Aircraft Fuel System Safety Program Report

Prepared by the International Aviation Industry

August 4, 2000

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AIR TRANSPORT ASSOCIATION

Aeromexico
Air Canada
Airborne Express
Alaska Airlines
Aloha Airlines
American Airlines
American Trans Air
America West Airlines
Atlas Air
Canadian Airlines International
Continental Airlines
Delta Air Lines
DHL Airways
Emery Worldwide
Evergreen International Air Lines
Federal Express
Hawaiian Airlines
KLM Royal Dutch Airlines
Mexicana Airlines
Midwest Express
Northwest Airlines
Polar Air Cargo
Southwest Airlines
Trans World Airlines
United Airlines
United Parcel Services
US Airways

AEA Association of European Airlines

Adria Airways
Aer Lingus
Air France
Air Malta
Alitalia
Austrian Airlines
Balkan
British Airways
British Midland
Cargolux
Croatia Airlines
CSA
Cyprus Airways
Finnair
Iberia
Icelandair
JAT
KLM Royal Dutch Airlines
Lufthansa
Luxair
Malev
Olympic Airways
Sabena
SAS
Swissair
TAP Air Portugal
Turkish Airlines

ASSOCIATION OF ASIA PACIFIC AIRLINES

Air New Zealand
All Nippon Airways
Ansett Australia
Asiana Airlines
Cathay Pacific Airways
China Airlines
Eva Air
Garuda Indonesia
Japan Airlines
Korean Air
Malaysia Airlines
Philippine Airlines
Qantas Airways
Royal Brunei Airlines
Singapore Airlines
Thai Airways International

Aerospace Industries Association

AAI Corporation
The Aerostructure Corporation
Alliant Techsystems Inc.
American Pacific Corporation
Analytical Graphics Inc.
Argo-Tech Corporation
B.H.Aircraft Company, Inc.
BAE SYSTEMS North America Inc.
Barnes Aerospace
The Boeing Company
Cordant Technologies, Inc.
Curtiss-Wright Flight Systems
Dowty Aerospace
Ducommun Incorporated
Dupont Company
Esterline Technologies
Fairchild Aerospace Corporation
Fairchild Fasteners
Final Analysis, Inc.
GKN Aerospace Inc.
GTE Internetworking
GenCorp
General Dynamics Corporation
General Electric Company
The BFGoodrich Company
Groen Brothers Aviation, Inc.
Harris Corporation
HEICO Corporation
Hexcel Corporation
Honeywell
Hughes Electronics Corporation
ITT Industries
Interturbine Corporation
Kaman Aerospace Corporation
Kistler Aerospace Corporation
Litton Industries, Inc.
Lockheed Martin Corporation
MOOG Inc.
The Nordam Group
Northrop Grumman Corporation
Omega Air, Inc.
Parker Hannifin Corporation
Raytheon Company
Robinson Helicopter Company, Inc.
Rockwell Collins, Inc.
Rolls-Royce North America Inc.
Senior Flexonics Inc
Stellex Aerostructures, Inc.
Swales Aerospace
TRW Inc.
Teleflex, Inc./TFX Sermatech
Textron Inc.
Triumph Controls, Inc.
United Defense
United Technologies Corporation
Woodward Governor Company

The European Association of Aerospace Industries

AECMA

Aerospatiale Matra
Airbus Industrie
Alenia
BAE SYSTEMS Airbus
BAE SYSTEMS Regional Aircraft
Britten Norman
CASA
DaimlerChrysler Aerospace Airbus
Dassault Aviation
Fairchild Dornier
Fokker Services
MTU
Rolls-Royce
Rolls Royce Deutschland
SNECMA
Saab
and consolidated with
AAI (Austrian Aeronautics Industries group)
GEBECOMA (Belgian Aerospace Industries Association)
AAM CR (Association of the Aviation Manufacturers of the Czech Republic)
FDAI (Foreningen for Dansk Aerospace Industri)
FAI (Finnish Aerospace Industries)
GIFAS (Groupement des Industries Françaises Aéronautiques et Spatiales)
HAIG (Hellenic Aerospace Industries Group)
BDLI (Bundesverband der Deutschen Luft- und Raumfahrtindustrie)
FAEI (Federation of Aerospace Enterprises in Ireland)
AIAD (Associazione Industrie per l'Aerospazio i Sistemi e la Difesa)
LAI (Luxembourg Aerospace Industries)
NAI (Netherlands Aerospace Industries)
ADAP (Associação do Desenvolvimento Aeronáutico de Portugal)
ATECMA (Agrupación Tecnica Española de Constructores de Material Aerospacial)
SAI (Swedish Aerospace Industries)
SBAC (Society of British Aerospace Companies)

Also

Bombardier Aerospace

CONTENTS

Contents (continued)

Contents (continued)

GLOSSARY

AAL	American Airlines
AAPA	Association of Asia Pacific Airlines
ACN	Air Canada
AD	Airworthiness directive
AEA	Association of European Airlines
AECMA	Association Europeenne des Constructeurs de Materiel Aerospatiale
AFR	Air France
AFSSP	Aircraft Fuel System Safety Program
AIA	Aerospace Industries Association
AMM	Airplane maintenance manual
ANA	All Nippon Airways
A/P	Airplane
ARAC	Aviation Rulemaking Advisory Committee
ASA	Alaska Airlines
ATA	Air Transport Association
ATA	American Trans Air
AWG	Airplane working group
BAB	British Airways
CAL	Continental Airlines
CAN	Canadian Air Force
CAT	Cathay Pacific Airways
COR	Corse Air International
DAL	Delta Air Lines
FAA	Federal Aviation Administration
FED	FedEx
FOD	Foreign object debris
FQIS	Fuel quantity indication system
FSSLT	Fuel System Safety Leadership Team
FTHWG	Fuel Tank Harmonization Working Group
HMV	Heavy maintenance visit
IEEE	Institute of Electrical and Electronics Engineers
ISB	Inspection service bulletin
JAL	Japan Airlines

KLM	KLM—Royal Dutch Airlines
LMALC	Lockheed Martin Aircraft and Logistics Centers
MLI	Magnetic level indicator
NG	Next Generation
NPRM	Notice of Proposed Rule Making
NTSB	National Transportation Safety Board
NWA	Northwest Airlines
OEM	Original equipment manufacturer
QAN	Qantas
SAE	Society of Automotive Engineering
SB	Service bulletin
SDR	Service difficulty report (FAA)
SFAR	Special federal aviation regulation (FAA)
SOV	Shutoff valve
SIL	Service information letter
SWA	Southwest Airlines
TC	Type certificate
TWA	Trans World Airlines
UAL	United Airlines
UPS	United Parcel Service
USA	US Airways

1.0 EXECUTIVE SUMMARY

1.1 Introduction

On July 17, 1996, a Boeing model 747-131 operated by Trans World Airlines, Inc., (TWA) exploded in flight shortly after takeoff from John F. Kennedy International Airport in New York. This tragic accident launched the most complicated and comprehensive wreckage recovery, aircraft reconstruction, and accident investigation in the history of commercial aviation. An investigation headed by the National Transportation Safety Board (NTSB) has not, as of this date, determined the primary cause of the accident. Information gathered from the investigation suggests that the airplane's center wing fuel tank exploded. However, the ignition source remains unidentified.

In the wake of this accident, the collective realization emerged that additional information needed to be gathered regarding the condition of airplane fuel tank systems in the world fleet. Because effective action and enlightened regulation both depend on a solid grounding in facts and data, it became clear that the industry needed to develop a comprehensive understanding of

- How and to what degree the fuel tank systems of the world fleet are aging in service.
- What effects environmental factors such as geographic distribution might have over time on airplane fuel tank systems.

1.2 About the Aircraft Fuel System Safety Program (AFSSP)

Consequently, the industry in 1997 committed itself to assessing the state of the in-service fleet around the world. To accomplish this ambitious goal, the AFSSP was formed. Participants in this voluntary industry program include present and past turbine-powered airliner manufacturers, airlines, industry organizations, and airworthiness authorities from around the world. The following mission statement has guided and focused the efforts of the AFSSP:

> *"Through worldwide industry collaboration, take appropriate action to ensure, maintain, and enhance the safety of fuel systems throughout the life of the aircraft."*

Different airplane working groups (AWG) in the AFSSP addressed the airplanes in the world fleet built by different original equipment manufacturers (OEM). The AWG OEMs began by reviewing

- Their fuel system design requirements.
- The drawings used to build their airplanes.
- The processes used to manufacture and install the fuel systems of their airplanes.

Following this comprehensive review of fuel system design and manufacture, the AFSSP defined the requirements for a sampling inspection program to be conducted of the in-service airliner fleet. AFSSP participants—operators, OEMs, or both together—performed the actual inspections.

1.3 Scope

The AFSSP, a voluntary industry program, has gathered ample information about the overall integrity of the design and maintenance of the in-service fleet. Well over 100,000 labor-hours have been expended performing inspections of the world fleet. As of June 1, 2000, inspections have been completed on 990 airplanes operated by 160 air carriers in diverse operating environments on six continents. A small number of additional inspections remain to be performed and are scheduled for completion in 2000. This effort attests to the industry's ongoing commitment to continuously enhancing the safety of air travel.

1.4 About This Document

This document presents the final report of the AFSSP. In Section 2, the AFSSP participants are identified, the overall results of the inspection effort is given, and industry recommendations for continued and enhanced fuel system safety are presented.

Sections 3 through 8 of this document are the individual reports of the six AWGs: Airbus, BAE SYSTEMS, Boeing (including former Douglas/McDonnell Douglas commercial jetliners), Bombardier, Fokker, and Lockheed Martin. These AWG reports offer detailed, OEM-specific inspection findings about the respective in-service fleets. They describe actions that have been taken or are being taken as a result of the findings.

It should be noted that this document addresses only the AFSSP, which is just one of many important efforts undertaken by the aviation industry to enhance fuel systems in response to the loss of TWA Flight 800. Examples of other activities that are providing valuable insight and actions to enhance airplane fuel system safety include the TWA 800 accident investigation; the Aviation Rulemaking Advisory Committee (ARAC) Fuel Tank Harmonization Working Group (FTHWG); the FAA's Notice of Proposed Rule Making (NPRM) 99-18 "Transport Airplane Fuel Tank System Design Review, Flammability Reduction, and Maintenance and Inspection Requirements;" the Aging Aircraft System program; numerous government- and industry-sponsored research projects; ongoing regulatory authority continued airworthiness programs; and manufacturer and operator safety programs. These activities are generating and will continue to generate improvements and enhancements to aircraft fuel systems.

1.5 Findings

Overall, the design/manufacturing reviews and fleet-sampling inspections performed by the AFSSP have shown that fuel tanks and fuel systems are not degrading over time, and that manufacturers' design requirements are conservative and provide ample design margin as well as built-in redundancy.

- Fuel systems were generally found to be in good to excellent condition unless subject to initial manufacturing error or subsequent modification or damage.
- No indications were found that components or installed wiring were being adversely affected on a long-term basis by prolonged exposure to the fuel tank environment.

- No correlation was found between geographic location of airplane operation and fuel system integrity.
- In some instances, degradation was found in bonding values relative to original manufacturing specifications, but the measured values were well within safe margins for continued airworthiness. Each manufacturer is addressing any unique issues related to its fleet.
- The vast majority of bonding jumpers were found in as-manufactured condition—there were isolated instances of broken, corroded, or missing jumpers, but those events showed a random distribution with no correlation to airplane age.
- Before the inspection program, findings suggested that the use of metallic conduit to route wiring might result in unacceptable levels of degradation to the wiring. This finding was confirmed during the inspection program and is being addressed accordingly.
- Because discrepancies generally have external causes, tanks with fewer entries are less likely to have them.

1.6 Actions and Recommendations

The results of the AFSSP have shown that issues are specific to, or unique for, a particular manufacturer or component design, specification, process, or installation. As such, each aircraft manufacturer is developing the necessary corrective actions to address these issues.

In particular, the industry is now addressing the existing use of metal conduit to route wire through fuel tanks. This practice will be critically evaluated to determine how present designs can be enhanced and whether periodic inspections are desirable. Alternate wire routing methods will be considered for new designs to alleviate the concerns associated with this practice.

Based on AFSSP findings, the industry recommends additional training for manufacturing and maintenance personnel, and will be reviewing or modifying the existing fuel system maintenance practices to:

- Substantiate the integrity of bonding straps through
  - Long-term periodic visual/tactile inspection to verify bond integrity.
  - Enhancements to existing maintenance instructions for bonding jumper maintenance and replacement.
- Provide periodic inspection criteria for FQIS wiring and components that are more detailed to better define conditions and items to be inspected during general tank inspections.
- Provide for the periodic in-situ inspection of fuel pumps and associated wiring, fuel lines, and fittings.

The following items are presently part of the periodic heavy maintenance or structural inspections that are already being conducted, so no change to existing practices is recommended.

- Inspection for foreign object debris.
- General tank condition.

While the AFSSP inspection program has confirmed that manufacturers' standards for fuel tank bonding are effective and robust in service, it has also highlighted the fact that these standards vary. Therefore, in addition to the bonding inspections noted above, the industry recommends that groups such as the SAE or IEEE develop uniform standards or processes for

- Fuel tank bonding requirements and test techniques.
- Bonding jumpers used in fuel tanks.

As a final note, the AFSSP inspection program did not require the removal or teardown of fuel system components for a detailed inspection of individual pieces and parts. However, findings outside of this inspection program have shown that improper repair or maintenance of fuel system components can lead to safety issues. The industry therefore believes that it is critical to have well-documented maintenance procedures and qualified repair stations and personnel maintaining fuel system components to ensure that design integrity is maintained.

1.7 Conclusions

In the wake of the TWA 800 disaster, questions were raised as to whether airplane fuel systems were deteriorating as airplanes aged in commercial service. As described above, the large-scale design review and in-service airplane fleet inspection effort performed by the industry via the AFSSP has answered these concerns with facts and data showing that the fuel tank systems of the world fleet are soundly designed and do not tend to degrade as airplanes age. This survey process has also showed where improvements can be made to further enhance fuel-system safety and ensure the continuing airworthiness of the in-service fleet.

2.0 OVERVIEW

2.1 Introduction

On July 17, 1996, a Boeing model 747-131 operated by Trans World Airlines, Inc., (TWA) exploded in flight shortly after takeoff from John F. Kennedy International Airport in New York. This tragic accident launched the most complicated and comprehensive wreckage recovery, aircraft reconstruction, and accident investigation in the history of commercial aviation. An investigation headed by the National Transportation Safety Board (NTSB) has not, as of this date, determined the primary cause of the accident. Information gathered from the investigation suggests that the airplane's center wing fuel tank exploded. However, the ignition source remains unidentified.

On December 13, 1996, the NTSB issued four preliminary recommendations for changes in regulations to the Federal Aviation Administration (FAA). On April 3, 1997, the FAA issued a notice soliciting public comments on the feasibility of implementing these recommendations. This notice addressed a wide variety of subjects. In support of the FAA's request for comments, airplane manufacturers and airline operators from around the world decided to combine their expertise and jointly initiated a comprehensive review of fuel system design and airline operational practices to study the proposals and other options to enhance fuel system safety. A response titled, "The response to the Federal Aviation Administration's Request for Comment Titled *'Fuel Tank Ignition Prevention Measures' Dated April 3, 1997"* dated August 1, 1997, was submitted jointly by the Air Transport Association of America (ATA), the Association of Asia Pacific Airlines (AAPA), the European Association of Aerospace Industries (AECMA), the Association of European Airlines (AEA), and the Aerospace Industries Association (AIA).

In the course of preparing the industry's response, and as one of the industry's recommendations, an extensive voluntary program was initiated to assess the condition of fuel tank systems in the fleet and determine whether design and continuing airworthiness philosophies employed in the design and maintenance of fuel tank systems ensured the safety of the traveling public. The program is titled the Aircraft Fuel System Safety Program (AFSSP). This report summarizes the results to date of this industry program.

2.2 Scope

The AFSSP is one of many important efforts undertaken by the aviation industry to enhance fuel systems in response to the loss of TWA Flight 800. Other activities that are providing valuable insight and actions with regard to airplane fuel system safety include the TWA 800 accident investigation; the Aviation Rulemaking Advisory Committee (ARAC) Fuel Tank Harmonization Working Group (FTHWG); the FAA's Notice of Proposed Rule Making (NPRM) 99-18 "Transport Airplane Fuel Tank System Design Review, Flammability Reduction, and Maintenance and Inspection Requirements;" the Aging Aircraft System program, numerous government- and industry-sponsored research projects, ongoing regulatory authority continued airworthiness programs, and manufacturer and operator safety programs. These activities are generating and will continue to generate improvements and enhancements to aircraft fuel systems.

The scope of this report is limited to the AFSSP.

2.3 Industry Commitment

The following excerpt from the industry's "Fuel Tank Ignition Prevention Measures" response to the FAA outlines the goals of the AFSSP.

> *"The industry is fully committed to enhancing aviation safety and believes that efforts should be based on facts. The data available at this time indicates that the best prevention strategy should focus on improvements—design, operation, or maintenance—to enhance fuel tank systems. Therefore, the industry plans to voluntarily undertake either a sampling of high-time aircraft or major fuel tank inspection programs to verify (1) the integrity of wiring and grounding straps; (2) the conditions of fuel pumps, fuel lines and fittings: and (3) the electrical bonding on all equipment. The inspection program will not be limited to the Boeing 747; rather, Airbus, Boeing, Lockheed Martin, and McDonnell Douglas[1] have agreed to jointly sponsor a program that covers all of their respective models. In addition, the airlines represented by the ATA, AEA, and the AAPA have agreed to participate in these inspections. The inspection programs findings will be coordinated through the international industry fuel tank inspection task forces. The industry proposes that task force participation include the FAA and international authorities. Subject to agreement with the authorities, the industry would propose to share task force findings and plans with the public on a timely basis."*

The following mission statement was developed by the AFFSP to guide and focus the efforts of this program:

> *"Through worldwide industry collaboration, take appropriate action to ensure, maintain and enhance the safety of fuel systems throughout the life of the aircraft."*

The AFSSP has encompassed four areas of activity:

- Assess the in-service condition of fuel systems in the commercial aviation fleet.
- Analyze data and share results.
- Based on inspection data and analysis, recommend enhancements to current design, operations, and maintenance practices and programs.
- Communicate results.

[1] British Aerospace, Fokker, and Bombardier became official members of the AFSSP shortly after the inception of the program.

2.4 Participants and Organizations

The AFSSP is jointly sponsored by the following organizations:

- Air Transport Association of America (ATA).
- Association of Asia Pacific Airlines (AAPA).
- European Association of Aerospace Industries (AECMA).
- Association of European Airlines (AEA).
- Aerospace Industries Association (AIA).

The AFSSP is directed by the Fuel System Safety Leadership Team (FSSLT), which is chaired by the ATA and comprises senior expert representatives from the air carriers, manufacturers, and airworthiness authorities. Organizations participating on the FSSLT include the following:

Manufacturers
Airbus Industrie
BAE Systems
The Boeing Company
Bombardier Aerospace
Fokker Services b.v.
Lockheed Martin

Air Carriers
Air Canada
American Airlines
American Trans Air
British Airways
Continental Airlines
Delta Air Lines
Federal Express
KLM Royal Dutch Airlines
Northwest Airlines
Qantas
United Airlines
United Parcel Service
US Airways

Figure 2-1: AFSSP Participants

In addition to the carriers noted above, many airlines and other operators participated in the airplane inspections coordinated by the different manufacturers' airplane working groups (AWG). This extensive participation allowed the collection of a wide range and variety of data encompassing the worldwide in-service fleet. Figure 2-2 identifies these participating operators.

