# Introduction to Aerospace Engineering

## Lecture slides


# Design & certification approach

## Safe life, fail safe, damage tolerant

Faculty of Aerospace Engineering

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# Introduction

## Outline of lectures/lecturer

- 9/11 Material physics & properties / environment
- 16/11 Structures
- 23/11 Loads
- 30/11 Materials & manufacturing
- 7/12 Selection of materials & structures / space
- 14/12 Design & certification / fatigue & durability

- 4/1 Manufacturing & joining

- Lecturer
  - Name: R.C. Alderliesten
  - Room: NB0.45
  - Email: R.C.Alderliesten@tudelft.nl

# Learning objectives

## Student should be able to…

- Explain the role of the three responsible parties in aviation
- Describe the three major design philosophies

# Structural safety

## Measure of safety

- What is safety?

# Structural safety

## Measure of safety

- What is safety?
- How do you measure safety?
  - Fatalities per passenger kilometre?
  - Fatalities per flights/hours?
  - Fatalities per flights kilometre?

| Deaths per billion journeys | |
|---|---|
| Bus | 4.3 |
| Rail | 20 |
| Van | 20 |
| Car | 40 |
| Foot | 40 |
| Water | 90 |
| **Air** | 117 |
| Bicycle | 170 |
| Motorcycle | 1640 |

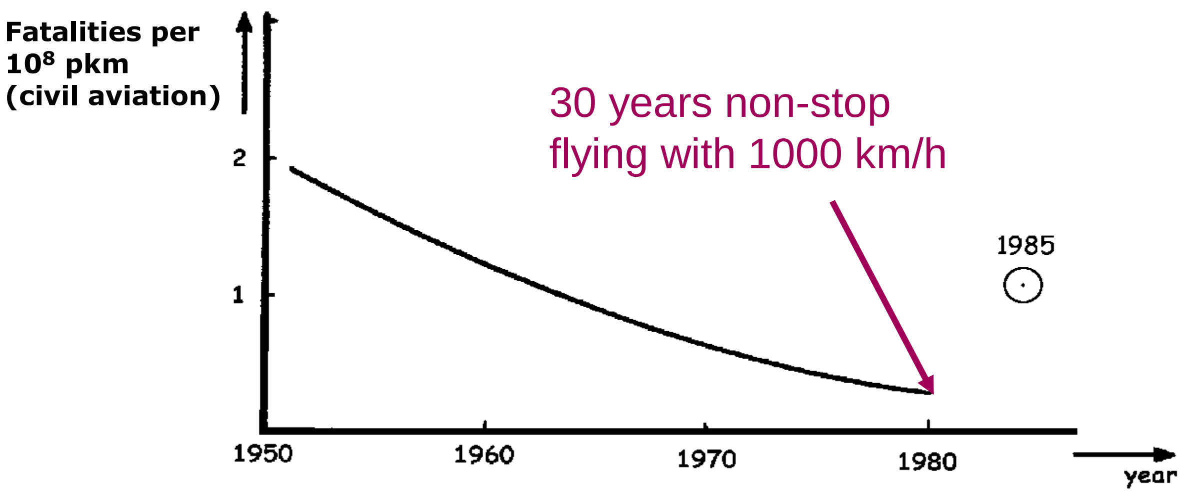
| Deaths per billion hours | |
|---|---|
| Bus | 11.1 |
| Rail | 30 |
| **Air** | 30.8 |
| Water | 50 |
| Van | 60 |
| Car | 130 |
| Foot | 220 |
| Bicycle | 550 |
| Motorcycle | 4840 |

| Deaths per billion kilometres | |
|---|---|
| **Air** | 0.05 |
| Bus | 0.4 |
| Rail | 0.6 |
| Van | 1.2 |
| Water | 2.6 |
| Car | 3.1 |
| Bicycle | 44.6 |
| Foot | 54.2 |
| Motorcycle | 108.9 |

# Structural safety

## Measure of safety

- What is safety?
- How do you measure safety?
  - Psychological aspect (one large accident vs. several smaller accidents)
  - Large fluctuations per year
  - No distinction routes, operators, range, age of aircraft
  - Safety level established for every new aircraft type



