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Experimental Mechanics: an introduction

Janice M. Dulieu-Barton

FAM FORUM FOR APPLIED MECHANICS

BSSM BRITISH SOCIETY FOR STRAIN MEASUREMENT

What is Experimental Mechanics?

Experimental mechanics is defined as the understanding of the **mechanical** behaviour of systems under load through **experiment**

The system can be a structure, a material, some soft matter such as human tissue, a fluid-structure coupling ……

Implicit in the definition is that some kind of **measurement system** is used to capture an attribute that defines the system behaviour

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Typical measurement devices

- Force or displacement transducer
- Accelerometer
- Strain gauge
- Thermocouple
- Acoustic sensor
- Optical fibre

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Full-field techniques

- Laser speckle interferometry
- Photoelasticity
- Thermography
- White light optical techniques (DIC)

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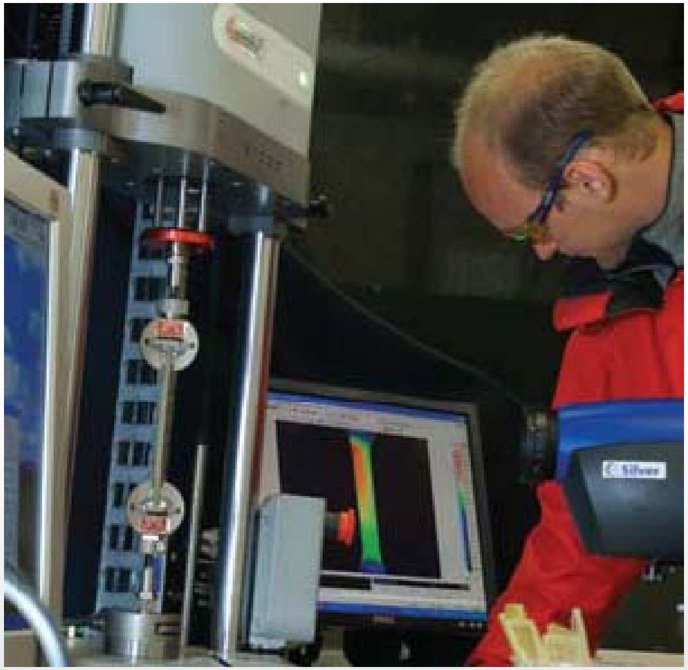
Experimental techniques

- Infra-red thermography (pulse phase, TSA)
- Digital image correlation (DIC)
- Acoustic emission
- Electronic speckle pattern shearing interferometry (ESPSI)
- Optical fibre sensors (FBGs on silica and polymers)
- Computed tomography
- Microscopy



Full scale tests

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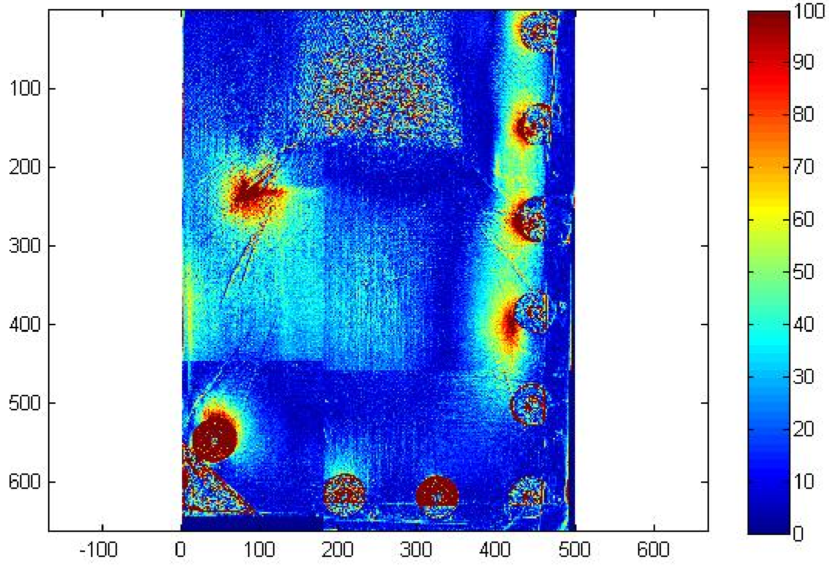

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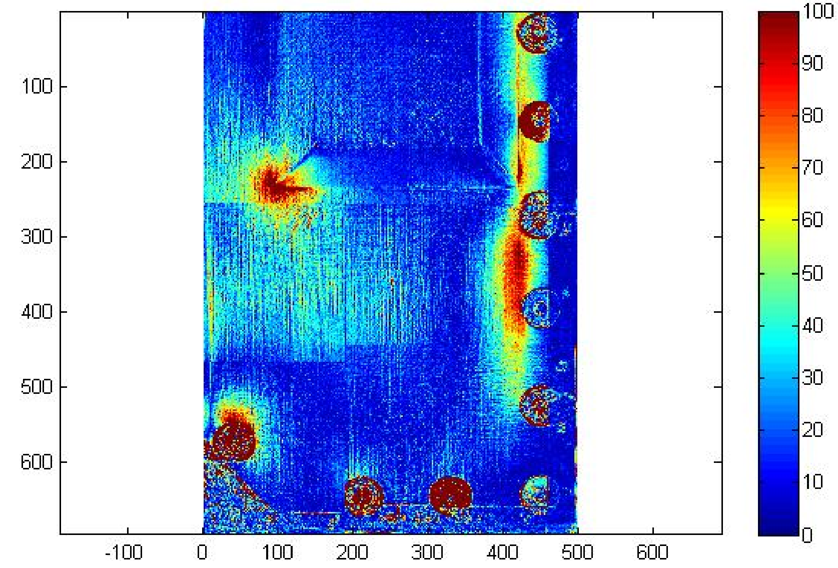

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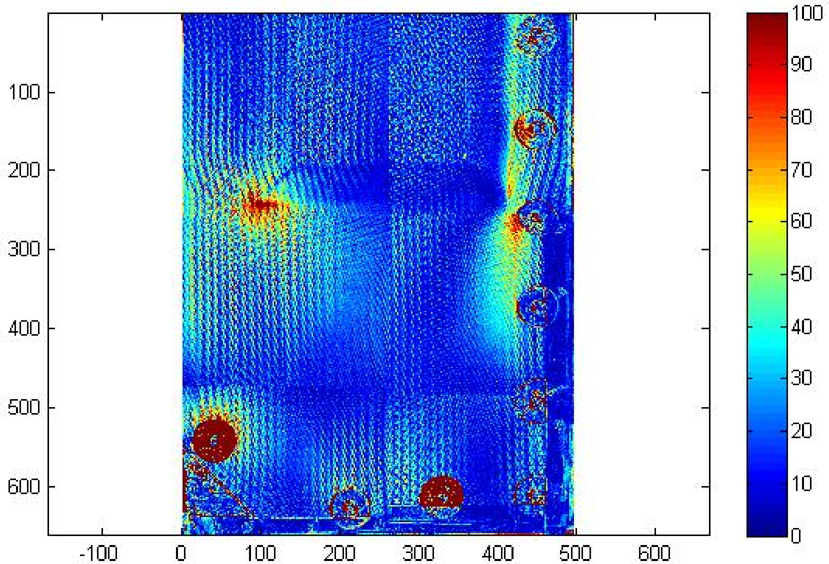

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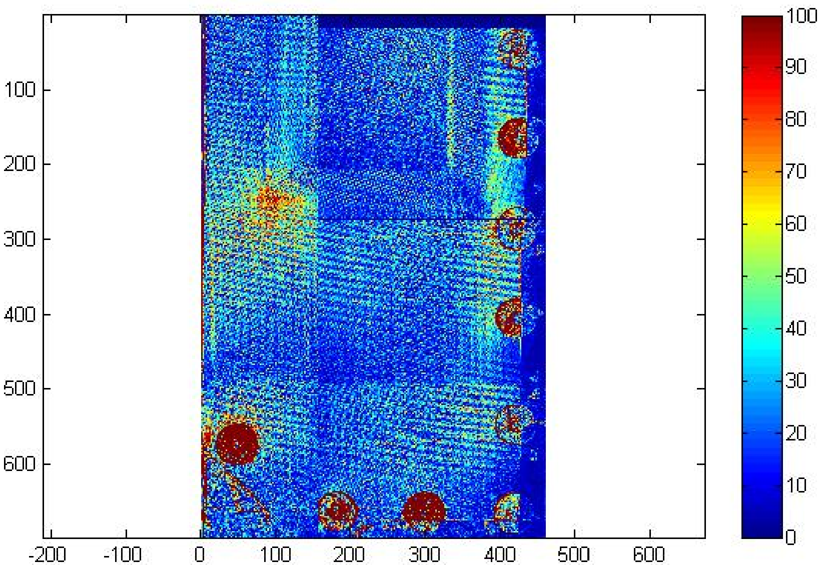
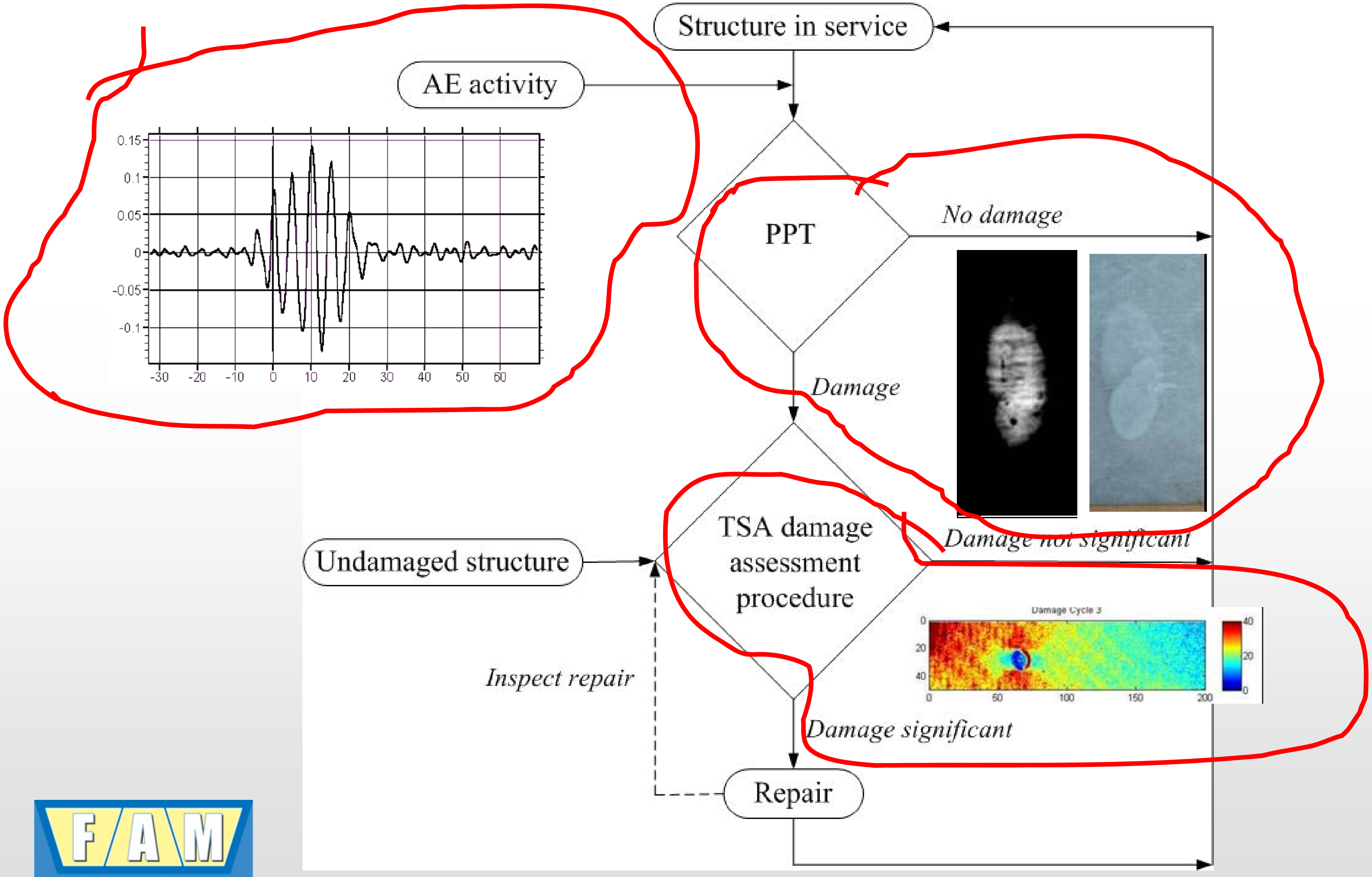


NDE and in-service examinations



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British Society for Strain measurement

The BSSM stands at the interface between industry, academia and the wider engineering community.

By promoting interaction the Society facilitates the wide dissemination of new ideas and best practice in the field of engineering measurement.

www.bssm.org

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‘Strain’ Journal

Strain is recognised as a leading publication in the field of experimental mechanics, with a circulation covering more than 50 countries and an impact factor of 0.642. It is available online along with Experimental Techniques. BSSM members receive 6 free issues of Strain per year.

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Forum for Applied Mechanics

- The Forum for Applied Mechanics exists to promote interactions between all organisations in the UK with an interest in applied mechanics both experimental and theoretical.

- It seeks to promulgate information on recent developments and to enhance standards employed by both researchers and practitioners. This will be achieved by expert meetings under both its own auspices and those of constituent organisations

- Members are NAFEMS, IMechE, BSSM, IOP, Engineering Integrity Society, British Gear Association

- http://www.appliedmechanics.org/

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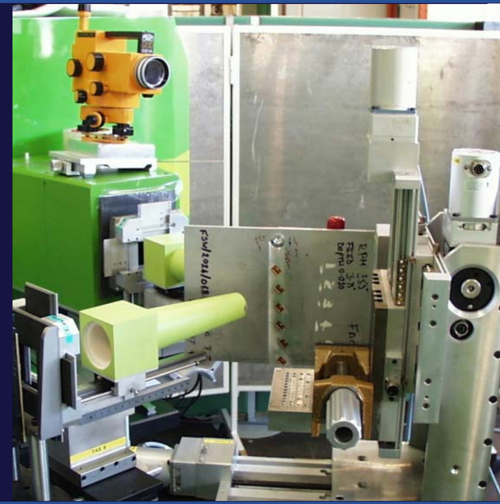
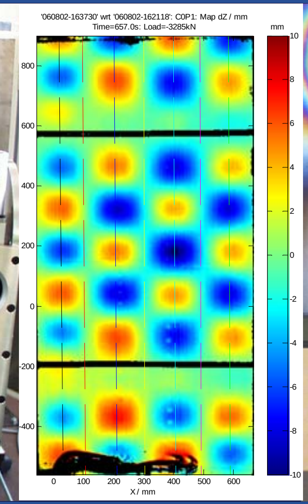
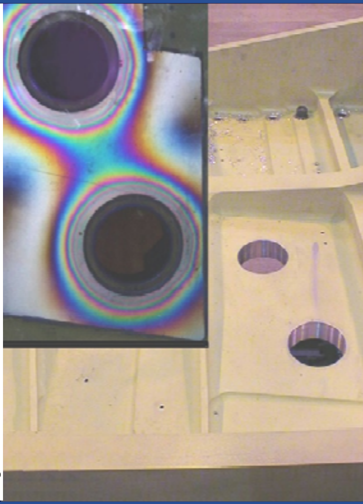
13th November 2008

Presented by

Richard L Burguete
Experimental Mechanics







The Importance of Experimental Mechanics in Solving Aerospace Problems

Forum on Applied Mechanics Webinar, BSSM/NAFEMS 2008

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Outline

- Introduction
- Objectives
- Applications
  - R&D
  - Design
  - Development
  - Manufacturing
- Summary
- The Future

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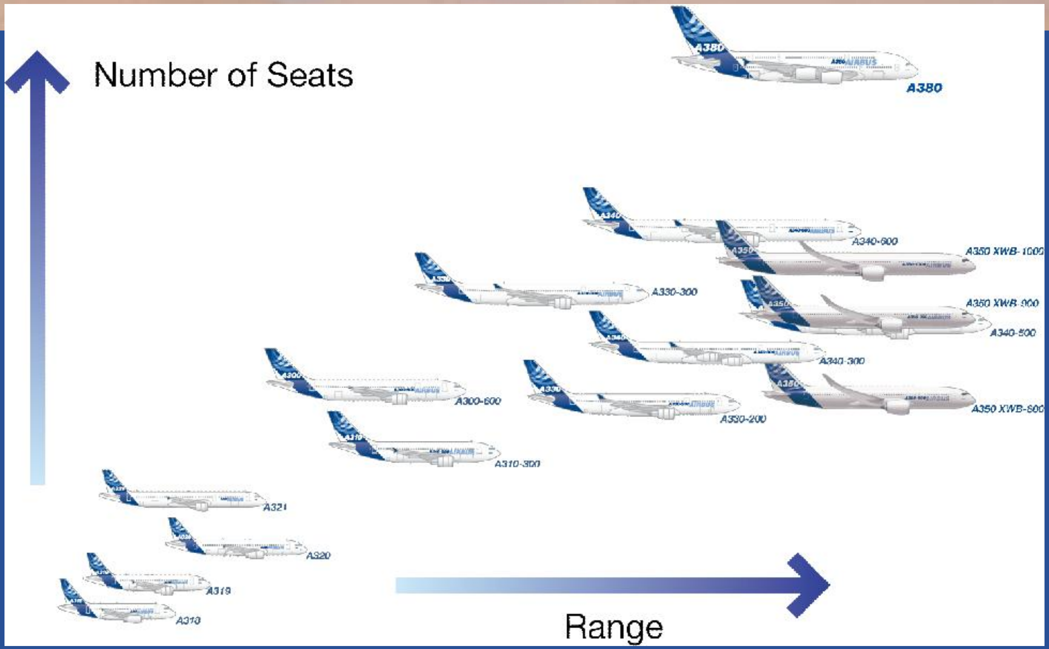


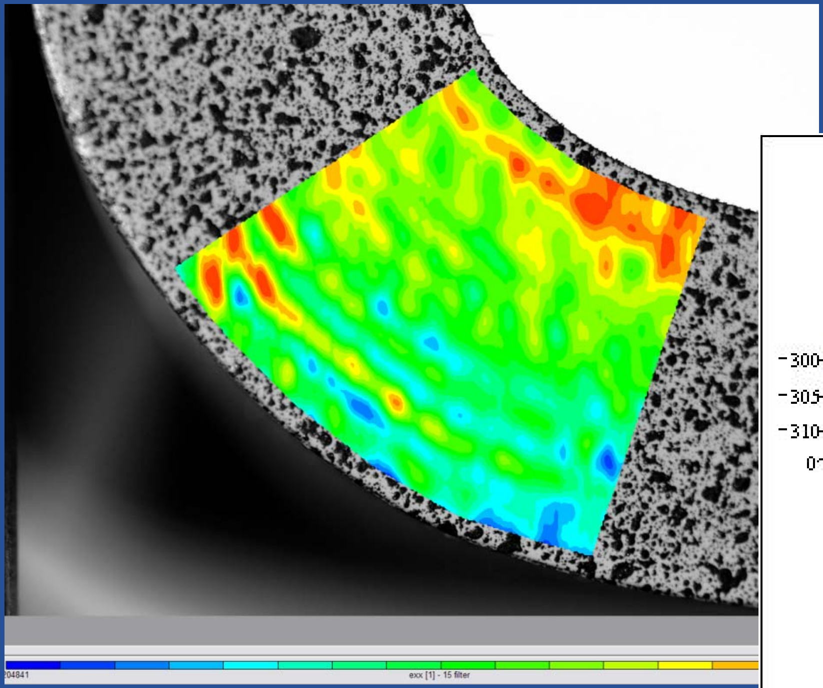
Introduction

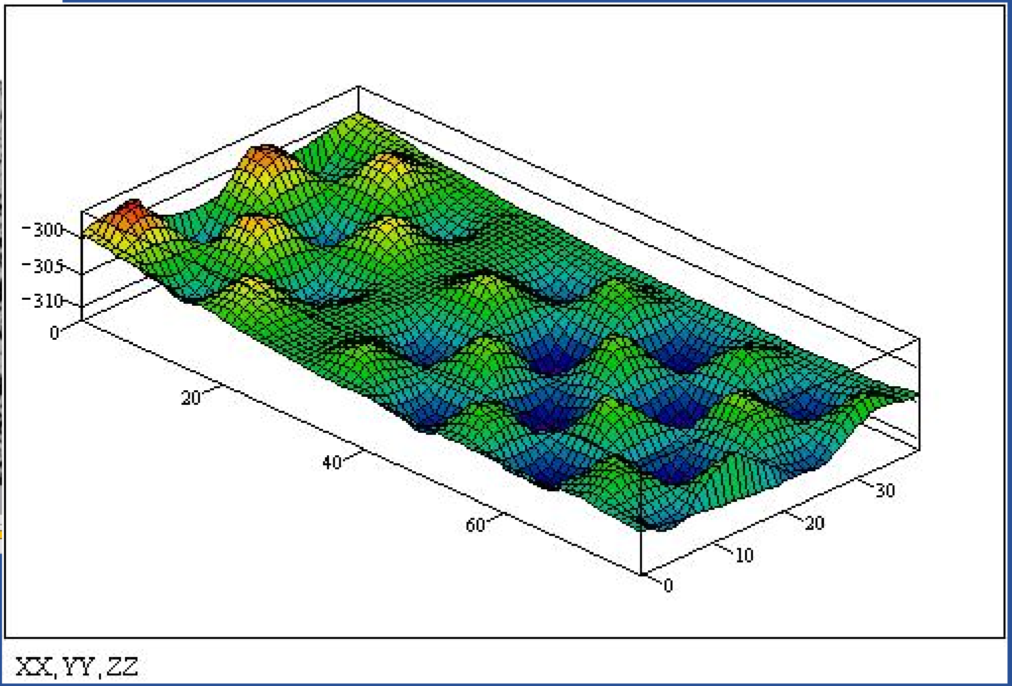
- Monitoring/measuring shape or strain distribution during testing (determination of buckling, deformation modes, strain distributions, stress concentrations, residual stress)
- Validation of numerical or mathematical models (optimisation, reduction of expensive testing)
- Damage detection (Barely visible impact damage, dents and scratches)

