Australian Government

Department of Defence

Defence Science and Technology Group

RMIT UNIVERSITY

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RUAG

Swiss Titanium Research Experiments on the Classic Hornet (STRETCH)

ICAF2023

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June 2023

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Introduction

- Experimental research partnership focusing on fatigue crack growth in titanium combat aircraft structure.
  - Australian Department of Defence (DoD) partnered with RMIT.
  - Swiss Federal Council Department of Defence, Civil Protection and Sport (DDPS) partnered with RUAG.
- Full scale testing of titanium Swiss F/A-18C/D centre barrel structure.
  - Classic Hornet configuration unique to Swiss Air Force.
  - Similar material utilised in F/A-18E/F/G Super Hornet and F-35 Lightning II operated by the RAAF.
- 2010 DSTG[1] FINAL program tested 18 retired F/A-18A/B centre barrels saved the DOD $400M [1].

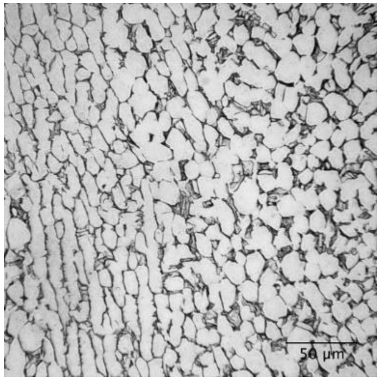
DSTG[1] – Defence Science and Technology Group

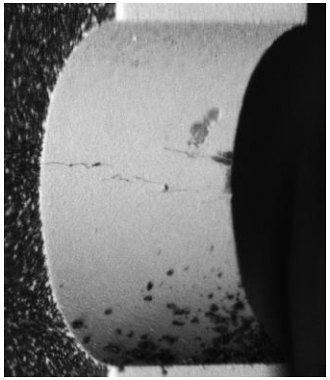
Project objectives

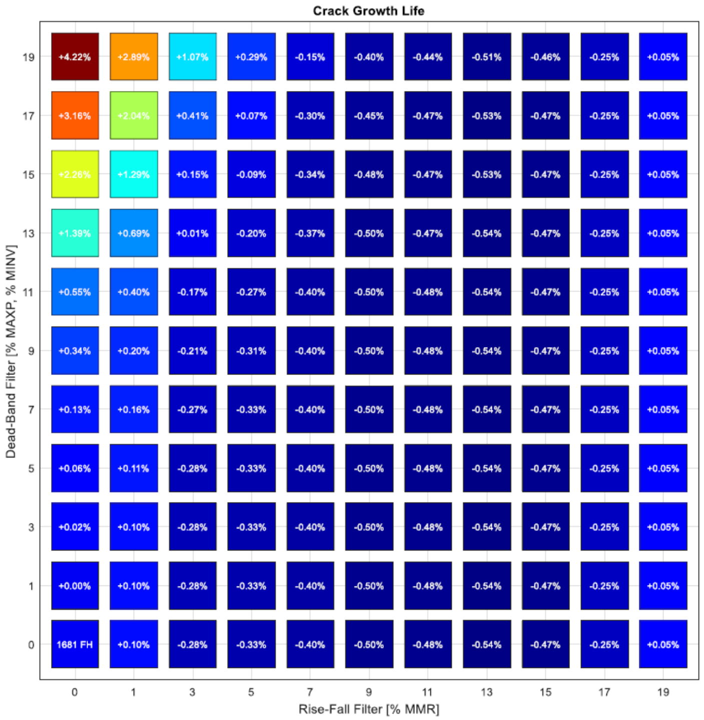
- Collaborate on experimental fatigue crack growth research into titanium combat aircraft centre fuselage structure (the ‘test article’).
- Provide the Swiss DDPS the experimental evidence and data necessary for optimum ASI management of their F/A-18 fleet and its life extension.
- Provide the DOD with titanium fatigue crack growth research results that will inform the ASI management of their combat aircraft fleet.

Spectrum development

- A series of coupon tests were conducted.
  - Ti-6Al-4V Recrystallised Annealed
  - SEN(T) Coupons
  - Spectrum truncation
  - Marker band studies
- Deadband filter and rise-fall filter trialed.
- Analytical analysis showed deadband filter had more significant detrimental effects.
- 9% rise-fall filter chosen.
  - Reduced load lines by 97.58%.
  - 0.5% analytical life increase.

