

**The 11th Israeli Symposium on
Jet Engines and Gas Turbines (25 October, 2012)**

CONTINUED AIRWORTHINESS OF AIRFRAME / ENGINE INTERFACES

Based on study performed in
Cranfield University, England

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Continued Airworthiness

ICAO DOC 9713: “Continuing or continued airworthiness is all of the processes ensuring that, at any time in its life, an airplane complies with the technical conditions fixed to the issue of the certificate of airworthiness and is in a condition for safe operation”

Continued airworthiness is not only aircraft and equipment maintenance, but also:

- Monitoring performance of products in service,
- Recording service difficulties,
- Responding with timely action where airworthiness is affected,
- Devising and provisioning rectification action,
- Promulgating the necessary information to restore safety levels,
- Providing feedback to design/production.

Continued Airworthiness Domain



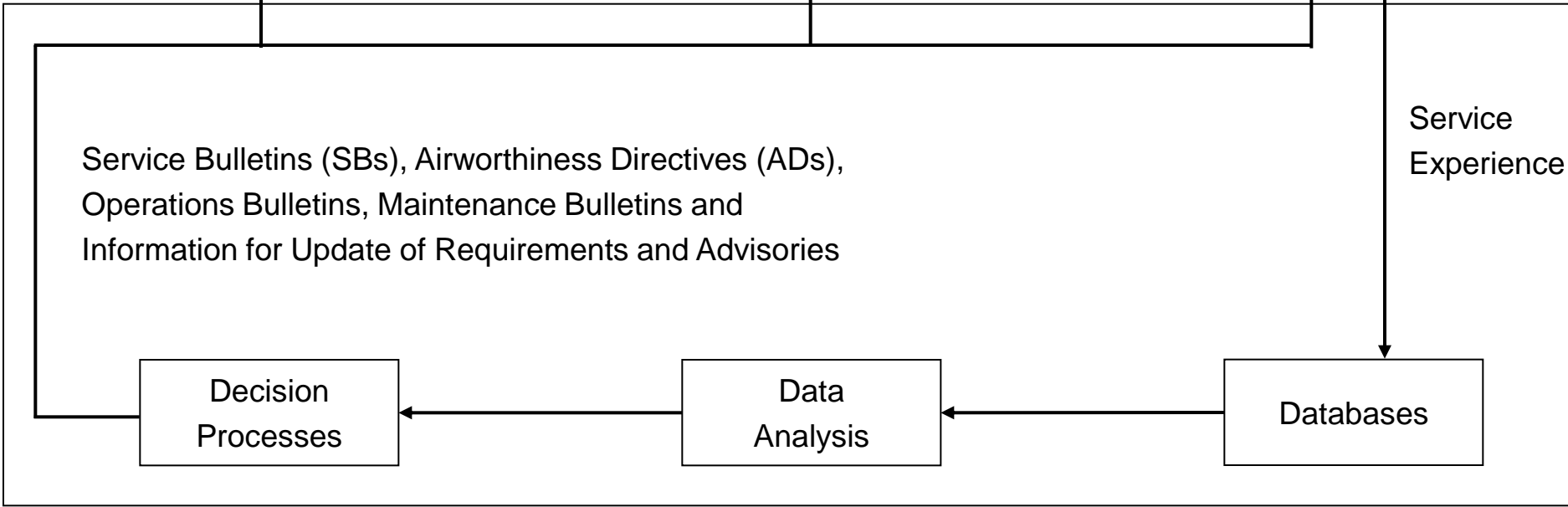
Service Bulletins (SBs), Airworthiness Directives (ADs), Operations Bulletins, Maintenance Bulletins and Information for Update of Requirements and Advisories

