Australian Government
Department of Defence
Science and Technology

Towards the Virtual Fatigue Test

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Defence Science and Technology

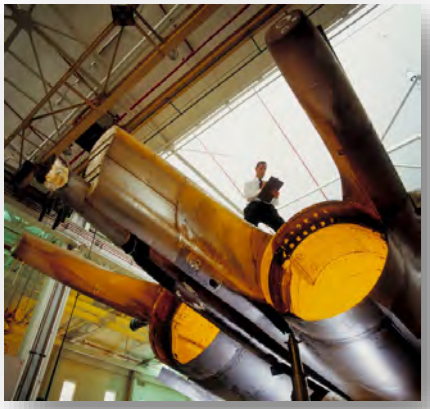
Outline

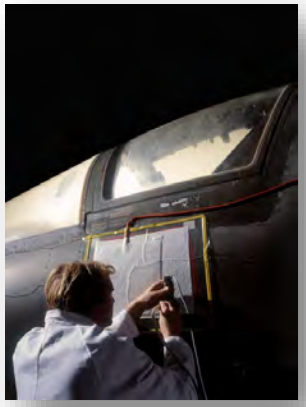
- Roles of DST - Aerospace Division in Defence
- Digital trends in the Aerospace Domain
- What are the benefits of a virtual fatigue test?
- DST's pathway to a virtual fatigue test - ASSIST
  - identify and publish sources of error in fatigue predictions
  - partner in S&T research to reduce errors
- Progress
  - blind prediction challenges
  - current research directions

Defence Science Technology (DST):

Leads Australian Defence and National Security S&T

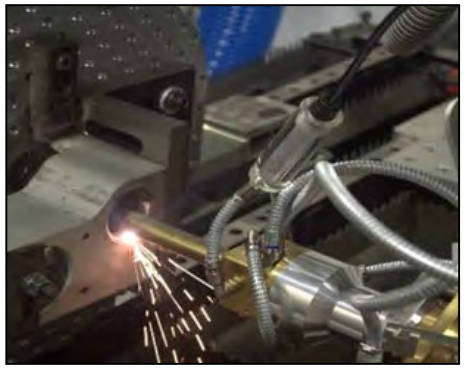
Aerospace Division: Provides support and solutions to enhance the operational effectiveness, performance, survivability, availability and safety of ADF aerospace capabilities





DST Roles in the Aerospace Domain

Defence Operations



Sustainment

Acquisition Projects

Strategic Research

Cost of ownership – US Navy perspective

Office of Naval Research: Naval S&T Strategic Plan (2011):

- Total Ownership Cost is one of 9 focus areas
- Drivers: decreasing budgets, increasing cost of manpower, materials, labour
- Vision: insert technology to reduce acquisition, lifecycle and **sustainment costs**

Innovative Sustainment

- F/A-18 A/B (IFOSTP $700M, FINAL $443M, HOWSAT $10M)
- P-3C (SLAP $432M)
- C-130J (FSFT – re-wing?)

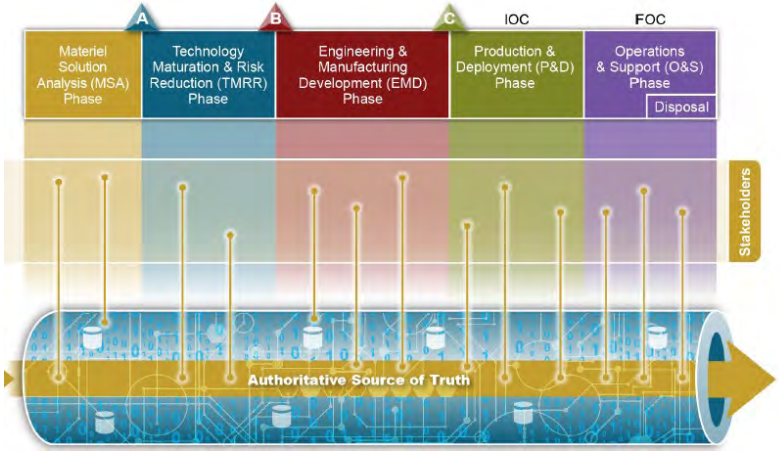
Test based – BUT also innovative analysis methodologies

F/A-18 A/B: IFOSTP

P-3C: SLAP

Digital trends - within Aerospace Domain

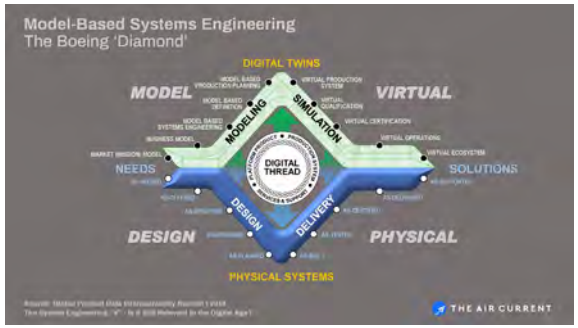
U.S. DoD



US Department of Defense, *Digital Engineering Strategy, June 2018*

benefits of digital twins are clear to: designers, manufacturers, regulators and operators.

Boeing



https://theaircurrent.com/aircraft-development/tracing-the-origins-of-boeings-diamond-from-apollo-to-nma/ *accessed: 05/08/2019*

Airbus

https://www.airbus-sv.com/projects/9
accessed: 05/08/2019

Validating Airframe Structural Strength

To bring new aircraft designs into service:

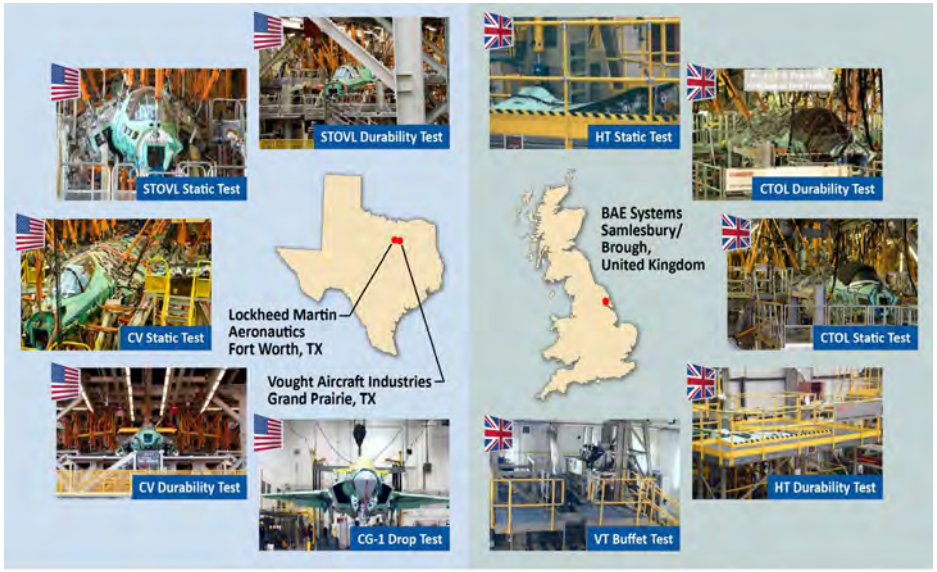
- airframe strength and durability needs to be demonstrated
- via a series of qualification tests and analyses
- and a full scale fatigue test (FSFT) :

  time (10 +years)

  engineering effort ('000s hours)

  costs ($50M+)

this includes new materials or advanced methods (e.g. additive manufacturing)