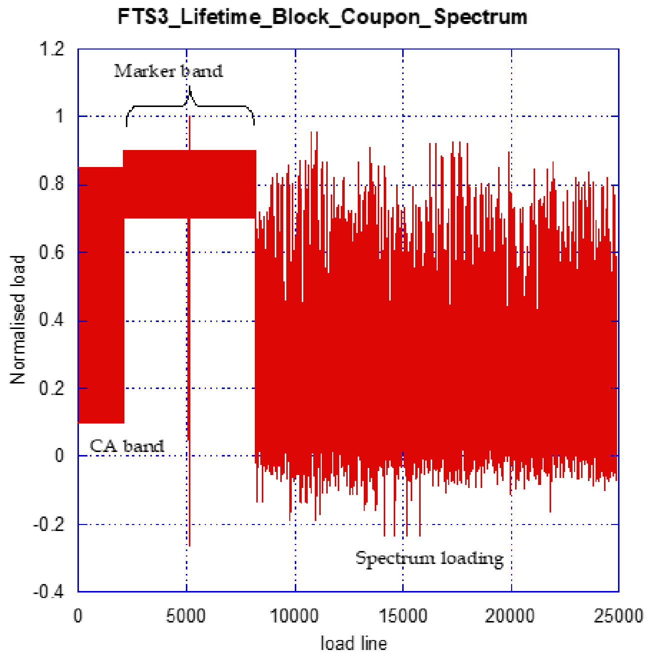






Spectrum development cont.

- 1 lifetime (6,000 SFH) produced by 20 blocks (300 SFH each).
- Marker band at the end of each block.
- CA[1] block at the start of each lifetime.
  - Equivalent to VA[2] growth.
  - Marks crack length at the start of each lifetime.
- Marker band primarily high R cycles with underloads.
  - Roughly 10% of total growth.

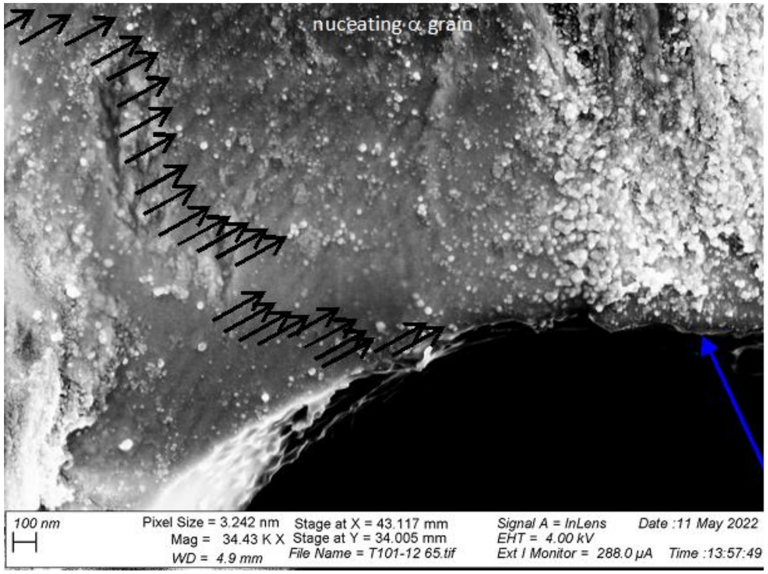


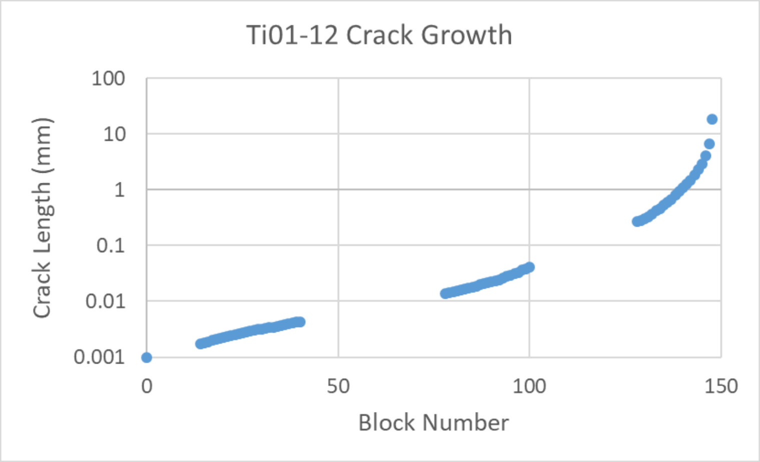
Name	Min. (normalised)	Max. (normalised)	Cycles
High R	0.7	0.9	1499
Low R	0.05	0.9	20
Load Line	0.02	-	0.5
Load Line	-	0.99	0.5
Load Line	-0.26	-	0.5
Load Line	-	1	0.5
High R	0.7	0.9	1499

CA[1] – Constant Amplitude
VA[2] – Variable Amplitude

Spectrum development cont.

- Coupon tests validated both truncation and marker bands.
- Crack growth curves obtained from Ti-6Al-4V coupons.
  - Down to crack lengths ≈ 1 μm.
  - Not all regions have visible marker bands.
  - Fastest growing crack is exponential [2].
- Compare FTS3 crack growth data to SLAP predictions.
  - Reassess service life based on improved data.

