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# RAL Activities in Condition Monitoring of Wind Turbine Blades (1989-2005)

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Rutherford Appleton Laboratory

Supergen Wind  
Theme X Workshop  
2 July 2007



# Introduction

- Thermoelastic stress analysis - theory and practice
- Small scale coupon tests - sectional wind turbine blades
- Full scale blade tests
  - acoustic emission
  - thermoelastic evaluation (including a new approach)
- Blade modelling (the Supergen Wind project)



# Equipment used

## Thermoelastic stress analysis:

- Deltatherm 1000 (InSb detector array, 3-5  $\mu\text{m}$ )
- (SPATE) (HgCdTe single detector, 8-12  $\mu\text{m}$ )

## Infra red temperature measurements:

- Agema 880
- (Deltatherm 1000)

## Acoustic emission:

- Physical Acoustics Ltd. MISTRAS system



# TSA - theory

Isotropic materials:

$$\Delta T = -\frac{T}{\rho c_p} \alpha \Delta (\sigma_{11} + \sigma_{22})$$

Orthotropic materials:

$$\Delta T = -\frac{T}{\rho c_p} (\alpha_{11} \Delta \sigma_{11} + \alpha_{22} \Delta \sigma_{22})$$



# Large scale testing and TSA

Viewing large structures presents additional problems:

- displacements can be high
- object size, subsidiary test equipment, and other rigs can restrict the available field of view
- the structure may reflect infra red radiation from other sources in the laboratory
- the object cannot be viewed in a single frame (hence need method to ensure repeatable locations)
- test frequencies are low



# Calibration

Three approaches to calibration:

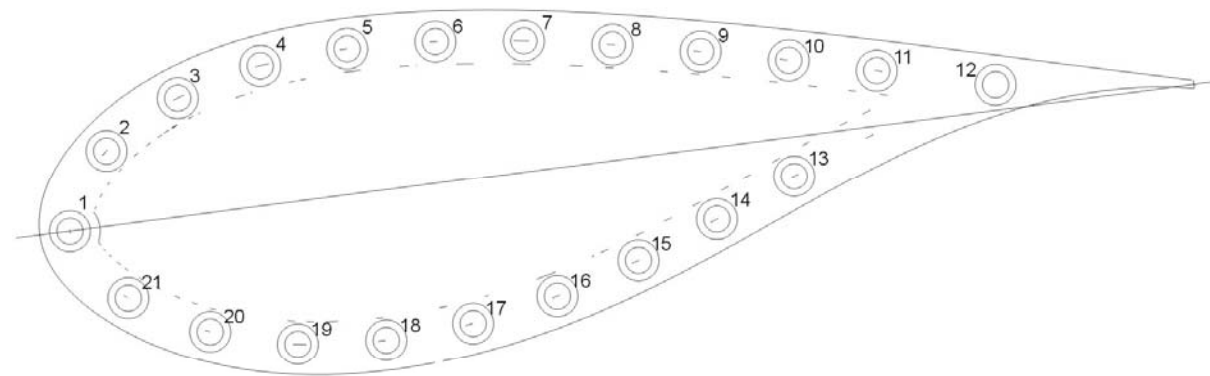
- manufacture specific test coupons (simple geometry) to characterise the basic material
- take thermoelastic stress measurements at a given area of the test object and then apply strain gauges to determine calibration constants
- construct a finite element model of the test object, derive calibration constants from one (well behaved) region and evaluate this against other areas



# Sectional Blades

Three design concepts:

- stud-bolt connection
- T-bolt connection
- connecting tubes



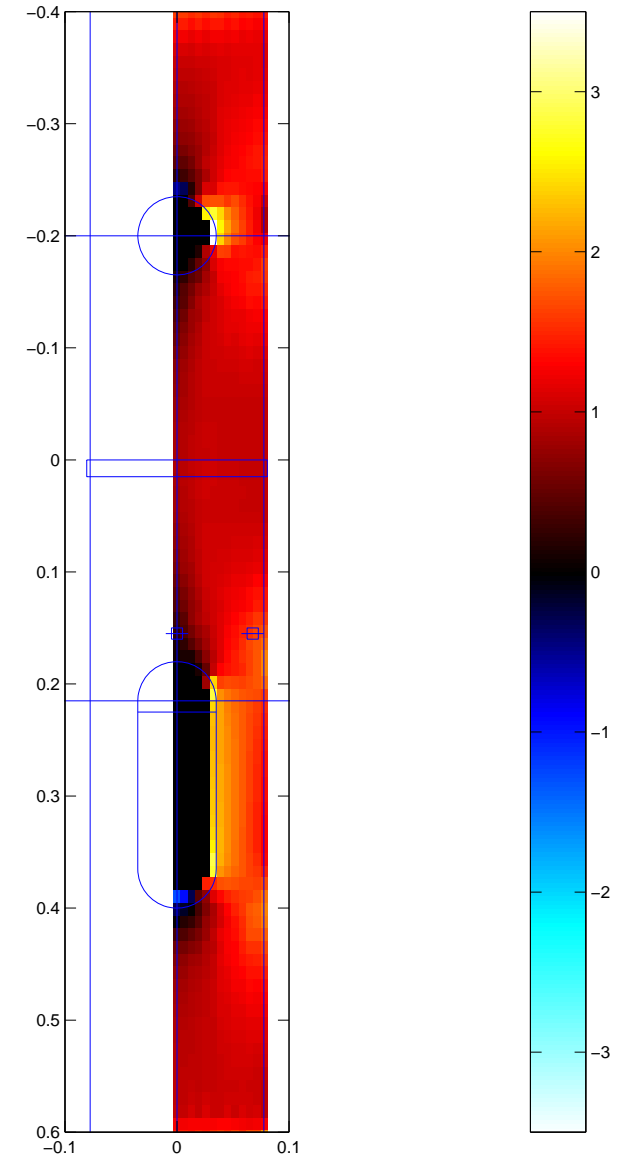
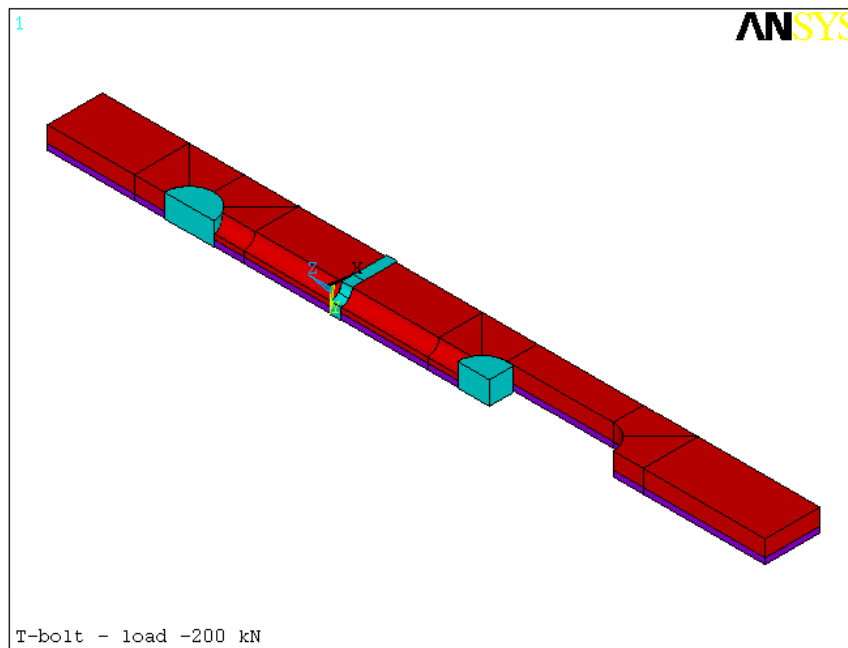


