Certification of Adhesive Bonded Repairs for Environmental Durability

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- **RAAF**

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Technology Organisation

Talk Outline

- Background (DSTO History)
- Current Status of Bonded Repairs (RAAF Usage)
- Preferred Status for Bonded Repairs (Justifying credit)
- Environmental Certification (Definition and Issues)
  - Strategy
  - Current DSTO and RAAF Efforts
  - Current Limitations to Approach
  - Solutions

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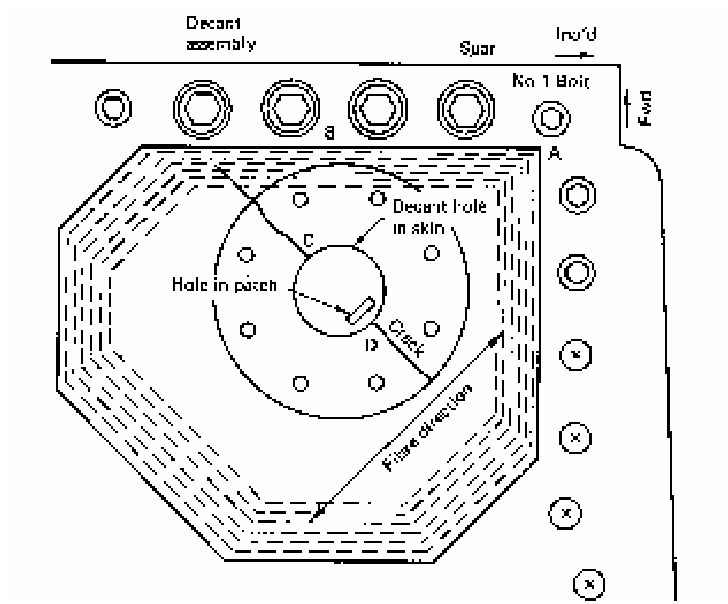
Background (DSTO History)

- DSTO Research into Crack-Patching pioneered by Alan Baker
- Large range of applications to RAAF Aircraft since mid 70's
    - examples include:
        - MB-326H
        - Mirage III
        - C-130E
        - F-111C

Background (DSTO History)

- **Mirage III** cracking out of fuel decant hole
- 180 repairs
- 7 bonding failures over 8 years due to voiding in adhesive during cure, caused by high humidity in tropics

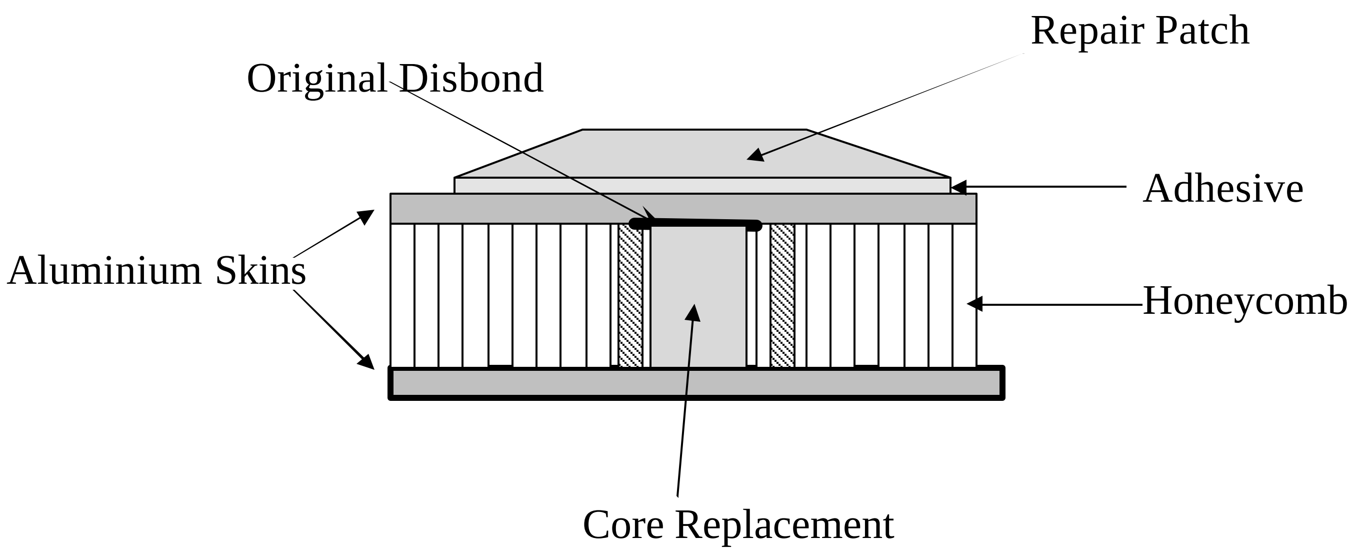


Background (DSTO History)