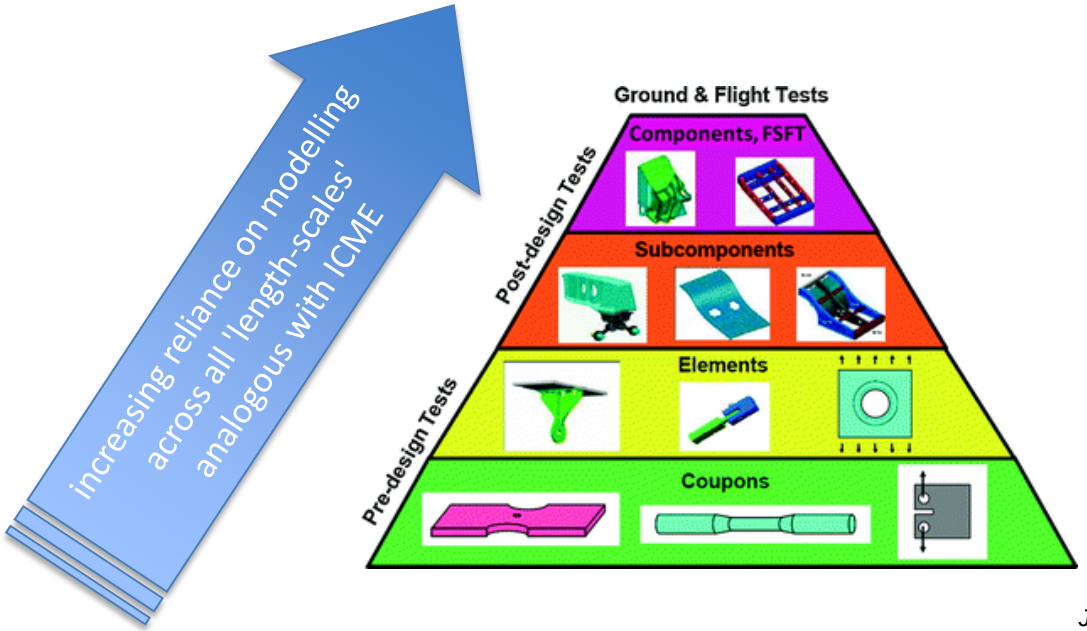


F35 Structural Design Development and Verification
Presenter: Mr Robert Ellis - Lockheed Martin Co
ASIP Conference, Phoenix, AZ, USA, Nov 26-29 2018

Advancing structural test and simulation, why?

To reduce delays in

- fielding of innovative designs or modifications
- benefiting from advances in manufacturing and material technologies
- responding to meet challenges from emerging technologies

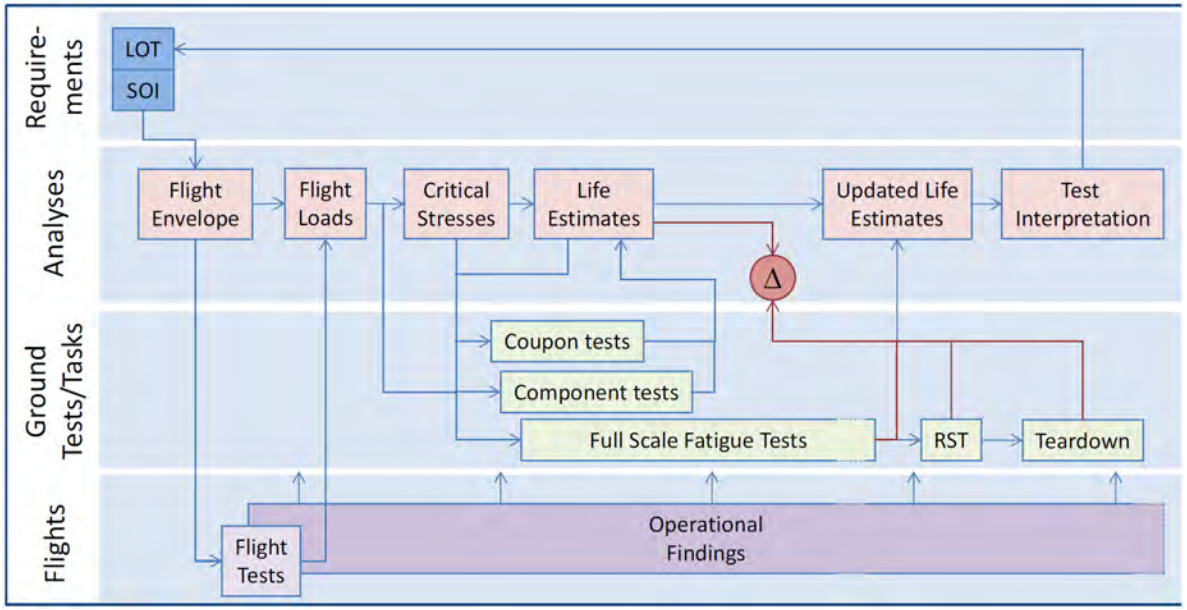


ICME - integrated computational materials engineering

Joint Strike Fighter Airframe Durability and Damage Tolerance Certification
D. Ball and D. Norwood, **AIAA 2006-1867**

ASSIST - Background

- Two years ago Research Leader Aircraft Structures Dr. Albert Wong proposed TITANS (Transglobal Integrated Tests and Analyses Network for Structures).
- Collaborative program to help progress to virtual fatigue test.
- Now ASSIST:
  Advancing Structural
  Simulation to drive
  Innovative
  Sustainment
  Technologies



A. K. Wong, 2017, Blueprint TITANS: A Roadmap towards the Virtual Fatigue Test through a Collaborative International Effort, In: 29th ICAF Symposium, Nagoya, Japan: 7-9 June 2017

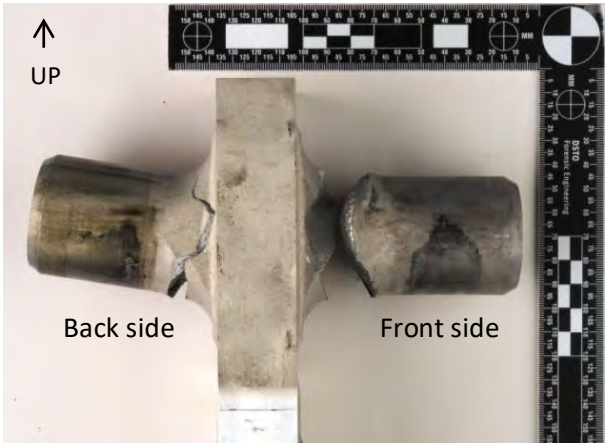
ASSIST - DST aims

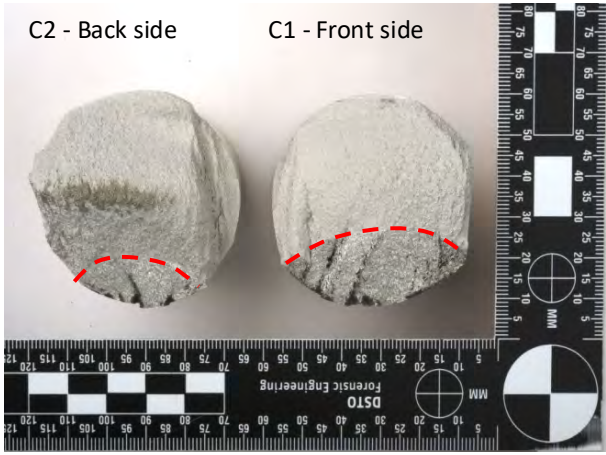
- To encourage the building of a sovereign collaborative network, that can support Defence in responding to technological changes and providing sustainment options to reduce the cost of ownership and/or increase platform availability.
- To provide information and foster discussions within the Engineering community on S&T that can advance structural test and simulation outcomes.
- Developing efficient pathways for innovative platform sustainment solutions to be transitioned into Defence capability options.

