ENGINSOFT

futurities

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The Simulation Based Engineering & Sciences Magazine

SPOTLIGHT

Living innovation forward

- Editor's Note

This year marks EnginSoft's 40th birthday! To celebrate the fact, our **Spotlight** in this issue reviews the birth, evolution, and growth of EnginSoft from its embryonic days through to its current status as a world leader in knowledge and technology transfer in the fields of engineering digitalization and simulation-based engineering sciences. It also traces the evolution of engineering simulation software from its clunky, clumsy early versions that were only usable by true nerds, and by risk-embracing fanatics and true believers, through to the highly sophisticated and fully democratized versions that grace our work surfaces today. It has been a crazy, fun, stimulating journey generously spiced with mutually rewarding collaborations of both technical and commercial nature, fascinating research and innovation undertakings, and massively challenging engineering projects. Given the chance, we would definitely do it all over again – and we look forward to our next forty years that are sure to be even more exciting, challenging and rewarding, considering the current state of play of technological evolution.

It was with all of this in mind that we began choosing a cover design for this issue. We wanted something that captured the essence of innovation and engineering but that still allowed for manifold interpretations by the viewer. We would like to think that the cover we chose does just that: the spiral design stimulates many ideas relating to engineering – from materials science and structural engineering to CFD studies of vortices both liquid and aerial and more. Obviously, the spiral is also strongly associated with the Fibonacci sequence and its numerous connotations to physics, number theory, algebra and geometry, as well as to computer algorithms, biology, art and, of course, design. The mosaic, a word with Medieval Latin (mosaicum, musaicus) roots meaning "work of the Muses", stimulates thoughts of art, design, creativity, teamwork, concentration, focus, multiple disciplines, diligence, mathematical precision and more. This was the design that we felt captured, exemplified, and best transmitted the ethos that is EnginSoft's approach – both in the past and into the future.

Our **Know-how** section has an interesting article from Dallara Automobili that examines the use of Particleworks to model fuel tank sloshing to achieve better performance in motor racing cars. Our **Research and Innovation** section contains an update on the EU LIFESAVER project, which aims to create a clone of prenatal conditions near the placental interface to measure the risks of foetal exposure to drugs and chemicals. There is also an EU FF4EuroHPC project case study from Spanish plastic profile manufacturer Soprefa. The FF4EuroHPC funding and support produced a framework to enable the company to automatically optimize its extrusion dies for the production of plastic profiles that are widely used in industry.

This edition also includes a **Face-to-Face** interview with Daniel Campbell of Capvidia on model-based definition (MBD) and its potential for the future of digital manufacturing. The **Technology Transfer** section in this issue contains three interesting articles. The first article is from the University of Pisa and is based on a master's thesis in automotive engineering that examines the implementation of a hysteretic tyre model for radial dynamics to improve the reliability of multibody simulation. The second article, from Pierburg Pump Technology and Rheimmetall examines thermal management strategies, particularly the characteristics of 3D thermal analysis, to address the challenges of developing electrified motors for the automotive sector. The third article, from Endurica, continues the theme of examining the differences between fatigue analysis of metals and rubber, this time from the perspective of their thermal behaviour.

I would like to conclude by wishing you and your teams and families our very best wishes for the festive season on behalf of all of us at EnginSoft and to thank you for your support, collaboration and contributions – in whatever capacity and for however long – over the past forty years. It is our fervent wish that you will continue to be a part of and play a role in our next forty years!

Stefano Odorizzi

Editor in chief

"It is our fervent wish that you will continue to be a part of and play a role in our next forty years!

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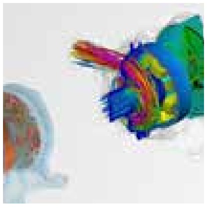
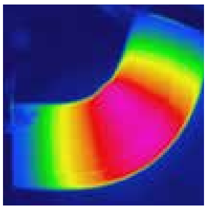




FACE TO FACE

SPOTLIGHT

Of timelines past and present

Twenty twenty-four (2024) marks EnginSoft's 40th anniversary, as well as the 40th anniversary of the International CAE Conference, and the 21st birthday of EnginSoft's *Newsletter*, now called *Futurities*. In our **Spotlight** article, EnginSoft co-founder, Stefano Odorizzi looks back over the key events, projects, and engineering software and technology developments that have occurred during the company's evolution over these four decades. But what was the global context within which this happened?

In 1984, the world population was just under five billion people, compared to today's more than eight billion people[1]. Apple launched the first Apple Mcintosh computer[2]; Raf released the song "Self Control" which was also covered by Laura Brannigan and became a commercial success in Europe that summer, while Queen released "Radio Ga Ga" which reached number one in 19 countries; South African anti-apartheid activist Bishop Desmond Tuto won the Nobel Peace Prize[3]; British geneticist Alec Jeffreys accidently discovered what he later called "DNA fingerprinting"[4]; and Ronald Reagan was elected for a second term as US President.

Back then, personal computers were mostly Commodore 64s and Apple IIs. It was also the year the first mobile phone call was made, on the Vodaphone network, although individual mobile phone ownership was still very rare, and the devices were as large as bricks – landlines and coin-operated pay phones were in common use. By comparison, according to the Digital 2024 Global Overview Report, in January 2024, there are 5.61 billion individual mobile phone users[5] in the world. During the Eighties, the Kennedy Space Centre in the USA launched 32 space shuttle flights and GE Aerospace launched and continued developing its F110 jet engine, which to this day still powers the American military's F-15s and F-16s, as well as other countries' fighter planes[6].

The year 1989 was an important year: the Berlin Wall fell, and Sir Tim Berners-Lee invented the Internet. By January 2024, more than two-thirds (66%) of all people in the world – 5.35 billion people – use the Internet4. 2002 saw the arrival of the Euro currency in circulation. Two years later, Mark Zuckerburg launched his first version of Facebook in the USA at Harvard University where he was a computer science student. Today, there are more than five billion active social media user identities, which equates to 62.3% of the global population4 and represents a growth from 2023 of 5.6% or 266 million identities.

Nowadays, we shop online and have our purchases delivered 24 hours later – in some places, even by drone; we read books and watch films online and compile the soundtracks of our days, years and lives on a digital streaming service as opposed to the old cassettes that required you to press the forward or rewind buttons on your cassette player to get to the right song. We can even go for days or weeks without ever having to leave our homes, thanks to remote working, high speed internet connectivity, online grocery shopping or food delivery services.

Much has changed and will continue to change. Yet through it all, EnginSoft has steadfastly remained, facing the risks and the inevitability of evolution in all its aspects and implications, with the conscious enthusiasm that challenges can be met and overcome through the artful application of skill aligned with the development of specific knowledge and the purposeful selection of technologies and techniques to solve the particular problem in hand. This has made the company and its network a safe and reliable space for customers and collaborators to find the resources, the skills, the support, and the guidance, as well as the attitude necessary to create innovative solutions – for now and the future.

Please note that the *Spotlight* feature includes contributions from some of the significant people that have been associated with EnginSoft over the years. We included the contributions that were received in time for publication after extending an invitation to all our partners and collaborators – past and present.

The main article mentions both open source and commercial technologies that in some cases are no longer on the market, in other cases have been acquired and/or have changed their names, and in all cases are trademarks or registered trademarks belonging to their respective owners.

[1] www.worldometers.info/world-population/world-population-by-year/

[2] www.britannica.com/money/Apple-Inc#ref377817

[3] www.nobelprize.org/prizes/peace/1984/tutu/facts/

[4] geneticsunzipped.com/transcripts/2020/3/26/the-accidental-discovery-of-dna-fingerprinting

[5] datareportal.com/reports/digital-2024-global-overview-report

[6] www.geaerospace.com/news/articles/rebirth-classic-f110-engine-celebrates-40-years-continuous-production-and-renaissance

Simulating tomorrow's future today: Forty years of EnginSoft and counting

by Stefano Odorizzi
EnginSoft

If I had to say in a nutshell why the numerical approach to the physical continuum in the various domains has the quite clear centrality and impact in engineering applications that it does, I would have to nominate the extreme simplification and incomparable amplification of the practical application possibilities resulting from turning a system of partial differential equations into a system of algebraic equations.

From apples and pears…

If this were true, as a young boy I would have foreseen that I would found EnginSoft, especially after I discovered the solution to a simple mathematical word problem before we were taught it at school: on Monday my mother goes to the market and buys 2kg of apples and 2kg of pears, spending 2,000 lire; on Tuesday she buys 1.5kg of apples and 1kg of pears, spending 1,200 lire; how much do apples and pears cost per kilogram?

It was exciting, especially because the mechanism (today we would say algorithm) I had found seemed to work irrespective of whether my mother bought grapes or plums as well as apples and pears – it only required more effort.
Later, when the teacher gave us more information about systems of algebraic equations and tried to stimulate us by mentioning the six hundred equations that were solved to define the wing profile of the G91, I imagined a crowd of mathematicians armed with chalk and erasers hunched over a blackboard the size of a town square.

Much later at university in the early 1970s, when I had access to CINECA's CDC 6600 – then the world's fastest supercomputer with performance of up to three megaflops – I dreamed enthusiastically of ever-expanding frontiers, although I never imagined that working with a few tens of millions of equations would become the routine that it is today.

In the beginning, and in my thesis, these ever-expanding frontiers mainly took the form of civil engineering applications, where it was relatively easy to describe structural frameworks because interaction with the computer was only possible via punched cards. It was much more complex to work formally with finite elements, which were just starting to emerge.

EnginSoft was founded in 1984 as a more structured expression of an earlier team that formed in 1975. I would like to describe this nucleus as if I were telling the beginning of a fairy tale. The starting point was work done for the two nuclear power plants at Mantua and Trino Vercellese for which we had to document the readings from numerous piezometers around the target sites with summary tables and highlight them with contour plots. The data was collected by a large number of casual workers, mostly students, and transcribed onto punched cards by an equally large number of casual workers - a process that made filtering out errors a challenge; even ensuring that the tens of thousands of punched cards did not deteriorate was a problem.

That was the beginning.

From there on, still in its embryonic stage before the establishment of EnginSoft, the initiative developed in two directions: the use of a supercomputer for finite element modelling; and the use of one of the very first fully algebraic desktop calculators, the HP9825A, purchased by the company in 1975.

Onto expanding horizons

For finite elements, the "commercial" packages available at the time were:

- NASTRAN, produced by NASA in the late 1960s.
- SAP (Structural Analysis Program), originally released in 1973 first as SAP II and then as SAP IV, produced by the Earthquake Engineering Research Centre of the University of California in Berkeley.
- STRESS and ICEM for applications closer to civil engineering.
- ANSYS, first released in 1971, but which came to Italy much later.

I mention SAP (described as "A Structural Analysis Program for Static and Dynamic Response of Linear Systems", and that later included non-linear parts in the 1974 NONSAP version) because it included the source code: there were just over 600 Fortran instructions for SAP2, just over 2500 Fortran instructions for SAP4, and just over 4000 Fortran instructions for NONSAP!

It seems incredible but even with such a minimal core it was possible to develop models of a few thousand equations from one to three dimensions in static and dynamic analyses (even seismic, both in time and frequency domains!) and with some material and geometric non-linearities.

In addition to the SAP commercial computer code, those of us in the sector who dealt with finite elements ended up producing their own codes, either using a sort of meta-language to perform recurring operations on the matrices (SMIS in our case), or using semi-analytical or semi-numerical methods (finite prisms and finite strings, e.g. PRISM) or using programs intended for specific applications e.g. LUSH, FLUSH and later PLUSH probabilistic software for seismicity in a nuclear environment – codes originally developed by Prof. J. Lysmer of Berkley and approved by the International Atomic Energy Agency (IAEA) in 1975.

These were all programs whose source code was available, and which could therefore be adapted for the application or extended with new functions and algorithms. For our own developments, coming from the school of Olgierd Zienkiewicz, we almost immediately discovered (and it was like finding Columbus's egg) iso-parametric elements based on the elementary idea of using the same shape functions to approximate the expansion of displacements within the finite element, and to map the element itself in space.

A radical simplification, coupled with the idea of using polynomial shape functions and performing the necessary integrations numerically, made it possible to reduce the construction of the resulting stiffness matrix (and thus the resulting system of equilibrium equations) to just a few Fortran instructions and a few recursive operations: this opened the door to a universe where it was easy to quickly construct one's own finite elements according to the specific application required. In those early days we used the aforementioned CDC 6600 for our calculations.

Seeds of innovation

Alexander von Humboldt was at first astonished by a letter he received from his great friend Goethe responding to his doubts. For many months, von Humboldt had been unable to form a complete and organic view of the immense amount of data he had collected measuring, observing, and cataloguing the diversity that South America's rich natural world had offered him. Goethe had suggested to him that the only way to make sense of this ocean of numbers and notes was through... poetry.

As a passionate researcher and scientist, von Homboldt found it difficult to process this valuable advice immediately, but in his great and highly motivated admiration for Goethe, he reflected deeply on its meaning. Over the past few decades, I have often wondered how such advice would resonate with managers or business leaders, both of whom are overwhelmed by ever-changing technology and the relentless race for results against the competition.

Von Helmboldt finally succeeded in understanding and translating Goethe's meaning leading to the creation of a new vision of his own. Nature as we knew it ceased to exist. The cultural and scientific consequences of this breakthrough were as immense as the amount of work and effort involved: maps of new territories unknown to Europeans and the classification of thousands of new animal and plant species, but above all a new vision of the interplay between all the elements of nature and a new approach to the complexity of the world.

It was the beginning of the eighteenth century, and even today the value of Humboldt's discoveries should be reassessed. Certain innovations take a long time to transform the culture of one or more civilizations. There remains the very relevant testimony of both the *method and the process that made it effective and, in a sense, eternal.*

Today, like then – and even more so – rivers of data and calculations flow into process control and management, adding to the oceans of numbers and calculations generated for every activity. While there is no shortage of technology, and indeed we are producing ever faster and more effective technology, one senses that the "poetic" contingent is decidedly inadequate.

By "poetic" I mean the ability to imagine and describe a structured holistic vision of reality by combining information and analytical elements with one's own personal intuitive hypothesis about the possible trajectories of a new reality.

Goethe urged von Humboldt to develop an over-arching idea by giving free rein to his intuitive capacity to initiate a synthesizing process capable of intelligently incorporating the objective data derived from his observation of the phenomena he was studying. The technological field, however useful and often astonishing, exposes us to the danger of underestimating the importance of feeling and human intuition.

For a few decades now, we have been living through an anthropological transformation of enormous proportions, resulting specifically from our ability to generate and disseminate information through images of all origins. Some scholars have already classified this new condition by changing the label from homo sapiens to homo videns.

The cultural impact of this new dimension will be better observed in the coming decades, but the change that is taking place is already evident, both in the quantity and the speed of its diffusion.

In these few lines, I do not intend to address the monumental question of the nature of knowledge and the ways in which it can be distinguished. However, it is incumbent upon us to remember that the question of knowledge from the ancient Greeks to the present is far from being exhausted and resolved, and it will certainly not be technology and the incredible developments of its most advanced applications that will free man from his inescapable role as a thinking being.

In contrast, today's innovation might be to return to writing with a fountain pen or quill and inkwell, rather than stimulating our five senses with sensations and experiences we have never had before. One could implement personalized and gradual periods of screen reduction to achieve a kind of planned visual "diet" over time, as the effects of overexposure to images are already changing the cognitive attitudes of new generations. In short, we need to realign human priorities in the face of continuing technological dominance.

The tsunami of images and information that is sweeping over us all has noticeably and generally reduced the moments of reflection and assimilation of knowledge, and this new pervasive norm does not facilitate the development of authentic personal development paths.

One statistic in particular should give us pause for thought: the growing phenomenon of the so-called "return to illiteracy", which particularly affects highly qualified professionals such as doctors, engineers and architects, who have been identified as the categories most prone to the inability to translate and interpret more or less complex texts outside their specific field of expertise.

Experience has shown that the digitalization process and the transition to 4.0 have encountered enormous difficulties in many companies, and that the process of retraining and adapting the available and necessary human resources to organize work comfortably and efficiently is still long and bumpy.

In recent years, I have appreciated the many initiatives that EnginSoft has launched to promote the exchange of ideas and experiences among companies and professionals involved in digital transformation. They have always been very stimulating occasions, characterized by the awareness that a mix of different skills and experiences offers a great opportunity to understand both the critical issues and the most beneficial and useful ways to address the great cultural revolution that is underway.

In particular, I have always appreciated EnginSoft's natural inclination to emphasize creativity and human intuition in the process of analysing and solving the "challenges" that needed to be addressed from time to time.

The ability to observe, measure, and develop simulation models of processes in different domains requires a multidisciplinary approach that encourages the exchange of different skills and, consequently, a holistic view, even if it is aimed at areas of great specialization. In the experience of EnginSoft, I see a continuity of the approach and method I mentioned earlier in reference to Alexander von Humboldt and his extraordinary discoveries.

Without detracting from all the aspects that need to be considered when we talk about innovation (the time, cost and critical mass needed to face the challenges of increasingly sophisticated and predatory competition), I think it is really necessary to pay more attention to the mother of all innovations: humanity.

by Giovanni De Luca
Former Director of RAI Veneto

At the same time, and in a slightly different way, we were using the HP9825A (marketed as a fully algebraic desktop calculator). A very expensive gem at the time, it had language (HPL) and computer-like capabilities that made it a kind of precursor to desktop computers. It offered array functions (that could be multidimensional and dynamically defined), cross-references, subroutines with parameter passing, local variables and multiple returned parameters, and more, such as keywords like prt (print) and gto (go to) which could jump to line addresses or labels.

This marvel that had "up to" 600 indexable memory locations ("r" registers), an interface consisting of a display with "up to" 36 characters, and a tape drive (actually a magnetic card) capable of storing 250kb, enabled us to perform real miracles. For example, starting from the basic assumption of finite elements i.e. imposing geometric congruence by deriving equilibrium as an application of the virtual work equation, we firstly developed the beam on a bed of independent springs (Winkler model), then the slab for airport pavements (Wieghardt model), and then with the same 1D logic connecting beams and rings treated with the Boyle-Mariotte law, the analysis of tanks with axial symmetry, and so on.

Taking inspiration everywhere

Inspired by the static condensation used in FEM models, we were able to deal with the dynamic response of complex buildings by reducing them to three degrees of freedom per floor, constructing a stick model for the cyclic condensation of frames and, in the case of stair or lift cages, applying Rosman's method. In a sense, we were also able to develop the first applications of digital manufacturing, for example to plan production of casting lines for precast concrete slabs or to optimize machining sequences for custom-made window frames.
Another memory illustrating our ability to make do with what we had is how we managed to "transform" a dot-matrix printer – one of the first to appear on the market in the 1970s – into a graphics printer by cyclically programming the dot-matrixes, which in turn were treated as sub-matrices of the successive lines of special characters available on the sheet.

Based on this knowledge and these methods, which we understood and had tested to the limit, Alberto Mezzena, Gino Perna, and I founded EnginSoft in Trento in 1984, with Cementi Riva as our industrial partner, convinced that the time had come to offer independent computer simulation services. Initially we conducted the calculations remotely on CINECA's CDCs (with card readers) or we would pay a group visit to Bologna to CINECA's headquarters when the urgency or formal complexity of the models to be developed made this necessary.

Shortly afterwards, we equipped EnginSoft in Trento with a VAX-11/750, one of the first to be marketed in Italy, making us completely self-sufficient. Admittedly, this step was a demonstration of our conviction, determination – and an enthusiasm bordering on recklessness, given the exorbitant cost of the computer and the difficulties of managing it.

To me, EnginSoft is a "faith" that you hold on to because you believe in it – it is and always has been for me, despite the storms I have encountered over the years. In fact, it is only this faith and trust that allowed me to always find an open door here -- even after certain decisions have taken me away from a place I have always considered my home.

EnginSoft is a work-life project entailing far more than just the economic aspect. It is a project that brings people together to work together for common purposes and not just as a place to pursue a career, a project bringing together different minds to deal with different issues on a daily basis, with the only common denominator being an approach very close to that of applied research (EnginSoft's involvement in various capacities in different national and European research projects is proof of this).

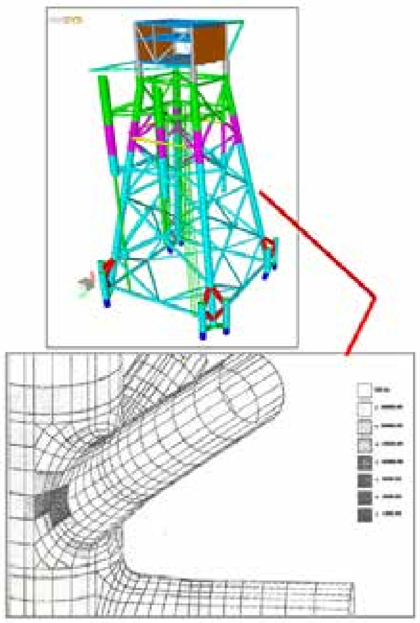
The company was born from the resolute and firm conviction of a single individual (Stefano Odorizzi) that numerical simulation was the touchstone to support, grow and guide the various forms of engineering projects, processes and product choices. And I believe that, as a project, it cannot be ignored, precisely because of its multifaceted nature, which is the lasting legacy of its founder's courage and foresight in creating a company that is a leader in the sectors in which it operates: the sale of software with high scientific content, technical-scientific consultancy, training, and the development of research projects.

Odorizzi's overall vision is still profoundly necessary to transform EnginSoft from what it is today to what it will become, without abandoning its fundamental and founding characteristic, which is first and foremost (at least for the author) technical-scientific and dedicated to the dissemination of knowledge so that its customers can grow in competence and competitiveness.

So, before losing our memories and focusing our gaze only on aspects of mere economic growth (which should not be overlooked anyway), I believe it is important to remember that the history of the company, the laboratory of ideas and the real opportunities on which we have bet and are betting by investing ourselves, is created in the first person by those who have the heart to seek, the hands to do and the head to think.

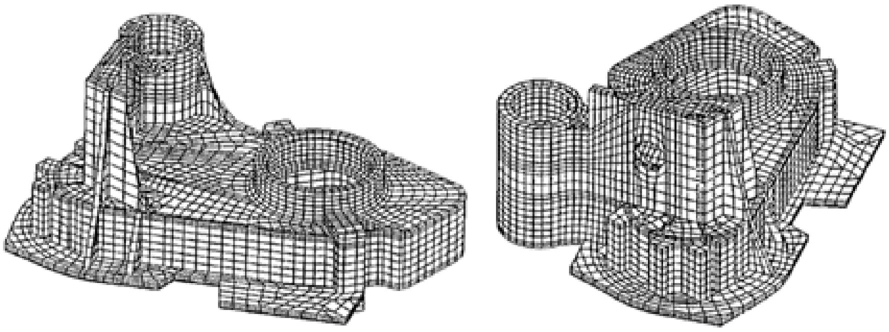
by Livio Furlan
EnginSoft

As we were all qualified civil engineers, we initially focused our efforts on the civil sector, where the use of simulation methods (in particular FEM) was envisaged and/or permitted in the following fields: seismic engineering, nuclear engineering with a focus on seismic aspects, and offshore engineering, mainly as a result of the initial exploitation of oil reserves in the North Sea. Back then, FEM was beginning to be mentioned in the technical specifications for installations crafted by highly scientific commissions and even in some regulations such as those issued by the American Petroleum Institute (API) and by Det Norske Veritas (DNV).

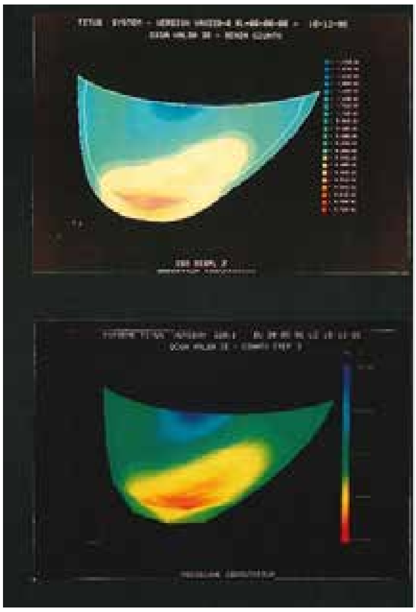


1989: Fatigue analysis of forged nodes for a jacket structure. Damage calculation from the bivariate (Hs-Tz) distribution of sea states. The black and white figure is the fatigue life in years and refers to the original application, which then became the ENI-Tecnomare method.

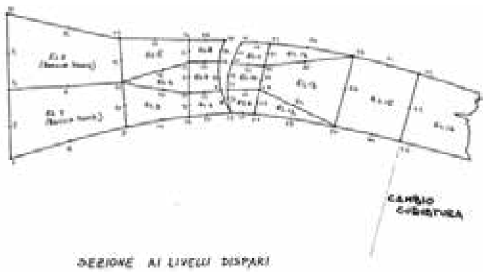
Recognition of EnginSoft's expertise in offshore projects in the North Sea.



1992: Fatigue analysis of a gearbox (Systus appl. 12179 parabolic elements). The model was aborted after running on a Digital Vax workstation for one week due to a power failure and was… restarted.



1987: Analysis of edge joint effect on a dam (TITUS).



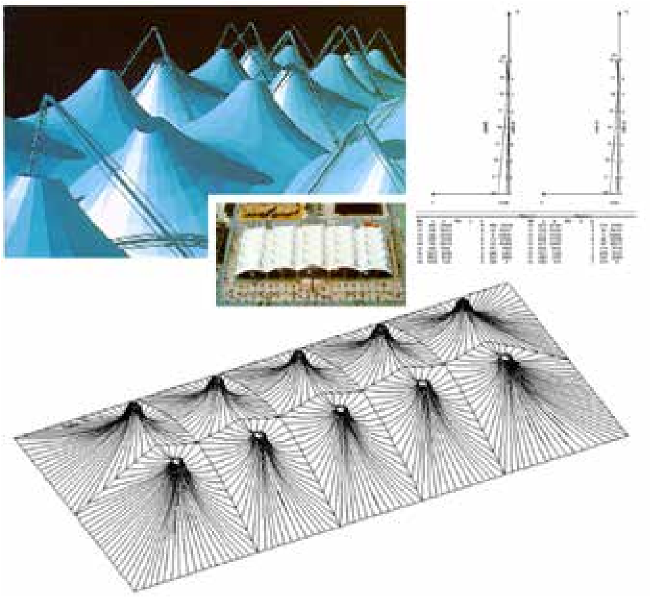
At the time, we were contacted by Framasoft, a subsidiary of Framatome (now Areva), an international leader in the nuclear sector, inviting us to promote their Systus software in Italy (which was then known as TITUS). We immediately accepted because we deemed the demand for specific applications for the nuclear sector to be considerable, and because we were familiar with NONSAP, the original Systus framework. We were convinced that Systus could be the European answer to commercial CAE software. In addition, Systus had been installed almost immediately on the first graphics workstations (produced by Apollo Computer, a company later acquired by Hewlett Packard in 1988).

