DURABILITY OF ADHESIVELY BONDED STRUCTURES

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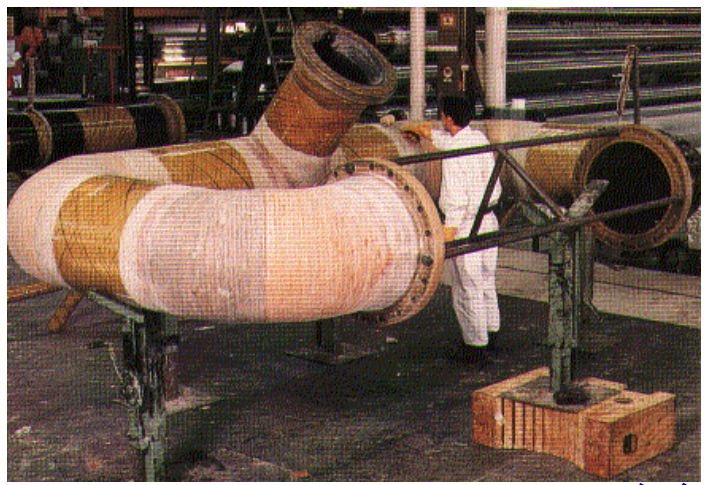
ADHESIVE BONDING
CAA, Aviation House, UK
October 26-27th 2004

ANALYSIS OF BONDED STRUCTURES



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OUTLINE OF PRESENTATION

- Durability Definition for Bonded Structures
- Current Evaluation Test Methods
- The use of Fracture Mechanics for Debond Prediction
- The use of Fracture Mechanics for Environmental Effects
- Incorporating Rapid Inspection Techniques
- High Cycle Fatigue

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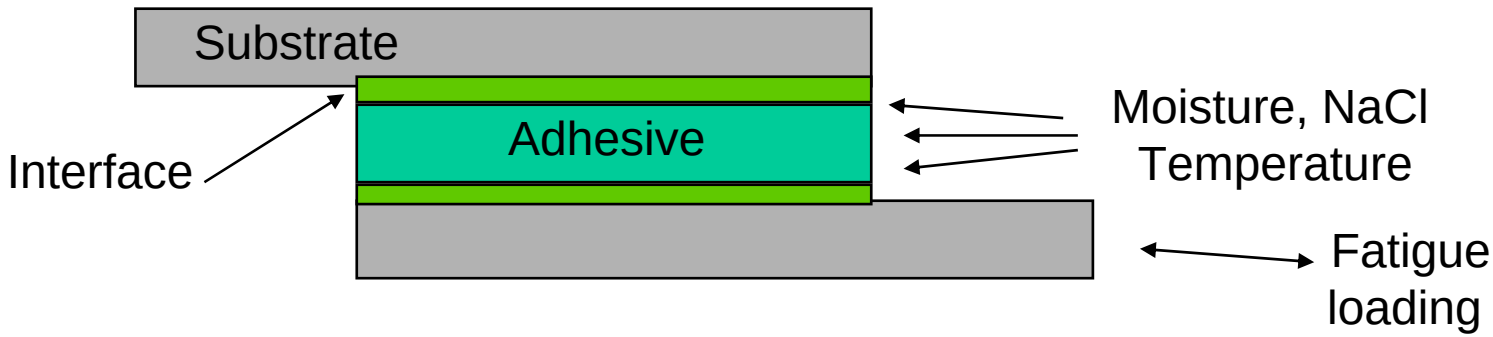
DURABILITY - A COMBINATION OF STRESS AND ENVIRONMENTAL DEGRADATION



Modes of failure:

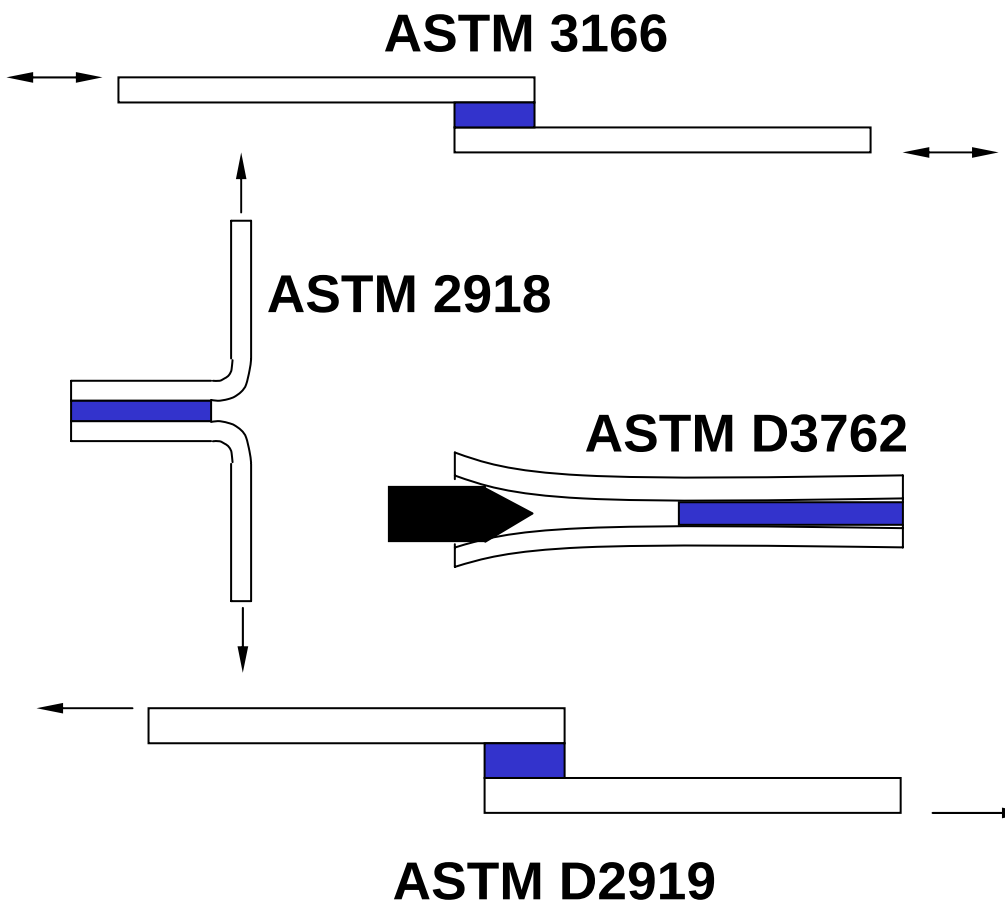
- Cohesive in adhesive
- Weak layer at interface
- Interfacial
- Delamination in composite
- Substrate failure

Environmental degradation:

- Reduction in cohesive strength
- Reduction in interfacial strength
- Substrate corrosion
- Substrate failure

CURRENT STANDARD TEST METHODS

Fatigue loading of lap joints



Environmental resistance (static stress + moisture)

REQUIREMENT FOR A NEW APPROACH

Current methods

- Results are relative and test piece dependent
- Environmental assessments do not account for cyclic fatigue loads
- At best give relative ranking - At worst are misleading
- Cannot use for detailed design purposes

Fracture Mechanics offer advantages

- Use as basis to not only rank systems but also for design analysis
- Use to accelerate environmental durability testing under fatigue loads
- Crack growth a function of strain energy release rate (G)
- da/dN vs G is assumed to be property of the system (adhesive/substrate/surface preparation)