Photographer: CPL David Gibbs

What is ASSIST?

- Built around *Airframe Prediction Challenges* – predict fatigue lives for realistic loads and structures.
- Collaboration – All of the Aerospace community are welcome to participate.
- Detailed forensic examination of results to drive improvement in predictive methods.



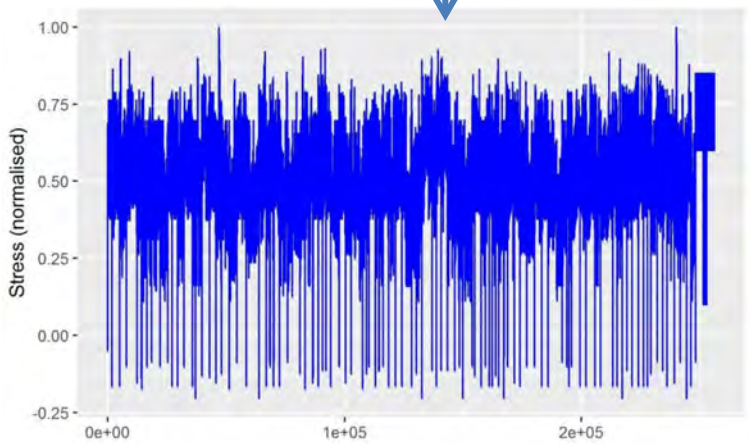


Main et al., 2019, Lessons from a Fatigue Prediction Challenge for an Aircraft Wing Shear Post. Int. J. Fat. 123

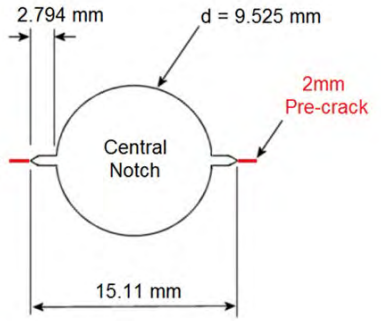
The Challenges

Real-world aircraft structure problems -
First 3 based on problems relevant to Defence

2. Helicopter spectrum truncation



1. Fighter wing root shear tie (completed)

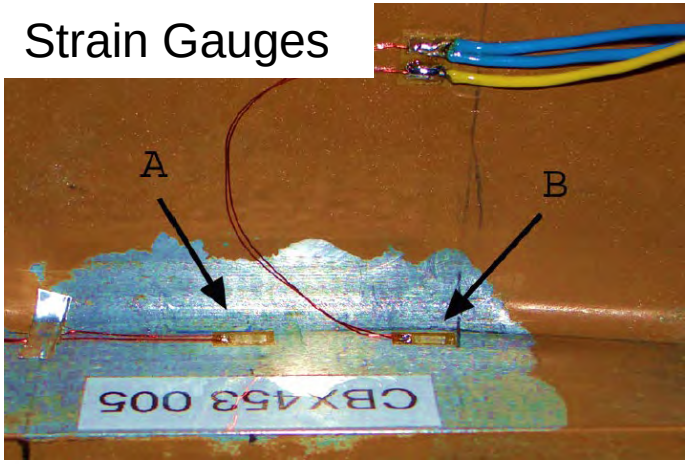


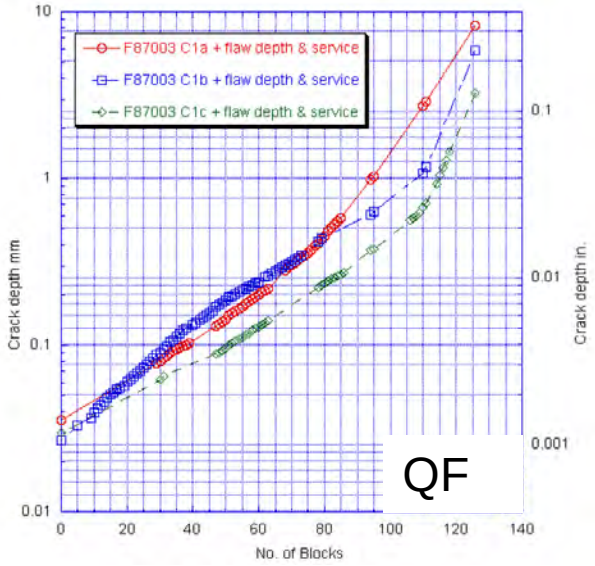
3. Long cracks in transport aircraft

The Challenges

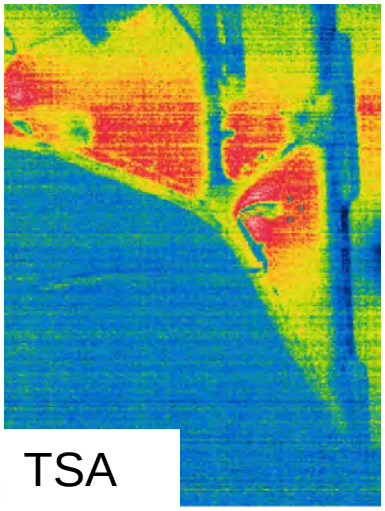
- Focus on specific parts of life prediction
- Detailed forensic examination of results:
  - Test Results + Additional data (e.g. strain gauges, Finite Element Models (FEM), Digital Image Correlation (DIC), Thermoelastic Stress Analysis (TSA), Quantitative fractography (QF)
  - Collaborative review at online community
  - Identify most critical parts of the process.
  - Identify limitations and areas for improvement of predictive capabilities
  - Provide focus for future research

