NAFEMS

Engineering Simulation: Is Your Analysis Fit For Purpose?

Tim Morris – Chief Operating Officer, NAFEMS

FEMCI Workshop 2005

Outline

- What does “fit for purpose” mean?
- What needs to be fit for purpose?
- How does NAFEMS fit in?
- Current state of the practice
- Ongoing activities
- Future issues

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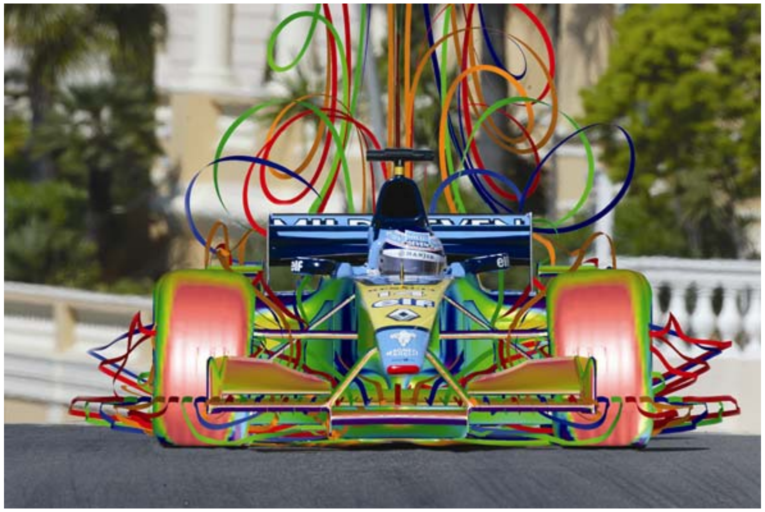
What does "fit for purpose" mean?

- It depends who you are……….

What does "fit for purpose" mean?

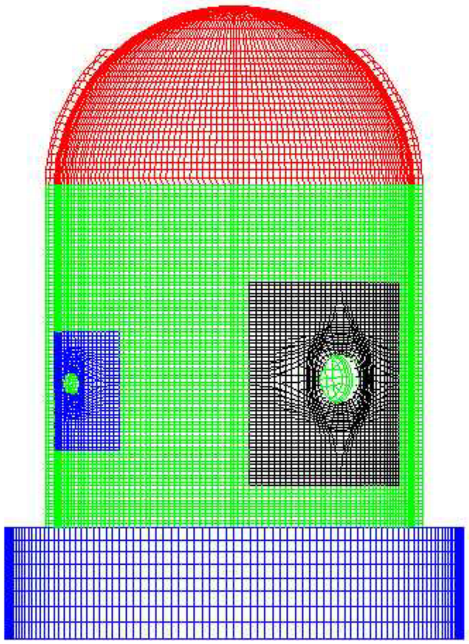
- For a Formula 1 engineer, speed is <u>everything</u>



"Even for a whole car aerodynamics model, we don't need to perform any validation – we just know that it works. That's good enough for us"

What does “fit for purpose” mean?

- For a nuclear power safety engineer, reliability is everything



“We need to demonstrate overall reliability for the power station of 10^{-x}. We can’t perform any tests. What is the reliability of an FEA calculation?”

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What needs to be fit for purpose?

- Software (and hardware)
- Analysts!
- Procedures employed

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NAFEMS Background

- Founded in 1983 *"To promote the safe and reliable use of finite element and related technology"*
- Membership association
- Not-for-profit organisation
- International: 700 companies from around the world
- Focused on engineering simulation technologies such as Finite Element Analysis and Computational Fluid Dynamics

NAFEMS Background

- Board of directors formed from senior industrialists
- Current chairman: Dr. Costas Stavrinidis, Head of Mechanical Engineering, ESTEC

NAFEMS Benchmark Studies

"It has become possible for experienced designers, or novice engineers, with no knowledge of the finite element method (or desire to know) to model a structure and deliver answers. The Finite Element Method has become a black box, and no expert may be on hand to diagnose abuses of the system……

"Is NAFEMS Hitting the Right Target", G. Davies, Imperial College, 1989

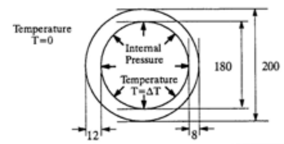
NAFEMS Benchmark Studies

…….NAFEMS has been trying therefore to ensure that codes have no mistakes; will produce respectable answers from respectable models; and are backed by a user community which can recognise faults and poor approximations when it sees them”

“Is NAFEMS Hitting the Right Target”, G. Davies, Imperial College, 1989

NAFEMS Benchmark Studies

9. THERMAL RATCHETING OF ECCENTRIC TUBE	NAFEMS NON-LINEAR MATERIALS BENCHMARKS
	Case NL9
	Issue: 1



Short tube of non-uniform thickness subjected to constant internal pressure and cyclically varying linear through-thickness temperature gradient.

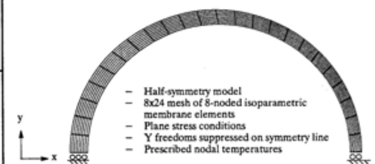
Inside bore is eccentric from outer surface by distance of 2.

