



Australian Government

Department of Defence
Science and Technology

Towards the Virtual Fatigue Test

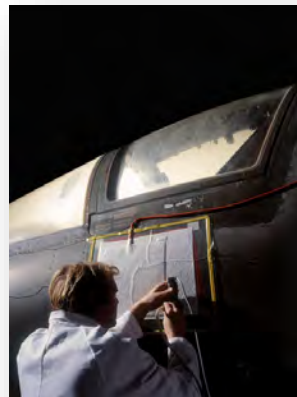
Ben Dixon & Madeleine Burchill
Defence Science and Technology

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

Total Ownership Cost



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

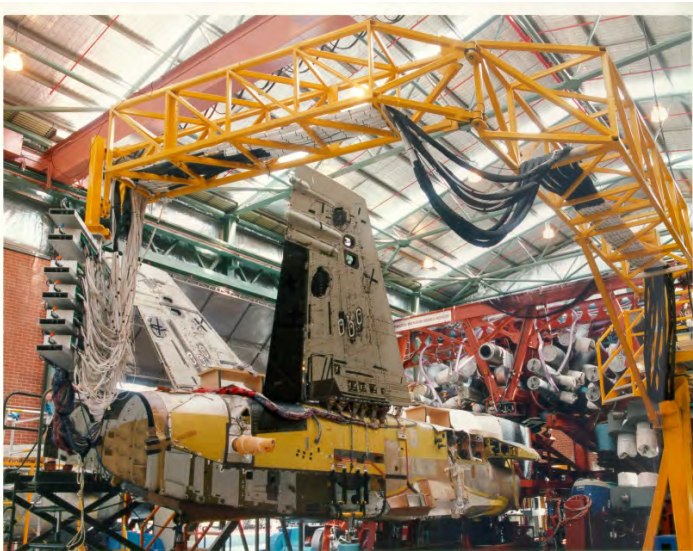
- Total Ownership Cost is one of 9 focus areas
- Drivers: decreasing budgets, increasing cost of manpower, materials, labour
- Vision: insert technology to reduce acquisition, lifecycle and **sustainment costs**

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

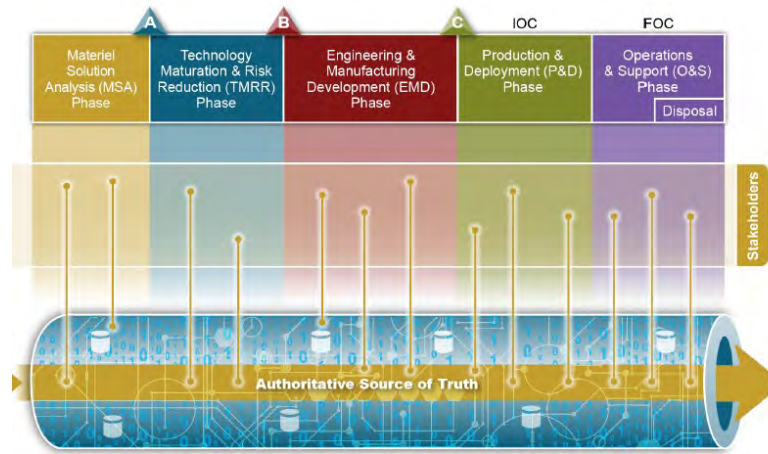


P-3C: SLAP



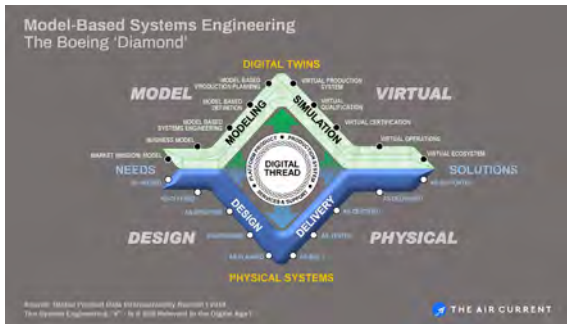
Digital trends - within Aerospace Domain

U.S. DoD



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

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

Airbus



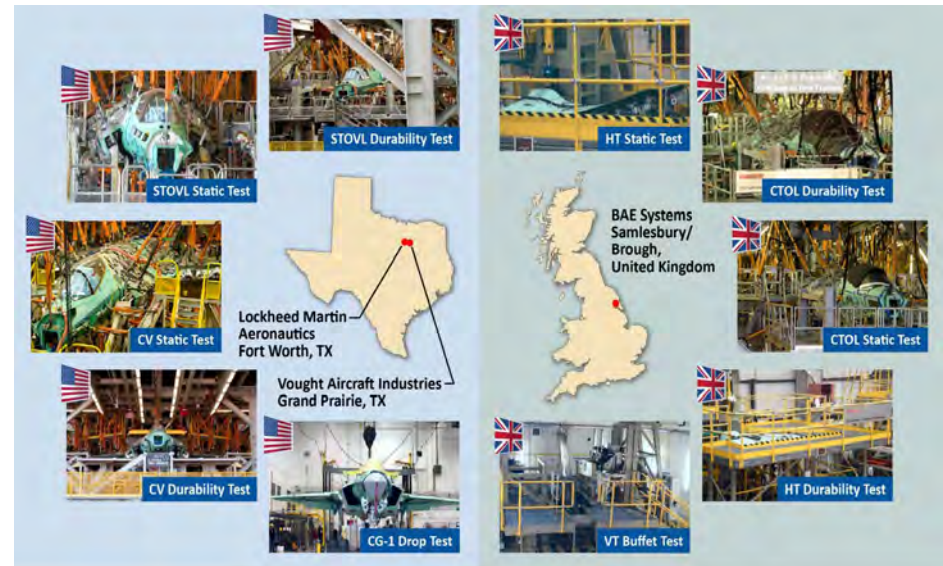
<https://www.airbus-sv.com/projects/9> accessed: 05/08/2019

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)