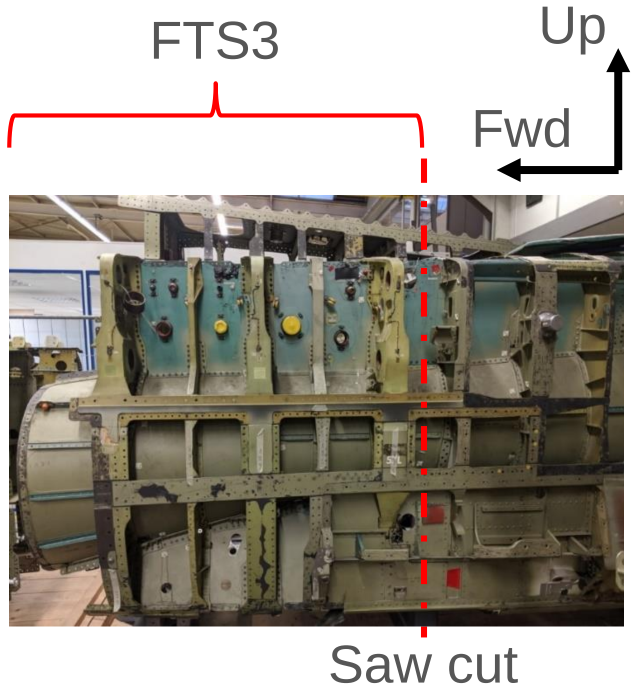


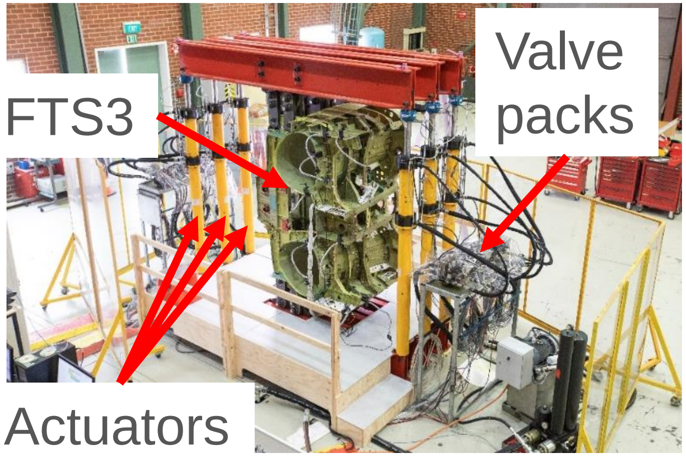


Further details: Measuring small fatigue crack growth with the aid of marker bands in recrystallized annealed Ti6Al4V. – Session 7, Tuesday.

Test article preparation

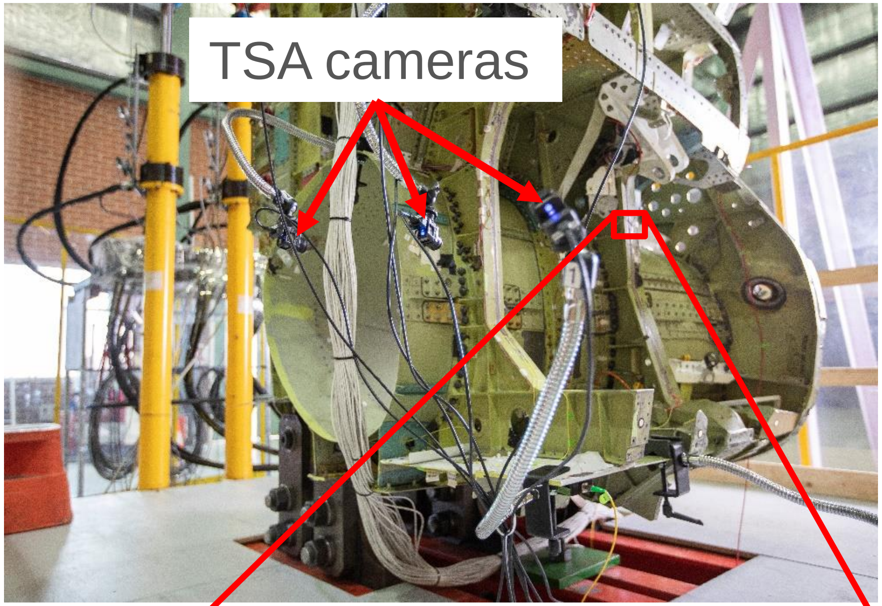
- Centre barrel test article ‘FTS3’ removed from original full scale fatigue test article ‘FTS1’.
  - Original FTS1 test article tested for 10,400 SFH (deemed equivalent of 2 × FTS3 lifetimes).
- Cracked FTS1 structure repaired prior to sending to DSTG.
- FTS3 installed in testing rig.
- 6 × 150 kN actuators apply WRBM loads.