- **C-130E** wing risers
- Stress-corrosion cracking
- More than 1000 repairs
- 20 years of service, but few cases of cracking occurring after patching
- RAAF able to retain original wing skins for full service life ($130M savings)

Background (RAAF History)

- **F-111C** metal-to-metal repairs on honeycomb sandwich panels
- Grit-blast and silane treatment
- 30 repairs per month since 1995, only 2 known bond failures due to technician disregarding process requirements



Current Status of Bonded Repairs
(RAAF Usage)

• Repairs to Primary Structure use *"Fail-Safe" Approach*

✵ *Reinforcement* only allowed if original safety margin on DLL is retained if patch is lost (no-credit given to repair)

– eg. Fighter aircraft- crack in single load path component retains DLL strength (OK for preventative patch, small crack or slow growth)

– eg. Transport aircraft- multiple load path component retains Fail-Safe load strength if single path has failed (doesn't significantly alter current maintenance and inspection process)

Preferred Status of Bonded Repairs
(RAAF Usage)

- Repairs to Primary Structure given Full Credit

  1. credit given for patch to restore static strength (DUL)

  2. credit given for fatigue life restoration

     2.1 patch managed using *Damage Tolerant* approach

     2.2 inspection intervals based on time for crack in repaired structure to reach critical size for DLL

  3. credit given for **Environmental Durability**

Environmental Certification of Bonded Repairs

-Strategy

- Patch Structural Credit only achievable if guarantee is provided for:
  - **Environmental Durability**
    - Define requirement
    - Define acceptance test
    - Define pass/fail criteria
    - Correlate test against service performance
    - Develop Risk and Reliability (R+R) Model to Quantify Repair Failure Probability

Environmental Certification of Bonded Repairs
– Requirement

1. Retain initial design capability for required life of repair

2. Any reduction in design capability will be identified by a management strategy prior to any compromise in air worthiness

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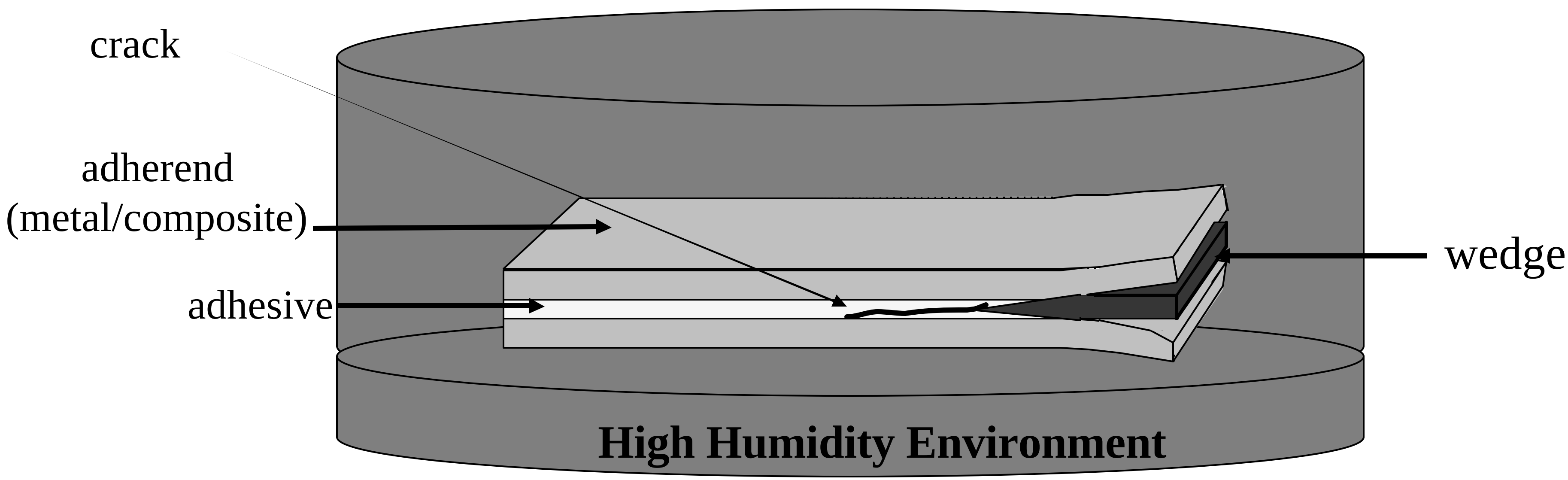
– Acceptance Test

