Fuselage Structural Integrity Forum – Historical Perspective of Fatigue Requirements

Federal Aviation Administration

September 2011

Overview of Presentation

- **The purpose of this presentation is to provide you with a perspective on the evolution of transport category airplane fatigue requirements, including:**
  - Definition of fatigue damage,
  - Key historical events, and
  - Resulting changes to requirements.

What is fatigue damage?

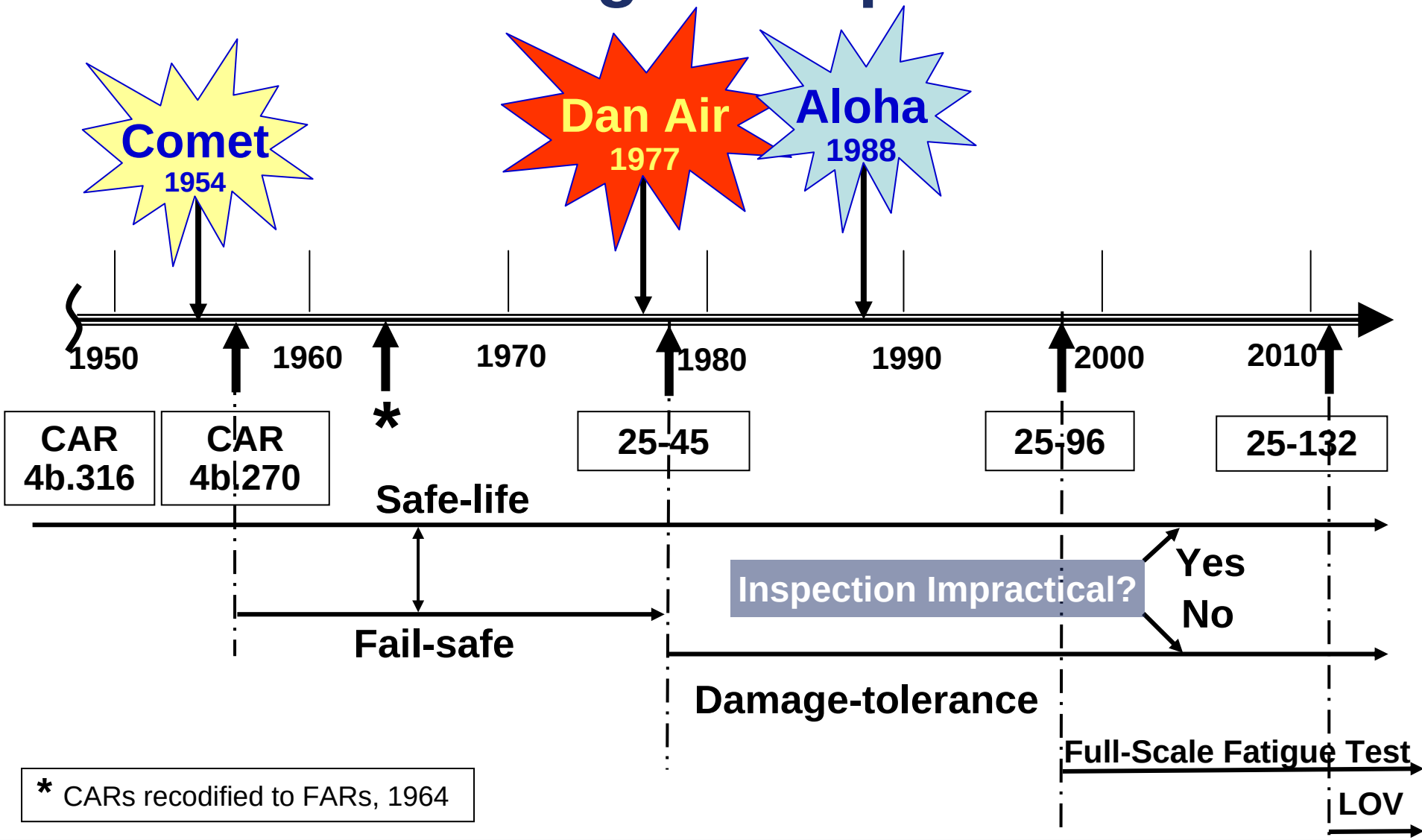
- **Fatigue damage**
  - Is progressive, beginning as minute cracks in metallic structures that grow under the action of the repeated loads, and potentially ends with fracture
  - Can occur locally or globally (widespread) on the fuselage
  - Can reduce the strength of structure below safe levels, resulting in local or catastrophic failures

Fatigue Requirements

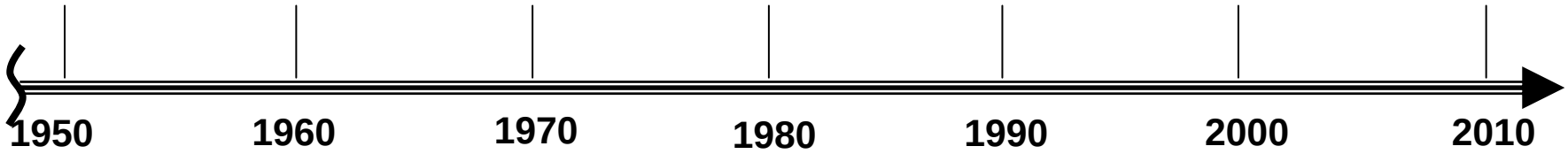
- **FAA certification requirements have always existed for applicants to consider fatigue**