A two-dimensional section of the tube is taken, under plane stress conditions.

ATTRIBUTES:

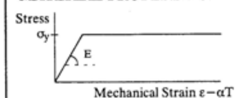
- Elasto-plastic analysis
- Ratcheting and alternating plasticity
- 2-dimensional continuum stress field
- Perfect plasticity

FINITE ELEMENT MODEL:



- Half-symmetry model
- 8x24 mesh of 8-noded isoparametric membrane elements
- Plane stress conditions
- Y freedoms suppressed on symmetry line
- Prescribed nodal temperatures

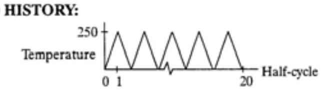
MATERIAL PROPERTIES:



Modulus of elasticity, E	160,000
Yield stress, σ_y	160
Poisson's ratio, ν	0.3
Coefficient of expansion, α	0.00002

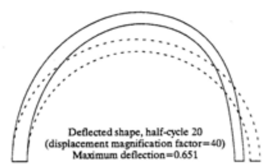
Von Mises yield criterion.
Associated flow rule of plasticity.

LOAD HISTORY:

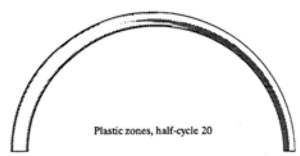


Steady internal pressure, p=6.7413

TARGET SOLUTION:

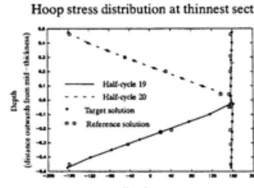


Deflected shape, half-cycle 20
(displacement magnification factor=40)
Maximum deflection=0.651



Plastic zones, half-cycle 20

Hoop stress distribution at thinnest section



Results at thinnest section, half-cycle 20

Depth (distance outwards from mid-thickness)	Hoop Stress	Hoop Strain Total	Hoop Strain Elastic	Hoop Strain Plastic
[illegible]	-159.47	0.003806	-0.00099	0.004805
[illegible]	-121.87	0.003850	-0.00076	0.004610
[illegible]	-83.335	0.003883	-0.00052	0.004405
[illegible]	-30.223	0.003929	-0.00019	0.004121
[illegible]	8.6455	0.003961	0.000050	0.003910
[illegible]	42.414	0.004006	0.000386	0.003619
[illegible]	101.66	0.004038	0.000633	0.003405
[illegible]	155.98	0.004083	0.000973	0.003109
[illegible]	159.7	0.004114	0.000999	0.003115
[illegible]	159.42	0.004157	0.000997	0.003159
[illegible]	158.84	0.004185	0.000996	0.003189
[illegible]	158.54	0.004222	0.001001	0.003220
[illegible]	157.96	0.004244	0.000996	0.003248
[illegible]	157.57	0.004273	0.001011	0.003261
[illegible]	156.96	0.004297	0.000992	0.003304
[illegible]	156.41	0.004330	0.001031	0.003299

Aims of NAFEMS

Primary purpose is to help members who are using engineering analysis to achieve better:

- Collaboration with others in the industry
- Innovation in the products that they develop
- Productivity in their engineering design process
- Quality of their simulations

Technical Working Groups

- Education & Training Working Group
- Computational Structural Mechanics Working Group
- CFD Working Group
- CAD/Integration Working Group
- Analysis Management Working Group

Comprised of experts from industry and academia

Direct the technical activities of NAFEMS

Produce books, best practice guidelines etc.

Regional Steering Groups

- Germany, Austria & Switzerland
- UK
- Italy
- Nordic
- North America
- France
- Spain and Portugal

Comprised of leading figures from industry, academia and software vendors

Direct the local activities of NAFEMS

Host seminars, meetings etc.

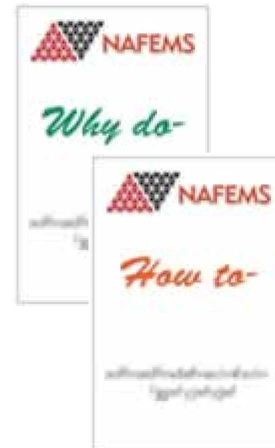
Provide feedback on the requirements of local NAFEMS members

Publications

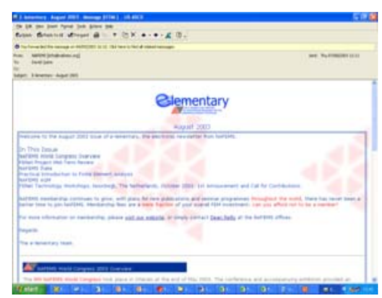
Library of internationally acclaimed publications developed over the years including:

- Primers
- "How to…" Guides
- "Why do..." Guides
- Benchmarks

Issued to members as deliverables as they are developed



BENCHmark



e-lementary

The E-Bulletin from NAFEMS, The International Association for the Engineering Analysis Community

Events

- Seminars in local regions
- World Congress every two years
- Highly focused events
- Independent of vendors
- Well supported by developers, industry and researchers