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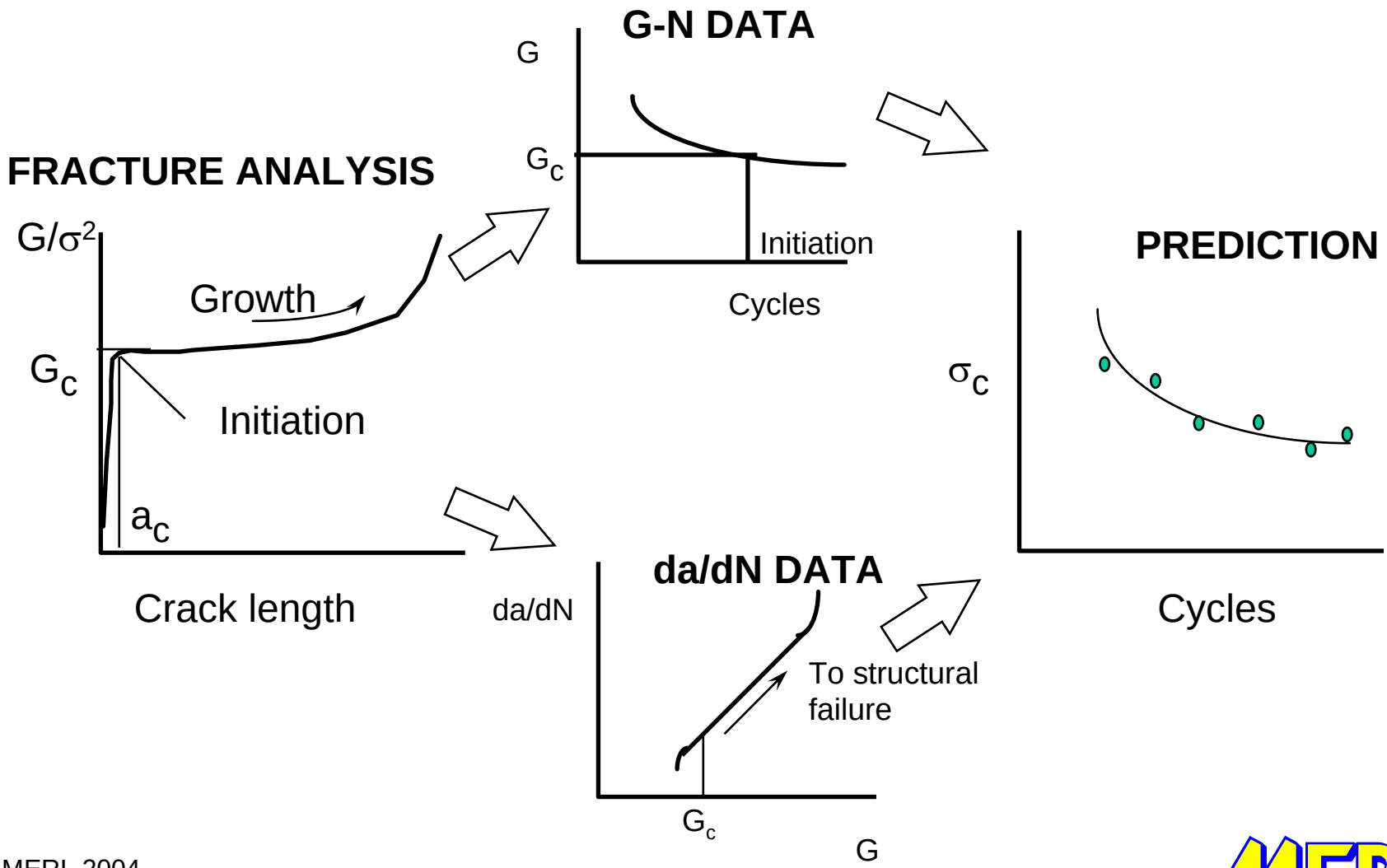
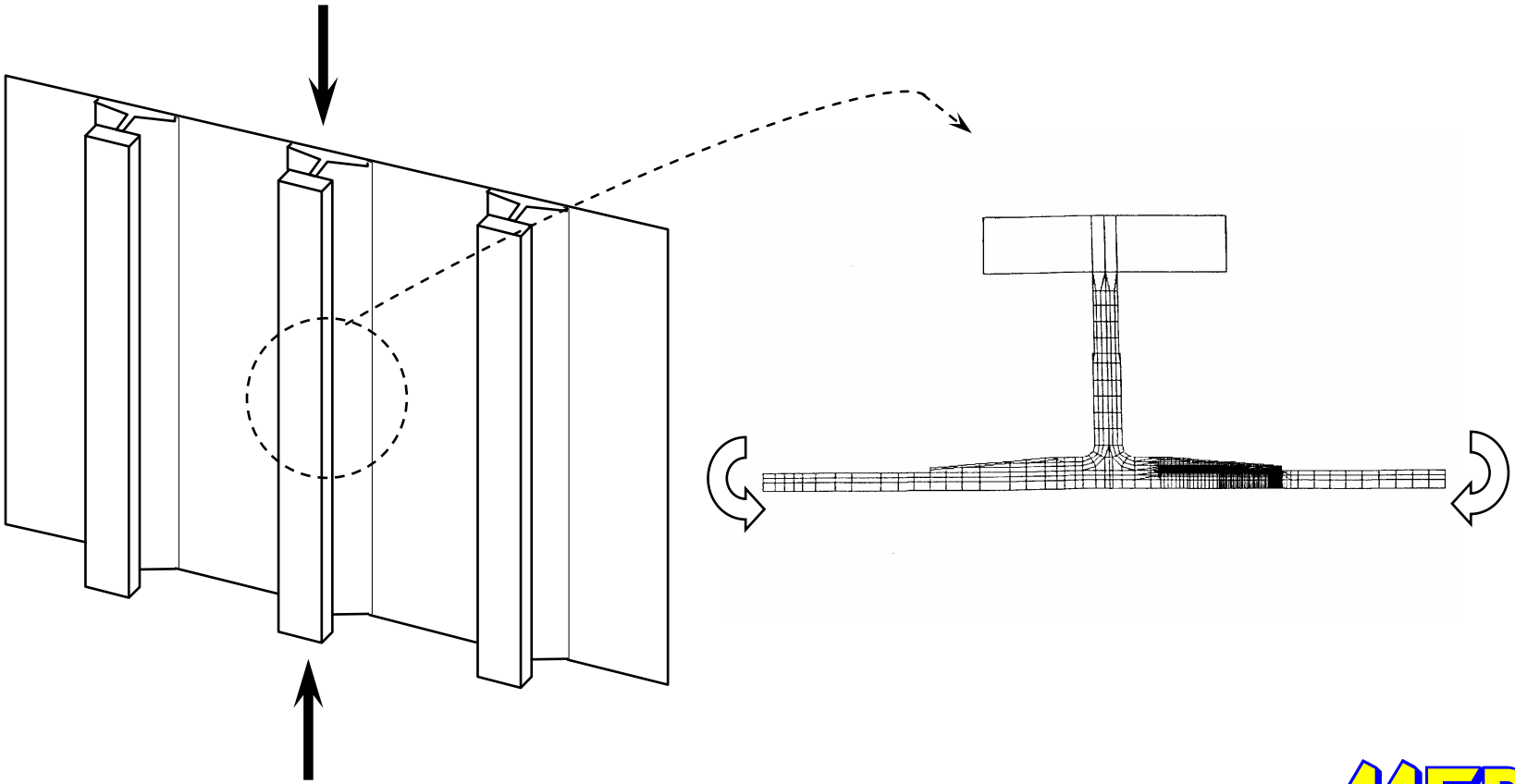
FRACTURE LIFE ASSESSMENT METHODOLOGY



CASE STUDY: FM AS A DESIGN TOOL
STRINGER DEBOND ON COMPRESSION PANEL

Buckling analysis predicted buckling strain - NASA Publication
No prediction of failure strain at -0.0035
Post failure: stiffener debond, cap delamination, panel failure



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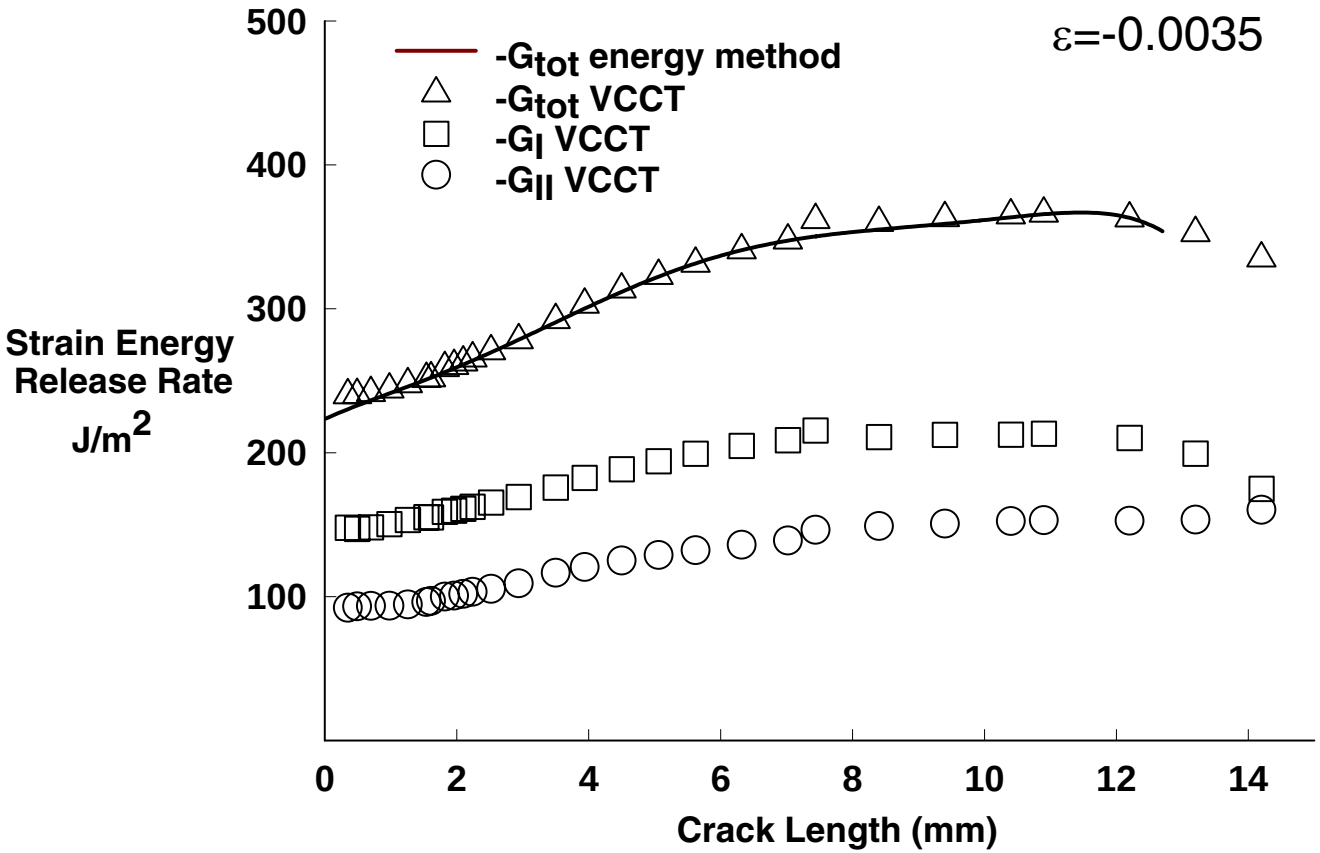
UTILISING ANALYSIS FOR DESIGN PURPOSES