- **Certification requirements addressing fatigue have changed over the years, largely based on key historical events**

Evolution of Fatigue Requirements



Evolution of Fatigue Requirements - Genesis



CAR 4b.316

Safe-life

Pre-1956 (Safety-by-Retirement)

- **CAR 4b.316 relied on safe-life approach (safety-by-retirement) to address fatigue in two optional ways**

1. Design the structure to preclude having any cracking occur (e.g., operate below the endurance limit)

2. Retire the structure before the fatigue life is exhausted (e.g., setting life limits based on “safe-life”)

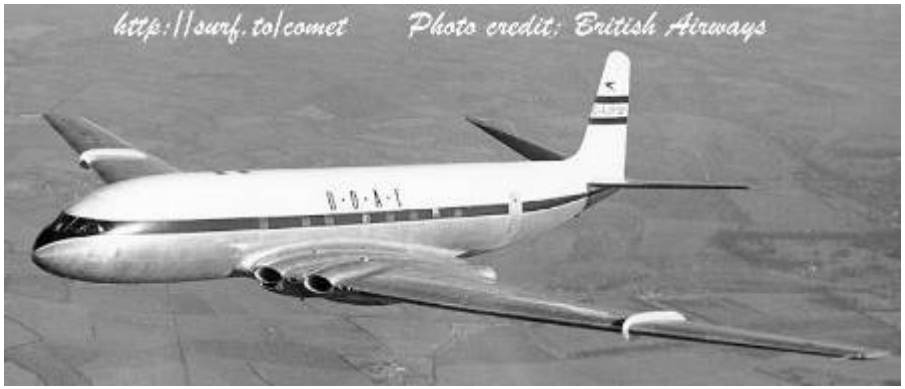
Comet 1 Accidents - 1954

This material are used for educational purposes from:
http://www.geocities.com/CapeCanaveral/Lab/8803/comet.htm

http://accidents-ll.faa.gov/ll_main.cfm?TabID=1&LLID=28

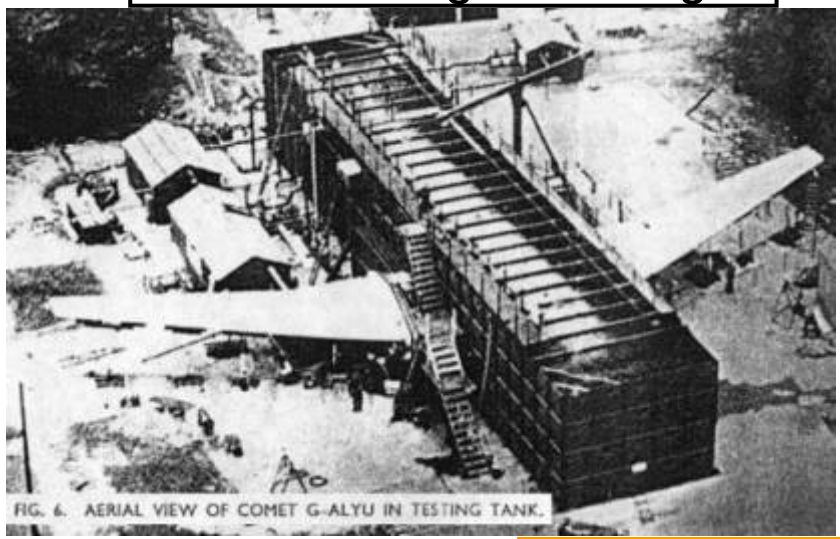
Comet 1 Accidents - 1954

First commercial flight in January 22, 1952

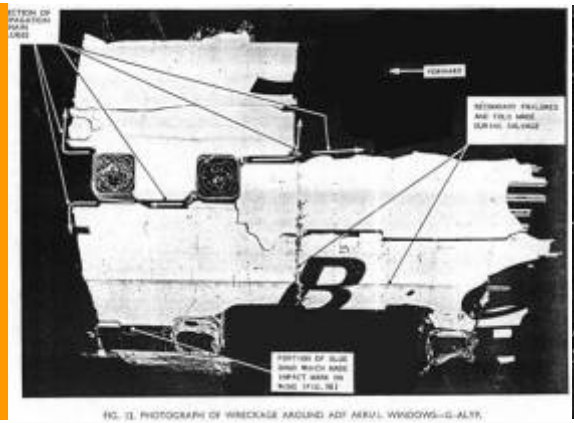


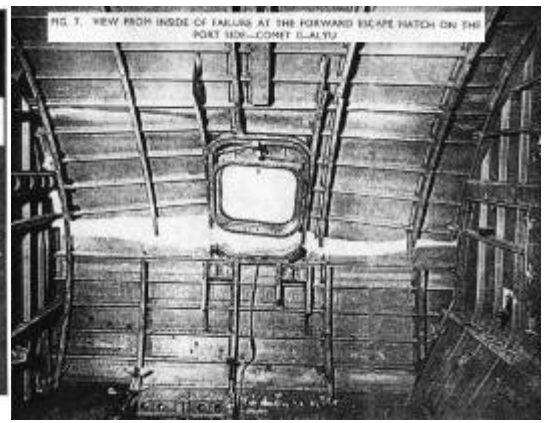
First sign of problem in May 2, 1953, and two more crashes to follow within a year

G-ALYU, was subjected to full-scale fatigue testing.