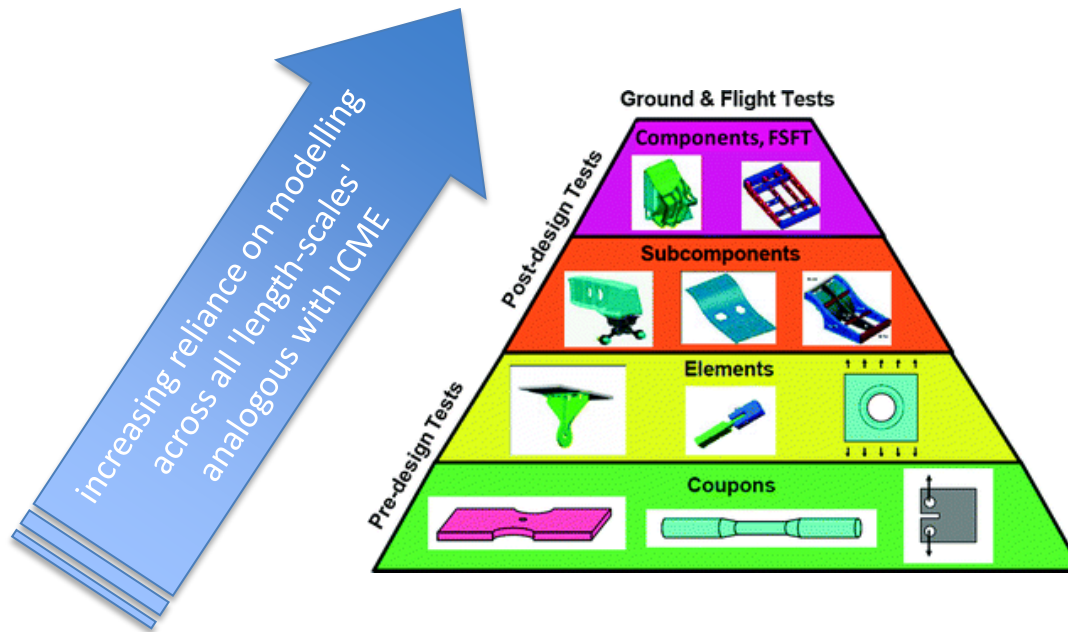
UNPRECEDENTED MULTI-VARIANT GROUND TEST PROGRAM

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

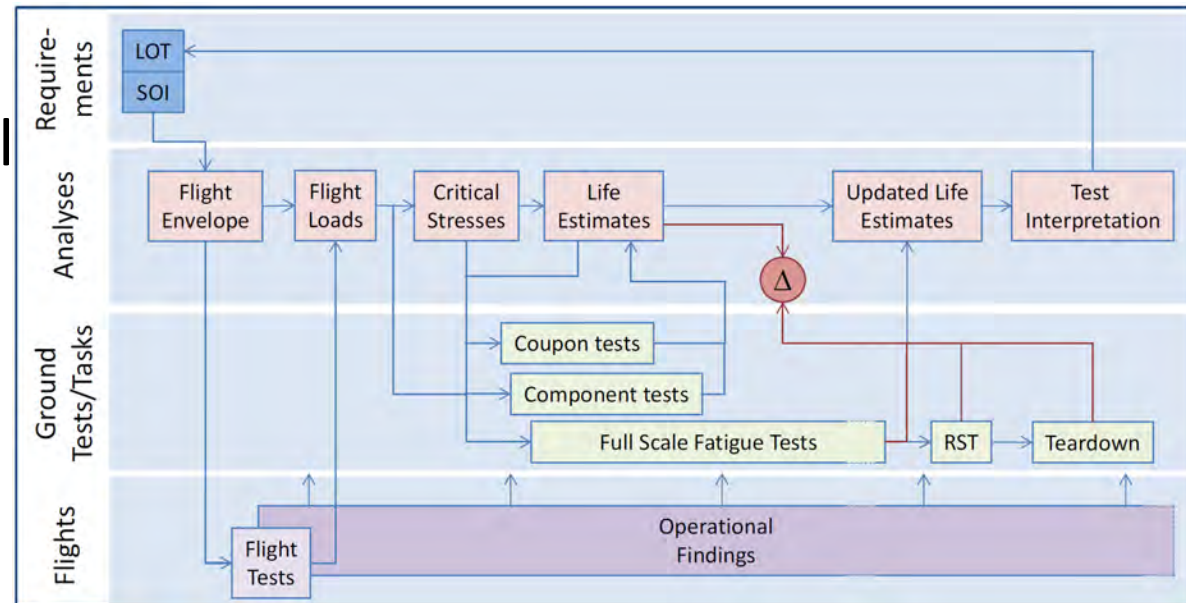
- fielding of innovative designs or modifications
- benefiting from advances in manufacturing and material technologies
- **responding** to meet challenges from emerging technologies



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 (**T**ransglobal **I**ntegrated **T**ests and **A**nalyses **N**etwork for **S**tructures).
- Collaborative program to help progress to virtual fatigue test.
- Now ASSIST:
Advancing **S**tructural **S**imulation to drive **I**nnovative **S**ustainment **T**echnologies



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

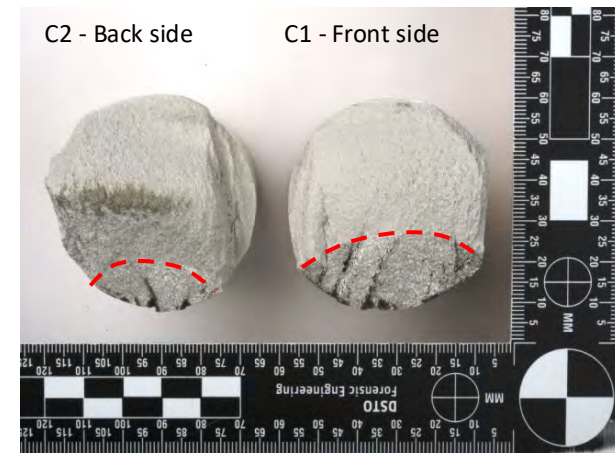
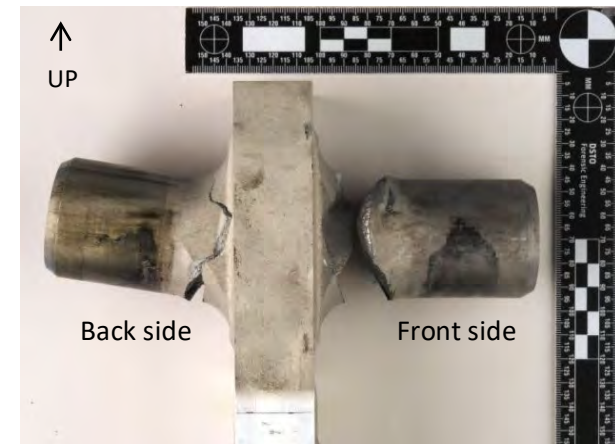
- To encourage the building of a sovereign collaborative network, that can support Defence in responding to technological changes and providing sustainment options to reduce the cost of ownership and/or increase platform availability.
- To provide information and foster discussions within the Engineering 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
Copyright: © Commonwealth of Australia, Department of Defence

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.

