ENGINSOFT

The Simulation Based Engineering & Sciences Magazine

Newsletter

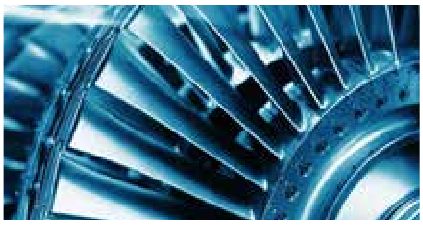
Year 17 n°2

Summer 2020

Optimization of the SLM/DMLS process to manufacture an aerodynamic Formula 1 part

Testing ParticleWorks coupled with Recurdyn to simulate water behavior in water technology products

Tools and methodologies for generating digital twins in medical research

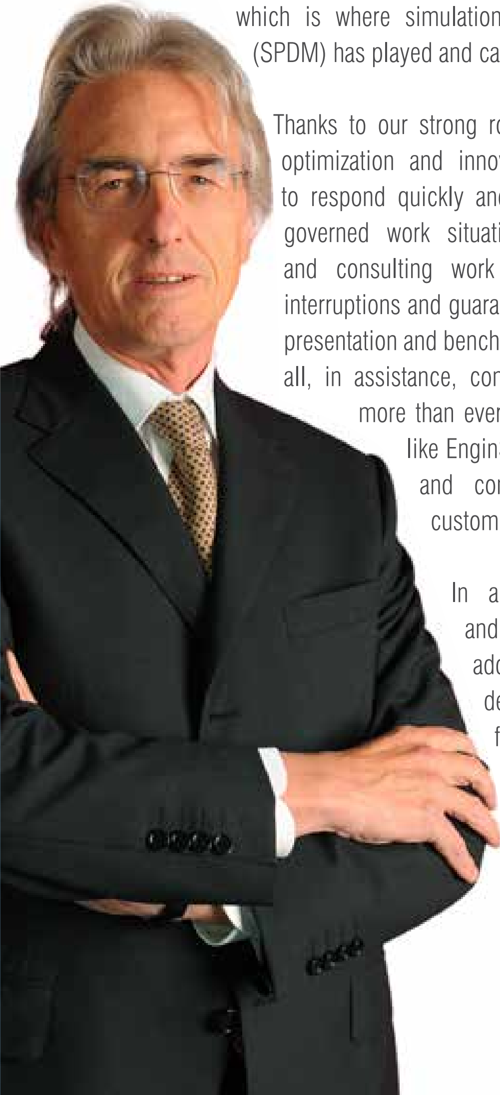


Semantic MBD for metrology: approach and benefits

Flash

As we move fully into summer, most of Europe is slowly reopening after various levels and models of shutdown to combat the Covid pandemic. Attention globally is focusing on emergency and long-term interventions to combat the economic impact of these shutdowns, which some are hailing as worse than the disease.

According to McKinsey and Company's June 18, 2020 Covid 19 Briefing Note[1] more than $13 trillion has been earmarked by governments around the world to support failing economies and stimulate recovery. A massive amount, but with dismal figures still rolling in -- McKinsey's estimate that government deficits could amount to $30 trillion by 2023 -- many are questioning whether it is sufficient and whether linked reforms announced in tandem with the support packages go far enough. All around the world, the lockdowns have resulted in a move en masse to remote working, as companies empowered employees to continue working without leaving their homes. Objectively, this new status quo exponentially decreased the number and duration of meetings but highlighted the growing importance of communication and the sharing of information in a virtual workplace. For engineers, particularly, this evidenced the importance of sharing technical information and technical coordination on projects in forms and in languages that promote understanding, while documenting ideas, solutions, progress and achievements – both to facilitate collaboration and management, which is where simulation project data management (SPDM) has played and can play a central role.



Thanks to our strong roots in digital technologies, optimization and innovation, EnginSoft was able to respond quickly and seamlessly to the Covid-governed work situation, continuing its project and consulting work continuously and without interruptions and guaranteeing continuity in product presentation and benchmarking activities and, above all, in assistance, consulting and training. Today more than ever, having an all-round expert like EnginSoft can help give substance and content to the models our customers need to generate.

In addition to our consulting and technical work, EnginSoft addressed the increased demand during the lockdown for training and upskilling through an arrange of timeous and punctual webinars, rich in technology updates and in the presentation of transversal and, where appropriate, multidisciplinary methodologies geared to the specific needs of designers of components and assemblies.

In this vein, the International CAE Conference, this year in its 36th annual edition, and which will take place virtually to accommodate the post-Covid limitations on travel and gatherings, has doubled down on its commitment to honor its traditional values of knowledge sharing and transfer, networking and representation. This year, the program again promises an extraordinary wealth of speakers and exhibitors, as well as increased international participation to ensure that participants are guaranteed a return on their time invested.

Along this line, EnginSoft continues to recognize the importance of knowledge and skills development and transfer and is committed to being at the leading edge of training and education in the engineering simulation and business sciences sector in order to ensure that the way in which it is delivered and followed is better articulated and richer. As a result, the company is currently developing coherent training paths that are optimized for time commitment and by topics. Consequently, all EnginSoft's training proposals are now available in online delivery mode and, as EnginSoft's contribution to the economy during this pandemic period, the company is offering a 25% discount on the list price for courses booked by August 31, 2020.

The use of all EnginSoft's training proposals is subject to the tax benefits for Italian companies provided by the Transition 4.0 Plan in Italy[2], which takes the form of a tax credit of 50% for small businesses, 40% for medium businesses and 30% for large businesses. Furthermore, the comprehensive catalogue of courses and training courses that can also be created ad hoc for companies can be entirely financed by the Italian Inter-professional Funds for Continuous Training (Fondimpresa[3], or Fondirigenti[4], etc.) through business plans and training vouchers. The entire training catalogue is available on the company's website at the following link: www.enginsoft.com/it/calendario-2020/online/

The forthcoming business period is likely to present us all with many challenges that require innovation, creativity, perseverance, and courage. May we all find the necessary strength and energy to confront these challenges and succeed, as the innovative engineers that we are!

[1] https://www.mckinsey.com/business-functions/risk/our-insights/covid-19-implications-for-business
[2] https://www.mise.gov.it/index.php/it/incentivi/impresa/credito-d-imposta-formazione
[3] https://www.fondimpresa.it/chi-siamo
[4] https://www.fondirigenti.it/

Stefano Odorizzi,
Editor in chief

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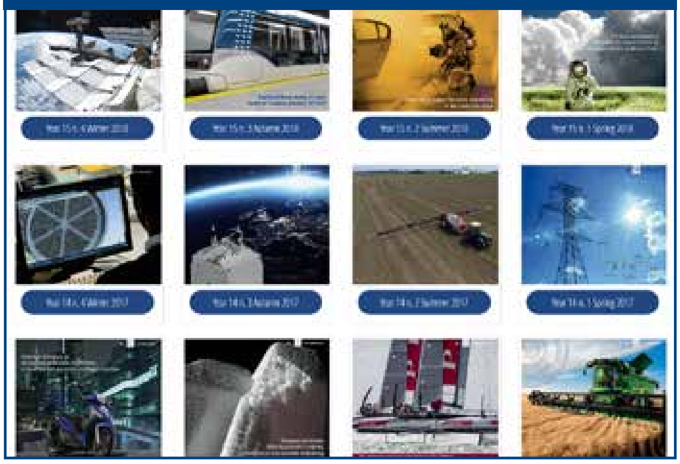

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Year 17 n°2 - Summer 2020
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The EnginSoft Newsletter is a quarterly magazine published by EnginSoft SpA

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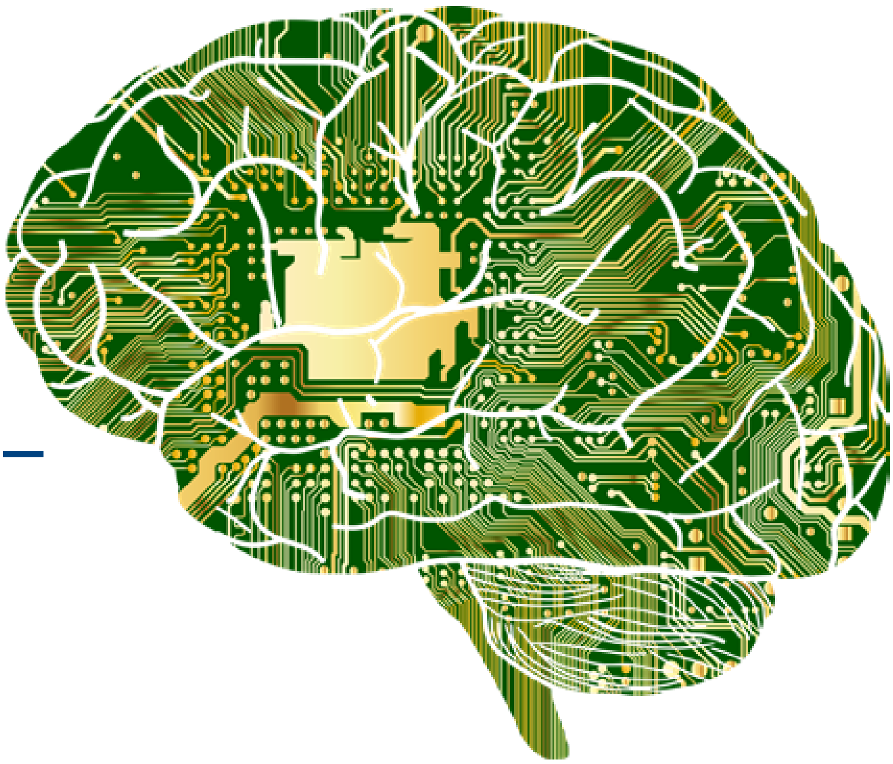
PRINTING
Grafiche Dalpiaz - Trento

Autorizzazione del Tribunale di Trento
n° 1353 RS di data 2/4/2008

The potential for AI in industry and among SMEs – busting the myths



By Kathleen Grant
EnginSoft

Luca Formaggia

Pierluigi Contucci

The interest in artificial intelligence (AI) is growing apace. Scarcely a day goes by without the publication of some article in the press concerning its abilities. However, many of these articles, particularly in the mainstream media, remain sensationalist and do not come to grips with the real potential for artificial intelligence in the business, and particularly, industrial sectors.

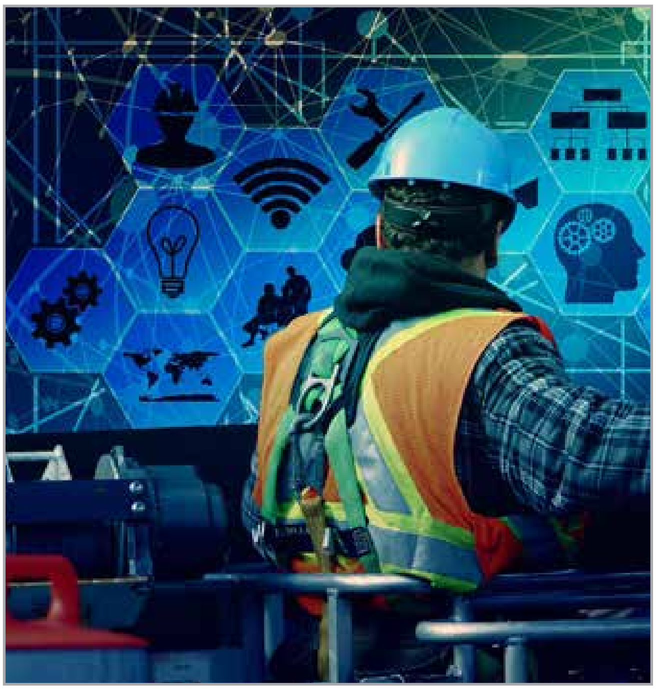
Aiming to provide more clarity for our readers, we interviewed Luca Formaggia, Professor of Numerical Analysis at the Politecnico di Milano, Italy, and President of SIMAI (the Italian Society of Industrial and Applied Mathematics) and Pierluigi Contucci, Professor of Mathematical Physics at the University of Bologna, and Coordinator of the National Research Plan (2019) on AI, Robotics and Cybersecurity.

Q: In the widest engineering context, what are the real capabilities of AI as it stands today?

PC: The term AI today most often refers to the methods that have emerged in machine learning and deep learning in the last 10 years. In reality, AI consists of two main approaches, both of which began in the Fifties. There is classical AI, which consists of classical programs in different programming languages such as object oriented (OO) programs or those that use symbolic or sub-symbolic methods. I can illustrate classical AI with an example from autonomous driving. A number of car manufacturers are particularly advanced in this area, for instance Elon Musk's Tesla. As the car drives with an inactive driver inside it, it is constantly observing the road ahead. If it suddenly "sees" an unexpected obstacle such as a stationery car ahead of it in the road, the vehicle must apply its brakes. This decision to brake is made by classical AI which follows "if… then…" reasoning – if I am proceeding at a certain speed and I draw closer and closer to the stationery object, then I will apply the brakes.

The other main approach in AI today, called machine learning or deep learning, also started in the Fifties, but has experienced a boom more recently due to the increase in computer processing power and the availability of large databases. To go back to the example of autonomous driving, machine learning here is being used to "see" where pedestrians are, to recognize a pedestrian that is crossing the road, to identify that it is a human, and so on. These methods are known as machine learning because no classical AI program exists that can say whether the obstacle in the road is a human or an inanimate object.

These activities are done by machine learning which has a whole series of capabilities that are being developed along three principal lines: the first is image recognition; the second is language recognition, specifically spoken language, written language and text translation, etc.; and a third category, which is a growing ability to profile buying customers – the great promise of marketing. This third area, which is experiencing very rapid growth, is already being used by the largest organizations such as Amazon and Google and is far less publicized because it obviously directly transforms into revenue for these companies, giving them a competitive advantage. There are thousands of examples of these three main categories, some of which are very spectacular.



LF: At the moment neural networks work well at classification. If I, as a human being, need to identify whether the obstacle in front of my car is a pedestrian, or distinguish a cat or a dog in a photo, the cerebral processes (which, incidentally, is where the name neural networks originates) used are largely unknown and extremely complex.

Deep neural networks are trying to replicate these processes in a simplified way. If there is sufficient, good quality data available, then they can be trained to achieve results as efficiently, or even more efficiently, than the human brain. While this is extraordinary from a technical perspective, it is not really surprising. I will explain with an analogy: if I use a calculator to perform an operation on two numbers of ten digits each, the calculator gives me the result in a millisecond. This means my simple calculator is much superior to the human brain in this area. So, by extrapolation, it really should not surprise us that other algorithms like deep learning methods may be able to achieve specific results better than humans can.

I believe the problem for these technologies arises from some of the more superficial articles about AI that almost imbue them with the superior intelligence of understanding – as if the self-driving car "understands" what it is doing. Let me be quite clear: there is NO understanding. There is simply an algorithm that is highly competent in executing certain functions. Perhaps machine understanding may be possible in some far distant future, but for now, fortunately, understanding is something that is uniquely human. Understanding lies with the creator of the machine and with the person who can correctly interpret the results that the machine generates, and who can then instruct the machine, because the machine needs to be taught.

Every now and again one sees sensationalist articles that make outrageous claims for AI. The most recent that I saw claimed that a neural network had "discovered" Kepler's laws of planetary motion! This was not true. The neural network had simply correctly fitted certain parameters together based on certain information that it had been previously given. Kepler instead created his theory based on very little data, just a few observations, after which he followed a process of logical reasoning and deduction to formulate the laws governing the motion of the planets – he did not just simply fit together certain data.

This brings me back to a topic that was discussed in the workshop at the 35th International CAE Conference in October 2019, and that is this: these methods are not a substitute for knowledge; they are not a substitute for the engineer who understands how to perform a good simulation, or the fluid dynamics of a hydraulic system.

On the contrary, I believe these machine learning AI techniques will be extremely useful, especially from an industrial perspective, if we integrate them with our prior knowledge, but not if we expect them to replace it.

So, in my opinion, one of the most important things for readers to understand is that existing knowledge can certainly leverage these techniques because they allow different types of analysis and are capable of analyzing huge quantities of data much more effectively and efficiently than a human could ever do. But they achieve their greatest purpose if they are integrated with prior knowledge and experience.

A neural network trained on a large quantity of data including and excluding defects would ultimately be able to identify a potential defect better than a human being could. But the ability to understand WHY the defect occurred and HOW to correct it requires an understanding that goes way beyond what these networks will be capable of doing for at least the next decades.

Q. A recent article by McKinsey Global Institute [1] states that Greenfield AI solutions are prevalent in business areas such as customer service management, and in healthcare, in particular. What is your take on this?

PC: I agree with McKinsey.

The medical field is a very promising area of direct applications. An example that has been circulating just recently is very topical. A neural network trained in China with the data from CAT scans of patients' lungs has a high probability of recognizing the coronavirus in just minutes, as opposed to the time required for the entire procedure of taking a swab from the person. Since diagnostic imaging is an important part of medicine today, it is obvious that an automated tool that can recognize an image and classify it quickly falls directly within the realms of greenfield AI, as expressed by McKinsey.

Autonomous driving is very impressive, even though it is not imminent in the short term. This is not because of technological reasons, but for legal reasons in the sense that there are still no laws that govern autonomous driving on public roads. Autonomous driving today faces a similar phase to motor cars just after their introduction in the 18th Century: there was a long, slow period of adjustment of the laws. Insurance, for instance, was not compulsory in the beginning, but became obligatory over time because, occasionally, drivers would cause such serious accidents that they could not cover the damages. So, in a similar way, how would insurance have to be adapted to the issues of autonomous driving? This gigantic lag in legal adaptation means that the impetus of the pace of technological development will eventually force the launch of autonomous driving, overcoming the delays arising from the institutional difficulties in instituting the rules to govern it.

LF: The prerequisites for any AI application to work successfully are the availability of sufficient, significant data and expert guidance. It is insufficient to have a lot of data – it must be significant data. If placing 100 sensors, as opposed to 30 or 40, simply generates more of exactly the same information, then that extra amount of data is not helpful and makes absolutely no difference. While this is a trivial observation, it is sometimes overlooked: you need the right type of data, with informational content in a technical sense, to train a neural network effectively.

Medicine represents an enormous field of possibility – image processing is a substantial area where neural networks have already been used successfully. AI is already assisting diagnostic imaging in the automatic recognition of tumors and other pathologies. But we should also not ignore the neural network's ability to integrate or somehow interpret seemingly minor data. For instance, the new health monitors in smart watches can give us our heart rate, metabolic rate, and other simple data, such as body temperature. Training a neural network with such data may help doctors detect possible pathological situations using "hidden" information that was not obvious or recognized beforehand. This is possible and could definitely provide some enormous advantages to medical diagnosis or monitoring.

There are also some other fields of application that will have an impact over a longer time. They are currently more niche and the subject of active research and involve the integration of previous knowledge with deep learning. Simulation algorithms based on physical principles are particularly good at calculating, for instance, the displacement of a bridge under a certain load or the efficiency of a wing. So how can we take advantage now of these new techniques? In many ways. For example, we can train a neural network for the better characterization of materials, especially new, complex composite materials, where it is difficult to find constitutive relationships simply.

Machine learning can also help with various difficult numerical aspects. Some of my colleagues work with neural networks applied to turbulence models where the calculations are very complex and require enormous computing power. If AI can be applied to that, it can improve our capabilities. For instance, AI can provide the best parameters to put into a computational fluid dynamic code for a given flow condition. This may allow one to improve the predictive capabilities of the numerical simulations and enable their use in fields where they were not employed before because they were too expensive or inaccurate.

Q: Is there enough trust in the mathematical models used by AI? I am thinking for example of the Boeing airplanes that had to be grounded because of the repeated number of accidents, in spite of the numerical analyses of the performance of the planes and their components.

PC: It is important to distinguish between human trust and institutional trust. They are two different things that will proceed along independent tracks. The legal tools to "certify" a machine learning program will have to be developed over time, while machines will earn the trust of human beings in time and, if they make some mistakes, they will "pay" for them with a loss of trust. It is important to acknowledge and understand that machine learning is not a science yet. I always draw a parallel with the industrial revolution and thermodynamics. At the beginning of the industrial revolution, steam engines were invented and worked. But no one knew why they worked because thermodynamics was not yet understood. Physicists and mathematicians generated the theory of thermodynamics to explain why steam engines worked. It provided a series of laws, a few principles, from which the mechanical object's operation and efficiency could be deduced.
This is what is now required for machine learning. We need a theory that clarifies why it works and determine its efficiency. This is the work that is currently being undertaken by mathematicians and physicists and to which Luca alluded when he said we want to transform this set of empirical knowledge which is very interesting and even functional, but which cannot yet be described with rigorous tools. A lot of these competences still need to be developed, and there has to be a joint venture between governments and industry to promote it.

I would like to appeal to business decision makers to finance research into this topic. Business has much to gain from these instruments, and so should contribute to their development and to the development of skills and education in this area. To develop the field, we will need new courses in artificial intelligence, and we will need to train people to use and program it.

LF: We definitely need to better understand deep learning so that it can be used with sufficient trust in critical areas where one needs more precise bounds on the results. Until then, we will still need human decision makers to make the final decisions.

Q: What are some of the important areas of future development around machine learning?

PC: In addition to those we have already mentioned, one huge area is the interpretability of the results that are generated. There is a great effort to integrate machine learning's predictive ability with interpretation and explanation skills. Answering the "Why?" questions: Why did you give me that answer? Let us suppose that from the data emitted by this machine one could predict, just a few seconds before it does so, that it will break and at that point there. While this predictive information is valuable, the machine owner would want to move beyond that to the why: why were you able

to predict it? An experienced technician may hear a change in the noise the machine makes and would stop it. Upon investigation, he may find a crack. But machine learning sometimes does a lot more and we often do not know why the neural network gives the correct predictions and response that it does. This enormous effort into interpretability and explainability is an unexplored frontier of machine learning.

I have no illusions; however, I think there are pockets of machine learning that will always remain strangely difficult to explain. In explaining this to my students, I draw a parallel with a human – even a child – that sees a cat and can immediately identify it as a cat instead of a dog. But, why is that identified as a cat and this other animal as a dog? A human will say, "Ah, because a dog is bigger. A cat moves one way and it meows, while a dog barks," – incidentally, the barking is a sound input – but there is no classical computer program to which one can explain how to recognize a cat as a cat and a dog as a dog. A neural network's ability to recognize these two animals and to distinguish between them is one of the most impressive things about machine learning. So, explainability in the recognition of an image meets intrinsic obstacles. I do not think everything can be explained to learning machines. I think a lot can be translated into explanations and interpreted in the way we mean, but there will be a whole range of correct answers from machine learning that have no explanation because they are far removed from classical coding. The coding would say: If a parameter is satisfied, then I can make a conclusion.

But what is the “if” parameter that tells me it is a cat in the picture. We just do not know.

LF: Neural networks want to imitate the functioning of the human brain, albeit in a hyper-simplified manner. But we humans also do many things without understanding in the least why we can do them. For instance, we learn how to walk naturally, but we know very little about how our brains learn that. This fact also applies to the interpretability and explainability of the results generated by neural networks. We observe that in several situations they work extremely well, but we still have to understand why. It is extraordinarily complex, and I agree that perhaps we will never be able to explain it fully.

These are issues that are less visible in newspaper articles. The scientific community is trying to understand how and why neural networks work. Understanding will help us to design better algorithms or decide which type of AI tool should be used for a specific problem, and what its properties and limitations are. The design of a neural network today is still often done by trial and error. In a sense, we are still at the Wright brothers’ stage – trying a longer wing or a different shape until the plane takes off. We still have to get to the stage of aviation today where we know the Navier Stokes equations and have a clear idea of why planes fly. There is a very big gap to close around the “why” in machine and deep learning, which is what is keeping many mathematicians and physicists busy in this field.

Q. Some people tend to think of AI as only being available and valuable for large organizations. What is your opinion on this?

PC: The Italian economy is characterized by SMEs that are largely represented by Confindustria. Typically, these small industrial realities have several tens or a few hundred to a few thousand employees. For instance, around Bologna, the entire mechanical sector and all its satellite businesses consists of mid-sized companies. AI can do fantastic things for these companies.

To give you a concrete example, we did some work with the company GD Italy. It is not really a large mechanical company, but they are the world leaders in their area. They make machines for high-speed cigarette making and packing, and related solutions for the tobacco industry. Tons of tobacco arrive at the assembly line and the tobacco has to leave the factory already rolled into cigarettes which have been packed into individual boxes of cigarettes, that in turn have been packed into cartons of cigarettes, which have been packed into bulk packaging. For the cigarette companies, it is vital that this assembly line is smooth and continuous. GD builds enormous high-speed packing machines that take care of this entire packaging assembly line. For them, the ability to predict or foresee a malfunction or a breakdown is something that has an incalculable value. Until now, this has been done by technicians that supervise the machines as they work. Now, however, with the enormous quantity of data available, a diagnostic method for error or failure prediction can be developed. The quality of the data is essential, however. More sensors located in relevant points in the machine can provide the necessary data, and it is the human technician who is best able to suggest where to place these sensors. So, integrating human competence with machine learning capacity is essential.

Q. There are many disparate individual national attempts and some coordinated international attempts being made to create a policy approach for AI. At what point are we in Italy with regard to a policy governing the regulation and use of AI?

PC: The academic and scientific communities are very aware of the potential of AI and of what needs to be done. For structural reasons, everywhere in the world, institutions are always late. Now, imagine how late they could be in a country where, on average, a government lasts one year at a time, and each new government almost always effectively denounces and annuls everything done by the preceding government. Regulating an important policy approach in this type of political environment, which has gone from bad to worse since the Second World War, is incredibly difficult. However, there is a huge sense of urgency around problem solving among individuals in this country, so there is no need to be pessimistic. There is a strong awareness that this topic needs to be governed, and while this work will be protracted and will face many obstacles, we should be able accomplish something successfully thanks to focused work being done by small groups in the country.

References

[1] McKinsey Global Institute - Notes from the AI frontier: Applications and value of deep learning https://www.mckinsey.com/featured-insights/artificial-intelligence/notes-from-the-ai-frontier-applications-and-value-of-deep-learning

Getting bounced: Investigating the loads and durability of a Pogo Stick

A light-hearted coronavirus lockdown project with a useful outcome

By Tim Hunter[1], Will Mars[2]
1. Wolf Star Technologies, LLC - 2. Endurica

This light-hearted technical article discusses a project undertaken between WolfStar Technologies' Tim Hunter and Endurica's Will Mars during the Coronavirus lockdown – to create a digital twin of a Pogo Stick in order to calculate its fatigue damage in the hands of a novice user. The Pogo Stick was turned into a load transducer using finite element analysis (FEA) so that the strain gauge locations could be identified, and the strain data collected, to create the operating deflection shapes of the toy. These were then fed into Endurica to subsequently calculate the fatigue damage on the rubber – with all load and damage calculations processed in real time.

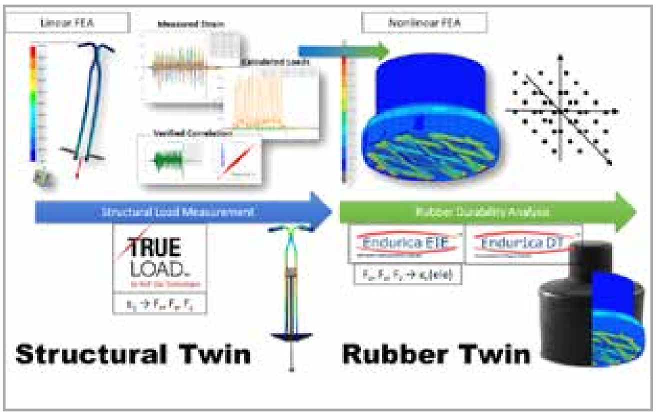
What happens when two engineers are quarantined for three months? Well, one of them (me, Tim Hunter) decides to buy and learn how to use a Pogo Stick. The other one (Will Mars) wants to know how long the Pogo Stick will last under my less-than-proficient usage. So we connected and embarked on this light-hearted quarantine project: we turned the Pogo Stick into a load transducer and drove the Pogo Stick loads into the rubber to calculate its fatigue damage. Sure, other engineers out there were doing great things developing 3D printed masks, respirators, or contact tracking apps – we had to solve the Pogo Stick problem!

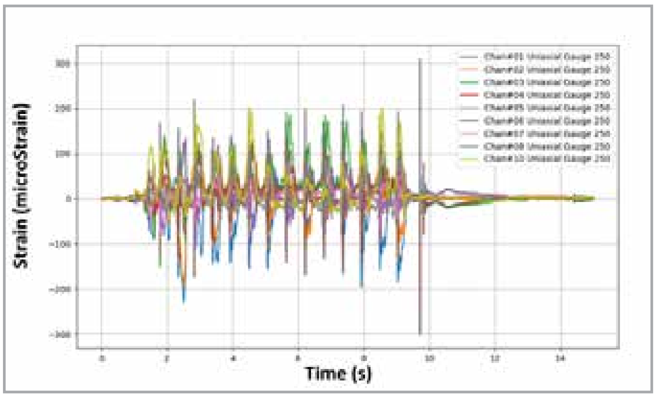
In this article, we will describe how we turned the Pogo Stick into its own load transducer with True-Load by leveraging the finite element analysis (FEA) model. True-Load identified the strain gauge locations on the Pogo Stick. The strain data was collected by me while using the Pogo Stick. We then transformed these strains into loading time histories, which were used to create the operating deflection shapes of the Pogo Stick. I passed these deflection shapes on to Will Mars at Endurica, whose software then simulated the complete nonlinear time histories of the rubber's response to these loads. Subsequently, Endurica calculated the fatigue damage on the rubber. The processes involved were mathematically efficient and fast enough to process the load and damage calculations in real time.