Service Experience

Decision Processes

Data Analysis

Databases



Example: Boeing 707/720/720B AD 2012-16-12

- The FAA is adopting a new airworthiness directive (AD) for all The Boeing Company Model 707 airplanes, and Model 720 and 720B series airplanes.
- This AD was prompted by reports of cracking of the midspar fittings, and of the engine and nacelle strut separating from the airplane.
- This AD requires performing a detailed inspection of the midspar fittings of the nacelle strut to confirm that the correct part number is installed, and installing the correct part number if necessary; performing repetitive high frequency eddy current (HFEC) inspections of the midspar fittings of the nacelle strut for cracks, and repair if necessary; and performing repetitive general visual inspections of the nacelle struts to verify that the nacelle strut has not drooped below its normal position, applying the droop stripe to the nacelle strut and sailboat fairing if necessary, and performing repair if necessary.
- The FAA is issuing this AD to detect and correct cracking of the midspar fitting, which could result in separation of the nacelle strut and engine from the airplane while in flight, and consequent loss of controllability of the airplane.
- This AD is effective September 21, 2012.

Continuing Airworthiness Management

EASA Part-M

(FAA Part 119/121/135 Operating Certificate)

- Focuses on the management of maintenance activities in continued airworthiness,
- Establishes the measures and administrative requirements to ensure continued airworthiness,
- Specifies the conditions to be met by related persons or organizations involved in continuing airworthiness,
- Lays down principles and requirements to related persons or organizations in continuing airworthiness management.

Maintenance Organization Approval EASA/FAA Part-145 (Organizations/Repair Stations)

- Governs the maintenance organizations to ensure flight safety,
- Lays down the requirements from maintenance organizations for aircraft and equipment,
- Establishes the procedures which the regulatory authority should follow to administrate Part-145 in maintenance organizations,
- Contains requirements to the maintenance organizations involving aircraft, assemblies, components, equipment, tools, personnel, occurrence reporting and exchange of maintenance data.

Continued Airworthiness of Airframe / Engine Interfaces

Case Study

- Choice of accident/incident related to airframe engine interfaces,
- Analysis of related information to find problems not found before,
- Discussion of involved paragraphs of airworthiness regulations.

Lessons and Suggested Requirements Revisions

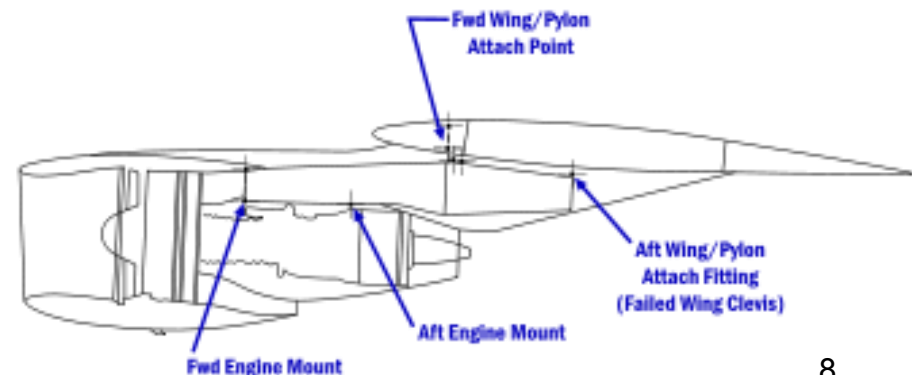
- Conclusion of the findings and related causes,
- Forming lessons to continued airworthiness and suggestions to related requirements revisions.

Suggested Continued Airworthiness Program

- Participants and responsibilities,
- Proposed continued airworthiness process,
- Suggestions on maintenance plan.