Different kinds of shells

I cannot help but recall a few anecdotes from those early days.

The first concerns Ferrero's Mon Chéri chocolates. I was contacted by a Ferrero technician who asked me cryptically if we "had any experience with shells". In FEM, the shell is a special element because if the surface represented tends to zero curvature, there is numerical instability in the so-called drilling degrees of freedom. At the time, this was a problem that "experts" knew how to solve with more or less plausible workarounds. Assuming that it would be applied to a mechanical component, based on my previous experience, I replied: "Of course." Imagine my surprise when I discovered that it was the shell of the Mon Chéri, whose geometry had to be slightly corrected to extend the time between production and consumption to avoid the tendency of the sides of the shell to become concave due to the evaporation of the alcohol inside and the ambient conditions!

Still on the subject of shells, this time in non-linear applications, I remember the models for the plastic containers of Coccolino fabric softener (still used today) and problems of



1982: Canopy project for Ortona Tensostrutture Note the sheet cutting list, which is crucial to avoid wrinkles in the canopy upon assembly.

deformability, labelling and storage. A more complex challenge was the model for the mirror of the Giotto satellite, launched in 1986 to follow Halley's comet, which had to be optimized for lightness while simultaneously meeting the rigidity requirements essential for optical quality.

From those early days I remember how we developed one of our computational codes (derived by Gino Perna from a code I had written to calculate tensile cable structures) to study shapes, right through to the executive design (including shape design, cutting and joining of the fabric) of structures composed of sheets and cables, which was widely used, especially in Spain.

The graphical user interface and (somewhat later) 3D geometric modelling facilitated the creation of complex geometric models typical of mechanical engineering. The demand for FEM applications in mechanical engineering was – and still is – much higher than in civil engineering because design in that sphere is driven by the urgency of time-to-market and being the preferred product in the marketplace over competitors. Furthermore, with a few exceptions, the designed product is a slightly optimized variant of its previous version with respect to optimality criteria that may be either technical, functional, aesthetic or cost related. The data obtained from direct experimentation can be supplemented or replaced by the computer model.

That is why, at the time, we spoke of digital prototyping and/or digital testing as an extension of geometric digital mock-up. At EnginSoft, we coined the term iDP (intelligent digital prototyping) – and even included it in the company's mission statement – to emphasize the added value we offered over “conventional” DP, using the model in a kind of “design by analysis” guided by the pursuit of specific objectives.

While the interactive graphics were good, it was more difficult to produce colour versions of the calculations. Anecdotally, we solved the problem by photographing the computer screen, avoiding reflections and so on by wrapping the camera and monitor in a light shield made of black rubbish bags, and optimizing the lens aperture and exposure times accordingly.

CFD adventures

Shortly after the formation of EnginSoft, we began to use simulation in non-mechanical areas. In computational fluid dynamics (CFD), Professor Spalding was the reference and his software, PHENIX, was the tool used. PHENIX had its first commercial success when it was promoted by CHAM, a company founded by Prof. Spalding himself. Initially we only used it in a university environment and later used its more user-friendly derivatives (such as easyFLOW) for consultancy and services.

Among the very first applications at that time, I remember the problem of fire detection and suppression in spacecraft, which was particularly complex because it involved a zero-gravity environment. After easyFLOW, CFX-4 (produced by AEA Technology and a successor to Flow3D) was the first code chosen by EnginSoft because it was sufficiently rich and structured to be fully used in CFD applications.

To complement it we started using TASKflow (later acquired by AEA itself) in the early 1990s particularly for turbomachinery applications as well as various meshing tools and applications in specific contexts. CFD quickly became a flagship for EnginSoft due to the high level of expertise required (and expressed by us) to carry out applications in various fields, from aerodynamics to combustion and process chemistry.

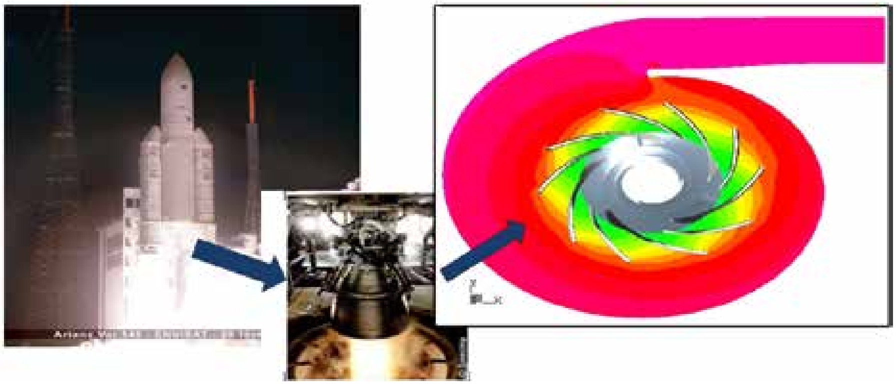
In the field of acoustics, we opted for LMS International technology in the early 1990s: SYSNOISE for the study of sound radiation and RAYNOISE for the study of room acoustics. SYSNOISE uses the boundary element method (BEM), which is suitable for solving linear partial differential equations formulated as boundary integrals. It is almost impossible to use FEM in this field because sound radiates

Do you remember the days when we used to use Boolean operations?

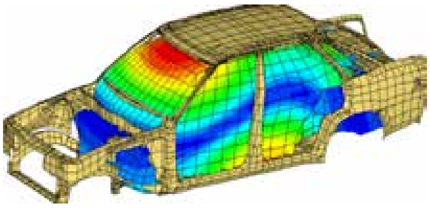
This question, dear Roberto [Gonella], is a testimony to our strong and long-standing relationship since the early 1990s. Back then I was working at Riva Calzoni (the first Ansys client in Italy) and we worked together on industrial applications problems that would not have received the necessary, and in some cases indispensable, in-depth study without the aid of finite elements – an absolute innovation in the engineering approach available at the time.

Looking at the evolution of the software – which has been impressive yet is based on the same principles and approximations as in the beginning – one wonders how essential the vision and passion of people like us has been in making engineering simulation a "method" (if not the method) in industrial design processes.

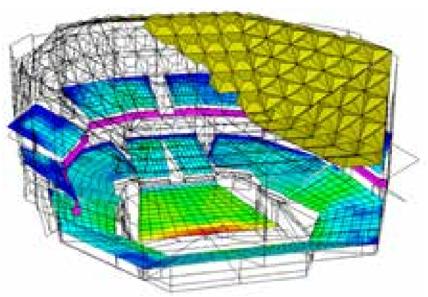
by Roberto Borsari
Former Director of Forming Technologies at Tetrapak in Modena



1999: Arianne LOX turbopump.



1991: Vehicle cabin acoustics (SYSNOISE).



1991: Acoustic response of a theatre (RAYNOISE).

outwards into space, which cannot be discretized with FE; RAYNOISE uses the ray tracing method. For acoustics in large open spaces, techniques based on the statistical treatment of acoustic energy are used instead.

About FEM, how to FEM, and beyond FEM

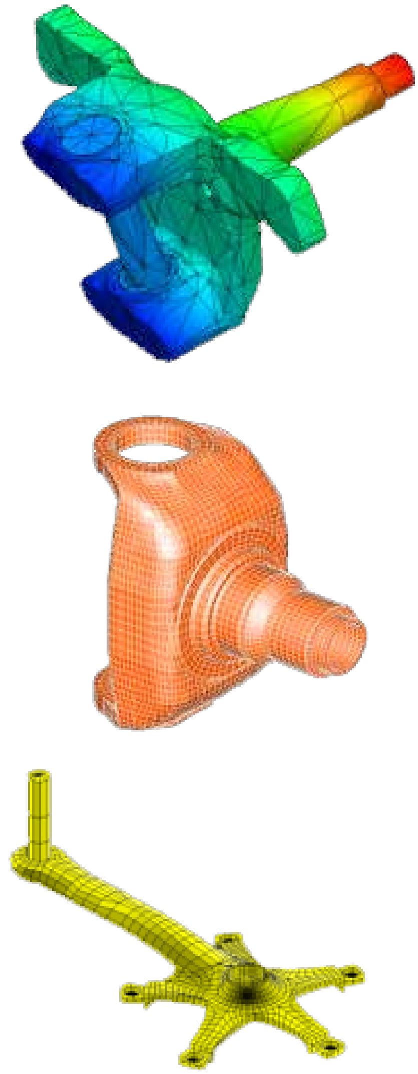
The extension of applications to different physics and domains, but also within the same domain, involves the use of different numerical methods, which in turn require different skills and different modelling methods. FEM dominates the problems of the mechanical continuum, finite differences, and control volumes those of fluids, boundary integrals those of acoustic radiation, and so on… To highlight this aspect, I would like to mention two cases that have become particularly important for us among the various initiatives and partnerships with software technology producers that we launched at the time.

The first is the RASNA software package. Founded in California in 1987, RASNA was one of the fastest growing private companies in the US. We came across it by chance and were intrigued by the basic idea of the technology: that of replacing the shape functions used in conventional finite elements with series developments in which the number of terms in the series is increased in an iterative process, evaluating their convergence by deformation work. In a sense, it extended the “old” finite prism or finite string methods to three dimensions.

The person who had briefly introduced the method described it as quite simple but easy to use, and therefore suitable for general studies and for non-experts. Gino Perna and I could not resist our curiosity and went to the RASNA office in the USA to find out more.

It was an exciting week. Exciting for us, because we realized that the correct choice of subdomains and the correct control of convergence made the method potentially much more accurate and precisely controllable than traditional FEM. Exciting for our hosts, who said they had never met people so mentally prepared and able to identify the exact commercial fit of the method, its merits and its flaws. We celebrated this combination of interest and curiosity at festive dinners over the lobsters and crabs proudly proposed to us by the CEO, accompanied by an expensive Barrique Chardonnay. And so, we began to use and promote RASNA.

It must be said that the same classical schools of FEM later christened the method the P-element or geometric element method (the traditional one being the H-element method) and recognized its "super convergence".



1989: Models developed with RASNA Pro-MECHANICA compared with FEM models developed with Systus according to the modelling guidelines (images obtained by photographing the screen).

In the dynamic domain, for example, in the case of the H-method, the eigenpairs usually extracted by iterative methods such as subspace iteration – necessarily and only converge to those possible for the mesh used and may therefore be far from the physically true ones. It is possible to find out how far apart they are by repeating the calculation several times, but with gradually refined meshes that respect a convergence criterion such as that of Melosh: a path that can be formally quite complex and artificial compared to the most users' habits.

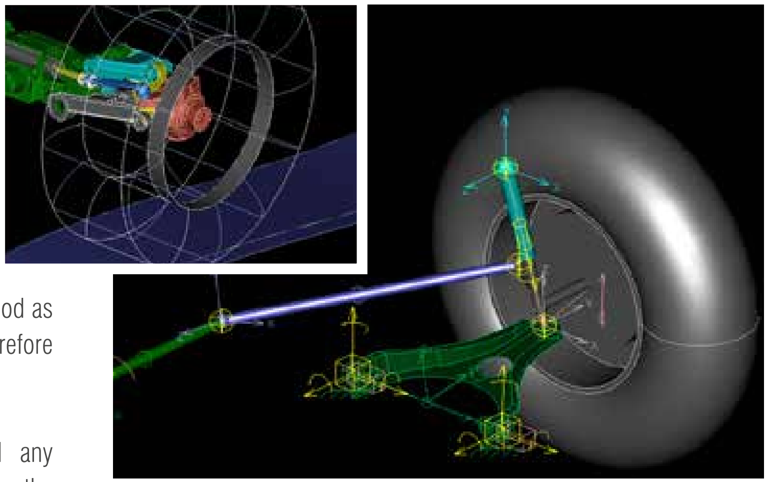
With P-elements, convergence to the physically correct solution is almost “automatic” by the nature of the method, which would seem to favour this method and make it very easy to use. Obviously, this is not the case for three reasons: 1) because the matrices produced are much denser than those of the H-elements, 2) because of the convergence checks necessary to avoid impractical computation times and endless loops, and 3) because of the choice of subdomains.

RASNA also made it possible to create models of multi-body structures without considering the deformability of the components but allowing optimization studies to be conducted.

For EnginSoft, RASNA was a unique experience: we were the first to use it in Europe, and we were the most successful distributor with a specific marketing approach that earned us worldwide recognition (we went so far as to organize the first international congress on the method in Venice in 1994).

But RASNA also turned out to be an adventure that eventually presented us with serious practical problems. In 1995, RASNA was acquired by PTC, which tried to promote the method as an automatic downstream use of the geometric model, and therefore without limits and difficulties for anyone.

This approach effectively killed the technology, crippled any professional use of it, and ultimately caused it to disappear from the market.

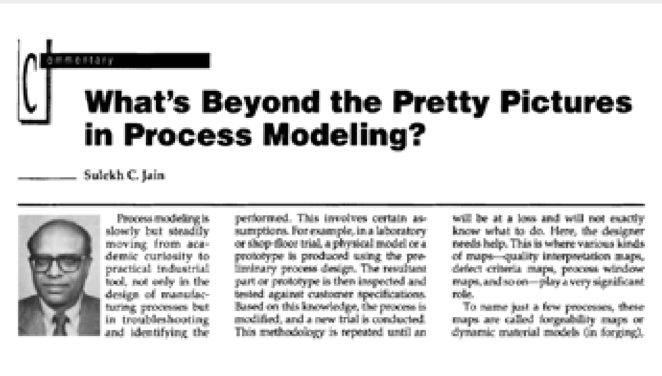


1991: Studies of suspensions (ProMECANICA/Motion).

Numerical simulation and the foundry industry: a brief history of an interdisciplinary journey

In the early 1990s, the possibility of using numerical process simulation at an application level in metallurgy began to emerge. However, a degree of scepticism may have prevailed, both because of the objective difficulty of the subject (the need to combine fluid-dynamic, thermal, and mechanical models with the appropriate metallurgical equations) and because of the decidedly empirical approach that dominated the field.

An editorial published in the prestigious Journal of Metals *in June 1992, entitled "What's beyond the pretty pictures in process modelling?" very aptly described the situation:*



Commentary

What's Beyond the Pretty Pictures in Process Modeling?

Sulekh C. Jain

Process modeling is slowly but steadily moving from academic curiosity to practical industrial tool, not only in the design of manufacturing processes but in troubleshooting and identifying the performed. This involves certain assumptions. For example, in a laboratory or shop-floor trial, a physical model or a prototype is produced using the preliminary process design. The resultant part or prototype is then inspected and tested against customer specifications. Based on this knowledge, the process is modified, and a new trial is conducted. This methodology is repeated until an will be at a loss and will not exactly know what to do. Here, the designer needs help. This is where various kinds of maps—quality interpretation maps, defect criteria maps, process window maps, and so on—play a very significant role.

To name just a few processes, these maps are called forgeability maps or dynamic material models (in forging).

It was therefore a rather pioneering scenario, and it was a pleasant surprise for me, then a young metallurgical researcher at the University of Padua, to discover that an engineering company, EnginSoft, also based in Padua, was offering software for the simulation of metallurgical processes, with particular reference to foundries.

A few meetings with Stefano Odorizzi and, in the following months with Nicola Gramegna and colleagues from EnginSoft, revealed a remarkable affinity and a common will to work in a cutting-edge field using scientific and interdisciplinary methods and to bridge two disciplines — numerical calculation and metallurgy — that were at the time rather inaccessible to each other.

In 1995, we published a review on numerical simulation of metallurgical processes with Odorizzi and immediately realized the breadth and novelty of the areas of work, including:

- *the experimental validation of numerical models of casting processes,*
- *the implementation of metallurgical equations to predict microstructure and properties,*
- *the potential of using simulation as an optimization tool,*
- *the integration of numerical simulation in the design chain,*
- *the essential role of interdisciplinary operator training.*

Some examples are:

- *The Foundry Project (1997-2000), involving the Venice Research Centre, to experimentally validate fluid dynamic and thermal simulations.*
- *The Leonardo COPROFOUND project (1999-2001) to produce training material on the simulation of foundry processes for cast iron, steel, and light alloys.*
- *The EU IDEAL project (2002-2005) on the use of numerical process simulation in the design chain of aluminium alloy automotive castings.*
- *The EU METRO project (2004-2006), which developed online teaching modules on the simulation of metallurgical processes (anticipating modern MOOCs by almost 20 years).*
- *The EU NADIA project (2006-2010), in which EnginSoft coordinated 26 partners representing the entire production line of aluminium and magnesium alloy castings for automotive applications — the work carried out in NADIA also led to the development of two European standards (2014) on defects*

in aluminium castings and on the mechanical potential of aluminium alloys for foundry use.

- *The EU MUSIC project (2012-2016), which demonstrated that process simulation can be fully integrated into the monitoring and control of light alloy die casting processes through the introduction of machine learning approaches.*

The natural consequence of this dense network of collaborations has been the intensification of scientific relations with leading international institutions: the Swedish University of Joenkoeping (Prof. Svensson) and the Norwegian University of Trondheim (Prof. Arnberg).

At the same time, the collaboration between EnginSoft and my department at the University of Padua, the Department of Management and Engineering (Dipartimento di Tecnica e Gestione dei Sistemi Industriali), has also had a strong territorial aspect that led, in 2016, to the creation of SINFONET, one of the first regional innovation networks, which now has almost 70 member companies and which over the years (2017-2022) has managed and coordinated several collaborative projects (GAP, FORSAL, AGILE), all related to foundry and its modernization.

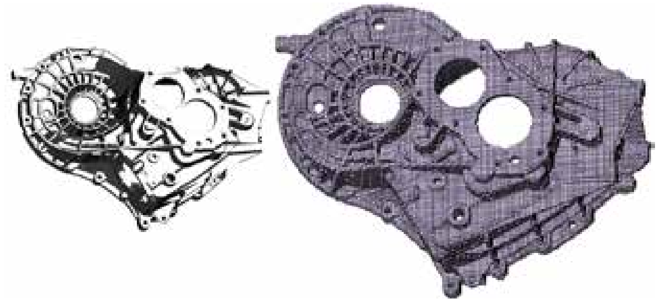
Almost 30 years after our first joint publication, it is only natural to take stock of this ongoing collaboration. It has been a harmonious journey of searching for innovative solutions and contributing to the training of several dozen engineers and foundry technicians. These have been years in which the quality of the people, the sincerity of the relationships, and the spirit of innovation have always been the driving forces behind each project.

Rereading the title and the content of that 1992 Journal of Metals *editorial today reveals a prophetic vision:*

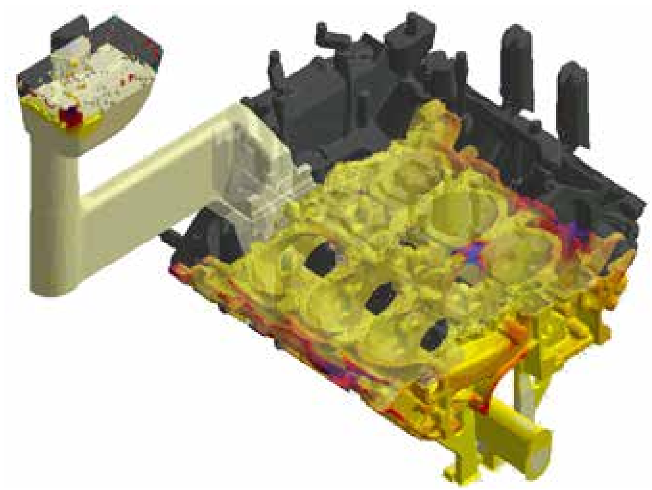
> *"Further benefits of these numerical techniques include identifying process windows, optimizing the process, and designing process control strategies. This is a new and positive trend in the use of numerical modeling techniques in process design."*

I believe that, together with EnginSoft, we have succeeded in transforming a "positive trend" into consolidated multidisciplinary engineering expertise open to increasingly complex technological challenges.

by Prof. Franco Bonollo
University of Padova - DTG



1995: First application of Magma – Gear housing.



2013: Example of a recent application of MAGMA. In presenting it at our conference "Engineering Simulation Today", we commented: ***"…Simulation will not just be 'simulation as usual' however;*** *rather, it will be focused on the modelling of complex, inter-related engineering systems and on the acquisition of results that meet specified standards of precision and reliability. Hence engineering simulation will develop new methods, devices, procedures, processes and planning strategies. All these will be* ***key elements for achieving progress in engineering and science."***

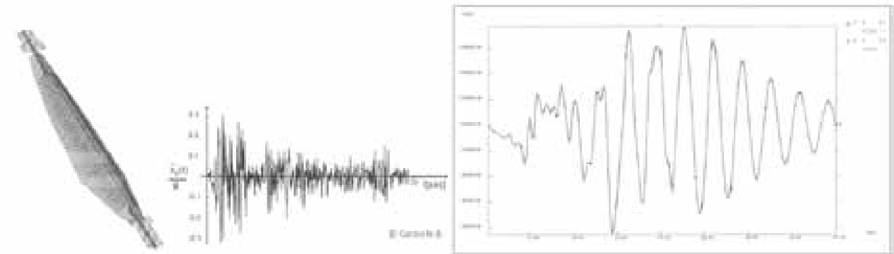
The second case is MAGMA. Founded in 1988 by Prof. Peter Sahm as a spin-off of the Foundry Institute of the RWTH Aachen University, MAGMA Giessereitechnologie deals with the simulation of casting processes in all the various forms from gravity casting to high pressure die casting for both ferrous and non-ferrous materials.

Without delving into the extreme complexity of simulation in this sector, I would like to mention the practical methodological approach used to create the models: it applies the Control Volumes (CV) method, which greatly simplifies meshing by "brushing" the volume containing the object to be meshed in the three coordinate directions with a "ray" that recognizes a solid the first time it hits a surface of the model, a void the next time, and so on. All the components of the casting system (feeders, runners, coolers, filters) are then automatically described from the parameters that define them.

However, the calculation is extremely demanding from a modelling point of view, both in terms of the number of CVs, the physics to be processed, and the integration over time. As a company, EnginSoft became involved in simulating casting processes from the beginning and collaborated with the University of Padua to contribute to the implementation of models and methods in the field.

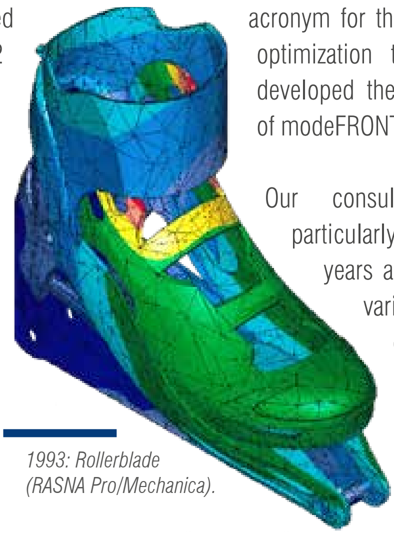
The beginnings of optimization

In the 1990s, we put a lot of energy into optimization, which was then conceived as a way of exploring the parametrically described design space to guide the choice of an optimal solution with respect to defined objectives and design constraints. Today, everyone talks about optimization and artificial intelligence (particularly in the form of machine learning), but back then these were the first implementation ideas.



One of the different solutions studied for the suspended Archimedes bridge: time domain analysis, including large displacements, vortex shedding effects and the application of earthquake-induced displacements at the anchorage points of the stays. These displacements were obtained by integrating the accelerations recorded in the El Centro earthquake.

In 1992, EnginSoft participated in the European SPINOZA2 project, which created the OPTIMUS software, and later in an advanced phase of the FRONTIER project (started in 1995), which resulted in the modeFRONTIER software. OPTIMUS, produced by LMS and later marketed by Noesis, was very good for Design of Experiment (DOE) and treated optimization as constrained optimization of a single objective.

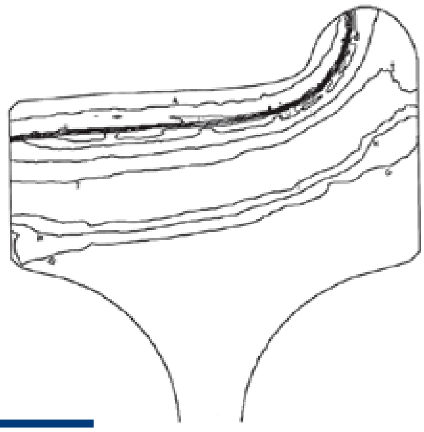


1993: Rollerblade (RASNA Pro/Mechanica).

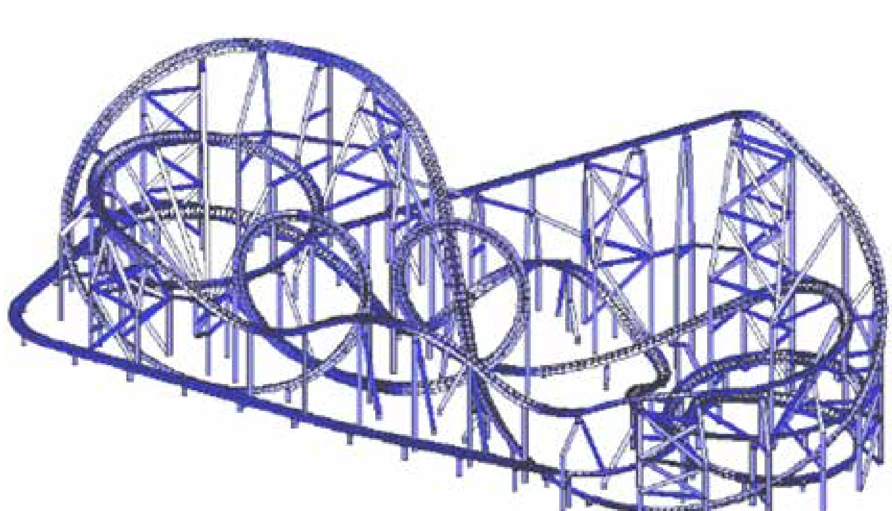
modeFRONTIER, on the other hand, directly addressed the problem of multi-objective and multi-disciplinary optimization, solving it with Genetic Algorithms (GA), a sub-category of Evolutionary Algorithms (EA), and introducing the concept of the Pareto frontier as the optimum frontier with multi-criteria decision techniques to act on it. EnginSoft was initially a distributor of OPTIMUS and went on to co-found ESTECO (an acronym for the Italian of EnginSoft optimization technologies), which developed the commercial version of modeFRONTIER.

