Technology Overview

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5	**February 2004**	Technology Overview D4005 **Updated following discussions at the Technology Workshops, Noordwijk, the Netherlands, Oct. 2003 and the Annual Industry Meeting, Hamburg, Germany, Dec. 2003 and taking account of recent deliverables.**

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Executive Summary:

FENET is a Thematic Network, funded by the European Commission, which seeks to improve both the quality of industrial applications of finite element (F.E.) technology and the level of confidence that can be placed in the computed results.

Its principal objective is to collate and structure existing information and to facilitate the efficient exchange of experience and knowledge within, and between, different industrial sectors within the European Community.

To meet this objective the eight industry sectors are charged with reviewing the existing state of practice and the technical requirements in their sectors and reporting on them annually [1]. Similarly the technological state of the art is kept under continuous review [2] and initiatives to promote the effective uptake of the technology within industry are monitored [3].

This report attempts to collate and summarise the main findings from the above reviews. The objective is to provide a sound basis for planning the Network's activities. In particular it is intended to stimulate RTD activity of direct relevance to industry and facilitate the development of RTD project proposals.

This document should be viewed as a live document which is updated and expanded as the project develops. In particular, the methods for categorising the importance of particular technical requirements (PLs) and the general level of maturity (TRLs) will to be refined in order to provide a more rational basis for prioritising effort.

The current version takes account of responses to the June 2003 world-wide web survey carried out as part of the Education and Dissemination tasks and input from the Annual Industry meeting in Hamburg in Dec 2003.

1 Introduction

This report examines FE technology used in various industrial sectors, from the perspective of both the State of Practice and the State of the Art.

Here the State of Practise refers to the degree of uptake of a technology by industry - it is in effect a reflection of the maturity of the industrial usage. State of the Art refers to the degree to which a technology has been developed to meet a perceived need..

Three measure have been used to qualify the situation in the various industry sectors: Technology Readiness Level (TRL) quantifies the availability of the required technology (0 not available, 9 fully developed), Maturity level (ML) quantifies the extent to which the technology has been adopted (0 not adopted, 9 fully utilised) and Priority Level quantifies the importance of the technology to the industry sector (0 not needed, 9 business critical).

The Technology Overview report also considered such issues as Areas for Research, Business Drivers and the Barriers to further uptake of the technology.

2 Industry Perspective

In the last decade or so, finite element technology has become a generic enabling technology across a broad spectrum of industrial sectors. However the scale, depth and level of maturity of application varies widely. This diversity is to be expected given the differing issues and drivers confronting the different industrial sectors. Nevertheless there are a number of common issues confronting all industrial sectors. These include:

- Integration of finite element technology and simulation into the wider business enterprise in order to deliver real business benefit.
- How to ensure and measure quality of finite element analysis. (this covers diverse topics including verification and validation, Q.A., the role of testing, data provenance etc.)
- How to categorise and analyse modern materials.

Some of the other principal issues in each of the industrial sectors covered in the network are discussed below.

2.1 Aerospace

The use of finite element technology in the aerospace industry is well developed and the key issue confronting practitioners is how to integrate existing technology into the overall CAE process more effectively. This is in response to the driver for a continually better product and foreshortened time to market. In many areas of technology (for example; optimisation, adaptive analysis and design sensitivity analysis) a technical requirement has been foreseen and developed but its uptake has been slow. More importantly there are still considerable process-related issues that have still to be effectively addressed. These include establishing “standard” analysis processes, maintaining life cycle information with the product data and industry standards for the exchange and storing of life-time product data. Data provenance and the treatment of legacy data is also an issue.

Furthermore, the newly emerging technological area of smart structures will impose new requirements on the FE technology. These will be concerned with structural health monitoring, damage or malfunctioning, identification and structural control.

In common with other industries there is also considerable potential saving if simulation can reduce the amount of prototype testing and there are some initiatives aimed at satisfying the regulatory bodies that aircraft can be satisfactorily certified on the basis of analysis alone. The key issue here is thus a priori validation of safety- critical structures.

At a technical level there is considerable demand for more holistic modelling, which for example, couples aero-elastics with structures and acoustics, and the improved characterisation of the failure and damage behaviour of advanced materials with respect to damage. There is also renewed interest in probabilistic methods.

