FRANC3D Training Workshop: Part 1

Fatigue and Damage Tolerance Philosophies

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Training Objectives

- General introduction to fracture and FRANC3D:
  - capabilities and limitations
- Present theories and approaches to computational fracture mechanics implemented in FRANC3D
- Hands-on sessions give participants time to use software
- Opportunity for participants to ask questions and work on their own models

Training Schedule

- Parts 1-3
- Parts 4-6
- Parts 7-8
- Part 9
- Parts 10-11
- Free time for users to work with the advanced tutorials or their own models.

Workshop Agenda

- Part 1: Introduction to Fatigue and Damage Tolerance
- Part 2: Introduction to Fracture Mechanics Analysis
- Part 3: Introduction to FRANC3D
- Part 4: FRANC3D User Interface
- Part 5: Finite Element (FE) Model Import
- Part 6: Crack Insertion
- Part 7: Static Crack Analysis & SIF Computation
- Part 8: SIFs from FE Analysis
- Part 9: Crack Growth
- Part 10: SIF History & Fatigue Life
- Part 11: Miscellaneous Topics

Fatigue and Damage Tolerance Philosophies

An important and
challenging task for designers:
avoid failures.

Fatigue and Damage Tolerance Philosophies

- Safe Life Design
- Fail Safe Design
- Damage Tolerance Design
- Future Trends in Fatigue Design

Safe Life Design Philosophy

- Products are designed to survive a specific design life
- Employed in critical systems that are either:
  - Very difficult to repair or
  - Cause severe damage to life and property if they fail
- Systems are designed to work for years without requiring repairs
- Treats fatigue as a crack nucleation process
- Does not explicitly consider the possibility for crack growth
- Until the mid-1950s, safe-life design concept was used to certify commercial aircraft designs

Safe Life Design Philosophy

- Prevent structural damage from developing
- Determine the life-span (based on testing and analysis), when a structural component (or a complete structure) must be removed from service before critical damage limits are reached.
- Nearly always based on constant amplitude stress or strain (σ or ε) versus number-of-cycles (N) data/curves.

Safe Life Design Philosophy

- Advantages:
  - Does not (or should not) require in-service inspections

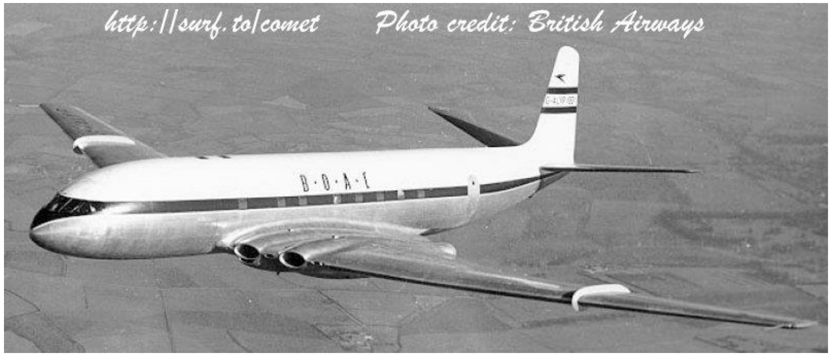
- Disadvantages:
  - Even with built-in conservatism and large scatter/safety factors, cracks and failure can occur before the design safe-life is reached.
  - Many (most) components are retired unnecessarily.
  - If cracking is discovered in-service, safe-life provides no information about the relative risk due to the damage.
  - Does not account for in-service loads that differ from those considered during design.

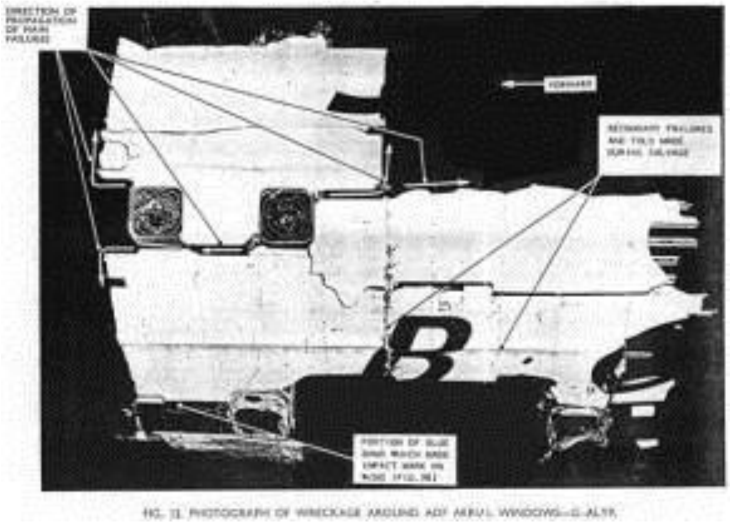
Safe Life Design Philosophy

- USAF Bad Experiences with Safe-Life
  - Early widespread cracking in C-5A lower wing structure
  - Crash of F-111 in Dec 1969 after only 107 flights
    - The F-111 test program had demonstrated multiple lifetimes without failure.
    - The lost F-111 contained a forging defect that caused early cracking.