EM techniques routinely used for research, to support design, analysis and testing

Introduction

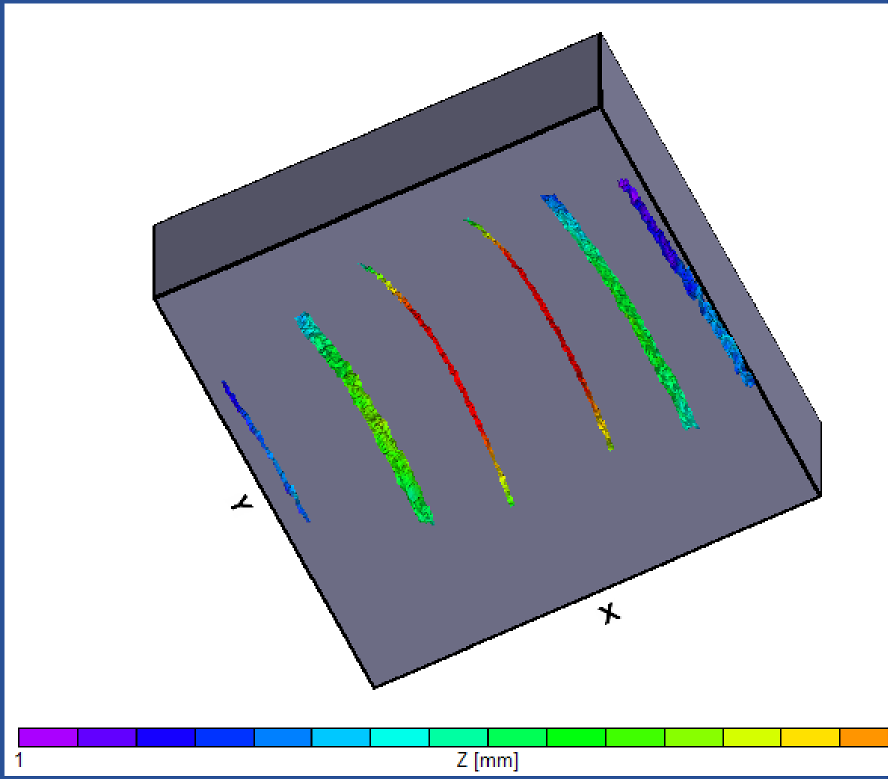
- Monitoring/measuring shape or strain distribution during testing (determination of buckling, deformation modes, strain distributions, stress concentrations)

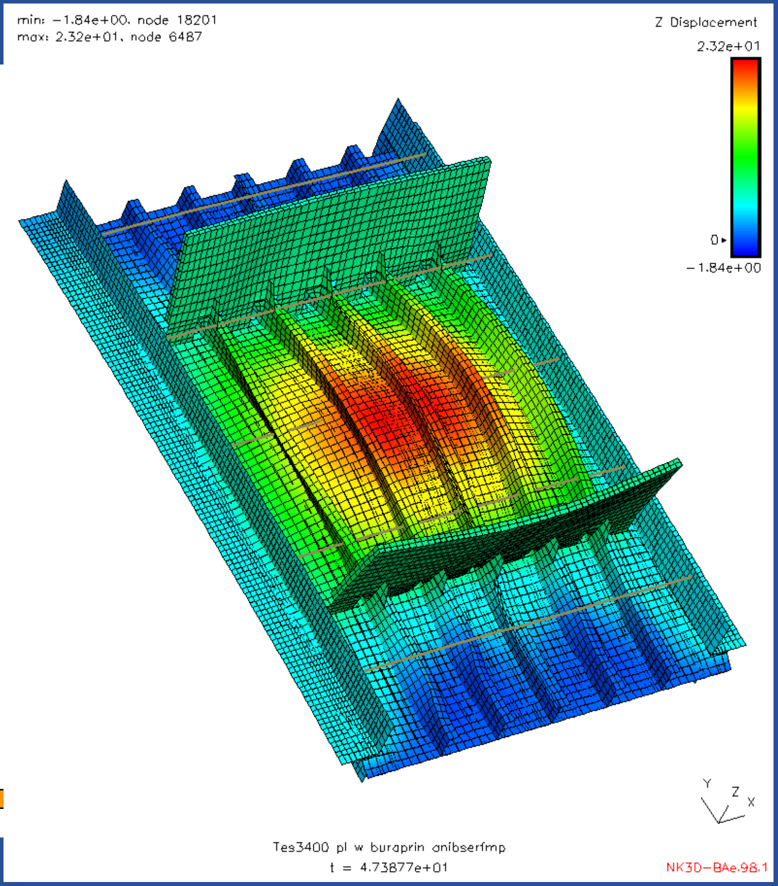




Introduction

- Validation of numerical or mathematical models (optimisation, optimisation of expensive testing)





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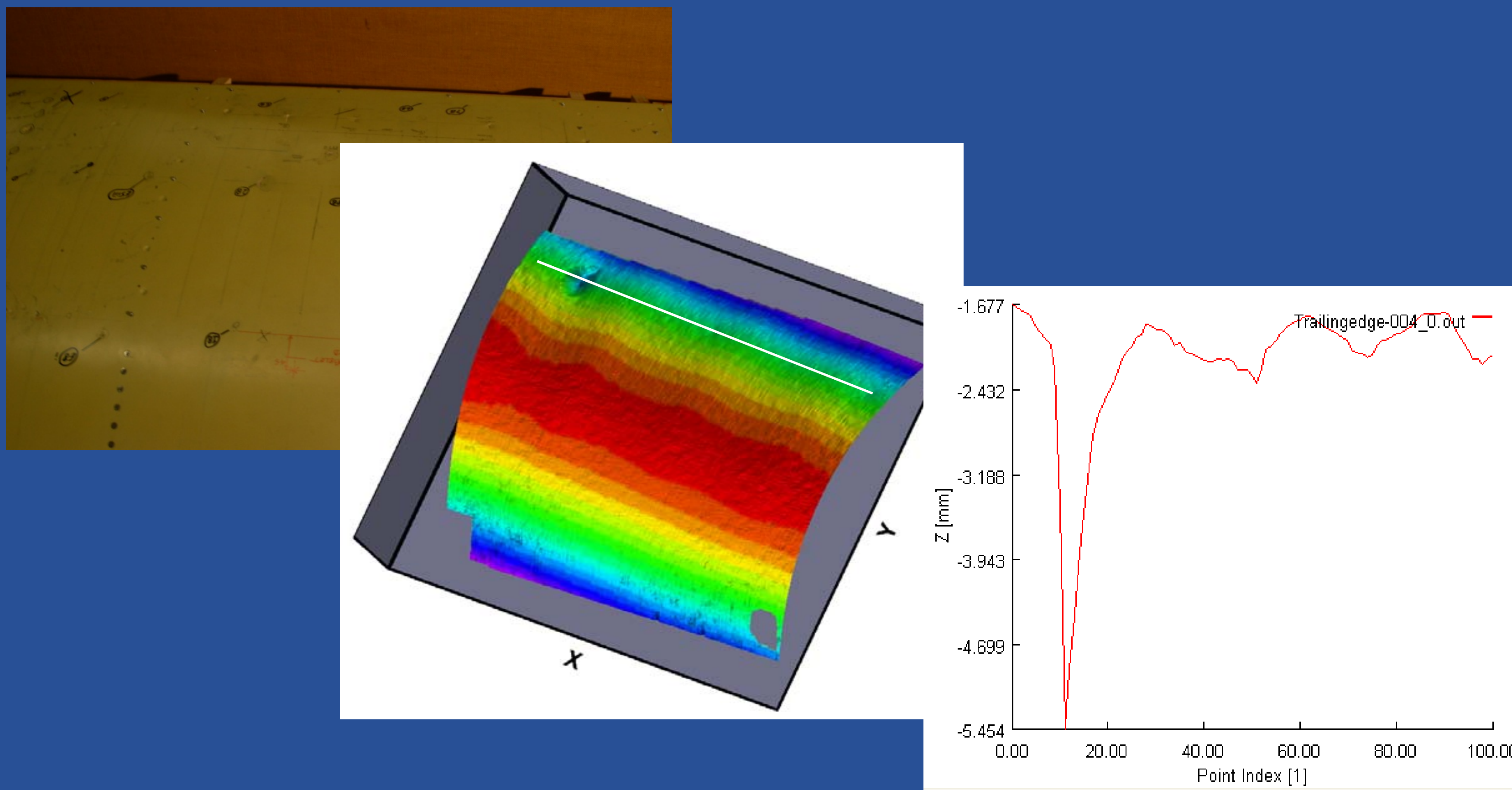
Introduction

- Damage detection (Barely visible impact damage, dents and scratches)



Objectives

- Demonstrate that a variety of Experimental Mechanics methods are being used routinely to advance the state of the art in Aerospace Engineering
- Show the versatility and broad range of application of EM methods, they are useful for much more than material or structural testing and are sometimes critical for solving aerospace engineering problems
- Why are these methods are important?
  - Give a true world view
  - Data richness makes it is easier to understand complex behaviour
  - A better understanding of materials and structures allows more extensive optimisation

Applications

- R&D – Development and assessment of Friction Stir Welding
- Design
- Development
- Manufacturing

R&D – Development of Friction Stir Welding

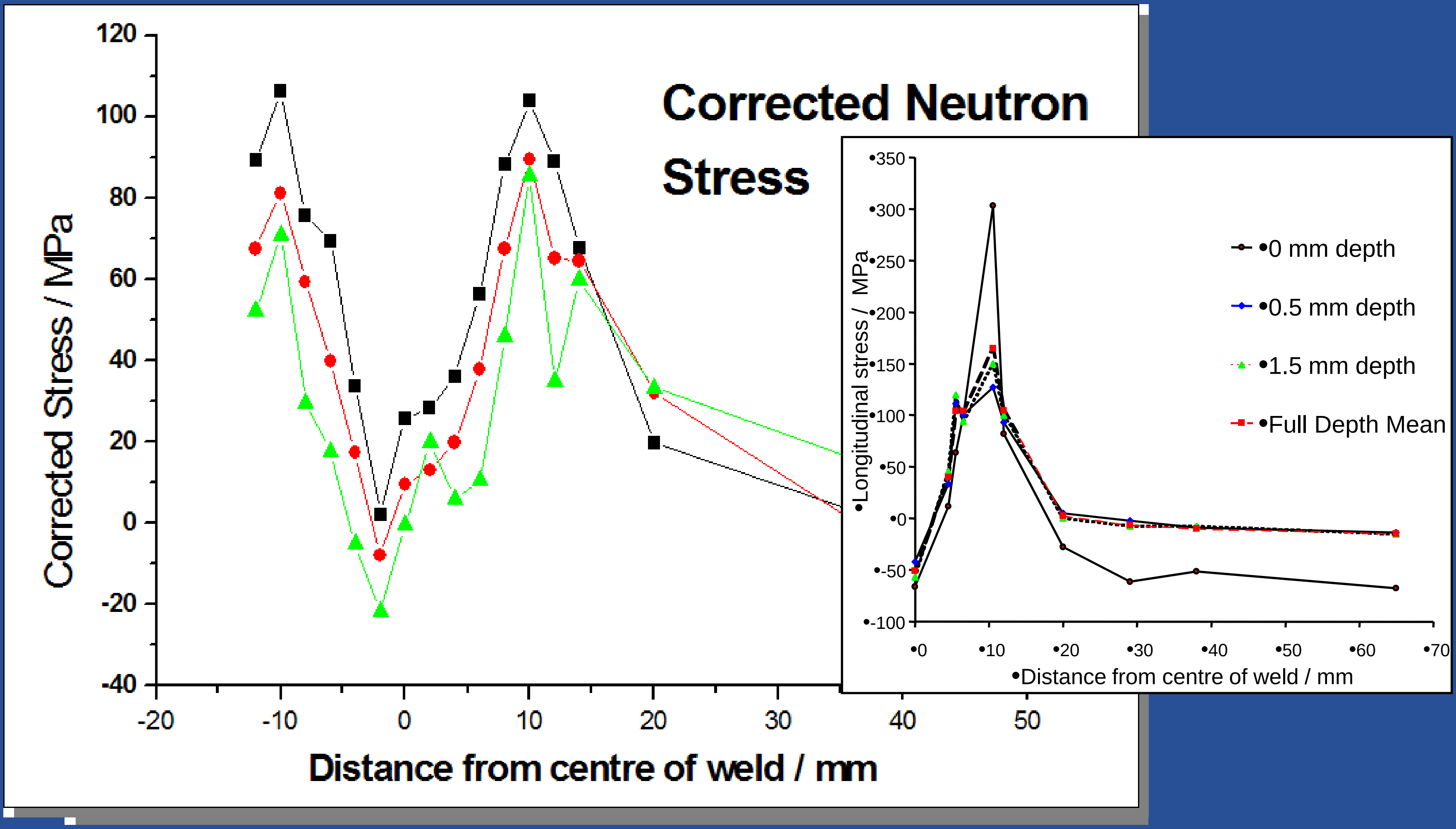
- The friction stir welding process

R&D – Development of Friction Stir Welding

- Measurement of residual stress using Neutron Diffraction and Synchrotron X-Ray Diffraction

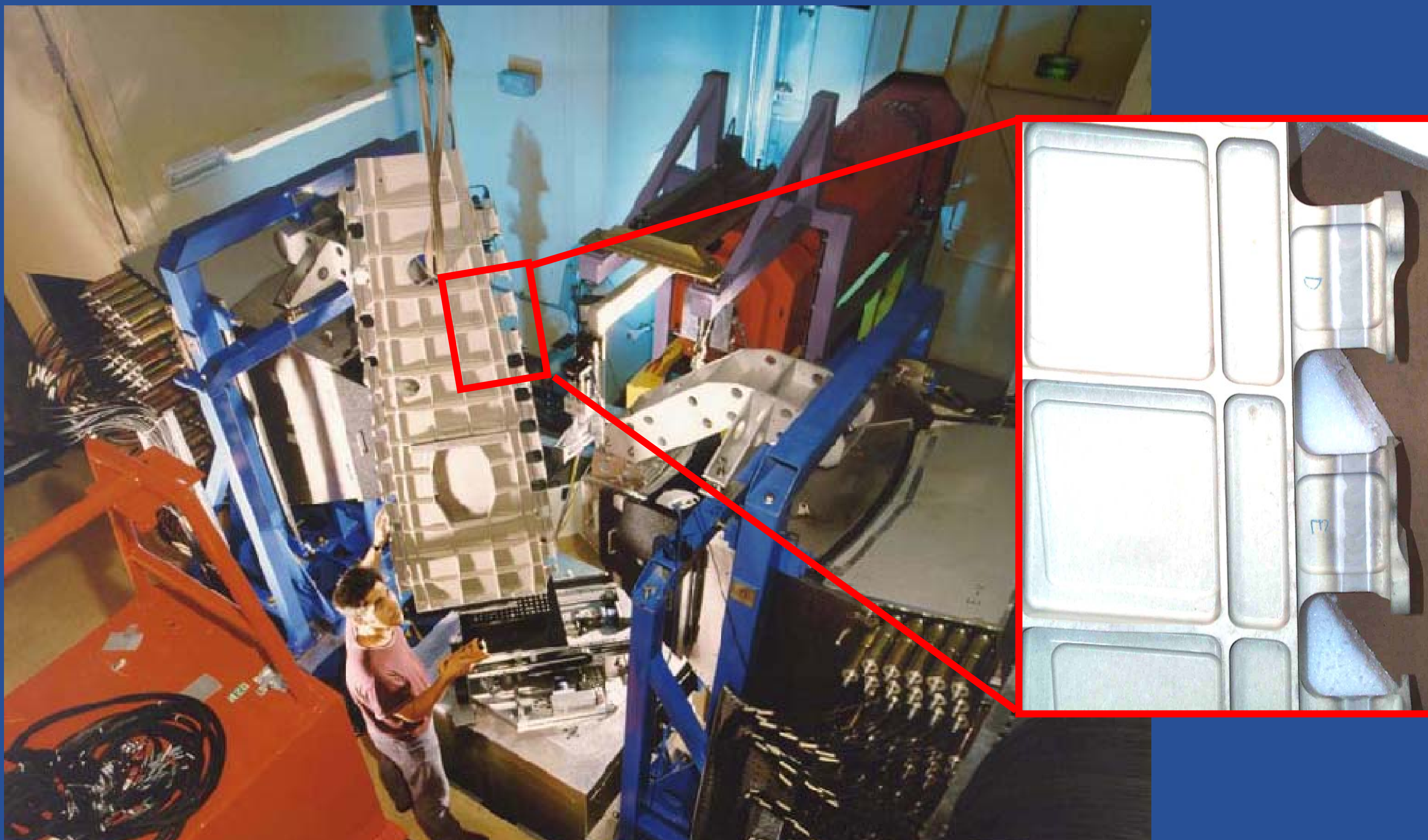
R&D – Development of Friction Stir Welding

- RS distributions in FS welds, ND vs. ICHD



R&D – Development of Friction Stir Welding

- …and why it's all necessary!