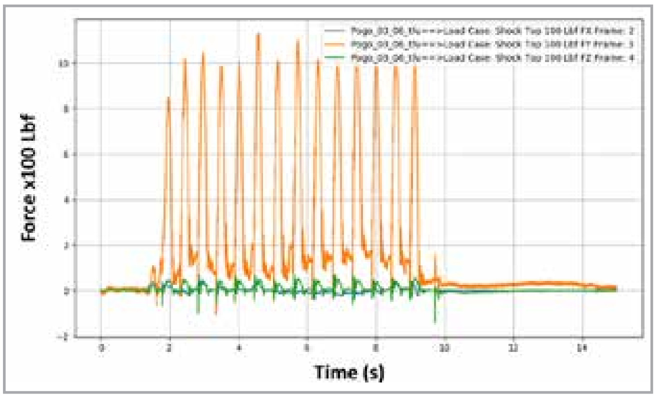
Details of the project

At the macro level, the process for calculating the durability of the rubber component with Endurica began with load measurement. Due to the complex structure of the Pogo Stick, we used the in-situ technique of measuring the loads using True-Load.

See the diagram below for the schematic of this process. The first step was to apply the unit load cases to an FEA model. Once the response to these unit loads had been calculated, the True-Load software identified the locations in which to place the strain gauges. The strain gauge placement guaranteed



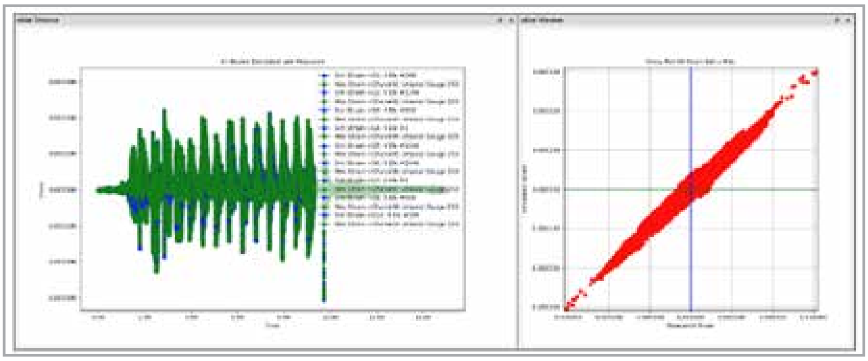




that the loading from measured strains could be calculated backwards. Once the strain gauge locations had been identified, the physical structure was then fitted with these strain gauges.

We then collected the strain data while using the Pogo Stick. The measured strains were subsequently used to calculate the loads on the structure using the True-Load software. Once the loads had been calculated, they were passed over to the Endurica software for the durability analysis.

Endurica EIE uses a set of pre-computed finite element solutions to rapidly generate the corresponding strain histories for each finite element in a model of the rubber tip. These strain histories were then fed to the Endurica DT incremental fatigue solver to compute the damage accrued in each element in the rubber tip. Damage accrual is tracked in two ways: firstly through the effect on crack growth; and secondly through the effect on the computed residual life.

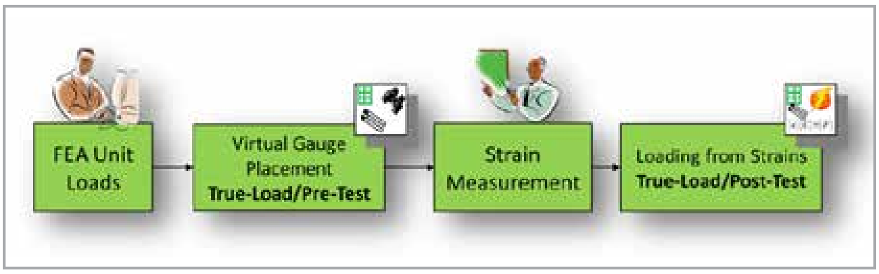


After processing each new set of loads, the software presented the results on a dashboard that allowed us to track the remaining fatigue life in the rubber tip. This process is repeated each time a new set of load measurements becomes available.

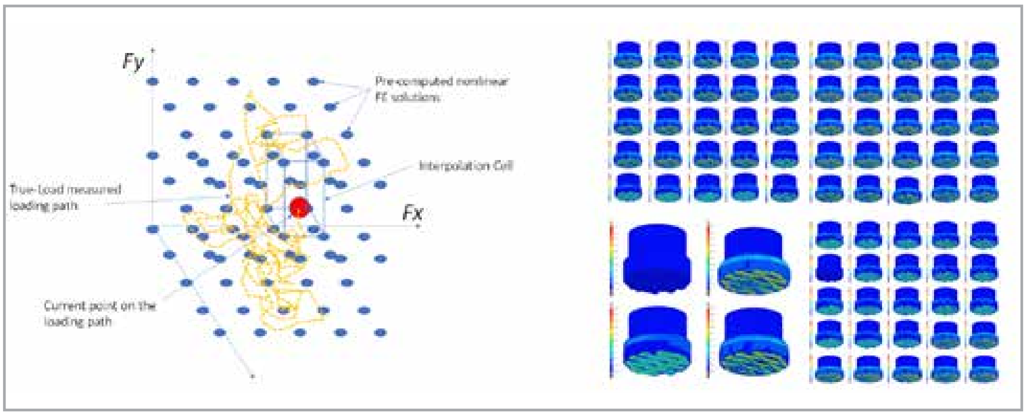
Load reconstruction with True-Load

Below we summarize the steps involved in recovering the dynamic loads acting on a component fitted with a finite number of strain gauges to measure the time-varying strains. The flow chart below shows the major steps of the load reconstruction process.
This process recovered the loading on the Pogo Stick. The Flybar™ Super Pogo Stick was purchased from Amazon. The 3D model of the Pogo Stick was reverse engineered. Wolf Star Technologies' Senior Application Engineer, Cynde Murphy, performed the instrumentation work. Data was collected for normal operation of the Pogo Stick on a variety of surfaces. The figure below shows a typical trace of the strain data gathered.

Once the strain data was collected, it was processed to reconstruct the applied loading to the system. This is achieved by multiplying the measured strain data by the correlation matrix that was extracted from the FEA model. This generates a time history of loading scale factors for each of the loads applied to the Pogo Stick.



The True-Load/Post-Test software was used to perform this load reconstruction. Several other automatic post processing tasks were also performed. This produced an HTML report that contained the plots of the reconstructed loads and a set of plots showing the measured strain and simulated strain from the reconstructed loads at the strain gauge locations in the FEA model. These measured/simulated strain plots have been summarized in an overall plot with the simulated strain shown in blue and the measured strain shown in green. The software also generates a cross plot of the simulated vs. the measured strain, which, ideally, would be a perfectly straight line at a 45-degree angle.



Endurica rubber durability

Because of rubber's nonlinear behavior, the linear superposition of unit load cases is not a valid method for converting load history into strain history. Nor is it an option to run a full FEA of the load history at each update, given that typical model run-time is approximately one hour for only a few seconds of real-time loading history. Instead, we used the Endurica EIE interpolation engine.

Endurica EIE uses a pre-computed, nonlinear map that connects possible loading states of the rubber tip, as specified by the x, y, and z force components acting on the tip, to the corresponding strain states that occur in each element of the FE model. EIE leverages the assumption that there is a unique, one-to-one correspondence between points in the 3-channel loading space and the deformation states of the material. Since rubber is nonlinearly elastic, this assumption is generally accurate.

Once the strain history for the surface elements of the rubber tip was known, the next step was to accrue the associated damage. This was accomplished using the Endurica DT incremental fatigue solver. The incremental solver is based on the following calculation (Mars et al 2018), and is made for each possible failure plane in each element. This formulation uses the same crack growth rate laws and input variables as are used to initialize the residual life, but integrates over cycles from time N_i to time N_{i+1}, rather than over crack size.

The result of the integration is the change of length $\Delta c_{i->i+1,j,k}$ of a crack for each finite element j and each potential failure plane k

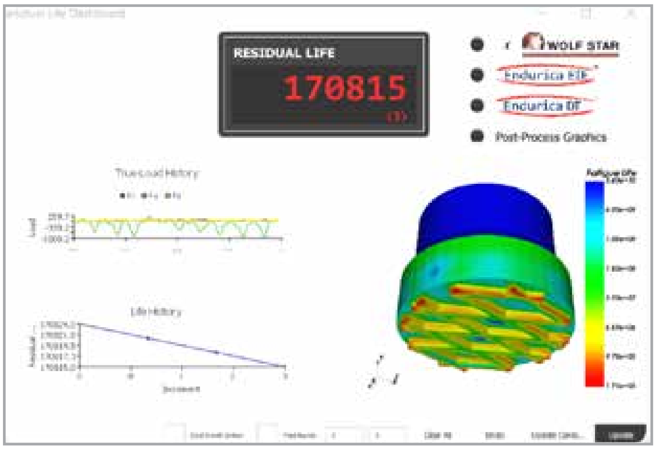
$$\Delta c_{i\to i+1,j,k} = \int_{N_i}^{N_{i+1}} r(T(\varepsilon_{nom}(N),\theta(N),c(N)))dN$$

Equation 1: Incremental fatigue solver formulation

of the model. The accumulated crack lengths for each element are written to a file during the analysis, so that future additions of load history may begin at the point at which the prior increment left off.

Putting it all together

We developed a custom dashboard to display the current state of the Pogo Stick's digital twin. The application manages the initialization and update processes describe above, and then plots the results following each update. The most recent value of the residual life is displayed at the top of the screen, with the change in residual life from the most recent update noted in parentheses. In the upper right-hand side of the screen, there are indicator lights for each step of the update process, which are provided to demonstrate the relative computational load of each step. Two plots are provided on the left side of the screen. The topmost plot is the load history from all three channels for the most recent update. The bottommost plot is the history of the residual life over all prior updates. A contour plot is provided in the bottom right corner of the screen displaying either the residual life distribution (default)



or the change in the distribution of crack length (if the checkbox is checked). New updates to the digital twin can be processed by clicking the "Update" button and selecting a new input file with loads from the latest round of Pogo Stick jumps.

This project provided an outlet for our pent-up creativity during lockdown, and allowed us to demonstrate how to leverage best-in-class load reconstruction with one-of-a-kind rubber durability to create a durability dashboard for our Pogo Stick that updates the damage calculations in real time.

Please feel free to contact us: we would be happy to help you with your product loading and durability issues.

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Fig. 1 - RENAULT F1 Team Race Car

Optimization of the SLM/DMLS process to manufacture an aerodynamic Formula 1 part

By N. Gramegna[1], D. Boscolo[1], P. Veronesi[2], M.F. Bolinauri[2], F. Baiocchi[3], N. Forghieri[3]
1. EnginSoft - 2. Università degli Studi di Modena e Reggio Emilia - 3. ADDITIVA Srl

Metal additive manufacturing (AM) is widely used in Formula One, motorsport and racing to manufacture complex parts in a short time. Power Bed Fusion (PBF) technologies, such as selective laser melting (SLM) and direct metal laser sintering (DMLS), are currently used to manufacture parts (e.g. exhaust systems, aerodynamic inserts and wings, pipes, roll hoops, etc.) in aluminum, titanium, Inconel and other high-performance superalloys [1,2]. The main success factors driving the increased use of metal AM in motorsport are the maximum freedom assured during the design phase; and the possibilities of manufacturing lightweight parts, using complex geometries, and using lattice structures with controlled variable densities. Nevertheless, metal AM is not synonymous with perfection; it has its own limits and constraints. One of its critical issues is the distortions that occur to the part during the laser melting process. In particular, this happens with thin-walled titanium components, which frequently deviate from the nominal 3D CAD geometry despite stress-relieving treatments. The use of simulation tools to limit and compensate for the distortions can dramatically reduce the risk of scraps and delays in delivery, and the related costs. This paper presents the RENAULT F1 Team's AM process for an aerodynamic insert in titanium Ti6Al4V. Production was optimized by identifying the best orientation for the parts and the best positioning for the support structures in the melting chamber, in addition to using the ANSYS Additive Print module, a simulation software useful for predicting the distortion of a part and for developing a new, 3D, compensated model that guarantees the best "as-built" quality.

Metal additive manufacturing (AM) is one of the enabling technologies of Industry 4.0. It differs from conventional manufacturing processes (e.g. machining, forging, casting, etc.) in that three-dimensional parts are produced by adding material layer by layer.

Metal AM has several advantages over conventional manufacturing processes:

- maximum weight reduction (by "putting the material just where it is required")
- maximum freedom in design (complex geometries, lattice structures, variable density control)
- highest levels of part customization

- no tooling or other production equipment costs
- reduced time from design to functional part
- simplification of the bill of materials since a subassembly of different parts that are welded together is replaced by a single AM monolithic part (zero leakage, and reduced assembly and inspection costs)
- ability to develop new materials and previously non-existent microstructures
- ability to replace worn out or broken parts that are either out of production or out of stock

Power Bed Fusion (PBF) technologies, such as selective laser melting (SLM) and direct metal laser sintering (DMLS), are currently used to manufacture parts (e.g. exhaust systems, aerodynamic inserts and wings, pipes, roll hoops, etc.) in aluminum, titanium, Inconel and other high-performance alloys [1,2]. As a result of the wide range of parameters and variables in the SLM/DMLS processes, there are often several ways to print the same part, each with different manufacturing times, costs and quality levels. Moreover, the current limitation of 3D printing renders some 3D models more expensive, or even unfeasible, by AM.

The most critical limits and constraints of metal AM are:

- low productivity (limited mass per hour melted by the lasers)
- the high cost of 3D printing machines and the metal powders
- the need to provide support structures (to prevent the first layer of molten metal collapsing on the powder bed)
- distortions occurring during the melting process

It is, therefore, useful to fine-tune the 3D model of the part to reduce the AM cost, achieve a better trade-off between quality and cost, or ensure the realization of a suitable part by AM. The Design for Additive Manufacturing (DfAM) guidelines support designers in achieving this objective, enabling them to understand the real strengths and weakness of the technology in order to maximize the first and limit the second.
One aspect addressed by DfAM concerns the simulation of laser melting to predict and correct the distortions that can occur in parts during melting.
The high energy density and, most importantly, the rapid solidification causes residual stress whose intensity depends on: the building strategy; the part's orientation in the melting chamber; the presence/absence of support structures; the geometry, density, mass and distribution of the supports; and the thermal conditions. Residual stress induces distortions in the as-built part, even before the supports are removed, resulting in differences between the nominal dimensions of the 3D CAD model and the real shape and dimensions of the AM part. Manufacturers usually manage this critical issue with a "trial and error method", or by taking decisions based on their own experience. However, if they are not correctly engineered, parts can be out of tolerance at the end of the process, meaning they are discarded, resulting in higher costs and longer delivery times. As a result, the prediction of and compensation for distortions is a fundamental objective.

Knowledge of material properties is essential to understanding how the powder changes in the melt pool and how it creates the part, layer by layer. The first aspect occurs at a microscopic scale, while the latter occurs at a much larger scale. Hence, a multi-scale approach is required to predict the possible results of the AM process.

Modern CAE simulation tools offer new opportunities to add value and diversify a company's services in this area by providing the ability to re-design the product from the beginning using advanced simulation tools that can accompany the entire product development process. Once the shape of the part has been defined, the designer and the manufacturer can shift their focus to the AM production process, in order to predict possible defects or non-conformities, and to better manage the parameters of the 3D printers. Simulation plays a decisive role thanks to modern techniques that can virtually reproduce the printing phase, analyzing the complex multi-scale and multi-physical (thermo-structural) phenomena in a transitory manner. This phase becomes even more appealing when performed via a direct interface between the 3D printers and the simulation software, allowing the file in the print format to be read and the metallurgical quality (porosity, residual stress, anisotropy, etc.) of the material to be forecast.

F1 wing challenges

The main factors driving the increased use of metal AM in motorsport and racing are weight reduction; maximum design freedom; the use of high-performance materials; and short lead times. One of the most important uses for AM in Formula One concerns aerodynamic inserts and wings, with their complex geometries, internal cavities, and thin walls. Thanks to its strength and stiffness, Titanium Ti6Al4V is the best material to use for heavily loaded aerodynamic structures like the one shown in Fig. 1.
For a part like that, the most critical requirements concern:

1. Surface roughness (SLM/DMLS guarantees "as built" surface roughness within the range of $5.6 \div 7.2 \mu m$ Ra, meaning that several finishing processes are required to achieve at least $1.6 \div 2.4 \mu m$ Ra)
2. Tolerances of 0.6 mm
3. Part weight (the component must be positioned to allow the support structures to be perfectly removed during post-processing so that no residue will alter the weight. It is vital to establish the correct position for the part inside the melting chamber to avoid generating non-removable supports, particularly inside cavities that may be not accessible after printing is complete).

Motorsport and racing impose short lead times, this means that parts must be printed properly at the first attempt without distortions that generate scraps. This is the core challenge for both the manufacturer and for the simulation software, which must be able to model the melting process without excessive computing time.

Optimization of the AM process

The optimization project described in this paper was produced by a team of experts – in materials (University of Modena and Reggio

Emilia), in metal AM (Additiva Srl), and in the virtual optimization of the AM process (EnginSoft SpA).
The process to evaluate the best configuration for the part to be printed was developed as follows::

A. Printing a reference shape and measuring the distortion to calibrate the model
B. Executing a set of rapid simulations to identify the best orientation/positioning for the part inside the build platform
C. Analyzing the distortion tendency (maximum and average displacement)
D. Analyzing the process time

	Z axis height [mm]	Printing time [hrs]	Simulation time [h]	Max Displacement [mm]	Level of distortion	Internal support volume [mm³]	Workload for support removal
1	88	8:30	3	0.96	high	803	++
2	58	5:50	2	2.50	high	863	+
3	19	3:00	1	0.28	low	1868	++++
4	107	9:30	4	0.74	low	331	++

Table I - Results of screening on part orientation

A. Model calibration
In order to configure the 3D printing machine set-up and the laser parameters identified to melt the aerodynamic wing part, a cross-shaped sample was printed using a CONCEPT LASER M2 system. This sample was measured to establish its deviations from the nominal ones used by the software in order to calibrate the model's response. This approach is used in the preliminary stages of modelling to accelerate computing time while ensuring that the model suitably represents the process.

B. Orientation and positioning
Four positions were developed for the part, as shown in Fig. 2. Two of them (2 and 3) were selected to minimize the printing time (minimum job height), while the other two (1 and 4) were expected to result in a minimum mass for the supports in the critical areas of the part.

The software enables the maximum displacement of the part to be estimated, and the areas where that distortion is expected to be identified. Table I summarizes the results of this screening phase (the qualitative levels of distortion and the workload necessary to remove the supports was assessed by the manufacturer based on experience).

Orientation no. 2 had the maximum expected displacement, while Orientation no. 3 had the minimum one. Orientation no. 3, however, would require a high mass of support structures that would be difficult, or even impossible, to remove. While the internal support structures could be left inside the cavities, this would unacceptably increase the weight of the part. Consequently, Orientations no. 2 and 3 were discarded and not investigated further.

Orientation no. 1 showed a maximum displacement that was higher than the one of Orientation no. 4, yet, Orientation no. 4 had the maximum height in the Z axis, leading to greater printing time and cost. This simplified model showed that neither Orientation no. 1 nor no. 4 fulfil the design requirement of a maximum distortion less than 0.6 mm.

When considering both the manufacturing times and the distortion tendency, however, Orientation no. 4 was the most promising candidate for printing: the increased printing time did not cause consistent variations in the total production cost, and the primary purpose of the project was to reduce the number of deformations.

C. Analysis of the distortion tendency
The third step consisted of developing a compensated geometry. ANSYS Additive Suite simulates the laser melting process, predicts distortions, and develops a new compensated geometry by reversing the distortion effects. The melting of this new compensated geometry should significantly reduce the distortions, resulting in a part as close as possible to the original 3D model.

Fig. 3 shows the new compensated geometry. A maximum displacement of 0.70 mm was observed on the red surface. The slight difference from the analysis described in (B) was due to the simulation assumptions: in this case, to obtain a better estimate of the distortion, a finer mesh was used in addition to the actual scan pattern.

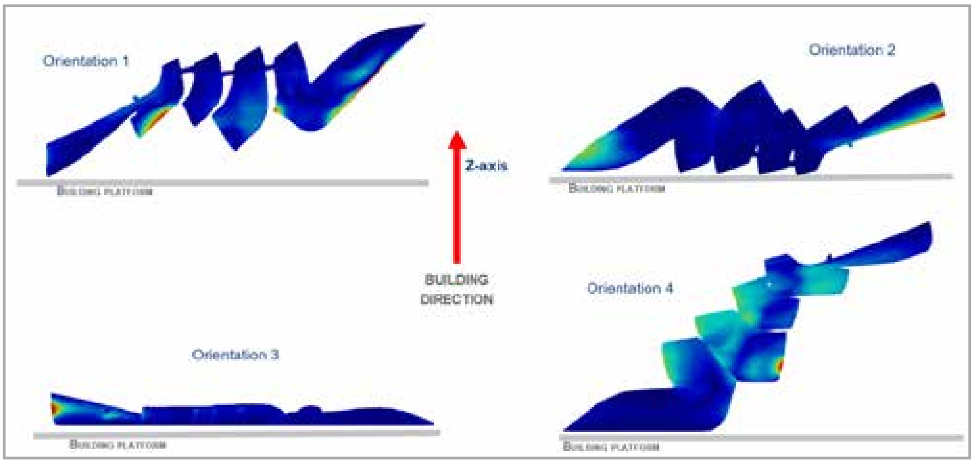

Fig. 2 – Comparison of different orientations

The part was printed both using the uncompensated geometry (not shown) and the compensated geometry for Orientation no. 4 (Fig. 4). 3D optical scanning was used to measure the surface of the part in three scenarios: after the melting process (with parts and support structures still attached to the build platform); after stress reduction; and after removal of the supports. The results of the dimensional

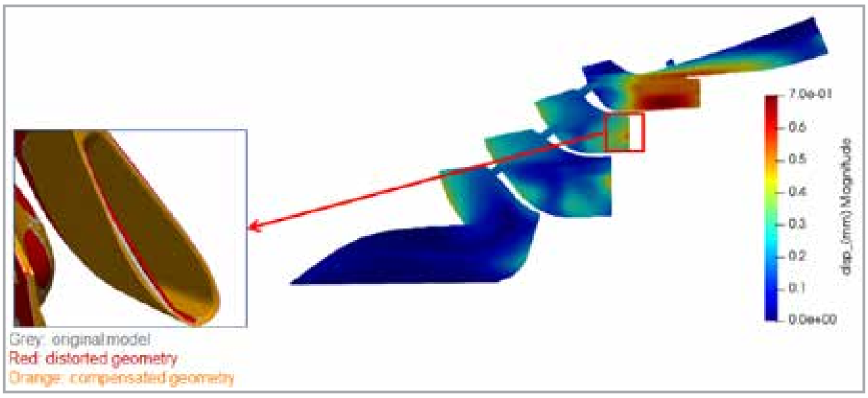

Fig. 3 – Simulation results: (right) simulated distortion in printing orientation 4 and (left) automatic compensated geometry generation

	componente	supporti	contour
potenza laser [W]	370	170	220
velocità scansione [mm/s]	1250	1300	1750
spot size [µm]	150	100	70
hatch distance [mm]	0.16	-	-

Fig. 4 – Printing parameters and final 3D printed wing (compensated geometry)

measurements, shown in Fig. 5, are in agreement with the simulation result in terms of position, maximum and minimum deviation from the nominal values, as well as the tendency towards improvement by moving the solution from four different orientations.

The comparison between the simulation results and the 3D scans of the printed parts clearly shows how it is possible to obtain an accurate output through simulation, which can predict the location of the maximum distortions in the upper part of the component.

Just from the preliminary simulations, it was possible to keep the maximum distortion below 0.59 mm. Compensation further improved the quality of the part, with a maximum displacement of 0.48 mm and a lower average and standard deviation of the absolute value of the distortions. These results were achieved with a single simulation iteration; better results could be achieved with more iterations in order to better estimate the effects of distortion, and thus generate a more effective compensated geometry.

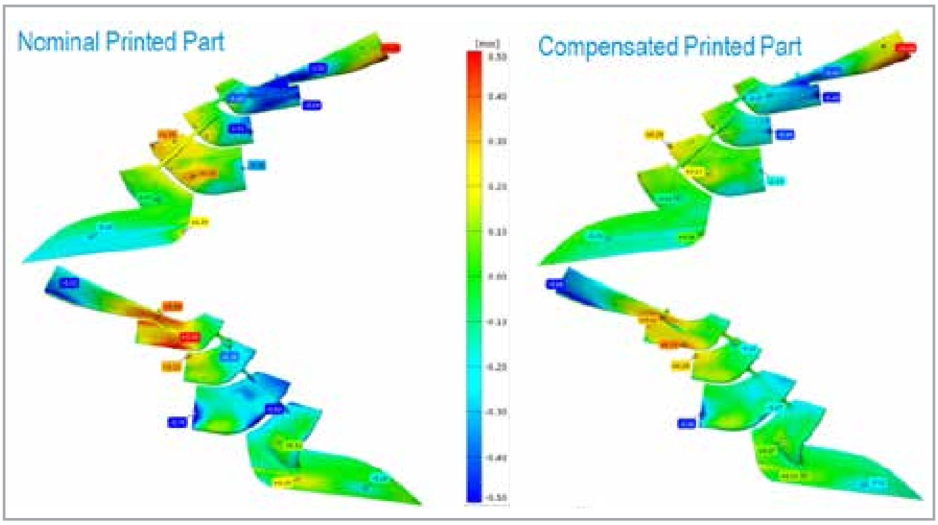

Fig. 5 – Distortion comparison between the nominal part (left) and the compensated part (right)

Conclusions

Metal AM allows new complex parts to be designed and produced in a very short time. This is particularly true in demanding fields like motorsport and racing, where mechanical properties (elastic modulus and strength) are mandatory, with minimum manufacturing times to rapidly introduce new solutions for each race. This project has shown that it is possible to print complex parts that conform to design specifications through a correct understanding of the SLM/DMLS process and use of simulation tools.

Through rapid simulations on simplified models, it is possible to study the effects of different part orientations and to identify the most promising one in terms of the distortion tendency. This also makes it possible to identify areas affected by high displacements and, if necessary, to locally modify the support structures.

Using a more accurate model, it is possible to predict the distortion range and generate a compensated geometry that allows parts closer to the nominal geometry to be manufactured. This approach has the potential to further extend the DfAM field, including not only classical topological optimization, but also the design of parts and processes that minimize residual stress or distortion.

Acknowledgments

The authors would like to express their deepest appreciation to the collaborators and technical staff who gave us the opportunity to complete this project. Special gratitude goes to the RENAULT F1 Team whose contribution was fundamental in directing the project, especially its dissemination.

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Testing ParticleWorks coupled with Recurdyn to simulate water behavior in water technology products

By Chiaki Miyazawa[1] and Akiko Kondoh[2]
1. LIXIL Corporation - 2. Prometech Software

One of the important lines of business for LIXIL Corporation, Japan's largest building and equipment manufacturer, is the water technology products, such as baths, kitchens and toilets. LIXIL is trying to introduce Particleworks, a meshless multiparticle simulation (MPS) computational fluid dynamics (CFD) tool in the research and development of these products. Particleworks is developed by Prometech Software, Inc.

Dr. Miyazawa of LIXIL's Advanced Core Technology Division explains: "I am mainly in charge of digital technology fields such as CFD simulation and virtual reality (VR). Previously, we largely focused on airflow analysis using a finite volume method (FVM) simulation tool that was effective for airflow evaluation even when toilet water flow analysis was necessary. However, since FVM requires a lot of computational resources, when it became necessary to evaluate many small droplets, such as for showers, I started looking for a suitable tool.

This was when I found Particleworks, which was introduced with the keywords "liquid splashing" and "mixing". So, I started a trial of Particleworks. Currently, we are verifying the reproducibility of shower toilets and showerheads, water splashing phenomena in kitchens, and kitchen sink flow behavior and have already begun using prototypes for research."

Simulation of a shower head

First example of RecurDyn-Particleworks coupling

LIXIL's "Ecoful Shower" shower head product (Fig. 1) consists of a structure in which the impeller incorporated in the shower head rotates at high speed and blocks half of the shower holes. This mechanism increases the pressure inside the shower head, producing a regular shower sensation for the user, however the water consumption is 48% lower than that of the conventional water volume (10 L/minute). Besides conserving water, it is also important to optimize the water pressure and the size of the water drops to improve comfort. Particleworks was used for these evaluations.

