A REVIEW OF FEA TECHNOLOGY ISSUES CONFRONTING THE AEROSPACE INDUSTRY

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SUMMARY
This paper presents an overview of needs and requirements for the improvement of engineering analysis for the aerospace industry sector as collected during four years of the FENET project. As much as possible the relative importance of these needs and requirements was quantified, as well as the current state of practice and the technology readiness level.
Almost fifty requirements are listed in tabular form. The most important seem to be in areas of better integration of the engineering analysis practices and tools into the overall design and development process, on guidance and training in best modelling practices, better knowledge of material properties, and then a wide range of more specialist areas like non-linear analysis and probabilistic approaches.

1: APPROACH TO DEFINITION OF INDUSTRY REQUIREMENTS

One of the main tasks of the aerospace industry sector coordinators in the FENET Project was to collect and categorise the engineering analysis needs (requirements) pertinent to aerospace and turn this into a concise overview.

Table 1:Overview of requirement characterisation levels

Level	Technology Readiness Level (TRL)	State of Practice (SoP)	Priority Level (PL)
	How well is the technology developed?	*To what extent is the technology used in practice?*	*How important is the technology for the industrial process?*
0	Not applicable	Not used	No need at all
1	Basic principles observed and reported	Information received	Perhaps nice to have
2	Concept and application of method / algorithm(s) formulated	Evaluation of temporary licence	Nice to have
3	Proof of concept demonstrated for critical aspects of method / algorithm(s)	First trials	Probably useful in some activities
4	Method / prototype tool validated on simple representative test cases	Occasional use	Benefit for some activities, but alternative exists
5	Method / prototype tool validated on comprehensive representative test cases	Regular use	Needed for some activities
6	Method / prototype tool demonstrated on representative 'real world' analysis problems – implemented functionality complete – performance / interfacing solved in principle	Used in some important activities	Needed regularly
7	Method / 'beta-release' tool validated on representative 'real world' analysis problems – implemented functionality, performance and interfacing complete	Used in all development activities	Important, needed in many activities
8	Robust method / tool, routinely used in industrial product development environments – with adequate software problem handling, distribution, user documentation and support	Essential for a successful workflow	Very important, needed in core activities
9	TRL 8, plus method / tool fully integrated in the industrial product development processes	Necessary for design sign off	Essential, the work cannot be done without it

In order to make the specified needs more tangible, and in order to attach some quantitative measure to facilitate selection of research or education topics, we introduced during the first FENET annual industry meeting in Wiesbaden the concept of Technology Readiness Levels, which are an established scale that is used in space industry R&D planning, in particular by ESA and NASA. The FENET members adopted this for all requirements definition and later also State of Practice Levels and Priority Levels were added. The definition of these scales is given in Table 1.
This paper provides a consolidated overview of the requirements for aerospace industry

sector that were gathered and documented over the course of the FENET project and in particular during the four annual industry workshops:

- Wiesbaden, November 2001,
- Prague, December 2002,
- Hamburg, December 2003,
- Lisbon, December 2004.

In addition, a quite extensive industry-side FENET survey was carried out in the autumn of 2002. Out of a total of almost 900 respondents, 135 were from the aerospace sector.

2: ENGINEERING ANALYSIS REQUIREMENTS FOR THE AEROSPACE INDUSTRY SECTOR

The engineering analysis requirements are categorised per the four FENET research and technology development themes:

- Durability and Life Extension
- Product and System Optimisation
- Multi-Physics and Analysis Technology
- Education and Dissemination

The requirements are not taking into account finite element analysis alone, but more in general engineering analysis, including e.g. finite difference, finite volume, lumped parameter analysis methods. The requirements are presented in tabular form. The table were initially constructed from the original set of industry requirements collected during the first year and then gradually refined. Two additional columns were added that contain the response of the aerospace sector respondents regarding their perception of the State of Practice (industrial maturity) and Priority Level for the individual topics. Furthermore, new topics were added as they arose during subsequent years.
Most requirements are derived from the well-established 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.

A major objective of the exercise was to identify potential research and education candidates. If for example a particular issue has a high Priority Level but a low SoP or TRL then this indicates that this is a potential research candidate; e.g. integration of engineering analysis into the design and development process (#14) or enable access to captured design/analysis experience (#29). Obviously, other issues with a low priority and a high state of practice are then unlikely candidates for research. This is extremely valuable information for the research community as it can help to direct their limited resources to those areas, which are vital to the industry.