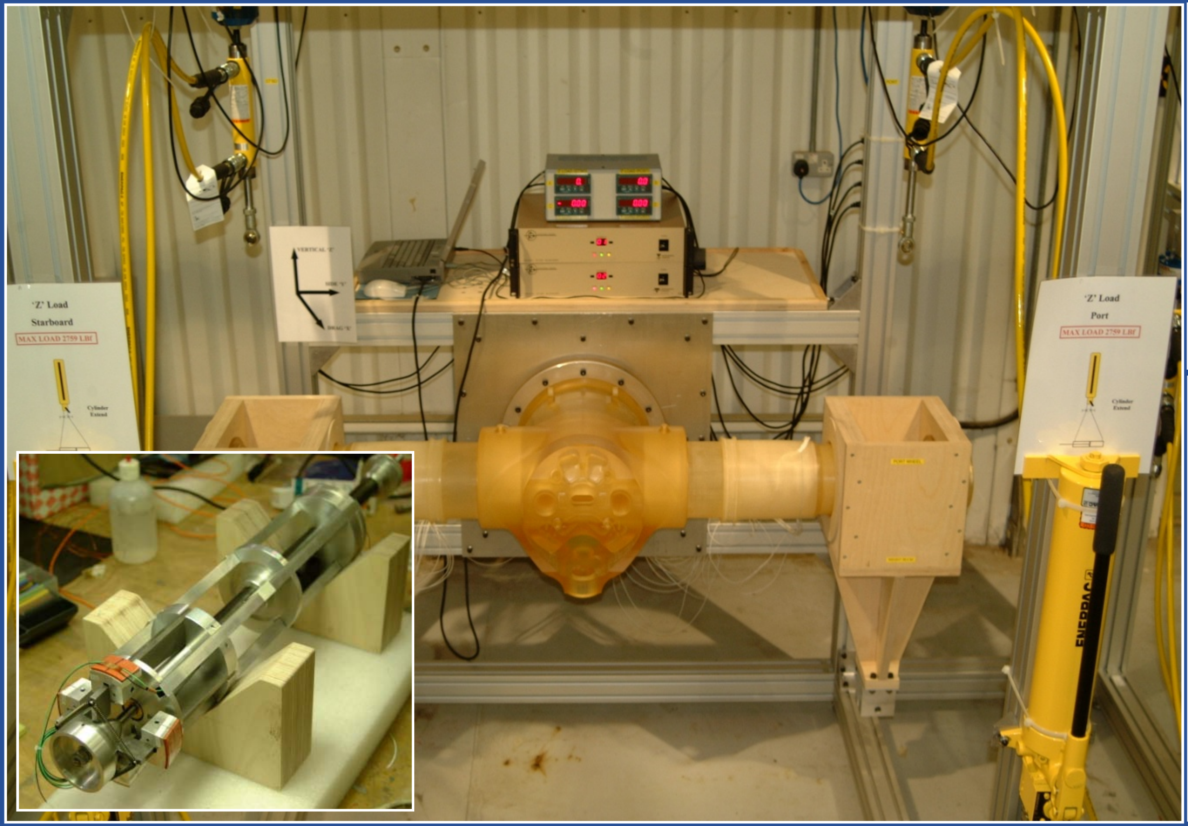


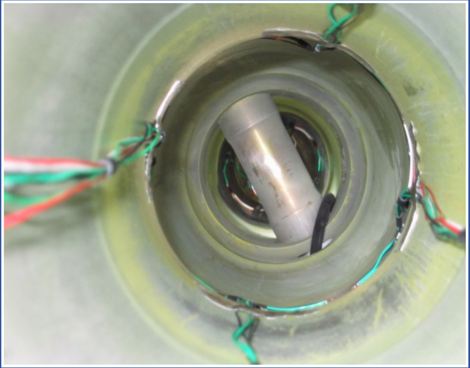
Applications

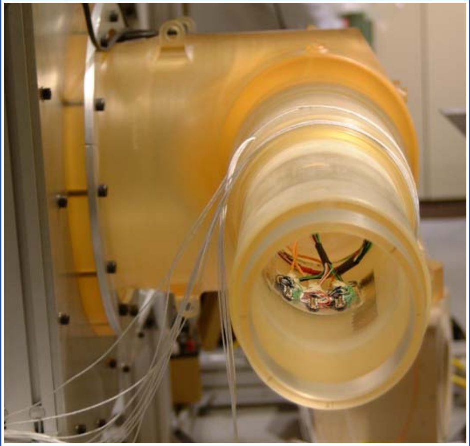
- R&D
- Design (Axle design for landing gear flight test)
- Development
- Manufacturing

Design – Flight test axle design and development

- Stereolithography model used to test suitability of strain gauge locations







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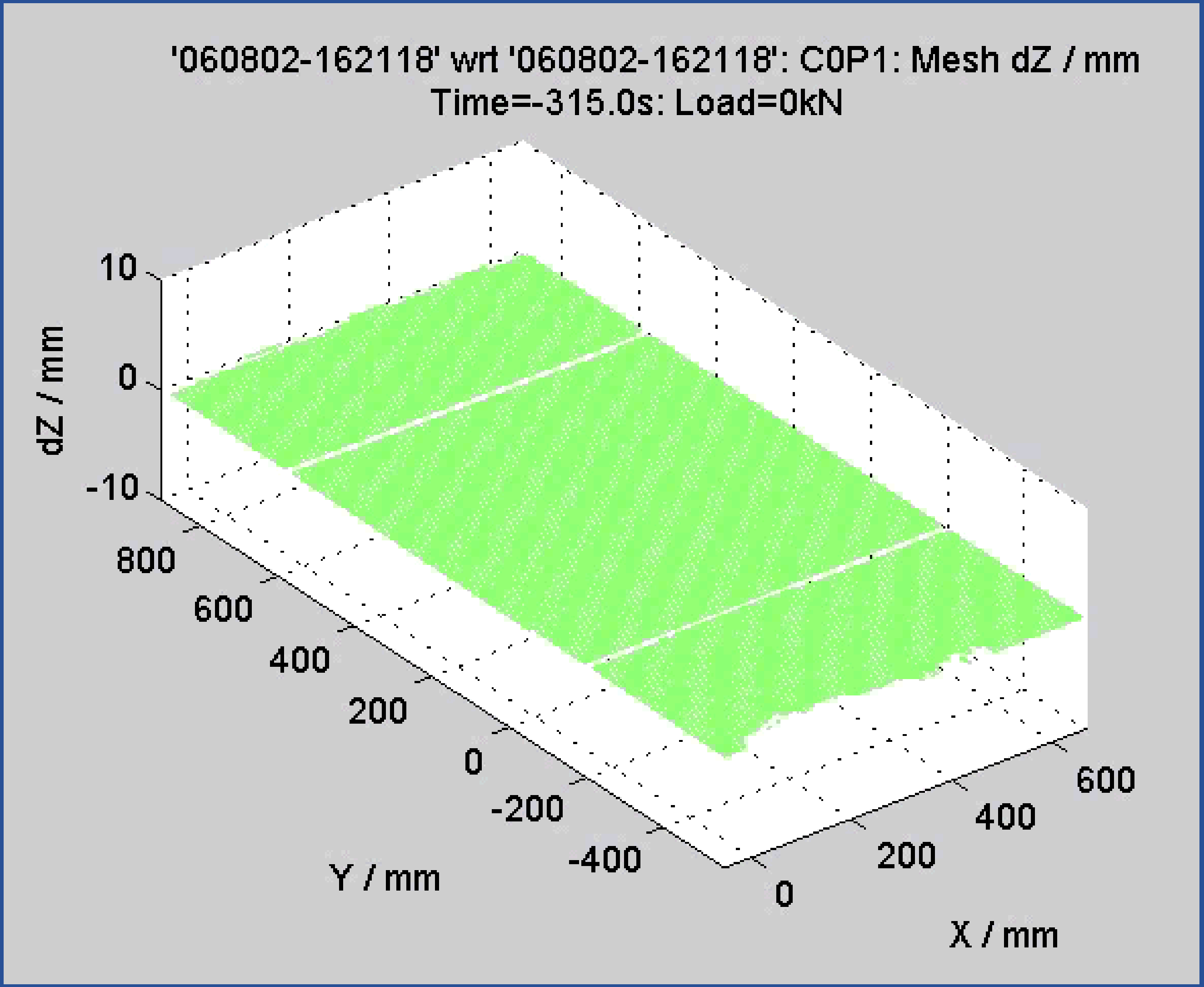
Applications

- R&D
- Design
- Development (Structural and material testing)
- Manufacturing

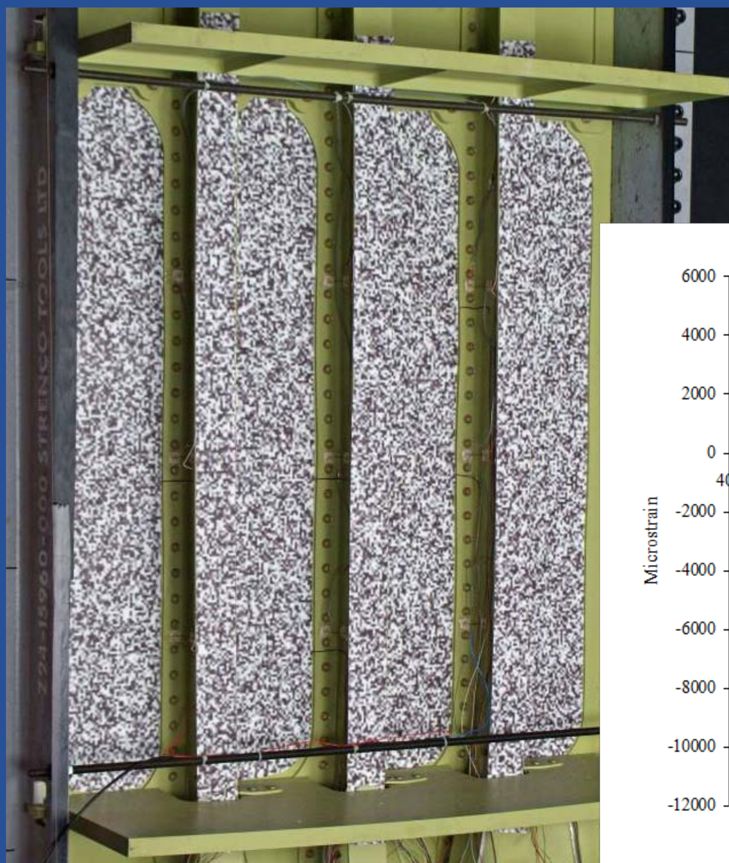
Structures and Materials Testing

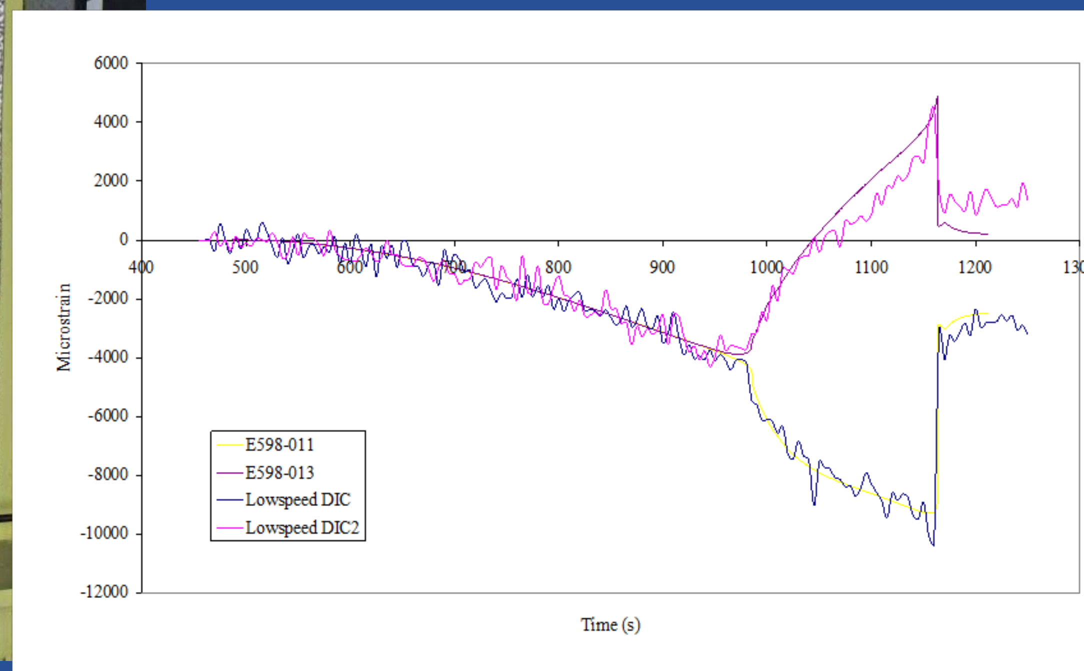
Structures and Materials Testing



Structures and Materials Testing

- Strain measurement on compression panel – typical result
- Speckle pattern on printed sticker, resolution not optimised





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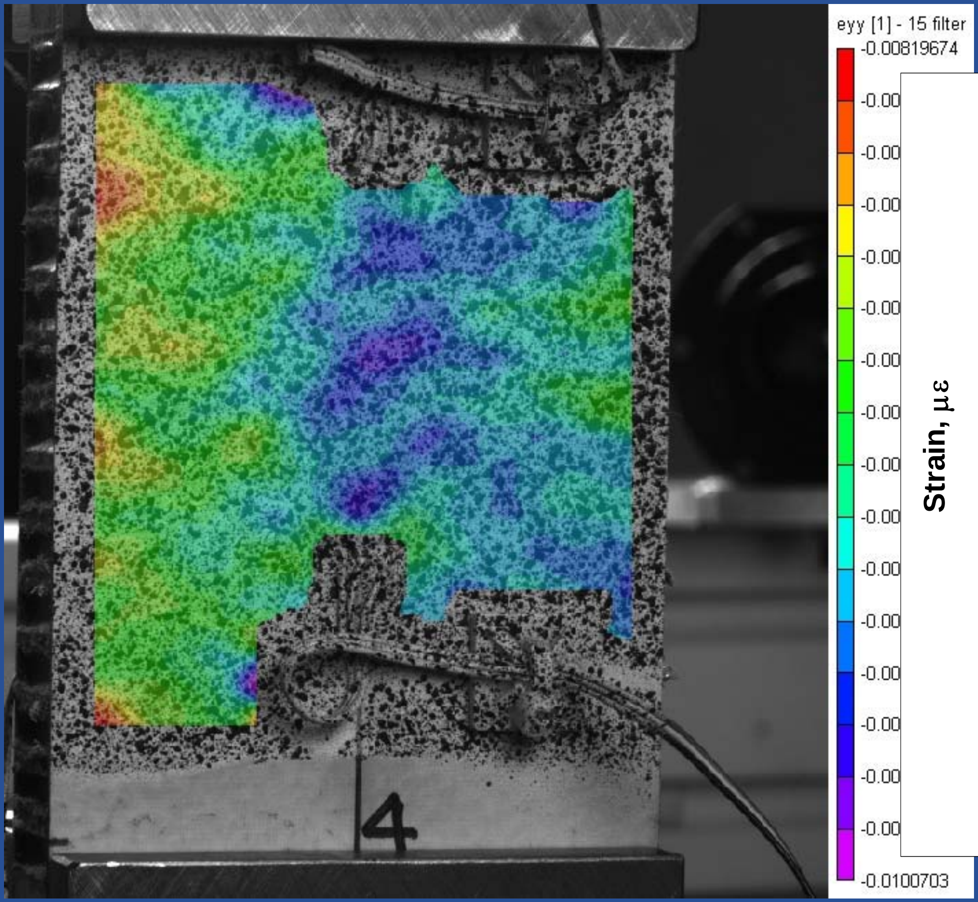
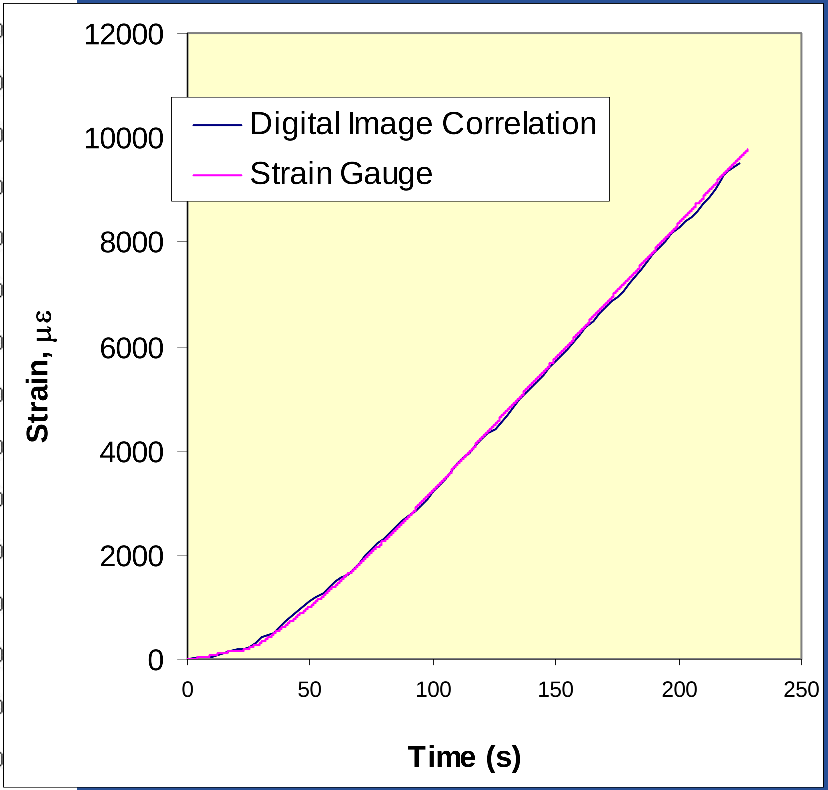
Structures and Materials Testing

- Strain measurement in composite honeycomb – best example
- Speckle pattern sprayed on





Applications

- R&D
- Design
- Development (High speed applications – Birdstrike tests)
- Manufacturing

High speed applications – Birdstrike tests

- General set-up

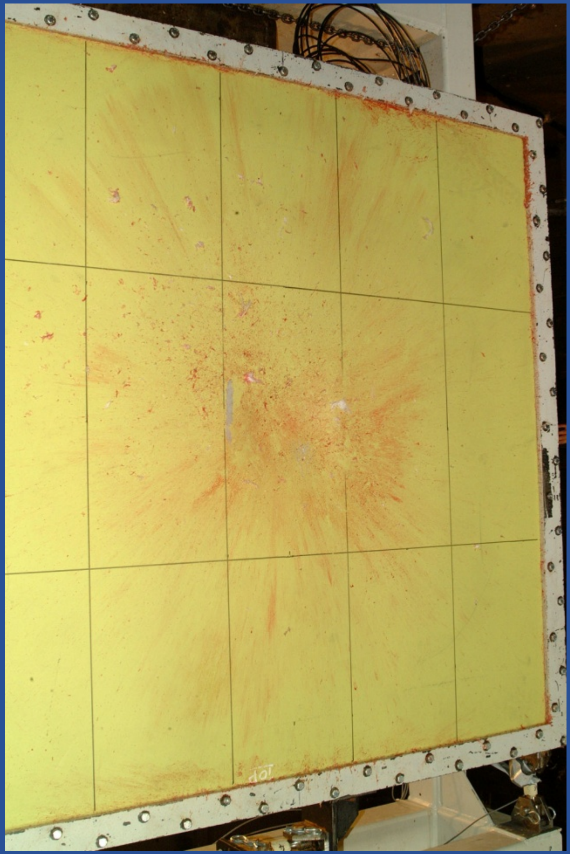
High speed applications – Birdstrike tests