# Structural safety

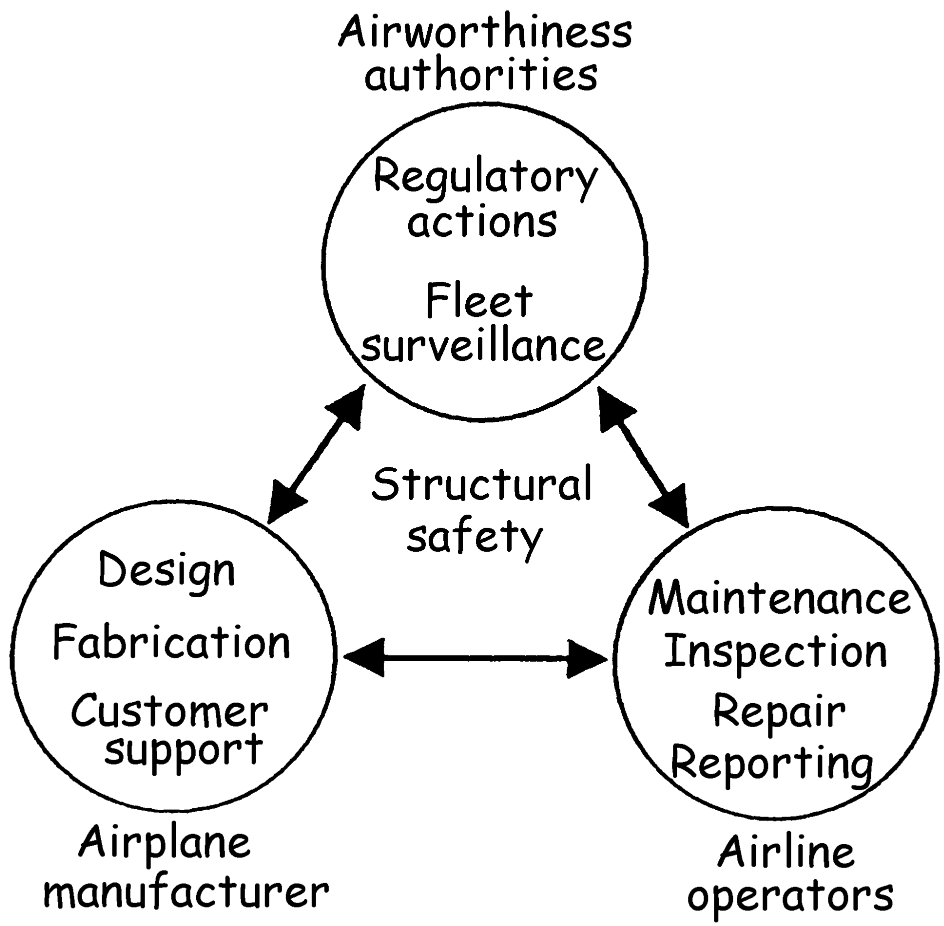
## Measure of safety

- What is safety?
- How do you measure safety?
- Relation to structural safety?
  - Limited amount related to structural failures (~70% human factors)


# Structural safety

## Interaction of disciplines

- Jointly responsible parties
  - Manufacturer
  - Operator
  - Authority



# Safety requirements

## Structural requirements

- Requirements related to
  - Strength (resistance to failure and standards with regard to risks)
  - Load cases (exact 'estimation' of the external forces on the aircraft during its life)

  - This 'estimation' relates to acceptance of risks:

| Risk | Load case |
|---|---|
| Event 1 → | External forces |
| Event 2 → | External forces |
| … | … |

# Safety requirements

## Structural requirements

- Requirements related to
  - Strength (resistance to failure and standards with regard to risks)
  - Load cases (exact ‘estimation’ of the external forces on the aircraft during its life)
  - Life time!

