benchmark

the international magazine for engineering designers & analysts

accelerating design

jan12 e-dition

also in this issue . . . simulation on a smartphone | rocket science
nafems conferences | atmospheric modelling | stress on railway vehicles
nafems.... a growing community | icons of cfd

NAFEMS

benchmark

the international magazine for engineering designers & analysts

Published quarterly by NAFEMS, benchmark is the only truly independent publication geared towards the analysis and simulation community. Read by some of the world's leading organisations, across a wide range of industries, the magazine is truly a benchmark of the community and an essential read for all engineering designers and analysts.

Subscribe Now

I'll spare you the "new year" editorial about the passage of time and looking forward to the coming 12 months. I'll even let you get away without mentioning the Christmas break we've all just come back from. Might skip a discussion on winter weather, and I'm definitely not going to write about new year's resolutions.

Promise.

Right. Now that's out of the way, we can concentrate.

This issue of benchmark includes an article on using a smartphone to run simulation software. Yes, you heard me. Running analysis on your Android-powered device is becoming a reality. Whilst this will obviously never (never say never....) replace supercomputing, it's a development that I'm sure many of us would never have seen coming a few years ago. Yet, it's a mark of just how Moore's Law continues to change the world we live in. What next? NASA mission control being run from someone's kitchen on an iPhone? NNSA being run out of a garage using an array of tablets, netbooks and iPads? The mind boggles. Whilst we're not exactly at that stage (yet!), it's certainly a real-world eye-opener into how quickly technology is developing and how nothing in the world of high-performance computing stays the same for very long.

In November last year, I had the opportunity to sit down and talk to a number of keynote speakers at the Siemens NX CAE Symposium in North Carolina. One of those interviews is included in this issue, and my discussion with Nathan Christensen from ATK Launch System certainly raised a number of interesting points and gave me an insight into the simulation processes at a high-technology company such as ATK. With simulation data management being a topic of much discussion within NAFEMS over the past few years, it was interesting to note that companies as advanced as ATK have the same problems and issues with this as everyone else. The role of NAFEMS in bringing the simulation community together, across industries, to look at how best to manage simulation data, has in my view never been more important. We can all learn from each other, no matter what industry or specialty we focus on, and sometimes looking "outside" our own industries and departments can be the most effective way of finding a solution to long-standing or seemingly impossible problems.

And so, to NAFEMS. It's a busy time at the moment as we prepare for our 2012 regional conference programme. We hope that you'll be able to participate in some of our events this year, as we gear up to give you a number of conferences and events covering topics which are of interest to you and your colleagues. We can't emphasise enough that NAFEMS is YOUR organisation – if you think we need to be looking at certain topics more closely, tell us. If you want us to produce more publications on a certain technical area, tell us. If you think we're doing something right, tell us! Our technical working groups and regional steering groups are busier than ever, which in turn leads to more benefits for our members and the wider analysis community. So the message is the same as ever – get involved.

Let's make 2012 the year you become more active in your community (I KNEW I couldn't make it to the end without saying something like that!).

David Quinn | Editor | david.quinn@nafems.org | twitter.com/benchtweet

Editorial

Editor
David Quinn
david.quinn@nafems.org

Deputy Editor
Nicola McLeish
nicola.mcleish@nafems.org

Design/Production
d2 print
info@d2print.com

Advertising
Paul Steward
paul.steward@nafems.org

Subscriptions
Christine Bell
christine.bell@nafems.org

Membership
For information on membership of NAFEMS, contact Paul Steward on paul.steward@nafems.org

ISSN 0951 6859

Publisher

NAFEMS
Beckford Business Centre
Beckford Street
Hamilton, Lanarkshire
ML3 0BT
UK

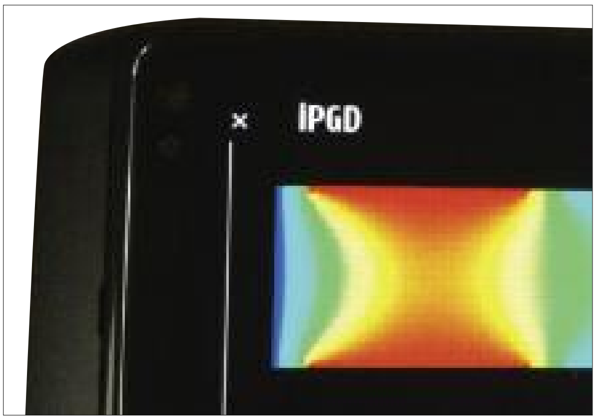
t +44(0)1355 225688
f +44(0)1698 823311
e info@nafems.org

Errors & Omissions: While every care is taken in compiling benchmark, neither the Editors, nor NAFEMS, can be held responsible for the consequences of any errors in, or omissions from, the contents. The views expressed by contributors are their own and all information is accepted in good faith as being correct at the time of going to press. The Editors will not accept any advertisement considered by them to be misleading or otherwise unsuitable for inclusion in benchmark, however, the presence of any advertisement should not be considered to convey or imply any form of commendation by NAFEMS.

benchmark

the international magazine for engineering designers & analysts

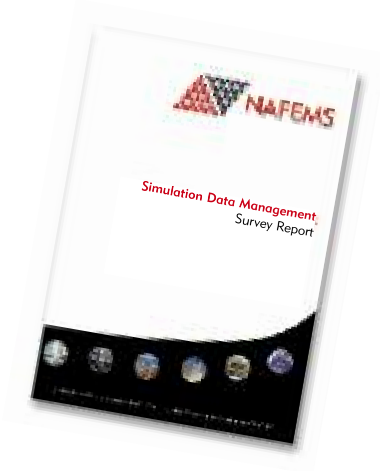
jan12 e-dition



regulars

New Publications from NAFEMS

A number of new books have recently been published by NAFEMS, and will be mailed to our members as part of their member benefits package. These are also now available on the NAFEMS website for non-members to purchase, and for members to purchase additional copies.



Simulation Data Management Survey Report
There is a considerable amount of interest within the NAFEMS community in the emerging technology of Simulation Data Management (SDM). It offers significant potential for impacting the management of data, models, processes, documents and metadata.

The initial work of the Simulation Data Management Working Group was focused on compiling a baseline set of user requirements for SDM. This involved the completion of an industry survey, the results of which are explored within this report.

Further publications aimed at developing a common understanding of what SDM comprises, and explaining how to justify investing in SDM are already nearing completion and will be distributed to you in due course.

Why Do Multi-Body System Simulation?
Multi-Body Simulation (MBS) techniques provide engineers with a way of developing an understanding of complex dynamic systems. They have been successfully used to describe the real-world behaviour of systems in a range of industries such as transportation, industrial machinery, aerospace systems and consumer goods.

MBS has been part of the technology encompassed by NAFEMS for some time, yet this is our first publication dedicated to its application. The purpose of the book is to provide a high-level overview of the methodology, demonstrate through examples how it is used in various industries today, and illustrate the benefits gained from doing so. This introductory book has been written under the auspices of our Education and Training Working Group. Its creation has spawned the recent formation of a new NAFEMS working group dedicated to Multi-Body Dynamics, which now has plans to produce a range of further guidelines dedicated to the subject.

Idealisation of Joints
Components are joined together using a variety of methods. As simulation is now routinely used to assess performance and integrity, it is necessary to represent a variety of joints with an idealisation that represents the stiffness characteristics and allows the recovery of loads for application to more detailed models.

This document provides a synopsis of a NAFEMS seminar on the Idealisation of Joints including a summary of the information that was provided and copies of the papers which were presented.

www.nafems.org/publications

benchmark Survey 2012

We would like to invite you to complete our benchmark and NAFEMS publications survey. Your feedback is extremely important to us so please use this opportunity to tell us what you think of the magazine and other NAFEMS publications.

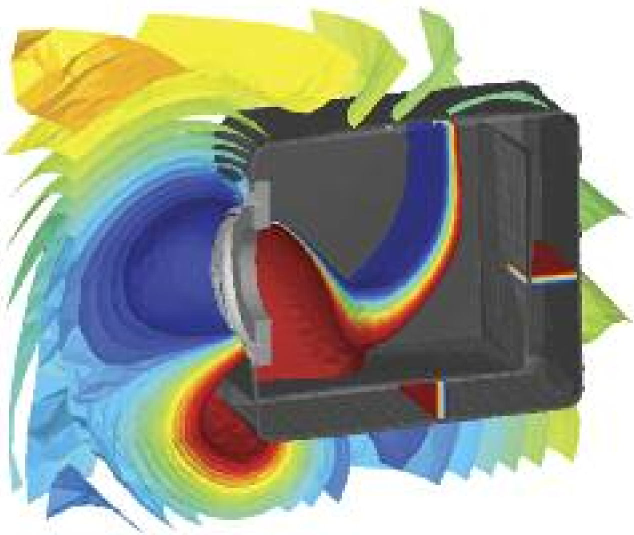
The survey should only take five minutes to complete, and can be accessed from **www.nafems.org/survey**

Date	Event	Type	Location
Mar 20 2012	Introduction au Calcul de Structures, aux Elements Finis et a la Simulation Numerique	course	Paris, France
Mar 20 2012	Practical Introduction to FEA	course	Stratford-upon-Avon, UK
Mar 21 2012	Engineering Optimisation for Industrial Applications	seminar	Gaydon, UK
May 7 2012	Einfuehrung in die praktische Anwendung der Finite-Elemente-Methode (FEM)	training course	Bamberg, Germany
May 8 2012	Practical CFD Analysis	course	Bamberg, Germany
May 8 2012	DACH Konferenz 2012	conference	Bamberg, Germany
May 22 2012	Nordic Conference 2012	conference	Gothenburg, Sweden
May 30 2012	UK Conference 2012	conference	Lincolnshire, UK
Jun 5 2012	France Conference 2012	conference	Paris, France
Jun 6 2012	Introduction au Calcul de Structures, aux Elements Finis et a la Simulation Numerique	course	Paris, France
Jun 19 2012	Practical Introduction to FEA	course	Stratford-upon-Avon, UK
Jun 27 2012	Practical Introduction to Non-Linear Analysis	course	Nottingham, UK
Sep 11 2012	Practical Introduction to FEA	course	Stratford-upon-Avon, UK

www.nafems.org/events

NAFEMS TRAINING

As the only independent, international association dedicated to engineering analysis and simulation, NAFEMS provides a range of training courses which are open to all, in both face-to-face and e-learning formats.



Introduction au Calcul de Structures, aux Elements Finis et a la Simulation Numerique
training course, Paris, France
20 March 2012

Practical Introduction to FEA
training course, Stratford-upon-Avon, UK
20 March 2012

Einfuehrung in die praktische Anwendung der Finite-Elemente-Methode (FEM)
training course, Bamberg, Germany
7 May 2012

Practical CFD Analysis
training course, Bamberg, Germany
8 May 2012

Introduction au Calcul de Structures, aux Elements Finis et a la Simulation Numerique
training course, Paris, France
6 June 2012

Practical Introduction to FEA
training course, Stratford upon Avon, UK
19 June 2012

Practical Introduction to Non-Linear Analysis
training course, Nottingham, UK
27 June 2012

Practical Introduction to FEA
training course, Stratford upon Avon, UK
11 September 2012

New courses and dates are announced regularly – visit
www.nafems.org/training
for full details

Dear CAE Community,

In my last column, I briefly talked about trust and how it relates to CFD[1,2]. I outlined that our primary goal in the (relatively) newly formed CFD group is to have CFD results trusted by others within the vehicle development division, even to the point of equivalency with wind tunnel results. While that is indeed a worthy goal, I think that this idea of trust can be expanded to include other items of note within the world. This certainly applies to the U.S. Congress, which is enduring its worst approval ratings in modern history (in the ~10% range)[3]. This concept of trust also relates to specific topics rather than groups of people. Take global warming for instance[4]: I think that all the "but", "if", and "how about" items brought up by global warming naysayers can all be adequately argued away and it all comes back to trust – or, more specifically, mistrust – in the government[5]. There just seems to be a small, but vocal, group of people that just does not trust "government". Here in the U.S, they just seem to get a disproportionate amount of coverage. That they understand the full implications of this mistrust is not clear; for example, the states that want smaller government receive the most government funding[6].

Anyway (enough of that), these past few months of leading my company's new CFD group have seemed longer than usual – probably having to do with trust being hard to establish, but easy to lose. I think we should be making more progress towards creating better CFD models faster and producing better analysis, but the advancement we're making seems slow. Perhaps it is the Law of Accelerating Returns in action, which states that technological progress occurs exponentially instead of linearly[7]. While most take this as meaning that each new advancement enables several higher advancements instead of just one higher advancement, and concordantly, every year, more useful inventions and discoveries are made than were made in the last[8], to me, however, this means that people – including me – tend to overestimate the near-term benefits, or progress, of some new procedure or method. Think of the copier or the personal computer. In the early days of their usage, both struggled to gain wide acceptance; probably to the dismay of their inventors/producers. Now, however, both are so ubiquitous that it is impossible to imagine modern society without them and I would judge that their penetration into society is well beyond the imagination of those initial inventors/producers. To me, this means I just need to stay the course and keep planning for the future, whether near-, mid-, or far-term.

In other news: it looks like I will be moving again – as in changing desk locations. We have decided to re-organize at the division level and pair like-minded groups under the same management. Not wanting to waste a crisis, our manager decided to restructure the aero-thermal department, but I was able to hold on to the fledgling CFD group in its current form – I mean, we've only been at this a few months and we'd lose everything if we got swallowed up a larger management structure. I will be going back to the same size/type desk that I had before – with a newer, bigger, badder workstation under my desk and so I will probably need to revive my thermal mitigation apparatus[9]. Nevertheless, with this new management structure, it looks like we'll have to break in some new people to our way – the CAE/CFD way – of thinking. I'll let you know how it goes in future columns.

What are your thoughts on any of this? Drop me an e-mail at: **thecaeguy@nafems.org**

-The CAE Guy

References

[1] "The CAE Guy", Benchmark, NAFEMS, October 2011

[2] My Dad – an avid CAE Guy reader – also pointed out that "Trustworthy" is the first Boy Scout Law, http://usscouts.org/advance/boyscout/bsoathlaw.asp

[3] "Congress Approval Rating Lower than Porn, Polygamy, BP Oil Spill, 'U.S. Going Communist'", The Huffington Post (on-line), November 15, 2011.

[4] I think the statement that global warming is actually pretty much settled; whether it is caused by people is the current battle front.

[5] This is my humble, but informed, opinion: It would be too long, and well beyond the scope of this forum, to outline this in its entirety. You'll just have to trust me on whether this is, indeed, possible or not.

[6] "Federal Taxes Paid vs. Federal Spending Received by State, 1981-2005", The Tax Foundation, October 19, 2007, http://www.taxfoundation.org/research/show/22685.html

[7] The Singularity is Near, Kurzweil, R., Penguin Books, 2005. "http://www.singularity.com/" http://www.singularity.com/

[8] http://en.wikipedia.org/wiki/The_Singularity_Is_Near

[9] "The CAE Guy", Benchmark, NAFEMS, July 2008

ONE

ASSOCIATION

1000 MEMBER ORGANISATIONS

Find out about membership today

NAFEMS

www.nafems.org

Interactive Simulation on a Smart Phone

E. Cueto, Universidad de Zaragoza, Spain
A. Huerta, Universitat Politecnica de Catalunya, BarcelonaTech, Spain
F. Chinesta, EADS Corporate Foundation Chair, Ecole Centrale de Nantes, France

Traditionally, Simulation-based Engineering Sciences (SBES) made use of static data inputs to perform the simulations. Namely parameters of the model, boundary conditions, etc. were traditionally obtained by experimentation and could not be modified during the course of the simulation. More recently, large efforts have been invested in developing dynamic data-driven application systems (DDDAS): systems in which measurements and simulations are continuously influencing each other in a symbiotic manner. It should be understood that measurements should be incorporated in real time to the simulations, while simulations could eventually control the way in which measurements are done.

F. Darema in a NSF workshop on this topic coined the term Dynamic Data-Driven Application System in 2000. The document that initially put forth this initiative stated that DDDAS constitute "application simulations that can dynamically accept and respond to 'online' field data and measurements and/or control such measurements. This synergistic and symbiotic feedback control loop among applications, simulations, and measurements is a novel technical direction that can open new domains in the capabilities of simulations with a high potential pay-off, and create applications with new and enhanced capabilities. It has the potential to transform the way science and engineering are done, and induces a major beneficial impact in the way many functions in our society are conducted, such as manufacturing, commerce, transportation, hazard prediction/management, and medicine, to name a few" [1].

A crucial aspect of DDDAS is that of real-time simulation. This means that the simulations must run at the same time (or faster) than data are collected. While this is not always true (as in weather forecasting, for instance, where collected data are usually incorporated to the simulations after long time periods), most applications require different forms of real-time simulations. In haptic surgery simulators, for instance, the simulation result (i.e., forces acting on the surgical tool) must be translated to the peripheral device at a rate of at least 500 Hz, which is the frequency of the free hand oscillation. In other applications, such as some manufacturing processes, the time scales are much bigger, and therefore real-time simulations can last for seconds or minutes.

