and right and left outboard and inboard. The total fuel quantity is 14, 531 gallons.

Defueling is accomplished using two standard 2 1/2-in fueling adapters on the right side of the aircraft.

Fuel is used in the order: center, inboard, and outboard except during takeoff when the center tank is not used. The tank sequence is automatic, but can be controlled manually at any time. A cross feed system allows both engines to feed from one side, or all fuel to be used in one engine.

Two jet pumps are used for fuel scavenging and to keep the boost pump collector boxes full.

A basic schematic of the fuel system is shown in appendix B.

Fuel System Components and Features.

- Line Sizes - The engine feed lines are 2 inch, refuel and defuel are 1.5-in to 3.0-in, and the APU feed is 3/4-in.

- Boost Pumps - Electrically driven, 6000 rpm centrifugal pumps with a 40,000 lb/hr flow rating at 9 psig are used. Ten are supplied, six run continuously from the start of the flight, reducing to four as the tanks are emptied. The inner and center tank pumps have a zero flow pressure of 37 psig, the outer tank pump 18 psig.; cruise flow is approximately 4000 pph.

- Ejector Pumps - Two jet pumps, one in each wing, are used to keep the outer tank pump collector box full. They run continuously.

- Suction Feed - Suction feed during aircraft flight would occur only as a result of major pump and/or electrical failure.

- Filters - The boost pump inlets have 8 mesh wire screens. No other filters are supplied with the airframe.

- Pressure Refueling - Two standard 2 1/2-in adapters are used for pressure refueling. An automatic shutoff valve utilizing a pilot valve with small orifices is used in this system. The system is also used for suction or pumped defueling.

- Fuel Distribution - Several diffuser sections, consisting of 1 to 2 foot lengths of 2-in pipe with 1/8-in-diameter holes, are used to distribute the fuel and reduce static charge build-up during the fueling operation.

- Vent Systems - The vent system contains fine honeycomb mesh flame arrestors.

- Heat Exchangers - No fuel heat exchangers are supplied with airframe.

- Fuel Quantity Gauging System - A capacitance type fuel quantity gauging system is used on this aircraft. Thermistor type point level sensors are used for high- and low-level sensing and to shut-off the center tank pumps when the tank is empty.

- Density Measurement - A fuel density measurement device called a Cadensicon is supplied with this aircraft.

- **It utilized a mass balance method to measure fuel density and a sensor which measures fuel dielectric constant.**

- Auxiliary Power Unit (APU) - A Garrett GTCP-311-250 unit is supplied. This unit has a 10-micron synthetic fiber filter, and an 8300 rpm gear pump that supplies 2100 pph at 700 psig. Twelve fuel nozzles are used, 6 with an opening of 0.012 inch and 6 with an opening of 0.014 inch. The fuel control bypass metering line varies from 0 to 0.020 inch.

3. CONCLUSIONS.

Based on the analysis of all data obtained, it is concluded that:

a. There was insufficient data to firmly conclude that fixed or flexible fuel lines have either contributed to or prevented post-crash fire incidents.

b. There appears to be a benefit to the flexible fuel line technology.

c. The question of the value of the flexible versus rigid fuel line and its contribution to the loss of life is an extremely important question that needs to be addressed further. A test program may even be warranted.

4. REFERENCES.

Aircraft Crash Survival Design Guide, Volume V - Aircraft Post Crash Survival, USARTL-TR-79-22E, January 1980, paragraph 4.2.2 Fuel Lines, p. 57.

Fuel Containment Concepts - Transport Category Airplanes, FAA Report DOT/FAA/CT-87/18, November 1987, paragraph 6.7, General Approaches, Approach No. 1, pp. 6-40 to 6-43.

Appendix A

Summary of NTSB Accident Data

Table A-1. ALL ACCIDENTS VERSUS FIRE-INVOLVED ACCIDENTS (1983-1989)

	NUMBER OF ACCIDENTS FROM ALL CAUSES				NUMBER OF ACCIDENTS WITH FIRE					
YEAR	NO.	OCCUPANTS	FATAL ACCIDENTS	AIRCRAFT OCCUPANT FATALITIES	NO.	OCCUPANTS	NUMBER FATALITIES ON AIRCRAFT	AIRCRAFT FATALITIES IMPACT	FIRE	NUMBER SURVIVORS
1983	18	1340	4	15	7	355	4	4		351
1984	16	1395	1	4	2	41	4	4	0	37
1985	22	1557	7	525	7	309	237	221	16	72
1986	23	2478	2	4	4	393	3	3		390
1987	36	2958	4	186	5	247	186	186		61
1988	29	3414	3	274	3	255	14		14	241
1989	30		11	276	6	735	124	89	35	611

Source: NTSB

Table A-2. ALL ACCIDENTS VERSUS FIRE-INVOLVED ACCIDENTS (1983)

