



Accelerating  
the future  
of aerospace

NLR-TP-2026-008 | February 2026

# Failure/accident investigation

Lecture notes

NLR

**engine 4**

**engine 3**

Royal NLR - Netherlands Aerospace Centre

# Failure/accident investigation

## Lecture notes



### Executive summary

This report focusses on failure and accident investigation of modern engineering constructions, such as aircraft and their engines. Examples are given of the relation between fundamental design principles and actual failures.

The design philosophies behind current engineering constructions, such as infinite life design, fail-safe design, safe life design, damage tolerant design and on condition approaches, including their historic context, are highlighted. Effects and implications of a particular design philosophy on aircraft and engine safety, performance, maintenance and materials usage are indicated. Many actual military and civil aircraft accidents have been analysed and the root cause of the accidents, in relation to the lifing approach used, have been explained.

Conditions in current aircraft engines are indicated, including their effect on mechanical or thermal loading of individual components. Creep and fatigue failure mechanisms, including the difference between low and high cycle fatigue, are explained in actual failure cases. It is shown that small defects in manufacturing

#### REPORT NUMBER

NLR-TP-2026-008

#### AUTHOR(S)

A.J.A. Mom  
M.J. Bos (ed.)

#### REPORT CLASSIFICATION

UNCLASSIFIED

#### DATE

February 2026

#### KNOWLEDGE AREA(S)

Health Monitoring and  
Maintenance of Aircraft  
Platform Integrity  
Aerospace Materials  
Aircraft Material and  
Damage Research

#### DESCRIPTOR(S)

Gas Turbines  
Materials  
Lifing  
Loads  
Design Philosophies

and coating processes can have very serious effects on aircraft and engine performance and might result in major accidents.

Finally, the approach and subsequent stages of accident and failure analyses are described, including the necessity of performing independent research. Sensitive areas such as conflicting interests of various parties, press, politics, etc. are highlighted.

This course material has been compiled by the first author. It is partly based on work and research performed in the past by the Royal Netherlands Aerospace Centre NLR. It has now been brought together to become part of a lecture series on Mechanical Engineering, given by Mr. Peter Wichers Schreur, senior lecturer at the Saxion University of Applied Sciences, Enschede.

In order to safeguard the copyright of this material, it was decided to publish it in the form of an NLR document. This was edited by the second author.

**Royal NLR**

Anthony Fokkerweg 2

1059 CM Amsterdam, The Netherlands

📞 +31 88 511 3113

✉ info@nlr.nl 🌐 www.nlr.nl



Accelerating  
the future  
of aerospace

NLR-TP-2026-008 | February 2026

# Failure/accident investigation

Lecture notes

NLR




**AUTHOR(S):**

**A.J.A. Mom**  
**M.J. Bos (ed.)**

Mom CS  
NLR

*The contents of this report may be cited on condition that full credit is given to NLR and the author(s).  
 Unauthorised use or reproduction of any part of the teaching material that is contained in this report without prior written permission by the first author is strictly prohibited.*

<b>OWNER</b>	NLR + partner(s)
<b>DIVISION NLR</b>	Aerospace Vehicles
<b>DISTRIBUTION</b>	Unlimited
<b>CLASSIFICATION OF TITLE</b>	UNCLASSIFIED

<b>APPROVED BY:</b>		
<b>AUTHOR</b>	<b>EDITOR</b>	<b>MANAGING DEPARTMENT</b>
A.J.A. Mom 	 Marcel J. Bos 2026.02.12 08:29:06 +01'00'	 Marcel J. Bos 2026.02.12 08:29:19 +01'00'

## Summary

This document contains teaching material on failure and accident investigation of modern engineering constructions, such as aircraft and their engines. This course material has been compiled by the first author. It is partly based on work and research performed in the past by the Royal Netherlands Aerospace Centre NLR. It has now been brought together to become part of a lecture series on Mechanical Engineering, given by Mr. Peter Wichers Schreur, senior lecturer at the Saxion University of Applied Sciences, Enschede.

In order to safeguard the copyright of this material, it was decided to publish it in the form of an NLR document. This was edited by the second author.

# Contents

<b>1</b>	<b>Scope</b>	<b>5</b>
<b>2</b>	<b>Course material</b>	<b>6</b>

# 1 Scope

Saxion University of Applied Sciences, Enschede

Guest Lecture on failure/accident investigation

About Life: everything might fail

*André Mom*  
1 December 2025

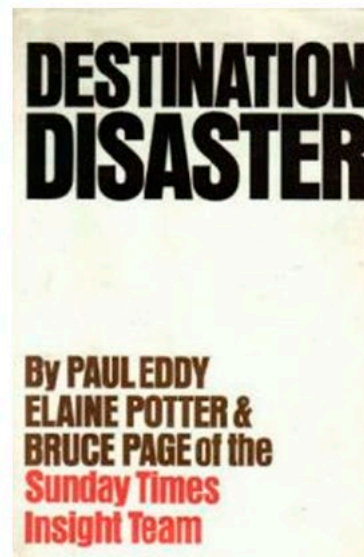


Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

1

## Literature: absolutely required

Authors: Eddy, Page and Potter, Sunday Times



About the DC10 crash north of Paris. March 1977.  
Heavy competition between Boeing, MDD, Lockheed



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

2

## 2 Course material

### Design philosophies

1. Infinite Life Design
2. Fail-Safe design
3. Safe Life Design
4. Damage Tolerant Design
5. On condition



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

3

### 1. Infinite Life Design

- Unlimited safety is the oldest criterion (component should never fail under the applied stresses)
- It requires local stresses or strains to be essentially elastic and safely below the fatigue limit.
- For parts subjected to many millions of cycles, like engine valve springs, this is still a good design criterion.
- This criterion may not be economical (i.e. global competitiveness) or practical (i.e. excessive weight of aircraft) in many design situations.



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

4

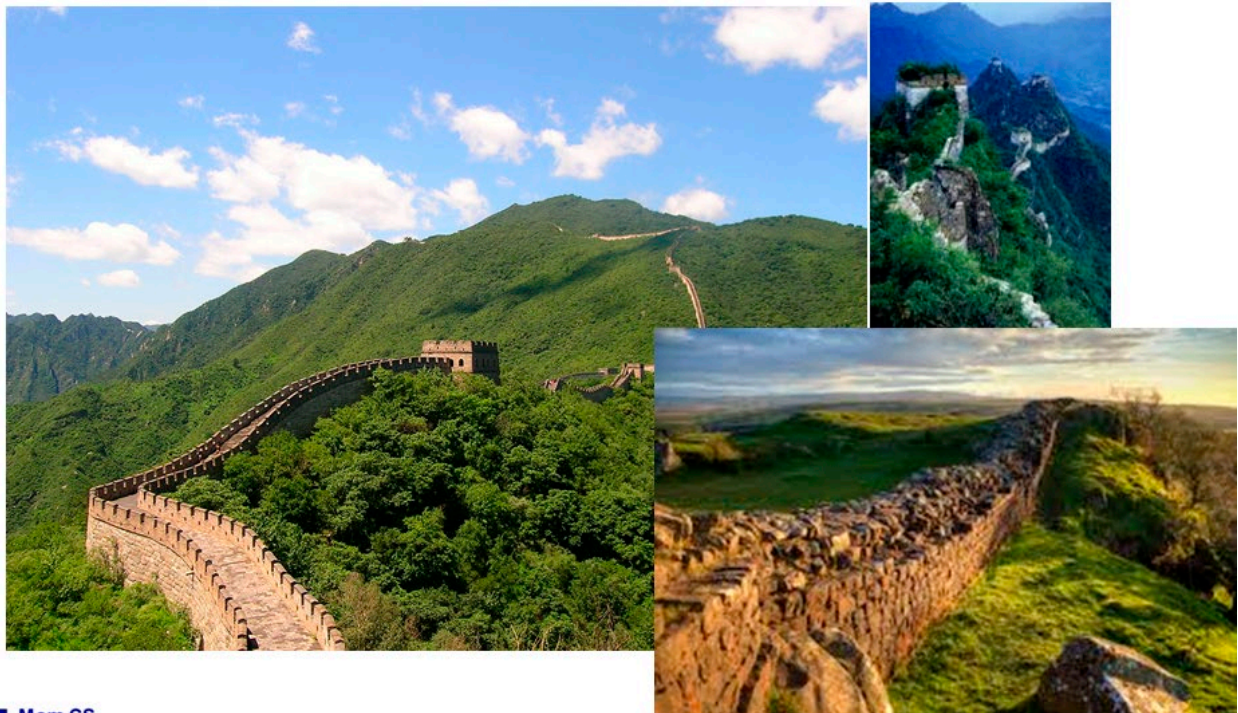
# Infinite Life Design



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

5

# Infinite Life Design



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

6

## 2. Fail-Safe Design

- Fail-safe design requires that if one part fails, the system does not fail
- Fail-safe design recognizes that fatigue cracks may occur, but: structures are designed in such a way that cracks will not lead to failure of the structure before they are detected and repaired
- Multiple load paths, load transfer between parts of the structure, crack stoppers built at intervals into the structure, and inspection are some of the means used to achieve fail-safe design.



