T56 2ND STAGE COMPRESSOR WHEEL RISK MANAGEMENT PLAN

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New Zealand DEFENCE FORCE Te Ope Kātua O Aotearoa

A FORCE FOR NEW ZEALAND

Introduction

- Why
  - In 2016 Rolls-Royce introduced 2nd Stage Compressor Wheel finite life of 8760 cycles. This resulted in an assessment of the NZDF's T56 Series III engine fleet, this found eight wheels beyond this life.
- How
  - Rolls-Royce risk assessment per engine and a Defence Technology Agency (DTA) assessment per aircraft was conducted against EASA risk criteria for Part 25 aircraft.
- What
  - Using the assessment results the NZDF developed a management plan to remove all affected 2nd Stage Compressor Wheels from service.

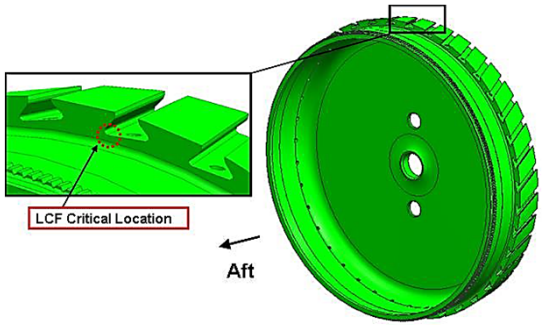


Image courtesy of Roll-Royce plc

Typical geometry and critical LCF location for Stage 2 Wheels

References

- T56 Series III USAF 2017 Structural Life Analysis Management (SLAM), *Roll-Royce plc (EDNS04000004956/008)*
- Risk Assessment of NZ T56 2nd Stage Compressor Cracking, *Rolls-Royce (EDNS04000092339)*
- C1440 review of Rolls-Royce Risk Analysis: T56 Stage 2 Compressor Wheels, *Defence Technology Agency (3739/F1320)*
- T56 Second Stage Compressor Wheel Risk Management Plan, *Royal New Zealand Air Force (AKDCAM 11530 PROP T56-01)*
- EASA AMC/GM to Part 21
- EMAR 21 AMC & GM

Rolls-Royce Lifing Methodology

- Rolls-Royce generated the SLAM programme for the USAF
  - The main lifing consideration for Compressor Wheels is Low Cycle Fatigue around the Dovetail Fillets.
  - In 2015 Rolls-Royce made a change to the statistical basis underlying its legacy lifing methodology.
    - -3.00σ (1.174 probability of failure) at a 95% Confidence Level (CL), rather than -3.72σ at 90%CL.
    - USAF have elected to use -3.00σ at a 50%CL. Resulting in critical part lives differences between 95% and 50% CLs.
  - In the case of 2nd Stage Compressor Wheels (at AMS 5613 material spec) this resulted in:
    - At 95%CL a Finite Life of 8670 cycles.
    - At 50%CL a Finite Life of 10633 cycles.
  - As a constant speed engine cycles are a function of a major on/off cycle.
    - USAF analysis determined an engine hour to Cyclic Exchange Ratio (CER) of 1.875.
    - RNZAF analysis found a CER for the C-130H(NZ) fleet of 1.78 and for the P-3K2 fleet 2.3.
    - RNZAF annual C-130H(NZ) usage is 500Hrs per aircraft.

NZDF Application of the SLAM

- The SLAM forms the basis for lifing of the NZDF C-130H(NZ) and P-3K2 T56 fleet.
- NZDF Technical Airworthiness Authority (TAA) directed that to align with the pending move to DARS the EASA Risk Criteria for Part 25 Aircraft is to be the basis for any risk assessment.
- Based on this the NZDF elected to use the Rolls-Royce probability of failure of -3.00σ at 95%CL as opposed to the USAF probability.
- An analysis of the NZDF C-130H(NZ) and P-3K2 T56 fleet found eight C-130 2nd Stage Compressor Wheels that had exceeded the 8760 cycle finite life. No P-3K2 T56 engine were effected due to the higher CER.