FENET Highlights

- 110 participants - industry,academia, s/w
- 12 European states
- 4 years (Aug 2001- July 2005)
- 2.2 M€ funding from EC
- NAFEMS is the coordinator

FENET Rationale

- Scale, depth & maturity of application of FE technology varies widely across industry
- Benefits from sharing knowledge and experience
- Current dissemination of “best practice” is not good

FENet - Technology Strategy Plan

- Drivers in key industrial sectors
- State of the art in relevant technical areas
- State of practice in industry sectors
- Research and technology development needs
- Barriers to uptake of technology
- Candidate topics for workshops/collaborative initiatives

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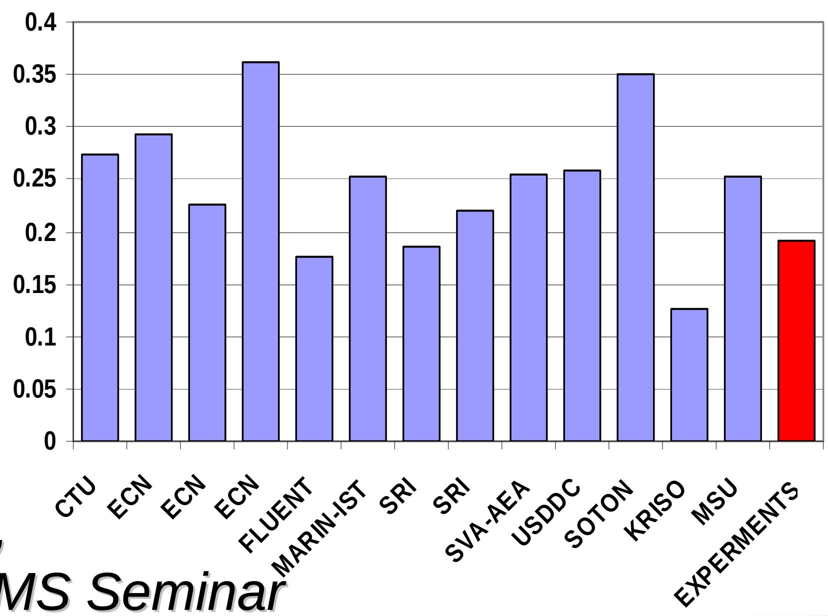
Are Most Analyses Fit For Purpose?

- In recent years, a number of Round Robin exercises have been carried out.
- Different analysts have submitted results to particular problems.
- The results have been compared with each other, and with test.
- The following slides show some example results.

Example Analysis I

- Results from the Workshop on CFD in Ship Hydrodynamics, Gothenburg 2000
- Form factor prediction for the KRISO 300K tanker hull