- **Potential Candidate: Wedge Test**
  - crack measured in elevated temperature/high humidity
  - pass/fail based on crack-length, crack-growth and failure mode
  - presently used by RAAF for technician and process qualification



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– Pass/Fail Criteria

- **Wedge Test**
    - Provides a template for assessing the major risks associated with the adhesive bonding operation
    - Test Matrix can be defined to establish
        - pass/fail criteria for given system for ideal case
        - sensitivity studies to establish effect of process deviations, environmental effects and human factors
        - data-basing can establish long-term trends (batch effects, individual performance, unit standards....)

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– Correlation with Service Data

- compare service performance of bonded repair to wedge data
  - service performance determined through
    - tear down inspection
    - crack growth measurements (structure)
    - NDI (ultrasonics, tap-hammer)
  - need to define repair condition
    - strength (flatwise tension…)
    - failure mode (cohesion, adhesion…)

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– Risk and Reliability (R+R) Model

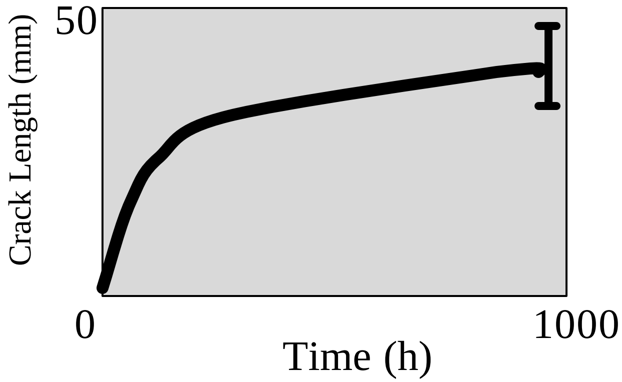
- **Modelling to Quantify Risk of Repair Failure**
  - optimise wedge test for pass criteria and develop R+R model
  - modify model for application to bonded repairs
  - validate model by correlation with service performance
  - optimise model for service loads, location and environment
  - verify optimised model with independent service data

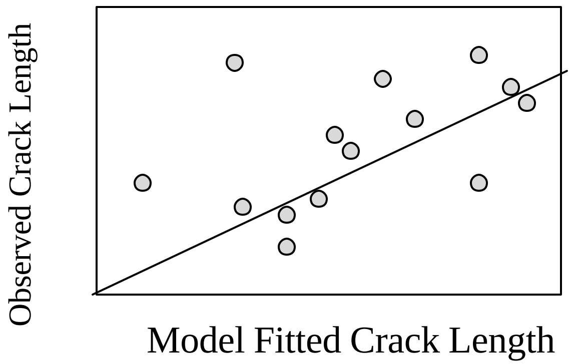
R+R Model

1. Optimise Wedge Test

Step 1:

“Current”





- regression model current wedge data with current measurable predictor variables

$$crack(mm)=\beta_0+\beta_1X_1+\beta_2X_2$$

β: fitted coefficients

X: predictor variables

eg. Adhesive batch, age, surface treatment, alloy

- determine pass/fail rate based on acceptance criteria (eg. 1/100)

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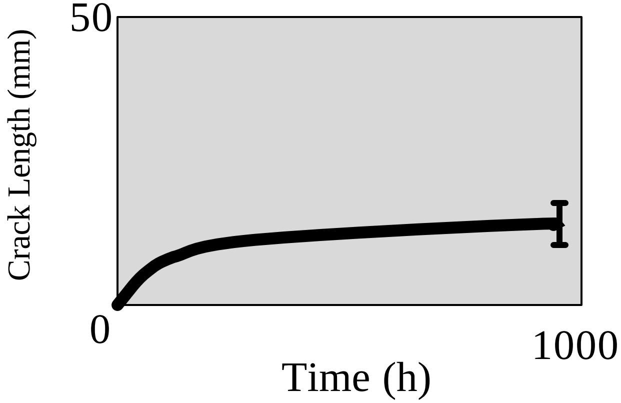
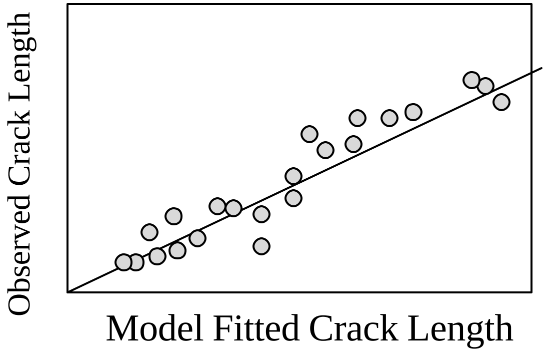
R+R Model