EASA Risk Criteria

- Mean Cumulative Fleet Risk
  - 1.5E-4 for Catastrophic Event per Aircraft
  - 1.5E-2 for Hazardous Event per Engine
- Risk Rate per Airframe Flight Hour (AFH) for an Individual Event
  - 1E-9 for Catastrophic
  - 1E-7 for Hazardous
- Risk Rate per Engine Operating Hour (EOH) for an Individual Event
  - 1E-7 for Hazardous
- EASA Campaign Periods (EASA Decision 2003/1/RM Section 3)
  - Allow for an increased risk rate over a set period.
  - For example: Over a 500AFH campaign period the max risk rate to ensure campaign risk does not exceed the catastrophic event limit is:

$$\text{Max Risk Rate} = {}^{1.5\,E^{-04}}\!/_{500} = \; 3.0\,E^{-07}\; events\; per\; AFH$$

EASA Risk Criteria Application

- For Part 25 aircraft the maximum total risk of a catastrophic event for the certification basis is 1E-07 per AFH. Note the total risk is considered to be made up of 100 potential events at 1E-09 per AFH.
- Therefore over an aircraft life of 60000AFH lifetime risk becomes

$$1.0\ E^{-7} \times 60000 = 6.0\ E^{-3}$$

- EASA guidance proposes additional risk to allow for corrective action campaigns at 25% of the total lifetime risk.

$$6.0\ E^{-3} \times 25\% = 1.5\ E^{-3}$$

- EASA discusses further that there are typically 10 such campaigns.

$$1.5\ E^{-3} \div 10 = 1.5\ E^{-4}$$ Probability of a Catastrophic Event

NZDF C-130H(NZ) Campaign Risk

- A representative life of 32500AFH over a 65 year period (based on a 500AFH per year) was used for the campaign period analysis.
- Fleet retirement is expected by 2026, therefore a 9 year campaign period was utilised.

Cumulative Risk of Catastrophic Event	% of Aircraft Life	Average Reaction Time (AFH)	Average Reaction Cycles	Max Allowable Catastrophic Risk per AFH	Reaction Time (Years)
1.5E-04	25	8125	4565	1.8E-08	16.3
1.5E-04	13.8	4485	2520	3.3E-08	9.0
1.5E-04	6.25	2031	1141	7.4E-08	4.1
1.5E-04	5.0	1625	9013	9.2E-08	3.3
1.5E-04	2.5	813	456	1.8E-07	1.6

Max Allowable Risk over Campaign Period= $^{1.5\,E^{-04}}/_{4485} = 3.3\,E^{-08}\ events\ per\ AFH$

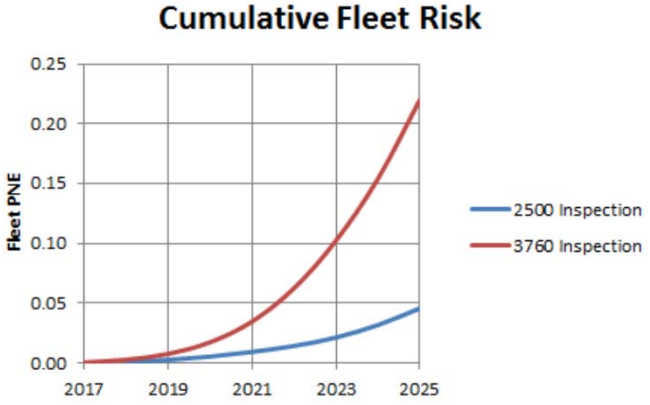
Rolls-Royce Risk Assessment for the NZDF

- This was carried out using a Monte Carlo analysis.
- Risk rate is a function of cycles since new and time since last inspection.
- Assumptions were:
  - All wheels have a non-detectable crack upon production.
  - 90% confidence for crack initiation and propagation.
  - 0.035” crack detectable at inspection.
  - If a crack is detected replacement with zero time wheel will occur.