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

8

If one part fails, the system does not fail

Cable car



Fuse



2 engines



Back-up



Safety gear for elevator



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

9

### 3. Safe Life Design

- The practice of designing for a specific finite life is known as "safe-life" design: this component might be used for e.g. 10,000 hrs, or 5000 cycles or 100,000 km's
- **All components are replaced when they have reached this safe life, whether they have a crack or not**
- Used in many industries, e.g. automotive, pressure vessel design, aircraft engines
- Calculations are based on statistical analyses of fatigue data
- Safe life must include a margin for scatter in fatigue results



Distribution chain



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

11

### Safe life aspects

- **Safe Life = 1 in every 1000 disks develops a crack of 1/32 inch (0.76 mm), not yet critical.**
- **Most disks have a much longer service fatigue life!**

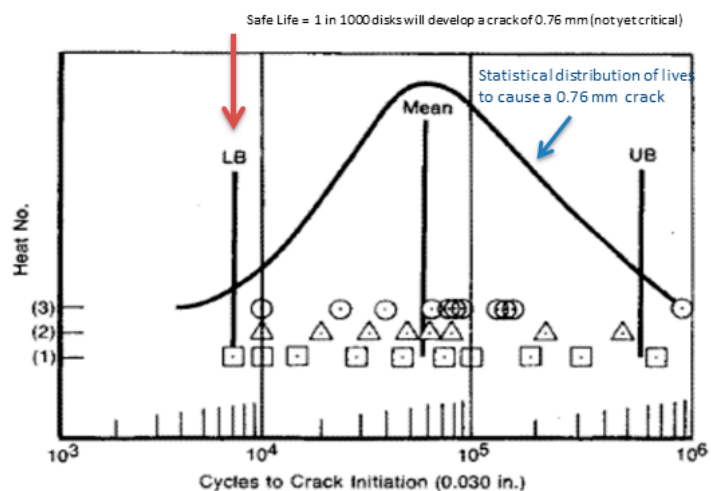


Fig. 2 Material data scatter results in conservative life prediction.

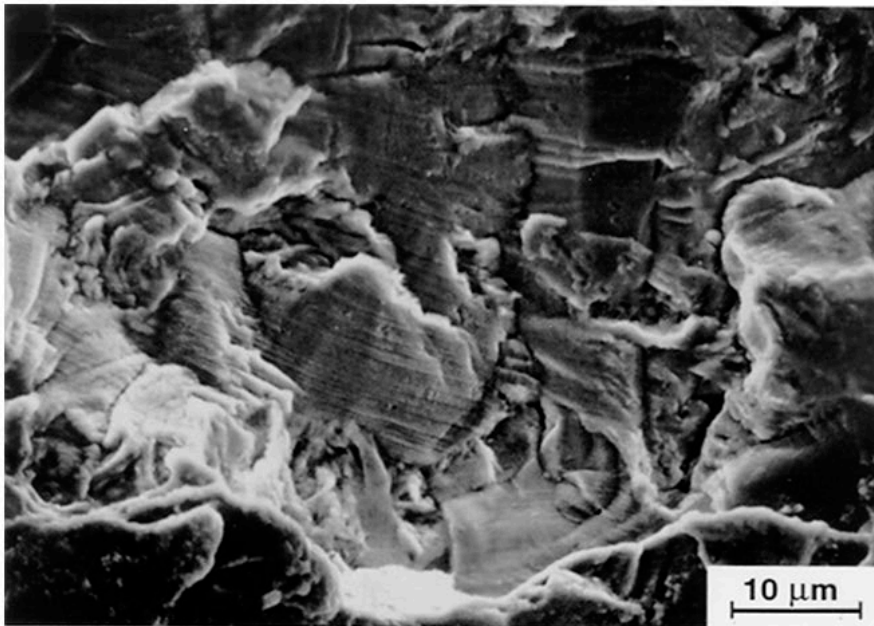
**Fatigue tests on material under simulated service conditions**



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

12

## Characteristics of a fatigue fracture surface



The striations are clearly visible (parallel lines).

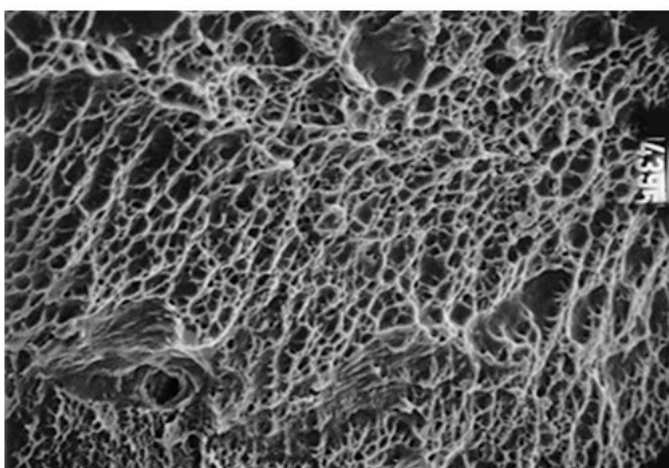
Each striation is caused by one load cycle.



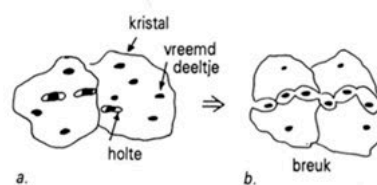
Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

13

## Characteristics of fracture surface after overload fracture



Fracture caused by formation and subsequent combination of small holes; typical surface after overload fracture.



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

14

## Safe Life approach:

## Is it safe in practice?

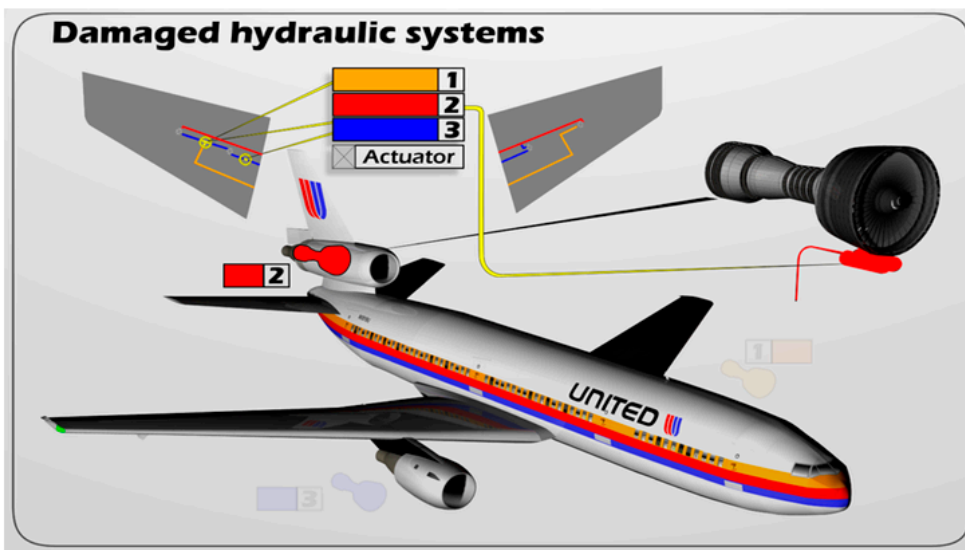


Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

15

## Crash of United Flight 232

Sioux City, Iowa, 9 July 1989, uncontained fan disk failure



Uncontained -in flight- failure of the fan disk of the engine of a DC 10.

The high-speed debris exiting the engine penetrated the hydraulic lines of all three independent hydraulic systems in the tail wing.

Flight controls were inoperative.

The crew tried to land on the airfield where it just had left.



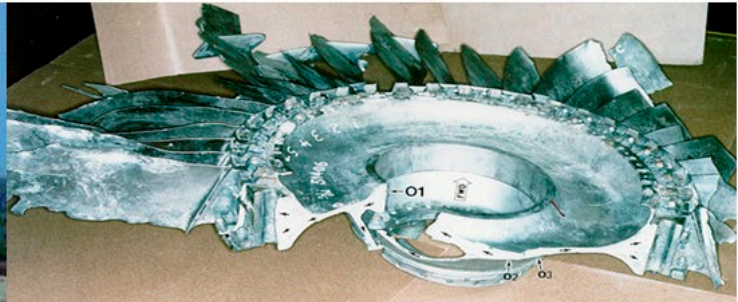
Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

16

## Crash of United Flight 232

The aircraft crash landed, 111 people died, 185 survived.

A defect that went undetected in a titanium fan disk was responsible for the failure of the disk.



