



No Left Turns: United Airlines Flight 232 Crash

Leadership ViTS Meeting
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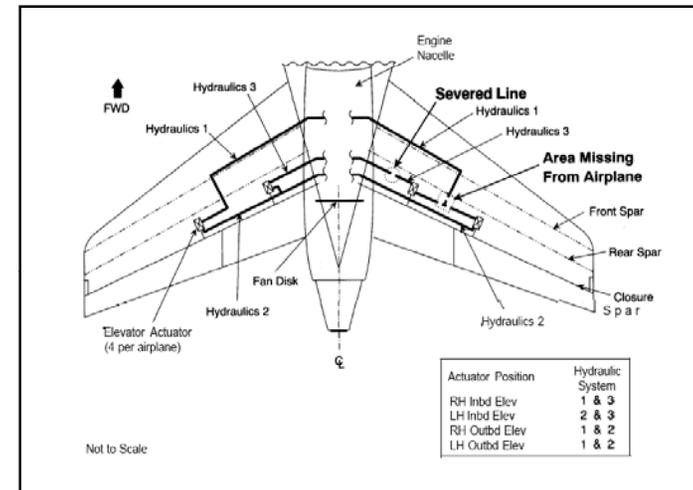
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Hydraulic Control Loss

- On July 19, 1989, just after reaching the 37,000 ft. cruising altitude, the tail mounted (number 2) engine of United Airlines Flight 232 explosively ruptured.
- Fragments of the fan rotor disk ripped through both the DC-10 aircraft's horizontal stabilizers, severing the first and third hydraulics lines and also removing entire pieces of the first and second hydraulic systems (later recovered on the ground).
- All hydraulic fluid was drained within 2 minutes of the explosion. Without hydraulic fluid, there was no way to operate the aircraft's control surfaces or landing systems (rudder, ailerons, flaps, brakes, landing gear, etc.).

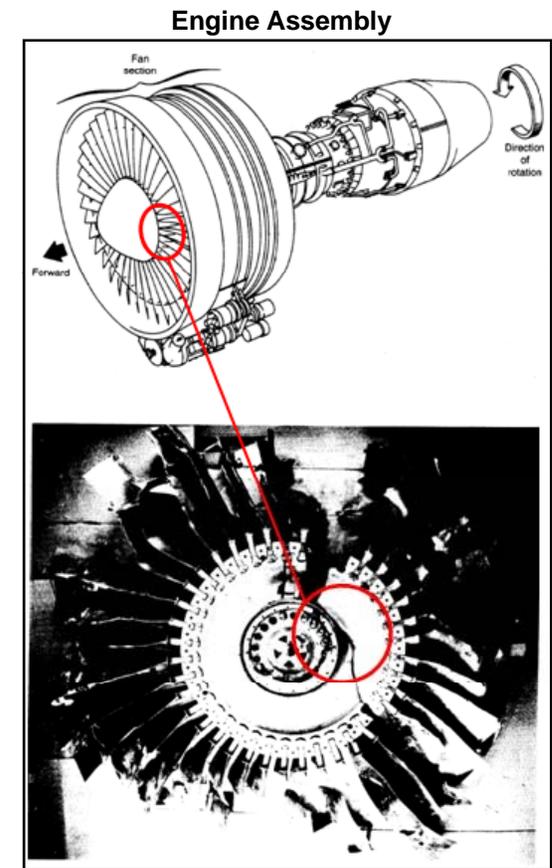


- A DC-10 flight instructor (deadheading as a passenger) assisted the pilots in landing Flight 232 using only the right and left engine throttles in a miraculous display of teamwork (textbook crew resources management).
- With no landing gear and little control over attitude at touchdown, the right engine hit the ground during landing and burst into flames. The main body caught fire as the plane snapped at the nose and the tail.
- **111 of the 296** total passengers and crew died in the tragedy.



Failed Inspection

- The number 2 engine was at 16,899 take-off/landing cycles, which was within the 18,000 cycle limit established as a factor of safety of 3 by the Federal Aviation Administration.
- The engine lifetime was calculated assuming that all parts were “defect free”; however, the original manufacturing process by General Electric Aircraft Engines (GEAE) had produced microscopic defects (“hard alpha inclusions”) in the titanium-alloy rotor. These defects are sites where cracks could form and grow with increasing sortie cycles.
- The particular engine rotor had been inspected as recently as 1 year prior to failing, with no reported defects. Back calculations for possible crack sizes that might have existed at that inspection suggested that the maintenance team should have reported at least one detectable crack.
- The National Transportation Safety Board (NTSB) investigation found residue around the crack area from the Fluorescent Penetrant Inspection (FPI) technique used by United Airlines maintenance crews. Therefore, the NTSB cited human error in failing to detect the crack despite having inspected the affected area.
- Due to prolonged fatigue stresses, one or more cracks propagated to its critical crack length, causing the catastrophic failure of the fan rotor and the subsequent catastrophic failure of the engine.



Re-assembled fan rotor with crack(s)



Proximate Cause

- The propagation of one or more cracks under prolonged fatigue stresses led to the catastrophic failure of the fan rotor and expulsion of fragmented fan blades, which severed and removed all three hydraulic control systems.

Root Cause/Underlying Issues

- Latent Manufacturing Defects
 - The engine certification in 1971 set the safety limit of operations assuming a “defect-free” system.
 - GEAE claimed responsibility for the faulty manufacturing process that produced the flawed engine parts.
- Failed Detection
 - The engine had undergone six mandatory maintenance inspections, of which the most recent had been one year prior to the mishap. No abnormal operations were reported.
 - Post-accident calculations by the GEAE fracture mechanics experts noted that there must have been one or more cracks large enough to have been detected by inspection teams.
 - The NTSB investigation found fluorescent residue indicating that maintenance teams had inspected the affected area but failed to detect any cracks.
- Lack of Procedures and Training
 - All three independent hydraulic lines were compromised in the engine failure, and there were no additional provisions for manual control of the aircraft. Thus, a common cause failure mode existed in this particular design without true effects mitigation.
 - The flight manual contained procedures for loss of one or two hydraulic lines but not all three.
 - Pilots had not been trained to handle such scenarios, and even post-accident simulation testing concluded that maneuvers were not trainable.



NASA Applicability

- Design of critical systems must protect against single credible failures nullifying redundancy.
- Initial assumptions supporting calculations of safety margins should be periodically re-evaluated to ensure their current validity.
- A high level of rigor and thoroughness for critical inspections and necessary maintenance must continue throughout the program and project lifetime regardless of the lack of a history of previous failures.
- Contingency plans and training for off-nominal conditions should be based on a realistic and thorough understanding of the system details and capabilities. Documented emergency maneuvers for all credible failures should be thoroughly tested and trained.



United Airlines Flight 232 Memorial
in Sioux City, Iowa.