Safe Life Design Philosophy

- Comet 1 Aircraft
  - Was certified with safe-life for 16,000 flights and 10 years of service
  - There were two crashes in 1954 due to operational pressurization higher than that used in design at the time (8.25 psi vs 5 psi)
  - Crashes of two Comet 1 airplanes in the mid-1950s led to the adoption of **Fail-Safe design approach**





Fail Safe Design Philosophy

- Consists of primary structural element and a redundant or backup structural element.
- Fail-safe design is known as a redundant design or a multi-load path design.
- Requires that if one element fails, the system does not fail.
- Requires development of an inspection program capable of detecting fatigue cracks.
- Recognizes that fatigue cracks might occur, and structures are designed/arranged so that cracks will not lead to failure before cracks are detected and repaired.

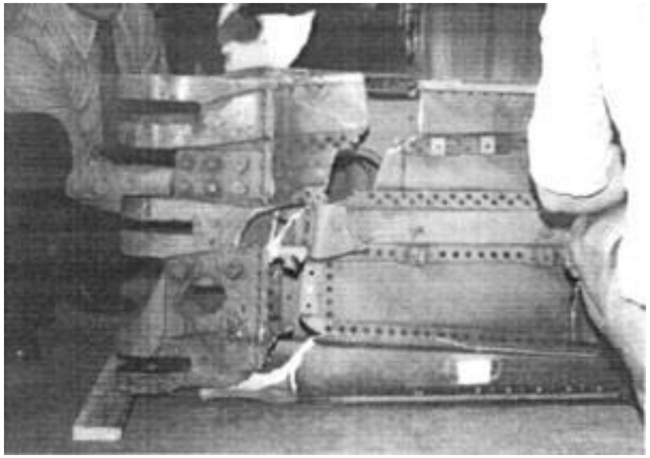
Fail Safe Design Philosophy

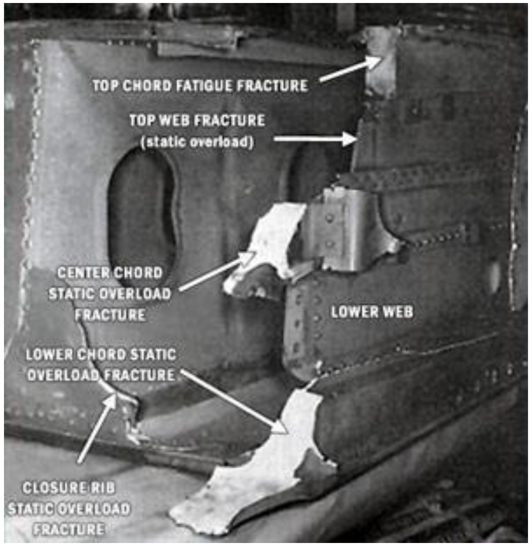
- Advantages:
  - Able to manage unexpected damage if element failure occurs

- Disadvantages:
  - Over-design can lead to an overweight structure
  - Difficult to accurately predict failure modes of the structure

Fail Safe Design Philosophy

- Boeing 707-300 crashed in May 1977
  - The 707-300 airplane had been designed using a 'fail-safe' philosophy
  - Crash was due to fatigue of the horizontal stabilizer rear spar
  - Inspections of the Boeing 707-300 fleet, conducted after the crash, found another 38 aircraft had similar cracks
  - This crash led to dropping fail-safe design and adopting damage tolerance design





Damage Tolerance Design Philosophy

- Linear elastic fracture mechanics approach (LEFM) is used to predict crack stability and crack growth.

  *FRANC3D is used for this type of prediction

- Requires inspections.
- Objective is to assess the effect of cracks in the structure between inspections.

Damage Tolerance Design Philosophy

- Permits a structure to retain its structural strength for a period of use after it has sustained a given level of fatigue or accidental damage.
- Knowledge of damage growth rates and residual strength is used to set inspection intervals.
- Assumes that defects are already present at critical locations in new structures.