# T-bolt connection - geometry





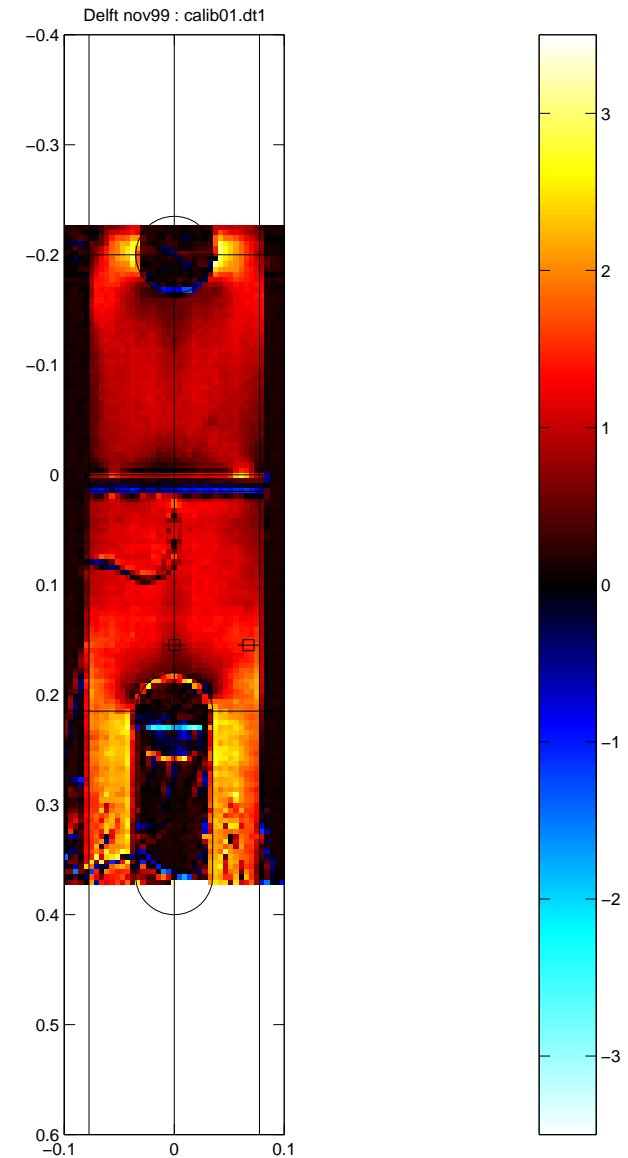
# T-bolt connection – FE analysis





# T-bolt connection – TE stress meas.

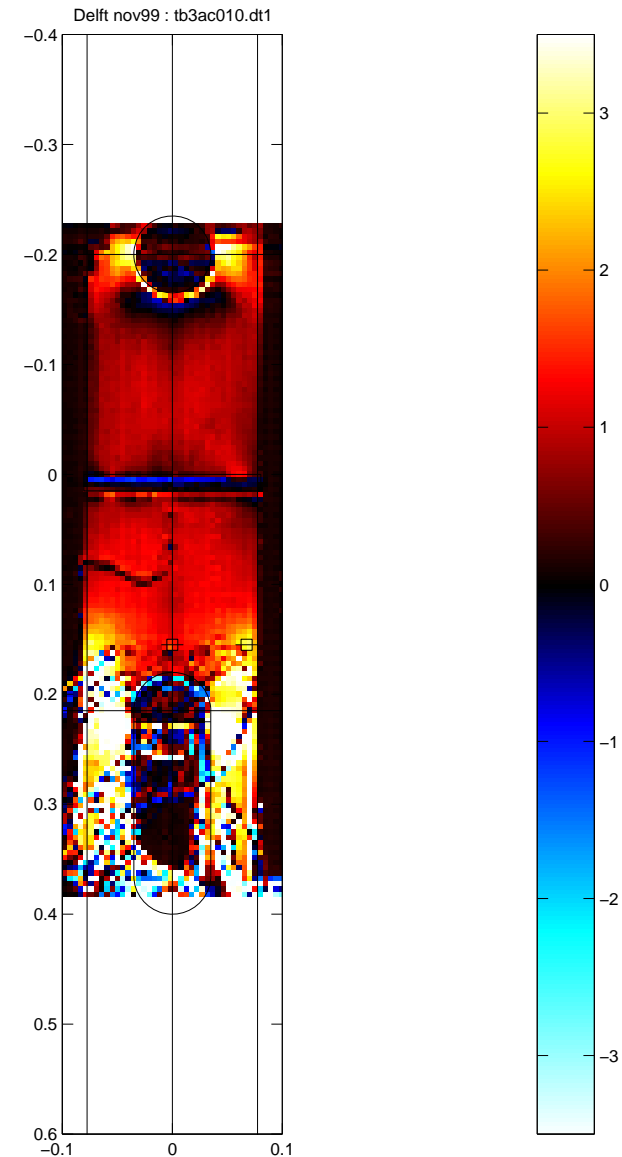
- Reversed loading fatigue test
- Calibration load





# T-bolt connection – TE stress meas.

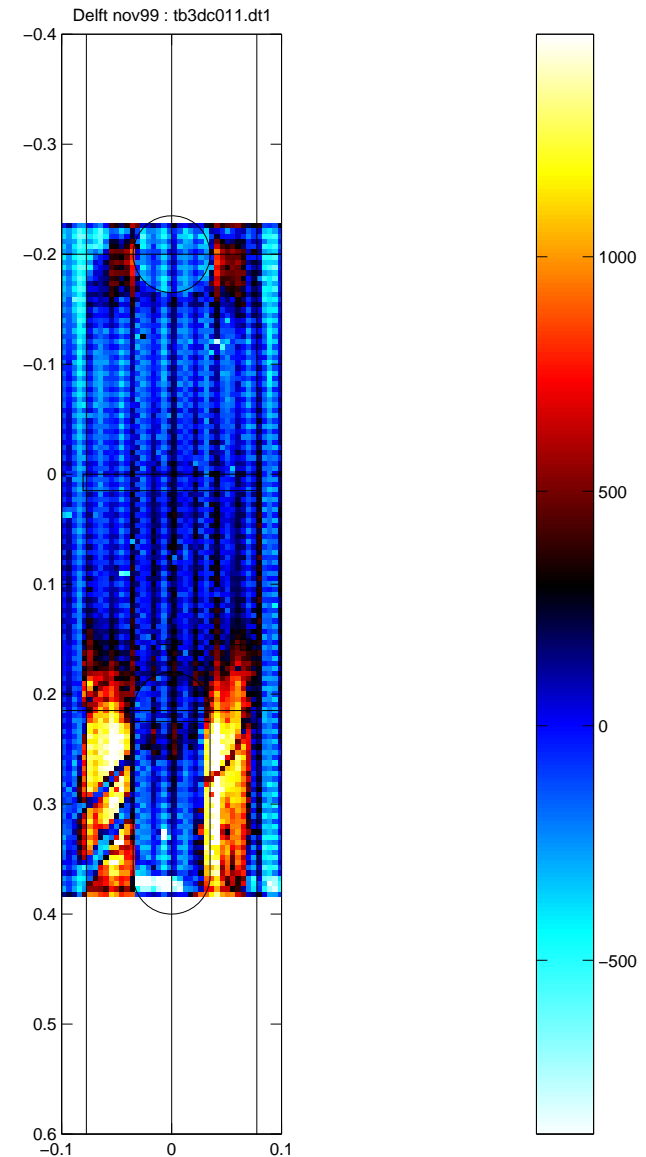
- Reversed loading fatigue test
- Fatigue test load