Case #1: DC-10, May 25, 1979, Chicago

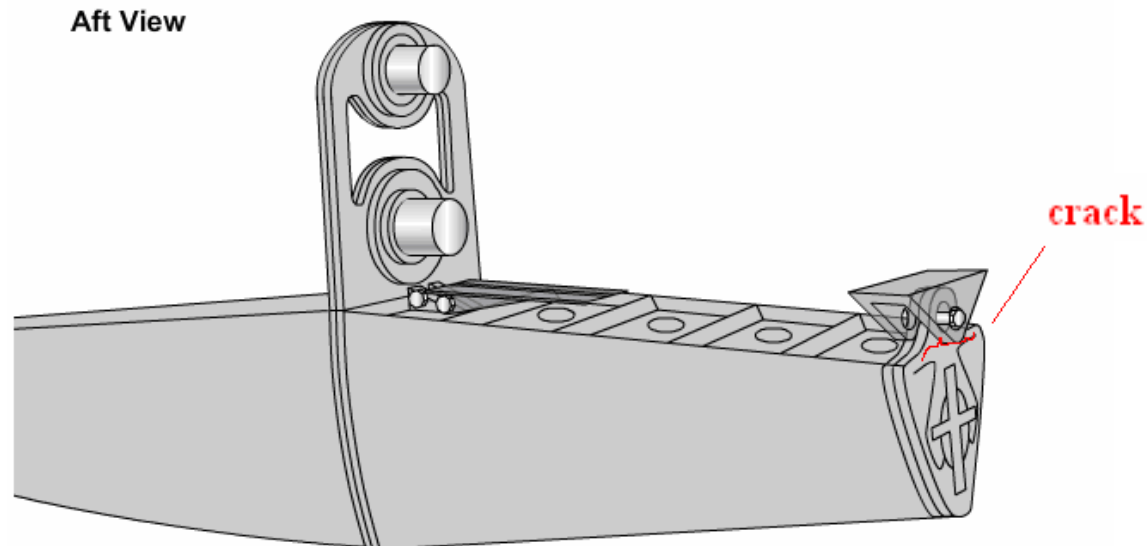
On May 25, 1979, DC-10 (American Airlines, Flight 191) took off from Chicago, O'Hare Airport. While the aircraft was banking, both left engine and strut assembly have separated from the wing. The pylon separation resulted in corresponding hydraulic lines severance. Thus, a loss of associated hydraulic pressure and retraction of all slats outboard of the left engine, were caused consequently. The resulting lift asymmetry led to a loss of control of the aircraft. Finally, the aircraft overturned and crashed.



Case #1: DC-10, May 25, 1979, Chicago (Cont.)

Root Cause

American Airlines mistakenly assumed that it is acceptable to remove/reinstall engine and pylon together. Based on such assumption, forklift was used for maintenance procedures and caused unintended structural damage during engine/pylon reinstallation. The damage led to the separation of the engine and pylon assembly at a critical point during takeoff.



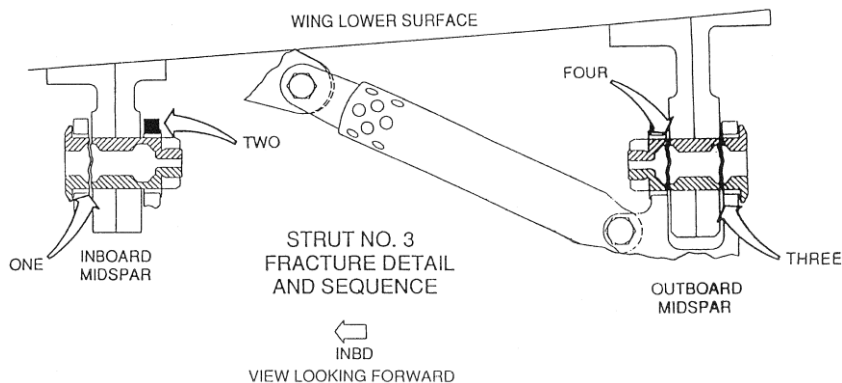
Case #1: DC-10, May 25, 1979, Chicago (Cont.)

Findings

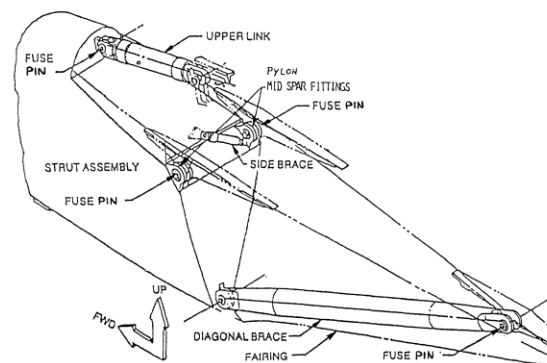
- Operators complied with EASA Part-M M.A.302(c) “When the continuing airworthiness of the aircraft is managed by a continuing airworthiness management organization approved in accordance with Section A, Subpart G of this Annex (Part M), the aircraft maintenance program and its amendments may be approved through an indirect approval procedure”, in an **improper** way.
- While developing maintenance procedures different from continued airworthiness manuals, maintenance organizations **missed** detailed considerations and discussions with type certificate holder TCH/manufacturers.
- Maintenance organizations **missed** deep exploration of incidents occurred in continued airworthiness processes, and **missed** exchanging circumstances on the maintenance procedures.