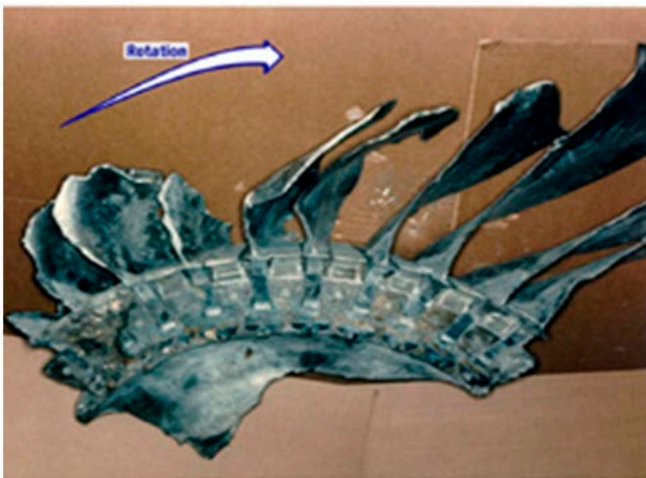
Fan disk had 16.899 cycles; safe life was 18.000 cycles

Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

17

## Crash of United Flight 232

### Remnants of failed fan disk

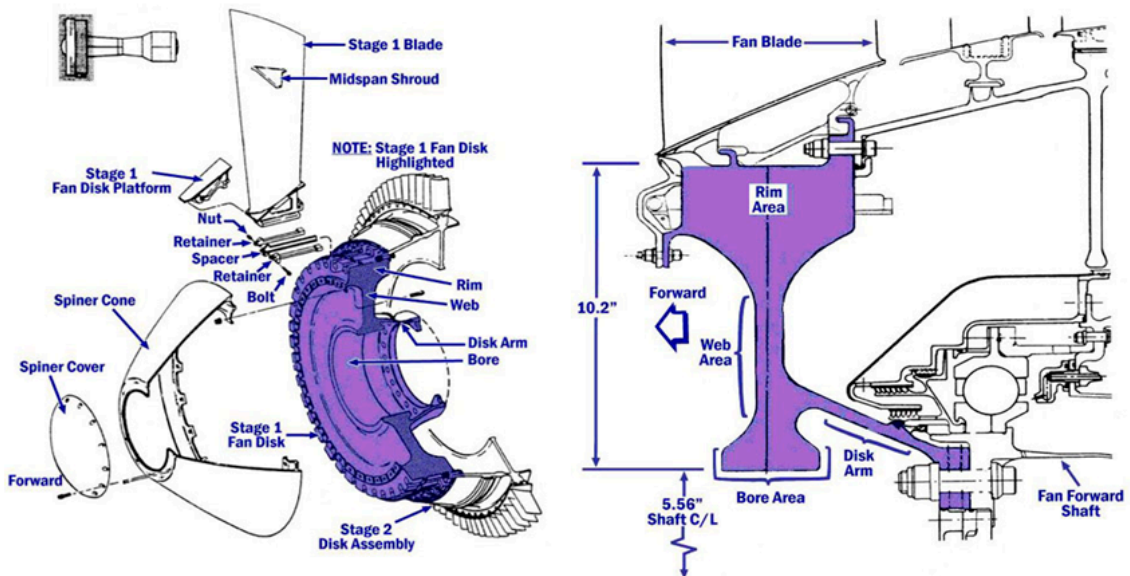


Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

18

## Crash of United Flight 232

### CF-6 Fan Assembly Showing Fan Disk



**Fatigue crack originated at a hard  $\alpha$  defect present after manufacture**

Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

19

## Crash of American Airlines Flight 383

**28 October 2016: uncontained turbine disk failure**

- Failure of the right-wing engine occurred on a Boeing 767-300 during take-off at Chicago O'Hare International Airport.
- The uncontained failure of the GE CF6-80C2B6 engine occurred at 6,550 feet from runway 28R threshold; aircraft came to a full stop at 9,225 feet from the runway threshold.
- An emergency evacuation of the 161 passengers and nine crewmembers onboard was conducted.



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

20

## Airport Overview with disk fragment locations

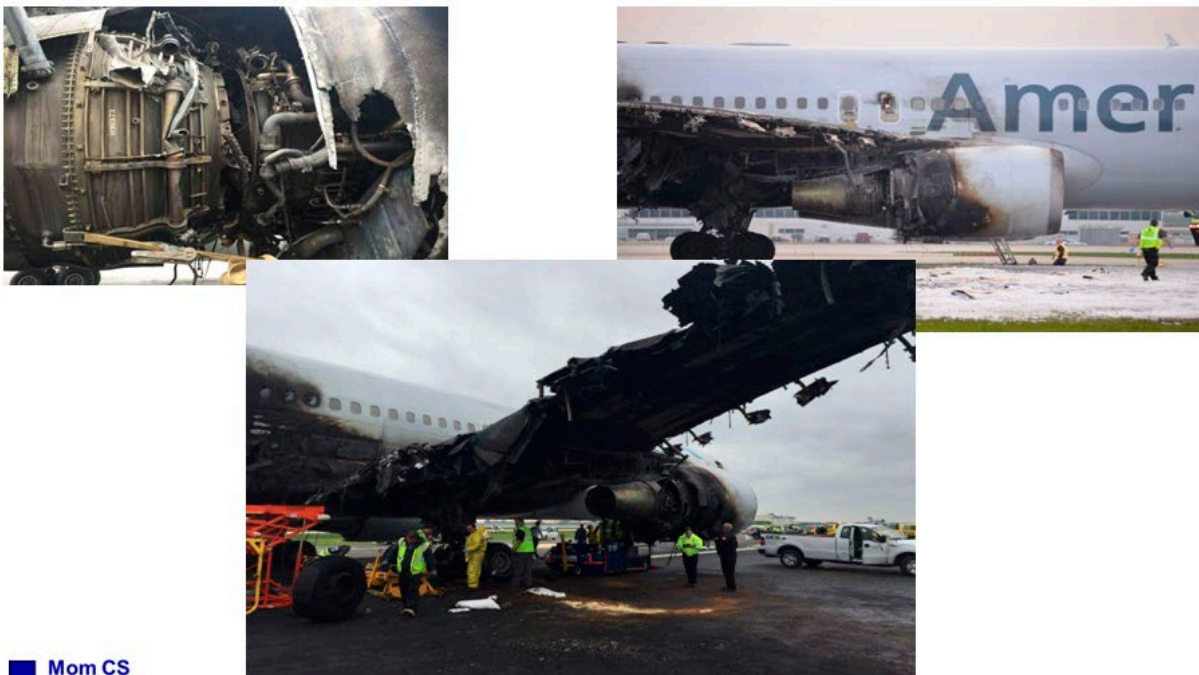


Airport Overview with Disk Fragment Locations



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited. 21

## American Airlines flight 383 Cause: Turbine Disk 2 failure



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited. 22

## American Airlines flight 383

### Recovered stage 2 HPT disk pieces



As a result of the uncontained engine failure, a fuel leak occurred, which resulted in a fire under the right wing.

Airport Rescue and Fire Fighting personnel began applying foam within 2 minutes 51 seconds of being notified of the emergency.

The right engine stage 2 high pressure turbine disk fractured into at least 4 pieces. One piece went through the inboard section of the right wing, over the fuselage and into a UPS warehouse facility (location A).



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

23

## American Airlines flight 383

### Fatigue crack location on a disk fracture surface

- Engine and wing debris were found at far-off locations.
- The majority of the stage 2 disk was recovered.
- One of the fractures exhibited features consistent with fatigue cracking initiating at an internal inclusion in the hub's inner bore.



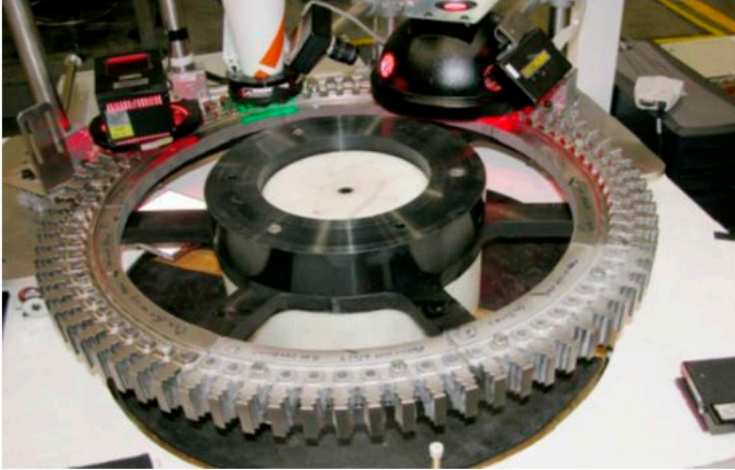
The disk had 10,984 cycles and had a life limit of 15,000 cycles.