DATE	LOCATION	OPERATOR	AIRCRAFT AND TYPE OF OPERATION	DESCRIPTION OF ACCIDENT	TOTAL OCCUPANTS	TOTAL NO. FATALITIES	FATAL TRAUMA	FATAL FIRE RELATED
1/9/83	BRAINARD, MN	REPUBLIC	CONVAIR 580-111 SCH PAX	COLLISION WITH SNOW BANK-POST CRASH FIRE	31	1	1	0
1/11/83	DETROIT, MI	UAL	DC-8 SCH CARGO	POST-CRASH FIRE	3	3	3	0
3/23/83	CASPER	WESTERN	B-737	GEAR-UP LANDING	95	0	0	0
5/21/83	KING SALMON, AK	WOODS AIR FUEL	C-46F NON SCHD CARGO	INFLT-FIRE	2	0	0	0
6/8/83	COLD BAY, AK	REEVE-ALEUTIAN	L-188C SCHD PAX	PROP FAILURE DECOMPRESSIN FIRE ON GROUND	15	0	0	0
6/11/83	DETROIT, MI	UAL	B-727 SCHD PAX	ABORTED T/O FIRE IN #1 ENGINE	125	0	0	0
12/20/83	SIOUX FALLS, SD	OZARK	DC-9 SCHD PAX	R WING COLLIDED WITH SNOW REMOVAL EQUIPEMENT-FIRE ON GROUND (1 FATAL IN EQUIPMENT)	(DC-9) 84	0	0	0

Source: NTSB

Table A-3. ALL ACCIDENTS VERSUS FIRE-INVOLVED ACCIDENTS (1984)

DATE	LOCATION	OPERATOR	AIRCRAFT AND TYPE OF OPERATION	DESCRIPTION OF ACCIDENT	TOTAL OCCUPANTS	TOTAL NO. FATALITIES	FATAL TRAUMA	FATAL FIRE RELATED
5/30/84	CHALKHILL, PA	ZANTOP	L-188 SCHD CARGO	INFLT BREAKUP FIRE IN (R) WING AFTER BREAK-UP	4	4	4	0
12/16/84	JASPER, AL	FLT TRAILS	C-440 NONSCHD PAX	INFLT FIRE RIGHT ENG	37	0	0	0

Source: NTSB

Table A-4. ALL ACCIDENTS VERSUS FIRE-INVOLVED ACCIDENTS (1985)

DATE	LOCATION	OPERATOR	AIRCRAFT AND TYPE OF OPERATION	DESCRIPTION OF ACCIDENT	TOTAL OCCUPANTS	TOTAL NO. FATALITIES	FATAL TRAUMA	FATAL FIRE RELATED
1/21/85	RENO, NV	GALAXY	L-188C NON SCH PAX	CRASHED INTO STORE AND 7 RVS AFTER T/O GROUND FIRE	71	70	54	16
1/29/85	DOBBINS, MI	GALAXY	L-188 SCHD CARGO	LANDED WITH R GEAR RETRACTED-FIRE IN GEAR AREA	3	0	0	0
5/04/85	PERRIS, GA		DC-3 NON SCHD PAX	FIRE IN LEFT ENG DURING T/OFF	33	0	0	0
5/31/85	NASHVILLE, TN	GEN. AV. INC.	G-159 SCHD CARGO	ENG. FAILURE AT T/OFF-GROUND FIRE	2	2	2	0
6/19/85	W. TRENTON, NJ	PROVINCE AIRLINES	GEN. DYNAMICS 240-27	LOSS OF ENG AT T/OFF-CRASHED IN WOODED FIELD & BURNED	2	0	0	0
8/2/85	* DALLAS, TX	DELTA	L-1011 SCHD PAX	WINDSHEAR-AIRPLANE BROKE APART ON IMPACT AND BURNED	163	134	134	0
9/6/85	MILWAUKEE, WI	MIDWEST EXPRESS	DC-9 SCHD PAX NON SCHD PAX	ENG. FAILURE AT T/OFF-STEEP DESCENT	31	31	31	0

* AUTOPSIES NOT CONDUCTED - ON ALL OCCUPANTS
ASSUMPTION THAT FATALITIES WERE TRAUMA
ALTHOUGH SOME SURVIVORS HAD THERMAL INJURIES

SOURCE: NTSB

Table A-5 ALL ACCIDENTS VERSUS FIRE-INVOLVED ACCIDENTS (1987)

DATE	LOCATION	OPERATOR	AIRCRAFT AND TYPE OF OPERATION	DESCRIPTION OF ACCIDENT	TOTAL OCCUPANTS	FATAL TRAUMA	FATAL FIRE RELATED
4/13/87	KANSAS CITY, KS	BUFFALO AIRWAYS	B-707 SCHD CARGO	CRASHED SHORT OF RUNWAY - FIRE ON GROUND	4	4	
8/16/87	ROMULUS MI	NW	DC-9 SCHD PAX	STRUCK LT. POLE AFTER T/OFF BROKE APART ON IMPACT GROUND FIRE ON GROUND	155	154	
8/20/87	NEWBURGH NY	ROSENBAUM AVIATION	DC-8 SCHD CARGO	GROUND COLLISION -2 AIRCRAFT	6	0	
11/15/87	DENVER CO	CONTINENTAL	DC-9 SCHD PAX	TAKE OFF ACCIDENT FIREBALL THROUGH CABIN DURING IMPACT SMALL FIRE AT WING ROUT EXTINGUISHED BY FIREFIGHTERS	82	17 (9-died of Mechanical asphyxia)	0

SOURCE: NTSB

Table A-6. ALL ACCIDENTS VERSUS FIRE-INVOLVED ACCIDENTS (1989)