2.2 Land transport

There has been a marked increase in the use of analysis and simulation technology over the last decade by the producers of cars and trains. This industry now faces many of the issues confronting the aerospace industry discussed above; for example the integration of analysis technology into the CAE and overall business processes. However it appears that some industrial applications have not achieved the same level of technical maturity as aerospace and there is perhaps some scope for cross – dissemination. Examples include crack propagation and composite materials.

Reduced time to market, reduced development cost and improved performance are strong drivers and in response there is a requirement for better simulation and "virtual assessment" modelling – both in respect of basic technology and in guidance about their use.

In addition the public demand for better safety has focussed attention on "crashworthiness". The high cost of prototype testing has increased the routine use of crash simulation codes, however there is a need to provide reliable information on model validation techniques and guidance on realistic crash scenarios where experience is still relatively limited. On the other hand, the applications of smart structure technology are perhaps more common, particularly in the field of crashworthiness. This, in conjunction with the progress in microsystems technology is now expanding into intelligent automobiles concept.

Market pressures are dictating lighter vehicles to improve fuel economy, this involves a high degree of optimisation to reduce component mass. Increasing use is being made of alternative manufacturing methods, such as adhesive bonding where suitable methods and materials data are scarce and there is a generic need to improve confidence in the modelling of connections. The requirement to predict failures and service life are important to vehicle performance and ultimately the acceptance of the product in the marketplace.

TRL's for the Land Transport Industry Sector is given in the table below.

Issue	**State of Practice**	**State of Art TRL**	**Priority Level**
Durability & Life Extension			
Fatigue life prediction & assessment	7	5	9
Modelling and assessment of welds	9	5	9
Modelling and assessment of bonding	9	4	8
Composite materials characterisation (material data base)	9	3	7
Product & System Optimisation			
Linear/non linear multi-objective optimisation (shape)	6	4	7
Linear/non linear multi-objective optimisation (mat, thick)	6	6	7
Non linear multidisciplinary optimisation	5	5	6
Multi-Physics			
Contact Analysis	9	5	9
Support for materials, with respect to Failure and damage criteria		5	9
Automatic Meshing		5	9
Adaptive Meshing		5	8
Education & Dissemination			
To diffuse the simulation mentality within the industry through the training of tomorrow designers	5	7	9
Leading-edge research in modelling	6	5	6

The items shown in the table have been selected from Ref [4], Land Transport Industry Sector Requirement where full list can be found. They are characterized by very high priority with the level in many cases equal to 9 and, in many cases by a low TRL's, with significant differences equal to 4.

Business drivers include design cost reduction, weight reduction and increased fuel efficiency. Barriers include business focus on short term priorities.

2.3 Biomedical

The use of analysis and simulation for bio-medical purposes is increasing dramatically but is still quite immature. In contrast to other industrial sectors most analysis work is carried out by "specialists" in consultancies, universities or research establishments and industrial "practises" are in there infancy. Nevertheless the potential benefits are substantial.

There are two distinct drivers; firstly an improved understanding of the biomechanics of human body with view to development of artificial implants, e.g. hip replacements, artificial heart valves. Secondly the simulation of body kinematics in crash scenarios in response to the need for safer cars, trains etc.

In the first case the use of CAE techniques gives insight into the load mechanisms, material behaviour and response of the implants and the biomedical materials (bone, cartilage, ligaments, muscles, etc.). They can support the product design and development process in many aspects, such as wear predictions, structural behaviour, component loading etc. In the second area the interest is understanding how the human body interacts in crash situations when subject to very rapid decelerations, with a view to designing safer vehicles.

The main challenge in both areas is how to tackle the highly nonlinear and currently ill-understood biomechanical behaviour of specific materials using the available simulation tools. Much of the “material” behaviour is not easily characterised by conventional models e.g. “solids” usually behave in a complex inelastic manner and fluids are non-Newtonian. Other technology challenges include a general lack of credible data, ill-understood scale effects and the ability of material to change behaviour in response to environment. It is thus essential to bring together the specialist bio-medical knowledge and the expertise and experience of finite element analysis specialists, in order to adapt the already existing advanced finite element formulations and techniques on the special biomechanical requirements.

