Accident / Incident Summary
Lessons Learned Training and Infrastructure

Accident **Air India**

Location New Delhi

Date May 7, 1990

Introduction

Since the certification of the Boeing Model 747-100 airplanes on December 30, 1969, there have been five serious accidents that involved in-flight and ground separation of the engine/strut assemblies. Two of the accidents have resulted in total hull loss and fatalities. These accidents have led the FAA and the Boeing company to reevaluate the conventional strut-to-wing attachment break away philosophy for commercial transport category airplanes.

This lesson provides an overview of the five accidents and the regulatory impacts they have on the design and maintenance of the affected structure.

Accident Summary

On May 7, 1990, an Air India 747-200 landed at New Delhi. Upon thrust reversal, the No. 1 engine strut partially detached from the wing. No fatalities or injuries occurred. The aircraft had accumulated 57,617 flight hours and 17,211 flight cycles.

The fuse pin at the diagonal brace underwing fitting had been improperly installed, allowing it to migrate out of position. Migration of the fuse pin resulted in an overload, and failure of the upper link fuse pin. This secondary failure allowed rotation of the engine/strut down to the runway.

The fuse pin at the diagonal brace underwing fitting had been improperly installed, with the primary retention devices omitted during maintenance, allowing it to migrate out of position under vibration.

In 1985, Boeing released Service Bulletin 747-54-2083 providing instructions to install secondary retention devices at all the fuse pin locations, but the Air India did not accomplish the modification until it was mandated by the FAA in 1995, as part of the 747 strut-mod program.

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Accident **China Airlines**

Location Taiwan International Airport

Date December 29, 1991

Accident Summary

On December 29, 1991, a China Airlines' 747-200F departed Taiwan International Airport. Ten minutes after takeoff, at an altitude of 5000 feet, the pilot reported engine problems, and that he had lost lateral control of the airplane.

The airplane lost control and crashed into terrain. Flight data recorder indicated that two engines lost power simultaneously during climb. Wreckage was concentrated on the land, except the No. 3 and 4 engine/strut assemblies, which had fallen into the ocean some distance away. The JT9D-7R4G2 powered airplane had 45,869 flight hours and 9,095 flight cycles.

Fracture of the No. 3 strut midspar fitting lugs had contributed to the in-flight separation of the engine/strut assembly which subsequently struck and separated the No. 4 engine/strut assembly. During the investigation, an approximately 0.03" long fatigue crack was revealed on both lugs of one of the midspar fittings of the No. 3 strut. The No. 3 engine had been installed 1,464 flights before the accident. The most recent A-check (prescribed maintenance) was accomplished just eight days before the accident at 9,082 flight cycles. The most recent C-check (also prescribed maintenance) had been accomplished ten months before the accident at 8,409 flight cycles. The midspar fitting lugs on all struts had been inspected per Boeing Service Bulletin 747-54-2100 before the accident. All the fuse pins had been inspected per Boeing service bulletins less than 800 flights before the accident.

Accident **El Al Airlines**

Location Schipol Airport

Date October 4, 1992

Accident Summary

On October 4, 1992, the No. 3 and 4 engine/strut assemblies separated from the right wing of an El Al Airlines' 747-200F over Lake Gooimeer, shortly after departure from Schipol Airport, near Amsterdam, in the Netherlands. About 10 minutes after takeoff at an altitude of 6000 feet, the pilot radioed that he was having problems with the engines. An emergency was declared and the flight crew attempted an air turnback. Enroute back to the airport, the aircraft lost control, and crashed into an eleven-story apartment building about 8 miles from the airport, in a suburb of Amsterdam.

The airplane had 45,764 flight hours and 10,107 flight cycles, and was delivered new to El Al in 1979. Fatigue cracking and deformation of the fuse pin at the inboard midspar fitting of the No. 3 engine strut may have contributed to the accident. This damage could have resulted in the in-flight separation of the No. 3 engine/strut assembly which subsequently struck, and caused the separation of the No. 4 engine/strut assembly. The airplane's right hand wing leading edge flaps and structure suffered severe structural damage as a result of the engine/strut separation, and there was also severe damage to the hydraulic, pneumatic, electrical, and fuel systems on the right hand wing.