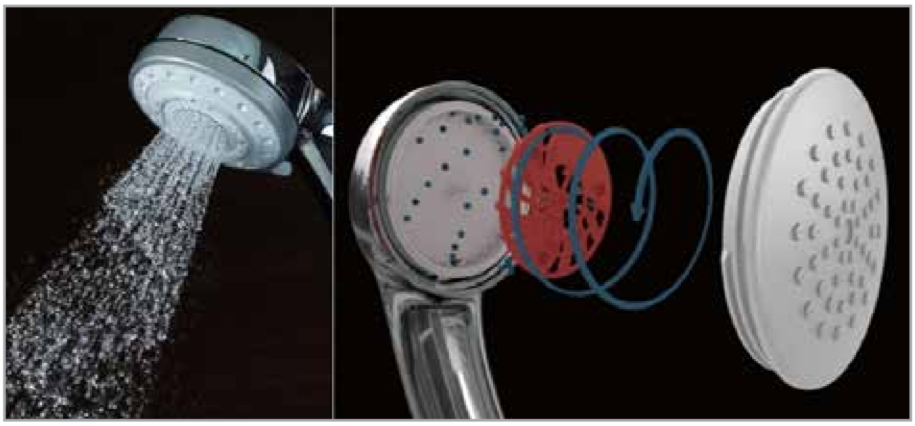

Fig. 1 - Ecoful Shower – The red impeller rotates at high speed blocking half the shower holes

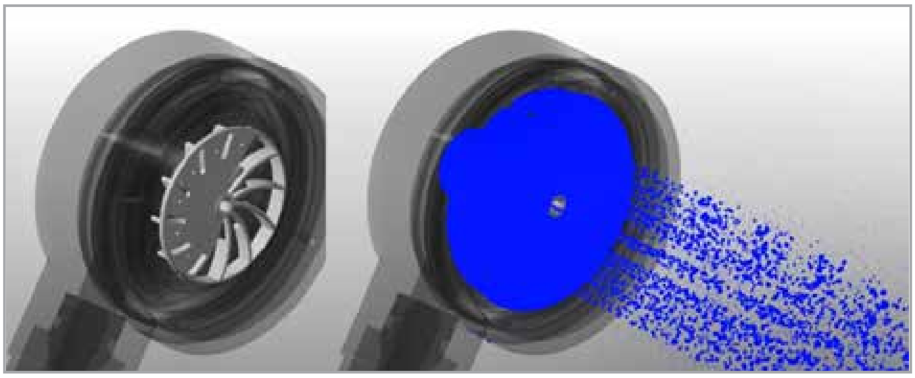

Fig. 2 - Simulation of the shower head

In this shower head mechanism, the impeller rotates due to the water flow, and the number of rotations changes according to the flow velocity. Since Particleworks itself only provides a constant rotation speed regardless of the water flow, we used a coupled simulation with the multi-body dynamics simulation software RecurDyn to confirm the effects of both stable rotation speed and rotation changes.

The results of the fluid behavior simulation were generally good because they met LIXIL's guidelines compared to the measured values. The rotation speed of the impeller gradually increased at first, decreased gradually after reaching the peak, and finally stabilized. The transition states obtained by simulation were roughly consistent with the measured values.

Regarding the internal pressure of the shower head, we verified that the results almost matched the measured values. The size of the particles was measured with a high-speed camera, and the difference from the calculated value was also within the company's guidelines. Overall, it was evaluated as a good result for a shower head simulation.

Simulation of waste flushing from kitchen sink

Second example of RecurDyn-Particleworks coupling

Kitchens are easier to use if they are easier to clean. To achieve this, it must be easier to flush dirt and waste to the bottom of the sink and to clean it away efficiently.

LIXIL's new product introduced the "Niagara Flow Type", where the bottom of the sink slopes more from the left and right edges, preventing water from spreading and flowing smoothly towards down. This allows for efficient drainage from anywhere in the sink. Particleworks was used to evaluate how effective the new shape is. The kitchen sink design was evaluated in tests based on a very large number of assumptions, including how to flush waste.

In the Particleworks simulation, we first tried to reproduce how easily it was for regularly spaced waste to flow. The analysis

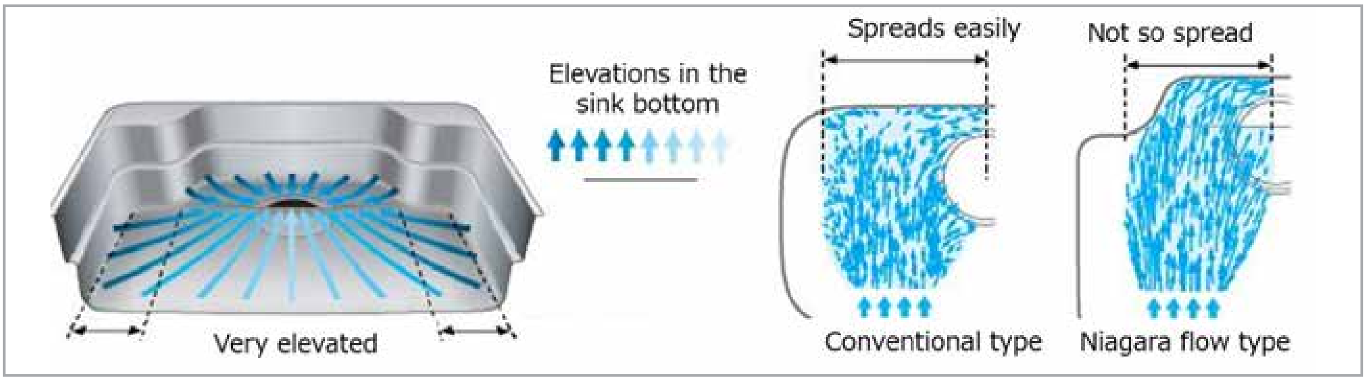

Fig. 3 - Difference between a Niagara Flow Type and a conventional type of sink shape

currently being performed checks how the waste placed at equal intervals flows. Instead of performing detailed settings by coupling Particleworks with RecurDyn, as was done in the shower head simulation, the water supply conditions were set using the Particleworks function.

Initial simulations showed that the water flowed faster, slipped more, and spread less compared to the test. The waste was also flowing unnaturally. Therefore, a test was conducted on a simple shape to obtain parameters by associating the test results with the simulation results. In actual phenomena, a film of water penetrates under the waste and surrounds it making the waste slippery.

In the Particleworks calculations, particles didn't penetrate below the waste as easily in the first trial. This was solved by making the particles smaller. However, this required a lot of computational resources.

To reduce the computational load and shorten the simulation times to less than a day, it was necessary to enlarge the particles to some extent. However, this caused some differences from the actual phenomenon. Therefore, several attempts were made to adjust the frictional force parameters to approximate the behavior of the particles.

Regarding the definition of the frictional force, it was found that it was easier to adjust the parameters by setting the waste with polygons in RecurDyn, so a simulation was performed coupling Particleworks with RecurDyn.

Next, the frictional force and particle shape were defined to prevent the waste from moving before the water supply. A correlation was made by adjusting the frictional force and the transition speed.

Through trial and error, the reproduction of water spread and the behavior of the waste were improved compared to the first simulation, and could also be improved compared to the actual test.

Although the final result for this simulation has not been obtained, LIXIL continues to try to simulate through trial and error.

Dr. Miyazawa said, "The Particleworks features are a great advantage because they allowed the behavior of the shower and the internal impellers to be easily reproduced."

About LIXIL Corporation

LIXIL Corporation is the largest building materials and equipment manufacturer in Japan, offering a wide range of high-quality products that support people's lives and living with world-leading technologies and innovations based on the Japanese manufacturing tradition. LIXIL's products are used by over 1 billion people in more than 150 countries around the world. One of LIXIL's main businesses is water technology. It provides water-related products such as baths, kitchens, and toilets.

Fig. 4 - Water flow simulation for conventional type (left) and Niagara Flow Type (right)holes

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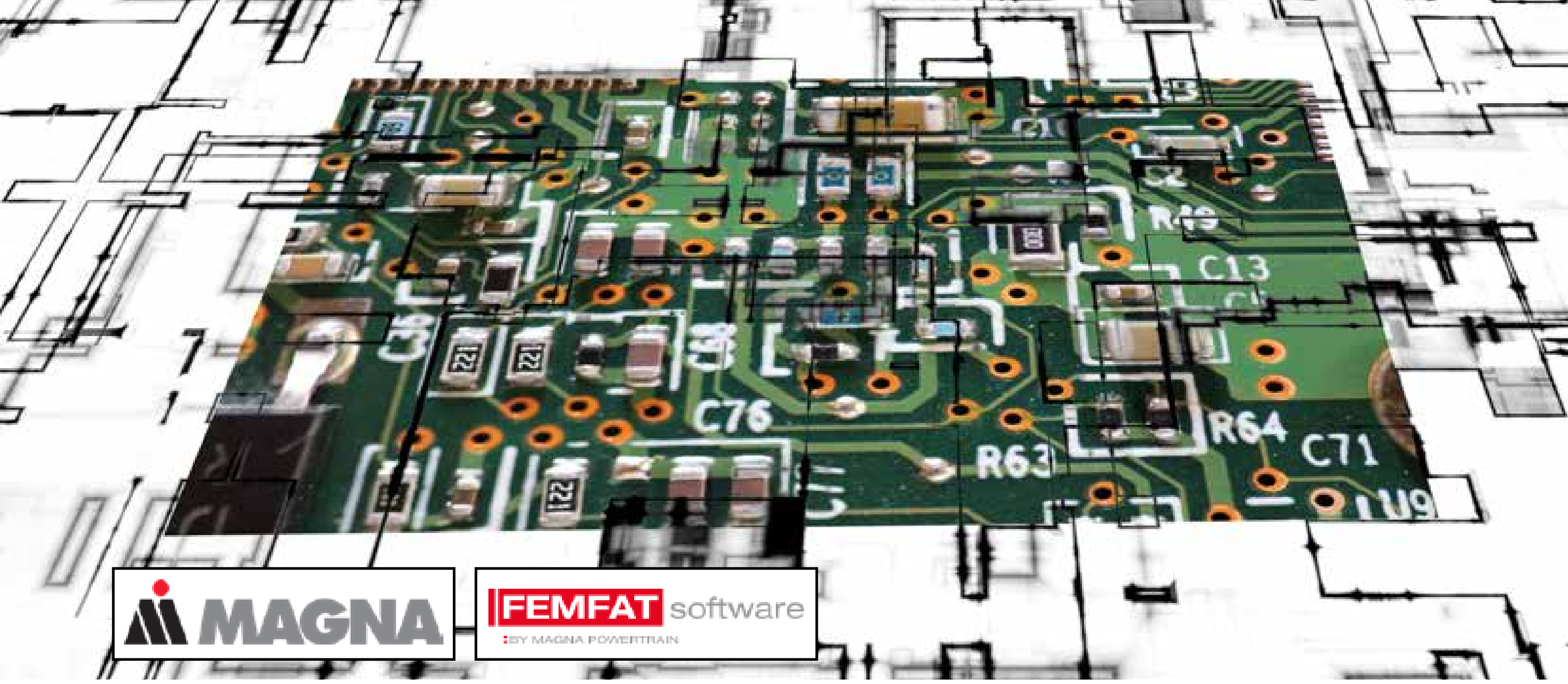


New process to analyze vibrational fatigue of solder joints on printed circuit boards used in electric vehicles

High degree of automation allows assessment of massive number of solder joints and electronic components

By Harald Ziegelwanger and Gerhard Spindelberger
MAGNA Powertrain's Engineering Center Steyr

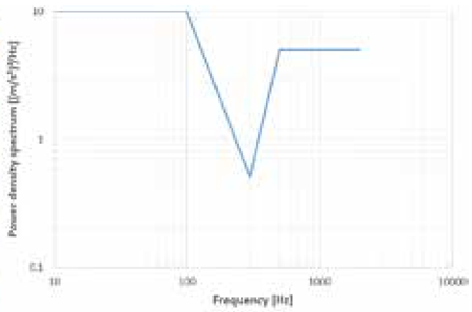
Calculating the vibrational fatigue to solder joints requires detailed finite element (FE) models of these solder joints. However, just a single PCB of a 48V-inverter houses several hundred electronic devices (tens of different device types) and several thousand solder joints (the number of types of solder joints on a PCB is usually of the same order as the number of device types). The electronic devices (generally surface mount devices, SMDs) used are typically multi-layer ceramic capacitors (MLCCs), electrolytic capacitors (e-caps), resistors, small-outline integrated circuits (SOICs), chokes, diodes, power resistors, and transformers. Devices in the SOIC category can be further differentiated according to the type of solder joint, i.e. gullwing-lead, j-lead, no-lead, or ball-grid arrays (BGAs). Large devices may also make use of through-hole technology for soldering.

While Electrical CAD (ECAD) software can generally export a PCB and its electronic devices as CAD files, the information contained in these exported files is usually not sufficient to build an appropriate FE model because the exported geometric information mainly describes only the maximum package sizes of the electronic devices and excludes the solder joints completely. For this reason, we propose the use of a simulation process that automatically builds the required FE models of the electronic devices and the solder joints, reducing to a minimum the manual effort required to calculate the vibration fatigue of the solder joints.

The trend towards electrification of vehicle transmissions requires the development of electronic components that can withstand different forms of vibration and acceleration levels, such as harmonic and stochastic acceleration or mechanical shock. In the automotive sector, electronic components must be tested according to the mechanical requirements of the relevant standards, such as VW80000 [1]. VW80000 distinguishes whether a component is mounted on the engine, gearbox or chassis. For instance, gearbox-mounted components like a 48V-inverter must be tested for a power spectral density (PSD) of up to 2 kHz, as shown in Fig. 1. This poses the major challenge of vibrational fatigue to the solder joints, for which vibration is usually considered to be an undesirable condition [2].

Vibration excitation	Wide-band random vibration	
Test duration for each spatial axis	22h	
RMS value of acceleration	96.6 m/s²	
Vibration profile	Frequency in Hz	Power density spectrum (m/s²)²/Hz
	10	10
	100	10
	300	0.51
	500	5
	2000	5

Test parameters – vibration, wide-band random vibration for gearbox-mounted parts



Vibration profile, wide-band random vibration for gearbox-mounted parts

Fig. 1 - Vibration profile (PSD) for gearbox-mounted components [1].

Eventually, the peak damage values of the sub-model calculations are mapped to the corresponding pins of the substitute FE models in the electronic devices to display the results in the overall model.

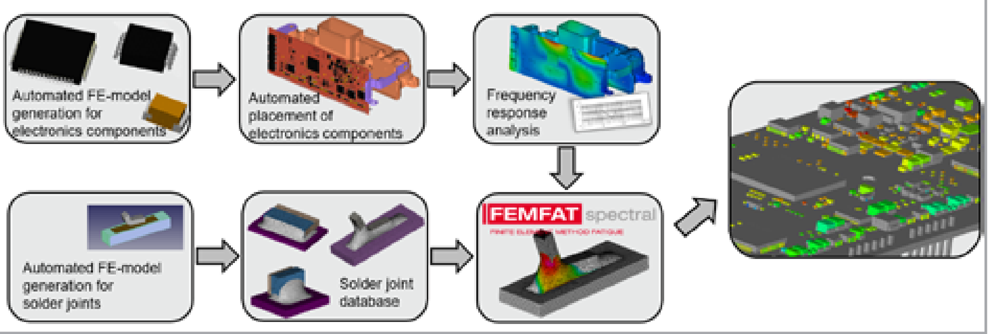


Fig. 2 - The simulation process has two process paths. In the first path, FRAs of the overall model containing a PCB equipped with FE models substituting electronic devices are performed and the section forces in the pins are evaluated. In the second path, static analyses of automatically generated solder joint sub-models are conducted. The results of both paths are used as input data for FEMFAT spectral calculations where the vibration fatigue for each solder joint on the PCB is calculated. Finally, the FEMFAT spectral results are collected and displayed on the overall model.

Method

The simulation process (illustrated in Fig. 2) to calculate vibration fatigue in solder joints uses a sub-modelling approach and is built around FEMFAT spectral. In short, first a modal-based frequency response analysis (FRA) is performed for the overall model of an electronic component containing a PCB equipped with substitute FE models of electronic devices, in whose pins the section forces are measured as a function of frequency. The section forces of each individual pin are then scaled by static analyses of a corresponding solder joint sub-model and the damage in the solder joint is finally calculated in FEMFAT spectral for a given PSD.

The number of electronic devices on a single PCB can be very high. Since the simulation process requires substitute FE models for each electronic device and an individual solder joint sub-model for each pin type and pad variation, it was essential to develop and implement algorithms to automatically build the substitute FE models for the overall model and sub-models for the solder joints. Below, we describe these algorithms, which build the core technology in the pre-processing phase of our simulation process, as well as the calculation and post-processing phases.

Pre-Processing

Automated generation of FE models to substitute electronic devices

First of all, the required electronic devices must be abstracted as substitute FE models so that they are available in the electronic device database. Generating substitute FE models is a semi-automatic process and consists of manual data retrieval steps and an automatic construction step (Fig. 3). First, the electronic device's geometric information must be retrieved from the datasheet. Then, the type of the electronic device is selected in ANSA and the input mask is completed with the relevant geometric information. ANSA then automatically generates the substitute FE model, which can be used in the ABAQUS FE solver. The final FE model contains one B31 element in each pin, a set of soldering nodes (the endpoints of the pins that would be connected to the PCB by a solder joint) and a set of contact surfaces (eg. SOIC surfaces that would be connected to the PCB by a heat paste).

At the moment, the simulation process supports a limited set of electronic device types (see Fig. 4), considered to be the most relevant for power electronics in the automotive sector: SMD resistors, power resistors, MLCCs, electrolytic capacitors, SMD diodes, SOICs, and transformers.

The algorithm was implemented as an ANSA plug-in (with Python 3.3) [3] and is not dependent on any external library. The plug-in can, therefore, be easily installed in ANSA using the integrated BETA Packager Installer.

Automated placement of substitute FE models in the overall model

Once the substitute FE models of all occurring types of electronic devices on the PCB have been built and are available in the electronic device database, the devices can be placed on the FE model of the PCB. Before placing the substitute FE models, it is mandatory to have an FE model of the overall model containing the PCB (either as a shell or solid mesh) and a set of shell elements or solid facets representing the top and bottom surfaces of the PCB in ANSA.

A Pick-and-Place file is used to enter the positional information of the electronic devices, for instance exported from the PCB layout software Altium Designer. The Pick-and-Place file contains information about the x and y coordinates of an electronic device in the local coordinate system of the PCB, the rotation of the device and whether the device should be placed on the top or bottom surface of the PCB. For each item in the Pick-and-Place file, the corresponding substitute FE model is merged into the overall model, rotated and translated to the position in the Pick-and-Place file (see Fig. 5). The B31 elements of all substitute FE models are collected in an element set. The soldering nodes and contact surfaces

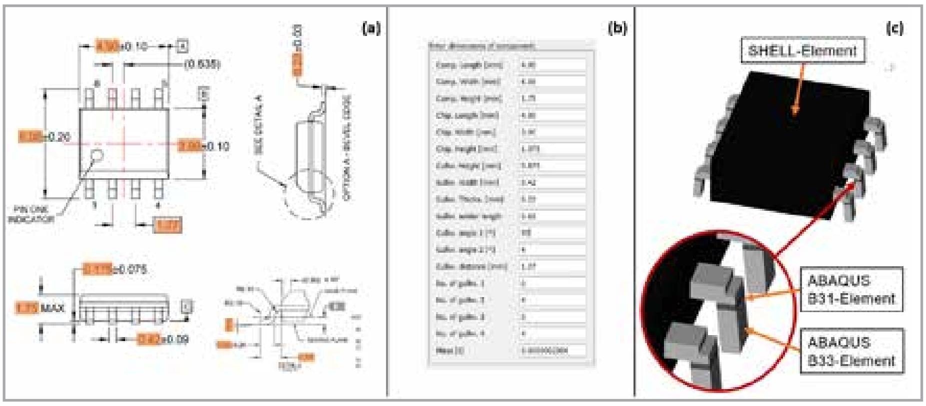


Fig.3 - Automated generation of FE models to substitute electronic devices: retrieval of an electronic device's geometric information (data taken from the 8-Lead SOIC Package: Fairchild FAN7171_F085) (a), data entry in the ANSA plug-in (b), automatic generation of the substitute FE model (c).

of all substitute FE models are collected in node and surface sets. Finally, these sets are connected to the PCB via TIE contacts.

This algorithm was also implemented as an ANSA plug-in (with Python 3.3) and is not dependent on any external library. The plug-in can therefore be easily installed in ANSA using the BETA Packager Installer.

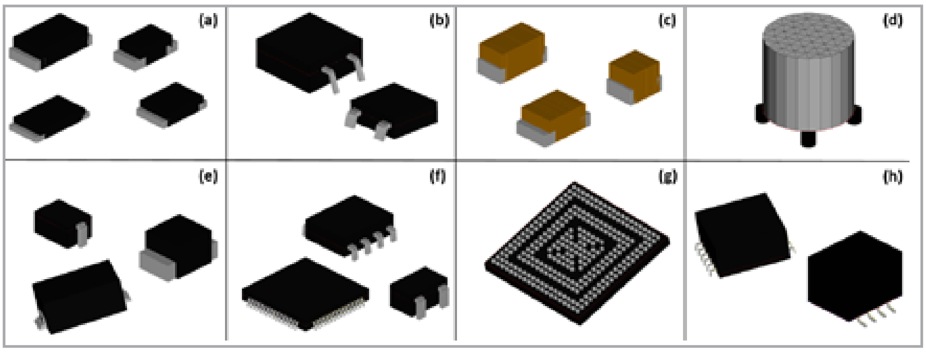


Fig. 4 - Electronic device types supported in the proposed simulation process: SMD resistors (a), power resistors (b), MLCCs (c), electrolytic capacitors (d), SMD diodes (e), SOICs (f), BGA-chips (g), and transformers (h).

Automated generation of solder joint sub-models

The geometric information used to generate the electronic devices' substitute FE models can be reused to generate the solder joint sub-models. Thus, in the routine, the user must first select (in the electronic device database) the substitute FE model for which they want to build a corresponding solder joint sub-model. The routine then loads the available geometric information from the previously constructed substitute FE model. Next, the user specifies additional information about the corresponding generic or layout-specific pad dimensions on the PCB, which can either be retrieved manually from the electronic device's datasheet or automatically from a PCB layout software such as Altium Designer. Once the mandatory geometric information has been specified, the sub-model construction algorithm starts. The different stages of the construction algorithm are shown in Fig. 6 (right side). In the first stage, CAD models of the pin and of a cutout zone of the PCB are created. To this end, the geometric information is applied to a parametric CAD model of the corresponding solder-joint type in FreeCAD. The parametrized CAD model is then automatically exported from FreeCAD as a standard for the exchange of product model data (STEP) file and automatically loaded into ANSA.

In the next stage, the solder meniscus geometry is automatically calculated. The calculation starts by generating a simple initial shell mesh of the solder surface, which is adapted to the geometry of the pin and the pad. The software Surface Evolver [4] is then used to calculate the meniscus by considering the solder material's surface tension at solder temperature, the gravitation, and the pin and pad dimensions. The final geometry is automatically loaded as a STEP file into ANSA.

In the last stage, several geometry and mesh processing routines are applied automatically to the model in ANSA. The stage involves the projection of the relevant curve on surface (CONS) of the three parts (pin, solder, PCB), the cutting of the relevant faces at the projected CONS, the topographic (TOPO) routine, the shell mesh generation, the volume definitions, the solid mesh generation, and the definition of material properties, constraints, boundary conditions, and loads. At the end, the algorithm exports two input decks, one for the ABAQUS FE solver and one for the NASTRAN FE solver.

Currently, the proposed simulation process supports a limited set of solder joints considered to represent the most important types of solder joint types for power electronics in the automotive sector: SMD capacitors, SMD resistors, gullwing leads, and ball-grid arrays (see Fig. 7).

The algorithm was implemented as an ANSA plug-in (with Python 3.3) and is not dependent on any external library. However, the algorithm requires the Surface Evolver and FreeCAD to be installed. Nevertheless, this plug-in can also easily be installed in ANSA using the integrated BETA Packager Installer. In plug-in settings, the user must specify the path of the Surface Evolver and FreeCAD installation directories.

Calculation

The core of the vibration fatigue calculation is a FEMFAT spectral calculation for each pin in the overall model. Each FEMFAT spectral calculation requires a modal basis of the solder-joint stresses and an individual load spectrum. The modal basis of the solder-joint stresses is represented by the stress output of the static analyses of the solder joint sub-model. The load spectrum is retrieved by calculating the section forces of a pin in the modal based FRAs of the overall model.

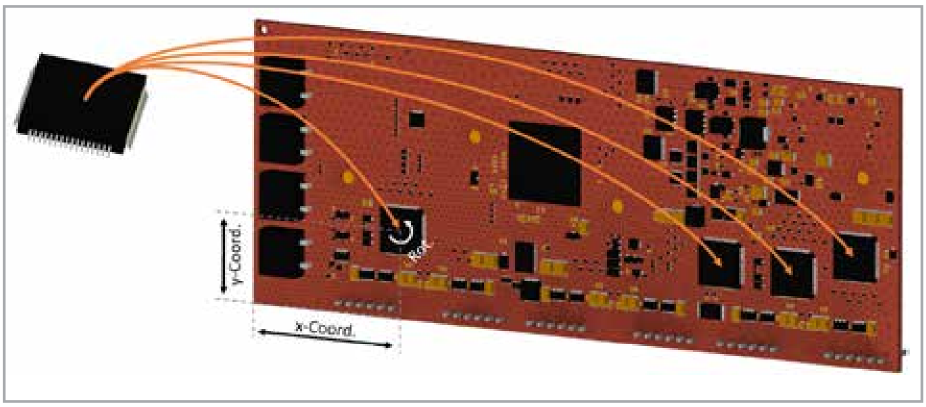


Figure 5 - Based on a Pick-and-Place report, for instance exported from Altium Designer, substitute FE models of the electronic devices taken from the database are positioned on the FE model of the PCB. The Pick-and-Place report provides the x and y coordinates, the rotation of the device, and whether it has to be placed on the top or bottom surface of the PCB.

(Modal-based) frequency response analysis (FRA) of the overall model

The calculation process starts with the modal based FRAs of the overall model, where the PCB is equipped with the substitute FE models from the electronic device database. As mentioned in the introduction, the overall task is to calculate the vibration fatigue for a

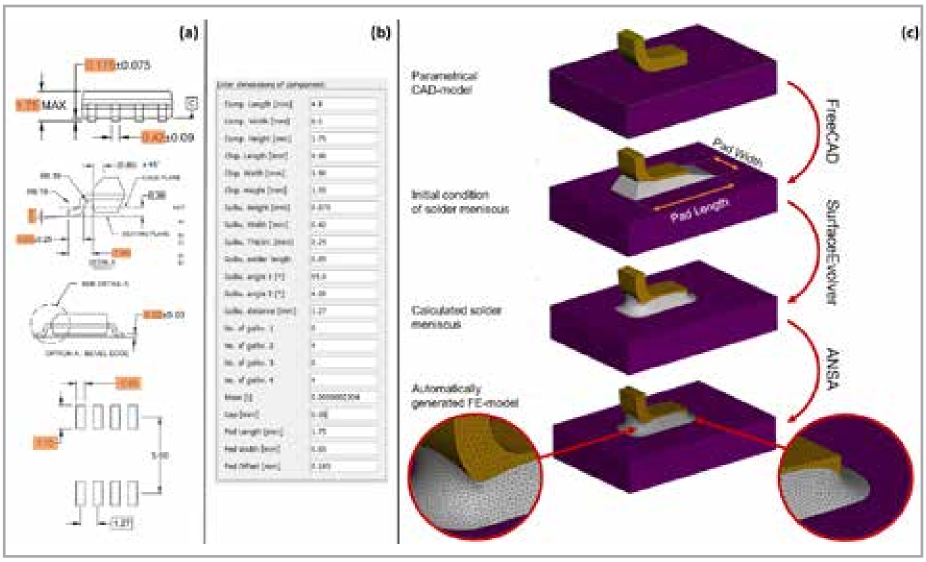


Fig. 6 - Automated generation of solder joint sub-models: Retrieval of electronic device's geometric information (data taken from 8-Lead SOIC Package: Fairchild FAN7171_F085) (a), data entry in the ANSA plug-in (b), automatic generation of the solder joint sub-model (c).

random acceleration of the electronic component specified by a PSD. Thus, the mounting points of the electronic component are coupled by kinematic coupling and a boundary condition is set at the reference node of the coupling. The PSD must not be included in the FRAs, instead unit accelerations are used (base motions in ABAQUS) to calculate the transfer functions from the mounting points of the electronic component to the section forces in the pins of the electronic devices on the PCB. For the modal-based FRA we recommend a modal basis up to 1.5 times the highest frequency of the PSD (which is 3 kHz in Fig. 1) and a frequency bin distance of 0.5 Hz in the FRA. The six section forces in the B31 elements of all pins are written as simulation outputs to the ABAQUS output database.