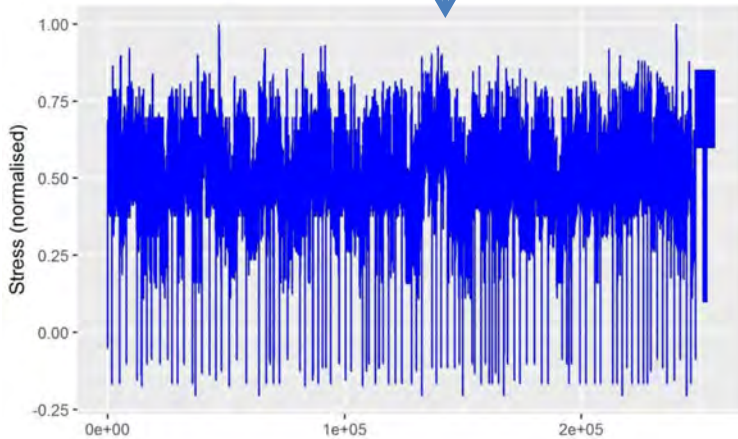


Main et al., 2019, Lessons from a Fatigue Prediction Challenge for an Aircraft Wing Shear Post. *Int. J. Fat.* 123

The Challenges

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

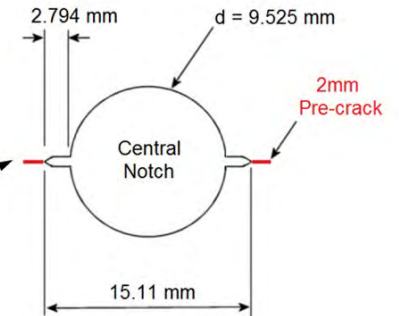
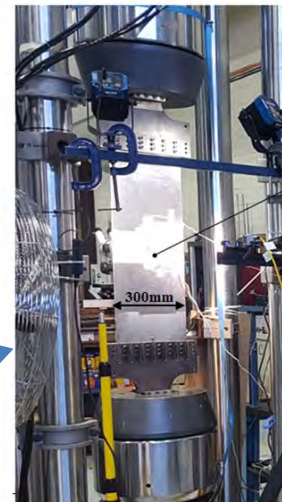
2. Helicopter spectrum truncation



1. Fighter wing root shear tie (completed)



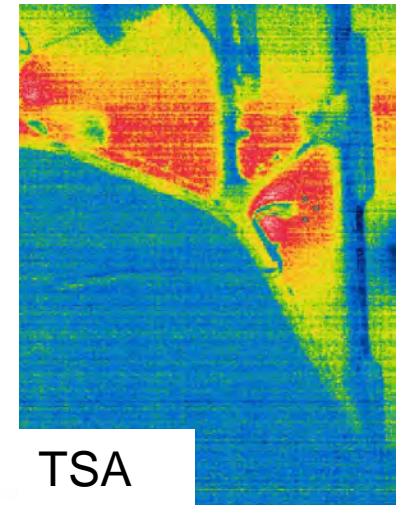
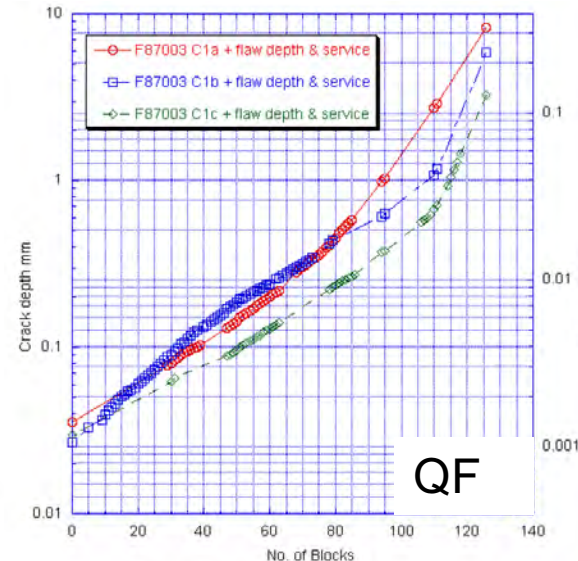
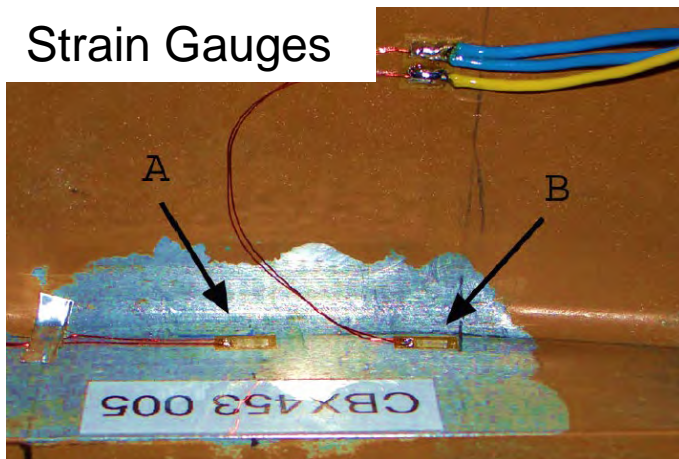
3. Long cracks in transport aircraft



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



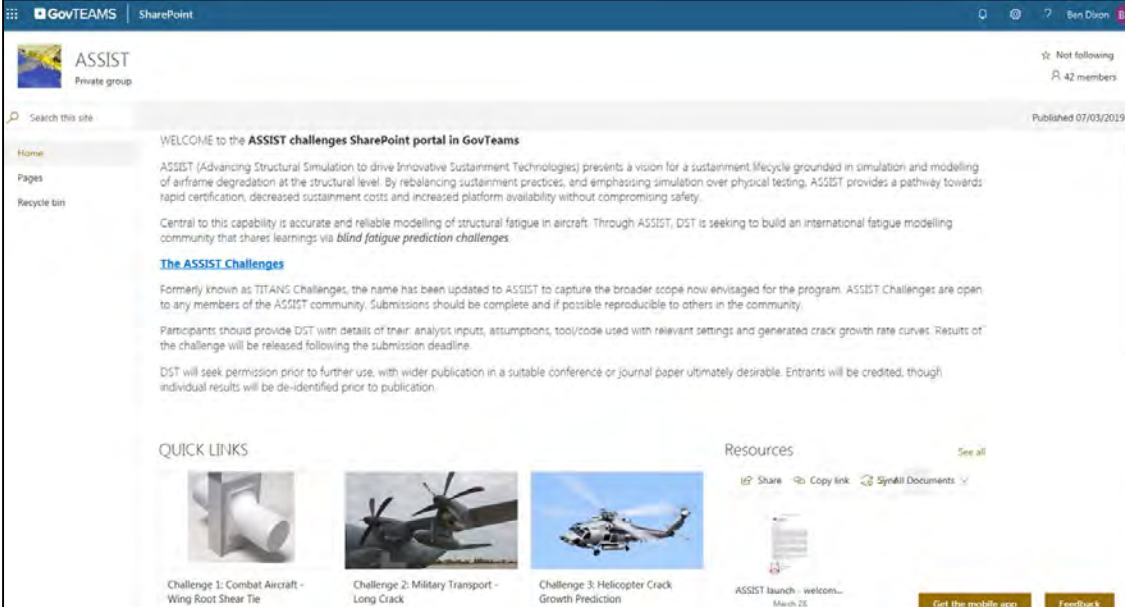
ASSIST Community

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)