Strain Gauges





QF



TSA

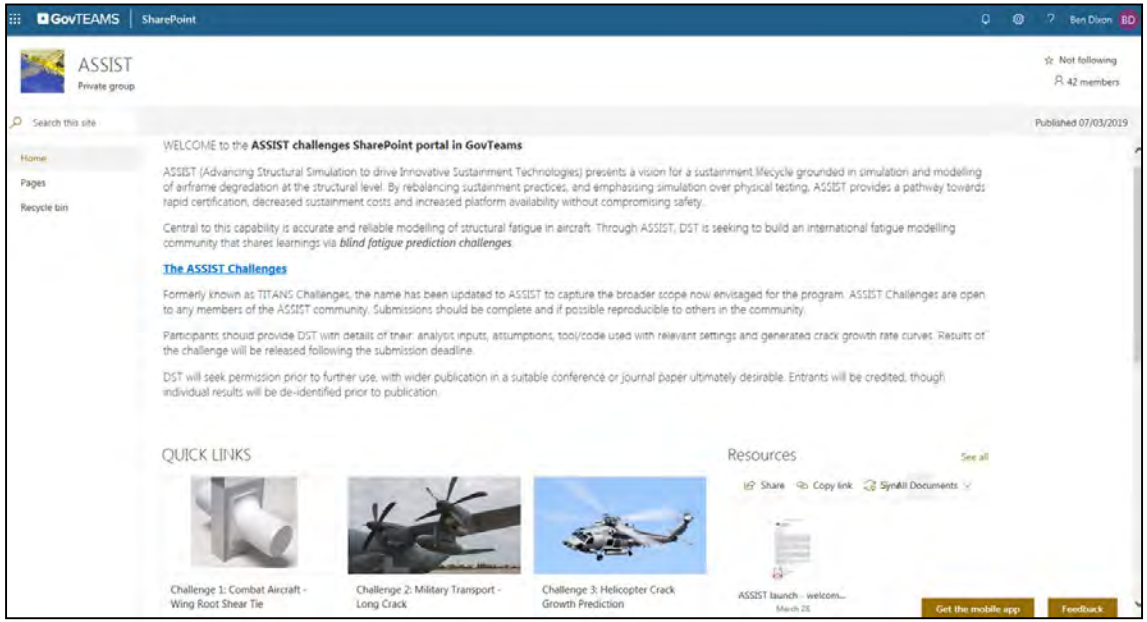
ASSIST Community

Hosted on SharePoint: *https://govteams.gov.au*

To join email: *ASSIST2019@dst.defence.gov.au*

YOU CAN:

- ✓ Participate in the blind challenges
- ✓ Participate in/comment on the post-challenge reviews
- ✓ Post your own challenges
- ✓ Suggest improvements to ASSIST challenges/processes (e.g. Additional data to collect during testing)

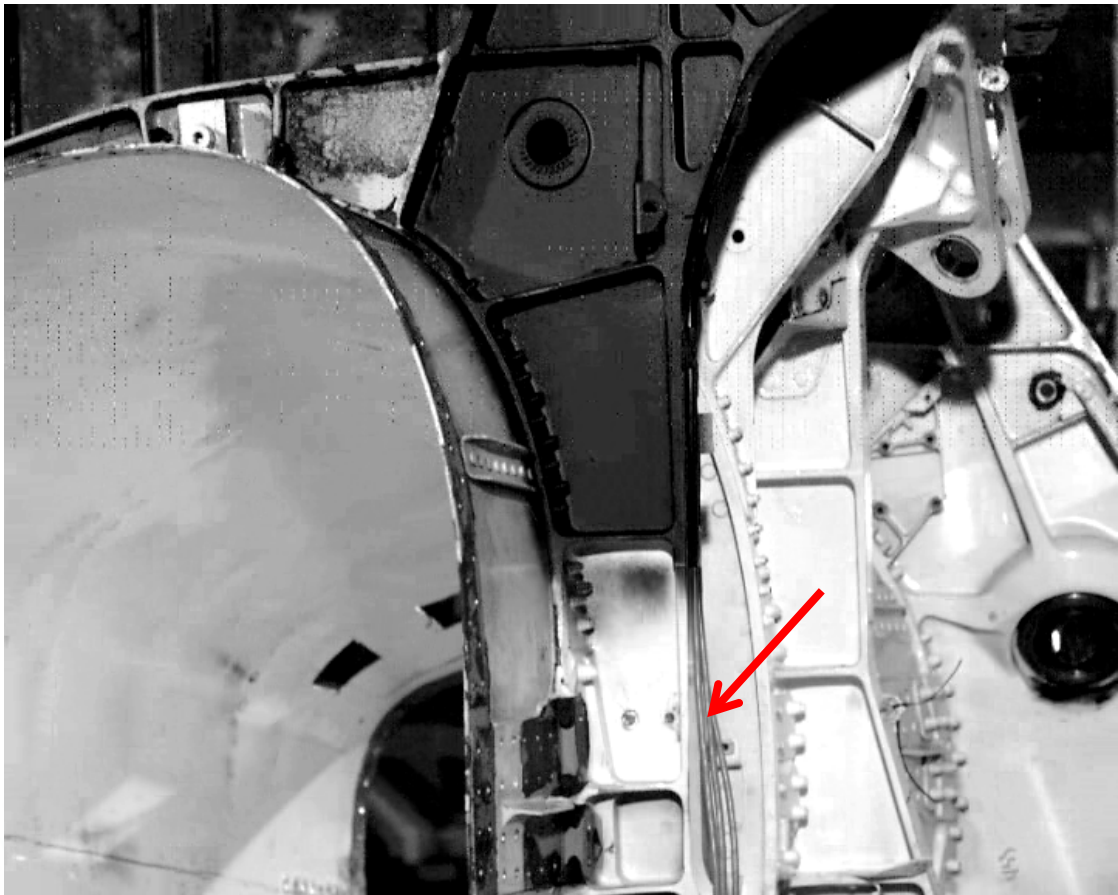


Aiding the pathway to a virtual fatigue test

- Operators want no surprises → impact to availability
- Full Scale Fatigue/Durability Tests still give surprises
- Need to establish, with confidence, analytical identification of all hot spots & the error bands for modern methodologies

Growing ASSIST database of challenges can:

1. Benchmark and improve our ability to ID hot spots.
2. Establish error bands
3. Help reduce error bands



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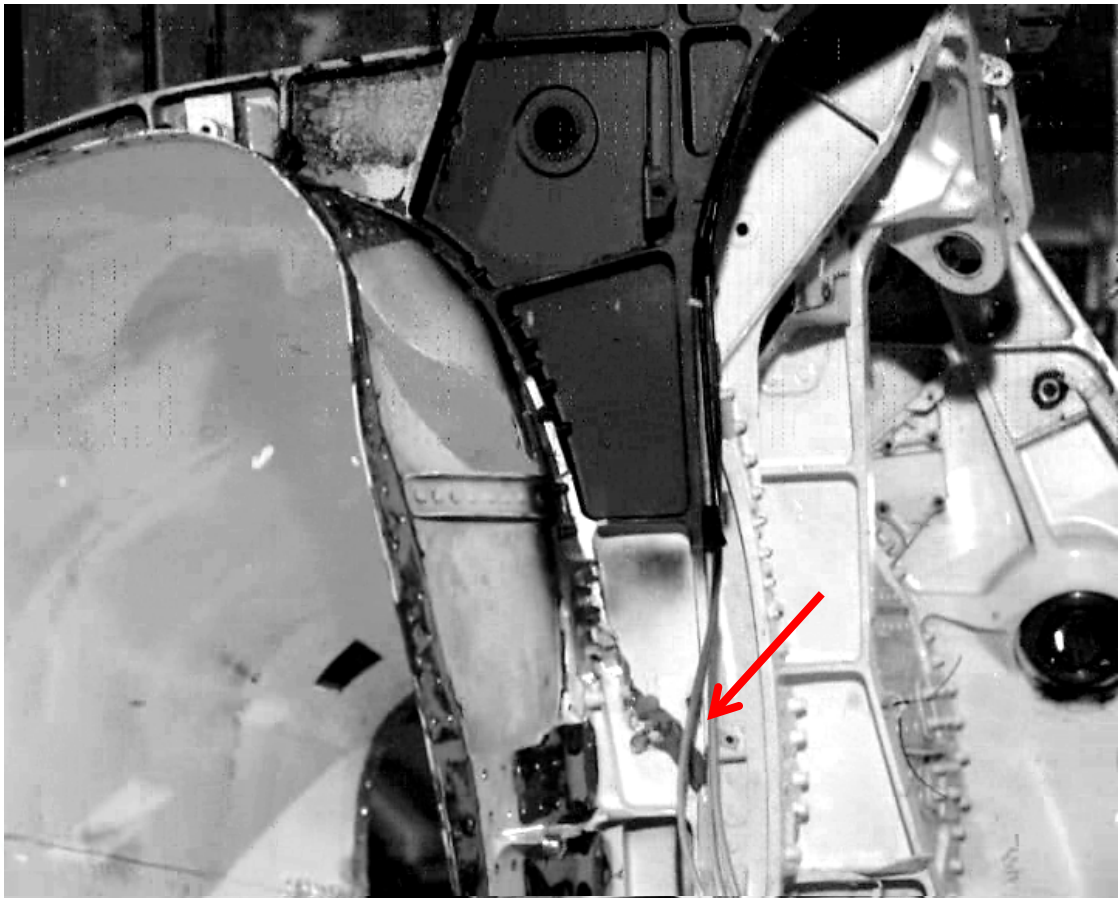
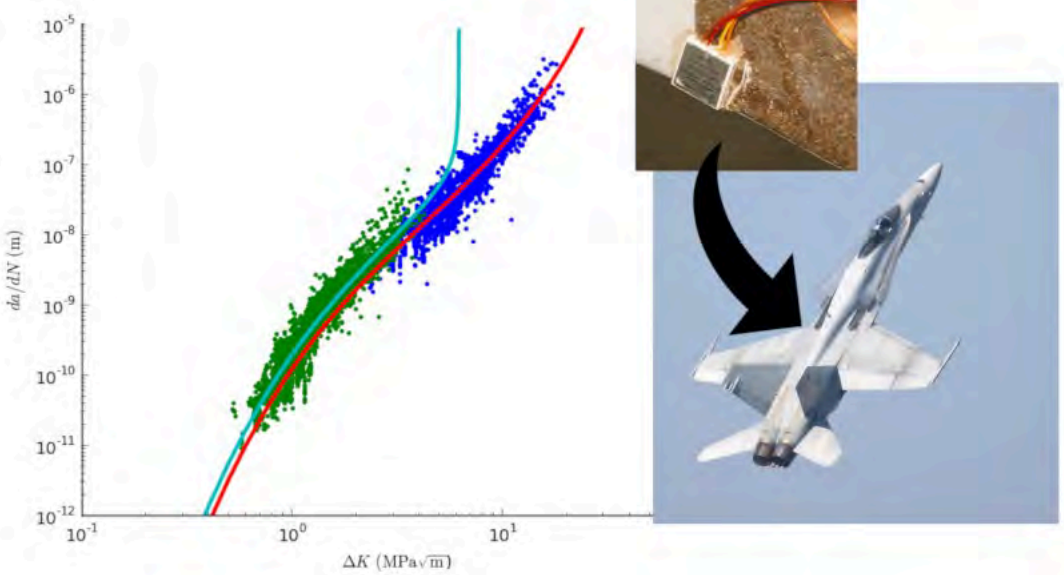


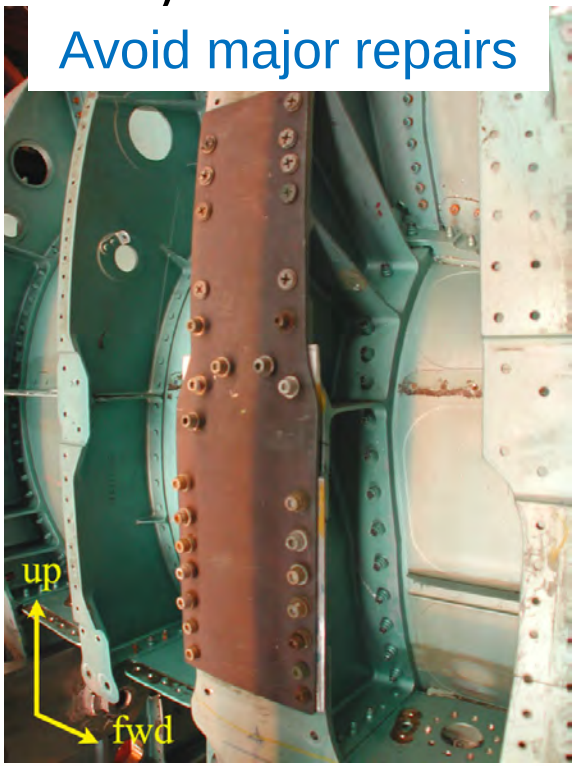
Medium term benefits

- ✓ Improved outcomes from design and certification (i.e. test interpretation / correlation & Individual Aircraft Tracking – IAT)
- ✓ More efficient Full Scale Fatigue/Durability Tests (not so much downtime!)
- ✓ Streamlined certification (for analytical clearances).

Improved IAT

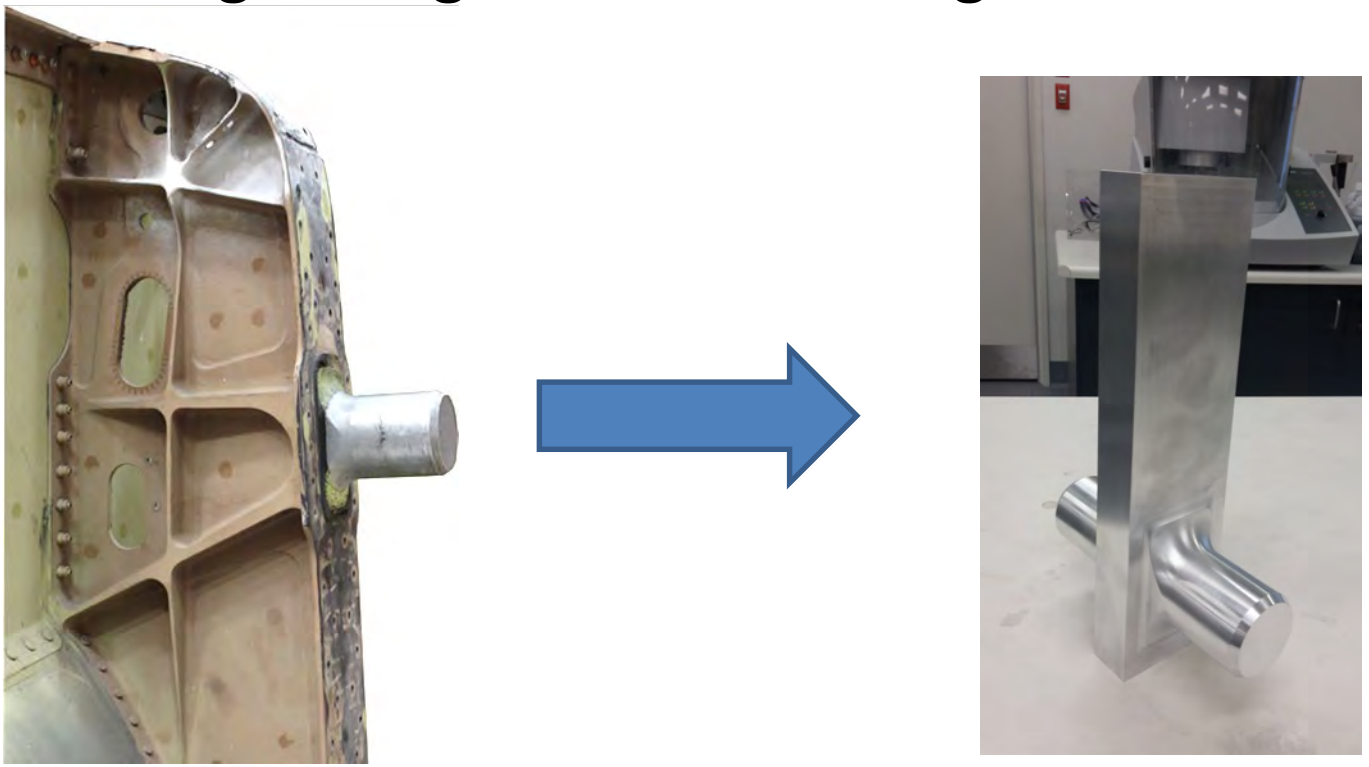


Avoid major repairs



ASSIST in Action

Challenge 1: Fighter aircraft wing root shear tie post.



