DTA of PC-9/A Wing Main Spar with Miss-drill Damage

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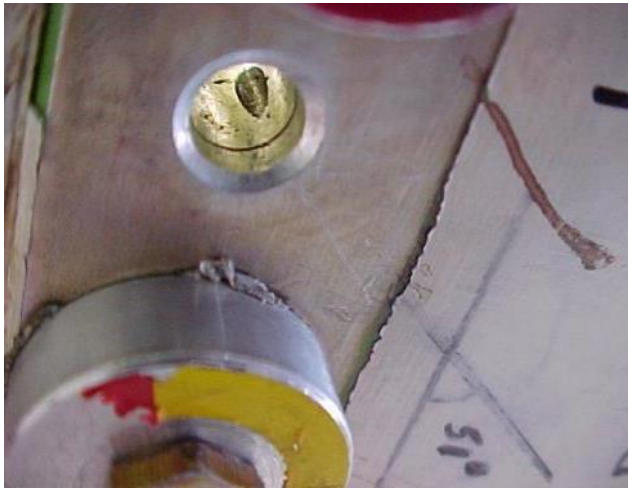
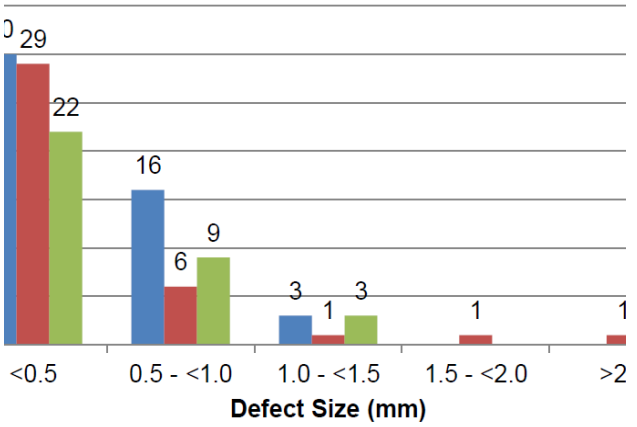
Background

- In 2003, during replacement of a MLG support bracket, Miss-drill damage was found in the lower cap of the main wing spar on a RAAF P/C-9 aircraft
- Introduced at manufacture as a result of pilot hole miss-alignment
- Fleet wide X-ray inspection performed to detect presence of manufacturing defects in lower caps of main spar
- A total of 142 Miss-drill defects detected in 42 wings
- Based on location and sizing from X-ray images, worst case Miss-drills repaired across fleet (one wing scrapped)





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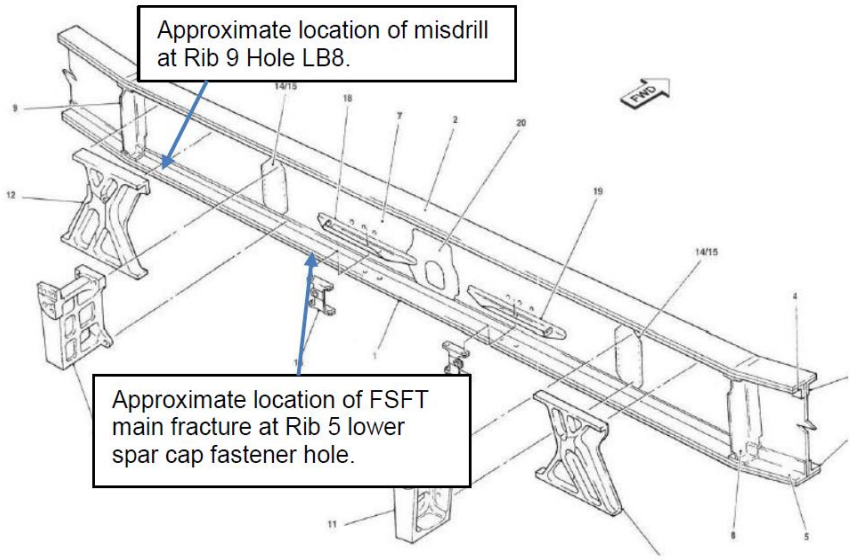
Background (cont.)