DATE	LOCATION	OPERATOR	AIRCRAFT AND TYPE OF OPERATION	DESCRIPTION OF ACCIDENT	TOTAL OCCUPANTS	FATAL TRAUMA	FATAL FIRE RELATED
2/24/89	HONOLULU HI	UAL	B-747 SCHD PAX	EXPLOSIVE DECOMPRESSION-FIRE IN ENGINE	356	9	
3/15/89	W. LAFAYETTE	MID PACIFIC AIRLINES	YS-11A NON SCHD CARGO	INFLIGHT LOSS OF CONTROL CRASHED & BURNED	2	2	
3/17/89	OAKLAND CA	CONTINENTAL	B-737 SCHD PAX	CREW UNAWARE OF APU FIRE PRIOR TO ENG START. AFTER T/OFF - SEVERE VIBRATION - LND WITHOUT INCIDENT	69	0	
3/18/89	SAGINAW TX	EVERGREEN	DC-9 SCHD PAX	CRASHED WHILE IN STEEP DESCENT - FIRE ON GROUND	2	2	
7/19/89	SIOUX CITY IA	UAL	DC-10 SCHD PAX	INFLT FAILURE #2 ENGINE - LOSS OF HYDRAULICS - CRASH AND FIRE	287	111	35
10/14/89	SALT LAKE CITY, UT	DELTA	B-727 SCHD CARGO	FIRE ERUPTED WHILE SERVICING 0_2 SYSTEMS	19	0	