Case #2: Boeing 747-200F, Oct 4, 1992, Amsterdam

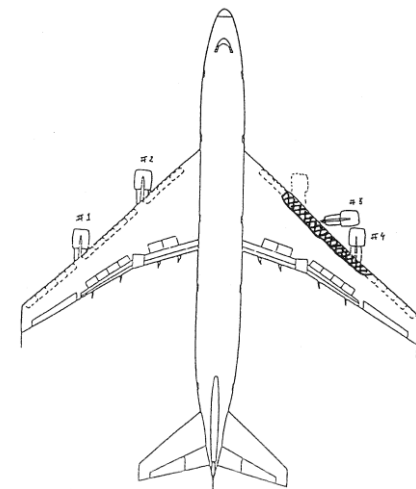
On October 4, 1992, Boeing 747-200 freighter of El Al Israel Airlines, powered by four Pratt & Whitney JT9D-7J engines, left Schiphol Airport in Amsterdam, Netherlands. Less than 10 minutes after takeoff, engines number 3 and 4 and their corresponding struts separated from the aircraft causing lost of aircraft control. The flight crew tried to control the aircraft by following the instructions from air traffic control (ATC), but ended with crash.



Strut number 3 fracture details and probable separation sequence



Pylon to wing attachment RH wing



Estimated damage to RH wing leading edge

Case #2: Boeing 747-200F, Oct 4, 1992, Amsterdam (Cont.)

Root Cause

The initial failure occurred in the number 3 engine strut. The failure of inboard midspar fused pin, resulted in a ductile fracture of the inboard midspar fitting outboard lug. Subsequent failure occurred in the upper link, then in the diagonal brace. According to manufacturers' assumption, the strut should safely separate from the wing and fall away from the aircraft or rotate over the wing. Instead, the separated number 3 engine travelled in outboard direction, impacted the number 4 engine, and caused the breakaway of this engine and its strut from the aircraft.

Related Case

On December 29, 1991, China Airlines' 747-200 freighter left Taiwan International Airport. Ten minutes after takeoff, the airplane experienced an engine separation failure. Number 3 engine & pylon departed from the wing, struck and caused separation of number 4 engine & pylon. The aircraft crashed. It was concluded that the fracture of the number 3 engine midspar fitting strut lugs had contributed to the in-flight separation of the number 4 engine and its strut.

Findings

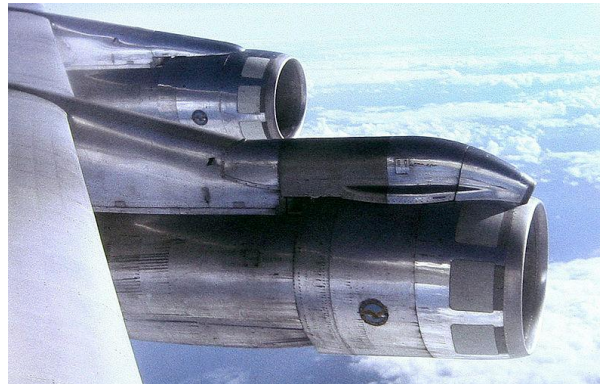
The manufacturer missed consideration of previous experience obtained from other design (Boeing 707/720 incidents). It is mandatory to thoroughly reanalyze the in-service performance and failure history of other designs.

Case #3: B707-324C, April 25, 1992, Miami

On April 25, 1992, Boeing 707-324C of Tampa, Colombia, left Miami Airport. Shortly after takeoff, engine number 3 and corresponding pylon separated from the airplane and struck number 4 engine nose cowling. Although number 4 engine inlet cowling and pylon skin damage, the airplane returned and landed without passengers or crew injuries.