Our consulting activity was particularly intense during these years and developed around various initiatives carried out by the three offices in Trento, Padua, and Bergamo. The most important of these, both in terms of content and the commitment required of the company, were the models developed for the design of the Messina Strait crossing with a suspended Archimedes bridge. This is not the place to discuss the merits of the project proposed by the ENI-Saipem-Tecnomare consortium as an alternative to the bridge, however, the technical merits of this solution are undeniable. To give an idea of the impact of using simulation models, I will just mention that EnginSoft alone was contracted for 60,000 hours of work in the preliminary phase.

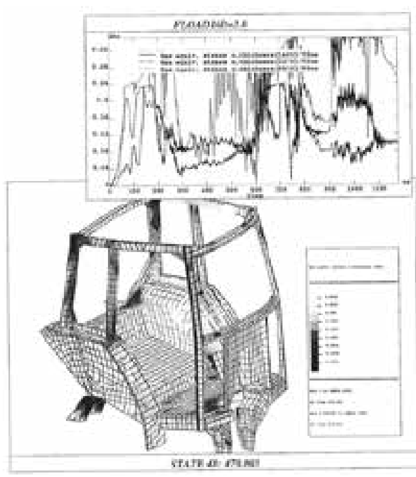
A subject in which it is decidedly complex to find optimal solutions from different perspectives is the regular work we do for manufacturers of "flying structures" of all kinds: roller coasters, balloon races, merry-go-rounds and the like. It starts with simulation of the dynamics of the systems and goes right down to the detail of the



1994: Wheel quenching (LOVERE SIDERMECCANICA, then privatised and purchased by the Luccini Group). Figure shows the distribution of pearlite.



1995: First model of a rollercoaster with completely automated pre- and post-processing.



1996: SAME-DEUTZ-FAHR Tractor – reproduction of series and crush tests (PAM-CRASH).

verifications. For example, to optimize a roller coaster track the work entails using all the energy from the fall to perform different types of evolutions to stimulate rider sensations without causing discomfort (by avoiding accelerations outside the median sagittal plane of the human body) while also simplifying the construction itself, and moves on to testing at the final installation site, etc. The first fully developed model was for the first roller coaster installed at the Prater in Vienna. Apart from the excitement of tackling such a unique problem, the colleagues at EnginSoft still remember the sensations experienced during the tests, and even more so during the physical experiments to obtain useful data for the calculations.

The start of SBES

We thus entered the third millennium with an exceptional range of skills and technologies in the various fields of CAE (we would later call it Simulation-Based Engineering or SBES), materials processing simulation and associated technologies for optimization, integration, and its use in collaborative engineering environments, complemented by related IT services. It was a unique proposition that positioned us, in every sense of the word, as capable of real technology transfer to industry. In recognition of this, we changed our previous slogans – referring to iDP or design chain solutions – to "key partner for design process innovation".

Our ability to carry out real technology transfer in the field of SBES (also officially recognized in the Official Gazette No. 298 of 22 December 1994) rested on four pillars:

- the type of technology chosen for its applicability to different industrial contexts;
- consultancy services focused on the specialization of technology implementation and its integration into the design process and any related tool chain of the customer company (our other motto was "design chain solutions");
- education and training;

It was the early 1990s. Computer science and electronics had moved beyond the confines of basic research and were rapidly spreading into the industrial world because of applied research and innovation. Few people realized it, but we were moving from an era of knowledge for knowledge's sake to an era of expertise, where knowledge must be enhanced through application.

Information technology and electronics were – and are – cross-cutting technologies for the various spheres of human endeavour. Even then, it was easy to predict that they would revolutionize the entire world of work, not only through technological changes in the way people design, experiment, and produce, but also through their impact on organizations and their cultures.

IT offered tools and methods to reduce the time and cost of developing products, processes, and services by one or more orders of magnitude, requiring the creation of new professional profiles and greater delegation to different organizational levels. It became essential to reduce the hierarchical levels of the past and make room for the creativity, enthusiasm, proactivity, and scientific rigor of the IT-skilled newcomers entering the public and private workplaces.

For the Centro Ricerche Fiat (or FIAT Research Centre), applications of computer science and electronics were distinct skills to be developed as a priority. In order to develop them to excellence, we had to search universities and research institutions for people with unique profiles that were very rare at the time: these people had to be able to apply and implement scientific knowledge in business, not just produce excellent academically valid scientific reports that would stand up to peer review, but also get their hands dirty in the industrial world, speak the language of customers, and combine their scientific skills with economic and market knowledge. In short, they had to be both professors and entrepreneurs.

In this period, we were fortunate to meet Prof. Stefano Odorizzi, an expert in the field of computer applications, especially in the development of predictive numerical simulation, with whom we shared visions, challenges, and successes for many years.

With Stefano we also shared the desire to find other excellent partners to train young engineers in new technologies and, thus, the TCN Consortium (Technologie per il Calcolo Numerico or Technologies for Numerical Computing) was born together with the Centro di Ricerca, Sviluppo e Studi Superiori, CRS4 (Centre for Research, Development and Advanced Studies) in Sardinia, chaired by Carlo Rubia, Nobel Laureate for Physics, and the Istituto per la Ricerca Scientifica e Tecnologica, IRST (Institute for Scientific and Technological Research), today known globally as the Fondazione Bruno Kessler. The consortium achieved outstanding results, such as winning European projects, which facilitated the subsequent development of training courses that were groundbreaking at the time, including the first master's degree in numerical computing.

Finally, for me and thanks to Stefano, another very important achievement was the introduction to the beautiful province of Trento, where innovation is as ubiquitous as the air of home starting from the Regional Council with its young presidents and ending with the dynamic Lorenzo Dellai, when CRF opened a branch in Trento.

Those were exciting years, remembered now perhaps a little wistfully, but mostly with gratitude for Stefano and the other remarkable people I met during that time. Thank you again, Stefano; and thank you to all the friends from Trento.

by Giancarlo Michellone
Former Chief Executive Officer of Centro Ricerche Fiat

The field of mechatronics

In the 1970s, mechatronics emerged as a cross-disciplinary field combining mechanics, electronics, computer science and automation. It was not very popular at first. Later, however, it began to appear in university curricula and, subsequently, became a subject of interest to industry.

At the beginning of the third millennium, therefore, it was also important for EnginSoft to clarify to the industry whether and where there were interesting synergies with the mechanics being approached.

At that time within TCN — our training structure — we were organizing "mini masters": intensive training initiatives halfway between a traditional course and a master's degree. We therefore organized a "mini masters" for mechatronics, a kind of treasure hunt, and hired a renowned Columbia University lecturer to coordinate it. The initiative was so successful that it was repeated several times. Organizing it, however, was rather complex and bizarre: the lecturer wanted to bring a huge trunk (a kind of mini container) full of physics experiments for the students to practice with.

The lecturer also insisted that the students turn up in shorts and short-sleeved shirts, because that was what he wore, and it was summer (the mini masters were held in the summer). There were two problems for us: getting the mini-container through customs, to the client (who on one occasion returned it to the sender) and back to Columbia University; and secondly, getting the unusual clothing accepted in contexts where the custom was very different — especially among non-students.

We used to shrug and say, "What you have to do to survive!"

by Mirella Prestini
EnginSoft

- applied research carried out in industry-led partnerships to feed the chosen technology with the necessary data on the physics involved and to provide articulated proofs of concept of the possibilities, benefits and limitations of the applications.

Here I would like to focus on training, for which we created a specific structure together with Centro Ricerche Fiat at the CRS4 and the Fondazione Bruno Kessler: the TCN (Technologies for Scientific Computing, Higher Education Centre).

The TCN produced teaching materials for face-to-face and online courses, publications on specific topics, e.g. contact mechanics, and learning systems for practical use, as well as offering mini-grants – through EU-funded projects – to participate in third-party initiatives across Europe (European Atelier for Engineering and Computational Science, EUA4X).

From this solid base and with this business model we experienced a very strong growth in the early 2000s, both in terms of the expansion of our organization (opening a total of six offices in Italy and branches abroad in Germany, France, England, Spain and Northern Europe, and shortly afterwards in the United States and Türkiye) and in terms of the growth of our IT infrastructure, and the expansion of our offering of technologies and services, training and industrial research.

From a technological point of view, Ansys had a major impact. At the time, Ansys produced software addressing only mechanical analysis problems and had been distributed in Italy by ItalCAE since 1987. In 2002, following the death of ItalCAE's founder and owner, Antonio Mancino, the opportunity arose for EnginSoft to acquire the company. We were immediately interested – especially after the RASNA misadventure – and we appreciated the strong affinity between the staff of the two companies and the business models promoted by the founders and directors.

Little did we know at the time that Ansys would experience such enormous growth, achieved through the systematic acquisition of third-party technologies developed to solve problems in areas other than mechanical engineering and beyond. We gradually found ourselves with almost a single point of contact for SBES issues outside of the highly vertical/specialist ones. In fact, the technologies that Ansys was steadily acquiring were the very ones that EnginSoft was already working with independently, demonstrating EnginSoft's ability to anticipate market demand and identify the best technologies. Whenever we signed a new contract to promote a piece of software, we jokingly wondered how long it would be before Ansys acquired the application.

I will not go into too much detail about this phase of EnginSoft's life, which, however, expresses the full blossoming and consolidation of the company's identity in its authentic and useful role for the industry it serves, because this newsletter, *Futurities*, which began publication as the EnginSoft *Newsletter* in 2003, is a faithful record of it, full of case histories, testimonies, interviews, information and updates on technologies, training proposals, and news/opportunities to participate in co-financed industrial research projects or to join centres of excellence and networks for the dissemination of knowledge on methods.

Besides the *Newsletter*, the international conference (and accompanying exhibition) that we have held every year since the founding of EnginSoft, accurately reflects developments in the world of simulation, enriched by contributions from key players among technology producers and users – with examples of relevant applications in industry, as well as their needs and obstacles – and from the world of research and academia.
In addition to EnginSoft's 40th anniversary, this year marks the 40th anniversary of the International CAE Conference, the 20th anniversary of the publication of this newsletter, and the milestone achievement of our 100th industrial research project won within consortia mainly at international level.

2006: Company kick-off meeting.

At this point, I would like to emphasize the research aspect and place it in its proper context. The problem of technology transfer from the places where knowledge is developed and formalized (universities, research centres) to industrial users seems almost insurmountable: instead of a disciplined flow, there is constant talk of distance, of a gap, of extremes that never meet. EnginSoft has had, and continues to have, the genuine ability to bring these two extremes closer together, to improve and make the most, in practical application, of what is produced in the abstract by pure research – wherever, however, and whenever this is reasonably practicable. While many boasts that they know how to do this, few actually do.

EnginSoft has been recognized by the European Commission as a Key Innovator for its cutting-edge contributions to four European projects.

The most recent of these is the OPTIMA project, which focused on developing a customized high-performance computing (HPC) solution for computational fluid dynamics (CFD). Another project, SYNCH, saw EnginSoft develop the Brain Neuromorphic Synapses Builder, an innovative tool designed to explore the potential of artificial neuronal networks for in vivo applications as neuro-prostheses to replace damaged brain networks. Further progress was made in the FORCE project, where EnginSoft developed a Decision Support System (DSS) to address complex chemical formulation challenges, and in the RECAM project, which focused on versatile manufacturing systems and agile production planning. This recognition is testament to EnginSoft's ability to drive innovation across a wide range of sectors. By leveraging its extensive expertise and capacity for cross-fertilization and multidisciplinary collaboration, EnginSoft consistently delivers highly impactful solutions that bring significant benefits to European Innovation Leadership.

In a world that, in the space of forty years, has gone from its first uncertainties to a wealth of content unimaginable at the time of its creation, following a combined process of transversal expansion, democratization of technologies and vertical development with appropriate solutions for specific problems, Enginsoft has been able to ride the new and the evolution of the new with mastery and perfect balance, while remaining true to its mission.

2008: CAE Conference Perspective – We will get to a point of science fiction becoming science fact within the next decade or two where design engineers will be spending all their time imagining product variants and product innovations whilst computers will be churning away in the background spitting out predictions for the engineers to review in real time.

In addition to general applications for problems in the fields of FEM, CFD, acoustics and electromagnetism, which we have primarily solved within the Ansys platform, there have been and are many specializations in specific topics or specific numerical approaches.

Among these, I would like to mention a few, not only because of the particular receptivity they have had and have in the market, but above all because of the valuable contribution they make to specific application areas, providing a solution that leads me to speak of the elegance of software whenever I have the opportunity, due to the orderliness of the approach to a specific application within a reference physics, the numerical approach, the solution method chosen and its implementation.

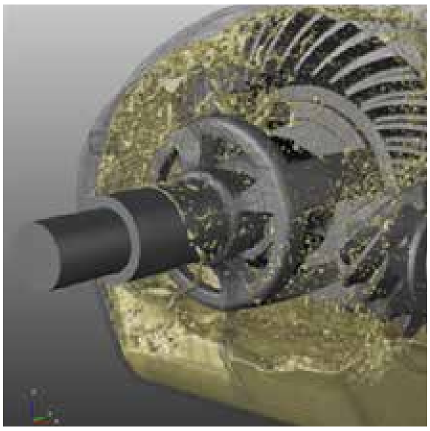
As it was almost 20 years ago when we started collaborating with EnginSoft before we started the NADIA project. It has always been a fascinating journey in design optimization and digital innovation. I particularly enjoyed each International CAE Conference (a fantastic event to meet specialists from all over the world) and other special meetings; thank you for the opportunities to present there, too. I can say that the teamwork is excellent, and I have learnt a lot (actually, I still do!). The team brainstorming and innovation for advanced simulation tools was inspiring: to see how everyone's expertise came together to share insights into cutting-edge optimization techniques. Per laborem ad astra – et ultra.

by Prof. Michael Gasik
Seqvera

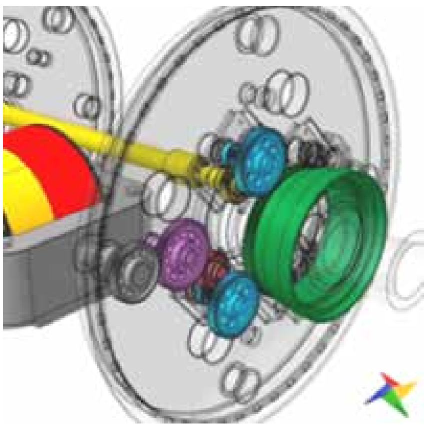
Particleworks, produced in Japan by Prometech, offers an approach to CFD based on the moving particle method (MPM), i.e. meshless, where integration over time is solved using a semi-implicit algorithm. Unbeatable in the simulation of lubrication and high viscosity fluid situations, the software is suitable for a wide range of other recurring and complex simulation problems: cooling of electric motors, vehicle behaviour on flooded roads, water splashing, sloshing, injection moulding, scrap metal flushing, powder-liquid mixing, conjugate heat transfer, painting, etc.

RecurDyn, produced in South Korea by FunctionBay, addresses the problem of multi-body dynamics and allows the treatment of flexible – even highly flexible – bodies.

Cetol6σ deals with 3D model-based tolerance analysis and links to 3D CAD environments such as PTC Creo, Siemens NX, CATIA or SolidWorks.



2019: Particleworks simulation of the lubrication of a gear.



2018: Recurdyn multibody example.

And many others, for which we refer you to the relevant reports and examples in various editions of the *Newsletter* and *Futurities* and to the website of EnginSoft and related companies.

As an extension of SBES, EnginSoft has also approached the world of digital manufacturing and automation, using both third party technologies (such as industrialPhysics and MapleSim) and its own platform, smartPRODUCTIVE, created to build simulation environments of production processes to enable, for example, predictive maintenance and/or to determine the risks and consequences of failures leading to plant downtime and/or to optimize initial choices with respect to target requirements, up to building the digital twin of the plant. Digital manufacturing has its own hierarchy of issues, which is similar and, in some ways, parallel to that of engineering simulation.

Therefore, all the boundary technologies typical of AI and IT for data management, optimization and in general, can be naturally applied.

In 2023, with the intention of allowing it to fully pursue its mission and maintain its identity, EnginSoft spun off its subsidiary EnginSoft Simulation Software Italia to allow it to focus on the commercial promotion of Ansys. EnginSoft retains all the technical expertise on the software, which is made available to customers and to the subsidiary itself.

As a result, EnginSoft can be viewed as a key partner for industry in the digital transformation of its design and production processes, without any of the strict commercial constraints that could distract from the substance of the problems faced by the customers it serves.

Digitalization is a key challenge for companies wishing to remain competitive and innovative in the Italian industrial landscape. This context, together with the impetus created by the Ministry of Economic Development as part of the Industria 4.0 plan and the funding received from the National Recovery and Resilience Plan, led to the establishment of eight competence centres (or competitiveness clusters) in Italy.

Structured as public-private partnerships, the competence centres focus on creating an ecosystem that fosters real synergies between universities and researchers, manufacturers and technology providers, and start-ups on the topic of digital transformation.

SMACT is the competence centre of the Tri Veneto region in Italy. The name represents the five technologies treated: Social, Mobile, Analytics, Cloud and The Internet of Things. It currently has over 100 partners (EnginSoft is a founding member) and provides an environment where companies can experiment with innovative solutions, test prototypes, and receive expert feedback. This approach reduces the risks associated with implementing new technologies and accelerates the innovation process.

EnginSoft's active involvement in SMACT is a positive example of how specialized technical expertise can be made available to companies to support their digitalization. EnginSoft's specific contribution to SMACT concerns digital manufacturing, which aims to optimize production processes by combining the fundamental elements required to create a digital twin, namely: guided collection of useful and targeted data, the process simulation model, and artificial intelligence. All of this activity considers the characteristics of the industry in question, which is supported with great value in terms of the quality of the product in relation to the cost of development and, above all, in relation to the technical choices to be made in terms of the go-to-market strategies required to beat the competition

by Matteo Faggin
General Manager of SMACT

The longest journey starts with the first step

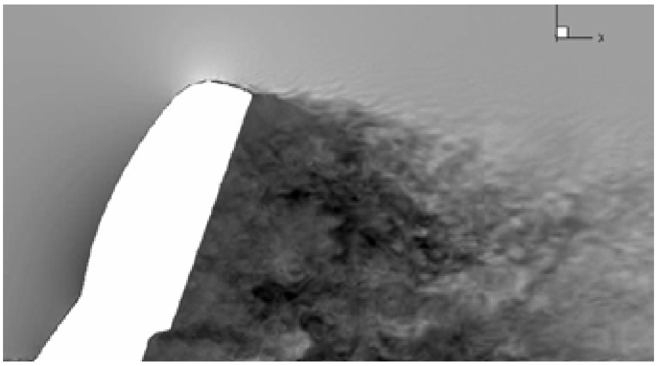
It has been a long journey, which I think is well described in the words of the Head of our Consultancy Services and CFD divisions. He explains: Our CFD adventure began on a chilly night in 1992 spent in the middle of winter in an unheated room at the Bear Hotel in Wantage in Oxfordshire in the UK where we had signed a contract with AEA Technology to use and promote their technology. We then had to explain to potential clients that CFD did not stand for "Contract for Difference" as in banking, but was a software technology for simulating fluid problems, and that it cost a lot of money, we are not sure why.

Then came a miraculous first sale and the first case where the results matched the measured data… again with no real understanding of why. We then decided to promote the technology in a structured way. Compared to its FEM counterparts, CFD presented problems both in terms of true/reliable modelling and convergence of the solution. We were stuck in a backward trajectory, spending days watching the vortex form in the face of a dramatic change in geometry, with constantly varying results in terms of the mesh, the turbulence model, the finite difference scheme, and its solver. We used to joke that the best finite-difference scheme was QUICK, which does not mean 'fast' (if only!) but is the acronym for Quadratic Upstream Interpolation for Convective Kinematics; in practice, a third-order algorithm that would converge exactly – but only on perfect meshes, so… never!

Without giving in to the difficulties and in overcoming all the psychological resistance, we reached the end of the second millennium, well able to carry out, for example, CFD simulations of turbogas to limit emissions and pollution – before the focus on the climate issue that exploded shortly afterwards: we did not know it, but EnginSoft was already making the world a better place.

Then came the first meeting of people interested in CFD: three days in 2000 in a villa on Lake Garda; three rainy days during which we took stock with the participants of the potential of CFD and its possible developments. From there, we began a real transfer of technological knowledge and also began to broaden our horizons through research projects co-funded by the European Community.

Launched in 2006, NEWAC was one of the first of these projects: the aim was to reduce CO_2 emissions by 20% by 2020 (amongst ourselves we called it the 202020 target). It was a major challenge



2012: The turbulence produced by a side rear-view mirror (charLES).

It is now 15 years since the establishment of the Distretto Tecnologico Aerospaziale (or Aerospace Technology District) in 2009, of which EnginSoft was a founding partner. At that time, EnginSoft had recently opened its office in Mesagne and immediately, thanks to the mutual collaboration with University of Salento, shared the ambition and determination to create in Apulia an initiative that would gather around it public and private partners, industrial and scientific entities, with the aim of creating a network that would later become the Aerospace Technology District.

Over the past 15 years, it has proved to be an excellent experience, capable of becoming a winning practice across the European cluster landscape. It has been a long journey in which EnginSoft, like the other partners, has brought its expertise but also its market challenges to the table for shared value.

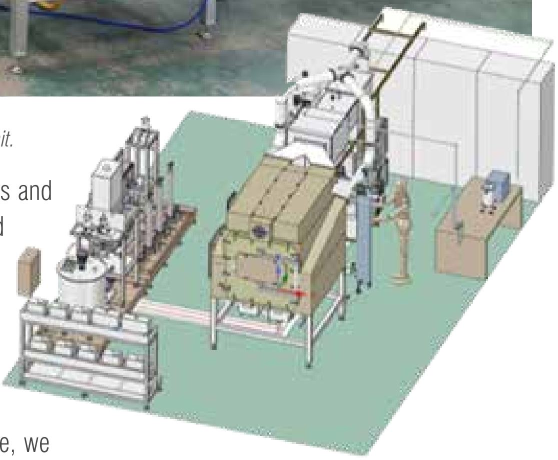
They have been years of extensive and intensive research and development that have fostered the development of new services or approaches to the market. One of these was the fleet management project led by partner Ge Avio Aero, in which EnginSoft participated by researching and developing new opportunities.

During these years, EnginSoft has contributed to the professional training initiatives of the district by participating in numerous postgraduate master's courses, from which it has drawn some of its employees. In addition to some more specific collaborations, aimed at generating value for the company itself, it has participated in numerous orientation activities for schools and students, as well as national and international events dedicated to the aerospace community and citizens. We are very happy with what we have done together and with the contribution that EnginSoft has made to the project of building the aerospace ecosystem in Apulia, instilling a strong collaborative mindset and the habit of thinking and acting in complex systems.

I still remember the aperitif in a bar in Mesagne with Prof. Paolo Cavaliere, from the Department of Innovation Engineering at the University of Salento and Prof. Stefano Odorizzi, President of EnginSoft, and the subsequent meeting with EnginSoft's CEO, Marco Perillo, a professional with whom I have a friendship as well as a collaboration. Those were the days when we tried to shape the future and combine it with our ambitions to make Puglia's aerospace industry more competitive and modern. It is satisfying to look back today and see that this has become a reality, and that time has done nothing but strengthen our collaboration, our commitment, and our friendship.

by Giuseppe Acierno
President of the Distretto Tecnologico Aerospaziale in Apulia

2019: Inauguration of the MELiSSA PaCMAN unit.



for aeronautics, combustion processes and CFD...even if emissions did indeed fall in the target year, thanks to the pandemic.

In the meantime, we gained a lot of expertise, and our skills were recognized internationally: for example, we received an invitation from the prestigious organization within Stanford University that deals with turbulence modelling. And we continued to grow, as EnginSoft itself continued to grow, as easily as a champion surfer rides the waves in which few others can even stand up.

That was the secret: EnginSoft has always perceived the "nine waves" before they arrived, which is why it has been able to ride them for almost half a century.

What does the future hold for us?
EnginSoft has now landed in both Europe and the USA. All that remains is to go to the moon. And indeed, according to the well-known principle of the biggest wave, we have been selected by the Melissa Consortium to study life support systems for astronauts on the next mission to Mars. And many acronyms and simulations later, we have built the first state-of-the-art facility to study crop cultivation (in the MELiSSA project's PlAnt Characterization unit for closed life support system engineering, MANufacturing and testing (PaCMAN) unit) in space mission scenarios: CFD – but also cutters, screwdrivers, and wrenches!

Coming full circle

Like the head of our CFD department, the heads of our other divisions may have stories to tell – and it would be instructive to listen to them. Overall, it may seem like a nice fairy tale, all triggered by a problem relating to the prices of fruit. But it wasn't.

What it was, and what it continues to be, is a wonderful adventure made possible only by the shared objectives, the shared spirit and the shared methods (I would say, above all, the shared style) of the colleagues and collaborators who, with great enthusiasm and each in his own field, have contributed with constant dedication, commitment, intelligence and initiative to the growth of the company, while preserving its identity.

Concluding with an image: EnginSoft has provided and continues to provide fertile soil, but it is its people, in freely expressing their creativity, who grow the most beautiful flowers and nurture them with love.

EnginSoft

From this land,
you were a child full of grace,
taking your first steps.
Then, your fingers on a keyboard,
sowed the seeds of a spark
a passion that grew
a young seedling reaching skyward
member of an expanding family,
heeding the call
and from that smoke
a flame was born.