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

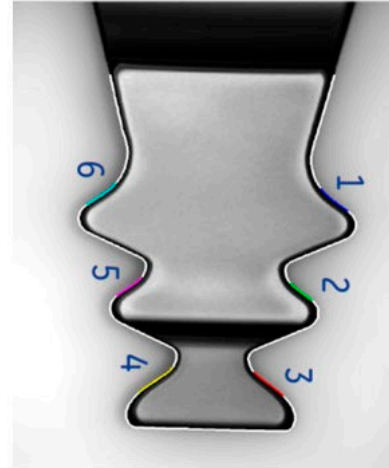
24

## Eddy current - Dove tail slot inspection in disks



### Dovetail slot inspection in engine disks

Eddy current systems enable faster and more accurate inspection of engine disk dovetail slots to locate potential cracks



The coloured lines correspond to the pressure faces

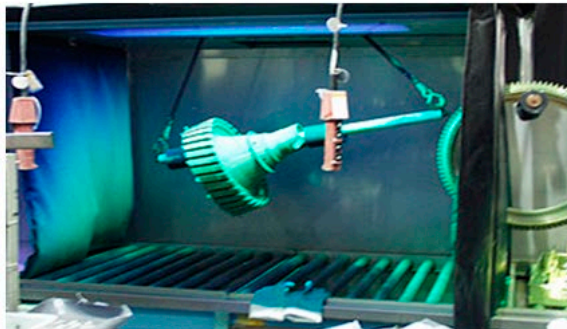


Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

25

## Jet Engine Inspection – an example

- After being in service for a period of time, aircraft engines are overhauled
- Overhaul: complete disassembly, cleaning, inspection, repair (if required), reassembly and engine test
- **Fluorescent penetrant inspection** is used to check many of the parts for cracking



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

26

## Some parts have no life limit:

# On condition maintenance/lifing

For example: compressor blades (rotor and stator),  
Often also turbine blades (rotor and stator)



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

27

## F16 crash

# North Sea/Lauwersmeer

## June 1981

Engine failure (stall/explosion): no thrust any more. Pilot activates ejection seat and lands safely. Aircraft lands in Lauwersmeer; engine relatively undamaged; engine is recovered and investigated at Woensdrecht AFB.



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

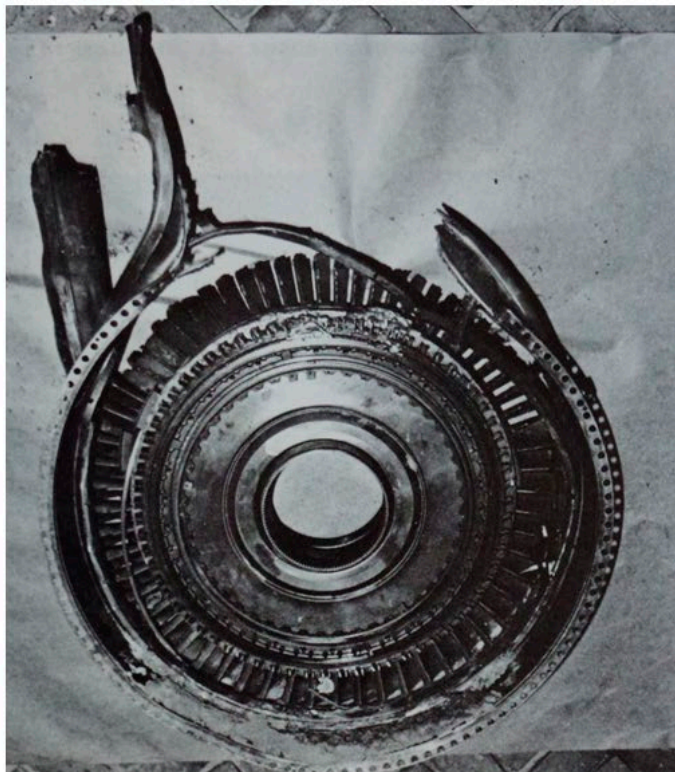
28

# F16 crash Lauwersmeer June 1981



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

29



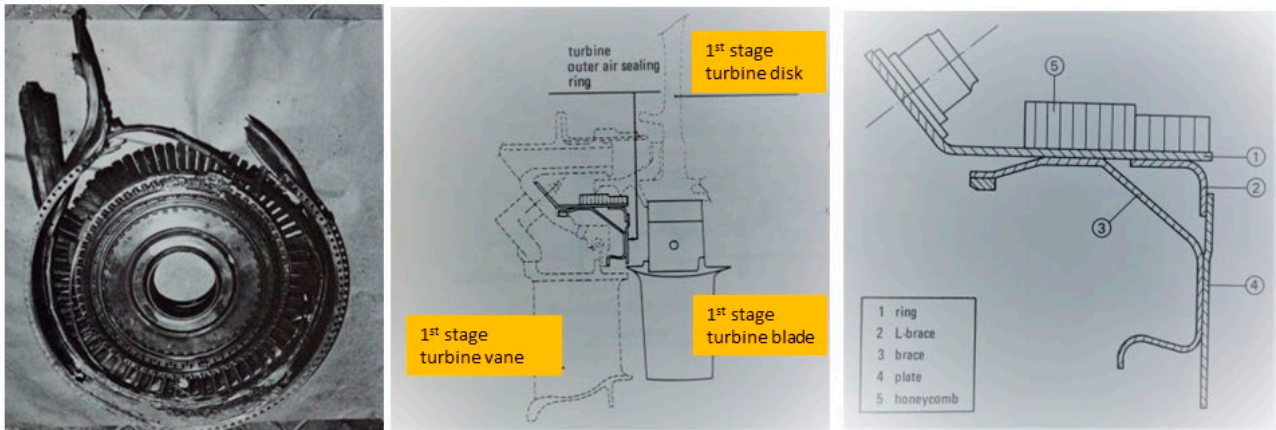
After disassembly of the engine, it turned out that the inlet of the turbine was heavily damaged. Broken 1<sup>st</sup> stage turbine blades are clearly visible; 2<sup>nd</sup> stage relatively undamaged.



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

30

# Brazing joint failure

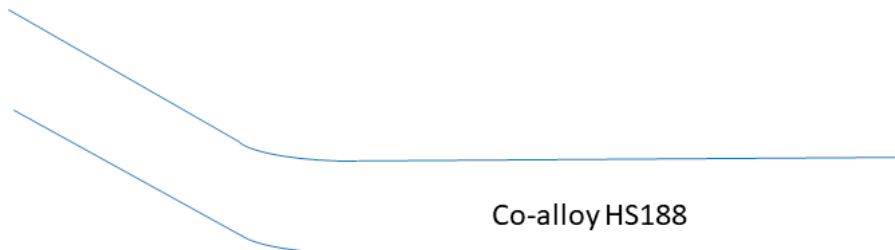


Turbine sealing ring failed by braze joint failure between ring 1 and part 2 and 3.  
 Cause: oxide layer build up during Ni-plating prior to brazing (NLR MP 87037, presented at BVM symposium, Wageningen, 1986)



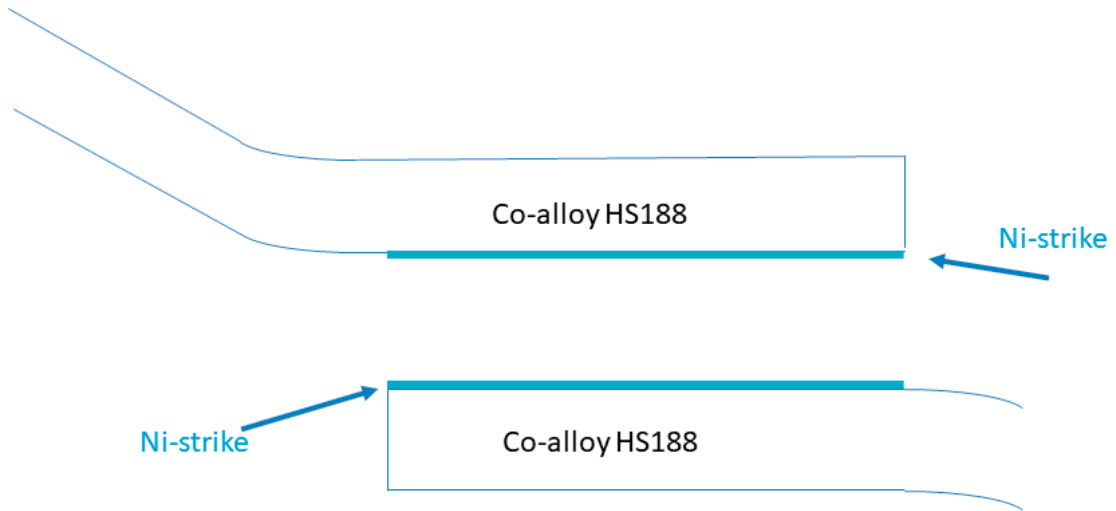
Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

31



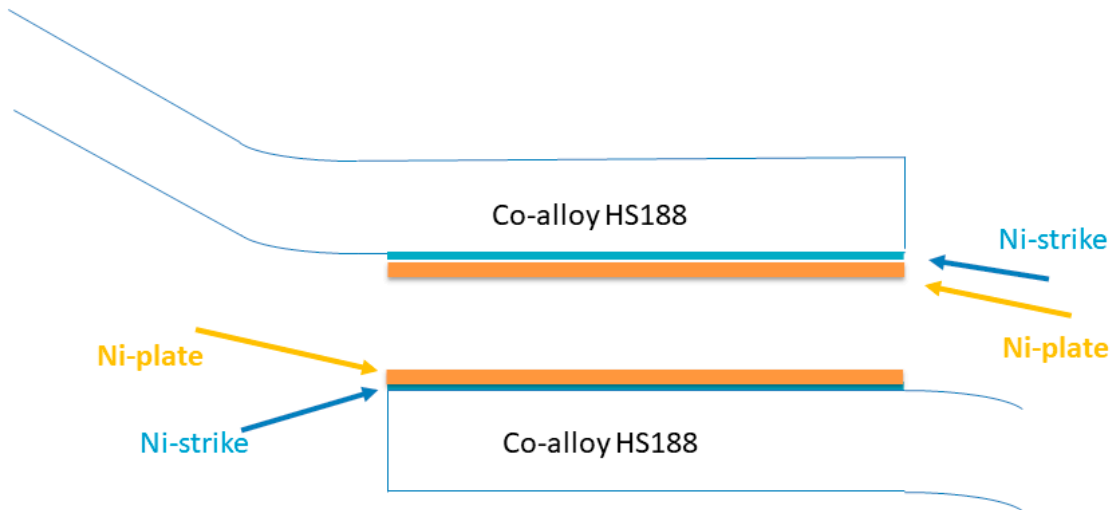
Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