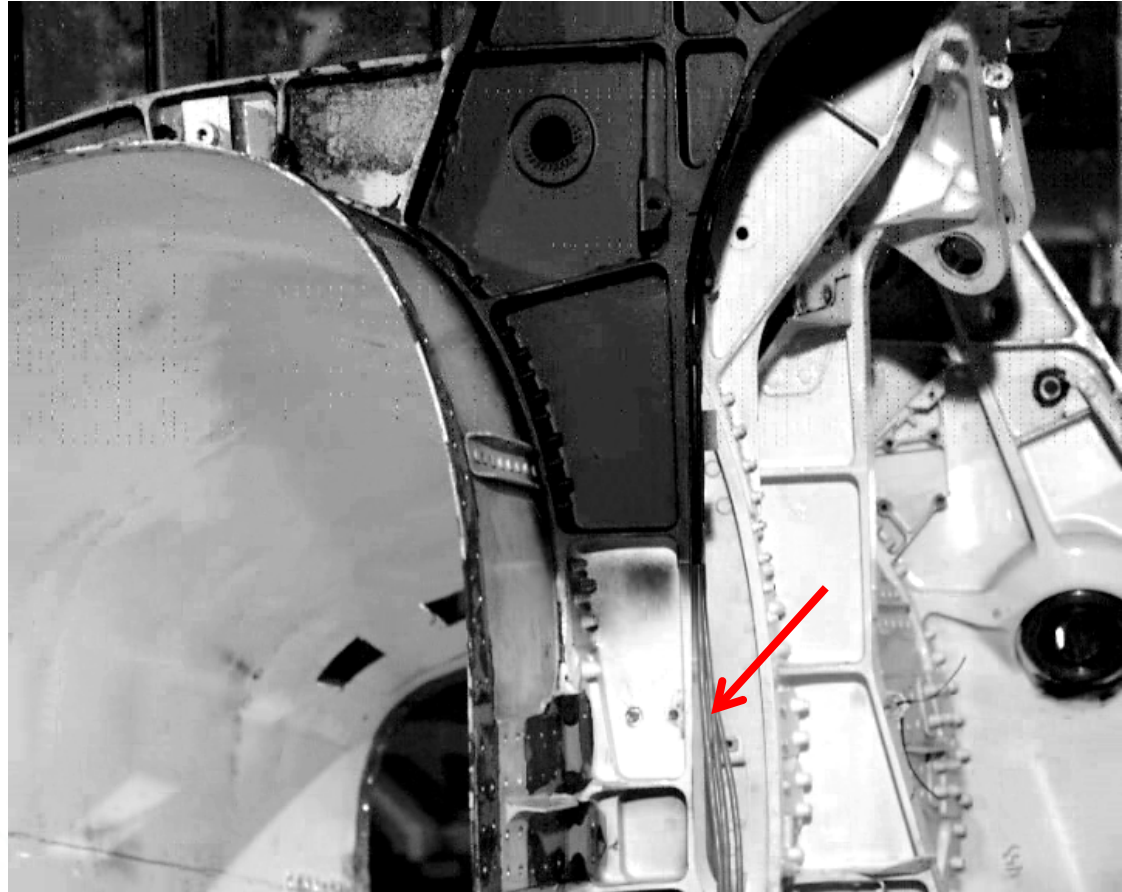
The screenshot shows the ASSIST SharePoint portal within the GovTEAMS environment. The page title is "ASSIST Private group" and it indicates 42 members. The main content area features a welcome message: "WELCOME to the ASSIST challenges SharePoint portal in GovTeams". Below this, there is a paragraph describing ASSIST's vision for a sustainable lifecycle grounded in simulation and modeling of airframe degradation. A section titled "The ASSIST Challenges" explains that the program is open to all members and provides details on submission requirements and the release of challenge results. A "QUICK LINKS" section displays three challenge cards: "Challenge 1: Combat Aircraft - Wing Root Shear Tie", "Challenge 2: Military Transport - Long Crack", and "Challenge 3: Helicopter Crack Growth Prediction". A "Resources" section is also visible with options to share, copy link, and sync documents. The page footer includes a "Get the mobile app" button and a "Feedback" link.