Root Cause

Manufacturer and FAA inspection requirements for detection of cracks in midspar fitting were inadequate before the incident. The support fitting of engine number 3 pylon had been cracked due to fatigue. The crack resulted in the separation of engine number 3 and pylon.



Unclassified

Case #3: B707-324C, April 25, 1992, Miami (Cont.)

Related Case

In March 31st, 1992, Boeing 707-321C lost its number 3 and 4 engines, while climbing through 31,000 feet altitude over southern France. The accident was caused by the fracture of engine number 3 pylon fitting. Engine number 3 separated from the wing and struck and tore away number 4 engine.

Findings

- The manufacturer supplied **inadequate inspection schedules** and **ineffective maintenance procedures** to detect cracks in-time. The maintenance organizations failed to report the manufacturer and authorities about the circumstances of implementing of their directives.
- During continued airworthiness maintenance, it is vital to choose **effective method to detect fatigue cracks**. In case of key-joint structure failure, some methods are inappropriate and unreliable because of varying results due to **human factors**.

Case #4: B747, March 31, 1993, Alaska

On March 31, 1993, Boeing 747-121 of Japan Airlines encountered severe turbulence, shortly after its departure from Anchorage International Airport. After several strong pitch and roll oscillations, the aircraft lost engine number 2 pylon. As a result the aircraft was substantially damaged. No casualties were reported.

Root Cause

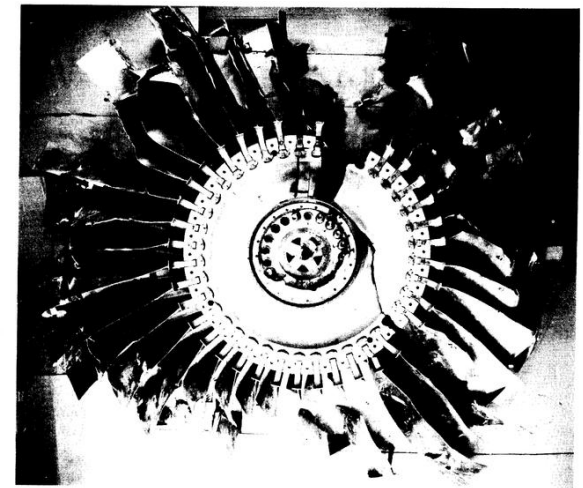
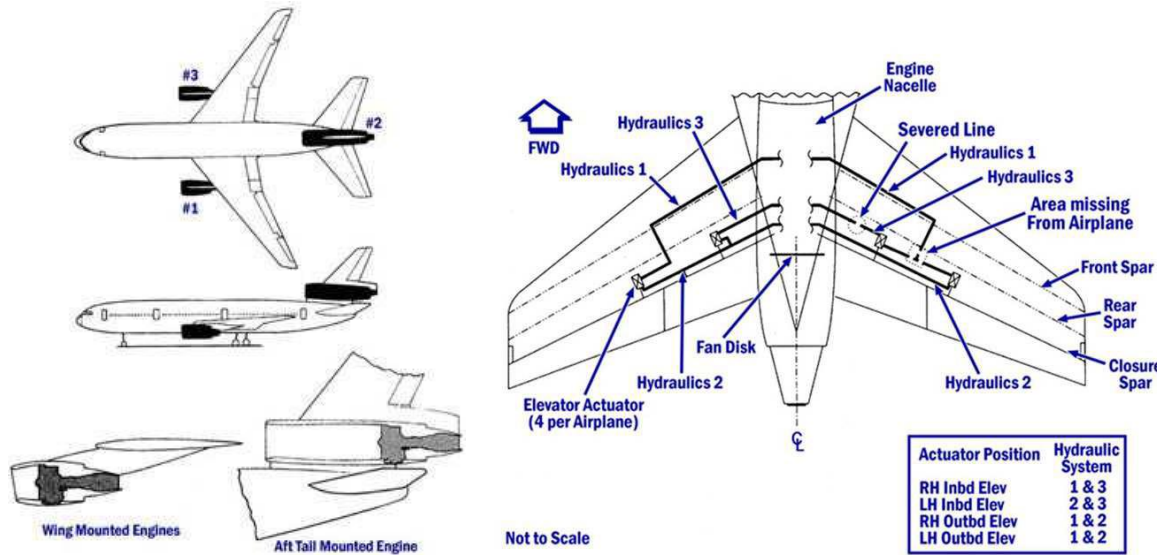
The lateral load-carrying capability of engine number 2 pylon was reduced due to fatigue cracks. The fatigue cracks near the forward end of the pylon's forward firewall web, have been found later. When the aircraft encountered a severe turbulence that resulted in “dynamic multi-axis lateral loadings that exceeded the ultimate lateral load-carrying capability of the pylon”, the engine number 2 pylon separated laterally from the wing.