Static analyses of the sub-models

A static analysis must be done for each new solder joint sub-model in the solder joint database. Six load cases must be considered: the application of three forces and three moments in the local coordinate system of the cutting cross-section of the pin. The static analysis of the sub-models is sufficient for the vibration fatigue calculation because usually the eigenfrequency of the first eigenmode of all the supported sub-models is larger than 100 kHz. Thus, in these sub-models natural vibrations do not occur in the relevant frequency range. Note that if new solder joint types were to be added to the simulation process in the future, the eigenfrequency of the first eigenmode would have to be checked for each type of solder joint and the simulation process would have to be adapted if the first eigenfrequency lies within the relevant frequency range of the FRA of the overall model.

Fatigue calculation in FEMFAT spectral

In the FEMFAT spectral calculations, we combine the results from the overall model and from the sub-models. The section force spectra from the modal based FRAs of the overall model represent the load data. The static analyses of the sub-models represent the modal basis of the solder joint sub-models. A FEMFAT spectral calculation must be done for each pin in the overall model.

The first input is a file containing the modal stresses of the sub-model. Remember that in the sub-models natural vibrations do not occur and, thus, the six static load cases represent our modal basis for the FEMFAT calculation. FEMFAT spectral interprets static load cases as modes, thus there is no need to transform the data. The second input is a file containing the participation factors as a function of frequency. In our case, the section forces in the pins of the overall model represent the participation factors of the static load cases in the sub-models. Thus, the section force output from the FRAs must be transformed to a file format that FEMFAT spectral can interpret as the participation factor spectrum, for instance a *.dat text file (ABAQUS), which contains the section forces as GPU and GU values. The transformation is done with an ABAQUS python script, which reads the section forces from the overall-model.odb file and writes the section forces of each pin into an individual EL#.dat file (where # represents the element number of a pin's B31 element in the overall model) as the participation factor spectrum. The third input is the PSD data (example shown in Fig. 1). A python script automatically generates an individual FEMFAT job file (EL#.job) for each pin in the overall model and a shell script to automatically start the FEMFAT jobs in a queue.

Post-Processing

META is used for post-processing the vibration fatigue calculations. In META, first, the overall-model.inp file must be loaded as the geometry. Then, the FEMFAT spectral results for all pins must be collected and the maximum damage values must be mapped back to the pins of the electronic devices in the overall model. To this end, a plug-in collects the FEMFAT spectral results, writes them to text files (in the META Column ASCII format [5]) and reads these files as results into the META session. For better visualization, the results at the B31 elements are extrapolated to their neighboring elements. An example of the maximum damage values visualized is shown in Fig. 8a.

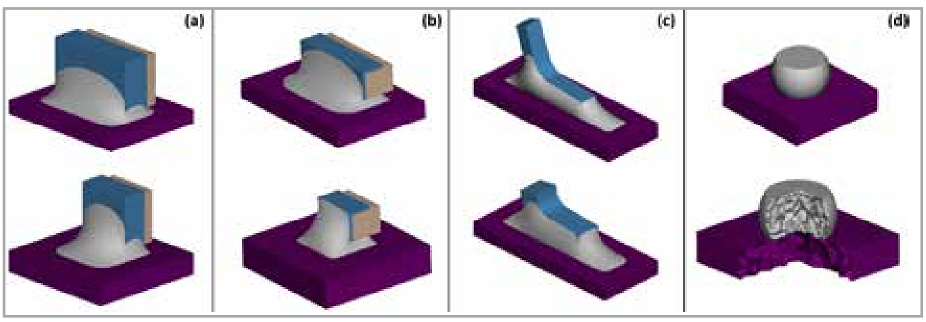


Fig. 7 - Types of solder joints currently supported in the proposed simulation process: SMD capacitors (a), SMD resistors (b), gullwing leads (c), and ball-grid arrays (d).

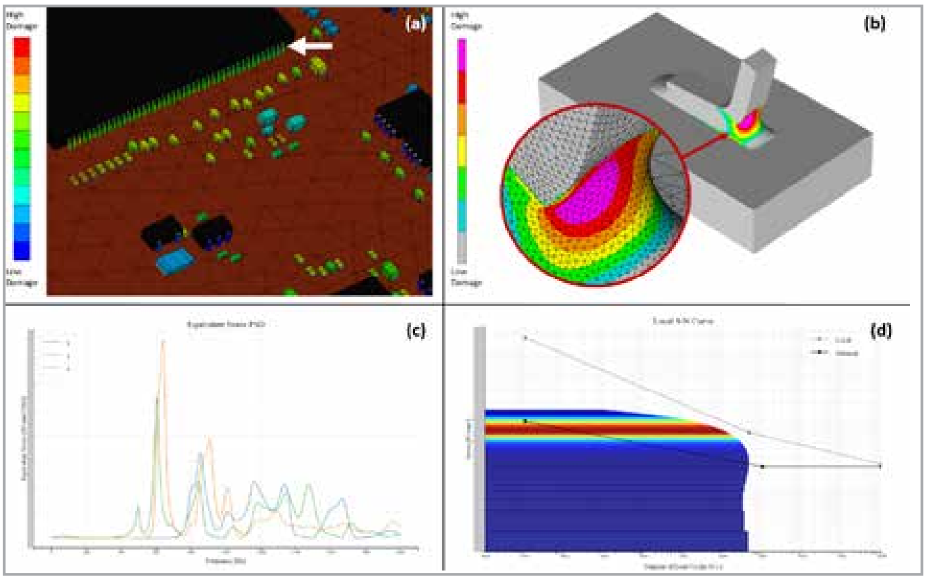


Fig. 8 - Damage values mapped back from the FEMFAT spectral calculations of all individual sub-models to the pins of the substitute FE models in META (a). Damage values for a specific sub-model (marked by the white arrow in Fig. 8a) in FEMFAT visualizer (b). Equivalent stress PSDs in the most damaged node of the sub-model in Fig. 8b for all acceleration directions (c). Local S-N curve for the most damaged node of the sub-model in Fig. 8b (d).

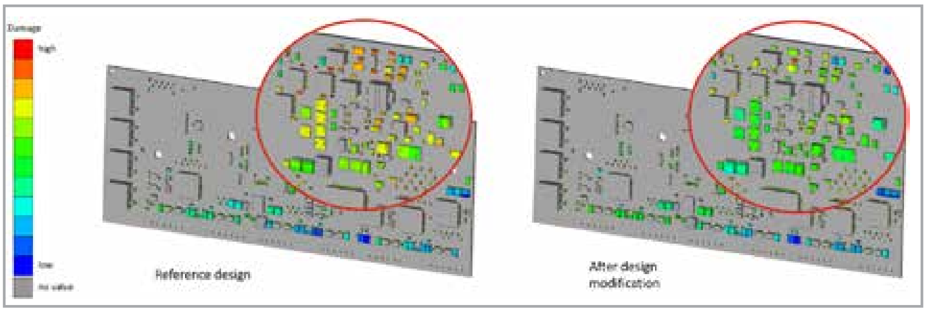


Fig. 9 - Maximum damage values in the solder joints before and after a design modification to a PCB mounted in a 48V-inverter.

Detailed results of the FEMFAT spectral calculations for the individual pins can be obtained directly from META.

We implemented plug-ins for the user to select the B31 element of the desired pin after which META either opens the corresponding *.fps file (FEMFAT result file) in the background in FEMFAT visualizer (Fig. 8b), or plots the equivalent stress PSD (Fig. 8c) and the local S/N-curve (Fig. 8d) of the most damaged node directly in META.

The post-processing functions were implemented as META plug-ins (with Python 3.3) and are not directly dependent on any external library. However, the algorithm requires a native installation of Python3.3 (including the h5py-module) and of FEMFAT visualizer. Nevertheless, this plug-in can also be easily installed in META using the integrated BETA Packager Installer. In the plug-in settings, the user must specify the path of the Python3.3 and FEMFAT visualizer installation directories.

Sample Results

In Fig. 9, sample results for the PCB of a 48V inverter are shown – before and after a design modification. For both designs, the whole simulation process was applied to the inverter.

Firstly, the most critical solder joints were detected by visual inspection of the maximum damage values on the pins of the electronic devices in the overall model in META. Secondly, the dynamic weaknesses of the reference design were efficiently found by evaluating the equivalent stress PSDs of the most critical solder joints and by evaluating the operational deflection shapes at the peak frequencies of these equivalent stress PSDs. Note that the peaks in the equivalent stress PSDs of the most critical solder joints indicate the frequencies of those operational deflection shapes that contribute most to the damage of a solder joint.

The peaks in the equivalent stress PSDs and thus the damage values in the solder joints were reduced by modifying the existing mounting points of the PCB and by introducing an additional mounting point. The reduced maximum damage values are shown in Fig. 9 (right side).

Remember that the proposed simulation process involves three modal based FRAs (for different acceleration directions) with 4000 frequency steps and that the number of solder joints on a PCB can be in the range of thousands. However, with the proposed post-processing functionality, the most critical operational deflection shapes and thus the underlying mode shapes were found within minutes.

Summary and Outlook

This article presents a new process to assess the fatigue of solder jointed electronic components on printed circuit boards. The great advantage of the new process lies in its high degree of automation which enables a massive number of solder joints and electronic components to be assessed. Future developments include extending the number of electronic device and sub-model types supported. Secondly, the simulation must be extended to consider not only random load signals but also harmonic load cases, for instance to simulate logarithmic sweep excitations of the electronic component.

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Simulation model simplification that retains result resolution, saves time and money

A FE methodology to mechanically analyze a high-performance internal combustion engine's cylinder liners

By Saverio Giulio Barbieri, Matteo Giacopini, Roberto Rosi
Astra Research Engineering Consulting

Modern engines must meet strict engine pollution emission norms and minimize fuel consumption. This leads to higher mechanical and thermal loading of the engine components, which in turn means that the design procedures used to conduct structural and thermo-structural analyses of them must be constantly improved to satisfy demands for higher performance. Finite Element analyses are frequently used to analyze and optimize the geometries of cylinder liners to resist bore distortion and predict their likely fatigue damage, however several engine components must be included in these analyses, substantially complicating the simulations and increasing computing requirements and time. The simplification of these numerical procedures can dramatically reduce this time and cost, as well as the number of experimental tests required prior to the final approval of the cylinder liner design. This technical article from Astra Research describes just such a methodology using a high-performance, four-stroke, eight-cylinder V-type turbocharged engine for supercar applications.

Turbocharging (downsizing), high compression ratios, and advanced spark ignition strategies are just some of the techniques used to increase efficiency in modern engines in order to fulfil strict engine pollution emission norms and minimize fuel consumption. The resulting higher specific loads lead to higher mechanical and thermal loading of the engine components. Therefore, the design procedures used for structural and thermo-structural analysis of the engine components must be constantly improved to satisfy the pressing demands for higher performance.

During the first design stage, Finite Element (FE) analyses are important and useful for analyzing and optimizing cylinder liner geometries. Since these models usually consider several engine components, which introduce many non-linear sources, cylinder liner fatigue analyses demand substantial computing effort. The use of simplified numerical procedures could reduce the time, cost and number of experimental tests in advance of the final approval of the cylinder liner design.
This article describes a methodology for simplifying the FE evaluation of the liner bore distortion and the prediction of fatigue damage. The

engine in question is a high-performance, four-stroke, eight-cylinder V-type turbocharged engine for supercar applications.

Experimental tests

Experimental tests were conducted to measure the distortion of the cylinder liner bore. These tests should mimic the conditions of a cold engine assembly. The components used in this analysis are the engine block, bolts, gasket and the test engine head. Fig. 1 shows the test engine head, which is made of steel. For this test, the cylinder liners

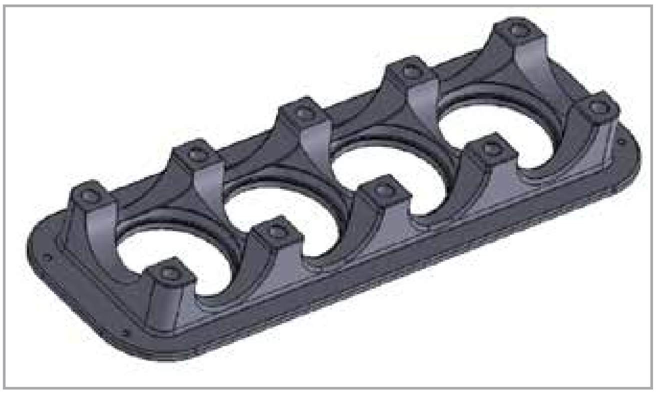

Fig. 1 - The test engine heads

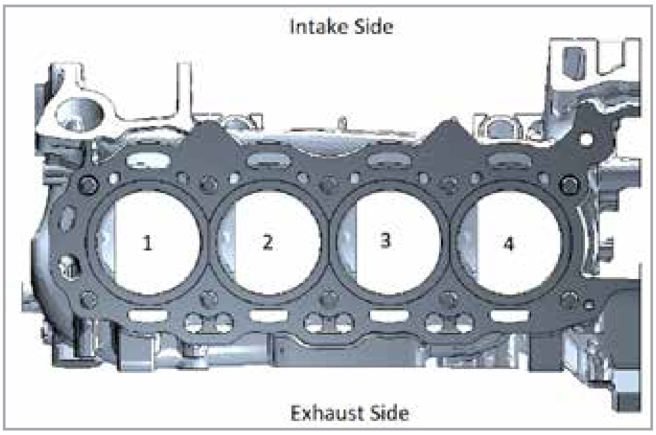

Fig. 2 - The layout of the engine bank

were inserted into the engine block, the gasket was placed between the bridge and the head and the bolts were tightened at the end. The test engine was then tied to a test support and the distortion of the cylinder liner bore was measured. A 3D DEA coordinate tool was used to measure the inner surface of each cylinder liner. The measured shape was compared to the undeformed shape, measured before the test engine was assembled. This enabled the distortion of the liner bore to be identified. For brevity, only the results for liner number 2 are presented (see Fig. 2). These results were post-processed and a predominantly oval shape was detected. The fourth order, which is governed by bolt tightening, is not predominant in this engine. This result is very common for wet cylinder liners such as those studied; in fact, the water jacket insulates the liner from the bolts.

The FE model of the experimental test

The experimental test was reproduced using an FE model. The software used was Hypermesh2017 for the discretization of the components and Marc2013.1 for the non-linear FE solution. Only a single-engine bench was considered for this analysis. Fig. 3 shows

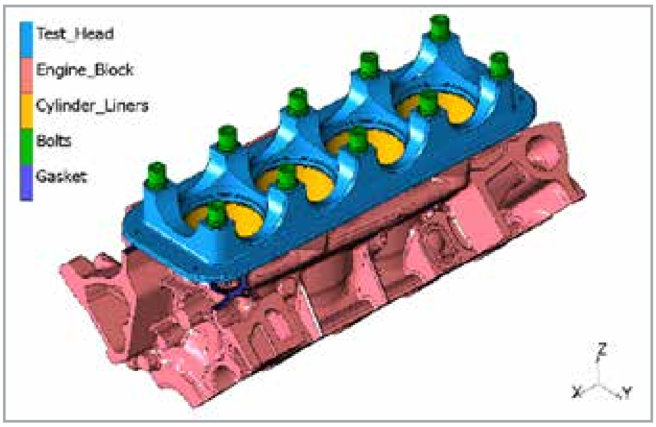

Fig. 3 - The FE model of the experiment

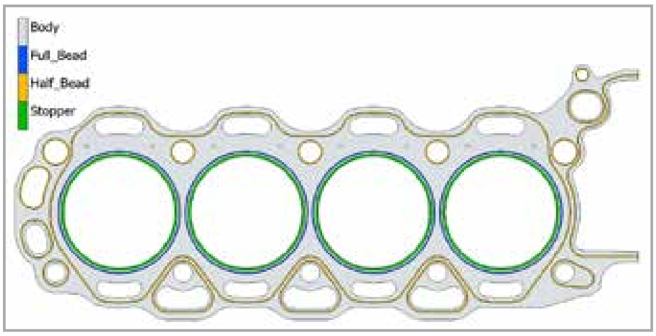

Fig. 4 - The FE model of the gasket

the discretized components: the test engine heads, the bolts, the gasket and half of the engine block (by taking advantage of the plane of symmetry plane). The liner, bolts and engine head are made of generic steel, while the material used to model the engine block is generic aluminum. Particular attention was paid to the modeling of the engine gasket: the actual non-linear loading and unloading curves of the different sealing parts were considered (see Fig. 4). A static model mimicking the assembly process was created. The main objective of this analysis was to compare the FE results with the experimental evidence. The liner bore distortion of the FE model matched the experiment's measurements.

Creating the simplified FE model

Decreasing the number of elements and non-linear sources can certainly reduce the computing effort required. However, instead of limiting the number of elements by using a coarser mesh, all unnecessary elements should be removed. Consequently, we removed the head, gasket and the upper part of the bolts, while maintaining the liners and the block at the same mesh resolution. The enabled us to remove three different sources of non-linear contact. On the other hand, the contact interaction between the liners and the block, which strongly affects the bore distortion, was maintained (see Fig. 5).
The removed components were then replaced with appropriate loadings. In particular, a negative (tensile) pressure was applied to the cross-section of each remaining portion of the bolts to reproduce the tightening of the bolts (see Fig. 6), while the contact interaction between the liner's flange and both the full bead and the gasket stopper were replaced by the corresponding contact pressures (see Fig. 7). The contact pressures corresponding to the stopper and the half bead surrounding the threaded hole were defined using the

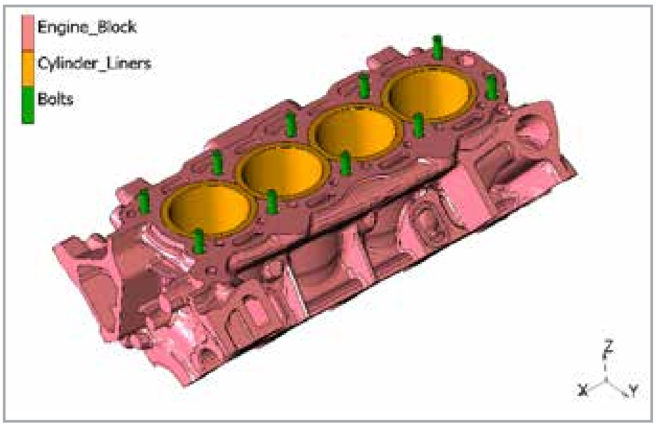

Fig. 5 - The simplified FE model

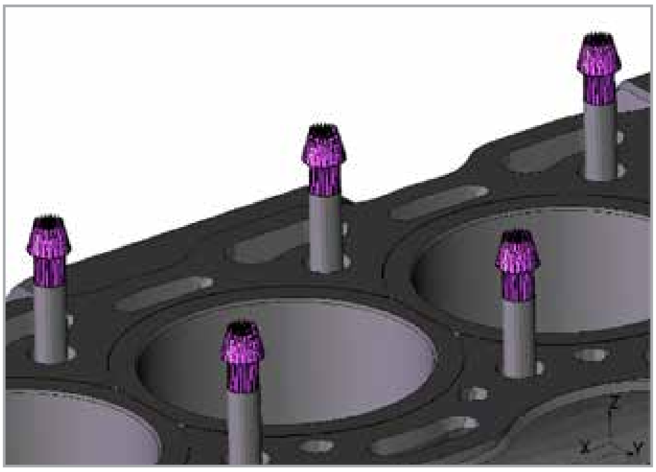

Fig. 6 - The tensile pressure corresponding to the bolt tightening

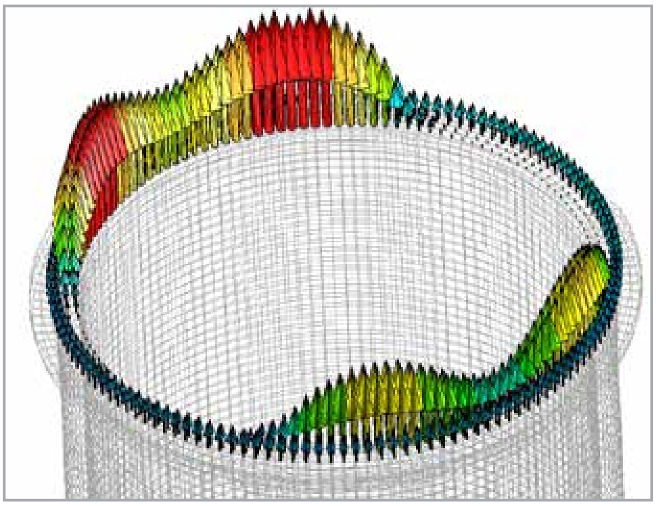

Fig. 7 - The pressure on the full bead and on the stopper

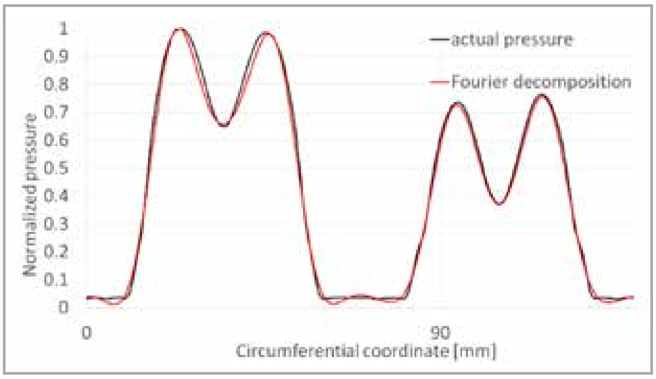

Fig. 8 - The Fourier decomposition

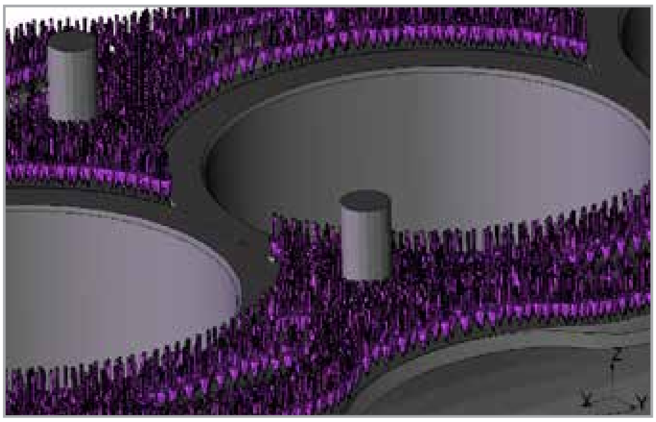

Fig. 9 - The balancing pressure applied to the engine plate.

results of the complete model. The contact pressure acting on the half bead was measured and the mean value was obtained. The distribution of the contact pressure between the stopper and each flange of the liner was analyzed using a Fourier decomposition up to the 10th order (see Fig. 8).

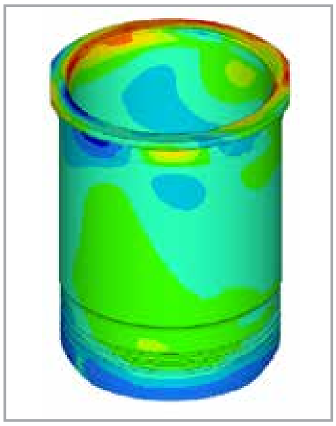

Fig. 10 - Percentage difference in the von Mises stress.

Finally, homogeneous pressure was applied to the faces of the block plate to balance the bolt tightening (Fig. 9). Fig. 10 shows the percentage difference in the von Mises stress between the original model and the refined simplified model. This result is dependent upon the small deviation between the actual profile of the stopper contact pressure and the Fourier decomposition applied in the refined simplified model. You can observe the high quality of the results. The maximum and minimum deviations are 3% and -2% respectively.

The FE model of the actual engine

The test head was replaced by the actual engine head and further simulations were performed to assess the distortion of the liner bore that the piston rings must withstand during engine operation and to predict the fatigue behavior of the cylinder liners. A decoupled thermo-structural simulation of the actual assembled engine during operation was performed. First, a thermal analysis was performed. Appropriate thermal boundary conditions were applied to the modeled components, averaged over the engine cycle. Fig. 11 shows the engine temperature contour plot. Next, a static model was created on which the mechanical loads and the nodal temperature distribution obtained from the previous thermal simulation were superimposed. Suitable boundary conditions were applied to account for bolt tightening, contact with the lower engine block and the plane of symmetry. Two load cases imitating the minimum and maximum combustion gas pressures were considered. After this complete analysis, the same methodology presented in the previous steps was used. The head, the gasket and the upper part of the bolts were removed, while the liners and the block were retained.

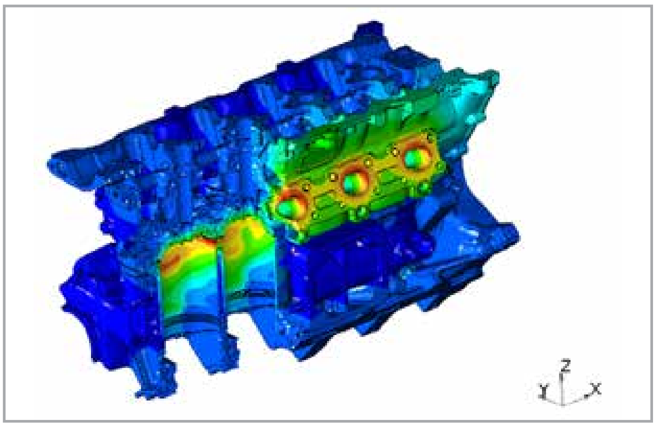

Fig. 11 - Temperature contour plot

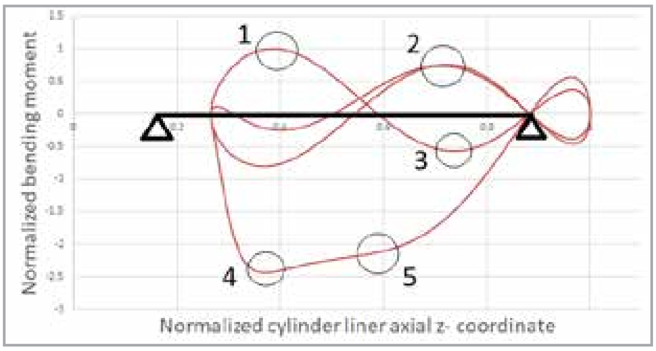

Fig. 12 - The profile of the bending moment

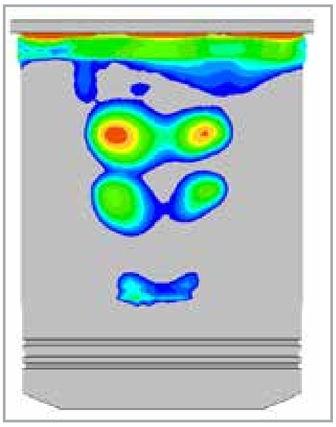

Fig. 13 - Dang Van safety factor contour plot of the complete model

The cyclic thrust force of the crank mechanism may cause fatigue failure in the cylinder liner. The piston's thrust profile was analyzed to identify the extremes of the fatigue cycle and to minimize the computing effort by reducing the number of simulations necessary to calculate the resulting distribution of the fatigue safety factor. The value of thrust force alone cannot determine the fatigue cycle because the stress state of the liner depends on the actual position of the piston for each different crank angle. Thus, the liner layout was considered as a beam simply supported between its mountings and the profile of the bending moment was estimated (Fig. 12). Five different local maxima or minima were identified and were used to identify the corresponding static mechanical analyses to be performed. The crank mechanism was then added to the previous model and a static thermo-mechanical model was created for each load case. Thereafter, a fatigue analysis was performed, based on the Dang Van criterion (Fig. 13).

About Astra Research

Astra Research Srl is an Italian engineering consultancy based in Modena. Its main activity is to solve customers' engineering problems to make them competitive in the market. The company's CAE knowledge is based on the solid foundation established by Professor A. Strozzi. Indeed, Astra Research was founded in 2008 as an academic spin-off of the University of Modena and Reggio Emilia (UNIMORE)'s "Enzo Ferrari" engineering department. The link with the university has greatly influenced the company in that it combines theoretical and practical skills, a quality that is difficult to find in this field.