SOURCE: NTSB

Appendix B

Aircraft Manufacturer Schematics

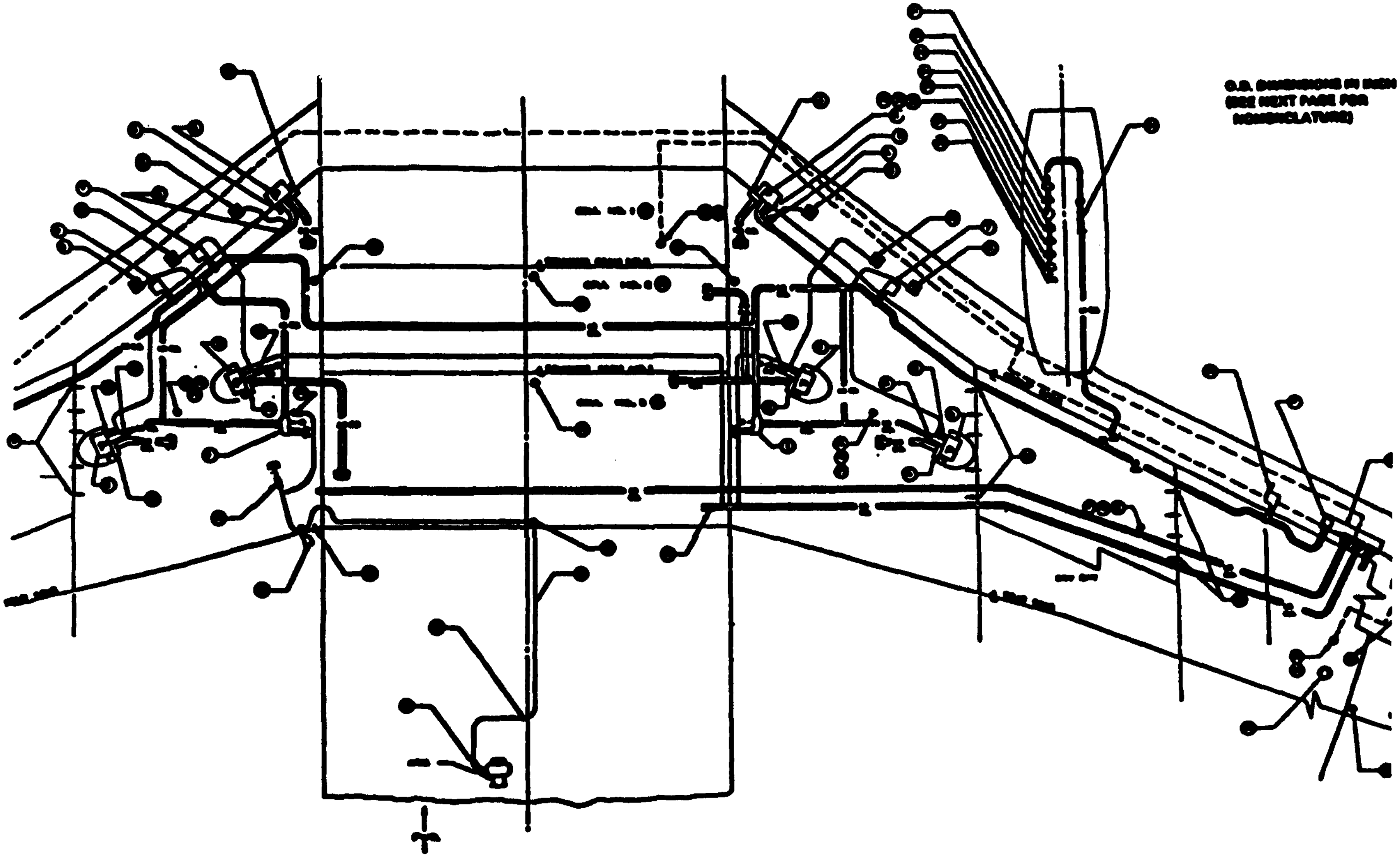

FIGURE B-1. BOEING 737 FUEL SYSTEM SCHEMATIC

ITEM	NOMENCLATURE
1.	Boost Pump By-Pass Valve
2.	Boost Pump
3.	Pressure Switch
4.	Pump Inlet Manual Valve
5.	Check Valve
6.	Check Valve Boost Pump
7.	Fuel Shutoff Valve
8.	Check Valve Boost Pump
9.	Cap Pressure Fueling
10.	Flexible Fuel Hose
11.	Temperature Bulb-Fuel
12.	Sump Drain Valve
13.	Stick and Core Assy. Dripstick (Calibration In Inches)
14.	APU Check Valve
15.	Baffle Rib Check Valve
16.	APU Fuel Shutoff Valve
17.	Manual Defuel Valve
18.	Seal Gasket
19.	Sump Drain Valve
20.	Hose Assy-Fire Proof
21.	Engine Pump 1st Stage
22.	Fuel Heater
23.	Fuel Filter
24.	Engine Pump 2nd Stage
25.	Fuel Control Unit
26.	Fuel Nozzle
27.	Fuel Oil Cooler
28.	Fueling Manifold
29.	Metallic Flex Hose
30.	Valve Vent Float
31.	Hose Assy-Fire Proof
32.	Check Valve
33.	Float Switch
34.	Filler Cap Ass'y
35.	Flowmeter Transmitter (KGS)
36.	Flowmeter Transmitter (LBS)
37.	Hose Assy
38.	Sump Drain Valve
39.	Fuel Bladder Cells (1 Cell Config.)
40.	Fuel Bladder Cells (2 Cell Config.)
41.	Fuel Bladder Cells (3 Cell Config.)
42.	Stick & Core Assy. (Dripstick) (Calibration in Lbs)
43.	Pressure Switch
44.	Flowmeter Transmitter Rate-Pointer
45.	Stick and Core Assy Dripstick (Calibration in Kilograms)
46.	Float Switch