- Fatigue Management of RAAF PC-9 wing based on results from PC-9 FSFT conducted at DSTO
  - Tested to 67,150 SFH
  - Failure occurred at Rib 5 lower spar cap fastener hole
- Wing Spar Safe-Life calculated based on DEF STAN 00-970 requirements
  - 1.2 DLL at 54,718 SFH
  - 3.33 Scatter Factor
  - Safe-Life of 16431 SFH
- FSFT Wing Spar lower cap did not contain Miss-drill defects



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Task Objectives

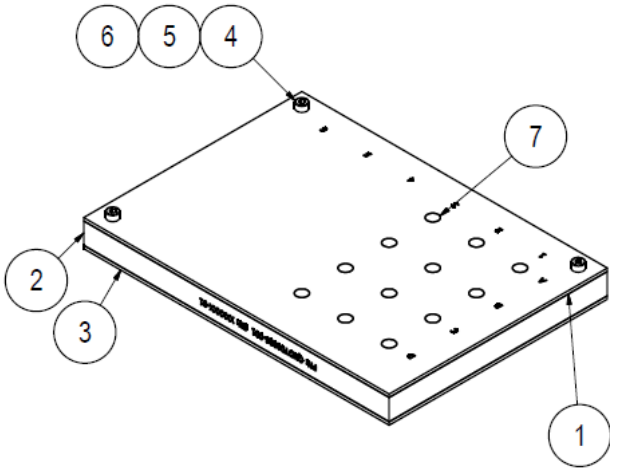
- Verify mis-drill damage size that can be reliably detected by the earlier fleetwide X-ray inspections
- Determine a wing spar lower cap safe life (inspection threshold) in the presence of undetected mis-drill defects

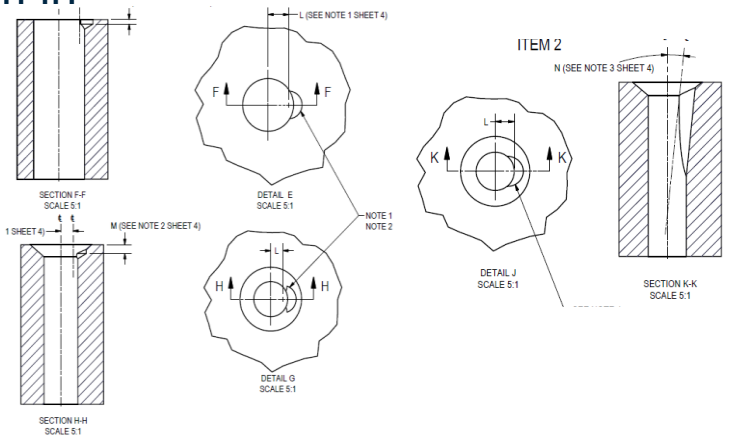
Topics

1	NDT Evaluation
2	Baseline Crack Growth Analysis
3	Miss-drill Stress Analysis
4	Miss-drill Crack Growth Analysis
5	Task Outcomes
6	Follow On Work

NDT Evaluation

- Procedure (X-Ray) used by RAAF to inspect all spars for Miss-drill damage evaluated by QinetiQ NDT
- Test pieces developed for various spar cap thicknesses
- Various Miss-drill damage introduced at spar holes
  - Based on pilot hole diameter (2.5 mm)
  - Various depths and distances from main hole edge
  - Range of drill angles with respect to main hole centreline
- Trials by NDT gave a detectable Miss-drill size of 1.2 mm in the spar cap for RAAF radiography
- **NB – This size is for Miss-drills (Voids) not cracks**
- This size was used as the limit Miss-drill size in crack growth analysis





