PC-21 – A Damage Tolerant Aircraft

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PC-21 – A Damage Tolerant Aircraft

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- Dave Boorman, Pilatus Aircraft Limited
- Simon Walker, Jesmond Engineering Limited

Overview

- Introduction to the PC-21
- Fatigue Design
- Fatigue Design Spectrum
- Fatigue Analysis
- Full Scale Fatigue Testing
- Fatigue Monitoring System
- Conclusion

Introduction to the PC-21

- Military training system with a training envelope from Basic Training through to Advanced and Fighter Lead-In Training
- Jet-like flight characteristics due to high wing loading and Power Management System.
- Avionics capable of emulating specific front-line mission systems with easy upgradability
- Pressurised cockpit
- +8g/-4g limit load factor
- Max operating speed 370 KEAS

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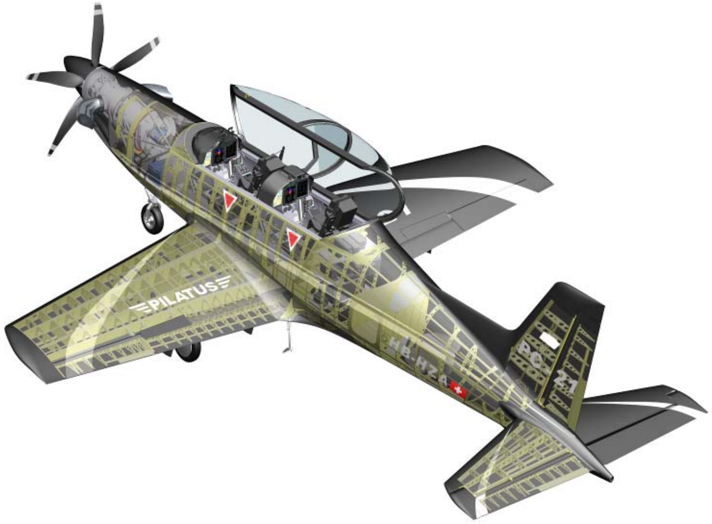
Fatigue Design: Design Philosophy

- Traditionally, Pilatus designed aircraft to safe-life requirements
- For the PC-21, the design philosophy was shifted from Safe Life to Damage Tolerance because of
  - Life-cycle cost
  - Safety
  - Inspectability
  - Material selection



Fatigue Design: Benefits of Damage Tolerance

- Life-cycle cost
  - Development more expensive, less testing but more analysis
  - Savings in the long run due to focused and efficient inspections
- Safety
  - Inspection intervals based on conservative assumptions, i.e. initial cracks considered at day one of aircraft life
- Inspectability
  - Damage tolerant aircraft have to be designed to enable access to critical locations for inspections.
- Material selection
  - Alloys with balanced static and fatigue properties enable light-weight as well as durable and damage tolerant structures.

Fatigue Design: Certification Aspects

- The regulations and the guidance material of FAR-23 do not provide a complete set of requirements for a damage tolerant aircraft.
- Military specifications were therefore reviewed resulting in some specific certification requirements:
  - Fatigue Design Spectrum (design similar to expected usage)
  - Fatigue Analysis (risk mitigation in the design)
  - Full Scale Fatigue Test (scatter factors)
  - Fatigue Monitoring System (Individual Aircraft Tracking, IAT)