Operators			
Abu Dhabi	Aer Lingus	Aeroflot	Aerolineas Argentinas
Aeromexico	Air 2000	Air Afrique	Air BC
Air Canada	Air France	Air Gabon	Air Holland
Air Hong Kong	Air India	Air Kilroe	Air Littoral
Air Madagascar	Air Malta	Air National	Air New Zealand
Air Nova	Air One	Air Transat	Airbus Industrie
Airtours International	Alaska Airlines	Alitalia	All Nippon Airways
Alpi Eagles	Amedeo Aviation Corp.	American	American Trans Air
America West	Ansett Australia	Ansett New Zealand	Arco
Argentine Air Force	Asiana	Atlantic Coast Airlines	Atlas Air
Austrian	Avianca	Belgian Air Force	Biman Bangladesh Corp.
Braathens	Britannia	British Airways	British Midland
Caledonian Airways	Canadian International	Canadian Regional	Cargolux
Cathay Pacific	China Airlines	China Southern	Comair
Continental	Corse Air	C–S Aviation	Cyprus Airways
DAT	Delta Air Lines	Denim Air	DHL
Dubai	Eastern Australia	Egyptair	El Al
Emerald Airways	Emirates	Empire Airlines	European Air Transport
Eurowings	Evergreen	FedEx	Finnair
Flight West Airlines	Flying Colours	Futura	Gameco
Garuda	German Air Force	Greenlandair	Gulf Air
Hapag-Lloyd	Highland Air	HM the Sultan's Flight	Horizon Air
Iberia	Icelandair	JAIR	Japan Air Systems
Japan Airlines	Japan Asia Airways	Jersey European	Kitty Hawk
KLC	KLM	KLM UK	Aerospatiale
LAM Mozambique	Lauda Air	LTU	Lufthansa
Lufthansa City Line	Malaysia Airlines	Manx Airlines	Martinair
Mesaba	Mexicana	Monarch	Mongolian Airlines
Mountain Air Cargo	NASA	National Jet Systems	Nav Canada
Northwest	Olympic Airways	Pakistan	Pegasus
Polar Air Cargo	Polish Air	Portugalia	Precidencia Argentina
Private (B3R B4A)	Qantas	Qatar Amiri Flight	Romanian Air Transport
Royal Air Maroc	Royal Flight of Oman	Ryanair	SA Airlink
Singapore	Sky Service	South African	Star Air Tours
Sabena	SATA	Saudi Arabian	Saudi Royal Flight
Sudan Airways	Swissair	TAM Brazil	Thai Airways
Trans World Airlines	Transaero	Transasia Airways	Transworld
Triangle Aircraft Svcs.	Tunisair	Turkish Airlines	United Airlines
United Parcel Service	US Airways	US Airways Shuttle	USAF
Virgin Atlantic	WestJet	Whirlpool	Wuhan Airlines

Figure 2-2: Participants in the AFSSP Fleet Inspection Program

Sections 3 through 8 of this document list the above operators according to their participation in the various manufacturers' inspection efforts. Many operators are named in more than one of these sections because airplanes built by more than one manufacturer were inspected within their fleets.

2.4.1 Airworthiness Authorities

Shortly after the inception of the AFSSP, it was decided to invite the participation of the airworthiness authorities from different regions of the world, providing the opportunity for these organizations to monitor and contribute to the activities undertaken by the industry. Their participation was key to the success of this effort.

- Federal Aviation Administration (FAA) of the United States.
- Civil Aviation Authority (CAA) of the United Kingdom.
- Joint Airworthiness Authority (JAA) of Europe.
- Direction Générale de l'Aviation Civile (DGAC) of France.
- Transport Canada.

2.4.2 AFSSP Organization

The organizational structure of the AFSSP is as follows:

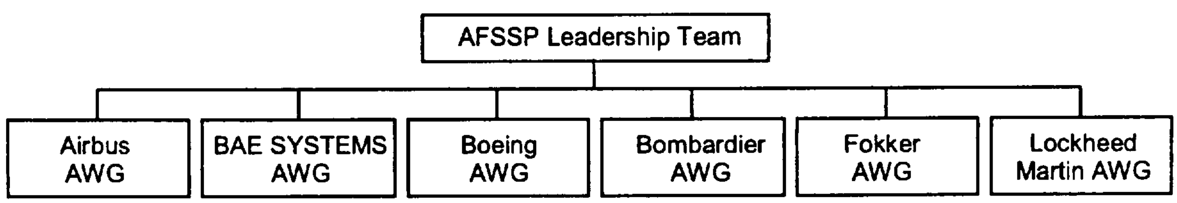

Figure 2-3: AFSSP Organizational Structure

The role of the leadership team is to

- Ensure commitment to the program.
- Manage goals, objectives and schedule.
- Monitor the "working together rules," act as arbitrator.
- Manage external communication.
- Ensure timely completion of the program and publication of this final report.

The leadership team met 11 times over the last three years and is responsible for monitoring progress, exchanging results among working groups, and providing direction for the program.

2.4.3 Airplane Working Groups

There are presently six airplane working groups (AWG) representing the manufacturers as noted above. The AWGs are responsible for the following activities:

- Planning and scheduling of airplane inspection programs.
- Creation of inspection documents (e.g., service bulletins).
- Validation of inspection documents (e.g., lead airline process).
- Collection and analysis of inspection data.
- Review of past service records, findings, and reports.
- Assessment of the effectiveness of current maintenance practices.
- Recommendations for follow-on actions.
- Inputs to the final report.

Each manufacturer is the focal for its AWG and is responsible for coordinating these activities with its member airlines. The following diagram outlines the process that the AWGs incorporated into their individual fuel-system safety programs.

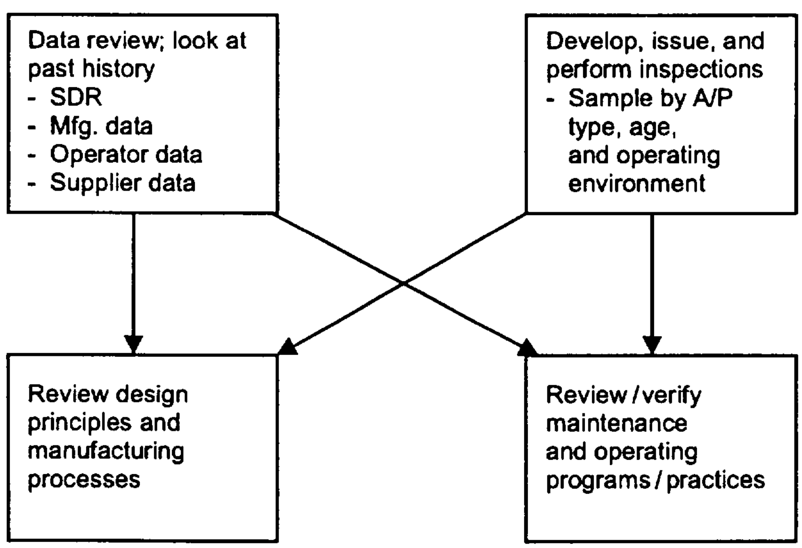

Figure 2-4: The AWG Process

Initially, the airplane working groups were tasked to conduct a historical review of operator and manufacturer data related to fuel system findings. This review provided a list of "lessons learned" that could be applied in the design reviews and development of maintenance or operating instruction enhancements. Generally, a review of design principles and manufacturing processes was performed to develop or validate the inspection instructions for each model addressed by the AWG inspection programs.

In preparing the fuel system inspection documents, each AWG addressed the following key areas:

- Integrity of wiring and bonding straps.
- Condition of fuel quantity indication system wiring and components.
- Condition of fuel pumps, fuel lines, and fittings.
- Electrical bonding and grounding of fuel system equipment.
- Inspection for foreign object debris.
- General tank condition.

Subsequent sections of this document present reports by the various AWGs established by the participating manufacturers. These sections provide additional information on the FSSLT composition, the inspection approach, and the inspected airplane type families. Included in these reports are statistics about the inspection process, the actual inspection results, and actions that have been or are being taken as a result of the inspection findings.

2.5 Industry Inspection Results

As of June 1, 2000, AFSSP inspections had been performed on 990 airplanes built by seven different manufactures (Boeing and McDonnell Douglas were of course separate OEMs for type design and manufacture). These airplanes are flown by 160 air carriers in diverse operating environments on six different continents. A small number of additional inspections remain to be accomplished and are planned for completion in 2000.

The following table summarizes the airplanes inspected:

Aircraft type	Inspected	Remaining
Airbus A300/A310	90	0
Airbus A320/A321	24	0
Airbus A330/A340	19	0
BAE HS 748/ATP	11	0
BAE J31/J32	14	0
BAE J41	15	0
BAE 146/Avro RJ	29	0
Boeing 727	15	0
Boeing 737	97	3
Boeing 747	440	0

As of June 1, 2000.

Aircraft type	Inspected	Remaining
Boeing 757	80	0
Boeing 767	57	0
Bombardier Dash-7 / -8	18	4
Bombardier CRJ	12	0
Fokker F27/F50/F60	9	13
Fokker F28/F70/F100	33	11
Lockheed Martin L-1011	6	0
McD'll Douglas DC-9	6	0
McD'll Douglas MD-80	5	0
McD'll D. DC-10/MD-11	10	0
Industry total:	**990**	**31**

Figure 2-5: AFSSP Airplane Inspections in the World Fleet

This AFSSP large-scale sampling inspection of the world fleet produced the following findings.

2.5.1 Integrity of Wiring and Bonding Jumpers

The vast majority of the bonding jumpers were found to be in excellent condition. There were isolated instances of broken, missing, or corroded jumpers, but these were random in nature and did not exhibit any correlation with aging or location. Even though there were reports of minor corrosion/discoloration of bonding jumpers, the data showed that bond integrity was not affected. Any discrepancies found were resolved by each manufacturer on a case-by-case basis.

With respect to other wiring in the fuel tank, findings showed that the types of wire being used in the fuel tank were not degraded by the fuel tank environment (see next topic below). Again, some discrepancies were found related to the installation and are being addressed on a case-by-case basis by the manufacturers.

Findings in many cases showed that wire installed in metallic conduits is susceptible to abrasion. The affected manufacturers have evaluated or are evaluating their fuel system wiring conduit installations to address this issue.

2.5.2 Condition of FQIS Wiring and Components

The wiring and components of the fuel quantity indication system (FQIS) were found to be in good condition across the fleet except as noted below.

Boeing issued a service bulletin for the 747 Classic (747-100, -200, -300, SP, and SR), which the FAA has mandated, specifying the inspection and replacement of wiring in the fuel tank that is attached to older style fuel probe terminal blocks, which can possibly damage the FQIS wiring.

For those manufacturers whose designs included the routing of FQIS wiring in metal conduit, additional review and corrective action has been taken to address abrasion and wire separation issues.

Instances of sulfide contamination were observed on various models where there was exposed copper or silver on the wiring or the components, but no system issues were reported associated with this contamination. The FAA is addressing sulfide contamination with a research effort to determine its effect and, if required, the process for cleaning and sealing affected components.

2.5.3 Condition of Fuel Pumps, Fuel Lines, and Fittings

Overall, the condition of the fuel lines and fittings is excellent. Most discrepancies were isolated and minor in nature and were either related to an installation design or to collateral damage caused during an entry into the fuel tank for other purposes. Nothing indicated a chronic problem requiring immediate or long-term action. There was one instance where Bombardier de Havilland issued a service bulletin, mandated by Transport Canada, to inspect and rectify a fuel coupler that was incorrectly installed.

The external inspection of fuel pumps showed them to be in good condition. Again, only minor discrepancies were noted. It should be noted, however, that the AFSSP inspection process did not require the removal, teardown, and detailed component inspection of fuel pump installations.

Currently, a number of fuel pump installation issues exist across the fleet with respect to internal wear or corrosion. The industry and responsible regulatory authorities are aware of these issues and have taken the appropriate action to address them.

2.5.4 Electrical Bonding and Grounding of Fuel System Equipment

Electrical bonding and grounding of fuel system components falls into three areas:

- Static bonding.
- Fault current bonding.
- Lightning bonding.

The inspections showed that static bonds do not exhibit aging. There were no trends to suggest that the older the airplane, the higher the bonding resistance of the static bonds. Findings did show that some static bonds were exceeding their original manufacturing resistance limit, but they were still well within an acceptable limit for the dissipation of static-charge buildup.

With respect to fault current bonds, dependent upon the model/manufacturer, these bonds were either acceptable or showed some aging effects. For those manufacturers whose fault current bonds are aging, the designs are being enhanced to increase existing margins, and periodic inspections are being considered to ensure that these margins are maintained.

Overall, there were no issues associated with lightning bonds. Ongoing studies are now being conducted by some manufacturers to validate lightning bonding criteria and in-service limits to further enhance knowledge in this area.

2.5.5 Inspection for Foreign Object Debris (FOD)

There were no significant findings regarding the presence of FOD in the fuel tanks or damage caused by FOD in the fuel tanks.

2.5.6 General Tank Condition

The general condition of the fuel tanks across the operational fleet was found to be excellent regardless of the age of the airplane.

2.5.7 Geographic and Environmental Conditions

When evaluating the data collected on the items noted above, each manufacturer assessed the inspection results with respect to determining if there were any correlation between the geographic location or operating environment of various airplane fleets. All manufacturers observed a random distribution of inspection findings regardless of geographic location or operating environment of inspected airplanes in their in-service fleets.

2.6 Actions and Recommendations

This inspection program's results have shown that issues are specific to, or unique for, a particular manufacturer or component design, specification, process, or installation. As such, each aircraft manufacturer is developing the necessary corrective actions to address these issues.

In particular, the industry is now addressing the existing use of metal conduit to route wire through fuel tanks. This practice will be critically evaluated to determine how present designs can be enhanced and whether periodic inspections are desirable. Alternate wire routing methods will be considered for new designs to alleviate the concerns associated with this practice.

Based on AFSSP findings, the industry recommends additional training for manufacturing and maintenance personnel, and will be reviewing or modifying the existing fuel system maintenance practices to:

- Substantiate the integrity of bonding straps through
    - Long-term periodic visual / tactile inspection to verify bond integrity.
    - Enhancements to existing maintenance instructions for bonding jumper maintenance and replacement.
- Provide periodic inspection criteria for FQIS wiring and components that are more detailed to better define conditions and items to be inspected during general tank inspections.
- Provide for the periodic in-situ inspection of fuel pumps and associated wiring, fuel lines, and fittings.

The following items are presently part of the periodic heavy maintenance or structural inspections that are already being conducted, so no change to existing practices is recommended.

- Inspection for foreign object debris.
- General tank condition.

While the AFSSP inspection program has confirmed that manufacturers' standards for fuel tank bonding are effective and robust in service, it has also highlighted the fact that these standards vary. In addition to the bonding inspections noted above, therefore, the industry recommends that groups such as the SAE or IEEE develop uniform standards or processes for

- Fuel tank bonding requirements and test techniques.
- Bonding jumpers used in fuel tanks.

As a final note, the AFSSP inspection program did not require the removal and teardown of fuel system components for a detailed inspection of individual pieces or parts. However, findings outside of this inspection program have shown that improper repair or maintenance of fuel system components can lead to safety issues.

Therefore, the industry believes it is critical to have well-documented maintenance procedures and qualified repair stations and personnel maintaining fuel system components to ensure that design integrity is maintained.

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3.0 AIRBUS WORKING GROUP REPORT

3.1 Introduction

Airbus Industrie were active from the outset of the aviation industry initiatives to enhance fuel system safety after the TWA 800 accident. The AFSSP is one of the many programs in which Airbus Industrie has active participation although the events that led to these activities did not involve its products.

At the time of the AFSSP launch, the Airbus Industrie product line covered three distinct model families, the A300B/A300-600/A310 widebody (W/B) family, the A319/A320/A321 single-aisle (S/A) family, and the A330/A340 long-range (L/R) family.

Within the Airbus Industrie partner system organization, the overall design, integration and certification responsibility for fuel systems rests with the U.K partner, Airbus UK, while sub-part manufacture, design, and installation are conducted by other partner companies within the Airbus Industrie partner system. Technical support, continue airworthiness, and maintenance program evolution are led by various departments located at Airbus Industrie headquarters in Toulouse.

From the outset of the AFSSP, Airbus Industrie elected to devise sample inspections for all tanks, rather than focusing on any particular tank. This approach provided the data to assess whether certain tanks, because of the fuel-transfer and usage-time variations, would exhibit any variance in their long-term condition.

3.2 Scope

As one of the initiating manufacturers of the AFSSP, Airbus Industrie worked closely with other manufacturers to define the scope of the program. Although the design and certification requirements for fuel systems as a whole remain common between manufacturers, the implementation of specific engineering solutions may be different. Within the Airbus Industrie inspection program, therefore, there were some inspection items that were particular to Airbus as well as some that were not included because Airbus does not use those particular design features.

3.2.1 Additional Activities

Airbus Industrie have ongoing activities with the local certifying aviation authorities that are complimentary or supplementary to the AFSSP. These other activities are part of the continuous airworthiness process. Where there were issues discovered during the AFSSP inspection program that need an appropriate in-service action, the item was immediately transferred to the existing continuous airworthiness process involving Airbus Industrie's certifying authority.

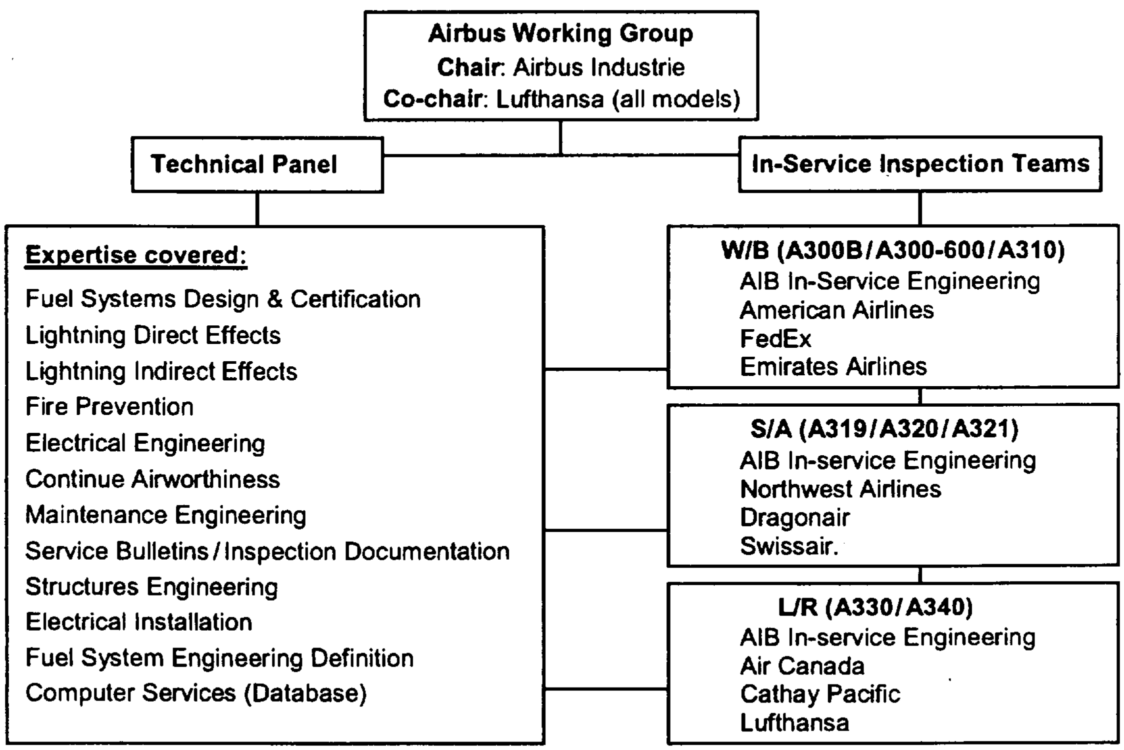
3.3 Working Group Teams

The Airbus Airplane Working Group (AWG) make-up is based on its aircraft product line and with each airline member representing each product where it had the most interest. There were airlines within the Airbus AWG having all of the product line and hence provided the added support in conducting inspections for all types.