- The unit of time
  - ‘Flights’ seems more relevant than ‘flying hours’
  - ‘Flying hours’ often easier for aircraft operator (in relation to planning)

  - Each part has its own unit of lifetime depending on type of lifetime reducing factor (fuselage pressurization vs. engine part rotation)

# Safety requirements

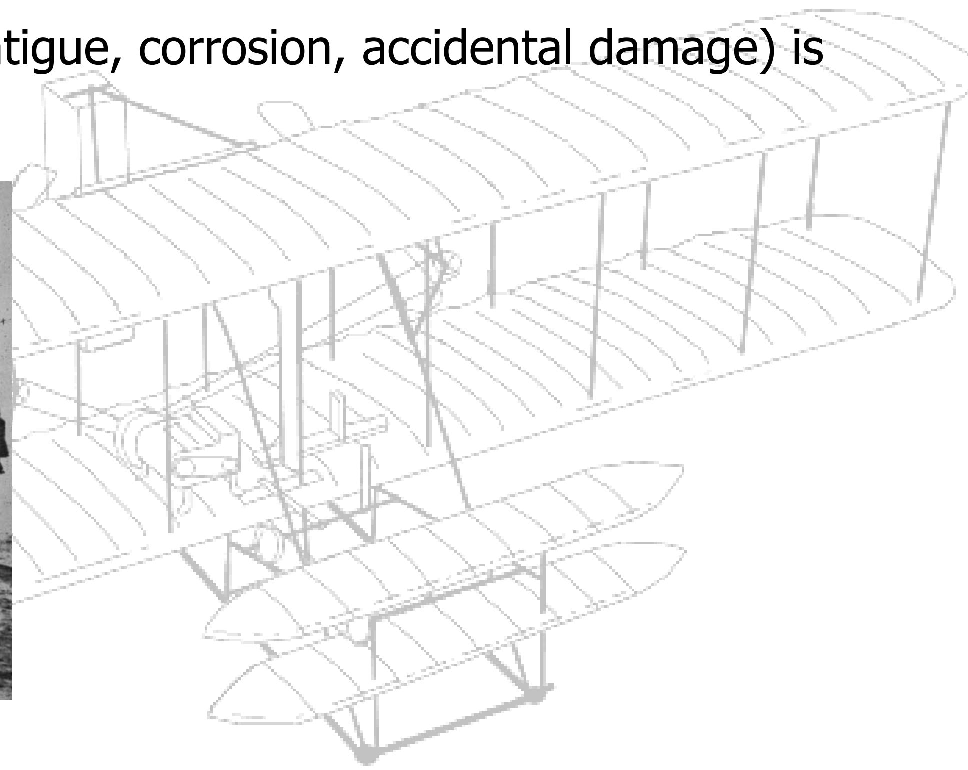
## Structural design philosophies

- Safe life
- Fail safe
- Damage tolerance

# Safe life

## Safety-by-retirement

- 1903: Wright brothers – First aircraft types
  - Static strength design
  - Damage during service (fatigue, corrosion, accidental damage) is not taken into account