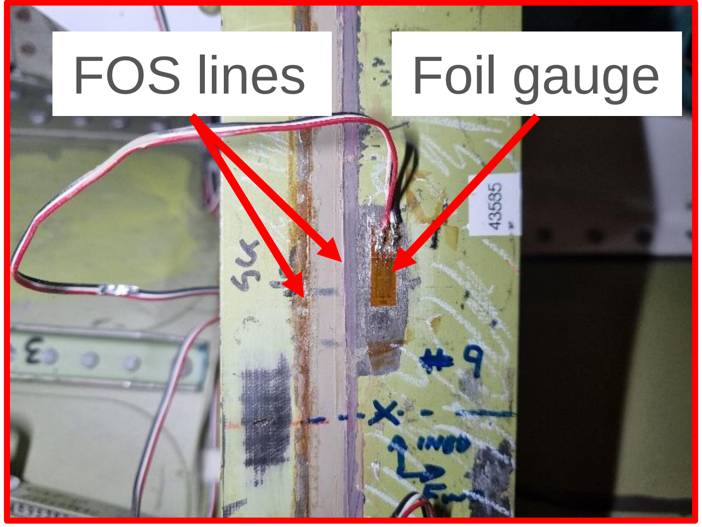


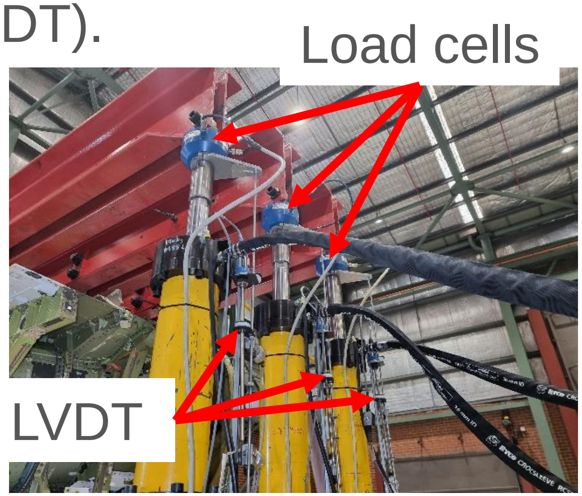


Test instrumentation

- Strain measuring instrumentation:
  - 89 × foil strain gauges.
  - 8 × Fibre Optic Sensor (FOS) lines.
  - 8 × Thermoelastic Stress Analysis (TSA) cameras.
- Other instrumentation:
  - 6 × Linear Variable Displacement Transducers (LVDT).
  - 6 × load cells.



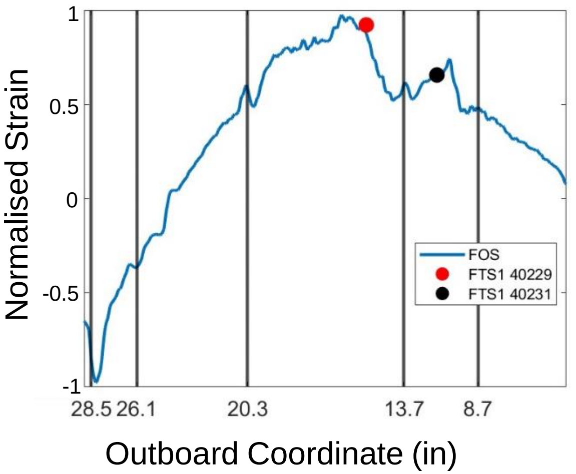




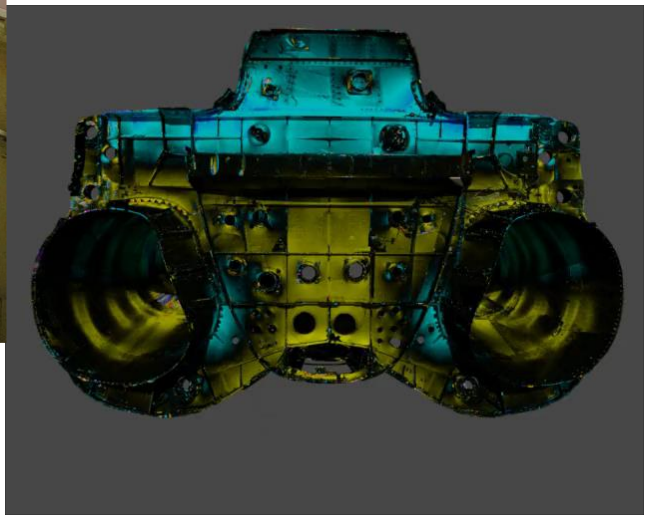
FOS and TSA data

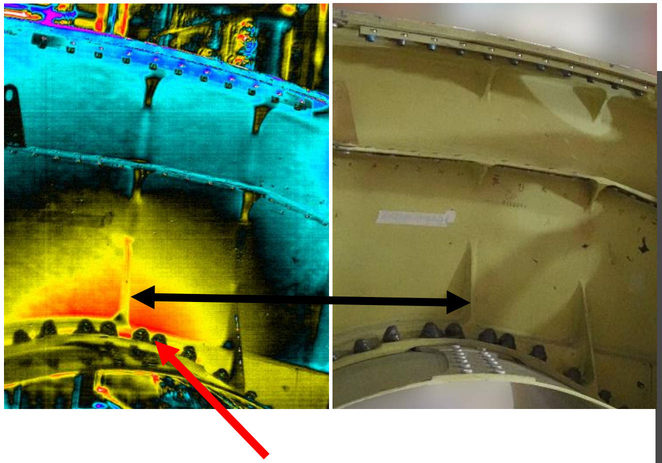
- FOS and TSA is less widely utilised for strain measurements compared to foil gauges.
- FOS generally in close agreement to foil gauges.
  - Provides detailed 2D strain distributions.
- TSA able to provide large coverage strain data.
  - Easily identifies strain hotspots.