1. Optimise Wedge Test

Step 2:

“Optimised”





- Identify new predictor variables and establish measurement procedures
- Implement new process and remodel data

$$crack(mm)=\beta_0+\beta_1X_1+\beta_2X_2+ \beta_3X_3 + \beta_4X_4+\ldots$$

β: fitted coefficients

X: predictor variables

Adhesive batch, age, surface treatment, alloy, technician experience, location, surface condition, adhesive condition.…

- determine new pass/fail rate based on acceptance criteria (eg. 1/1000)

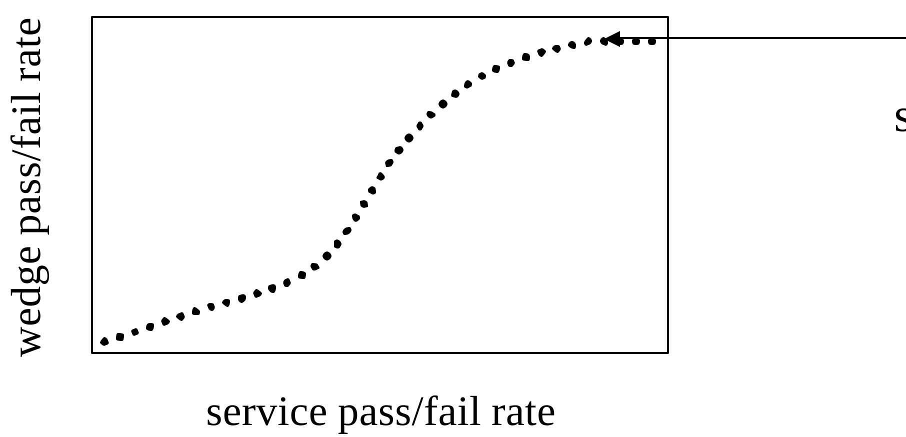
R+R Model

2. Correlate Wedge Test with Service Data

Step 1:

- determine service condition of repairs (establish acceptance criteria and testing)
- establish controls employed during repair application
- back-calculate wedge performance and the “effective” pass/fail rate
- correlate wedge against service pass/fail rate

“correlation”



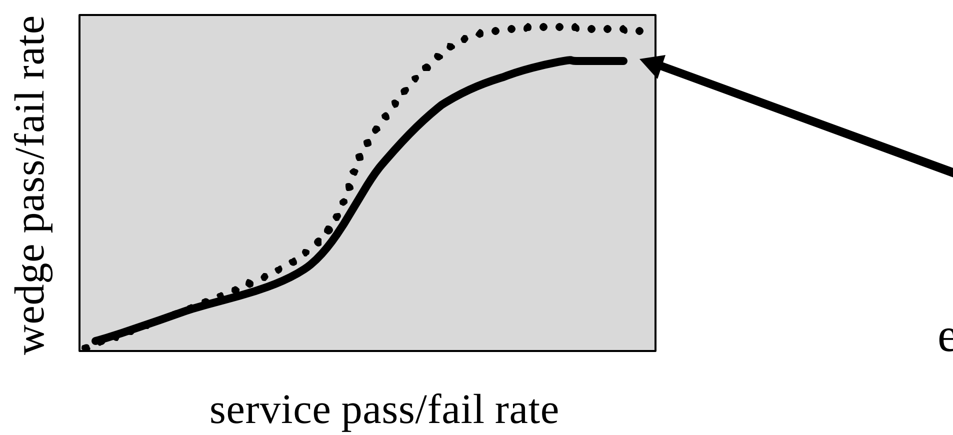
R+R Model

2. Correlate Wedge Test with Service Data

Step 2:

- identify additional predictor variables unique to repair application
- implement controls to record predictor variables during repair to conform with wedge acceptance criteria
- determine effect of recorded repair application variables on wedge result
- remodel wedge test and re-calibrate against service performance

"level 1 calibration"