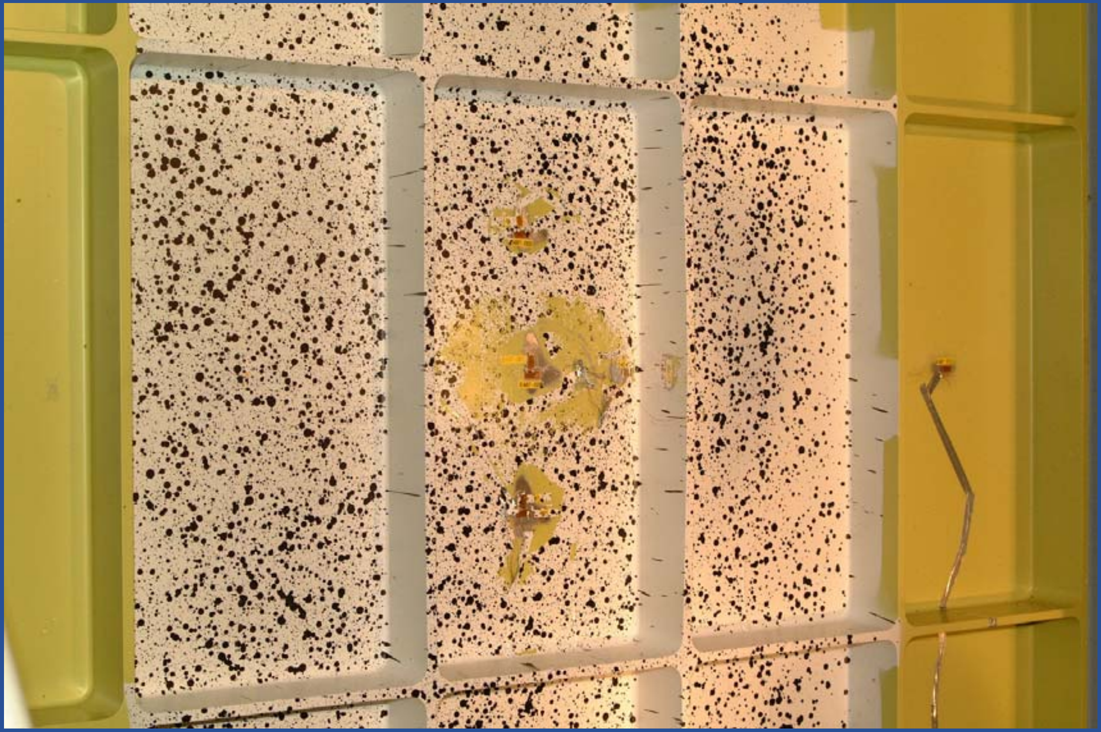
Camera set-up

- Rigid camera positioning
- Camera debris protection

High speed applications – Birdstrike tests

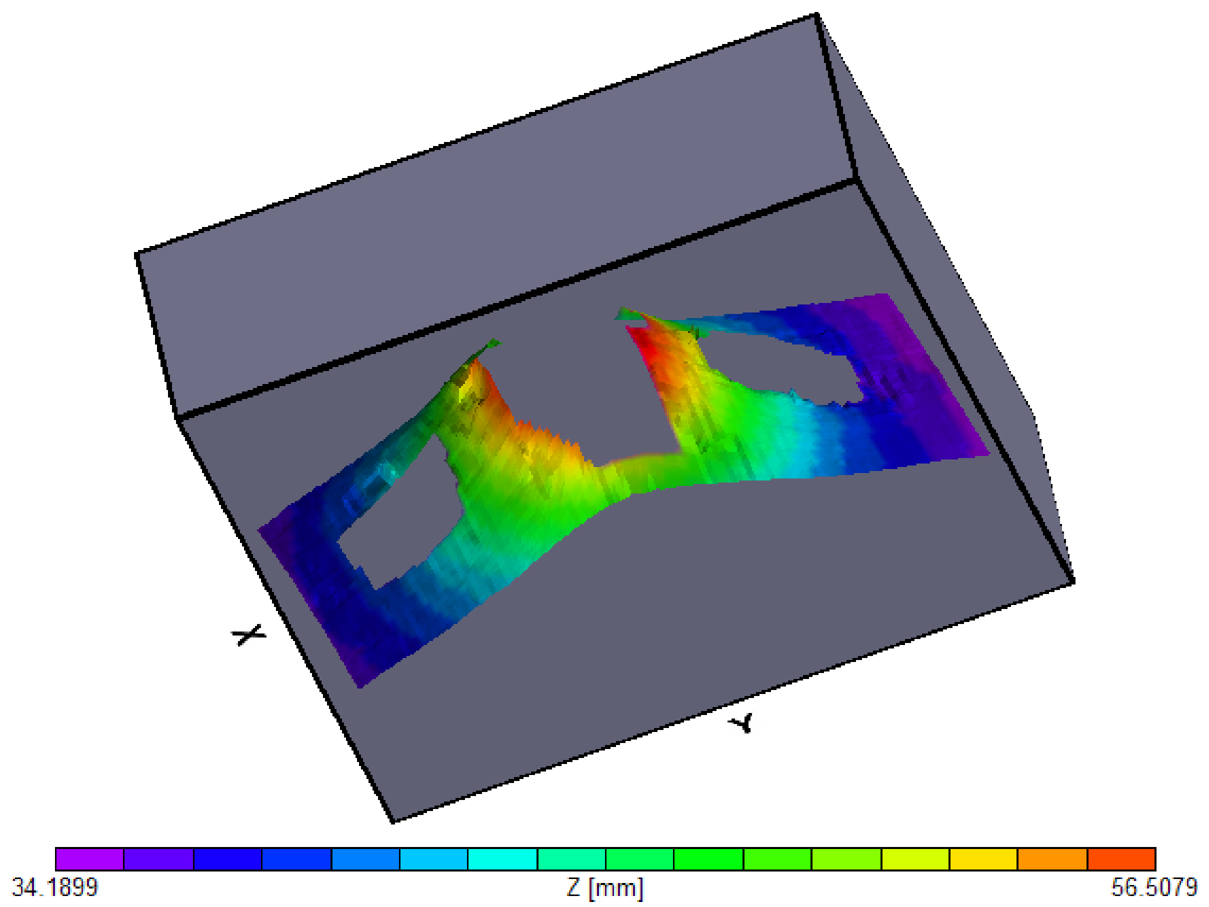
- Resulting damage to the panel:
- Paint and strain gauges/wiring destroyed in high strain/strain rate area
- Accelerations can be as high as 10^5 g and strain rates of 10^4 s^{-1}





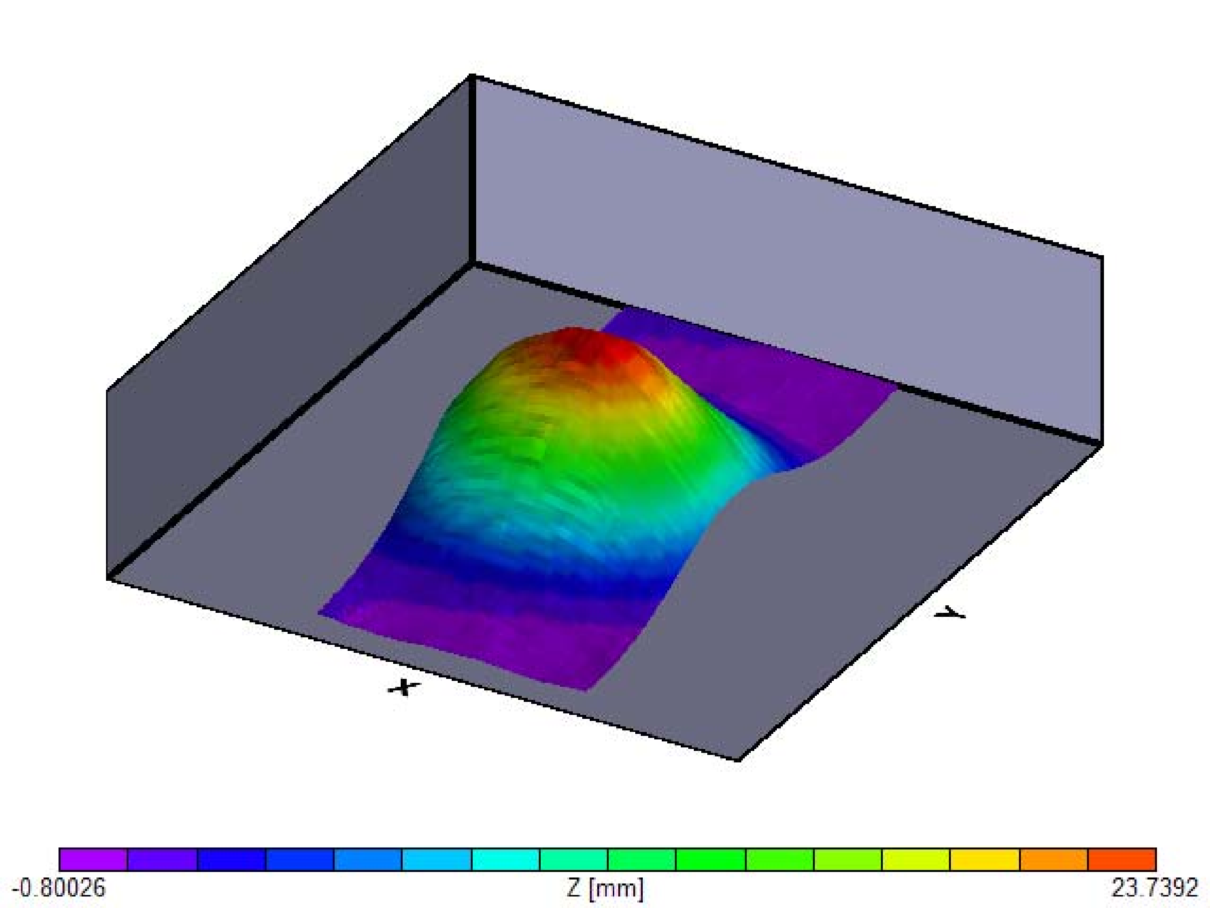
High speed applications – Birdstrike tests

- Resulting deformation plots of central section



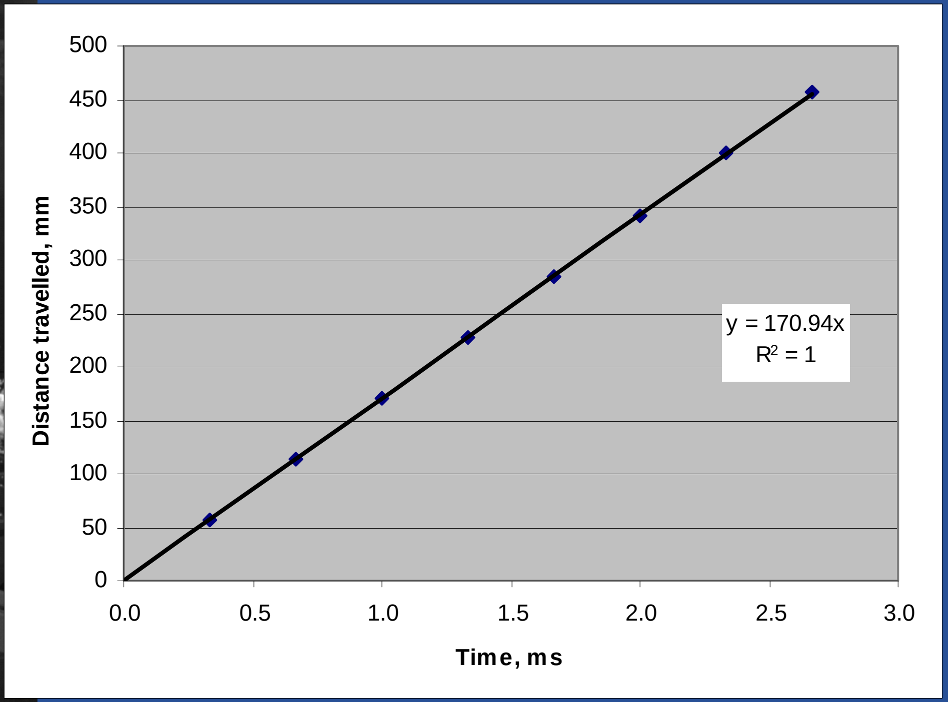
High speed applications – Birdstrike tests

- Resulting deformation plots of central section



High speed applications – Tyre debris test

- 2-D DIC used to determine the velocity of a projectile prior to impact



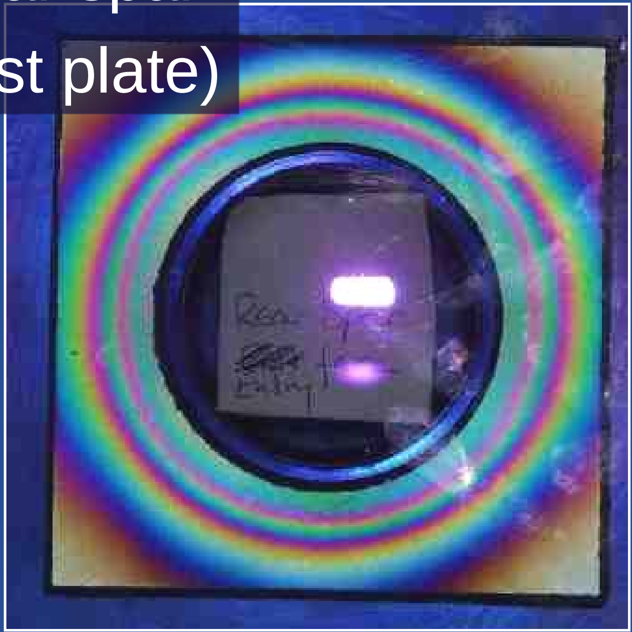
Applications

- R&D
- Design
- Development
- Manufacturing (Analysis of hole cold expansion for FTI ForceMate™ Bush)

Manufacturing – Cold expansion of holes

- Reflection Photoelasticity used to assess quality of production process (A340-600 FTI ForceMate™ Bush)
- Analysis assisted in the development of the final production process

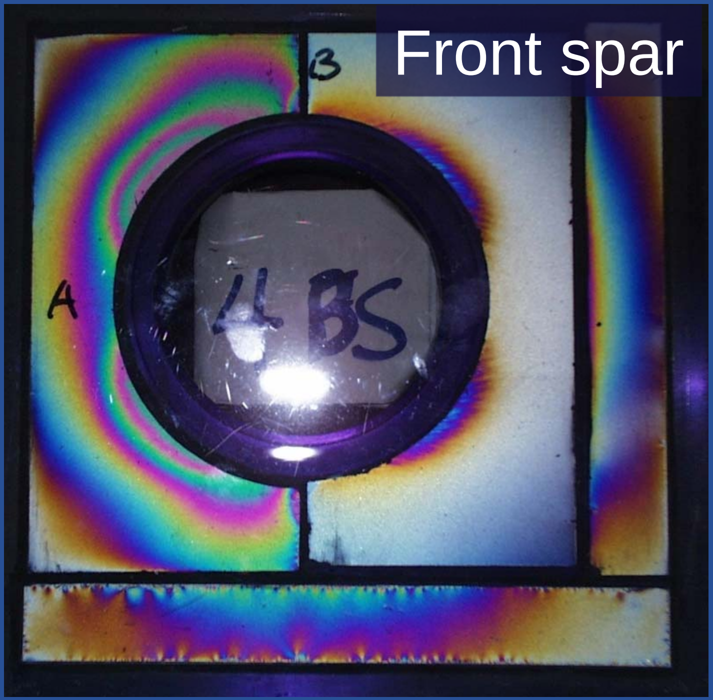
Front spar (test plate)



Rear spar (test plate)

Manufacturing – Cold expansion of holes

- Reflection Photoelasticity used to assess quality of production process (A340-600 FTI ForceMate™ Bush)
- Analysis assisted in the development of the final production process



Front spar

Rear spar

Manufacturing – Cold expansion of holes

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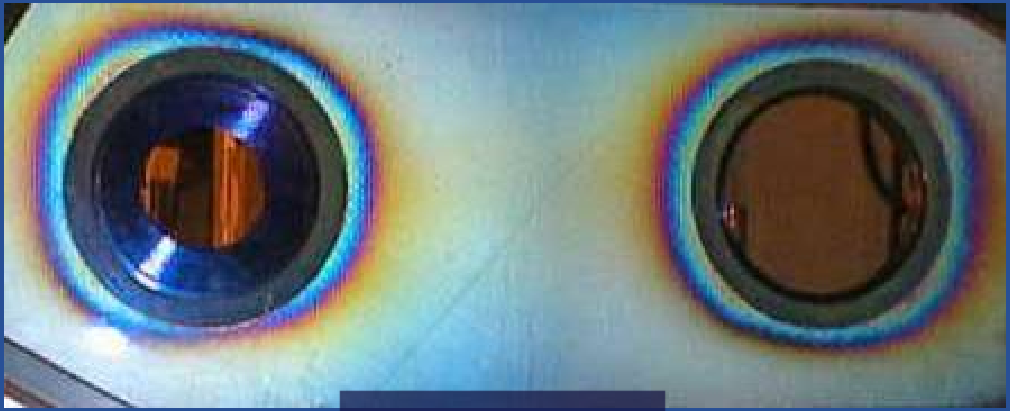

Front spar

Rear spar

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Summary

- Demonstrated the value and perhaps critical importance of Experimental Mechanics methods for solving Aerospace problems
- Applies to engineering in general, in many cases these methods provide data that is invaluable and unobtainable any other way
- That it is worthwhile learning these methods and continuing research, finding new applications and developing systems

The Future

- There is a big future for Experimental Mechanics because the areas of application are always increasing
  - The accuracy of strain determination is continuously improving
  - Better methods and tools for comparison of full field data sets need to be developed
  - Techniques are being applied to other developing fields: industrial metrology, NDT, maintenance and support
  - Calibration methods and processes to achieve verification and traceability of measured data are being prepared
  - The availability of education and training programmes is increasing

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AN EADS JOINT COMPANY WITH BAE SYSTEMS

University of Glasgow | Faculty of Engineering

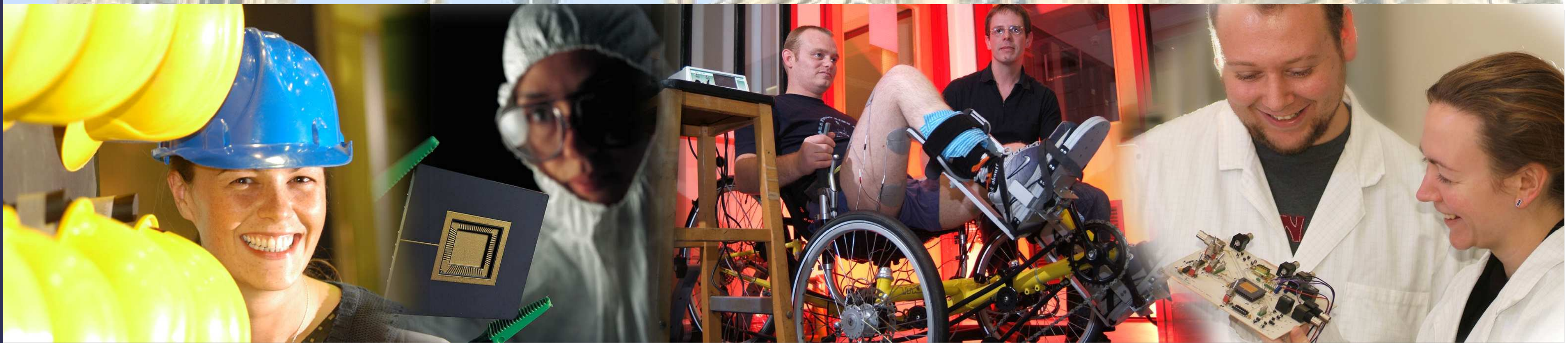
Applications of Power Ultrasonics in Engineering

BSSM/FAM Webinar

November 13th 2008

Prof Margaret Lucas

Dept. Mechanical Engineering



Power ultrasonics: usually 20 – 100 kHz

The ultrasonic vibration has a permanent effect on the medium.

e.g. sonochemistry, cleaning, metal forming, food processing, welding, machining, cutting, surgery

Power ultrasonic devices are usually tuned to resonate at the operating ultrasonic frequency, often in a longitudinal mode of vibration, and are therefore commonly constructed from one or multiple half-wavelength components.

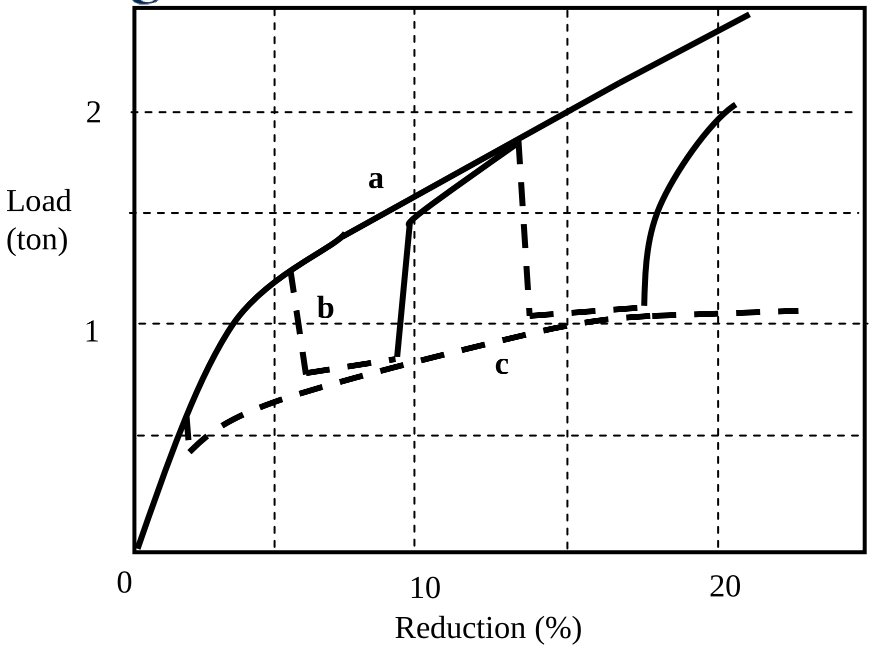
Power Ultrasonics in Metal Forming

Early uses of power ultrasonics were in extrusion, wire drawing and metal can shaping applications.

Claims were made that forming forces could be reduced by around 50% and that one of the main contributing factors was friction reduction.

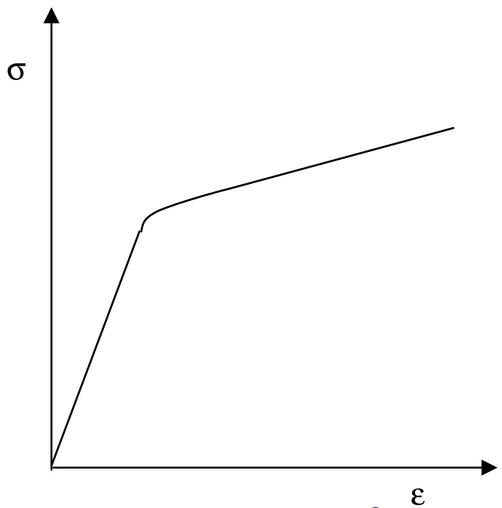
There was considerable argument as to the existence of “acoustic softening” as a mechanism of forming force reduction, due to ultrasonic excitation in these processes.