It is perhaps worth noting that the perceived state of practice as derived from the aerospace sector survey is generally low in comparison to the technology readiness levels estimated. Unfortunately, the survey did not record the position in the supply chain of those who responded. It may perhaps be that many of those who did respond are not as familiar with state of the art technology as the FENET aerospace members (main contractors and agencies) who made the original estimates. It may however also be the case that the state of practice levels are indeed below the original estimates in which case the need for further research and development is greater than originally assumed.

The responses on the aerospace sector survey have been integrated into the requirement tables. The ratings of issues in terms of maturity (state of practice) and priority were taken from the survey. Many survey questions/topics were already addressed in the initial aerospace sector requirements, but also some interesting new issues have however also been identified, e.g. the integration of virtual reality tools and FE and the field of reliability and probabilistic analyses.

The most important topics that were raised at the annual industry meetings in the second, third and fourth years were:

- 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.
- 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, for wide application areas. This was indeed a recurring theme and noted as a universal problem in all FENET industry sectors.

Here after follow the actual requirements in four tables, one for each of the FENET research and technology development themes.

Table 2: Aerospace requirements - theme Durability and Life Extension

#	Engineering analysis requirement	SoP	PL	TRL	Remarks
1	Failure mechanisms of fibre reinforced composite materials	-	-	7	
2	Fracture mechanics/fracture control	4	6	8	
3	Crack propagation and residual strength	4	6	8	More than 15 years of co-operation between ESA and NASA for the development of relevant methodologies and numerical tools, e.g. NASGRO and ESACRACK.
4	Damage/damage tolerance	3	5	3-8	Extension to non-metallic materials and elastic-plastic conditions needed.
5	Support maintenance and upgrades of legacy aircraft - life cycle >30 years	4	6	6	Needs for data integrity and standardisation, long term archiving.
6	Assessment of structural damage: dents, de-laminations, etc.	3	5	7	
7	Determination of stress-intensity-factors (SIF)	-	-	7	FE and BE.
8	P-element method	-	-	8	Tools PROBE, StressCheck and NASTRAN used at ESA.
9	Linking FEM and BEM	-	-	6	Fluid-structure interaction.
10	Integration of tools for structural analysis and life (cycle) analysis, in particular w.r.t. geometry, loads, material property databases, probabilistic analysis	-	8	4	
11	Modelling and assessment of residual stress (due to welding, moulding, casting, etc.)	3	5	5	
12	Modelling and assessment of welds	3	4	4	

Table 3: Aerospace requirements - theme Product and System Optimisation

#	Engineering analysis requirement	SoP	PL	TRL	Remarks
13	Multi-level process integration.	3	5	5	
14	Integration of engineering analysis into design and development processes	5	7	5	Objectives are: More effective, shorter engineering analysis cycles. Support collaborative, concurrent, multi-disciplinary engineering.
15	Model data management and configuration control	5	6	5	Provided by some PDM tools, but integration with CAE tools need to be improved.
16	Automation of the structural analysis process	4	6	5	
17	Extended enterprise interoperability	3	4	5	
18	Simulation of manufacturing processes: cold working, interference fits, sheet metal forming	3	4	7	
19	Non-linear dynamic analysis for impact, crash, bird-strike, etc.	4	6	8	
20	Non-linear static analysis of metallic structures with accurate failure prediction	4	5	6	
21	Widespread industrial application of structural optimisation	4	6	5	
22	Use of legacy models and data	3-7	8	5	Need for better data integrity, open standards, configuration control, meta-data.
23	CAD-to-CAE model idealisation	4	8	5	Need for idealisation benchmarks. Automated simplification and de-featuring of CAD models
24	CAE-to-CAD modification feedback	3	8	2	
25	Support heterogeneous mix of tools/computing platforms	4	5	5	Need for more open standards.
26	Use of open standards: e.g. ISO/STEP (AP203, AP214, AP209,...), W3C/XML, OMG, NCSA/HDF5,…	4	7	4-8	Maturity level depends on used standard and application domain.