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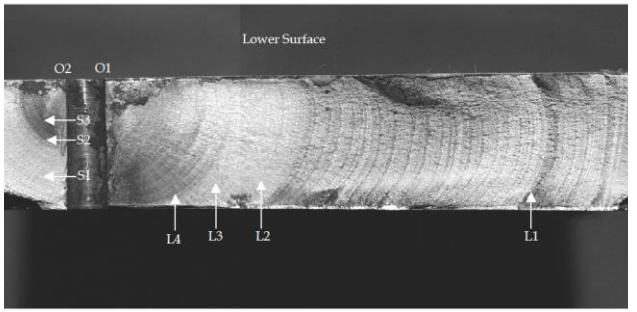
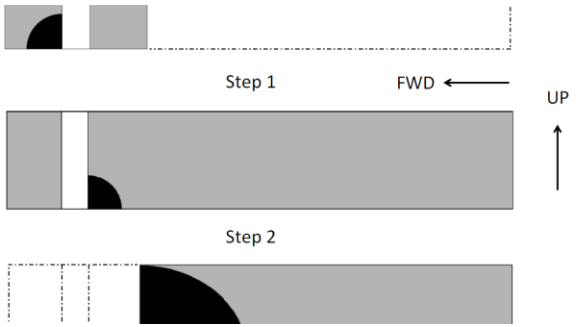
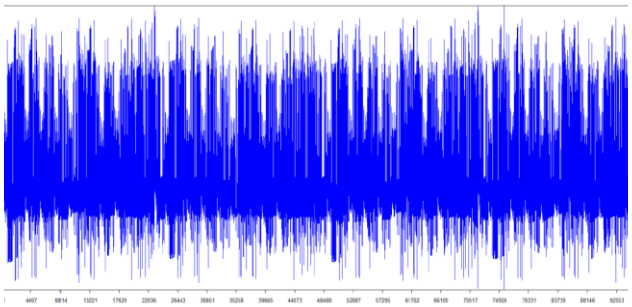
Baseline Main Spar Crack Growth Modelling

- Crack growth model developed based on cracking observed during FSFT
- AFGROW used to perform crack growth analysis:
  - Material data (2024-T351 Al Alloy) from NASGRO database
  - Geometry Factors developed for fore / aft cracking from spar fastener holes based on library beta solutions and compounding based on local spar geometry.
  - Main spar lower cap stress spectra developed from FSFT strain gauge readings







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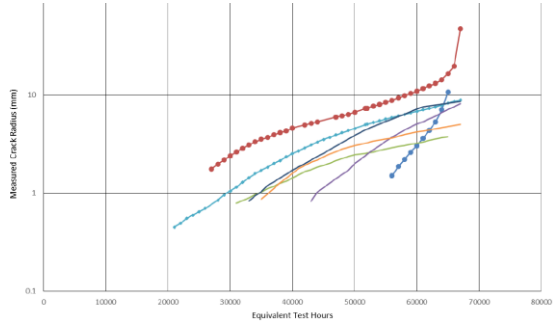
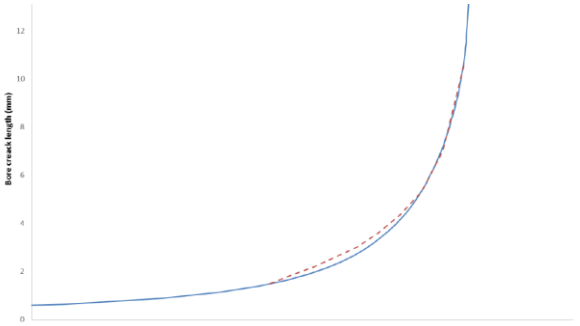
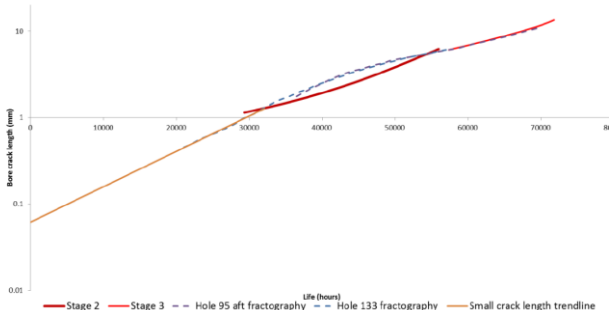
Baseline Main Spar Crack Growth Modelling (cont.)

