A REVIEW OF FEA TECHNOLOGY ISSUES CONFRONTING THE MARINE & OFFSHORE INDUSTRY SECTOR

John D McVee, Technical Manager, QinetiQ Platform Support Services, Scotland
Jack Reijmers, Principal Naval Architect, Iv-Nevesbu b.v., The Netherlands

SUMMARY

This paper presents the outcome of deliberations undertaken for the Marine and Offshore industrial sector as part of the FENET Thematic network. It begins by giving a brief history of the evolution of the application of finite element analysis (FEA) in Marine and Offshore from early beginnings to today's virtual product development environment where linear dynamic and non-linear static calculations are standard practice with increased experience of the users and improved software. General and specific business drivers are considered along with the current state of the art and the state of practice in the sector. R & T development needs, barriers to the uptake and dissemination of FEA technology within the sector and impediments to its advanced use are discussed along with candidate topics for collaboration and possible workshops.

1: INTRODUCTION

The use of FEA in the shipbuilding industry stretches back to the late 1950s when a curved grillage analysis was first applied to a computer model of a complete ship section between bulkheads and experimentally validated. This was followed by the development and application of static and dynamic plane frame and grillage analysis to structural problems occurring on ships decks and bulkheads. Analogous computer programs such as ASSSAI and BOSOR IV were developed for the axisymmetric stress analysis and buckling analysis respectively of submarine pressure hulls. In the late 1960s, the Suez crises prompted the building of super tankers with related transverse strength design problems. This in turn stimulated the development of general purpose sector orientated FEA computer programs such as SESAM, and the subsequent application of NASTRAN, ANSYS and ASAS to marine and offshore problems during the 1970s. The 1980s saw the advent of departmental computing coupled with interactive computer graphic pre and post processors, for example PATRAN and FEMGV, accompanied by the application of the geometrical and non-linear analysis capabilities contained in codes such as ABAQUS, ASAS/NL, FABSTRAN and BOSOR V to determine the buckling and collapse strength of ships, submarines and offshore platforms. It also saw the development and use by naval shipbuilders of the boundary element Underwater Shock Analysis (USA) code, which was coupled to several FEA codes including STAGS, NASTRAN and ABAQUS, to predict the effects of shock and whipping on both ships and submarines. Structural optimisation techniques were also applied to commercial ships and warships using MAESTRO.

Widespread introduction of CAE/CAD systems was a major feature of the 90s during which time various FEA codes with contact algorithms such as LS-DYNA were applied to ship collision problems and codes such as PISCES and DYTRAN enabled ship slamming to be considered in a rudimentary fashion. Since the millennium, the linear and non-linear fracture mechanics capabilities available in codes such as MARC and ABACUS, aided by ZENCRACK, have been used to predict fatigue crack propagation rates. LS-DYNA coupled to USA has become the dominant code for shock and whipping predictions and like ABAQUS now includes a well established Euler module for modelling water or air and which can be readily coupled to a Lagrangian structural module. FEA is also embedded in the CADMID systems offered by the Classifications Societies.

Today's Virtual Product Development (VPD) environment is well established in the Marine and Offshore (M&O) Sector and applied worldwide by shipbuilders and offshore fabricators as evidenced by the most recent ISSC [1], PRADS [2] and OMEA [3] conferences. In particular, FEA relating to all aspects of computational structural mechanics, computational fluid mechanics and multiphysics is now part of the VPD process and is practised by large and small organisations throughout the M&O community in Europe [4].

2: BUSINESS DRIVERS

As always, the main business drivers are safety, time to market, reductions in production and operating costs, environmental issues and human comfort. Thus, the primary technical drivers regarding the use of FEA methods in M&O are, design checks on primary structure; evaluation of stress levels relating to low and high cycle fatigue considerations; determination of the ultimate strength of undamaged and damaged structure; buckling calculations of stiffened structure; mitigation of propeller induced vibrations and cavitation; simulation of the effects of fabrication; prediction of fatigue crack propagation rates; safety regulations including fire, flooding and capsizing; quantification of naval loads resulting from underwater explosions or air blast on structure and equipment; and asymmetric terrorist attack.