Detailed description of Challenge at:

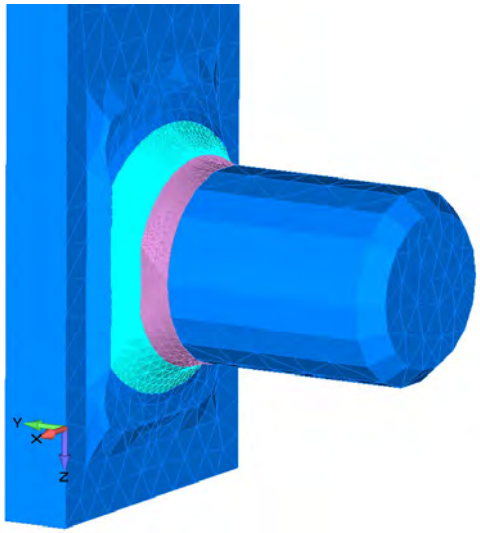
Main et al., 2019, Lessons from a Fatigue Prediction Challenge for an Aircraft Wing Shear Post. Int. J. Fat.; 123

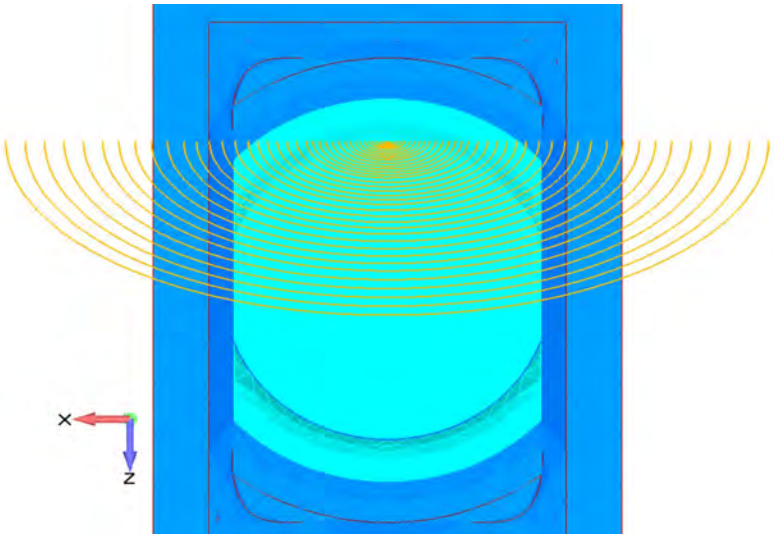
Three challenge participants

1. RUAG AFGROW (Swiss F/A-18 sustainment)
2. DST easigro
3. DST FASTRAN

- Participants given geometry, manoeuvre + buffet spectrum, material properties, FEM, strain data from critical radius
- All solutions based on Linear Elastic Fracture Mechanics (LEFM).
- Main differences: crack growth data/models, crack geometry and local stress conditions (β models)
- Blind predictions compared to 10 test results (5 test specimens)
- Participants bring unique strengths

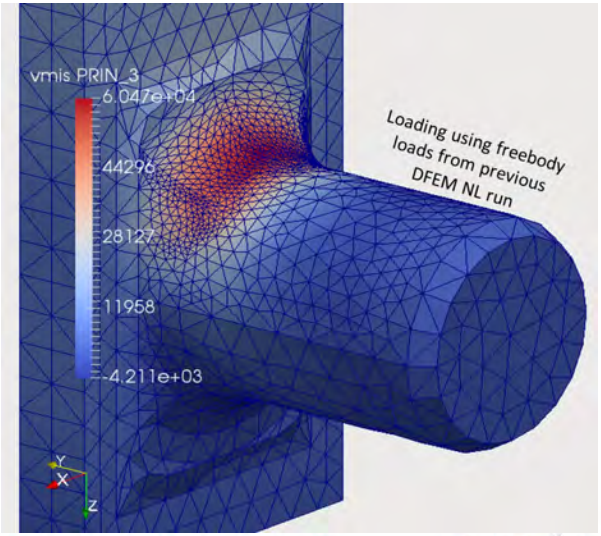
RUAG AFGROW – Finite Element Modelling (FEM)

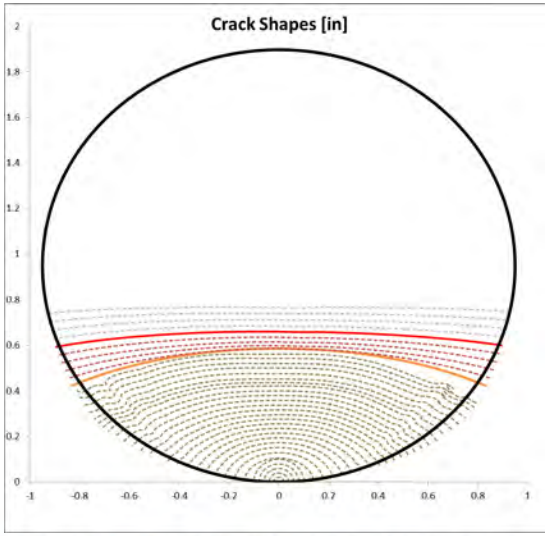




Energy Release Rate (ERR) – 38 crack steps in NX NASTRAN FEM.

Software Code_Aster used to simulate 3D crack growth through component (39 steps).