Accident / Incident Summary
Lessons Learned Training and Infrastructure

Accident **Evergreen Airlines**

Location Anchorage, Alaska

Date March 31, 1993

Accident Summary

On March 31, 1993, the No. 2 engine/strut assembly of a 747-121, separated shortly after takeoff from Anchorage, Alaska. The airplane had been leased from Evergreen Airlines, and was being operated by Japan Airlines. Severe turbulence had been reported during takeoff. In fact, the airport had closed passenger operations due to severe turbulence.

Shortly after takeoff, at an altitude of 2,000 feet, the airplane experienced an uncommanded left bank of about 50 degrees. The crew reported a "huge" yaw. The No. 2 engine throttle slammed to its aft stop, its reverser indication showed thrust reverser deployment, and its associated electrical bus failed.

The airplane experienced several severe pitch and roll oscillations before the No. 2 engine/strut assembly separated from the airplane. The captain declared an emergency, and initiated a large radius left turn and landed successfully.

The NTSB determined that the probable cause of this lateral engine/strut assembly separation was severe turbulence that resulted in dynamic multi-axis lateral loading exceeding the lateral load carrying capability of the strut, which was already weakened by the presence of fatigue cracks near the forward end of the strut's forward firewall web. Two fatigue cracks were found on the web.

Accident / Incident Summary
Lessons Learned Training and Infrastructure

Accident **Northwest Airlines**

Location Tokyo International Airport

Date March 1, 1994

Accident Summary

On March 1, 1994, a Northwest Airlines' 747-251B landed at Tokyo International Airport with the forward portion of the No. 1 engine/strut assembly separated from the wing. A fire broke out in the aft portion of the engine. All crew members and passengers exited without injuries.

No turbulence was reported during the flight. The upper link forward fuse pin was discovered fractured. The diagonal brace had disconnected at its aft connection, and was found lying inside the trailing edge fairing door. There were traces of fire on and around the upper portion of the strut. The operator had previously installed fuse pin retention devices at this location per Boeing Service Bulletin 747-54-2083. However, during the most recent maintenance activity, one of the fuse pins had been installed without any retention devices. Migration of the fuse pin at the aft connection of the diagonal brace may have contributed to the accident.

Chronological Order of The Accidents

Locations

1. Air India - New Delhi, India
2. China Airlines - Taiwan, People Republic of China
3. El Al Airlines - Amsterdam, The Netherlands
4. Evergreen Airlines - Anchorage, Alaska, United States
5. Northwest Airlines - Tokyo, Japan

Date

1. Air India - May 7, 1990
2. China Airlines - December 29, 1991
3. El Al Airlines - October 4, 1992
4. Evergreen Airlines - March 31, 1993
5. Northwest Airlines - March 1, 1994

Accident Summary

The 747 airplane strut (pylon) is essentially a two cell torque box connecting the engine to the wing. The strut reacts the engine vertical, side, torsional and thrust loads. The original 747 airplane connected to the wing at five points:

- An upper link connects the strut front spar to the underwing front spar fitting.
- Two midspar fittings connect the strut midspar to the underwing midspar fittings.
- A diagonal brace connects the strut lower spar fitting to the underwing lower spar fitting.
- A single side brace connects one of the strut midspar fitting to the underwing side brace fitting.

In this arrangement, the strut was designed to be fail-safe for vertical loads. To prevent possible wing and fuel tank damage from extreme overloads due to engine failure, abnormal flight or landing, each of the load paths employed a structural fuse pin to allow a clean breakaway of the strut/engine.

In the 747 fleet history, there have been five incidents of in-flight separation of an engine/strut assembly. There had been a history of in-service fatigue cracking of the strut-to-wing attachment of the 747 Classic airplanes involving the fuse pins and strut fittings. In addition to fatigue cracking, a static load problem was identified in service. On several occasions, so-called “crank-shafting” of fuse pins was reported, which is, a plastic deformation of the fuse pins and can occur at operational load conditions. A deformed fuse pin can migrate out of its installed position, and/or fail prematurely.

