PC-21 – A Damage Tolerant Aircraft

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PC-21 – A Damage Tolerant Aircraft
Acknowledgment

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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 lightweight 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:**

  Durability Testing
  - Service Life 1: 15'000 FH
  - Service Life 2: 15'000 FH

  Damage Tolerance Testing
  - Service Life 3: 15'000 FH

  Residual Strength Testing

  Tear Down Inspection

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 Master (Pilatus)**
- PC-21 Data Analysis and Reporting
- Fatigue Data Processing and Reporting

**HDAS Satellites (Other customers)**

**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
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 Index

100

Action required

Severe Usage

Design

Benign Usage

No action required

Flight Hours

15'000

Fatigue Index
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?