From the branches you gazed at the sky,
A burning torch, blazing brightly.
A boot moulded you
from its mountains to its olive trees,
a daughter of the infinite stars,
growing, you soared free
in the blue origami sky,
a world with its moon,
unfettered mind
part of the numerical
path of philosophy.

You became a plant,
and among the currents of its movement
the struggles of advancing genius
pushing forward with solutions
amidst the noise of a turbojet
I devoted all my time to you.

Now you are woman,
daughter of Athena,
child of genius,
in the full splendour of your being,
poised to speak to me of neural networks,
of grand themes and diverse projects,
of the firmament and every adventure,
from your hands,
and your mouth,
and of those perfect forms,
of your feelings for others,
of grand dreams, bold and brilliant,
a technological galaxy,
you are always at the edge of engineering.

by Davide Daloisio
EnginSoft

Fuel tank sloshing: digital modelling with meshless CFD

by Giuseppe Usai[1], Michele Merelli[2]
1. Dallara Automobili - 2. EnginSoft

The highly competitive nature of motorsport drives designers to seek even the slightest advantage over their rivals. One potential area of improvement lies in reducing fuel sloshing and optimizing fuel extraction from the tank.

In this context, a new approach to fuel tank optimization is proposed. It aims to simplify the workflow by significantly reducing computational time compared to traditional finite volume method (FVM) CFD (computational fluid dynamics) tools. The proposed approach also explores the use of free solid bodies within the tank to mitigate fuel sloshing.

For applications such as these, conventional FVM CFD tools are computationally expensive and time-consuming. Using moving particle simulation (MPS), the proposed method provides a more efficient solution by using a Lagrangian formulation of the Navier-Stokes equations as opposed to the Eulerian approach used in FVM CFD. The analyses conducted demonstrated that meshless CFD software such as Particleworks can perform these types of simulations in less time and with fewer hardware resources than traditional FVM CFD methods.

Introduction and boundary conditions

One way a racing car manufacturer can improve the performance of a car is to lower the centre of gravity (COG) as much as possible. In fact, the performance of a racing car is affected by the position of its centre of gravity (COG): a higher COG results in greater lateral load transfer during cornering.

When the vehicle undergoes lateral acceleration, a "rolling" moment is induced by the fact that the COG is at a certain height above the ground. This moment must be balanced by the forces exerted on the tyres by the ground. The result is that the outer tyre is loaded than the inner tyre, resulting in less lateral "grip" and therefore slower lap times. Moreover, a higher roll moment causes more body roll, usually resulting in a loss of downforce, which is essential for maximizing cornering speed.

Another critical aspect to consider is the engine. At the bottom of each fuel tank are the so-called "feed pumps", which draw fuel from the tank to the high-pressure pumps that feed the engine's injection lines. Due to the high accelerations a racing car is subjected to, often exceeding 2g, it can happen that the fuel pumps do not receive

Accelerations

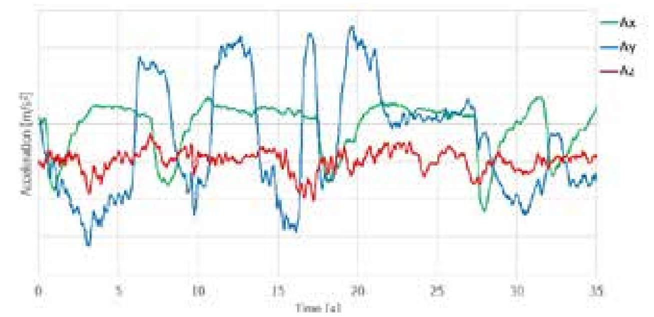


Fig. 1. Variation in the cost of a product depending on the stage of development.

enough flow to keep the engine running properly, causing a sudden power loss. The mass of the fuel cannot be neglected, and a proper analysis could be performed to limit the sloshing (movement) of the fuel when accelerating. The tools that can be used to develop this analysis are traditional CFD methods and meshless CFD.

This paper examines the MPS approach [1,2] with the objective of evaluating its cost-effectiveness compared to FVM CFD and studying the use of free solid bodies inside the tank to mitigate fuel sloshing. Specifically, the first part of the analysis aims to find the best compromise between computation time and accuracy by changing the particle size (PS). Then, a new solution involving the use of PTFE beads (commonly known as "Teflon®") to limit the sloshing was investigated.

A modern racing car was used as a case study. Its tank contains six feed pumps at the bottom and the accelerations shown in Fig.1 are imposed on the tank. Only the lap summary was considered, avoiding the study of the parts of the track where the accelerations are relatively low, since these sections do not produce results relevant to the analysis. The parameters observed are runtime, x, y, and z COG positions, and fuel flow rate in each pump.

Results of the particle size sensitivity study

Before analysing the effect of particle size (PS) on the results, it is important to note that the Particleworks simulation at PS 2.5mm and CFD are aligned. By changing the PS, a negligible difference is observed in the x and y coordinates of the COG. However, in the z direction, a maximum error of 0.9% is observed when the PS is increased from 2.5mm to 3mm, which increases to 1.0% and 2.1% when the PS is changed to 3.5mm and 4mm, respectively.

Examining the volume of fuel extracted from the tank, Fig.2 shows the instantaneous normalized volumetric flow rate of pump 3. The simulations performed with the 3mm and 3.5mm particle sizes show volumetric flow rates that closely match the 2.5mm simulation. However, the 4mm PS simulation deviates significantly from the predicted flow rate of the 2.5mm simulation.

Compared to traditional CFD tools, Particleworks allows for significantly reduced pre-processing and simulation times. Considering first the fluid-only simulation, the runtimes are shown in Fig.3: all Particleworks simulations were run on a single Nvidia A40 processor for a physical time of 36s, while the CFD simulations were run on a dedicated 8-node cluster with a total of 512 cores.

The results show that a PS of 3.5mm is the optimal compromise between accuracy and computational time, so this discretization was used for the solid sphere model.

Solid sphere model

A peculiar approach to the sloshing problem is to partially fill the tank with Teflon spheres, as revealed by some racing teams. To understand why it's important to study this scenario, consider the following examples:

- In distance-based races (e.g. Formula 1, Formula 2) where refuelling is not allowed, the tank will most likely be designed for the worst-case scenario of very high fuel consumption. On circuits where the expected fuel consumption is less than the tank capacity, teams can gain an advantage by limiting fuel sloshing by introducing other bodies into the tank, since the tank will not be completely full.
- In endurance racing (e.g. WEC, IMSA) cars undergo a balance of performance (BOP) process, where the series organizer intervenes in certain parameters to ensure a level playing field that allows virtually anyone to win a race. Some of the parameters that can be affected by BOP are: 1) engine power, 2) car weight, 3) stint energy (combination of fuel load and battery level).

Pump 3

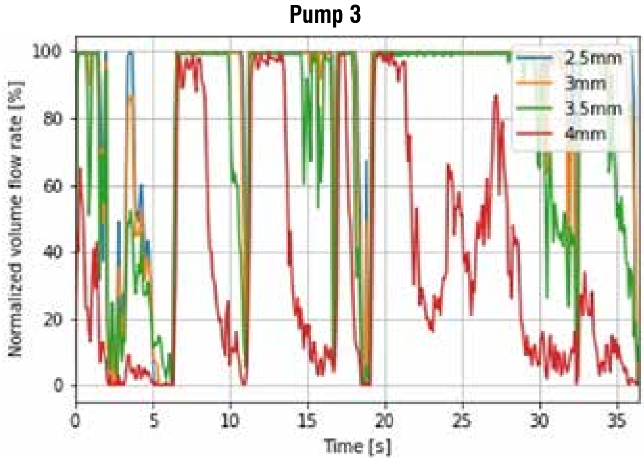


Fig.2. PS effect on the flowrate of pump 3.

CFD and Particleworks runtime

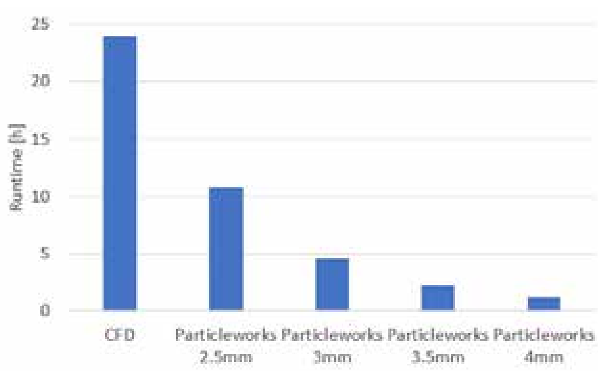


Fig.3. Comparison between FVM CFD and MPS in terms of runtime.

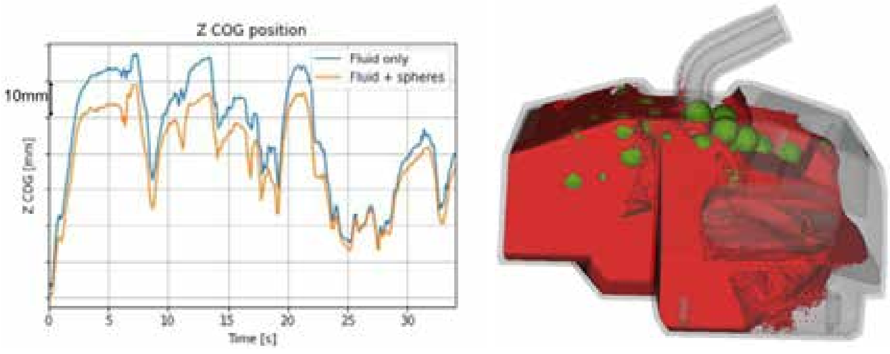


Fig.4. Left - Comparison of the Z COG position between the simulation with fuel only and fuel plus spheres. Right - The Teflon spheres (green) inside the tank.

Obviously if a given car is forced to refuel less than its maximum, it will have a partially empty tank immediately after the pits, and thus an advantage can be gained by limiting fuel sloshing.

This type of simulation (spheres are solid bodies and subject to buoyancy and gravity forces) cannot be performed with FVM CFD tools used by Dallara. We studied this solution with Particleworks.

The simulation runtime with Teflon spheres increased to 31 hours, mainly because of the reduced time step and higher particle count. Fig.4 shows the results of the analysis and compares them to a simulation where only fluid is present in the tank. It is evident that the inclusion of the spheres plays a significant role in limiting the movement of the COG.

Comparing the COG positions in the x, y, and z directions with the condition in which the tank is filled with fuel only, the addition of the spheres results in a reduction of the COG motion by approximately 14% in the x direction, 8% in the y direction, and 17% in the z direction.

Interestingly, no significant changes in fuel flow rate were observed during the transition from one configuration to another. This suggests that the presence of the spheres does not significantly affect the fuel extraction process.

Conclusions

The meshless CFD approach has proven to be an effective tool for the optimization of fuel tanks in racing applications. Through a particle size sensitivity study, it was determined that a particle size of 3.5mm provides highly accurate predictions of the COG position and flow rate. In particular, the use of Particleworks resulted in a significant reduction in both pre-processing and simulation times compared to traditional CFD tools.

The reduced run time allows Dallara to run sloshing simulations on more tracks. Whereas FVM CFD took 24 hours to simulate 36 seconds of physical time, the mesh-less approach allowed Dallara to run 400 seconds of physical time in the same timeframe.

In the final stage of the analysis, a comparison was made to assess the effect of introducing solid Teflon spheres into the fuel tank. The presence of these spheres was found to reduce fuel sloshing by approximately 14% in the x direction, 8% in the y, and 17% in the z direction, while no discernible effect on flow rate was observed.

Ultimately, the analysis allowed Dallara to better understand the sloshing problem and be prepared to extract maximum performance from fuel tank design in future projects.

Article from: www.nafems.org/publications/resource_center/bm_jul_24_3/

About Dallara Automobili

Dallara Automobili was founded in 1972 by engineer Giampaolo Dallara, who is also its current president, assisted by engineer Andrea Pontremoli as partner and Managing Director. The company headquarters are in Varano de' Melegari (province of Parma in Italy), Mr. Dallara's hometown. The company also has offices in Stradella di Collecchio (Parma in Italy) and Indianapolis (USA).

Today, the Dallara Group today is one of the world's leading companies specializing in the design, development and production of high-performance racing cars and is currently the sole supplier of cars for the IndyCar, Indy NXT, Formula 2, Formula 3, Euroformula, Formula E and Super Formula championships. Dallara builds cars for the WEC, ELMS, IMSA and NASCAR championships and provides expert advice and professional support to manufacturers and racing teams in the development of both competition and road cars.

In recent years, the company has also developed solutions for the aerospace and defence sectors. The Dallara Group currently employs over 750 people.

For more information:
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Università di Pisa

Improving the reliability of multibody simulation by implementing a hysteretic tyre model for radial dynamics

by Federico Mammini, Marco Pinelli, Michele Sgamma, Francesco Bucchi, and Francesco Frendo
University of Pisa

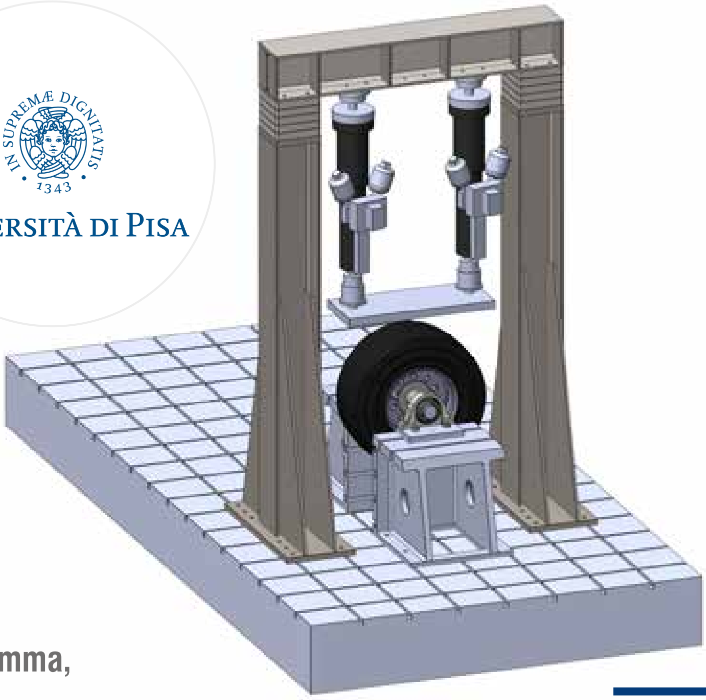

Fig.1. 3D model of the test bench designed to test the tyres (SolidWorks Educational Product. For educational use only).

Multibody simulation is a cornerstone of modern engineering, enabling accurate prediction of structural loads and dynamic behaviour in complex systems. In the automotive and industrial vehicle fields, such simulations are essential for improving design efficiency, durability, and safety. For land vehicles, accurate tyre modelling is critical for reliable simulation results because the forces exchanged between the vehicle and the ground are generated by the tyres.

The vehicle analysed in this study is a forklift from Toyota Material Handling Manufacturing Italia (TMHMI). Forklifts lack a suspension system, so the tyre — characterized by a solid rubber section — plays an even more important role in the vehicle dynamics. The authors' aim is to develop an effective tyre model for radial dynamics to improve the reliability of multibody simulations.

Accurate modelling of tyres has long been a challenge due to their inherently nonlinear and hysteretic behaviour. In this study, a hysteretic Bouc-Wen model was used to capture the radial dynamics of solid rubber tyres. The parameters of the model were obtained from an experimental campaign conducted on the forklift's wheels, ensuring that the model accurately reflects real tyre behaviour.

As a method to validate the performance of the model, the vertical acceleration signals of the front and rear axles of the vehicle during an obstacle crossing (cleat) test were compared with the signals obtained from multibody simulations of the same test, performed using RecurDyn software. The performance of the hysteretic model was then compared with that of a simpler viscoelastic spring damper model to assess the advantages of the hysteretic approach in capturing the complex dynamics of the tyre.

Dynamic wheel behaviour

The dynamic behaviour of the front and rear wheels of the vehicle under study was analysed on a test bench at the University of Pisa (see Fig.1), using static and dynamic tests. The static tests were performed with a triangular displacement profile, while the dynamic tests were carried out with a sinusoidal displacement profile with an amplitude of 0.5mm, varying the preload conditions and frequencies.

The test parameters are given in Table 1.

Test type	Velocity/ Frequency	Preload	Sampling frequency	Number of cycles
Static	0.1mm/s	0mm	20Hz	3 cycles
Dynamic	1/5/10Hz	48/62/76% max displacement	0.1/0.5/1kHz	100 cycles

Table 1. Table of tests carried out.

The results obtained for the front and rear wheels are shown in Fig.2. The figure shows a force-displacement graph illustrating both the static and dynamic cycles. It is clear that the wheels exhibit hysteretic behaviour even when deformed under quasi-static conditions, along with an increase in stiffness during the dynamic tests.

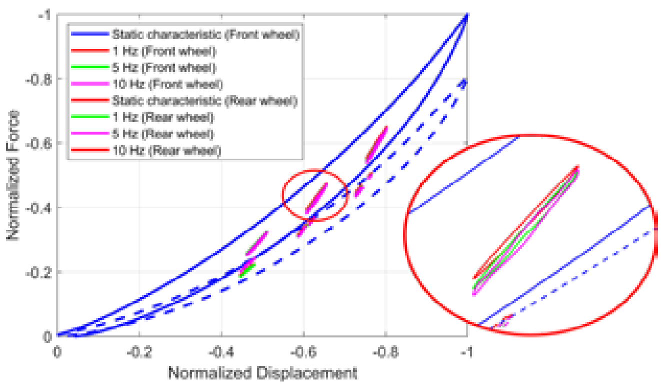

Fig.2: Results of front and rear wheel static and dynamic bench tests and zoom in on dynamic tests with 62% of maximum displacement preloaded.

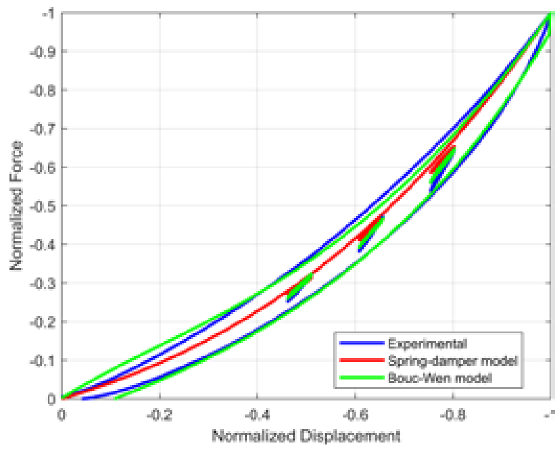

Fig.3. Comparison for the front wheel between models and experiment.

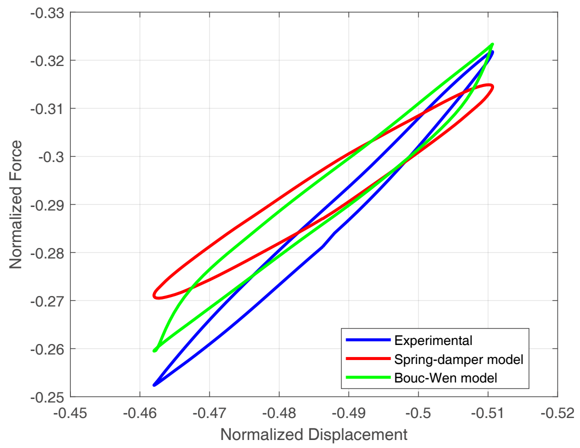

Fig.4. Zoom in on dynamic tests with 48% of maximum displacement preloaded at a frequency of 10Hz.

Wheel	Spring damper model	Bouc-Wen model
Front	6.8%	2.1%
Rear	6.2%	2.4%

Table 2: Relative errors of the fitting models.

Rheological models for wheel dynamics

Two models were proposed and compared to fit the results obtained from the bench tests: a spring damper model and a more complex model consisting of the previous model with an additional force component to evaluate the hysteretic behaviour according to the well-known Bouc-Wen formulation. The model was introduced by Bouc in 1971 [1] and later extended by Wen in 1976 [2].

Since then, the model has been widely used in engineering to describe the nonlinear hysteretic behaviour of materials subjected to cyclic deformation. The equations describing the radial force for the two proposed models is given below. For the spring damper model, the radial force F is expressed as a function of displacement x and the rate of deformation $\dot{x}$ according to the equation.

$$F = k_1x^3 + k_2x^2 + k_3x + c\dot{x}. \quad (eq.1)$$

The model is thus characterized by four parameters: k_1, k_2, k_3 and c. The implementation of the Bouc-Wen model includes the addition of the term αz, where z is obtained by solving a first-order non-linear equation characteristic of the model (Equation 3). The model is therefore characterized by a total of nine parameters.

$$F = k_1x^3 + k_2x^2 + k_3x + c\dot{x} + \alpha z \quad (eq.2)$$

$$\dot{z} = A\dot{x} - \beta|\dot{x}|z|z|^{n-1} - \gamma\dot{x}|z|^n \quad (eq.3)$$

The results are shown in Figs.3 and 4. You can see that the spring damper model does not reproduce either the static hysteresis (Fig.3) or the increase in stiffness during the dynamic tests (Fig.4). This results in a higher relative error than the Bouc-Wen model, as shown in Table 2.

Implementation of tyre models in RecurDyn and dynamic simulation of the obstacle crossing test

This section explains how the vehicle, and more specifically the wheels, were modelled to simulate the obstacle crossing test. The multibody model, developed using RecurDyn, is a reduced assembly of the forklift, consisting of the following elements: front axle, chassis, counterweight, rear axle, cab and wheel assemblies. Except for the wheels, all other bodies are rigidly connected by fixed joints.

The wheel assembly, the modelling of which is of particular interest for this study, consists of the rim and the solid tyre. The rims are connected to the axles via planar hinges. The tyres are modelled as rigid bodies.

An in-plane joint limits the displacement in the y-direction (reference system in Fig.5) between tire and rim, while an orientation joint prevents relative rotation between the two bodies. As a result, the wheel system has three degrees of freedom: two associated with the relative displacement between tyre and rim in the x-z plane and one associated with the rotation between rim and axle.

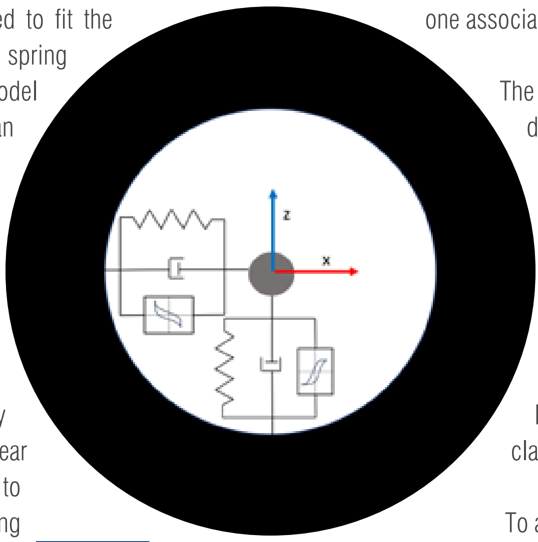

Fig.5. Diagram of the tyre model with force element representation.

The relative displacement in the x and z directions (along with the corresponding velocities) was used as input to calculate the x and z components of the radial force, following the equations of the rheological models presented above. Fig.5 shows a diagram of the wheel with the tyre in black, the axle in grey, and the force elements shown according to the Bouc-Wen model (the rim is omitted for clarity).

To accurately represent the interaction between the wheel and the road, it was necessary to implement contact functions that impose a

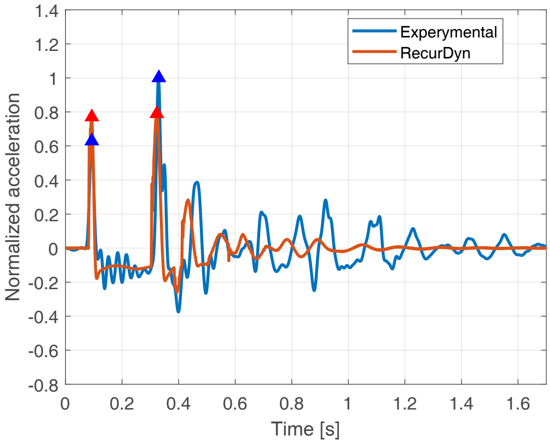

Fig.6. Spring damper model, front accelerometer.

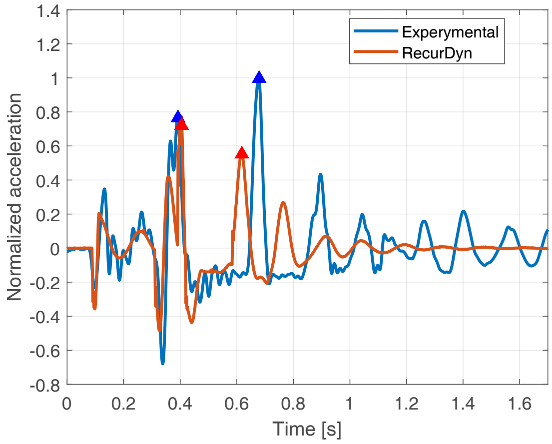

Fig.7. Spring damper model, rear accelerometer.

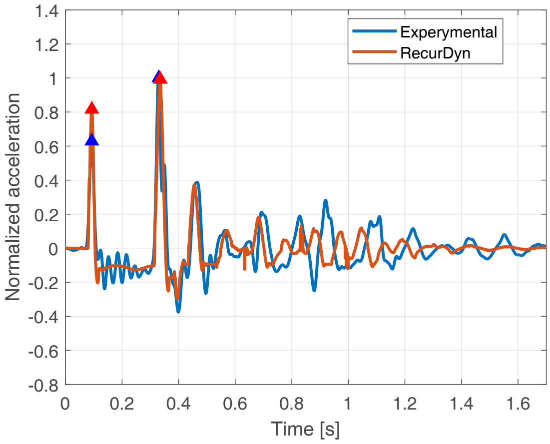

Fig.8. Bouc-Wen model, front accelerometer.