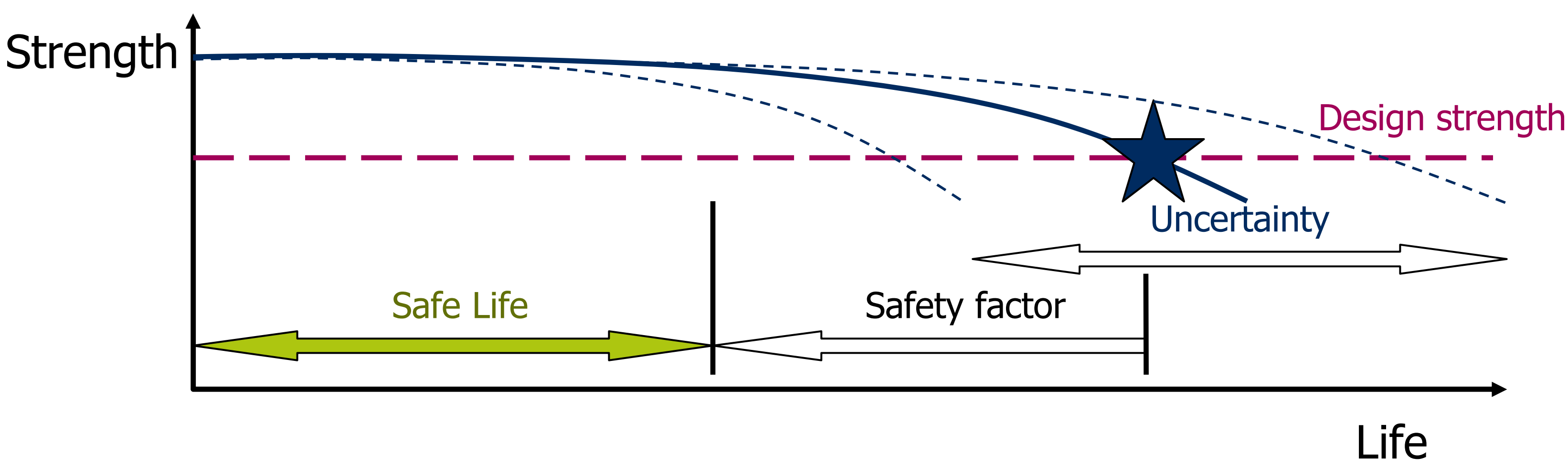


# Safe life

## Safety-by-retirement

- 1930's: Introduction of metal structures

Safe-life of a structure is the number of flights, landings, or flight hours, during which there is a low probability that the strength will degrade below its design strength.



# Safe life

## Safety-by-retirement

- 1930's: Introduction of metal structures

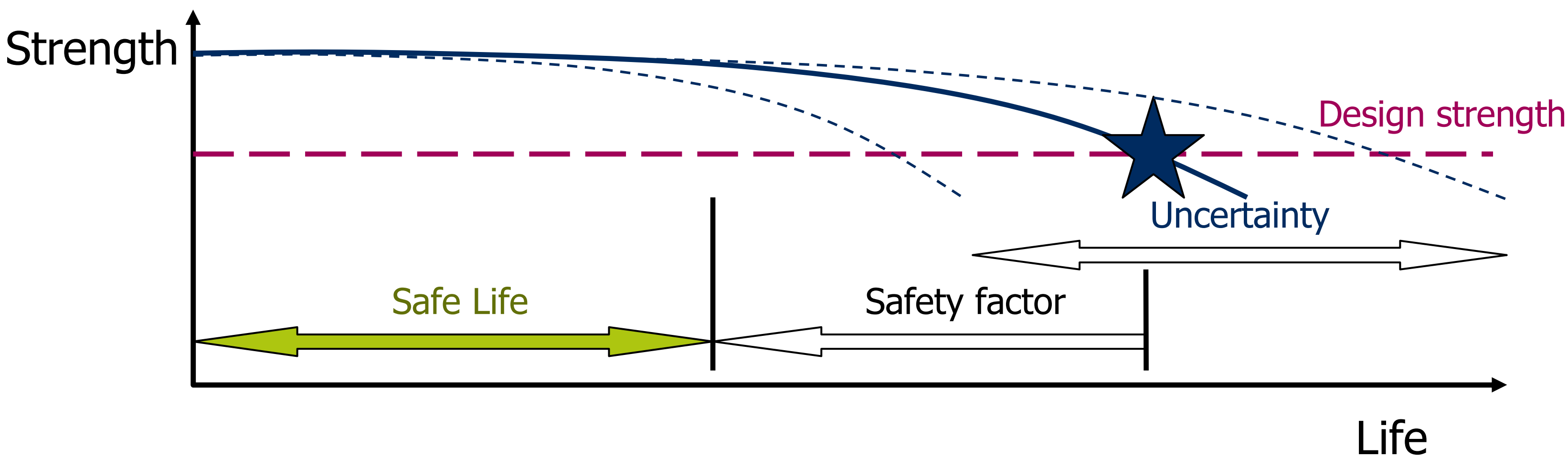
Safe-life of a structure is the number of flights, landings, or flight hours, during which there is a low probability that the strength will degrade below its design strength.

