C-130J-30 Wing Fatigue Test - Test Interpretation

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Agenda

1. History of C-130J WFT
2. Type Certification Basis (TCB)
3. Test Interpretation
4. TI Tools/ Data
5. Verification and Validation
6. Selection of Locations
7. Spectrum
8. Spectrum
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History of C-130J WFT

• The WFT primary objective was to:
  – Maximise the Structural Life of Type (SLOT) of primary wing structure
  – Maximise aircraft availability throughout the defined SLOT

• Combined RAAF and RAF test
  – Test at MA in UK
  – Teardown by AIRBUS at Richmond
  – Separate Test Interpretation (TI)

• Test Spectrum OLM based
  – Selection of RAF and RAAF flights
  – Super block 1500 flights (3100 flying hours)
  – 5 x standard block 250 flights
  – 1 x 250 flights with higher amplitude cycles
    – i.e. few more severe flights
History of C-130J WFT

• Test at MA in UK

• Test article
  – Centre and outer wings
    – No TE or LE
  – Fuselage support structure
  – Nacelle structure

• Loading
  – 40 actuators
  – Vertical, lateral and torque loads applied to each engine
  – Airbag for Fuselage pressurisation
  – 600 gauges to assist TI, confirm loads and compare to OLM
History of C-130J WFT

- Damage tolerance testing
  - 9 cracks introduced cracks late in test

- Reached durability goal

- Residual Strength Test (RST)
  - 1.2 DLL

- Accelerated testing + additional RST

- Failed past limit load on 6th RST
  - Wing root
  - Failure location expected

- Teardown
  - By AIRBUS at Richmond
  - CW
  - 1 OW
  - 2nd OW past engines
Type Certification Basis (TCB)

- For C-130J-30 Service Entry - MIL-S-5700 series standards supplemented by
  - Aeroelasticity requirements of MIL-A-8870
  - Durability guidelines of AFGS 87221A
  - Damage tolerance requirements of MIL-A-83444
  - Gust requirements of DEF-STAN 00-970

- For WFT TI
  - JSSG 2006
  - EN-SB-08-001 and EN-SB-08-002
  - Interpretation by Authority
    - Convert specification into suitable requirements
    - Difficulty in retrospectively applying these to a designed aircraft
Test Interpretation

• TI undertaken by QinetiQ and DST Group
  - QinetiQ - Standard locations
  - DST Group – Some complex MSD/MED locations

• QinetiQ Part 21 Designs
  - ICA
  - ASIMP Vol 2 Updates
    - ADF MAwL and ICA
  - Implementation impact considered
    - Fleet status compared to ICA
    - Time for implementation
    - Alignment with major servicing’s

• LOT
  - Preliminary estimates for individual TI locations
  - TDLL
  - Probability Risk Assessments later TI stages
Test Interpretation

- Replace current ICA
  - OEM based ASIMP Vol 2

- TI Process documented within guides

- Specific Tools / data developed

- V&V of Data, tools and process
  - TCB
  - Data integrity
  - Robust
  - Process documentation

- Authority approval before process starts
**TI Tools/ Data**

- DADTA template
  - FASTRAN
    - Retardation crack growth model
  - FAMS
    - Strain life model
  - Generates crack growth curve
  - Calculates Intervals
  - Includes
    - Spectra
    - Material data
  - Accounts for multiple phase crack growth
    - Continuing damage
TI Tools/ Data

• Geometry Factors
  – Stress check & classical solutions into generic tabulated data
  – Allows build up of locations
  – Developed for each situation
  – Significant compounding to develop solutions
  – Up to 12 crack phases for some locations
• Geometry Factors
  - For calibration
    - Beta at fractographic recorded point
      - Same point on the crack face
      - Not at 5 and 80 degrees
    - Crack aspect ratio
    - Test crack progression
      - Crack interaction
  - For DTA
    - Fixed aspect ratio a/c = 1.00
    - Nominal blueprint geometry
    - DTA crack progression
    - Consistent with calibration Beta
**TI Tools/Data**

- **Coupon testing**
  - Da/DN data
  - short and long crack lengths
  - Fatigue test spectrum clipping