Additional group of problems stems from ever increasing use of micromechanisms and microsystems in medical applications. Typical devices include microfluidic, electrical and sensing components. Problems associated with design and use of these devices requires solution to coupled physics issues such as:

- flow
- heat transfer
- chemistry
- diffusion
- free surface
- two-phase effects
- cavitations
- structural analysis
- electrostatics
- electromagnetics
- plasma

Advanced tools are emerging. However the computing power required is demanding and there is considerable scope for research directed at better models.

2.4 Civil construction

In contrast to the aerospace and land transport industries the use of finite element technology in civil engineering is still quite immature and it has yet to be integrated into the overall business process. Much design work is characterised by a culture of highly prescriptive codes of practise and in many areas it is not clear how to use rigorous analysis methods effectively in the design process. The industry deals with natural phenomena which are intrinsically variable and often ill-defined (e.g. earthquakes, wind loading, soil strata) and an attendant issue is how to treat the uncertainties that arise.

An important driver is the attention to more sustainable and environmentally sound forms of construction with the attendant interest in reducing cost of construction. This is leading to a greater interest in the use of IT and the import of manufacturing industry business processes. In a number of areas there is evidence of considerably increased use (e.g. in hydrology and river modelling, in geotechnics and foundation engineering. In both these areas a key issue is how to characterise the uncertainties of the real world with the analytical model). Safety (of constructions) is also an important driver.

There is also considerable use of finite element technology for the support and maintenance of civil infrastructure. Analytical models provide the basis from which to optimise the maintenance-spend of the infrastructure while at the same time ensuring structural integrity.

At a technical level there are a number of requirements:

- Improved models for non-linear behaviour (especially concrete) under dynamic loads
- More robust non-linear models
- Automatic calibration of material parameters
- Coupled analyses of various physical processes
- Pre and post processors
- Integration of CAD – FEM

An emerging area is concerned with application of smart structure technology. So far examples include vibration control and active damping of high-rise structures, structural health monitoring (e.g. bridges, dams, wind turbines, historical structures) and system identification (e.g. historical structures, bridges).

TRL's for the Civil Construction Industry Sector are shown in the table below.

	Maturity	Priority
Deep Underground		
Material models	6	8
Borehole stability	6	7
Surface subsidence as a result of mining/extraction	7	8
Gas/oil reservoir production	8	8
Stability of storage caverns	4	7
Geo-technics		
Groundwater Flow – soil saturation	6	8
Stability of slopes	7	8
Stability of saturated dikes	5	7
Surface subsidence as result of tunnelling/excavations	6	9
Transport of environmental pollutants	4	7
Soil-liquefaction	4	7
Material models	6	9
Transport Infrastructure		
Building process of steel bridges	8	8
Building process of concrete bridges	6	8
Dynamic behaviour of bridges – transient analysis	6	8
Dynamic behaviour of bridges – modal analysis	8	8
Impact resistance of bridges	6	7
Building process of tunnel in rock	7	7
Building process of tunnel in soft soil	5	8
Fire/explosion in tunnels	4	8
Earthquake analysis of bridges	6	8
Wind loading	6	8
Reassessment of infrastructure	6	8
Non-linear material models	6	8
Buildings		
Building process simulation	6	7
Limit analysis of buildings	8	6
Dynamic behaviour of buildings	7	8

Fire/explosion resistance of buildings	4	8
Earthquake analysis of buildings	5	8
Light-weight structures: cables and membranes	7	8
Re-assessment of buildings	7	8
Material models	6	8

The items shown in the table have been selected from Ref [4], Civil Construction Industry Sector Requirement where full list can be found. They are characterized by high priority, with average level near 8 and, in most of cases, by high maturity. It is worth to note some areas which are of high priority but relatively low maturity with the biggest difference being 4. These are material models, fire/explosion in tunnels and fire/explosion resistance of buildings.

In the area of the state-of-the-are worth noting are trends to use more FEA in assessment, repair and rehabilitation of civil construction, which is a consequence of increasing maintenance costs.

Other important issues are associated with various aspects of non-linear material models, to be used e.g in modelling of soil behaviour or in modelling of concrete cracking.