		Cycles			Cycles
Crack Initiation to 0.035”	3.72σ, 90% Confidence	7612	Crack Propagation to Failure	Mean	4580
	Mean, 90% Confidence	16532		Min	2290

Rolls-Royce Risk Assessment for the NZDF

- The assessment showed a large sensitivity to inspection interval.
- As a result the NZDF based its risk assessment on a 3760 cycle interval.



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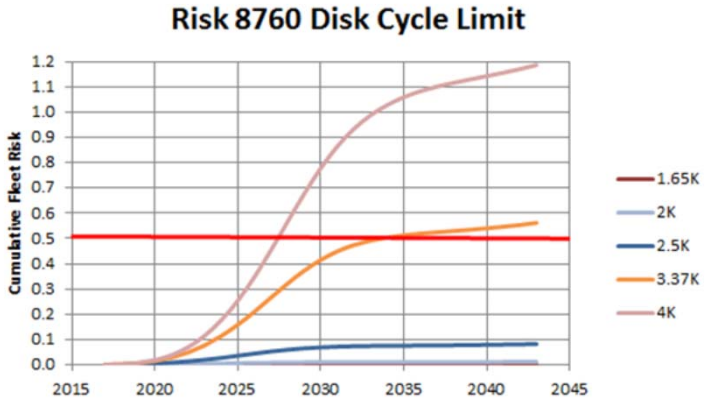

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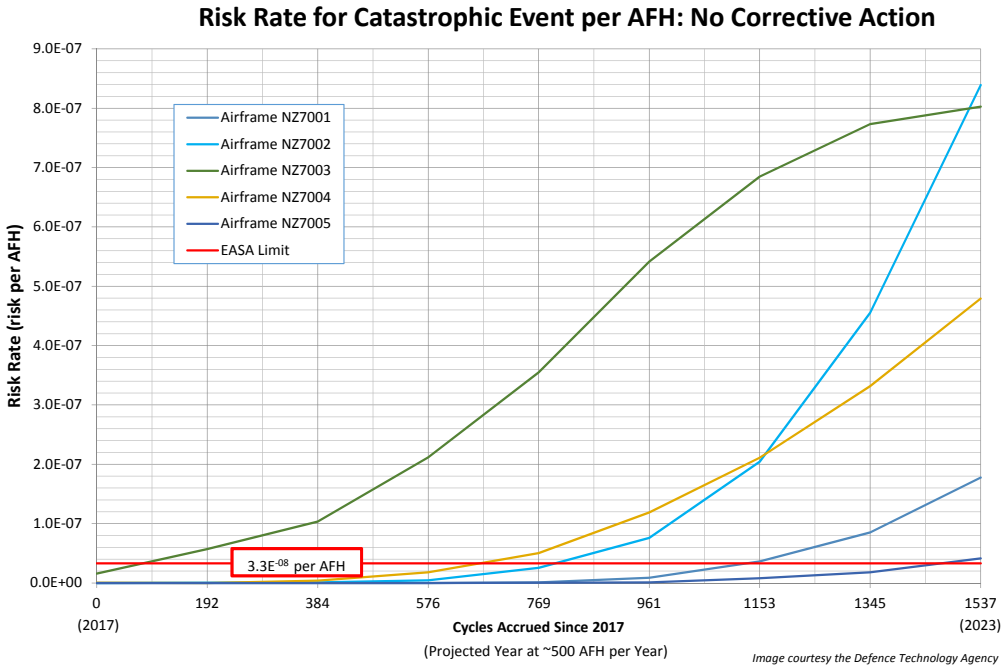
DTA Review of RR Risk Assessment

- Rolls-Royce provided results per wheel based on a year by year basis.
- The Defence Technology Agency (DTA) reproduced these results as cycle limits per engine and the cumulative risk per aircraft based on specific engine installation.
- As seen in the next two slides no action would see all affected aircraft exceed the EASA limit within the campaign period.
- Out of the five aircraft NZDF fleet NZ7003 held the highest risk.