NOMENCLATURE FOR FIGURE B-1

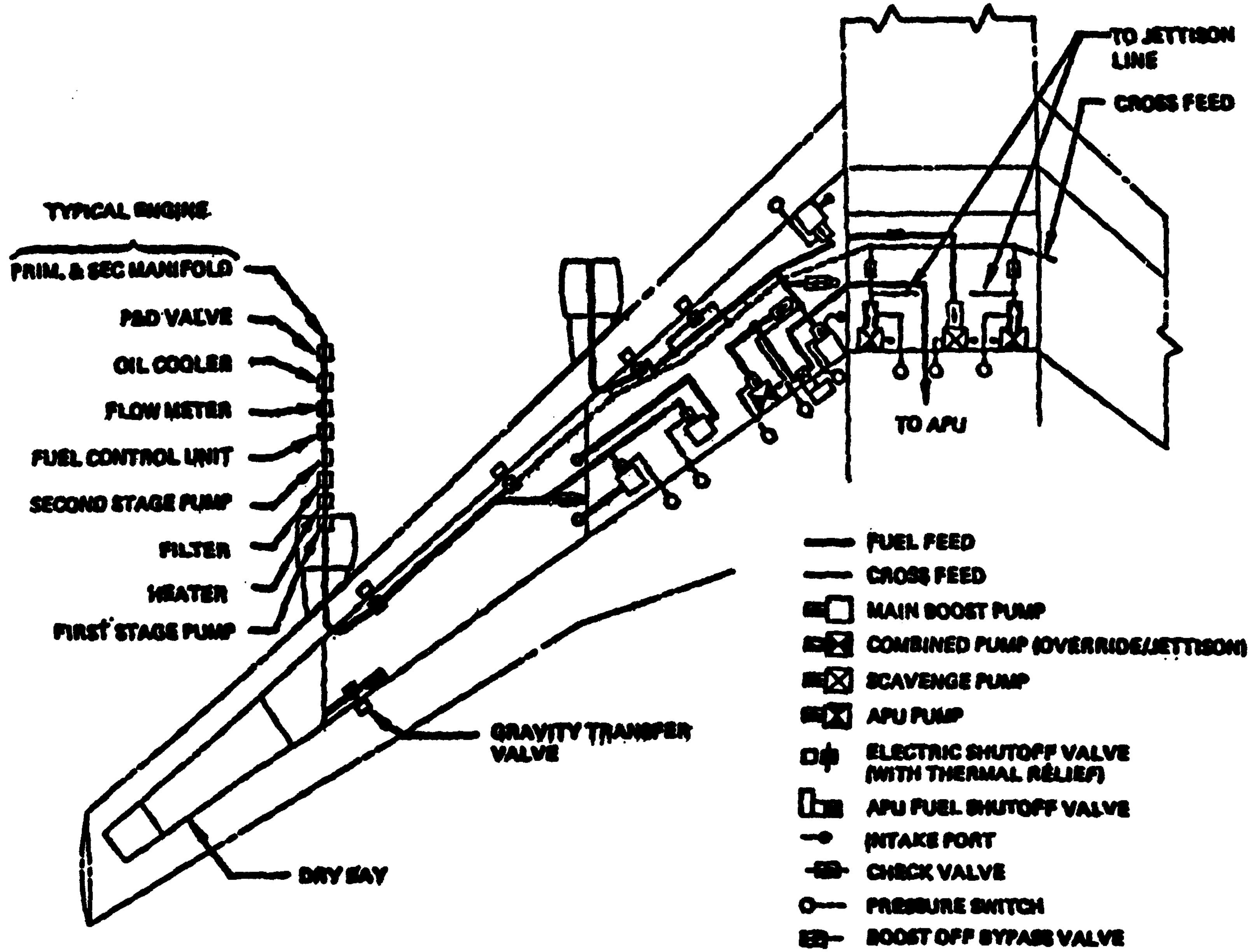

FIGURE B-2. BOEING 747 FUEL SYSTEM SCHEMATIC

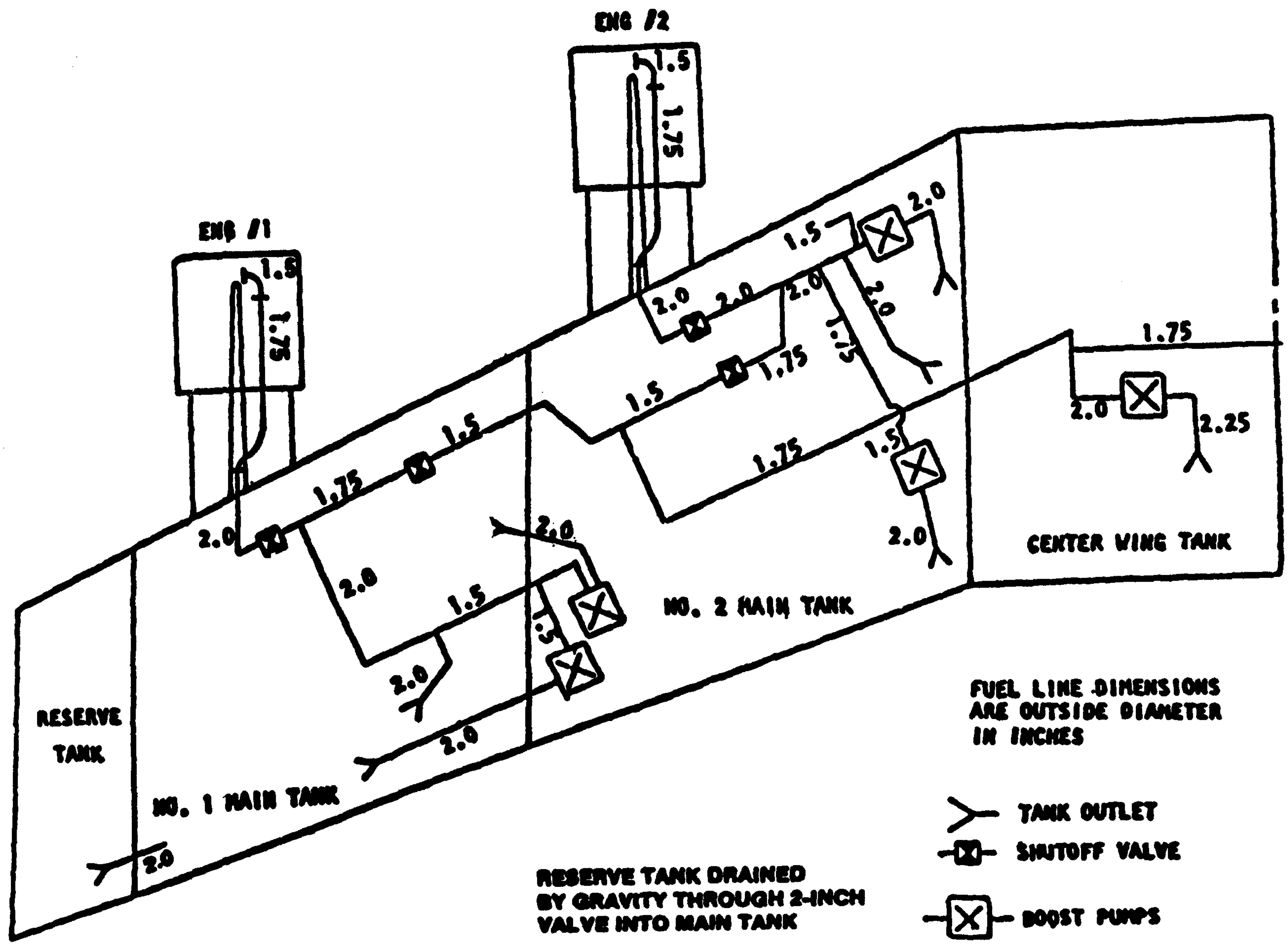

FIGURE B-3. BOEING 747 FUEL SYSTEM LINE SIZES

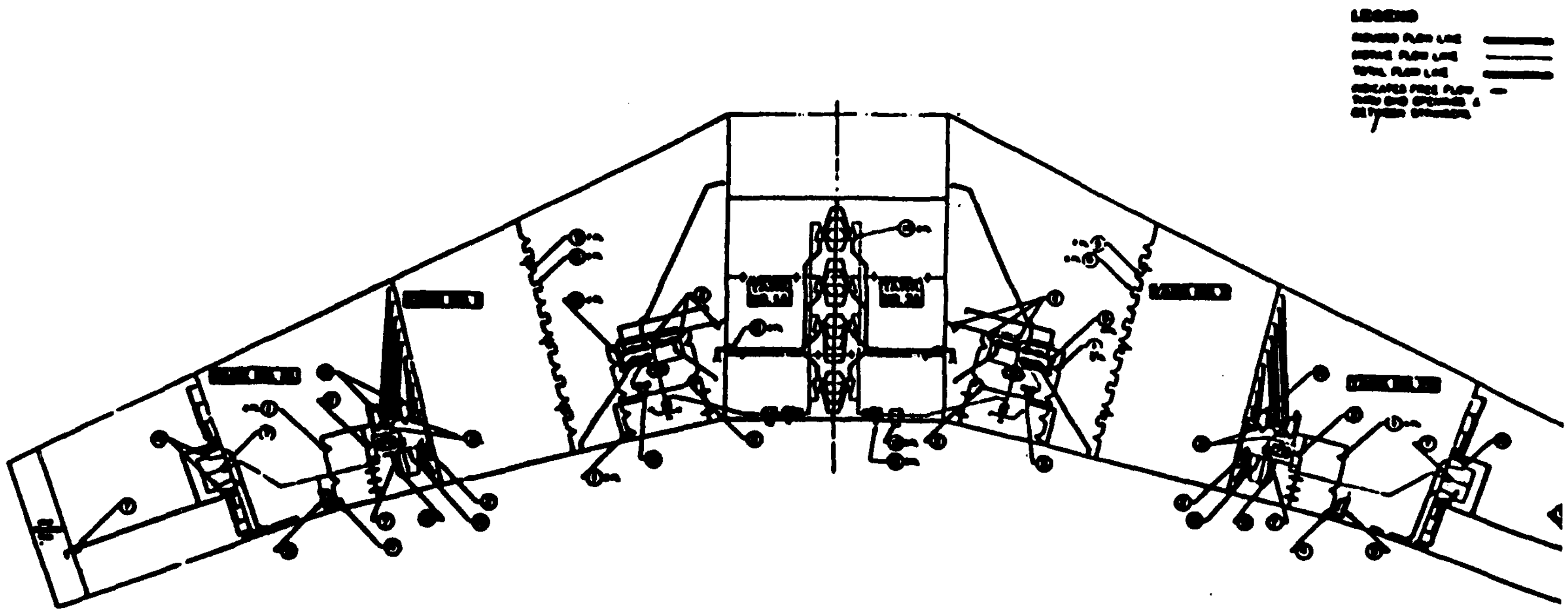

FIGURE B-4. LOCKHEED L-1011 FUEL SCAVENGE/TRANSFER SYSTEM

ID NUMBER NOMENCLATURE

1. FLAPPER VALVE
2. FLAPPER VALVE
3. FLAPPER VALVE
4. FLAPPER VALVE
5. FLAPPER VALVE
6. FLAPPER VALVE
7. CHECK VALVE
8. JET PUMP-SMALL
9. JET PUMP-LARGE
10. JET PUMP-COMPOUND
11. CHECK VALVE
12. STRAINER-CHECK VALVE
13. TRANSFER & SCAVENGE MOTIVE FUEL VALVE
14. JET PUMP-COMPOUND

NOMENCLATURE FOR FIGURE B-4.