Form Factor = C_T/C_{FO}-1

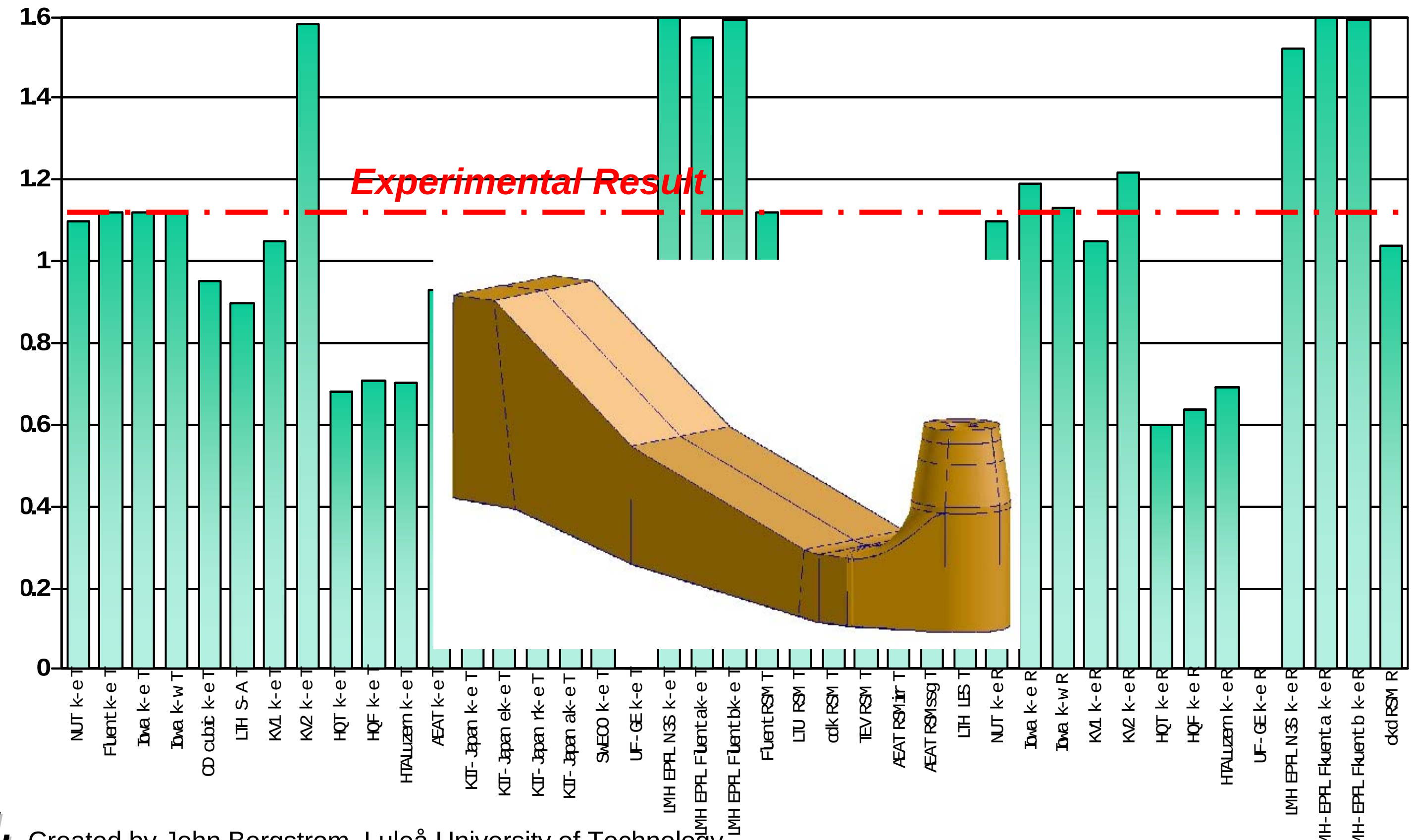


- Variation Coefficient = 26.4%
- Different results from the same code and turbulence model
- Different results from different turbulence models
- Variation increased at full scale

Atkins, NAFEMS Seminar March 2004

Example Analysis II

- Pressure recovery factor (efficiency) of a draft tube

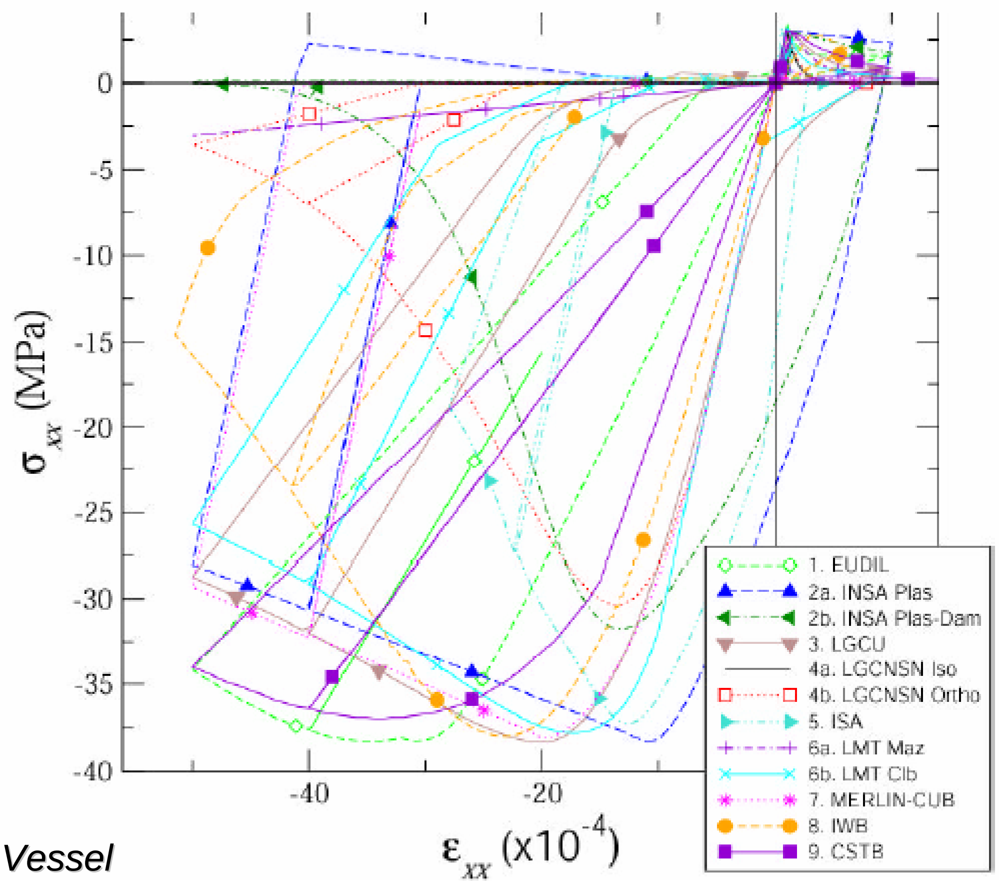


Qinetiq, Created by John Bergstrom, Luleå University of Technology
NAFEMS Seminar
March 2004

Example Analysis III

Test case results : Test A, Point wise response (load reversal)