Current specific FEA related drivers are: increased safety of personnel by improved risk management and reliability techniques; acquisition and validity of material properties of metals and composites. integration of CAE with CAD; much better prediction of fatigue life to reduce the initiation of fatigue cracks; crack propagation prediction to enable reliable management of cracked structure via improved inspection schemes; increased design by analysis accuracy without increasing the engineering time; improved simulation of the fabrication process (e.g. welding) to reduce cost and provide better understanding of the state of materials during and after the production phase (e.g. residual stresses); and reduction of weight of yachts and top-side weight by novel techniques involving fibre-reinforced plastics.

3: STATE OF THE ART IN RELEVANT TECHNOLOGY AREAS

State of the Art refers to the degree to which available technology has been developed to meet perceived needs and is presented under availability in Table 1 for the M&O sector in terms of the range of ‘Technology Readiness Levels’ (TRLs) as defined by NASA, where TRL 1 is ‘Basic principles observed and reported’, and TRL 9 is ‘Robust method, fully integrated in the industrial product development process’.

References 1 to 6 exhibit extensive application of FEA in M&O. Particular recent applications are to: fatigue and fracture; ultimate strength of damaged structures, sandwich steel, very thick monolithic steel (for container ship decks) and stiffened panels; buckling of hatch covers; composites; double hulls; aluminium fast ferries; and trimarans. Extensive work has also been done regarding ship collision and grounding.

Analysis technology has also advanced with the improved availability of faster solvers and better multiprocessing and parallel processing; eigenvalue extraction, component mode synthesis, superelements and data management..

Fatigue and fracture is of primary interest to the international ship structures community. Although, the SN-approach has a long history and with a clearly defined load it works well, fatigue loading is stochastic and the nature of the loading still requires to be fully understood. Storm conditions can be forecast since sea-states have been monitored for quite some time. However combinations of wind, tidal current and swell can cause unexpected loads with severe impact. Moreover, fatigue damage regularly occurs at locations other than anticipated.

Crack-growth can be tackled with modern software but results in refined models. The application to large marine and offshore structures with many fatigue-sensitive joints is not easy and often requires well developed sub-modelling transition tools coupled with crack front directional tracking capabilities.

Ultimate strength has been shown to be more accurately predicted using an integrated 2D FEA load-shortening stiffened plate approach at specified frame stations rather than from a 3D collapse approach using FEA.

Vulnerability and survivability assessment of naval ships to above water attack by missiles and underwater explosions are areas where rudimentary multi-physics has been applied for many years and more sophisticated techniques are now emerging [5] including the development of suitable acoustic elements and the successful simulation of bubble jetting from close in charges.

There is increasing concerns regarding the validity [7] of numerical simulations and the inferences drawn from them [8] especially if testing cannot be carried out.

4: STATE OF PRACTICE

There is a tendency for leading companies to carry out state of the art analyses, whereas smaller companies with a moderate staff are only able to resource more modest analyses. Therefore, in general, the state of practice in the Marine and Offshore industry is variable, although small shipyards have demonstrated their ability to create custom built CAD to FEA ship design systems which can cater for static and dynamic analysis, propeller induced vibrations and cavitation.

The state of practice refers to the degree of uptake of a technology by the industry. It is in effect a reflection of the maturity of the industrial usage of available technology and is presented in Table 1 for the average M&O company. It is based on the industry survey held in 2002-2003 among a small group of approximately 30 participants involved in the following types of analysis:

91% Linear Statics
73% Non-linear Statics
64% Linear Dynamics
47% Fatigue
44% Non-linear Dynamics
38% Non-linear material - time independent
36% Contact & Wear
35% Optimisation
27% Steady State Thermal

22% Seismic
20% Composite Materials & Structures
20% Non-linear material - time dependent
20% Crack Propagation or Assessment
18% Thermal Stress Analysis
16% Damage/ deterioration modelling
16% Transient Thermal
13% CFD
13% Acoustics
<13% Impact, Coupled, Sensitivity, Probabilistic, Buckling etc.