FOS vs foil gauge



TSA map of test article

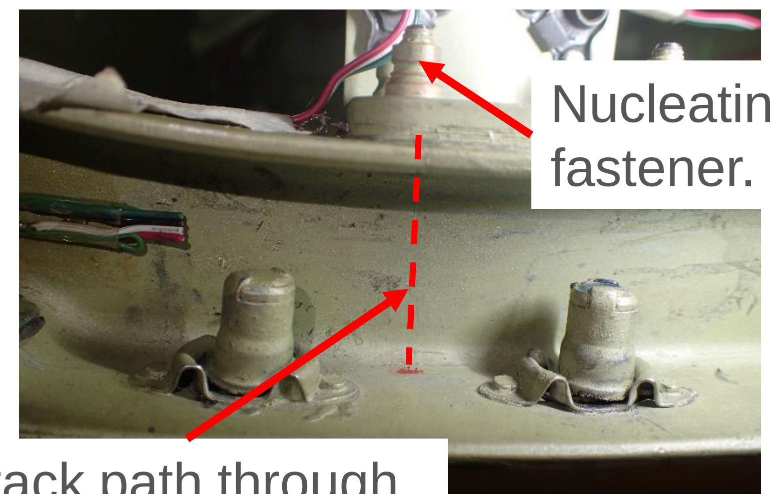




Y488 bulkhead upper duct flange hotspot.

Durability testing

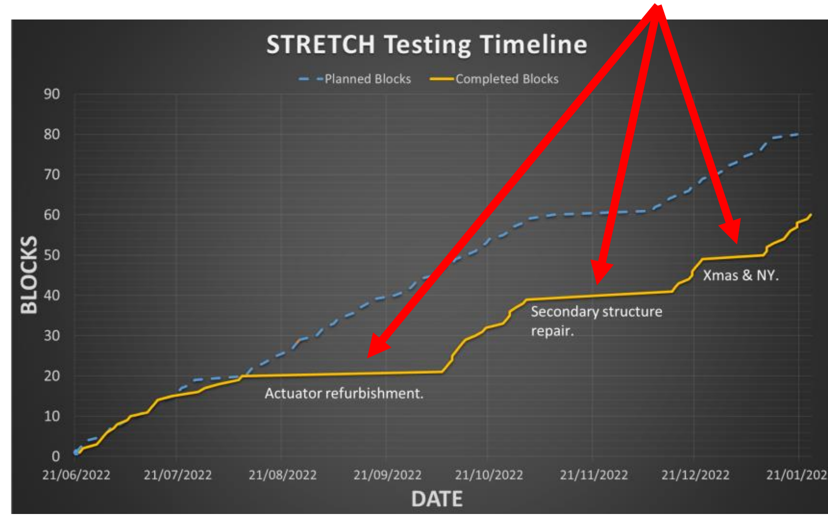
- End of 1st lifetime: actuator refurbishment to help with control issues.
- End of 2nd lifetime: minor cracking in secondary structure repaired.
- End of 3rd lifetime: aluminium former cracking found.



Nucleating fastener.

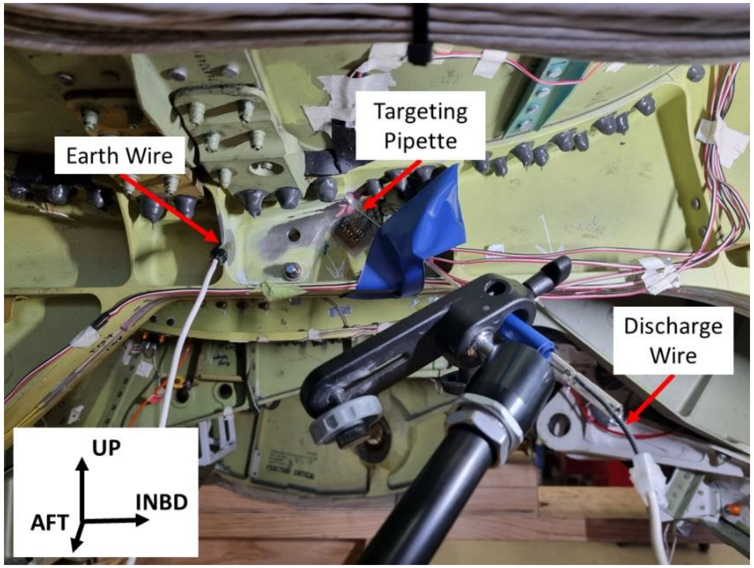
Crack path through secondary structure.