Findings

- The manufacturer did not concern about **enough safety margin** regarding the lateral design loads for engine pylons during severe turbulent conditions.
- The manufacturer did not **define properly the area** which should be checked for fatigue cracks.

Case #5: DC-10, July 19, 1989, Iowa

On July 19, 1989, United Airlines (UAL) Flight 232, a McDonnell Douglas DC-10-10, departed from Denver. During the flight, engine number 2 failed due to catastrophic uncontained fan disk burst. Engine debris damaged the aircraft's three hydraulic systems in the aircraft tail area. The flight crew could hardly control the aircraft with the use of asymmetric thrust control. The aircraft crashed while attempting to land.



Hydraulic systems and damage of the rear of the aircraft

The recovered fan disk from the center engine

Case #5: DC-10, July 19, 1989, Iowa (Cont.)

Root Cause

A metallurgical defect was formed during the initial manufacture of the titanium alloy material and was not detected by inspections during the manufacturing process. The defect caused the initiation of a fatigue crack located on the surface of the disk bore that eventually grew to a critical size and produced a catastrophic separation of the disk. The accident investigation determined that the fatigue crack was of sufficient size to be detected by the previous fluorescent penetrate inspections, if only they were properly performed.

Related Case

On September 22, 1981, Lockheed L-1011 of Eastern Airlines experienced an engine uncontained failure. Engine number 2 fan burst. Three of the four hydraulic systems were lost due to massive system damage.

Findings

- **Human factors** were not sufficiently taken into account by maintenance organizations while developing inspection methods for continued airworthiness.
- The manufacture did not properly **analysis zonal hazards** caused by uncontained failure of engine during hydraulic systems redundancy design.

Case #6: B737-236, August 11, 1985, Manchester

On August 22, 1985, Boeing 737-200 of British Airtours, departed from Manchester International Airport, UK. During takeoff, the left engine experienced a failure. The flight crew decided to abort takeoff and found fire in the left wing. Fuel leaking from the wing ignited and burned. The aircraft was burned severely. The crew organized evacuation through the right-hand side of the airplane. Fifty-five lives were lost, others survived through successfully escaping.



Case #6: B737-236, August 11, 1985, Manchester (Cont.)

Root Cause

There was an uncontained failure in the left engine. A section of the repaired combustor can, which remained in service beyond its fatigue life, was ejected from the engine and fractured an under-wing fuel-tank access panel. The panel was insufficiently constructed to withstand the impact from the failed engine pieces. Thus, fuel leaked from the wing, ignited and burned.



Findings

- Not only fan blade or turbo rotor can induce uncontained failure of engine but also **combustion chamber**. The manufacturer did not perform sufficient analysis of possible failure scenarios.
- The manufacturer supplied **incomplete maintenance procedures** due to lack of repaired components life predication data. The operator did not pay attention for this lack of data and did not request clarification from the manufacturer.

Case #7: B727-224, October 7, 1998, Miami

On October 7, 1998, Boeing 727-224 of Continental Airlines experienced an engine failure during takeoff from Miami International Airport. The captain have already advanced the engine power levers for takeoff, then decided to give up the mission and have turned the aircraft off the runway.

All crewmembers and passengers deplaned and there were no reported injuries.