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

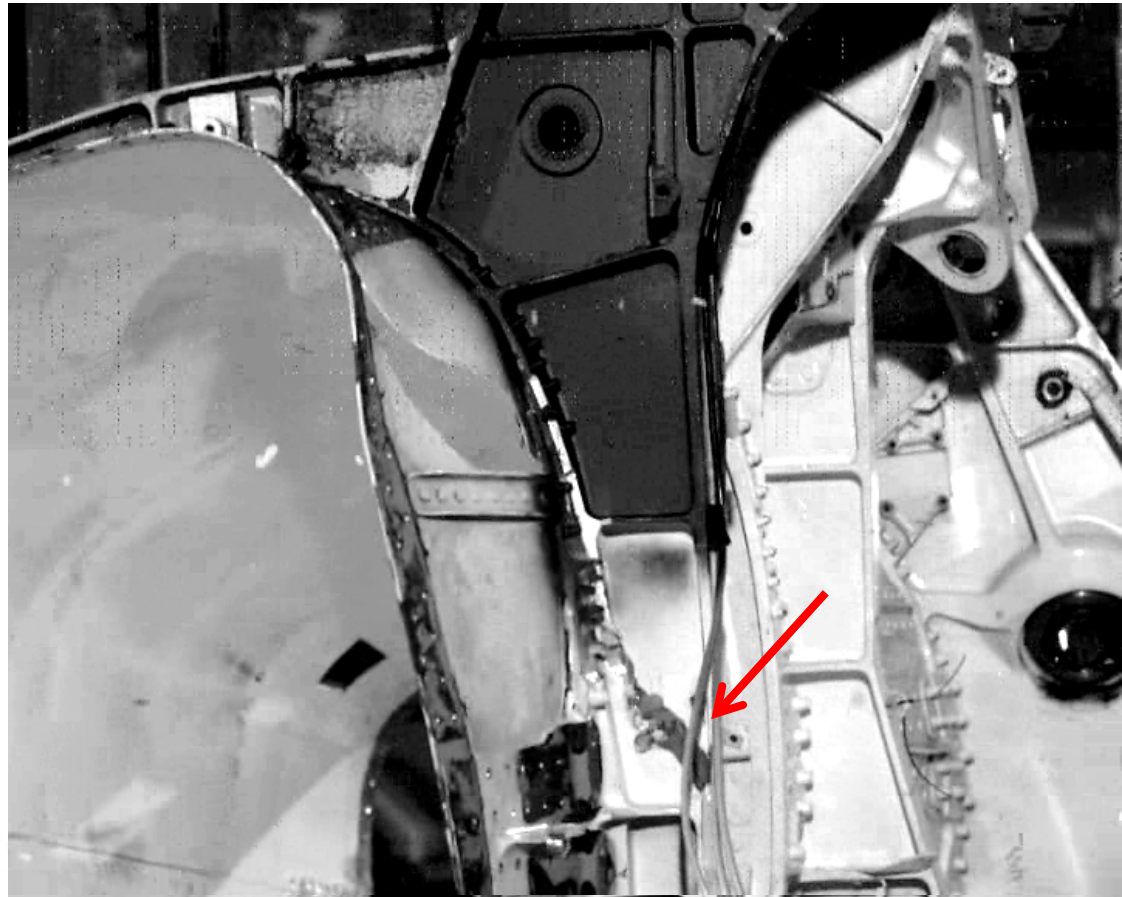


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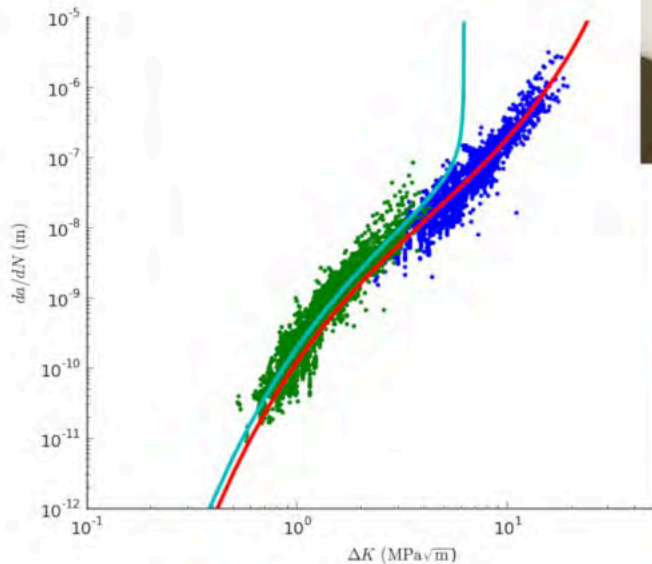
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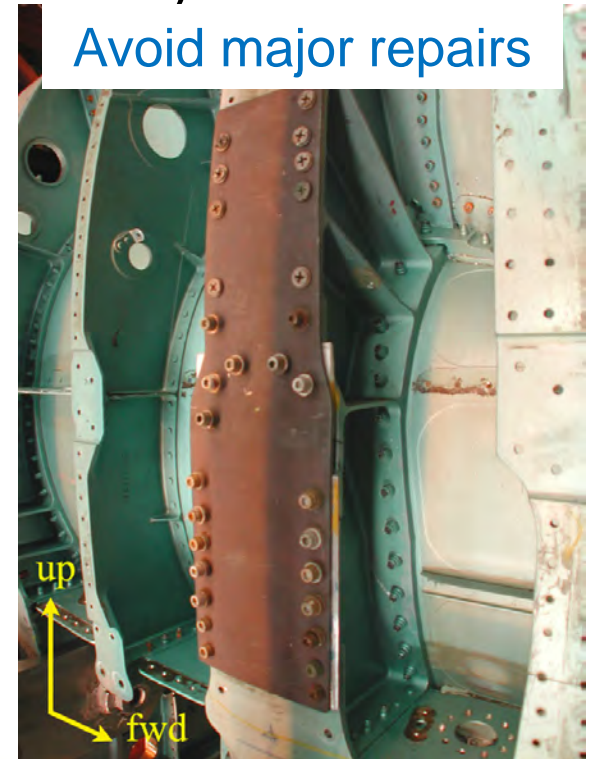
Medium term benefits