Compression



EDF

NAFEMS Seminar

June 2003

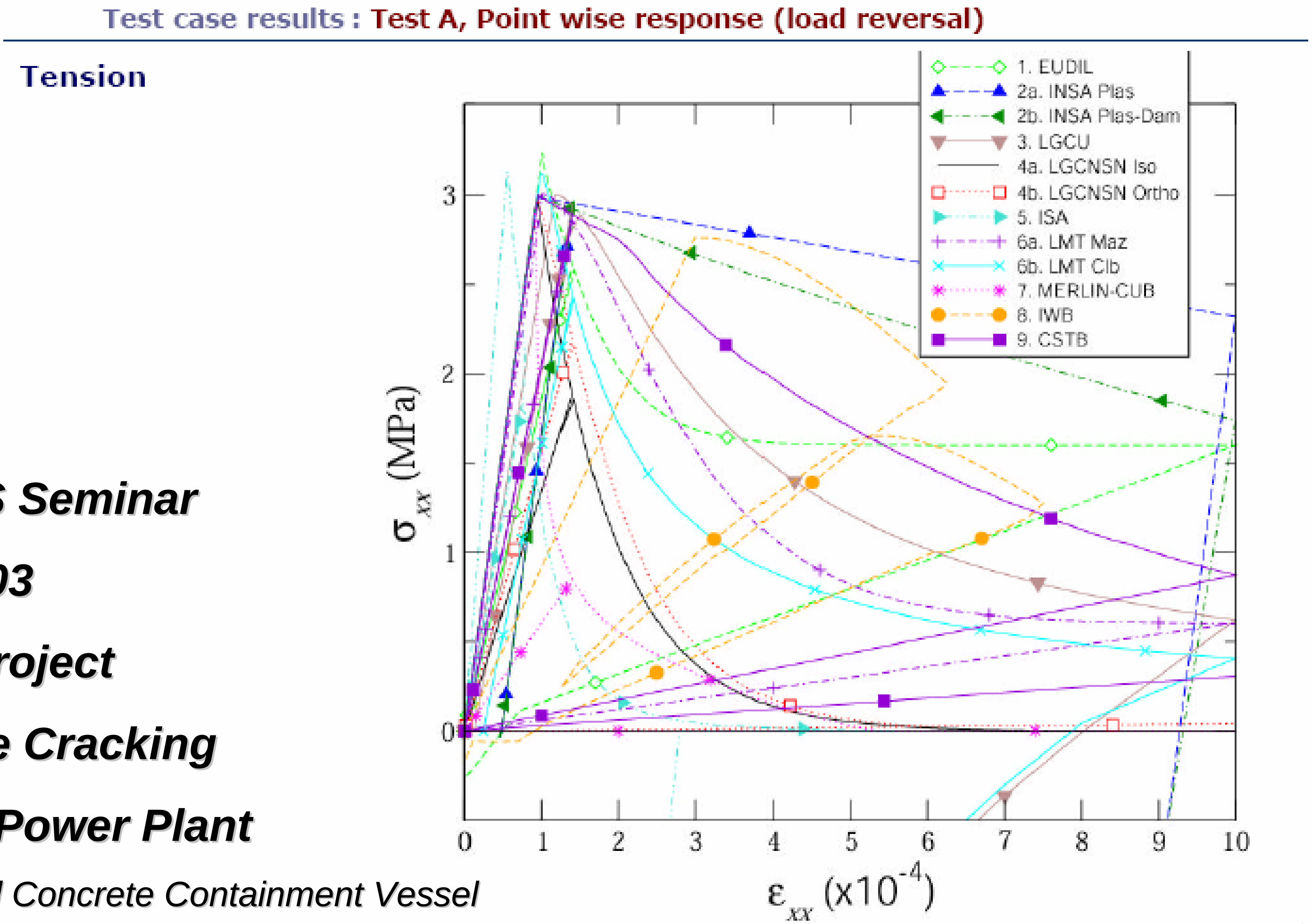
MECA Project

Concrete Cracking

Nuclear Power Plant

Prestressed Concrete Containment Vessel

Example Analysis III