- Crack growth model correlated based on fractography results for the main spar cracks published by DSTO
- Correlation of AFGROW model carried out by developing an SMF to tune the AFGROW crack growth curve to match the FSFT crack growth behaviour for crack sizes greater than 1.27 mm in size
- For small cracks (< 1.27 mm), a trend line was determined directly from fractography data







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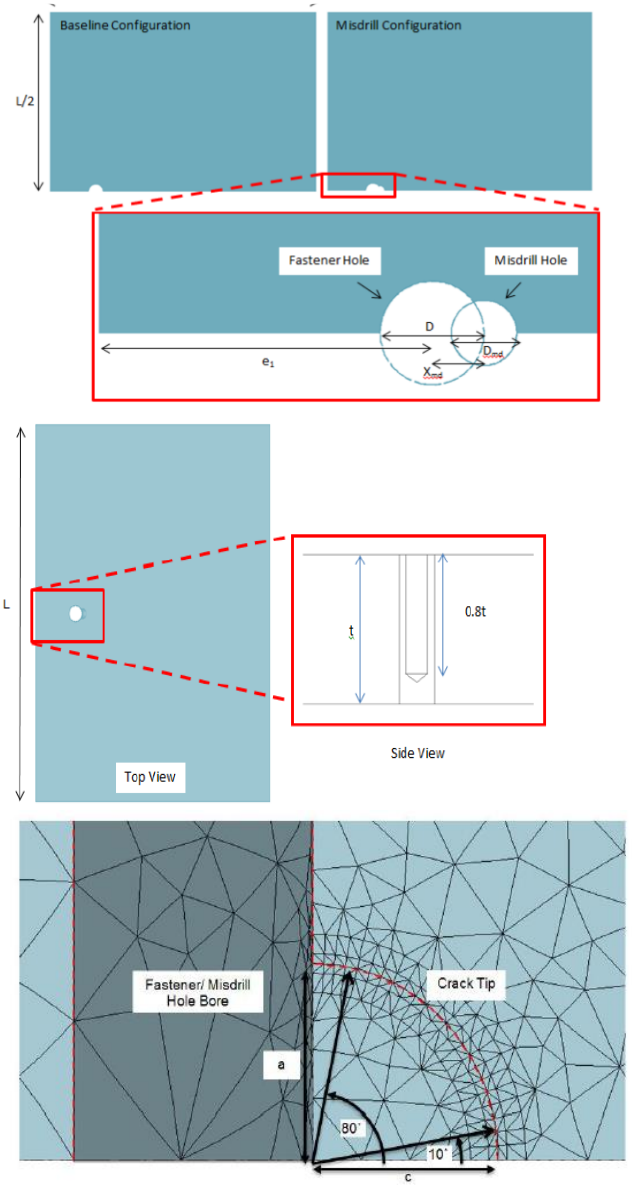
Miss-drill Stress Analysis

- Based on detectable Miss-drill size of 1.2 mm, FEA conducted to establish likely worst case miss-drilled spar hole configurations for further consideration
- Peak stress (Kt) used as primary guide for selection along with stress distribution
- Based on FEA, two configurations selected to represent undetected Miss-drill damage:
  - Through thickness Miss-drill (1.2 mm in size) next to main hole (i.e. ‘Figure 8’ hole)
  - As above, but Miss-drilled pilot hole is blind and penetrates to 80 percent of the spar thickness

Miss-drill Damage Crack Growth Modelling

- StressCheck FEMs built to represent main spar cap Miss-drilled holes
- Used to determine stress intensity factors for cracks at Miss-drilled holes.
- Results used to develop geometry factors for a range of crack sizes / aspect ratios
- StressCheck results input into AFGROW as user defined geometry factor tables for crack growth analysis



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Miss-drill Crack Growth Modelling (cont.)