- ✓ 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

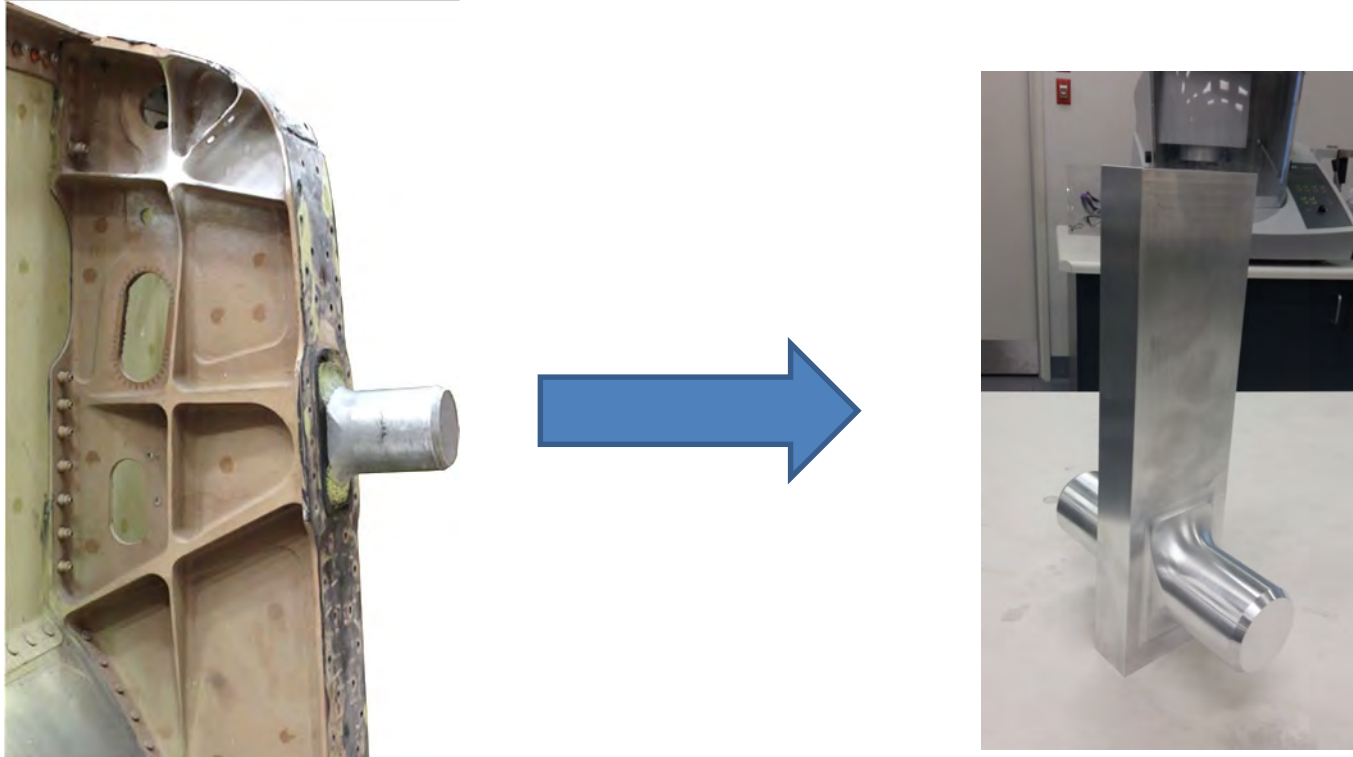


Avoid major repairs



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

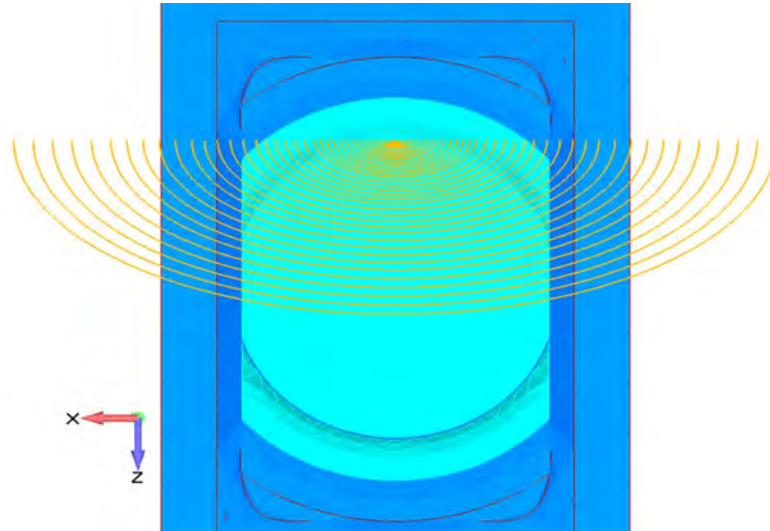
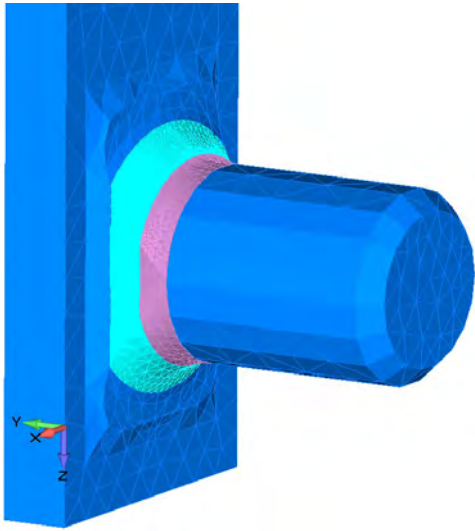
1. RUAG AFGROW (Swiss F/A-18 sustainment)

2. DST easigro

3. DST FASTRAN

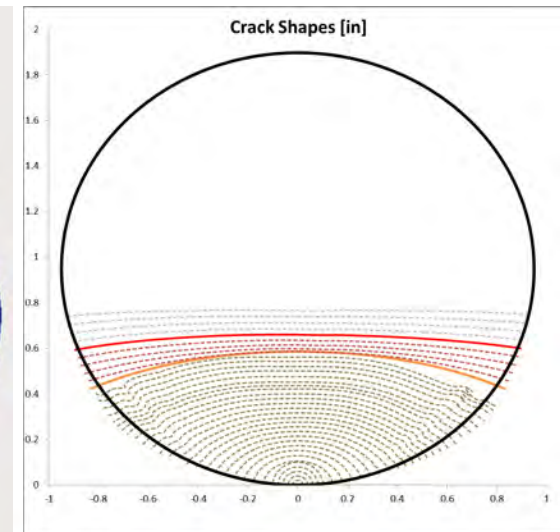
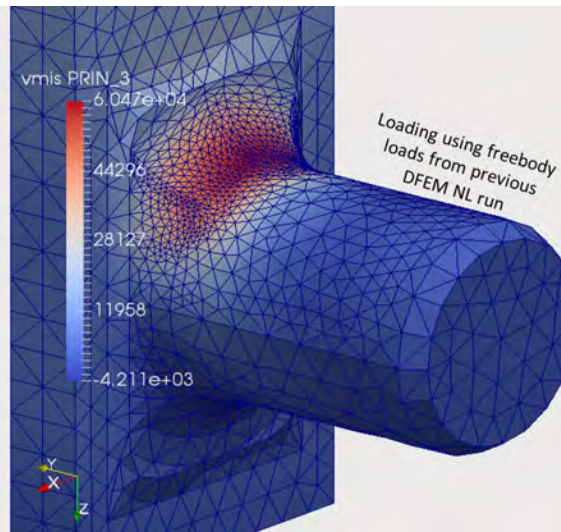
- Participants given geometry, manoeuvre + buffet spectrum, material properties, FEM, strain data from critical radius
- All solutions based on Linear Elastic Fracture Mechanics (LEFM).
- Main differences: crack growth data/models, crack geometry and local stress conditions (β models)
- Blind predictions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

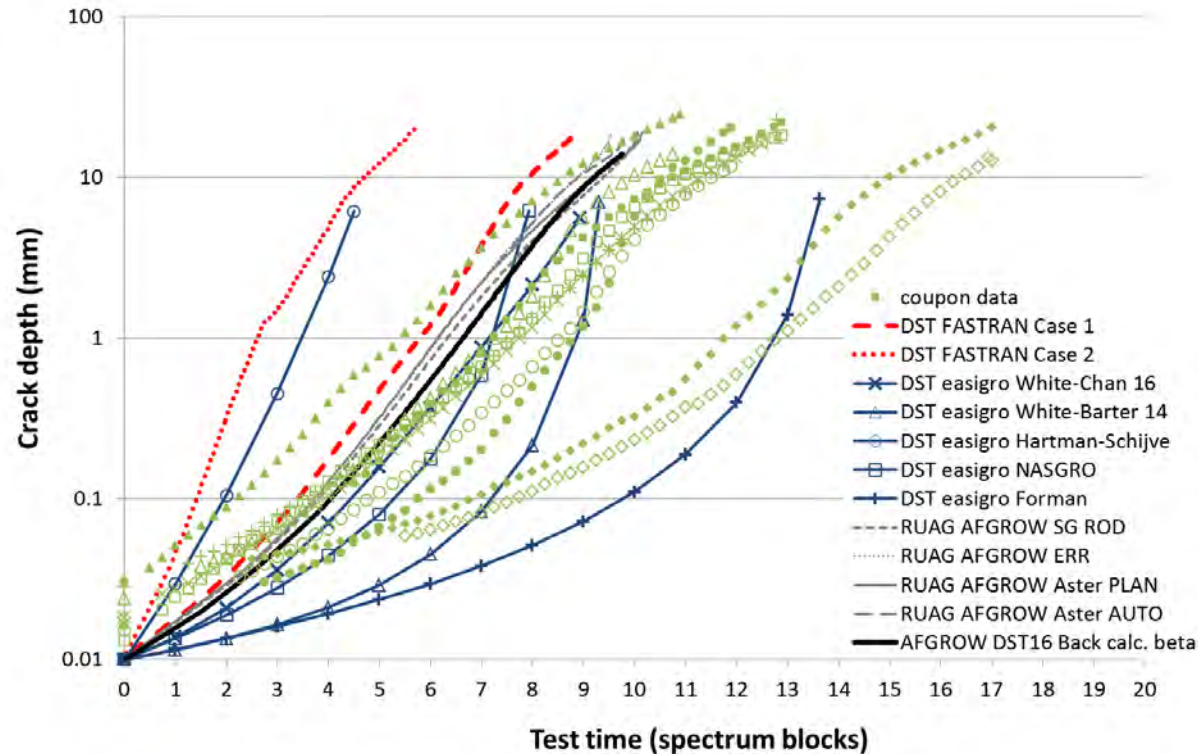
$$da/dN = D \left[\frac{(\Delta K - \Delta K_{thr})}{\sqrt{(1 - K_{max})/A}} \right]^\alpha$$