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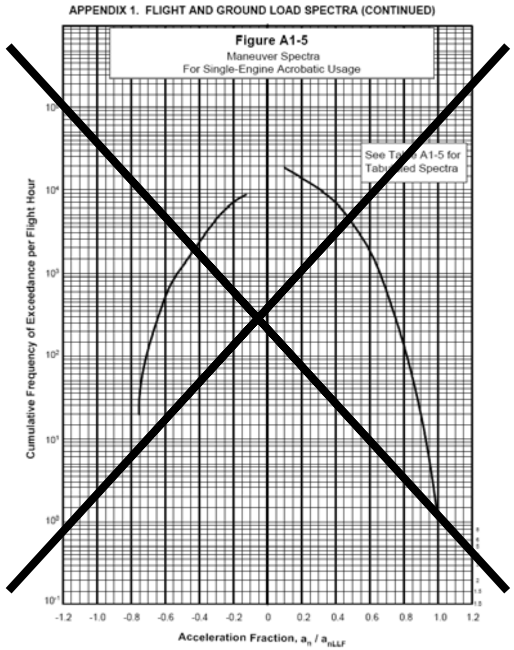
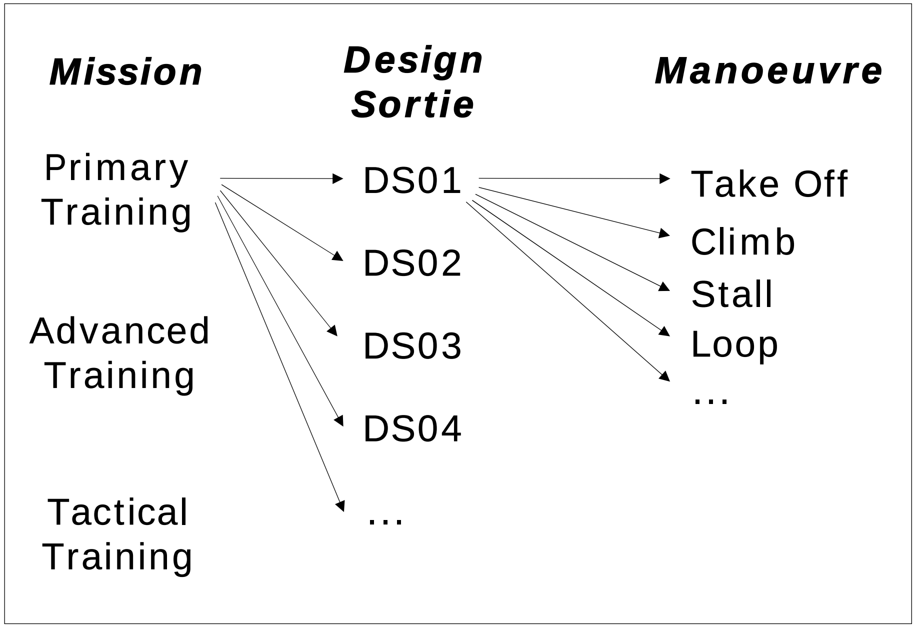
Fatigue Design Spectrum

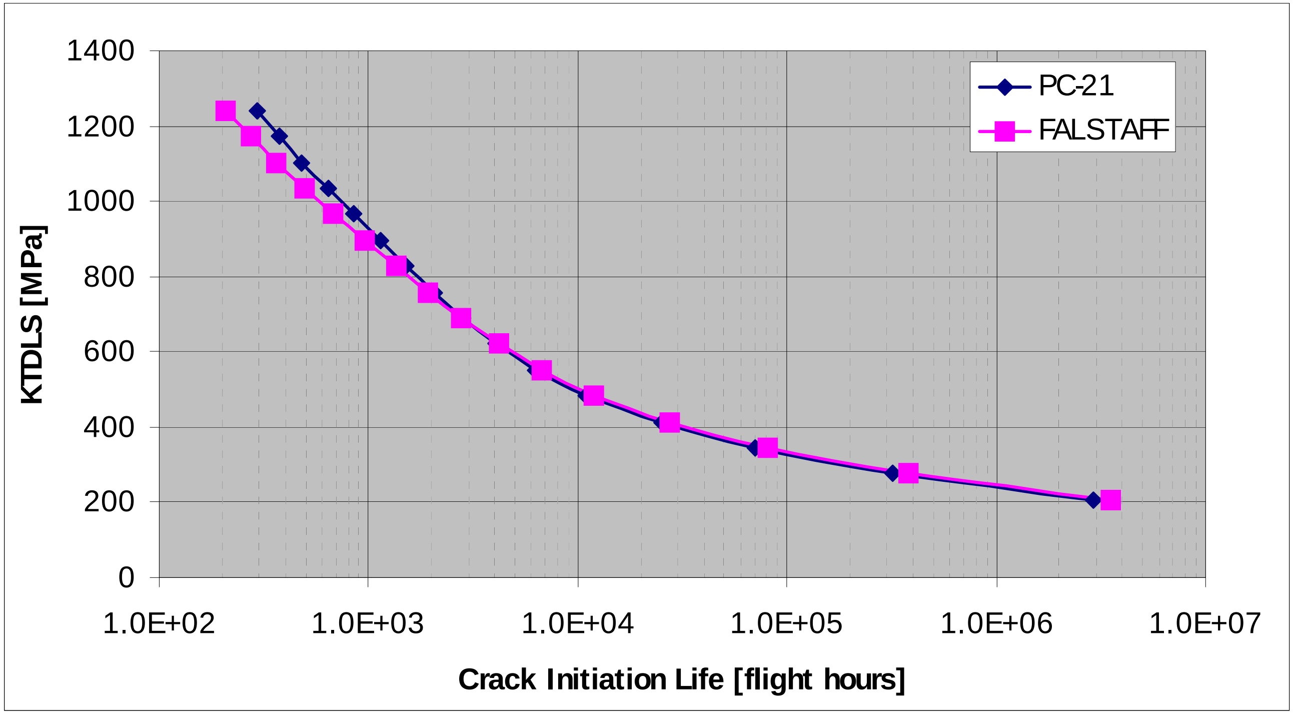
- AC 23-13A guidance material for acrobatic a/c was not considered
- Instead: Building block approach based on mission specification