# T-bolt connection – IR thermography

- Reversed loading fatigue test
- Fatigue test load
- Uncalibrated temperature units





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# AEGIS

# AEGIS

## Acoustic Emission monitoring for Integrity of Structures

*AEGIS = Shield of Zeus (impregnable defence)*

CLRC Rutherford Appleton Lab., UK

CRES Wind Energy Department, GR, Delft University of Technology, NL,

Envirocoustics Abee, GR, Euro Physical Acoustics, S.A., FR

Geobiologiki S.A., GR, Aerpac B.V., NL

University of Patras, GR, Cranfield University, UK



## Why apply AE (or TSA) to blade tests?

- Increasing size, investment, inaccessibility
- Certification tests for new blades
  - static test (extreme load)
  - fatigue test
- Audible emissions common during static tests
- AE can locate and monitor damage
- Information can be fed back to the designer



## AEGIS blade certification test procedure

AEGIS proposed blade certification test procedure:

- static test with AE examination loading
- AE-monitored fatigue test
- residual strength test to failure
- For further details see: *Acoustic emission proof testing and damage assessment of wind turbine blades (AEGIS)*, EC Contract No. JOR3-CT98-0283, Final Report, December 2002



CCLRC  
Rutherford Appleton Laboratory



KAPN  
CRES



TU Delft  
Delft University of Technology



Envirocoustics  
Non Destructive Testing



UNIVERSITY OF PATRAS  
DEPARTMENT OF  
MECHANICAL  
ENGINEERING &  
AERONAUTICS  
SECTION OF APPLIED  
MECHANICS



EURO  
PHYSICAL  
ACOUSTICS



GEOVIOLOGIKI

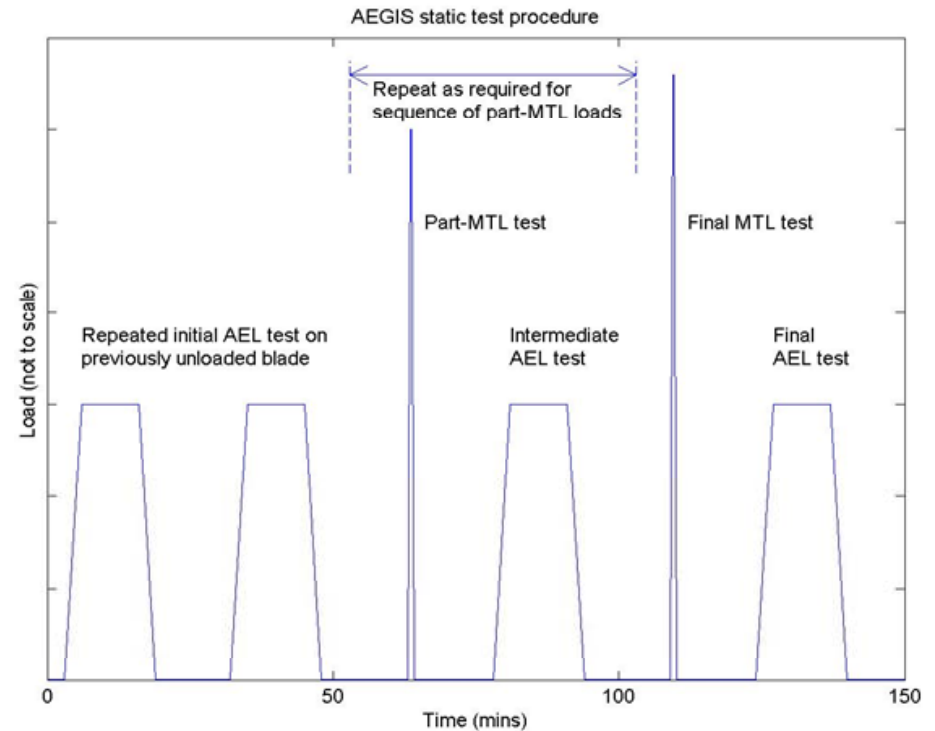


Cranfield  
UNIVERSITY

## AEGIS – static blade test procedure

### Two part test:

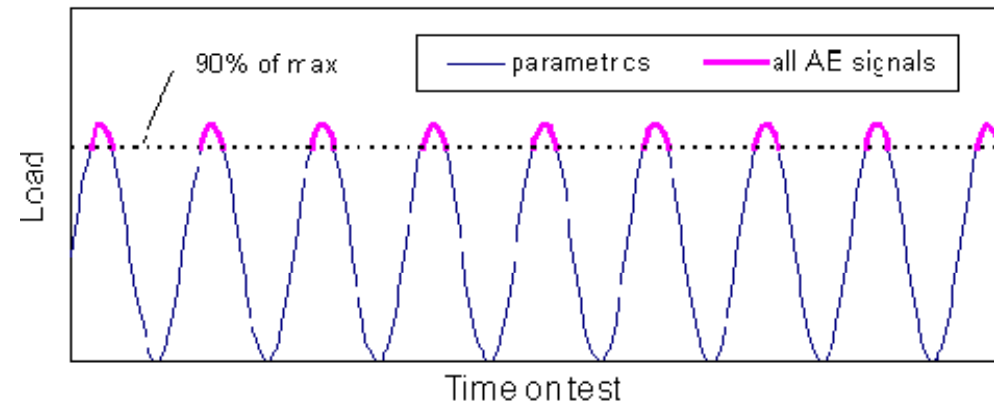
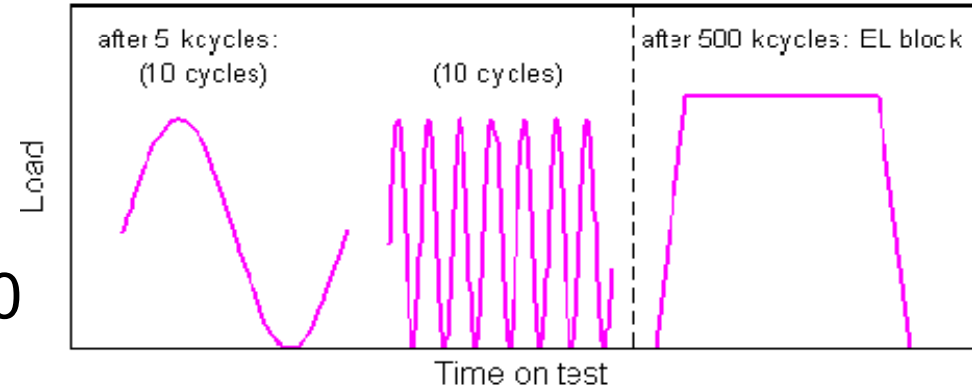
- Mandatory certification loading to maximum test load (MTL) – typically a 10s “spike” load (representative of the 50 years’ maximum gust)
- AE examination loading (AEL) – trapezium-shaped load envelope including a 10 minute load-hold period, performed before and after any certification loading