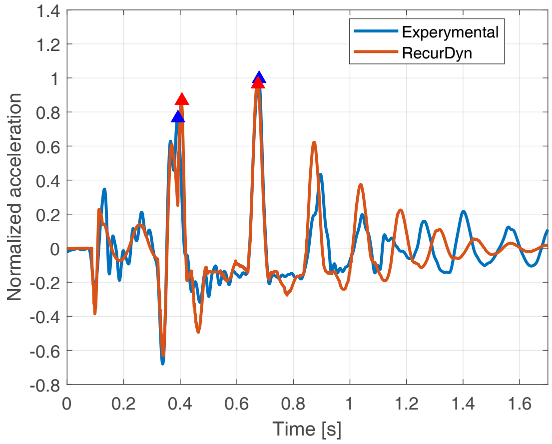

Fig.9. Bouc-Wen model, rear accelerometer.

unilateral constraint, allowing the wheel to lift off the ground, an effect that was observed experimentally after the impact with the obstacle.

The function used is the Geo Curve to Surface contact, where a circle corresponding to the wheel's median plane with a radius equal to that of the wheel is used as the action body, and the ground surface (including the obstacle) is selected as the base body.
The contact parameters were chosen by trial and error, with particular emphasis on the choice of stiffness k. This parameter was set to provide a contact stiffness significantly higher than that of the tyre, so as not to influence the results of the model. In this way, the contact function serves only to impose a unilateral constraint.

The target speed for hitting the obstacle was achieved by applying a velocity profile to the front wheels (driven) that increased to the target angular velocity according to a step function. To achieve this, it was necessary to include friction in the contact function to generate a traction force on the vehicle.

Experimental validation of the models

Experimental validation was carried out by replicating the cleat test with an equipped vehicle. Specifically, two accelerometers were installed on the vehicle: one placed on the front axle and one on the rear axle. The vertical acceleration measured during the experimental campaign was compared with the vertical acceleration signals obtained in RecurDyn from corresponding markers placed in the same positions as the accelerometers.

Figs. 6-9 show the normalized acceleration signals as a function of time. The first column corresponds to the front accelerometer signals, while the second column corresponds to the rear accelerometer signals. The first row compares the experimental signals to those obtained in RecurDyn using the spring damper model. The second row compares the experimental signals with those derived from the Bouc-Wen model.

In the graphs, the peaks corresponding to the impact of the wheel on the obstacle (first peak) and the rebound of the wheel from the ground (second peak) are marked with triangles. The wheel lifting phases can be identified by the time intervals in which the acceleration is approximately constant and negative.

The following observations can be made:

- The spring damper model underestimates the second peak, and the third peak appears earlier. The oscillatory behaviour dampens after a few cycles and there is a reduced number of wheel bounces. This suggests that the system is overdamped.
- In contrast, the Bouc-Wen model accurately predicts both the second and third peaks. This model also shows the correct number of wheel bounces.

These observations suggest that the use of a hysteretic model such as the Bouc-Wen results in an appreciable [3] improvement in the reliability of the simulation compared to a simpler spring damper model.

Conclusion

This study led to the development of two models for the radial dynamics of the solid rubber wheels of a TMHMI forklift: a viscoelastic model (spring damper) and a hysteretic model (Bouc-Wen formulation).

These models were derived from wheel characteristics obtained from bench tests, which showed hysteretic tyre behaviour and an increase in stiffness under frequency-induced deformation.

By fitting these characteristics, the parameters defining each model could be determined. The fitting results show that the spring damper model cannot reproduce the hysteresis observed in static tests and the increase in stiffness observed in dynamic tests, whereas the Bouc-Wen model can, equating to a significantly reduced fitting error.

The model was validated by comparing the experimental vertical accelerations of the front and rear axles with those obtained from multibody dynamic simulations. The comparison shows that the Bouc-Wen hysteretic model provides significantly better simulation accuracy.

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About the Department of Civil and Industrial Engineering of the University of Pisa (DICI)

The Mechanical Design and Machine Construction group of the Department of Civil and Industrial Engineering of the University of Pisa deals with both numerical methods and experimental analyses for the study of complex mechanical structures. Numerical simulations, including FEM and multibody techniques, are often applied to cases from the automotive and other fields, frequently based on input from collaborating companies. Experimental validation is a cornerstone of the group's work and is conducted in the department's state-of-the-art laboratories equipped for static and dynamic characterization of samples, components, and systems. Customized test benches are often developed to address specific industrial challenges.
For more information: francesco.bucchi@unipi.it

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Thermal management: challenges in and strategies for developing electrified products

by Gaia Volandri[1], Duccio Griffini[1], Gilles Simon[2], Raffaele Squarcini[1]
1. Pierburg Pump Technology Italy - 2. Pierburg Pump Technology France

The constant demand to make products more efficient, compact, and reliable while reducing costs typically drives the activities of R&D departments in the automotive industry and beyond. Thermal management (TM) is one of the key challenges to be addressed and needs to be considered from the earliest stages of defining the design, especially when dealing with electrified products. So, what is it?

Thermal management refers to all the strategies, technologies and tools that keep a system within its optimal range of operating temperature, thus ensuring that all its parts operate safely, reliably, and efficiently.

This general definition can be applied to daily work as a pragmatic mixture of thermal assessments with different levels of complexity and a "system view". These two key elements can support all phases of product development with the right effort and provide opportunities to:

- avoid multiple design loops and prototypes,
- avoid compartmentalized design,
- optimize reliability and efficiency.

The result is faster time to market, cost savings and the best system solution.

Fig.1. Main subsystems of a typical electrified product.

After briefly introducing electrified products and their requirements in the initial design phase, this paper focuses on some characteristics of 3D thermal analysis, typically reserved for advanced phases of development when designs are verified and improved.

Electrified products

The authors work for the Rheinmetall group in the Thermal Management Business Unit (BU-TM). The company has several divisions, one of which – Power Systems – deals with automotive/civil applications. In its turn, the Power Systems Division also has several business units including Thermal Management, which focuses on developing components, modules and systems for e-mobility and industrial applications. BU-TM's electrified product portfolio includes:

- electric water pumps (eWP) mainly used for TM,
- electric oil pumps for both lubrication and TM,
- electrified valves for system management,
- high voltage components such as hydrogen recirculation blowers (HRB) for fuel cells,
- thermal modules for automotive and non-automotive applications,
- components for home heating and other industrial applications.

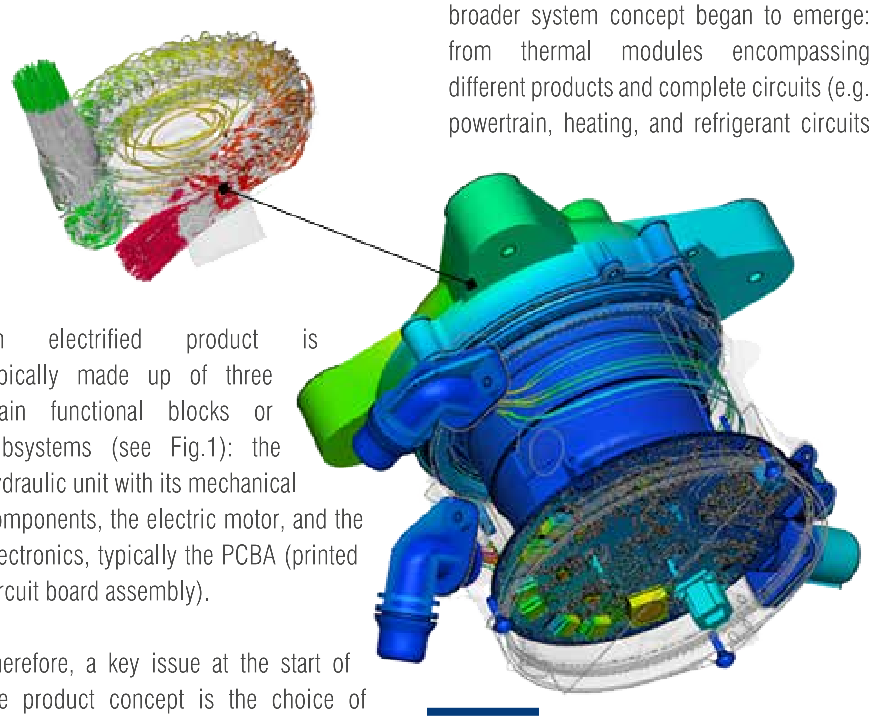

Fig.3. Examples of a fully coupled model complexity.

An electrified product is typically made up of three main functional blocks or subsystems (see Fig.1): the hydraulic unit with its mechanical components, the electric motor, and the electronics, typically the PCBA (printed circuit board assembly).

Therefore, a key issue at the start of the product concept is the choice of the assembly layout. This refers to the relative positioning of the aforementioned subsystems and their interfaces, which constrain each other and strongly influence the thermal paths used to dissipate heat. As a result, preliminary thermal assessments are made in the pre-design phase, usually through analytical or 1D approaches. Note that high overall product efficiency and lean design are only possible with an advanced view: products are systems, no longer single-level physics.

Fig.2. Capability evolution in model development.

Against this background, the company's Modelling and Simulation (M&S) department started working on a new way of thinking. With this new mentality, and considering the evolution of the automotive market, an even broader system concept began to emerge: from thermal modules encompassing different products and complete circuits (e.g. powertrain, heating, and refrigerant circuits of a passenger car) up to an entire vehicle, supporting a general cultural evolution within the company. In parallel, dedicated know-how and a complete set of tools have been developed, from 1D model-based system engineering to 3D thermo-fluid dynamic simulations, the objective of this paper.

Thermal modelling: focus on 3D thermo-fluid dynamic analysis

The first 3D thermo-fluid dynamics research and simulations started around 2009 as a structured and systematic approach in the M&S department of the BU-TM, with the first publication of its results in 2011 [1].

The evolution of skills in terms of increased know-how, improved networking between people responsible for different sub-systems, and improvements in CAE tools now make it possible to build very complex models that take into account all the physics involved in TM.

As an example, in 2009, a typical 3D model of an electrified product in a commercial CFD tool could contain about one million cells, whereas in 2024 it is feasible to build models with around 30 million cells in a reasonable amount of time (see Fig.2). This increase in detail and physics increases the resolution of the thermal results as well as their accuracy.

As mentioned, this type of analysis usually takes place when designs are verified and improved. At that point, the most pressing question is whether the electric motor and electronics are properly cooled. To answer

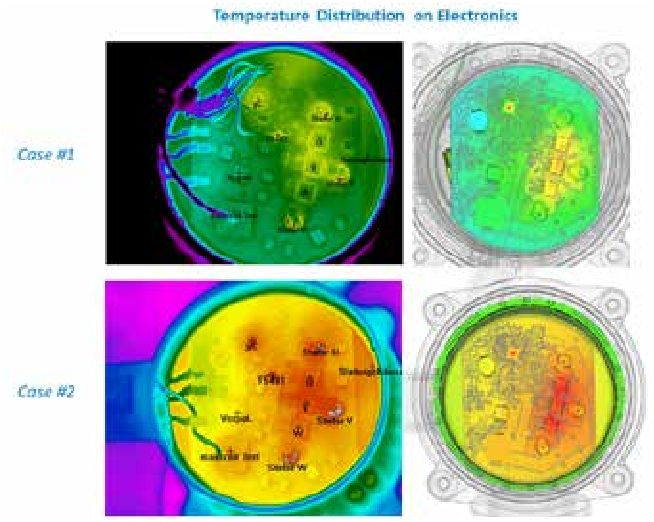

Fig.4. Comparison between experimental and virtual thermography of a PCBA.

this question, a standard analysis must provide the following key results: the temperature distribution within the product, a virtual thermography of the PCBA, and the distribution of the heat flows to highlight the thermal paths for heat dissipation.

Two main model options are available during configuration, depending on the coupling method between fluid and solid domains:

- an all-in-one model with matched interfaces (conjugated heat transfer, CHT method) [2],
- co-simulation between a solid and a fluid model (coupled heat transfer method) [3].

Both of these methods have their advantages and disadvantages, and the choice is made on a case-by-case basis, depending on the goal of the analysis and the physics involved. Simplified approaches can also be used, keeping the computational effort to a minimum. Fig.3, which shows the results of a CHT method from a high-voltage HRB, gives an idea of the complexity that can be achieved. The model consists of a pneumatic set providing the required recirculation of hot gas, an externally fed cooling jacket, and the complete 3D assembly including air gaps and cavities.

In terms of geometry, these models can easily contain up to forty parts for the pump assembly and thousands of parts for the PCBA alone. Such a remarkable number of components allows reliable results to be obtained with incredibly detailed resolution. Fig.4, which shows an example of virtual versus experimental thermography for two case studies of an eWP, gives an idea of the quality achieved.

Thermal verification loop: behind the scenes of full 3D analysis

Of particular note is the information required to feed a fully coupled 3D simulation. The diagram in Fig.5, which highlights all the necessary steps of the thermal loop, illustrates the complexity of this topic.

Starting with the design of the hydraulic unit and assembly, fluid dynamics and mechanical analysis are performed to obtain torque at the shaft. This output plus the rotational speed and electrical constraints are the main inputs for the e-motor experts and, subsequently, the electronics experts to provide predicted thermal losses. Once all the information is available, thermo-fluid dynamic analysis can provide temperature fields and thermal paths. These outputs can be used to iterate the loop and eventually, once convergence is achieved, to guide design verification and improvement.

It is becoming increasingly clear that the loop involves the contribution of several disciplines and departments. All these actors must be in constant dialogue to manage the exchange of information and coordinate activities (see Fig.6), always guided by the "system view". In this sense, thermal management is also a matter of human relations between people, cultures, and professional specializations.

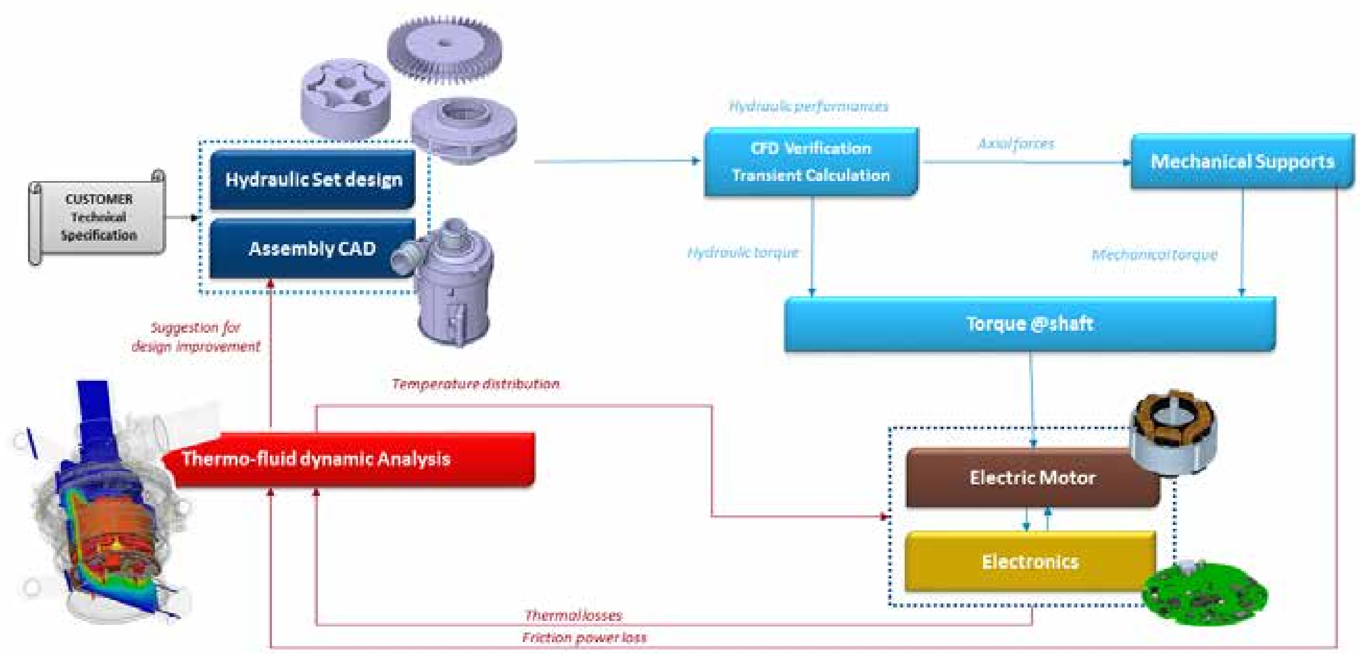

Fig.5. Thermal verification loop for an electrified product.

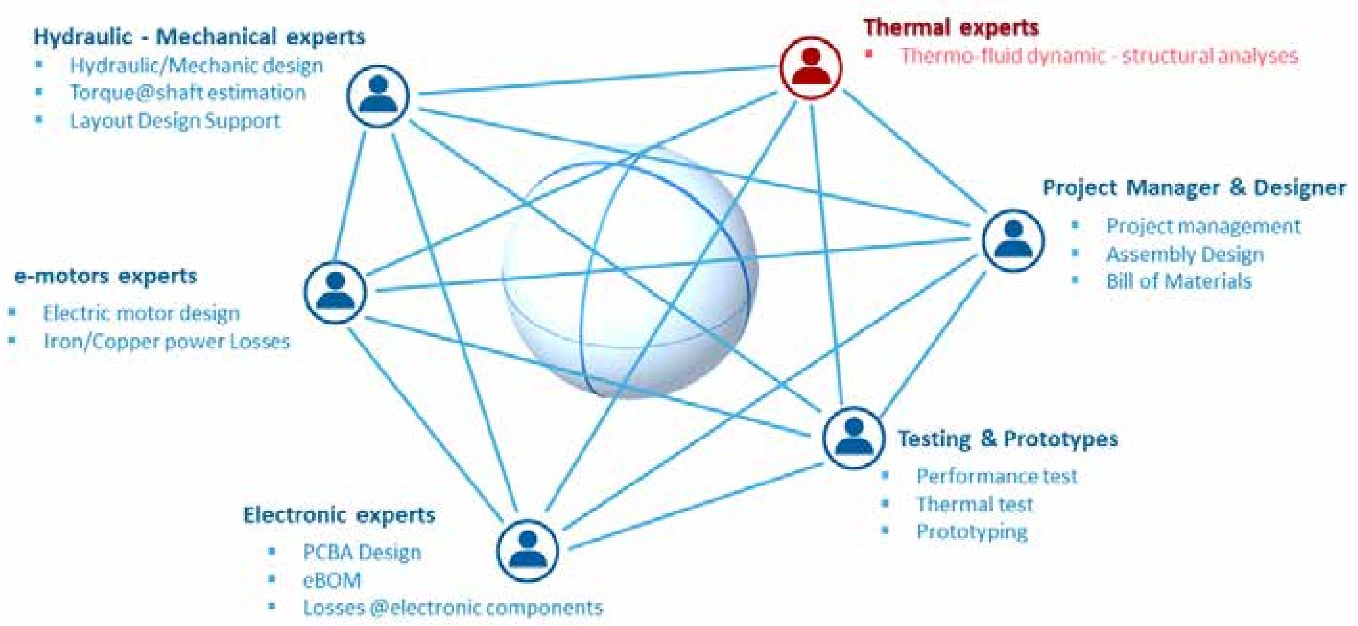

Fig.6. Relations for thermal management.

Conclusions

Thermal management is a growing trend in the automotive industry and beyond.

It is now a standard part of the overall design process and is typically addressed by the M&S department through different levels of analysis and modelling strategies, ranging from analytical estimates to fully coupled 3D thermo-fluid dynamic analysis. The latter approach can ensure reliable and accurate results that can be used to verify and improve the design. Underlying this is an inherent complexity in terms of the relationships and information exchange required between different complementary skills.

Above all, thermal management represents a cultural evolution and a change of perspective capable of recognizing a product as a system and extending interest and know-how beyond the product itself.

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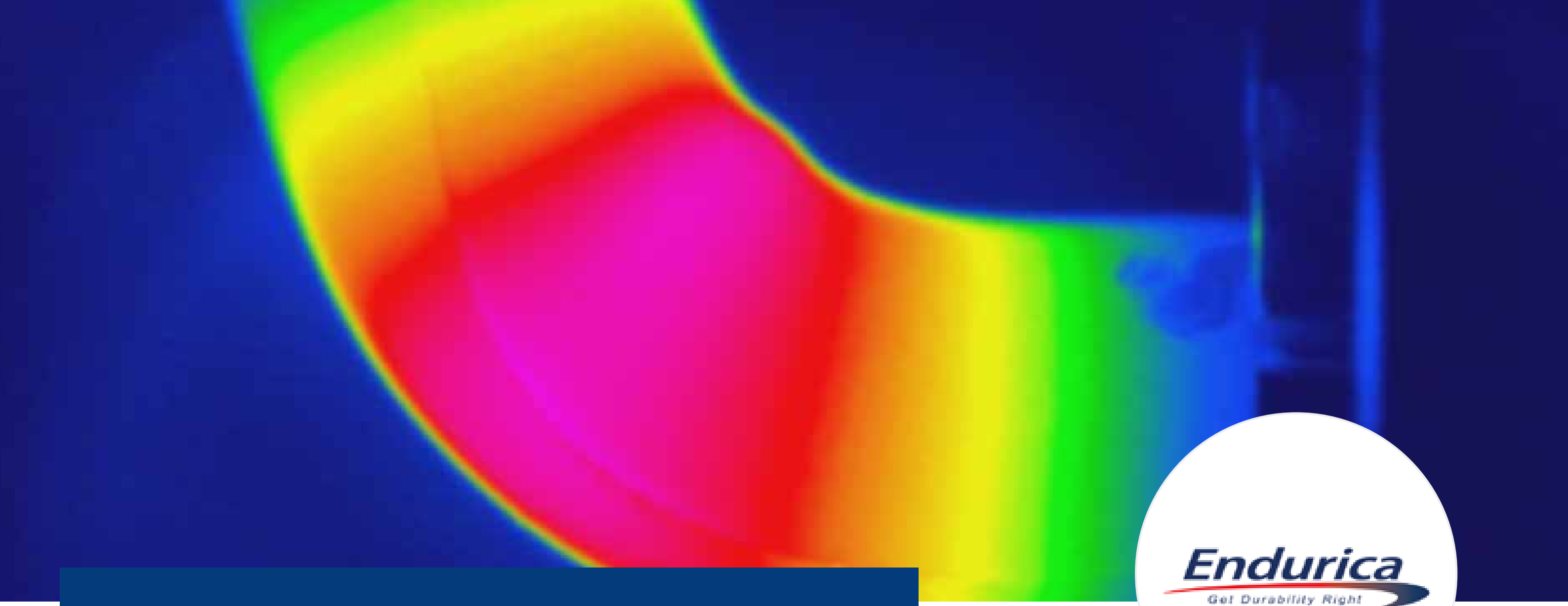
About Rheinmetall

As an integrated technology group, the listed company Rheinmetall AG, headquartered in Düsseldorf in Germany, represents a group that is as strong in substance as it is successful internationally. The organization is active in various markets and offers an innovative range of products and services. Rheinmetall is a leading international systems supplier in the defence industry as well as a driver of forward-looking technological and industrial innovations in civilian markets. The company employs 30,000+ employees in 167 sites.

Pierburg Pump Technology Italy and Pierburg Pump Technology France, which belong to Rheinmetall, specialize in the manufacture of various types of pumps, such as mechanical and electrical oil pumps, vacuum pumps and water pumps. All products are continuously developed by the R&D team, so that the companies can offer their customers a wide range of customized solutions for all engine applications and requirements.



Rubber fatigue ≠ metal fatigue: thermal effects

by William V. Mars
Endurica

All materials are temperature dependent, but some more than others: metals tend to be crystalline solids and will melt at sufficiently high temperatures; in contrast, crosslinked elastomers are always solids. They can be glassy or rubbery, crystalline or amorphous. When heated to extreme temperatures, they burn rather than melt, producing new substances, usually low molecular weight hydrocarbons (i.e. tarry substances and smoke). Of course, you do not have to melt or burn a material to see the effects of temperature. In fatigue analysis, we are concerned with stress-strain and crack growth behaviour. These can be temperature dependent for both metals and rubbers. However, while metals have a very high thermal conductivity, rubbers have almost the lowest. Therefore, fatigue analyses involving large temperature gradients are much more common in rubber than in metal.

As shown in Fig.1, while a 100°C temperature gradient in a metal can affect the fatigue tensile strength or the fatigue limit by 10% [1], the same 100°C temperature gradient in rubber can reduce the fatigue life by four orders of magnitude [2]!

Temperature and segmental mobility

The mechanisms underlying the elasticity of metals and rubbers could hardly be more different. Under stress, atoms in a metal's crystal lattice are displaced from their equilibrium positions, and potential energy is stored in strained interatomic bonds. In rubber, however, the strain energy is not predominantly stored in strained atomic bonds. Rather, elasticity arises because the constituent long-chain molecules are much more likely to be randomly coiled than to be fully extended.

Thus, provided the molecules are sufficiently agitated by random thermal fluctuations, an entropic spring effect is created, meaning that potential energy can be stored by working to reduce the entropy of the polymer chain network by increasing the end-to-end distance of individual polymer chains [3].

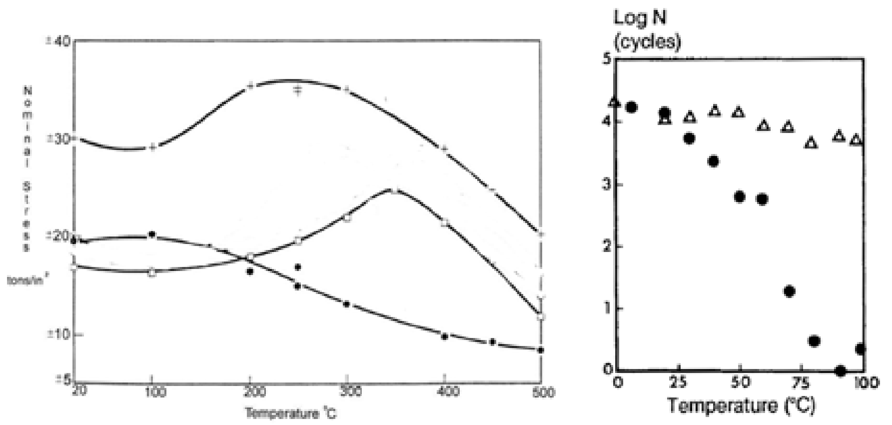


Fig.1. Left – Effects of temperature on carbon steel showing tensile strength (+), yield stress (•), and fatigue limit (o), [1]; Right – Effects of temperature on natural rubber (Δ) and styrene butadiene rubber (•), [2].