3.3.1 Team Composition

Given the worldwide distribution of the Airbus fleet, there was a requirement to see if there were any variations in tank condition according to the operating environment or any other regional variances such as fuel quality.

The Airbus AWG had the appropriate worldwide coverage of operators who volunteered to be part of the inspection definition process, and later to perform the inspections. The following flow chart shows the Airbus working group organization and its composition.



3-1: Airbus Working Group Organization and Composition

The Technical Panel members in the AWG are either from the Airbus partner companies or particular departments based in Toulouse headquarters. Their main function is to ensure that the inspection criteria and documentation format meet the agreed common set of requirements set by all the participating manufacturers and promulgated through the FSSLT.

Each In-Service Inspection Team had the task of scrutinizing each inspection document to ensure its practicality before it was released for use in the field.

3.3.2 Team Activities

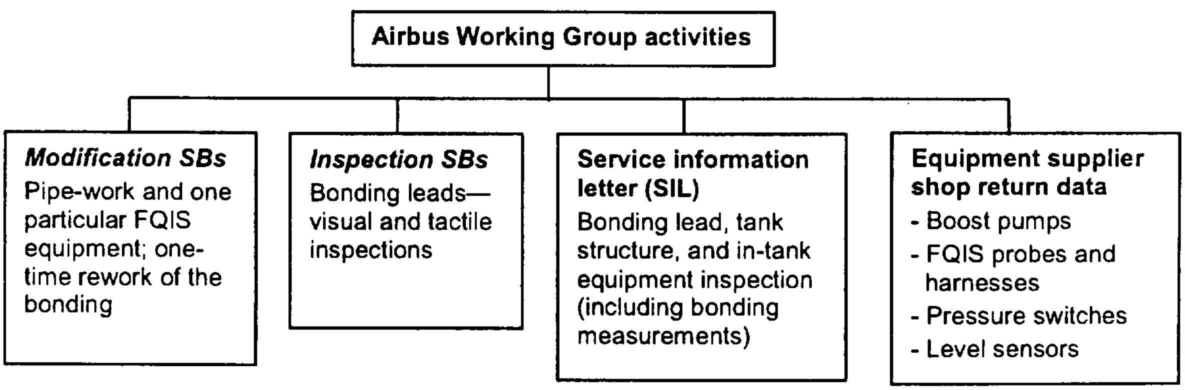
Regular meetings were held during the initial definition phase of the inspection program. The Technical Panel had internal meetings to define the inspection criteria as agreed between all the participating manufacturers. The Service Bulletin/Documentation department would then produce a draft set of inspection documents for review within each of the product-line AWG sub-groups.

The inspections were carried out with one lead airline member within each product-line subgroup to ensure validity and accuracy. An Airbus In-Service Support engineer would usually participate to assist in performing the first aircraft inspection of each model type.

3.4 Working Group Approach

At the outset of the program, each manufacturer agreed on the basic premise that the inspections must be sufficiently thorough without the potential for causing intrusive damage. In addition to participating airlines, therefore, the Airbus AWG also involved some of the major fuel system equipment suppliers. Where internal items could not be inspected, the fuel system component suppliers assisted by providing data on equipment returned for shop repair.

This chart shows the scope of activities and data gathering performed by the Airbus AWG:



3-2: Scope of Airbus Data Gathering

The items contained in the Airbus inspection documents were the list as drawn up by all the AFSSP-participant manufacturers and promulgated to each of the product-line subgroups. Where items were particular to Airbus, separate documentation were issued, i.e., the decision was taken to implement a one-time rework of some the pipe work on the A300 and A320 family rather than carry out an inspection.

During the scheduled maintenance of one aircraft, model A300/B4, MSN 161, an unexpected number of bonding leads (or jumpers) were found damaged in a localized area. This discovery initiated an investigation, the results of which were fed back into the AFSSP. The resultant action was for the Airbus AWG to issue a dedicated visual/tactile inspection service bulletin (SB) for bonding leads. The voluntary inspection items and bonding checks were included in the service information letter (SIL).

At the request of AWG airline members, the ISB and SIL inspection requirements were combined in one document. As a result, the SIL incorporated all the requirements of the ISB, which meant that operators who accomplished SIL inspections were also credited with accomplishing the ISB.

3.5 Inspection Criteria

The inspections were carried out during scheduled fuel tank entry intervals. For Airbus aircraft, fuel tanks are typically opened up every 4 to 5 years for routine inspection tasks.

Although there were items unique to individual manufacturers, the following common set of items was used by all manufacturers in the development of their respective inspection programs:

- Fault current bonding.
- Internal power wiring and insulation.
- Static and lightning bonding.
- Couplings.
- FOD and tank condition.
- FQIS wiring and probes.
- Flame arrestors.

Fault Current Bonding

Some of the manufacturers bond electrical components in the flammable and flammable-leakage zones of the aircraft to fault current curves that are specified in or derived from MIL-B-5087B. These curves were developed through testing. This level of bonding provides a very low resistance path to ground, ensuring that any unintended ground paths, external to the equipment, are ignored and that the circuit protective devices are able to activate appropriately. The MIL-B-5087B has been superseded by MIL-464, which in turn refers to FAA Advisory Circular AC 20-53A to define the protection requirements.

This advisory circular, while being specific to the lightning protection requirements of the fuel system, also provides an appropriate design solution for short circuit fault current dissipation. The Airbus approach is to ensure that sufficient cross-sectional area and alternate/redundant bonding paths are incorporated into the design. Quality control over this build standard and in-service maintenance actions (when components are replaced) is then maintained through bonding verification checks in accordance with the original type certification requirements.

Where a bonding check is requested within the Airbus inspection program, the measured resistance values were noted and compared with the initial build requirement leaving the factory. If exceedances were recorded, the inspection documents instructed those bonds to be re-worked to the initial build requirement.

Internal Power Wiring and Insulation

On all of the Airbus product line, power supply to boost pumps, which are 115 V AC, are routed external to all the fuel tanks. Hence, within the Airbus inspection program, there were no requirements to inspect external power wiring.

Bonding for Static and Lightning Protection

The integrity of the fuel tank is ensured during a lightning strike by demonstrating compliance with the aforementioned advisory circular and other airworthiness guidance material. Areas inside fuel tanks are therefore bonded for a static and lightning requirement.

The bonding of the fuel tank access panels (or manholes) and over-wing refuel panels form part of the external fuel tank surfaces, and within the Airbus inspection program a sample bond check in these areas was requested. This requirement was to assess whether there were any aging of the bonding from the last closure of the panels to the subsequent reopening during the next tank entry. As stipulated in all manufacturers' maintenance manuals, each time a fuel tank access panel is opened, the closure task includes a bonding check to the value of the initial build.

Airbus require the bonding of internal components to the structure inside the tank, hence providing a dual path. To measure these resistances would require breaking the bonding path, which is time consuming and not necessary. As there is visual and tactile inspection stipulated for each lead inside each tank, the integrity of a minimum of one path is preserved. Bonding checks are only requested if a bonding lead shows signs of heavy deterioration, such as fraying of the outer braid or excessive blackening or contamination with copper sulfide.

Couplings

Airbus has designed in a secondary path in its couplings, and where a secondary path has been assured by inherent bonding as it is with the W/B and S/A product lines, a dedicated bonding path has now been initiated via a one-time rework SB. The L/R product line uses a dedicated secondary path using bonding leads, hence the rework SB action does not apply on the L/R product.

FOD and Tank Condition

This will be a general inspection inside each tank and surrounding components. Airbus has also within its AWG the boost pump suppliers to monitor and report any signs of FOD from shop return in order to check if debris can enter the screening that are provided to prevent FOD from entering the pump impellers.

'Tank condition' was defined as the general visible tank integrity, i.e. any visible corrosion, looseness of components or structural FOD.

FQIS Wiring and Probes

FQIS wiring is a low-power system that includes all fuel probes, level sensors, temperature sensors, compensators, and densitometers fitted inside the tank.

Airbus FQIS is a low-energy system. The harnesses are routed through sleeving or non-metallic conduit secured by clamps fixed to structure. The FQIS computer is designed to limit the current provided to the in-tank components. Inspection of FQIS components and wiring looked for FOD, chafing of the wires, and any sulfide corrosion. Airbus together with all the other manufacturers agreed that there is no requirement to dismantle wiring installation in the inspection process, as this could potentially introduce damage from the intrusion.

Flame Arrestors

Airbus uses flame arrestors on the open end of fuel tank vents to prevent ignition during a ground fire. These will be visually inspected for FOD in the SIL.

3.6 Inspection Program

The following tables provide the fleet data and the number of returned results. It should be noted that a high number of operators volunteered to perform inspections even though they were not part of the initial AWG activities.

Aircraft type	First delivery	Total delivered	Currently operating	Flight-hours		Flight cycles	
				Average	Highest	Average	Highest
A300B	10-May-75	249	142	36192	55967	22455	35918
A300-600	25-Mar-84	241	230	19751	47996	10211	27794
A310	25-Mar-83	255	236	30127	60331	11821	25779
A319*	25-Apr-96	249	249	4067	9654	2586	8697
A320	26-Mar-88	838	832	15625	46650	9030	25839
A321	27-Jan-94	164	164	6923	14778	5069	16026
A330	30-Dec-93	156	156	7648	24160	2675	7966
A340	29-Dec-93	181	179	15230	33586	2424	5898

As of June 30, 2000.

* The A319 data is shown as the aircraft was in service during the launch of the AFSSP program; as the inspections were carried out within the schedule 4C check (between 4 to 5 years), however, there were no results due to the AFSSP cutoff date.

Figure 3-3: Airbus Fleet Data

Twin-aisle	Modification SBs [one-time rework]	Bonding Lead Inspection SB [visual / tactile inspection]	Service Information Letter (SIL) [includes bonding checks]
	Mandated by DGAC AD 98-174-248(B) Compliance: next '4C' check		One-time voluntary inspection (ISB requirements incorporated)
A300B	SB 28-0073 Estimated labor-hours: 183 Mod 11848	ISB 28-0072 Estimated labor-hours: 150	SIL 28-065 Estimated labor-hours: 180
A310	SB 28-2130 Estimated labor-hours: 100 Mod 11847	ISB 28-2128 Estimated labor-hours: 150	SIL 28-066 Estimated labor-hours: 200
A300-600	SB 28-6058 Estimated labor-hours: 183 Mod 11848	ISB 28-6057 Estimated labor-hours: 140	SIL 28-067 Estimated labor-hours: 200
Single-aisle	**Recommended at next '4C' check scheduled maintenance interval**		One-time voluntary inspection (ISB requirements incorporated)
A319/320/321	SB 28-1077 Estimated labor-hours: 160 Mod 27150 & MOD 27955	ISB 28-1075 Estimated labor-hours: 160	SIL 28-068 Estimated labor-hours: 200
Long-range twin aisle	Mandated by DGAC: - A330: AD 98-099-066(B) Compliance: within 72 months of issue date (25 FEB 1998) - A340: AD 98-103-082(B) Compliance: within 72 months of issue date (25 FEB 1998)	Recommended at next '4C' check scheduled maintenance interval	One-time voluntary inspection (ISB requirements incorporated)
A330	SB 28-3053 Estimated labor-hours: 8 Mod 45580	ISB 28-3054 Estimated labor-hours: 260	SIL 28-070 Estimated labor-hours: 180
A340	SB 28-4069 Estimated labor-hours: 8 Mod 45580	ISB 28-4070 Estimated labor-hours: 290	SIL 28-069 Estimated labor-hours: 290

Figure 3-4: Airbus SB and SIL Documents

The results data sets from 133 aircraft inspections were loaded within a dedicated database especially implemented by Airbus for the AFSSP. This database was also used for the results analysis and evaluation. The total number of aircraft and model types inspected within the Airbus program is shown in the following tables:

Aircraft type	Number inspected	Flight-hours			Flight cycles		
		Lowest	Average	Highest	Lowest	Average	Highest
A300B	21	20,947	33,944	43,667	9,520	23,006	35,040
A300-600	22	4,392	13,724	31,884	3,835	9,931	19,058
A310	31	9,824	28,545	47,212	2,828	12,040	24,514
A320/321	13	7,053	16,763	20,212	5,360	8,338	12,977
A330	3	10,423	11,311	12,241	6,146	6,426	6,610
A340	12	755	18,271	30,121	816	2,719	3,858

Figure 3-5: Aircraft Data for the SB Inspections

Aircraft type	Number inspected	Flight-hours			Flight cycles		
		Lowest	Average	Highest	Lowest	Average	Highest
A300B	6	33,217	38,137	44,089	11,189	19,978	26,950
A300-600	5	6,770	21,859	35,955	3,349	14,321	24,540
A310	5	25,616	30,411	33,968	5,973	11,444	16,000
A320/321	11	12,606	22,138	32,438	5,768	14,609	19,667
A330	2	13,666	13,733	13,799	6,116	6,202	6,289
A340	2	29,850	30,053	30,255	3,774	3,785	3,797

Figure 3-6: Aircraft Data for the SIL Inspections

Operator	Inspection data (SB)			Inspection data (SIL)		
	Aircraft category* and number					
	W/B	S/A	L/R	W/B	S/A	L/R
All Nippon Airways					2	
Ansett Australia					1	
Aeroflot	4					
Air Canada		2			2	
Air India	4			2		
Air France					3	
Air Afrique	1					
Airbus Industrie	2					
Austrian Airlines	2					
Amedeo Aviation Corp.						

Operator (cont'd)	Inspection data (SB)			Inspection data (SIL)		
	Aircraft category* and number					
	W/B	S/A	L/R	W/B	S/A	L/R
Airtours International		1				
L'Aerospatiale	1					
British Airways		2				
China Airlines	1			1		
Canadian Airlines		1				
Caledonian Airways		3				
Cyprus Airways	1					
C–S Aviation				1		
Deutsche Lufthansa	3	1	7	1	2	2
DHL	3					
European Air Transport	1					
Federal Express	12			1		
Finnair				1		
German Air Force	3					
Gulf Air			1			
Japan Air System	26			2		
Malaysia Airlines	1					
Mexicana		1				
Monarch Airlines	1					
Mongolian Airlines	1					
Olympic Airways	1					
Private (B3R, B4A)			2			
Qatar Amiri Flight			1			
Romanian Air Transport	1			1		
Sabena			4			
Singapore Airlines	2					
Sudan Airways	1					
South African Airways	1			1		
Sky Service		1				
Saudi Arabian Airlines				1		
Thai Airways				1		2
Turkish Airlines				3		
Tunisair	1					
Transasia Airways		1				
United Airlines					1	
Total	**74**	**13**	**15**	**16**	**11**	**4**

* Widebody (W/B), single-aisle (S/A), and long-range (L/R).

Figure 3-7: Participants in the Airbus Fleet Inspection Program

3.7 Results

3.7.1 Bonding Leads

As stated, the inspection results for one aircraft, A300B4 MSN 161, led the Airbus AFSSP in January 1997 to issue inspection SBs to see if the phenomenon existed on other aircraft. The issue on this aircraft was the unexplained occurrence of a high number of bonding leads found broken or frayed in a localized area within the wing tanks. At that time, Airbus did not have sufficient inspection data to determine whether this was an isolated case.

Subsequently, a 133-aircraft data set—the majority of which representing A300/A310 widebody family inspections—showed clearly there is no issue with bonding-lead degradation. As expected, this inspection data proved that the A300B4 MSN 161 findings were an isolated case. Because the issue of broken leads may be linked to mechanical damage resulting from tank entry, Airbus will add warning notices to its aircraft maintenance manuals (AMM) advising that special care be taken when work is performed inside fuel tanks.

Overall, the Airbus AWG inspection data showed the vast majority of bonding leads to be in good condition and performing their intended function. The number of leads requiring removal for corrosion and fraying damage was very low, and the number of missing or broken leads requiring replacement was rarer still. These minor instances of incorrect bonding-lead findings on pipes and couplings did not present any loss of bonding function because redundancy is designed and built into the system.

This inspection program also proved that even on heavily corroded, frayed, or otherwise damaged bonding leads, as long as the attachment points are secured and sealed for corrosion protection, the bonding functions remain intact. Actual bonding checks showed that they were still within the initial-build-standard value.

This inspection program indicates that the current schedule for visual inspections is sufficient to identify and remove degraded or broken leads.

Finally, this inspection data from aircraft operating in different regions and environments around the world does not shown any aging effect attributable to geographic differences.

3.7.2 Component Bonding

All the key components in the fuel system were checked using the SIL. The results have shown that a vast majority of the components having a specified bond requirement remain within their initial build standard. There were a very small number of bonding value exceedances, most of which have no impact on the ability of the bond to perform its intended function. The very few number of exceedances do not require immediate action.

The inspection data indicates no evidence that bond values degrade to an unacceptable level with age. There is also no evidence to indicate any geographic variations among the widespread operator base within the Airbus inspection program.

Airbus also wanted to assess if there were any indication that the different tanks (i.e., center wing, wing, and tail-plane tanks) exhibit any differences in condition. Clearly there was no evidence to suggest that they do. Airbus-designed fuel tanks have no other variables except in the sequence that some tanks are depleted in use relative to other tanks.

3.7.3 FQIS Wiring and Probes

There were no discrepancies with FQIS wiring and probes apart from the one finding of a level sensor wire insulation protection conduit found chafed on an A300B aircraft. Investigations had shown that the wire conduit was in close proximity to a magnetic level indicator (MLI) housing and subsequently chafed against it. This finding only relates to the A300B and A300-600 type, in which the installation of the sensor conduit are similar. No other Airbus model type is affected.

The chafing did not reach the wire insulation. However, the finding was immediately relayed to the continuous airworthiness process for action. An alert SB was issued to inspect the wiring protection conduit in this sensor location, with a restoration work to tie back the conduit so that it cannot chafe against the MLI housing.

3.7.4 General Tank Condition and FOD

No discrepancies found with the number of aircraft inspected.

3.7.5 Tank Structure

There were findings of corrosion and fretting damage on some manhole covers. However, because the Airbus inspection program calls for a bonding check before access panel removal, there was no impact on the bonding function.

There are launched actions within the Airbus Support division to address the corrosion findings.

3.7.6 Flame Arrestors

No discrepancies found with the number of aircraft inspected.

3.8 Conclusions

3.8.1 Bonding Leads

The inspection data received to date has shown that the degradation of bonding leads has minimal impact on Airbus aircraft. The data shows that the number of leads requiring removal is very low and that these leads are not in a concentrated area. The minor instances of incorrect bonding lead findings on pipes and couplings do not present any loss of the bonding function because there is redundancy built into the system.

Based on the inspection data, Airbus will continue to use the same bonding lead material. In the short to medium term, suppliers will be requested to enhance the manufacture quality and control process. In the longer term, Airbus will continue to look for improved materials for in-tank use.

The current scheduled maintenance interval has proven to be efficient in finding and replacing damaged leads. Furthermore, it is suspected that one of the primary cause of broken leads is tank entries and the frequency thereof.

3.8.2 Component Bonding Exceedances

The very few findings of bonding exceedances do not require any immediate action. As mentioned earlier, they are exceedances against a factory-build quality check standard and not a reflection of an out-of-limit, in-service requirement.

3.8.3 General Conclusion

From this extensive and valuable industry program Airbus Industrie has shown, based on in-service inspection data, that its original design, manufacture, and maintenance objectives for fuel systems remain robust and functional throughout the design life of its aircraft.

4.0 BAE SYSTEMS WORKING GROUP REPORT

4.1 Introduction

BAE SYSTEMS Regional Aircraft has two distinct aircraft fleets, turboprops with 19 to 64 seats (J31, J32, J41, ATP, and HS748) and turbofans (aircraft with fanjet engines) with 70 to 112 seats (BAe 146 and AVRO 146-RJ). There are some 1,100 aircraft worldwide flying with 230 different customer operators. Only the AVRO 146-RJ is currently in production.