## AEGIS – fatigue blade test procedure

### Four load stages:

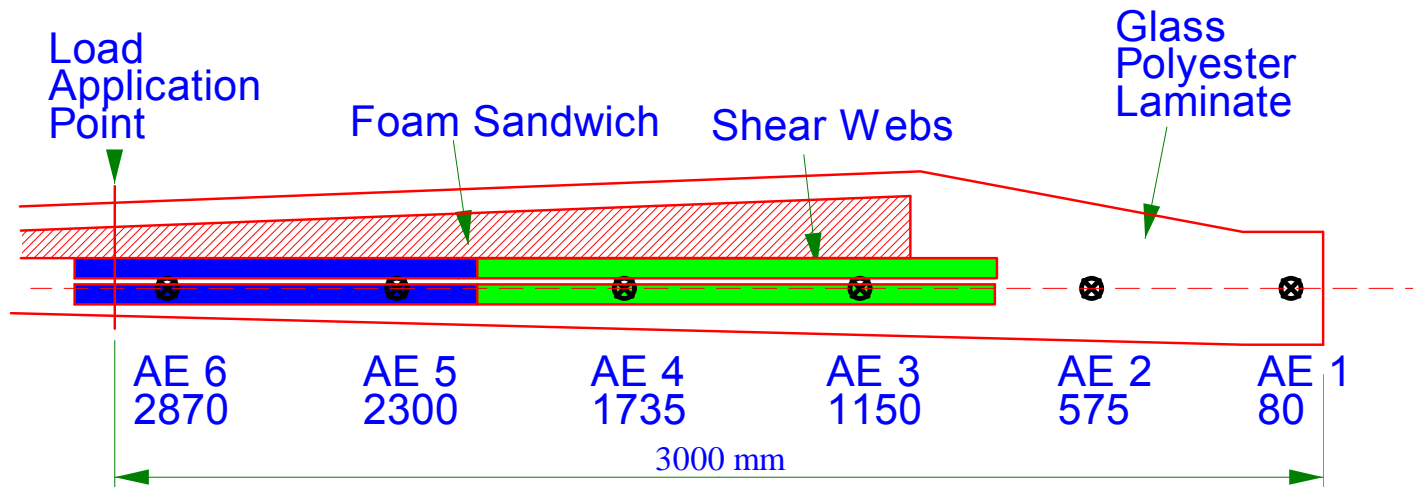
- initial (low level) static AEL to operating load
- static AEL test to 10% above peak fatigue load at start and after every 500000 cycles
- fast sinusoidal fatigue cycles to the peak fatigue load (AE hits recorded for the top 10% load of each cycle)
- after every 10,000 cycles, load application rate reduced to 10% giving 10 slower cycles








# AEGIS - small blade design

## 4.5 m Small Blade



### Key:

-  Blades 1 to 4 Shear Webs to 2100 mm
-  Blades 5 to 10 Additional Shear Webs to 3100 mm
-  AE Sensor Symbol
- AEn** Ref Number
- 850** Distance from Root [mm]



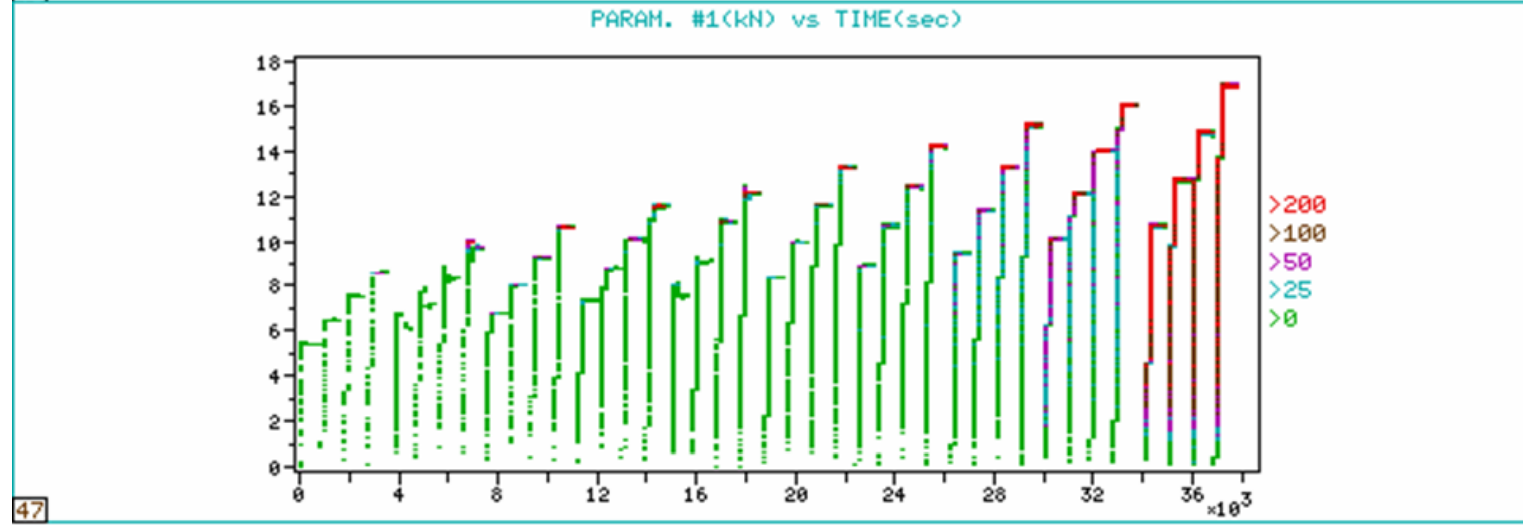
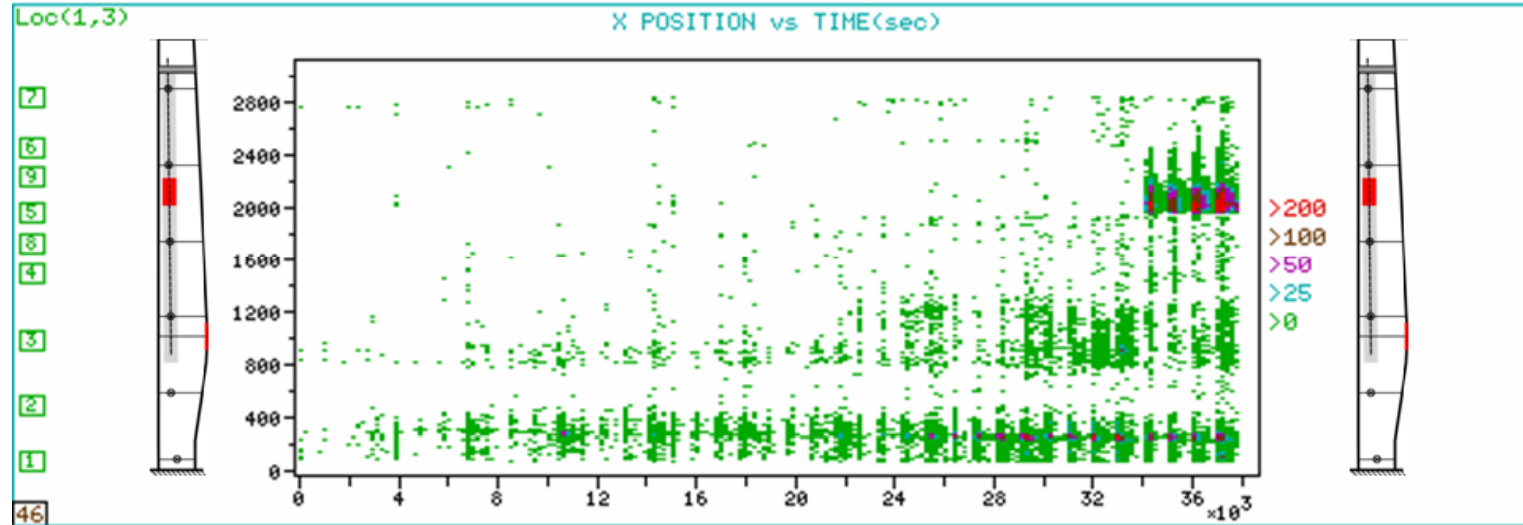
# AEGIS : AE results - blade 7s static