Polymers in general can exhibit both glassy and rubbery behaviour, depending on the temperature. The rubbery state — in which entropic elasticity dominates — exists above the glass transition temperature T_g if the molecular motion rate is sufficiently high. In the rubbery state, very large strains are possible and the rubbery elastic storage modulus E'_r determines the stress-strain curve.

Below T_g, however, the lack of thermal molecular mobility prevents molecular reconfiguration, resulting in a glassy stiffness

E'_g that is several orders of magnitude higher than E'_r. Polymers operating below T_g are thus not capable of large elastic strains and instead exhibit inelastic behaviour when strains exceed a few percent. Fig.2 shows how the storage and loss moduli vary through the glass transition (left), and how the molecular motion rate depends on temperature (right). The relative rate $\varphi(T)/\varphi(T_g)$ of molecular motion as a function of temperature T is described by the WLF equation [4], which has material constants A and B.

$$\ln\left(\frac{\varphi(T)}{\varphi(T_g)}\right) = \frac{A(T-T_g)}{B+T-T_g}$$

Since the fracture mechanical properties of rubber depend on the viscoelastic dissipation in the crack tip process zone, with higher dissipation associated with lower crack growth rates, frequency and temperature effects can be inferred accordingly. Viscoelastic master curves, such as those shown in Fig.2, can be used as part of the material property rate dependence specification in the Endurica solver.

Self-heating and thermal runaway

During a charge cycle, work W_L is done on the charge stroke, some of which W_U is recovered on the discharge stroke, as shown in Fig.3. The unrecovered part of the work H remains in the material as heat energy, increasing the temperature.

The rate of viscoelastic heating of rubber depends on strain amplitude, cycle rate (i.e. frequency) and temperature. The strain amplitude dependence of the viscoelastic storage and loss modulii, G' and G'' respectively, can be specified using the Kraus model [5, 6]:

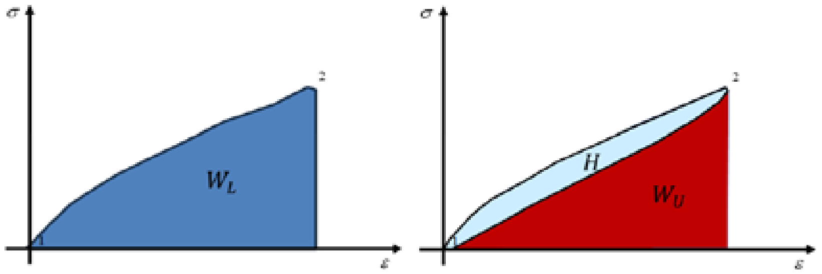


Fig.3. Work input W_L on the loading stroke is partially recovered as W_U on the unloading stroke. A portion H of the energy remains in the material as heat.

$$G'(\varepsilon_a) = G'_\infty + \frac{G'_0 - G'_\infty}{1+\left(\frac{\varepsilon_a}{\varepsilon_{a,c}}\right)^{2m}}$$

$$G''(\varepsilon_a) = G''_\infty + \frac{2(G''_{max}-G''_\infty)\left(\frac{\varepsilon_a}{\varepsilon_{a,c}}\right)^{m} + \Delta G''_U}{\left(\frac{\varepsilon_a}{\varepsilon_{a,c}}\right)^{2m}+1}$$

where ε_a is the strain amplitude, and where G'_∞, G'_0, $\varepsilon_{a,c}$, m, G''_∞, G''_{max}, and $\Delta G''_U$ are material parameters. The viscoelastic heat rate per unit volume can be calculated from:

$$\dot{q} = H\omega = \pi\omega G''(\varepsilon_a)\varepsilon_a^2$$

Due to the low thermal conductivity of rubber, small amounts of viscoelastic self-heating can produce large temperature gradients. Accurately accounting for thermal effects on rubber durability generally requires both a structural finite element analysis to calculate the stress and strain fields, and a thermal finite element analysis to calculate the temperature field. Endurica fatigue solvers can provide heat rate calculations in a coupled finite element simulation for both transient and steady-state thermal analyses.

In cases where the temperature in the rubber exceeds a critical value T_x, an additional heat rate contribution $\dot{q}_x$ occurs due to exothermic chemical reactions. The effect is illustrated in Fig.4, for a rubber cylinder subjected to a rotating bending load [7]. The thermal runaway starts after about 250 seconds. Both experimental (dashed line) and Endurica calculated (solid line) simulation results are plotted for the cylinder centre line (blue) and for the cylinder outer surface (green).

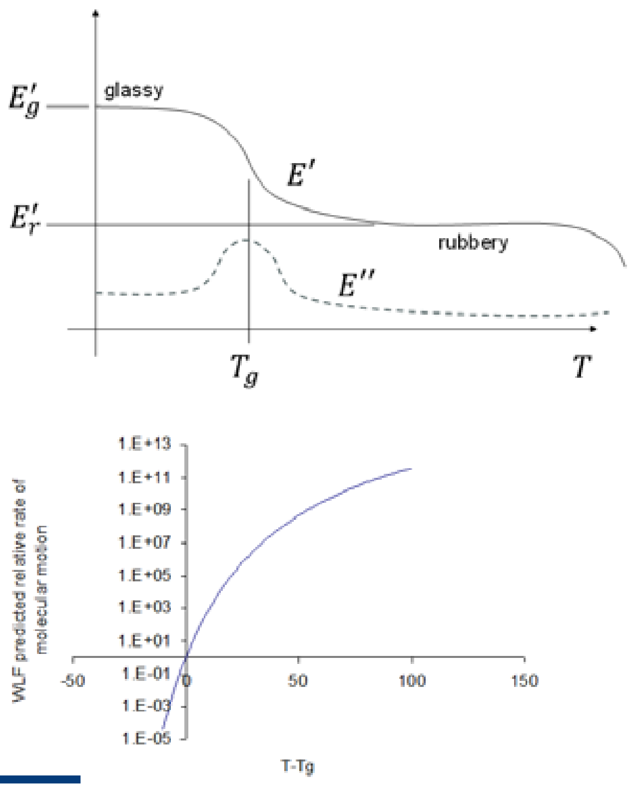


Fig.2. Top: Rubber's elastic and viscous responses depend on temperature relative to the glass transition temperature T_g; Bottom: The rate of molecular motion depends on temperature relative to the glass transition temperature Tg.

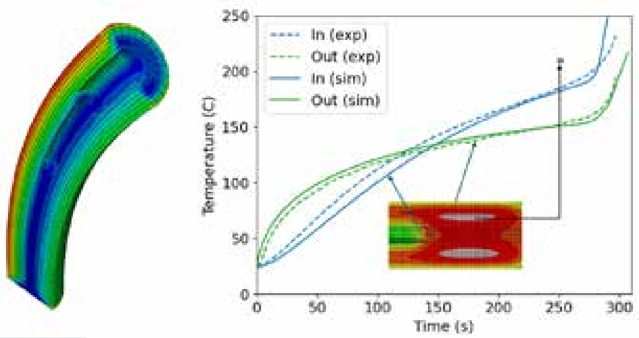


Fig.4. When temperature exceeds a critical value T_x, exothermic chemical reactions can produce a thermal runaway failure. Plot (right) shows Endurica calculated transient temperature history (solid lines) for a rotating bending cylinder (structural finite element model shown on left). For comparison, experimentally measured temperature histories are also shown (dashed lines).

The thermal runaway event typically results in rapid decomposition of the rubber into hydrocarbon gases (i.e. smoke/burning rubber) and low molecular weight substances (tar).

Reversible temperature effects

The crack growth properties of rubber reversibly depend on temperature. Higher temperatures tend to reduce the tear strength T_c of rubber and increase the crack growth rate, as shown in Fig.5 [8]. At lower temperatures, the tear strength is increased and crack growth is retarded. Endurica's crack growth models can be specified with a temperature dependence via the temperature sensitivity coefficient (see Table 1) or via a table look-up function.

Fig.6 shows the fatigue life as a function of temperature calculated from the parameters in Table 1 [2]. Over a range of 100°C, natural rubber loses approximately a factor of two in fatigue life, and styrene butadiene rubbers loses four orders of magnitude!

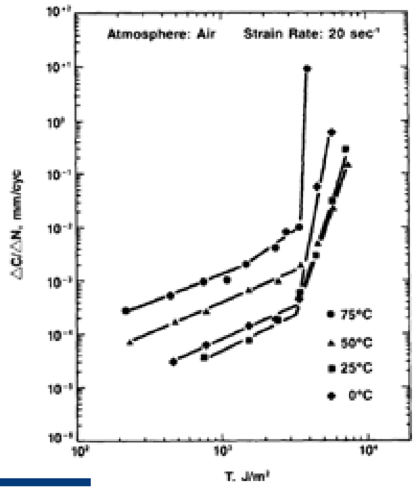


Fig.5. Increasing temperature causes the crack growth rate to increase. Results are shown for natural rubber [8].

Some rubbers undergo strain crystallization, which is beneficial when operating under non-relaxing conditions. The crystallization effect is strongly temperature dependent and decreases with increasing temperature.

Fig. 7 shows the Haigh diagram calculated by Endurica for three different temperatures: 23, 90 and 110°C. For example, at a mean strain of 100% and strain amplitude of 20%, the fatigue life at 23°C exceeds 10^6 cycles, but at 110°C the fatigue life is approximately 10^3 cycles. This effect has been confirmed experimentally in recent work by [9].

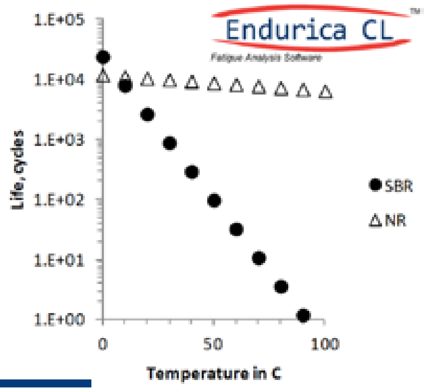


Fig.6. Endurica calculated dependence of fatigue life on temperature for natural rubber (Δ) and for styrene butadiene rubber (•), [2]. Compare to Fig.1.

	Natural Rubber	Styrene Butadiene Rubber
Shear Modulus G, MPa	0.26	0.26
Precursor crack size c_0, mm	0.025	0.055
End of life crack size c_f, mm	1.0	1.0
Reference temperature θ_0, $°C$	20	20
Temperature sensitivity coefficient, 1/°C	0.0061	0.110
Tear strength T_c, kJ/m^2	10.0	2.5
Intrinsic Strength T_0, kJ/m^2	0.04	0.06
Crack growth rate r_c at T_c, mm/cyc	5 x 10^{-3}	50 x 10^{-3}
Thomas law slope F	2	4
Strain crystallization	Yes	No

Table 1. Crack growth properties and temperature sensitivity for natural rubber (NR) and styrene butadiene rubber (SBR), estimated from measurements reported in [2].

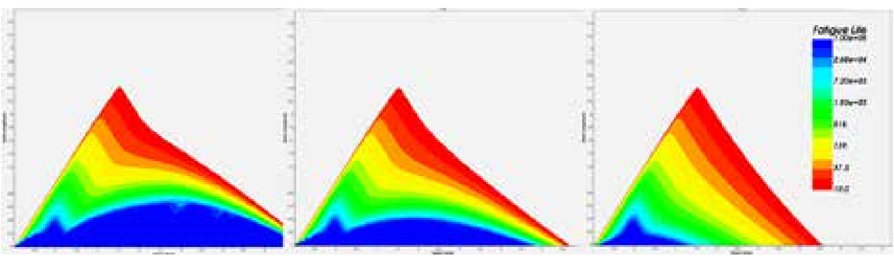


Fig.7. Endurica calculated Haigh diagrams for natural rubber at 23, 90 and 110°C. Increasing temperature tends to reduce strain crystallization, with the result that the mean strain benefit associated with strain crystallization is reduced or even eliminated at high temperatures.

Irreversible temperature effects/ageing

Prolonged exposure to high temperatures can cause permanent changes in the cross-link density and mechanical properties of rubber, including stiffness and crack growth properties. The effect depends on the availability of oxygen [10], as shown in Fig.8.

When aged under Type I aerobic conditions, rubber becomes brittle as its strain at break λ_b decreases while its stiffness M_{100} increases. When aged under Type II anaerobic conditions, rubber tends to soften while its strain at break decreases.

The rate at which thermochemical ageing of rubber progresses can be specified in Endurica using the Arrhenius law [11] and its activation energy parameter E_a. When following a temperature history $\theta(t)$, Endurica integrates the Arrhenius law to determine an equivalent exposure time τ at the reference temperature θ_0. R is the real gas constant.

$$\tau = \int_0^t e^{\frac{E_a}{R}\left(\frac{1}{\theta(t)} - \frac{1}{\theta_0}\right)} dt$$

The equivalent exposure time controls the evolution of the stiffness and crack growth properties with thermal history. As shown in Fig.9, the evolution of the crack growth

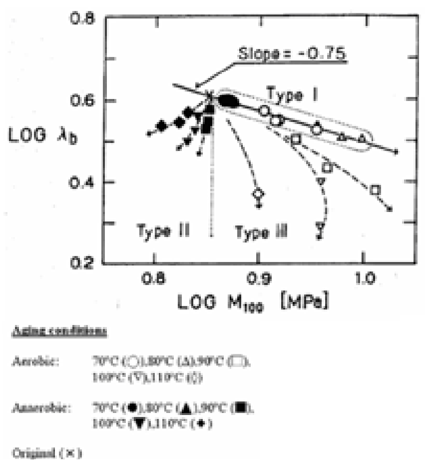


Fig.8. The evolution of rubber's properties during ageing depends on the availability of oxygen, and on the temperature [10]. Under aerobic conditions, ageing tends to increase stiffness while strain at break decreases. Under anaerobic conditions, ageing tends to decrease stiffness while strain at break decreases.

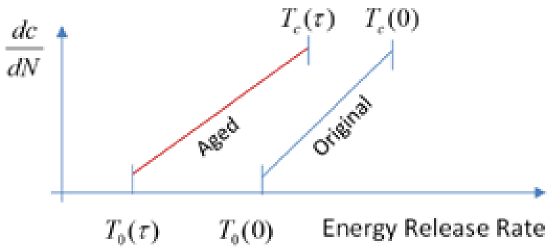


Fig.9. The crack growth rate law evolves as a function of the equivalent exposure time τ. Crack growth property evolution is specified in Endurica by the dependence of the rubber's tear strength $T_c(\tau)$ and its fatigue limit $T_0(\tau)$ on exposure time.

rate law is specified by a tabular function that gives the stiffness $E(\tau)$, the tensile strength $T_c(\tau)$ and the fatigue limit $T_0(\tau)$. The material properties are then updated iteratively according to the co-simulation workflow shown in Fig.10. This allows the effects of thermal history and ageing on fatigue performance to be considered.

Conclusion

There are many ways in which metals and rubbers differ in their behaviour, and thermal behaviour is one of the most important.

Rubber more often requires careful attention to thermal effects due to its exceptionally low thermal conductivity, its entropy-elasticity, its visco-elastic properties and tendency to self-heat under cyclic loading, the sensitivity of crack growth properties and strain crystallization to temperature, oxidation and ageing.

Endurica's fatigue solvers provide material models and workflows that capture these thermal effects, enabling accurate analysis and "right first time" engineering.

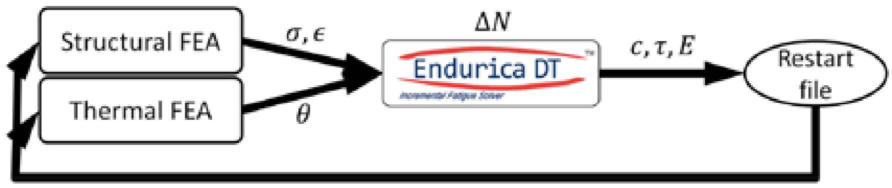


Fig.10. Endurica DT's co-simulation workflow updates the crack length c, exposure time τ, and stiffness E so that stress, strain, and temperature fields can be updated during solution.

About Endurica

Endurica provides software, materials characterization services, consulting, testing instruments and training to help companies meet rubber durability targets during product design. The company's solutions put engineers in control of rubber durability issues early in the development cycle, when the greatest opportunities exist to influence performance, and before investing in costly testing of prototypes. Endurica is the world's best-validated fatigue life simulation system for elastomers and its workflow gets rubber products to market faster. Endurica serves leading companies in many sectors including aerospace/defence, agriculture, automotive, chemicals, consumer products, education/research, energy, healthcare/medical devices, high tech, industrial manufacturing, infrastructure, marine, raw materials suppliers, silicone suppliers, rail, and tyres. It provides rubber fatigue analysis tools that are accurate, complete and scalable. Visit endurica.com

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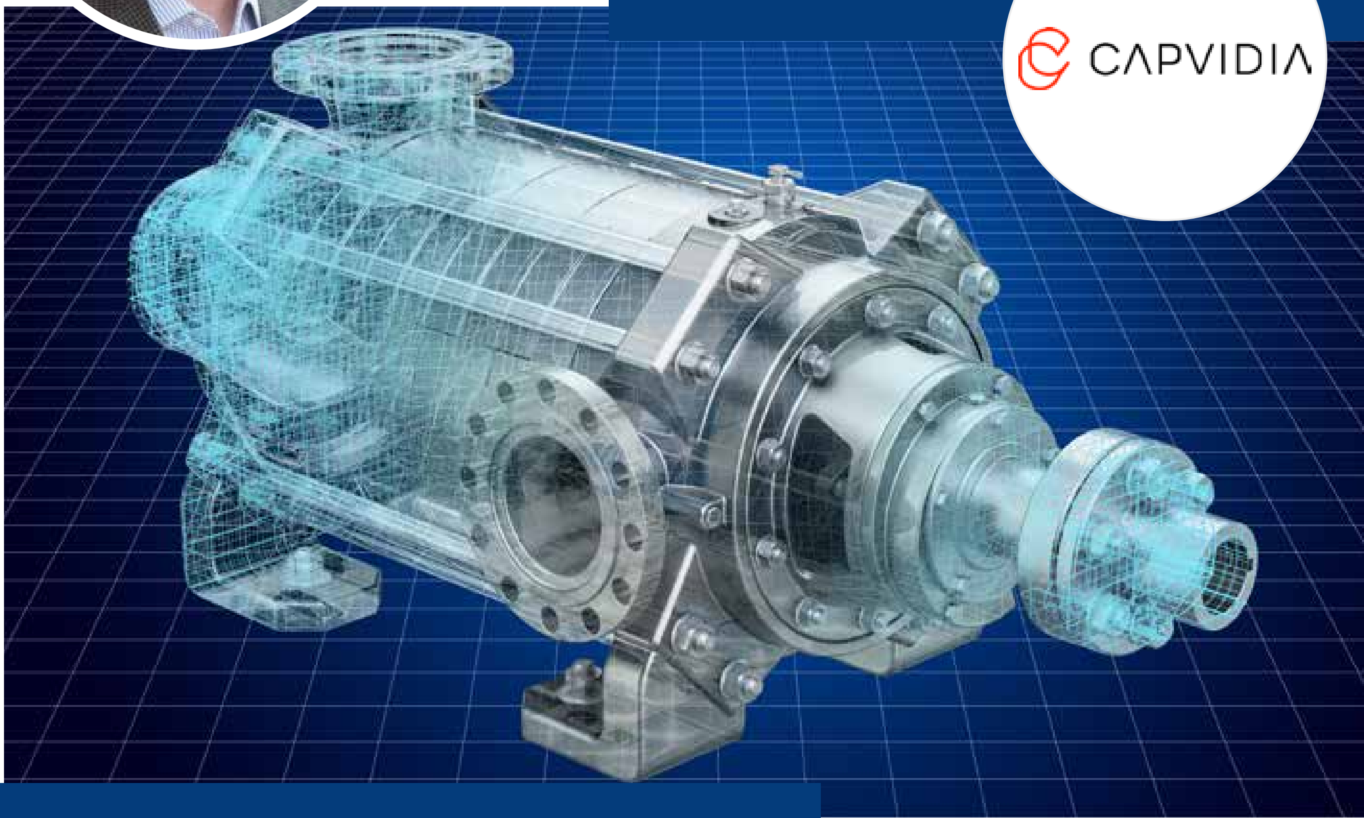
face to face with Daniel Campbell

VP of MBD at Capvidia



The future of digital manufacturing starts with Model-Based Definition (MBD)

by Enrico Boesso
EnginSoft

Concepts such as Industry 4.0, digital twin, digital thread, and model-based enterprise (MBE), all rely on data-rich 3D models to create the foundation for integrating digital technologies throughout the product lifecycle.

In this *Futurities* Face to Face interview between Enrico Boesso, Senior Dimensional Management Engineer at EnginSoft, and Daniel Campbell, VP of MBD at Capvidia, we explore the importance of model-based definition (MBD) and how it is transforming industry.

Enrico: In the 12 years that I have been with EnginSoft I have seen changes in the manufacturing sector – particularly in the areas of digital twins and digital thread technologies.
I would like to explore some of the underlying terms and technologies with Capvidia's Daniel Campbell and these start with model-based definition or MBD. Daniel, could you explain what MBD is?

Daniel: Certainly, Enrico, thank you. Model-based definition uses a digital 3D model as the ***single source for all product design information.*** Instead of engineers juggling separate 2D drawings and documents, all critical details — such as dimensions, annotations, and manufacturing information — are embedded directly in the 3D model, eliminating the need for traditional paperwork.

Enrico: So, it is a drawing-free approach?
Daniel: Well, yes and no. MBD is about much more than just going paperless. Its **key feature is that it is machine-readable,** meaning that the data can be read and processed by other software and machines, enabling automation and less reliance on manual work. The big wins are better accuracy, faster time to market, and lower costs.

Enrico: So all the dimensions, tolerances, material specifications — everything — is embedded as information directly in the 3D model. This model is then used throughout the product lifecycle because its data is interoperable with other programs, right?
Daniel: That is correct. The 3D model is the definitive single source of truth, creating a digital thread in the process, both upstream and downstream.

Enrico: In theory, MBD sounds like the perfect solution for manufacturers to adopt, so why don't all companies do it?
Daniel: Implementing MBD can be challenging, especially for companies used to working with 2D drawings. ***The biggest hurdle is the cultural change*** — accustoming teams to working with 3D models. There is also a learning curve for the new software and for ensuring that systems are compatible. The company's workflows may also need to be restructured. Overall, there is a significant upfront investment in terms of training, time, growing pains, etc. but the long-term benefits of faster, better, and cheaper production make it worthwhile.

Enrico: Yes, at EnginSoft we usually find that cultural change is one of the biggest hurdles to overcome. Many companies are used to their bespoke methods and do not see the change as adding value.
Daniel: We see the same thing at Capvidia. However, many of us older team members remember life and work before and after the Internet. In many ways, the rise of Internet-enabled e-commerce and its impact on brick-and-mortar stores parallels the digital transformation taking place in manufacturing.

Enrico: Exactly! The Internet changed so much in such a brief time. Everyone has a smartphone now.
Daniel: And every business has either a website or offers e-commerce. And those that did not adopt or adapt found themselves playing catch-up to competitors, while others went out of business. Another good example is how Netflix disrupted the movie rental business.

Enrico: So, are you saying that MBD is disruptive?
Daniel: Whether it is MBD today or some future technology tomorrow, the primary goal in manufacturing will always be "better, faster, and cheaper". MBD enables manufacturers to achieve this real value today and will be inevitable in the future as we increasingly move into an AI, automation, and data-driven world.

Enrico: Speaking of value, what are the specific benefits of MBD for designers, quality inspectors, and suppliers?
Daniel: ***MBD simplifies real-time collaboration because everyone is working from the same 3D model.*** Since engineers, manufacturers, and quality teams are all accessing the same data, miscommunication is reduced. For designers, MBD streamlines the process by embedding everything directly into the 3D model, reducing the potential for errors. Quality teams can use the same model to inspect parts and ensure everything matches the design. Suppliers benefit by using the digital model to program machines, speeding up production and improving accuracy. Overall, it makes the full process more efficient and keeps everyone on the same page.

Enrico: Another related buzzword is model-based enterprise or MBE. How does MBD relate to MBE?
Daniel: MBD is the backbone of an MBE. In an MBE, digital models are used across all functions, from design to production to maintenance. MBD is the technology that keeps the design consistent throughout the product lifecycle, connecting all data and eliminating the need for paper or separate systems.

Enrico: Can you explain the relationship between native and neutral formats with MBD, which is another question we are often asked.
Daniel: Native formats, such as Catia or Creo, are specific to the software used to create the 3D model and are best suited for in-house processing. ***Neutral formats, such as STEP AP242, 3D PDF, and QIF***, are more flexible and can be used by different systems, making them ideal for sharing models across teams and suppliers. Native formats are great for internal use, while neutral formats allow for easier collaboration across the supply chain.

Enrico: How does an MBD transformation process begin?
Daniel: The ***lowest hanging fruit for an MBD pilot project is the characterization and generation of inspection plans*** such as first article inspection (FAI) and production part approval processes (PPAP). These tasks are extremely important and typically very manual and time consuming. In these situations, MBD provides immediate results and implementation can build from there. Of course, it also helps to work with technology partners and service providers such as Capvidia and EnginSoft who can provide not only the software but also the support needed to make the transition to MBD.

Enrico: Thank you, Daniel, for these insights. I hope they prove useful to our readers as they consider their own digital manufacturing futures.