Business drivers include design for lifetime costs, safety and durability and environmental issues. Barriers include little experience and low maturity level in application of the FE technology to use in asset management, ie. maintenance, rehabilitation or assessment.

2.5 Consumer goods

The consumer Goods Industry Sector is a wide one with products varying from small handheld devices to heavier household equipment. Modern consumer goods have short operational lives compared to many other products; cycle times need to be correspondingly short, with the gap from concept to product being measured in months rather than years. To effectively integrate FE into the design process communication between CAD packages and analysis packages must be easy and accurate, (not necessarily the same thing). Accurate tracking of material properties that go with the model and validation of the results must all be considered as part of the analysis process that is followed all the way to the display shelf. CAD plug-ins and “designer level” analysis systems promise “one-click” analysis, but the question of the required level of training and expertise for these programs has yet to be properly answered independently from the vendors. With the next generation of these packages promising automatic optimisation of features based on broader criteria than shape alone, the line between draughtsman and analyst is becoming difficult to draw.

It can be said that the use of FE and CFD in the European consumer goods industry has been either led by enthusiastic vendors or held back by hardened sceptics, and is still waiting for *independent* answers to the following questions:

- What are the true benefits of FE for consumer goods design? Are there areas where the benefits have, in the past been understated? Areas previously under explored?
- Is there a consumer goods design methodology that delivers maximum benefit of FE in terms of design optimisation using “virtual prototypes” & speed without imposing limits on creativity and aesthetics, and while ensuring that appropriate validity tests are still carried out?

- Are there simple rules that can be established for CAD systems to improve interoperability with FE and downstream processes?
- Which is better; an integrated approach (CAD plug-in route) or the translation method (CADfix etc.)? If it's horses for courses, can we produce guidelines?
- For the new "one-click" systems, what are the risks? What are the benefits? In terms of training, how can we minimise the first, and maximise the latter, at minimum cost?

TRL's for the Consumer Goods Industry Sector are shown in the table below.

White Goods	***Maturity***	***Priority***
Abuse Loads: Dropping Packaged Appliance Dropping Unpackaged Appliance	 4.64 4.36	 6.27 6.07
Linear elastic analysis for Plastic Material	4.85	6.14
Non-linear Materials (plasticity) and Contact for catches & snap-fits, inserts (press fits or shrink fits)	4.00	5.93
Brown Goods		
Abuse Loads: Dropping Packaged Appliance Dropping Unpackaged Appliance	 4.64 4.36	 6.27 6.07
Linear elastic analysis for Plastic Material	4.85	6.14
Non-linear Materials (plasticity) and Contact for catches & snap-fits, inserts (press fits or shrink fits)	4.00	5.93
Small Electronics		
Abuse Loads: Dropping Packaged Appliance Dropping Unpackaged Appliance	 4.64 4.36	 6.27 6.07
Linear elastic analysis for Plastic Material	4.85	6.14
Non-linear Materials (plasticity) and Contact for catches & snap-fits, inserts (press fits or shrink fits)	4.00	5.93

The items shown in the table have been selected from Ref [4], Consumer Goods Industry Sector Requirement where full list can be found. They are characterized by high priority with average level at about 6 and, in majority of cases, by medium maturity. Average difference is close to 1.5.

The state-of-the-are topics include dynamic studies of abuse loads and coupled field solutions. Technology needs and future research requirements include various aspects of non-linear material models, acoustic analysis, risk reduction and durability.

Business drivers include reduction time to market. Barriers include high costs of simulation and quality control, low CAD integration and lack of people with adequate skills.

2.6 Marine and offshore

Design and construction practises for marine and offshore structures have been transformed in the last two decades. Considerable use is now made of CAE allied to prefabrication and the industry now ranks amongst the best in terms of business efficiency. Over the same period new technologies and new materials have been espoused to develop improved hull forms e.g. trimarans, fast ferries, Ro-Ros and cruise ships. At the same time, the life extension of existing vessels and offshore platforms to meet changed operational requirements has generated considerable technical challenges, which to some extent are still on-going. These include the prediction of seaway loading, ultimate hull girder strength, fatigue life of primary structure, deterioration modelling, fracture analysis including critical crack lengths and robust repair techniques recently including use of composite materials.