EDF

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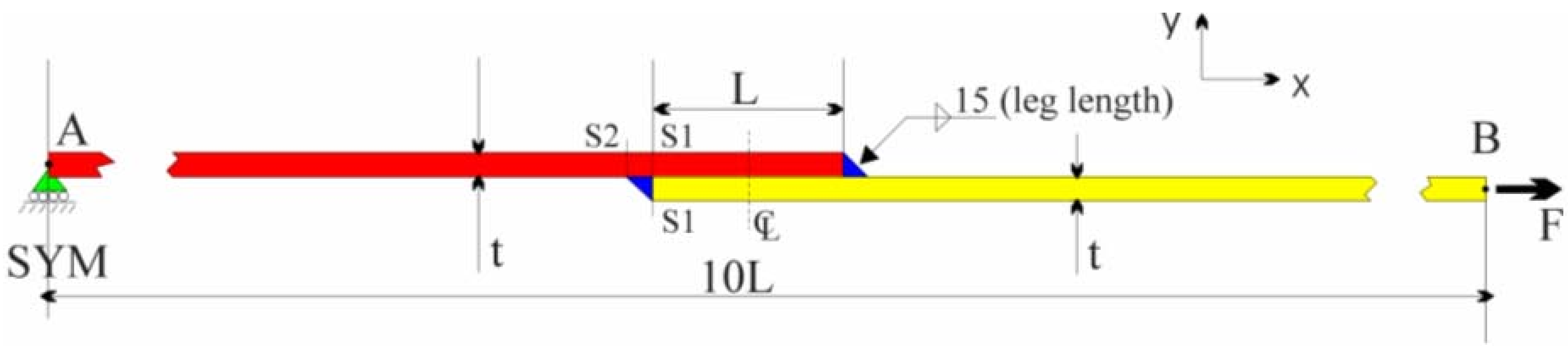
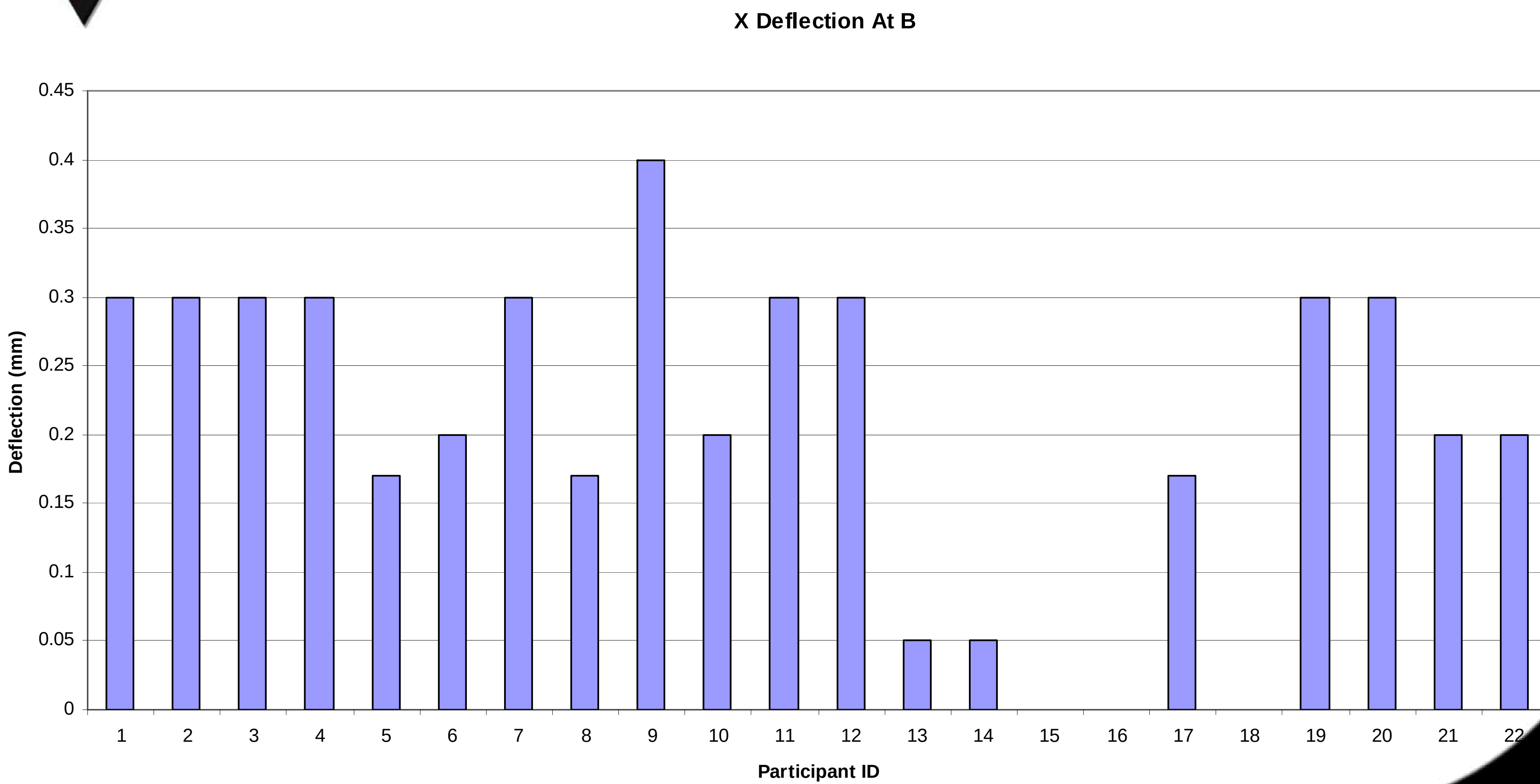
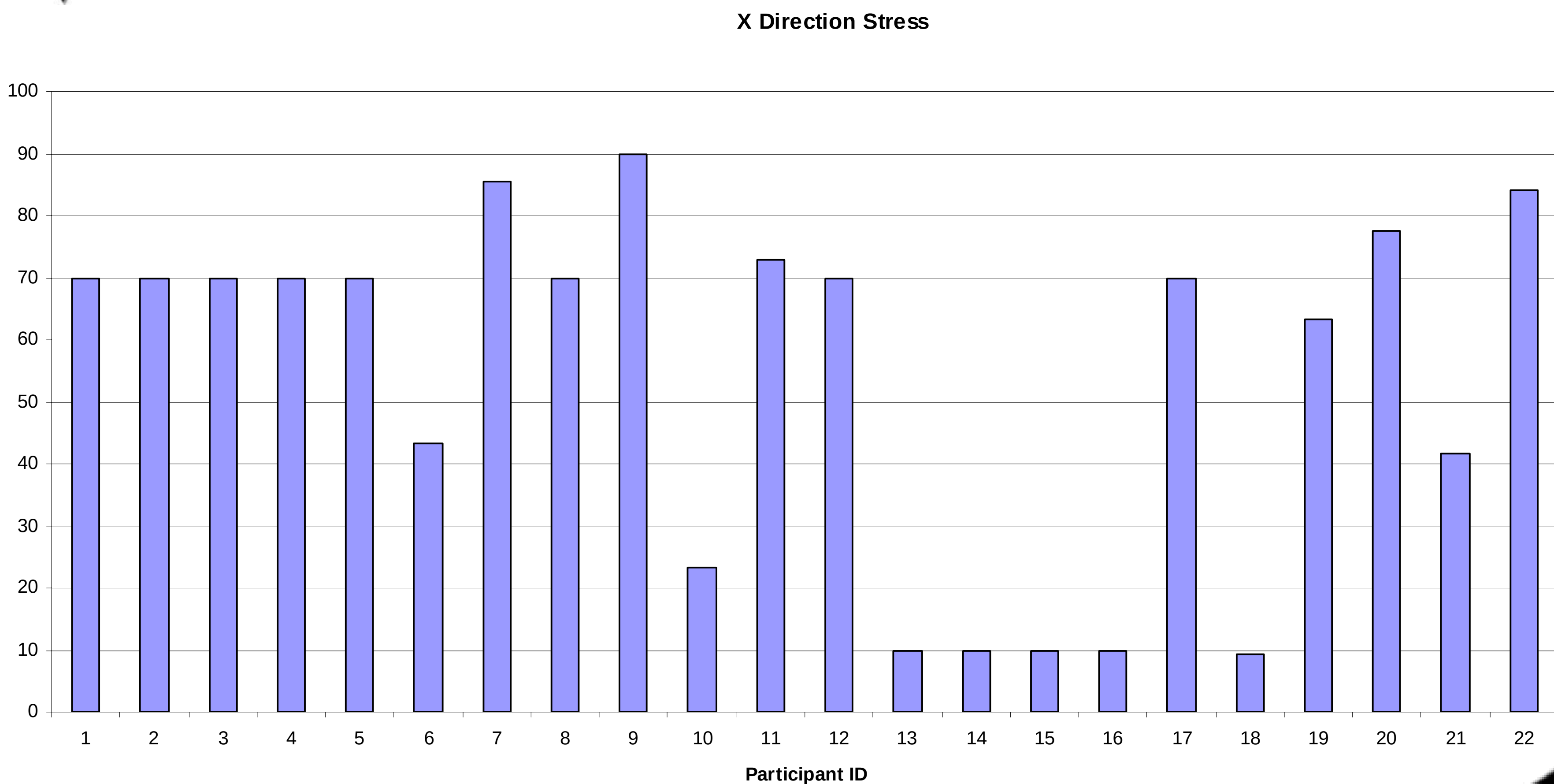
Joint Benchmark