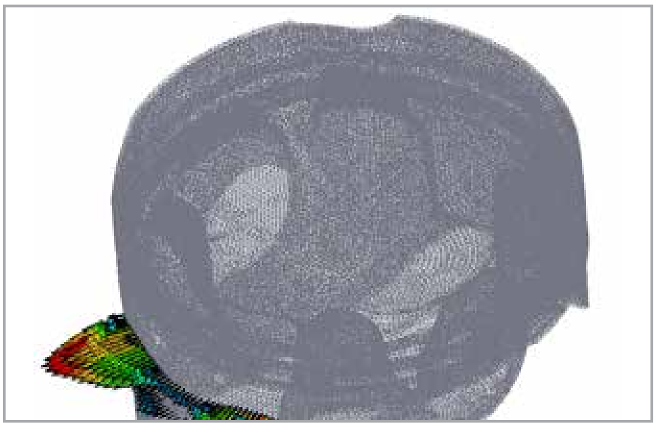

Fig. 14 - Normal contact forces

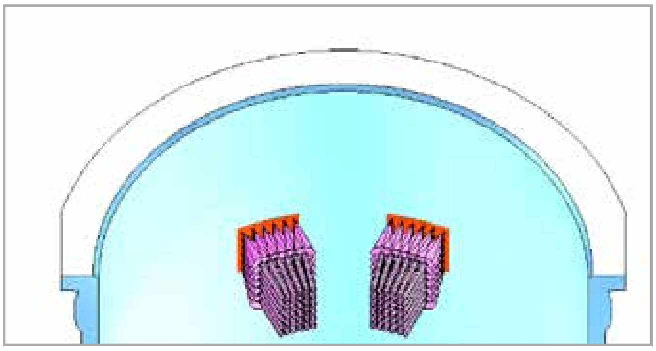

Fig. 15 - Homogeneous pressure applied to the liner

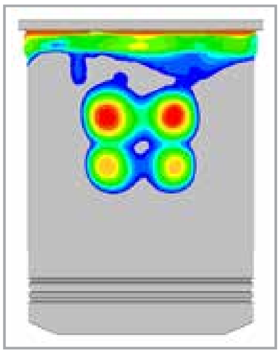

Fig. 16 - Dang Van safety factor contour plot of the simplified model

The resulting simplified model of the fatigue analysis

The crank mechanism was substituted with a suitable pressure distribution on the liner to imitate the piston-liner interaction to further simplify the model. The distribution of the contact pressure on the piston was analyzed to identify the load case of the absolute maximum bending moment (Fig. 14). The resulting force was then applied to the liner using a simple and homogenous pressure distribution (Fig. 15). A static analysis was calculated for each load case identified and a fatigue analysis was performed. Fig. 16 shows the contour plot of the Dang Van safety factor obtained using this simplified approach. The distribution of the minimum safety factor is similar to that obtained from the complete model described in the previous section, with a maximum relative deviation of 10% and a reduction of 90% in the calculation time.

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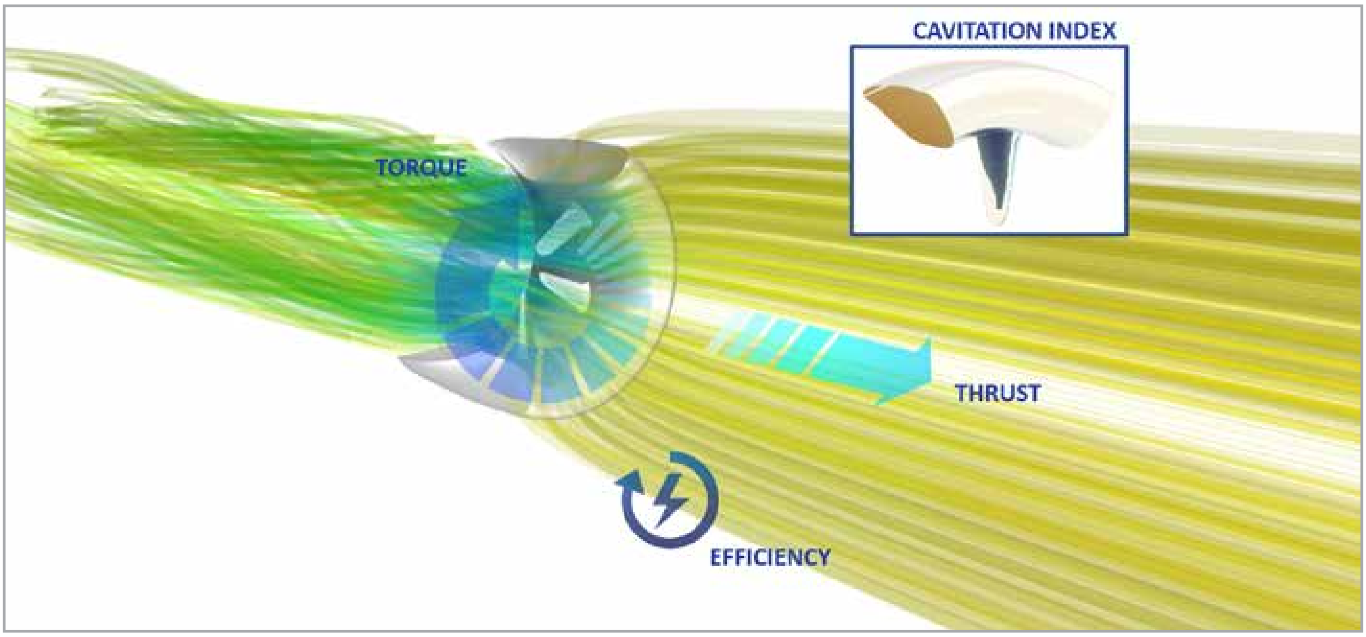
Propulsion efficiency by design: towards a zero-emissions sailboat

Simulation-driven propeller design ensures efficiency, and onboard comfort while lowering manufacturing costs



Sailboat rim-driven propeller for optimization of the hydrodynamics

The marine industry has experienced significant technological changes in recent years with the emerging use of shaft-less rim-driven propellers. Such electric propulsion systems – in addition to their compact size – have many advantages compared to conventional ship propulsion plants, significantly reducing noise, and increasing onboard comfort.

MICAD, an Italian design house active in all sea-related industries, took this innovative propulsion system as a baseline to build a prototype of a zero-emissions electric sailboat within the framework of the P.E.R.Na. European Regional Project.

About Esteco

ESTECO is an independent software provider, highly specialized in numerical optimization and simulation data management with a sound scientific foundation and a flexible approach to customer needs. With 20 years' experience, the company supports leading organizations in designing the products of the future, today.

Naval engineers at MICAD used ESTECO's modeFRONTIER software to improve the hydrodynamic rim-driven propeller's performance for sailboat applications. modeFRONTIER is a comprehensive solution for process automation and optimization and provides a modular environment to reduce complexity, improve efficiency and cut development time. Using modeFRONTIER, engineers at MICAD were able to create a workflow automation of the simulation process. By applying modeFRONTIER's multi-disciplinary top-of-the-range optimization techniques they were able to find the best set of parameters to design the optimum propeller blades. From the initial shape, which was created manually, the optimization process enabled MICAD to choose a design that almost doubled the propeller's efficiency from among hundreds of propeller variants, much faster. Subsequently, this optimal propeller design was created via additive manufacturing in synthesized nylon and tested in open sea conditions, where it achieved an adequate operative range.

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Tools and methodologies for generating digital twins in medical research

An overview of the latest advances of the use of CAE technologies in the medical field

By Marco Evangelos Biancolini[1], Ubaldo Cella[1], Corrado Groth[2], Stefano Porziani[2]
1. Università di Roma Tor Vergata - 2. RBF Morph

The pervasive use of engineering simulation during the design phase and for virtual testing, thus eliminating the need for multiple prototypes prior to product launch, is well established today. The continuously growing availability of computing power and simultaneous algorithmic improvements now make high-fidelity numerical resolution of complex problems possible, integrating methodologies that are becoming established procedures in many fields of engineering. Clinical research has benefitted from these advances. Furthermore, the advent of technologies such as big data management, augmented reality, automated computer-aided engineering (CAE) processing in high performance computing (HPC) environments, and additive manufacturing are changing the way healthcare is delivered with implications for the skills required by the next generation of healthcare professionals and academic researchers. The use of numerical simulation to address clinical problems has been consolidated in Europe through several research activities that also involved non-medical institutions specialized in engineering technologies. This article provides a non-exhaustive overview of some of the latest advances in the adoption of CAE technologies in the medical field by citing some ongoing EU research programs.

The need for numerical simulations capable of accurately predicting the behavior of a device or prosthesis is constantly increasing [1] [2]. Furthermore, in the era of in-silico medicine, the combination of computer simulations with big data is mandatory. Engineering simulations generate tremendous amounts of data to be processed and that must be rapidly integrated and correlated with patient data. Such data-intensive research can be adequately supported by creating dedicated cyber-infrastructures that integrate data, tools, and research protocols in a unified and easily accessible environment: this is the Digital Twin concept. Healthcare is rapidly embracing this technology. The goal of this trend is to provide personalized data-driven medicine.

Digital twins are built on computer-based, or in-silico, models powered by individual and population data. They have been applied to complex systems in different fields of engineering. As a virtual representation of a physical object or system across its life cycle, digital twins aim to model systems computationally to develop and test them more quickly and economically than is possible in a real-life context. Ideally, in medicine, the concept of the digital twin can be translated to patients to improve diagnostics or treatment, and to accelerate medical innovation and regulatory approval using an ideal replica of a human body showing the physiological and pathological results in the present and future. From this perspective, digital twins provide a safe environment to test the impact of changes on the performance of a healthcare system, improving the selection of optimal solutions and reducing the risk of harm to patients.

Despite the efforts in research, the extensive use of scientific computing tools in medical practice is still in its infancy. Bringing innovation to the healthcare sector is a long and costly process that requires clinical evaluation and regulatory approval. The validation of numerical simulations through clinical studies therefore remains challenging and scarce, or limited to small cohorts. The European Union is improving innovation by funding several programs focused on the role of digital twins in medical research. The heterogeneous know-how involved in the development of such technologies promotes the generation of a new class of consortia in which several highly specialized non-medical competences work side by side in a novel and extraordinarily stimulating environment. In this scenario, the "Tor Vergata" University of Rome is playing an important role by sharing engineering technologies, joining research partnerships and leading international networking training programs. Here is an overview of some of the EU research on this topic and relevant examples of where different CAE numerical technologies have been adopted to generate digital twins able to model the physics involved in clinical problems.

Digital twin technologies

A wide range of technologies can be adopted for the generation of a digital twin. Similar to many biological mechanisms, which require modelling by combining different numerical environments, digital twins can be based on CAE tools with different levels of "fidelity" combined together to model complex multi-physical phenomena. A common example is the fluid structure interaction (FSI) mechanism, typical of the dynamics of most biological fluid flows. The numerical tools involved in such models include computational fluid dynamics (CFD), finite element method (FEM) and coupling procedures that are efficiently implemented by adopting radial basis function (RBF)-based mesh morphing technologies. When the model response must be as fast as possible and when accuracy requirements can be relaxed, the adoption of reduced order models (ROM) offers the possibility to limit the computational burden and to provide a powerful and viable medical digital twin [3] generally able to interact in real time. Additive manufacturing is another technology that offers new opportunities in medical research. The combination of personalized digital twins and 3D printing techniques to create custom models and in-vitro testing are opening new frontiers in the development of tomorrow's prosthetic devices.

RBF mesh morphing

Mesh morphing consists of adapting a computational grid commonly used for CAE. The solid or shell mesh of a structural part ready to be processed by a finite element analysis (FEA) solver, or a volume mesh complete with boundary conditions for a CFD solver, can be adapted to a new shape by simply updating the nodal positions. This means that the topology of the mesh (node count, cell count, connectivity) remains unchanged. Only the x,y,z coordinates of the nodes in the part of the model whose shape is being modified are updated. Mesh morphing can be used for different purposes: to create shape parameters (i.e. to modify a length, an angle or a thickness), to switch to a new known shape (i.e. to obtain the geometry as manufactured, or designed by CAD), to switch to a shape provided by the CAE solution (automatic shape optimization with adjoint or biological growth method (BGM)), and/or to support Multiphysics (to move the CFD mesh according to the evolution of the one connected to the FEM, enabling erosion/deposition).

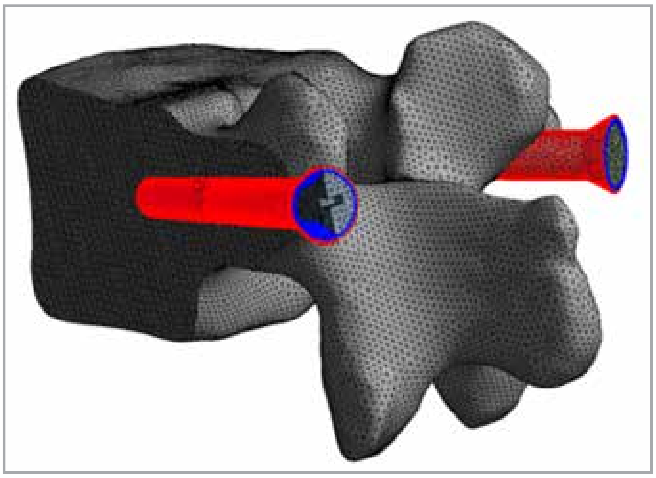

Fig. 1 – Example of RBF Morph design technology in a study of surgical screws in a vertebra (courtesy SPINNER)

Usually mesh morphing is faster than remeshing for a number of reasons: it avoids the "remeshing noise" (having the same mesh adjusted means that the effect of a parameter is not confused with the effect of a new mesh structure), so the variation effects can be evaluated even with a coarser mesh; the CAE model can be updated in the background keeping all the original settings (boundary conditions); and updating the nodal positions usually requires less computational effort than a complete mesh regeneration. Creating shape parameters with mesh morphing is generally faster than creating a parametric CAD model.

One of the most efficient mathematical frameworks to address the problem of mesh morphing is recognized as radial basis functions (RBF) [4]. RBFs are mathematical tools capable of interpolating known fields on a cloud of points. Mesh morphing defines a displacement field on a cloud of source points (usually some of the surfaces/curves of the CAE mesh) and then propagates it over a cloud of target points (usually the volume/surface mesh nodes of the CAE model being adapted). The method is well-suited to the needs of mesh morphing: its meshless nature allows you to easily manage partitioned meshes used for HPC parallel computing while its node-based nature allows you to have full control of specific areas. The computing cost of RBF can be very high, so specific algorithms (fast radial basis functions) are necessary to reap these benefit for industrial applications.

Fluid structure interaction analysis

Many physiological systems require the ability to explain the structural deformation induced by fluid flow. For this class of simulations, an FSI study based on numerical environments that combine structural solutions and fluid dynamics solvers is mandatory. Several approaches are possible to solve the problem, ranging from the uni-directional dependence of the fluid dynamics domain on the structural response [5] to a complete coupling of the two in an iterative cycle (the so-called two-way procedure) [6]. RBF-based tools are excellent candidates to implement the bidirectional link between structural and fluid dynamics solvers. The workflow of a steady two-way FSI analysis is summarized in Fig. 2.

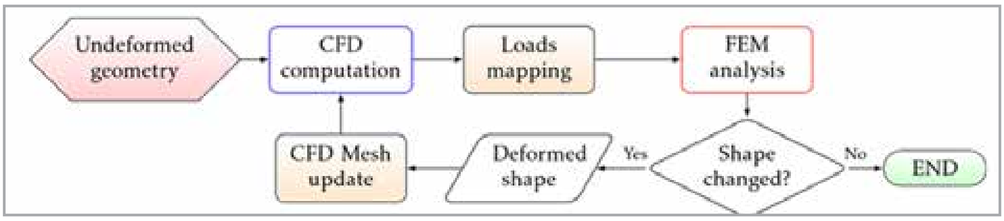

Fig. 2 –Workflow of an RBF-based two-way FSI analysis procedure

The process begins with the CFD analysis of the rigid model in the desired condition. A mapping procedure is then applied to transfer the fluid loads into an FEM model of the object under investigation. The structural analysis solution, in terms of wet surface displacement, is used as a target for the morphing action of the meshes in order to update the fluid dynamics domain based on the estimated deformed shape.

The CFD calculation is restarted on the new configuration and the cycle continues until a final deformed shape (for a steady condition) is reached.

Reduced order models

As their name suggests, reduced order models (ROM) are simplified numerical models of complex systems (fluid, structure, or other physics) capable of operating very quickly (usually in real time). They are defined by applying data compression algorithms to many different instances (also known as snapshots) of the model to be reduced. ROMs are key enablers of the digital twin: the original system is modelled using high fidelity CAE methods (such as CFD and FEA) taking into account multiple configurations (different shapes, different boundary conditions or modifying any input to the model) that are screened using a large amount of computing resources (ROM creation); the compression stage allows the model to be compressed into a lighter and more portable piece of software. The ROM obtained can then be used as part of a complex simulation workflow or embedded in a physical resource to enable the digital twin. Mesh morphing is an excellent companion to ROM, as a constant mesh topology is required for ROM creation; this is related to the nature of the compression methods that extract the ROM.

ROM are commonly used and successfully applied in different fields of classical mechanics for highly complex systems, in order to replace the complete model with a low degree-of-freedom one so as to drastically reduce the overall computing cost. Contrary to classical mechanics, however, the implementation of ROM in the field of biomechanics is very recent and limited to a few works [7][8]. In generating digital twins for medical applications, ROMs are a promising solution that offer the possibility to interactively predict the consequences of the change of state in a biological system from healthy to pathological.

Additive manufacturing

Additive manufacturing is a technology whose role over the last decade has evolved from that of a tool for prototype generation to a manufacturing approach to be fully integrated into the production process. One great potential of this technology is the significant flexibility it offers in generating complex components by circumventing many of the limitations imposed by more traditional manufacturing approaches. 3D printing technologies offer a cost-effective option not only as a fast prototyping tool but also for small- and medium-scale production, revolutionizing the manufacturing and design process.

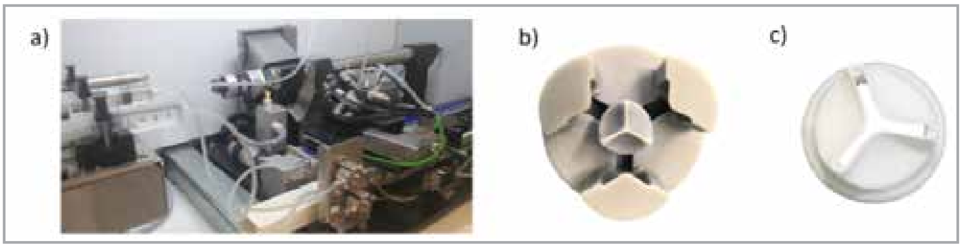

Fig. 3 – Spray machine (a) for additive manufacturing, custom mold/modular outer mold system (b) and final valve (c)

Complex shapes can be easily produced for greater design flexibility and new geometries can be reshaped directly from the physics without having to consider rigid manufacturing constraints. In medical applications, 3D printing techniques could allow the creation of personalized models for each patient.

Various technologies are available for additive manufacturing. Fig. 3 shows, for example, the spray deposition technique used to manufacture a polymer aortic valve.

Examples of medical digital twins

Below is a non-exhaustive selection of examples where the technologies introduced above have been used to generate digital twins for biomedical research. RBF-based mesh morphing is the

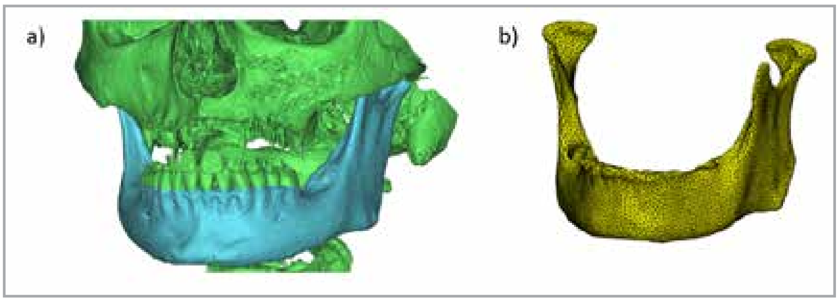

Fig. 4 – Mandible model from CT scan (a) and the generated mesh (b)

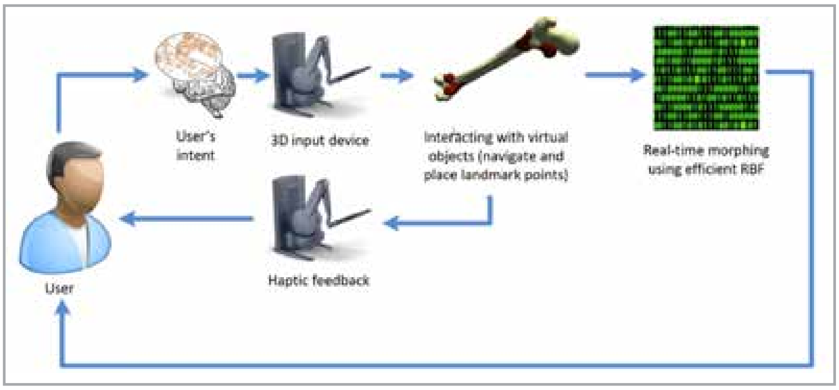

Fig. 5 – Schematic diagram of the methodology integrating the haptic device with force feedback and the RBF mesh morphing algorithms

protagonist of the methodologies implemented and allows the parameterization of the shapes used to build the whole numerical framework.

Parametric model of the mandibular (jaw) bone

Parametric modelling is useful in biomechanics to create patient-specific models based on a limited set of measurements (from the patient or x-rays). In this example, the RBF mesh morphing technique was used to generate a parametric model of the jaw bone. The aim was to create a tool for the creation of patient-specific morphologies as an alternative to CT scans (not always available for the definition of bone morphology).

The procedure consisted of generating a database of CT scans of mandibular bones from patients of different ages and genders. The images were segmented using a threshold filter (HU) to retain only bone tissue (Fig. 4). A subsequent remeshing process removed inaccuracies due to the process and reduced the number of nodes. All jaw models had to share an iso-topical mesh so that Principal Component Analysis (PCA), which is a statistical technique in which an orthogonal transformation is used to convert a set of observations of possibly related variables (called principal components) into a set of linearly unrelated variables, could be applied. Given a tolerated approximation range, PCA allows the number of principal coordinates to be reduced. In this case, eight principal components were sufficient to explain the 85% variability in the original set of mandibles. The next step was the generation of a template mesh that was parameterized using an RBF morphing algorithm, based on the morphing modes, to match all other mandibles. A morphing mode is a set of nodal displacements that defines the transition from the average shape to another shape.

The whole procedure was tested on two mandibles that did not belong to the PCA database. The accuracy of the reconstruction ranged from 0.025 to 3.235mm with an average accuracy of less than 1mm. The largest errors were observed in the lateral alveolar parts. The test was repeated on a mandible with a significantly different shape from the other mandibles. The maximum error in this case was 2.587mm with the most critical areas being located on the lateral alveolar parts, the central alveolar part, and the chin area.

Interactive sculpting of a human femur

Mesh morphing can be effectively used in predictive medicine workflows where a patient-specific numerical model is taken as a reference to understand the physics of interest using simulation-driven techniques. The example of Fig. 5 proposes a methodology for interactive geometric remodeling of the human femur with a force-feedback device, which is used to guide the morphing of an FEA template model onto the patient's geometry by positioning a series of landmark points. A first morphing action allows the solid model to be warped according to the RBF deformation field produced by the landmarks points, performing a final projection onto the target surface to complete the task [9]. The complete configuration involves four main steps: three interactive steps (Fig. 6) and one batch run. The initial step (Step 0) consists of positioning the landmark points on the target geometry; the user is guided through the sequential definition of the positions of the landmarks in correspondence with the predefined positions already present on the template shape. Once the landmarks are positioned, the first RBF-based step (Step 1) can be enabled. The RBF field is defined using the landmarks. The landmarks on the template geometry are used as sources and their corresponding real scalar values are obtained by subtracting the landmark point in the target destination from those in the template. The displacement field is applied to all the points on the tessellated surface mesh representing the original shape. The last interactive step (Step 2) concerns the definition of a second RBF

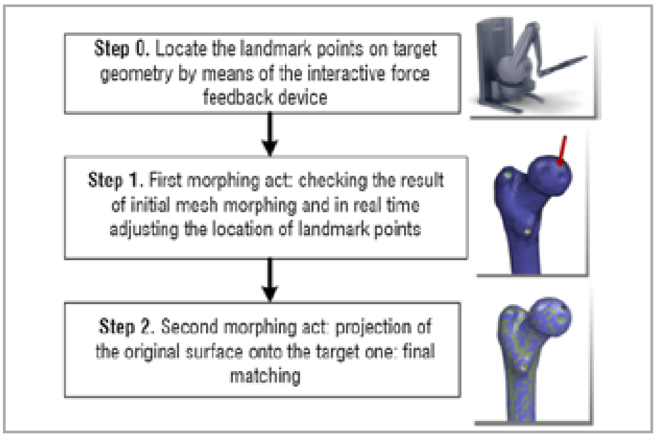

Fig. 6 – Interactive mesh morphing workflow

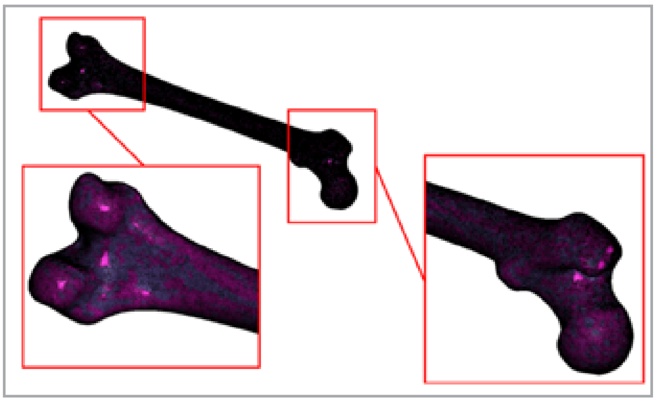

Fig. 7 – Final morphed mesh (Step 3) superimposed on the target (initial) CAD geometry

field capable of projecting the calculated approximate shape obtained at the end of the Step 1 onto the target entity. The final step (Step 3, performed in a batch) involves a sequential application of the two morphing fields generated for the final update of the FEA volume mesh.

The approach proved to be fast, effective, and ergonomic thanks to the haptic device and the high level of interactivity. New patient-specific CAE models were generated in a very short time, preserving the excellent quality of the computational mesh and the coherence with the input CAD model (Fig.7).

Aortic heart valve

Heart valve disease is one of the leading causes of heart failure worldwide. In such pathologies, prosthetic heart valves are commonly used to address the increasing prevalence of the disease. An ideal prosthetic heart valve replacement would closely mimic the characteristics of a normal native heart valve. In-silico characterization plays a key role in the development of new aortic valve (AV) designs. In-silico evaluation of prosthetic heart valves can be addressed by structural simulations, simplifying the pressure loads without considering fluid flow or taking the FSI mechanism into account. The first approach is simpler, but usually leads to overestimation of the deformations since pressures are applied uniformly on the valve leaflet throughout the opening phase. The latter, on the other hand, is more accurate but requires more computing resources and a more complex configuration. The study described in [10]. sketched in Fig.8 and briefly reported here, concerned the design of a polymer AV for a surgical application addressed with an FSI analysis and its experimental verification. The geometric model of the tri-leaflet aortic valve prosthesis was generated in the closed position by elliptic hyperbolic surfaces. FEM analyses were conducted throughout the entire cardiac cycle by separately simulating the systolic (valve opening) and the diastolic (valve closing) phases. In the systolic phase, the system is affected by both static and dynamic pressures. In contrast, in the diastolic phase, fluid flow velocities have become negligible, so the system is only affected by the static physiological transvalvular pressure.

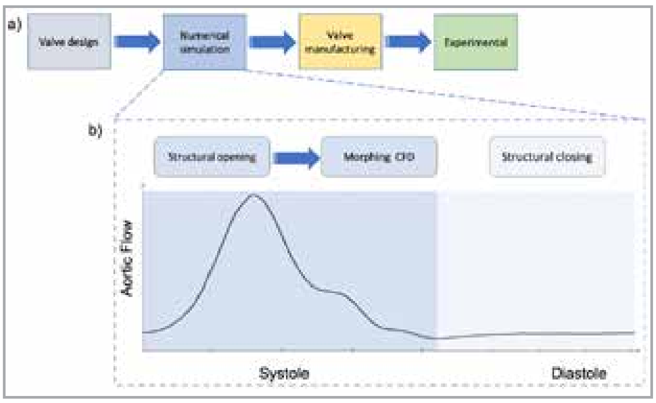

Fig. 8 – Overall study workflow (a) and schematic workflow of the numeral approach

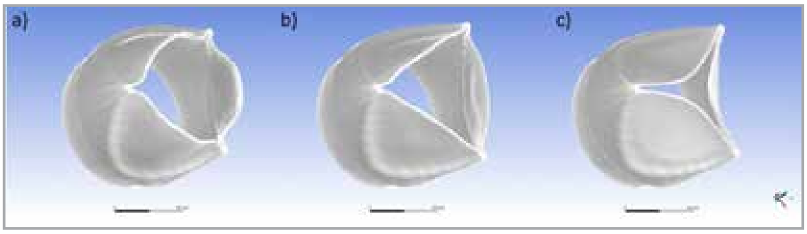

Fig. 9 – Morphing at three opening levels: maximum (a), mid (b), minimum (c)

The FSI analysis was performed for the systolic phase according to the following steps:

- A transient structural analysis was performed by applying the systolic physiological pressure to the valve leaflets as a load;
- The deformed structural shapes of the valve were used to configure the mesh morphing procedure (Fig. 9);
- An FSI simulation was conducted by imposing the adaptation of the fluid domain based on the position of the leaflets (Fig. 10).