32



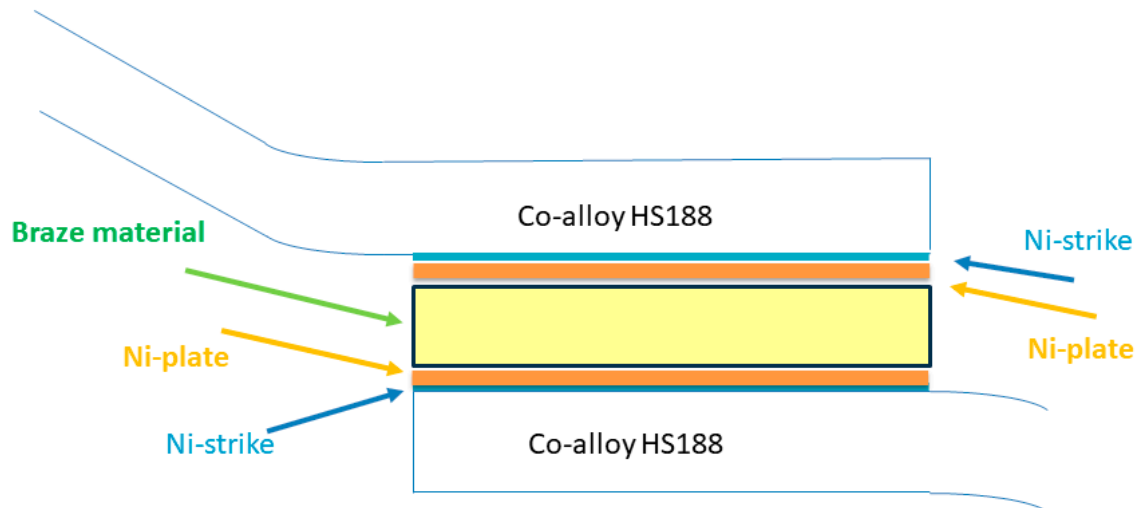
Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

33



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

34



#### Cause of failure:

- Production process was interrupted between application of Ni-strike and Ni-plate (production fault)
- Formation of extremely thin oxide layer between Ni-strike and Ni-plate
- Lower Co-alloy ring sheared off from upper ring (because of internal hot gas pressure) and cut all first stage turbine blades.



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

35

**Several Netherlands NF5 aircraft showed severe engine problems:  
In-flight breaking (by fatigue) of compressor drive shaft of GE - J85 engine.**

**The broken parts damaged remaining engine; often in-flight fire resulted.**

**But luckily: the NF5 has 2 engines. So, pilots could return sometimes safely.**



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

36

**Many NF5 aircraft experienced severe engine problems,**

**But luckily: they have 2 engines**

**Cause: compressor drive shaft cracking**



Mom CS

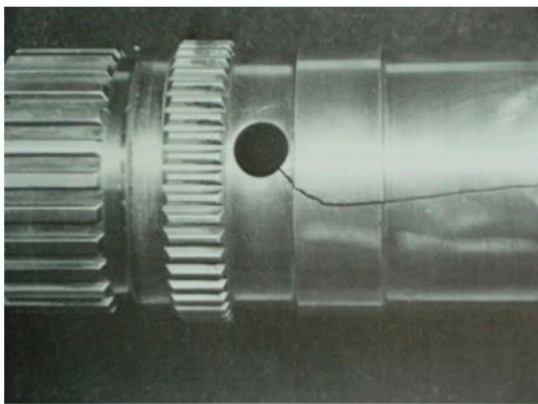
Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

37

**Fatigue failure in drive shaft; but: calculated stresses at that location were much too low to cause fatigue cracking.**

**GE introduced several solutions:**

- 20% thicker shaft
- 100% thicker shaft
- **But: this did not work; even more failures occurred.**



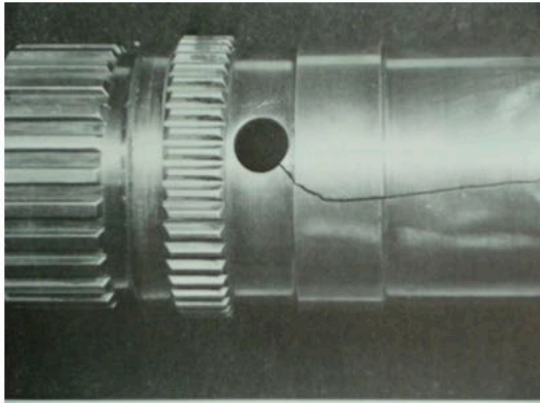
Mom CS

Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

38

## Fatigue failure in drive shaft

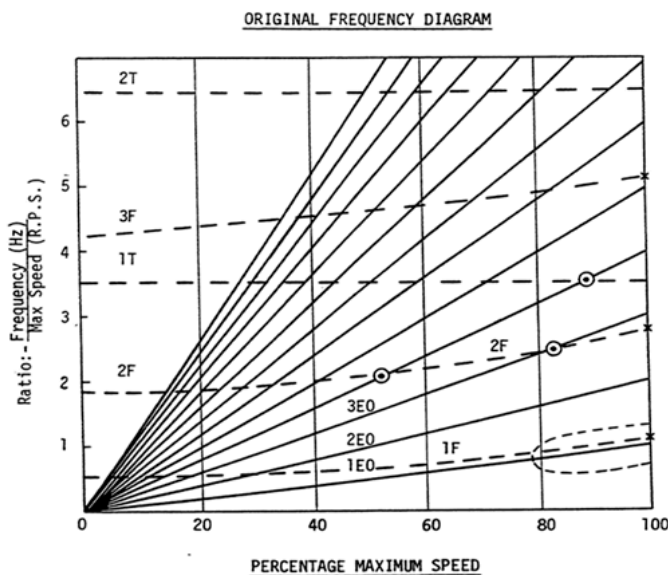
After extensive and expensive in-flight measurements on instrumented engine, done by Netherlands Air Force/NLR, it became clear that rumble in afterburner (with same frequency as torsion frequency of shaft) caused high torsional stresses at vent hole



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

39

## Campbell or 'spoke' diagram



A Campbell diagram plot represents a system's response spectrum as a function of its oscillation regime. It is named for Wilfred Campbell, who introduced the concept., also called interference diagram. The 'eigenfrequencies' often depend on the rotation rates



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

40

# Creep failures in aircraft engines

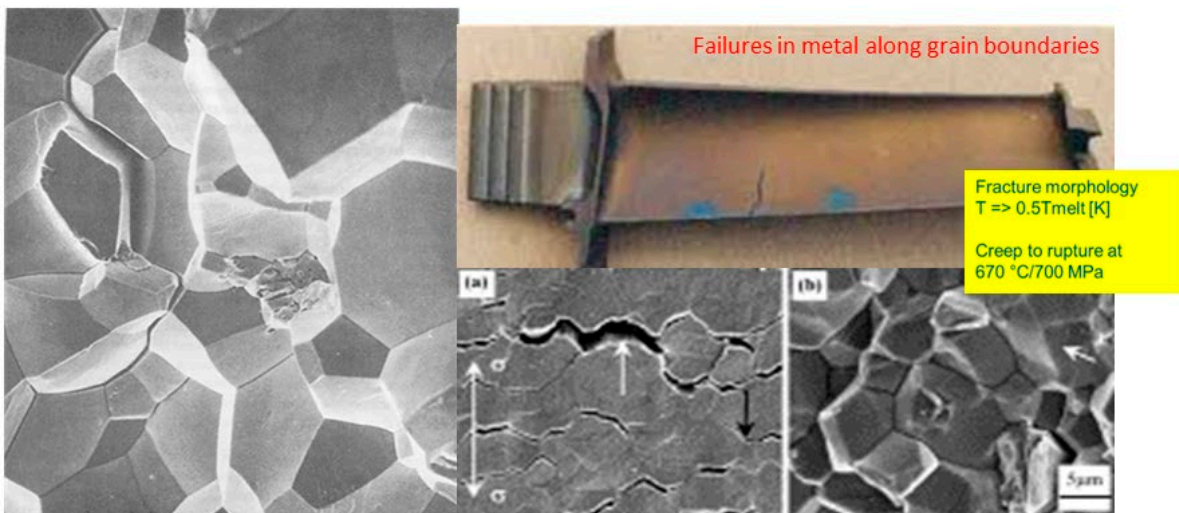


Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

41

## Creep

Creep is the tendency of a solid material to deform permanently under the influence of a mechanical stress. It will more easily occur at high temperatures.