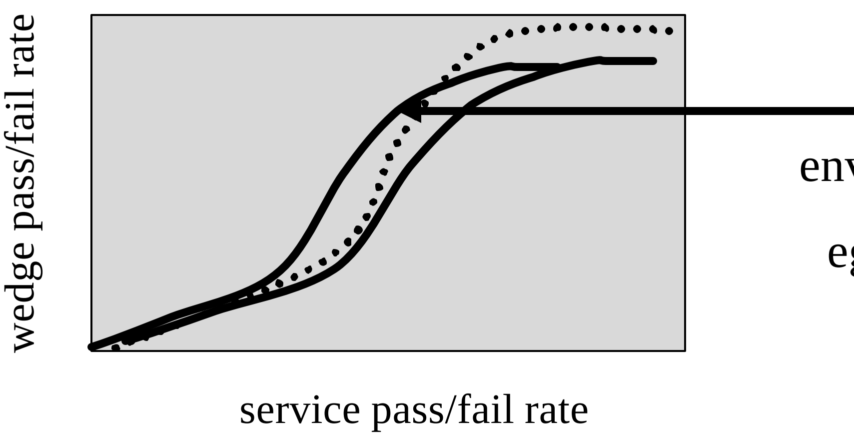
R+R Model

2. Correlate Wedge Test with Service Data

Step 3:

- identify and record predictor variables unique to repair service environment
- determine effect of recorded repair environment variables on service performance
- remodel wedge test and re-calibrate against service performance

“level 2 calibration”



eg. Hot/wet, highly loaded

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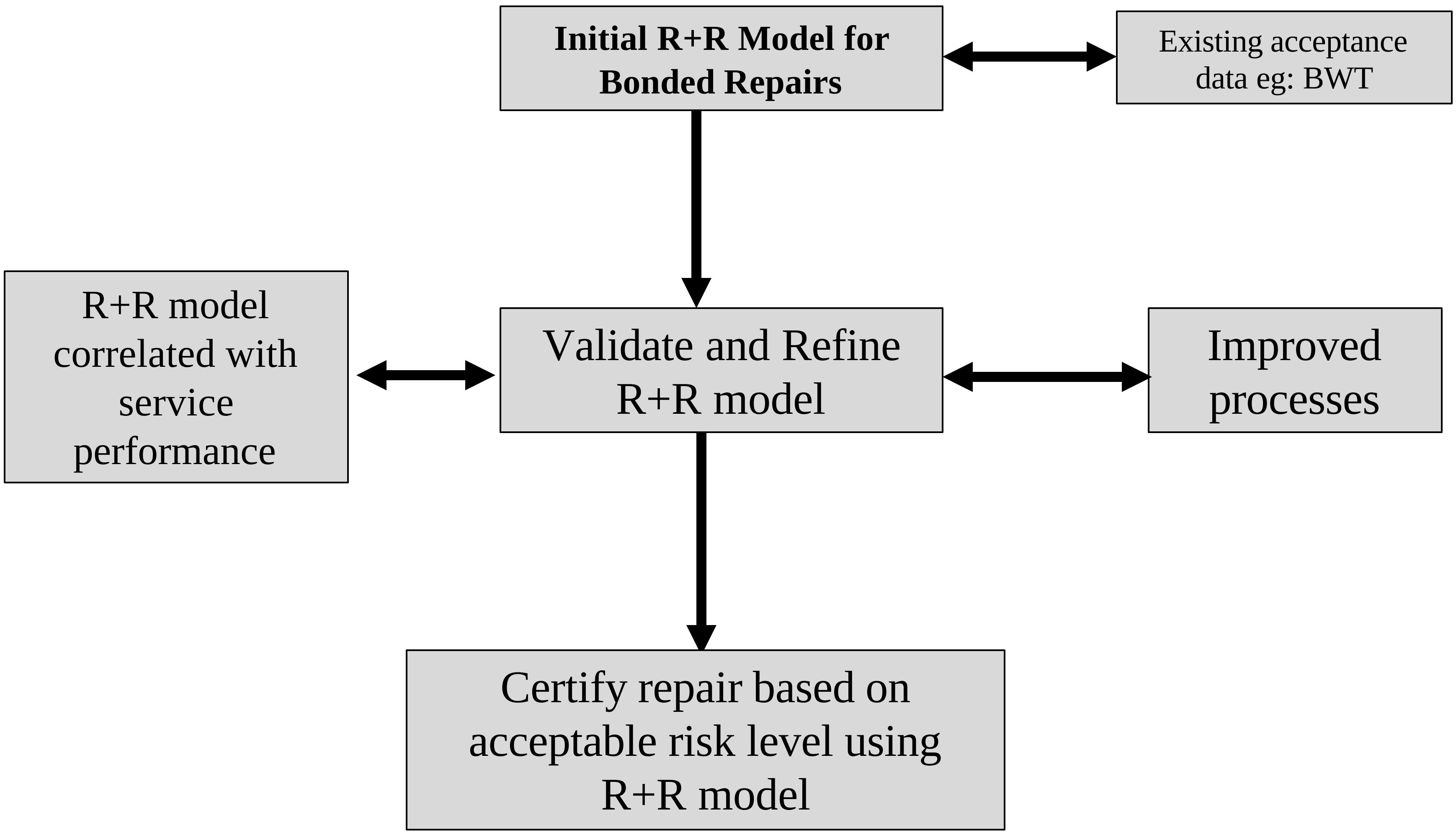
•**Risk Modelling Summary**