A new generation of simulation techniques, ***Proper Generalized Decomposition*** (PGD), has received an increasing level of attention by the SBES community. Because it empowers SBES with fast simulations able to cope with uncertainty, multiscale phenomena, inverse problems and many other

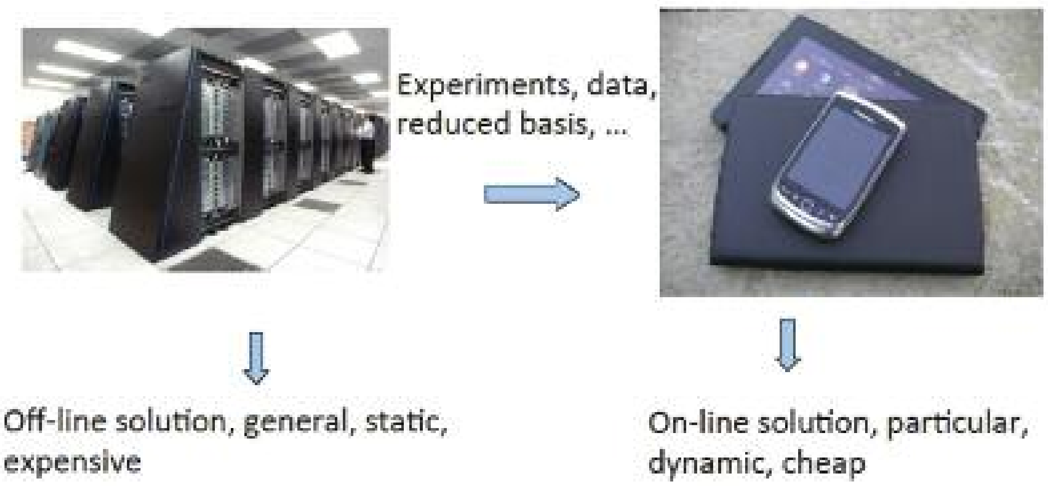


Figure 1. "Off-line" solution of a general enough parametric model and "on-line" particularization of such a general solution in a particular context. Source: http://es.wikipedia.org/wiki/Archivo:UPM-CeSViMa-SupercomputadorMagerit.jpg

features that will be discussed. PGD was initially introduced in multidimensional models encountered in science and engineering [2] and was then extended to address general computational mechanics models.

What really constitutes a novelty about the PGD method is its ability to construct ***physics-based meta-models without the need for any prior computer experiment.*** These meta-models are then used to perform real-time simulations for which very light computing platforms are enough. The so-called deployed platforms (smartphones, tablets) are often enough to equip engineers with a powerful tool to analyze complex problems and take decisions in very short lapses of time, as will be demonstrated.

Imagine for example that we are interested in solving the heat equation but the material's thermal conductivity is not known, because it has a stochastic nature or simply because no experimental measures are available. Three possibilities arise: (i) wait to know the conductivity before solving the heat equation (a conservative solution); (ii) solve the equation for many values of the conductivity (a sort of Monte Carlo method); or (iii) solve the heat equation only once for any value of the conductivity. Obviously the third alternative is the most appealing one. To compute this quite general solution it suffices to introduce the conductivity as an extra independent coordinate, taking values in a certain interval and playing a similar role as standard space and time coordinates. Thus, by solving only once the resulting multidimensional thermal model, the most general solution is computed; that is, a solution that produces at each physical point and instant the value of the temperature for any value of the thermal conductivity.

This approach is feasible and, as shown below, the results are promising. Note also that many other extra-coordinates can be accounted for: source term, initial conditions, boundary conditions and even the domain geometry. Thus, moving loads in structural mechanics, geometrical parameters

Figure 2. The PGD-based application is able to determine the optimum values for working temperatures in the pultrusion furnace and provides a color map of the temperature field. In the event of malfunctioning values (a heater is broken, for instance), thermocouples will send a signal to the pone to indicate that they are registering non-optimal temperatures. The following step, determines which heater is not working well, by solving, always in real-time, the corresponding inverse problem. Once it is identified, the working temperature of the "healthy" heaters should be optimized again (bottom left figure) to allow the furnace to continue working in the presence of a broken heater. The resulting optimized temperature field in the case of one malfunctioning heater is shown in the bottom right figure.

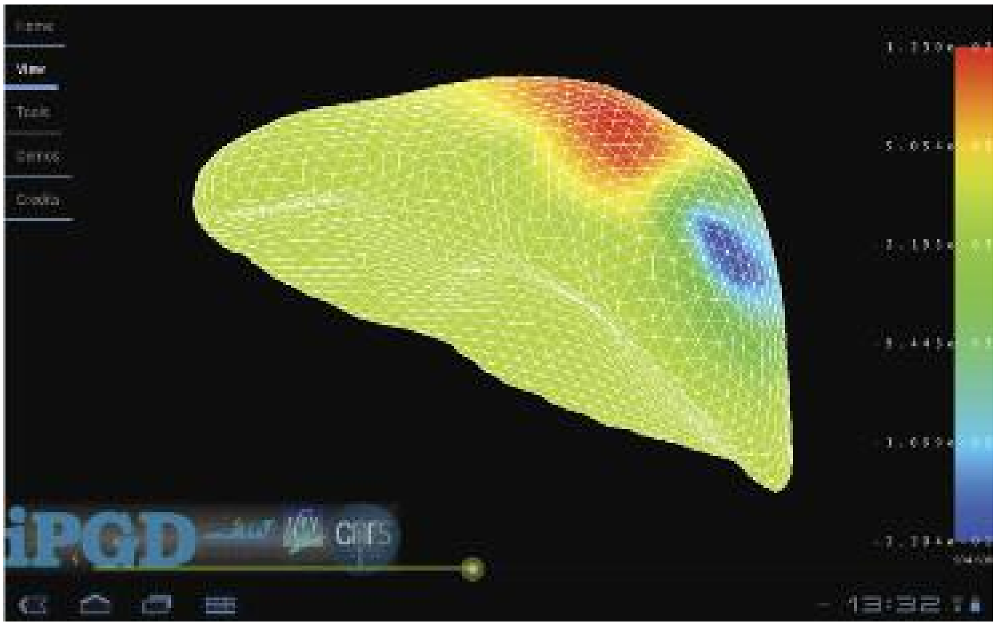


Figure 3. A PGD model of a human liver running in real time on a Motorola Xoom tablet under Android 3.0. The user can perceive not only the anatomy of a particular patient, but deform it in real time by simply touching in the screen. This same architecture could eventually be linked to haptic devices to construct surgery simulators.

in shape optimization, material parameters in material characterization, boundary conditions in inverse analysis or process optimization, etc., can be treated as extra-coordinates to compute off-line multidimensional parametric solutions that could then be used on-line, running in real time. These general solutions computed off-line could be introduced in very light computing devices, as for example smartphones, opening an unimaginable field of applications that Figure 1 caricatures. This methodology constitutes, in the authors' opinion, a new paradigm of real-time simulation.

PGD techniques are designed to preclude the "curse of dimensionality". That is, high-dimensional problems become non-computable because the number of degrees of freedom in a model grows exponentially with the number of dimensions of the space! A separated approximation of the unknown function reads:

$$u(x_1, x_2, \ldots, x_d) \approx \sum_{i=1}^{m} X_i^1(x_1) \cdot X_i^2(x_2) \cdot \ldots \cdot X_i^d(x_d)$$

where each x_i constitutes a coordinate, not necessarily physical. For instance, as referred earlier, conductivity of a material, if it is unknown, can be seen as a new coordinate. This constitutes no more than a generalization of the method of separation of variables to solve partial differential equations. Note that functions x_i^j unknown and must be determined. They are obtained off-line by means of the weak form of the problem (principle of virtual work). The price to pay is that now the problem is non-linear even if the original one was linear. However, it is solved only once and off-line. The resulting solution is precisely the desired meta-model that can be used on-line with the required speedup to obtain real-time response.

This methodology enables, for instance, the control of industrial processes like pultrusion, and even to identify malfunctioning and decision making with the help of optimization tools that run in real time. In order to determine optima in the solutions there is no more the need to perform really complex and repetitive simulations; now the solution is known for all parameter values, physical position and time instant, and it can be conveniently stored in separated form in our smartphone. Figure 2 illustrates the use of a Nokia phone to control a pultrusion equipment in the event of a breakdown of some of the heaters.

This same framework can be applied in a variety of fields. For instance, for surgery planning, complex anatomical deformable models can be handled in real-time by surgeons, allowing them to have accurate information to take decisions prior to practicing surgery (see Figure 3).

As can be noticed from the above examples, PGD methods open unimaginable possibilities in the field of DDDAS. We continue exploring the capabilities, and also the possible limitations, of this new generation of numerical simulation techniques that can revolutionize the way we think of simulation based engineering sciences.

Acknowledgements

The authors wish to thank all their students and collaborators, who did the most important part in the work here presented: Icíar Alfaro, Felipe Bordeu, Chady Ghnatios, David González, Adrien Leygue, David Modesto, Siamak Niroomandi, Françoise Retat-Masson, …

References

[1] F. Darema, Engineering/Scientific and Commercial applications: differences, similarities, and future evolution, Proceedings of the Second Hellenic European Conference on Mathematics and Informatics. HERMIS, vol. 1, pp. 367-374, 1994.

[2] A. Ammar, B. Mokdad, F. Chinesta, R. Keunings, A new family of solvers for some classes of multidimensional partial differential equations encountered in kinetic theory modeling of complex fluids, J. Non-Newtonian Fluid Mech., 139, 153-176, 2006.

[3] Ch. Ghnatios, F. Masson, A. Huerta, A. Leygue, E. Cueto, F. Chinesta. Proper Generalized Decomposition Based Dynamic Data-Driven Control of Thermal Processes. Computer Methods in Applied Mechanics and Engineering, to appear, 2011.

ONE

VISION

300 TECHNICAL GROUP PARTICIPANTS

Find out about membership today

NAFEMS

www.nafems.org

Rocket Scie

At the recent Siemens NX CAE Symposium, held in Charlotte, NC, USA, benchmark took some time to speak to Nathan Christensen of ATK Launch Systems about their analysis processes, and use of simulation.

Nathan joined ATK as a design engineer in composite structures, designing and analyzing missiles and rockets. He spent a significant portion of his 28-year career working with PLM/CAD/CAE and computational tools for design and analysis. Christensen is one of the technical founders of ATK's PLM system, which now manages hundreds of thousands of pieces of product and engineering information used at ATK facilities across the US. He has published numerous technical articles and papers on rocket motor design and analysis, CAE tools and computational methods. He also holds a patent for hybrid pressure vessels.

Christensen was first appointed manager of the CAE group in 1992, with responsibilities for engineering computational tools and methods. In his current position as manager of Engineering Tools and Analysis group, his responsibilities include PLM/CAD/CAE tools, trend analysis, rocket motor performance databases, analytical methods and software development, reliability engineering and high-performance computing.

Background image courtesy of ATK Launch Systems. Nathan Christensen photographed by Branco Liu, Siemens

How do you benchmark your use of simulation compared to other organizations?

Traditionally we review our work with our customers, prime contractors and joint venture partners – comparing tools, methods and approaches with their technical people. More recently, we've been working with several different partners, like GM and Northrop Grumman to benchmark inside and outside of our business sector. Through organizations like Siemens PLM World, we have made cross-industry contacts that are interested in sharing best practices and in benchmarking. By benchmarking ourselves, we have adopted a strategy to understand and apply cross-industry best practices to improve what we do in our own business sector.

We are under a lot of cost pressure internally to do more with less. Both the US economy and government spending is down substantially in certain areas of aerospace. The challenge for ATK is to produce the same great products for less money or produce improved products for the same price.

We've done benchmarking with GM, Ford, Lockheed, and Northrop Grumman. It's been great working with GM since we're not in the same industry. That's one reason GM is participating too. Since we don't compete in the same market space, we can share more openly than we would with a competitor in our own market sector. GM was looking to non competing industries to share and benchmark themselves. We thought that was a great idea, and we've started doing quite a bit of that too.

So this cross-industry cooperation and discussion must really help you drive your processes forward?

I think that it does; I think it gives us a different perspective. Sometimes it's easy to get too comfortable in your own processes and in accepted practices in your own industry sector. Looking across industry certainly has made us think more about the processes we use. I think that historically aerospace has focused primarily on performance and safety. Cost and efficiency has taken a back seat. These days, we are using tools like value stream mapping and Toyota production system to improve our cost and efficiency.

It's interesting to see that race shops like Joe Gibbs Racing are making part and system changes in a week that would take aerospace a year or more to implement. I think that there is a lot to be learned when we share ideas and methods across industries.

It seems like aerospace has always been at the forefront of analysis and simulation. Things start with aerospace and then falls down to automotive etc etc?

You're right, we in aerospace have been using numerical simulation since the beginning. Automotive has really leveraged that development and expertise from aerospace. What has changed from the early days is that analysis and simulation has become much more trustworthy. People are using it for things we never even dreamed of before. Things like golf clubs, recreation equipment, consumer packaging, and high speed machines used to make consumer goods like Pringles potato chips, diapers or shampoo.

So how has simulation changed what you do over the time you've been using it?

I think the biggest change is the acceptance of simulation. A major simulation project I was involved in early in my career was the Space Shuttle Challenger failure in 1986. During the failure investigation and subsequent redesign, we relied heavily on simulation to understand the O-ring seal and joint failure mechanisms that are attributed to causing the Challenger disaster. At that time, simulation was only accepted when accompanied with significant validating physical tests. Today, analysis leads physical testing. Our customers demand that we run extensive simulations and predict exactly what the physical testing will show prior to testing. When we run a multi-million dollar test, they don't want any surprises. If our simulations don't predict exactly what is going to happen in the physical tests -- it's a bad day for our Engineering team.

When I first started as an engineer, analysis was "nice to have" but it wasn't really a trusted source or even viewed as necessary for design sign-off. Physical tests were the final word and were required for design validation. Today, we wouldn't dream of coming to a critical design review with our customers, without an array of simulation models and results.

Nowadays, we have to predict what the test is going to do with a high degree of integrity well in advance of the test. We have to understand and share with our customers, exactly what the test results will be. If we don't match up with test results, all kinds of issues, problems and questions will ensue. For example, we conducted a large solid rocket motor booster ground test about a year ago where we had some problems with a test controller. It took weeks to simulate the issue, resolve the controller issues and reschedule the test.

Our business has become extremely risk averse and simulation is a key technology. In a lot of our designs, we have to predict, within a very narrow margin, what testing is needed and what it is going happen. If we don't, it's back on us: what's wrong with the analysis, what went wrong with the test, and what didn't you understand?

So what's changed? Historically testing was the final word; now testing is just the final step in the part certification process. ATK customers are very demanding. NASA is extremely demanding in that area, and if we don't hit our predictions right on, then there is a lot to explain. We're very careful with our analyses, and we do a lot of subscale testing to make sure we correlate our models. We'll conduct a static motor ground test, sometimes recording 200-300 channels of data. We're actually looking at accelerometers, strain gauges and pressure transducers trying to match everything we've already predicted in simulations then correlate our models to make sure our simulation is right.

We recently completed and test fired the Orion Multi-Purpose Crew Vehicle launch abort motor. The reverse thrust motor with nozzles at the head end of the motor was a concept first demonstrated by the Russians, but this was the first time it's been demonstrated on a US space program. It is an interesting design aimed at accomplishing two things: 1) re-locate the pressure center and center of mass in a manner that increases aerodynamic stability and 2) move the rocket motor exhaust and heat from the nozzle as far away from the crew capsule as possible. This design is a substantial variation from the Apollo launch abort systems, which used aft thrust nozzles and produces substantially less thermal load on the crew capsule.

This first use on a US space program was correct on the first test firing. In this very complex rocket firing, we hit all of our simulation predictions within a few percent. Our customers including NASA were very impressed.

So now you're involved in using multi-physics simulations?

Yes, we routinely do a lot of multi-physics analyses that we didn't do even 10 years ago. We regularly couple fluid flow, thermal and structural analyses. This is done either as loosely coupled (a manual method where results from one discipline fed as input to the next) or tightly coupled (an automated method where solvers iterate and converge on a multi-physics based solution with minimal intervention). We use commercial off the shelf and internally developed solvers with internally developed solver coupling software to perform multi-physics analyses.

For example, today we regularly analyze fluid-structure interactions (FSI) in solid propellant grain (shape) design. A typical design concern we regularly analyze with FSI is "bore choking". In a solid rocket motor, the solid fuel typically has a center perforation (hole) down the full length of the motor. When the motor ignites, the entire surface is burning from the center radially outward until all of the fuel is consumed. The expanding gases travel along the center bore and exit the nozzle to create the thrust that propels the rocket. If not designed properly, exiting gas creates a structural load closing down the center bore resulting in an overpressure that can cause the rocket to explode catastrophically. That's just one of the typical multi-physics simulations we routinely run today in our design and analysis process.

So what software do you use for this?

We typically use a combination of commercial off the shelf software coupled with internal software. In the aforementioned bore choking example, SIMULIA's Abaqus and Ansys's Fluent commercial codes are coupled with an ATK internally developed FTSI (Fluid-Thermal-Structural Interaction) code called FEMBuilder. We term this analysis method "tightly coupled" even though the physics is not integrated into a single solver, because the computational interactions are largely handled automatically by the FTSI code. We're also using other commercial codes like NX NASTRAN, NX Thermal, NX Simulation, Hypermesh, Optstruct, Ansys, iSight, ADAMS and MATLAB in multi-physics simulations. We generally try to use commercial software wherever we can and only develop internal code when we can't find adequate or advanced capabilities commercially. Since much of our design and analysis work is export controlled or restricted by ITAR (International Traffic in Arms) regulations, we use numerous government and internally developed software for multi-physics work.

Other ATK internally developed software includes HERO (thermal/ablation solver) CaseBuilder (composite design/analysis), SHARP (fluid flow) and RECESS (propellant ballistics).

We have benchmarked a few commercial integrated solver multi-physics packages in the past, but they didn't work out as well for us. Perhaps future versions will do better. I think these types of packages are getting there, put I think it's a little bit premature for the level of sophistication and complexity that we need. Generally speaking, I think an integrated solver is will be easiest to use, they just lack the sophistication needed for complex interactions.

What about data management?