C:\AEALL.DTA  
Scr#13

REPLAY DONE  
LNXYZN12.PCX

AEGIS Small Blade 7 AE examination tests  
The following data set was LINK'd

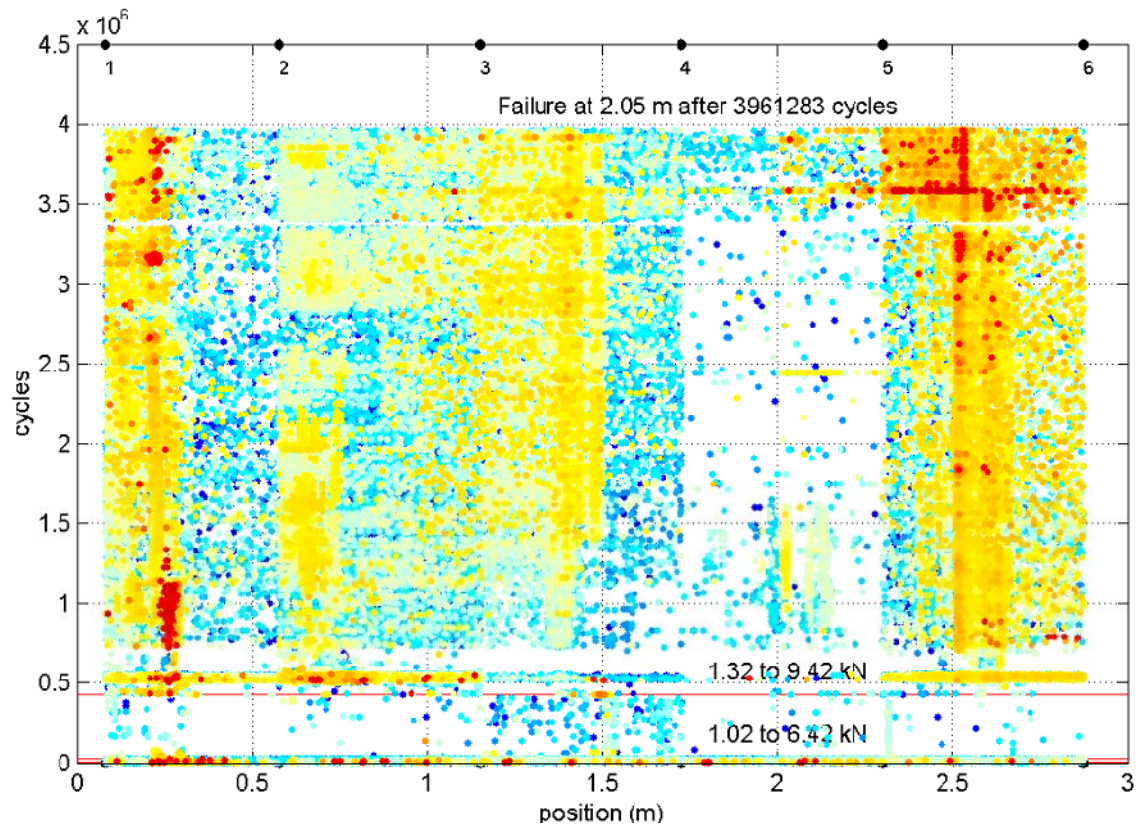
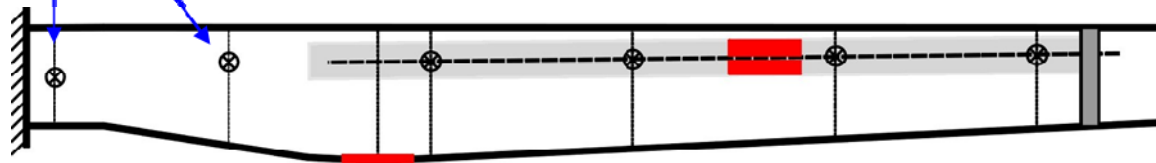
Apr 3, 2001 19:14:41  
0 10:37:53