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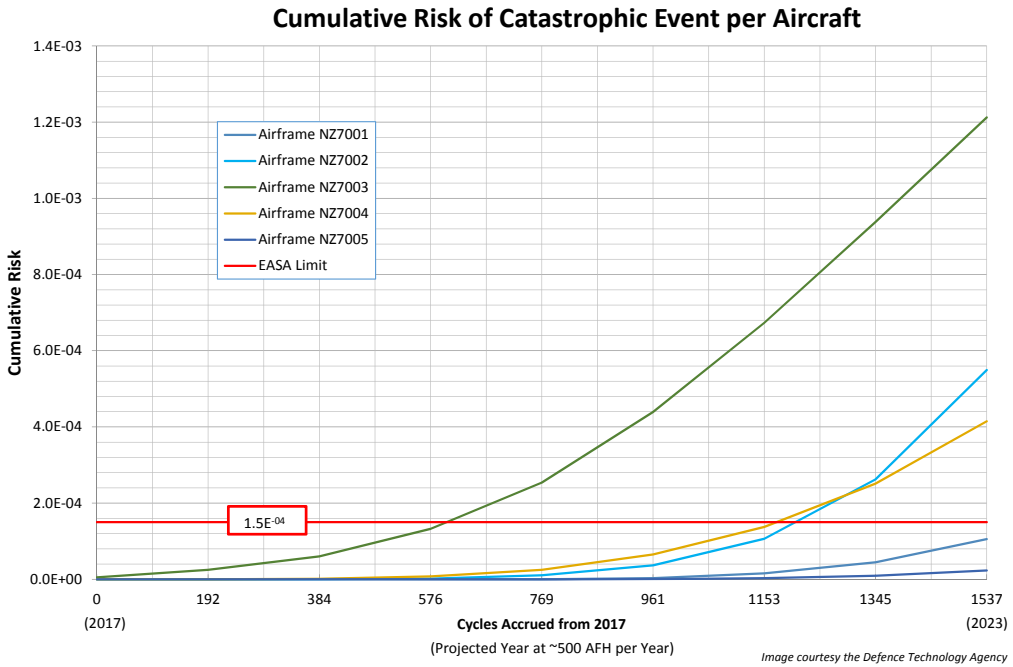

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RNZAF Risk Management Plan

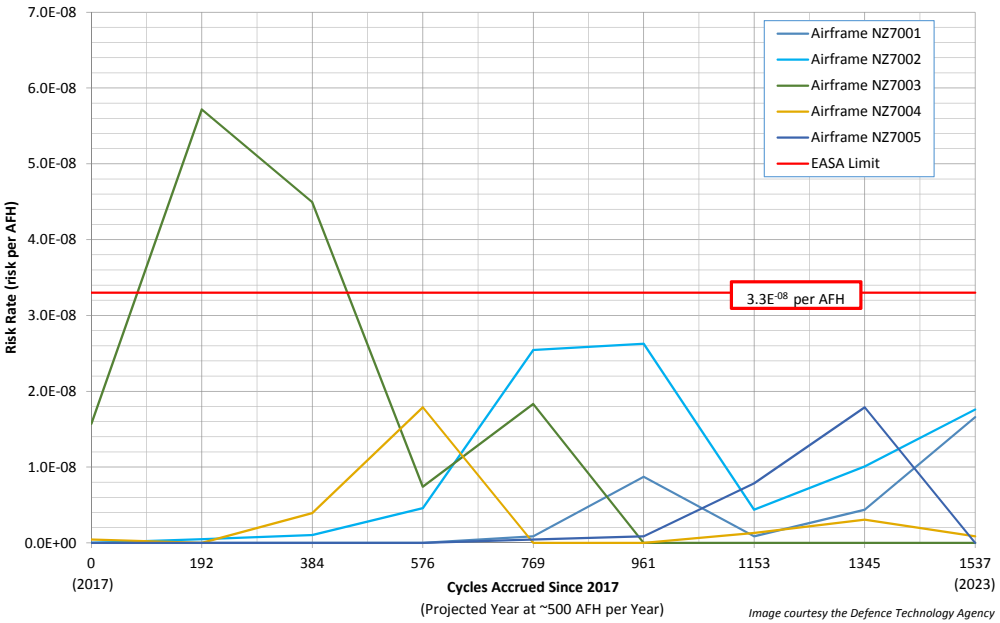
- This plan summarised the Rolls-Royce and DTA reports, and proposed a treatment action.
- This plan was then submitted to the NZDF TAA for acceptance.
- The overall assessment was put into context against the NZDF Airworthiness Risk Management Matrix.
  - A likelihood of 3.3E-08 per AFH for a catastrophic event over the campaign period resulted in a MEDIUM risk.
  - Based on the NZAF TAA earlier directing that the risk was to be reduced to LOW, cycles remaining on the affected wheels were defined and a removal plan proposed.
- On-wing management is being achieved by NZ Special Maintenance Instruction.
- This plan is being monitored as an NZDF Risk at the Airworthiness Management Committee and Airworthiness Board level for the C-130H(NZ).