ATK is using Siemens Teamcenter Enterprise and Teamcenter Unified suites for PLM. We've been using PLM for nearly 30 years and have a very mature implementation. We are long time Tc Enterprise customers migrating to Tc Unified. Tc Unified is our 6th generation PLM system. ATK is an agglomeration of smaller aerospace companies which have been united under the ATK brand. This legacy brings challenges in managing and uniting business processes under a single PLM system. ATK PLM manages 5 CAD standards with the Teamcenter suite – (NX, Catia, Pro/E, AutoCAD and Solidworks). PLM at ATK manages the full gambit of product and process data including procurement, design, simulation, manufacture, inspection, test and refurbishment.

PLM is implemented at more than half of ATK's 60 sites in the US. PLM is administered through a corporate Center of Excellence (COE). The COE model minimizes development time and the necessary investment. ATK sites act as individual profit centers and are sometimes hesitant about making investments in PLM. We find that when sites are hesitant to implement PLM it's because they don't understand the business benefits. PLM is very complex. It takes time, but people get on-board once they understand it and see the benefits.

David Quinn

NAFEMS DEUTSCHSPRACHIGE KONFERENZ '12

8. – 9. MAI | BAMBERG, DEUTSCHLAND

BERECHNUNG UND SIMULATION – ANWENDUNGEN, ENTWICKLUNGEN, TRENDS

Die Welt steht derzeit vor wahrhaft globalen Herausforderungen. Die ökologischen Wandlungen mit nicht abzusehenden Folgen, die Suche nach neuen Energiequellen und ein schier unbegrenztes Wachstum der Erdbevölkerung erfordern auf allen Gebieten die Bereitschaft, neue Wege zu gehen.

Diese gravierenden Veränderungen führen auch zu neuen Herausforderungen im Ingenieurbereich und verlangen nach Entwicklung und dem Einsatz neuer Technologien. Eine große Chance bieten Simulationsverfahren, die sich aufgrund der rasch fortschreitenden Leistungsfähigkeit von Computern und dazugehörender.

Anwendungssoftware an vielen Stellen etabliert und den Nutzeffekt überzeugend bewiesen haben. Der Fortschritt dieser Verfahren erlaubt es, immer genauere Ergebnisse zu liefern und immer stärker in Design-Entscheidungen einzugreifen.

Die Finite-Element-Methode ermöglicht es, beispielsweise die Lebensdauer dynamisch beanspruchter Bauteile zu prognostizieren, aber auch das Crashverhalten komplexer Fahrzeugstrukturen. In Verbindung mit immer schnelleren Rechnern können verlässliche Aussagen zu.

Strömungsphänomenen, z. B. für die Auslegung von Windkraftanlagen, gewonnen werden.

Schwingungseigenschaften und akustische Effekte spielen beim Betrieb von Maschinen eine wesentliche Rolle; mittels des Einsatzes von Finite-Element-Verfahren und Mehrkörpersystemen können diese immer besser analysiert und beherrscht werden. Stark in den Vorder-grund gerückt sind infolge aktueller Anforderungen Simulationen von elektromagnetischen Effekten. Die angeführten Methoden können gekoppelt werden, um die Wechselwirkung zu simulieren, wodurch eine weiter verbesserte Aussagekraft erreicht wird.

Auch für die Fertigungsvorbereitung spielt die Computersimulation eine bedeutende Rolle, z. B. für Ur- , Umform- und Fügeprozesse. Die Medizintechnik ist ein weiteres Gebiet, in dem diese numerischen Verfahren in immer stärkerem Maße einsetzt werden.

Im industriellen Umfeld muss die Simulationstechnologie in die Arbeitsprozesse integriert werden. Die Arbeitsabläufe müssen so gestaltet sein, dass die für die Berechnungen benötigten Informationen (Geometrie, Belastungen, Material usw.) aktuell und zeitgerecht verfügbar sind. Eine wesentliche Voraussetzung dafür sind sorgfältig festgelegte Prozesse, die die Schnittstellen zu CAD, zu den Analyse- bzw. Auswerteverfahren und den Testergebnissen berücksichtigen. Eine besondere Bedeutung kommt dabei dem Datenmanagement zu.

Mit der Konferenz bietet NAFEMS eine Plattform, auf der neuen Techniken und Tools präsentiert werden sollen und den Teilnehmern die Möglichkeit geboten wird, auf breiter Basis erfolgreiche Anwendungen und Trends mit Spezialisten aus Forschung und im besonderen Maße aus der Industrie zu diskutieren.

Erwünschte Beiträge

Beiträge, die interessante oder beachtenswerte industrielle Anwendungen, Weiterentwicklungen in der Technologie oder Theorie, zur Sicherung der Ergebnisqualität, zur Verbesserung des.

Datenmanagements und der Systemintegration sowie zur Verbesserung der Aus- und Weiterbildung auf diesem Gebiet beinhalten, werden zu folgenden Themenkreisen erbeten:

- **Strukturmechanik**
- **Strömungsmechanik**
- **Elektrotechnik**
- **Akustik**
- **Multiphysik**
- **Werkstoffe**
- **Stochastik**
- **Optimierung**
- **Schnittstellen im CAE-Prozess**
- **Simulation von Fertigungsprozessen (Urformen, Umformen, Verbinden, ...)**
- **Aus- und Weiterbildung**
- **High Performance Computing (HPC)**

Wir freuen uns auf Ihren 1/2-seitigen, deutschsprachigen Titel + Abstract per e-mail an info@nafems.de bis zum **1. Februar 2012**

Nach Festlegung der Agenda erhalten Sie eine entsprechende Bestätigung. Für den Tagungsband benötigen wir ein "Extended Abstract" von typischerweise 2 - 4 Seiten in deutscher Sprache.

NAFEMS

www.nafems.org/dach2012

NAFEMS NORDIC CONFERENCE '12

22 – 23 MAY | GOTHENBURG, SWEDEN

ENGINEERING SIMULATION: BEST PRACTICES, NEW DEVELOPMENTS, FUTURE TRENDS

The NAFEMS NORDIC Conference 2012 will be held at the Radisson Blu Scandinavia Hotel in Gothenburg on 22-23 May 2012. Entitled "Engineering Simulation: Best Practices, New Developments, Future Trends", the conference will give delegates an unrivalled independent insight into best practices and state-of-the-art technologies which consequently demonstrate upcoming trends, tendencies and the necessary future needs in FEA, CFD, MBS and associated technologies.

The two-day conference aims to increase awareness and provide a discussion forum for topics that are important and relevant to engineering industrialists and academics.

If you are an analyst, engineer, team leader or manager that has a responsibility for ensuring that a fit-for-purpose engineering solution is obtained from the use of modern simulation software, then you should attend.

The event is open to both members and non-members of NAFEMS, with members with sufficient remaining credits being able to attend the event for free, as part of their membership benefits package.

Call for Presentations

The NAFEMS NORDIC conference will include keynote speakers, exhibitions, and breakout sessions.

You are invited to submit an abstract (by e-mail to nordic@nafems.org) exploring the following subjects:

- **Structural mechanics**
- **Computational fluid dynamics (CFD)**
- **Electric / electronics**
- **Acoustics**
- **Heat transfer / thermal**
- **Multi-physics**
- **Materials**
- **Stochastics**
- **Optimization**
- **Robustness and confidence of analysis results**
- **Interfaces in CAE Processes**
- **Simulation of manufacturing processes**
- **Education and training**
- **High performance computing (HPC)**
- **Software development**

Abstracts of 300-600 words should be submitted for consideration by **13 February 2012**

Abstracts must be marked with the author's name, organisation, address, fax, phone numbers and email address. If you intend to submit an abstract, please send it by email to nordic@nafems.org.

Authors whose abstracts are accepted will be asked to prepare an extended abstract (typically 1-2 pages) and a PowerPoint presentation. Full written papers will not be required.

Sponsorship and Exhibition Opportunities

We would like to extend an invitation to your company to be part of the NAFEMS NORDIC Conference 2012. There are several outstanding opportunities available for your company to sponsor or exhibit at the conference, giving you maximum exposure to a highly targeted audience of delegates, who are all directly involved in simulation, analysis, and design. Please request further information via nordic@nafems.org.

NAFEMS www.nafems.org/nordic2012

NAFEMS UK CONFERENCE '12

30 – 31 MAY I **GRANTHAM, UK**

ENGINEERING SIMULATION: REALISING THE POTENTIAL

Simulation has the potential to transform a company's engineering processes – providing unprecedented insight into product performance and inspiring innovation by allowing novel concepts to be explored and evaluated.

NAFEMS, the independent association for the engineering analysis community, is holding its UK conference during 30-31 May 2012 with the primary aim of helping attendees realise the full potential of their engineering simulation and analysis. The 2012 NAFEMS UK Conference will explore the extent to which this potential has now been realised, and what more can be achieved.

The two day conference will focus on existing best practices as well as state-of-the-art FEA, CFD and associated technologies – ensuring delegates receive a fully comprehensive overview of the technology available to them. The conference intends to increase awareness and provide a discussion forum for topics that are important and relevant to engineering industrialists and academics, with an educational theme throughout.

Following on from the extremely successful 2010 conference, the 2012 event will certainly be the UK's leading event on simulation technology aimed at the engineering analysis community – bringing together leading industrial practitioners, consultancies, academic researchers and software developers in a neutral forum.

NAFEMS

www.nafems.org/uk2012

Conference Themes

- Design Driven by Simulation
- Pioneering Simulation Technology and Application
- Engineering Analysis, Verification and Validation
- Simulation Adding Value to Business

Why Should I Attend?

The conference will be of interest to all analysts, engineers, team leaders and managers who have a responsibility for ensuring that a fit-for-purpose engineering solution is obtained from the use of modern simulation software. Those involved with the manufacturing and design process at any level will benefit from attendance.

The event is open to both members and non-members of NAFEMS.

Attendance is free for NAFEMS members, subject to sufficient remaining seminar credits.

Venue

The 2012 UK Conference will be held at Belton Woods in Grantham. Being in the heart of the UK, the conference is easily accessible from anywhere in within the UK and Europe.

Sponsorship & Exhibition

We would like to extend an invitation to your company to be part of the NAFEMS UK Conference 2012 – Engineering Simulation: Realising the Potential.

There are several outstanding opportunities available for your company to sponsor or exhibit at the conference, giving you maximum exposure to a highly targeted audience of delegates, who are all directly involved in simulation, analysis, and design.

As the only International Association for the Engineering Analysis Community, NAFEMS is the leading independent source of information and training for engineering analysts and designers at all levels. Sponsors and exhibitors will have the chance to promote their participation prior to the event through the various sponsorship packages on offer. Your participation in this conference will provide a positive impression of your company's commitment to best practices in the area of engineering simulation. The NAFEMS UK Conference provides an excellent opportunity for promotional and product/project awareness, and direct access to technology leaders.

A Unique Opportunity

The NAFEMS UK Conference presents a unique opportunity by providing a forum where all individuals, worldwide, can represent their solutions in a single location to a large number of potential clients, and collaborate with other vendors in this field. What better way to justify your support of this event?!

The exhibition area will be central to the conference itself, ensuring that there is a consistent level of traffic at all times, giving you the chance to meet as many of our delegates as possible.

In addition, this year we will be offering exhibition passes where delegates will not be required to pay for the full conference and attend any presentations, and can register to visit the exhibition area only.

To view all of the sponsorship and exhibition opportunities available, please visit www.nafems.org/uk2012

PRINCIPAL SPONSOR

MSC Software

ADDITIONAL SPONSORS

Altair   ITI TranscenData

NAFEMS   www.nafems.org/uk2012

NAFEMS FRANCE CONFERENCE '12

6-7 JUIN | **PARIS, FRANCE**

SIMULATION NUMÉRIQUE: MOTEUR DE PERFORMANCE

Appel à communications

Technologies | Méthodologies | Applications | Études de cas

LE Congrès de référence pour la communauté simulation numérique industrielle en France

Un évènement qui vous concerne

Le Congrès NAFEMS s'adresse à tous les ingénieurs, concepteurs, scientifiques, managers et décideurs exerçant une responsabilité dans le choix, la mise en œuvre et l'utilisation performante des outils de simulation numérique dans l'entreprise.

Le congrès est centré sur vos besoins et s'attache à favoriser les échanges productifs industrie–recherche–offreurs. Une occasion unique de découvrir, approfondir, confronter et débattre de vos problématiques de simulation numérique dans un contexte neutre et résolument professionnel.

Le programme et les thèmes du congrès traitent de l'état de l'art et des tendances en matière de technologies, de méthodologies et de bonnes pratiques de simulation numérique.

Études de cas, témoignages d'experts, débats et échanges informels permettront à chaque entreprise de mieux cerner l'impact de la simulation numérique sur son innovation, sa performance et sa compétitivité

Une opportunité unique de contacts et de progrès pour chaque entreprise

Pour soumettre une proposition, merci d'envoyer un titre et un résumé de 300-600 mots avec vos coordonnées détaillées (auteur, société/organisation, adresse, téléphone et email) à fr2012@nafems.org

Merci de sélectionner également la ou les rubriques dans lesquelles votre présentation peut s'insérer.

NAFEMS

www.nafems.org/fr2012

Thèmes du Congrès

Le congrès NAFEMS offre à chaque ingénieur et chaque entreprise l'opportunité de valoriser ses travaux et son savoir-faire auprès de la communauté industrielle dans un contexte neutre et hautement professionnel.
Toutes les propositions de communication sont bienvenues et seront étudiées avec soin.

Méthodologies et bonnes pratiques

- **Conception pilotée par la simulation**
- **État de l'Art des Technologies et Applications**
- **Benchmarking, V&V, Confiance dans la Simulation Numérique**
- **Optimisation, Conception Robuste**
- **Éducation, Formation, Gestion des Compétences, Coopération Industrie Recherche**
- **Impact Industriel de la simulation numérique, Processus Qualité**

Technologies et domaines d'étude

- Matériaux (Composites, Matériaux hyperélastiques, Polymères, Métal/Plasticité, Viscoplasticité /Fluage, Bétons, Matériaux fragiles (Céramiques, Verres), Géomatériaux, Biomatériaux, Nano matériaux…)
- Calcul des Structures (statique linéaire et non linéaire, dynamique linéaire et non linéaire, Essais physiques/essais virtuels, V&V, Fatigue, Endommagement/Rupture/Durabilité, Contacts et frottements, Flambement, Assurance qualité…)
- Dynamique et tests (Fréquences propres, Réponses (harmonique, aléatoire, sismique), Machines tournantes, MBS, Chocs, Impacts, Crash, Airbags, Explosion, Balistique …)
- Mécanique des Fluides (Incompressible and compressible, LES – DNS - RANS, Monophasique/Multiphasique, Thermo-hydraulique, Combustion, Turbomachines, Validation, Optimisation…)
- Optimisation / Robustesse (Plan d'Expériences Numériques, Surfaces de réponse, Optimisation Multi-objets/MDO, Optimisation topologique…)
- Électrique / Électronique / Électromagnétisme/ Piézoélectricité
- Thermique, Transferts thermiques
- Acoustique
- Multi-physique (Thermomécanique, Thermoélectrique, Vibro-acoustique, Multi-échelles, Interaction Fluide-Structure (FSI), Couplages faibles/couplages forts…)
- Analyse Stochastique/Fiabilité
- Simulation de Process (Emboutissage, Forge, Injection, Fonderie, Moulage, Assemblage, Soudage…)
- Méthodes avancées, solveurs
- Sciences de la vie et de la terre
- Intégration CAD/CAM (applications métiers, Modeleurs intégrés, Plateformes d'intégration, Analyse réglementaire, Interfaces métiers…)
- SDM, Integration PLM, virtual testing
- Calcul Intensif (HPC, Parallélisation, Visualisation, GPU, Big data/Serveurs…)
- Outils Logiciels, Sciences de l'Ingénieur (Mailleurs/remailleurs, Open source, Pré-post processors, Librairies, Composants, Langages…)

Une attention particulière sera portée aux présentations à caractère industriel, qu'elles soient présentées par des utilisateurs eux-mêmes ou, si cela se justifie, par des chercheurs, des sociétés d'ingénierie ou des éditeurs de logiciels. Les auteurs sont invités à noter que NAFEMS est une association scientifique neutre et indépendante. Les présentations commerciales ne pourront être acceptées au Congrès.

Partenaires >
Vous êtes éditeur de logiciels, revendeur, société d'ingénierie, laboratoire universitaire ?
Devenez Partenaire de l'évènement et bénéficiez dès maintenant du programme de communication du Congrès !

Demandez le dossier Spécial « Partenaire du Congrès 2012 » à francois.costes@nafems.org

NAFEMS www.nafems.org/fr2012

Atmospheric Modelling

Applications of Large-Eddy Simulations for Flows and Dispersion in Urban Environments or Industry Sites

This article aims to demonstrate the promising large-eddy simulation techniques for flows and short-range dispersions (e.g. up to a few hundred metres). Three different geometries – (1) a group of staggered cubes, (2) a group of staggered obstacles with square bases and (3) the DAPPLE site (i.e. London Marylebone Rd region) – are simulated as test cases. We focus on area-source dispersion for the first and second geometries, and on point-source dispersion for the third geometry.

The prediction of the instantaneous properties and behaviour of releases in the vicinity of building blocks by computational means is still challenging at present, which significantly restricts the current capability in many associated aspects. The first challenge is the physical complexity of the problem. For example, the variation of weather-scale winds must have a non-negligible effect on the dispersion. How to use these as boundary conditions for Computational Fluid Dynamics (CFD) and how to assess the uncertainties is a big issue. Thermal buoyancy effects might not be negligible in relatively calm days. It is also difficult to model the effects of roughness elements on building and ground surfaces and to assess the uncertainties.

The second challenge is the limited capability of current numerical approaches. In order to predict short-range (e.g. up to a few hundred metres) dispersion in urban environments or industry sites, the resolution of the building-resolved CFD simulations is required to be in the order of 1m. This is expensive for a reasonable domain size, e.g. 1 km in the horizontal directions. Large-Eddy Simulation (LES) is essentially more accurate than Reynolds-Averaged Navier Stokes (RANS) approaches, e.g. k-ε models. However, using LES is more challenging. For example, LES is more computer-resource demanding than RANS. Probably due to these reasons, benchmark numerical simulations are sparse for these applications so far.