STRINGER DEBOND IN COMPRESSION PANEL



$G_c@G_I/G_{II}=1.5 = 220J/m^2$

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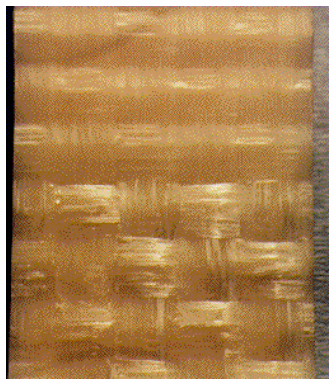
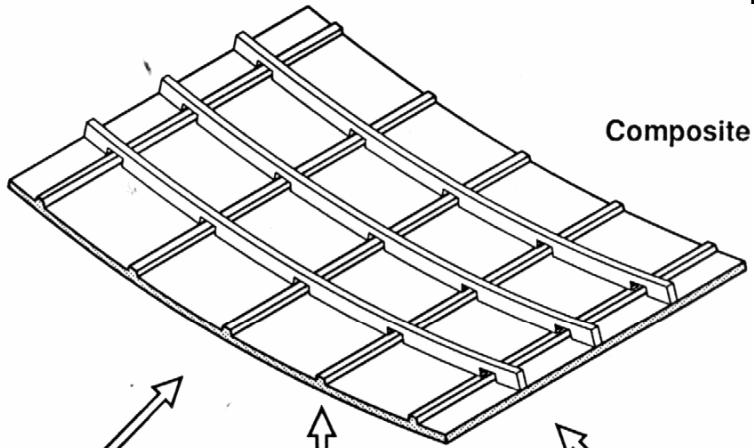
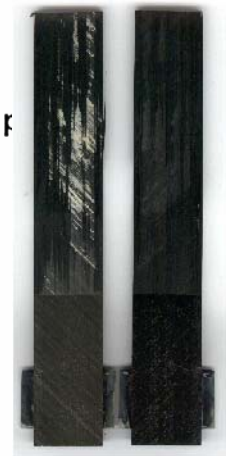
FM TECHNIQUE WELL VALIDATED

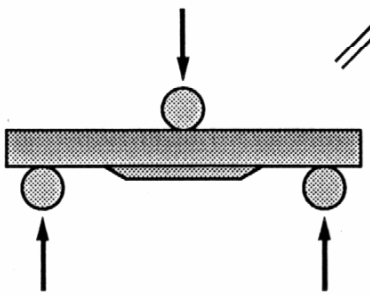
Woven materials

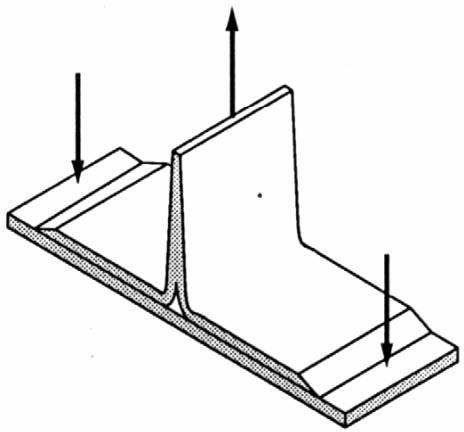


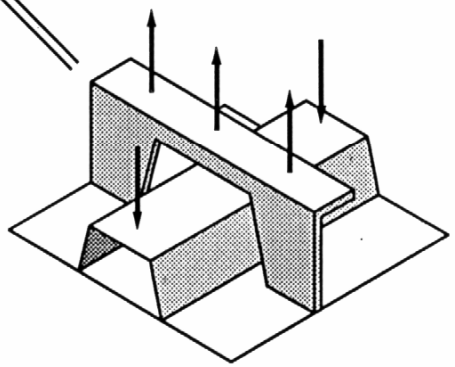


Hybrid materials









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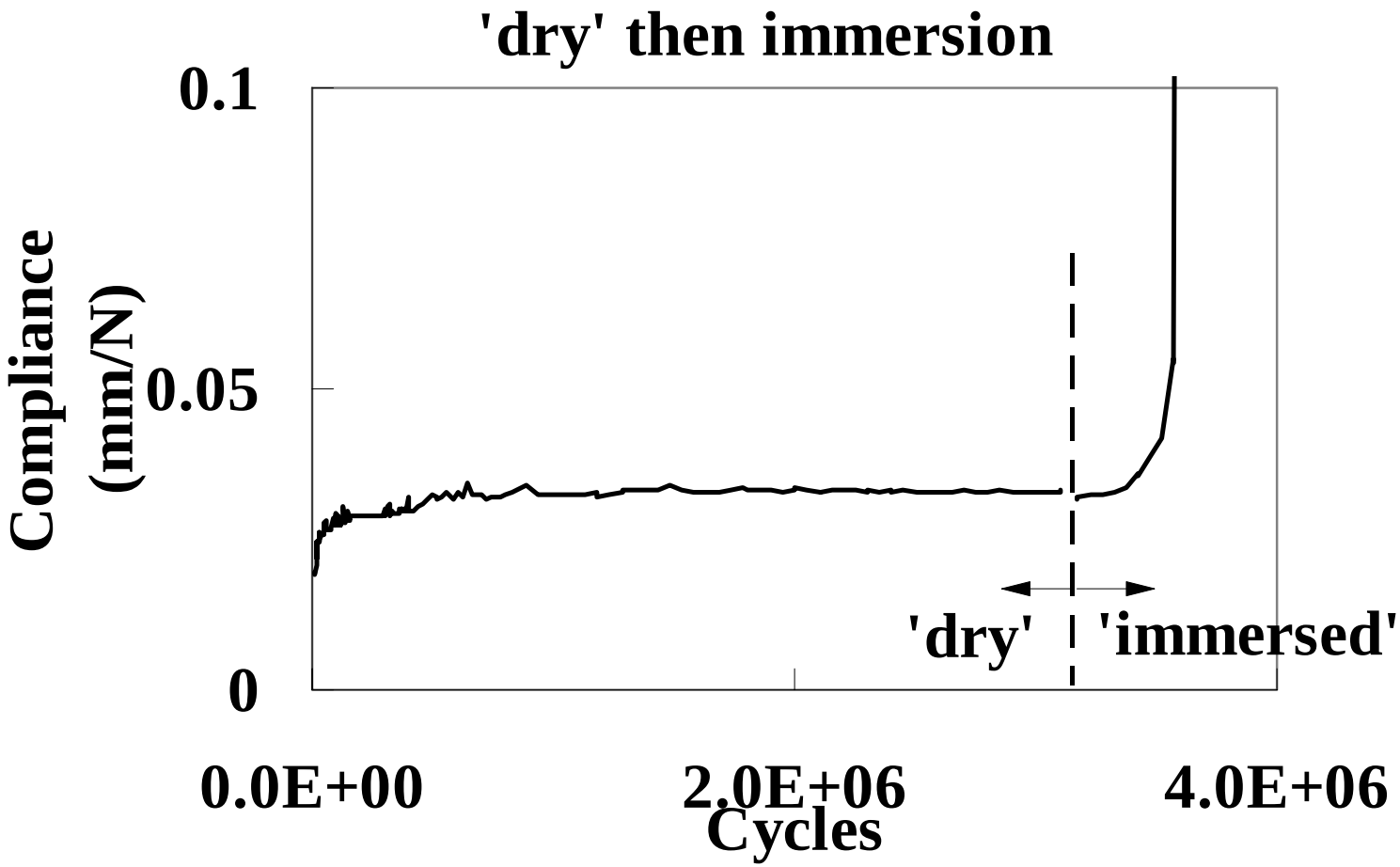
EFFECT OF MOISTURE ON FATIGUE