Fracture is often intergranular



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

42

## Outer casing combustor Inconel 718 pressure vessel 25 bars/550C

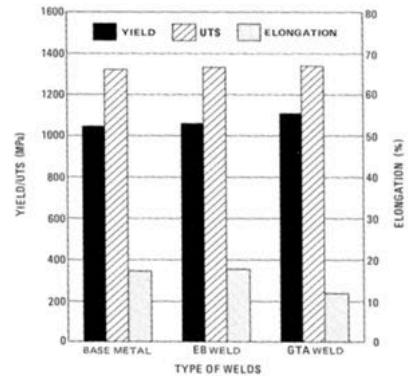


Fig. 9 Mechanical properties of fully heat treated Inconel 718 welds in O.D. skirt material



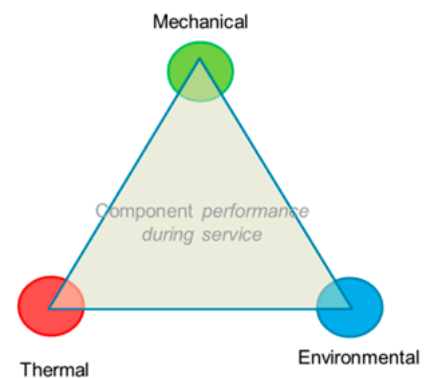
Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

43

## Which Loads?

### Loads:

- Mechanical loads
  - Centrifugal loads
  - Aerodynamic loads (pressure differences)
  - Vibrational loads
- Thermal loads
  - Difference in heating up
  - Difference in thermal expansion coefficient
- Environmental loads
  - Sand, dust, rain causes erosion
  - Corrosion (cold and hot section), oxidation
  - Fretting/contact wear



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

44

## Damages related to manufacturing and coating

Many KLM engine failures CF6-50, Boeing 747  
End 70's – beginning 80's



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

45

## Damages related to manufacturing and coating

Many KLM engine failures CF6-50, Boeing 747  
End 70's – beginning 80's

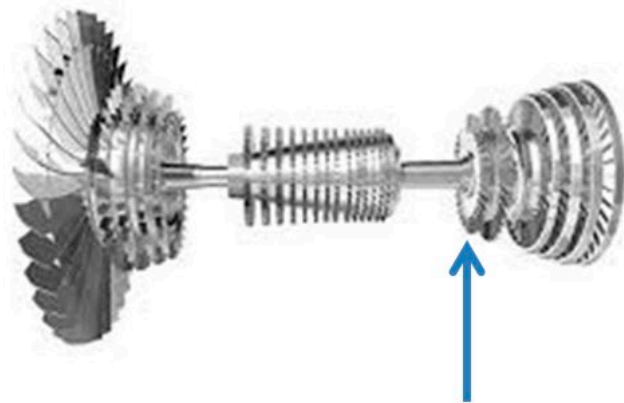


Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

46

## Damages related to manufacturing and coating

Many KLM engine failures CF6-50, Boeing 747  
End 70's – beginning 80's



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

47

## Damages related to manufacturing and coating



Broken and damaged 1<sup>st</sup> stage turbine blades in civil aircraft engine



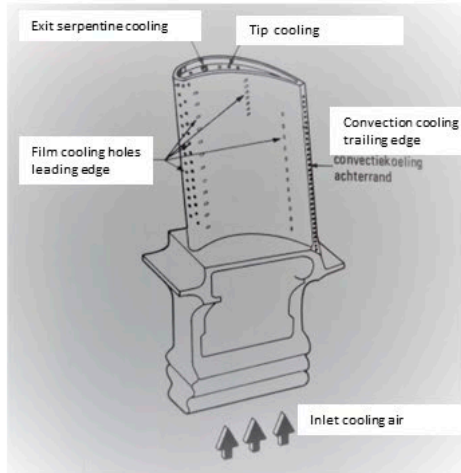
Detail of crack formation in leading edge of 1<sup>st</sup> stage turbine blade



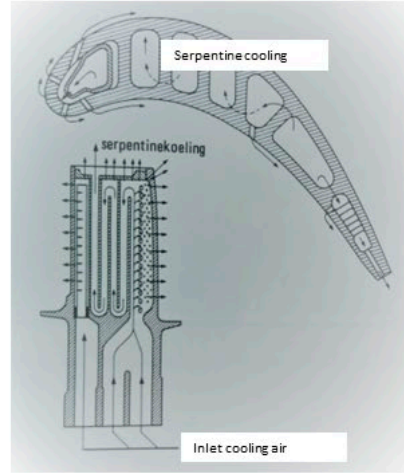
Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

48

## Damages related to manufacturing and coating



1<sup>st</sup> stage turbine blade and type of cooling



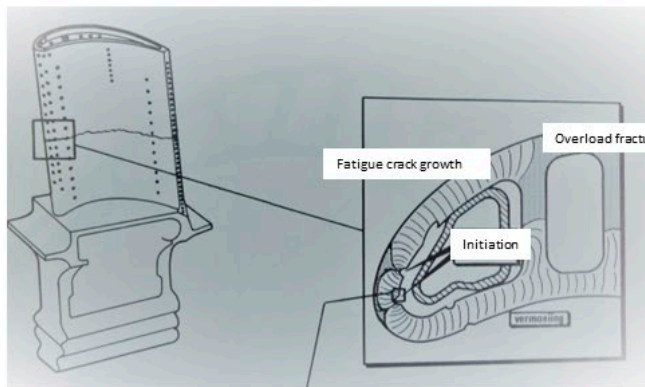
1<sup>st</sup> stage turbine blade; internal cooling circuit



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

49

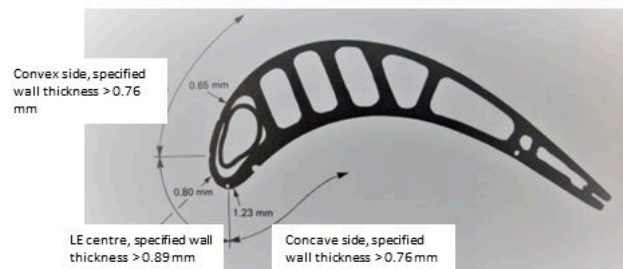
## Damages related to manufacturing and coating



Crack initiation, fatigue crack growth and overload fracture



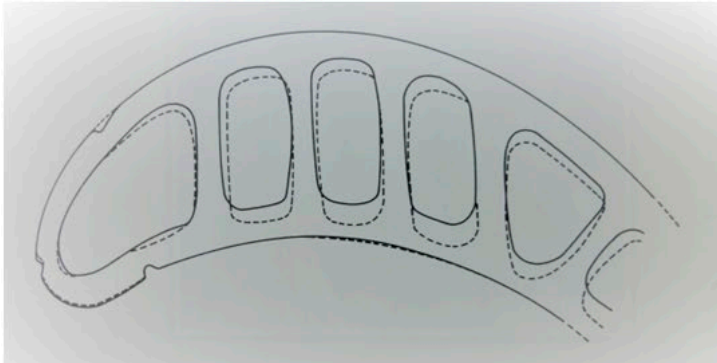
Crack initiation at location where film cooling hole intersects blade wall



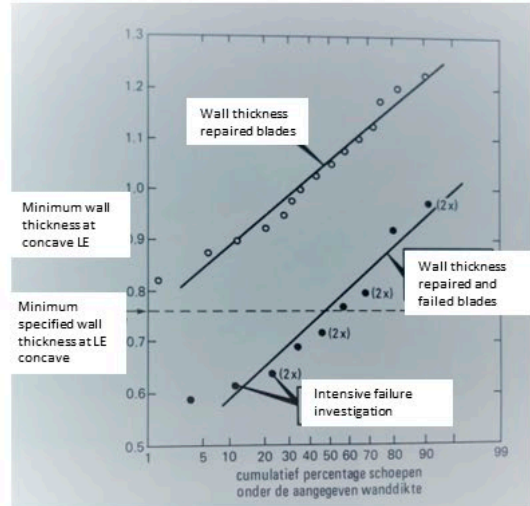
Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

50

## Damages related to manufacturing and coating



Shift in location of internal cooling circuit for 2 different blades



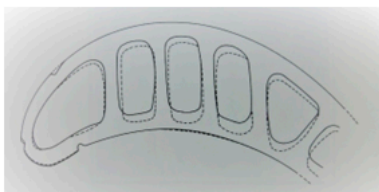
Probability curves wall thickness for repaired blades



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

51

## Damages related to manufacturing and coating



### • Primary causes:

- ceramic core shift during casting leading to thin leading edge convex walls
- acid stripping of old coating during repair: leading to cooling hole enlargement
- reduced internal blade pressure (total airflow restricted); ineffective cooling

## Increased stresses resulted in LCF crack initiation and blade failure by HCF



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

52

## Crash of an Breguet Atlantic (September 1978) in the Atlantic Ocean close to Scotland, crew of 14 survived, aircraft was never recovered, but: after extensive and lengthy investigation we still found the cause!