- Design life with reserve/safety factor
  - Fatigue failure is not likely to occur during design life
  - At the end of its design life the aircraft component is scrapped/replaced
- Because aircraft were obsolete before design life was reached approach worked

# Safe life

## Safety-by-retirement

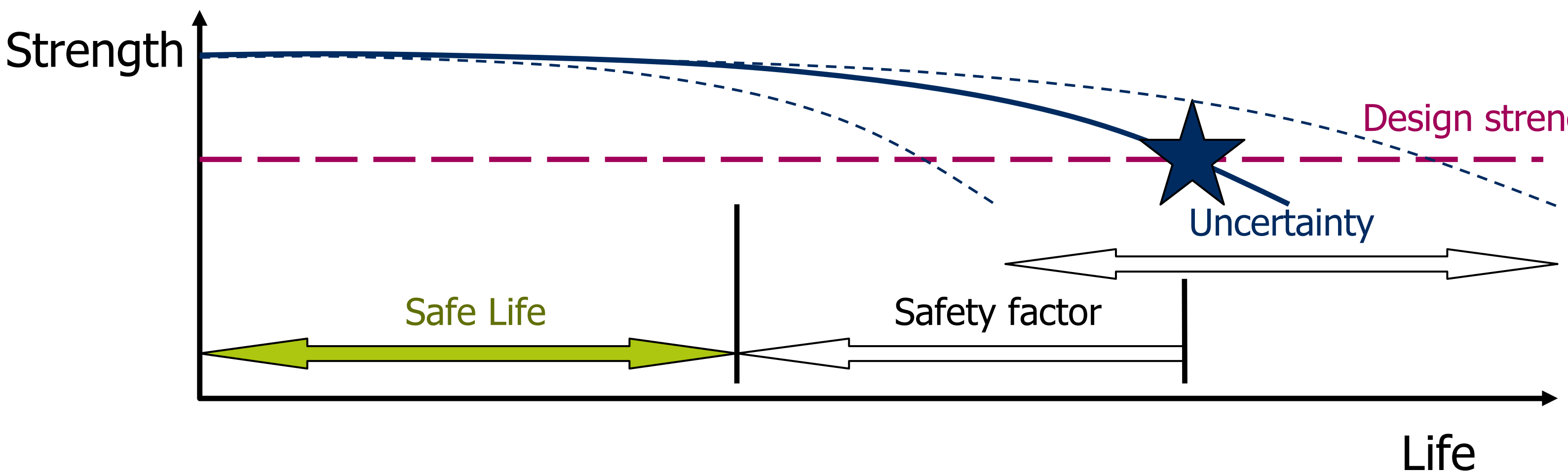
- Fatigue becomes an issue when…



# Safe life

## Safety-by-retirement

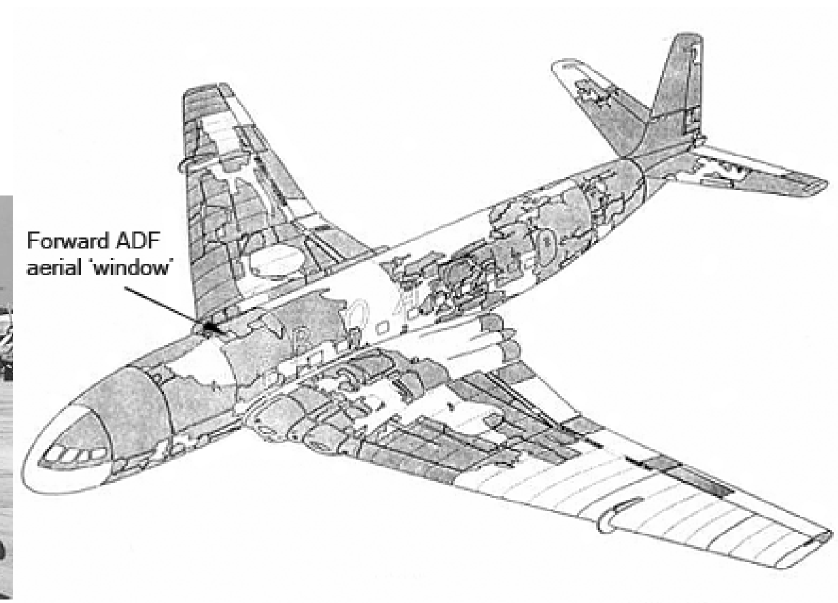
- Fatigue becomes an issue when
  - Increase of design lives (economic reasons)
  - Increase of loads (higher altitude ⇒ cabin pressure)
  - Improvement of (accuracy of) methods (smaller margins/safety factors)
  - Application of stronger materials, but with poor fatigue properties, crack growth and residual strength