Oscillatory Stress Superposition

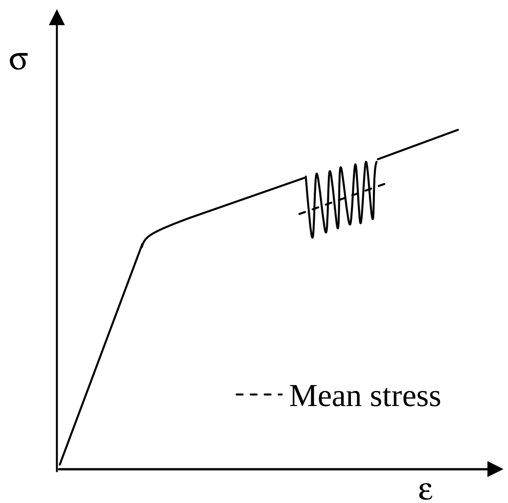


Measured compressive load due to superimposed ultrasonic vibration, (a) without ultrasonic vibration, (b) two intervals of superimposed ultrasonic vibration, (c) continuous ultrasonic vibration.

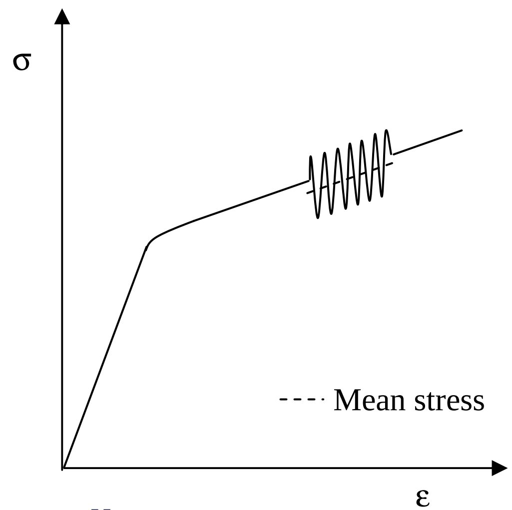
Izumi et al, On the superimposing of ultrasonic vibration during compressive deformation of metals, Trans. J. Inst. Metals, 7 (1966).



stress-strain curve for an elastic-plastic material

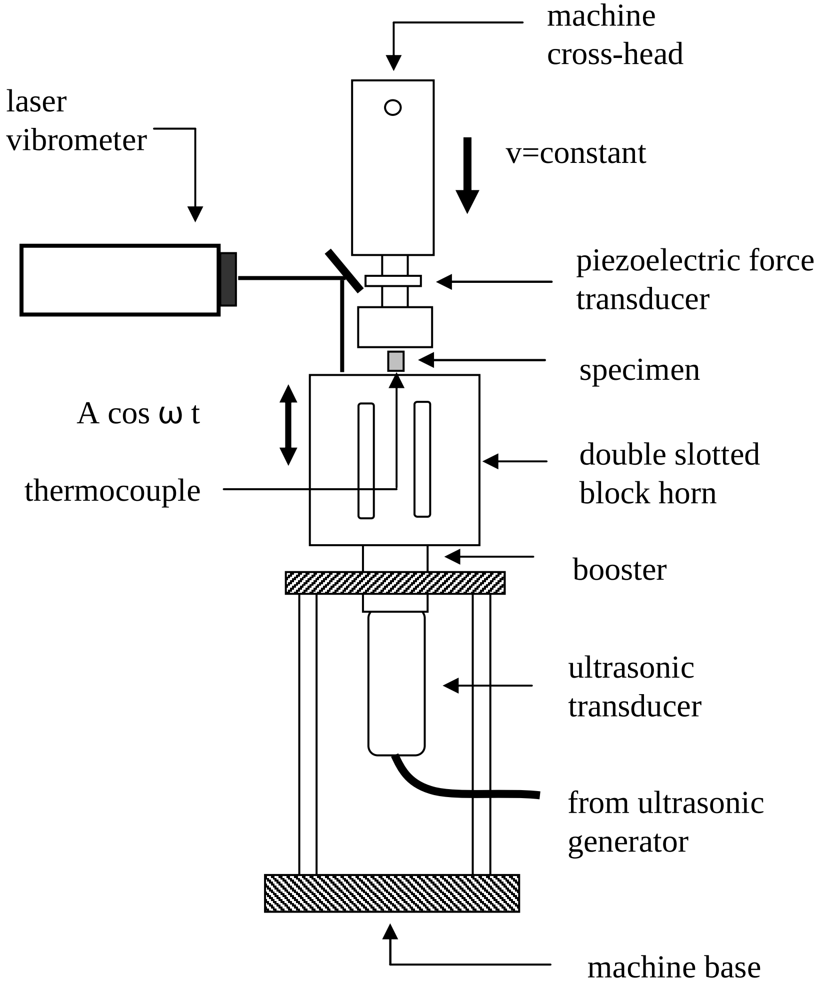


oscillatory stress superposition for a rate independent material

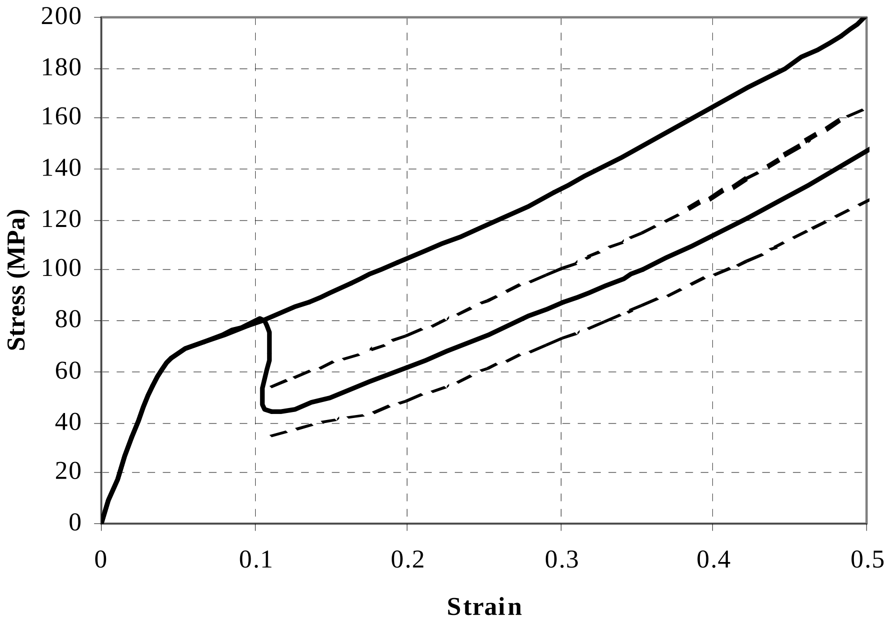


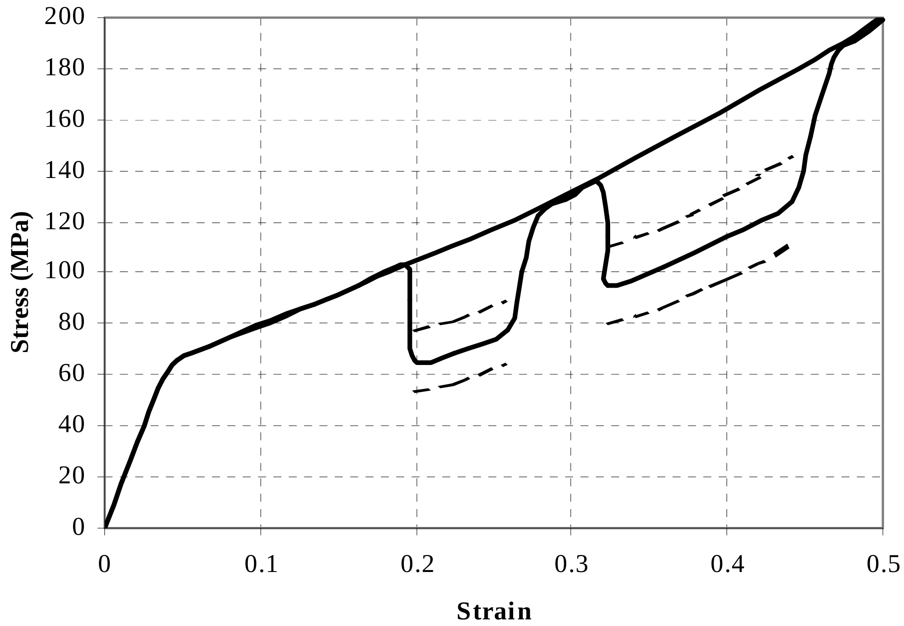
oscillatory stress superposition for a rate dependent material (overshoot)

Ultrasonic Compression Tests Set-Up



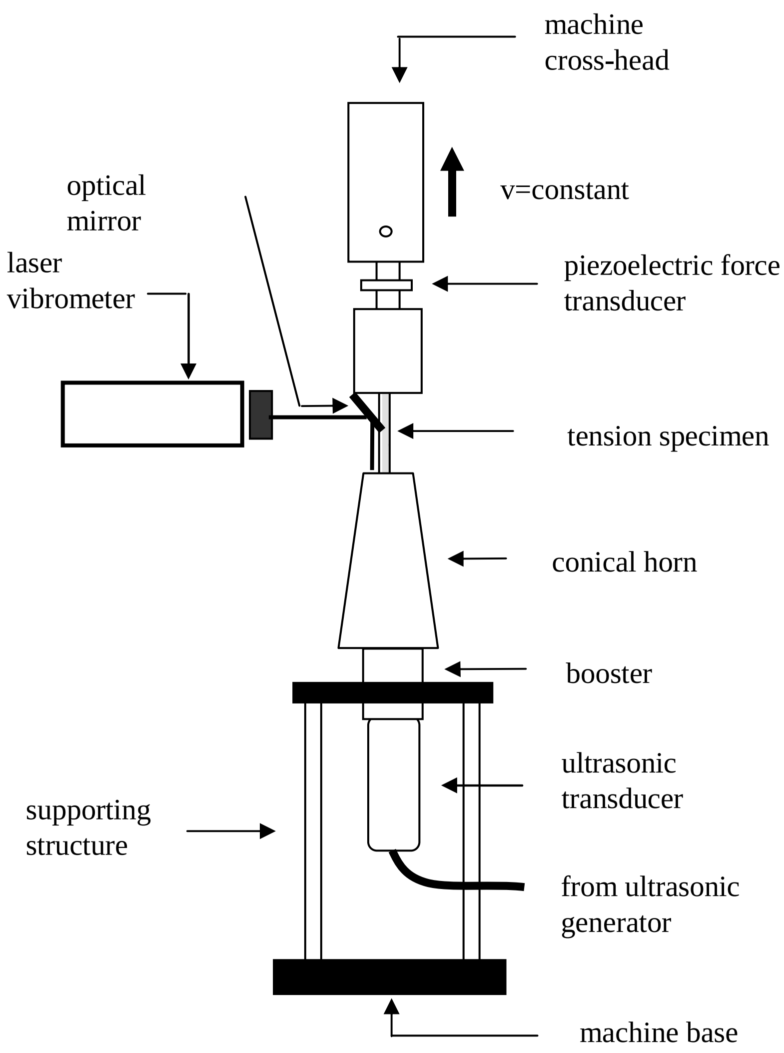
Ultrasonic Compression Tests



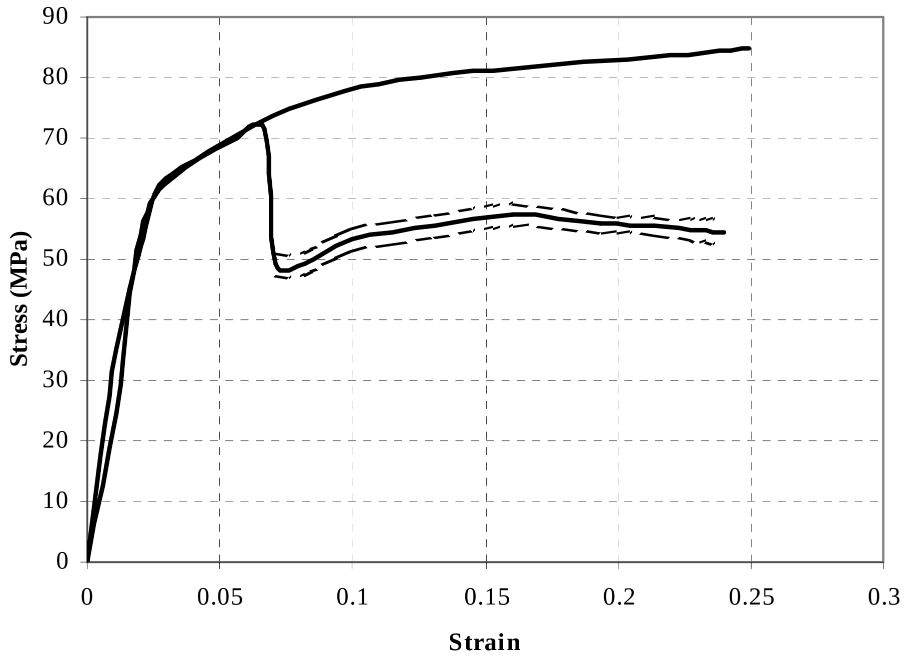


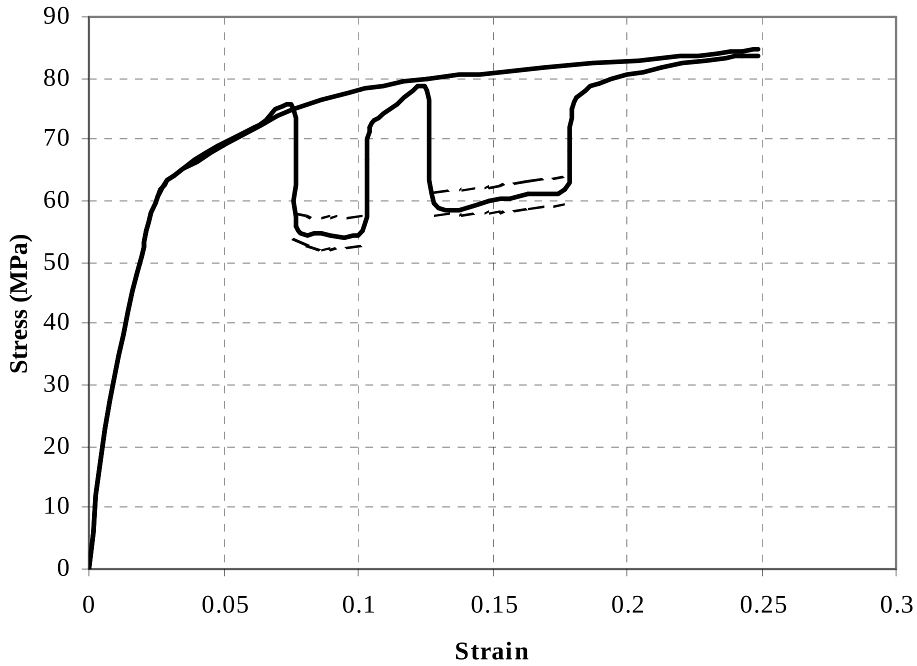
Measured static and ultrasonic compression test for dry surface, showing:
— static and mean stress, ----- paths of max. and min. oscillatory stress.

Ultrasonic Tension Tests Set-Up



Ultrasonic Tension Tests



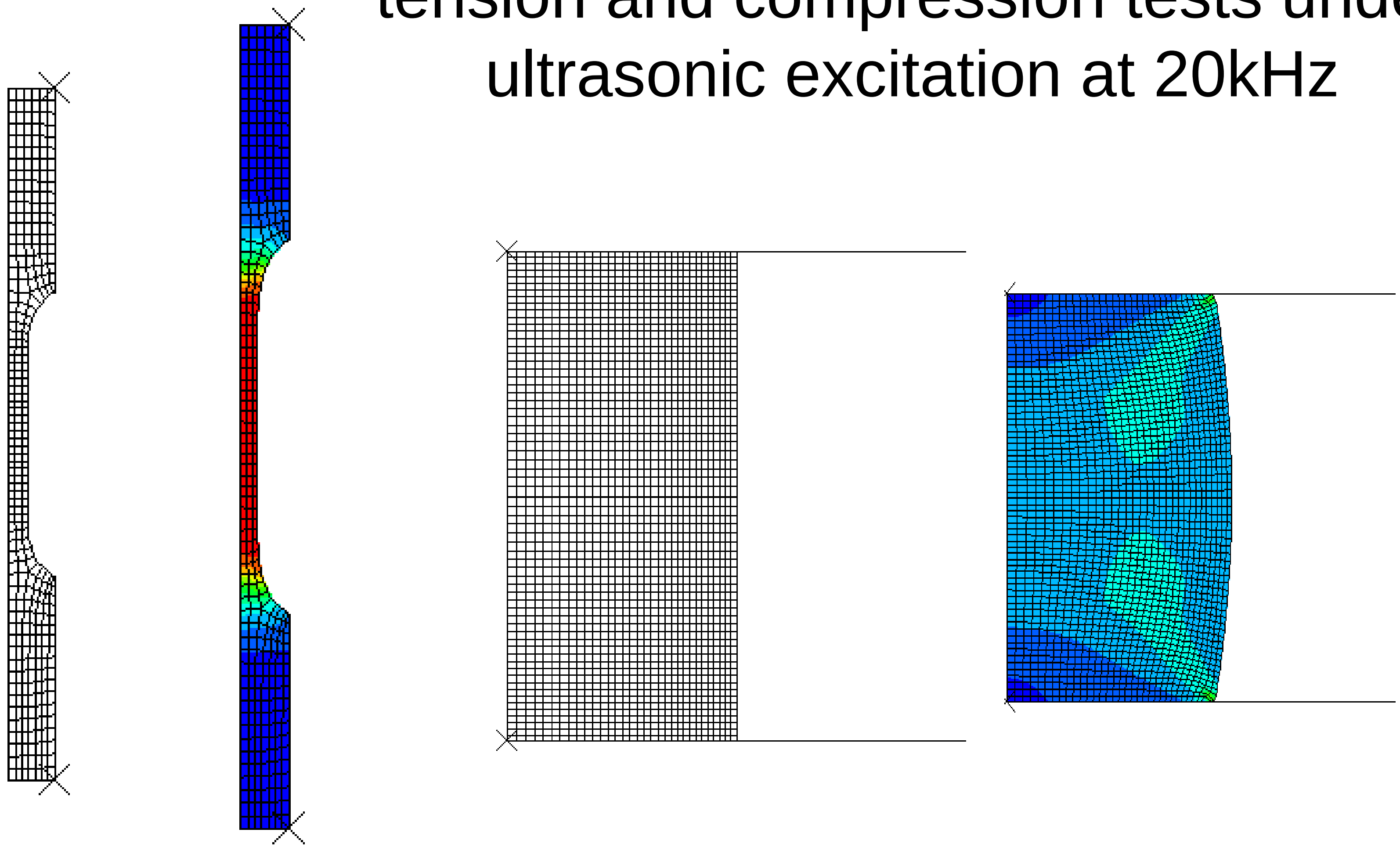


Measured static and ultrasonic tension tests, showing:

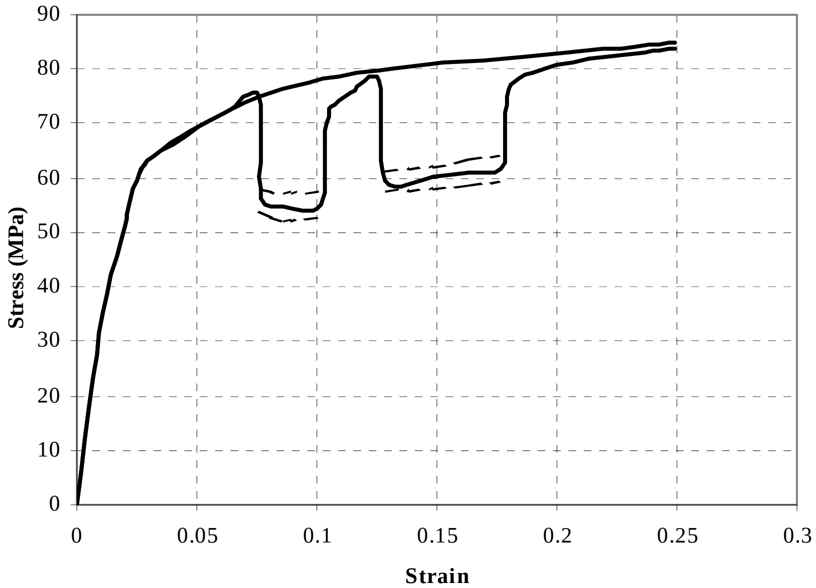
— static and mean stress, ----- paths of max. and min. oscillatory stress.