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

53



By Adrian Pingstone - Own work, Public Domain



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

54

## Overview of degradation mechanisms for different parts

Component	Degradation mechanism(s)
Compressor blades	Fatigue, erosion, low T corrosion (water, salt, SO <sub>2</sub> )
Discs	Fatigue, corrosion
Drive Shaft	Fatigue
Combustor	Thermal degradation, (thermal) fatigue
Turbine stator vanes	Oxidation, hot corrosion, thermal degradation, (thermal) fatigue
Turbine rotor blades	Oxidation, thermal degradation, (thermal) fatigue, creep



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

55

## Difference between Low Cycle Fatigue (LCF) and High Cycle Fatigue (HCF)

- LCF often defined as: cracking of metals in less than 50,000 cycles
- A more fundamental distinction is:
  - LCF : high plastic strain in component
  - HCF: strain in component is predominantly elastic
- HCF occurs e.g. in blades due to vibration, elastic regime, very many cycles
- LCF occurs e.g. in disks due to cyclic loading, very high stresses, plastic regime, (1 start-stop cycle per flight)
- Measures to increase HCF life, such as:
  - Improved material cleanliness
  - Avoidance of surface defects
  - Introduction of residual compressive stress
 do not have similar beneficial effects in the LCF range

### Conclusion:

- LCF (in engines) is often caused by the cyclic loading of an engine (start-stop cycles, intermediate cycles (idle – cruise - military, etc);
- HCF is often caused by vibrational loading with a very high number of cycles.



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

56

## Safe life aspects

- Safe Life = 1 in every 1000 disks develops a crack of 1/31 inch (0.76 mm), not yet critical.
- Most disks have a much longer service fatigue life!

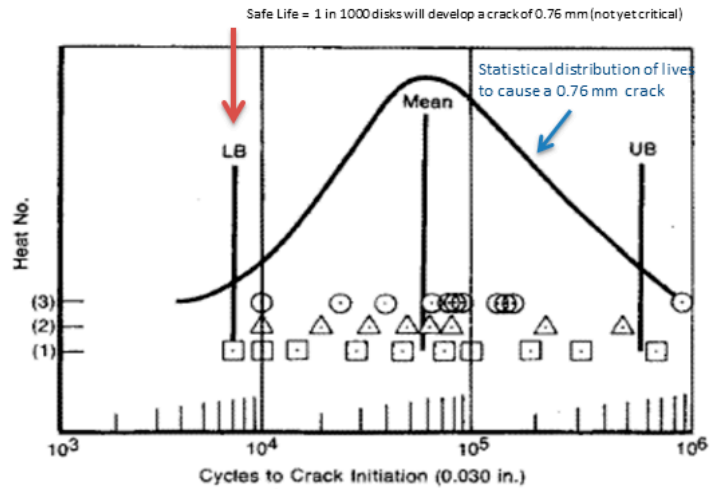


Fig. 2 Material data scatter results in conservative life prediction.

**Fatigue tests on material under simulated service conditions**



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

57

## Safe Life

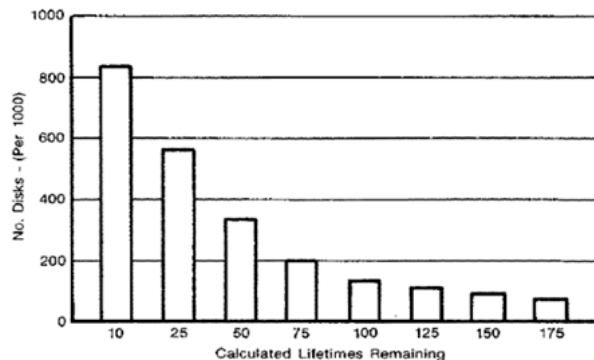
- Used for critical systems which are very difficult to repair or may cause severe damage to life and property. These parts are designed to work for years without requirement of any repairs.
- Drawback: components are over-dimensioned: uneconomical. Most parts have much lifetimes remaining!
- A considerable life ahead is not used. Therefore: alternative design philosophies were developed, such as damage tolerant design.



PHOTO 27: HPT STAGE 2 RELEASED BLADES AND DISK LUG FRACTURE



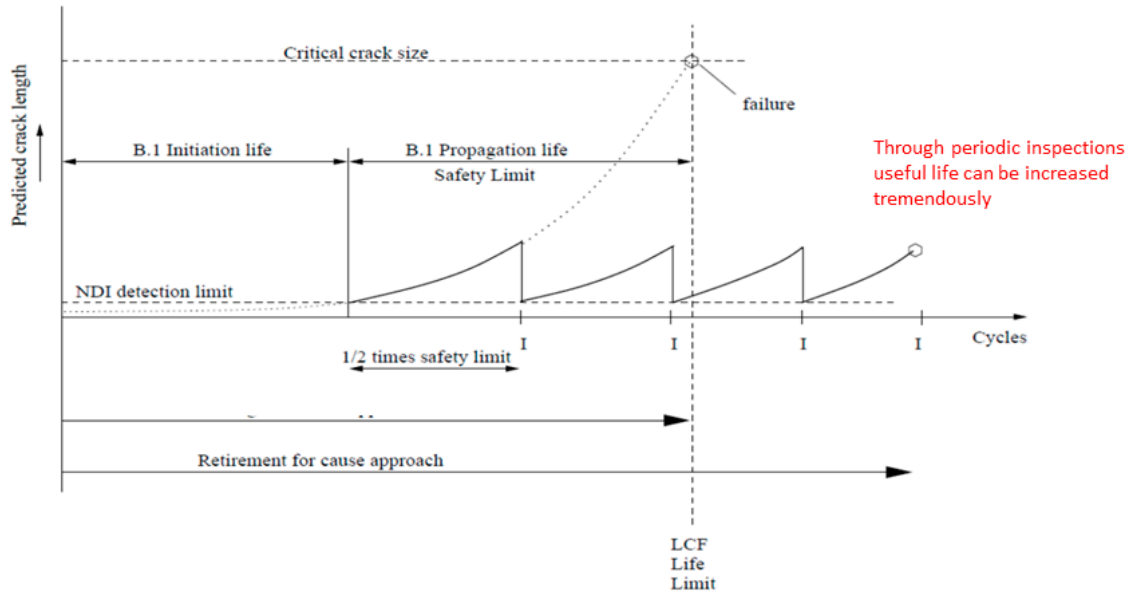
PHOTO 28: CLOSE-UP OF HPT STAGE 2 DISK LUG FRACTURE  
PHOTOS COURTESY OF IAE



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

58

### Pratt & Whitney Damage Tolerance and Retirement For Cause approach



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.



## Aircraft: 4X-AXG

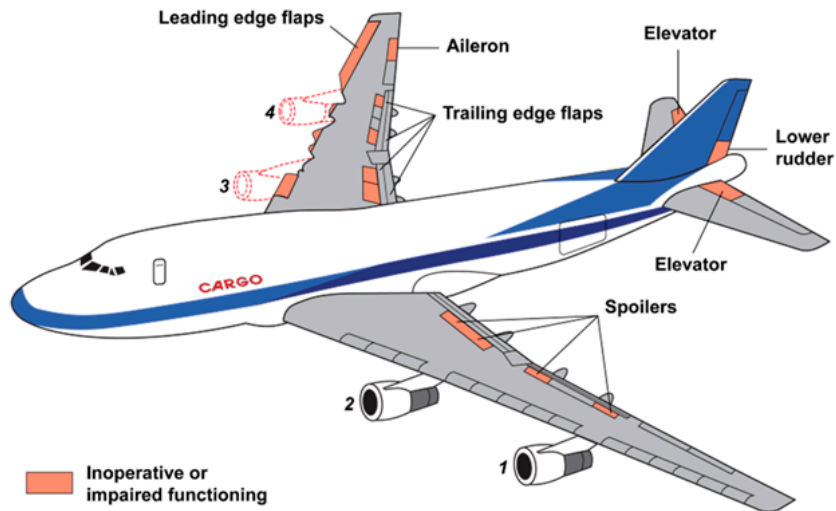




Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

Australian Government  
Department of Defence  
Defence Science and Technology Group

## In-flight final situation

Netherlands Aerospace Centre NLR and Defence Science and Technology Group DSTG (Australia)

65

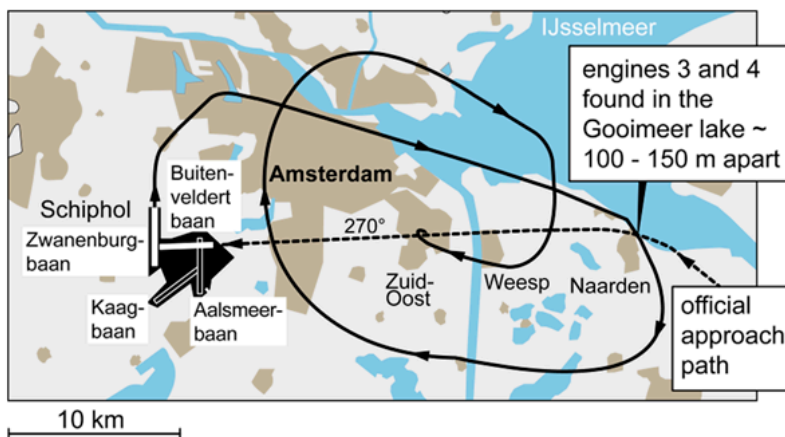


Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

61

Australian Government  
Department of Defence  
Defence Science and Technology Group