# Safe life

## Safety-by-retirement

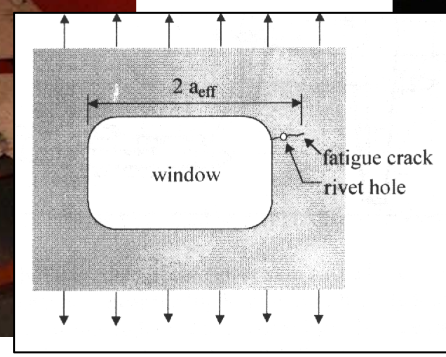
- 1954: Two Comet accidents
  - Fuselage exploded at cruising altitude
  - Crash after 1286 and 903 flights
  - Crack started from ADF windows

# Safe life

## Safety-by-retirement

- 1954: Two Comet accidents (design)
  - High stress levels
  - Material choice not optimal (notch sensitivity)
  - Corner crack from window (large effective crack)

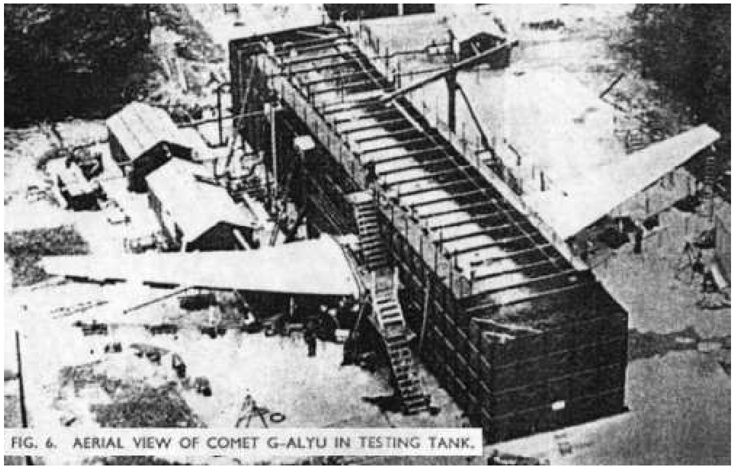



# Safe life

## Safety-by-retirement

- 1954: Two Comet accidents (testing)
  - Full scale test performed ⇒ cracks observed after 16000 flights!
  - Same test article as static test (2Δp) for economic reasons
    (Local plasticity ⇒ Stress redistribution ⇒ Unconservative test results)

  - Cabin pressure tests repeated on existing aircraft
    ⇒ Failure after 3060 cycles
    ⇒ Crack started from escape hatches



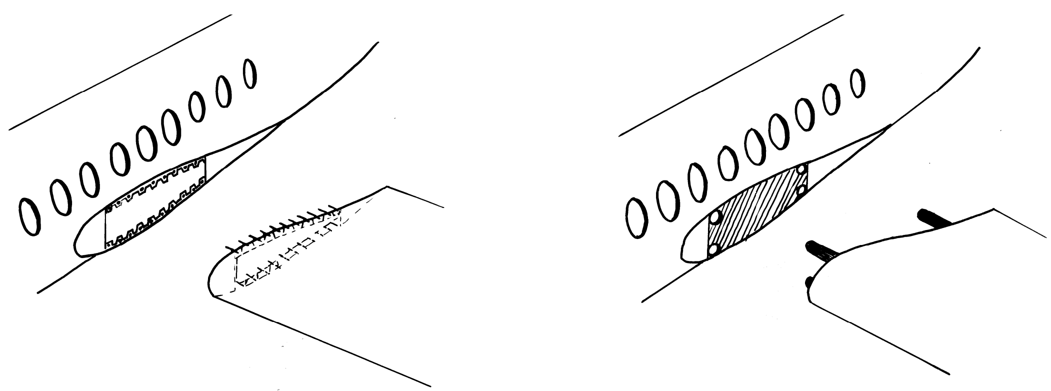

- "What are we testing?"