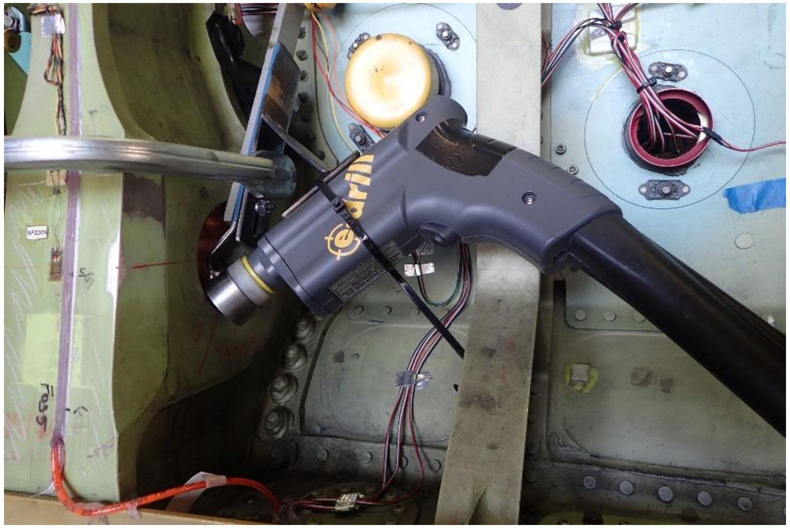
Testing downtime

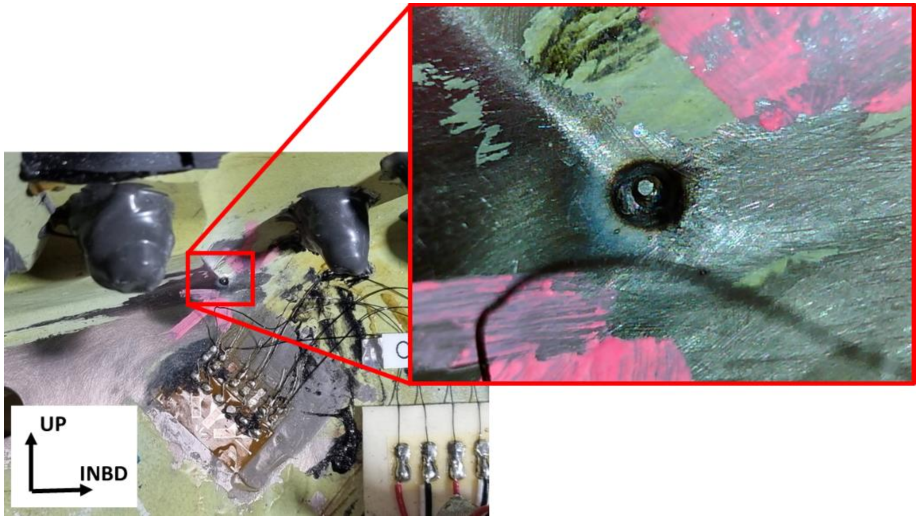


Damage Induction

- 17 fatigue hotspots damaged.
- Two unique damage methods used:
  - Plasma arc spot melting.
  - E-Drill modified as EDM.
- Plasma arc ideal for roughly 0.01” damage.
- E-Drill ideal for roughly 0.05” damage.







Damage tolerance testing

- Two damage tolerance (DT) lives completed with the third scheduled.
- NDT found crack growth in both an E-Drill and arc burn damage location.
- Significant additional cracking found in aluminium former.
- Bonded aluminium repair of former installed at end of 2nd DT lifetime.

Cracking of arc burn location

Direct Image of Damage Location

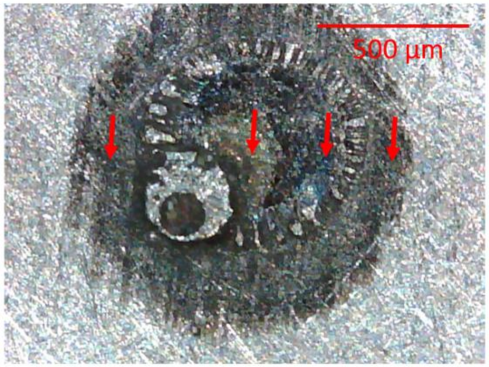
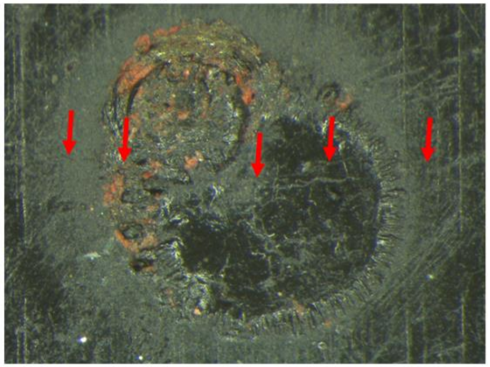
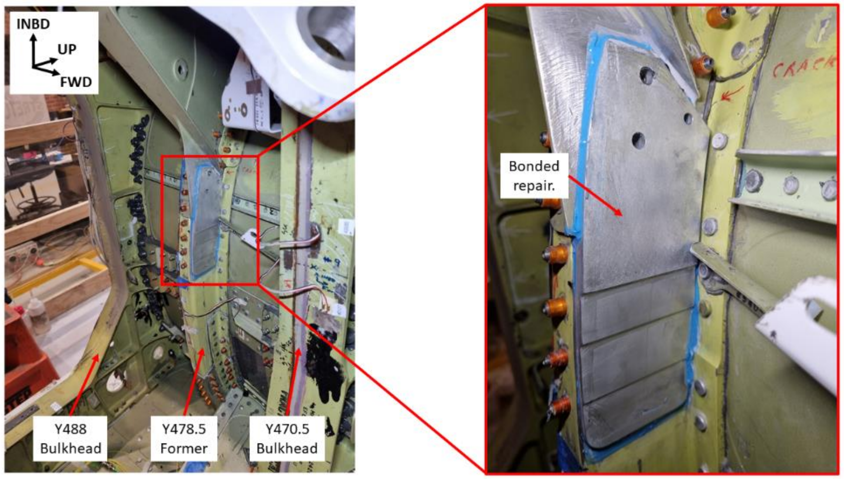