Examination of the aircraft after the incident showed that engine number 2 had experienced an uncontained failure. Two forward pieces of cowling separated from engine number 2 and damaged the aircraft vertical tail.

Pieces from the 8th stage high pressure compressor (HPC) disk were located inside the aircraft vertical tail, about 500 feet to the right of the aircraft, and about 500 feet to the left of the aircraft.

Case #7: B727-224, October 7, 1998, Miami (Cont.)

Root Cause

The 8th stage HPC disk hub of engine number 2 was plated with improper adherence contrary to the prescribed plating procedures and requirements of the plating company. Such action resulted in the engine failure. Investigation revealed that the engine repair company used an unauthorized repair subcontractor which was responsible for the improper plating.

Findings

- The competent authority and the operator who was in charge of the continued airworthiness of the aircraft, **lacked close supervision** to the related maintenance organizations.
- The engine maintenance organizations **lacked effective oversight** of the procedures that their subcontractors had applied for the engine maintenance.

Lessons and Suggested Requirements Revisions

1. Maintenance instructions for continued airworthiness should be clear to avoid misunderstanding which may lead to catastrophe. Operators should fulfill maintenance procedures based on manuals and mission related documents,
2. Developing of continued airworthiness processes need detailed considerations and sufficient evaluations. Maintenance organizations should get concurrence with TCH/manufacturer based on effective communication, during drafting of related maintenance program,
3. Exchanging of information about aircrafts incidents in service among operators and maintenance organizations should be encouraged. The exchanging of experience among operators and maintenance organizations is undoubtedly helpful for revealing of unsafe conditions and factors,
4. Operators should take serious considerations to the incidents occurred during the maintenance processes. Operators and maintenance organizations can reduce the possibility of incidents by deeply studying incidents with related maintenance processes, and analyzing the possibility of hazardous conditions and results,

Lessons and Suggested Requirements Revisions (Cont.)

5. If a structural design adopts assumptions of previous design, it is necessary to understand the origins of these assumptions and deeply analyze the in-service performance and failure history of the previous design,
6. Continued airworthiness instructions or procedures coming from manufacturers or regulators are not always definitely effective. Maintenance organizations are required to supply their comments and suggestions on how to promote improvements,
7. There are high risks to check fatigue cracks in limited area only, of the interfaces between aircraft and engine,
8. Continued airworthiness processes, inspections and quality control procedures may have inherent reliability limitations even through repetitive actions due to human factors. It is important to take human factors into consideration while working-out maintenance procedures for continued airworthiness,

Lessons and Suggested Requirements Revisions (Cont.)

9. In systems and structure redundancy design, it is important to analyze possible reasons to cause failures. Redundancy design should consider isolation of systems based on zonal functional hazard assessment (FHA) results,
10. In addition to the uncontained engine burst resulted from fan blade or turbo rotor, there are other components in engine which could also lead to uncontained failure due to unique working conditions of the engine (high pressure, high temperature, high rotation speed). Preventative design should be accomplished by appropriate maintenance procedures, based on analyzing possible interfaces involved and failure scenarios,
11. For engine continued airworthiness, maintenance procedures should be accomplished in accordance with clear instructions provided by original engine manufacturer, or approved alternative procedures. If alternative procedures are accomplished by operators, it is important to avoid miscommunication between operators and manufacturers. Proper communication and close cooperation between operators and manufacturers promote improvements of the engine airworthiness,

Lessons and Suggested Requirements Revisions (Cont.)

12. It is important to set up and implement effective procedures of supervision to a certain level of details, not only for the regulators but also for the manufacturers, operators and maintenance organizations. Every relevant organization should strictly complies with safety-related rules.

Clause Revision Advice

1. Part-M M.A.302(b) “The aircraft maintenance program and any subsequent amendments shall be approved by the competent authority”

Suggestion: Add some content with similar description as “get the concurrence from related type certificate holder TCH/manufacture if necessary”.

Reason: Enhance supervision in case of serious violation and omission.

2. Continuing Airworthiness Management Part-M & Maintenance Organization Approval Part-145

Suggestion: Add a clause related to communications among maintenance organizations.