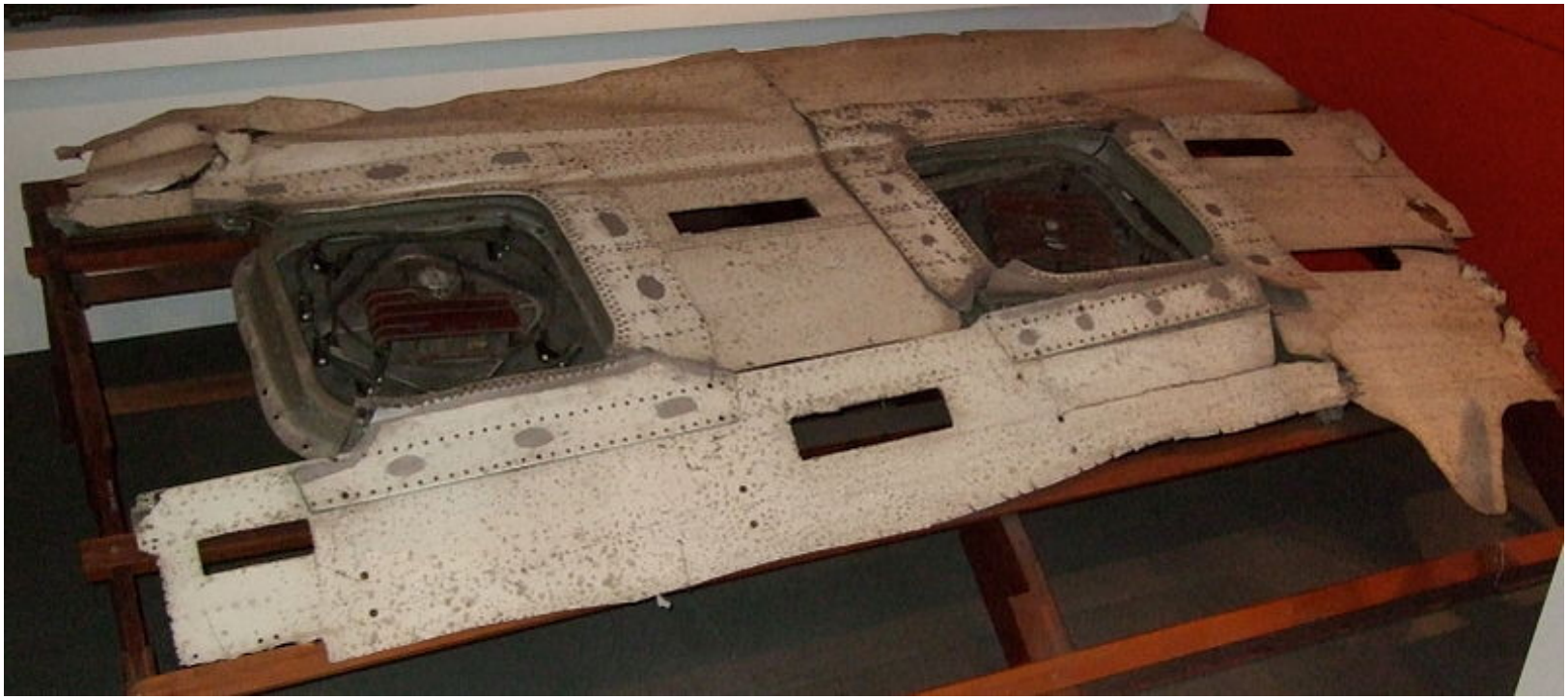
G-ALYP sections recovered from the sea confirmed the test results; in this airplane the crack was at the ADF Aerial Window





View from inside of failure at fwd escape hatch on post-accident fatigue test airplane

Comet 1 Accidents - 1954



The fuselage fragment of *G-ALYP* on display in the Science Museum in London. Fuselage fragment of de Havilland Comet G-ALYP, which crashed January 10, 1954, was retrieved from the bottom of the Mediterranean Sea. Fatigue crack at window corners was determined to be the original cause of the crash.
Ref: ObjectWiki- Science Museum. 24 September 2009