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–Current DSTO and RAAF Efforts

- **Optimisation of RAAF Wedge Test Results**

  - **Process Control Improvements**

    – "Worm-Plot" to monitor process drift, new controls

    – Infrared to assess quality of epoxy-silane

    – grit-blasting to be monitored in-situ using Gloss-Meter

    – coupling agent kits (accuracy and pH control)

    – Surface Quality Meter to replace water-break test

    – Still some deviation cannot be explained through failure analysis:

    Surface Analytical tools being applied (ToF-SIMS, XPS, FT-IR…)

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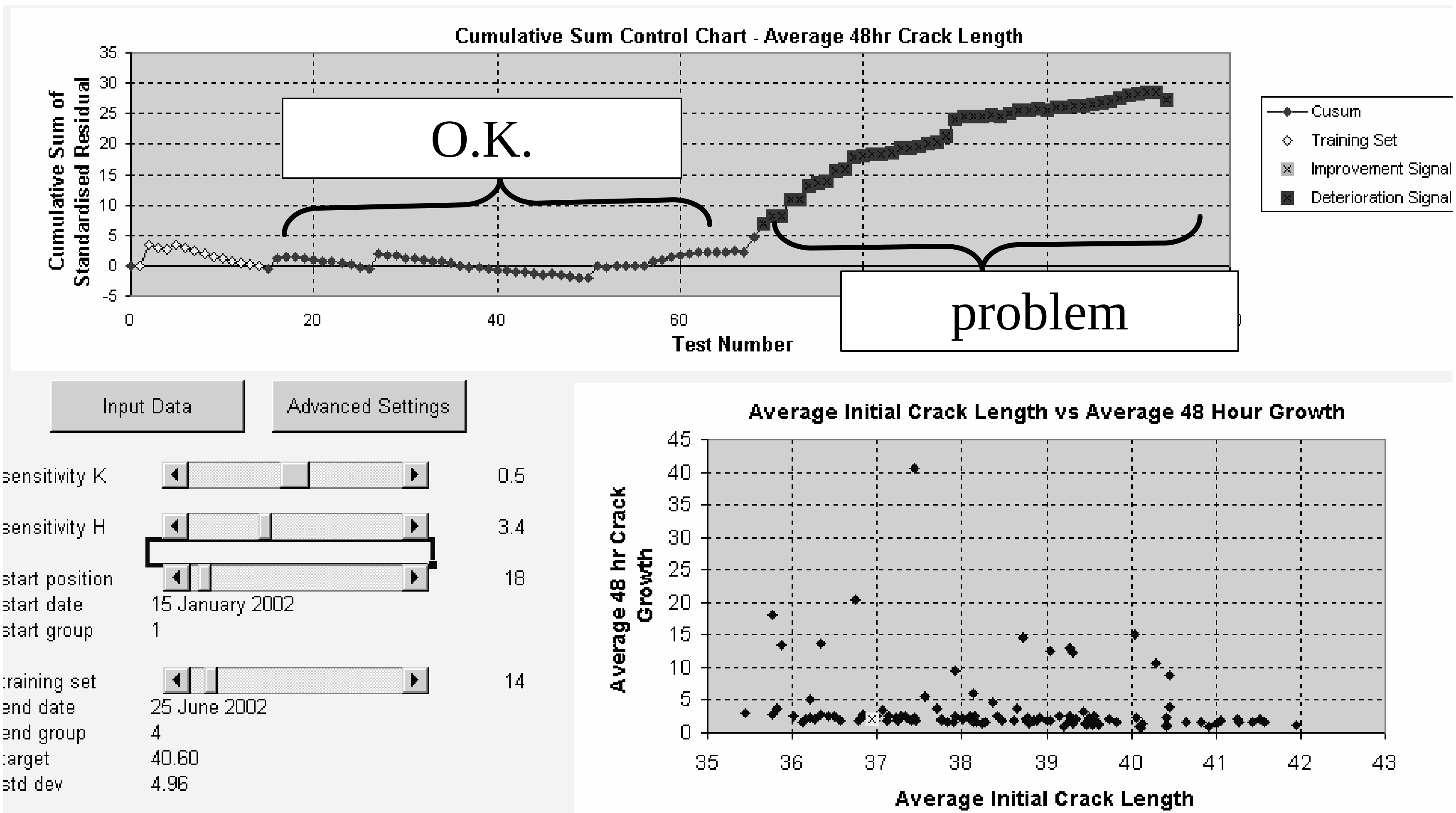
–Current DSTO and RAAF Efforts