# Fail safe

## Safety-by-design

- 1950's
  - Problems with Safe Life design (limited service lives of critical components)
  - Introduction of Fail-Safe concept

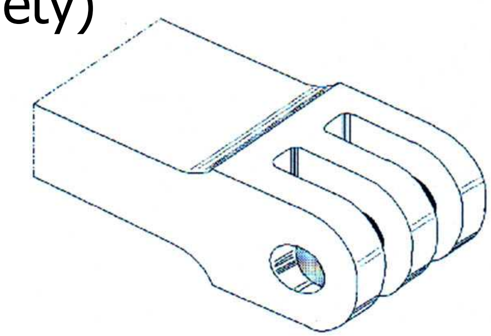
Fail-safe is the attribute of the structure that permits it to retain required residual strength for a period of un-repaired use after failure or partial failure of a principal structural element.



# Fail safe

## Safety-by-design

- Failure of a primary member by fatigue or otherwise must not endanger flight safety
  - Emphasis on ‘multiple structural member concept’
  - Static strength analysis of various damage scenarios
  - Each structural item adequate Safe-Life
- Economically more viable than safe-life concept
- In time damage detection possible (increase safety)



- From service experience:
  - Not all failure modes anticipated.
  - No partial failure anticipated.

- Multiple Site Damage (MSD): Fail Safe ineffective (aging aircraft)

# Damage tolerance

## Safety-by-inspection

- Since 1978 in FAR/JAR

> Damage Tolerance: The ability of the structure to sustain anticipated loads in the presence of fatigue, corrosion or accidental damage until such damage is detected through inspections or malfunctions and is repaired.

- DT concept is not a replacement: Combination of Safe Life, Fail Safe and Damage Tolerance needed!
- Damage and imperfections assumed to be present (from day 1)
- Damage (fatigue, corrosion, impact) until detection and repair (restore to UL)
- Sufficient durability (economics)

# Damage tolerance

## Safety-by-inspection

- Aloha airlines accident (1988)
  - Cause: MSD (Multiple Site Damage) in riveted joint
  - Operation in warm, humid, maritime air
  - Joints were susceptible to corrosion, operator informed by Boeing (*insufficient inspection!*)


# Durability

## Design philosophies

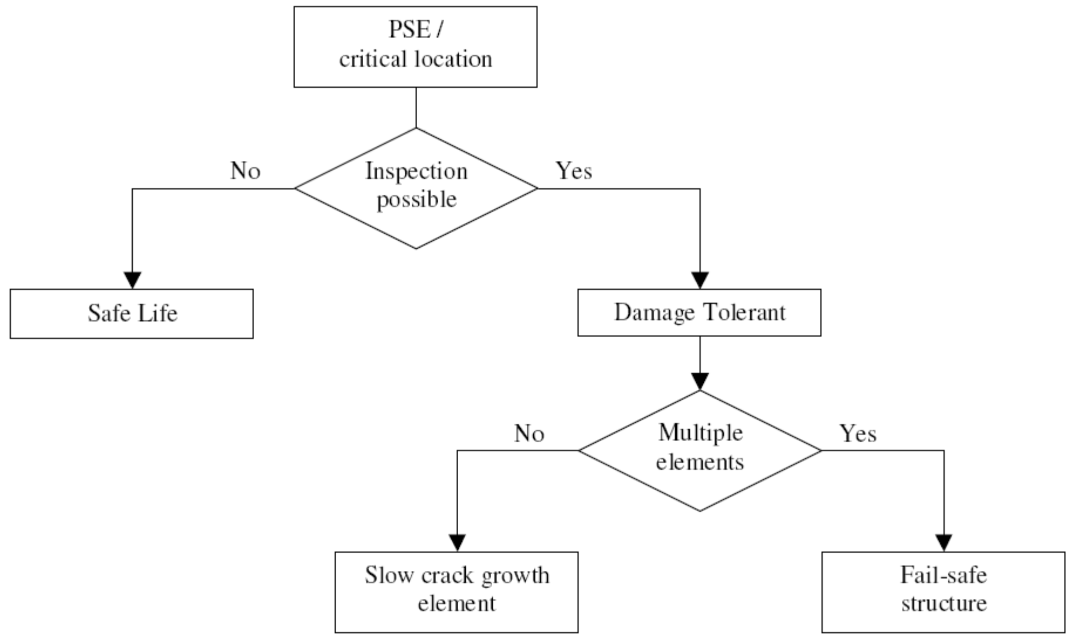
- Modern structural design must satisfy:
  - Damage Tolerance
  - Durability