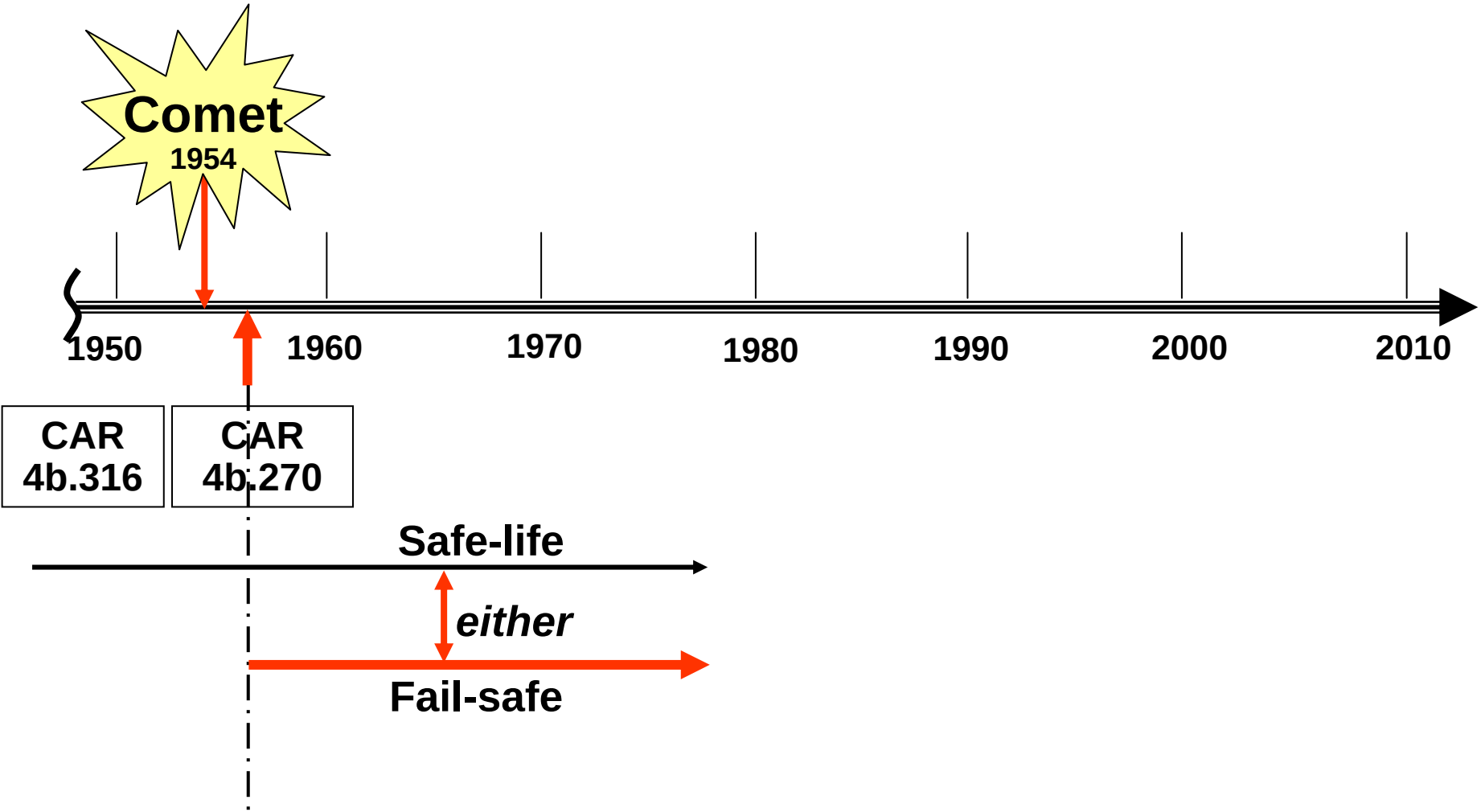
Comet 1 Accidents - 1954

- **Use of safe-life approach**
- **Fatigue test conducted after static test, led to erroneous fatigue test results**
- **Fatigue was premature and structure exhibited no crack arrest capability**

Impact of Comet Failures

- **The failures increased:**
  - Awareness of fatigue
  - Merit of fail-safe approach (safety-by-design)
  - Concern with respect to pressurized fuselage design
- **Precipitated addition of CAR 4b.270 in 1956 that included the fail-safe approach as an option to safe-life**

Evolution of Fatigue Requirements



Fail-Safe (Safety-by-Design)

- **Fail-safe approach relied on—**
  - Obvious detection of fatigue damage, and
  - Design redundancy to avoid catastrophic failures
- **Considered superior to safe-life and easier to implement**
  - No full-scale fatigue testing required
- **Fail-safe certified airplanes had indefinite life**
- **Preferred strategy for majority of transport category airplanes certified in '60s and '70s**