Joint Benchmark – Sample Results



Joint Benchmark – Sample Results



Are Most Analyses Fit For Purpose?

- We mustn't jump to misleading conclusions.
- Round Robin exercises rarely carried out using the quality control procedures that are usually adopted.
- Nevertheless, the results do illustrate the need for adopting Best Practice Guidelines and working within a Quality Controlled set of procedures.

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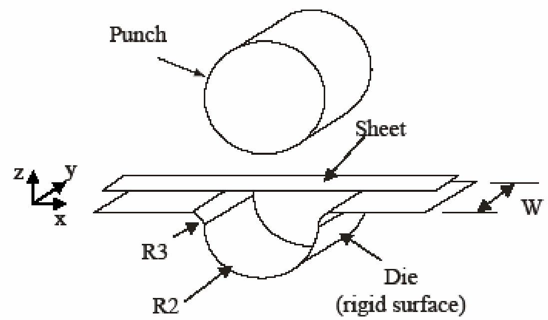
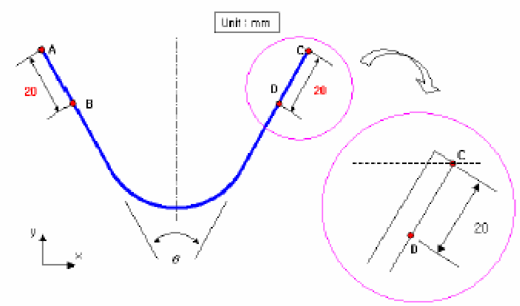
- Analysts!
- Procedures employed