Finite Element Models

Finite element models of standard tension and compression tests under ultrasonic excitation at 20kHz



Ultrasonic Tension Test Data



Tension test data:

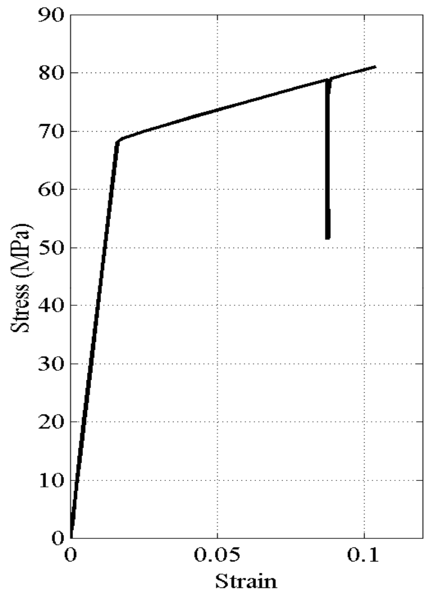
Reduction in mean stress is 23 MPa and pk-pk oscillatory stress is 5.5 MPa

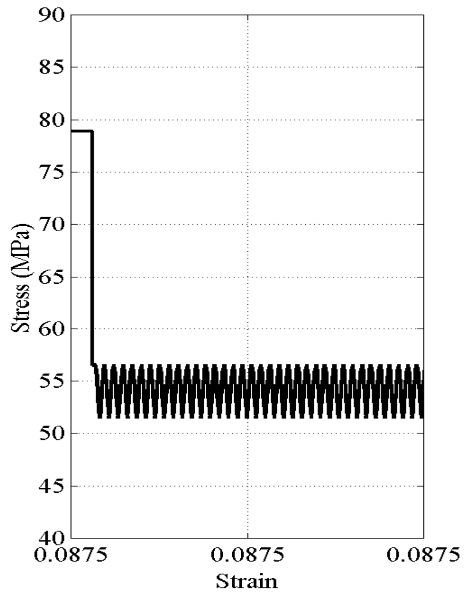
FE model of tension test:

A short interval of superimposed ultrasonic excitation; original material during static loading and softened material during static-ultrasonic loading.

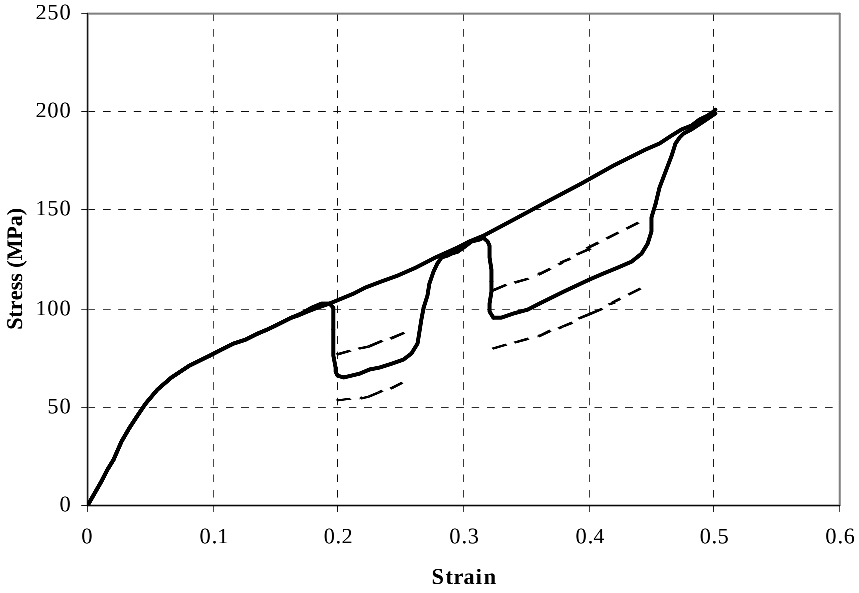
Close correlation is achieved with the experimental data:

Reduction in mean stress is 24 MPa and oscillatory stress amplitude is 5 MPa.





Ultrasonic Compression Test Data



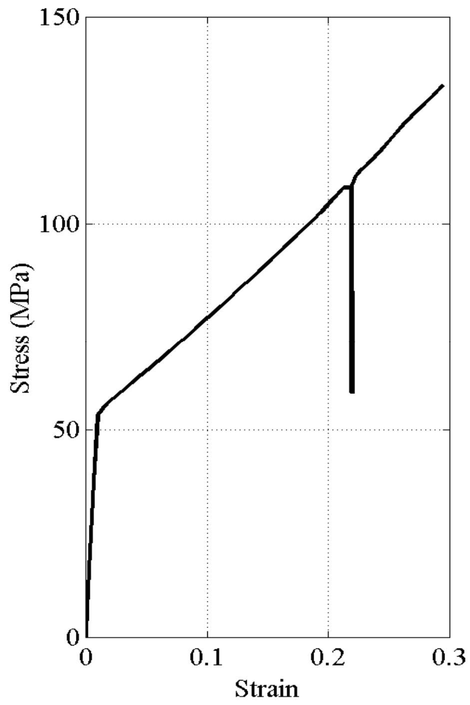
Compression test data:

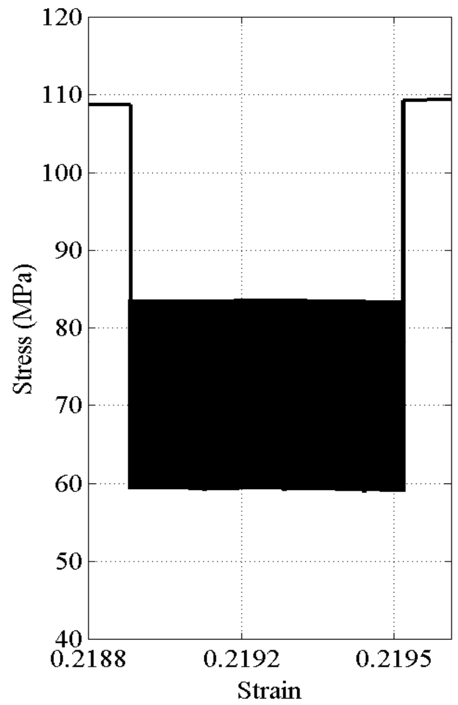
Reduction in mean stress is 40 MPa and pk-pk oscillatory stress is 24 MPa

FE model of compression test:

Combines a change to the softer material properties with a change in coefficient of friction from μ=0.25 to 0.15 during ultrasonic compression.

Reduction in mean stress is 38 MPa and pk-pk oscillatory stress is 24 MPa





Ultrasonic Cutting

Power ultrasonic has been used in food cutting for a couple of decades, but is still very limited in its application.

Proven benefits are:

Improved cut accuracy

Reduced waste

Self-cleaning blades

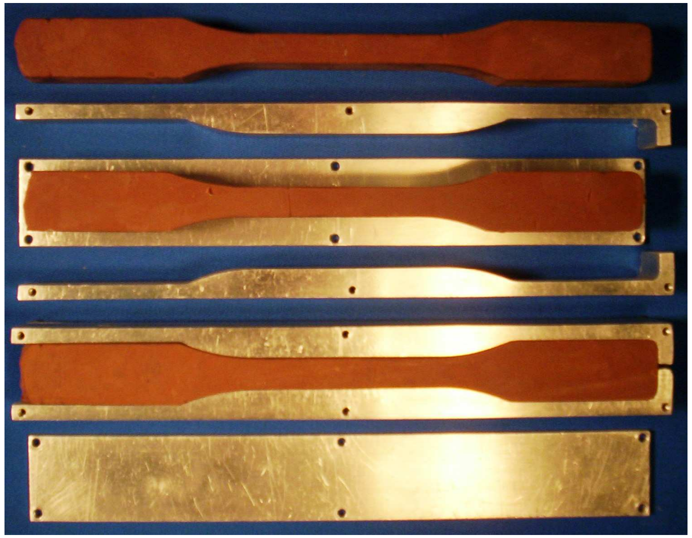
More recently, power ultrasonics has been applied to surgery, to cut both soft tissue and bone for a number of surgical procedures.

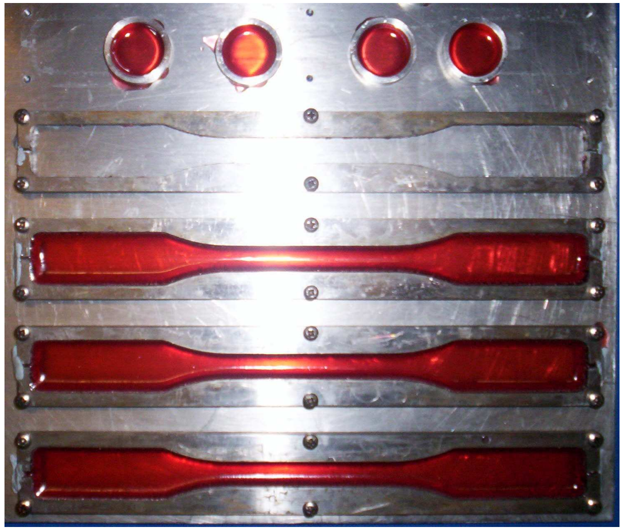
Ultrasonic Cutting of Food

(a) (b) (c)

Commercial Ultrasonic food cutting systems (Branson Ultrasonics and Dukane) in (a), (b) guillotine orientation and (c) slicing orientation