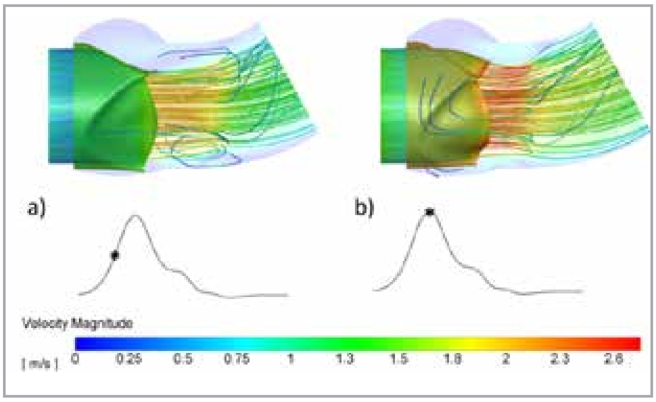

Fig. 10 – Flow velocity streamlines at two instances in the cardiac cycle

The diastolic simulation was performed with a structural transient analysis in which the surfaces of the leaflets were loaded with a pressure equal to the diastolic physiological transvalvular pressure (Fig. 11). Also in this case, the FEM mesh adaptation task required an RBF mesh morphing procedure.

The valve leaflets were manufactured using spray technology and an external modular custom 3D printed mold system (Fig. 3). The valve ring was manufactured using fused deposition technique and positioned on a tubular mold. The hydrodynamic performance of the

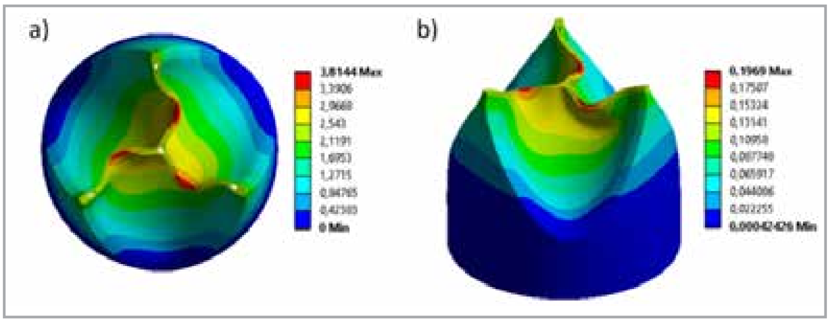

Fig. 11 – Radial displacement in mm (a) and equivalent strain (b) resulting from the FEM analysis in the diastolic phase

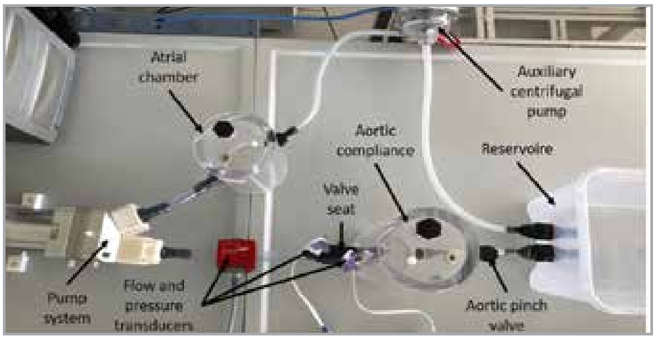

Fig. 12 – In-vitro experimental setup

valve was evaluated by in-vitro testing according to the ISO-5840 standard guidelines (Fig. 12). The experimental tests confirmed that the numerical solution correctly reproduced the AV kinematics. The advantage of adopting an RBF-based mesh morphing approach was demonstrated in [11] where this option was shown to provide a computational configuration that was about 16 times faster than a remeshing-based configuration. Furthermore, no significant differences were observed between the fluid dynamics solutions provided by the two numerical environments.
A video describing the study reported here was awarded the best simulation example at the 2019 Ansys Hall of Fame competition (https://www.ansys.com/blog/ansys-hof-2020).

Thoracic aorta hemodynamics

Among the victims of cardiovascular disease (CVD), the ascending thoracic aortic aneurysm (aTAA) is the 19th most common cause of human death. There is therefore a clear interest in the development of digital twins in order to provide a structured, reproducible and predictive framework for the interpretation and integration of clinical data, thus paving the way for the development of personalized and preventive management strategies for CVDs. The rigid wall assumption, which could be a reasonable simplification in cases of high arterial stiffness, is not applicable for the numerical fluid dynamics solution of the aortic aneurysm. The interaction mechanism of the fluid structure cannot be neglected in this case. However, the high-fidelity numerical solution of such a complex problem remains prohibitively expensive in many query and real-time contexts, both in terms of CPU time and memory demand. To overcome this limitation, many stochastic approaches have been proposed to provide answers in acceptable times for clinical

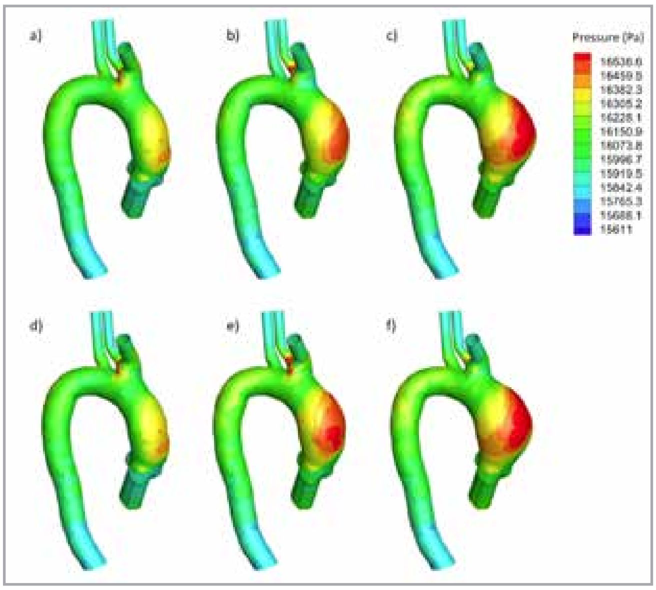

Fig. 14 – Comparison of the evaluation of the pressure contours between ROM (above) and CFD (bottom).

timing. Such techniques take into account material properties and geometrical variations, as well as a series of uncertainties that may affect finite element simulations. Recent advances in numerical tools to support computational analyses, such as reduced order models (ROM) can deepen the knowledge of complex phenomena related to clinical scenarios. Combined with efficient RBF mesh morphing techniques, ROMs enable a very powerful and practical medical digital twin that provides real time solutions.
The typical workflow for the generation of a ROM is divided in two main tasks: the generation of training data, which involves the generation of a database of high fidelity solutions, and the extraction of the ROM. The first step is the most time-consuming activity while the second step requires minimal user intervention and provides almost real-time solutions. Fig. 13 shows the ROM workflow in the Ansys

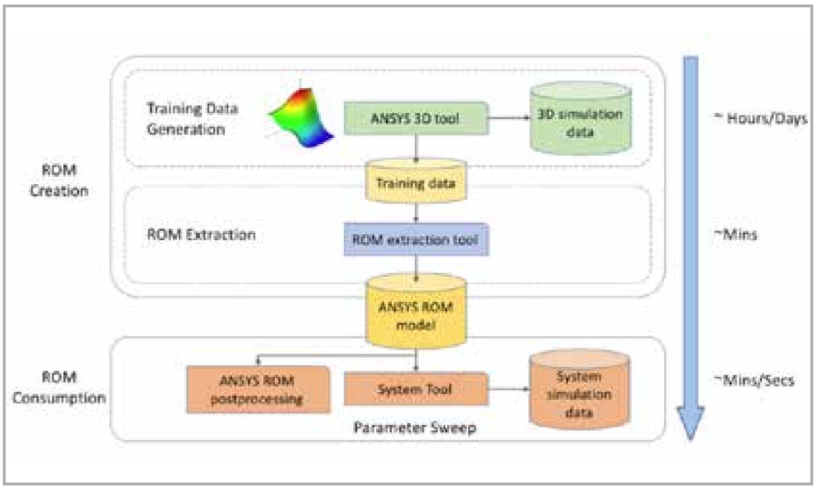

Fig. 13 – ROM generation workflow in the Ansys framework environment

Fig. 15 – A patient-specific high-fidelity FEA model representing one vertebra and two prosthetic screws was created; mesh morphing allows the diameter and length of the screw to be updated to optimize individual patient treatment

framework environment. The key concept of the ROM workflow is its integration with the response surface (RS) technique. Using RS, outer parameter values are obtained as a function of the input parameters at the design points defined in the configuration of the design of experiments. Finally, interpolation methods are used to construct the entire model.

In order to verify the ROM strategy in this new hemodynamic context, both reduced and not reduced i.e. the complete system of differential equations describing the CFD case were compared using a single geometric parameter that gradually morphs the healthy aorta into an aneurysmatic one, monitoring the difference in the main quantities of interest. In Fig. 14, the ROM and CFD simulations were compared at three stages of accretion ranging from healthy, (a) for ROM and (d) for CFD, to a fully developed aneurysm, (c) for ROM and (f) for CFD. The images (b) and (e) refer to the ROM and CFD evaluations for the medium developed shape, respectively. The differences between the two solutions are negligible from a practical point of view.

ROM-assisted spinal surgery

Back pain is an extremely common problem with more limited solutions than limb joints. The number of patients requiring complex spinal surgery is rapidly increasing and the biomedical engineering industry needs properly trained innovators to produce cost-effective solutions to support the healthy ageing of Europe's population. The European Spinner project (spinner-eid.eu) was created to study the use of medical digital twins for spinal surgery applications.

A high-fidelity FEA model was defined by using the geometry of the real patient's vertebra with the prosthetic screws positioned so that an assessment of the stress on the prosthetic part and on the patient's bone tissue was possible (Fig. 15).

The image data made it possible to define an accurate structural model that matched the patient's shape and the actual bone density distribution. Then an offset of the screw placement and size was introduced by mesh morphing.

Two parameters enabled the possible screw sizes (length and diameter) to be navigated and four parameters were used to modify the positioning (vertical and lateral adjustment for both vertebrae). The parametric shape with six degrees of freedom was then evaluated for 200 configurations using HPC.

ROM technology was then used to compress the simulation results into the digital twin, resulting in a portable tool for real-time inspection that is easily available to the medical doctor and his staff (Fig. 16).

The environment of EU-funded research programs

The "Mario Lucertini" Enterprise Engineering department of the "Tor Vergata" University of Rome has substantial experience in developing CAE-based numerical analysis tools for mechanical applications.

The company RBF Morph, developers of the homonymous mesh morphing technology based on radial basis functions and an Ansys advanced solution partner, is active in several research projects concerning biomedical engineering. Recently, two Marie Skłodowska-Curie Innovative Training Network (ITN) programs, involving the RBF Morph technology, have been activated: MeDiTATe, which aims to develop digital twins for the treatment of aneurysms, and SPINNER, which studies materials and techniques for spinal surgery.

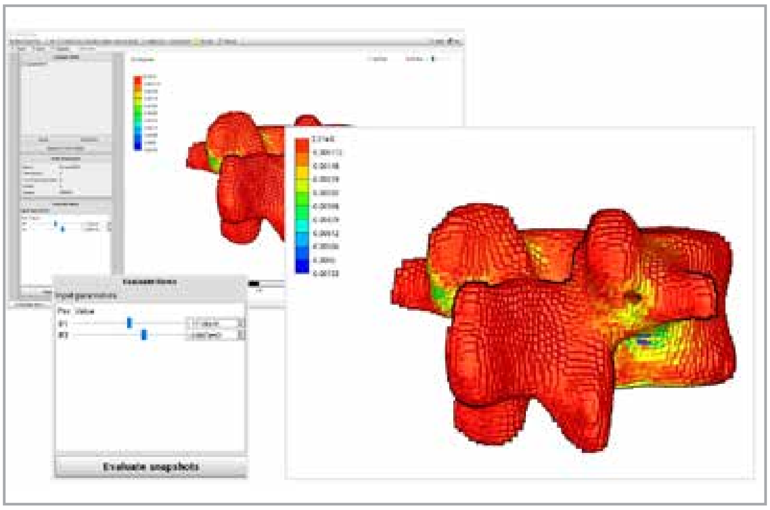

Fig. 16 – The Twin Builder Viewer, powered by a mesh-less and solver-independent rendering tool, allows interaction with the Digital Twin of the vertebra. The P1 and P2 sliders allow you to update the diameter and length of the screw in real time and to see how the minimum principal strain varies

MeDiTATe

MeDiTATe ("The Medical Digital Twin for Aneurysm Prevention and Treatment") will provide a comprehensive framework of simulation and imaging technologies aimed at industrial and clinical translation to accelerate the process of personalized cardiovascular medical procedures, validated through an integrated experimental program to ultimately improve patient care.

The main idea of MeDiTATe is therefore to develop a digital twin and make it available as a "service" for everyone in academic, hospital and industrial settings. To achieve these objectives, the following techniques are integrated:

- Clinical and imaging data;
- Computer-aided engineering (CAE) Multiphysics simulation with radial basis function (RBF) mesh morphing, finite element method (FEM), computational fluid dynamics (CFD), fluid-structure interaction (FSI), inverse FEM;
- Real-time interaction with the digital twin via augmented reality, haptic devices, and reduced order models (ROM);
- High performance computing (HPC) tools, including graphic processing units (GPUs) and cloud-based paradigms for fast, automated CAE processing of clinical databases;
- Big data management for the patient population's imaging data and high-fidelity CAE twins;
- Additive manufacturing of physical mock-ups for surgical planning and training.

The MeDiTATe project is led by the "Tor Vergata" University of Rome.

SPINNER

SPINNER (SPINe: Numerical and Experimental Repair strategies) is a doctoral training program aimed at early stage bioengineering researchers, to train bioengineers in the design of next-generation repair materials and techniques for spinal surgery. SPINNER brings together partners from the biomaterials, implantable devices, and computational modelling industries with orthopedic clinicians and academic experts in cell, tissue and organ scale biomaterials and medical device testing. The project covers topics such as biomaterials, clinical biomechanics, in-vitro testing and in-silico biomechanics. An inter-disciplinary training program between academia and industry is planned.
The SPINNER project is led by the University of Sheffield.

Conclusions

The basic concept of a digital twin is that a computer model can predict the specific functioning of an individual's body. It is well known that the patient-specific computational model can provide additional information by extrapolating data that is not clinically available. In this context, numerical simulations can help identify patients prone to adverse outcomes by providing detailed information on hemodynamic factors. In addition, numerical models can support clinicians by virtually simulating different interventional strategies.

This article provided an overview of the tools and methodologies adopted for the generation of digital twins in medical research along with a brief description of the methods that represent the key components in the development of numerical modelling as well as a series of examples of where digital twins have provided reliable models of biological phenomena.

The roles of the "Tor Vergata" University of Rome and its partner RBF Morph were highlighted within the framework of the EU research programs on medical research.

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Acknowledgment

The MeDiTATe and SPINNER projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement numbers 859836 and 766012 respectively.

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Semantic MBD for metrology: approach and benefits

Cost and time savings and error reduction represent low-hanging fruit; potential for numerous longer-term benefits

By Deniz Ozturk, Daniel Campbell, Jimmy Nguyen
Capvidia

The use of model-based definition (MBD) enables the engineering design department to generate a 3D-MBD model of designs that can include details for both human and machine interpretation. This enables improvements in product quality, cost reduction and data collection based on the use of a single reference source for all the workflows related to the product – both up- and downstream. The use of MBD eliminates the need for human involvement in the translation, interpretation and data re-entry required by existing metrological processes, freeing engineers to solve engineering problems while reducing the possibility for error with the corresponding consequences of wastage, misuse of resources, and time and cost increases. This technical article details the transition process and related requirements as well as providing results of industrial test cases. Three practical live-world examples are included: supplier control, quality inspection reporting and CMM workflows.

The practice of model-based definition (MBD) is considered to be one of the major advancements to have occurred in product development in recent years. Engineering design practice has been in constant evolution – from pencil/paper drafting, to 2D CAD drafting, to 3D CAD modeling… However, until the MBD era, the main output from engineering design departments has remained unchanged: a 2D drawing. With the dawn of the MBD era, this is now changing to a 3D-MBD model, which can include details for both human and machine interpretation that would otherwise be conveyed through 2D drawings purely for human consumption.

A 3D-MBD model with product and manufacturing information (PMI), also known as 3D annotations, can include all of the following data: geometric dimensioning and tolerancing (GD&T), the bill of materials (BOM), surface finish, weld symbols, manufacturing or measurement process plan data, metadata and notes, the history of engineering changes, orders, legal/proprietary/export control notices, and other definitive digital data.

From this point of view, MBD can be defined as the practice of conveying PMI on 3D models. This is, however, an inadequate description, considering that other details such as the purpose and use case for the information, the data structure and quality of the information, etc. are not naturally covered by this definition. To define MBD more precisely, one should consider the true reason for the use of MBD: the ability to rigorously and strictly define interactions and workflows within an organization to maximize product quality, minimize costs and collect data to measure key performance indicators [1]. This can only be achieved through MBD models that bear semantic and unambiguous PMI. This point is emphasized in the following sections, while a complete definition of 'semantic MBD' term is also provided.

Why semantic MBD is important

What, exactly, are the benefits of MBD? The main benefits of MBD fall into two major categories: interoperability and data traceability.

Interoperability

Interoperability is simply the ability to use the data with different computer systems or software. In the current discussion, the data produced in the engineering design department needs to be used by many downstream processes within an organization (or beyond), such as the manufacturing and metrology processes. If the interoperability criterion is not met, the use of data for communication between an organization's different working groups remains restricted.

For MBD workflows to facilitate the propagation of data from design to downstream processes and back, the structure and format of the initial data is crucial. This data should be suitable for consumption in different processes, which requires interoperability. It is of the utmost importance to identify suitable data formats and structures to apply a semantic-MBD workflow. There are various standard data formats that can be used, such as quality information framework (QIF) and the STEP AP242 standard. A classic example of the importance of MBD interoperability is the ability to avoid manual data input to a coordinate measuring machine (CMM) software by importing a QIF file containing the PMI. Later in this article, a case study is presented that focuses on this automation process.

Data traceability

Data traceability is the ability to map the MBD data, and all data derived from it, back to the original source of the information, the CAD model. Consider the massive amount of raw product and process data gathered by the 3D scanning devices being used in modern manufacturing enterprises. To a large extent, this data is used to make "PASS/FAIL" decisions related to the conformance or non-conformance of a part and is then effectively discarded. If properly organized and mapped to the definition of the "authority product", this data could be of enormous value. This notion could tilt the scales and induce industry to consider metrology as a source of value, rather than as a source of cost. To create and maintain context, the derivative MBD models must maintain the traceability of all metadata to this 'authority model'. This is sometimes referred to as the "single source of truth" concept. In metrology processes, it allows one to tie the measurement results back to the authority model for further analysis.

Data for semantic MBD: requirements

In order to achieve the goals of interoperability and data traceability, good quality data is crucial. The data requirements for a proper semantic MBD workflow are unambiguity and semanticity.

Unambiguity

A model cannot pose ambiguities, for instances tolerances that can be interpreted in different ways, potentially causing bifurcations in the process. A proper understanding and application of modern tolerancing standards, like the ISO geometrical product specification (GPS) or ASME Y14.5, is crucial to the success of an MBD deployment. For instance, plus/minus tolerancing is often used when geometric tolerances would more precisely define the requirement. As a specific example, a plus/minus tolerancing approach can mistakenly be used instead of applying a surface profile to control the acceptable height range for a trapezoidal prism to be manufactured. In the real world, the bottom and top surfaces of this geometry will not be exactly parallel. Because of this, depending on which side (i.e. the bottom or top) is used as a reference in the measurement process, different results will be obtained. This can lead to a perfectly functional component being rated as scrap, costing time and money. A concise video demonstrating this basic example can be found at [2]. In other words, the techniques used to define a product should have only one correct definition and must carry unambiguous information for downstream applications.

Semanticity

The second requirement is machine readability or semanticity. It is already widely agreed that computerized processes are faster, less prone to random errors, and more repeatable than their human counterparts. This has led to the continuing tendency to computerize/automate processes. However, unless the data can be interpreted without human involvement, automation is impossible.

As an example, consider a PMI callout indicating the size and position tolerances for multiple holes on a part. If this PMI makes reference to only one of the holes in the component using the term "3X", a human could interpret this information to mean that the PMI is referencing three different holes. A machine, however, would only interpret one of them. Another similar example is a cylindricity tolerance that refers only to the top edge of a cylinder. Again, this can be interpreted by a human, but will be useless for automated downstream operations.
Therefore, semantic MBD data serves as a building block for semantic, automated MBD workflows and minimizes human involvement.

Evaluating semanticity

Today, it is possible to pre-analyze the semantics of MBD data and evaluate it prior to its use in MBD workflows.
Once this check is completed and the semantic characteristic of the MBD data is ensured, then it is appropriate to use the term semantic MBD to define the workflows/interactions created for this data.

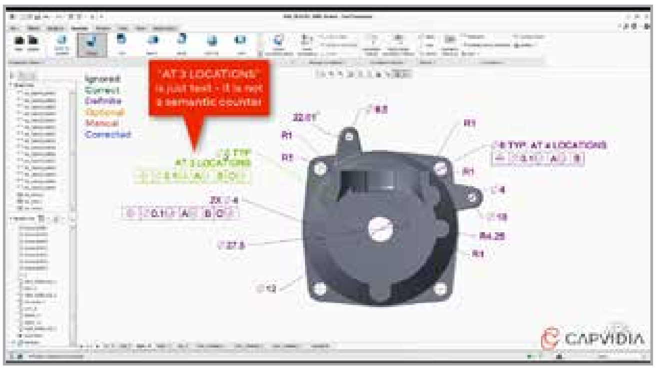


Fig. 1 – A snapshot of MBDVidia capturing the incorrect feature counters that impede full-semanticity

An example of non-semantic PMI due to an incorrect feature counter is mentioned above. Fig. 1 shows the MBDVidia software capturing a PMI element with this inconsistency. It is generally possible to heal such PMI elements automatically. However, the best practice is to learn to properly prepare them in the design phase.

Considering all of the aforementioned requirements, as well as the reason for using MBD, a more precise definition can be stated as 'the practice of having a single reference source – a 3D CAD model with semantic PMI – be the definitive authority model for all enterprise workflows. From design to manufacturing and then back upstream, all product and process definitions and derived data are mapped to one place.'

Data standards for MBD: QIF and STEP AP242

While there are several potentially suitable data formats for MBD workflows, this text focuses on the application of the QIF standard (ANSI QIF, ISO/DIS 23952).

QIF is an open CAD format that meets the requirements mentioned above for the application of semantic MBD workflows. It was introduced to facilitate the propagation of 21st Century concepts such as digital transformation, digital thread, digital twin, and Industry 4.0 to computer-aided technology and engineering applications.

In a semantic MBD workflow, QIF is published as a derivative of the native CAD model (authority and "single source of truth") with the ability to map the full metadata to the authority model throughout the entire product lifecycle. QIF is based on the XML framework from which its suitability for integration and interoperability with other systems and web/internet applications is adapted.

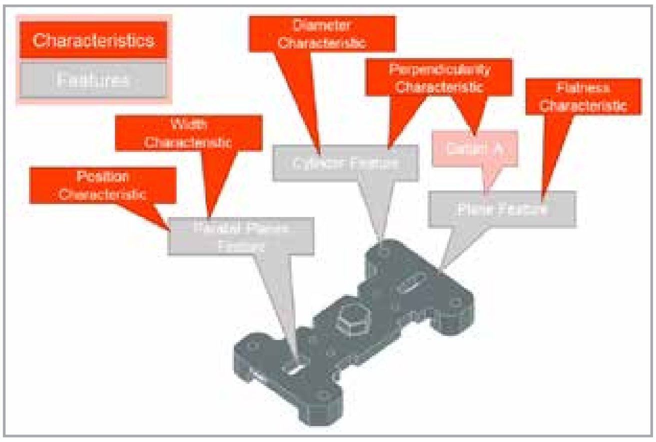


Fig. 2 – The fundamental constructs behind QIF: features and characteristics

The concept of tolerance and measurement features is central to the QIF data model. Note that these are different to CAD features. QIF functionalities serve as abstractions to describe a specific functional region of the model, which can further refer to underlying CAD surfaces. These functionalities are then referenced by characteristics such as GD&T. Fig. 2 below shows the fundamental constructs behind QIF:

An important advantage driven by QIF from a metrological point of view is the ability to store all necessary information -- from design/tolerances to measurements, results and statistics. The continuous lifecycle of a QIF model is shown in Fig. 3. As can be seen, the starting point is the QIF derivative, which is validated to fully represent the

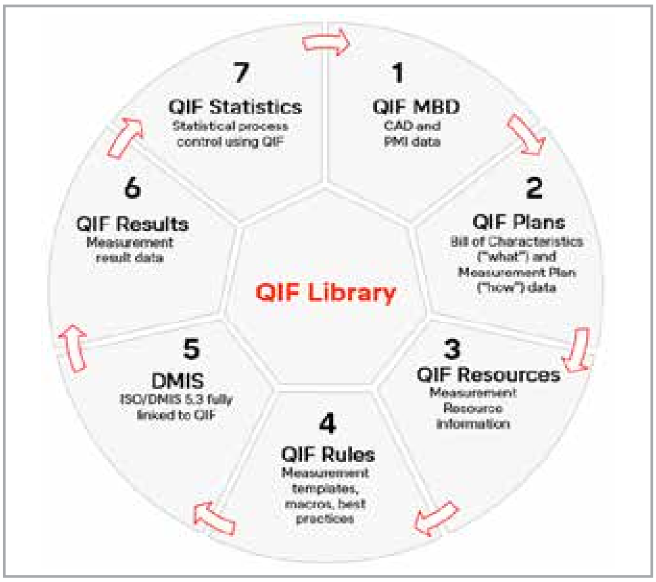


Fig. 3 – QIF components

authority model. The QIF plans are used to design the measurement process based on the features to be measured and how this will take place. This process is sometimes referred to as inspection planning or control planning. QIF also has other attributes, such as the ability to assign resources and rules related to the measurement process, which are outside the scope of the current article.

For upstream metrology applications, QIF serves as a container for the results and maps these back to the original model. The results can have different forms, originating from different measurements processes (manual, CMM, etc.). With this approach, the measurement results remain linked to the original model (CAD+PMI), and all ambiguities are eliminated. The results can be presented together with the 3D model, further statistical operations can be performed, and they can be used as factual data to iteratively improve tolerance simulations.

The immediate benefits and low-hanging fruit of MBD workflows

There are various aspects of metrology and related processes where large cost and time reductions can be achieved through semantic MBD workflows. One of the challenges for organizations planning to benefit from MBD is to ensure a smooth and simple transition from the traditional approach to semantic MBD. This transition must be structured to prevent any disruptions to existing workflows. Furthermore, the return on investment should be maximized by ensuring a high 'impact' to 'effort' ratio, for instance, by selecting less invasive implementations that generate significant time and cost savings. While most time-based metrics can be obtained through simple pilot studies, some additional benefits, such as improved process repeatability and reduced risk of human error in manual translation and interpretation activities, cannot be measured.

There are specific reasons for these extreme time and cost savings. Existing metrological processes require human involvement for translation, interpretation and data re-entry, all of which is usually time consuming. A fairly complex part can contain ~200 or more PMI elements. If this information comes in a non-machine-readable format (such as a static 2D drawing), an engineer would have to manually manage all of these PMI elements to produce a first article inspection (FAI) form or CMM measurement plan.

Another side benefit is that, with the automation of these processes, organizations can free the engineers to solve engineering problems, which is what they are trained to do (rather than copy/paste or transcribe). In addition to this, all of the above tasks are potentially subject to human error. As the likelihood of error increases, the potential for waste and misuse of resources increases, resulting in lost time and increased costs.
A good strategy is to start with processes where some tasks can be left unchanged while semantic MBD is applied to other tasks to generate substantial savings. Over the last few years, some metrological processes of this nature have been identified. Three implementation examples of this nature are:

(1) The automatic creation of FAI forms
(2) The automatic importation of 3D-MBD data (3D-CAD + semantic PMI) into a CMM software
(3) Data harvesting for computer aided tolerancing (CAT)

Automatic creation of FAI forms

Traditionally, FAI reports are created manually, based on 2D drawings. This can be extremely time consuming, up to weeks per part, and mistakes can be easily made. Therefore, the automation of this task is a ripe opportunity for MBD. PMI can easily be extracted directly from the CAD model and compiled into an inspection form in a common format like Microsoft Excel.

Previously, it was mentioned that to ensure a smooth transition to MBD workflows, any unnecessary disruptions to existing workflows should be avoided. In MBD-based FAI form publishing, the only change required is the way the form is created. The inspection process itself is remains unchanged i.e. measurement and compilation of the Excel sheet. Indeed, the technician/engineer handling the measurement process may not even realize that the form has been published based on MBD. Since the rest of the inspection process is unchanged, MBD-based FAI form publishing requires a minimal change in the existing workflow.
In addition, MBD-based FAI forms allow measurement results to be imported, linked to the 3D-MBD model, visualized in 3D, statistical operations to be performed, and more. As an example, one can import measurement results from different suppliers and see how the different suppliers perform for a specific part/operation.