The Maturity scale applied is from 0 - available technology not used at all, to 9 - general use of the state of the art technology.

5: R&T DEVELOPMENT NEEDS

Importance levels are a measure of the industrial need for a technology. The importance scale applied in Table 1 is from 0 - technology is not needed at all to 9 - urgent demand for this technology.

Inspection of Table 1 shows that:

- Accurate failure prediction, and fatigue life prediction both have a high priority, but low maturity. So these topics are typically areas for continued research.
- In multi-physics, contact analysis has the highest priority. On the other hand, although the maturity level was initially stated as being relatively high, it has been recently revised to be much lower and is interesting research for the near future.
- Both automatic meshing and adaptive meshing with high priority and relative low maturity are important research areas.
- The integration of engineering analysis into design and development process is rated with a high priority. CAD/CAE integration is therefore an important topic.

- Finally, according to the survey the priority of buckling analysis is high, but strangely enough, none of the respondents of the questionnaire is involved in buckling analysis.

6: BARRIERS TO UPTAKE AND DISSEMINATION

As in every industry, there is a gap between the available and applied technology owing to barriers to the uptake of this technology. The main barriers for the M&O industry to use the latest technology are:

Internal and external costs of acquisition and maintenance of state of the art FEA software (and hardware) along with staff costs, all of which quite rightly have to be corporately justified.

Structures are normally built according to the rules and regulations of Classification Societies. The rules for ship type structures especially are empirical and based on extensive experience. Finite element analysis is often thought to be only marginally required.
Most ships and offshore structures are custom built as opposed to mass production so that time consuming improvements of the design, possible via optimisation, are therefore much less profitable.

Although rudimentary optimisation techniques have been applied in M&O, naval architectural constraints often inhibit its use.
Finally, software products carry a disclaimer on liability regarding use of the software. Products are pushed into industry and there is often a limited flow of information in both directions regarding functional applicability. It is imperative that software vendors become even more involved in the detailed needs of industry.

7: IMPEDIMENTS TO SUCCESSFUL USE OF FEA TECHNOLOGY

Linear finite element analysis is well established in the industry, but there is still a lot to be gained by accurate determination of the wave-induced loading on ship and offshore structures. Fatigue calculations for ship structures has met with only limited success. The correlation between the predicted and encountered fatigue cracks is still low. A great number of research programs are addressing this topic. As noted previously, ultimate strength considerations are not made using conventional FEA.

Other areas of interest are automatic and adaptive meshing and the integration of CAD/CAE software (conversion of models). Improved software integration would reduce the modelling time of large ship models.

In the naval ship community there is an obvious need for integrated signature management encompassing noise, near and far field acoustics and target echo strength including radar cross section analysis and electromagnetic radiation.

8: CANDIDATE TOPICS FOR WORKSHOPS/COLLABORATIVE INITIATIVES

More attention needs to be given to structural and cost optimisation, reliability, probabilistic methods and the ready application of sensitivity and parametric studies in both linear and non-linear analysis, including the effects of residual stresses and initial imperfections.

There is scope for collaboration regarding multi physics applications to ship seaway response to wave loading including fore and aft slamming.

Workshop topics could include realistic structural modelling including the incorporation of geometrical imperfections, fabrication stresses and variations in material properties and loads.

Consideration is also being given to the life extension of ageing ships and offshore platforms.