Fatigue Design Spectrum (continued)

- Comparison of PC-21 vertical acceleration spectrum to FALSTAFF showed equivalent severity



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Fatigue Analysis Before Full-Scale Testing

Durability and Damage Tolerance Analysis was used

- to prevent early failures
  by demonstrating 4 service lives of Crack Initiation for critical locations
- to ensure feasible inspection intervals
  by demonstrating 2 service lives of Crack Growth for critical locations

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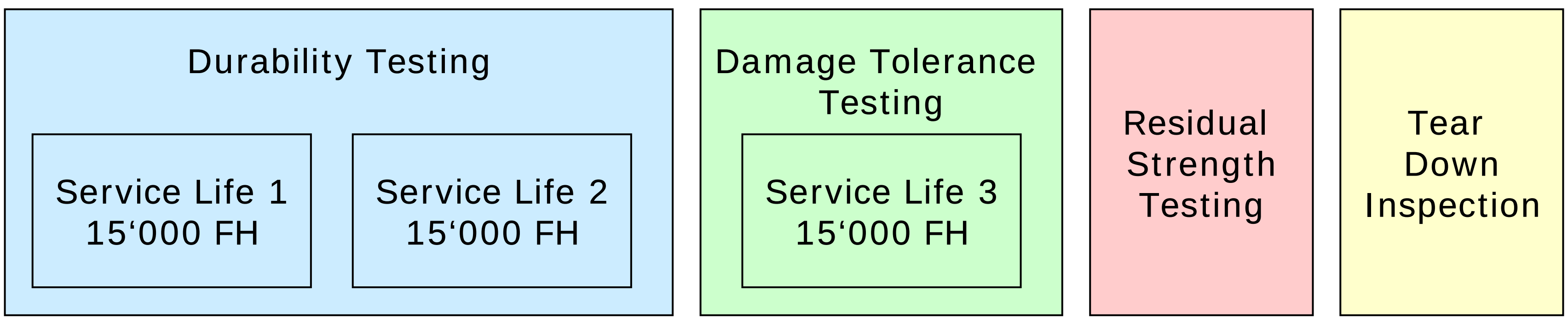
Full Scale Fatigue Test

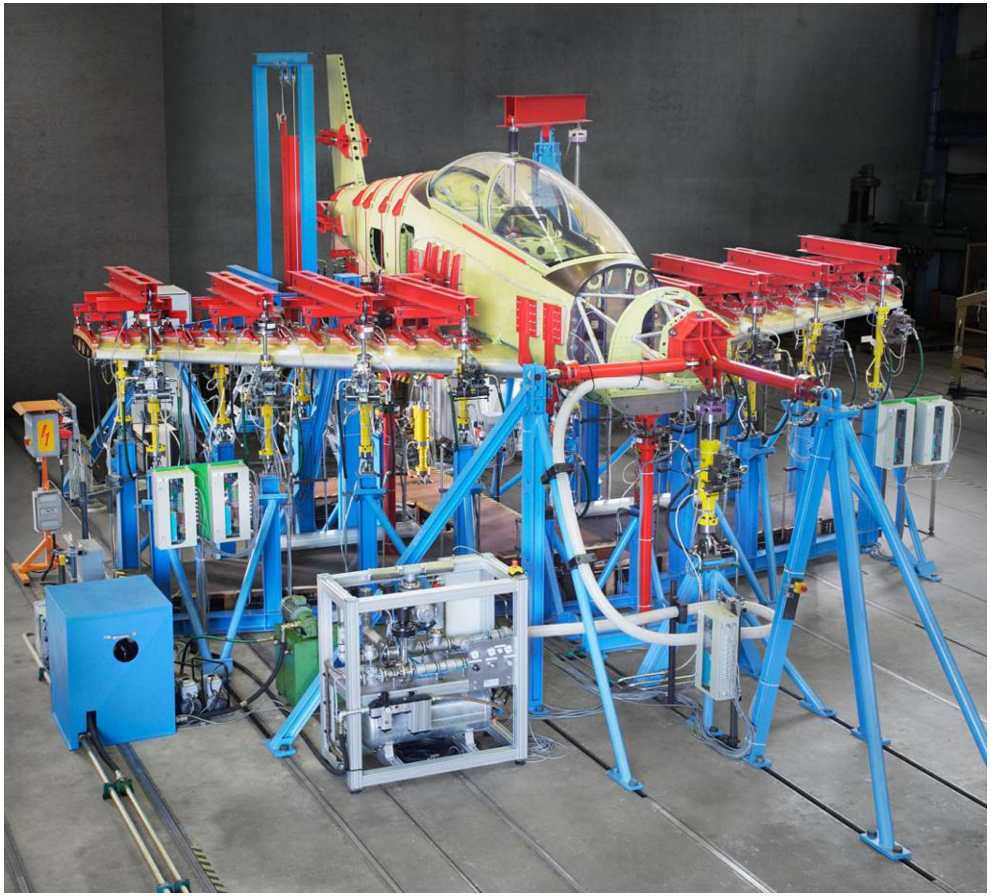
- Objectives:
  - To substantiate the service life of the aircraft
  - To verify the damage tolerance capability of the airframe
- Schedule:



Note: After the durability testing artificial damages were introduced.

Full Scale Fatigue Test Concept

- Spectra considered: manoeuvres, pressurisation, vertical tail, engine mount
- Load introduction: shear pads, contour boards, fittings, and dummies
- Test setup: Wing loaded from above by actuators supported from below to provide access to lower skin for inspection
- Test instrumentation: strain gauges, displacement transducers, load cells and pressure gauge



Fatigue Analysis After Full-Scale Testing

Durability and Damage Tolerance Analysis was used

- to take test results into account by pegging the analysis to results (adjusting the stress level to match the test result)
- to determine intervals for scheduled Non-Destructive Inspection (NDI) inspections

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Fatigue Monitoring System

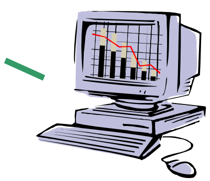
- Objective:
  - To ensure that operators don‘t exceed the design spectrum
  - To enable operators to distribute fatigue usage across the fleet
- System:
  - Strain-based fatigue monitoring
  - Evaluation of strain monitoring locations in the FSFT (linear relationship between strain and predominant load such as wing bending moment)
  - Instrumentation in the wing, fuselage, and empennage
  - Strain sensor calibration using ground and flight test procedures
  - Fatigue Indices (FIs) are calculated for several locations using crack initiation calculations (strain-life, Neuber, Palmgren-Miner)

Fatigue Monitoring System Overview

DASU

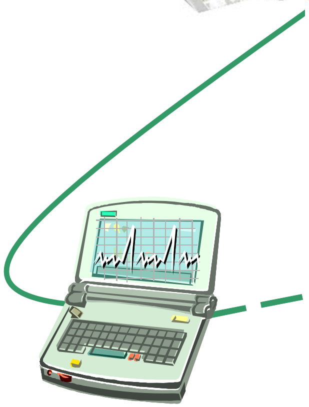
- Data Acquisition
- Fault detection

HDAS Satellites (Other customers)



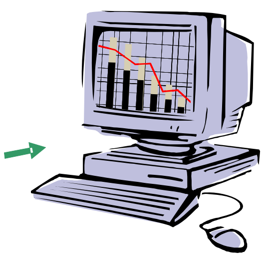
HDAS Master (Pilatus)

- PC-21 Data Analysis and Reporting
- Fatigue Data Processing and Reporting



LTE

- A/C Data Download and Transfer
- Fault Diagnostics
- Other Maintenance Functions



HDAS Satellite (Customer)