Image of Replica from Damage Location



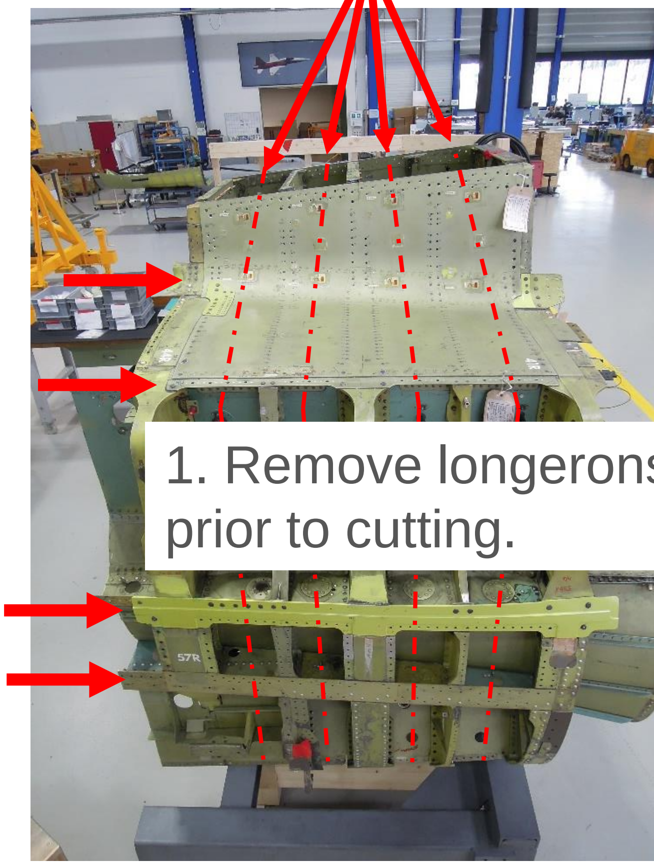
Former repair patch



Article teardown

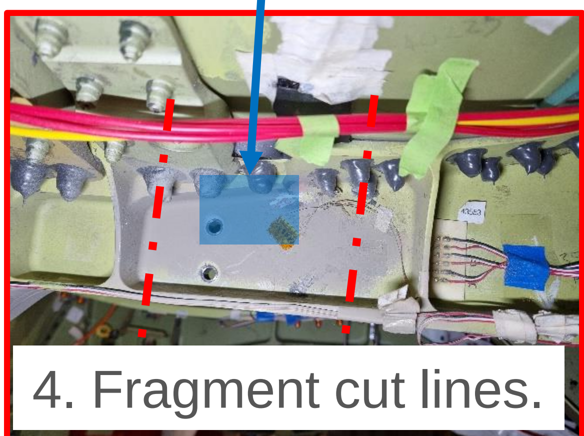
- Break down structure into manageable sections.
- Open existing fatigue cracks and damage locations.
- Conduct fractographic analysis.

2. Cut lines.



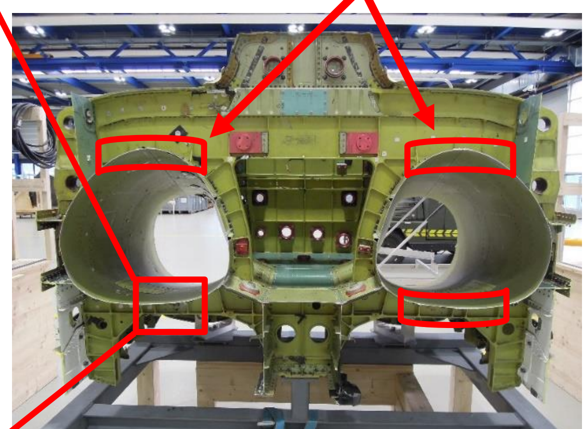
1. Remove longerons prior to cutting.