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Table 1: Marine and Offshore FEA Issues Ranked According to Availability, Maturity and Importance

Topics	Availability	Maturity	Importance
A - Specific Marine and Offshore Modelling Requirements			
Linking diffraction (pressure) analysis with FEM model (including phase information)	6	2.8	4.4
Reliable whole ship model analysis	7	3.3	5.6
Non-linear static analysis of metallic structures with accurate failure prediction	7	4.3	6.8
Hydrodynamics-structure interaction (e.g. springing)	4	3.5	5.6
CFD Structure interaction (e.g. flow around propeller)	7	3.2	5.8
Determining Sea State Loading	5	3.7	5.5
Application of sea loading to FEM model	6	3.7	5.9
Wind Loading (vortex induced vibrations)	6	3.1	5.3
Slamming (load and response)	4	3.4	5.7
Loading and location of Green Water	4	2.5	4.4
Ship collision and grounding	5	2.7	4.0
Influence of fabrication techniques on final structural behavior	4	3.2	5.3
B - Integration			
Multi-level process integration	3	3.1	4.6
Integration of engineering analysis into design and development processes	5	5.4	7.2
Model data management and configuration control	4	5.2	6.7
Automation of the structural analysis process	4	4.3	5.7
Extended enterprise interoperability	6	3.1	4.0
Support for a heterogeneous mix of tools/computing platforms	6	3.9	5.0
Use of open standards: e.g. ISO/STEP (AP209,...) W3C/XML, OMG, NCSA/HDF5,...	5	3.7	5.8
Catalogues of parts/components with FEM representation	5	2.7	6.5
Enable access to captured design/analysis experience	5	3.8	4.6
Knowledge based feature suppression	3	4.6	4.6
C – Durability & Life Extension			
Fatigue life prediction & assessment	5	4.6	6.4
Fracture mechanics, crack assessment and residual strength prediction	3	4.0	5.2
Damage/deterioration modeling and assessment	2	3.3	4.8
Reliability and probabilistic analyses	5	3.3	5.0
Creep and related time-dependent phenomena	4	3.5	3.5
Buckling and post-buckling	8	4.1	6.0
Composite materials - characterisation, modeling and assessment	5	4.2	4.7
Modelling and assessment of residual stresses (due to welding, moulding, casting etc)	3	4.0	5.8
Modelling and assessment of welds	4	3.6	5.1

D – Product and System Optimisation			
Application of structural and system optimisation tools	4	3.6	4.8.
Multi-objective optimisation of analysis parameters (shell thickness,	2	3.6	5.3
material property etc)			
Multi-objective optimisation of shape & form	2	3.5	4.4
Use of general purpose optimisation tools for “non-FE” models	1	3.1	3.5
Use of decision support tools for management issues	1	2.9	4.1
Use of decision support tools for design issues	1	3.0	4.6
E – Multi-Physics			
Structure - compressible fluid interaction	3	4.1	4.7
Structure - incompressible fluid interaction	5	6.7	5.6
Coupled analyses for structure/ aero-elastics/ aerodynamics/ acoustics	4	2.7	4.0
Thermo-mechanical interaction and thermo-elastic deformation	7	4.1	4.4
Sheet & plate metal forming	6	2.9	3.3
Welding Processes	5	3.9	4.4
Heat treatment processes	5	3.3	4.1
Contact Analysis	7	3.8	7.1
F - Analysis Technology			
Dynamic (near-) real-time mathematical model test correlation/update	7	3.4	5.1
Support for materials, with respect to Physical Representation	8	4.1	~7
Support for materials, with respect to Failure and damage criteria	4	3.7	6.4
Support for materials, with respect to Links to design tools	4	3.3	5.6
Tools for software parallelisation	8	2.6	4.9
Less memory-intensive codes	8	2.8	5.0
Integration of virtual reality tools & FE	2	2.3	4.2
Specific software for coupling FEA with other techniques	7	2.7	5.5
Automatic Meshing	8	5.1	~8
Adaptive Meshing	6	4.0	6.9

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