- Fleet Data Analysis and Reporting

Fatigue Monitoring System Certification

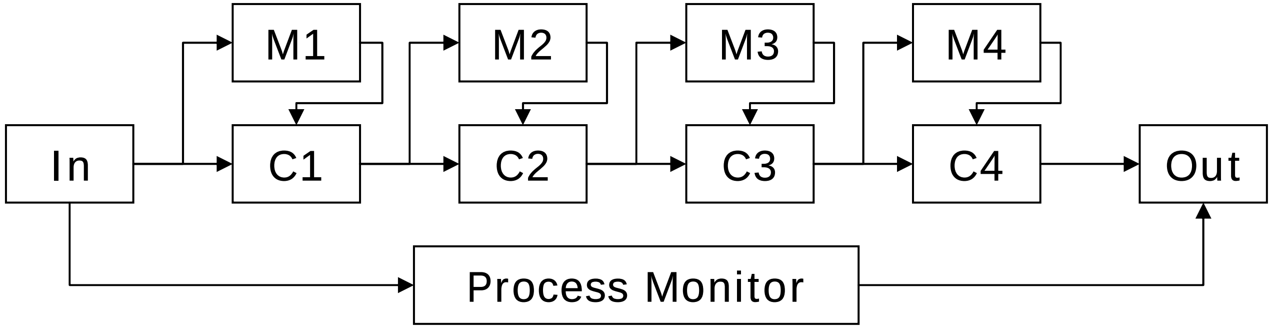
- Fatigue Monitoring System (FMS) + FAR 23 aircraft = Novelty
  - Neither requirements nor guidance material existed for FAR 23
  - Guidance of rotorcraft Advisory Circular was considered (AC 27-1B)
  - In general, both criticality and complexity of rotorcraft monitoring systems are high
  - How to certify?

Fatigue Monitoring System Certification (cont.)

- Classical approach to system certification (AC 23.1309-1C):
  - Failure hazard assessment to identify critical failure modes
  - Determine the resultant criticality
  - Assign design assurance level (software, systems)
- However: How can the Fatigue Index contribute to a failure?
  - Scenario:
    - Erroneous FI calculation (software, corrupt input data)
    - Consistent under-prediction of usage (FI)
    - Severe usage, i.e. usage exceeds the design spectrum
    - Crack initiation and growth at critical location
    - The fatigue crack is missed in scheduled inspection

➔ **Failure scenario is remote and not quantifiable**

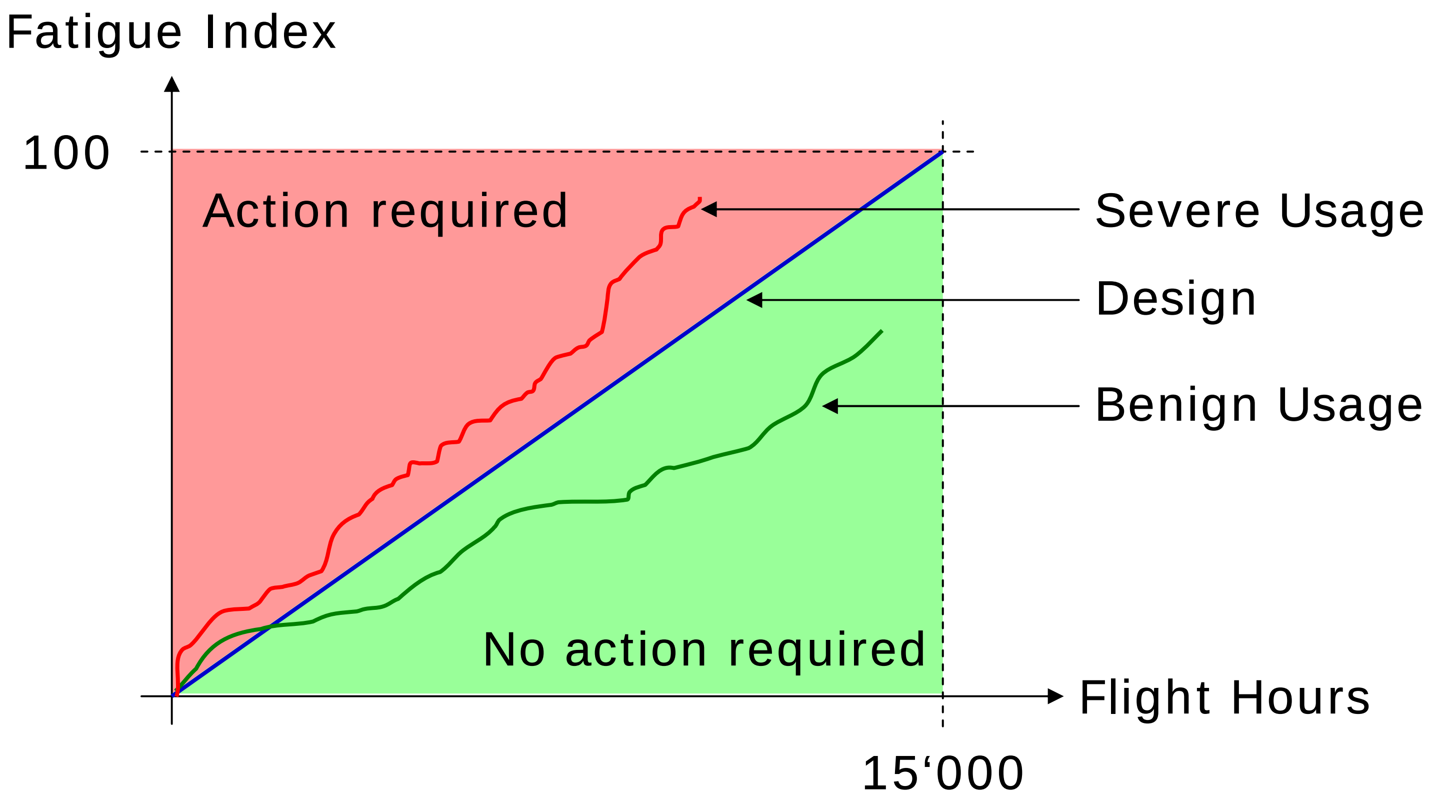
Fatigue Monitoring System Certification (cont.)