- **OEM Fracture toughness**

- **Handbook yield strength**
**TI Tools/ Data**

- **IMSst**
- **Data repository**
  - Test defects
  - Fragments
  - Findings
  - All test reports
  - NDI
  - Fracto
  - Repair decisions
  - Defect reports
- **Assists in data quality**
- **Web based**
Verification and Validation

• DADTA template
  – FASTRAN
  – FAMS
  – Outputs comply with TCB
    – In particular continuing damage

• Confirm TIRS

• Material
  – Da/DN data
  – Other data

• Transfer factors
  – TIRS to EFH
  – Converting outputs to match individual tracking program (IATP)
Verification and Validation

- WFT loading
  - OLM to WFT gauge results
  - Along / across the span
  - Over time
    - Ensure loading remains constant

- Comparison of WFT cracking with DTA

- Authority sign off
  - When DaDTA tools used correctly ICA will be compliant with TCB
Selection of Locations

• 1400 findings
  – Most findings will not undergo fractography and DTA

• Extant SSI from LM Aero

• Critical test cracking
  – Size and density of findings
  – Criticality of failure

• Priority
  – Test crack size
  – Time of cracking
  – Extant maintenance program impacts
Spectrum

• Seven AP spectra
  – ATS & TIRS

• Stress Transfer Factor (STF)
  – Strain gauge
  – OEM data
  – FEM

• Test Representivity Factor (RF)

• Applied Test Spectrum
  – ATS = AP ATS x STF x RF
  – For fatigue test cracking

• Calibration Factor (CF)

• Test Interpretation Spectrum
  – TIRS = AP TIRS x STF x CF
Calibration Factor

• Factor on overall stress
  – CF x ATS

• DTA of cracking

• Compare with qualitative Fractography results

• Overcomes deficiencies
  – STF
  – Beta
Calibration Factor

- Iterative process
- Simple beta
  - Refined if required
  - Account for other geometry
  - Account for crack interaction
  - Load redistribution
- Similar CF for adjacent cracks
- May have multiple CFs if local failure allowed
  - Accounts for local stress transfer
DTA

• Cracking Scenario
  – Worst of test cracking
  – LM DTA
  – Or other?

• Multiple test cracks not necessarily the worst case
  – TCB requires only a single 0.05” flaw
  – TCB continuation damage flaw

• Multi phase crack growth

• Intervals derived from crack growth curve as per TCB
Interpretation

• TIRS intervals converted to EFH
• EFH intervals for ICA
  – Allows IATP
• Configuration differences between the test article and the fleet
• Comparison of derived crack growth curves with relevant in-service and test cracking data
  – Account for all findings in control area
• Sense checks for comparable programs
• Implementation urgency
Interpretation

• Need for modifications
  – Low recurring interval
  – High access cost
  – Planned change vs Repair when found

• Suitability of NDI procedures
  – Extant OEM procedures
  – Would service cracks be found
  – Alter $a_{ndi}$ or alter NDI type
Implementation

- EFH intervals tracked by IATP
- ASIMP Vol 2 updates
- Ensure adequate time for implementation
  - Escalate if any immediate safety issue present
    - Reduced Threshold Interval
    - Reduced Recurring Interval
- Provide aircraft specific ICA if needed
- Aim to align with major routine servicing’s
- All may need refinement of analysis (not 100% on what this is)
- Suggestions for CAMO
Summary

• By end of TI
  – 1400+ findings
  – 55+ Fractography reports will be required
  – 46 CF curves
  – 57 DTAs
  – 91 Locations
    – locations covered DTA at more critical points
  – 11 areas were MSD
    – Just started to well advanced
  – 6 locations with developed MED
  – 4 locations for PRA

• Currently Completed
  – 22 locations
  – 13 DTAs
  – 19 CF curves
Summary

• Increase in thresholds and recurring intervals
  – Can be aligned with routine servicing's
  – Increased aircraft availability
  – Less chance of inspection damage

• Improvements believed to be due to more advanced tools
Lessons Learned

• Fracto excellent
  – used to account for load changes due to crack interaction
  – Provides confidence

• Usefulness of strain gauge locations
  – Not ideal for STF (local strain effects)
  – Great for OLM comparisons
  – Identify if load redistributes during course of testing

• Confidence in TI Process is dependent on V&V at multiple stages of development

• Full understanding of Test outcome gives confidence in ICA outcome

• Next stage LOT
  – Probabilistic Risk Assessments