## Last flight of EL AL 1862: October 4, 1992

Netherlands Aerospace Centre NLR and Defence Science and Technology Group DSTG (Australia)

66



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

62

 **Crash into apartment blocks, October 4, 1992** 





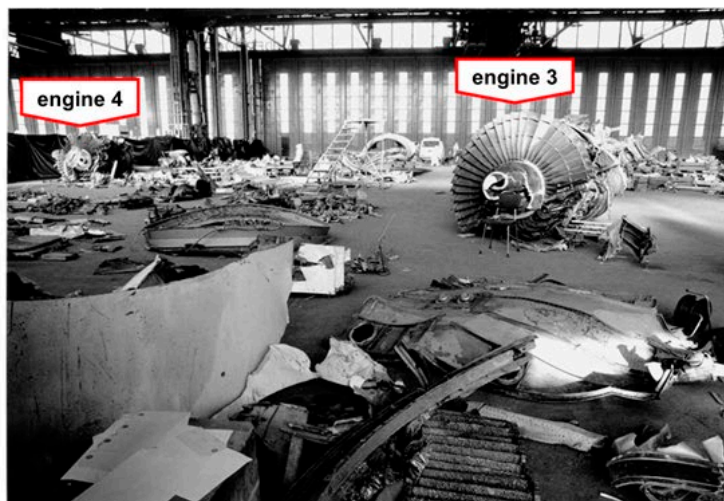
Netherlands Aerospace Centre NLR and Defence Science and Technology Group DSTG (Australia) 67



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

63

 **Some of the wreckage, including engines 3 and 4 recovered from the Gooimeer lake** 



Netherlands Aerospace Centre NLR and Defence Science and Technology Group DSTG (Australia) 68

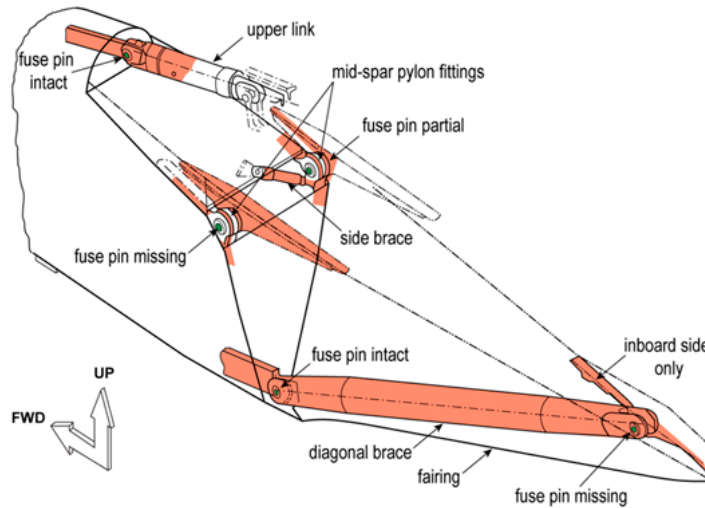


Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

64



## Recovered components from engine 3 pylon-to-wing connections



Netherlands Aerospace Centre NLR and Defence Science and Technology Group DSTG (Australia)

67



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

65

## Probable cause

The design and certification of the B 747 pylon was found to be inadequate to provide the required level of safety. Furthermore, the system to ensure structural integrity by inspection failed.

This ultimately caused - probably initiated by fatigue in the inboard midspar fuse-pin - the n°3 pylon and engine to separate from the wing in such a way that the n°4 pylon and engine were torn off, part of the leading edge of the wing was damaged and the **use 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.



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

66

## Failure analysis; what is important (1)

1. Background knowledge:
  - a. What is the lifing philosophy of the component or system which failed
  - b. Type of component, which loading (mechanical, thermal, environmental)
2. The investigation needs a careful plan: the investigation needs carefully planned steps; be aware of not making irreversible steps!
3. Important
  - a. Visual investigation, by eye, loupe, microscope, internal
  - b. Relevance of what you see
  - c. Photo's, editing/securing the information, write down what you see, careful description/formulation
  - d. What is/was the exact position/function of the specific component
  - e. Involve more people with appropriate qualifications, communicate!
  - f. In addition: literature survey; keep up with related literature
4. Next steps:
  - a. Detailed investigation in microscope, SEM, TEM, EDAX, (take care: after cutting the part you can't go back! Fracture surface, microstructure, etc
  - b. Compare with new/undamaged part
  - c. Questions to user/authorities/client/OEM/etc. Take care: different interests!
  - d. Look at different scenario's; sometimes there is no clou; missing information: Breguet Atlantic, NF5, MH370



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

67

## Failure analysis; what is important (2)

5. Search intensively to 'missing' information
  - a. Royal Netherlands Marine Forces KM had a fleet of ships searching for sunken Breguet Atlantic; shepherds were offered money in case they found something. However: still not enough information!
  - b. Very expensive instrumentation and extensive flight testing of NF5
  - c. Intensive search on MH370
6. Keep to the investigation plan; don't let yourself being scared or rushed by public, OEM's, politics, press. Don't let yourself being pushed, barked or bluffed by parties (which all have their own agenda). Independent research is a necessity (USA: NTSB).
7. Keep out of discussions about responsibility or liability. That frustrates the basic 'what happened question'. People should be allowed to talk about backgrounds in confidence, openness and liberty.
8. Example: anonymous reporting of incidents by pilots.



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

68

***The Australian EA-18G Growler aircraft (variant of Boeing F/A F18 Super Hornet), lost in an accident at Nellis Air Force Base (AFB), Australia, on 27 January 2018.***



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

69

**The aircraft experienced an uncontained F414 engine fan disc failure during the latter stages of its take-off roll at Nellis AFB.**

**The righthand engine failed; uncontained material from that engine caused the simultaneous failure of the lefthand engine and a fierce fuel/airframe fire.**



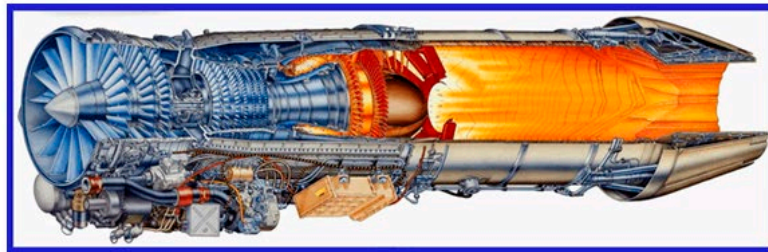
EA-18G accident aircraft ablaze (snapshot taken from USAF Go-Pro)



Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

70

The crew conducted an emergency abort and brought the aircraft to a safe stop. Fire brigade was very fast. The two crewmembers were uninjured, only “a little shaken”.



Mom CS

Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

71



### Cause of failure: uncontained Ti fan disc failure

The uncontained failure of the 1st stage fan disc was considered to be an unusual event by metallurgists. Subsequent discussions with the OEM sub-contractor responsible for producing the 1st stage fan disc forgings revealed that they had previously experienced three cracked forgings during manufacture, affirming the conclusion that the failure of A46-311 engine component was introduced during the forging process.

Mom CS

Unauthorised use or reproduction of any part of this presentation without prior written permission by the author is strictly prohibited.

72



Accelerating  
the future  
of aerospace

## Royal NLR - Netherlands Aerospace Centre

NLR operates as an objective and independent research centre, working with its partners towards a better world tomorrow. As part of that, NLR offers innovative solutions and technical expertise, creating a strong competitive position for the commercial sector.

For over 100 years, NLR has been an ambitious applied research organisation, driven to keep innovating for the benefit of making aerospace more sustainable, safer, efficient and effective. Objectively and independently, we are now laying the foundation for a future meaningful, societal impact.

In a rapidly changing world, mobility and stability needs are constantly evolving. Aware of the social urgency, NLR helps pave the way for promising concepts to quickly see the light of day and transform into disruptive solutions or incremental improvements. We do this by combining a deep understanding of customer needs, multidisciplinary expertise and the use of our leading research facilities. In doing so, NLR plays a pivotal role between science, industry and government at home and abroad, bridging the gap between fundamental research and practical applications.

NLR is taking a leading role to achieve Dutch and European objectives. Together with our partners, we are working hard on a resilient and sustainable mobility system, and we support Dutch Defence in all military domains, with space and cyberspace playing an increasingly prominent role. From its headquarters in Amsterdam and Marknesse and our two satellite sites and in this way, NLR contributes to a safer and more sustainable society, strengthening the competitive position of Dutch industry.

For more information visit: [www.nlr.org](http://www.nlr.org)

### Postal address

PO Box 90502  
1006 BM Amsterdam, The Netherlands  
✉ [info@nlr.nl](mailto:info@nlr.nl) 🌐 [www.nlr.org](http://www.nlr.org)

### Royal NLR

Anthony Fokkerweg 2  
1059 CM Amsterdam, The Netherlands  
☎ +31 88 511 3113

Voorsterweg 31  
8316 PR Marknesse, The Netherlands  
☎ +31 88 511 4444