Further difficulties are arising from developments of new fields in deep water. Associated issues require modelling of a large variety of phenomena, such as behaviour of complex mooring systems, structural behaviour of risers made form composite materials or long term resistance of FPSO moored for many years in harsh environment.

Safety and environmental issues are also contributing to the demand for improved simulation technology particularly in areas as diverse as response to extreme loadings, integrated hydrodynamics/ kinematics/ structural response and design for maintenance and reliability.

In response to these challenges the marine and offshore industries have witnessed increasing use of commercial FE packages, particularly those with non-linear capabilities. Furthermore, the safety concerns in the offshore industry have been a driver in development of the reliability theory and, more recently, its integration with FE codes.

The TRL's for the Marine and Offshore Industry Sector are shown in the table below.

	Maturity	TRL	Priority
Marine and Offshore Topics			
Non-linear static analysis of metallic structures with accurate failure prediction	4.3	7	6.8
CFD Structure interaction (e.g. flow around propeller)	3.2	7	5.8
Application of sea loading to FEM model	3.7	6	5.9
Slamming (load and response)	3.4	4	5.7
Integration Topics			
Automation of the structural analysis process	4.3	4	5.7
Use of open standards: e.g. ISO/STEP (AP209,...) W3C/XML, OMG, NCSA/HDF5,...	3.7	5	5.8
Catalogues of parts/components with FEM representation	2.7	5	6.5
Durability & Life Extension			
Fatigue life prediction & assessment	4.6	5	6.4
Buckling and post-buckling	?	8	6.0
Modelling and assessment of residual stresses (due to welding, moulding, casting etc)	4.0	3	5.8
Product and System Optimisation			
Multi-objective optimisation of analysis parameters (shell thickness, material property etc)	3.6	2	5.3
Multi-Physics			
Structure - incompressible fluid interaction	6.7	5	5.6
Contact Analysis	5.8	7	7.1
Analysis Technology			
Support for materials, with respect to Physical Representation	4.1	8	~7
Support for materials, with respect to Failure and damage criteria	3.7	4	6.4
Support for materials, with respect to Links to design tools	3.3	4	5.6

Specific software for coupling FEA with other techniques	2.7	7	5.5
Automatic Meshing	5.1	8	~8
Adaptive Meshing	4.0	6	6.9

The items shown in the table have been selected from Ref [4], Marine & Offshore Industry Sector Requirement where full list can be found. They are characterized by high priority with average level at about 6 and maturity from 2.7 to 6.7. Average difference is close to 2.

Research activities at the state-of-the-art level include stochastic approach to fatigue problems, stochastic crack-growth modelling and vulnerability assessment of naval ships to above or underwater missile or explosion attack. Future research interests also include automatic meshing and CAD/CAE integration.

The main business driver is cost reduction and environmental issues. Some specific issues include improved fatigue management, improved structural safety and reduced cost of design and fabrication. Barriers are a consequence of the gap between the available and applied technology. They include inability of smaller companies to keep up with the new technology, rules and regulations are predominantly empirical and relatively little repetition of work.

2.7 Power and Pressure Systems

This industry ranges from the relatively demanding safety-challenged nuclear power sector to the manufacturers of industrial pressure vessels. The industry is characterised by codes of practise which seek to embody contemporary experience and which to some extent have yet to be adapted to take account of modern CAE capabilities. Thus for example much design is by “rule” – although “design by analysis” is being introduced in some codes.

In this environment the role for analysis and simulation is the traditional one of *post design* demonstration of structural integrity. In common with many industries there are demands in various sectors (e.g. nuclear power) to extend the life of existing plant, while at the same time improving operational efficiency. These demands introduce particular challenges in respect of the characterisation of ageing material (where the ageing process can involve corrosion and material degradation, fatigue and irradiation) and how to treat the uncertainties that arise. In some sectors (notably nuclear) the end-of–life decommissioning process can be dominated by safety concerns and simulation plays an important part in developing the associated safety case. Again long term material behaviour and the characterisation of other epistemic uncertainty are important issues. There is considerable interest in probabilistic models in respect of the latter.