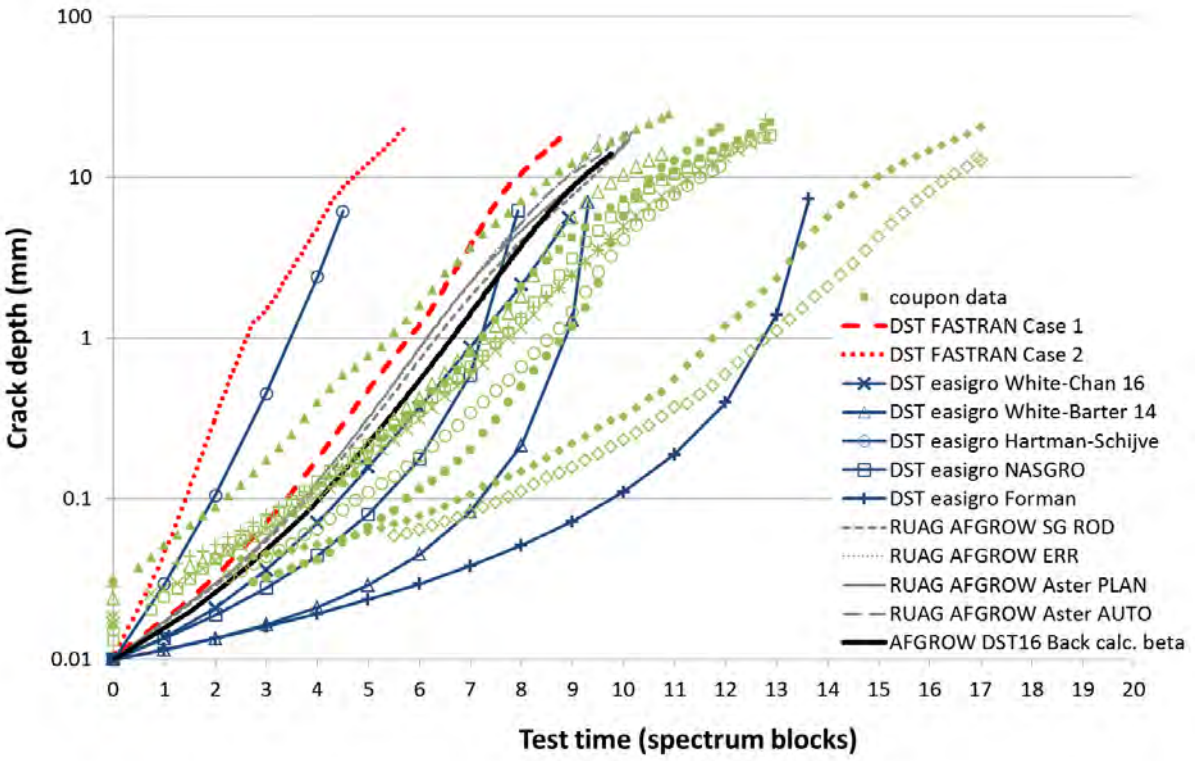


DST – Fatigue crack growth prediction research

- DST-developed software easigro (White, 2019, A guide to the program easigro for generating growth models, DST-Group-TR-3566)
- easigro can use many fatigue crack growth models, some DST developed.
- DST collects crack growth measurements for very small cracks to overcome limitations of traditional data sets.
- easigro can optimise crack growth models to match spectrum fatigue results.

Hartman-Schjive equation	White equation
$da/_{dN} = D\left[\frac{(\Delta K - \Delta K_{thr})}{\sqrt{(1-K_{max})/A}}\right]^{\alpha}$	$\frac{da}{dN} = \exp\left[a_w \log^3(\Delta K_e) - b_w \log^2(\Delta K_e) + c_w \log(\Delta K_e) - d_w\right] \times \exp\left[\frac{1}{(K_{1C}(1-R) - \Delta K)^{e_w}}\right]$ where: $\Delta K_e = \frac{\Delta K}{(1-R)^{fw}}$

Results

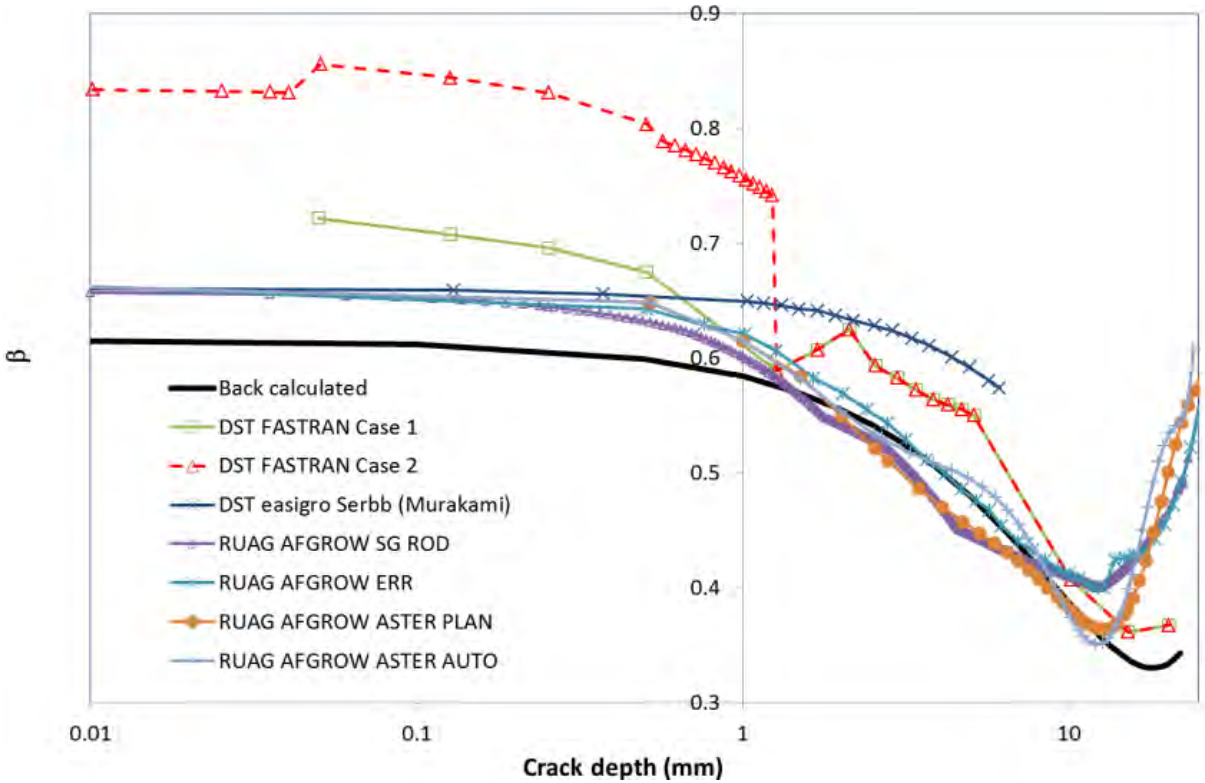


- All predictions within ~30% average life
- Nearly all conservative.
- All best predictions used cg models based on small crack measurements
- Optimised crack growth models especially good.
- QF data allows an examination of where models have limitations.

Green points are QF measurements –
each point = crack depth after *x* blocks of spectrum loading

Forensic Examination of Results

- All results benchmarked vs. back-calculated stress conditions local to crack (β).
- Another set of simple coupons run: QF of both sets of coupons enabled benchmarking of results



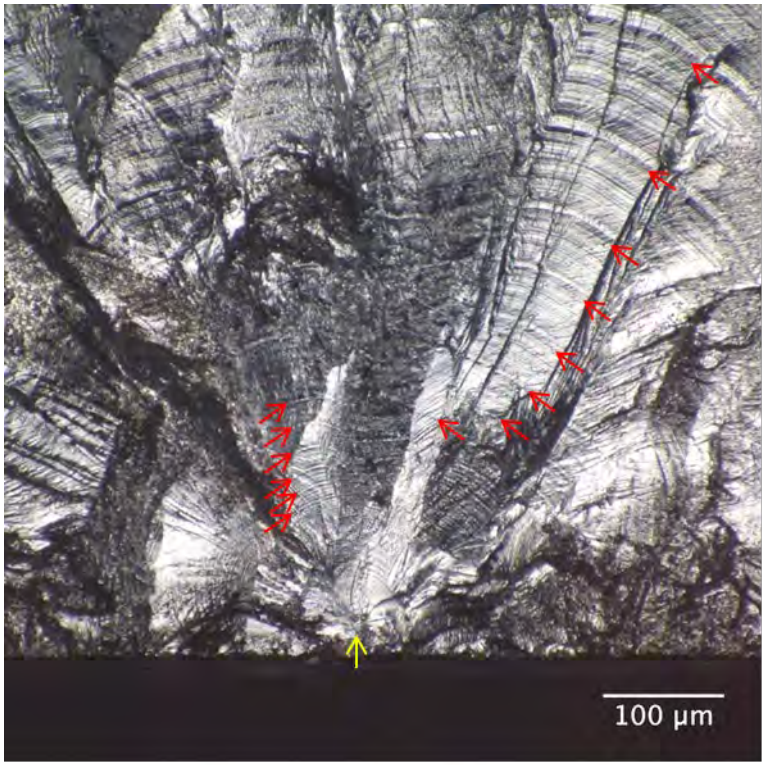
- Can see at what crack depths β models have problems
- RUAG modelling best.