…BUT!!!…

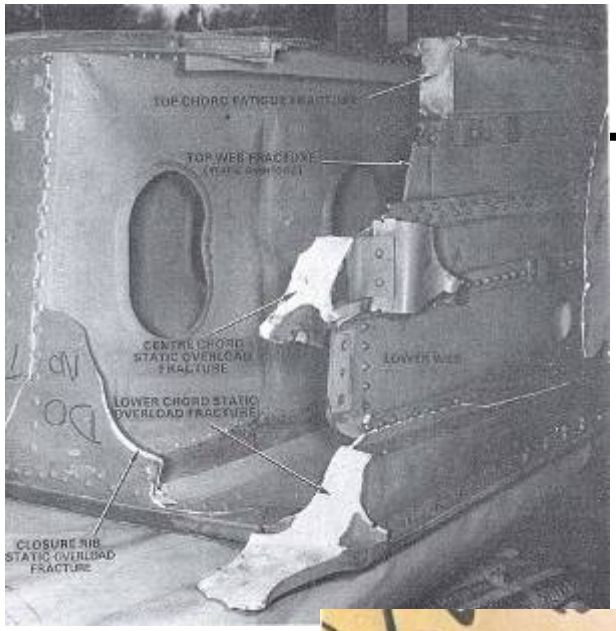
Fail-Safe Approach Concerns

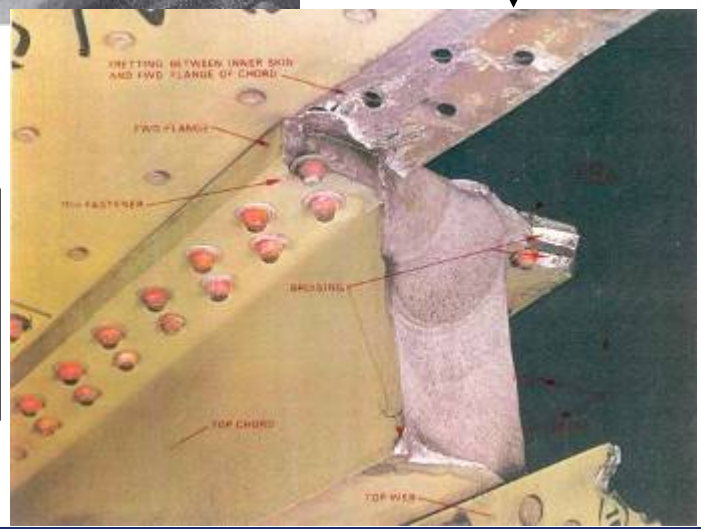
- **Concerns raised early on by certain segments of technical community**
- **Operational life limits set by CAA in early 1970s for certain fail-safe certified airplanes, e.g., 60,000 flight hours for Boeing 707**
- **Concerns reinforced by catastrophic failures of "fail-safe" airplanes**
  - **Hawker Siddley 748 wing separation, 1976**
  - **Boeing 707 horizontal stabilizer separation, 1977**

B707-300 Dan Air Accident - 1977

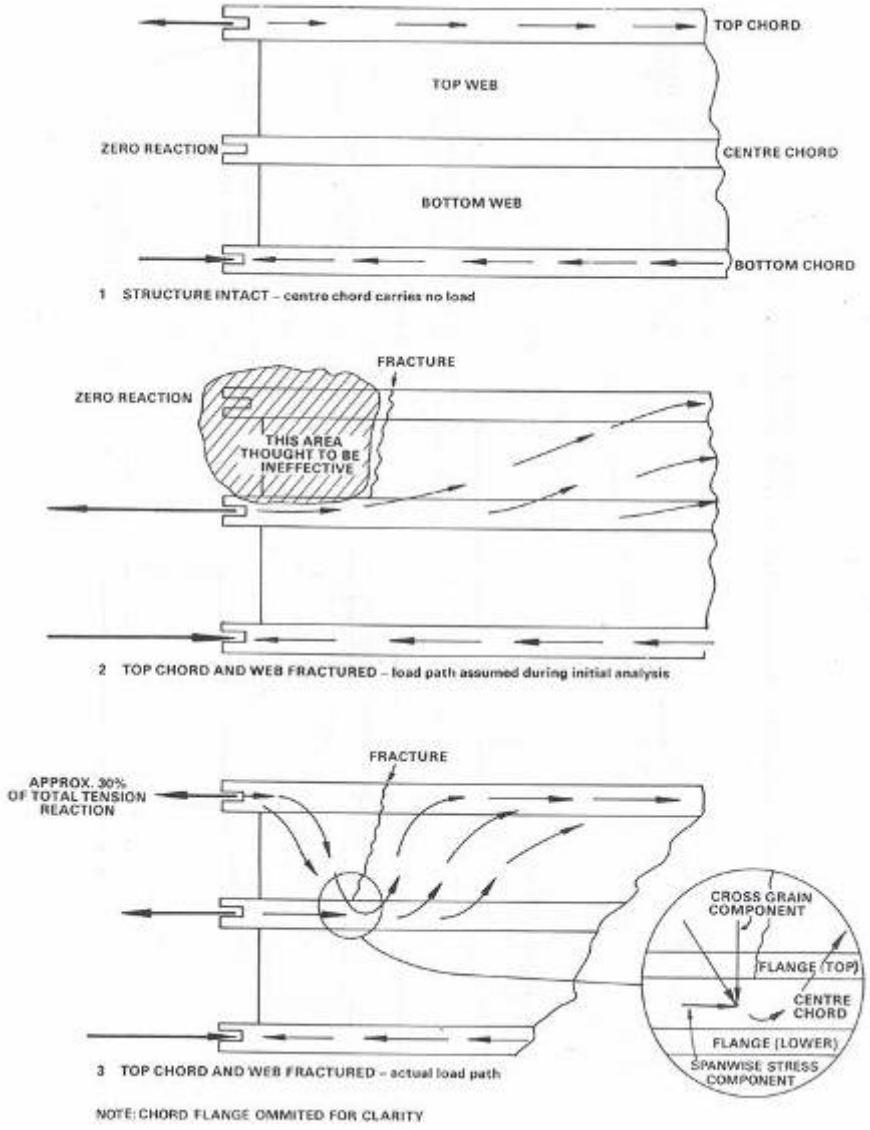
http://accidents-ll.faa.gov/ll_main.cfm?TabID=1&LLID=39