RNZAF Risk Management Plan

- Cycles remaining are taken from 01 Jan 17.

Wheel S/N	Engine S/N	Airframe	Required Removal (Cycles)
RR7345	106871	NZ7003	192
RR7322	105093	NZ7003	384
RR4452	105080	NZ7004	576
RR4445A	105076	NZ7002	769
WY10808	106870	NZ7003	769
RR4520	105090	NZ7002	961
RR4695	105092	NZ7001	961
RR4540	105078	NZ7005	1345

Risk Rate for Catastrophic Event per AFH: Risk Management Plan



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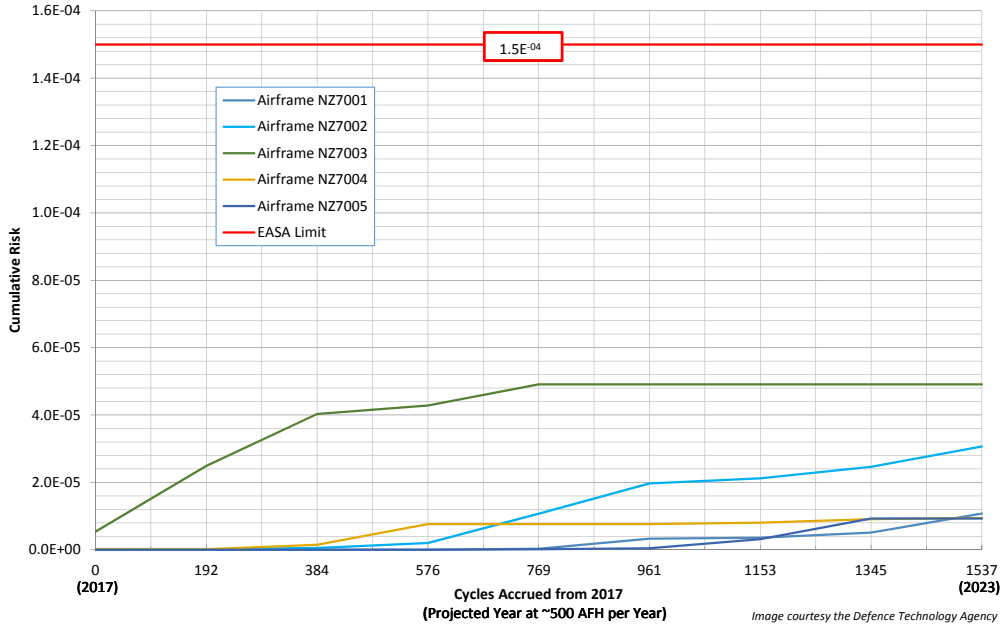
Cumulative Risk of Catastrophic Event per Aircraft: Risk Management Plan



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Questions

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