Our earlier LES investigations showed some insights on flow and dispersion over various kinds of building arrays, and some of them are presented in this article. In the next section, LES of flows over random height urban-like obstacles is presented. A few details on the passive scalar dispersion from a surface area source (ground) over such an array is also presented in this article. These simulations were validated using wind tunnel measurements [1] that were obtained using naphthalene sublimation technique. The flow and dispersion within a genuine city area –the DAPPLE site, located at the intersection of Marylebone Rd and Gloucester Pl in Central London is presented. This LES data on steady winds (i.e. an oblique and a perpendicular wind) was obtained using our recently developed inflow approach [2]. Furthermore, in order to investigate effects of the large scale variation of winds and also to pursue the capability of using the weather data to drive LES computations, realistic wind conditions measured on the BT Tower at 190 m above street level were processed and used as boundary conditions.

Figure 1: A view of one of the repeating units used in the experiments [4]. The oncoming flow is from top to bottom

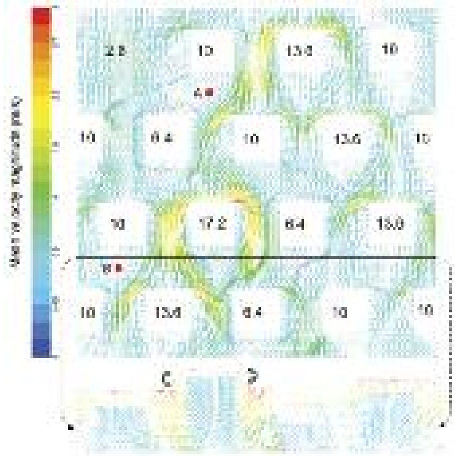


Figure 2: Mean velocity vectors (U, V) at z = 0.5h_m (top, flow is from top to bottom) and (V,W) at x = 5.6h_m (bottom, looking upstream). Numbers on each building block indicate its height in mm. U, V, W, streamwise, lateral and vertical respectively.

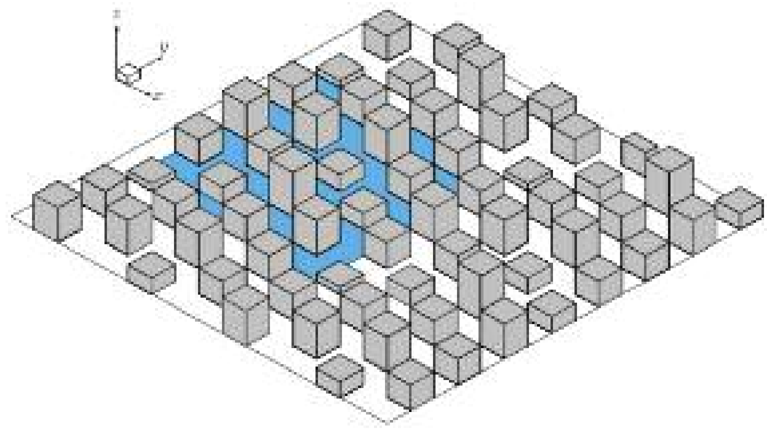


Figure 3: Sketch of 3D view of random height obstacles. The passive scalar area source on the ground is indicated by blue shaded region.

Flows over random urban-like obstacles [3]

The array chosen for computations was same as the one studied experimentally [4], in which the size of a 'repeating unit' as shown in Figure 1 is 80 mm × 80 mm. Each unit comprised an array of sixteen 10-mm-square elements and had height variation that followed approximately normal distribution. The standard deviation in block height was about 3 mm and the mean height, h_m was 10mm. The plan area coverage was 25%. The height of the computing domain was 10 h_m and it included four such repeating units.

A three-level polyhedral mesh (1.3 million cells) with 13×13×13 cells per $h_m \times h_m \times h_m$ in the near-wall region was used in the STAR-CD4 computations. It is known that polyhedral meshing is more flexible than the alternatives for complex geometries and it is also more accurate and less memory consuming than the widely used tetrahedral mesh. Our earlier work [5], which addressed meshing issues in some detail, concluded that grid sizes around the obstacles should be no greater than about 0.06h_m for adequate LES computations in the canopy region (and thus the surface drag); the localised errors implied by relatively large changes in mesh spacing were not found to prejudice overall solution accuracy.

Figure 2 shows mean velocity vectors (U,V) on the horizontal plane z = 0.5 h_m and (V,W) on the vertical plane x = 5.6 h_m (immediately behind row 3). The details within the canopy are complicated and depend greatly on the arrangement and the height of the blocks. For example, on the right side (facing downstream) of the 10-mm block in row 1, near station 'A' there is a large separation bubble, whereas on the left side there is no bubble because on that side the 13.6-mm block and 10-mm block form a relatively narrow channel, giving a strong negative pressure gradient in the streamwise direction and suppressing the reverse flow. This contrasts with the flow around the next 10-mm block just downstream and on the left, where there are similar separated zones on both sides.

On the vertical plane, a common phenomenon is that in the gaps between rows the flow is downward; consequently a clockwise circulation (looking upstream) is formed on the right side of the 17.2-mm block (anticlockwise on the left-hand side), as illustrated by the large arrows in Figure 2. This is the reverse of what would occur for an isolated single block, where the cross-stream circulations have the same sense as those in a trailing vortex system behind, for example, a delta-wing. Its cause is the strong downflow downstream of the gap, e.g. on the right of the 17.2-mm block (facing downstream), generated by the 13.6-mm block just downstream. The result emphasises that even the qualitative behaviour of the flow around a particular building surrounded by others may be very different from what would occur if the building were more remote, suggesting that extreme caution is necessary in extrapolating what might be known about the latter situation.

In summary, compared with our previous LES data of flows over uniform cubes, significantly different features in turbulence statistics are observed within and immediately above the canopy, which might be not surprising. It is also found that the relatively high pressures on the tallest buildings generate contributions to the total surface drag that are far in excess of their proportionate frontal area within the array.

Dispersion from surface sources in arrays of obstacles [6]

Here an array of random height obstacles (Figure 3) and an array of staggered cubes were studied (Figure 4). The cubes of the latter were arranged in the same way as that for the random obstacles. The domains are similar as that in Sect. 2. However, it was found that a resolution of 0.06 h_m (suggested in [5] for the simulation of flows) in the near surface source region is not adequate enough to simulate the scalar dispersion as it is critical to resolve the fine details in the near wall region of the latter. So a stretched mesh was used with the

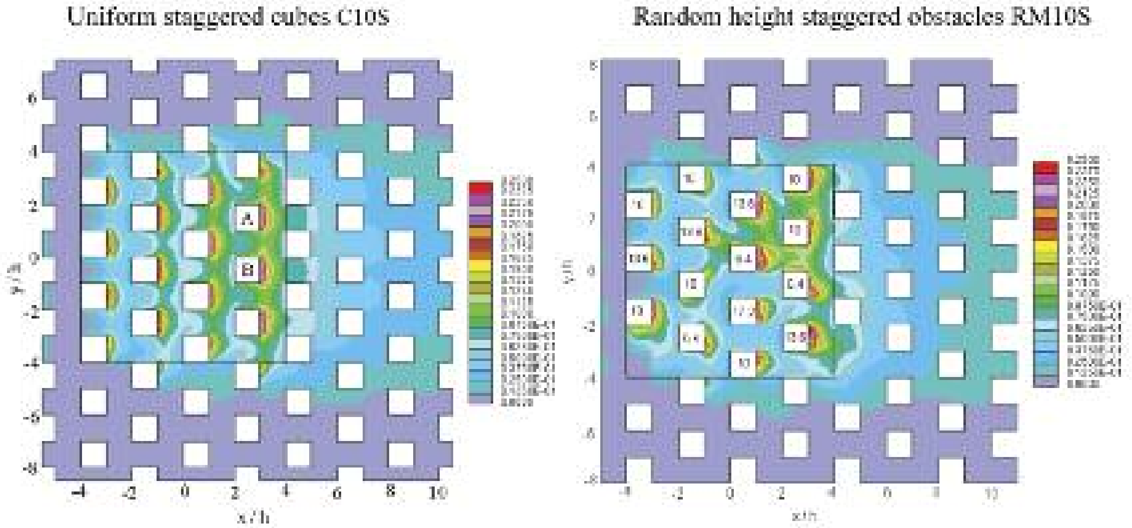


Figure 4: Contours of dimensionless concentration at z/h = 0.3 (square box represents the location of scalar on the surface) C10S, uniform cubes arranged in a staggered fashion with a hight 10 mm; RM10S, random height cuboids arranged in a staggered fashion with heights in mm indicated on the blocks for one repeating unit (also see Fig. 5)

near wall grid size approximately $0.015h_m$. In the wind tunnel experiment [1], the naphthalene was coated on the surface (i.e. z = 0) of one of the repeating units. In the LES study, the same arrangement was used and is illustrated by the shaded region in Figure 3 that shows the bottom view of the computational domain.

Contours of the mean concentration fields (normalised with the source concentration) for C10S and RM10S at z/h = 0.3 are shown in Figure 4 . Although similar behaviour is observed in both C10S and RM10S, the pattern is not regular in the latter, thus indicating strongly the differences in the transport processes for the two different surfaces. For example, the recirculation region in front of the tallest roughness element of height 17.2 mm has significant influence on the wakes of the upstream roughness elements.

In the experiments, a higher mass flux was noticed around the periphery of the source area. To study this in LES, contours of the normalized vertical viscous and SGS flux immediately above the source area (where it dominates turbulent fluxes) are plotted for C10S and RM10S in Figure 5. The first and foremost inference that can be drawn is that this near-wall flux distribution is quite different for the two surfaces. In C10S, the flux values are about twice as large in a few specific regions around the lateral edges of the area source, i.e. at y/h = −4 and 4, when compared to the other y/h locations. This can be seen quantitatively by comparing, for example, the region −3 ≤ x/h ≤ −2, y/h = −4 with the same x/h region at y/h = −2, 0, 2 and 4. These observations therefore confirm the experimental findings. Similar behaviour is observed in the RM10S case. In summary, the LES of these experiments demonstrates clearly the influence of the building block morphology on the dispersion processes.

Modelling street-scale flows and dispersion in London DAPPLE site [7,8]

LES with steady wind conditions:

LES in an oblique (i.e. -51° bearing clockwise from the west-east Marylebone Rd direction, see Figs. 6, 7) and a perpendicular (i.e. -90°) wind were performed for flows and dispersion within a genuine

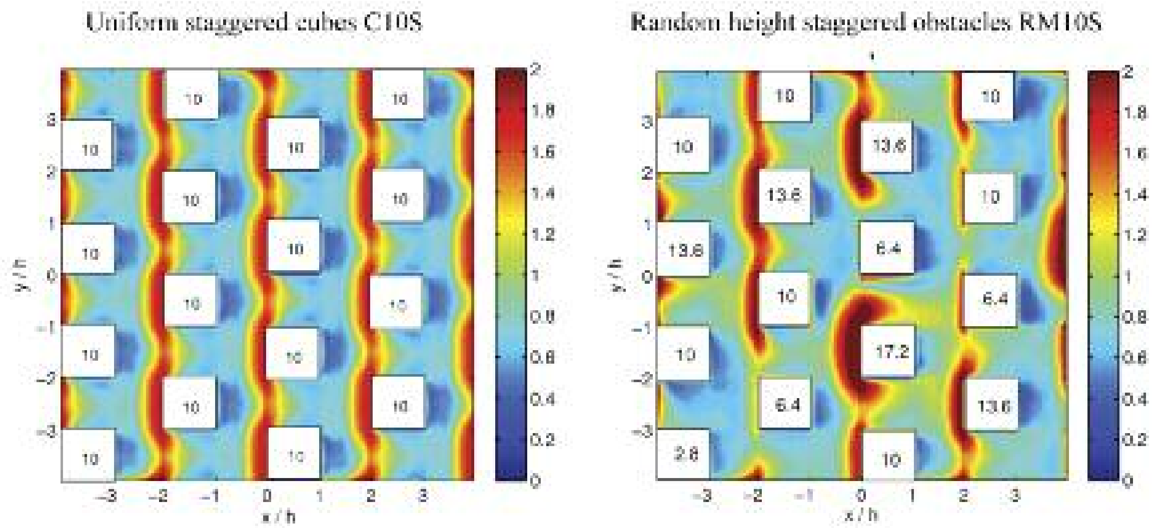


Figure 5: Contours of the vertical viscous flux from the region -4 ≤ x/h, y/h ≤ 4 and at z/h ≈0.007. This region is immediately above the area source shown in the Figure 3.

Figure 6: Full-scale field experiment site: X1,X2, source sites; square symbols, sampling sites. The base map is an Ordinance Survey/EDINA supplied service (© Crown copyright / database right 2010)

city area – the DAPPLE site. The resolution was down to 1 m in space and 1 s in time. We simulated flows and dispersion over the wind-tunnel model (WTM) that has 1:200 resolution and its plan view is shown in Figure 7. The arrows with solid and dashed lines indicate the wind direction at -90^0 and -51^0 respectively. Figure 6 shows the full-scale field experimental site.

Figure 8 shows the computational domain with the coordinate origin on the ground at the Marylebone Rd-Gloucester Pl intersection. The x axis is approximately from south-west to north-east, while the y axis is from south-east to north-west. The central part of the domain is the DAPPLE site. Upwind of the DAPPLE site, 14 artificial building blocks with a height h_m were placed since the upwind urban geometry data was not available. It was found that the results within the DAPPLE site were not significantly sensitive to the arrangement of the artificial buildings. Figure 8 also shows the 3D geometry of the building blocks (i.e. the blue ones) of the DAPPLE wind-tunnel model with a mean height h_m = 110 mm and a packing density of 0.5. Most of the buildings are essentially of cuboid shape with various low heights. Their arrangement is mainly in staggered and aligned patterns with intersections and T junctions. A street canyon pattern is also evident and is more dominant for south–north streets than for east–west streets. Also the surface mesh of the building blocks is presented to indicate the resolution down to h_m / 20, which is equivalent to 1 m in full scale and this resolution is almost uniform (except the first grid from the solid wall) in the DAPPLE site upto z/h_m =3.

It was found that the direction of the spatial average of the time-mean velocity within and immediately above the canopy changed. For the -51^0 wind, the velocity direction changes no more than 10^0 within the canopy. In contrast, for the -90^0 wind the velocity direction turns clockwise from -90^0 above the canopy to about -50^0 within the canopy. An interesting observation is that the velocity direction near the ground level is about -50^0 for both the forcing directions. To further interpret the directional change of the spatially-averaged velocity within the canopy in the -90^0 wind, mean velocity vectors (Um , Vm) on horizontal planes at different heights (i.e. z / h_m = 0.1, 0.5 and 1) over Marylebone Rd are plotted in Figure 9. Figures 9 a, b show a strong west-to-east rather than east-to-west flow along Marylebone Rd. This is likely due to the local arrangement of the buildings, i.e. the three slightly staggered buildings off Marylebone Rd that are marked 'staggered' in Figure 9 a. For example, the sudden increase in the street width at the east side of the Marylebone Rd-Gloucester Pl intersection induces air from Gloucester Pl to flow west-to-east. Also at the Balcombe St-Marylebone Rd and Baker St-Marylebone Rd intersections, similar flow patterns are observed that are likely due to the same mechanics. These at the three intersections together enhance forcing the in-street flow to go west-to-east in the -90^0 wind.

Both the integrative and local effect of flows and dispersion to these geometrical patterns were investigated. Figure 10 is a snapshot of concentration contours at pedestrian height in the -51^0 wind. It was found that the peaks of spatially averaged variances of turbulence fluctuations occurred

Figure 7: Plan view of the 1:200 wind tunnel model of the DAPPLE site. Numbers in italics on each building block indicate its height in mm; the model coordinates are marked in mm, with xt from west to east, y_t from south to north and z from ground to top respectively; x, y, z are the computational coordinates (see Figure 8).

neither at the mean height nor at the maximum height, but at the height of large and tall buildings. It was also found that the mean and fluctuating concentrations in the near-source field was highly dependent on the source location and the local geometry pattern. The LES results were found in reasonable agreement with the wind tunnel data. In summary, the LES demonstrated that a full-scale resolution of around 1 m is sufficient to yield accurate prediction of the flows and mean dispersion characteristics and to provide reasonable estimation of concentration fluctuations in steady winds and neutral thermal conditions.

LES with realistic wind conditions:

Computations on flows and dispersion over the DAPPLE site were performed using realistic wind conditions. 10-Hz resolution wind data were measured at 190 m above street level on the BT Tower [9] during 1600–1700 on 3 June 2004, which was approximately 1500 m east of the DAPPLE site. The measured wind data were processed as 60- and 30-s averaged data, which were used to generate inflow conditions to drive the LES. The LES was initialized at 1600 with the source release at X2 switched on at 1630 and off at 1645, and with the sampling and averaging started at 1630 until 1700. It was noticed that for this duration the wind-speed magnitude varied ±36% and the wind direction varied ±22°. In the release duration 1630–1645 and also afterwards up to 1700, the wind direction was fairly steady, almost south-west.