B707-300 Dan Air Accident - 1977





Fatigue Crack in the Rear Spar Upper Chord



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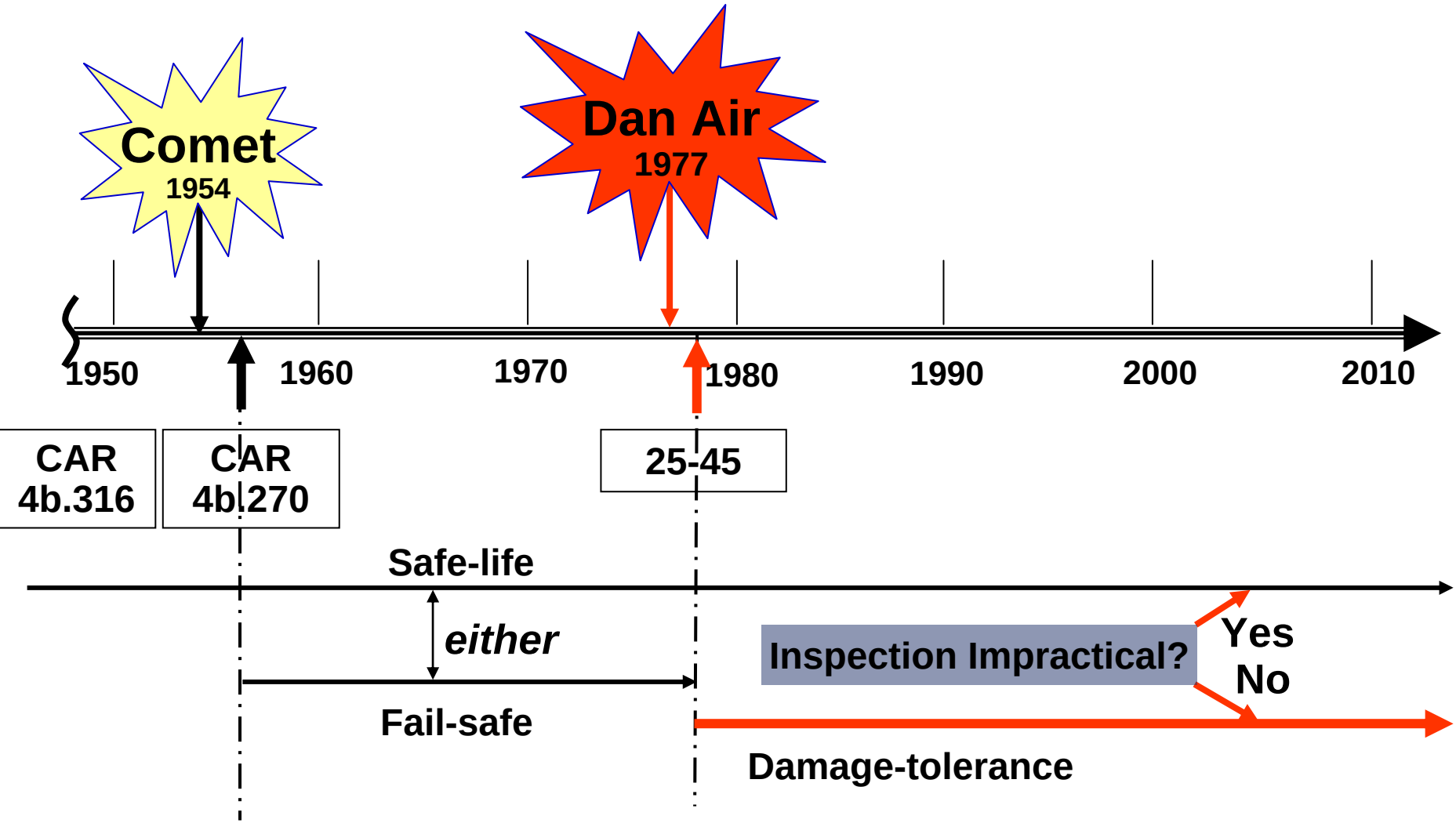

Adoption of Damage-Tolerance Requirements (Safety-by-Inspection)

- **<u>Damage-tolerance</u> approach relies on—**
  - Structure retaining its required residual strength for a period of use after damage has occurred
    - Inspections or other procedures are required to detect and correct damage before catastrophic failure occurs
- **Damage-tolerance rulemaking**
  - Future certifications
    - Amendment 25-45 to part 25, 10/1978
    - Advisory Circular 25.571-1
  - Existing airplanes
    - FAA AC 91-56, 12/1981
    - Implementation by airworthiness directives (ADs)