"Worm Plot"



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–Current DSTO and RAAF Efforts

Gloss-Meter

- reduce reliance on operator skill

Surface Quality Meter

•Water-break test limited

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–Current DSTO and RAAF Efforts

- **Regression Modelling**

  - wedge data from 15 years of research and RAAF requalification examined

  - obvious sensitivity factors identified and modelled

    – experience, location, adhesive batch, grit-blast quality, supervisor, organisation, coupling agent pH.

  - additional testing required to substantiate effects and data mining of available wedge data bases still needed

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– Current DSTO and RAAF Efforts

- **Teardown Inspection of Patches**
  - More than 50 patches from **C-130E** recovered and being inspected
    - – example of minimal treatment and low QA in hostile application
    - – limited cases of substantial environmental degradation
    - – Flatwise Tension Testing (FWT) and failure surface inspection
    - – NDI cross-check with aircraft records

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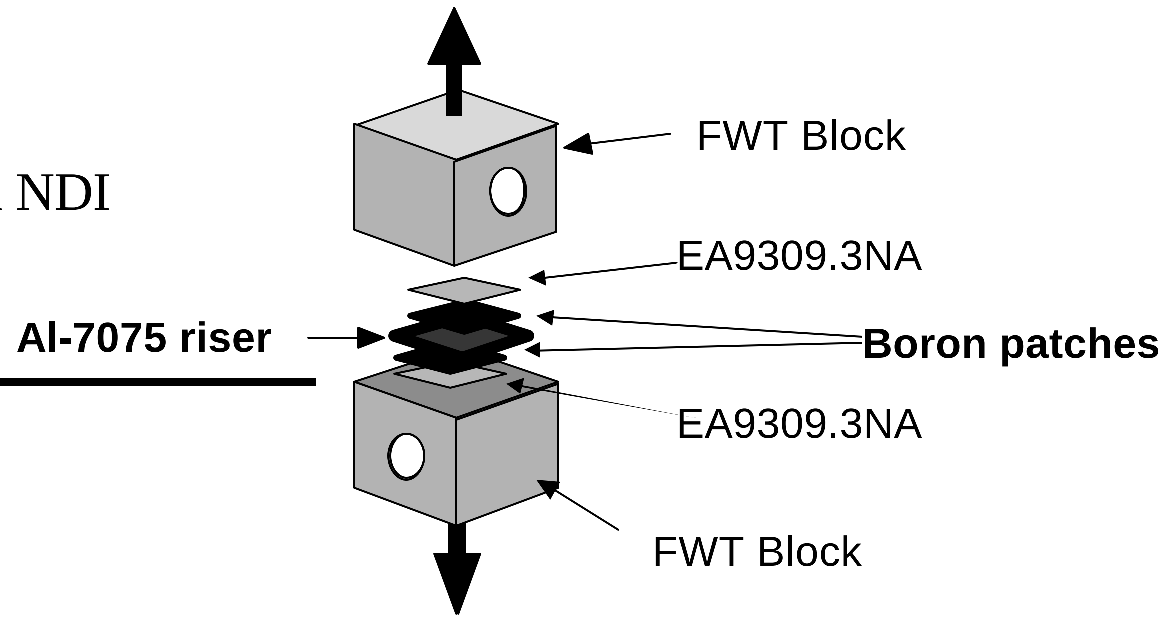
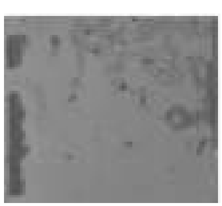
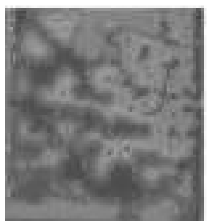
– Current DSTO and RAAF Efforts