Automatic importation of 3D-MBD data (3D-CAD + semantic PMI) into a CMM software

Another process of a similar nature is the creation of a CMM program. Traditionally, a shape-only model (e.g. initial graphics exchange specification (IGES) or STEP AP214) is loaded into the CMM software and the geometric dimensioning and tolerancing (GD&T) information must be entered based on the 2D drawing. This is time-consuming and error-prone. It also allows room for different human interpretations of the 2D drawing. Instead, this can be automated using semantic MBD while ensuring that the original data in the authority model remains

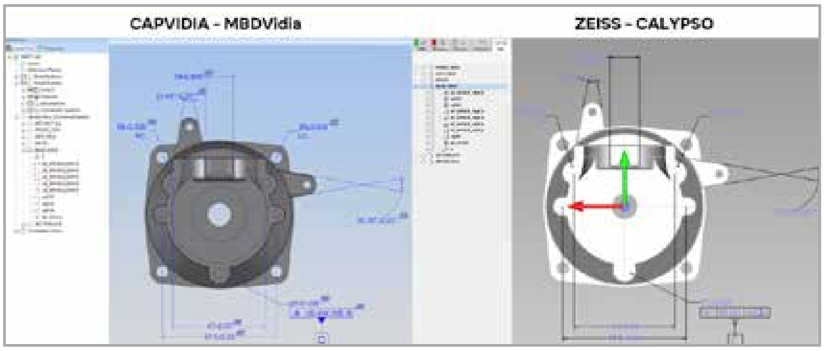


Fig. 4 – The same QIF file viewed in MBDVidia and ZEISS CALYPSO CMM software after import

intact during this task. There are various CMM software packages that allow QIF import. Fig. 4 shows an example of this import process. It shows the same view of a part displayed in MBDVidia and in ZEISS CALYPSO after the import operation, with a 100% PMI import rate.

Data harvesting for computer aided tolerancing (CAT)

Mapping the measurement results back to the authority model provides the opportunity to use the quality control data in a meaningful way to support decision making and more. The accumulated quality control data can be used to improve the computer aided tolerancing (CAT) system. Factual knowledge about the manufacturing quality of a component which is being simulated in a CAT tool is more precise than a distribution or a guess. Thus, this knowledge will vastly improve the CAT process. The main aspects of the connection between the results data and the CAT tool are the following:

1) The actual as-built data can be collected for the as-designed model.
2) This as-built data can be used to perform virtual assemblies using CAT tools.
3) By performing this virtual assembly, both product and process improvements can be made.
4) Production data can be automatically fed back into the CAT tools, creating a feedback loop of continuous process and product improvement.

This measurement data collection and storage approach, based on MBD, allows all data stored to be associated with the authority model, paving the way for extensive improvements in the CAT processes, as described above.

Case studies

1) A timing study comparing 2D drawing based approach with MBD-based approach from design, manufacturing, and quality control perspectives

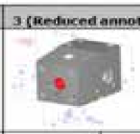
Test case	1 (Full annotation)		2 (Partial annotation)		3 (Reduced annotation)	
Model						
Processes	Drawing	MBD	Drawing	MBD	Drawing	MBD
Annotation (hours)	3.1	8.7	2.7	2.1	2.2	2
Machining (hours)	73.9	3.7	51.5	9.1	32	8.8
Inspection (hours)	6.1	5.7	6	2.8	3.5	2.7
Total	**83.1**	**18.1**	**60.2**	**14**	**37.7**	**13.5**

Table 1 – Test cases and time taken for annotation, machining, and inspection

Traditionally, the output of an engineering design department takes the form of a 3D CAD model accompanied by associated 2D drawings. In transitioning to MBD workflows, a natural question is whether embracing this technology will cause a reduction in efficiency or design cycle time.

A study conducted in 2016 by NIST, CAPVIDIA, and Mitutoyo America with the involvement of Honeywell Aerospace, Rockwell Collins, and DMSC focused on comparing the traditional and MBD-based approaches in terms of time spent on different tasks including annotation[2]. The study focused on multiple product designs suggested by the participating companies:

The test cases can be seen in Table 1.

- Test Case 1: This is a hollow-rectangular part requiring milling operations for manufacture. The MBD uses a fully dimensioned annotation method that combines dimensions, basic dimensions, and reference dimensions with geometric tolerances.
- Test Case 2: This is a cylindrical part requiring turning and milling operations for manufacture. The MBD uses a hybrid annotation method that combines dimensions with geometric tolerances. Test Case 2 reduces the annotation-presentation burden on the downstream-process user by not displaying the basic and reference dimensions.
- Test Case 3: This is a solid-block part requiring milling operations for manufacture. The MBD uses a reduced annotation method that combines dimensions with geometric tolerances only. Test Case 3, similar to Test Case 2, reduces the annotation-presentation burden on the downstream-process user by not displaying the basic and reference dimensions.

It is noted that, with a properly trained CAD designer, the design cycle times are shorter in the MBD-based approach than in the drawing-based approach. Therefore, the design-cycle time is negligible once the designer attains proper proficiency levels. This naturally means that CAD users need to be trained in the appropriate and recommended practices for creating semantic PMI in CAD systems. It is also concluded that, on average, the total time to complete one design cycle (annotation, manufacture, and inspection) for the drawing-based cycle was 60.3 hours (standard deviation of 18.5 hours). This number was measured 15.2 hours (standard deviation of 2.1 hours) for the MBD-based approach. These numbers correspond to a time reduction of 74.8% with a standard deviation of 6.2%. It is equally important to highlight the low standard deviation of the MBD-based approach, which means that the overall MBD process time is weakly dependent on design types.

Another interesting finding of this study is the number of questions raised by the supplier to resolve the ambiguities arising from the drawing-based workflow. The study compared two different suppliers, one working with 2D drawings and the other working with MBD models. The supplier who worked with the 2D drawing to rebuild the models used in its process asked 12 questions related to interpreting the product definition from the drawing.

All the questions related to the product-definition interpretation forced this supplier to stop working on the supplier model being rebuilt from the drawing. The average response time to a question was 2.8 calendar days. This equates to a total of 34 calendar days of work stoppage due to product-definition interpretation using the 2D drawings. In contrast, the supplier who worked with MBD models asked no questions during its manufacture and inspection work.

2) Automatic creation of first article inspection (FAI) forms / production part approval process (PPAP) forms

This section compiles some results reported by different companies after comparing drawing-based workflows with MBD-based workflows for FAI reporting. Exact workflows, company names and company-specific details are not shared; instead, a generic workflow is presented with the results in the form of time savings for different companies.

In a typical MBD workflow for first article inspection report (FAIR) management, a QIF derivative based on the authority CAD model is published first. To ensure that this derivative model represents the original model, it is validated by being compared to the authority model in terms of geometry and PMI. Then an Excel-based inspection

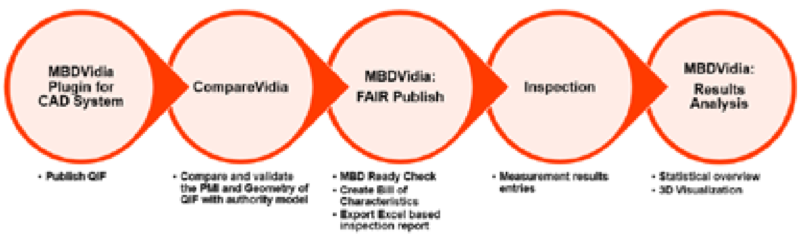


Fig. 5 – Semantic MBD-based first article inspection (FAI) form workflow

form is prepared and automatically published. After the inspection, the results are taken back from Excel to the QIF to return the data to the digital thread. This process allows the quality of the manufactured part to be evaluated both visually and statistically. This workflow is shown in Fig. 5.

Table 2 shows the time savings obtained by different companies. The results depend on industry, the complexity of the parts etc. Time savings of up to 80% were reported. To estimate the time savings in a particular organization, pilot projects with timing studies focusing on a limited number of parts are useful and encouraged.

Industry	Region	Outcome
Automotive	Japan	25% average time reduction
Appliances	US	minimum 60% time reduction
Defense	US	89% time reduction on partially annotated models

Table 2 – Time savings from MBD-based FAI form workflow

3) An ROI case study on an optimized model-based inspection

Traditional workflows for CMM inspections are extremely labor-intensive and error-prone. These workflows involve manual tasks that must be performed by highly skilled CMM technicians.

Programming a single part can take up to a few weeks and involves a high risk of transcription or interpretation errors in GD&T. Most importantly, this process relies on the experience and diligence of the CMM technician.

It is possible to automate the CMM inspection process using semantic MBD. This is viewed as another milestone for MBD-based metrological applications since it saves significant time and eliminates the possibility of human interpretation and error.

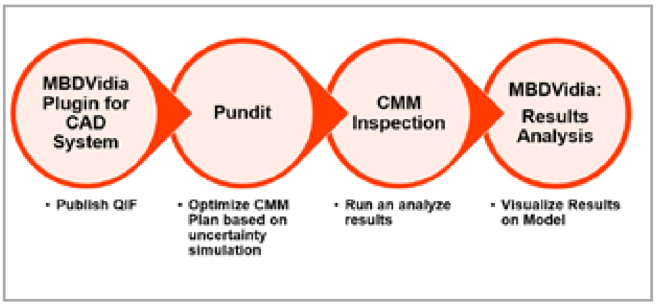


Fig. 6 – MBD-based CMM inspection workflow

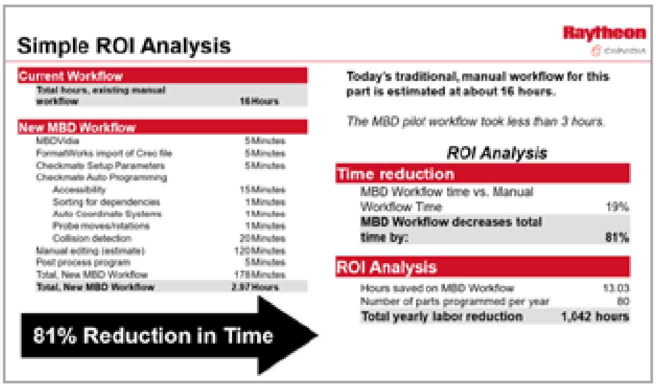


Fig. 7 – Time savings with the MBD-based CMM inspection

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The Raytheon Company, a major U.S. defense contractor, in collaboration with CAPVIDIA, performed a study comparing the traditional workflow and the MBD-based approach. A generalized workflow of this study can be seen in Fig. 6. First the QIF model was published from the CAD system (Creo in this case).

Subsequently, the inspection plan was optimized using an uncertainty simulation. After the CMM inspection, the results were mapped back to the original CAD for visualization and decision-making purposes.

During this study, the time taken for every step of the MBD workflow was measured with a stopwatch to compare it with the traditional CMM routine. The results are reported in Fig. 7, which shows a time reduction of 81% (3 hours compared to the traditional 16-hour workflow).

Conclusion

This article provides an overview of Semantic MBD for Metrology, from basic definitions to real industry applications and outcomes. Data structure and format requirements to facilitate semantic MBD workflows are addressed. The Quality Information Framework (QIF) is presented as a suitable format for such applications. Finally, industrial test cases are presented to encourage organizations to perform their own short, quick pilot studies to better track the impact of such implementations.

Finally, it is obvious that the use of MBD workflows brings time savings to metrology processes. However, this is only one of the immediate results of MBD workflows. The ability to store the measurement data and map it back to the original model enables various opportunities which can flourish in the long term, considering the amount of data that is discarded without MBD.

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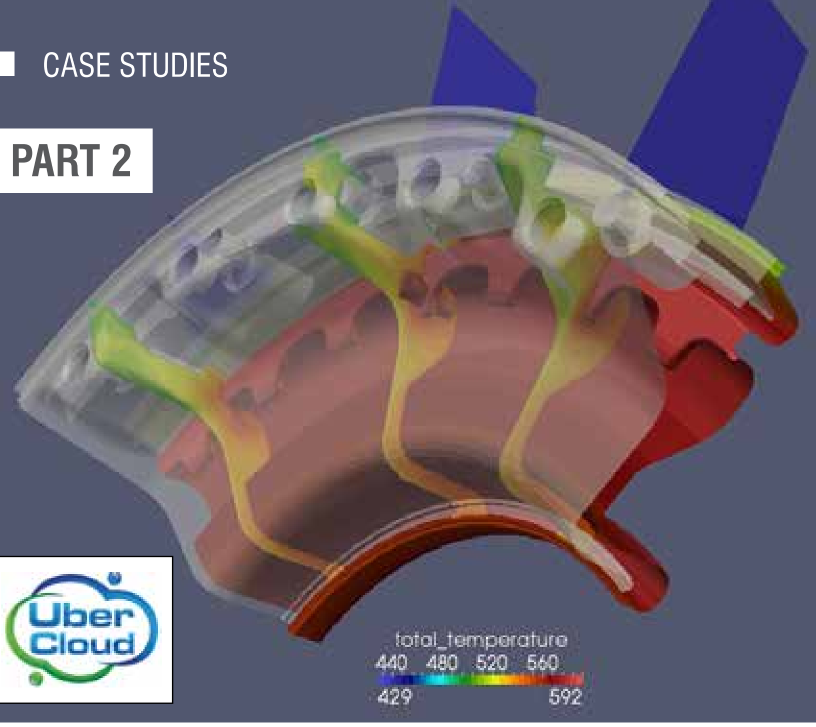
PART 2



Aerodynamics simulations with Ansys CFX and Fluent in the UberCloud

By Wolfgang Gentzsch and Praveen Bhat
UberCloud

This is the second part of an article published in the last issue of the Newsletter "Aerodynamics Simulations with CFX and Fluent in the cloud". Here, UberCloud presents two further aerodynamics case studies using cloud-based services with Ansys CFX and Fluent for engineering applications, as well as use cases that demonstrate the progress that has been made in cloud computing for the aerodynamics sector over the past few years.

This is the second part of an article from UberCloud examining the potential of the cloud and cloud-based applications for computer aided engineering (CAE). To date, UberCloud has performed more than 220 high performance computing (HPC) cloud projects and published 125 case studies, 25 of which were based on Ansys software such as CFX, Fluent, Mechanical, LS-DYNA, HFSS, and Discovery Live, as has been demonstrated in three previous articles in the EnginSoft Newsletter, [1], [2] and [3].

UberCloud started a series of cloud projects based on CAE simulations in 2012, moving engineers' complex simulation workflows to the cloud with the goal of analyzing the benefits and challenges of this virtual environment for CAE. These projects included defining the engineering use case, moving the application workflow to the cloud, running the simulation jobs in batch or in interactive mode, evaluating the results via remote visualization, transferring the final results back onto premises, and writing a case study.

Engineering companies have only recently become aware of the promise of cloud computing. Granted, the major reasons for this hesitation were a few severe roadblocks such as security concerns, traditional software licensing models (e.g. annual, perpetual, etc.), large data transfers, engineers' concern of losing control over their simulation assets (computing resources, software, data, etc.), and internal resistance from management and IT departments who often barricaded themselves behind existing compliance regulations that were not yet adapted to modern day requirements.

In the meantime, we have been able to remove most of these roadblocks by developing a software technology that hosts the engineer's complex workflows in an isolated HPC software "container" that can be housed on a dedicated and secure HPC resource in any cloud – public, private, hosted, and hybrid.

This second part of the article summarizes two further aerodynamics case studies based on CFX and Fluent. The project team for these two projects consisted of computational fluid dynamics (CFD) expert Praveen Bhat, Technology Consultant in India; software provider Ansys, which provided the licenses for CFX and Fluent; cloud resource providers, ProfitBricks and Opin Kerfi; and a group of technology experts, namely Fabrice Adam and Andrew Richardson from HPE, and Reha Senturk, Ender Guler and Ronald Zilkovski from UberCloud.

Studying wind turbine aerodynamics in the cloud with Ansys CFX

USE CASE

This case study describes the evaluation of wind turbine performance using CFD. The CFD models were generated with Ansys CFX. The simulation platform was built on a 62-core 240GB HPC cloud server at cloud provider ProfitBricks, the largest instance at ProfitBricks at that time. The cloud environment was accessed using a virtual network computing (VNC) viewer via a web browser. The CPU and RAM were dedicated to the single user. The Ansys software was hosted in an UberCloud application container.

Process overview

The step-by-step approach necessary to configure the CFD model in Ansys Workbench is described below:

1. Import the standard wind turbine designs in a CAD geometry format into the Ansys Design modeler (Fig. 1). The model was then modified by creating the atmospheric air volume around the wind turbine.
2. Develop the CFD model (Fig. 2) including the atmospheric air volume surrounding the wind turbine in Ansys Mesh Modeler.
3. Import the CFD model into the Ansys CFX computational environment.
4. Define the model parameters, fluid properties, and boundary conditions.
5. Define the solver configuration and solution algorithm. This portion of the configuration was mainly related to defining the type of solver, the convergence criteria, and the equations to be considered for solving the aerodynamic simulation.
6. Perform the CFD analysis and review the results.

The CFD simulation evaluated the pressure distribution and velocity profiles around the blades of the wind turbine as if they were being subjected to average wind speeds of 7 to 8 m/min. The plots in Fig. 3 and Fig. 4 illustrate the pressure and velocity distribution measured.

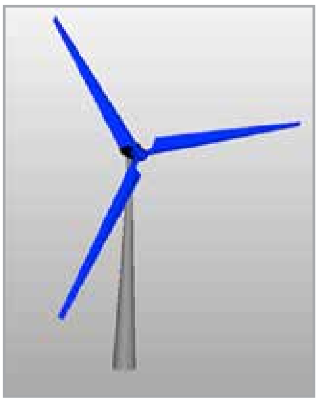


Fig. 1 – Wind turbine geometry

Fig. 2 – CFD model of the wind turbine

> *"The HPC cloud service enabled very fine mesh models to be solved and thus helped to reduce the CFD simulation time drastically."*

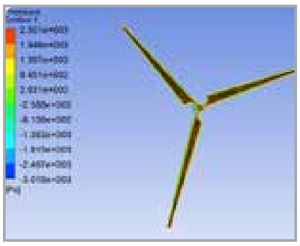


Fig. 3 – Plot of pressure distribution on the wind turbine blades

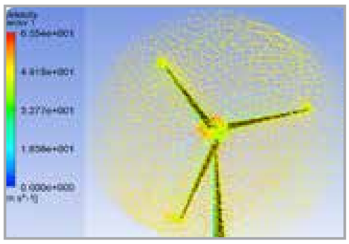


Fig. 4 – Vector plot of velocity profiles around the wind turbine blades

HPC performance benchmarking

The aerodynamic study of the wind turbine blades was conducted in an HPC environment built on a 62-core server with a CentOS Operating System and the Ansys Workbench simulation package.

The server performance was evaluated by submitting the simulation runs for different parallel computing environments and mesh densities. Three different parallel computing environments were evaluated: Platform MPI, Intel MPI and PVM Parallel.

Fig. 5 shows the solution time required for different mesh sizes for the cases where the simulation models used Intel MPI. Fig. 6 shows the solution times for different numbers of CPU cores for a mesh size of 250K elements.

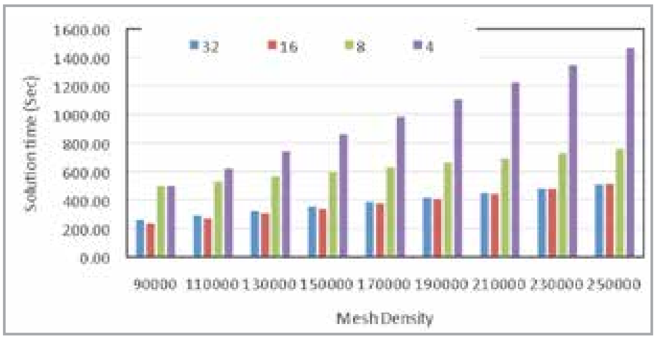


Fig. 5 – Solution time for different mesh sizes from 90K to 2,5M elements using Intel MPI

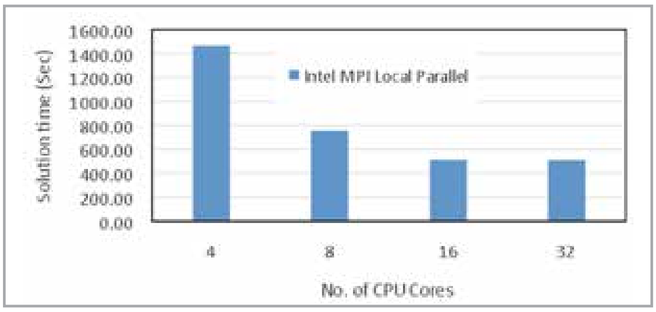
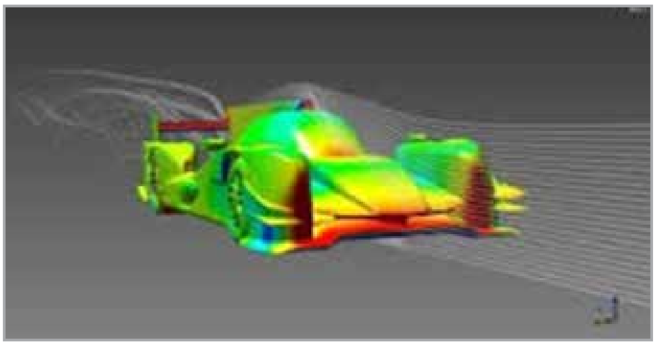


Fig. 6 – Performance comparison for a mesh size of 250K elements

Assessing race car aerodynamics in the Opin Kerfi cloud with Ansys Fluent

USE CASE

This aerodynamic benchmark study evaluated the air flow and the forces acting on a racing car to understand the air velocity and its impact on the car's stability during racing. The study focused on understanding the aerodynamic performance and quantifying the different forces acting on the racing car at certain speeds. The CFD analysis provided insight into the air flow, air pressure and



> *"The Opin Kerfi HPC environment with HPE's IaaS cloud management stack and UberCloud's software container for Ansys is an excellent fit for performing advanced computational simulations".*

the velocity distribution around the car, as well as the parameters required to calculate the aerodynamic forces. The 3D CAD model of the racing car including a dummy driver, generated within the Ansys 19.0 simulation environment on a max 256-core HPC computer cluster with 250GB RAM, was accessed using a VNC viewer via the engineer's web browser. Ansys Fluent was running in UberCloud's HPC application software container on the Opin Kerfi HPC cloud.

The following flow chart defines the configuration and modelling for running the simulation in the Ansys containerized environment:

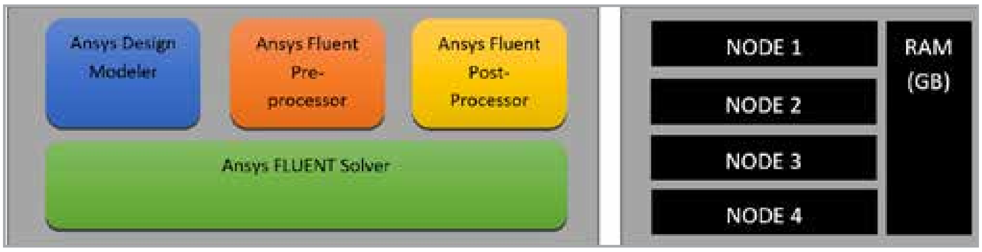


Fig. 7 – Container environment with Ansys Fluent application

The model construction and configuration were done as shown in the following flow chart:

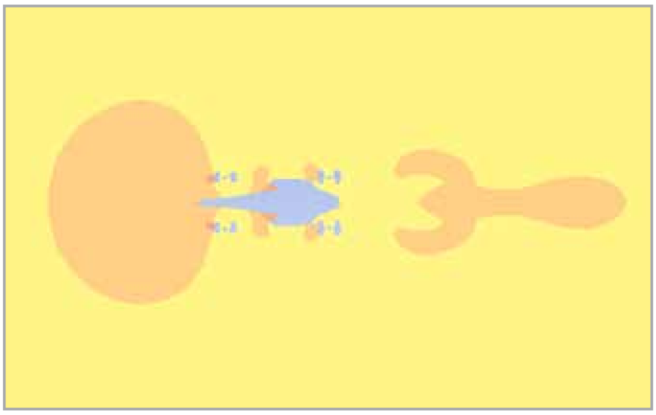


Fig. 9 – Pressure distribution at the mid-section of the racing car

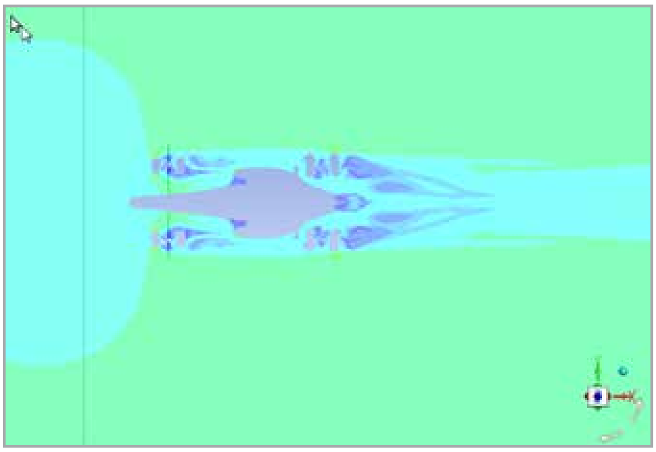


Fig. 10 – Velocity distribution at the mid-section of the racing car

Fig. 9 shows the pressure distribution measured at the mid-section of the 3D racing car. The pressure distribution across the section is uniform.

The velocity plot in Fig. 10 shows that the air velocity varies near the leading edge of the racing car. The air particle velocity is uniform with particles following a streamlined path near the car wall.

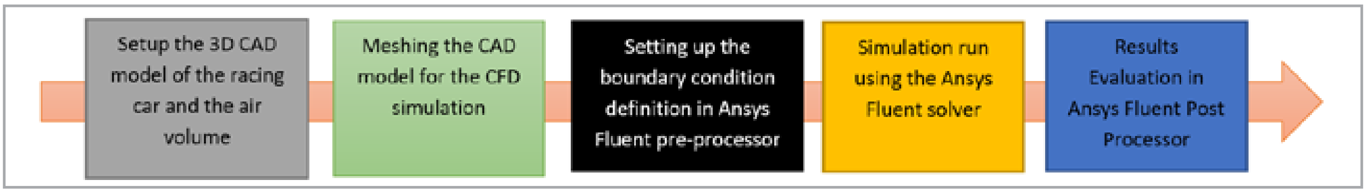


Fig. 8 – Different stages in the model setup and simulation run in Ansys Fluent

The step-by-step approach followed here for setting up the CFD model within the Ansys Workbench 19.0 environment is very similar to the previous case study.

The Ansys Fluent simulation was solved in an HPC cloud environment. The simulation model had to be precisely defined with a good number of fine mesh elements around the racing car's 3D geometry. The following illustration shows the racing car geometry considered and the 3D Fluent mesh model:

HPC performance benchmarking

The external flow simulation was carried out in the Opin Kerfi HPC cloud environment which was running on a 256-core server with a CentOS Operating System and the Ansys Workbench simulation package.

The server performance was evaluated by submitting simulation runs for different numbers of elements. Obviously, the finer the mesh size, the more time is required to run a simulation. The run

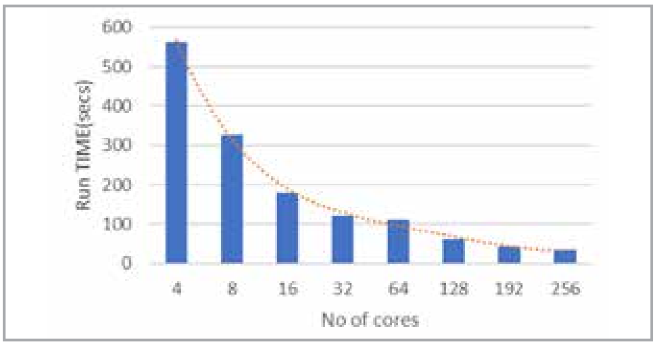


Fig. 11 – Runtime (secs) vs no. of cores for the 2 million mesh model

time can be minimized by using more cores. Fig. 11 highlights the solution time required for the 256-core system with 2 million elements.

As the number of CPU units increases, the simulation time reduces considerably. The solution time required with 64 cores for the fine mesh model is 3.8 times higher than the solution time required with a 256-core server for the same mesh model. For a moderate number of elements (~ 14 million), the 64-core server performs five times better than a normal quad-core system with respect to the total number of simulation jobs completed in a day.

Challenges, benefits, conclusions and recommendations

CHALLENGES

The two projects started with configuring the Ansys workbench with Ansys CFX and Fluent modeling software. The initial functioning of the applications was evaluated and the challenges faced during the execution were highlighted. Once the server performance was successfully improved, the next set of challenges faced was related to technical complexity. This involved accurately predicting the wind turbine blade behavior under aerodynamic loads, which was achieved by defining an appropriate element size for the mesh model. The finer the mesh, the greater the simulation time required; therefore, the challenge was to perform the simulation within the specified time.