SIDs for Existing Airplanes

Supplemental inspection documents (SIDs) for specific airplanes of concern

- **Developed using guidance of AC 91-56**
- **Mandated by FAA ADs**

– A300
– BAC 1-11
– B707/B720
– B727
– B737
– B747
– F28
– DC-8
– DC-9/MD-80
– DC-10
– L-1011

Aloha Accident - 1988

http://accidents-ll.faa.gov/ll_main.cfm?TabID=1&LLID=20

Aloha Accident - 1988

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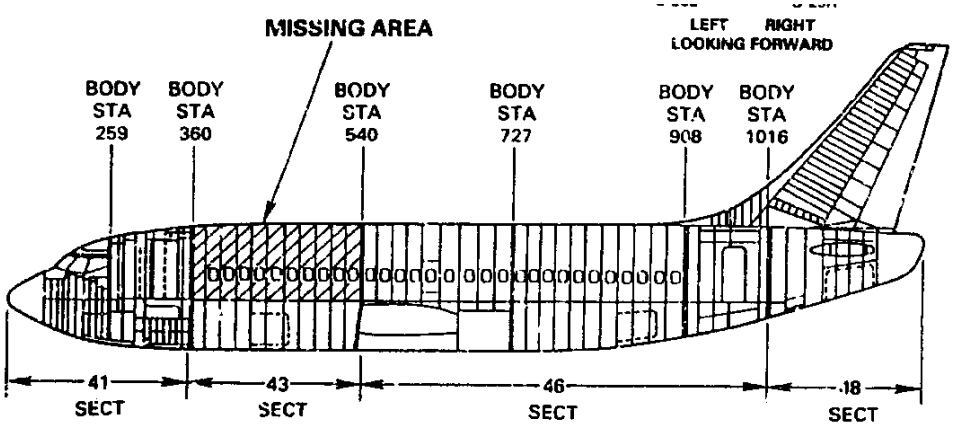

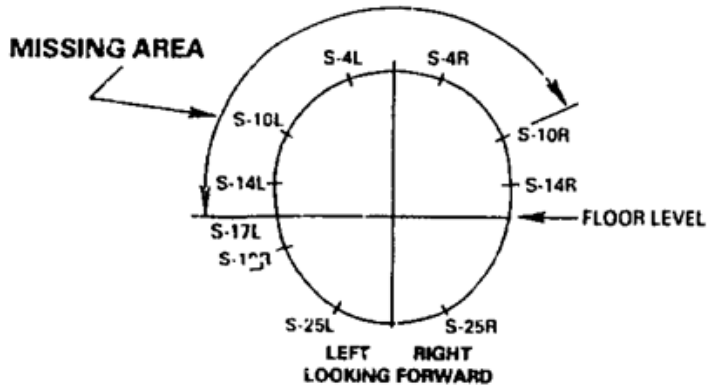

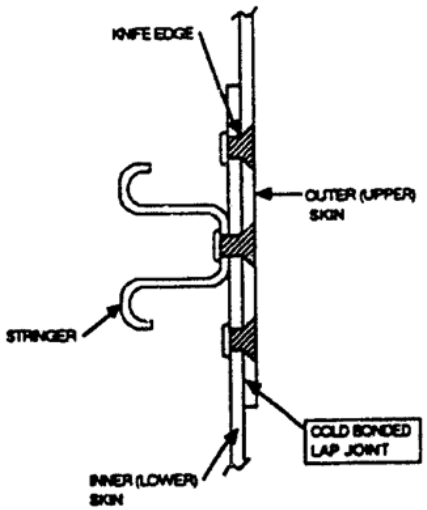

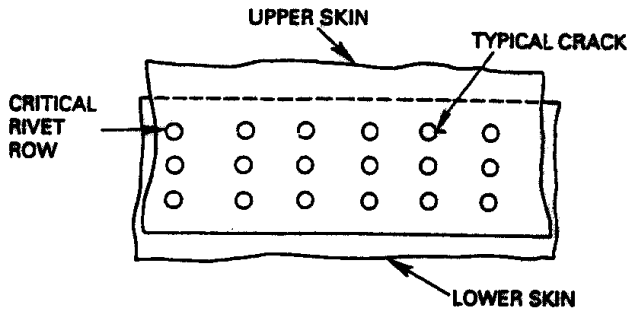

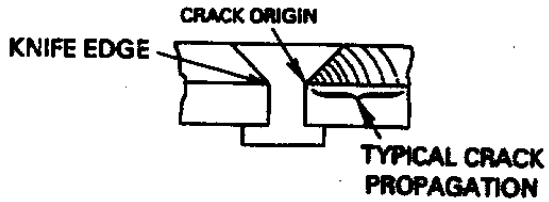

Aloha Follow On Safety Actions

- **Industry and national airworthiness authorities (NAAs) meetings**
- **Aging Airplane Safety Act 1991**
- **Aging airplane structure rulemaking**
  - Supplemental inspection program, revision to certain supplemental inspection documents: AD-mandated program
  - Mandatory modification program: AD-mandated program
  - Repair assessment program: Operational rule
  - Corrosion prevention and control program: AD-mandated program
  - Aging airplane safety rule: Operational rule and part 26 rule
- **Widespread fatigue damage (WFD) rulemaking**

Industry and NAA Consensus

- **Without intervention, multiple site damage and multiple element damage is inevitable**
- **Inspection should not be relied on to prevent an occurrence of WFD**
- **Structural replacement/modification should be the primary line of defense against WFD - any inspections, if practical, are supplementary**

WFD Rulemaking, 1998

- **Amended § 25.571 (Amendment 25-96)**
- **Introduced the term “WFD” into the regulations**
- **Introduced damage tolerance certification requirement to show freedom from WFD up to the design service goal by full-scale fatigue test evidence**

WFD Rulemaking, 2011

- **Amends § 25.571 and Appendix H (Amendment 25-132)**
  - Establish limit of validity (LOV) for future airplane models
  - Include LOV in ALS
  - Perform full-scale fatigue testing to validate the LOV relative to WFD

WFD Rulemaking, 2011, Cont.