#	Engineering analysis requirement	SoP	PL	TRL	Remarks
27	Catalogues of parts/components with FEM representation.	3	4	3	Applied in pilot projects. Needs further development.
28	Capture design / analysis experience	4	7	4	In principle large documented corpus of experience available at ESA and aircraft industry. Some courses are given.
29	Enable access to captured design / analysis experience	4	6	3	Link with knowledge management.
30	Integration of virtual reality tools and FE	2	4	5	
31	Knowledge based pre- and post-processors	3	7	4	

Table 4: Aerospace requirements - theme Multi-Physics and Analysis Technology

#	Engineering analysis requirement	SoP	PL	TRL	Remarks
32	Integration of engineering analysis into design and development processes	5	7	5	Objectives are: More effective, shorter engineering analysis cycles; support collaborative, concurrent, multi-disciplinary engineering.
33	Coupled analyses for aircraft structure aero-elastics/ aerodynamics: acoustics, ditching, etc.	3	5	5	
34	Thermo-mechanical interaction and thermo-elastic deformation	4	5	8	E.g. lightweight aircraft structures, spacecraft payloads, mounting interfaces, re-entry vehicles.
35	Structure – aero-thermodynamics interaction	3	5	8	
36	Structure – aero-acoustics/ compressible fluids interaction	3	4	7	E.g. Ariane-payload coupled loads analysis tool, Xenon tanks,…
37	Structure – aero-thermodynamics - chemical interaction	2	3	6	E.g. aero-engines, launcher and spacecraft propulsion, ablative heat shields, re-entry vehicles.
38	Highly non-linear problems	-	-	6	E.g. tank bladder collapse, large inflatable structures.

#	Engineering analysis requirement	SoP	PL	TRL	Remarks
39	Structure - optics interaction	2	2	6	E.g. spacecraft payload instruments, aircraft awareness/reconnaissance sensors.
40	Structure / micro-wave antenna interaction	2	2	4	
41	Structure / kinematics / control logic	3	4	7	E.g. Deployment of large flexible structures (antenna) with control-loop feedback, robots.
42	Probabilistic Analysis Approach	3	5	5	Tools ASKA RV[1], NASTRAN RV, ST-ORM used at ESA.
43	Dynamic (near-)real-time mathematical model test correlation/update	3	5	4	
44	Contact analysis	5	7	6	
45	Support for advanced materials, w.r.t.:				
45a	physical representation	4	6	4	
45b	failure criteria	4	7	4	composites, ceramics
45c	links to design tools	4	5	4	e.g. ESComp
45d	micro/nano-mechanics / multi-scale	2	4	4	

Table 5: Aerospace requirements - theme Education and Dissemination

#	Engineering analysis requirement	SoP	PL	TRL	Remarks
46	Increase the quality of FE models	4-8	7	N.A.	
47	Means to evaluate FE model quality	5	7	6	
48	Guidelines/standards for creating system simulation models	5	7	4	Standards/best practices under development under ECSS.
49	Standards for mathematical models	3	7	4	Standards/best practices under development under ECSS.

3: CONCLUSIONS AND RECOMMENDATIONS

An extensive collection of engineering analysis requirements for the aerospace industry sector has been established. They have been presented in a simple but effective way that allows for quick identification of the topics that need research and development focus and/or education and dissemination attention.

Some topics should be highlighted because they were found to have a relatively high priority and relatively low state of practice or technology readiness level. These are, in no special order:

- CAE-to-CAD and CAD-to-CAE model transfer.
- Better/deeper integration of engineering analysis into the design and development processes.
- Guidance, tutorials, reference standards on best modelling practices.
- Better material property data for wider ranges of applications.

A number of more specialist topics like failure prediction and (highly) non-linear are mentioned but do not show up prominently, probably because the needs were expressed by a rather generalist audience.

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REFERENCES

FENET — The four years EC Thematic Network on the industrial application of finite element and engineering analysis technology, see http://www.fe-net.org

ACRONYMS

BE(M)	Boundary Element (Model)
CAD	Computer Aided Design
CAE	Computer Aided Analysis
EC	European Commission
ECSS	European Cooperation for Space Standardization (http://www.ecss.nl)
FE(M)	Finite Element (Model)
HDF	Hierarchical Data Format (http://hdf.ncsa.uiuc.edu)
N.A.	Not Applicable
OMG	Object Management Group (http://www.omg.org)
PDM	Product Data Management
PL	Priority Level
SoP	State of Practice
STEP	Standard for the Exchange of Product model data (Casual name for ISO 10303, see http://www.tc184-sc4.org)

TRL	Technology Readiness Level (originally defined by NASA)
XML	Extensible Markup Language (http://www.w3.org/XML)
W3C	World wide web Consortium (http://www.w3.org)

[1] RV is Reliability Version