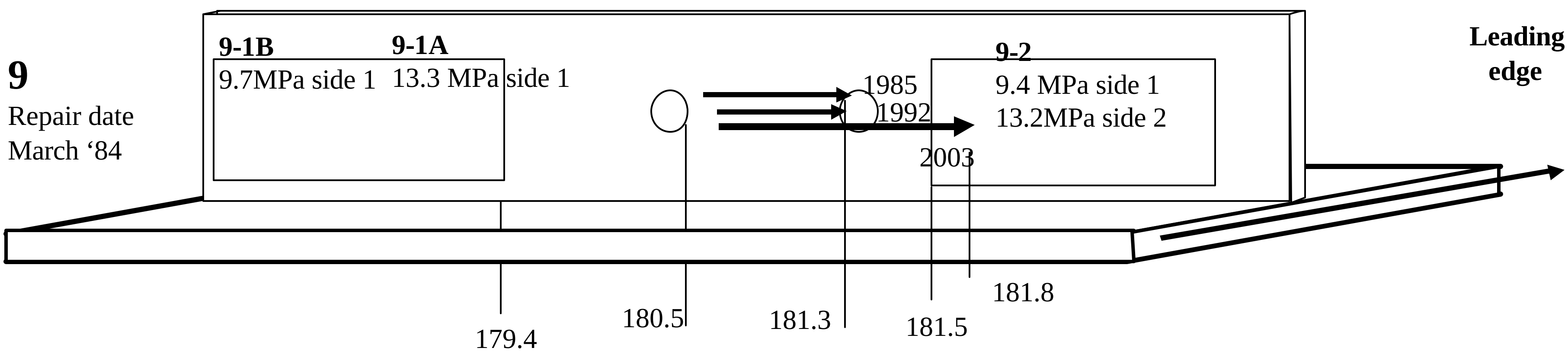
•C-130E Patch Testing and NDI



•failure surfaces







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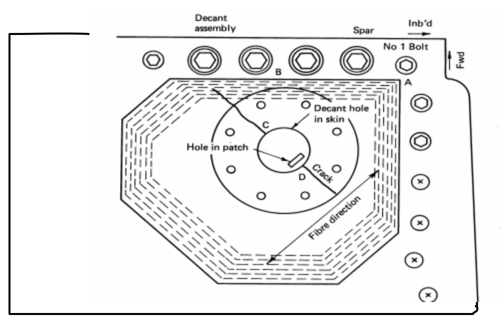
– Current DSTO and RAAF Efforts

- **Teardown Inspection of Patches**
  - 15 patches from **Mirage III** recovered and being inspected
    - – PANTA process, well documented procedures
    - – samples to be tested to failure (FWT?)
    - – NDI cross-check with teardown inspection



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– Current DSTO and RAAF Efforts

•Inspection of Patches

- Repairs conducted on **F-111C** from ’97-’99 being inspected
  - – grit-blast silane process, well documented procedures
  - – 500+ repairs “available”
  - – direct correlation with large wedge test data-base
  - – 45 repairs tap tested (to date)
  - – 2 repairs with damage (1 impact, 1 void in centre)
  - – retired panels to be inspected by teardown

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– Current DSTO and RAAF Efforts

•DSTO Repair Survey 2002

- More than 20 organisations contacted
- 7 countries responded
- 16 aircraft types
- More than 6000 repairs (composite and metal to composite)
- 10 different surface treatments
- 20,000+ flying hours
- some repairs “available” for teardown inspection
- clearly large database already in existence

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– Limitations

•Data and retired repairs

- More repairs required for teardown (“PABST”, C-141, USN F-5)
  - – provide sufficient correlation in service performance for varied operating conditions and model validation
- Wedge data from fabrication and repair required to establish effects that can only be established over long periods
  - – eg. Batch effects
- Additional testing to improve R+R models
  - – sensitivity factors, improved statistical confidence

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-Collaboration

•**Co-ordinated efforts**

- consensus on environmental certification strategy
  - acceptance test, pass/fail criteria, FARs, ASTM………..
- consolidate data collection and tear-down inspection
  - download wedge data to Web-site, secure or free access database
  - freely share teardown inspection data
  - define risk-model development phases and contact interested parties

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Comments or Questions?