Alternative approach based on qualitative assessment was pursued:

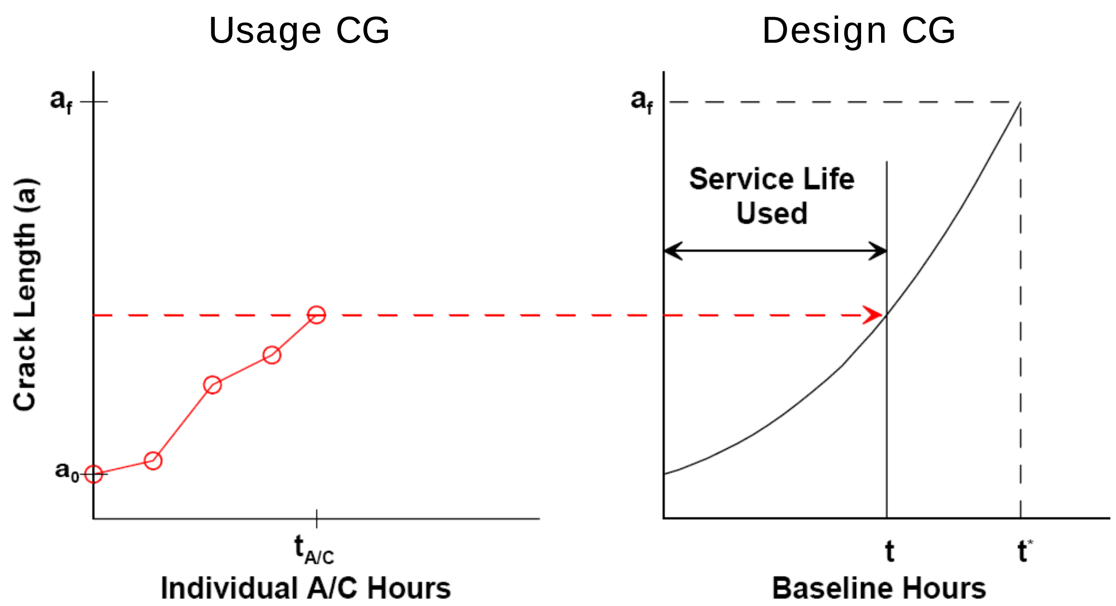
- The Fatigue Monitoring System was designed such that each component (C?) is independently monitored (M?). In addition, an overall process monitor is included to ensure integrity of FI results.
- The monitoring functions are implemented by means of quantitative checks, qualitative checks, and in-service procedures.

Fatigue Monitoring System Output



Fatigue Monitoring System Output (cont.)

- Fatigue Indices for major structural assemblies including pressurisation are calculated
- Usage statistics (e.g. landings) are determined
- FMS output will be used to schedule maintenance activities if the usage deviates significantly from the design



Source: Handbook for Damage Tolerant Design

Conclusion

The PC-21 was certified as a damage tolerance aircraft to FAR 23 requirements. The most noteworthy aspects of the certification approach include the following:

- Development of a deterministic fatigue design spectrum similar to FALSTAFF
- Fatigue analysis (CI/CG) in early design in order to improve damage tolerance behaviour and after full-scale testing to determine inspection intervals based on test results
- Full-scale fatigue test concept using lowered scatter factors and providing access to the lower wing
- Implementation of a strain-based fatigue monitoring system for Individual Aircraft Tracking (IAT) purposes with a significant level of redundancy

Questions?