Support to these fleets is provided by BAE SYSTEMS Regional Aircraft Customer Support based in Toulouse, France. This support is complemented by UK-based Engineering Type Design organisations at Woodford (Turbofans) and Prestwick (Turboprops). The certificating authority for all the aircraft types is the UK Civil Aviation Authority (CAA).

4.2 Scope

From the outset, it was decided to inspect a proportion of each aircraft family regardless of whether it would be covered by an anticipated future regulatory activity.

In accordance with the guidelines set out by the Fuel System Safety Leadership Team, the inspections conducted covered all fuel system aspects (i.e., aircraft wiring condition, component condition, bonding, and so on) within the aircraft fuel tanks. The specific areas of interest and detailed instructions were derived from design reviews of the fuel system on each type.

In the following sections, subsections are used where appropriate to reflect the slightly different approaches used for the turbofan and turboprop fleets.

4.3 Working Group Teams

Given the relatively low ratio of aircraft per operator and the worldwide spread of the customer base, only one operator working group (turbofan) was arranged. The inspection programme for the rest of the aircraft types was coordinated directly with individual operators, with BAE SYSTEMS providing on-site assistance in many cases.

4.3.1 Turbofans (BAE SYSTEMS Regional Aircraft—Woodford)

A working group was formed consisting of several BAE SYSTEMS Customer Support and Engineering departments and a cross section of the fleet operators to develop a process and method to gather relevant information. The members of the working group are listed below. Note that BAE SYSTEMS Asset Management Organisation (AMO) is listed as a customer as they own a number of jet and turboprop aircraft that are operated by various airlines on medium and long-term leases.

Airline	Aircraft type
Aer Lingus	BAe 146
Air UK	BAe 146
BAE SYSTEMS Asset Management Organization (AMO)	BAe 146 and Avro 146-RJ
British European	BAe 146
DAT	BAe 146 and Avro 146-RJ
Eurowings	BAe 146
Lufthansa City Line	Avro 146-RJ
Mesaba	Avro 146-RJ
TNT	BAe 146

Figure 4-1: Airline Participants

BAE SYSTEMS Regional Aircraft would like to publicly thank all the operators who volunteered aircraft for this voluntary inspection programme. They are listed below:

- DAT.
- Eurowings.
- Jersey European.
- Lufthansa City Line.
- Mesaba.
- National Jet Systems.

4.3.2 Turboprops (BAE SYSTEMS Regional Aircraft—Prestwick)

To gather sufficient information on the general condition of fuel tanks in aircraft affected by the proposed rulemaking, BAE SYSTEMS Prestwick opted to review all the civil aircraft types within their in-service responsibility.

No working groups were held for the turboprop aircraft types. All inspections were managed through Customer Support or the BAE SYSTEMS Maintenance and Engineering departments.

BAE SYSTEMS Regional Aircraft at Prestwick would like to publicly thank all the airlines that offered aircraft for the turboprop inspection programme. The airlines are listed in their respective aircraft type categories below.

Jetstream 41

Fifteen aircraft out of a fleet of 99 were inspected. The operators who volunteered aircraft for inspection are listed here:

- Atlantic Coast Airlines.
- Manx Airlines.
- SA Airlink.

Jetstream 31/32

Fourteen Jetstream 32 were inspected aircraft out of a fleet of 140. No Jetstream 31 aircraft have been inspected. However, the fuel systems of these two types are similar. The operators who volunteered aircraft for inspection are listed below:

- Air Kilroe.
- Air National.
- Ansett NZ.
- Flight West.
- Highland Air.
- JAIR.

BAe ATP

Eight aircraft were inspected out of a fleet of 60. The operators who volunteered aircraft for inspection are listed below:

- Manx.
- SATA.

HS 748

Three aircraft out of a fleet of 244 were inspected. The operators who volunteered aircraft for inspection are listed below.

- Belgian Air Force.
- Emerald Airways.

4.4 Working Group Approach

The ATA Leadership Team had been established for some months before BAE SYSTEMS joining. During that period, the basic concept and objectives had been established for the voluntary inspection programme. BAE SYSTEMS were able therefore to adopt a process that had already been thoroughly discussed and agreed by the world's major manufacturers and airlines. BAE SYSTEMS adopted the process with the intention of developing an inspection programme to cover all the fuel tank installations on its aircraft types. This approach was facilitated by the relatively simple designs of fuel systems on regional aircraft.

4.4.1 Inspection Types and Criteria

The basis of the inspections for all the BAE SYSTEMS aircraft types was as follows:

A. **FOD check**—check for freedom from foreign objects such as metal shavings, rags, and tools.

B. **Metallic structure and components**—inspect for cracks, overheating, dents, evidence of arcing, distortion, security and cleanliness of attachments, missing fasteners, deterioration of protective treatment, and corrosion.

C. **Mechanical component inspection**—check for any obstruction of drains, drainage paths, vent holes, or vent pipes. Check for security of all couplings. Check for any signs of sooting of vent pipes.

D. **Seals and gaskets check**—all visible seals should be visually checked for signs of damage, degradation, distortion, or evidence of heat leakage.

E. **Electrical bonding**—visually check that all sections of pipe and components are bonded to structure.

F. **Component checks:**

- **Bonding lead check**—inspect all bonding leads for signs of breakage, braid fraying, tarnishing, corrosion, security of end fastenings, spirap covering (where applicable), and any leads that may be missing completely.
- **Tank units check**—all wiring shall be inspected along the entire exposed routing within the tank for any damage or chafing to the insulation. Check for any sharp edges in close proximity to the wiring, such as where the wiring enters or exits tank structure or routing conduits. Ensure that all routing conduits have inserts at each end. Check for cleanliness and security of all connections. Ensure all terminal blocks and wire end fittings are free from corrosion and contamination.
- **Fuel boost pumps**—check all wiring conduits for kinks or damage. Particular attention should be paid to area of conduit bends.
- **Float Switches**—check there is no evidence of fuel leaks onto electrical connections. Check there is no evidence of loose/arcing connections. Where applicable, check that there is no evidence of any damage to the metallic conduit that houses the wiring.
- **Access panels**—check the condition of the metal mesh/conductive gasket on tank access panels.

4.4.2 Turbofans

The team identified in section 4.3.1 developed the information necessary to conduct the voluntary inspections on in-service BAe 146 and Avro 146-RJ jetliners. BAE SYSTEMS Customer Support issued this information as an Operator Information Message. The message detailed specific inspections to be carried out by operators on a voluntary basis. Those operators who volunteered to carry out inspections were then contacted on an individual basis, and the resulting inspections were coordinated through the BAE SYSTEMS Customer Support organisation.

Aircraft type	BAe146	AVRO 146-RJ
Total delivered	220	149
In operation	214	147
Highest flight-hours	43,878	16,723
Highest flight cycles	44,556	16,906
Total fleet flight-hours	4,357,850	1,109,708
Total fleet flight cycles	4,332,055	994,364

- Taken from available data as of 06/07/2000

Figure 4-2: Basic Jet Fleet Data

4.4.3 Turboprops

BAE SYSTEMS Prestwick elected not to have working groups for each of the various aircraft types, but rather to separately establish a voluntary inspection programme (similar to that of the BAe 146/AVRO 146-RJ) for all the civil aircraft types within our in-service responsibility. This information was then issued via Customer Support as an Operator Information Message, detailing specific inspections to be carried out by operators on a voluntary basis. Those operators who volunteered to carry out inspections were then contacted on an individual basis. The inspections were coordinated and, where practicable, were conducted by In-Service Engineering Prestwick or Customer Support personnel to establish continuity between inspections.

Aircraft type	Jetstream 31/32	Jetstream 41	ATP	HS 748
Total delivered	386	104	64	351
In operation	334	99	60	244
Highest flight-hours	30,198	16,984	20,275	55300
Highest flight cycles	37,787	16,197	27,069	62,507
Total fleet flight-hours	5,874,702	1,054,962	751,570	6,673,706
Total fleet flight cycles	7,501,155	1,053,843	972,279	7,240,281

- Taken from available data as of 06/07/2000

Figure 4-3: Basic Turboprop Fleet Data

4.5 Jet Inspection Results

Completed returns were received from 29 jetliners (5 BAe 146 and 24 AVRO 146-RJ) from the worldwide fleet of 361. The design of the BAe 146 and AVRO 146-RJ fuel systems is identical. Therefore, the results and findings are amalgamated in this report.

Feedback from the inspections revealed very few findings, and the tank systems were found to be in generally good condition. Findings were too few to Pareto so have been summarised as follows:

4.5.1 Integrity of Wiring and Bonding Straps

Bonding Lead Integrity

The inspections have shown a small number of degraded bonding leads. The degradation has been seen on some old and some relatively new leads. Investigation has shown the leads have corroded under attack by sulfur, which is present in all fuel types. The bonding leads used are of a tin-plated copper type. BAE SYSTEMS has reviewed bonding leads in association with Airbus Industrie, and this review has not revealed any trends that necessitate any immediate action. Evidence has shown that electrostatic bonding is maintained even with a bonding lead that shows signs of degradation (e.g., broken strands, tarnishing, blackening/deposits). A visual and/or tactile check is sufficient to identify any leads that require replacement before bonding is unacceptably degraded. The review is likely to continue, particularly to increase our collective understanding of use of alternative materials for bonding leads, such as aluminium.

Float Switch Wiring Condition

This wiring is changed whenever the switch is changed, which restricts the service life of the wiring. No reports of degradation of this wiring have been received from either the inspections of installed units or from the vendor on returned units.

4.5.2 Condition of FQIS Wiring and Components

Some abrasion was found on earlier BAe 146 FQIS wiring internal to the fuel tanks. The cable type used on these aircraft was KCTL/EL2124. Abrasion was noted where the cables were Ty-wrapped to an adjacent structure. The Ty-wraps used had abraded the FEP topcoat of the cable. On closer examination of samples of abraded cable, it was noted the abrasion had not degraded the insulation layer of the wiring.

Consultation with the cable manufacturer and some experience with other cable types led to the conclusion that the FEP topcoat is not a significant contributor to the overall insulation of this cable type and is used for cable type identification. The damage was very superficial, and thus no requirement exists for replacement or repair. No damage has been found on the insulation layer. Operators have been informed that no action is required if damage of this type is found.

This type of cable is now obsolete. The inspections have revealed no damage on the later standard cable type (ACT 150), which is used on Avro 146-RJ.

4.5.3 Condition of Fuel Pumps, Fuel Lines, and Fittings

All fuel system components internal to the fuel tanks were inspected for serviceability, corrosion and cleanliness, and bonding. No discrepancies have been reported.

4.5.4 Electrical Bonding and Grounding of Fuel System Equipment

No discrepancies have been reported in this area.

4.5.5 Inspection for Foreign Object Debris

No FOD items of any significance have been found during these inspections.

4.5.6 General Tank Condition

The fuel tanks inspected during this programme were found to be in good to excellent condition. There were no indications that components or installed wiring were being affected on a long-term basis following prolonged exposure to the fuel tank environment.

4.5.7 Other Items

BAE SYSTEMS included an inspection of fuel tank access covers in its programme. Results of these inspections show no discrepancies and indicate that lightning protection is being maintained with routine tank entry activities.

4.6 Turboprop Inspection Results

Feedback from the inspections revealed the need for a few corrective actions, but primarily the tank systems were found to be generally in good to excellent condition. Findings were too few to Pareto, so they have been summarised as follows:

4.6.1 Integrity of Wiring and Bonding Straps

Jetstream 32

Early aircraft inspections found evidence of chafing caused by cable ties attaching the harness to structure and by cable ties holding wire bundles together. Instances were also found of the bottom skin structure chafing wiring.

A mandatory SB has been raised to inspect and rectify wiring harnesses on all aircraft. A trial wiring harness is being produced that will be used to check the proposed routing and clipping improvements for the new harness, which will ultimately replace the repaired harnesses across the J32 fleet.

A dedicated inspection of the boost pump conduit will be included in the maintenance schedule.

Jetstream 41

Chafing was found on boost pump wiring below the cable tie at the backshell. Knife cuts through insulation were found that reflect a lack of care when stripping back braided sheath. Some twisting damage occurred to wires and conduits during maintenance.

A Mandatory SB has been raised to replace wiring harnesses on all aircraft and to replace conduits if found damaged.

A dedicated inspection of the boost pump conduit will be included in the MRB report.

4.6.2 Condition of FQIS Wiring and Components

BAe ATP

Silver sulfide contamination had been found on the FQIS tank probes before this inspection programme. Review of silver sulfide contamination has noted that operators who have had a reliability problem with the FQIS were those who aggressively clean the silver sulfide coatings from the probes and connectors. Conversely, those operators who do *not* disturb the system find they have virtually trouble-free operation. BAE SYSTEMS Prestwick believes that the problems experienced by these operators are the result of residues left after improper cleaning of the probes.

It is our intention to issue an SB requiring removal of the FQIS tank probes and inspection for contamination at the next tank entry. If contamination is found, the probes will be returned to the manufacturer for cleaning. We further intend to issue a letter to all operators instructing them not to actively clean silver sulfide deposits themselves, but rather to return any faulty units causing system malfunction to the manufacturer for cleaning.

HS 748

Silver sulfide contamination on the FQIS tank probes has been found but has not caused the same degree of problem experienced on the ATP aircraft. This has been attributed to a less intrusive cleaning action by operators. The fuel system on the HS 748 is very similar to the ATP, the latter being a reengined and stretched derivative of the former.

4.6.3 Condition of Fuel Pumps, Fuel Lines, and Fittings

No discrepancies have been reported in this area.

4.6.4 Electrical Bonding and Grounding of Fuel System Equipment

No discrepancies have been reported in this area.

4.6.5 Inspection for Foreign Object Debris

No FOD items of any significance have been found during these inspections.

4.6.6 General Tank Condition

The fuel tanks inspected during this programme were found to be in good to excellent condition. There were no indications that components or installed wiring were being affected on a long-term basis following prolonged exposure to the fuel tank environment.

4.6.7 Other Items

BAE SYSTEMS included an inspection of fuel tank access covers in its programme. Results of these inspections show no discrepancies and indicate that lightning protection is being maintained with routine tank entry activities.

4.7 Summary

BAE SYSTEMS, in cooperation with a wide cross section of their operators, have inspected a large number of aircraft. The results have been positive with few findings of significance reported. This result is believed to reflect the relative simplicity of the fuel systems, and the use of good design practice as promoted through existing airworthiness requirements. As the type design authority, BAE SYSTEMS is working with the UK CAA on the findings highlighted in the preceding report. In many cases, individual courses of action have already been agreed and enhancements have been implemented.

Data gathered during the AFSSP inspection programme will be used as part of BAE SYSTEMS' ongoing aging aircraft programme. This fuel systems knowledge will be used to help validate such aspects as maintenance schedules and inspection techniques.

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5.0 BOEING WORKING GROUP REPORT

5.1 Introduction

At the inception of the Aircraft Fuel System Safety Program (AFSSP), each airframe manufacturer formed its own airplane working group (AWG) to address the airplanes in their respective fleets. In August 1997, The Boeing Company and McDonnell Douglas merged. The designations Boeing Puget Sound and Boeing Long Beach today denote these two major commercial airplane centers.

Boeing currently produces the single-aisle 717 (which began as the MD-95), Next-Generation 737 (third generation of the 737 family), and 757. On the twin-aisle front, Boeing produces the 767, 777, and 747-400 (current generation of the 747). Boeing continues to support the 707, 727, earlier-model 737s and 747s, DC-8, DC-9, MD-80 / -90, DC-10, and MD-11.

5.2 Scope

The Boeing Working Group reviewed requirements, drawings, and manufacturing processes and performed inspections of fleet aircraft. Boeing conducted extensive requirements, drawing, and manufacturing reviews. The inspection portion of the program was a cooperative effort between Boeing and participating airlines to develop inspection instructions, conduct inspections, and make recommendations. The following details this effort and its results.

5.3 Additional Activities

The industry AFSSP is one of many efforts to investigate and enhance fuel system safety. Examples of other recent activities that have resulted in fuel system safety findings and enhancements are National Transportation Safety Board (NTSB) accident investigations, the Federal Aviation Administration's (FAA) Notice of Public Rulemaking (NPRM) and Special Federal Aviation Regulation (SFAR) on Fuel Systems, the Aviation Rulemaking Advisory Committee (ARAC) on Fuel Tank Flammability Reduction, and various government and industry research and test programs. There is also an established and active safety process within Boeing to review, assess, and implement safety-related changes regardless of other activities internal or external to Boeing.

As such, there have been a number of fuel system modifications and enhancements implemented on Boeing airplanes as a result of governmental, regulatory, and Boeing initiatives that were outside the scope of the AFSSP or the Boeing AWG. Some of the more significant items on Boeing products that were addressed outside of the AFSSP were the FAA-mandated inspection and/or addition of protective sleeving on fuel pump wiring, the FAA airworthiness directives (AD) on the 737 and 747 Classic airplanes requiring separation and shielding of fuel quantity indication system (FQIS) wiring, an AD for MD-80-series wing heater blankets, and the NTSB recommendation and FAA AD on the 747 Classic to remove specific fuel probe terminal blocks and inspect/replace FQIS wiring. In addition to these specific findings, there are additional research activities underway to assess potential issues and develop solutions that would further enhance fuel systems safety, which are also outside the scope of this program and therefore not included in this report.

5.4 Working Group Teams

The working group established to address the Boeing airplane family was split into three teams. One team addressed the Boeing Puget Sound single-aisle airplanes, the 707, 727, 737, and 757. Another addressed the Boeing Puget Sound twin-aisle airplanes, the 747, 767, 777. A third team addressed the Boeing Long Beach airplanes, the DC-9, DC-10, MD-80/-90, MD-11, and 717.

5.4.1 Team Composition

Figure 5-1 below shows the internal Boeing Engineering organizations and the air carriers that comprise the Boeing Working Group:

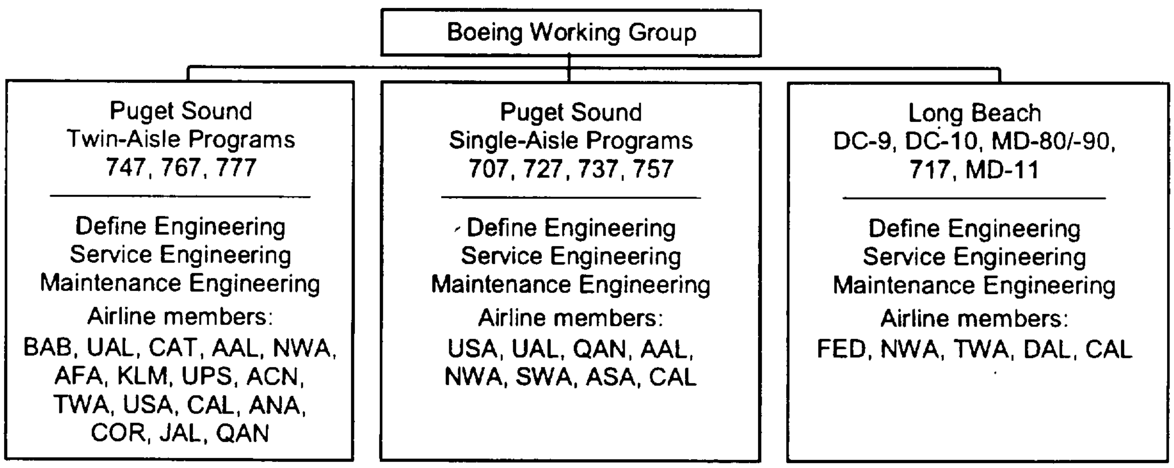

Figure 5-1: Boeing Airplane Working Group Organization

Each team, though similar in makeup and purpose, established individual procedures with respect to the industry commitment. Each team met regularly to track progress, report findings, and provide feedback to improve the process.