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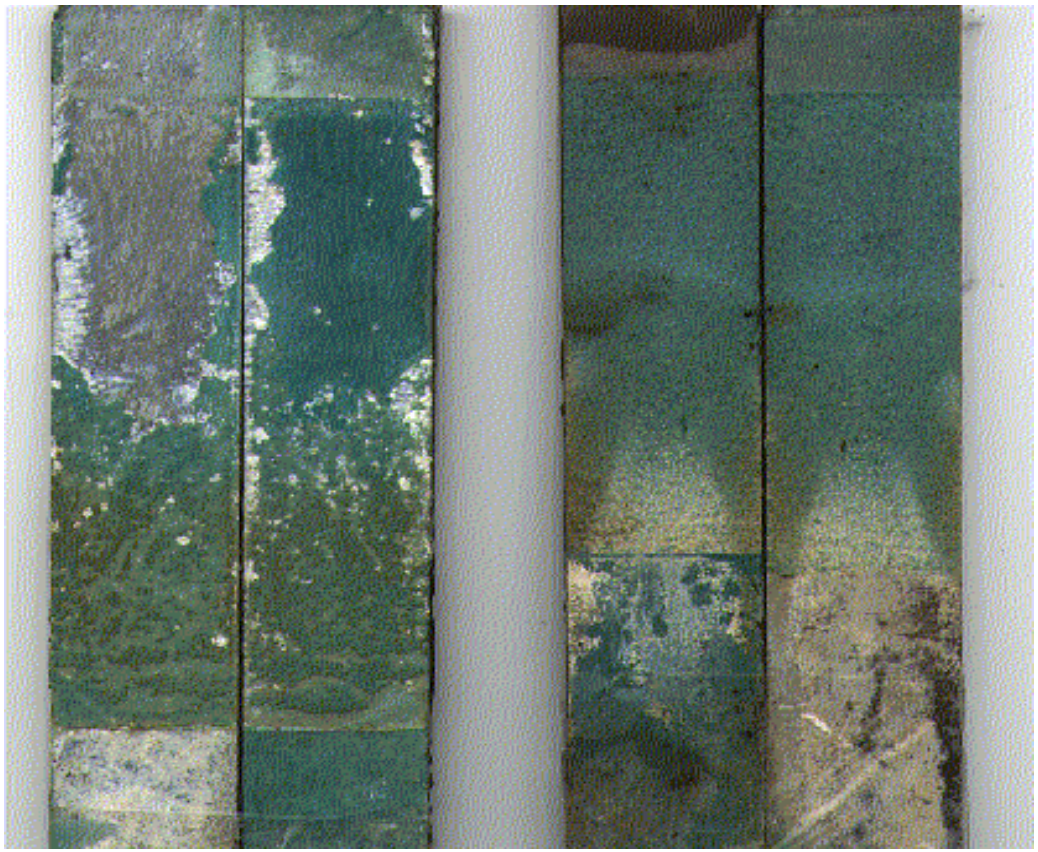
CHANGE OF FAILURE MODE IN ENVIRONMENT



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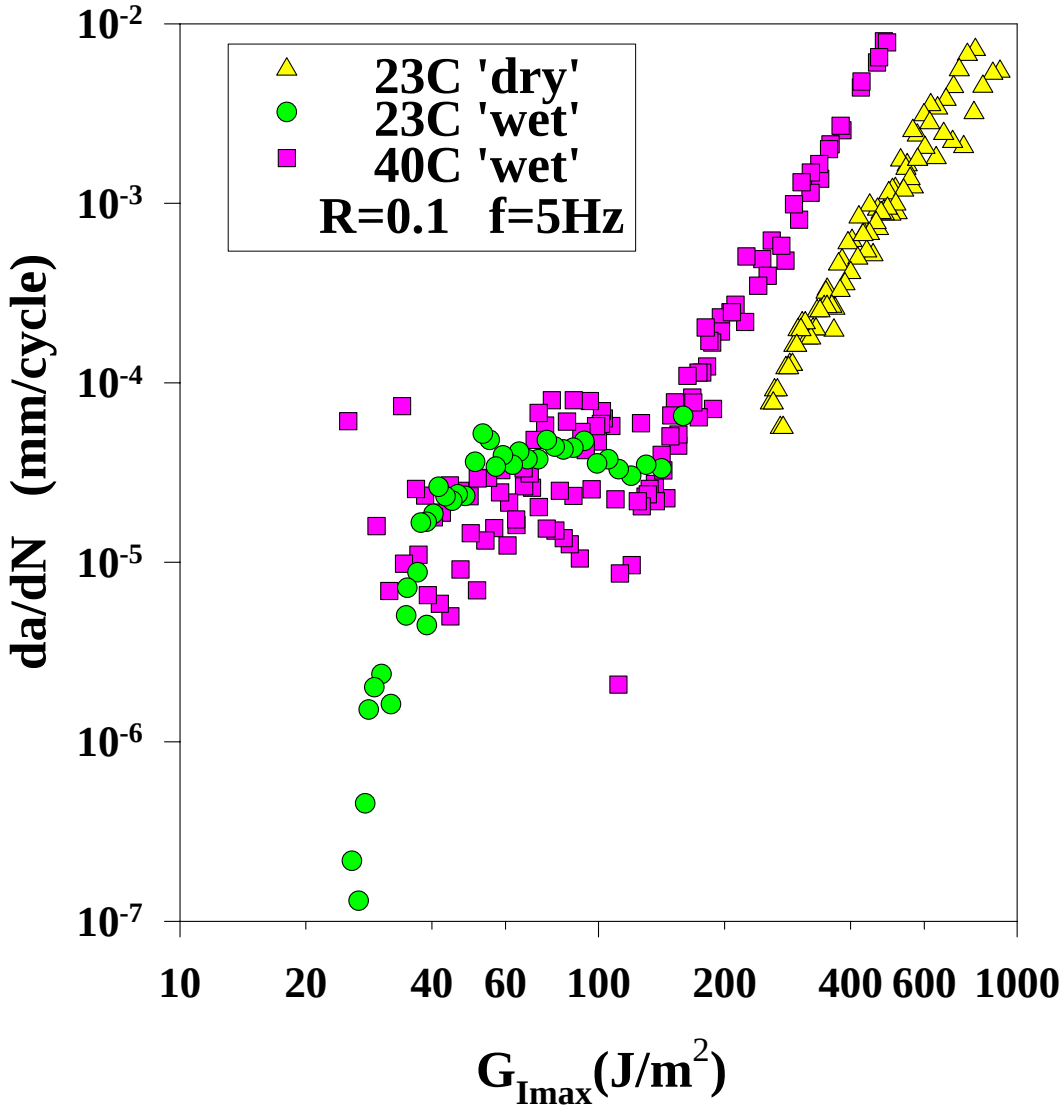
‘DRY’ AND ‘WET’ FATIGUE CRACK GROWTH



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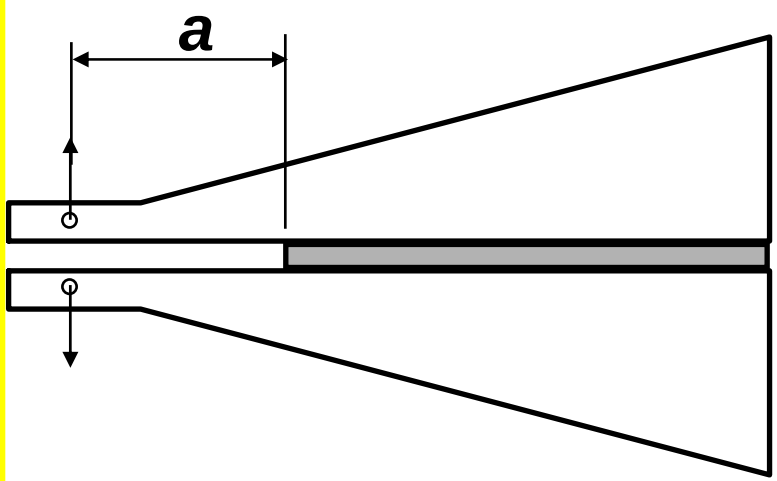
EUROPEAN BONDED JOINT AUTOMOBILE PROJECTS

Long Term Durability of Bonded Automotive Metallic Structures
A European Commission, 5th Framework Consortium Project January 1st 2002 - December 31st 2004 1.8MEuro
CEN Standard to be published in 2005

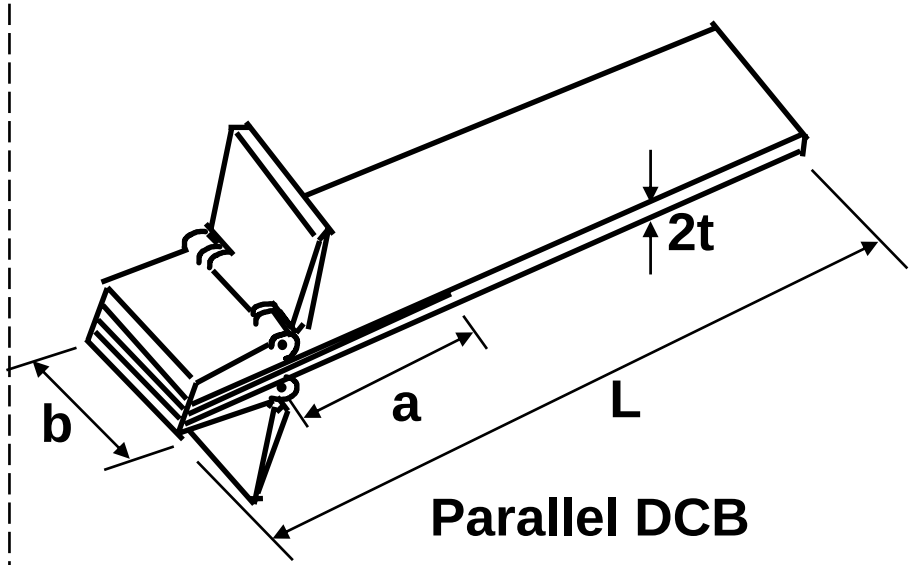
SuperLightCar
Mid 2005 - Mid 2009 20MEuro
A European Commission, 6th Framework Integrated Project
39 European partners
Objective: to develop lightweight technologies through vehicle for future low emission automobiles
MERL to evaluate durability of multi-material bonded and welded joints