Figure 11 shows a comparison of the 3-min averaged concentration at site 14 (see Figure 6) between the field measurements and the six sets of LES results in different wind conditions. The two cases 'LES run1, BT tower data' and 'LES run2, BT tower data' had two different initial conditions. The results from these two cases are found to be in fair agreement with

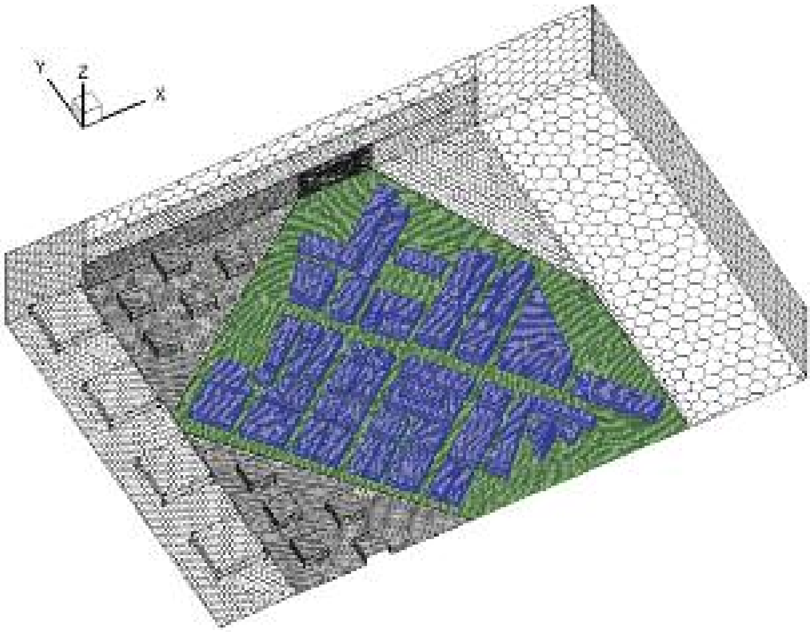


Figure 8: Computational domain with polyhedral mesh. The domain size L_x = 6 m,L_y = 4 m,L_z = 1 m in WTM scale

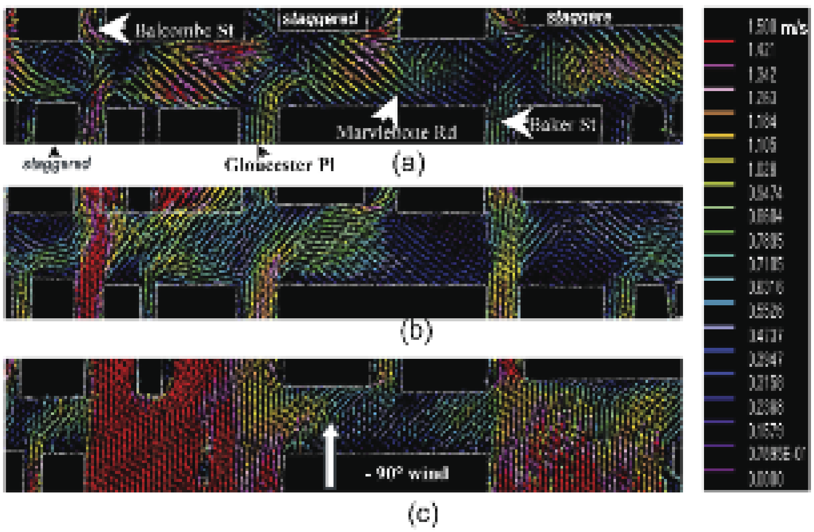


Figure 9: Mean velocity vectors over Marylebone Rd in –90 wind at different heights. (a) z= 2m; (b) z=11m;(c) z=22m (in full scale).

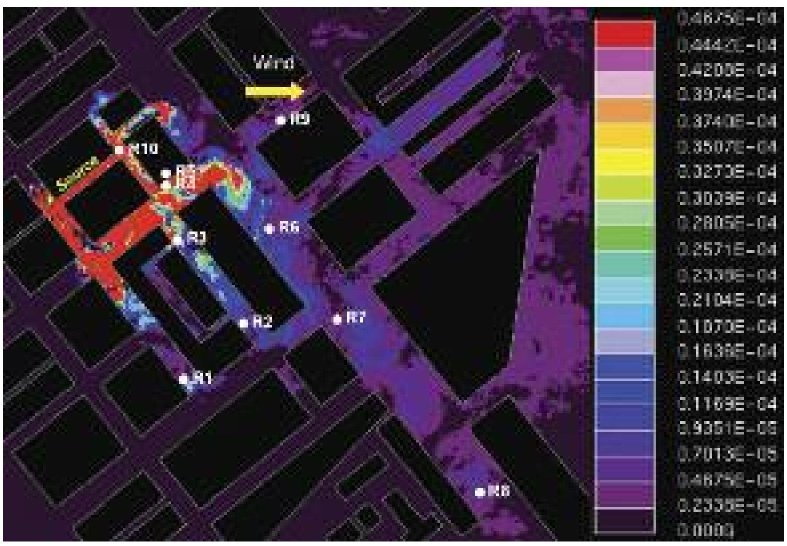


Figure10: Aerial view of Marylebone Road, London, receiving pollutant contamination from a source. Colours represent pollutant concentration levels at pedestrian height.

measurements thereby suggesting that the 3-min averaged concentration was not significantly sensitive to the initial conditions. The wind speed and direction of the case ‘LES, mean wind’ in steady wind conditions were equivalent to the mean wind speed <U> and the mean direction <θ> of the BT Tower data from 1630 to 1700. The three cases ‘LES, mean wind +6^{0}’, ‘LES, mean wind +12^{0}’ and ‘LES, mean wind –6^{0}’ in steady wind conditions, for which the wind speeds were <U> and the wind directions were <θ> + 6^{0}, <θ>+ 12 , <θ> – 6^{0} respectively, were investigated to check the sensitivity of wind direction on dispersion. Not surprisingly, Figure 11 shows that the 3-min averaged concentration in the steady winds is sensitive to the wind direction.

It was also noticed that the calculated peak mean concentration in the steady wind conditions can be of one order magnitude greater than those numerical results in the realistic wind conditions and the field measurements. One might argue that it is unfair to make a quantitative comparison of the 3-min averaged concentration at one site. However, the data at the other sites collectively confirmed these speculations. So it is concluded that LES in steady wind conditions over-predicted the peak concentration, whereas LES in realistic wind conditions produced significantly improved results compared with the field measurements.

Conclusions

All the above test cases demonstrate that LES is a promising technique for flows and short-range dispersion in urban environments and industry sites. For such studies, the adequate resolution required for LES was determined by comparing their results with the available experimental data. LES with realistic wind conditions provided validation and confidence for coupling mesoscale meteorological models, e.g. the UK Met Office’s Unified Model and the NCAR’s Weather Research & Forecasting Model, with the street-scale large-eddy simulations of urban environments.

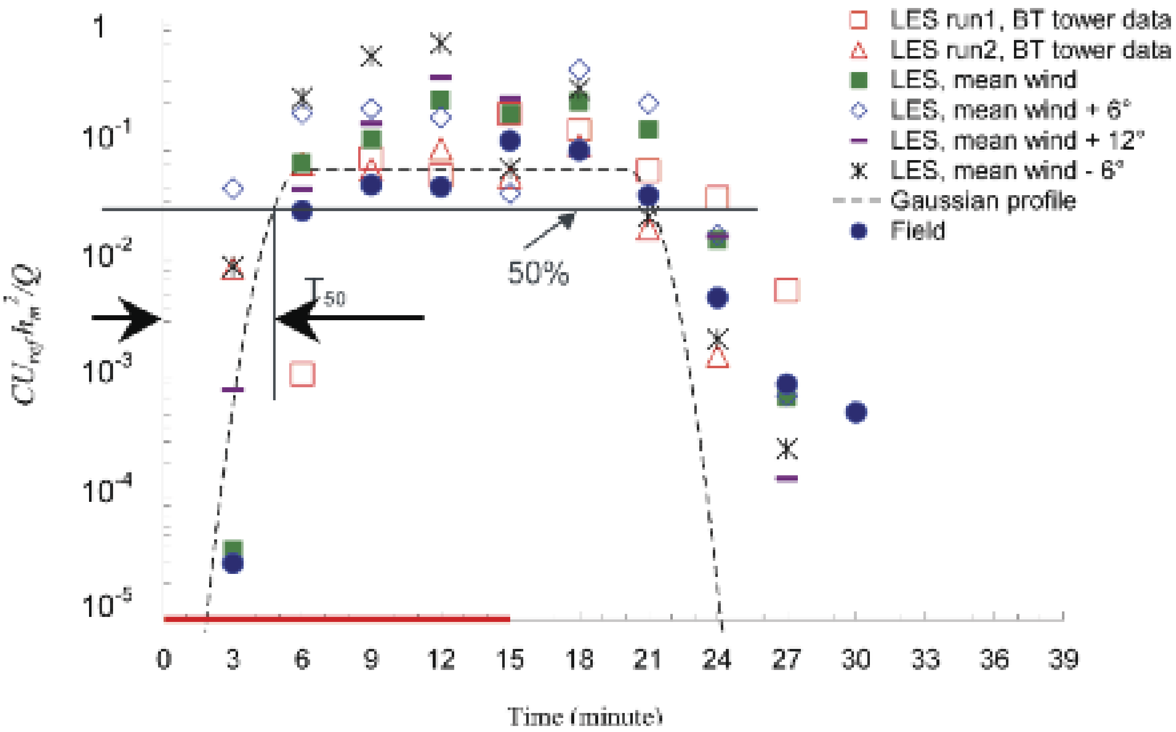


Figure 11: 3-min averaged concentration at site 14 (see figure6) in different wind conditions. Abscissa in full scale. Uref , free-stream velocity; Q, concentration flux at source; hm, mean building height; T50, advection time. Red solid line release duration, dashed line approximate location and width of a plume in combined Gaussian form, thin black solid line 50% level of maximum of the Gaussian profile. Filled circle field measurements, open square and open triangle, using the BT Tower data for inflow generation with different initial conditions; filled square, open diamond, dash, asterisk, using steady velocity magnitude and directions (for inflow generation) equivalent to <U> and <θ>, <θ> + 6°, < > + 12° and <θ> – 6° respectively, where <U> is the mean wind speed and <θ> is the mean direction of the BT Tower data from 1630 to 1700.

Acknowledgement

We are grateful to Pr I.P. Castro, Drs V.B.L Boppana and Fred Mendonca for their helpful advice and comments. All of the computations are done using Star-CD v4.0. The research is partially supported by National Centre of Atmospheric Sciences, NERC under the Urban Meteorology theme of the Universities Weather Research Network (UWERN, Grant No. R8/H12/38).

References

[1] Pascheke F, Barlow JF, Robins A (2008) Wind-tunnel modelling of dispersion from a scalar area source in urban-like roughness. Bound.-Layer Meteorol. 126:103–124

[2] Xie ZT and Castro IP (2008) Efficient generation of inflow conditions for LES of street-scale flows. Flow,Turb. & Comb., 81 (3): 449-470 [3] Xie ZT, Coceal O, Castro IP (2008) Large-eddy simulation of flows over random urban-like obstacles. Bound-Layer Meteorol 129:1–23 [4] Cheng H, Castro IP (2002) Near wall flow over urban-like roughness. Bound.-Layer Meteorol. 104:229–259 [5] Xie ZT, Castro IP (2006) LES and RANS for turbulent flow over arrays of wall-mounted obstacles. Flow Turbul Combust 76:291–312

[6] Boppana VBL, Xie ZT and Castro IP (2010) Large-eddy simulation of dispersion from surface sources in arrays of obstacles, Bound.-Layer Meteorol., 135(3), 433-454

[7] Xie ZT and Castro IP (2009) LES for flow and dispersion in urban streets, Atmos. Environ., 43 (13), 2174-2185 [8] Xie Z.T (2011) Modelling street-scale flow and dispersion in realistic winds - towards coupling with mesoscale meteorological models, Bound.-Layer Meteorol. In press. [9] Wood CR, Lacser A, Barlow JF, Padhra A, Belcher SE, Nemitz E, Helfter C, Famulari D, Grimmond CSB (2010) Turbulent flow at 190 metres above London during 2006–2008: a climatology and the applicability of similarity theory. Bound-Layer Meteorol 137:77–96

AUTHOR INFORMATION

Zheng-Tong Xie | University of Southampton, UK
z.xie@soton.ac.uk

benchmark

the international magazine for engineering designers & analysts

Published quarterly by NAFEMS, benchmark is the only truly independent publication geared towards the analysis and simulation community. Read by some of the world's leading organisations, across a wide range of industries, the magazine is truly a benchmark of the community and an essential read for all engineering designers and analysts.

Subscribe Now

Ford Motor Company Accelerates Design for Manufacturability of Conical Joints

Developing high-quality bolted joints is an integral part of vehicle chassis design. Robust joints are critical to improving handling and longevity of vehicle performance. Joints that are loose tend to exacerbate quality issues such as alignment, and ultimately the durability of the joined components. A properly designed joint is more efficient and can support larger loads with smaller size fasteners without loosening.

Engineers at Ford Motor Company were tasked to deliver a robust cantilevered conical joint design for the rear suspension system of a midsize passenger car [Figure 1]. To minimize time and cost while meeting functional targets, the team developed an automated Design of Experiments (DOE) process using Abaqus for CATIA (AFC) for structural analysis and Isight for process automation and optimization, both from the SIMULIA brand of Dassault Systèmes.

"Our team chose to deploy standard stress modeling and simulation practices in the form of templates to a broader group of engineers within the design organization," says Satyendra Savanur, chassis CAE engineer at Ford Motor Company. "We used response surface model, one of the approximation models, for finding optimal parameters to size the joint."

Analyzing Conical Joint Performance

A bolted joint is the most common type of attachment method used in the suspension of a car. In this application, a conical joint is used for connecting the toe-link to the rear knuckle with a cantilevered type connection. The two mating parts of the conical joint—the bushing inner sleeve and the knuckle—each have unique manufacturing tolerances of the cone angle.

To develop a robust conical joint between a steel inner sleeve and an aluminum knuckle the following aspects were considered:

- manufacturing tolerances of each component
- contact area between the cone and seat
- angle of the cone
- torque loss after the service load is removed.

To perform virtual tests of their design, the Ford engineers created the finite element model of the knuckle and the bushing inner sleeve with the geometry input and material properties from their model created in CATIA. Associativity was maintained to ensure that the model updates were robust when the CAD model is changed within the usable range of design variables.

During the physical assembly process, a forged steel inner cone is forced against an aluminum knuckle seat [Figure 2]. Due to the different manufacturing processes used to make each part, the angular tolerances of the conical design features are different on the inner sleeve and the knuckle mating surface.

"Because of the potential angular mismatch, there are variations in contact area when the two surfaces mate together and the joint is fully torqued," says Savanur. Local yielding can occur in the mating materials, leading to changes in contact area and pressure distribution during assembly of the joint. When the service load is applied, further changes to contact area and contact pressure can occur.

"It is therefore important to simulate both the joint assembly, and the loading and unloading, of service loads on the joint during the analysis," he says. "Our objective was to deliver a robust conical joint design for the entire range of conical mismatch between the cone and the knuckle."

For a robust contact analysis and even contact pressure distribution, the mesh of the inner sleeve was constructed to align with the mesh of the knuckle seat. To facilitate mesh alignment in the contact area, a separate "domain" of the knuckle seat, shown in light blue in Figure 4, was created to simplify meshing. This part was connected to the rest of the knuckle body with a tied contact.

To simulate the bolt assembly process, a virtual bolt between the inner sleeve and the knuckle joint seat was created. External service loads were applied on the sleeve center. Non-linear stress-strain curves for aluminum and steel were imported to facilitate the nonlinear analysis. Contact pairs and bolt tension were then created. Output of contact area and contact force magnitude were used during post-processing. Finally, the analysis file was output and submitted to the High Performance Computing (HPC) cluster for running the analyses.

Managing the DOE Process

Ford's need to evaluate a large number of designs with different combinations of parameters prompted the engineers to create an automated DOE process. In this process, CAD geometry updates and FEA model updates are completed in the same loop thus allowing a completely automated DOE approach.

At Ford, CAD startup is customized with an external product management system. Scripting is used to strip away the linkages to the product management system before initializing the interface.

Design parameters are then fed in with an external Excel file. The input parameters from the Excel file are mapped to the DOE task of the Isight manager. This enabled automatic updates of the excel sheet for each loop. Since Excel is synchronized with the design table, this results in automatic updates of the CAD geometry and FE.

"By developing a single integrated process, we were able to drive automatic updates of the geometry and mesh at the same time," says Savanur. The process automation manager was used to manage and control the DOE process. The resulting automation loop is completely integrated to run CAD updates, creating the FE models, and job submission for analysis and post-process results.