# Hits: 261703 # Ev: 179541 ΣN: 3448878 ΣEner: 7097898 Load 1: 0.20  
F10 TO CANCEL

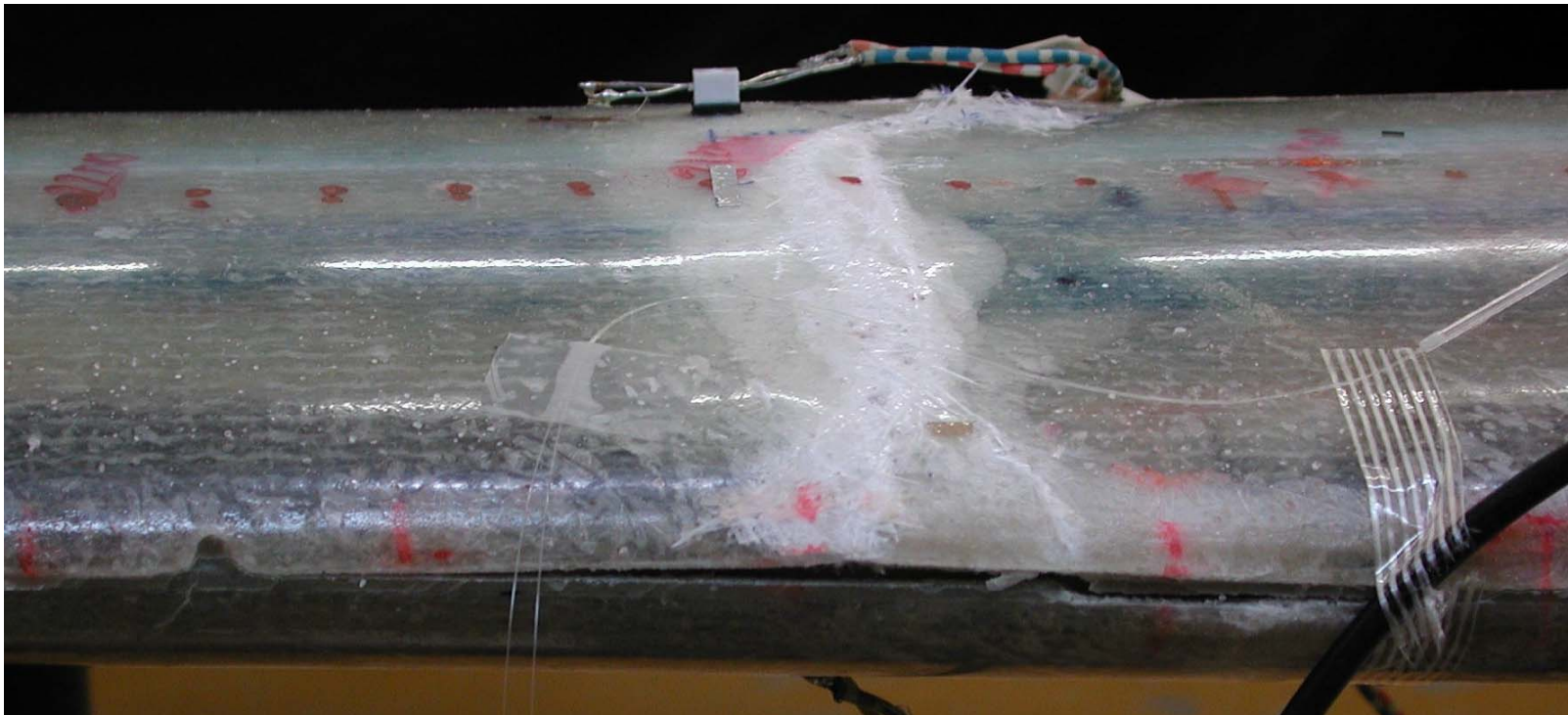
## AE sensors

# AEGIS : AE results - blade 10f fatigue



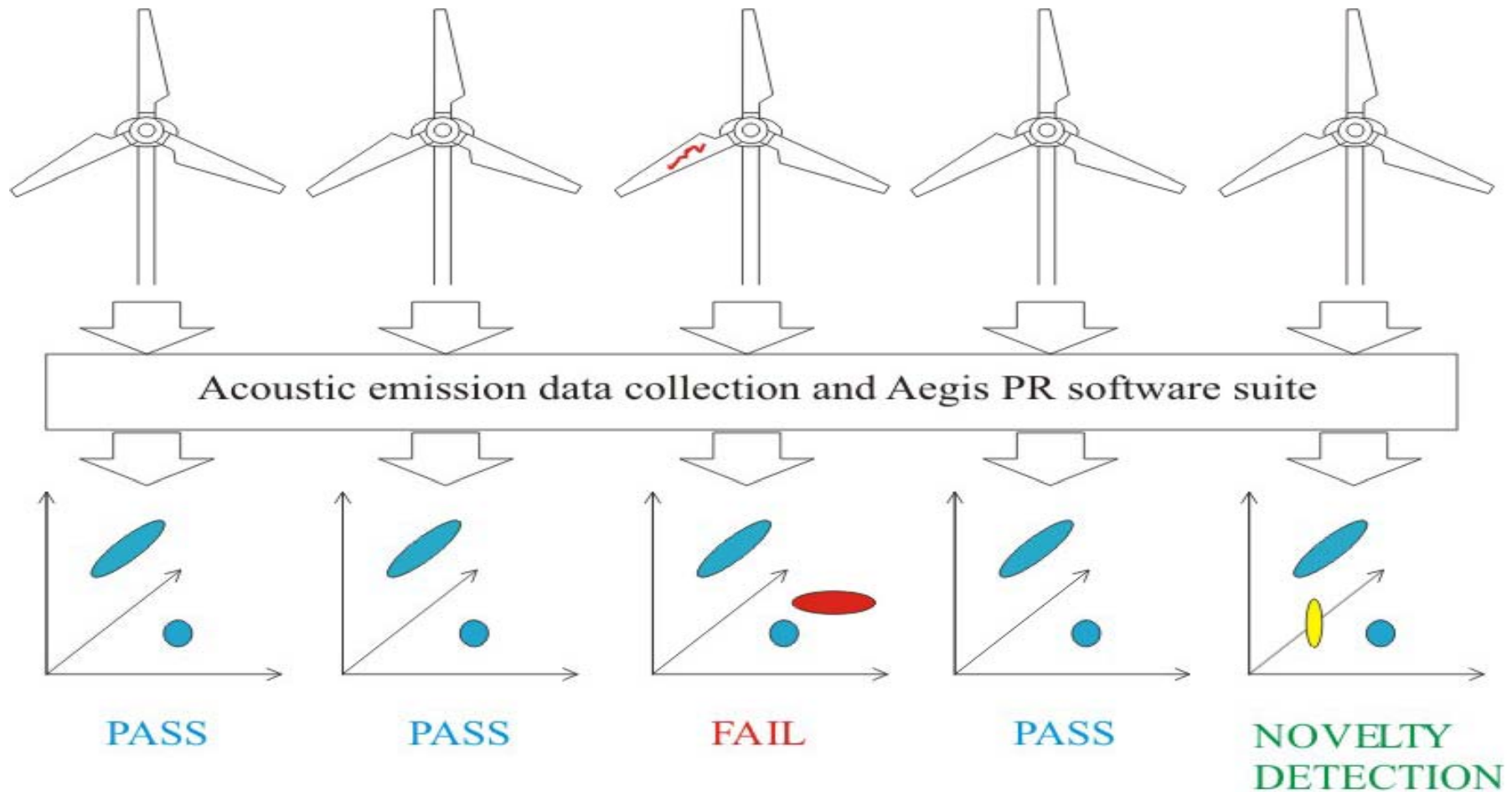


## AEGIS : Blade 10f - failure!





# Application of AE in a wind farm (concept)





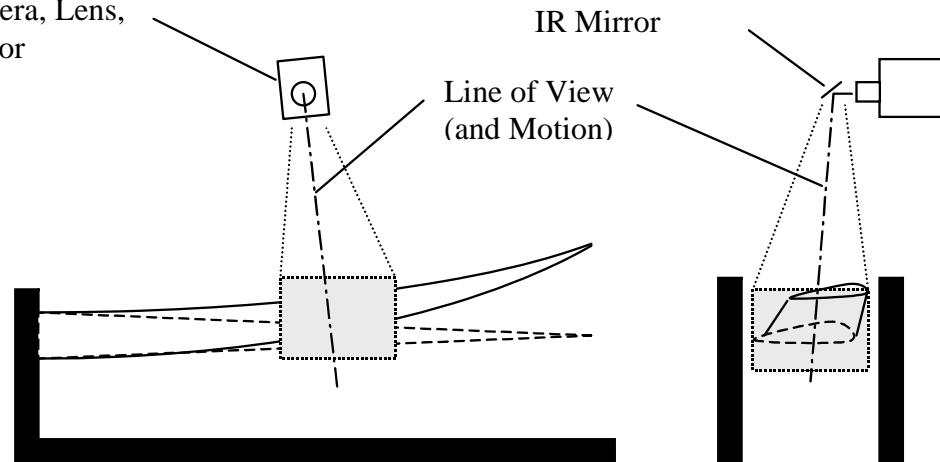
# AEGIS - test arrangement



Camera, Lens,  
Mirror

IR Mirror