FRACTURE MECHANICS TEST PIECES



Tapered DCB

- **Compliance constant with *a***
- **G constant for constant force**



Parallel DCB

- **Compliance increases with 'a'**
- **G *increases* with *a* (const. force)**
- **G *decreases* with *a* (const. disp.)**

$$G = \frac{P^2}{2b}\frac{\partial C}{\partial a}$$

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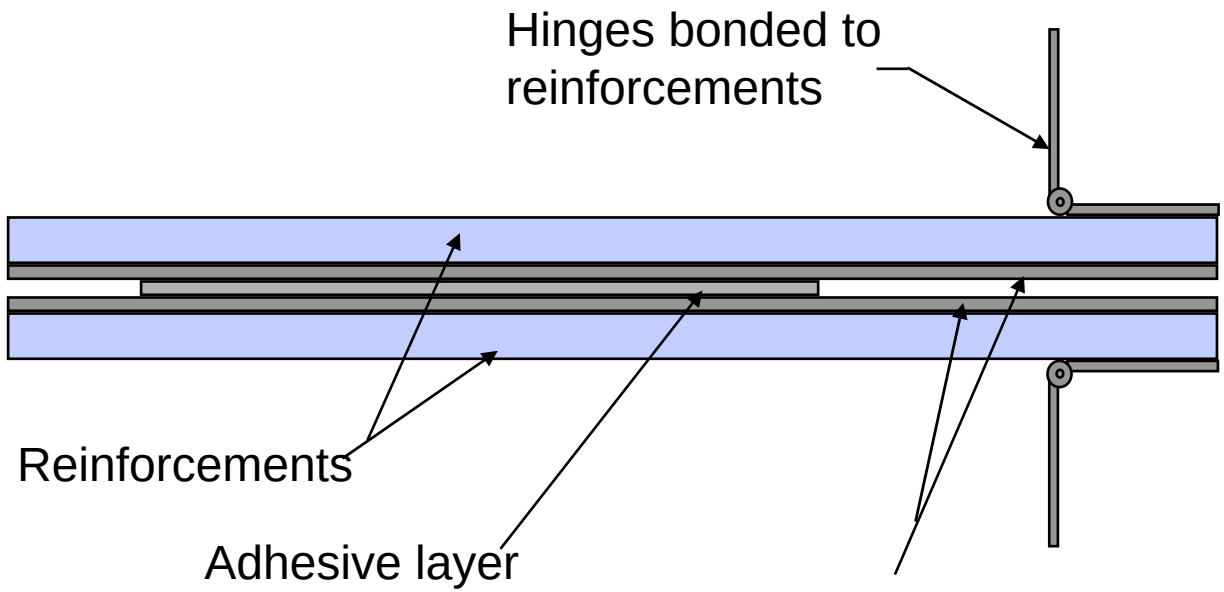
REINFORCED DCB TEST PIECE TO MAINTAIN "ADHESIVE SYSTEM" INTEGRITY



Thin gauge or multi-material substrates to maintain mode I loading AND factory surface preparation conditions

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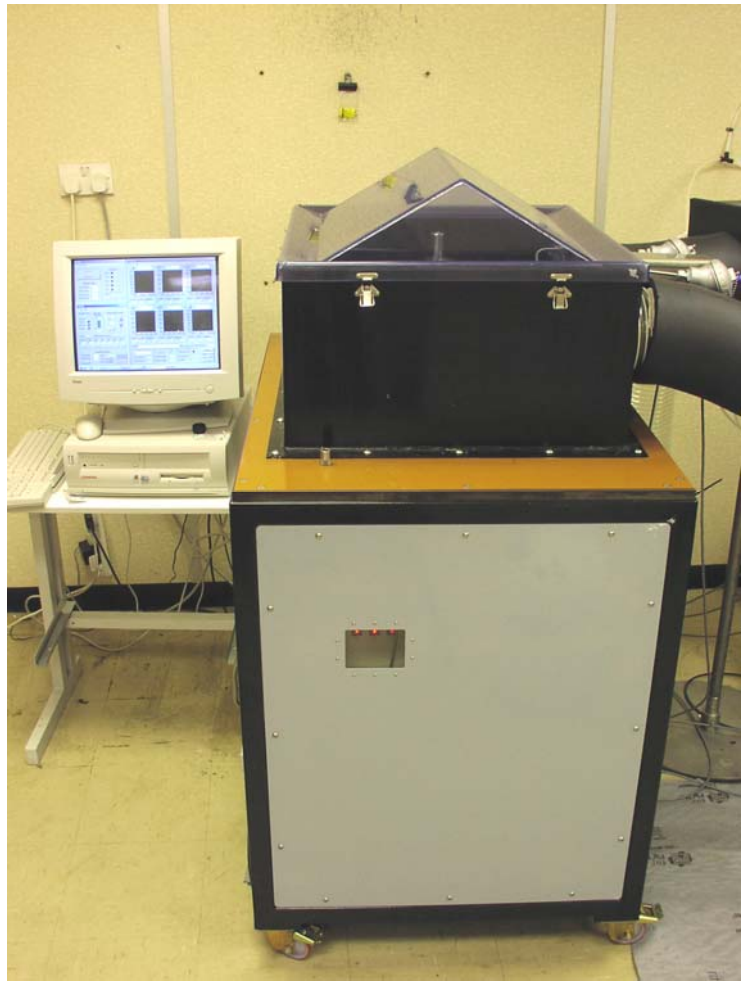
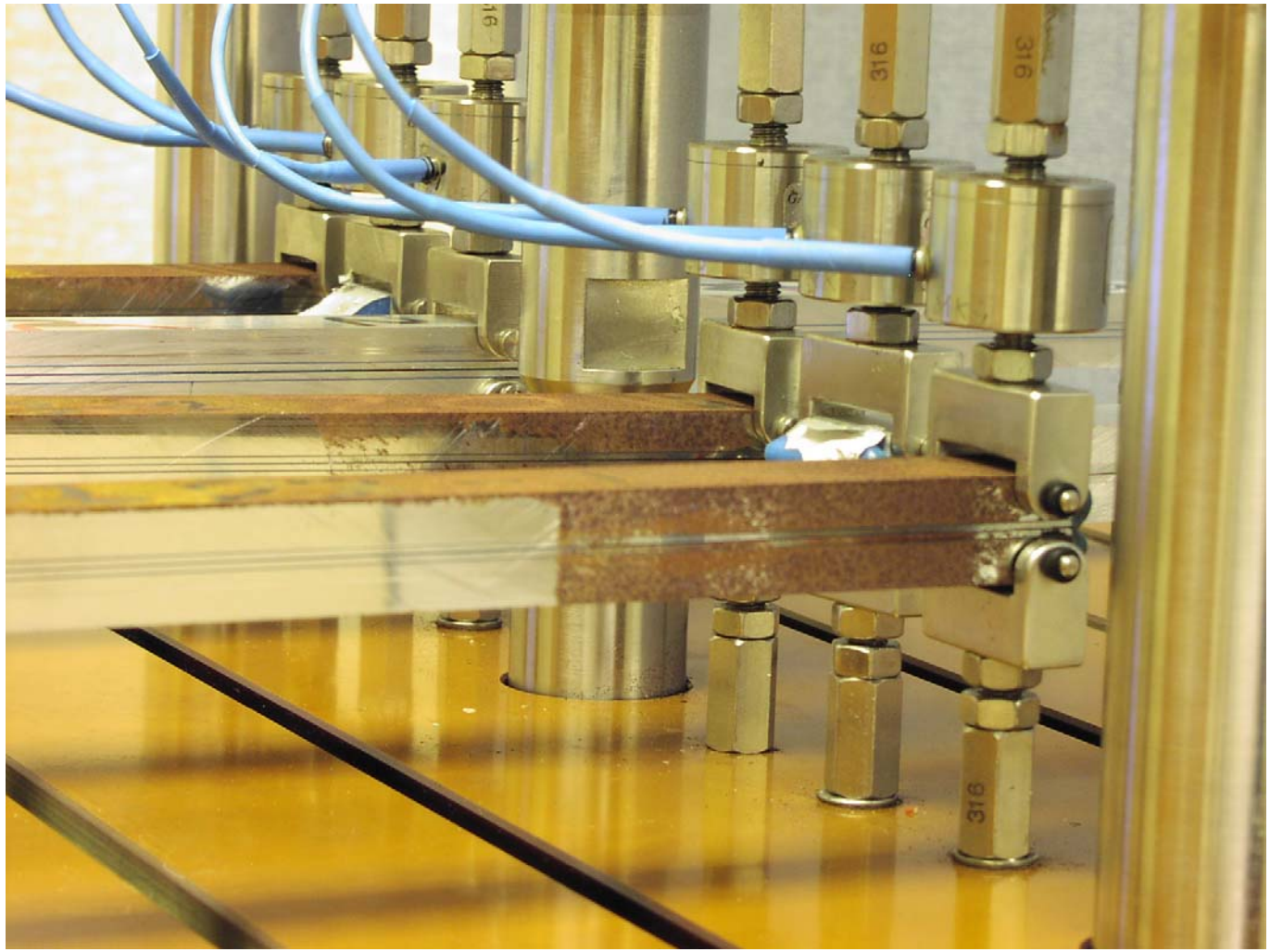
COMMERCIAL TEST EQUIPMENT