5.4.2 Team Activities

Periodic meetings of the entire Boeing Working Group were held in which detailed reviews of the inspection program status were provided and any resulting analysis was discussed. Working group discussions identified issues that were either resolved at the meetings or gave rise to action items for resolution outside the meeting. Group telephone conferences were also used within individual teams to address questions that came up during the inspection process. Altogether, a total of five meetings and several working-group telecons were held in addition to countless individual phone calls and telexes between the airlines and Boeing.

5.5 Working Group Approach

Two objectives of the AFSSP were to have the manufacturer validate (1) design principles and manufacturing processes and (2) maintenance programs and processes. To accomplish the first of these objectives, Boeing reviewed

- Fuel system design requirements.
- Drawings used to build Boeing airplanes.
- Processes used to manufacture and install fuel systems in Boeing jetliners.

5.5.1 Inspection Program

Fuel system design requirements—to verify that design features for ignition prevention are robust, Boeing performed a review of the basic requirements used in the design of its airplanes. Industry standards for ignition prevention can be traced back to before the first commercial jet transports. Boeing's fuel system design requirements were reviewed and confirmed to be based on industry standards as well as on testing and analysis performed by Boeing and its suppliers. Although detailed requirements have evolved from model to model, the basis for the requirements are generally the same. This review found that Boeing's requirements are conservative in providing design margin and have redundancy built in that enhances the level of safety.

Following this design-requirements review, a review of the design of each commercial fuel system designed by Boeing was done to ensure that these requirements were implemented into the design definitions. To date, Boeing has completed requirements reviews and detailed drawing reviews for the 717, 747, 757, 767, 777, DC-9, MD-80 / -90, DC-10, and MD-11 airplane models. The 707 has been reviewed for electrical bonding. The 727 and 737 airplane models are still in work.

During these design reviews, items were identified in some cases that warranted specific fleet inspections. Based on design review and fleet data, Boeing has incorporated, or is in the process of incorporating, revisions to Boeing production airplanes that provide additional enhancement of the bonding of parts or components in the fuel tanks. In many cases, these revisions include clearer instructions for manufacturing. Some changes will also provide improved bonding path designs.

In addition to the requirements and drawing reviews, Boeing conducted reviews of service bulletins and airworthiness directives for lessons learned that might be applied across all Boeing designs. Boeing also reviewed airplane maintenance logs, telexes, and component repair information from the participating airlines. The 747 review is complete, and review of other models is in progress. The data will be used primarily to enhance the maintenance programs for the fuel systems of Boeing airplanes.

Drawings used to build Boeing airplanes—the Boeing plan for reviewing manufacturing processes included a series of inspections of each model currently in production. The intent was to ensure that the design and build instructions contained in the engineering drawings were being properly implemented in the factory. Minor issues were identified and corrected during these inspections. None of them could adversely affect the safety or airworthiness of an airplane. Boeing Long Beach inspected its in-production models as a validation of the inspection documents.

A detailed review of the 747 manufacturing planning instructions was conducted to audit the process by which Manufacturing Engineering (planning) takes the engineering product definition and converts the information into instructions for the factory. This review identified a couple of areas where improvements could be made. These improvements have assisted in the capture of certain types of requirements found on engineering drawings to ensure consistent implementation in the factory across the entire Boeing product line.

Processes used to manufacture and install fuel systems in Boeing jetliners—the inspection plan defined by Boeing included inspections of center wing tanks and main wing tanks on high-time and low-time aircraft in the commercial fleet. The purpose of the inspections has been to gather data on the condition of fuel tank systems aboard in-service airplanes and determine the possible effects of aging. The data would be used to develop an enhanced maintenance program.

The inspection plan focused on the models with the majority of the current fleet experience (727, 737-200, 737-300/-400/-500, 747, 757, 767, DC-9, MD-80/-90, DC-10, and MD-11). Various airplanes from the relatively young 777 fleet were inspected at a limited level. While 707 airplanes were not physically inspected, 707 drawing reviews and similarity of the fuel system details to the 727 and 737 fuel systems will allow development of enhanced maintenance programs for the 707.

The DC-9 fleet was the primary focus at Boeing Long Beach because it had more hours and cycles, and thus provided a better indicator of how the fuel system design was aging. The Next-Generation 737 and the 717, both of which entered service after the inspection program began, did not undergo fleet inspections but will receive the applicable enhancements to their maintenance programs based upon drawing reviews and similarity to the other models that were inspected.

The inspections established by the Boeing Working Group teams were designed to verify (1) the integrity of wiring and bond straps; (2) the conditions of fuel pumps, fuel lines, and fittings; and (3) the electrical bonding on all equipment. To accomplish this, each team decided to inspect a number of aircraft as determined by that team. The process used by the Boeing Puget Sound Single-Aisle and Twin-Aisle Programs was to develop service bulletins that could be used by the airline, with or without Boeing assistance, to conduct the inspection, record the results, and provide the data to Boeing. Boeing Long Beach developed inspection documents that were used by Boeing personnel to perform each inspection.

Boeing Puget Sound developed and released service bulletins to conduct inspections of the 727, 737, 747, 757, and 767 airplane models. The center wing tank inspection service bulletins were applicable to all airplanes built at the time of release. To cover the large range of configurations, the center tank service bulletins were somewhat generic and covered the major configurations of a model, with notations where differences were expected. The main wing tank inspection service bulletins were designed for specific targeted airplanes, and the inspections were accomplished by the airlines with on-site support from Boeing.

The following two tables (figures 5-2 and 5-3) show the inspection documents developed for each affected aircraft model.

Airplane model	Service bulletin number	Service bulletin subject	Availability date
727	727-28-0122	FUEL – Storage – Center Wing Fuel Tank Inspection	March 1999
727	727-28-0123	FUEL – Storage – Inspection of the Number 1 and Number 3 Fuel Tanks	July 1999
737 -100/-200	737-28-1123	FUEL – Storage – Integral Fuel Tanks – Center Wing Fuel Tank Inspection	October 1998
737 -100/-200	737-28-1124	FUEL – Storage – Main and Surge Fuel Tank Inspection	July 1999
737-300/ -400/-500	737-28-1117	FUEL – Storage – Center Wing Fuel Tank Inspection	September 1998
737-300/ -400/-500	737-28-1118	FUEL – Storage – Main and Surge Fuel Tank Inspection	April 1999
747	747-28-2205	FUEL – Fuel Tanks – Center Wing Fuel Tank Inspection	June 1997
747	747-28-2213	FUEL – Fuel Tanks – Main Wing Fuel Tank Inspection	January 1999
757	757-28-0050	FUEL – Storage – Center Wing Fuel Tank Inspection	June 1998
757	757-28-0051	FUEL – Storage – Main and Surge Fuel Tank Inspection	January 1999
767	767-28-0051	FUEL – Fuel Tanks – Fuel System Inspection – Auxiliary Tanks	July 1998
767	767-28-0054	FUEL – Fuel Tanks – Fuel System Inspection – Main Tanks	October 1998

Figure 5-2: Puget Sound Airplane Service Bulletins

Boeing Long Beach developed inspection documents similar to service bulletins for the DC-9, MD-80/-90, DC-10, and MD-11. These documents were used by Boeing engineers from the fuel system, electrical, avionics, and product support disciplines. The inspection documents were also made available to the airlines if they chose to perform their own inspections.

Airplane model	Document number	Inspection document title	Release date
DC-9	MDC 98K9016	DC-9 Fuel Tank Inspection Report	March 3, 1998
DC-10	MDC 98K1056	DC-10 Fuel Tank Inspection Report	October 30, 1998
MD-80/-90	MDC 98K9027	MD-80/-90 Fuel Tank Inspection Report	May 12, 1998
MD-11	Addendum to MDC 98K1056	DC-10 Fuel Tank Inspection Report	Addendum released August 16, 1999

Figure 5-3: Long Beach Airplane Inspection Documents

The service bulletins and inspection documents developed for the inspection of Boeing airplanes addressed

- Bonding measurements.
- Examination of all bonding jumper installations.
- Condition checks for all mechanical and electrical components.
- Examination of all fuel quantity indication system (FQIS) wiring and components.
- Examination for fuel leaks.
- Examination of access doors, panels, and openings.
- Examination of general tank condition and sealant.
- Inspection for foreign object debris.

One of the many issues facing the program was that of sample size. As the inspection program evolved, the Boeing Working Groups recognized that similarities in findings would support a sampling approach for the total inspection program. The 747 center wing tank, which at that time already had hundreds of inspections, had shown little variation in findings after approximately 50 inspections. Because the fuel systems of all of the Puget Sound models were designed to the same basic set of standards and manufactured with the same processes, it was assumed that the findings from the fleet inspections should be similar across all models. Similarly, all Long Beach models were designed to a consistent set of standards and manufactured with the same processes, so the same assumption was applied. The findings have supported this early assumption.

A goal was set for the number of center wing tank inspections for each of the 737, 757, and 767 models. The information from these inspections would identify unique issues for these models and allow an assessment of any differences in general trends between these models and the 747. Further, it was determined that a smaller sample size for wing tank inspections was adequate to validate that there were no differences in aging patterns or design specifics between main and center wing tanks. For the smaller main wing tank sample size, Boeing engineers assisted on site in the inspections to ensure there was a detailed understanding of the findings in the smaller sample. It was also recognized that the center tank of the 727, which is actually a main tank because of the three-tank, three-engine configuration of this airplane, does not operate differently (never emptied) than the wing tanks of the 727. It was concluded that a small sample of the 727 center tanks, together with the 727 wing tank inspections, was sufficient to understand design and aging of the 727.

The sample size for the Long Beach airplane programs was also based on similarities in design and manufacture. Even though some differences existed for the DC-9, DC-10, MD-11, and MD-80 / -90 when compared to the Puget Sound airplane models, the differences were considered to be insignificant, and a smaller sample size was accepted.

Figure 5.4 provides an overview of the Boeing in-service world fleet.

				Flight-hours			Flight cycles		
Airplane type	First delivery*	Total delivered	Currently operating	Total fleet, average	Active fleet, average	Highest	Total fleet, average	Active fleet, average	Highest
707	9/30/58	941	260	39,731	48,753	93,273	15,427	19,702	51,168
717	9/23/99	26	26	775	775	1,957	564	564	1,346
727	11/16/63	1,831	1,418	53,397	53,838	85,703	39,966	38,977	78,564
737	12/28/67	3,691	3,485	26,858	26,006	89,723	22,519	21,141	96,526
747	12/13/69	1,249	1,116	50,416	47,976	115,664	10,915	10,335	34,670
757	12/22/82	926	922	22,899	22,939	60,726	9,921	9,940	31,735
767	8/19/82	792	786	29,708	29,787	71,731	9,698	9,719	34,630
777	5/15/95	288	288	6,101	6,101	20,949	1,790	1,790	9,672
DC-8	5/29/59	556	274	56,645	67,828	93,582	22,114	25,488	49,751
DC-9	9/18/65	976	814	57,849	60,100	95,177	61,016	62,666	100,629
DC-10	9/17/71	446	409	61,132	62,737	111,502	18,891	19,296	41,980
MD-11	12/7/90	197	192	24,542	24,441	47,481	4,444	4,423	8,399
MD-80	9/13/80	1,194	1,179	30,484	30,709	62,718	20,425	20,562	47,589
MD-90	2/24/95	112	111	6,156	6,167	16,194	4,828	4,802	10,132

* As of June 1, 2000

Figure 5-4: Boeing In-Service Fleet Summary

Operators		
Abu Dhabi Aviation	Aer Lingus	Aeromexico
Aerolineas Argentinas	Air 2000	Air Canada
Air France	Air Gabon	Air Holland
Air Hong Kong	Air India	Air Madagascar
Air Malta	Air New Zealand	Air One
Alaska Airlines	Alitalia	All Nippon Airways
America West	American Airlines	American Trans Air
Ansett Australia	Arco	Asiana
Atlas Air	Avianca	Braathens
British Airways	Britannia Airways	Canadian International
Cargolux	Cathay Pacific Airways	China Airlines
China Southern Airlines	Continental Airlines	Corse Air (Corsair)
Delta Air Lines	Dubai	Egyptair
El Al Israel Airlines	Emirates	Evergreen
FedEx	Finnair	Flying Colours
Futura	Gameco	Garuda
Greenlandair	Gulf Air	HM the Sultan's Flight
Hapag-Lloyd Flug	Iberia	Icelandair
Japan Airlines	Japan Asia Airways	Kitty Hawk
KLM–Royal Dutch Airlines	Lauda Air	LTU
Lufthansa	Malaysia Airlines	Martinair
Monarch Airlines	NASA	Northwest Airlines
Pakistan	Pegasus Airlines	Polar Air
Polish Air	Qantas	Royal Air Maroc
Royal Flight of Oman	Ryanair	Saudi Arabian
Saudi Royal Flight	Singapore	South African
Star Air Tours	Swissair	Transaero Airlines
Trans World Airlines	Transworld	Triangle Aircraft Services
Turkish Airlines	United Airlines	United Parcel Service
US Airways	US Airways Shuttle	USAF
Virgin Atlantic	WestJet	Whirlpool
Wuhan Airlines		

Figure 5-5: Participants in the Boeing Fleet Inspection Program

		Age (years)			Flight-hours			Flight cycles			Number of inspections	
Airplane model	Geographic region (quantity)	Oldest	Average	Newest	Most	Average	Least	Most	Average	Least	Center wing tanks	Main wing tanks
727	Americas (15)	25	21.6	20	71,367	50,085	15,162	48,288	34,426	12,010	10	10
737	Asia Pacific (12) Europe/Africa (42) Americas (43)	22	12.4	2	62,022	33,305	3,313	48,412	23,425	2,324	93	12
747	Asia Pacific (135) Europe/Africa (180) Americas (125)	30	13.7	3	110,595	54,993	1,337	33,831	11,562	1,312	435	20
757	Asia Pacific (17) Europe/Africa (30) Americas (33)	17	9.2	2	51,492	27,037	7,946	22,377	11,376	2,456	77	10
767	Asia Pacific (18) Europe/Africa (18) Americas (21)	18	9.8	3	65,573	32,242	4,834	33,422	10,596	2,708	54	12
DC-9	Americas (6)	33	31	29	83,911	73,538	66,800	84,221	72,009	64,175	6	12
DC-10	Americas (8)	29	26	22	74,518	61,939	48,329	26,955	23,110	14,494	8	24
MD-11	Americas (1) Europe (1)	6.6	6.5	6.3	28,055	27,835	27,615	5,199	4,343	3,487	2	6
MD-80	Americas (5)	17	11	9	47,461	27,131	15,000	43,251	23,187	14,795	5	10

Figure 5-6: Airplane Model Inspection Information

Out of this world fleet, a total of 710 airplanes have been inspected to date as part of the Boeing Working Group program. Results for the 747 are still coming in.

During this worldwide inspection effort, it was important in the data collection process to sample a satisfactory spread of age, flight-hours, flight cycles, and geographic operating areas. Figure 5-6 (see below in this section) shows the sampling variation and distribution that was achieved among the inspected airplanes.

A large number of air carriers (airlines and other operators) participated in this voluntary industry effort. In particular instances, inspections of center wing fuel tanks and main wing tanks were performed on the same airplanes. Figure 5-5 identifies the 94 operators who participated in the Boeing Working Group inspection program.

The commitment by the airlines and Boeing has been significant in accomplishment of these inspections. Based on Boeing's estimate of the time required to conduct a particular fuel tank inspection, it is estimated that more than 110,000 labor-hours have been expended in actual performance of the inspections. This estimate is likely conservative as feedback from the participating airlines indicate the Boeing estimate is low. In addition, many hours have been spent by the airlines and Boeing in preparation and planning for the inspections, in resolving questions about findings in the inspections, in restoring discrepancies to production levels, and in supporting working group meetings that are not included in the above estimate. The level of voluntary participation and effort expended by the airlines and Boeing in supporting all of the working groups is unprecedented and attests to the industry's ongoing commitment to continuously enhancing the safety of air travel.

5.6 Results

As stated, the program established by the Boeing Working Group included requirements reviews, drawing reviews, manufacturing process reviews, and in-service inspections. This program provided a comprehensive look at fuel system design, manufacture, and maintenance. The information, facts, and data collected from all of this activity are being used to identify areas of possible improvement and enhancement.

The inspection portion of the program provided a significant amount of data and information as to the overall condition of airplane fuel systems. Collectively, the data gathered provided ample information regarding the overall integrity of the design and maintenance of the Boeing in-service fleet. This data has been collected, analyzed, and reviewed for disposition. Design change (corrective action) and/or scheduled maintenance activity change recommendations are in work.

5.6.1 Electrical Bonding

All tubing, mechanical components (e.g., fittings, pump housings, valve bodies), and electrical components (e.g., pumps, valves, actuators, pressure switches) are typically bonded through the use of bonding jumpers or a mating surface (fay surface) bond on all Boeing airplanes. Every bond path between a piece of equipment and the primary structure of the airplane is installed to a predetermined resistance value. The inspection program measured these bond paths.

Development of the detailed inspection instructions used in the service bulletins and inspection documents was accomplished by performing a comprehensive review of the fuel system design for each model. An inspection value was assigned accordingly. If a bond exceeded the inspection-value, rework was specified to bring the bond back to the original manufacturing limits even if the measured value was still within safe limits. This manufacturing limit was chosen for rework to collect data on the causes of higher resistance values found.

The types of bonds measured were for static electricity (electrostatics), fault current handling, and lightning protection.

Findings were consistent across all models. Static bonds, used for bonding tubing and nonelectrical components, did not exhibit any aging problems. The small percentage of static bonds that did require rework to bring them back to the "as new" condition were well within the margin required to eliminate static charge buildup.

A condition was found on some Long Beach models where a bond path through a foil wrap on tube clamps was found to be delaminating. Airworthiness was maintained because redundant bonding is provided for each tube, and some of the foil typically remained in the clamp. An enhancement to the clamp is being studied with clamp suppliers.

Fault current bonds, installed external to the fuel tank on fuel system electrical components (pumps, valves, and so on), exhibited some increase in bonding resistance on the in-service airplanes. Those installations that required the most rework characteristically had an extremely stringent bonding resistance requirement of less than one milliohm (<0.001 ohm). In reviewing the designs of these bond paths and discussing the installations with manufacturing, it was determined that the design did not allow sufficient margin to ensure that once the bond was installed, it would stay within the established limits.

Reviewing and analyzing the findings from the fault current bond inspections revealed that there were no fuel tank ignition hazards associated with these parts or their installations. All of the electrical equipment that is bonded for fault current handling is installed external to the fuel tank.

Regardless, Boeing has taken action on the 747 by releasing Service Bulletin 747-28-2228, Override / Jettison, APU, and Electrical Scavenge Pump Bonding Jumper Modification, dated November 4, 1999. This service bulletin revises the electrical bond path for these pump installations to provide additional margin between the design capability and the resistance requirement.

In addition, for enhanced safety, Boeing is developing periodic maintenance recommendations for the fault current bonds on specific components to ensure that they stay within acceptable limits for the life of the airplane.

The proposal is to add a recommended periodic maintenance requirement for all pumps of all Puget Sound–built airplanes. This maintenance activity would include measuring the bonding resistance between the components and structure every heavy maintenance visit. If the measured resistance is above the limit, the operator will rework the bond path to the requirements outlined in the appropriate airplane maintenance manual.

Overall, there were no issues identified with respect to static, fault current, or lightning bonds that would affect the continued airworthiness of the fleet.

5.6.2 Bonding Jumpers

The design of fuel system installations on Boeing-built aircraft incorporates a large number of bonding jumpers for the bonding of tubing, mechanical components, and electrical components. These bonding jumpers are made up of braided wire and incorporate a mating lug on each end. In addition to the resistance measurement, the inspections included a visual inspection for signs of wear/deterioration, breakage, corrosion, and integrity of the fastening hardware.