The FE component inside the process management loop was used to extract outputs, including contact area and contact force magnitude for each run of the DOE. The input parameters

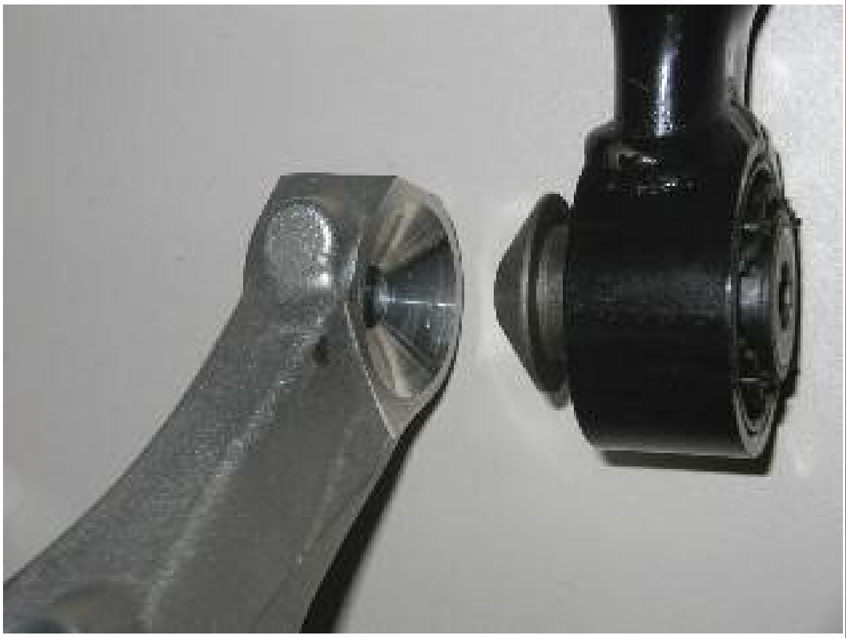


Figure 1: Close-up view of Knuckle Cone Seat and Inner-Sleeve

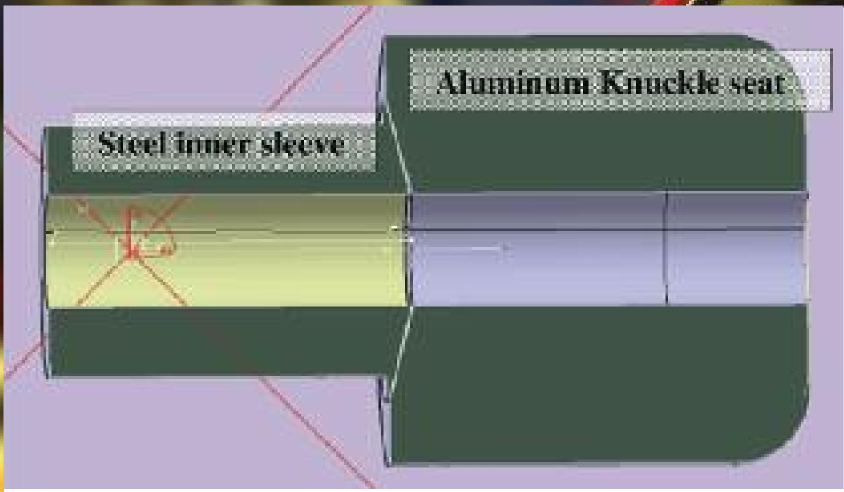


Figure 2: Section of the Conical Joint

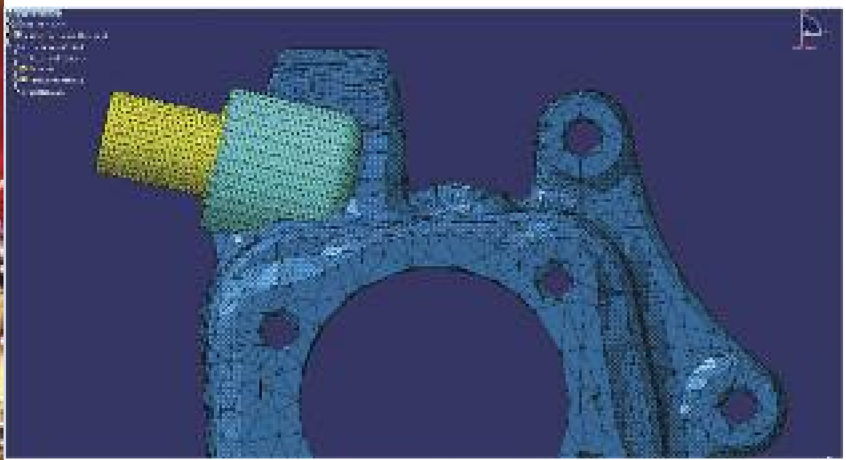


Figure 3: Detailed CAE model

from the Excel file are then mapped to these output parameters to create Isight approximation model.

"In our case, we used the response surface model method of approximation," says Savanur, as seen in figure 6. This approximate model of conical joint behavior can then be used to show how-input affects output and quickly optimize the conical joint.

"This is the first application of an integrated DOE automation loop to morph geometry using CATIA with Abaqus at Ford," says Savanur.

Isight Enables More Efficient Processes

The set-up and validation of the scripts, HPC job submission batch file, and the windows batch command file took time and resources to develop, but were well worth it as they are re-usable for subsequent projects with minor changes.

"Developing a comparable CAD model with an associated Excel design table, and linked to an associated FE model would take approximately three days to construct," says Savanur. *"Modifying and debugging the previously developed scripts to run with these new models would take another day. Using this method, it took about 3.5 hours for the process to complete 35 analysis runs."*

"Typically, the manual CAE process consumes two days just to complete one run. Of course, this timing can be reduced if the project is critical, but this is the typical day-to-day turn-around time balancing several projects per engineer," says Joe Peters, chassis CAE supervisor at Ford Motor Company.

Time inefficiencies typically occur in the transfer of data back and forth between CAE and CAD organizations, as people have multiple assignments and do not immediately stop their current work when new design iterations are requested; this is analogous to CPU time verses wall clock time.

"It is estimated it would have taken approximately 70 days to complete all 35 runs, while maintaining other day-to-day work; whereas, our new process eliminates the inefficiencies that were part of the manual CAD/CAE procedures," says Savanur. *"By setting up the integrated closed-loop automated DOE loop using Isight, we achieved this task in about four days. This was the only way to help achieve the program objectives of cost and timing with a lean CAE organization".*

"Using the automated DOE process, we were able to drastically cut down the time required to develop a robust conical joint with minimal resources," says Peters.

By creating an integrated closed-loop DOE process, Ford Motor Company was able to deliver a robust conical joint design. This joint exhibits good contact area and retains clamp load after load removal, within the specified manufacturing tolerances.

Conical Joint Description

Figure 1 shows a close-up view, before assembly, of the toe-link (black) and the rear knuckle (silver) using a conical joint.

Figure 2: Section of the conical joint

CAE Model Details

The CAE model, shown in Figure 3, has three distinct parts:

- bushing inner sleeve (yellow) made of steel,
- knuckle seat (light blue) made of aluminum
- And third is the knuckle body (dark blue) made of aluminum.

RSM approximation based on a polynomial fit via the least squares regression of the output parameters to the input parameters. The R^2 analysis is a measure of how well the model polynomial approximates the actual function. When R^2=1.0, the polynomial values and response function values are identical (at all design points).

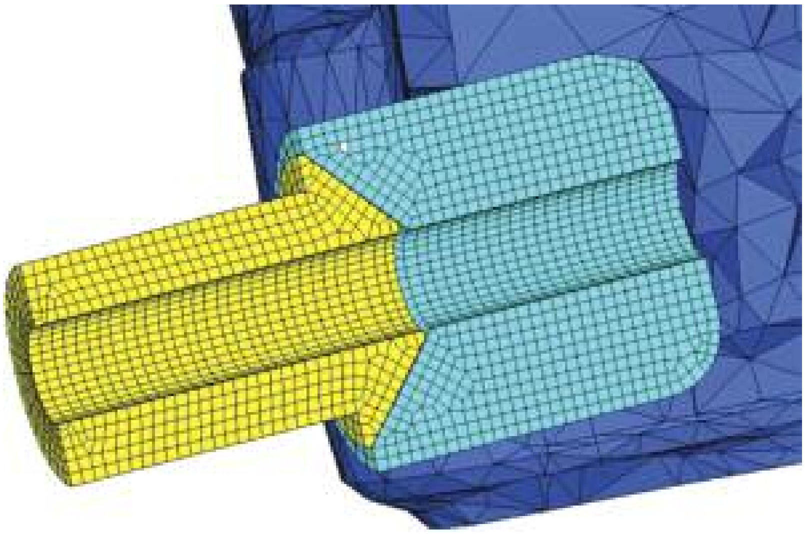


Figure 4: CAE Mesh details of the conical joint

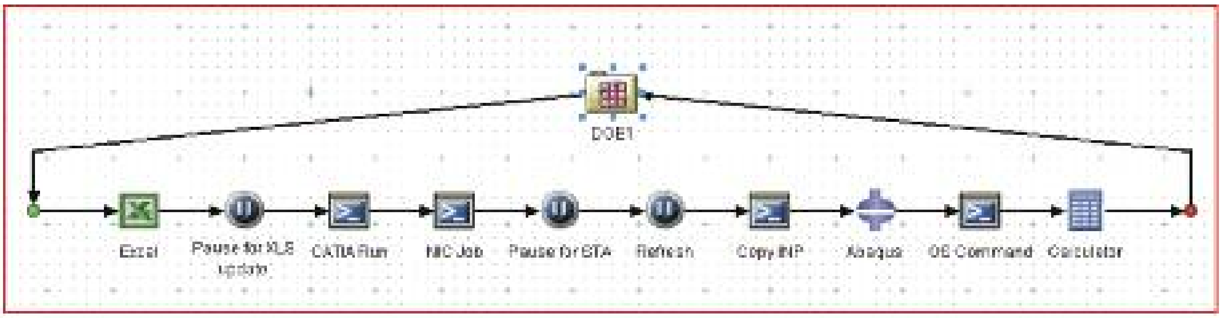


Figure 5: Integrated DOE Automation Loop Using Isight

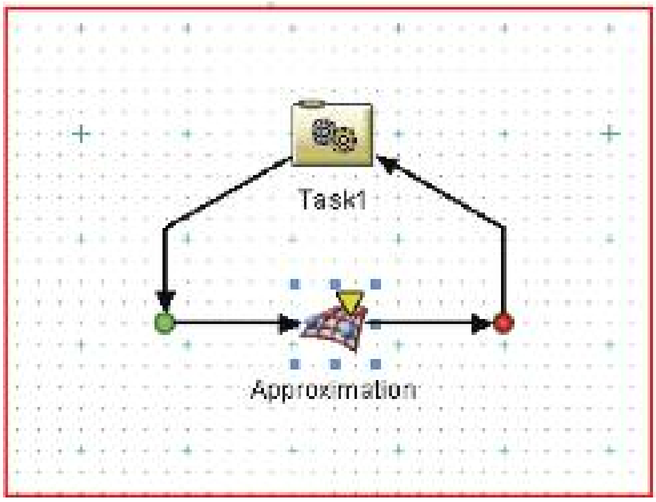


Figure 6: Response Surface Model Method

This case study was developed with the assistance of the following engineering team at Ford Motor Company: Satyendra Savanur, Elaine Hoffman, Rajesh Rajput, Xiaoming Liu, Joe Peters & Kyu Sohn.

Joint Durability on the Rails

Dipl.-Ing. Thorsten Weyh, Dr. Michael Speckert Fraunhofer Institut für Techno- und Wirtschaftsmathematik (ITWM), Kaiserslautern, Germany.

This article, taken from the newly released NAFEMS publication "FEM Idealisation of Joints", takes a look at a project led by the department of "Mathematical Methods for Dynamics and Durability" (MDF) at Fraunhofer ITWM in collaboration with a leading railway company, to analyse multi-bolted joints and their durability behaviour under service loads.

The finite element model that was used includes nonlinear contact formulations and friction between the specific parts of the railway ball joint connection. The service loads were represented by long 3-dimensional time signals, characterising a typical operating day of the railway vehicle.

Due to the length of the time signals a fully transient FE calculation was not an option. In addition, the commonly used linear quasi-static superposition approach could not be used due to the nonlinear contacts.

Within the project, ITWM developed a highly efficient method to compute the stress time signals of multi-bolted joints. The approach enhances the established method of the linear quasi-static superposition such that nonlinear contact formulations can be covered. It is based on the interpolation of suitably chosen static contact problems.

The new approach enables a profound comparison and improvement - in the early stages of the development process - of different design variants undergoing complex varying service loads even in case of nonlinear phenomena such as contact.

Bolted joints are one of the most common detachable connections in mechanical engineering. For the design of a single- or multi-bolted joint, the VDI guideline "Systematic calculation of high duty bolted joints / Joints with one cylindrical bolt, VDI 2230, Feb. 2003 [1]" has been used for many years. The guideline provides all the necessary calculation steps for a standard stress analysis of a bolted joint based on reduced and simplified model assumptions.

Nevertheless, not all possible connection designs are included in the guideline. In particular, the calculation of multi-bolted joints is not fully described. FEA is increasingly being used to assess these multi-bolted joints. On the other hand, there is no common guideline for the usage of FEA regarding modelling, calculation, and durability behaviour of single or multi-bolted joints. Thus, FEA does not replace the VDI guideline, but offers reasonable extensions to those joints, which can't be calculated with the reduced or simplified models of the guideline. Further details for single- and multi-bolted joints see [4].

In the case described here, nonlinear FE analysis is needed due to contact between different parts of the structure. Thus, the well known quasi-static superposition approach does not apply. A separate FE analysis for each time sample would be required. However, this is not possible due to the length of the load signal. Instead, only a few suitably defined combinations were calculated, building the basis for a new approach to obtain the stress results of the multi-bolted joint for the whole measured time series. Furthermore, a fatigue life analysis of the multi-bolted joint under the service loads was performed.

Model Details

In order to obtain reasonable fatigue life estimations, the requirements on the accuracy of the stresses calculated by FE models are high. Therefore the FE model has to be detailed enough. On the other hand it is hardly possible to include all the details of the bolted joint model (e.g. single thread turns) due to the increasing size of the FE model and the corresponding calculation time and hardware requirements. In the case described here, a compromise has been implemented to get reasonable stress results within the multi-bolted joints which are accurate enough for a subsequent durability analysis.

In Figure 1, the FE model of the joint investigated in this paper is shown.

The service load was given by measured time series (three forces Fx, Fy, Fz at 200 Hz sampling rate) representing the load of a typical day for this kind of railway vehicle. The time series were measured at the

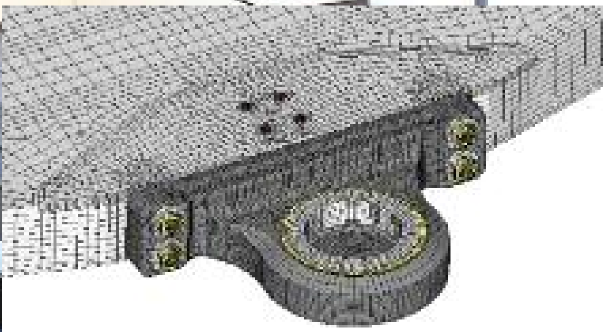


Figure 1: Finite element model of the railway ball joint connected by a multi-bolted joint.

ball joint connecting two railway wagons.

Details of the bolt joint:

- Type: M16 10.9, rolled before heat treatment, tapped thread joint, thread insert
- Tensile strength: 1000 MPa
- Yield strength: 900 MPa

Overview of the FE model:

- Elements: approx. 104.000 (predominantly Hexahedron-Elements)
- Material: Steel and Aluminium parts
- Friction coefficient between the parts: = 0.3
- Assembly preload at the bolts: FM = 41kN
- Solver: ANSYS 10.0 (see [5] for further details)

Analysing the Nonlinear Behaviour of the Structure

For a first overview regarding the model behaviour under service loads, the measured time series were analysed to identify the load range. The time series contains three forces Fx, Fy, Fz within the following range:

F_x [-45kN … +45kN]; F_y [-60kN … +60kN]; F_z [-5kN … -40kN]

F_x acts along the longitudinal axis of the bolt. It mainly represents the load acting on the bolt when the train accelerates (tensile stress) or due to braking events (compression stress).

F_y represents the load when the train is cornering. Depending on the curvature of the track, F_y creates tensile stresses at the bolts located in the direction of the outer curve radius and compression stresses at the bolts located in direction of the inner curve radius. It acts along the lateral axis of the bolt.

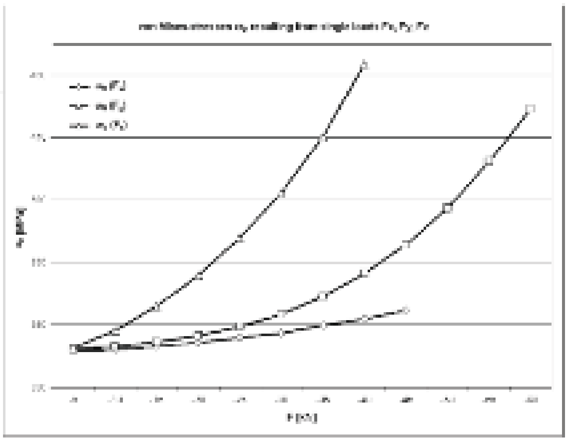


Figure 2: von Mises equivalent stress σ_V under single loads F_x, F_y and F_z.

Finally, F_z represents the part of the applied loads based on outer loads (tare mass and payload). F_z also acts on the lateral axis of the bolt. Depending on the driving condition of the railway vehicle, F_x and F_y may have negative and positive signs while F_z only acts in the negative direction.

To obtain an adequate resolution for the analysis, the load range was divided into 5kN steps and FE computations were performed on that grid. F_x was assumed to act within -5kN to -45kN, F_y within -5kN to -60kN and Fz within -5kN to -40kN. Therefore the total numbers of calculations was 9 (F_x) + 12 (F_y) + 8 (F_x) = 29. For one single load step including the preceding load step 'pretension', the calculation time is up to two hours. So the overall used calculation time was 58 hours (nearly 2 ½ days).

The equivalent stress results (von Mises) are plotted in figure 2. In each load direction the FEA model obviously shows nonlinear stress behaviour which is due to the nonlinear contact formulations.

Since linear superposition of these load cases is not allowed here, combinations of several loads had to be calculated in addition. For the combinations F_x/F_y, F_y/F_z and F_y/F_z. the same load step size of 5kN was used. Thus, we get 108 + 72 + 96 = 276 FE calculations, resulting in 552 hours computation time (23 days).

As can be seen easily, the stress depends on the forces again in a nonlinear fashion.

Transferring this fine resolution of 5kN steps to the three-dimensional load combinations, the overall calculation time would add up to slightly more than 144 days which of course was not executed. Nevertheless, the calculations performed so far clearly show the nonlinear behaviour of the stress as a function of the loads. Thus, linear quasi-static superposition is not applicable and a new approach had to be found.