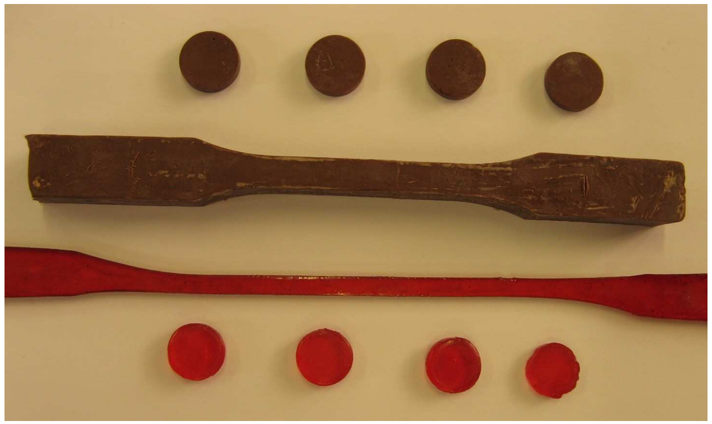
Food Specimen Preparation



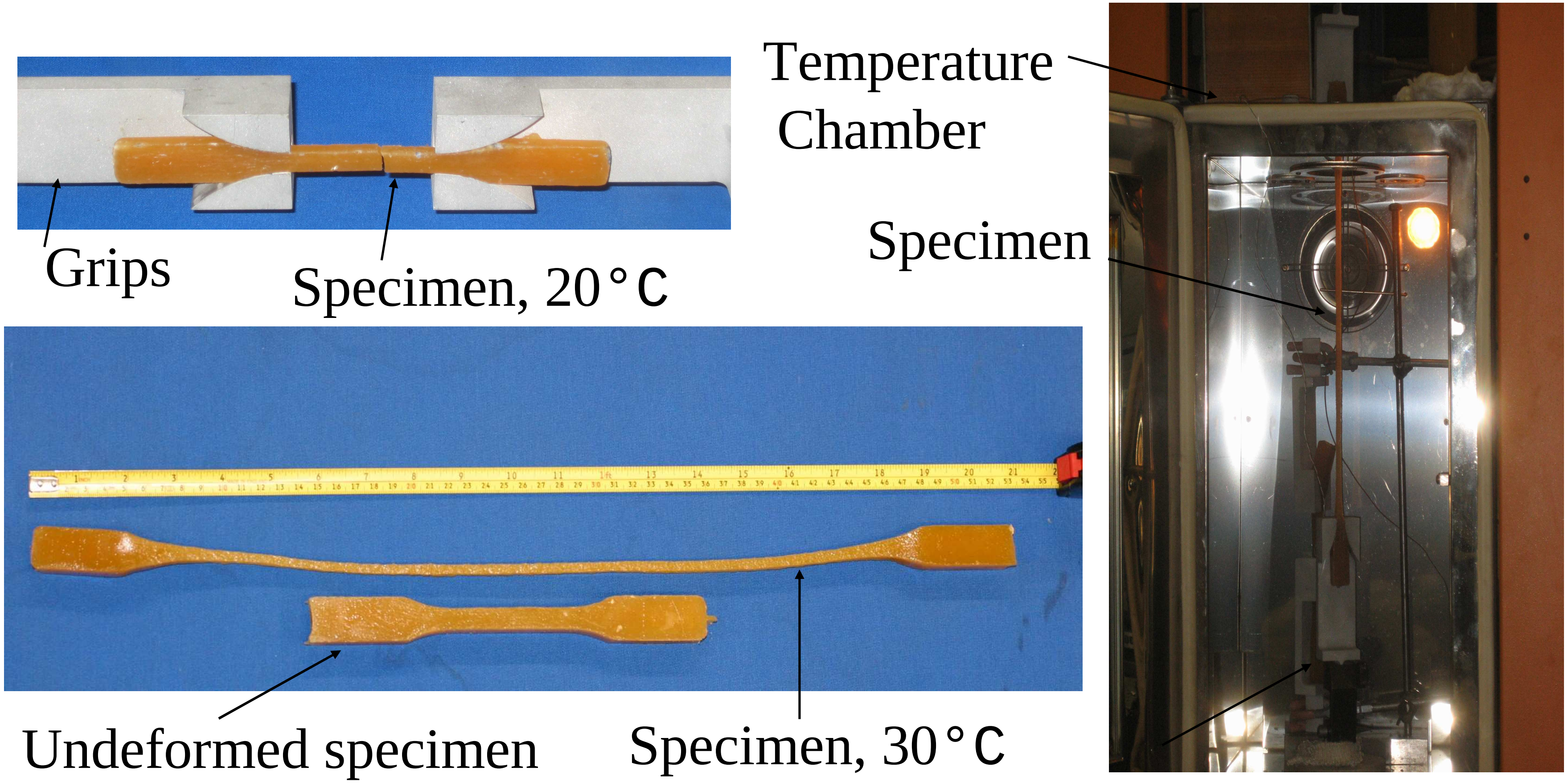


Moulds for tensile test specimens

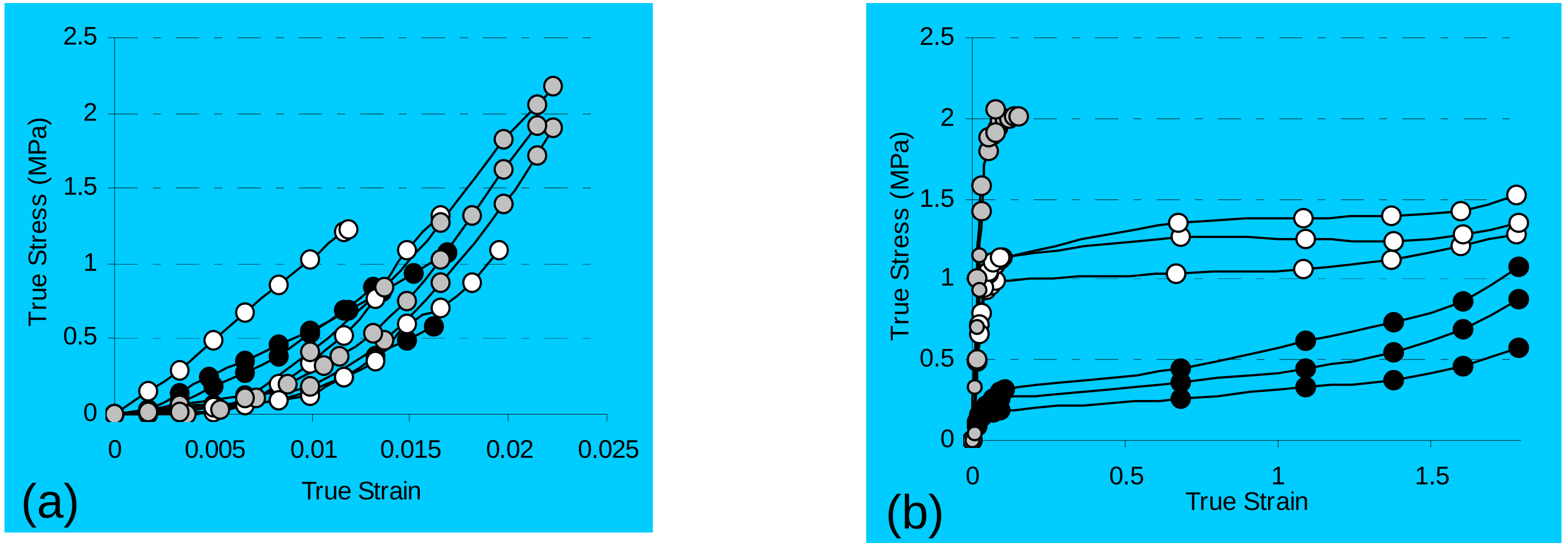
Specimens



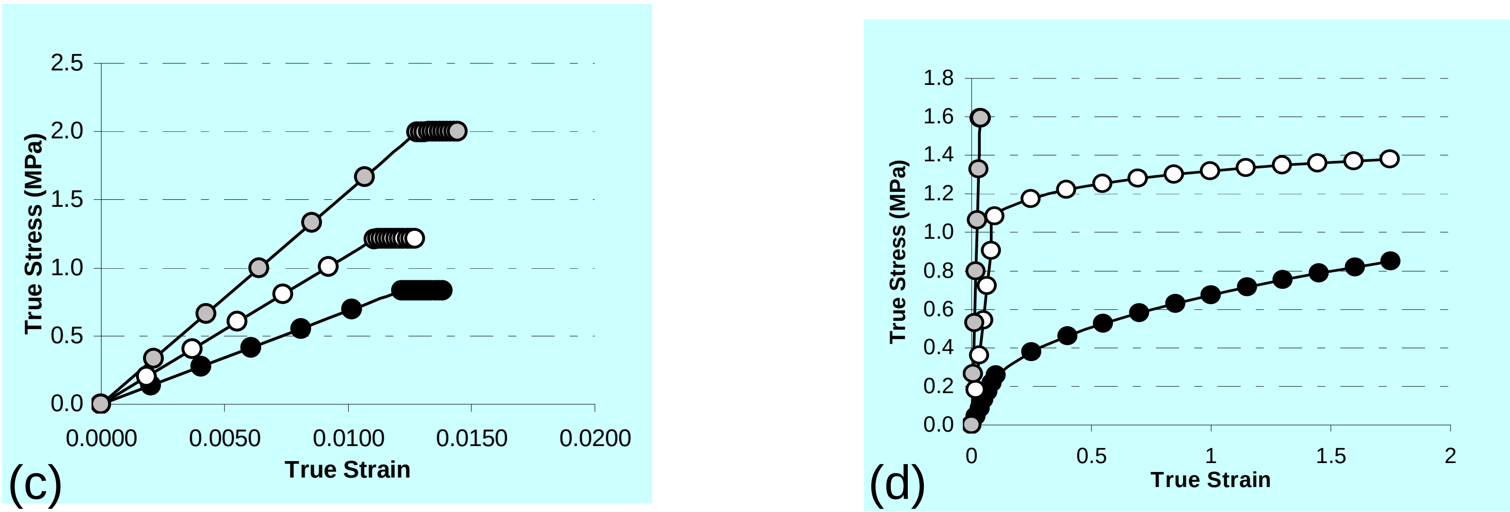
Tensile Testing of Toffee



Creating FE Materials Data for Toffee

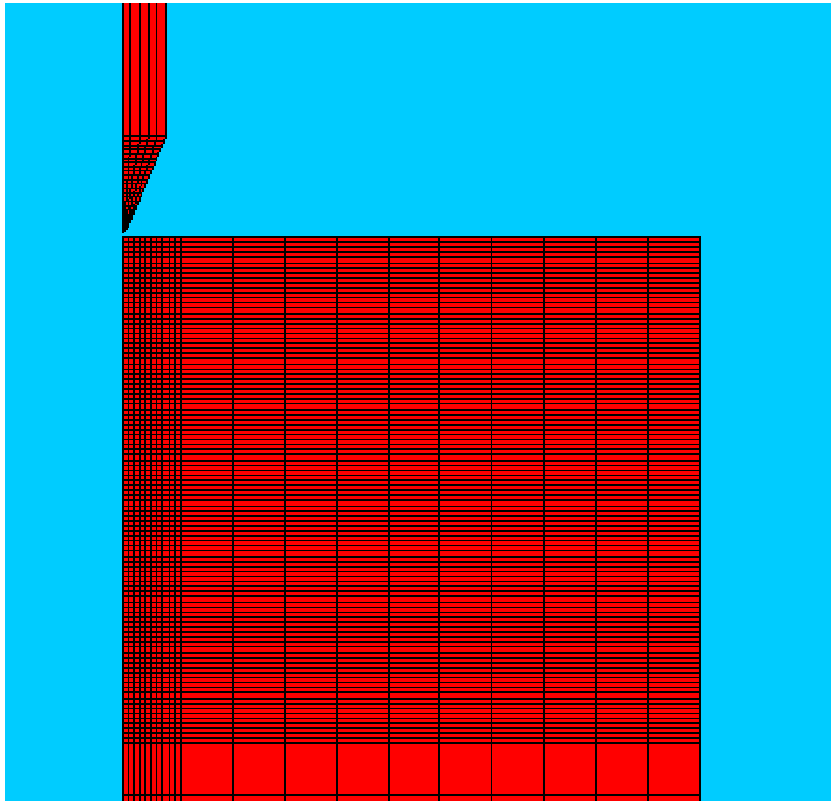


Experimental results (a) 25°C and (b) 30°C

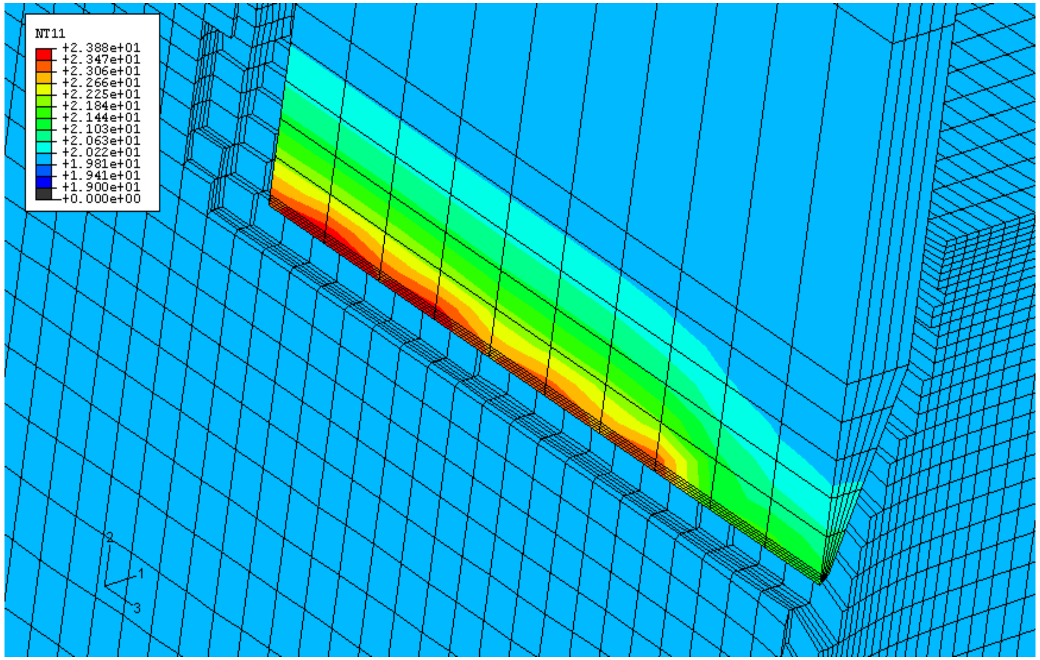


Curve fits of experimental results (c) 25°C and (d) 30°C

2D and 3D Ultrasonic Cutting Simulations

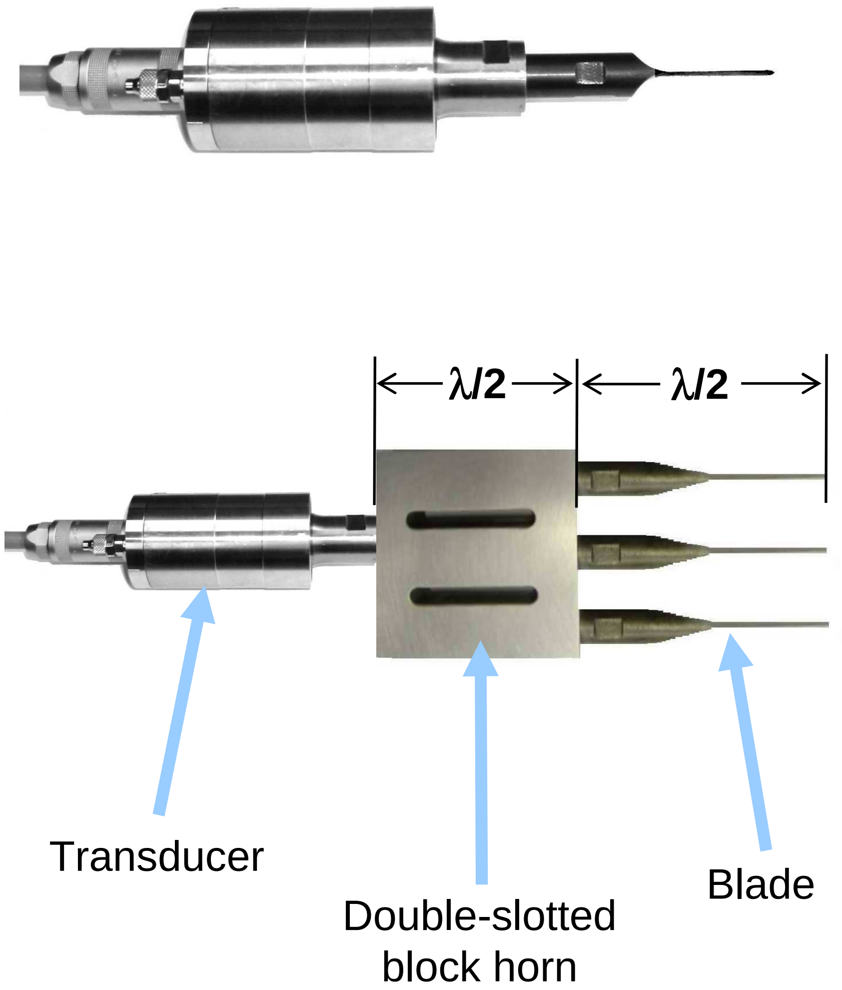


- Uses Abaqus explicit solver
- Utilises symmetry about cutting plane
- Uses shear failure criterion in plastic region of stress-strain curve
- Uses adaptive meshing if required

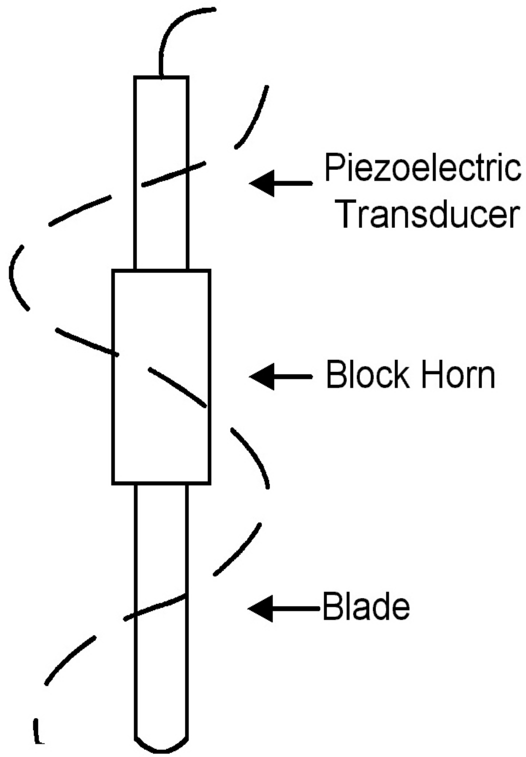


Temperature distribution in 3D fully coupled thermal stress FE model of ultrasonic cutting

Ultrasonic Bladed Cutting Systems

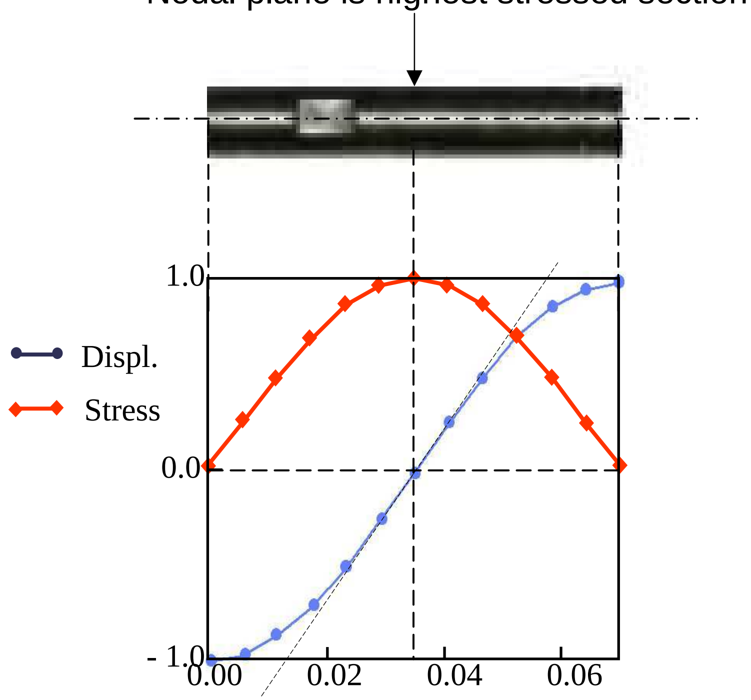


Schematic of system components



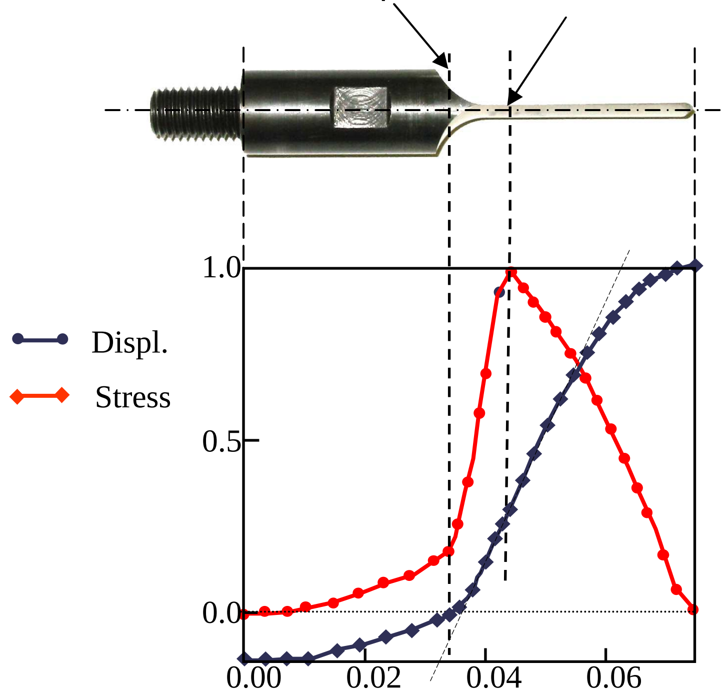
Normalised Stress and Displacement

Bar Horn of Constant Section



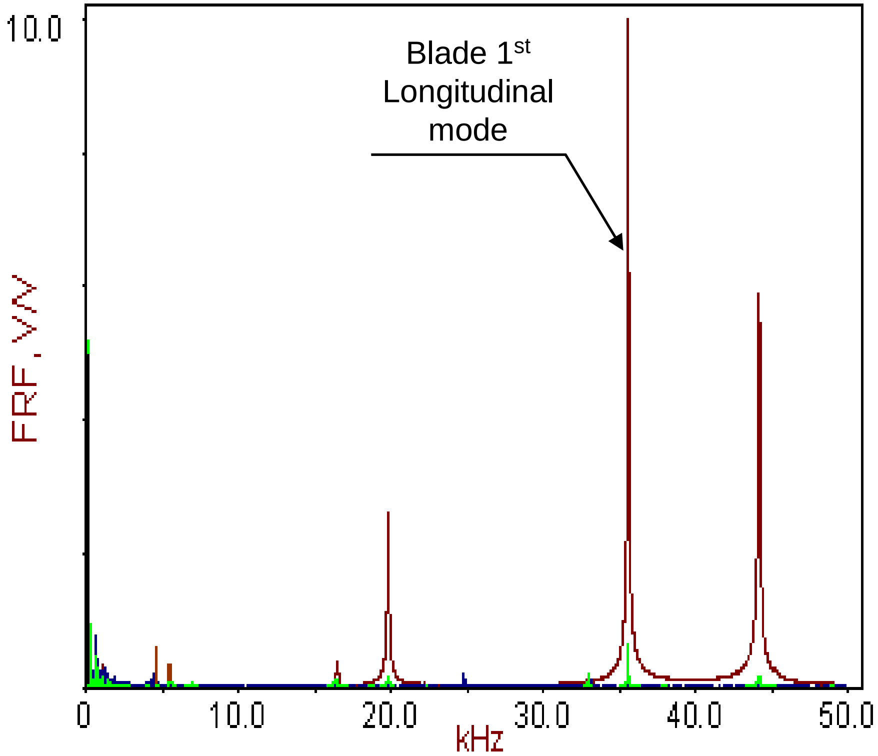
• In a cylindrical horn the longitudinal node corresponds to the highest stressed section.

High Gain Blade

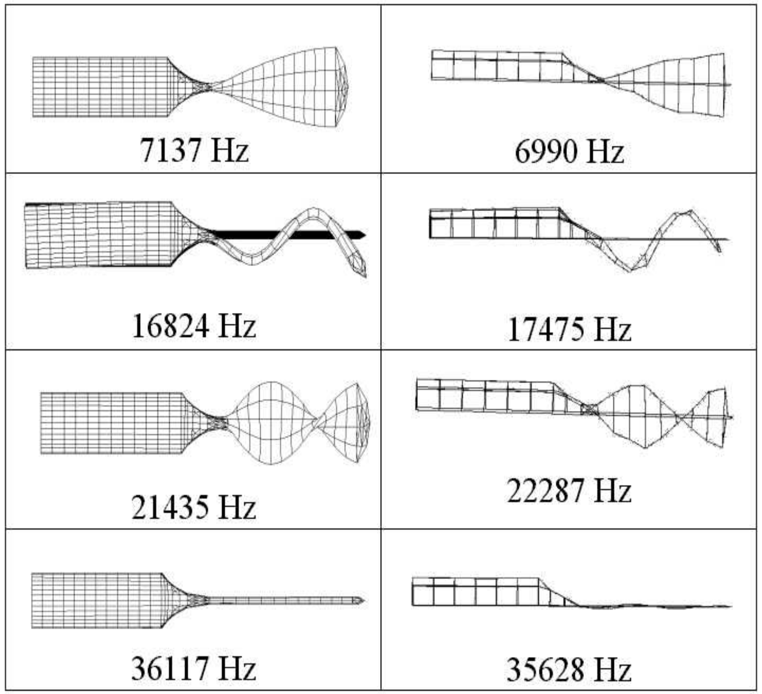


• The highest stress occurs at the end of the blade tapering because of the steep section reduction.

Experimental and FE Modal Analysis

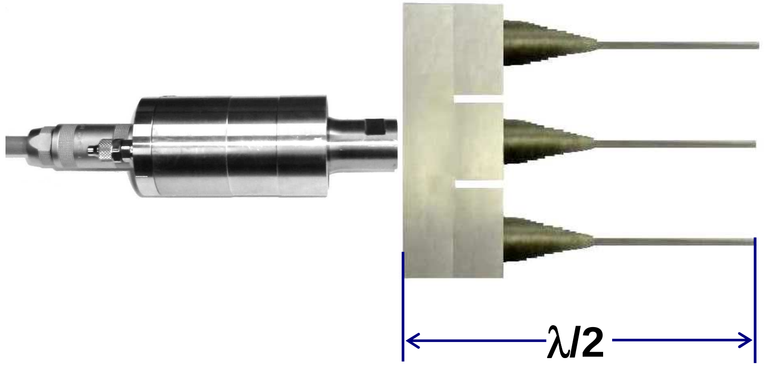


FRF from transducer-blade assembly measured using 3D laser vibrometer

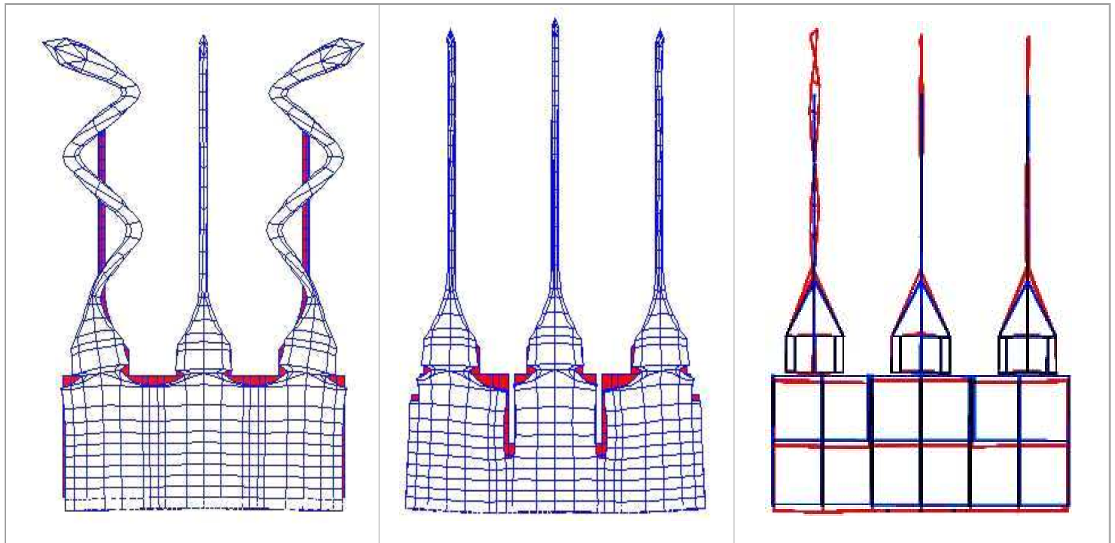


FE predicted and EMA measured blade modes of vibration

Cutting System Design



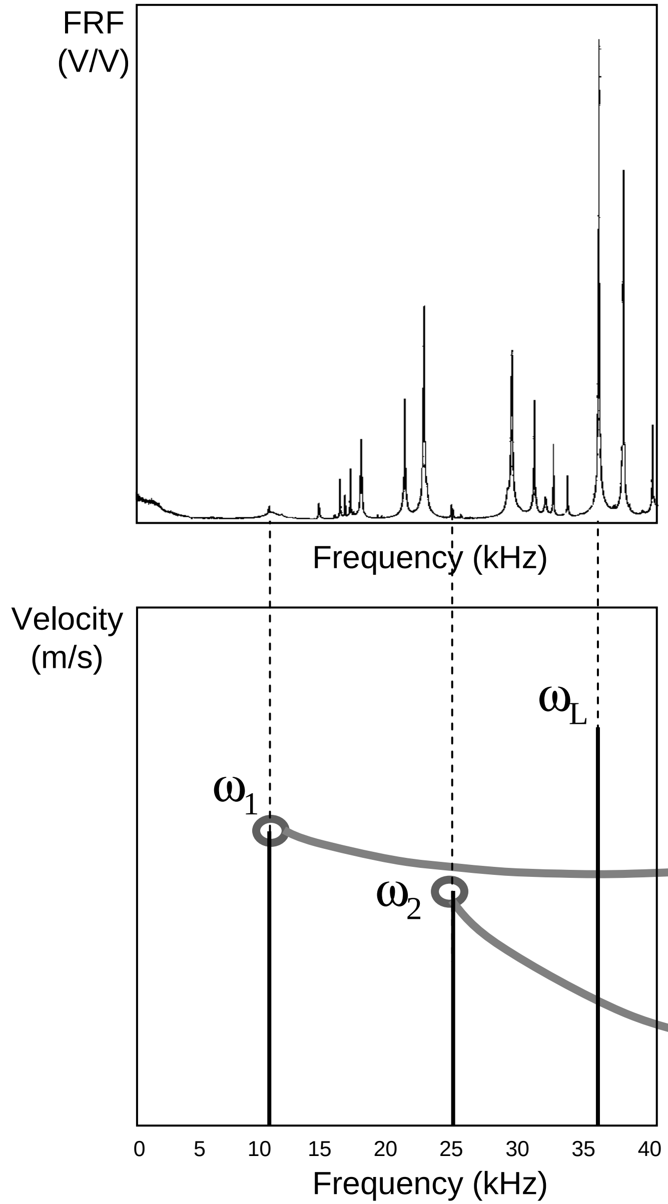
- Reduces the number of modes
- Same cutting length



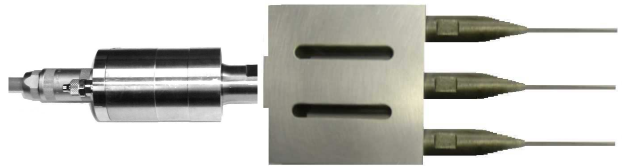
Solid block horn (FEA) | Double-slitted block (FEA) | Double-slitted block (EMA)

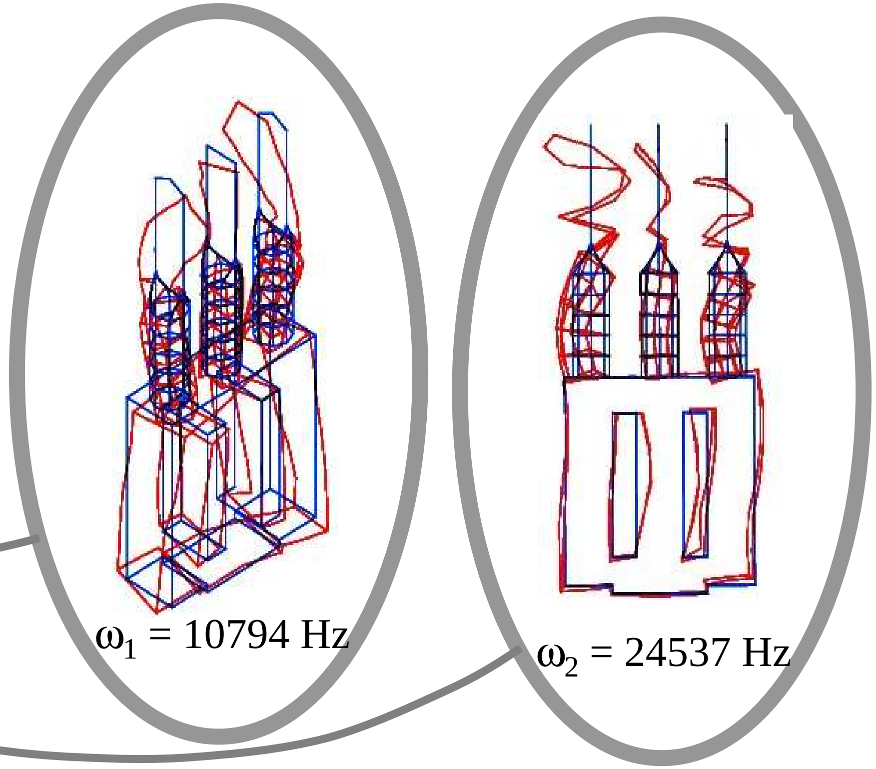
Slits remove the flexural responses of the outer blades.