Currently FE packages have the capability to perform cyclic loading analysis for fatigue and have material models for creep. There are standard methods available to assess fatigue damage and creep damage but techniques for assessment of combined fatigue/creep damage, seen in long period load cycles, using FE analysis have not been standardised. Also, different users have developed material models to take account of degradation due to irradiation or corrosion. The FE community will benefit if this information is exchanged. Of particular interest are damage mechanics models which can use the stress strain state predicted from an FE analysis to indicate material damage.

There is also the important issue of regulatory certification in areas such as the nuclear industry, including the movement of nuclear materials by transport containers and systems. There is a need to identify specific methods for conducting analysis and methods of validation to reduce variation and uncertainty.

TRL's for the Power and Pressure Industry Sector is given in the table below.

Issue	State of Practice	State of Art TRL	Priority Level
Durability & Life Extension			
Fatigue & Fracture	7	7	9
Aging/ Stress Corrosion Cracking/ Embrittlement (Need data to use the technology)	5	5	9
Accident Scenarios: Impact	4	4	8
Product & System Optimisation			
Sensitivity Studies	7	8	9
Structural Reliability Methods: Numerical	6	7	7
Structural Reliability Methods: FORM/SORM	4	4	7
Multi-Physics			
Residual Weld Stresses	4	4	9
Education & Dissemination			
Accreditation - self assessment then 3rd party	8	8	9
Benchmarking	6	7	9
Validation and Verification	7	7	9
QA Systems	8	8	7
Checklists	5	7	8

The items shown in the table have been selected from Ref [4], Power & Pressure Industry Sector Requirement where full list can be found. They are characterized by high priority with average level above 8 and also high maturity ranging from 4 to 8. Difference between these two measures is wide ranging from 1 to 4.

Interest in future research includes topics such as fracture mechanics for life extension and repair, analysis of welded and bolted joints and probabilistic analysis.

The business drivers include a need for the design by analysis, compliance with design codes and evaluation of limit loads. Barriers include difficulty with validation of FEA results, terminology, insufficient awareness of the DBA manual and difficulty with incorporation of empirical knowledge into the FEA.

2.8 Process and manufacturing

Predictive simulation of manufacturing processes is an area of fast growing interest for industry. Indeed it can be argued that in a number of cases the advantages of simulation, over traditional design approaches are significantly greater in this field, than in areas where FE and numerical simulation are already well-established. Process simulation includes, material forming, such as casting, forging, stamping, injection molding, plastic sheet forming and the like, but also welding and heat treatment simulation, such as surface treatments, quenching, and thermo-mechanical treatments in general. Methods and software products are particularly complex, as problems are highly non-linear, transient, requiring integration of a variety of physical phenomena and process parameters, and often related to variables of different physical fields.

Process optimisation, being a business driver from the perspectives of, productivity, cost and time to market however plays a key role. It is typically multi-objective: with a variety of inherently different technical issues, furthermore operational efficiency and cost targets have to be taken into account at the same time. Evolutionary and hybrid approaches are required, as well as MCDM methods to find out the best compromise among the non-dominated optimal solutions.

All this is at the forefront of numerical simulation. Hence a network of competencies (and related education) is crucial to support industrial applications.

3 RTD Perspective

From a technical perspective, industry faces a large number of technology issues. The network addresses these under the 3 broad Technology categories, namely Durability & Life Extension, Product &System Optimisation, and Multi-Physics & Analysis Technology plus an activity dealing with Education and Dissemination. These are discussed below.

3.1 Durability and life extension

Notwithstanding the modern “consumer society”, life assessment and extending the life of plant and machines are major concerns in many industries including aerospace, power generation, building, transport and offshore engineering. There is considerable demand for better predictive computational models to account for long term failure processes, particularly fatigue and fatigue life prediction, but also creep, fracture, corrosion, ageing and damage. A key issue here is how to model material behaviour to account for a wide range of behaviour, often non-linear, under different loadings and environmental conditions at a range of physical scales.

Examples include micro-scale damage models to describe the fracture processes in fibre-reinforced composites, continuum mechanics analysis of creep damage, debonding in microelectronics packaging, simulation of weld behaviour, and macro scale models of the long-term creep of concrete. For many industries, durability and life extension issues are stimulating considerable interest in how to model ageing and deterioration effects e.g. embrittlement of metals due to radiation, creep of plastics and metals, effects of corrosion in reinforced concrete or deterioration of historical structures, build masonry or stone. Efforts in this area concentrate on improved understanding of these phenomena at the material level and on development of continuously enhanced deterioration models.