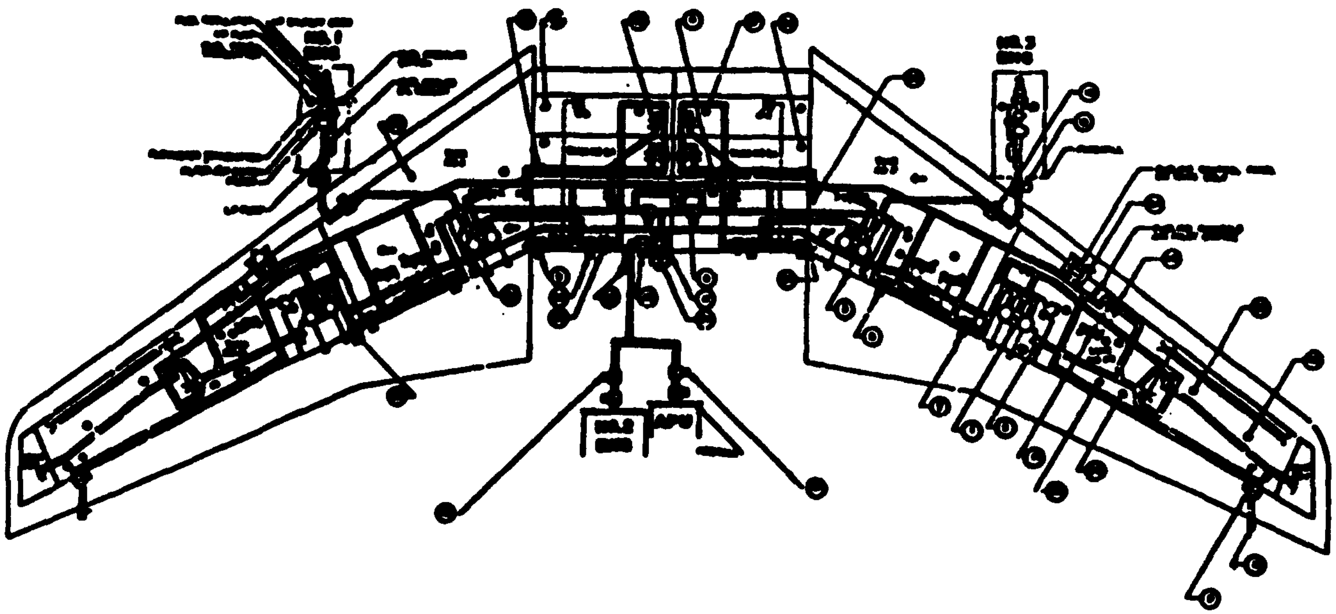

FIGURE B-5. LOCKHEED L-1011 FUEL SYSTEM SCHEMATIC

ID NUMBER NOMENCLATURE

1. BOOST PUMP WITH CHECK VALVES
2. VALVE TRANSFER CONTROL
3. PRESSURE SWITCH-BOOST PUMP
4. SHUTOFF VALVE
5. SHUTOFF VALVE DEFUELING
6. GRAVITY INTERCONNECTOR
7. SHUTOFF VALVE-DEFUELING
8. CROSSFEED VALVE-MOTOR OPERATED
9. SHUTOFF VALVE-JETTISON
10. FLAME ARRESTOR-JETTISON
11. SHUTOFF VALVE-MOTOR NO. 21 AND 28 TANK MANUALLY OPERATED
12. SHUTOFF VALVE-MOTOR OPERATED (FIREWALL)
13. SHUTOFF VALVE-MOTOR OPERATED (FIREWALL)
14. ENGINE NO. 2 TANK VALVE
15. ENGINE NO. 1 AND NO. 3 TANK VALVE
16. SHUTOFF-VALVE FUELING
17. SWITCH-FUEL LEVEL CONTROL
18. SHUTOFF VALVE-APU LINE (FIREWALL)
19. DRAIN VALVE
20. DRAIN VALVE-FUELING MANIFOLD
21. FLOW EQUALIZER
22. SHUTOFF VALVE-MANUALLY OPERATED (DRAIN AND TEST PORT)
23. CHECK VALVE-TRANSFER LINE
24. ADAPTOR-PRESSURE FUELING
25. OVERWING GRAVITY FILLER
26. SIGHT GAGE-FUEL LEVEL
27. SIGHT GAGE-FUEL LEVEL
28. GAGING PROBE ARRAY
29. TEMPERATURE SENSOR
30. TRANSFER & SCAVENGE MOTIVE FLOW VALVE
31. CHECK VALVE-FEED LINE
32. CHECK VALVE-TRANSFER LINE
33. GAGING PROBE ARRAY
34. DRAIN VALVE
35. STRAINER-CHECK VALVE
36. COMPOUND PUMP
37. FLAPPER CHECK VALVE
38. LEVEL SENSING UNIT

NOMENCLATURE FOR FIGURE B-5.

Appendix C

Committee Position: No. 9 "Crashworthy Fuel Systems"

The Airline Pilots Association (ALPA) Accident Survival Committee in Committee Position No. 9 has determined that investigation of the various engineering techniques used to construct crashworthy fuel systems should be given utmost priority. Among the various fire prevention proposals the committee is considering is the Engine Fuel Line Disconnect. The committee recommends that FAR 25.993 be amended to include a requirements that the fuel feed line between the wing/pylon structure and the engine fuel inlet point on turbine-powered aircraft incorporate a self-closing breakaway fitting which automatically closes off the flow of fuel in the event of accidental separation of the engine from the pylon. Further, the use of such breakaway fittings should be required at locations throughout the fuel system that are known as likely points of airframe distortion or failure due to crash forces. This is based on the U. S. Army's established design criteria for breakaway, self-closing fuel connections used in conjunction with crashworthy fuel tanks in helicopters that has proven successful. The ALPA Accident Survival Committee has declared that breakaway fuel fittings could have prevented the destruction of both an ONA DC-10 following an engine explosion and fire during takeoff at JFK Airport, and the EAL DC-9 following failure of the fuselage at the aft pressure bulkhead on landing at Fort Lauderdale, Florida. The full text of Committee Position: No 9 "Crashworthy Fuel Systems" is contained in the following pages.

COMMITTEE POSITION: NO. 9

CRASHWORTHY FUEL SYSTEMS

Construction improvements to the forerunner of the high-altitude, jet-powered aircraft have resulted in an airframe capable of remaining relatively intact when sustaining the survivable impact forces prevalent in those accidents occurring on or in the vicinity of the airport runway. There is still, however, the ever-present danger of fire caused by the spillage of highly flammable aviation fuels. Many aircraft occupants survive an accident, only to perish in the ensuing fire.

Programs either to prevent the occurrence or to minimize the severity of aircraft fires should reflect an appreciation of the crash-fire profile. Studies conducted by the International Civil Aviation Organization (ICAO), the British CAA, and ALPA indicate that 80% of aircraft accidents occur during landing or takeoff in the vicinity of the runway and overrun area. The bulk of these accidents occur when aircraft are moving at relatively low speeds and most are, or should be, survivable. Fire is the predominant hazard of typical accidents occurring in these areas. ICAO statistics relating fatalities occur during or subsequent to accidents within airport boundaries; 72% of aircraft fire deaths occur within the same area. Almost all of the fires are caused by inadequate fuel containment.

Investigation of the various engineering techniques used to construct crashworthy fuel systems should be given utmost priority. At present, the ALPA Accident Survival Committee is considering the following fire prevention techniques:

Low Volatility Fuel

Proposal: The appropriate sections of FARs 25 and 121 should be amended to require that fuel used by turbine-powered aircraft must have a flash point not less than 100 degrees Fahrenheit.