ADHESIVE BOND DURABILITY TESTING



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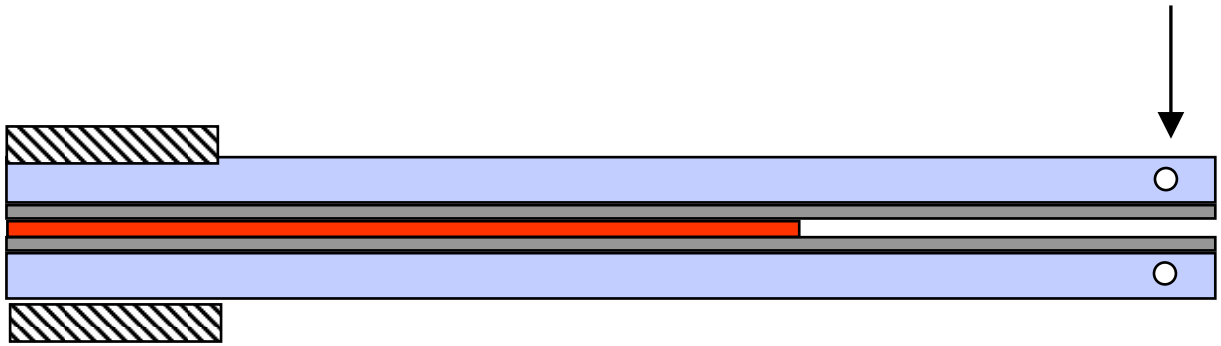
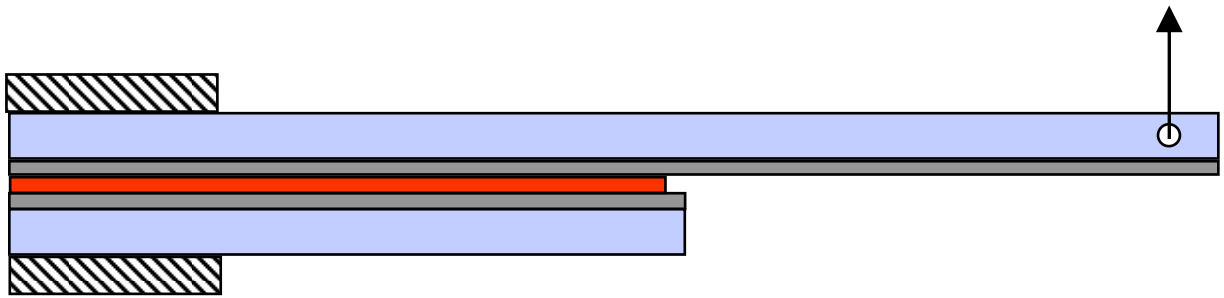
OTHER MODES OF FRACTURE

MODE II



Modified for mixed mode loading

MIXED
MODE I+II



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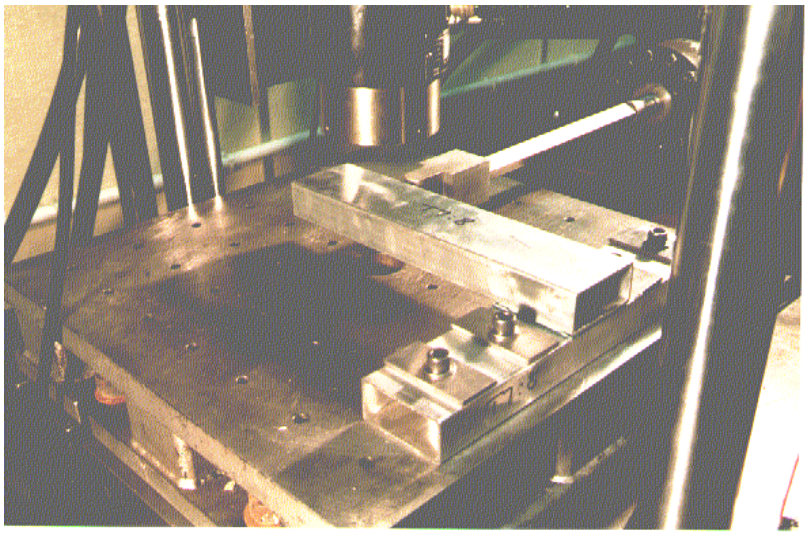
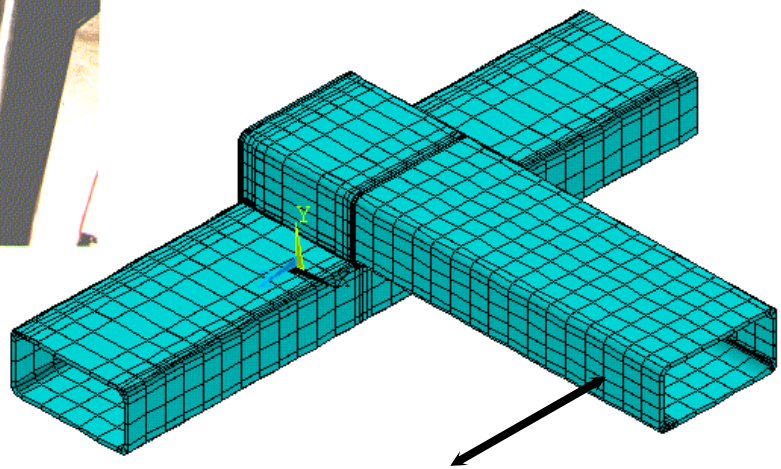
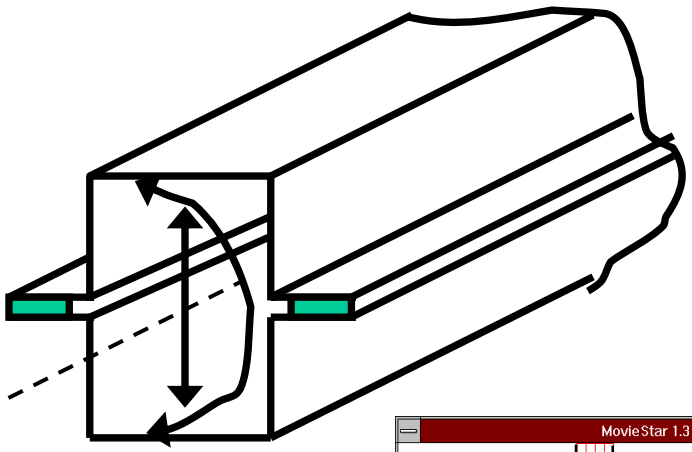
STRUCTURAL LIFE PREDICTION
Extruded Aluminium Profiles in Space Frame