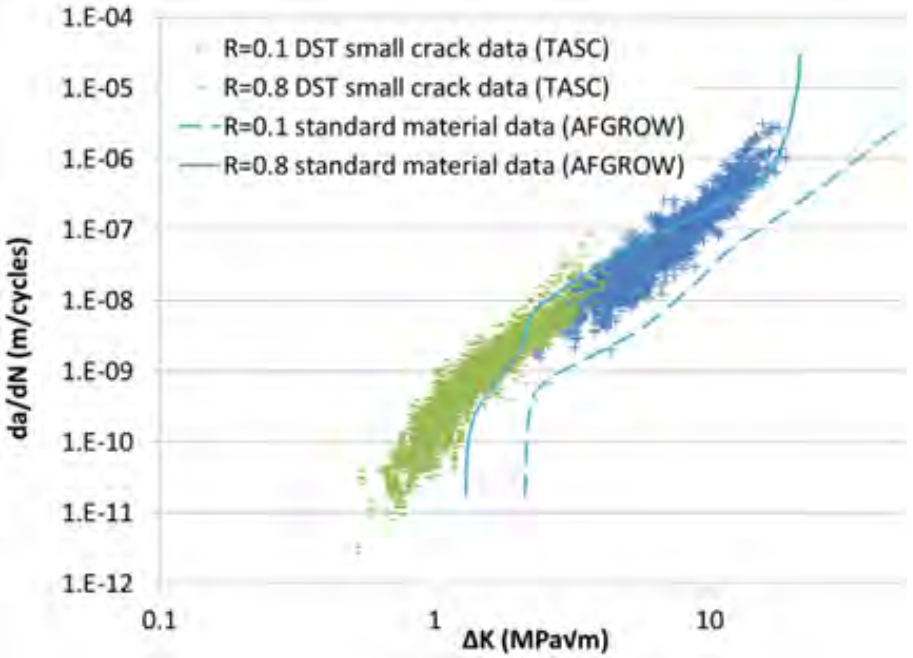
Lessons Learned

Because the crack was small for much of its fatigue life (i.e. < 1mm for more than 2/3 of fatigue life) it was very important to :

1. Accurately estimate the crack shape and the local stress conditions when the crack was small
2. Use crack growth models applicable to the growth of small cracks.

- Periodically summarise and publish Lessons Learned.





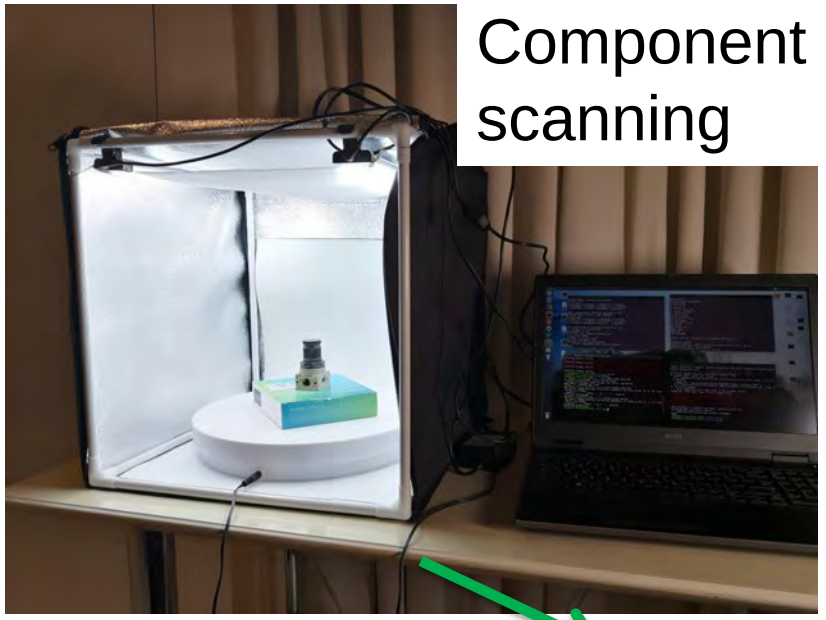
Burchill et al., 2017, *Improving fatigue life predictions with a crack growth rate material model based on small crack growth & legacy data,* 17th AAC, Melbourne.

Prediction Challenges - progress

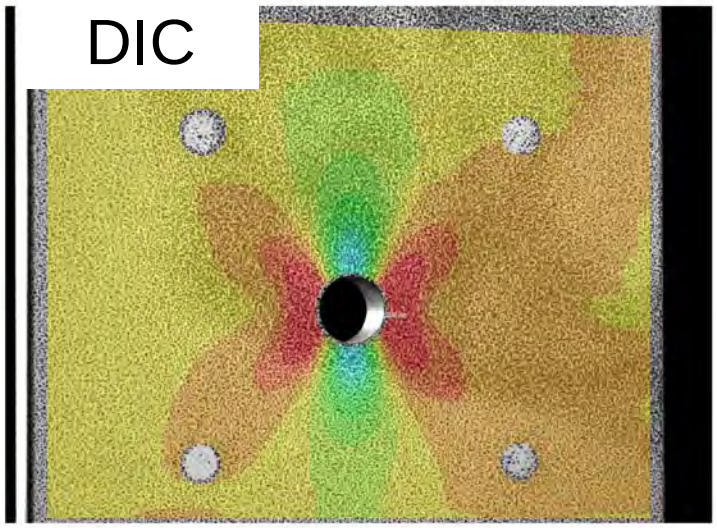
- 3 challenges completed
- Military Transport Aircraft & Helicopter Truncation challenge – still to be reviewed
- Entries from 8 organisations:
    - RUAG
    - Mississippi State University (FASTRAN)
    - DST Group
    - Southwest Research Institute (SwRI - NASGRO)
    - University of Adelaide
    - Monash University
    - United States Air Force (USAF)
    - National Research Laboratories (NLR, Netherlands)
- ASSIST Community has 58 members including DST, academia, industry and international partners
- Next challenge: Stiffened panel in Military Transport Aircraft

DST research directions

- High fidelity component scanning: transition to FEM.
- Incorporation of build quality into models
- DIC and TSA to calibrate models
- Improve fatigue prediction models (e.g. machine learning + atomic modelling)
- Improve full-scale test rates



Component scanning



DIC

Atomic modelling

SharePoint site: https://www.govteams.gov.au
To join email: ASSIST2019@dst.defence.gov.au