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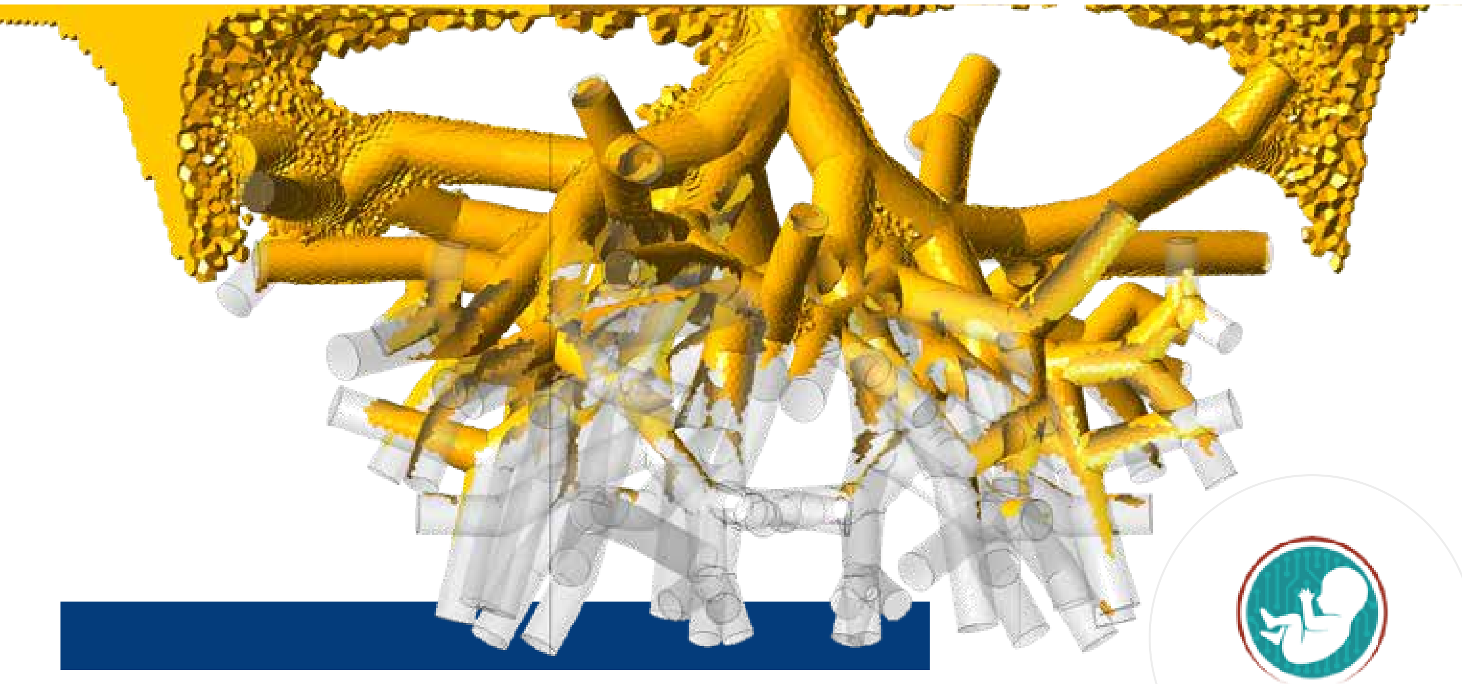

Modelling the placental villus and fluid field

by Francesco Franchini[1], Novella Saccenti[1], Erik Mazzoleni[1], Daniele Cortesi[1], Carla Baldasso[1], Alessandra Manzin[2], Riccardo Ferrero[2]
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How to model the complex geometry of the villus and surrounding fluids

The work presented in this article is part of the LIFESAVER project funded by the European Union and executed by the two main partners, the National Metrology Institute of Italy (INRiM) and EnginSoft.

The LIFESAVER project aims to simulate the structure and function of the placenta at the end of the first trimester (approximately 12 weeks of gestation) to simulate the transport of substances from the mother to the foetus. Little technical information is available in the literature on the structure and function of human placenta at this early stage of development.

The goal of the LIFESAVER project is to create and demonstrate a new, digitally cloned in vitro system to mimic prenatal conditions near the placental interface that can predict the risk of foetal exposure to a drug or chemical.

The focus is on a digital twin of the placenta, specifically the exchange of substances from the maternal to the foetal domain. The article briefly describes the geometries of a villus structure generated by INRiM and how these geometries were used to calculate the velocity and pressure fields and the mean residence time of blood in the domain.

Two different geometries and two different physical models were used to find the best fit, targeting fluid behaviour and residence time predicted from the literature. The blood residence time in the intervillous space (IVS) was derived from the literature and used as a guide to configure the porosity and permeability fields. INRiM created the geometry by following the expected structure of a first trimester human placental villus and then used it as the core of the computational fluid dynamics (CFD) simulations. CFD simulations of blood entry and diffusion within the domain were performed using commercial software.

Background: the LIFESAVER project

Pollution from microplastics, chemicals, and antibiotics has become a serious environmental problem over the past decade, posing a threat to human health, including the unborn. However, little is known about the effects on pregnant women and their foetuses when exposed to these pollutants or drugs. The placenta, which is essential for protecting the foetus by allowing essential nutrients and oxygen to pass through, unfortunately also allows harmful substances to reach the foetus. For example, microplastics have been found on both the maternal and foetal sides of the placenta.

Tests on pregnant women are ethically prohibited and tests on animals are ineffective because their placentas behave differently from human placentas. The LIFESAVER project, led by EnginSoft, will fill this knowledge gap. The project aims to develop a laboratory system that can predict how chemicals cross the placenta. The approach is based on the hybridization of several innovative

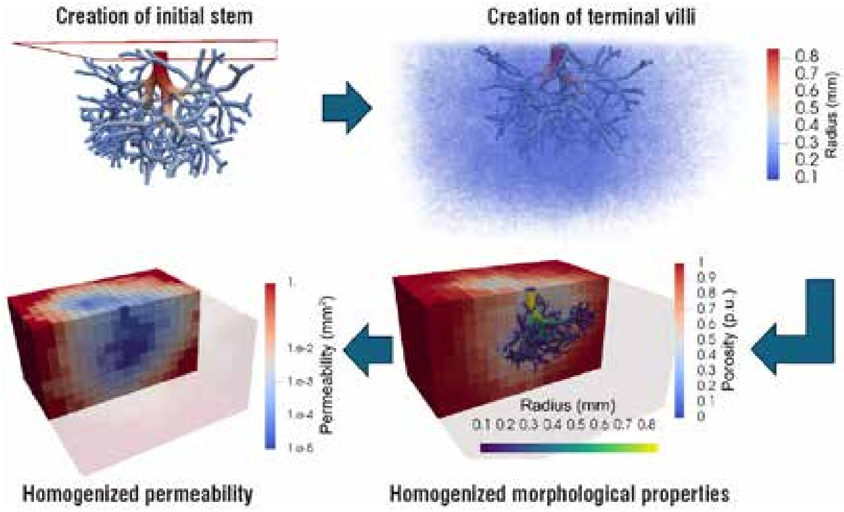

Fig.1. Diagram of the process used to generate the IVS space and determine the homogenous hydraulic properties for simulating porous flow.

technologies, integrating "biodigital twin" systems with perinatal derivatives to enable effective screening of chemicals and pharmaceuticals.

EnginSoft's role is to develop the biodigital twin, which simulates the fluid dynamics of maternal and foetal blood and, thanks to sophisticated machine learning algorithms, is able to predict in silico the diffusion of chemicals across the placenta. The high-fidelity biodigital twin was created in collaboration with INRiM, which provided a detailed model of the villi and the transport kinetics.

Geometry of a villus tree

INRiM generated a 3D structure of the villus and intervillous space (IVS) using the developed fractal algorithm based on the parametric formalism of the Lindenmayer system (L-system), resulting in a complex villus structure with a realistic villus surface-to-volume ratio. Initial parameters for setting up the fractal algorithm, such as initial villus radius, bifurcation strategy, and villus length, were derived from placental structure data collected from literature reviews.

Since the derived geometry cannot be handled by a full Navier-Stokes CFD approach, the computational complexity was overcome by introducing a simplified model in which part of the domain under study was treated as a porous media with multiple levels of porosity. The structure of the villi is simplified and only the main branches obtained from the first seven bifurcation steps are meshed. In the remaining part of the volume, equivalent homogenized properties are derived from the full villus structure.

In particular, this part of the IVS is divided into a grid of 20x20x20 cells. In each cell, equivalent structural/morphological properties such as equivalent villus diameter, equivalent villus length, and porosity were calculated.

Based on these properties, two porosity models were applied to obtain the corresponding equivalent hydraulic conductivity as input for solving the simplified Darcy equation in the porous domain. The first model is based on the well-known Carman-Kozeny equation, which is best suited for oriented fibre structures.

Therefore, we chose a second model, proposed by Nabovati et al. [1] for randomly oriented fibre structures, which is more appropriate for describing the structure of villi.

INRiM designed two geometric shapes, which EnginSoft used for the CFD simulations. These are: 1) the 3D model of the intervillous space, consisting of the main trunk of the villus branch plus an entrance artery and two exit veins, and 2) the 20x20x20 cell grid of the remaining volume, with equivalent homogenized properties obtained with the Carman-Kozeny and Nabovati models.

The computational model of fluids around the villus

Fluid dynamic simulations can be used to calculate important parameters such as residence time and pressure losses. Ansys software was used for these simulations.

The flow through the porous region is modelled by adding a viscous loss term to the standard fluid flow equations. This term is modelled by Darcy's law, which states that the pressure drop is proportional to velocity and hydraulic conductivity.

Since the physically present volume block is not represented in the model, the simulations report a surface velocity within the porous

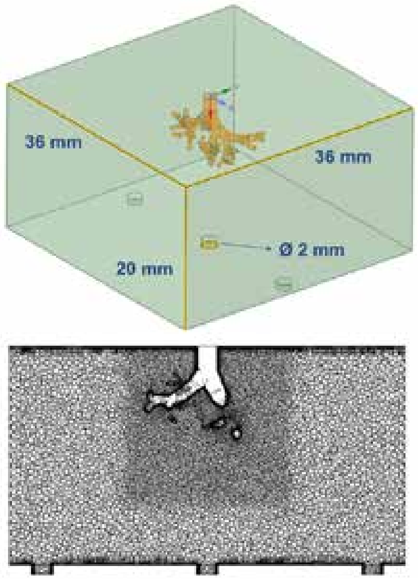

Fig.2. Geometry and meshing for Cases 1 and 2.

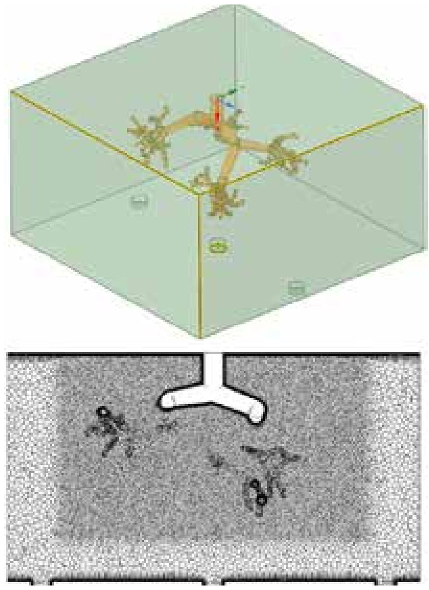

Fig.3. Geometry and meshing of Case 3.

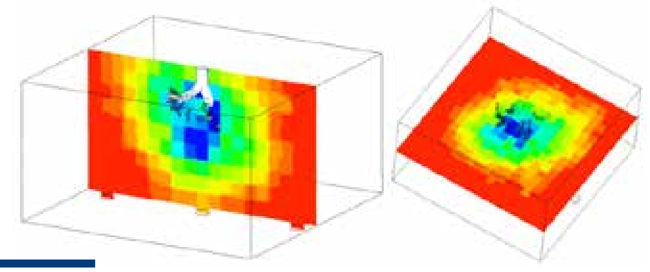

Fig.4. Case 1 porosity field.

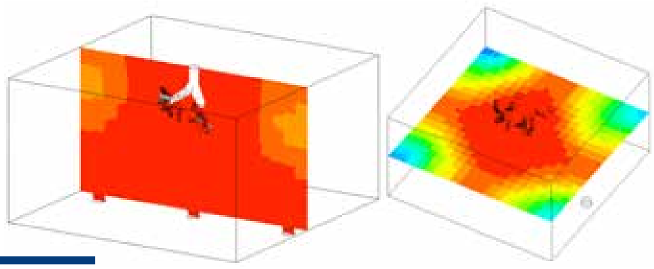

Fig.5. Case 2 porosity field.

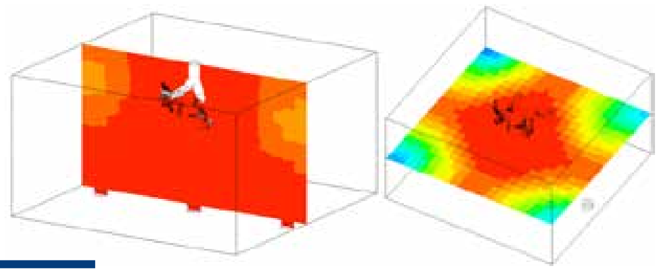

Fig.6. Case 3 porosity field.

medium based on the volume flow rate to ensure continuity of the velocity vectors across the interface of the porous medium.

In Case 1, the CFD simulation results highlight the presence of extensive areas of stagnant flow. This provided experimental evidence for the need to include a region of less restricted flow in front of the inlet artery, as suggested in previous work. To this end, INRiM modified the fractal algorithm used to generate the villus structure to include this feature. A flow rate of 0.0628ml/min was used as input.

In Case 2, the villus geometry is a modified version of the first geometry (Case 1), obtained by preserving the original first branches and including a rearrangement of the others to limit the presence of possible stagnant areas. A flow rate of 0.0619ml/min was set at the inlet.

In Case 3, a completely revised villus geometry was developed, fine-tuning the parameters of the fractal algorithm to achieve a more homogeneous villus structure and reconfigure the first two bifurcations to allow more space for flow to develop before the inlet. A flow rate of 0.0606ml/min was set at the inlet.
INRiM provided the porosity and permeability domains that EnginSoft used for each case, as explained in Figs 4–9.

The fluid domain is a $36x36x20mm^3$ volume, characterized by a villus structure at the top, a central circular inlet and two lateral circular outlets at the bottom, each 2mm in diameter. The boundary conditions and fluid properties were taken from the literature and from

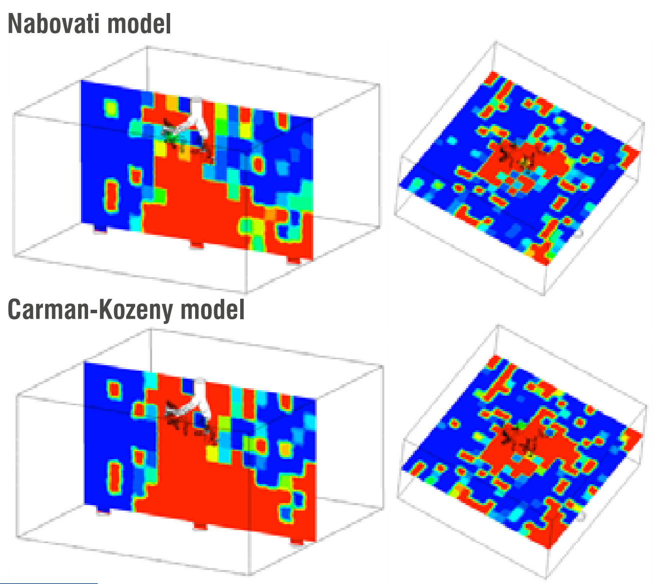

Fig.7. Case 1 permeability field.

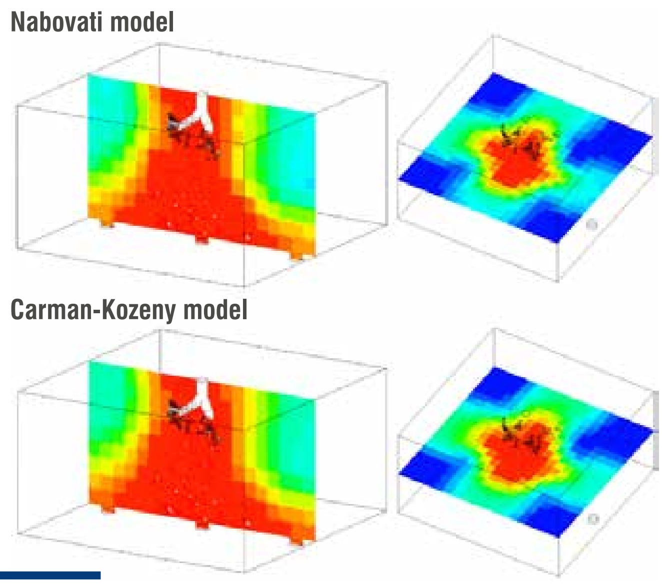

Fig.8. Case 2 permeability field.

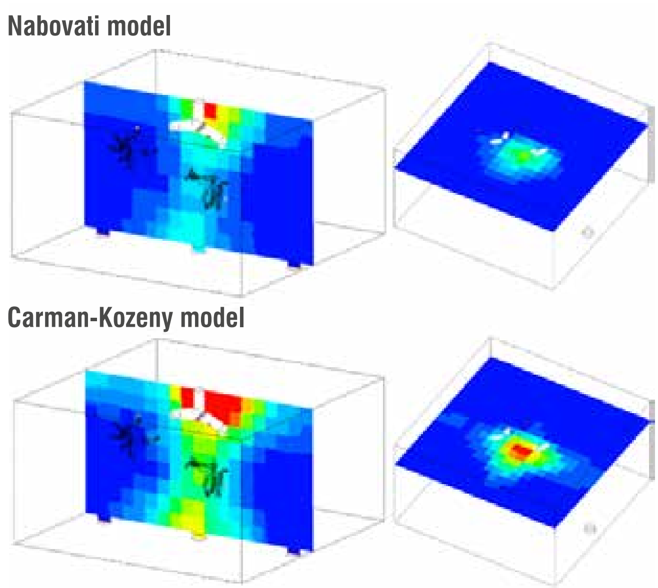

Fig.9. Case 3 permeability field.

Average static pressure at inlet	Volume average static pressure	Average residence time at outlet
29.6mmHg	24.1mmHg	25.11s

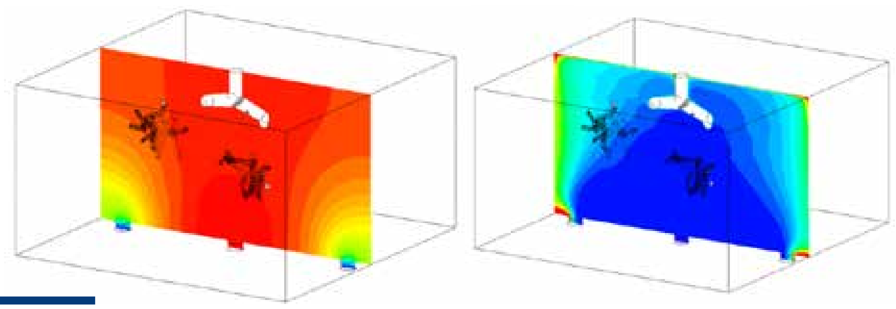

Fig.10. Case 3 - Nabovati pressure field and residence time.

Average static pressure at inlet	Volume average static pressure	Average residence time at outlet
21.0mmHg	17.8mmHg	25.07s

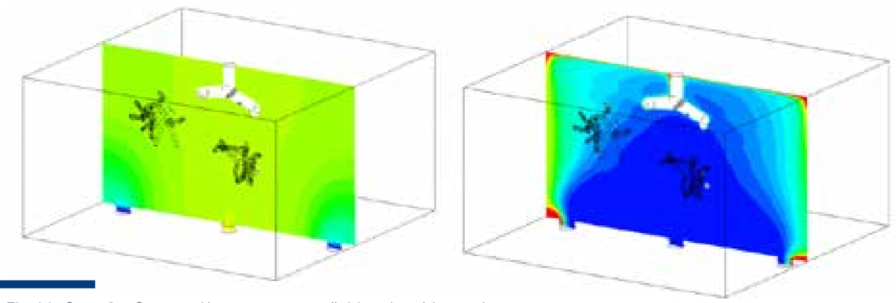

Fig.11. Case 3 - Carman-Kozeny pressure field and residence time.

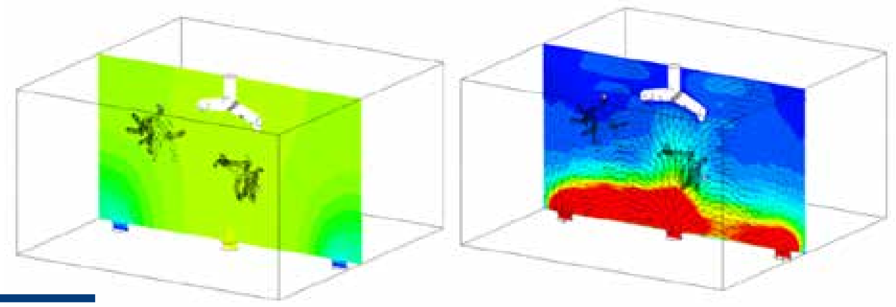

Fig.12. Pressure and velocity distributions for Case 3, using the Carman-Kozeny model.

research conducted by other LIFESAVER partners, with the viscosity of maternal blood modelled using the Carreau fluid equation and a density of 1055kg/m^3.
The outlet pressure was set at 5mmHg, while the inlet flow rate was calculated by implementing an optimization algorithm to obtain an average residence time of 25 seconds. The mesh generated consists of approximately 1–2 million polyhedral elements, depending on the geometry, with a minimum orthogonal quality of 0.1.

The Nabovati and Carman-Kozeny models were applied to each of the three cases and the best case was selected by analysing the velocity, pressure, and residence time fields and comparing the two models.

Conclusions

The modelling of the intervillous space in the first placental trimester was conducted to obtain a digital representation of the local fluid dynamics. INRiM and EnginSoft worked together to achieve this goal: INRiM developed two villus geometries using fractal algorithms and associating the correspondent permeability and porosity fields; EnginSoft performed the CFD simulations of the three cases (geometry 1 + porosity and permeability field 1; rearrangement of geometry 1 + porosity and permeability field 2; geometry 2 + porosity and permeability field 3).

In Case 1, a heterogeneous permeability map with values close to 1 or 0 and a low porosity in the centre of the fluid domain caused flow blockage and an increase in inlet pressure. Stagnation zones were found above the villus structure with residence times exceeding 1,000 seconds.

In Case 2, a more linear permeability map, with high values at the centre and decreasing values towards the corners, allowed continuous flow with low pressure gradients. The stagnation zones were limited to the corners where the residence time was around 100 seconds.

Case 3 is characterized by a permeability map with low values throughout the domain, resulting in higher pressure levels but no significant stagnation zones due to a more uniform porosity distribution. The difference between the Nabovati and Carman-Kozeny models was evident in the pressure distribution and residence time in this case.

In conclusion, Case 3 with the Carman-Kozeny model proved to be the most efficient, demonstrating a shorter fluid residence time without flow blockage and a pressure distribution within the IVS consistent with the data collected in the literature.

The project received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 101036702 and supports the European Green Deal in its study on exposure to industrial chemicals and pharmaceuticals.

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High Performance Computing for Profile Extrusion

by João Paulo Oliveira Vidal[1,2], Alberto Sacramento[2], Joel Guerrero[3], João Miguel Nóbrega[1]
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3. Wolfdynamics

Plastic profiles are widely used in a variety of industries, including healthcare, civil engineering, and aeronautics, due to their versatile material properties and design flexibility. In theory, these profiles can be customized to almost any cross-sectional shape, allowing them to be specifically tailored to unique applications. However, traditional design methods are often based on trial and error, heavily influenced by the designer's expertise. This process consumes a lot of time and material before the desired result is achieved. The challenges are even greater when dealing with complex geometries or when there is no prior experience with similar designs. These factors increase the cost of developing new profiles, which ultimately increases the final price of

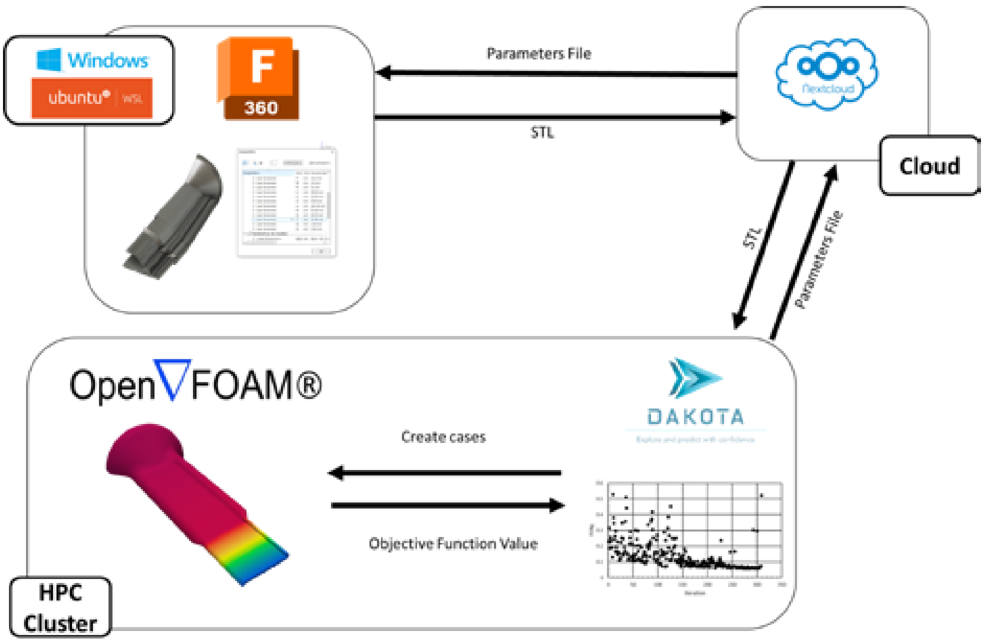


Fig.1. The implemented computational framework.

the end product and limits Soprefa's ability to grow its market.

A critical component in the plastic extrusion process is the extrusion die, the geometry of which must be adjusted to induce a uniform flow or velocity distribution in its output — a particularly difficult task when dealing with complex profile shapes. To address these challenges, Soprefa sought a simulation framework to optimize its design process, reduce costs and produce higher quality profiles within industry-standard timeframes. In pursuit of these objectives, the HPC4PE (High Performance Computing for Profile Extrusion) experiment [1], part of the FF4EuroHPC project [2], was launched to develop and test the necessary computational tools. The project provided Soprefa with high performance, open source computational tools. Key simulation codes were implemented in OpenFOAM and integrated with two CAD software applications (Onshape and Fusion 360) and the optimization tool Dakota, as shown in Fig.1.