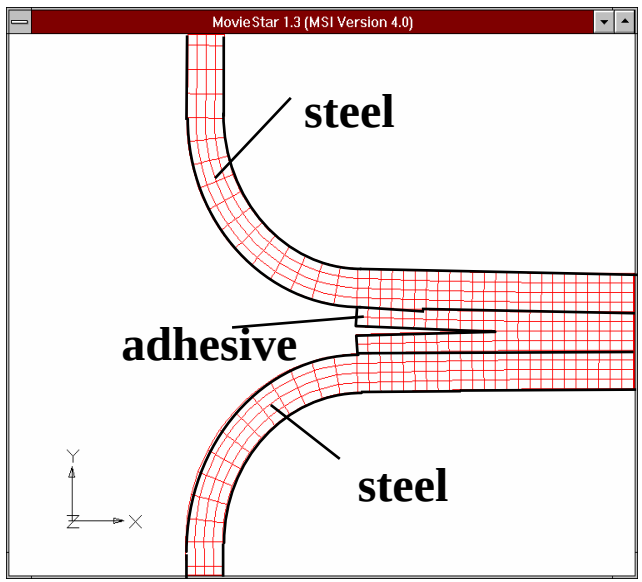


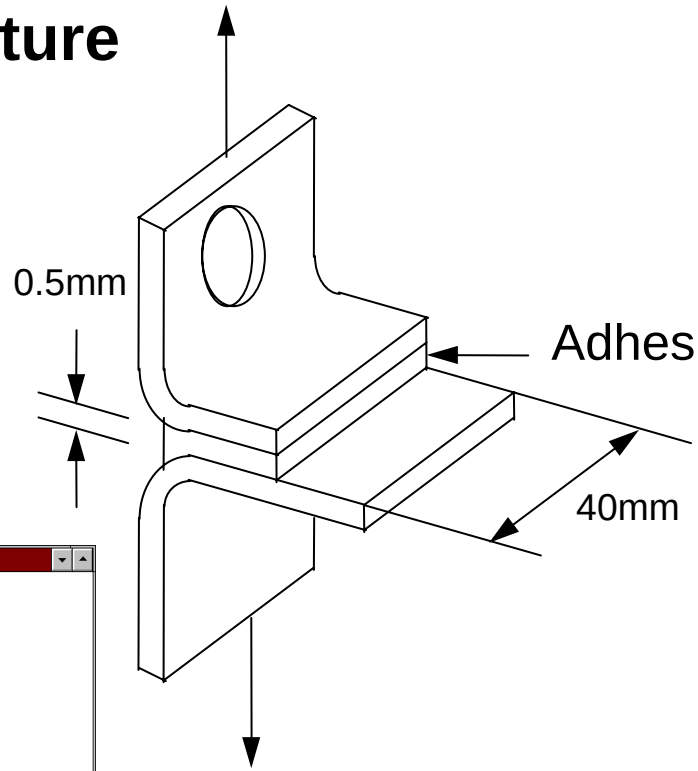


STRUCTURAL LIFE PREDICTION
Steel H Structure

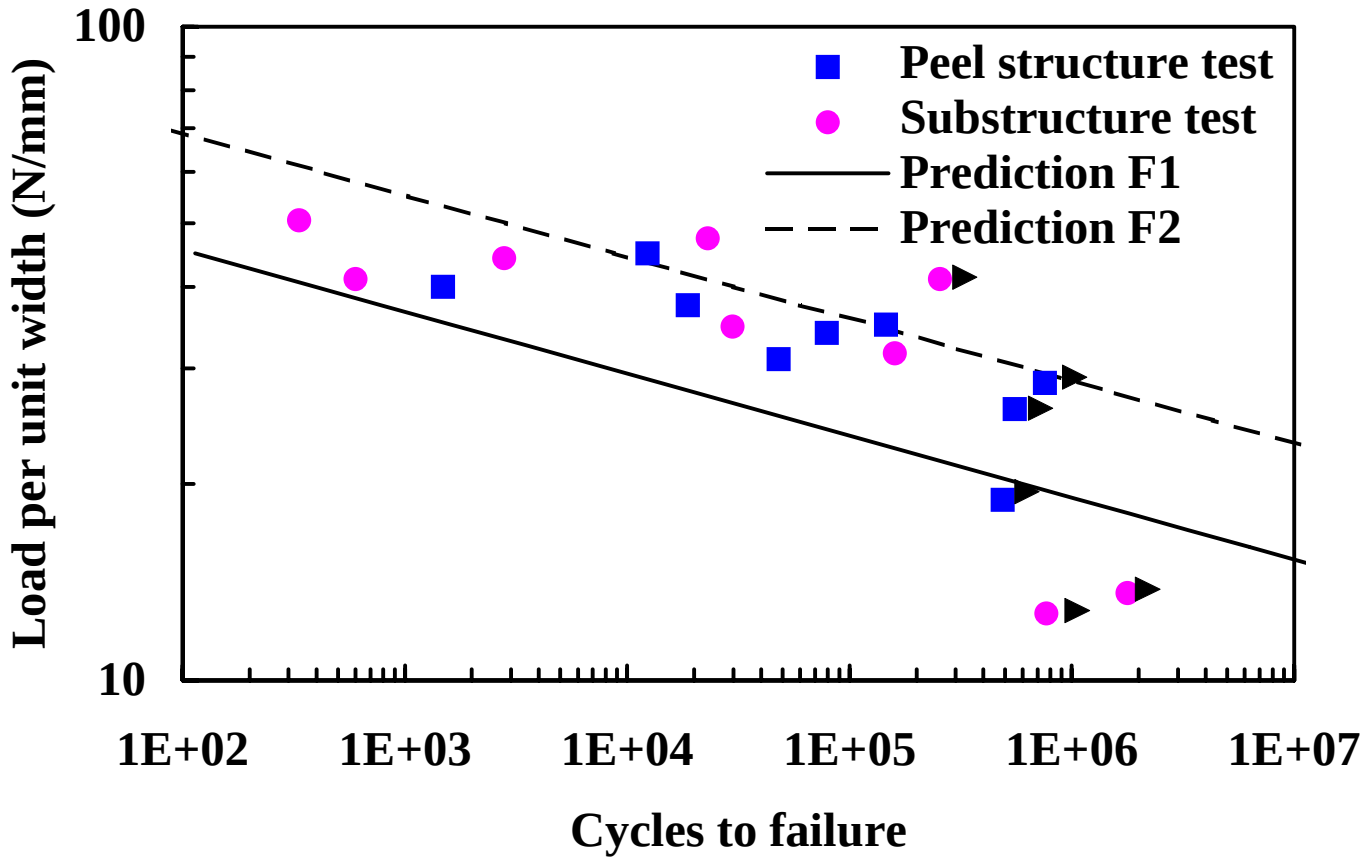


Double top hat

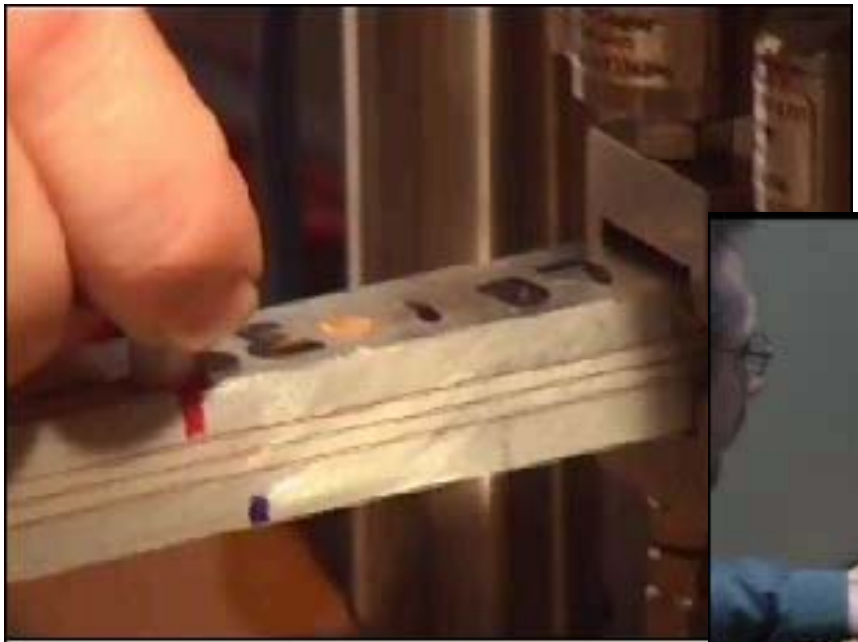




LIFE PREDICTION FOR BONDED ‘H’ STRUCTURE



NDT SOLUTIONS RAPIDSCAN ULTRASONICS



NDT scanner video.avi

Rapid Scan Demonstration 1

NDT Solutions

Intelligent Ultrasonics ...

Work conducted as part of a MoU between MERL and NDT Solutions

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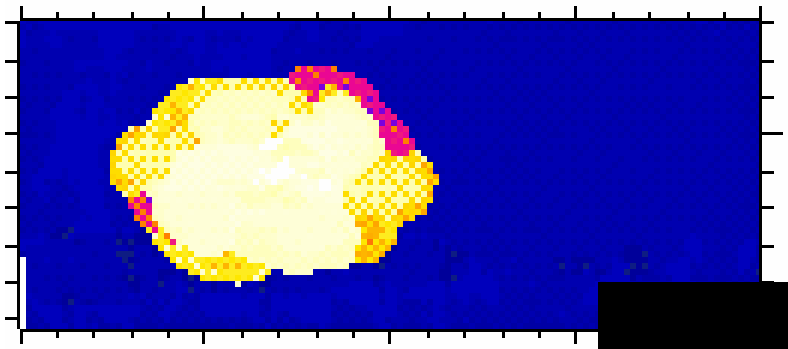
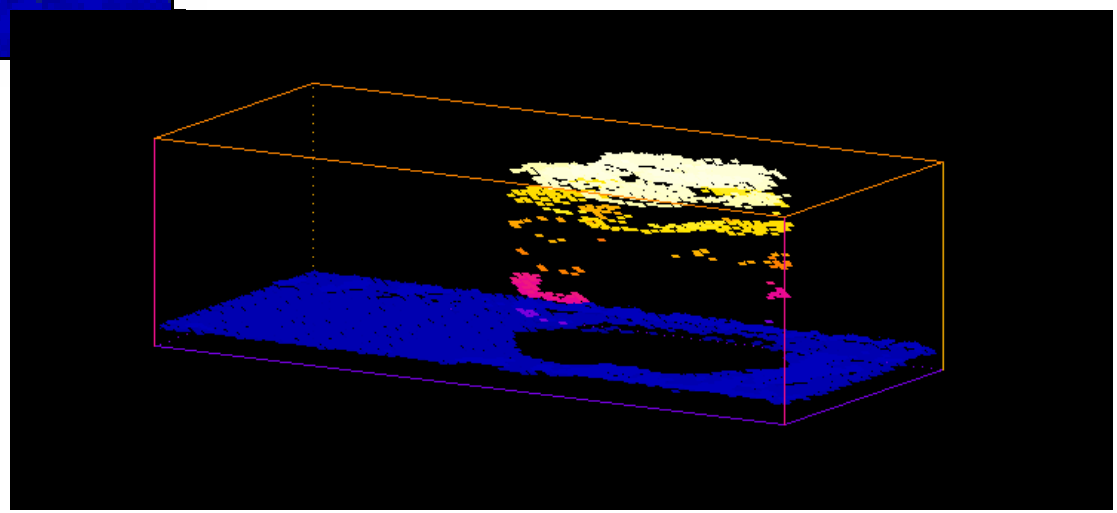
INTEGRATING RAPID NDT WITH EFFECTS OF DEFECTS ANALYSIS

RapidScan inspections give detailed 3D damage maps (Delaminations and debonds) that can directly be evaluated using the Fracture Mechanics approach





NDT Solutions

Intelligent Ultrasonics ...