Basic Idea of the Interpolation Approach

As already mentioned, the current state of the art process for calculating the stress time histories due to long load time series in combination with FEA models is the so called "linear quasi-static superposition" approach. For this approach, static unit load cases $\sigma_i(x)$

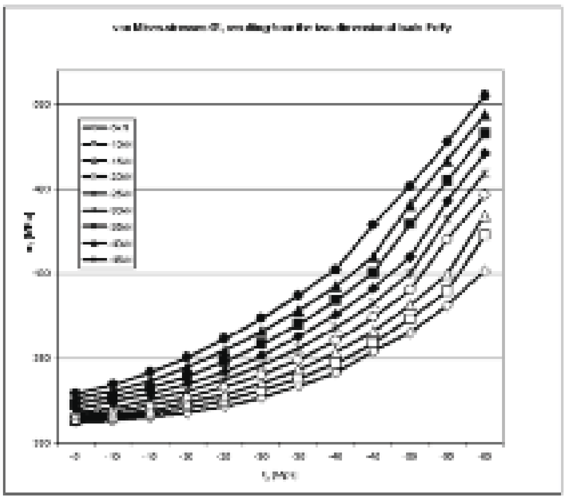


Figure 3: von Mises equivalent stress σ_v under two-dimensional loads F_x and F_y for one selected FE node. The legend refers to the value of F_x.

calculated by an FEA solver are superimposed with measured time series Li(t) in the form

$$\sigma(x,t) = \sum_{i=1}^{L} \sigma_i(x) \cdot L_i(t) \, .$$

This linear quasi-static approach requires linear model behaviour. For calculating the i-th unit load case $\sigma_i(x)$ the corresponding i-th load is set to 1 while all other loads are zero and the resulting static problem is solved. In case of nonlinear model behaviour, the quasistatic approach will not deliver correct results. To take the nonlinear effects of the present FEA model into account, the new "interpolation" approach extends the basic idea of the quasi-static approach to nonlinear models. Instead of the three unit load cases, a set of FE computations have to be performed on a suitably defined grid of loads.

As mentioned before, the main goal is to decrease the overall calculation time whilst keeping the error small. A first attempt to fulfil this requirement is to reduce the fine grid of 5kN steps to a coarser range of load steps. As shown in Figure 2, the nonlinear system response of stresses due to increasing F_x load starts at approximately -20kN. So the first load step is fixed at -5kN, the second one at -20kN where the beginning of a stronger nonlinear behaviour of the stress curves can be observed. The end point of the load range is given by the highest measured load at approximately -40kN. An additional point at - 30kN in between -20kN and -40kN completes the F_x-grid. With these four values the nonlinear characteristic of the stress curves can be reproduced with sufficient accuracy as will be shown below. The same procedure was used for the lateral and vertical forces.

Another step to reduce calculation time is to use the symmetry of the FE model. The load range in F_x direction cannot be reduced because of a lack of symmetry (differences in roll off and brake events). Also for F_z (tare mass of the vehicle and payload) which acts only in one direction, no symmetry can be exploited. However, for F_y it is sufficient to calculate only one load direction and reduce the overall effort to one half.

In the current example, the following load steps have been chosen:

- F_x [kN]: -45, -35, -20, -5, 5, 20, 35, 45
- F_y [kN]: -60, -45, -30, -5
- F_z [kN]: -40, -30, -20, -5

For each combination of F_x, F_y, and F_z (grid point in 3D load space) there will be a stress result, calculated by an FEA solver resulting in 8*4*4 = 128 FE calculations.

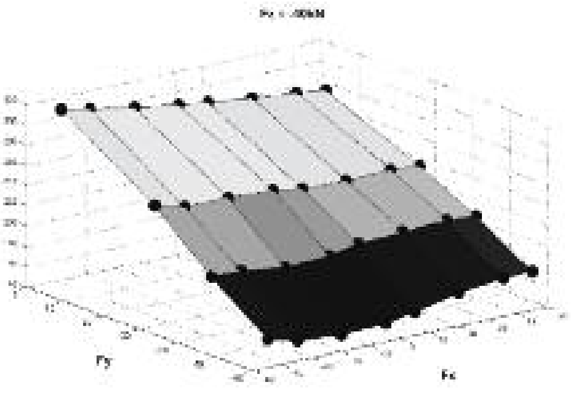


Figure 4: Stress σ_x in direction of the bolt under a three-dimensional load combination of Fx, Fy and Fz.

At a fixed load in one direction, for instance F_z, the stress results can be plotted as a surface in the remaining load space as shown in Figure 4 for the stress in longitudinal direction of a bolt.

For fatigue analysis, the von Mises stress is not appropriate. Therefore, the tensor component σ_x in longitudinal direction of the bolt is used in the following.

The basic idea of the interpolation approach is to substitute the results of the FE calculation for an arbitrary load combination with an approximation which is found by interpolating the stresses calculated on the 128 grid points in the load space. The system response σ_x depends on

- the given three-dimensional service load F_x, F_y, and F_z,
- the suspension load FM of the bolted joint, and
- the friction values between the head of the bolt joint and other parts

In the following calculation steps, the pretension force F_M and the friction coefficient μ were set to a certain constant value. Thus, from a mathematical point of view the system response σ_x in the bolt joint can be described by a function $\sigma_x = \sigma_X(F_x, F_y, F_z)$. For further investigations it would also be possible to construct an interpolation base with variable values for the pretension and friction coefficient.

The approximation function is required to deliver values which are close to the real system response. The way to find those approximation functions is sometimes called "response surface" method.

The grid decomposes the load range into 7*3*3=63 cells. Within each cell, the approximate interpolation function can be represented by a spline function $\tilde{\sigma}_{x,lokal}$ which can be described in the form

$$\tilde{\sigma}_{x,lokal}(F_x, F_y, F_z) = \sum_{i=0}^{3}\sum_{j=0}^{3}\sum_{k=0}^{3} c_{ijk} \cdot F_x^i F_y^j F_z^k \, .$$

To evaluate the unknown coefficients c_{ijk} for each cell, several properties are required, namely

- continuity and interpolation: the values at the grid points have to be equal to the values calculated by the FE analysis,
- smoothness: the first and second derivatives at the grid points of two connected cells have to be equal,
- the second derivatives at the boundary have to be zero.

The combination of all local splines for the whole load range is denoted by $\tilde{\sigma}_x$.

Besides this spline interpolation approach there are a lot more ways to find a response surface for instance by "least squares methods" or other interpolation approaches. Some of them have been implemented and compared to the spline $\tilde{\sigma}_x$. Since similar results have been found, these methods are not described in this paper.

Error Discussion and Application

To evaluate the difference between the approximation function $\tilde{\sigma}_x$ and the FE system response $\tilde{\sigma}_x$ one has to find suitable deviation measures either based on the absolute error $r_{absolute}=\sigma_x - \sigma_x$ or the relative error $r_{relative} = \frac{\sigma_x - \tilde{\sigma}_x}{\sigma_x}$. Here, the maximum error, the mean absolute error, or the mean relative squared error at a certain set of test points $(F_{x,i},F_{y,i},F_{zi,}), i=1,\dots,L$ can be used. As mentioned by Schumacher [2] another quality measure is the so called regression parameter R^2 which is defined by

$$R^2 = 1 - \frac{\sum_{i=1}^{L}(\sigma_{x,i} - \tilde{\sigma}_{x,i})^2}{\sum_{i=1}^{L}(\sigma_{x,i} - \hat{\sigma}_x)^2},$$

where L is the number of test points, $\tilde{\sigma}_{x,i}$ the value calculated by FE analysis, $\sigma_{x,i}$ the response surface value and $\hat{\sigma}_x = \frac{\min(\sigma_{x,i}, i=1,\dots,L) + \max(\sigma_{x,i}, i=1,\dots,L)}{2}$ the mean value of the highest and lowest stress. This measure is quite similar to the variance reduction mentioned in [3] for which $\hat{\sigma}_x$ is the mean value of all inspected stress values.

To evaluate the error of the approximation function, the grid points can only be used in the case of the least squares approach. For the interpolation approach the error on the grid points is zero by definition.

Therefore, new combinations besides the grid points have to be calculated by FE analysis. The following table gives an overview of the error between interpolated and FE results for 8 chosen test points.

Load combination	Error	
F_x, F_y, F_z [kN]	Absolute [MPa]	Relative [%]
-27.5, -50, -30	-1.3	-0.6
-27.5, -50, -15	0.9	0.3
-27.5, -15, -30	-2.7	-0.9
-27.5, -15, -15	2.8	0.8
12.5, -50, -30	0.9	0.4
12.5, -50, -15	-3.1	-1.1
12.5, -15, -30	1.5	0.5
12.5, -15, -15	2.7	0.8

Table 1: Error between interpolated results and FEA results.

In all of these 8 test points, the relative error is at most 1%, the absolute error at most 3 MPa. Thus, the interpolation approach was judged to be accurate enough to calculate the stress results for the multi-bolted joint.

By evaluation of $\tilde{\sigma}_x(t) = \tilde{\sigma}_x(F_x(t), F_y(t), F_z(t))$ for all time samples t of the measured loads $F_x(t)$, $F_y(t)$, $F_z(t)$ the interpolation approach delivers time series of interpolated stress results for all interesting positions of each bolted joint.

For each bolt 48 spots have been selected which gives in total 192 time series. Once the interpolation function has been obtained, the effort to calculate these stress time series is only several minutes, even for the long measured time series with over 3 mill. sampling points.

Based on these results, it is a straightforward task to perform fatigue life estimations for the bolts of the structure under investigation. This step is not described here.

Conclusion

In this paper, an extension of the well established linear quasi-static approach was introduced. It could be shown that the interpolation approach can take nonlinear effects into account, in contrast to the linear quasi-static approach.

It was also shown that the error of the interpolation approach was small enough for the bolted joint structure described here.

The overall time spent to obtain fatigue life estimations of the multi-bolted joint could be limited to a couple of days for the structure under investigation.

The time spent for the FE calculations to build up the interpolation basis took nearly 10 days on a single CPU machine. The calculation of the interpolation function took only several minutes. Also the calculation of the interpolated stress time signals at the spots of interest and the subsequent fatigue life estimation can be done very quickly.

Compared to the standard way of performing an FE analysis for each sample point of the measured load time signals, the interpolation approach decreases the calculation time in a tremendous way.

However, the approach described in this article applies only to loads and structures where a quasi- static behaviour can be assumed. Thus, the loads have to be slowly varying compared to the eigen- frequencies of the structure.

References

[1] Verein Deutscher Ingenieure e.V.: „Systematic calculation of high duty bolted joints / Joints with one cylindrical bolt", VDI 2230 Part 1, Feb. 2003, 171 Pages

[2] Schumacher, A.: "Optimierung mechanischer Strukturen: Grundlagen und industrielle Anwen- dungen", Springer, 2005, 308 Pages

[3] Wolberg, J.: "Data analysis using the method of least squares", Springer, 2006, 250 Pages

[4] Wiegand, H., Kloos, K.-H., Thomala, W.: „Schraubenverbindungen", Springer, 2007, 428 Pages

[5] ANSYS 10.0 Online help

a growing community

NAFEMS recently reached a landmark 1000 corporate member companies, a significant milestone in the continued development of our growing and vibrant community. Nicola McLeish spoke to Paul Steward, Head of Business Development, about what this means for NAFEMS and its members, as well what the future has in store for the association.

Tell us more about reaching a thousand member companies!

Well firstly I would like to start by expressing what an exciting time this is for NAFEMS and how thrilled we are to be able to say we are now a 1000 member organisation! This is an extremely proud moment for everyone at NAFEMS and is one we have looked forward to for a number of months. To have reached this number is not only a huge milestone for the business but is also clear evidence of the importance of NAFEMS within the engineering analysis and simulation community. Within each of these member organisations, there can be over 100 individuals, sometimes more, taking direct advantage of the benefits of NAFEMS membership, so that gives you an idea of just how significant the NAFEMS 'family' is in the context of the global engineering analysis arena.

There has been a lot of anticipation internally about hitting the 1000 member mark, and as we have grown closer and closer to that magic number, there's been a great sense of excitement when we've looked at the membership figures. We were closing in on this number at the backend of 2010, and the team were constantly looking at reports and getting really excited about that moment when we would be announcing NAFEMS as a thousand member organisation…. and here that moment is!

What have been the main factors for the recent growth?

I think we have grown consistently in all regions globally, but naturally as we've grown and developed over time we have started to focus on new regions which have not been exposed to NAFEMS as much in the past. This has certainly helped with the membership figures.

For example, we have seen a considerable amount of growth in India, where we launched our regional activities just a couple of years ago. As a nation which appears to really embrace best practice, companies in this region have been really keen to get involved with an organisation like ourselves which has a real focus on best practice. As a result, I think in the last couple of years India has shown extremely strong growth in terms of membership numbers.

However, North America is also really beginning to switch on to NAFEMS. We re-launched our activities there back in 2007, and with the efforts of the NAFEMS team including dedicated representation in the US, we've put together a regional program of events, a North American summit, and an innovative 'virtual conference' in 2010. As a result of that, we really began to grow our presence again in the region. I would suggest that over the past six months, North America has been one of the top performing regions in terms of growth and has definitely helped us in securing a thousand members.

Having said that you've got the other 'core' NAFEMS regions, UK, France, Italy, Iberia and DACH who are all regularly contributing to membership numbers and we are committed to growing the membership in all of these regions year on year. We have managed to do so even in adverse conditions.

Obviously when we enter a region and start co-ordinating local activities, there is a surge in membership sign-ups, but if we look at where our members come from, I think proportionately we are on a pretty even keel. There has been a lot of growth from North America and India over the last 24 months but always with support of the European regions. When we put a new regional steering group in place, there is a bit of an excitement, a bit of a buzz, new events in place and new initiatives. We have something to kick off, to say 'Hey, we're here, this is what we do for your community, be part of us'. That gives us a boost. I wouldn't say it was a 'shot in the arm' as such, but it is something that has contributed to our success of late.

It must be said that, all of growth is driven by the hard-work and efforts of the members of our technical working and regional steering groups. These are the people within the NAFEMS membership who give their time voluntarily to drive NAFEMS forward, and look at pulling together our publications and events. It's great to see so many members wanting to get involved in the groups, and donate their time to the community, and the tireless efforts of these groups is a major factor in the growth of the organisation. The number of people getting involved in this way grows year on year, and it is this growth that allows us to focus on new technology areas and regions. It would be remiss not to mention the NAFEMS Council at this point as well – this group of industry experts is drawn from the membership, and they act as our board of directors, shaping and moving the organisation forward, again on a voluntary basis.

Why are companies joining NAFEMS at the moment?

Although NAFEMS has continually grown and developed, the membership model to this day has not radically changed - what appeals to our audience, to new members, is the same as it was a number of years ago. However, I do think as an organisation we have become more intelligent, and more focused into understanding what new members want to see from the membership. I think to truly understand why companies are joining NAFEMS, we have to look at is the sectors that we actually recruit from, as reasons for joining are extremely varied between these. From vendors to industry to academia – each sector finds something in our membership model that appeals to them.

For a software vendor for example, I think the most appealing aspect of membership is the increased ability to reach out to a new audience and have a platform where they can properly engage with the end users of their software technology. We provide a very neutral arena and a comfortable one for them to do that. Through the membership package, we offer a unique opportunity to engage with that audience in many different ways. For example, one is through benchmark magazine where they can actually talk about different uses of their technology and how it aids the community from their own perspective which can help them reach new audiences. I believe being able to engage with the end user is the most appealing aspect from a vendor perspective.

For those in industry, I would suggest there is so much we can offer. A main attraction is the very real opportunity to be able to listen to fellow engineers, like-minded people who are using the same technology day in, day out, who are very willing to share their ideas within the community of NAFEMS. That's what the membership model offers. Companies are coming to an organisation which allows them to talk to experts from the same industry sector and they can gain an understanding of what is working well for them – truly attaining an insight into the real life uses of simulation and its related technology. I think what's exciting is that real communication with others who are using the same tools as you, experiencing the same problems and frustrations and both being able to learn from that. That is the key cornerstone of the membership product.

Also, With NAFEMS being an independent authority on the use of simulation technology there is a great attraction to those who are just beginning to use technology or even those looking at new ways of using the materials. The depth and breadth of knowledge within the NAFEMS community is undoubtedly appealing to anyone who is fairly new to the area or anyone who has a changing requirement.

Membership also appeals to academics, of course, as it offers a great way to introduce best-practice to young engineers who are up-and-coming and moving out into industry. As NAFEMS has been promoting and encouraging the best use of the technology for over 25 years, there is no better way to do this than through our materials, our management guides, our analysis theories, our reports, and our overall best practice approach. As well as this, membership also provides opportunities for publishing papers, speaking at seminars and conferences, and getting involved with our technical committees which all appeals to a wide range of our members, including academics.

There are a plethora of reasons why our members join us, and each of these is very individual. What I would say is that we do listen to those individual needs and how they change over time. A great example of this would be our introduction of e-learning which has been a huge success and has really been a great point of difference for us as an organisation. This was developed as a consequence of the NAFEMS team listening to our members, and looking to develop products which truly meet their needs and requirements. That is perhaps that is one of the greatest attractions to membership – our ability to listen to the community and its needs.

NAFEMS are working with individuals and organisations that are very passionate about what they do, which is dealing with analysis day in, day out. A great number of members join the organisation and straight away lend their time, efforts and experience to our working and steering groups. That always amazes me – the fact that not only do people want to be part of the community, but that they also want to contribute to the wider cause on a purely voluntary basis. We'd be no-where without such individuals and their passion. As an organisation I feel we meet that passion with the tailored offering we provide and our dedication to all of our members.

Have there been any barriers to growth?

One of the main obstacles that we have all faced is the economic downturn – something which undoubtedly has been huge obstacle for all businesses. In times of uncertainty, one of the first things to be affected is usually the training budget – the cost-centre where a NAFEMS membership fee would usually come from. These budgets are definitely among the first thing to be cut and members have to begin to question whether membership is a luxury or a necessity. 12-18 months ago this was a really daunting prospect and we were very concerned about losing members and the potential increased difficulty in recruiting new ones.