Parametrically Excited Systems



- **System driven at 35.463 kHz**



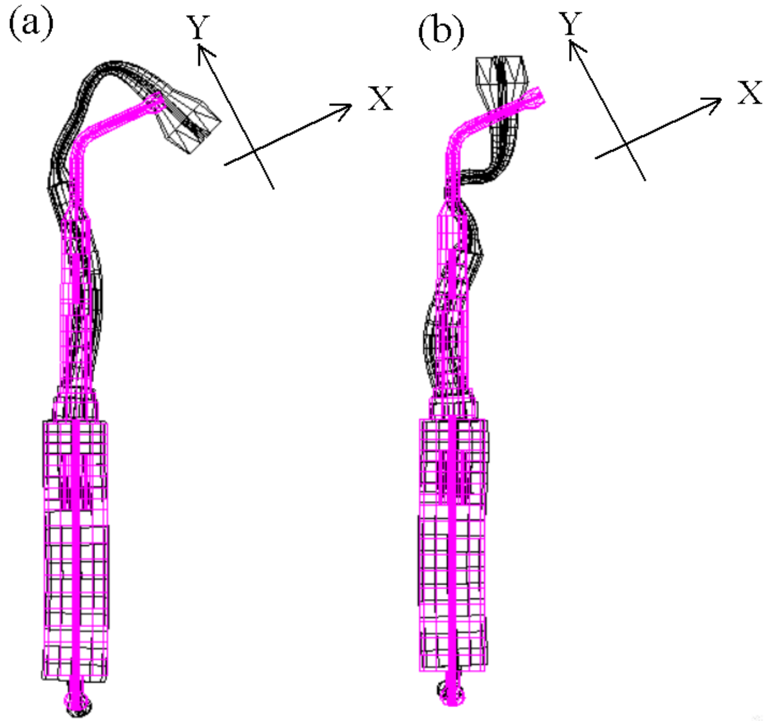


<u>Modal interaction</u>: $\omega_L \approx \omega_1 + \omega_2$

Ultrasonic Bone Cutting System

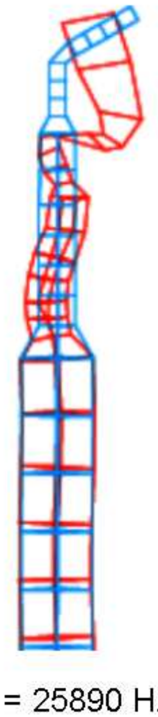
Mectron Medical ultrasonic osteotome:

Handpiece and inserts (Mectron tips)



FE predictions for the nominal mode

f = 25615 Hz



EMA using LDV: nominal mode

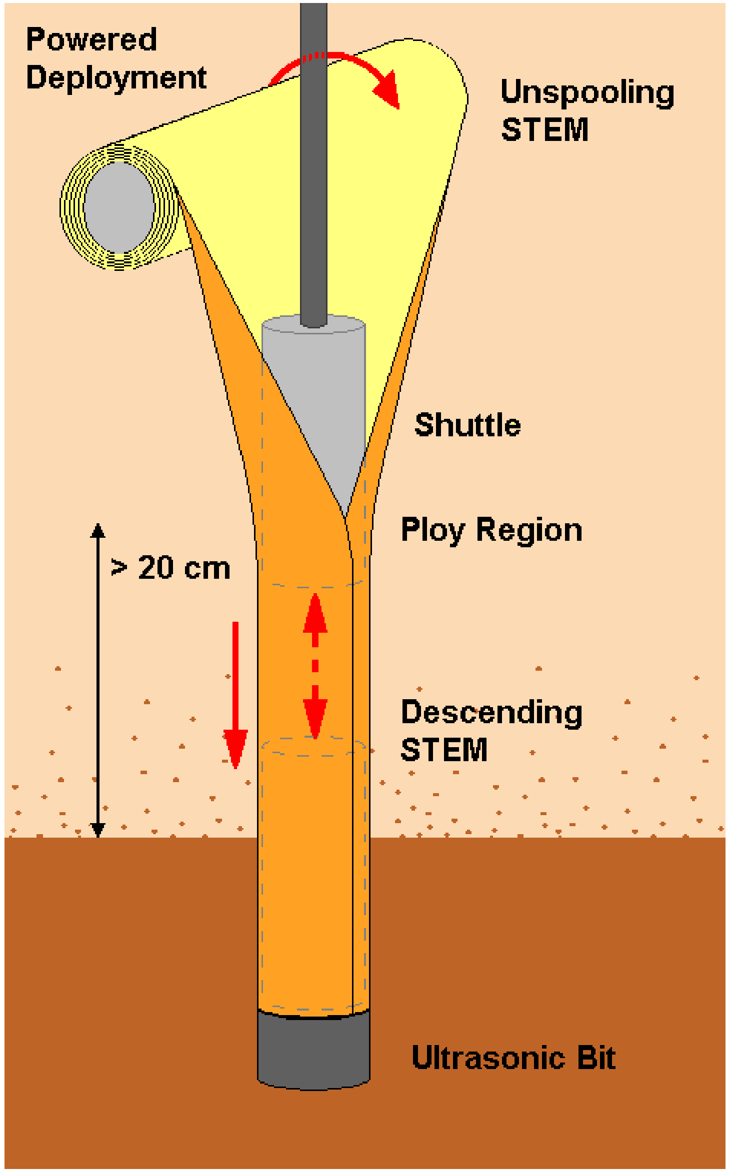
f = 25890 Hz

Ultrasonic Driller/Corer for Mars Rock Sample Return

The aim is to design an ultrasonic driller/corer to retrieve rock samples from several levels beneath the surface of Mars.

The idea is to design a non-rotating driller/corer by coupling a longitudinal and torsional mode of vibration at the ultrasonic operating frequency.

The shaft will be secured by a STEM-type structure – a storable tubular extendible member.

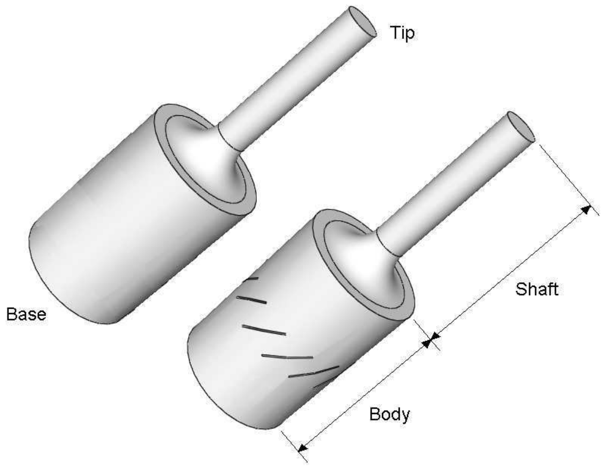


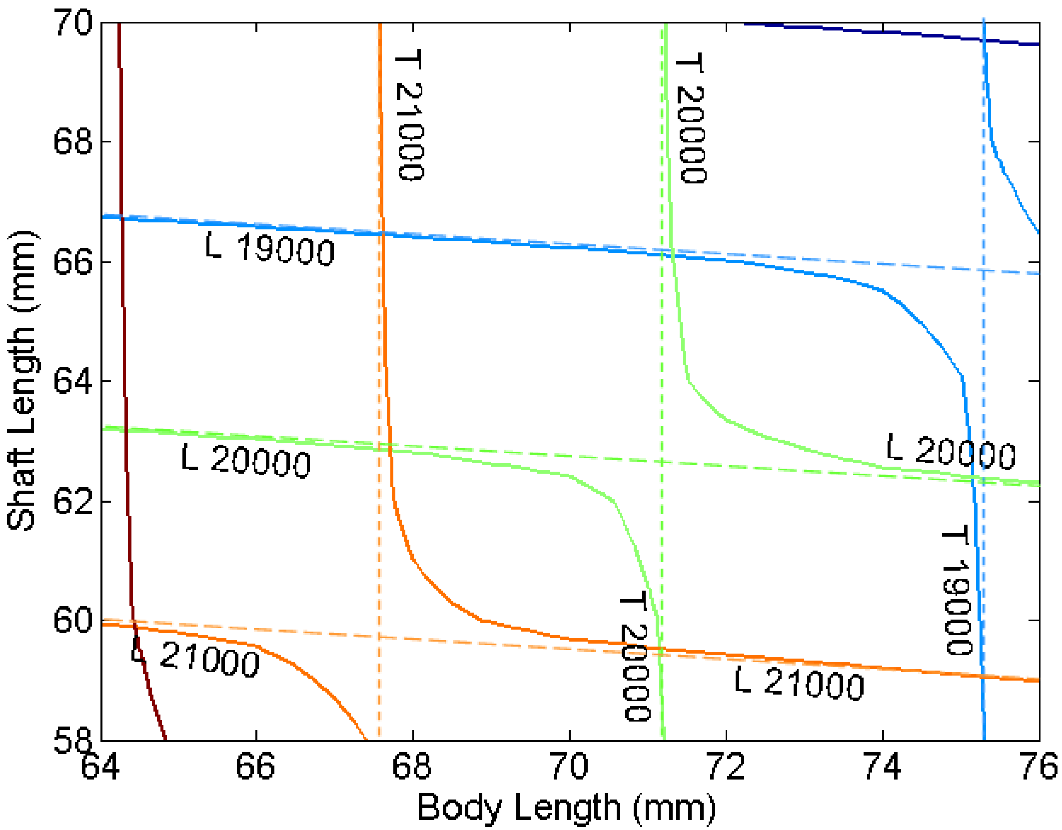
Ultrasonic Drill Bit Design

Finite element models incorporating slits to couple the longitudinal (L1) and torsional (T2) modes

There are two modes, each showing a gradual transition from L1 to T2.

Drill bit geometries at the transition curve in the isofrequencies exhibit two indistinguishable coupled L1T2 modes.



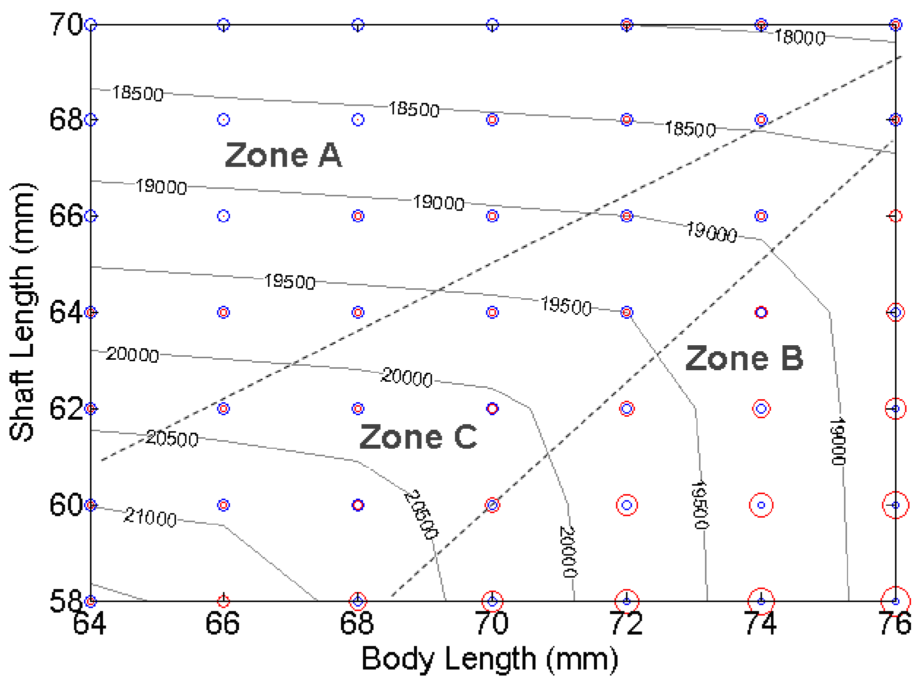


Ultrasonic Drill Bit Design

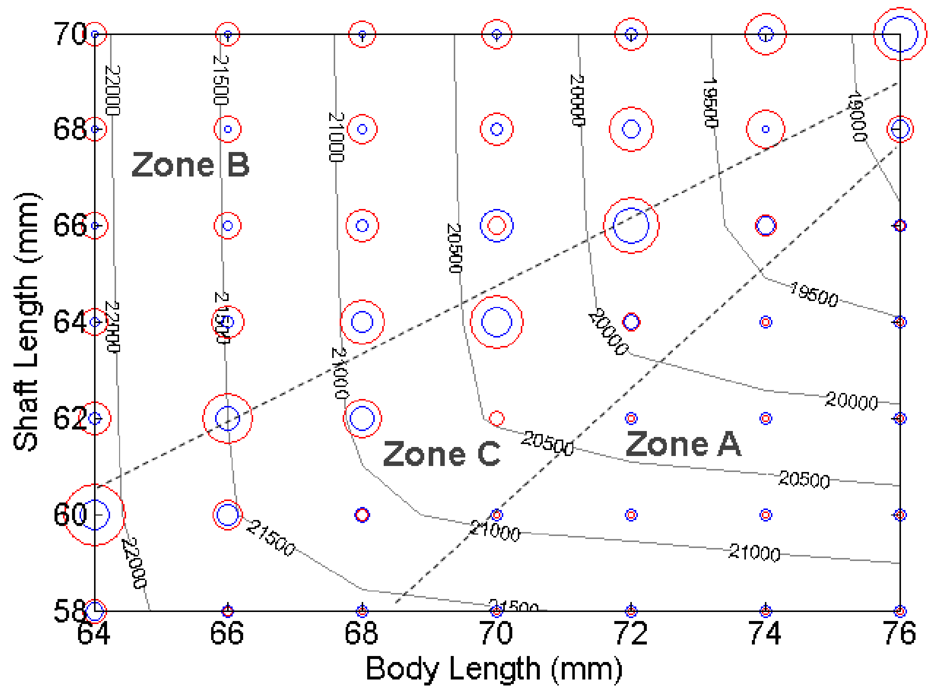
1. Normalised longitudinal (blue) and torsional (red) forced responses are represented on a bubble plot.

2. There is generally a greater torsional response (larger red circles) where the nature of the underlying mode is predominantly torsional.

3. Both the L1 and T2 response are largest of all in the transitional C-zone of the mode 2 response.

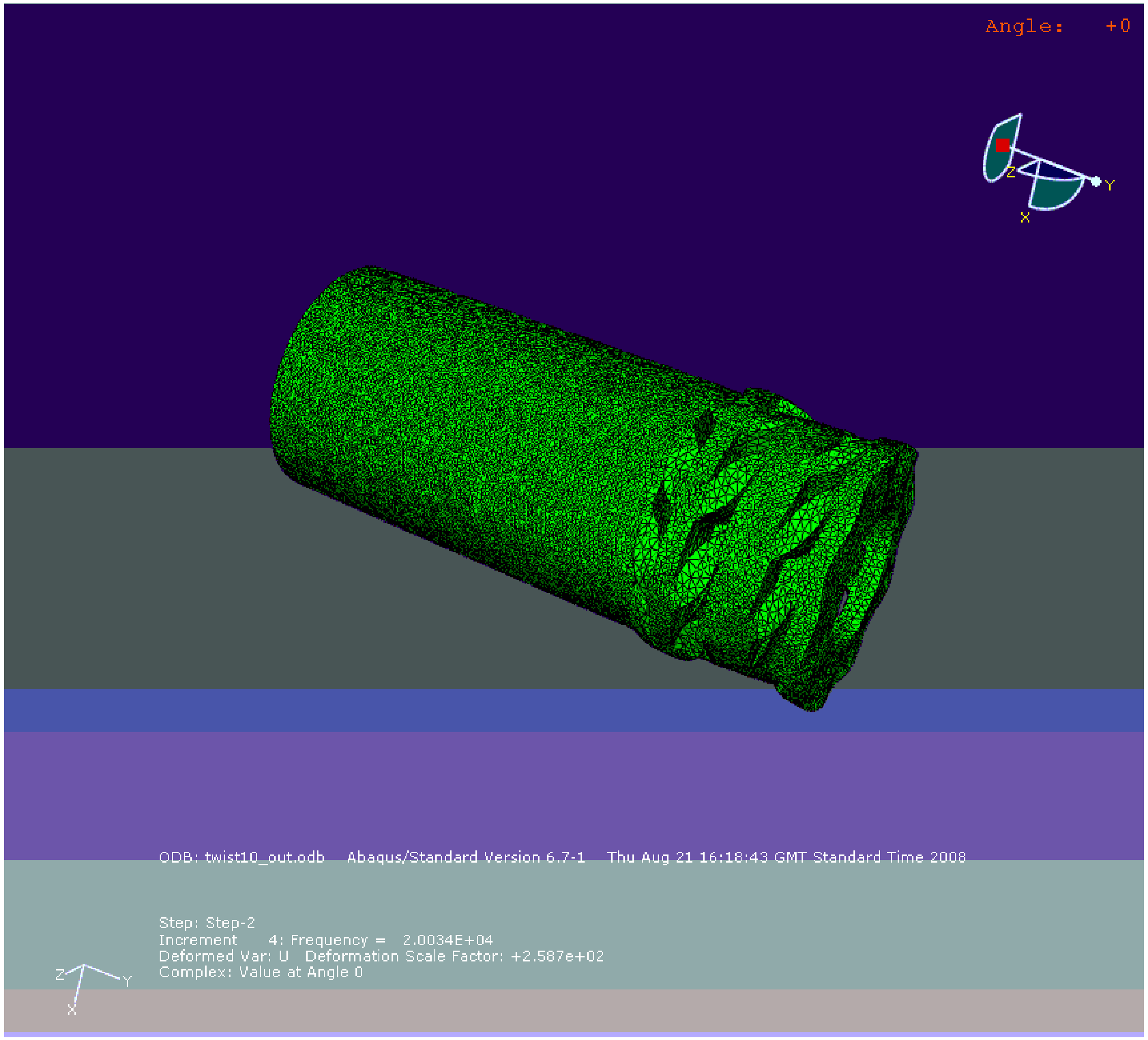


4 Slits; Mode 1



4 Slits, Mode 2

Ultrasonic Corer Design



Ultrasonic Drilling