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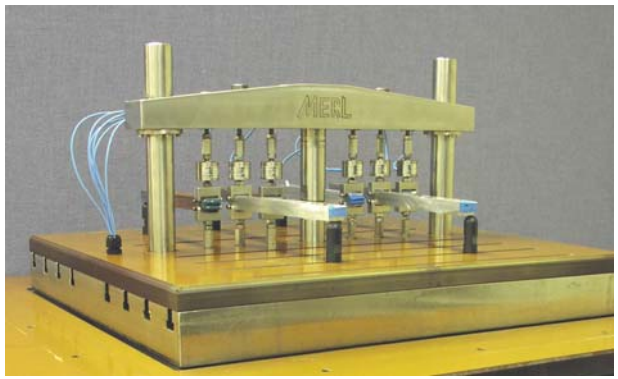
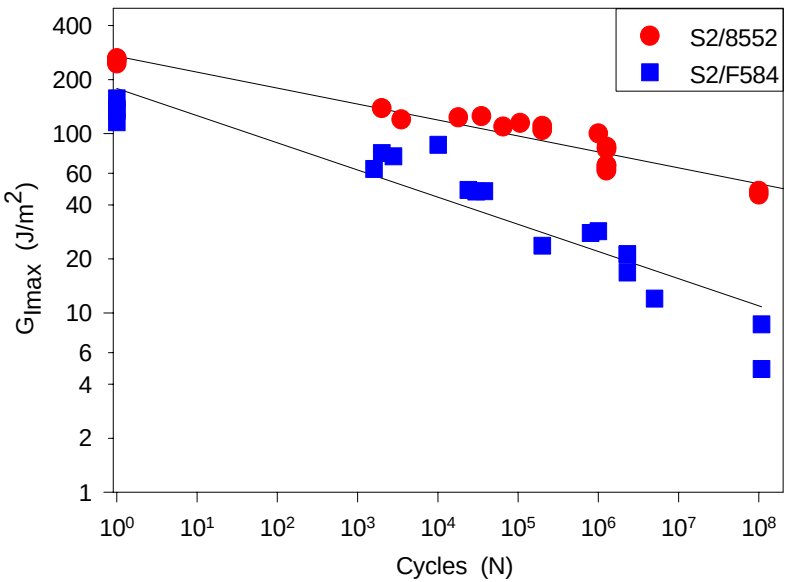
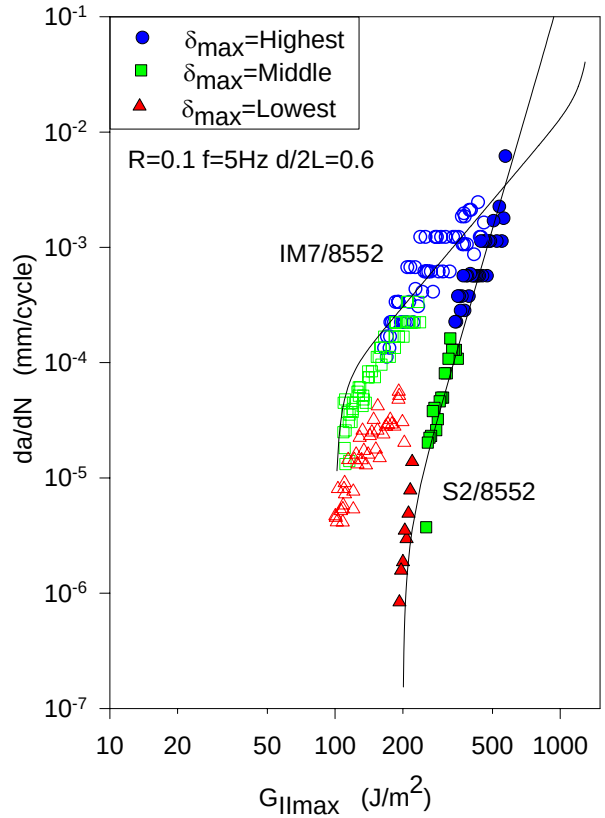
HIGH CYCLE FATIGUE/NO GROWTH THRESHOLDS



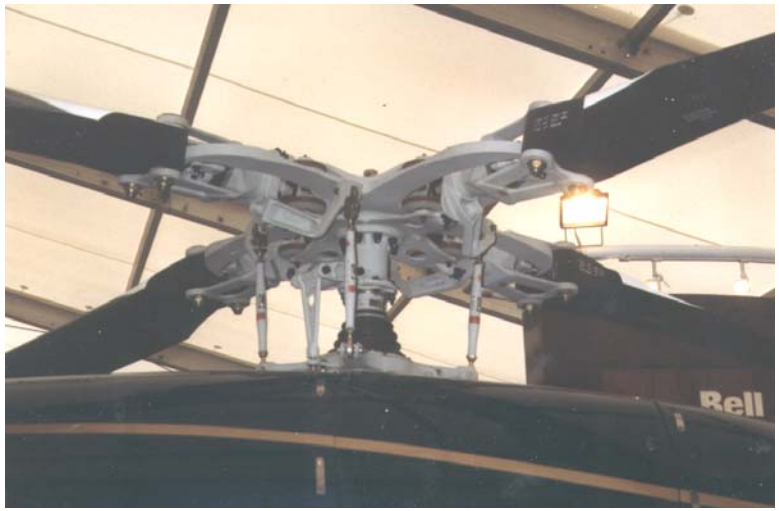


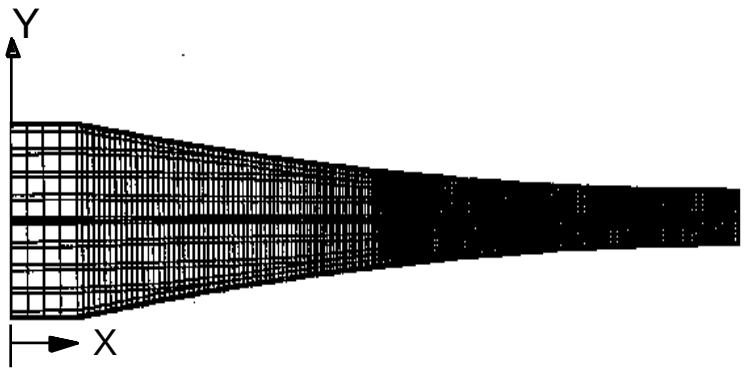
$$G_{\mathrm{Im}\,ax} = 10^{r}\left(N_{onset}\right)^{s}$$

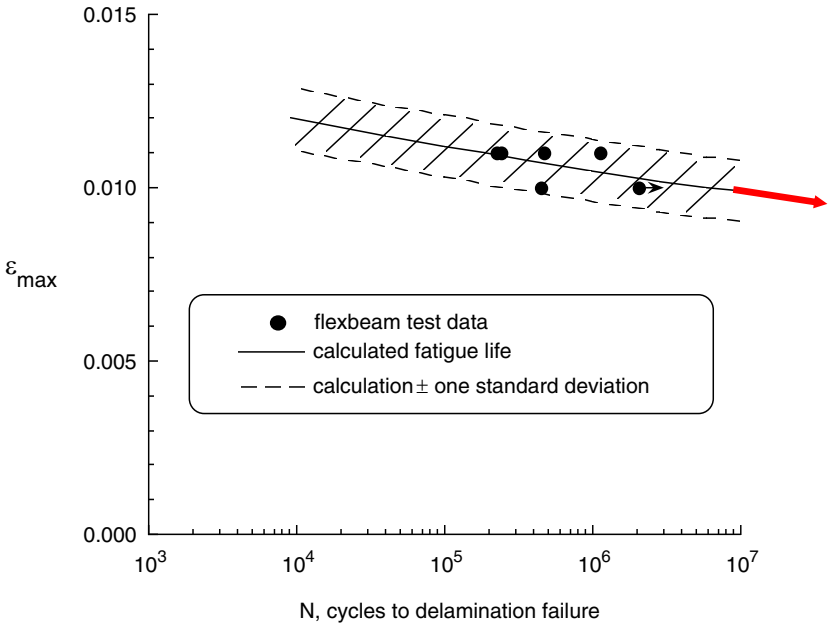


$$\frac{da}{dN} = 10^{A}\left(G_{\mathrm{IImax}}\right)^{B}\frac{\left[1-\left(\frac{G_{IIth}}{G_{\mathrm{IImax}}}\right)^{D}\right]}{\left[1-\left(\frac{G_{\mathrm{IImax}}}{G_{IIc}}\right)^{D}\right]}$$

EXTRAPOLATING TO HCF







G.B. Murri et al “Fatigue Life Prediction of Tapered Composite Laminates” 53rd AHS Meeting, May 1997

THANK YOU

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