Explanation and justification: It is clear that there are significant safety benefits to be derived from the exclusive use of Jet A (kerosene) fuel in turbine-powered aircraft, particularly when such aircraft are involved in accidents where spillage has occurred. Jet A fuel is more difficult to ignite than is Jet B fuel; and, when ignited, Jet A fuel flames propagate at a much slower rate than do those of ignited Jet B fuel, especially at normal fuel temperatures. These fuel variations can be vitally important as they relate to accidents during which a short delay in fire development would allow occupants to escape. The proposed rule amendment should permit adequate time for operators to arrange the necessary transport, storage, and dispensing of equipment at airports where Jet A fuel is not yet available.

Vent System Flame Arresters

Proposal: That FAR 25.975 be amended to include a requirement for the prevention or suppression of flame propagation in fuel tank venting systems when flammable fuel-air mixtures are likely to exist. Such a system must not impair the function of the venting system under the range of climate conditions for which the aircraft is approved.

Explanation and Justification: Vent system outlets are points at which fuel vapors are exposed to possible ignition by sparks or ground fires. This can occur if there is fuel spillage or an accident during which a ground fire develops in the vicinity of the vent outlet. Flame-arresting and flame-suppressing designs that have been proven effective are now available and offer a significant measure of protection against tank explosion.

Engine Fuel Line Disconnect

Proposal: That FAR 25.993 be amended to include a requirement that the fuel feed line between wing/pylon structure and the engine fuel inlet point on turbine-powered aircraft incorporate a suitable self-closing breakaway fitting which automatically closes off the flow of fuel in the event of accidental separation of the engine from the pylon. Further, use of such breakaway fittings should be required at locations, throughout the fuel system, that are known or likely points of airframe distortion or failure due to crash forces.

Explanation and Justification: The U.S. Army has established design criteria for breakaway, self-closing fuel connections used in conjunction with crashworthy fuel tanks in helicopters, and has accumulated favorable service experience with this system. Breakaway fuel fittings could have prevented the destruction of both an ONA DC-10, following an engine explosion and fire during takeoff at JFK Airport, and the EAL DC-9, following failure of the fuselage at the aft pressure bulkhead on landing at Fort Lauderdale, Florida.

For many years, the requirements of FAR 25.561, which are also applicable to the structure of fuselage fuel tanks by reference in FAR 25.963(d), have been recognized as being inadequate and obsolete. Tests have shown that properly restrained occupants can easily survive 20 G crash deceleration forces. Therefore, we advocate early development of an amendment to FAR 25.561 that will provide the fuel tanks with a label of strength commensurate with human survivability.

It is recommended that the FAA initiate a program to crash test those protective measures for which basic research and development have already been concluded. At least the following should be included:

1. crashworthy fuselage fuel containers conforming to U.S. Army helicopter fuel tank criteria;
2. operational inerting systems.

We believe that prototype designs of various forms of explosion prevention systems and crash-resistant fuel tank systems should be installed in aircraft having structural and crash response characteristics similar to contemporary large turbine transport aircraft. These systems should then be crash tested to demonstrate the effectiveness of each method and to obtain more reliable information on weight, cost, and other penalties. Such a program should be sponsored by the FAA, supported and assisted by industry and other government agencies. Anti-misting fuel additives are particularly promising means of drastically reducing the post-crash fire hazard. However, additional research and development work are necessary. It is recommended that the FAA assign sufficient priority and funding to enable follow-up research and development to proceed as rapidly as possible.

Fuel Containment.

Ignited fuel spillage inside the fuselage area will create almost instantaneously an unsurvivable cabin environment. In the event of a water-contact accident, spilled fuel floating on the water will cause serious damage to the lungs and respiratory tracts of survivors, potentially resulting in deaths.

Current requirements pertaining to fuselage fuel tanks include provisions for: isolating the tank from passenger areas (FAR 25.967[e]); withstanding emergency landing conditions (FAR 25.963[d]); and protection from ground contact. The emergency landing conditions are stated in FAR 25.561 as: upward 2.0 G; forward 9.0 G; sideward 1.5 G; and downward 4.5 G. These forces are known to be much lower than a person properly restrained in a seat can withstand without injury.

Wing-center-section fuel tanks are usually constructed as flexible, nonmetallic cells located within the wing box-bounded by spar webs, bulkheads, and upper and lower carry-through skin. The wing structure surrounding the cell is consequently strong and resistant to rupture. Areas in the fuselage outside the wing carry-through structure are less protected and more vulnerable to crash-damage. This results in increased potential for fuel spillage and fire, and decreases the probability of a successful postcrash evacuation.

The U.S. Army's development and application of crashworthy fuel systems for helicopters has been very successful. This design criterion is available and can be applied to the design of commercial transport aircraft-with some weight and capacity penalties. Weight penalties could be reduced to reasonable values by the selection of design requirements appropriate to the tank location.

Proposal: Any fuel carried in the wing center section of the fuselage fuel tank shall be contained in a tank-within-a-tank, the inner tank to be constructed of crash-resistant material. Such tanks shall be equipped with breakaway self-sealing connections. All vent lines for these tanks shall be equipped with a vent-flame-suppression system.