Damage Tolerance Design Philosophy

Components are qualified as:

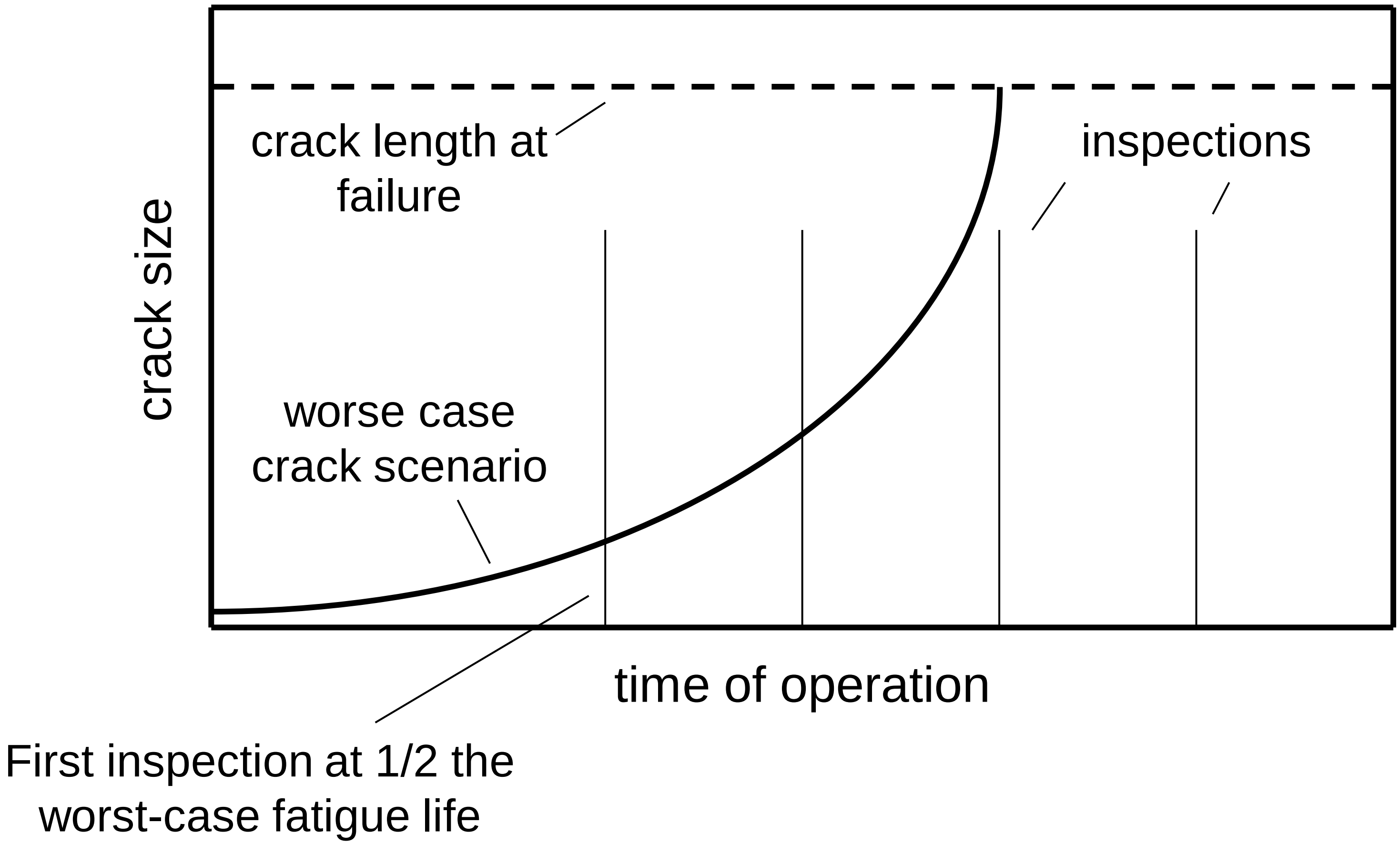
<u>Inspectable</u>:

- "Fail-Safe" - multiple load paths or crack arrest mechanisms
  - or
- Slow Crack Growth - crack will not grow to a critical size between *inspections*

<u>Non-inspectable:</u>

- Safe-Life - with an initial in-service inspection.
  - or
- Slow Crack Growth - cracks will not grow to a critical size *over the service life*

Damage Tolerance Design Philosophy



Damage Tolerance Design Philosophy

- Advantages:
  - Healthy structures can be used indefinitely.
  - Ease of model adaptation for new crack scenarios that might evolve in-service.
- Disadvantages:
  - Cost of periodic inspections.
  - Design approach has traditionally been deterministic, and the life prediction estimate is dominated by:
    - Choice of initial crack characteristics
    - Assumed load spectrum.
  - LEFM does not accurately model small cracks.

Future Trends in Fatigue Design

- Probability-based analysis and assessment
- On-board structural health monitoring (sensors)
- Prognosis systems
- Digital twins

End Part 1