NAFEMS: Fit For Purpose Software

- Continuing to develop Benchmarks in new areas

Title	**3D Sheet metal forming**
Contact Features	- Rigid and deformable bodies - Mesh dependency - Elasticity, plasticity and springback - Sliding contact around circular surface
Geometry	3D continuum elements or shell elements Prescribed punch displacement Punch radius 23.5 mm Die radius R2 = 25.0 mm Die shoulder R3 = 4.0 mm Width of tools = 50.0 mm Length of sheet (initially) = 120.0 mm Thickness of sheet = 1.0 mm Width of sheet = 30.0 mm Punch stroke = 28.5 mm
Material Properties	Young's modulus: $E = 70.5\ kN/mm^2$ Poisson's ratio: $\nu = 0.342$ Plasticity (Hollomon hardening) law: $\sigma = K\,\varepsilon^n$ Initial yield stress $= 194\ N/mm^2$ Constant, K $= 550.4\ N/mm^2$ Constant, n $= 0.223$
Analysis Type	Static Geometric non-linearity Elastic-plastic isotropic hardening
Displacement Boundary Conditions	Symmetry displacement restraints (half symmetry) Bottom surface fixed Prescribed vertical displacement for the punch = 28.5 mm
Applied Loads	No applied forces
Element Type	2D plane strain : 4-node linear continuum elements Shell: 4-node shell elements
Contact Parameters	Coefficient of friction, $\mu = 0$ and 0.1342
FE results	1. Forming angle 2. Angle after release 3. Plot of Punch force against punch displacement





NAFEMS: Fit For Purpose Analysts

- Registered Analyst Scheme

NAFEMS: Fit For Purpose Procedures

- Quality Assurance Procedures for Engineering Analysis
- Management of Finite Element Analysis – Guidelines to Best Practice
- Quality System Supplement to ISO 9001 Relating to Engineering Analysis
- SAFESA Guidelines
- How to Undertake Contact and Friction Analysis
- Workbook of Examples
- ………..

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FENET Findings – Primary Issues

1. How can we determine and demonstrate the level of confidence that we have in our simulation results?

2. Integration of simulation into the overall design process

3. Requirement to more accurately represent real behaviour of engineering materials

FENET Findings – Confidence In Results

The key issue is all about validation: of the model, and of the results

1. How much confidence can you have that your results are "correct"?
2. Can you rely on simulation alone, without building physical prototypes?
3. If you perform tests to validate your simulation, how can you compare the results?

FENET Findings – Integration

The way in which simulation is used in the design process is rapidly changing.

Increasingly analysis is being used by "designers" as part of front loaded development:

"Toyota has slashed development costs and time by 30-40% and solves 80% of all problems before creating initial physical prototypes"[1]

This brings up many issues concerning the requirements for training the wider pool of personnel who are to utilise simulation.

1. "Enlightened Experimentation, The New Imperative for Innovation", Stefan Thomke, Harvard Business Review, February 2001

FENET Findings – Materials Modelling

Requirement for improved tools in many technical areas. E.g.

- Representation of polymers
- Turbulence modelling of fluids
- Multiphysics
- Fracture mechanics (for many materials including metals, composites, concrete etc)
- Complex contact and friction in assemblies
- Representation of welding

Current analysis capabilities often restricted by two factors:

1. Lack of suitable, robust, verified constitutive models
2. Lack of sufficient material data

FENET Findings – Aerospace Industry Sector

- Annual Industry Meeting
- (Plus Around 200 aerospace respondents to FENET FEA Survey)
- Allowed ~50 Key Topics To Be Identified
- Technology Readiness Levels, State of Practice, Priority Levels Established
- Continuously Updated Throughout Project

FENET Findings – Aerospace Industry Sector

- Most requirements derived from the business drivers:
  - Shorter development time and time-to-market.
  - Reduction in mass and power (fuel) consumption.
  - Increasing safety / responding to more stringent safety requirements.
  - Increasing quality and reducing production defects.
  - More integrated development processes, increasingly multi-disciplinary design and optimisation.

FENET Findings – Aerospace Industry Sector

- Most important topics raised:
  - Shorter development time and time-to-market.
  - Need for knowledge based pre- and post-processors.
  - Too cumbersome interface between analysis and test.
  - Insufficient model validation and/or lack of test correlation leading to lack of confidence in results.

FENET Findings – Aerospace Industry Sector

- Most important topics raised (continued):
  - Serviceability and reliability requirements to ensure that a product remains functional throughout its intended lifecycle, e.g. analysis that is required for circumstances which are not reproducible in physical testing: satellites in space environment, aircraft crashworthiness. Also derived from important business drivers such as avoiding warranty costs, cost of product recalls, large damage claims (in particular in US).
  - Consistent handling of uncertainty in analysis, i.e. modelling uncertainties, material property uncertainties, shape tolerances, realistic representative loads, in order to avoid worst-worst-case overdesign. This leads to need for established / accepted probabilistic approach(es).
  - The difficulties to obtain good material property data

FENET Findings – Aerospace Industry Sector

- Tables available in Industry Reports
- Information available for download from www.fe-net.org

Summary

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