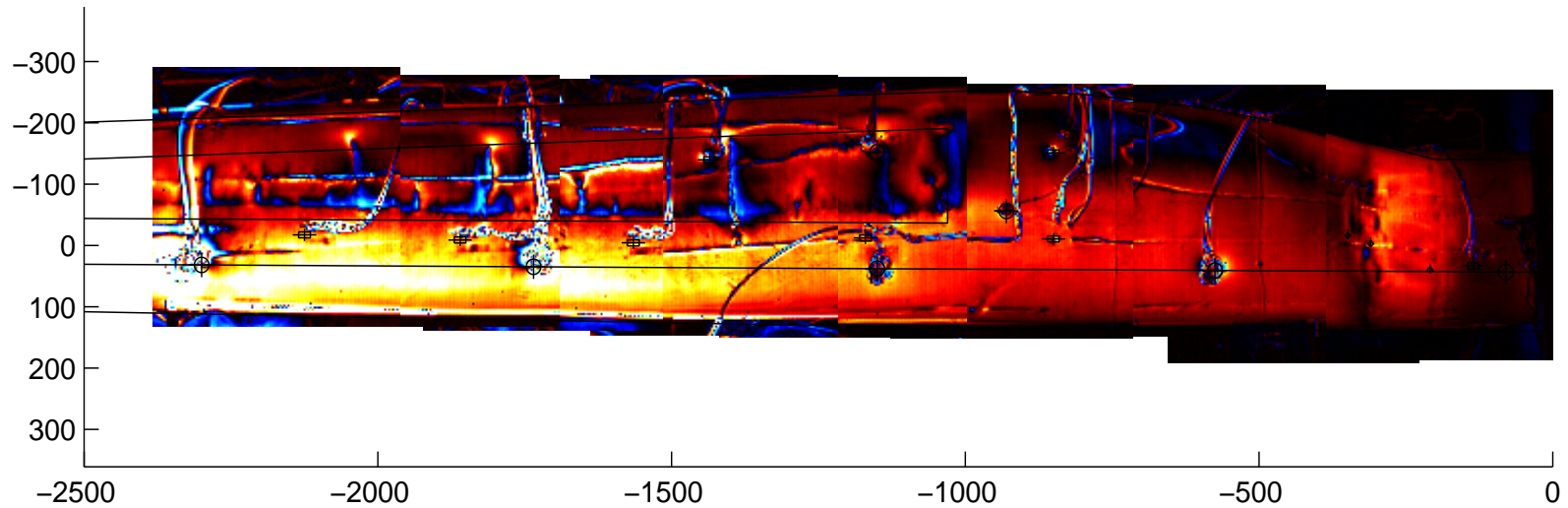
Line of View  
(and Motion)



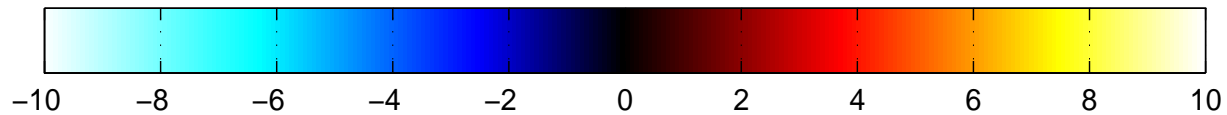


# AEGIS : TSA (blade 6f) - 75% of life

Thermoelasticity : Blade 6f – 03-Oct-2000



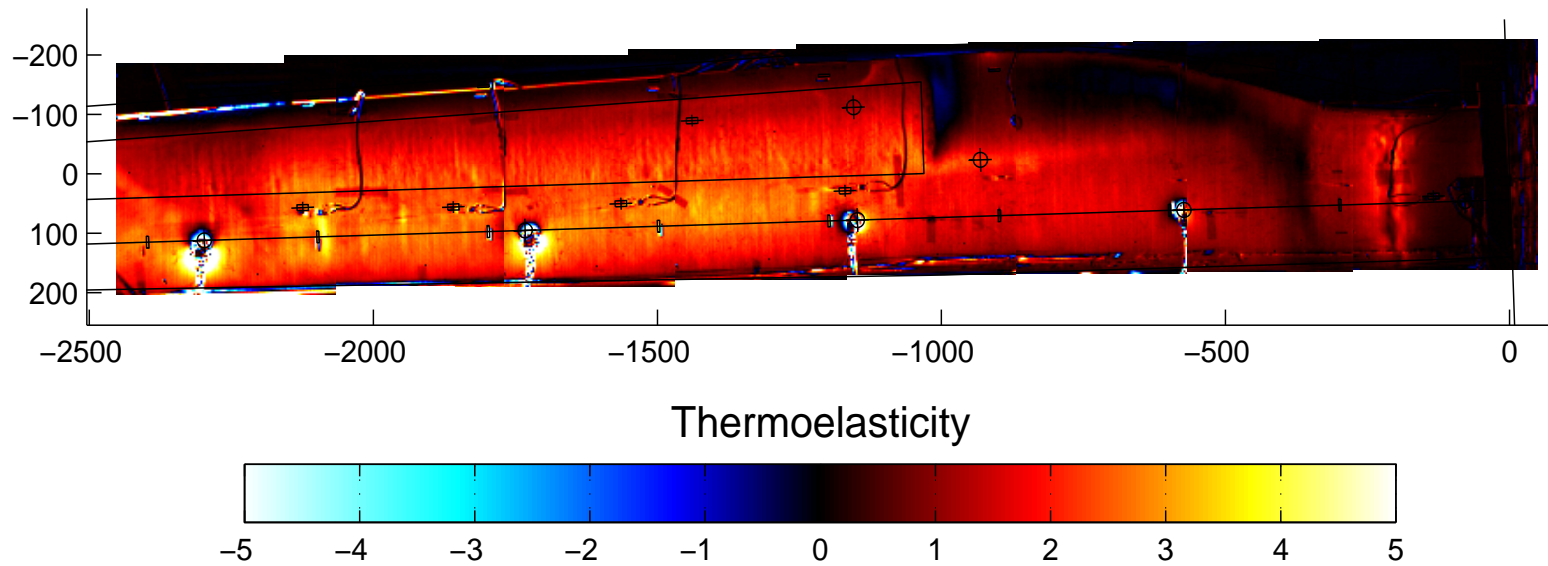
Normalised thermoelastic stress





# AEGIS : TSA (blade 10f) – 0% of life

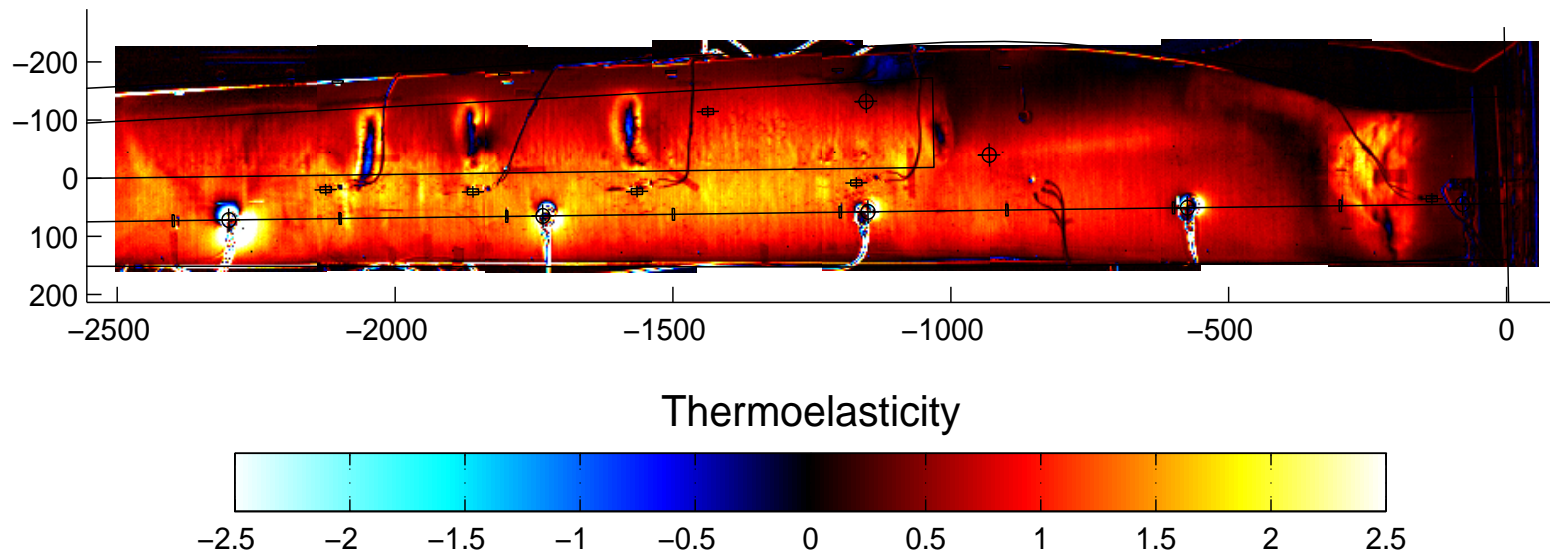
Thermoelasticity: Blade 10, 18 Jan 2001, 07 08 09 12 13 14 15 16