Data received from the Boeing fleet inspections indicates that the majority of the bonding jumper installations looked as they did when they were originally manufactured. In those instances where bonding jumper discrepancies were found, some of the noted conditions included bonding jumper discoloration, bonding jumper corrosion, broken tube bonding clamps, and a few missing bonding jumpers. None of the conditions found would impact the continued airworthiness or reliability of the affected airplane because alternate bond paths typically exist, and design measures minimize charging.

Of the conditions noted above, some types of bonding jumpers exhibited discoloration without any effect on measurements. On a few airplanes, some bonding jumpers were found to be deteriorating. Analysis of the deteriorated parts has identified issues with the tin plating not properly sealing the copper wire from exposure to the sulfur in the fuel. In a few rare cases, the tin had flaked off and the reaction between the copper in the wire and the sulfur in the fuel had caused some of the strands in the bonding jumper braided wire to become brittle and break. No instances have been identified in which the bonding jumper failed to perform its intended function. A few bonding jumpers were found to be missing on a small number of Puget Sound–built airplane models. Because of alternate bond paths, no safety issues were associated with the missing parts.

The AFSSP and its inspection program have brought about an increased awareness of bonding jumper integrity and installation. The installation instructions for several pumps have already been updated to incorporate lessons learned. Additionally, maintenance documentation and training programs for manufacturing and maintenance personnel are both being revised to include comprehensive instructions for inspection, installation, removal, and replacement of bonding jumpers within fuel systems.

Boeing is evaluating issuing service bulletins to inspect the fuel tanks of all Boeing Puget Sound–built airplanes. The purpose of the bulletins would be to inspect for missing bonding jumpers and install bonding jumpers as required. Boeing is proposing that this service bulletin be accomplished during the first heavy maintenance visit after the bulletin is released.

5.6.3 Tubing, Mechanical, and Electrical Component Condition

The service bulletins included condition checks for all the tubing and mechanical components installed in the fuel tanks. Examples of mechanical components include fittings, pump housings, valve housings, check valves, jet pumps, drain valves, pressure relief valves, vent scoops, and float assemblies. External to the fuel tank, condition checks were also accomplished on fuel system electrical components mounted on the outside of the tank walls which interface with equipment located inside the tank. Typical electrical equipment inspections included boost pumps, scavenge pumps, jettison pumps, refuel valves, transfer valves, jettison valves, temperature sensors, float switches, and pressure switches.

Condition checks did not reveal any chronic problems. There were some reports of damaged tubing, loose couplings, and loose or broken lockwire, none of which would affect the safety of the airplane. It could not be determined from the inspection results at what point in time the tubing may have been damaged. The damage may have occurred during the original manufacture of the airplane or during a subsequent fuel tank entry to address an airline maintenance or inspection requirement. In either case, the proposed plan is to enhance the existing zonal inspections to identify and correct these types of conditions.

The information reported indicates that there is very little corrosion going on inside the tanks. Most of the tubing and mechanical components generally look as they did when they were new.

External to the fuel tanks, the electrical component inspections noted occasional but generally minor conditions of corrosion. It was expected that there would be some corrosion because of the environment in which the equipment operates. Most of the electrical equipment that was inspected is located either on the front or rear spars of the wing or in the wheel well area. These components are exposed to rain, deicing fluids, cleaning fluids, salt fog, and other environmental conditions.

External wiring interfaces to the electrical equipment mounted on the fuel tank were also inspected. Only minor discrepancies were reported for the Puget Sound–built airplanes. Inspection of the Long Beach DC-9 models identified an instance where power wiring had been misrouted and was installed in runs with fuel quantity indication system (FQIS) wiring. A service bulletin was issued to correct this situation on all DC-9s, and the FAA followed up with an airworthiness directive to make the service bulletin mandatory. Investigation determined the root cause to be a rework service bulletin that was performed improperly.

There was one instance reported where the inspection found an incorrect bonding jumper installed on an Override/Jettison Pump Motor Impeller Unit. The jumper appeared to have been installed as the result of an incorrect maintenance action and was reworked appropriately.

Except for the items noted above, none of the conditions found during this phase of the inspection affect the continued airworthiness of the airplanes on which the conditions were found. However, consideration is being given to recommending a periodic visual/tactile inspection check for conditions of broken or damaged hardware, loose couplings, broken or loose lockwire, and corrosion of bonding jumpers. The proposal would be for the inspection to be accomplished at a heavy check interval, probably in conjunction with structural inspections.

5.6.4 Fuel Quantity Indication System

Most of the FQIS installed on Boeing airplanes use a capacitance measurement system for computing fuel quantity. These systems typically include tank units and compensator units. Newer systems may include densitometers. These systems are designed not to provide an ignition source even under conditions of failure.

The fuel quantity indication system is the only system that has electrical wiring installed internal to the fuel tanks on Boeing-built airplanes. As part of the service bulletin program, detailed instructions were given to inspect both the FQIS components and electrical wiring.

The component inspections included all tank units, compensators, densitometers, single-point sensors, and terminal strips. Items that were found during the inspections included a few loose terminal connections and sulfide contamination on the terminal blocks of components and terminal strips. Loose terminals were tightened per instructions in the service bulletins. The FQIS incorporates design features that tolerate the fuel tank environment factors such as corrosion and contamination. Boeing is working with the FAA on a study to determine what issue, if any, is posed by sulfidation. The FAA study also will provide recommendations on the prevention and removal of sulfidation, if required. Boeing testing done in advance of this study has indicated that there are no continued airworthiness issues due to sulfide contamination.

The wiring inspections included in-tank and out-of-tank wiring. The wiring was inspected for cracked, abraded, or overstressed insulation; exposed or broken conductors or shields; inadequate clearance from structure; missing or loose clamps; and misrouting. There were no chronic issues associated with this wiring. In the few instances where a discrepancy was found, the situation was rectified by following normal maintenance procedures. The visual/tactile inspection under consideration, as noted above, may include FQIS wire inspections for these conditions.

To enhance maintenance procedures and the process of removal and replacement of FQIS wiring and components, the maintenance manuals are being revised to provide increased awareness of a proper installation and will include more comprehensive instructions for periodic maintenance and corrective action. To date, the 747 and 757 manuals have been completed.

The inspection program identified no conditions associated with the fuel quantity indication system that would affect the continued airworthiness of any Boeing-built airplane. As noted in the introduction, the FAA has released an AD requiring separation and shielding of FQIS wiring on the 737 and 747. This action was the result of efforts separate from the inspection program.

5.6.5 Fuel Leaks

Examination for fuel leaks is covered in the existing zonal inspection process. There are existing maintenance practices in place. The inspection service bulletins attempted to capture conditions that may not otherwise be visible to the team. There were very few instances of fuel leaks reported via the inspection service bulletin, and these would be identified by the existing zonal inspections. No additional maintenance procedures for fuel leaks will be proposed as a function of data collected from the inspection service bulletins.

5.6.6 Access Doors, Panels, and Openings

After Service Bulletin 747-28-2205 had been released regarding the 747 center wing tank inspection, the Fuel System Safety Leadership Team (FSSLT) agreed to add fuel tank access doors, panels, and openings to the inspection criteria. Boeing added the criteria to the 727, 737, 757, and 767 service bulletins.

Other than some miscellaneous damage to the seals and minor corrosion, the only other finding was an instance where it was observed that maintenance procedures were being misinterpreted, and fuel tank access door gaskets were not being reinstalled. Changes to Boeing maintenance manual procedures will be made to clarify proper installation. Existing zonal inspection recommendations are sufficient for the other conditions noted.

5.6.7 Tank Condition

Examination of the tank conditions and sealant did not identify any significant conditions. There were no instances of corrosion reported inside the tank and only a few instances reported where sealant was missing or separating from the structure. Existing zonal inspection recommendations are sufficient for the conditions noted.

5.6.8 Foreign Object Debris

Exclusion of foreign objects from fuel tanks has always been a priority. Debris in tanks could cause FQIS anomalies and pump failures. All of the Boeing-built airplane inspection service bulletins and inspection documents looked for foreign object debris.

The inspections confirmed that the tanks are generally quite clean. There were few reports of debris found in the tanks. The findings were consistent with past experience and would not have compromised the continued airworthiness of the airplane.

5.7 Conclusions and Continuing Activities

Boeing, along with a large cross section of operators, has conducted a thorough inspection of the fuel systems of a large number of in-service airplanes. This collaboratively gathered data on in-service fuel systems has been supplemented with a comprehensive review of fuel systems design and manufacture.

Overall, the data and analysis have shown that the basic design, manufacture, performance, and maintenance of commercial air transport fuel systems are robust. This worldwide inspection program did not find any significant effects due to aging. Fuel tank systems intrinsically age well with any degradation over time instead being attributable to specific factors such as improper actions during tank entries for maintenance.

Likewise, this inspection program did not reveal any effects or degradation attributable to geographic location. The integrity of fuel tank systems was equivalent for airplanes that operate in hot, humid environmental conditions and in the presence of salt air.

Some of the damage found to tubing and components inside the tank has raised the issue as to how often a fuel tank should be entered. The consensus of the Boeing Working Group is that the number of planned fuel tank entries should be as few as possible to prevent inadvertent damage to fuel tank systems and components, and to limit the exposure of maintenance personnel to this hazardous and difficult work environment.

This program has identified areas where airworthiness enhancements can be made. Boeing and its operators are committed to enhancing fuel system safety and agree to make changes that will improve margins in product safety. Service bulletins for the proposed changes mentioned earlier are being issued to enhance the design margins of the affected parts. Many of these service bulletins have already been released.

In conjunction with the other airplane working groups, Boeing is determining what should be done to enhance airplane maintenance for fuel systems. The current plan is to take lessons learned from fleet history reviews, together with information from the inspection program, and combine them to develop a comprehensive maintenance program. This program will be implemented via the existing MSG (maintenance steering group) process to ensure consistent industrywide acceptance.

6.0 BOMBARDIER WORKING GROUP REPORT

6.1 Introduction

Bombardier Aerospace joined the Aircraft Fuel System Safety Program (AFSSP) in late 1997 through its Regional Aircraft group. Bombardier Aerospace Regional Aircraft focuses on 30 to 90 passenger regional airline operations through its fleet of de Havilland Dash 7 (DHC-7) and Dash 8 (DHC-8-100, -200, -300, and -400) turboprop aircraft and Canadair Regional Jet CRJ 100, 200, 700, and 900 turbofan aircraft. All of the above aircraft are presently in production except for the CRJ 900—which was only recently launched—and the Dash 7.

Bombardier Aerospace also produces business aircraft through its Learjet, de Havilland, and Canadair facilities, and fire-fighting aircraft through its Amphibious Aircraft department. These aircraft were not included in the AFSSP because they are not operated under FAR Part 121. The certification authority for the Dash and CRJ aircraft is Transport Canada (TC), which has participated in the AFSSP meetings and worked with the Bombardier Working Group.

Bombardier Aerospace, Shorts division, is the type certificate holder for the Shorts 330 and 360 regional aircraft, which are out of production. These aircraft were subject to a separate review with the CAA and were not intended participants in the Bombardier AFSSP aircraft inspection program. Therefore, they are not addressed in this report.

6.2 Scope

Bombardier Aerospace joined the AFSSP soon after its inception and has participated fully in this voluntary industry program. Bombardier has attended and hosted meetings and has performed a sampling inspection of its regional jetliner fleet worldwide.

6.2.1 Additional Activities

Bombardier Aerospace has been involved in fuel system safety enhancement initiatives concurrent with the AFSSP. Bombardier participated in the Aviation Rulemaking Advisory Committee (ARAC) Fuel Tank Harmonization Working Group (FTHWG) and worked with the industry to provide comments on the FAA's Notice of Proposed Rule Making (NPRM) 99-18, which was titled "Transport Airplane Fuel Tank System Design Review, Flammability Reduction, and Maintenance and Inspection Requirements."

During the program, an operator mentioned a previous case of conduit chafing inside the tanks. This led to Service Bulletin A601R-28-036 to inspect the conduits and install a clamp. Isolated findings of minor chafing were encountered and addressed during compliance with this bulletin.

6.3 Working Group Teams

The Bombardier Working Group is made up of several internal departments and several airlines, as described immediately below.

6.3.1 Team Composition

The following chart shows the Bombardier Working Group composition:

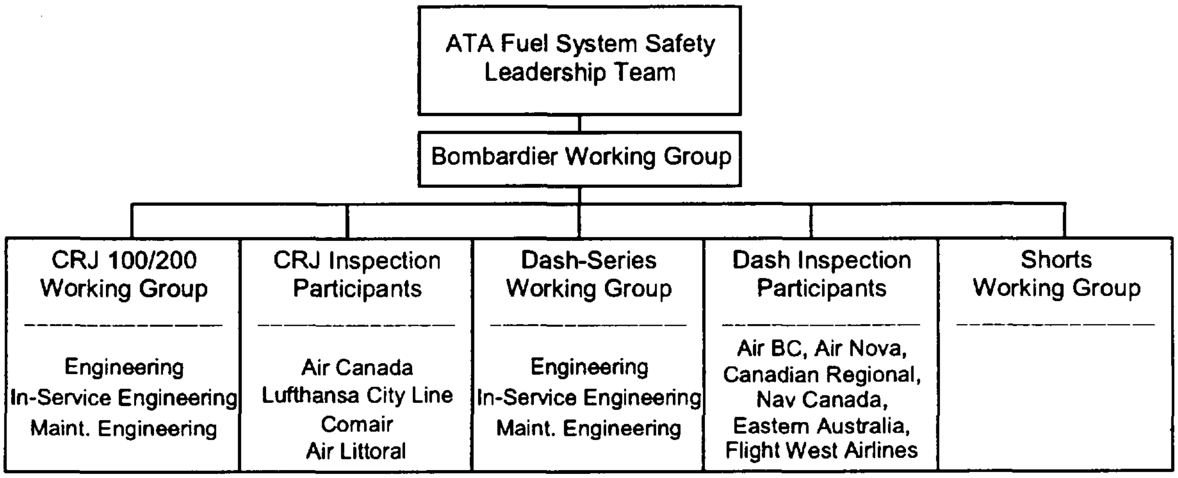

Figure 6-1: Bombardier Working Group

6.3.2 Team Activities

Communication between the various groups was maintained through regular meetings, which ranged from gatherings of CRJ Working Group members; CRJ and Dash groups; CRJ, Dash, Transport Canada, and airlines; and Bombardier participation in the AFSSP meetings.

6.4 Working Group Approach

The Bombardier Working Group worked in close cooperation with the industry as it defined and conducted its participation in the industry's voluntary AFSSP.

6.4.1 Objectives

Bombardier's main objective was to verify current maintenance programs, maintenance practices, design principles, and manufacturing processes by gathering data on the condition of in-service fuel tanks. This data is being used to ensure the continuing airworthiness of the Bombardier fleet by developing improvements as required to the aircraft maintenance program, and to help respond constructively to any new rulemaking.

6.4.2 Inspection Program

In accordance with guidelines set out by the Fuel System Safety Leadership Team (FSSLT), the inspections covered all fuel system aspects including wiring condition, general tank condition, component condition, and bonding. The field data was obtained through Bombardier Service Bulletin 601R-28-037 (CRJ) and Service Bulletin 8-28-31 rev B (Dash 8). The original plan was to inspect 20 CRJ 100/200, 14 Dash 8, and 4 Dash 7 aircraft. Note that the CRJ 100 and 200 have identical fuel systems; the CRJ 700 is not yet in service; the Dash 8-100, -200, and -300 series have very similar fuel systems; and the Dash 8-400 entered service after the initiation of the inspection program.

There were more than 110 electrical bonding measurements per aircraft in the CRJ service bulletin and more than 124 in the Dash 8 service bulletin. Both service bulletins required a thorough visual inspection of the entire fuel system. Inspections were intended to be conducted during regularly scheduled aircraft C Check downtime or other scheduled tank-entry maintenance opportunities. The inspection completion time for these service bulletins was 52 labor-hours for the CRJ and 60 labor-hours for the Dash 8.

Bombardier personnel provided on-site support for the first inspection performed with each operator. BCD M-1 bonding meters, manufactured by BCD Electronics Ltd., were primarily used. These meters can take readings from 0.01 milliohms up to 20 ohms.

To obtain data not covered by the service bulletins, two high-time CRJ electrical conduits were removed; one fuel boost pump and one valve. The entire assemblies, with wires in conduits, were inspected at the Bombardier Materials and Processes Laboratory.

In addition to data gathering in the field, aircraft- and component-level lightning research and development testing is being conducted in association with Lightning Technologies, a lightning specialist company. See section 6.7 for more information.

The following three tables summarize the Bombardier Working Group inspection program:

Airline	Aircraft type operated	Location
Lufthansa City Line	CRJ	Europe
Comair	CRJ	North America
Air Littoral	CRJ	Europe
Air Canada	CRJ	North America
Air Nova	DHC-8 (Dash 8)	North America
Air BC	Dash 8	North America
Canadian Regional	Dash 8	North America
Nav Canada	Dash 8	North America
Eastern Australia	Dash 8	Australia
Flight West Airlines	Dash 8	Australia

Figure 6-2: Airline Inspection Participation

Aircraft	First delivery	Seats	Average annual hours	Average annual cycles	High-time aircraft (hours)	High-time aircraft (cycles)
CRJ 100 / 200	1993	50	2,444	2,183	17,855*	16,300*
DHC-8 (Dash 8)	1985	37 / 57	2,207	2,632	40,082**	54,301**

* As of April 2000
**As of June 2000

Figure 6-3: Fleet Data

Aircraft	Inspected	Minimum hours	Maximum hours	Average hours	Minimum cycles	Maximum cycles	Average cycles
CRJ	12	6,392.9	15,160	11,778.4	5,662	14,635	10,527
Dash 8	18	16,502	34,361	24,860	18,210	43,416	30,779

Figure 6-4: Aircraft Model Inspection Information

CRJ inspections included aircraft from North America and Europe. Dash 8 inspections included aircraft from North America and Australia.

6.5 CRJ Results

The results of the inspection of Bombardier CRJ fanjet aircraft are provided immediately below followed by the results of the Bombardier turboprop inspection program. Both are summarized at the conclusion of this AWG report (see section 6.7).

6.5.1 Bonding Jumpers

All bonding jumpers were securely in place with no missing jumpers. No frayed, damaged, corroded, or disconnected bonding jumpers were found. All jumper measurements were within limits for electrostatic bonding and were performing their intended function.

6.5.2 Fuel Quantity Indication System (FQIS) Wiring

The fuel quantity transmitter probes and the compensators are variable capacitors that change capacitance in relation to the amount of fuel in the tank. No chafing, cracking, degradation, exposed connectors or any wiring deficiencies were found.

6.5.3 Condition of Fuel Pumps, Fuel Lines, and Fittings

A few instances of resistances above production limits were encountered because of the presence of blue anodizing on the faying surfaces of AN fittings. This nonconductive coating must be removed and the surface treated for corrosion protection before installation. Presently, Bombardier is using fittings with an ion vapor deposit (IVD) coating, which is conductive. Since August 1999, moreover, bonding measurements are being taken of 100 percent of these connections during production.

The couplings used on the CRJ are a self-bonding type manufactured by Wiggins, Hydra-flow, or both. One instance was encountered where the resistance was greater than 20 ohms (the meter's limit) and no measurement could be obtained. The coupling was disconnected, and the tubes were found misaligned. Once realigned and connected, bonding was within limits. The production line is now monitored for this condition, and bonding jumpers are installed across all Wiggins couplings to expedite production. No electrostatic issues affecting airworthiness were encountered.