> Durability: The ability of the structure to sustain degradation from sources as fatigue, corrosion, accidental damage and environmental deterioration to the extent that they can be controlled by economically acceptable maintenance and inspection programs.

- Recall lecture on Environmental Aspects & sandwich panel examples in lecture on Structures!

# Damage tolerance
## Design approach

- Critical location (primary structure)
  - Damage tolerance

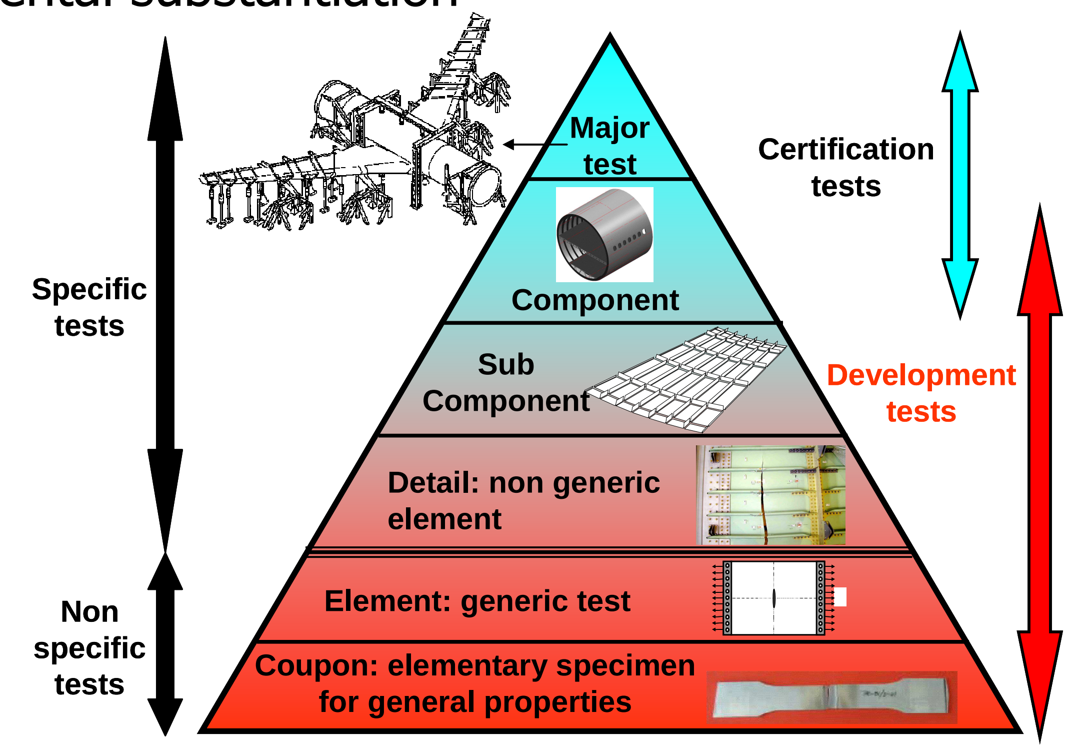



  - NB: Safe life is only allowed for landing gear and attachments

# Damage tolerance

## Design approach

- Experimental substantiation




- NB: Virtual testing ≠ testing (not allowed for certification)

# Summary

## Design & certification approach

- Three parties involved in aviation safety

- Design philosophies
    - Safe life
    - Fail safe
    - Damage tolerance