- Baseline AFGROW crack growth model updated with Geometry factors for cracks at Miss-drilled holes
- For small cracks (< 1.27 mm), the baseline crack growth rate (from fractography) was increased for Miss-drills using a power law relationship based on the ratio of Miss-drill to baseline Kt calculated from FEA:

$$\frac{da}{dN} = C\Delta K^n$$

$$\left(\frac{\Delta K_{MD}}{\Delta K_{BL}}\right)^n = \frac{\frac{da}{dN_{MD}}}{\frac{da}{dN_{BL}}}$$

$$Consider\ \Delta K = \beta\Delta\sigma\sqrt{\pi a}$$

$$\therefore \left(\frac{\Delta K_{MD}}{\Delta K_{BL}}\right)^n = \left(\frac{\beta_{MD}}{\beta_{BL}}\right)^n = \left(\frac{K_{t_{MD}}}{K_{t_{BL}}}\right)^n,$$

$$and\ for\ small\ cracks,\ \beta \propto K_t$$

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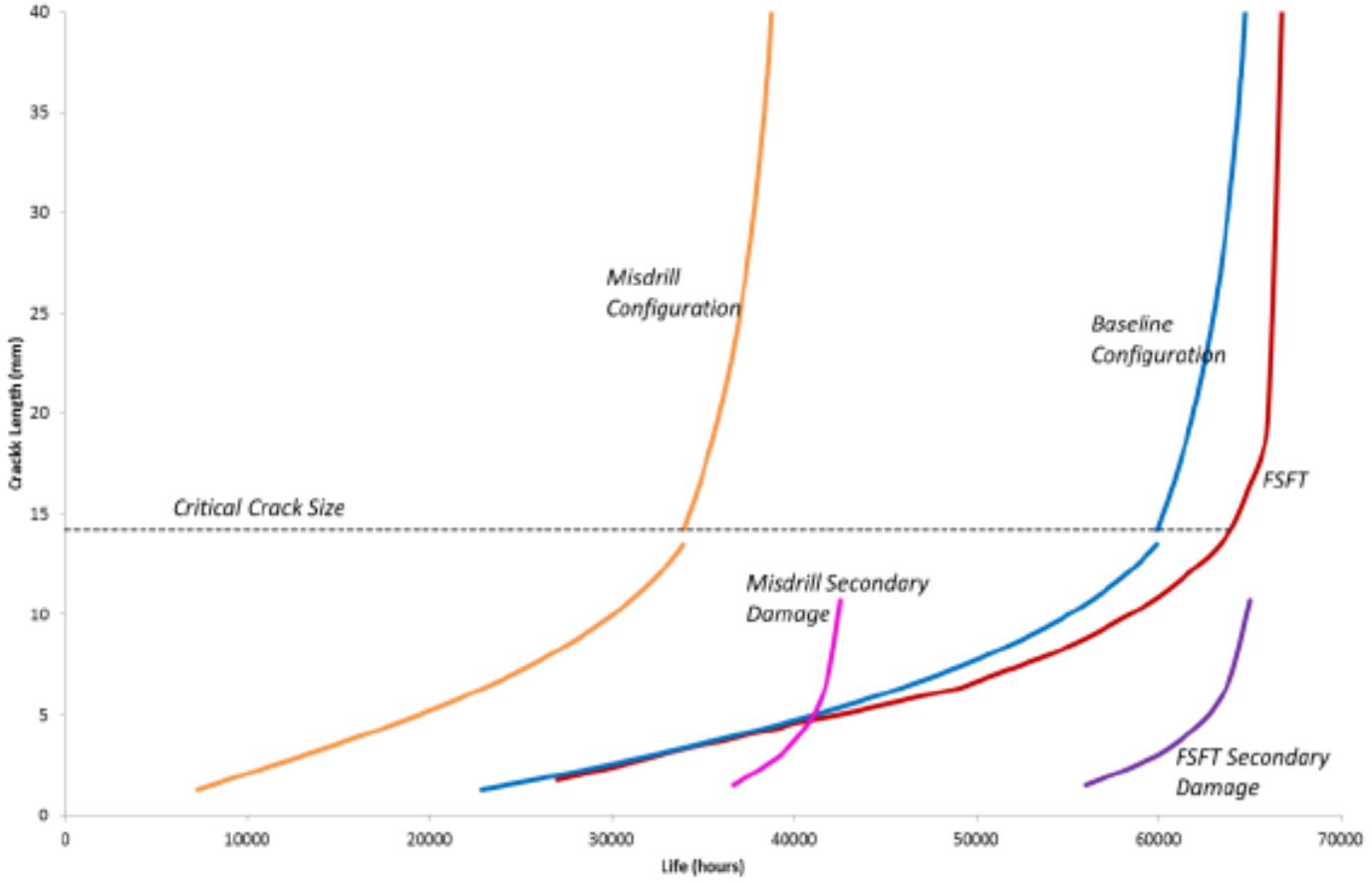
Miss-drill Crack Growth Modelling (cont.)