White equation

$$\begin{aligned} \frac{da}{dN} &= \exp[a_w \log^3(\Delta K_e) - b_w \log^2(\Delta K_e) \\ &+ c_w \log(\Delta K_e) - d_w] \\ &\times \exp \left[\frac{1}{(K_{1c}(1-R) - \Delta K)^{e_w}} \right] \end{aligned}$$

$$\text{where: } \Delta K_e = \frac{\Delta K}{(1-R)f_w}$$

Results

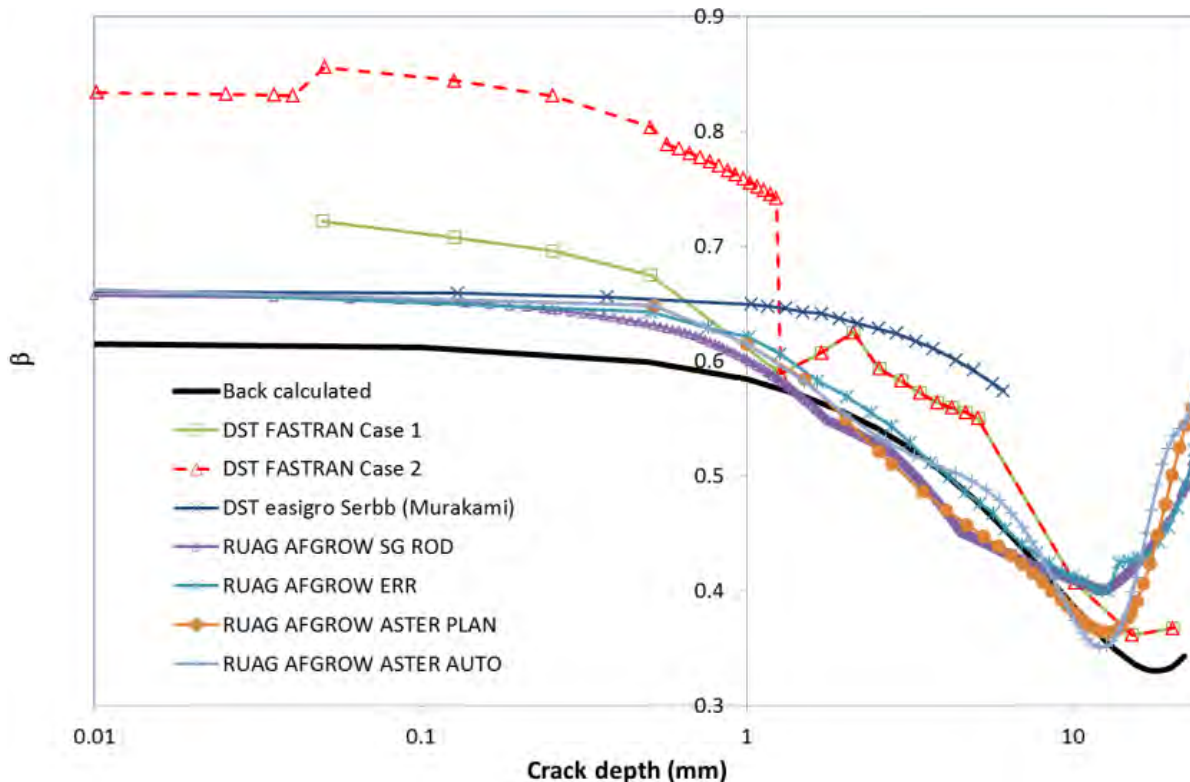


Green points are QF measurements –
each point = crack depth after x blocks of spectrum loading

- 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.

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

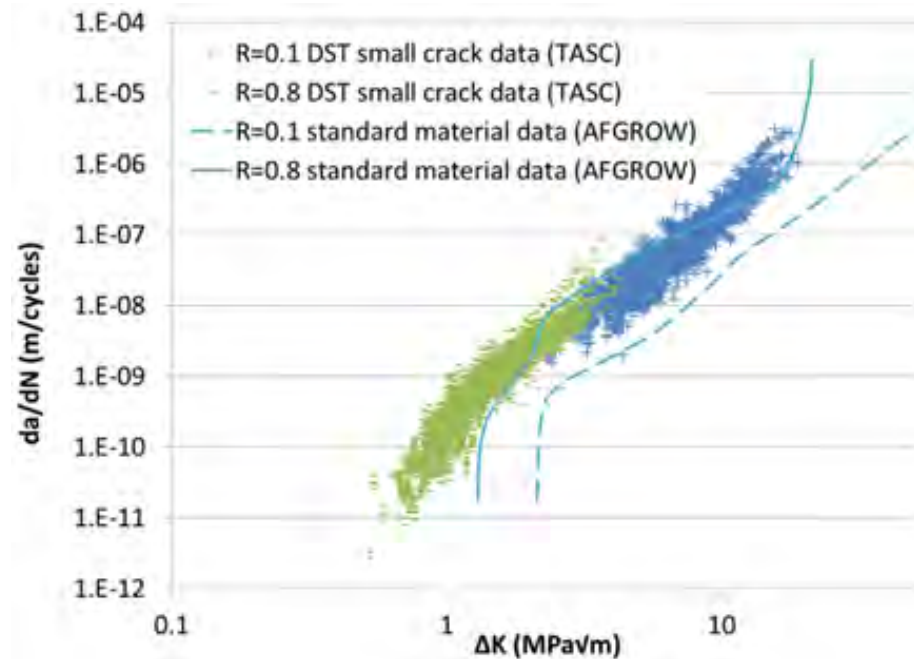
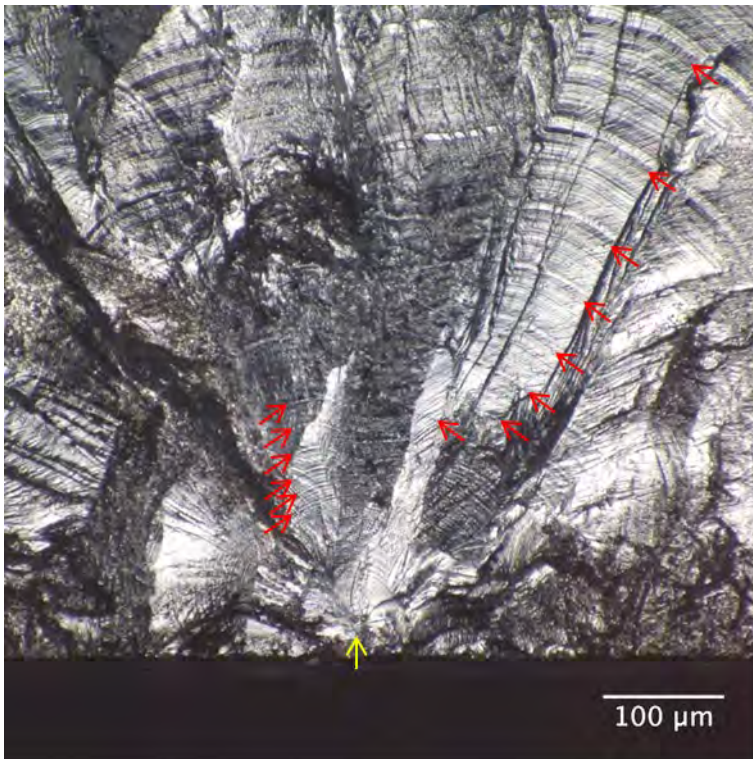


- Can see at what crack depths β models have problems
- RUAG modelling best.