The CRJ routes wires for valves and pumps through aluminum conduits. No damage or chafing of wire conduits was found during the inspections. Two conduits, with wires, were removed from a fleet leader, these being a fuel boost pump conduit and a fuel cross-flow shutoff valve (SOV) conduit. There was nothing to report on the boost pump conduit—no chafing or wire degradation. Minor chafing was found on the wiring in the cross-flow SOV conduit. After approximately 15,000 hours flight time, the outer insulation jacket of a three-wire bundle was found partially chafed. It has been decided to conduct a sampling program of these conduits consisting of units of varying ages to determine how they are wearing over time.

6.5.4 Electrical Bonding

The CRJ service bulletin comprises more than 110 bonding measurements. These included bonding jumpers (for vent lines and fuel lines to structure) and faying surfaces (pumps, level sensors, and temperature sensors). While measurements varied, no electrostatic issues affecting airworthiness were encountered.

The CRJ has three electric boost pumps per aircraft. On one aircraft, one of these pumps had a higher resistance than the others, possibly due to nonconductive sealant being used in conjunction with the conductive gasket. Difficulty sealing this gasket has been encountered, and a redesigned gasket is now used. A service bulletin to inspect for sealant and clean if necessary is scheduled for release in September 2000. The resistances encountered between these pumps and the aircraft structure were very low, with approximately 80 percent below 5 milliohms, and no airworthiness issue was present.

6.5.5 Foreign Object Debris

Two small nuts were found that are thought to be from production. No damage from foreign objects was found.

6.5.6 General Tank Condition

The general condition of the inspected tanks was excellent. No visible signs of aging, corrosion, wire degradation, foreign deposits, or damage were found. These tanks are too small to be fully entered by maintenance personnel, which reduces the likelihood of physical damage.

6.6 de Havilland Group Results

The results of the inspection of the de Havilland Canada (DHC) Dash 8 turboprop commuter airliner of Bombardier Aerospace are summarized below.

6.6.1 Electrical Wiring and Bonding Jumpers

Electrical wiring is routed within the fuel tank to support the operation of the auxiliary fuel boost pump, low fuel level warning, and the pressure relief valve position indication. See section 6.6.2 for a discussion of wiring associated with the FQIS.

One auxiliary fuel boost pump is located within the collector bay of each standard fuel tank. The pumps are powered from the 115-V AC bus. The pump wires routed within the fuel tank are located within aluminum conduit. The conduit is connected to the wing structure where the pump wiring enters the tank, and to the pump housing where the wire interfaces with the pump motor.

The low-level warning system comprises a float switch located in the collector bay of each standard fuel tank. The float switch is powered from the 28-V DC bus. The pressure relief valve indication system comprises a switch integral with the pressure relief valve located at the outboard extremity of each standard tank. The pressure relief valve indication switch is powered from the 28-V DC bus. The float and relief valve switch wiring routed within the tank is also in aluminum conduit. This conduit fully encloses the wiring, as in the case of the fuel pump.

The wiring and conduit design for the three systems described above are similar. The wiring and conduit for the fuel pump and pressure relief valve were removed during the inspection program. No evidence of chafing or degradation of the wiring was observed.

The DHC-8 aircraft uses numerous bonding jumpers for electrostatic bonding of fuel tubing. The bonding jumpers are fabricated from stranded aluminum wire with an aluminum mating terminal at each end. The inspection program carried out resistance measurements of the bonding jumper installation as well as a visual inspection for evidence of deterioration and wear, breakage, corrosion, deposits, security of attachment, and missing jumpers.

The inspection program showed the vast majority of bonding jumpers complied with the aircraft build standard. A small percentage of discrepancies was observed including missing jumpers, loose jumpers, jumpers with broken strands, and jumpers exceeding the build-standard resistance. There were no visible signs of corrosion or deposits. The bonding jumper discrepancies were rectified during the inspection program. These discrepancies are summarized in the table below.

Issue	Findings (% of inspected jumpers)
Damaged bonding jumpers (broken strands) and jumpers exceeding build-standard resistance	1.3
Missing bonding jumpers	0.4
Loose bonding jumpers	1.1

Figure 6–4: de Havilland Bonding Jumper Discrepancies

Because of the presence of redundant electrostatic bonding paths, the discrepancies associated with the missing and loose bonding jumpers did not impact the continued airworthiness of the aircraft inspected. The bonding jumper resistance levels that exceeded the build-standard resistance are well within the safety margin for electrostatic bonds.

Bombardier will issue a service bulletin recommending a one-time visual inspection of DHC-8 fuel tanks for missing, damaged, or loose bonding jumpers. Bombardier proposes that this inspection be accomplished during regularly scheduled maintenance activity. Also proposed is a periodic visual inspection of bonding jumper integrity as part of the aircraft maintenance program. This periodic inspection is also to be carried out during scheduled fuel tank maintenance activity.

Bombardier will also undertake a review of possible improvements to the bonding jumper specifications used on DHC-8 products.

6.6.2 FQIS

The primary FQIS for the DHC-8 uses a capacitance measurement system that includes six capacitance probes located throughout each standard fuel tank. The wiring that interconnects the probes inside the fuel tank is routed for support within segments of aluminum conduit.

Two magnetic dipsticks located within each standard tank provide an alternate means of measuring fuel quantity on the ground. The dipsticks use a mechanical design consisting of a calibrated rod sliding within a tube that extends vertically from the lower wing skin. The magnetic dipsticks are electrically bonded to the external surface of the lower wing skin for lightning protection. The magnetic dipsticks were visually examined for damage. In addition, the electrical resistance was measured between the dipstick and aircraft structure. The inspection program found no visible damage to the dipstick. The electrical bonding measurements indicated resistance levels that exceeded the build standard. The resistance levels are attributed to oxidation between the magnetic dipstick and the lower wing skin external to the fuel tank. The magnetic dipstick installation is designed to prevent lightning ignition sources within the fuel tank because of the use of a nonmetallic nut and internal sealing process. The increased resistance levels associated with the oxidation does not affect the continued airworthiness of the DHC-8.

The inspection program examined the capacitance probes for damage, corrosion, and deposits. The fuel probe wiring was examined for damage, chafing, and discoloration as well as for cracked and degraded insulation. Bombardier also conducted a design review for FQIS wiring routed external to the fuel tank. The external FQIS wiring is shielded and separated from high-power wiring.

No evidence was observed of damage, corrosion, or deposits associated with the fuel probes. There were isolated cases of chafing on capacitance probe wiring associated with relatively high-time aircraft. The chafing is attributed to the aluminum conduit. The FQIS fuel system wiring is designed not to provide an ignition source even under fault conditions.

Bombardier will carry out a one-time visual inspection of DHC-8 FQIS wiring for damage and chafing. Bombardier will also carry out a one-time functional check of the magnetic dipstick electrical bonding. Bombardier is proposing that these inspections be accomplished during scheduled maintenance activity. In addition, Bombardier is proposing a periodic inspection of FQIS wiring integrity as well as magnetic-dipstick electrical bonding as part of the aircraft maintenance program. These periodic inspections will be carried out during scheduled fuel tank maintenance activity.

6.6.3 Fuel Components, Fuel Lines, and Fittings

The inspection program specified a visual inspection of fuel tank tubing, components, and fittings including the low-level float switch, auxiliary fuel pump, pilot valve, pressure relief valve and conduit, scavenge ejector pump, refuel and transfer line, vent line, engine-feed line, waste fuel line, low-level warning conduit, pressure switches, solenoid valves, and shutoff valves. The tubing, fittings, and components were examined for damage, corrosion, leakage, and indications of heating or discoloration.

In general, the fuel tank components were found to be in excellent condition. There was one reported case of a damaged fuel line, which was replaced. During one of the initial DHC-8 aircraft inspections, it was determined that the fuel coupler on the vent and scavenge lines at station 249 of the right-hand wing had been installed incorrectly with the larger diameter of the coupler facing outboard instead of inboard. This condition resulted in fouling between the coupler and the inside surface of the wing access cover. Bombardier considered this finding to be an airworthiness item and issued a service bulletin, mandated by Transport Canada, to inspect the fleet and rectify the condition.

6.6.4 Electrical Bonding and Grounding

In general, fuel system components are electrically bonded by means of bonding jumpers and mating-surface bonds (direct-interface bond between components). These bonds are designed for electrostatic, lightning, and fault-current protection. Bombardier measured the electrical bonding resistance for numerous fuel system components and tubing.

As outlined in section 6.6.1, a small percentage of the bonding jumpers was found to exceed the build standard resistance. The bonding jumper resistance levels that exceeded the build-standard resistance are well within the safety margin for electrostatic bonds. In some cases, the bonding jumpers used for electrostatic protection may carry lightning currents. Bombardier is conducting a test program to investigate the effect of increased bonding-jumper resistance on lightning protection.

The fault current bonds for the 115-V AC-powered auxiliary fuel pump were within acceptable limits. The design review indicated that two fuel tank electrical components were not designed with fault current protection. The 28-V DC fuel shut off valve is located on the wing rear spar external to the fuel tank. The pressure relief valve position indication switch is a 28-V DC component located within the fuel tank. Bombardier will recommend a mandatory service bulletin to incorporate fault current bonding for these components. In addition, Bombardier is proposing a periodic functional check of the fault current bonding for fuel tank electrical components as part of the aircraft maintenance program. These periodic inspections will be carried out during scheduled fuel tank maintenance activity.

6.6.5 FOD

The inspection process produced no reports of foreign object debris within the fuel tanks, which were found to be very clean. The existing zonal FOD inspections have proven to be effective.

6.6.6 General Fuel Tank Condition

A general inspection of the integral fuel tanks including wing skins, spars, ribs, stingers, and access covers indicated no signs of degradation or corrosion with the exception of the contact interface between magnetic dipstick and external wing skin. In general, the fuel tanks were found to be in excellent condition.

6.7 Summary

Close inspection of the CRJ fanjet and Dash turboprop series aircraft fuel systems has revealed that they are in excellent condition. Minimal aging effects were encountered; aircraft of various ages were inspected with similar results. As well as a cross section of airplane ages, airplanes from different environments were inspected with no variances found in tank condition.

The few anomalies discovered have led to, or may lead to, changes or additions to maintenance programs, build practices, and design philosophy that enhance the aircraft airworthiness. The inspection program has heightened the awareness among operators and their maintenance personnel in particular, of the importance of fuel system condition and bonding.

The CRJ inspection program has identified an area of additional activity: long-term sampling and monitoring of wire in conduit installations. The intent is to confirm and calibrate the single finding of chafing for development of appropriate future inspection and/or maintenance actions.

For the Dash 8 (DHC-8) turboprop fleet, the discrepancies identified in the inspection program are being rectified through a one-time inspection, and the existing aircraft maintenance program for fuel systems will be updated to incorporate the findings. These findings will also be applied to the small number of DHC-8 long-range fuel tanks that are in service. Having completed the Dash-8 inspections, Bombardier will carry out a fuel system inspection program for the four-engine Dash-7 (DHC-7), which is no longer in production. This Dash-7 inspection program is expected to begin in the fourth quarter of 2000.

The DHC-8 fuel system inspections have identified two areas of additional activity. Bombardier will undertake to review possible improvements to the bonding-jumper specifications used on DHC-8 products as well as a lightning test program to understand the effects of increased bonding-jumper resistance with respect to lightning protection.

In light of an industrywide lack of available information, Bombardier has initiated a parallel research and development program in conjunction with the support of Lightning Technologies to determine the detailed effects at the component level of lightning strikes on aircraft. This test activity commenced in July 1999 and is ongoing. When completed, the resultant data will be used to validate and improve build techniques and margins for aging aircraft concerns and other in-service issues.

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7.0 FOKKER WORKING GROUP REPORT

Fokker Aircraft b.v. of The Netherlands, a manufacturer of airliners since 1919, produced the Fokker F27, F28, F50, F60, F70, and F100 turbine-powered transport airplanes. Production of these jet and turboprop models ceased sometime following the company's bankruptcy on March 15, 1996, and no additional Fokker aircraft have been produced since then. Today, Fokker Services b.v. is part of the Dutch Stork Group and the type certificate (TC) holder for these aircraft models and continues to provide certified inspection, repair, and modification services.

It should be noted that an additional 205 FH27 and FH227 aircraft were produced in the United States by Fairchild Hiller aircraft under license to Fokker Aircraft. Manufactured between 1956 and 1972, these U.S.-built aircraft do not fall under the TC purview of Fokker Services b.v.

7.1 Scope

Fokker Services b.v. joined the AFSSP in November 1997. Since that time, Fokker has actively participated in this voluntary industry program's meetings and its sampling inspection of the world turbine-powered commercial airliner fleet.

7.2 Working Group Approach

In 1997, Fokker Services implemented an internal fuel systems safety working group. Although this Fokker Working Group did not include direct airline participation, it kept customers who fly Fokker aircraft fully informed about the inspection program and actions taken through

- Customer conferences.
- Technical focus group meetings.
- The normal Fokker Services publications.

Fokker Services feels that this approach has been sufficient to meet the needs of Fokker operators.

7.3 Inspection Program

The inspection program initiated by Fokker Services in 1997 addresses every turbine-powered Fokker commercial aircraft type. To date, all Fokker 50 and 70 and most Fokker 100 inspections have been performed at the Fokker Services Maintenance facility under the supervision of the Fokker Working Group. All Fokker 27 and most F28 inspections were performed by operators.

Like the other AFSSP participants, Fokker Services is committed to enhancing fleet airworthiness and believes that the fuel system safety of the world fleet should be based on in-service reliability findings together with data gained from this inspection program. A fuel system inspection package was developed by Fokker Services and made available to any Fokker operator who elected to join the inspection program. To prevent customers from being excessively burdened, this inspection activity was structured for performance during regularly scheduled airplane downtime.

7.3.1 Fokker Turboprop Inspection Program

In the early 1950s, Fokker Aircraft began development of the Fokker F27 Friendship, a twin-engine turboprop transport. The prototype F27 made its first flight on November 24, 1955, with deliveries to customers commencing two years later. The last Fokker-built F27 Friendship was delivered in April 1987. Many commercial versions of the F27 were produced over the years with seating capacities ranging from 48 to 59. Several military versions have also been built. The F27 was powered by Rolls-Royce Dart 6 or 7 turboprops rated at a variety of shaft horsepowers.

In 1983, Fokker Aircraft initiated development of the Fokker 50, a successor to the F27 with the same overall configuration, a developed maximum seating capacity of 62 passengers, and two Pratt & Whitney PW125B or 127B turboprop engines. Deliveries to customers began in 1987. A total of 208 Fokker 50s were delivered before production ceased in 1996.

In 1993, the Fokker 60—a stretched all-cargo version of the Fokker 50 with two Pratt & Whitney PW127B turboprop engines—was developed at customer request. Four Fokker 60s were delivered before production ceased in 1996. As with the Fokker F27 and Fokker 50, the Fokker 60 has no heat sources located in the vicinity of the fuel tanks that can affect their temperature.

Airplane type	Fokker 27	Fokker 50	Fokker 60
First delivery	January 1957	August 1987	July 1996
Total delivered	580	208	4
In operation as of January 2000	422	207	4
Highest flight-hours (FH)*	84,362	24,101	2,965
Highest flight cycles (FC)*	89,997	34.769	2,797
Total fleet FH*	15,918,440	3,132,164	8,736
Total fleet FC*	17,180,625	3,594,368	7,500
Aircraft (a/c) inspected by June 2000	4®	5®	@
Additional a/c to be inspected ©	11	2	@
A/c with highest FH inspected #	25,132	19,633	@
A/c with lowest FH inspected #	16,331	15,834	@
Average FH of inspected a/c #	18,594	17,565	@
A/c with highest FC inspected #	33,609	20,568	@
A/c with lowest FC inspected #	23,100	18,332	@
Average FC of inspected a/c #	25,829	19,199	@

* Status as of January 1, 2000
\# Status June 2000
@ Because of their relative newness and 100 percent commonality with the Fokker 50, no Fokker 60s are planned for the inspection program.
© The planned inspection program has not been finalized before the issue date of this final report; nevertheless, Fokker Services has decided to continue the inspection program with more aircraft.
® Aircraft with the optional inboard tanks have not been inspected. Only a few F27s and no F50s or F60s fly commercially with these inboard tanks, which are normally used only on military versions of Fokker turboprops.

Figure 7-1: Fokker Turboprop Inspection Program

Figure 7.1 provides information about the Fokker turboprop world fleet and its inspection, while Figure 7.2 identifies the airlines participating in its inspection.

Airplane type	Operator(s)
Fokker F27	Mountain Air Cargo (MAC) Empire Airlines*
Fokker 50	Denim Air VLM SAS
Fokker 60**	None

* Aircraft inspections with Empire are under discussion.

** No Fokker 60s are planned for the inspection program because of their relative newness and 100 percent commonality with the fuel system of the Fokker 50.

Figure 7-2: Turboprop Inspection Participants

The first F27 Friendship inspection was performed in February 2000. The Fokker 50 inspection program began in January 2000. The Fokker Services turboprop inspection program covers the inspection items identified in section 2.0 of this document. In addition, the following items were inspected for:

- Insulation resistance of the FQIS wiring inside the fuel tanks.
- Insulation resistance of the solenoid wiring.
- Visual inspection of the condition of the bonding wires installed outside the fuel tanks on pipes of the fuel system on the wing, nacelles, and center wing.
- A bonding check on the ducting and bonding wires installed outside the fuel tanks on pipes of the fuel system on the wing, nacelles, and center wing.

7.3.2 Summary of Turboprop Inspection Findings

The inspections performed on Fokker turboprop aircraft revealed the following:

- The current routing of the FQIS wiring inside the main fuel tanks on the F27 makes it difficult to inspect the wiring condition.
- Several mechanical components inside the fuel tanks showed higher bonding values to structure than expected.

7.3.3 Fokker Jet Inspection Program

Fokker Aircraft launched the Fokker F28 Fellowship program in 1964. The prototype F28 flew on May 9, 1967. This airplane program saw 241 aircraft manufactured in several different versions or marks. The F28 had passenger seating ranging from 65 seats (Mark 1000) up to 85 seats (Mark 4000). Two Rolls-Royce RB183 turbofan engines power the F28 Fellowship.

The Fokker 100 program was launched in 1983. The prototype F100 twinjet made its first flight on November 7, 1987. A total of 278 Fokker 100s were produced for customers all over the world. The Fokker 100 has a maximum seating capacity of 122 and is powered by two Rolls-Royce TAY 620-15 or 650-15 turbofan engines.

The Fokker 70, a shortened Fokker 100 with seating for up to 85 passengers, was launched in 1992. Deliveries began in 1994, and 47 Fokker 70s were produced for a wide variety of customers all over the world. Two Rolls Royce TAY 620-15 turbofans power the Fokker 70, which—like the F28 and F100—has no heat sources located near the fuel tanks that can affect their temperature.

The Fokker 70 was initially excluded from the AFSSP inspection program because of its relative newness and 100 percent commonality with late-production Fokker 100s. However, deteriorated bonding wires were recently found inside the wing tanks of two Fokker 70 aircraft. Consequently, Fokker Services has decided to target a couple of Fokker 70s for inspection during the coming months to ascertain the cause of this bonding-lead deterioration.

Figure 7-3 below provides information about the Fokker world jet fleet and its inspection.