RLD Dutch Civil Aviation Authority Findings on the El Al Airlines Accident

The design and certification of the B747 strut was subsequently determined to be inadequate to provide the required level of safety. Furthermore, the prescribed maintenance inspection program to ensure structural integrity failed.

This ultimately caused - probably initiated by fatigue in the inboard midspar fuse-pin - the No. 3 engine/strut assembly to separate from the right hand wing in such a way that the No. 4 engine/strut assembly were also torn off, the leading edge of the wing was damaged, and the function of several systems was lost or limited. This subsequently left the flight crew with very limited control of the airplane. Because of the marginal controllability a safe landing became highly improbable, if not virtually impossible.

Relevant Regulations

The structure of the original 747 airplane strut was certified in 1969 in accordance with the following FAR’s.

Prevailing Cultural/Organizational Factors

The Boeing Model 747 is the company's second four-engine transcontinental commercial transport category airplane model. Its design was greatly influenced by the Boeing Model 707/720 airplanes (also powered by four engines).

Before the 747-100 airplanes were certified, there were numerous incidents of in-flight or ground separation of the engine/strut assembly in the 707/720 fleets. No serious wing or fuel tank damage was caused during these incidents.

The separation of the engine/strut assembly in these incidents was attributed to external forces acting on the engine/strut, such as severe turbulence, or hard landings. Therefore, before the 747 airplane accidents, the industry had little to no experience with unsafe in-flight separation of the engine/strut assembly. Thus, based on the similar fuse pin design of the Boeing 707/720 airplanes, Boeing employed the fused strut concept to protect the wing structure and fuel tanks against consequences of strut overloads as a result of engine failure, abnormal flight conditions or hard landings.

As part of the certification activity, a detailed fail-safe analysis was undertaken by Boeing. However, this analysis was inadequate in addressing the specific fail-safe loads, assuming a fatigue failure, or obvious partial failure of a single principal structural element.

In the case of an in-flight overload condition, the strut-to-wing attachments were designed for a controlled separation of the engine/strut assembly from the wing. This would allow the departing engine/strut assembly to travel upward to clear of the wing. With the fused strut concept employed in the design, consequential damage to the wing was unanticipated. The failure scenario we have seen in the China Airlines and El Al Airlines accidents, during which a separated engine/strut assembly striking the adjacent engine/strut assembly, was unanticipated.

The original 747 strut was NOT designed for **damage tolerance**, which is the attribute of the structure that permits it to retain its required residual strength for a period of use after it has sustained a given level of fatigue, corrosion, accidental or discrete source damage. During type certification, a then state-of-the art fatigue analysis of the strut structure was performed by Boeing in order to establish the maintenance requirements for the 747 fleet. However, this analysis did not turn out to be sufficiently reliable.

Unsafe Conditions

Fatigue cracking of the strut-to-wing attachments has resulted in in-flight separation of the engine/strut assembly. In addition to fatigue cracking, a static load problem was identified in service. On several occasions, so-called "crank-shafting" of fuse pins was reported,, which is, a plastic deformation of the fuse pins and can occur at operational load conditions. A deformed fuse pin can migrate out of its installed position, and/or fail prematurely.

As we have seen in the China Airlines and El Al Airlines accidents, in-flight separation of the engine/strut assembly was catastrophic to the airplane. In both accidents, the departing No. 3 engine/strut assembly struck and caused the separation of the adjacent No. 4 engine/strut assembly, and caused additional damage to the wing leading edge flaps/slats and associated systems, resulting in loss of control of the airplanes.

Safety Assumptions

When designing the original 747-100 airplane strut-to-wing attachments, Boeing employed a fuse pin design concept similar to that of the 707/720 airplanes. Safe separation was addressed by incorporating a "fuse" in each of the attachments. In the case of an overload condition (e.g. catastrophic engine failure), this would ensure a safe separation of the engine/strut assembly from the wing, and would not result in any catastrophic damage to the wing and fuel tanks

A detailed fail-safe analysis was undertaken by Boeing to establish maintenance requirements. However, this analysis was subsequently determined to be not sufficiently reliable in addressing the specific fail-safe loads, assuming a fatigue failure, or obvious partial failure, of a single principal structural element. At that time, full scale testing was not part of the USA airplane certification process.