Lessons Learned

Because the crack was small for much of its fatigue life (i.e. $< 1\text{mm}$ 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.



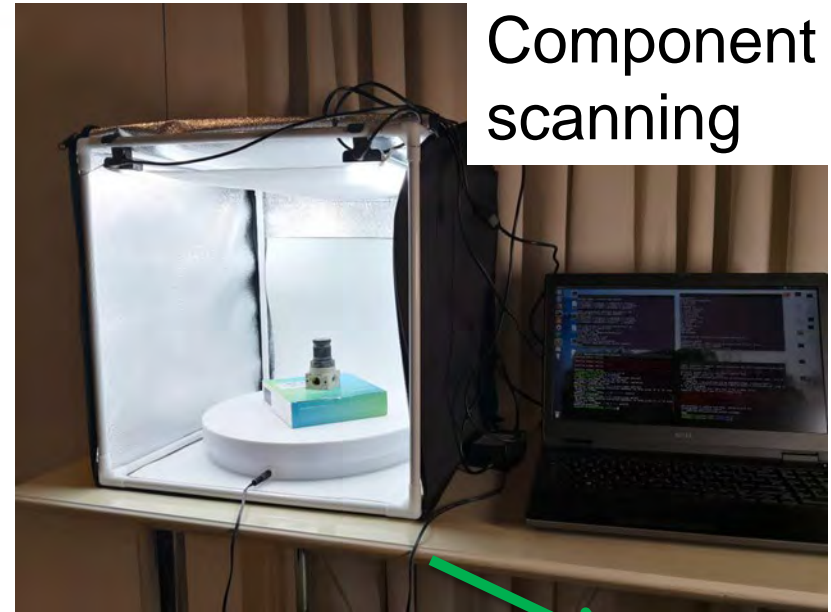
Burchill et al., 2017, *Improving fatigue life predictions with a crack growth rate material model based on small crack growth & legacy data*, 17th AAC, Melbourne.

Prediction Challenges - progress

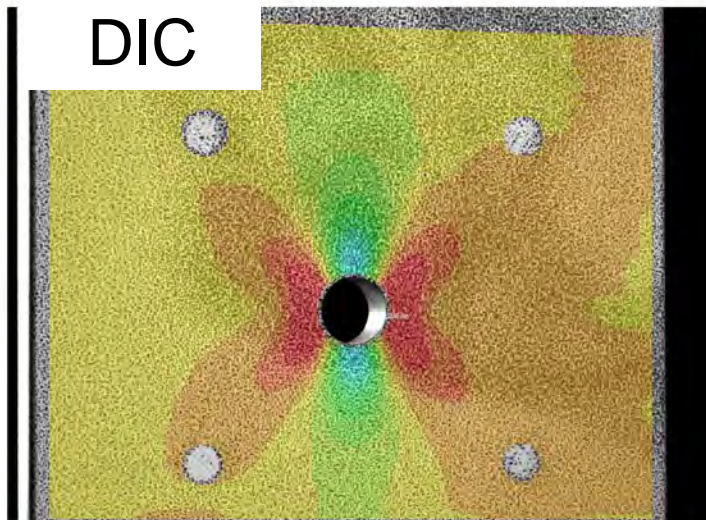
- 3 challenges completed
- Military Transport Aircraft & Helicopter Truncation challenge – still to be reviewed
- Entries from 8 organisations:
 - RUAG
 - Mississippi State University (FASTRAN)
 - DST Group
 - Southwest Research Institute (SwRI - NASGRO)
 - University of Adelaide
 - Monash University
 - 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

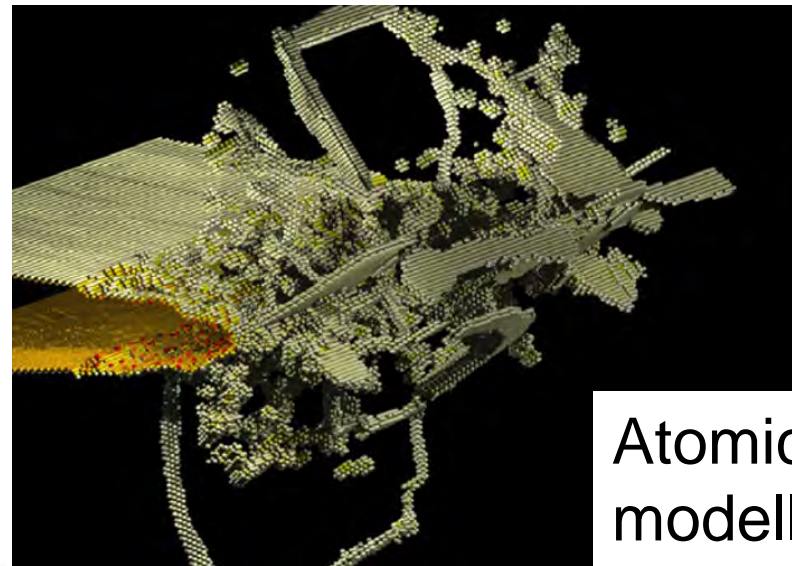
- High fidelity component scanning: transition to FEM.
- Incorporation of build quality into models
- DIC and TSA to calibrate models
- Improve fatigue prediction models (e.g. machine learning + atomic modelling)
- Improve full-scale test rates



Component scanning



DIC



Atomic modelling



SharePoint site: <https://www.govteams.gov.au>

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



Not following
42 members

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Questions

WELCOME to the **ASSIST** challenge community. ASSIST (Advancing Structural Simulation) is a community of airframe degradation at the rapid certification, decreased simulation time and international fatigue modelling. Central to this capability is access to a community that shares learning.

...unded in simulation and modelling ASSIST provides a pathway towards international fatigue modelling

The ASSIST Challenges

Formerly known as TITANS Challenges, the name has been updated to ASSIST to capture the broader scope now envisaged for the program. ASSIST Challenges are open to any members of the ASSIST community. Submissions should be complete and if possible reproducible to others in the community.

Participants should provide DST with details of their: analysis inputs, assumptions, tool/code used with relevant settings and generated crack growth rate curves. Results of the challenge will be released following the submission deadline.

DST will seek permission prior to further use, with wider publication in a suitable conference or journal paper ultimately desirable. Entrants will be credited, though individual results will be de-identified prior to publication.

QUICK LINKS

Challenge 1: Combat Aircraft - Wing Root Shear Tie

Challenge 2: Military Transport - Long Crack

Challenge 3: Helicopter Crack Growth Prediction

Resources

See all

Share Copy link SynAll Documents

ASSIST launch - welcome...
March 28

Get the mobile app Feedback