5. Open region of interest.



4. Fragment cut lines.

3. Remove fasteners and skin.



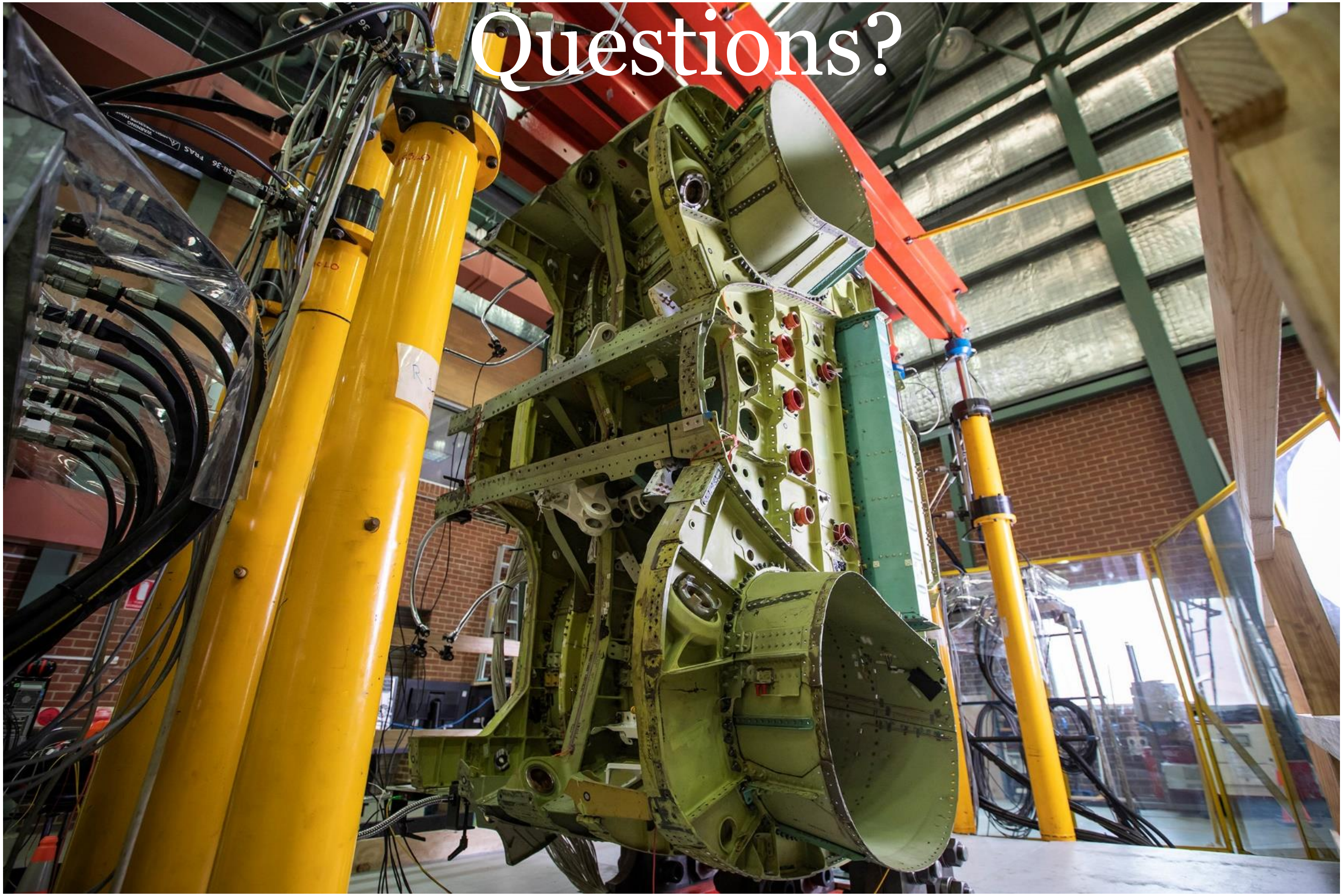
Conclusion

- 5+ lifetimes of testing successfully completed.
- Extensive strain data gathered with significant coverage obtained.
- Some naturally occurring fatigue cracks discovered.
- Crack growth data obtained verifying marker band method.
- Two novel methods of damage induction developed.
- Fatigue crack growth occurring from both damage methods.
- Initial development of the teardown plan completed.

Goals

- Collaborate on experimental FCG research ✓
- Obtain evidence and data for Swiss Hornet ASI management **(ongoing)**
- Provided DOD with Ti crack growth data **(ongoing)**

Questions?



References

1. Molent, L., Dixon, B., Barter, S., White, P., Mills, T., Maxfield, K., Swanton, G., and Main, B. (2009) Enhanced Teardown of Ex-Service F/A-18A/B/C/D Centre Fuselages, In: Proceedings of the 25th International Conference on Aeronautical Fatigue (ICAF) Rotterdam, Netherlands, pg 123-143.
2. L. Molent, S. Barter, and R Wanhill, ‘The lead crack fatigue lifing framework’, In International Journal of Fatigue, 33(3), pp. 323–331, 2011. https://doi.org/10.1016/j.ijfatigue.2010.09.009