This framework enabled automatic optimization of extrusion dies. By using high performance computing (HPC) systems, hundreds of tests could be performed in a single day, a feat unattainable through traditional methods.

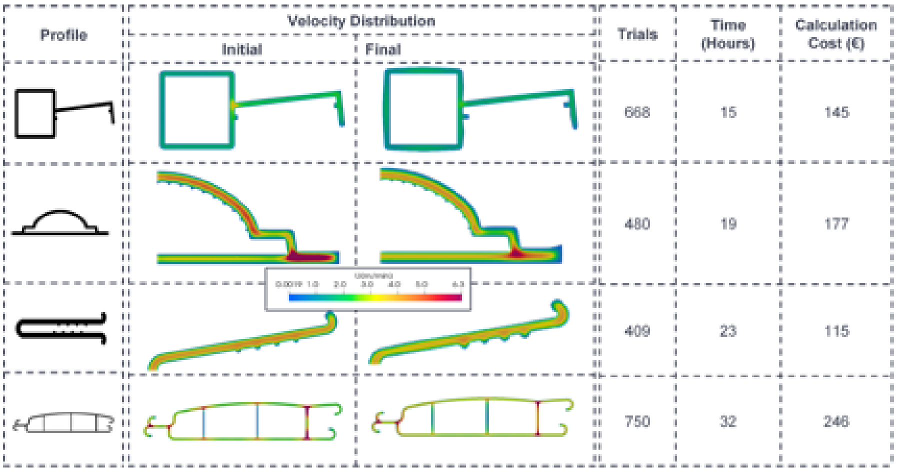
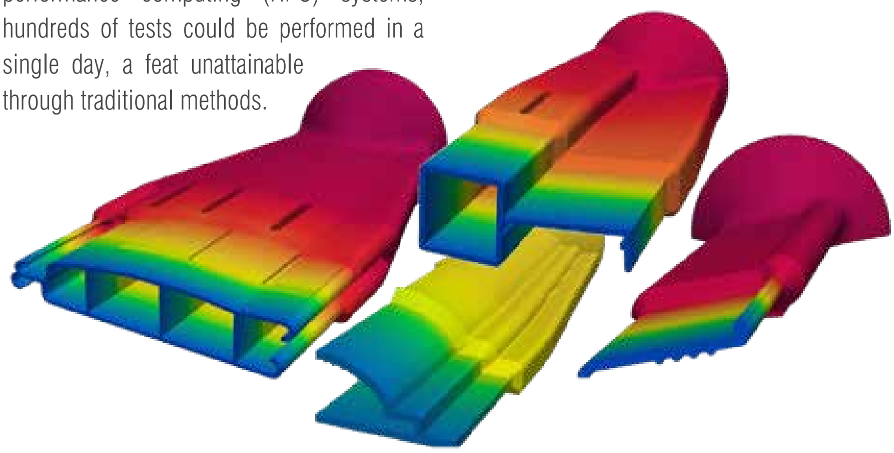


Fig.2. HPC4PE case studies – Profiles, improvements achieved, and resources used for optimization.

The framework was designed to work with two CAD software options: Onshape and Fusion 360. However, since Fusion 360 is incompatible with existing HPC platforms, additional methods were introduced to enable communication between the CAD software and the HPC system, through the Cloud.

The new computational framework was tested in four case studies, shown in Fig.2, improving both previously designed tools that were struggling to meet performance targets using conventional design methods, and newly developed extrusion dies. The results showed a significant reduction in both time to market (by 30–40%) and cost (by 23%) when using computational modelling on HPC systems.



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The FF4EuroHPC project has received funding from the European High-Performance Computing Joint Undertaking (JU) under grant agreement No. 951745. The JU receives support from the European Union's Horizon 2020 research and innovation programme and from Germany, Italy, Slovenia, France, and Spain.

The success story presented in this article was developed during the first tranche of the FF4EuroHPC Project. FF4EuroHPC supports the competitiveness of European SMEs by funding business-oriented experiments and promoting the adoption of advanced HPC technologies and services. The experiment is an end-user-relevant case study demonstrating the use of cloud-based HPC (high-performance computing) and its benefits to the value chain (from end-user to HPC-infrastructure provider) to address SME business challenges requiring the use of HPC and complementary technologies such as HPDA (high performance data analytics) and AI (artificial intelligence). The successful completion of the experiment has created a success story that can inspire the industrial community.

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Introduction to Ansys Lumerical for photonic device simulation

by Gun Park
TAE SUNG S&E

Ansys Lumerical is an optical and photonic device simulation software that supports both optical device design and system-level analysis. This article introduces various Ansys Lumerical solvers and their main applications.

Overview of Ansys Lumerical

Ansys Lumerical is the gold standard for process design and material modelling of photonic devices, providing powerful and reliable solutions for a variety of applications. It ensures optimal performance in the design and analysis of optical devices and systems. Ansys Lumerical is used in a wide range of areas such as data communications, semiconductors, biophotonics, sensors, displays, and complex photonic devices.

Ansys Lumerical products can be categorized broadly as either device level or system level solutions. There are several device-level tools for the design and analysis of photonic components. FDTD (finite-difference time-domain) is used for optical simulations, MODE specializes in waveguide design and analysis, and Multiphysics supports a variety of physical analyses, including electrical and thermal properties. At the system level, INTERCONNECT can be used to simulate photonic components designed at the circuit level.

The variety of Ansys Lumerical solvers allows not only the analysis of optical properties, but also the analysis of electrical and thermal properties caused by optical effects. Optical

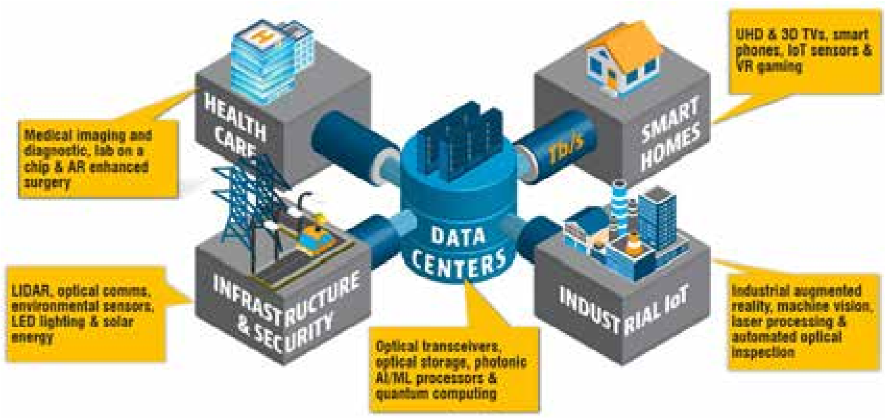

Fig.1. Ansys Lumerical applications.

	Product	Solver
Device Level	Ansys Lumerical FDTD	FDTD, STACK, RCWA
	Ansys Lumerical MODE	FDE, varFDTD, EME
	Ansys Lumerical Multiphysics	CHARGE, HEAT, MQW, DGTD, FEEM
System Level	Ansys Lumerical INTERCONNECT	INTERCONNECT
	Ansys Lumerical CML Compiler	CML Compiler

Table 1. Ansys Lumerical products and solvers.

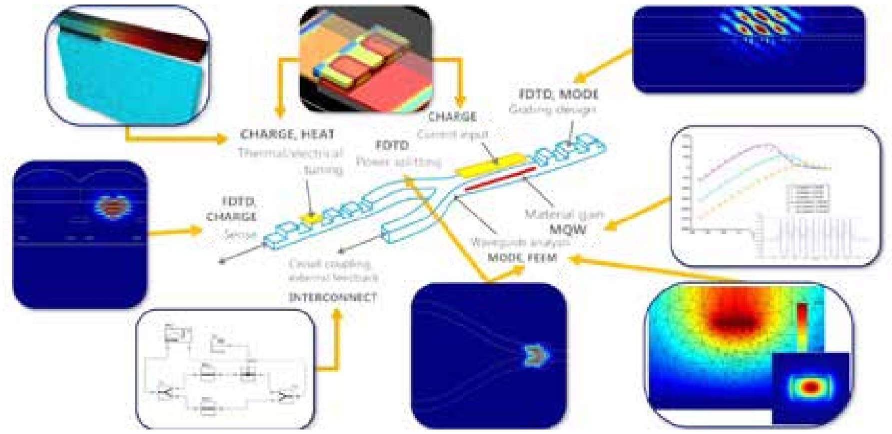

Fig.2. Design examples using various solvers in Ansys Lumerical.

properties caused by electrical, thermal, or quantum properties can also be analysed.

Introduction to Ansys Lumerical FDTD

Ansys Lumerical FDTD (Finite-Difference Time-Domain) simulates the propagation of electromagnetic waves by directly solving Maxwell's equations in the time domain.

This allows the time-varying behaviour of electromagnetic fields to be analysed accurately. It can be used to analyse near-field and far-field electromagnetics, reflection spectra, transmission spectra, absorption spectra, and Poynting vectors.

Ansys Lumerical FDTD contains three solvers: FDTD, RCWA (rigorous coupled-wave analysis), and STACK. Any analysis that can be performed with RCWA and STACK can also be performed with FDTD, but in some architectures and analysis environments, RCWA or STACK can generate simulations significantly faster while using less data than FDTD. When performing incident plane wave simulations on multilayer structures with different refractive indices for each layer, selecting the appropriate solver based on the type of structure can help to efficiently manage simulation time and resources. For multilayer thin film geometries such as coatings, the STACK solver is appropriate; for structures with periodicity, such as wire grids or gratings, the RCWA solver is effective; while for aperiodic random structures, the FDTD solver is the best choice.

Key applications that can be simulated and analysed with Ansys Lumerical FDTD include CMOS image sensors, OLEDs, metamaterials, diffraction gratings, and photonic crystals.

Introduction to Ansys Lumerical MODE

Ansys Lumerical MODE is a specialized solver for waveguide, fibre, and coupler design and includes three solvers: FDE (finite difference Eigenmode), varFDTD (variational FDTD), and EME (Eigenmode expansion). The FDE solver is used to analyse the eigenmodes and cross-sectional properties of waveguides or fibres, the varFDTD solver is suitable for analysing large-scale planar integrated devices, and the EME solver analyses tapered structures, periodic devices, and long-distance optical propagation.

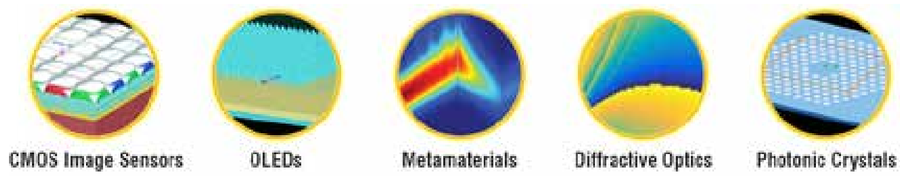

Fig.4. Main application areas of Ansys Lumerical FDTD.

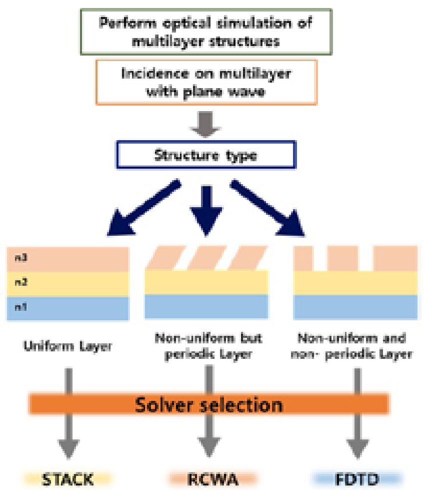

Fig.3. Ansys Lumerical FDTD solver selection method.

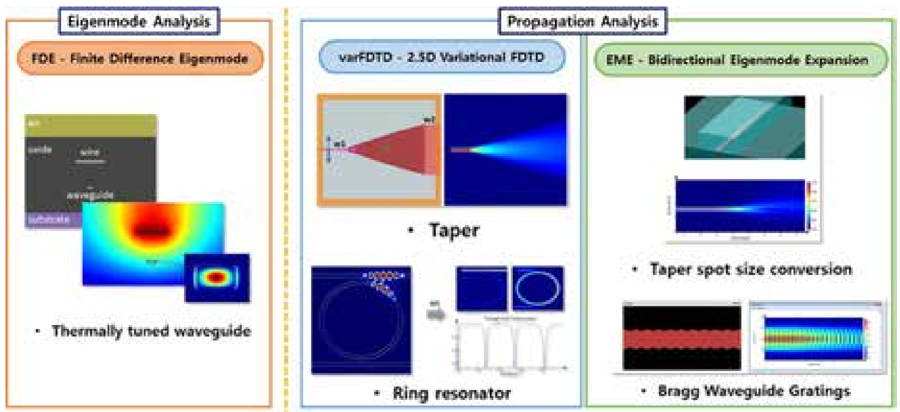

Fig.5. Ansys Lumerical MODE solver and applications.

Fig.6. Main applications of Ansys Lumerical MODE.

The FDE solver automatically computes the physical properties of the waveguide and calculates the correct modes present in the waveguide or fibre cross-section by solving the Maxwell equations on the waveguide cross-sectional mesh. The varFDTD solver reduces 3D planar waveguide structures to effective 2D materials, providing accurate 3D simulation results and enabling fast 2D simulations. The EME solver is highly scalable along the length of the device, making it ideal for analysing components such as tapers. A single simulation can produce results that account for variations in device length.

Key applications that can be simulated and analysed with Ansys Lumerical MODE include waveguides, fibres, tapers, couplers, ring resonators, and modulators.

Introduction to Multiphysics in Ansys Lumerical

The Multiphysics platform in Ansys Lumerical include the CHARGE, HEAT, DGTD (discontinuous Galerkin time-domain), FEEM (finite element Eigenmode), and MQW (multi-quantum well) solvers. Ansys Lumerical Multiphysics enables multiple physical phenomena to be analysed while maintaining model and material consistency across multiple simulations within a single design environment.

The CHARGE solver can analyse the charge distribution, electric field, and potential distribution of a device to evaluate the electrical performance of semiconductor devices and to analyse electron and gap density. It is widely used to analyse solar cells and CMOS image sensors, and also has applications in the design of electro-optic modulators, which use electrical properties to modulate the polarization and phase of light.

The HEAT solver can analyse optically and electrically generated heat as well as heat conduction, convection, and radiation in highly integrated optoelectronic devices. It can be used to study photothermal heating, the heat generated by high-intensity light in waveguides, and thermally tune devices where the optical properties of the waveguide are altered by thermal effects.

The DGTD (discontinuous Galerkin time domain) solver is used to analyse optical properties. Unlike FDTD, it uses a fine element mesh to provide high accuracy when simulating metal surfaces or complex curved shapes and structures. In addition, structure and material consistency is maintained within the unique design environment of the Ansys Lumerical Multiphysics platform, enabling reliable simulations when analysing Multiphysics phenomena.

The FEEM (finite element Eigenmode) solver, like the MODE solver, is specialized for waveguide design and analysis. The main difference is that FEEM uses a finite element mesh, which provides more accurate results for curved waveguide geometries. It also

Fig.7. Main applications of Ansys Lumerical CHARGE.

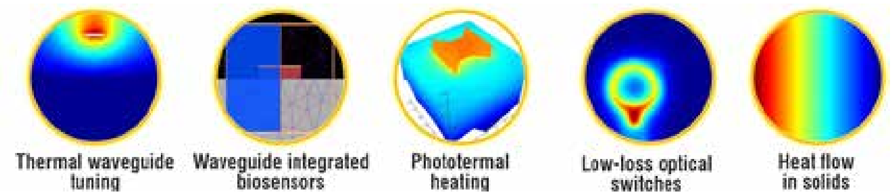

Fig.8. Main applications of Ansys Lumerical HEAT.

Fig.9. Main applications of Ansys Lumerical DGTD.

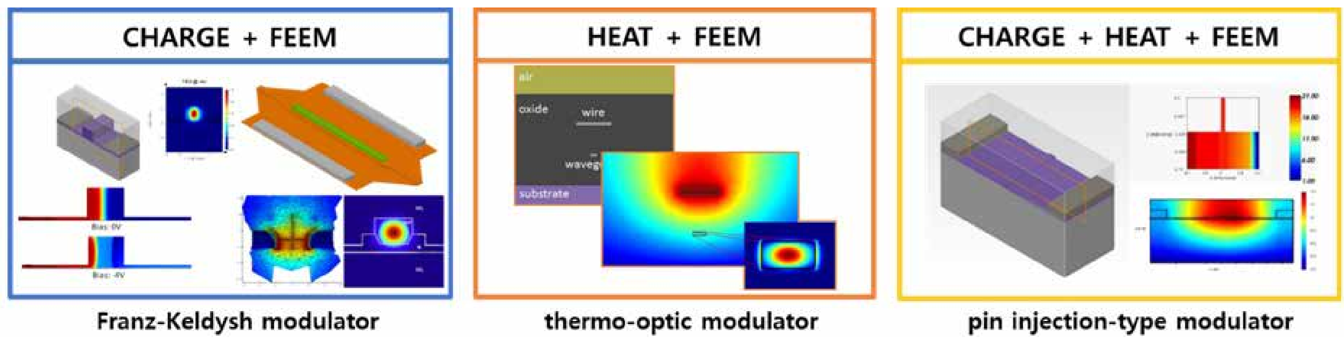

Fig.10. Applications of Ansys Lumerical FEEM and Multiphysics.

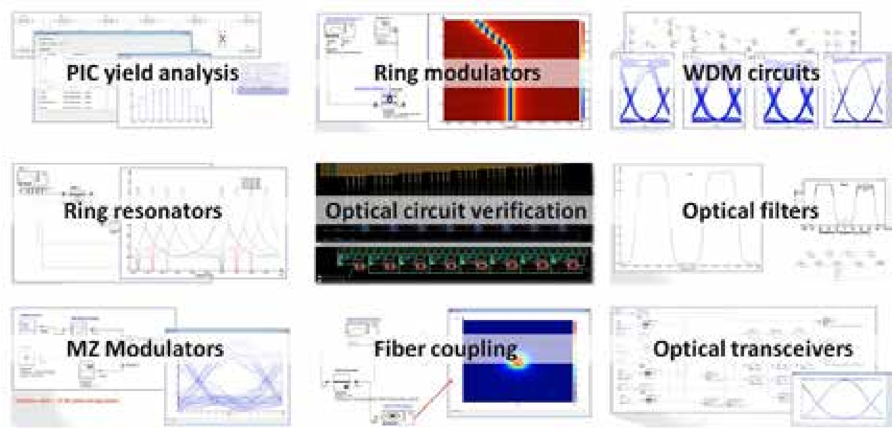

Fig.11. Applications of Ansys Lumerical INTERCONNECT.

ensures reliable simulations when analysing Multiphysics phenomena within the unique design environment of the Multiphysics platform.

The MQW solver is a physics-based 1D solver designed to calculate the optical and electronic properties of multi-quantum well stacks. It calculates fully coupled quantum mechanical band structures using the k·p method. Results from the MQW solver include gain and spontaneous emission coefficients, complex refractive index, electron band diagram, band structure, and exciton energies. MQW results are typically used as input for edge-emitting lasers or TWLM (traveling wave laser model) components in INTERCONNECT.

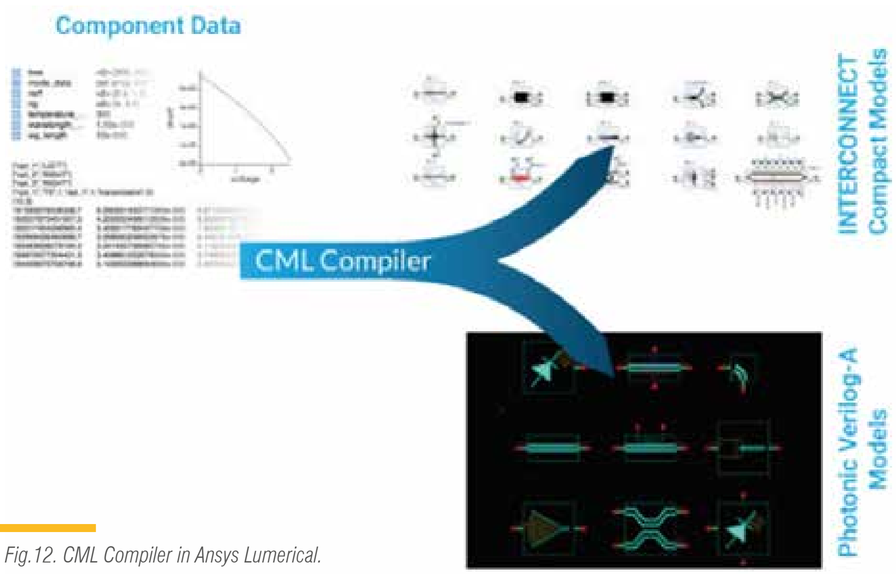

Fig.12. CML Compiler in Ansys Lumerical.

About TSNE

Since its establishment in 1988, TSNE has specialized in CAE, providing engineering programs and services to Korean customers. Tae Sung S&E (TSNE) aims to be the "One Stop Total CAE Solution Provider" (OSTS) both in domestic and global markets. The company leverages its large base of business capabilities and its team of CAE experts to provide services to customers in various industries (aerospace, automotive, civil engineering, biomedical, shipbuilding, electrical and electronics, energy, defence, chemical industries, etc.) and is expanding its business scope to research innovative technologies and apply them in the field. It strives to become a global engineering company and increase its potential as a sustainable engineering company. Tae Sung S&E partners all engineers who endeavour to solve challenges. Tae Sung S&E will work with you to achieve "NO PROBLEM, BE HAPPY".

Introduction to the Ansys Lumerical system- and circuit-level solvers

Ansys Lumerical system- and circuit-level solvers include INTERCONNECT, which enables the design and simulation of photonic integrated circuits (PICs), and the CML compiler, which is used to create compact model libraries (CMLs) for PIC design and verification.

The INTERCONNECT solver is dedicated to PIC design and provides a hierarchical schematic editor with an extensive library of basic components and foundry-specific PDK elements. It supports the development and maintenance of CMLs using measurement data and simulations from a variety of Ansys Lumerical solvers. INTERCONNECT is also interoperable with industry-leading EDA (electronic design automation) and PDA (photonic design automation) tools.

The CML Compiler automates the creation, maintenance, and QA (quality assurance) testing of INTERCONNECT and Verilog-A photonic CMLs based on measurement and simulation results. It automatically converts designed component data to CML, creates INTERCONNECT and Verilog-A models, protects IP, and enables co-simulation with third-party EDA simulators.

Conclusion

This article introduced Ansys Lumerical and various solvers as well as its main application areas. When designing photonic devices, Ansys Lumerical FDTD enables optical properties such as near-field and far-field electromagnetics, reflection spectra, transmission spectra, absorption spectra, and Poynting vectors to be accurately analysed. In addition, multiple solvers can be used together to produce accurate simulation results for a wide range of applications, including solar cells, CMOS image sensors, electro-optic and thermo-optic modulators. Analysing device data designed and measured in INTERCONNECT with the CML Compiler also enables circuit-level analysis.

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EnginSoft and Rockwell: strategic collaboration for the digital revolution in manufacturing

EnginSoft, an Italian multinational with 40 years of experience in technology transfer, has announced a strategic partnership with Rockwell Automation (NYSE: ROK), a world leader in digital transformation and industrial automation.

At the Automation Fair, recently held in the beautiful setting of Anaheim, California, EnginSoft was officially introduced as Rockwell Automation's newest systems integrator for the design, creation and implementation of software technology and solutions for data and operations to enable customized intelligent manufacturing in Italy.

"This agreement marks a pivotal moment in our evolution and opens the way to new opportunities for innovation," said Marco Perillo, CEO of EnginSoft.

He added, *"In a world where digital transformation is essential for industrial success, the alliance between EnginSoft and Rockwell Automation combines two forces at the forefront of technology. With our expertise in developing reliable and sustainable innovative technologies, combined with Rockwell's solid leadership, we are poised to redefine the future of smart manufacturing, connectivity, and automation. This collaboration marks the beginning of a new focus on innovation, excellence and digital transformation as key drivers and keys to our customers' success."*

Rockwell Automation's Connected Enterprise Production System will enable applications to be built for the specific needs of each customer, enabling companies to achieve operational efficiency, quality, cost savings and a real-time strategic view of production. Scalable, customized solutions that harness artificial intelligence, machine learning and the Internet of Things (IoT) will enable businesses to embrace an increasingly connected and automated future, while maintaining the highest standards of digital security.

EnginSoft and Rockwell Automation are ready to guide their customers into an ever-smarter digital future by contributing significantly to the growth and development of digital manufacturing across sectors.

Eric Chalengeas, Rockwell Automation's Regional Vice President of Sales for South EMEA, emphasized, *"Our goal is to contribute significantly to redefining the future of the manufacturing industry, from individual machines to large enterprises, to achieve production that is more sustainable, resource-efficient, flexible, and safer. This collaboration with EnginSoft is a further opportunity to expand our potential in developing integrated and customized solutions – adding value for customers in all industries."*

About Rockwell

Rockwell Automation, Inc. (NYSE: ROK), is a global leader in industrial automation and digital transformation. We connect the imaginations of people with the potential of technology to expand what is humanly possible, making the world more productive and more sustainable. Headquartered in Milwaukee, Wisconsin, Rockwell Automation employs approximately 27,000 problem solvers dedicated to our customers in more than 100 countries as of fiscal year end 2024.

To learn more about how we are bringing the Connected Enterprise to life across industrial enterprises, visit rockwellautomation.com.

About EnginSoft

EnginSoft is a leading technology transfer company in the field of Digital Manufacturing, Information and Communications Technologies, and Simulation Based Engineering Science (SBES). Since its foundation in 1984, EnginSoft has been a progressive technological innovator, characterizing itself in the market through its distinctive multidisciplinary skills and its capacity for technology transfer of cutting-edge solutions, resourcefully and reputably harnessed for the competitive advantage of its customers. The company's aptitude to innovate is underpinned by specific skills, intellectual dynamism and advanced competences in scientific computing, data management and digital processes and is supported by a constant investment in R&D.

For a complete overview, please visit enginsoft.com.


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