The challenge that we faced was actually making sure that we remained stable whilst still trying to grow as an organisation. However, not only did we maintain membership numbers during this difficult period; we actually increased our overall membership figures. I don't think there is any other membership association that can actually say that they maintained numbers and grew during that tumultuous backdrop – or at least not one that I'm aware of.

Naturally, during any period like this, there were the occasional members who did not renew but what we have found in reality in following financial year is that many of these members have re-joined. I think this is clear evidence that these companies realised they couldn't be without NAFEMS' support and materials. That's actually been really reassuring for us as it's testament to the quality of the membership product. We are clearly bringing value to a lot of organisations and this has definitely been our anchor in this challenging period. Although the economic downturn has certainly been one of our biggest challenges to date, we have actually grown in these adverse conditions, and overall I think that's down to the quality of our offering.

How does NAFEMS grow and develop as membership increases?

I think NAFEMS grows in a very natural way whenever a new member joins. Each member brings something new to the fold which helps us to grow and develop. We really welcome new members, as with more members there are more ideas, and more individuals coming into the community, which benefits everyone. The more members we recruit, the more fresh pairs of eyes we have and the more ideas we have being generated. Listening to all of our members is really important to us and we value what each and every one has to say and the differing perspective they can bring.

We have got to be open and listen to what our members want and the ideas that they have - what types of events they want to see from the association, do they have a say in that? Well yes they do. Again, that's one of the major benefits of membership. We want to listen our community and we thoroughly encourage our members to talk to us, to get involved in our events, to talk to our regional representatives - that way we are constantly evolving to meet their needs.

If there is an emerging interest, say coming from academia or from vendors or from industry, then we need to listen to this. Everyone has an equal say in our activities at that level. We listen to what they've got to say because our members are at the very forefront of this technology. We know from our own point of view what we think we should be doing, but there is no better way to go forward that to listen to our members who can share the benefit of their experience.

What about the future?

I think this is a really exciting time for NAFEMS, and hopefully it is only the beginning. Membership recruitment never stops. I think to have hit that milestone of a thousand member companies is fantastic. When I joined five years ago, we were on about 650 members and at that point we thought it would be great if we could increase it by another hundred or get even to reach 700 members. Since then we have achieved superb growth and now we've got to that magic number - but it won't stop there.

It's something we all buy into, not just in the NAFEMS offices, but in the working groups, steering committees, and all our members who commit to NAFEMS. As our member numbers grow, so does our community and the ideas that are formed within it. As we've moved into new regions and new industry sectors they have brought a whole new viewpoint to the organisation and I'm certain this will continue to happen.

At the moment, there are emerging industry sectors such as bio-medicine and even computer gaming, which will undoubtedly bring a whole new perspective to the mix. There is also a growing need for corporate membership through large companies who have a real thirst for the knowledge that can be gained through NAFEMS. Who knows where this kind of membership will take us in the future? It's certainly an exciting prospect.

As a final point I would like to say that our future really lies with our members and NAFEMS listening to and fulfilling their needs. As we continue to grow across existing and new regions, and different sectors, we will continue to listen to our members and let them shape the future of NAFEMS.

Nicola McLeish
nicola.mcleish@nafems.org

www.nafems.org/involved

ONE

COMMUNITY

OVER 3000

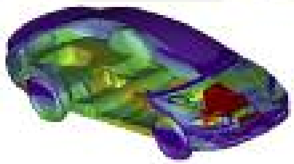
EVENT ATTENDEES

Find out about membership today

NAFEMS

www.nafems.org

icons of CFD



Lewis Fry Richardson

"The Father of Weather Forecasting"

It seems almost inconceivable that Lewis Fry Richardson (1881 – 1953) could have computed the first numerical solution of the partial differential equations governing the weather[1], by hand, and whilst serving as an ambulance driver at the French front in the 1914-1918 war. Yet that is the truth of the matter, for he was an extraordinary man.

Born in Newcastle upon Tyne in the north-east of England, he was the youngest of seven children from Quaker parents. Following early education at Bootham's Quaker school, York, and two years at Durham College of Science (eventually becoming the University of Newcastle upon Tyne), he studied physics at King's College, Cambridge, graduating with a first, in 1903. He remained at Cambridge for ten years, holding a number of research posts and positions in industry. It was while working as a chemist with the National Peat Industry Limited, 1906 -1907, that he was faced with the task of calculating the percolation of water through peat. This is a diffusion problem and so is governed by the Laplace equation, but the difficulty he found was that the boundary of the region had a complex topography, meaning that exact solutions could not be found. In anticipation of his later work in the numerical modelling of weather, he based his solution on a finite difference methodology. Following publication of his methodology[2] he submitted it as a dissertation in a competition for a Fellowship at King's College, but apparently mathematicians from Trinity College were of the opinion that this was "approximate mathematics and were not impressed"[3]. Richardson never returned to Cambridge.

Instead, in 1913, he joined the Meteorological Office, as Superintendent of the Eskdalemuir Observatory, Scotland. It was here that he worked on numerical methods for forecasting the weather, writing a first draft of the book[1] which was eventually to be published in 1922. He resigned in May 1916 and joined the Friends Ambulance Unit in France, working alongside French military ambulances, transporting wounded soldiers, often under shell fire. Over the next two years he refined his numerical methods and carried out the forecast described in his 1922 book, essentially providing the first 'CFD' solution of the Navier-Stokes equations which govern fluid flow. Let us read what Richardson has to say about his computations and in particular his imaginings of a "forecast-factory":

The Speed and Organization of Computing[1]

"It took me the best part of six weeks to draw up the computing forms and to work out the new distribution in two vertical columns for the first time. My office was a heap of hay in a cold rest billet. With practice the work of an average computer might go perhaps ten times faster. If the time-step were 3 hours, then 32 individuals could just compute two points so as to keep pace with the weather, if we allow nothing for the very great gain in speed which is invariably noticed when a complicated operation is divided up into simpler parts, upon which individuals specialize.

If the co-ordinate chequer were 200 km square in plan, there would be 3200 columns on the complete map of the globe. In the tropics the weather is often foreknown, so that we may say 2000 active columns. So that 32 x 2000 = 64,000 computers would be needed to race the weather for the whole globe. That is a staggering figure.

Perhaps in some years' time it may be possible to report a simplification of the process. But in any case, the organization indicated is a central forecast-factory for the whole globe, or for portions extending to boundaries where the weather is steady, with individual computers specializing on the separate equations. Let us hope for their sakes that they are moved on from time to time to new operations.

After so much hard reasoning, may one play with a fantasy ? Imagine a large hall like a theatre, except that the circles and galleries go right round through the space usually occupied by the stage. The *walls of this chamber are painted to form a map of the globe. The ceiling represents the north polar regions, England is in the gallery, the tropics in the upper circle, Australia on the dress circle and the antarctic in the pit.*

A myriad computers are at work upon the weather of the part of the map where each sits, but each computer attends only to one equation or part of an equation. The work of each region is coordinated by an official of higher rank. Numerous little "night signs" display the instantaneous values so that neighbouring computers can read them. Each number is thus displayed in three adjacent zones so as to maintain communication to the North and South on the map. From the floor of the pit a tall pillar rises to half the height of the hall. It carries a large pulpit on its top. In this sits the man in charge of the whole theatre; he is surrounded by several assistants and messengers. One of his duties is to maintain a uniform speed of progress in all parts of the globe. In this respect he is like the conductor of an orchestra in which the instruments are slide-rules and calculating machines. But instead of waving a baton he turns a beam of rosy light upon any region that is running ahead of the rest, and a beam of blue light upon those who are behindhand.

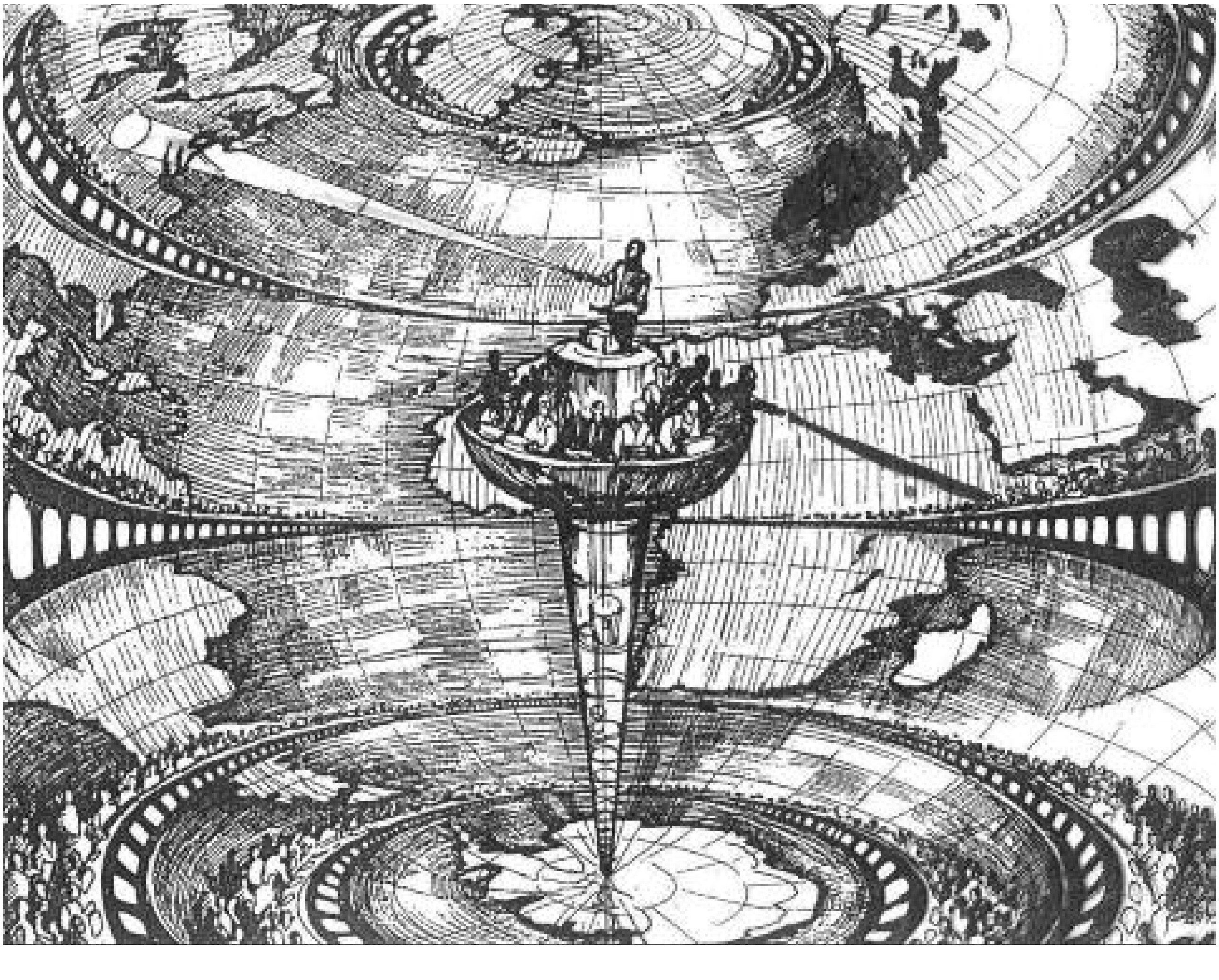
Four senior clerks in the central pulpit are collecting the future weather as fast as it is being computed, and despatching it by pneumatic carrier to a quiet room. There it will be coded and telephoned to the radio transmitting station.

Messengers carry piles of used computing forms down to a storehouse in the cellar.
In a neighbouring building there is a research department, where they invent improvements. But there is much experimenting on a small scale before any change is made in the complex routine of the computing theatre.

In a basement an enthusiast is observing eddies in the liquid lining of a huge spinning bowl, but so far the arithmetic proves the better way. In another building are all the usual financial, correspondence and administrative offices. Outside are playing fields, houses, mountains and lakes, for it was thought that those who compute the weather should breathe of it freely."

This is a remarkable vision, in which 'computer' means only one thing: a human calculator.

During his time in France, Richardson had calculated the weather for a six hour period over Germany, applying a precise and detailed implementation of an algorithm outlined by the Norwegian scientist Vilhelm Bjerknes. It was a spectacular failure, greatly over-predicting the rate of pressure rise. The mathematical techniques were



correct, but we now know that the initial conditions which Richardson used were 'noisy' and needed to be 'smoothed'. In addition, Richardson's computational time-step was too large. Peter Lynch[4] provides an interesting analysis of Richardson's prediction.

Nevertheless, through his audacious calculations Richardson had shown that numerical techniques could be applied to solve what appeared to be intractable physical problems.

Richardson rejoined the Met. Office upon his return from France in 1919. However, when the Met. Office was brought into the Air Ministry at the insistence of Winston Churchill – and the Air Ministry controlled the RAF - Richardson's pacifist convictions meant that he had no option but to resign. He continued his research whilst lecturing at Westminster Training College, where he taught physics and mathematics to prospective school teachers, publishing numerous papers and making outstanding contributions in the meteorological field. He gives his name to the Richardson number; a key non-dimensional parameter for turbulent flows affected by stratification caused by buoyancy. In a meteorological context, the Richardson number represents a ratio of the stabilizing/destabilizing effects of vertical density gradients on turbulent mixing, compared to shear-generated turbulent mixing.

The Richardson number is a crucial parameter in the field of atmospheric dispersion. For his contributions to the field of meteorology, he was elected as a Fellow of the Royal Society of London, in 1926.

It was in 1926 that Richardson completely changed his field of research, to psychology, again making important contributions – in particular in experimental and mathematical modelling methods in the field of sensory perception. In 1929 he moved to the Technical College in Paisley, but from 1935 his research shifted to yet another field; mathematical theories of human conflict and the causes of war. He pursued these studies until his retirement, in 1943, and in the process was first to characterise the irregularity of borders between countries by an index which we now recognise to be a fractal dimension. However, his research efforts did not end upon retirement, as in 1948 he published a key paper[5] on the diffusion of particles in turbulent flow, apparently based on experiments in which he and Henry Stommel threw parsnips into Loch Long – close to his last home.
Richardson was a bold visionary whose work has had a lasting impact. For instance, he devised a method[2,6] for the extrapolation of numerical solutions which is widely used today. However, we finish with a rhyme which he wrote to illustrate the cascade of energy from the large to small scales in turbulent flows, to be found on page 66 of his 1922 book, which incidentally is still in print - as a 2007 second edition with foreword by Peter Lynch.

"Big whirls have little whirls that feed on their velocity, and little whirls have lesser whirls and so on to viscosity"

Lewis Fry Richardson is most certainly an 'Icon of CFD', from the days of 'human computers'.

AUTHOR INFORMATION

Chris Lea | Lea CFD Associates
chris@leacfd.com

Acknowledgement
Much of the material for this article is gratefully drawn from Prof. Julian Hunt's excellent review[3] of the life and contributions of Lewis Fry Richardson.

References

[1] 1. Richardson L F, 1922, "Weather prediction by numerical process", Cambridge University Press.

[2] Richardson L F, 1910, "The approximate arithmetical solution by finite differences of physical problems involving differential equations, with an application to the stresses in a masonry dam", Phil. Trans. Roy. Soc. London, Ser. A, Vol. 210: pp 307 – 357.

[3] Hunt J C R, 1998, "Lewis Fry Richardson and his contributions to mathematics, meteorology, and models of conflict", Annual Review of Fluid Mechanics, Vol. 30, pp xiii – xxxvi.

[4] Lynch P, 2004, "Richardson's Forecast: What went wrong?", Symposium on the 50th Anniversary of Operational Numerical Weather Prediction, University of Maryland, College Park, MD, 14 – 17 June, www.ncep.noaa.gov/nwp50/Presentations/Tue_06_15_04/Session_1/Lynch_NWP50.pdf

[5] Richardson L F and Stommel H, 1948, "Note on eddy diffusion in the sea", J. Meteorology, Vol. 5, pp 238 – 240.

[6] Richardson L F, 1927, "The deferred approach to the limit", Phil. Trans. Roy. Soc. London, Ser. A, Vol. 226, pp 299 – 361. "Part I. Single Lattice." "Part II. Interpenetrating Lattices" by J A Gaunt.

benchmark

the international magazine for engineering designers & analysts

Published quarterly by NAFEMS, benchmark is the only truly independent publication geared towards the analysis and simulation community. Read by some of the world's leading organisations, across a wide range of industries, the magazine is truly a benchmark of the community and an essential read for all engineering designers and analysts.

Subscribe Now

ONE
NAFEMS
THE INTERNATIONAL ASSOCIATION FOR THE ENGINEERING ANALYSIS COMMUNITY

Find out about membership today

NAFEMS

www.nafems.org

Date	Event	Location
Feb 2 2012	International Simulation Conference of India 2012	Mumbai India
Feb 12 2012	SolidWorks World 2012	San Diego USA
Feb 22 2012	PLM Innovation 2012	Munich Germany
Mar 8 2012	LMS Nordic User Conference	Gothenburg Sweden
Mar 19 2012	STAR Global Conference 2012	Amsterdam Netherlands
Mar 19 2012	PLM 2012	Orlando USA
Mar 20 2012	European Conference on Spacecraft Structures, Materials & Environmental Testing	Noordwijk The Netherlands
Mar 28 2012	ESI India Forum 2012	Pune India
Apr 17 2012	Vibro Acoustics User's Conference & Aero-Vibro Acoustic Special Interest Group	Duesseldorf Germany
Apr 26 2012	ANSYS Austria Conference & 7th CADFEM Austria Users' Meeting	Vienna Austria
May 7 2012	Siemens PLM Connection Americas' User Conference	Las Vegas Nevada, USA

www.nafems.org/industryevents