Reason: Maintenance organizations get first hand experience about the conditions of aircraft, engines and components. Information exchange among them is undoubtedly helpful for finding unsafe conditions and factors.

Clause Revision Advice (Cont.)

3. **FAR/CS 25.571(a)(2)** “The service history of airplanes of similar structural design, taking due account of differences in operating conditions and procedures, may be used in the evaluations required by this paragraph”.

Suggestion: Deleted or reconsidered.

Reason: The “due” consideration of “differences in operating conditions and procedures” is hard to control appropriately. Such kind of use may easily distract the manufacturers and regulators from seeking effective methods and vital experiments for compliance with related clauses.

Statement:

I see only positive benefits arising from aircraft manufacturers reviewing the service history and structural design of previous aircraft, and utilizing this information towards the design of a new aircraft. Of course, the manufacturer needs to take "due account of differences in operating conditions and procedures" as is required by this paragraph. It certainly does not allow, or encourage, the manufacturer to blindly copy design details of one aircraft to a newer aircraft.

In view of this, I see no reason to delete or modify paragraph 25.571(a)(2) of the EASA or FAR regulations.

Abraham Brot

Fatigue and Damage - Tolerance Specialist and DER to the CAAI

Israel Aerospace Industries (IAI)

Clause Revision Advice (Cont.)

4. Part-M M.A.202(a) “Any person or organization responsible under M.A.201 shall report to the State of Registry, the organization responsible for the type design or supplemental type design and, if applicable, the Member State of operator, any identified condition of an aircraft or component that hazards seriously the flight safety”.

Suggestion: Do some amendments such as follows in order to be in accord with Part-145.A.60:

“Any person or organization responsible under M.A.201 shall report to the State of registry, the organization responsible for the type design or supplemental type design and, if applicable, the Member State of operator, any identified condition of an aircraft or component that hazards or may hazard seriously the flight safety”.

Reason: Accepting the forecast reporting based on experience from different operators could be beneficial for important information exchange and comprehensive study. That is helpful to find potential unsafe factors to prevent accidents.

Clause Revision Advice (Cont.)

5. Part-M M.A.302(e) “The aircraft maintenance program shall contain details, including frequency, of all maintenance to be carried out, including any specific tasks linked to the type and the specificity of operations”.

Suggestion: To add as follows: “The maintenance program shall take into account human factors and human performance and contain details, including frequency, of all maintenance to be carried out, including any specific tasks linked to specific operations”.

Reason: Human factors have always share a considerable ratio in all kind of aviation accidents including continued airworthiness failures. Lack of considerations to human factors, performance and limitations, may cause the maintenance program to be less effective, and even can cause catastrophe.

Clause Revision Advice (Cont.)

6. Part-M

Suggestion: Add a special subpart in Part-M, establishing the requirements from the TCH/manufacturers in the continued airworthiness.

Reason: TCH/manufacturers can not be ignored in continued airworthiness. They issue instructions for continuing airworthiness which are the key origin for setting maintenance procedures and building maintenance programs. TCH/manufacturers supply the most important technical information and reliable maintenance methods for aircraft, engines and components. Most of the continued airworthiness activities can not be executed without the participating and technical support of TCH/manufacturers.

Their technical lapse or defect can cause serious fault of subsequent maintenance programs which sometimes lead to catastrophe. Therefore, it is urgent to regulate the activities of the TCH/manufacturers in continued airworthiness, especially to ensure the correctness and unambiguousness of the instructions come from the TCH/manufacturers.

Clause Revision Advice (Cont.)

7. Part-145

Suggestion: Add a specific clause on contract maintenance to FAA/EASA Part-145 as independent clause, clearly stating the work scope of the entrusted maintenance organizations, the qualification of the entrusted organizations, especially emphasizing the intervention and overseeing of the regulators to the involved maintenance organizations.

Reason: Refer to FAR and CS, when maintenance organizations need subcontracts, it is important to closely supervise the maintenance processes of the subcontractors; the intervention of competent authorities, operators, or other related continued airworthiness organizations is necessary. Lack of overseeing may lead to hazardous conditions.