Precursors

Before the 747-100 airplanes were certified, there were numerous incidents of in-flight or ground separation of an engine/strut assembly in the 707/720 fleet, but no serious wing or fuel tank damage was resulted. Therefore, the industry had very little experience on unsafe in-flight separation of the engine/strut assembly.

Boeing designed the strut-to-wing attachments for a controlled separation of the engine/strut assembly from the wing in the case of an in-flight overload condition. This would allow the departing engine/strut assembly to travel upward to clear of the wing. With the fused strut concept employed in the design, consequential damage to the wing was unanticipated.

The precursor events, in this case helped to solidify the industry perception that in-flight engine/strut assembly separation was not an unsafe event for an airplane.

Regulatory and Policy Changes

In 1994, the latest regulations were applied to the strut-to-wing attachment structure.

Consequently, the 747 strut-to-wing attachment structure was upgraded by production changes or retrofit (i.e., The 747 strut-mod).

Major Airworthiness Directives Issued

- AD 95-10-16: (Strut-mod for airplanes equipped with Pratt & Whitney Model JT9D series engines, excluding Model JT9D-70 engines)
- AD 95-13-05: (Strut-mod for airplanes equipped with Rolls Royce Model RB211 series engines)
- AD 95-13-06: (Strut-mod for airplanes equipped with General Electric Model CF6-80C2 series engines or Pratt & Whitney Model PW4000 series engines)
- AD 95-13-07: (Strut-mod for airplanes equipped with General Electric Model CF6-45 or -50 series engines, or Pratt & Whitney Model JT9D-70 series engines)
- AD 2004-25-05: (Upper spar fitting inspections)
- AD 2005-03-01: (Post strut-mod inspections)
- AD 2005-19-06: (Thrust Link inspections)
- AD 2005-19-09: (Dual side brace inspections)

Lessons Learned

747 Airplane Strut Specific:

1. Design for strength, durability and maintainability.
2. Employ the damage tolerance design philosophy.
3. Address the possibility of damage due to heat, corrosion and accidents.
4. Address ultimate load conditions that are not all inclusive, such as:

   - Multiple blade out conditions.
   - Several multiple ultimate load conditions superimposed.
   - Severe and unusual turbulence exceedences.

Lessons Learned - Continued

General:

5. Improve fail-safety by integrating redundancies.
6. Include periodic directed inspections and/or function tests on flight critical components.
7. Previous assumptions regarding level of hazards observed on other airplane models may not be relevant to later designs.
8. There is no such thing as a "risk-free" change. Often actions taken to improve safety may actually introduce unintended faults and human errors, which themselves can be catastrophic.

List of Related Accidents

1. USAF Boeing KC-135-BN Stratotanker - On January 4, 1965, the airplane crashed after the No. 3 and 4 engines/struts separated in flight. All four on board were killed.

2. EgyptAir Boeing 707-336C - On December 5, 1972, the airplane crashed after the No. 4 engine/strut separated in flight. All six crew members on board were killed.

3. Trans-Air Service Boeing 707-321C - On March 31, 1992, the airplane performed an emergency landing after the No. 4 engine/strut separated in flight and fire broke out. No fatalities, but the airplane was written off after it overshot the runway and sustained more damage.

4. Tampa Colombia Boeing 707-324C - On April 25, 1992, the airplane performed an emergency landing after the No. 3 engine/strut separated in flight. No fatalities, but the airplane sustained substantial damage.

5. International Air Tour 707-355C - On November 1998, the airplane performed an emergency landing after the No. 3 engine/strut assembly separated in flight, resulting in associated hydraulic failures. No fatalities, but the airplane was written off after it overshot the runway and sustained more damage (landed on its belly).

Conclusion

This concludes our review of the 747 Struts accident. As you have learned, there have been five serious accidents that involved in-flight and ground separation of the engine/strut assemblies. Two of the accidents have resulted in total hull loss and fatalities. These accidents have led the FAA and the Boeing company to reevaluate the conventional strut-to-wing attachment break away philosophy for commercial transport category airplanes. This lesson provided an overview of five accidents and the regulatory impacts they have on the design and maintenance of the affected structure.