A further issue is how to treat the inevitable uncertainty that arises from the characterisation of such problems, for example using probabilistic or stochastic methods. Significant efforts are spent on data gathering and on development of sophisticated stochastic models for each deterioration phenomenon. This trend will inevitably continue as new materials will emerge, often with different deterioration characteristics and variabilities.

3.2 Product and system optimisation

This covers the need for simulation technology which allows the “system” to be optimised for a wide range of criteria and conditions. It includes for example improved methods of topology and weight optimisation, methods for treating uncertainties more rationally (e.g. reliability-based design optimisation) in addition to the detailed treatment of non-linear effects such as contact, friction, buckling etc. Other areas of interest are large strain effects encountered in modern forming and production processes and many others, impact modelling (including deformational response with large kinematics).

The quest of all engineering processes is to make things better. In the area of Computational Mechanics there have been huge advances in the last 30 years with parallel developments in computers and computational algorithms. Finite Element Analysis has evolved to such a stage of competency that the engineer/physicist can analyse any defined physical situation, linear or non-linear provided the material properties are known.

In the last ten years there has been significant academic research in the area of Structural Optimization to the stage where the algorithms needed for size, shape, topology and topography optimization are becoming more reliable and robust. We are now starting to see some limited commercial uptake of these analytical optimizers replacing the traditional engineering intuitively/heuristic driven iterative design optimization methods.

The eventual goal of all structural optimization systems it to be able to deliver on the design wish list of structural goals such as;

- Totally general and multiple load environments
- Totally general multiple support environments
- Totally general shape in 2D or 3D
- Multiple material environments
- Multiple modelling environments eg. static, dynamic and stability, separate or together
- Material and geometric non-linearity
- Multiple optimality conditions (Pareto) for all or portions of the structure in different combinations.
- Design must be manufacturable

None of the software products currently available deliver this whole list. None of them even address the last item in any realistic way. Currently there are two main computational techniques for structural optimization, mathematical programming with design variables (which can be the presence of an element, rather than a geometric entity) and heuristic methods. Several commercial FEA vendors offer one or both of these capabilities and there are several in-house proprietary codes. There is still much research and development to be done and much training of practicing engineers before Design and Structural Optimization becomes a routine part of the design process. The status at the moment is akin to that of FEA in the 1980's.

Equally as important, but still significantly lacking, is the integration of manufacturing process models into the design optimization loop. Indeed if we are to be commercially serious for the product under consideration then we should also include financial, marketing, environmental, support and service and retirement into the design optimization. Each of these activities has different analysis processes and data structures and responsibility resides in different locations in any commercial organization. Even between analysis and manufacturing models there are significant integration problems. This gap becomes even greater when other commercial processes are involved.

The challenge is therefore to guide the development and uptake of these new integrated analytical processes into true design optimization and to provide direction to all parties involved; code developers, researchers, designers and manufactures as to how the Computational Mechanics community should proceed from here.

3.3 Multi-physics and Analysis technology

This technology area is driven by the need (and increasingly the ability) to create holistic simulations which couple structural mechanics with fluid, thermal, acoustic, electrical and other descriptions of physical processes. Examples include aerodynamically induced noise and vibration effects in aircraft, metal casting processes, long term ground movements due to thermally and lithostatically induced pore water movements, piezo-electric phenomena, wave–structure interaction effects ranging from simple hydro-dynamic loading on ships to fully integrated kinematic and structural vessel response simulation to stochastically defined sea states.

In this category we also include issues to do with standards for the exchange of data and models between software, hardware and computer architecture advances, multi-processing, and the integration of simulation and CAE methods into the overall business process. In addition it covers improved (more robust) elements, meshless finite element analysis, front end modelling and post processing against the background of a continual demand for improved functionality and performance. New concepts such as stochastic and probabilistic methods also feature here as appropriate.

To represent the behaviour of complex engineering processes mentioned above sufficiently comprehensively, simulation capabilities characterised by:

- the interactions amongst continuum phenomena at the macro-scale - *multi-physics*, and
- the impact of behaviour across a range of length and time scales simultaneously - *multi-scale*,

are both needed.