- **Adds design approval holder rules for certain existing airplanes (part 26)**
  - Establish LOV
  - Include LOV in Airworthiness Limitations Sections (ALS)
- **Amends operational rules (parts 121 and 129)**
  - Incorporate LOVs into maintenance programs

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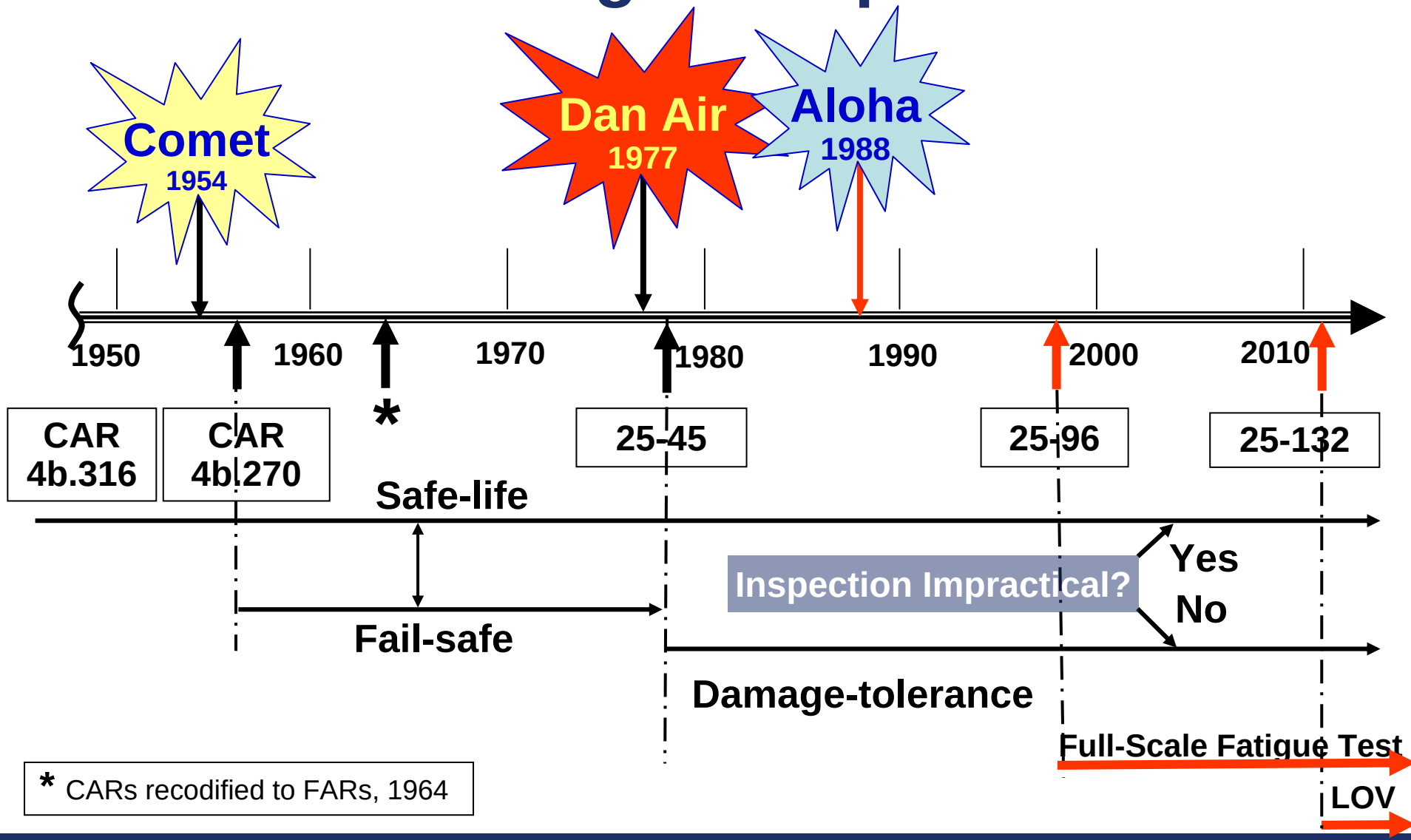

* CARs recodified to FARs, 1964

Summary

- **Evolution of fatigue requirements involved**
  - Implementing a safe-life approach
  - Understanding of fatigue as a phenomenon
  - Implementing a fail-safe approach
  - Learning the limitations of fail-safe approach
  - Implementing a damage-tolerance approach
  - Learning the limitations of a structural maintenance program
  - Implementing a requirement for limit of validity