Airplane type	Fokker 28	Fokker 70	Fokker 100
First delivery	1968	October 1987	March 1988
Total delivered	241	47	278
In operation as of Jan. 2000	203	47	275
Highest flight hours (FH)*	67,693	12,937	27,751
Highest flight cycles (FC)*	89,656	10,418	25,534
Total fleet FH*	7,176,280	374,082	4,689,773
Total fleet FC*	8,444,302	324,072	4,208,255
Aircraft (a/c) inspected by June 2000	21 / 4 ®	2 / 0 ◊	11 / 6 ®
Additional a/c to be inspected ©	±3 ^	3	5 ^
A/c with highest FH inspected #	46,887	12,448	24,438
A/c with lowest FH inspected #	12,167	11,549	11,477
Average FH of inspected a/c #	29,559	11,998	19,012
A/c with highest FC inspected #	53,374	7,726	22,881
A/c with lowest FC inspected #	15,388	6,942	11,098
Average FC of inspected a/c #	37,051	7,334	18,039

* Status as of January 2000
# Status June 2000
^ No airplanes with the ICWT have yet been inspected.
© The planned inspection program has not been completely finalized before the issue date of this final report; nevertheless, Fokker Services has decided to continue the inspection program with more aircraft.
® Total number of aircraft inspected/number of center wing tanks inspected on the total number of aircraft.
◊ Two Fokker 70s were visually inspected for problems with the bonding wires, as described above.

Figure 7-3: Fokker Jet Inspection Program

The first F28 inspection was performed in 1997 and the first Fokker 100 inspection took place in 1998. The Fokker Services inspection program covers the inspection items outlined in Section 2.0 of this document. In addition, Fokker also inspected for the following items:

- FQIS, boost pump, solenoid, and switch wiring insulation resistance inside the conduits in the wing fuel tanks.
- Visual inspection of the condition of the bonding wires installed outside the fuel tanks on pipes of the fuel system on the wing rear spar.
- A bonding check on the bonding wires installed outside the fuel tanks on pipes of the fuel system on the wing rear spar.

This table identifies the airlines participating in the Fokker jet fleet inspection effort.

Airplane type	Operators	
Fokker F28	Argentine Air Force Biman Bangladesh Corp. Canadian Regional	Horizon Air Precidencia Argentina
Fokker 70	KLC	
Fokker 100	Alpi Eagles British Midland KLM UK * LAM Mozambique	Portugalia TAM Brazil US Airways

* Aircraft inspections with KLM UK are under discussion.

Figure 7-4: Jetliner Inspection Participants

7.3.4 Summary of Jet Inspection Findings

The inspections performed on Fokker jetliners revealed the following:

- Boost pump wire cracking and chafing was detected on F28 aircraft during the inspection of the wiring.
- Fokker Services received reports of damage to the protection layer of the solenoid and level switch wiring on the F28.
- On two Fokker 70 aircraft, deteriorated bonding wires inside the wing tanks were discovered during an inspection not related to this sampling inspection program.
- In general, bonding values measured outside the fuel tank are higher than values found inside the fuel tanks, previously performed maintenance actions are the main cause for this.
- No correlation was found between airplane age and high or low bonding values.
- No correlation was found between geographic location of airplane operation and high or low bonding values.

7.4 Conclusions

In general, the fuel systems of Fokker aircraft were found to be in good to excellent condition. Specific findings of the Fokker Working Group's sampling inspection program are as follows.

7.4.1 Turboprop

For the F27, a modification is proposed to the routing that will protect against chafing and mechanical damage of the FQIS wiring inside the fuel tanks. This modification is similar to what is standard on the Fokker 50 and Fokker 60. An operator has successfully installed this new FQIS wiring routing on one aircraft. Comments and changes are currently under review by Fokker Services. A service bulletin is planned for the introduction of this alternative FQIS routing.

Fokker Services b.v. is currently investigating the reason for the higher bonding values of several mechanical components inside the fuel tanks. Corrective actions will be taken when required.

No airworthiness issues were identified during the inspections. The routing of FQIS wiring on the F27 and the higher bonding values to mechanical components inside the main fuel tanks do not in any way affect the continued airworthiness of the aircraft.

7.4.2 Jet

Fokker Services has effectively addressed the chafed boost pump wiring on the F28 with an inspection and modification service bulletin for the installation of improved pump wiring with an additional protection braid. This improved boost pump wiring is similar to wiring already used on the Fokker 70 and 100. The Dutch Airworthiness Authorities have made this service bulletin mandatory. The inspection part of this service bulletin effectively guarantees the continued airworthiness of the aircraft in the pre-mod configuration.

No chafed boost pump wiring was detected during the wiring inspection of the Fokker 70 or 100.

Fokker Services plans to issue a service bulletin in 2000 for the installation of protective sleeves around the solenoid and level switch wiring on the F28. Continued airworthiness of the aircraft has not been affected.

Since the solenoid and switch wiring on the Fokker 70 and 100 are identical to that installed on the Fokker F28, a service bulletin is also planned in 2000 for the Fokker 70 and 100 for installation of protective sleeves around this wiring. The continued airworthiness of these aircraft has not been affected.

The reason for the deteriorated bonding wires discovered inside the wing tanks of two Fokker 70 aircraft is under investigation. Additional Fokker 70 aircraft will be inspected to verify the extent of this phenomena. Corrective actions will be taken when required.

Fokker Services will investigate ways to prevent maintenance of line replaceable units from affecting the quality of bondings. Even though present maintenance manual procedures address the correct restoration of bonds, future more comprehensive maintenance procedures may be required. The airworthiness of the aircraft has not been affected.

No airworthiness issues were identified during this sampling inspection program. The Fokker jet fleet portion of this program has not entirely concluded as of this final report. Fokker Services has committed to continuing the jetliner inspections with more aircraft to be examined in 2000.

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8.0 LOCKHEED MARTIN WORKING GROUP REPORT

8.1 Introduction

This report summarizes Lockheed Martin's evaluation of the L-1011 fuel system in support of the AFSSP. Discussed below are the approach taken, inspection procedure used, findings, and actions being implemented in response to the inspection program results.

8.2 Scope

In accordance with the guidelines set out by the Fuel System Safety Leadership Team, Lockheed Martin performed inspections to assess all aspects of the L-1011 fuel tank system (e.g., aircraft wiring condition, component condition, bonding). A design review helped identify specific areas of interest to be inspected.

8.3 Working Group Team

At the time of inception of the AFSSP, the Lockheed Martin Aeronautical Systems Company of Marietta, Georgia, was the OEM facility responsible for the L-1011. The Marietta facility is credited for the initial research and development of the Lockheed Martin L-1011 contribution to the AFSSP. In 1998, the L-1011 program transferred from Marietta to the Lockheed Martin Aircraft and Logistics Centers (LMALC) facility in Greenville, South Carolina. LMALC, a sustaining rather than production organization, continues to support the AFSSP.

The L-1011 family consists of variations of the basic configuration. Models include the L-1011-1, L-1011-1-14, L-1011-1-15, and L-1011-3 models. Each of these models corresponds to specific gross takeoff weight capabilities, fuel tank arrangements, and engine types. The L-1011 family encompasses similar fuel system design philosophies and criteria common to all models.

8.4 Team Composition

The Lockheed Martin Working Group comprises the OEM and the three primary operators of the currently active Lockheed Martin L-1011 fleet: Delta Air Lines (24% of fleet), American Trans Air (16% of fleet), and Air Transat (12% of fleet) as of December 31, 1999.

Credit goes to Delta Air Lines for its participation and help in developing the inspection procedure document. Delta provided aircraft access and assisted with preliminary inspection method trials and photographs. American Trans Air's voluntary participation in the fuel tank inspection program is also gratefully acknowledged. ATA provided access to aircraft and personnel resources that greatly facilitated the development and execution of the Lockheed Martin Working Group fuel tank inspection program. The voluntary efforts of the Lockheed Martin Working Group L-1011 operators made the inspection program possible and are greatly appreciated.

8.5 Working Group Approach

The Lockheed Martin Working Group approached the AFSSP industry commitment by evaluating the design principles used in the production of the L-1011 fuel system. All relevant drawings were reviewed to ensure that applicable safety measures had been incorporated into the fuel system design.

In addition to proven Lockheed Martin fuel system design requirements, military specifications such as MIL–F–8615 (Fuel System Components: General Specifications for) and MIL–B–5087 (Bonding, Electrical, and Lightning Protection for Aerospace Systems) were used as a basis of safe design criteria for the drawing evaluation. Materials, methods, and processes were evaluated for the areas of concern established by the FSSLT. Incorporated design practices were confirmed to meet or exceed the referenced criteria.

After the incorporated design practices were verified, an instructional document was created to provide procedures for conducting the fuel tank inspections.

8.6 Inspection Program

Following FSSLT guidelines, the Lockheed Martin Working Group defined an airplane inspection plan to accomplish the following:

- Assess during major maintenance checks the in-service condition of fuel tanks and systems in the commercial fleets of participating L-1011 operators.
- Analyze and share significant findings.
- Enhance future design, operations, and maintenance practices.

The Lockheed Martin Working Group defined specific inspection categories based on the areas of concern identified by the AFSSP. Specific items to be inspected for included the following:

- Integrity of wiring and bonding straps.
- Condition of FQIS wiring and components.
- Condition of fuel pumps, fuel lines, and fittings.
- Electrical bonding and grounding of fuel system equipment.
- Presence of FOD.
- General tank condition.

In each of the above categories, components were examined for specific safety-related potential deficiencies as discussed below.

<u>Condition of Bonding and Grounding</u>

Fault current bonding is designed to protect an aircraft from damage if any electrical equipment incurs an electrical short or fault. During this inspection program, the condition of fault current bonding was recorded for electrical equipment in the L-1011's fuel system. The following components were evaluated for their fault current bonding:

- Fuel boost pump.
- Crossfeed valves.
- Jettison valves.
- Refuel valves.
- Gravity-feed valves.
- Transfer valves.
- Float valves.
- Isolation valve.
- Pump defuel valve.

All static ground straps were also inspected and the resistances were tested and recorded.

Condition of Internal Wiring and Insulation

All wiring passing into and through the fuel tanks was examined for deteriorated conduits, sleeves, and insulation. This examination included the boost pump electrical harnesses and conduits.

Condition of Pipe Couplings

Because loose and leaking couplings may compromise the safety of a fuel system, fuel line couplings were inspected. The inspection verified that the installation was secure and that the lock wire is in place.

Foreign Object Debris

FOD prevention is a standard aviation safety issue and a heavily emphasized maintenance practice. Inspection instructions required recording the presence of FOD and a description of the type of FOD found.

Condition of FQIS

The integrity of the FQIS was determined by performing a functional test on the system in accordance to the maintenance manual. The capacitance of each tank probe was evaluated.

Condition of Flame Arrestors

Vent-end flame arrestors were evaluated based on a visual integrity inspection of the screens in accordance with established maintenance procedures.

General Tank Condition

Were a condition to be found that technicians determined might be a hazard to the safe operation of the fuel system, a detailed description was to be recorded, and the Lockheed Martin Aircraft Working Group was to be notified immediately.

8.7 Inspections Performed

The active L-1011s commercial fleet numbered 108 aircraft as of December 31, 1999. Lockheed Martin's participation in the AFSSP saw the fuel systems of six L-1011s evaluated in accordance with the inspection methods established by the AFSSP.

Aircraft no	Total flight hours	Total flight cycles	Inspection type
1	64,039	28,761	Quantitative/qualitative
2	64,425	28,915	Quantitative/qualitative
3	64,846	28,756	Quantitative/qualitative
4	64,307*	16,623*	Quantitative/qualitative
5	48,864	13,149	Quantitative/qualitative
6	42,563	22,301	Qualitative
Average:	**58,341**	**23,084**	

* Wing and center tank inspections were performed at different maintenance checks so displayed values have been averaged.

Figure 8-1: Inspection Summary

Because of unavoidable circumstances, an initial goal of 10 inspections was not achieved. This program was dependent upon voluntary operator participation, operator schedules, available personnel and facility resources, and aircraft heavy maintenance visit (HMV) schedules. Although Delta Air Lines and Lockheed Martin had scheduled fuel tank inspections for the L-1011, none were conducted because of Delta Air Lines' subsequent decision to retire all L-1011 aircraft before their next scheduled HMV. This decision resulted in the cancellation of the remaining planned fuel tank inspections.

Despite this setback, the L-1011 inspection program yielded a sufficient if not ample amount of information. This valuable and highly useful data satisfies the Lockheed Martin commitment to the ultimate objectives formalized by the industry in the AFSSP.

The instructional procedure for conducting the fuel tank system inspection currently exists as a proprietary in-house engineering document, which serves its purpose of fulfilling the objectives of the AFSSP. If required, this inspection document will be issued as a service information letter (SIL). This SIL would serve as part of the compliance methods for the pending fuel system special federal aviation regulation (SFAR) that is soon to be issued by the FAA (reference: NPRM 99-18).

Results of the first five aircraft were based on a quantitative evaluation. Results of the sixth aircraft were based on a qualitative evaluation. The quantitative evaluations were conducted with the voluntary assistance of ATA (American Trans Air) and included all required numerical and deficiency code specific inputs—such as instrument readings—as specified in the inspection procedure document.

The qualitative evaluation of the sixth aircraft was based on the same inspection document but focused on a visual-integrity method of inspection. It should be noted that the sixth aircraft was a recently retired aircraft and not part of the ATA fleet. This fact does not bear significance to the finding's applicability toward the AFSSP. Identified discrepancies were independent of the retired condition of the aircraft. It should also be noted that the fuel boost pumps and valves had been removed before the inspection and were therefore identified as inaccessible.

The qualitative inspection approach was determined to be the most efficient and justifiable means of conducting the fuel tank system evaluation of the sixth aircraft based on allowable time and available resources. Thus, although the sixth aircraft inspection was not totally comprehensive, it did capture significant findings and contributed to the AFSSP.

8.8 Results

Specific findings from the inspected aircraft are as follows:

8.8.1 Fault Current Bonding

Among the first five airplanes inspected, the fault current bonding of two boost pumps and four refuel valves were found to be out of tolerance. On the retired L-1011 that was the sixth airplane inspected, these components were inaccessible for fault current bonding evaluation.

These out-of-tolerance measurements on the first five airplanes minimally exceeded the assigned tolerance criteria and were determined not to be significant with respect to compromising the integrity or safety of the aircraft. As called out in the inspection document, they warranted immediate corrective maintenance action in accordance with established maintenance practices to remedy the discrepancy. Although these specific findings were determined not to be safety critical, they identified the need for further investigation.

8.8.2 Component Wiring

No discrepancies were observed in the wiring of any of the six inspected airplanes.

8.8.3 Static Ground Straps

Among the first five aircraft inspected, a loose clamp was found that resulted in a static ground strap bonding value that was minimally out of tolerance. In contrast to this minor discrepancy, the fuel tank inspection of the sixth airplane produced significant findings: Fifteen static ground strap deficiencies were identified. Of these, 10 ground straps had not been installed, 3 were improperly installed, and 2 were damaged.

These missing static ground straps were determined to be an issue with the potential of affecting the safety condition of the aircraft. As such, they have warranted a preventative action evaluation.

8.8.4 Couplings

The first five aircraft showed no coupling deficiencies. The sixth included six improperly installed couplings and one that was damaged. As with the findings from the first five inspected aircraft, the findings of the sixth aircraft were determined not to be safety critical although the seven coupling discrepancies have identified a need for further investigation.

8.8.5 FOD

There were no significant FOD findings in any of the six inspected airplanes.

8.8.6 FQIS Wiring

No discrepancies were found.

8.8.7 Vent Flame Arrestors

No discrepancies were found.

8.8.8 General Tank Condition

The general condition of L-1011 fuel tank systems is good to excellent. No significant deterioration or factors affecting airworthiness have been identified.

8.8.9 Evaluation of Results

All findings were determined not to be design-related issues and were correctable by means of appropriate established maintenance procedures. As specified in the inspection document, the maintenance procedures performed to alleviate out-of-tolerance findings served as the immediate corrective action for each identified discrepancy during the inspection. Based on the evaluation of results, plans for preventative action and continued investigations were to focus on opportunities for improvement of maintenance practices.

The single significant issue resulting from the inspection program was the missing static ground straps of aircraft six. Evaluation of this issue determined that efforts toward developing a preventative action plan were warranted. All other findings were determined not to be significant with respect to compromising the integrity or airworthiness of the aircraft. Regardless, identified out-of-tolerance findings indicated a need for further research to complete a comprehensive investigation and ensure all aspects of the inspection had been adequately addressed.

8.9 Action Plan Approach

The intent of the Lockheed Martin action plan is to support the initial AFSSP mission statement by taking action that best ensures, maintains, and enhances the safety of the L-1011 fuel system. As indicated from the evaluation of results, effort toward implementing actions is to focus on preventative measures concerning possible improvements of maintenance practices.

The approach taken to identify the need and type of action is to first define the potential problem, next identify how the potential problem could occur (possible causes), and then determine how best to prevent the occurrence of the potential problem.

For each issue identified as warranting continued investigation, conceivable ways in which potential deficiencies could occur are to be identified by considering the following possible opportunities of occurrence:

- Maintenance procedures not provided.
- Maintenance procedures require clarification and/or increased attention or emphasis.
- Maintenance personnel unaware of and/or not applying procedures.

The applicable airplane maintenance manual (AMM) section is then to be evaluated to determine whether adequate instructions are provided. Where appropriate, required changes to maintenance instructions are to be developed to ensure that the intent of the instruction and all applicable safety measures have been adequately incorporated. Where deemed necessary, increased awareness of instructions is to be fostered by means of enhanced training programs, SILs, or other means of knowledge transfer.

8.10 Action Status and Continuing Efforts

Missing Ground Straps

Top priority was assigned to the issue of missing ground straps. A preventative action plan was accomplished as described in the previous section. A thorough review of the applicable maintenance manual procedures revealed that adequate instructions are provided for the repair and replacement of static ground straps as specified in Chapter 20: Standard Practices.

Review of Chapter 28: Fuel Systems of the maintenance manual yielded an opportunity for improvement. Evaluation of fuel system component installation procedures indicated an opportunity to better clarify the requirement of installing replacement ground straps. Currently, all applicable fuel system component installation procedures are being reviewed to ensure that adequate ground strap installation requirements are provided. Reference to the applicable Chapter 20: Standard Practices section will also be included in the installation procedures. As an additional safety assurance measure, the Lockheed Martin L-1011 operator training program will be enhanced to emphasize the function and importance of ground strap assemblies, instruct proper maintenance practices, and provide safety awareness issues for personnel who work on the fuel tank system.

By implementing the above actions, all identified opportunities of occurrence for missing ground straps will be addressed, and appropriate preventative action will be taken that best ensures, maintains, and enhances the safety of the L-1011 fuel system. These actions will ensure that appropriate AMM instructions are provided, that the instructions are comprehensive, and that actions are taken to promote awareness of procedures and safety concerns. The chosen vehicles to implement the maintenance practice improvements will include modification to maintenance manual instructions, issuance of a SIL, and modification of the Lockheed Martin L-1011 operator training program.

Additional Issues

As a result of the AFSSP, opportunities for improvement of maintenance practices are currently being investigated concerning the following issues:

- Fault current bonding procedures for boost pumps and valves.
- Coupling installation procedures.

These remaining issues warranting further investigation are based on findings, which were determined not to be significant with respect to compromising the integrity or safety condition of the aircraft. These issues are currently in the initial stages of the investigative process as discussed in the previous section. Based on the inspection program findings, potential safety concerns are being identified and MM procedures are being reviewed to ensure complete and comprehensive instructions are provided in the manual that best ensures the safety of the fuel tank system.

9.0 CONCLUSIONS

In the wake of the TWA 800 disaster, questions were raised as to whether airplane fuel systems were deteriorating as airplanes aged in commercial service. As described above, the large-scale design review and in-service airplane fleet inspection effort performed by the industry via the AFSSP has answered these concerns with facts and data showing that the fuel tank systems of the world fleet are soundly designed and do not tend to degrade as airplanes age. This survey process has also showed where improvements can be made to further enhance fuel-system safety and ensure the continuing airworthiness of the in-service fleet.

Although significant airworthiness issues were not found, the AFSSP did identify a number of opportunities for further enhancing fuel system safety. In general, identified issues were specific to or unique for a particular manufacturer and aircraft type design. As such, each manufacturer is developing the necessary inspections or corrective actions to address these issues, as described in working group report sections of the document.