The computational models of closely coupled *multi-physics* requires the employment of numerical solution procedures that have a measure of compatibility, so that the impact of one phenomena (e.g. electromagnetic fields) can be represented in another (e.g. fluid flow) in an appropriate time and space accurate manner. Moreover, when *multi-scale* calculations are involved, a variety of domain decomposition techniques are required, which again demands a measure of compatibility amongst the solvers for the phenomena at each of the scales. Even when the multi-level calculations are a realistic aspiration from the perspective of an analyst, then their integration into optimisation tools to facilitate the right first time design for manufacture or performance adds to the software engineering challenge of ensuring that software components for different aspects of the tasks are inter-operable. Multi-physics and multi-scale calculations are very computationally intensive - in an optimisation loop they are even more so. Therefore, the combined simulation-optimisation technology targeted as such applications will have to exploit high performance parallel computing systems. Significant efforts will occur over the next few years as the emerging accessibility of these technologies penetrate the manufacturing industry sectors and become more comon design tools.

3.4 Education & Dissemination

Barriers to the uptake and effective use of finite element technology can be grouped into two categories

- Education and training of key practitioners to the appropriate level
- Exploitation and Dissemination of the technology. This includes particular issues concerning Quality Assurance, IPR and software verification and validation

In the industry-focused discussions, education and training features highly in the wish list for improvement. There are, of course, numerous initiatives aimed at meeting this deficiency, ranging from academic short courses to code specific training courses, from web-based material to traditional text books. This diversity is both a strength and weakness: Industry tends to find the academic material too theoretical, too diffuse and insufficiently focused on industrial issues. Code specific training material can be too parochial and lacking in objectivity. In particular it tends to be skewed to what “can be done” – industry needs also to know what does not work. At the same time academics tend to be concerned at the apparent desire to de-skill the analysis process by “procedurising” it and by attempts to remove all mathematics from user manuals etc. Against this background there is an ongoing need to discuss and debate the real needs of industrial users and how, and in what manner, they should be met. This will then stimulate the production of material to satisfy the needs of industry and encourage more effective forms of delivery. For example initial discussions have identified a number of projects addressing the issue of training through emerging techniques such as web based learning. The web-based survey of finite element users identified ways of capturing and re-using experience as a high priority, and there is perhaps scope to revisit knowledge management and expert systems technology.

There is also a requirement to examine the need for certification of engineers and accreditation of courses to a uniform standard. It is envisaged that this would contribute to improving the quality of analysis being carried out and enhancing the confidence levels in the use of technology. There is much to be said for a pan European “standard” for short courses on Finite Elements covering many aspects of FE modelling, e.g. linear, non-linear, dynamic analysis, fracture mechanics, fluid mechanics, heat transfer, etc. The feasibility of devising a written examination to assess students for a “Certificate of Competence” in the relevant FE area might also be considered.

There are a number of exploitation and dissemination issues that currently limit the effective uptake of analysis and simulation technology; two of the most important ones being Q A and IPR. Quality Assurance in the broadest sense is about ensuring “fitness for purpose” of the analysis results and embraces the still maturing concepts of “verification” and “validation”. There have been a number of attempts to formalise these concepts, involving rigorous definitions and procedures, in the belief that these can then be integrated with the quality procedures for other business processes. A difficulty is that non-practitioners tend to want validation (and verification) to be an absolute process with a “black and white” answer: A set of results (or even the model!) is either valid or is not and no qualification is needed. Practitioners, on the other hand, tend to want to qualify their validation by highlighting all the uncertainties and assumptions that go into the simulation. Against this background current QA philosophies for simulation fit somewhat uncomfortably with the more formalised procedures of other business processes.

A further issue, which is likely to become more important as simulation is integrated more closely with product development and other business processes, is how Intellectual Property Rights can be preserved. Conflicts can arise between the desire to standardise and the desire to maintain competitive advantage by asserting ownership of a process, data etc. Again a forum to debate the nuances of the issue is needed.

4 References

1. D2211 - D2218 Updated Industry Requirements
2. D3421 - D3423 Updated Technology Issues
3. D5504 Updated Education & Dissemination Issues
4. D2311 – D2318 Updated Industry Requirements