- Several Scenarios considered to develop an appropriate inspection threshold (safe life) for the main spar with miss drill damage:
  - DEF STAN 00 970: Consistent with fatigue management of other RAAF PC-9 wing locations, an inspection threshold derived from FSFT results however main spar cracking adjusted to account for presence of worst case miss-drill damage based on crack growth modelling.
  - JSSG-2006: Damage Tolerance approach with blueprint geometry (no explicit modelling of Miss-drill) coupled with a 0.050 inch rogue flaw (primary damage) and 0.010 inch secondary flaws at the spar cap
  - JSSG-2006 Modified: Miss-drill geometry modelled with 0.010 inch primary and secondary flaws
- Residual Strength based on 1.2 DLL for all cases considered
- **N.B. DTA scenario where 0.050 inch rogue flaw used in addition to modelling effects of Miss-drill on crack growth considered overly conservative and not used to establish threshold.**

Miss-drill Crack Growth Modelling (cont.)



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Miss-drill Crack Growth Results

Case / Scenario	JSSG-2006	Modified JSSG-2006	DEF STAN
Miss-drill Modelled	No	Yes	Yes
Primary Initial Flaw Size	0.050 inches	0.010 inches	N/A (FSFT)
Secondary Initial Flaw Size	0.010 inches	0.010 inches	N/A (FSFT)
Kt	3.2	4.4	4.4
Residual Strength	1.2 DLL	1.2 DLL	1.2 DLL
Crack Growth Interval	26874 SFH	21354 SFH	33902 SFH
Safety Factor	2	2	3.3
Threshold (FI)	134	132	102

Task Outcomes

- X-ray inspection technique evaluated and minimum detectable Miss-drill size (1.2 mm) established
- StressCheck and AFGROW used to quantify effects of Miss-drills on spar crack growth
- Crack growth analyses performed to establish inspection thresholds using both JSSG-2006 (Damage Tolerance) and DEF STAN 00-970 fatigue criteria
- Results support an inspection threshold for wing main spar lower cap in-excess of 100 FI (Structural Life of Type of PC-9 wing)

Follow-On Work

- Selection of a retired PC-9 wing with evidence of Miss-drill defects
- Accelerated / simplified fatigue test of wing main spar to grow any cracks that are present
- Teardown / quantitative fractography to identify and investigate any main spar cracking
- Assess results against crack growth behaviour predicted as part of current work

Questions?


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