# AEGIS : TSA (blade 10f) – 98% of life

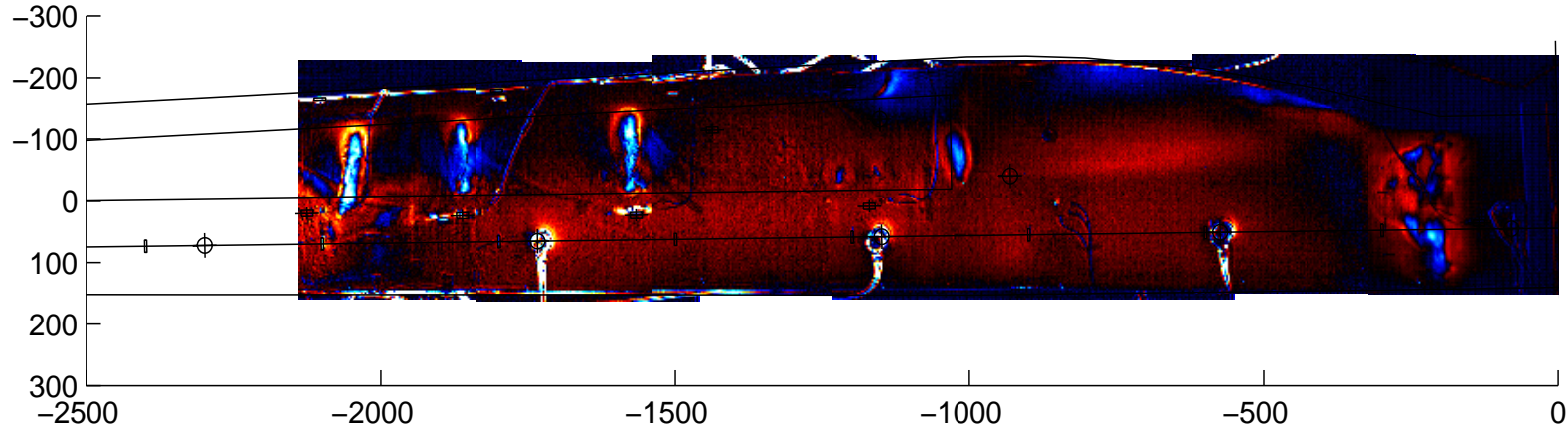
Thermoelasticity: Blade 10, 28 March 2001, 146 143 139 136 132 129 125 121



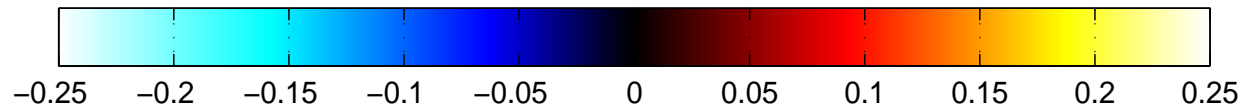


# AEGIS : 2nd harmonic TSA (blade 10f) - 98% of life

2nd Harmonic Thermoelasticity: Blade 10, 28 March 2001, 144 138 137 131 130 124 122



Thermoelasticity





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<b>Research</b>	<b>Industrial</b>
Prof W E Leithead, Strathclyde University Prof P J Tavner, Durham University Prof A Brown, Manchester University Dr A G Dutton, CCLRC Dr P Hancock, University of Surrey Prof P Hogg, Queen Mary College, University of London Mr C Mingham, Manchester Metropolitan University Dr S Watson, Loughborough University Prof S Williamson, Manchester University	AMEC Wind Energy Areva T&D UK Ltd. Chell Instruments Econnect Ltd. E.ON UK Renewables Ltd. ESR Network Garrad Hassan & Partners Ltd. HR Wallingford Ltd. New & Renewable Energy Centre Ltd. ScottishPower Generation Ltd. Smart Fibres Ltd. Vestas Blades Ltd



## SUPERGEN Wind - Objectives

Objective : To undertake research to improve the cost-effective reliability & availability of existing and future large-scale wind turbine systems in the UK

The Consortium will search for engineering solutions:

- to improve the efficiency and reliability of wind energy.
- to reduce the cost of energy production.
- to facilitate the siting of turbines in off-shore locations.



## SUPERGEN Wind - Themes

### 4 Themes:

- Theme W: *Baselining Wind Turbine Performance*
- Theme X: *Drive-train Loads & Monitoring*
- Theme Y: *Structural Loads & Materials*
- Theme Z: *Environmental Issues*

## THEME Y: Structural loads and materials

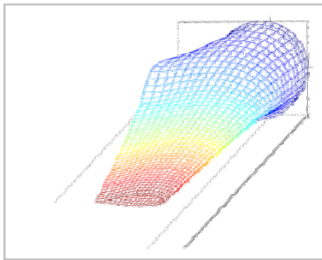
**TARGETS** : cost-effective availability & reliability  
optimal use of materials      increase strength  
reduce structural loads      enable larger machines  
improved fatigue life

↓ 4 Sub-Themes ↓

- Y1 : Wind turbine component design
- Y2 : Aerodynamic estimation for operational control
- Y3 : Active load reduction
- Y4 : Engineering large wind turbines

# Y1: Wind turbine component design

- Wake effects on blade loading  
Surrey University & Imperial



- Novel blade materials  
Queen Mary - London  
CCLRC-RAL

- Structural blade model  
CCLRC-RAL  
Queen Mary - London

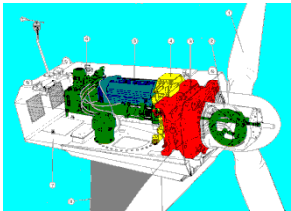


- Novel tower materials  
Queen Mary - London

R  
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## Y2: Aerodynamic estimation for operational control



- On-line estimation of aerodynamics  
from operational control variables  
Strathclyde University



- On-line estimation of aerodynamics  
from blade load measurements  
Surrey University & Imperial

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## Y3: Active load reduction



- Tower load reduction  
Strathclyde University

- Tower head and blade load reduction  
Strathclyde University



- Holistic approach to active load reduction  
Loughborough University
- “Smart” blades  
CCLRC-RAL

R	D	M
E		O
P	A	D
O	T	E
R		L
T	A	
S		S





- AE, TSA and IRT can be applied to large scale composite components during fatigue testing
  - experimental design is very important
  - AE proof test during static blade test works satisfactorily, but there are problems with the fatigue methodology
  - local (absolute) temperature increases occur due to viscoelastic material behaviour and damage → diagnostic of damage
  - second harmonic TSA approach identifies areas exhibiting non-linear stress behaviour
  - A good blade model is required to interpret the results and optimise sensor location (ongoing work)



# Acknowledgements

European Commission - project no. JOR3-CT97-0167 (Sectional Blades)

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EPSRC Grant GR/M99057/01 - Damage detection and characterisation in fibre reinforced plastics using IR emissions (University of Southampton)

EPSRC Grant GR/N04997/01 - Characterisation of damage in wind turbine blade tests using thermoelastic stress analysis and infra red thermography images

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