BENEFITS

1. The HPC cloud environment with Ansys Workbench made model generation easier and drastically reduced the processing times due to the HPC cloud resource.
2. Mesh models were created for different numbers of cells, and the experiments were performed using coarse-to-very fine mesh models. The HPC computing resource helped to complete the simulation runs more smoothly.
3. The computing requirement for a very fine mesh is high, which makes it impossible to achieve with a normal workstation. The HPC cloud enabled very fine mesh models to be solved and drastically reduced the simulation time. This allowed us to obtain the simulation results within an acceptable run-time (~1.5 hours).
4. The use of Ansys Workbench helped to perform different iterations in the experiments by varying the simulation models within the workbench environment. This further helped to increase the productivity of the simulation configuration effort and provided a single platform to perform the end-to-end simulation setup.
5. The experiments performed in the HPC cloud environment provided the extra confidence necessary to configure and run the simulations remotely in the cloud. Since the different simulation configuration tools required were already available in the HPC environment, the user was able to access these tools without any prior installations.
6. The use of VNC Controls in the web browser meant that accessing the HPC Cloud was extremely easy, with minimal or no installation of any pre-requisite software. The whole user experience was similar to accessing a website via a browser.
7. The UberCloud containers [5] helped the project run smoothly and provided easy access to the server resources. The regular UberCloud module for automatic email updates massively benefitted the user by allowing continuous monitoring of the job in progress without the necessity of logging into the server to check the status.

Conclusion and Recommendations

1. The selected HPC cloud environment with UberCloud-containerized Ansys on ProfitBricks and Opin Kerfi cloud resources is very well suited to conducting advanced computing experiments that involve high technical challenges and require greater hardware resources to perform the simulation experiments.
2. The Ansys Workbench environment helped us to solve the aerodynamic problems since it required minimal effort to set up the model and perform the simulation trials.
3. The combination of HPC Cloud, UberCloud Containers and Ansys Workbench helped speed up the simulations and complete the project within the specified time frame.

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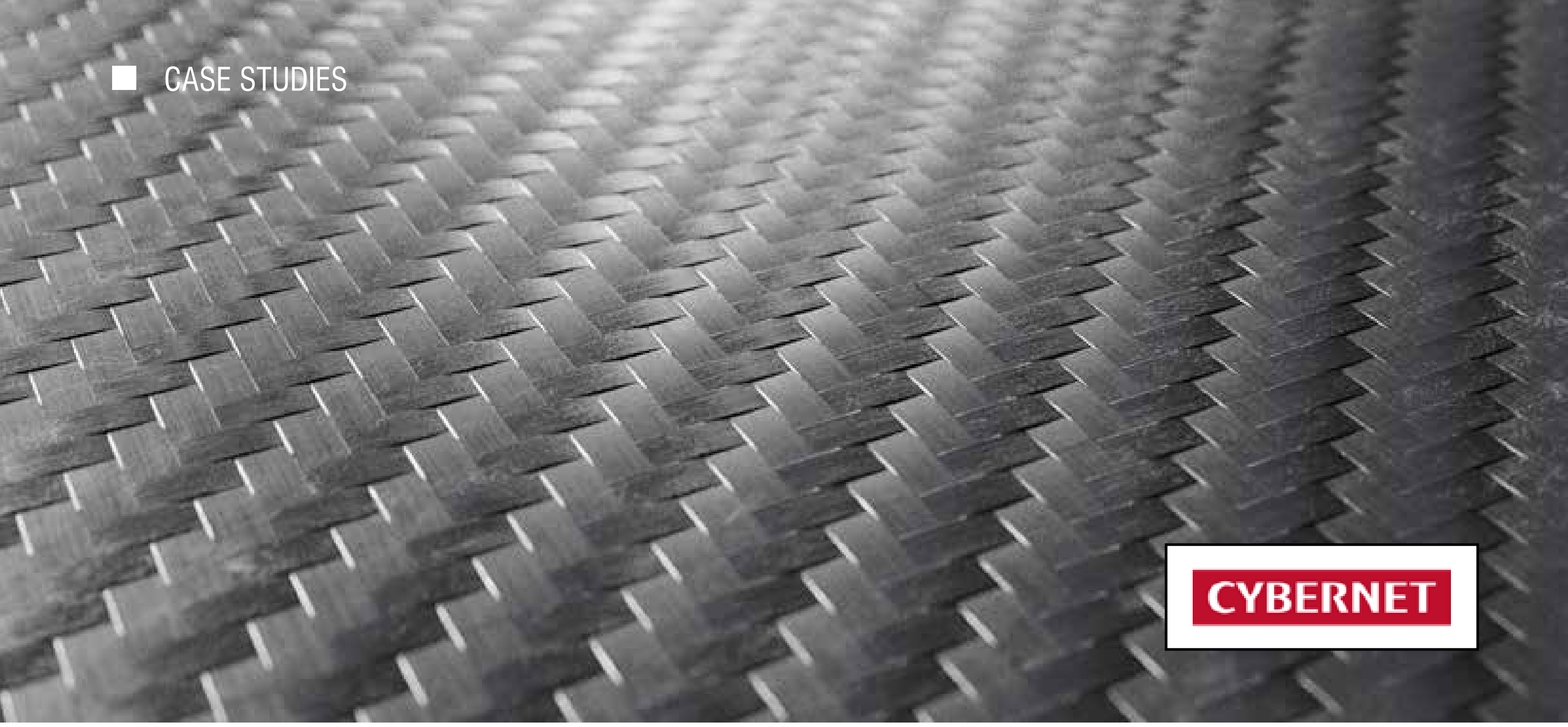

Predicting the strength of composite materials using Ansys Software

Applicable from material design to product design

By Koji Yamamoto
CYBERNET

Composite materials are substances formed by combining two or more different materials into one. Their greatest advantage is that these new materials have the characteristics and properties of their constituent parts. As a result, composite materials are widely used in many industrial fields today, particularly since the emergence of carbon and glass fibers with their superior properties. However, currently, there are substantially less simulation results available than for metals. This technical article discusses some of the problems of using finite element method (FEM) simulation software for composite material analysis and introduces new solutions from CYBERNET with Ansys Software for solving these problems.

The term "composite materials" refers to substances formed by combining two or more different materials into one. They have a long history: the earthen walls and earthenware seen in ancient buildings are splendid examples of composite materials made from straw and clay.

Their greatest advantage is the ability to prepare new materials that have the characteristics and properties of their constituent parts. Earthen walls have both the toughness of straw and the heat resistance of clay. Alternatively, one can say that the problem of the straw's highly combustible nature is mitigated by the clay.

Once using primarily natural fibers, composite materials today are widely used in many industrial fields since the emergence of carbon and glass fibers with their superior properties. In particular, the contribution of carbon fiber reinforced plastic (CFRP), which is a composite material made from carbon fibers and resin, has been remarkable in the aircraft field where the mandatory obligation of weight reduction has been met by taking advantage of the low density, high strength characteristics of the carbon. In addition, in recent years, its application has been actively increasing in the automobile industry where it is being used to reduce weight to improve fuel efficiency.

Consequently, composite materials have been receiving a lot of attention from industry, however, currently, the simulation results are significantly less than for metals. This article discusses some of the problems of using finite element method (FEM) simulation software for composite material analysis, and introduces the new solutions for solving these problems.

Problems in conducting composite material analysis

Compared to common metallic materials, composite materials have numerous significantly different properties. Here, we will address three typical and unique issues regarding composite materials that are important from an analytical point of view.

1. Material modeling

There are countless combinations of materials that make up composite materials. While this has the great advantage of expanding

	Metallic materials	Composite materials
Material behavior	Isotropic	Anisotropic
Material test	O (Easy)	Δ (Difficult)
Material database	O (Many)	Δ (Few)
Controllability of material properties	Δ (Difficult)	O (Easy)

Table 1 - Comparison of the general characteristics of metallic materials and composite materials

the range of material design, it has the problem that a general material database cannot be built like with metals. It is difficult and demanding to conduct a material test every time the combination of materials changes, and to prepare the material constants necessary for the analysis, with the result that the true usefulness of analysis, which lies in the low-cost trial-and-error testing of product designs, is nullified.
The main problem in obtaining physical property values lies in the fact that the material behavior is anisotropic. For example, in the case of fiber reinforced plastic, the rigidity of the fibers is higher than that of resin, meaning that the rigidity of the fibers in the orientation direction becomes much higher than in the orthogonal direction. In order to realize these material behaviors analytically, it is necessary to evaluate the rigidity in various tensile and pure shear directions by material testing, which is significantly more expensive than for isotropic materials.

2. Finite element modeling (FEM)

Composite materials also present specific challenges when it comes to creating finite element models. For example, there are composite materials in which the fibers are oriented in a continuous, straight direction, and composite materials in which fibers are woven into a laminated structure by layering thin sheets with different orientation structures in the thickness direction. In such cases, it is a common to change the laminated structure depending on the location in order to optimize the strength distribution of the structure. As a matter of course, when the combination of laminated structures becomes complicated, it is difficult to manage using only the modeling function of general FEM tools.

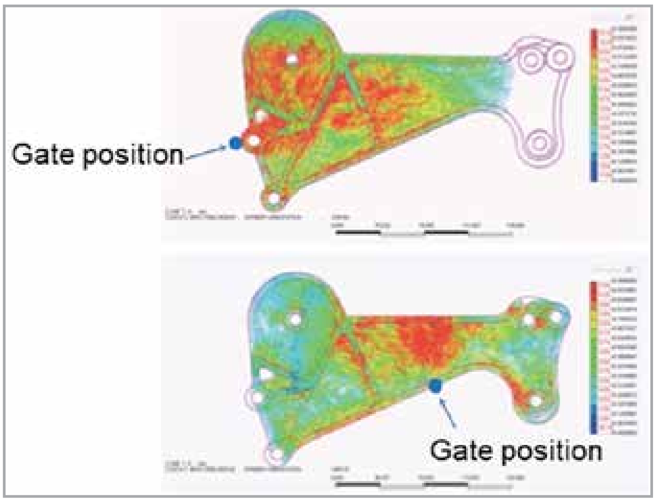

Fig. 1 - Fiber orientation distribution of injection molded products based on the difference in gate position

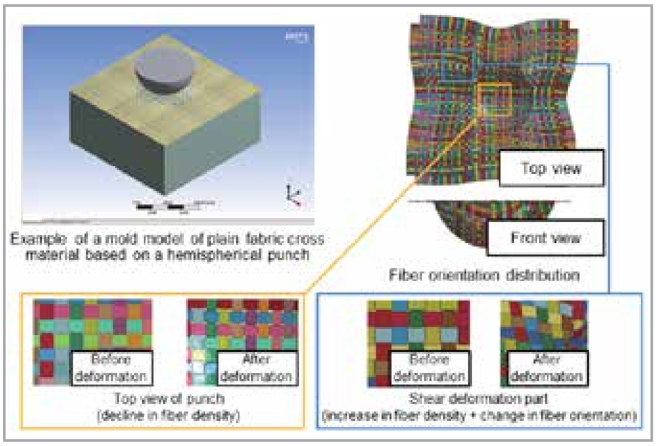

Fig. 2 - Fiber orientation and fiber density distribution of press-molded fabric materials

Furthermore, it is also important for the composite material's strength properties to be derived from the molding history. Simple images are shown in Fig. 1 and Fig. 2. Fig. 1 concerns injection molding and shows the fiber orientation when the resin with fibers is injected into the mold from different gate positions. The Planets X resin flow analysis tool developed by CYBERNET was used for the analysis. As can be seen, the fiber orientation of the final molded product depends largely on the gate position, because the fiber orientation is affected by the resin flow.

Fig. 2 shows the fiber orientation of a flat sheet of composite material containing woven fibers when it is press-molded with a spherical punch. The explicit analysis tool Ansys LS-DYNA was used for the analysis. Since the flat sheet has a strain distribution in the in-plane direction due to molding, it can be seen that the fiber orientation distribution and the fiber density are significantly different from those before molding. These problems show that unlike the isotropic behavior of metallic materials, it is not possible to obtain sufficient analytical accuracy even by defining the same material constants and material principal axes for the entire model.

3. Evaluation of fracture and damage

With the heterogeneous material structures found in composite materials, fracture and damage behavior are not easily simulated. This stems from the variety of fracture mechanisms. Some of the possible causes for the origin or progress of fractures and damage in fiber reinforced plastic laminates are a combination of the following:

- Interfacial delamination between fiber and resin
- Rupture of fibers
- Generation and progress of cracks in the resin
- Delamination between layers
- Various other factors.

Even if only crack propagation is taken into consideration, when hard materials such as fibers, etc. are present in the material structure, the crack growth is inhibited, so the propagation path strongly depends on the material structure. In other words, unless an analysis that considers the material structure is conducted, the fracture/damage behavior of composite materials cannot be predicted accurately, making it impossible to acquire knowledge for material design from the simulation results. The next section introduces new solutions developed by CYBERNET that use Ansys Software to solve these three problems.

CYBERNET solution lineup to solve each problem

Here, we introduce two analysis tools that are effective in solving problems with composite materials.

Multiscale.Sim: Prediction of material behavior based on a model of the material structure

Multiscale.Sim is an add-in tool for Ansys Software that was jointly developed by Nitto Boseki Co., Ltd., Quint Corporation, and Cybernet Systems Co.,Ltd. under the guidance of Professor Kenjiro Terada of Tohoku University. Its main purpose is to solve problems related to material modeling. By using the two functions of this analysis tool – homogenization analysis and localization analysis – it is possible to realize multiscale analysis in a way that considers the non-uniform material structure of composite materials.

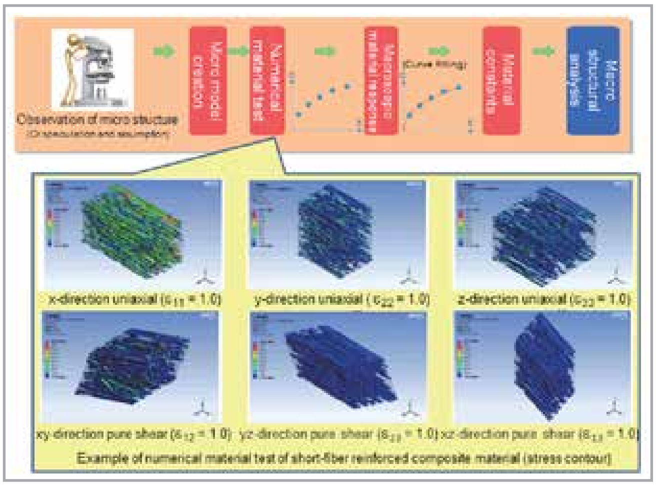

Fig. 3 - Flow of material – identification of constants by homogenization analysis

Homogenization analysis - CAE as a material test device

Homogenization analysis can be used to acquire information to predict the physical properties of composite materials. Fig. 3 shows the flow of homogenization analysis. Here, an inhomogeneous microstructure of a composite material is prepared as an analysis model (hereinafter referred to as a micro model). In the case of a plain weave material, it supports the woven shape of the fiber bundle, and in the case of a particle-reinforced material, it supports the particle shape and the dispersion form.

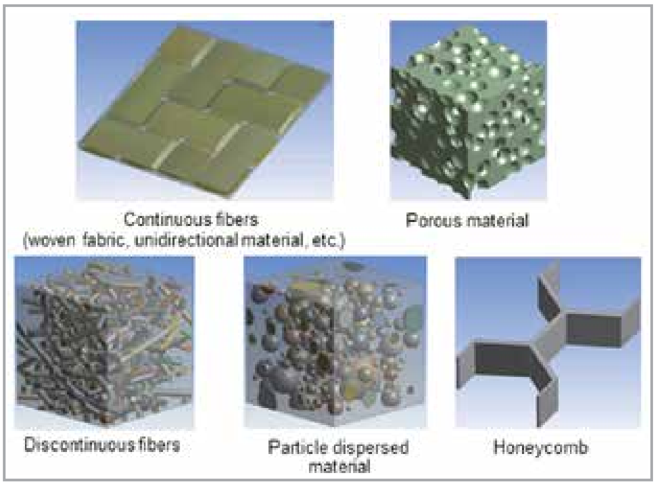

Fig. 4 - Example of micro-model shapes

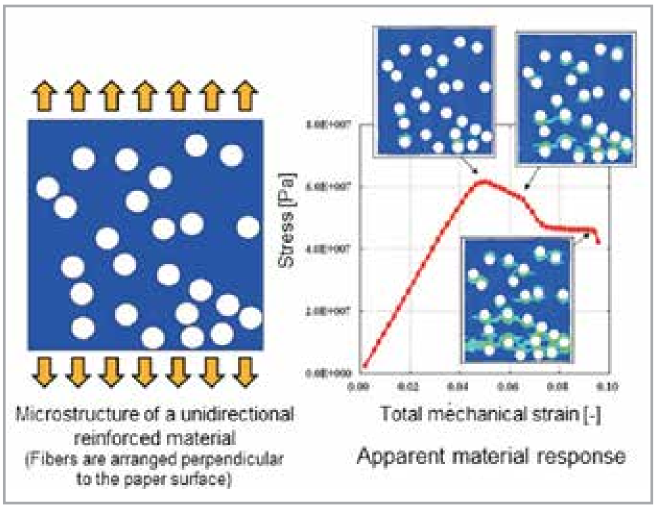

Fig. 5 - Example of a numerical material test of a fracture

Fig. 4 shows a typical example of a micro model. Templates are provided for automatically creating models of some typical microstructures.

By performing a virtual material test (called a numerical material test) using FEM on the created microstructure, it is possible to obtain the apparent material response (such as the stress-strain characteristics) of the micro model. At this time, it is assumed that the micro models are periodically arranged in an infinite direction, and an ideal single stress field can be easily applied to the single unit cell model. The big advantage is that difficult pure shear tests can also easily be applied to simulations during real material tests.

The material constants can be obtained by fitting the apparent material response thus acquired to the Ansys Mechanical anisotropic material model. While the fitting function for anisotropic material models is not provided as a standard function in Ansys Software, it is implemented as a function in Multiscale.Sim. Material constants can be easily identified if material test data for each direction is available.

The information obtained by numerical material testing does not include only the apparent material response and the material constants. Since the microstructural inhomogeneities are actually modeled, the stress and strain distributions in the material can also be evaluated. Identification of the fracture mechanism is extremely important information for material design, but it can be said that it was obtained for the first time only by introducing this analysis method.

Fig. 5 shows the results of a numerical material test performed by applying a material model of a fracture in the resin.

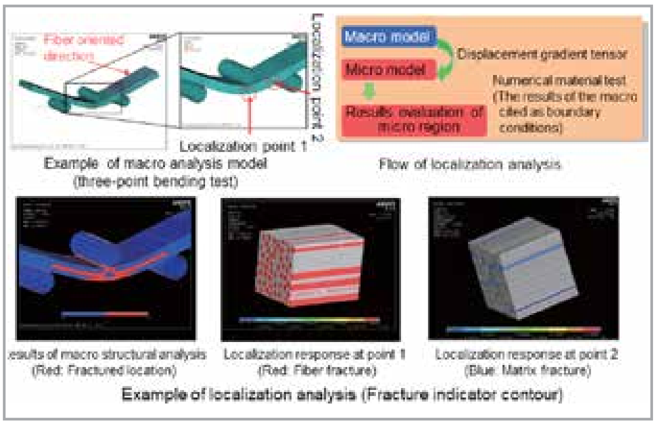

Fig. 6 - Example of fracture mode observation based on localization analysis

You can see that the cracks (transverse cracks) that occurred inside the resin are proceeding while bypassing the fibers.

Localization analysis - CAE as a microscope

If the material constants for fractures in the composite material can be obtained using the homogenization method above, it is possible to estimate the occurrence of fractures in the actual structure, as well as various general fracture areas using different general-purpose CAE tools such as Ansys Software. However, it is not possible to estimate the specific factors of the fracture when analyzing a model in which an originally inhomogeneous material is replaced by a homogeneous material. This problem can be resolved using Multiscale.Sim's localization analysis feature.

The localization analysis function is introduced using a simple analysis example. Fig. 6 shows an example of a three-point bending test on a composite material. The sample is a unidirectional reinforced material in which the fibers are oriented in the longitudinal direction, and for which the fracture strength was acquired by homogenization analysis. It can be confirmed that the fractured regions shown in red are present on the bottom and top surfaces, as well as on the mid-surface of the sample. Localization analysis can be used to zoom in on parts of a homogenized analysis model to evaluate the material structure scale results.

Localization point 1 in Fig. 6 shows the localization result on the bottom surface of the sample, and localization point 2 shows the localization result on the mid-surface. Since the bottom surface of

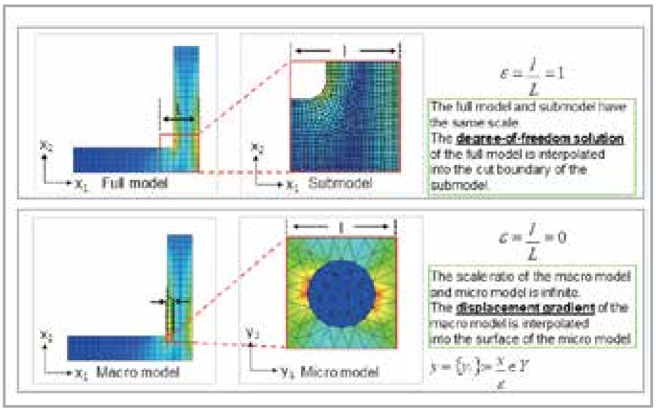

Fig. 7 - Differences between sub-modeling and localization analysis

the sample exhibits a deformation mode in which it is pulled in the direction of the fiber, the fibers with a lesser rupture strain than the resin will break first, which results in a fracture of the composite material. On the other hand, since the shear deformation mode is dominant on the mid-surface, the fibers are hardly affected by the stress, and it can be confirmed that the fracture occurs due to the debonding of the fibers and the resin, and due to the expansion of the crack inside the resin. Identifying the cause of fractures using conventional CAE is difficult, therefore, and is one of the reasons why using CAE for the material design of composite materials is considered difficult.

The localization analysis function may, at first glance, seem similar to a sub modeling approach, but the major difference is that the two models being integrated have different size ratios. In the sub-modeling approach, the two models to be integrated must be of equal size, whereas in localization analysis, the size ratio is expected to be extremely large (see Fig. 7).

Ansys Composite PrepPost: FE modeling of laminated structures

Ansys Composite PrepPost (hereinafter referred to as ACP) is a tool developed to efficiently implement the pre- and post-processing that is unique to composite materials. In this section, we introduce the

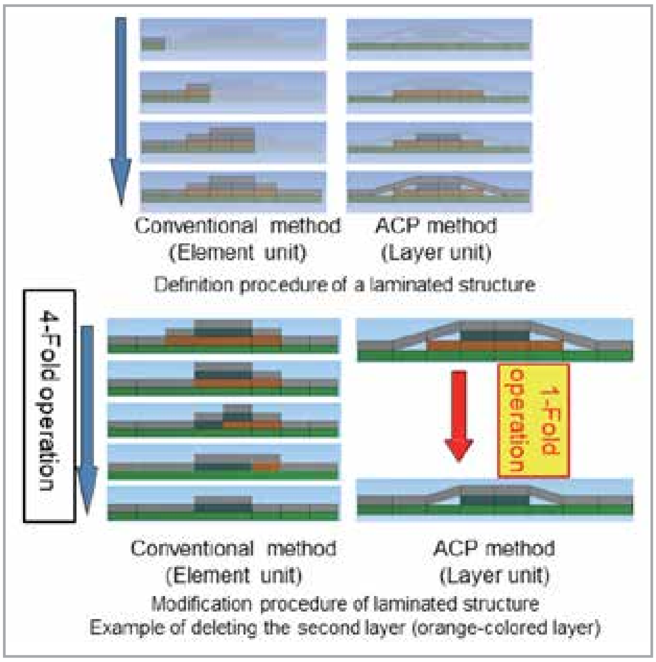

Fig. 8 - Differences between the conventional method for defining laminated structures and the ACP method

pre-processing functions for the definition of laminated structures and the definition of the fiber orientation.

Definition of the laminated structure: From the definition method of the element unit to the definition method of the layer unit

The FEM analysis tool in Ansys Mechanical has always provided functions for defining laminated structures. However, it has certainly not been the most suitable modeling technique for defining the complex and large-scale laminated structures of actual structures

in recent years. Fig. 8 shows the differences between these conventional tools and the ACP laminated structure modeling approach.
In conventional modeling methods, laminated structures are defined on an element (or segmented surface) basis. When the laminated structure of each region is different, as shown in Fig. 8, it is necessary to define the number of layers in each region, the material constants for each layer, and the principal axis of each layer. On the other hand, the definition method in ACP involves specifying the layer units, and it is possible to stack arbitrary materials by specifying the region sequentially from the bottom surface. This procedure is similar to the creation process of the actual material, so the modeling can be performed intuitively, and the more complex the model becomes, the more efficiently the process can be applied with fewer menu operations compared to conventional approaches. These differences in specifications have a significant impact not only when defining the laminate structure, but also when making modifications. The composite material design process often involves trial and error tasks such as deleting certain layers, changing the material of layers, and interchanging the order of laminates. Even when such modifications are performed, operational efficiency is greatly improved by the ACP definition specifications. These sophisticated approaches to laminated structures improve work efficiency and play an important role in reducing the probability of human error.

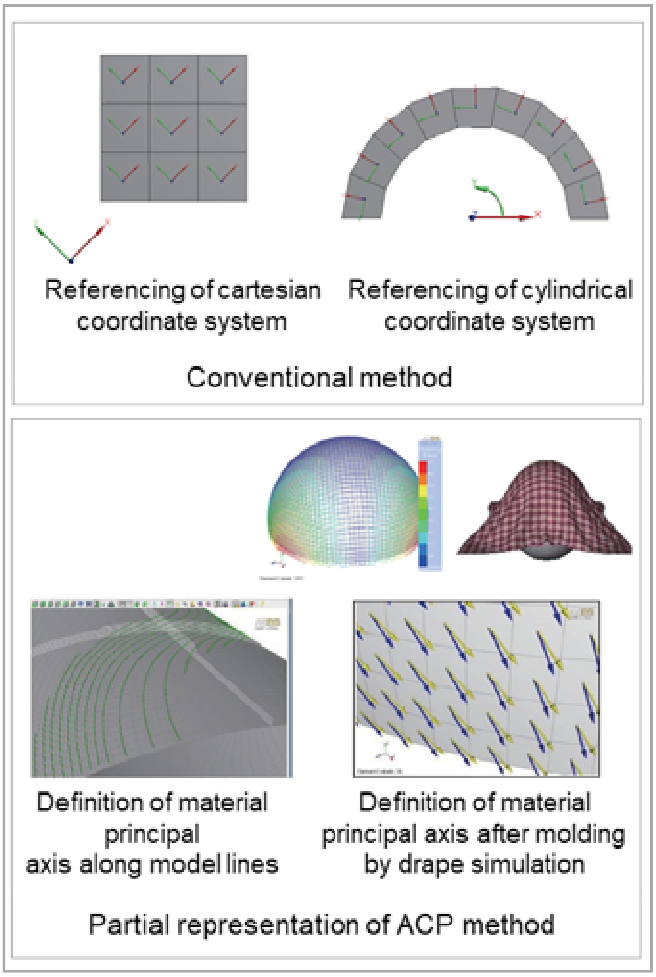

Fig. 9 - Differences between the conventional method and the ACP method for defining a material's principal axis

Definition of the oriented direction: Departure from the definition method based on the local coordinate system

In an anisotropic composite material, the orientation of the material's major axis must be defined. The conventional Ansys Mechanical definition method for a material's principal axis is to create a coordinate system that specifies its orientation and which references the coordinate system in any family of elements. In the case of a model in which the material's principal axis is curved, a technique of arranging a cylindrical coordinate system at the center of the curvature and aligning the material's principal axis in the angular direction was used. While this can be very effective for simple, cylindrical models, it is necessary to create a large number of cylindrical coordinates when applying it to structures with complex curved surfaces, which is work intensive.
On the other hand, the methods of defining the material's principal axis by ACP are extremely diverse, and were devised to handle the various complex geometric shapes found in composite materials. Fig. 9 is an example of a partial definition. It is also possible to define the material's principal axis along the lines that configure the model. This is an extremely useful tool for models with complex shapes. The drape simulation function in ACP enables engineers to predict changes in fiber orientation once a flat composite material is shaped on a curved surface; these results can also be used as the material's principal axis for structural analysis.

Conclusion

This article addresses three issues related to the analysis of composite materials using the finite element method: material modeling, FEM modeling, and fracture and damage assessment, and introduces the Multiscale.Sim multiscale analysis tool and Ansys Composite PrepPost pre-processing tool dedicated to composite materials, which are effective in solving these problems. There are many challenges in the analysis of composite materials, and it is necessary to combine multiple tools to solve them comprehensively. However, CYBERNET's portfolio of composite material solutions is implemented on all Ansys Workbench platforms, enabling seamless data integration and limiting tedious tasks to the bare minimum.

This time, we only introduced the function to predict the distribution of the fiber orientation using drape simulation as an analysis solution that considers the molding history. However, this is just one of many composite material molding techniques. At CYBERNET, we are continuously working on developing analytical tools and improving analytical technology for composite materials. In the future, we plan to introduce advanced analysis solutions for material design as needed.

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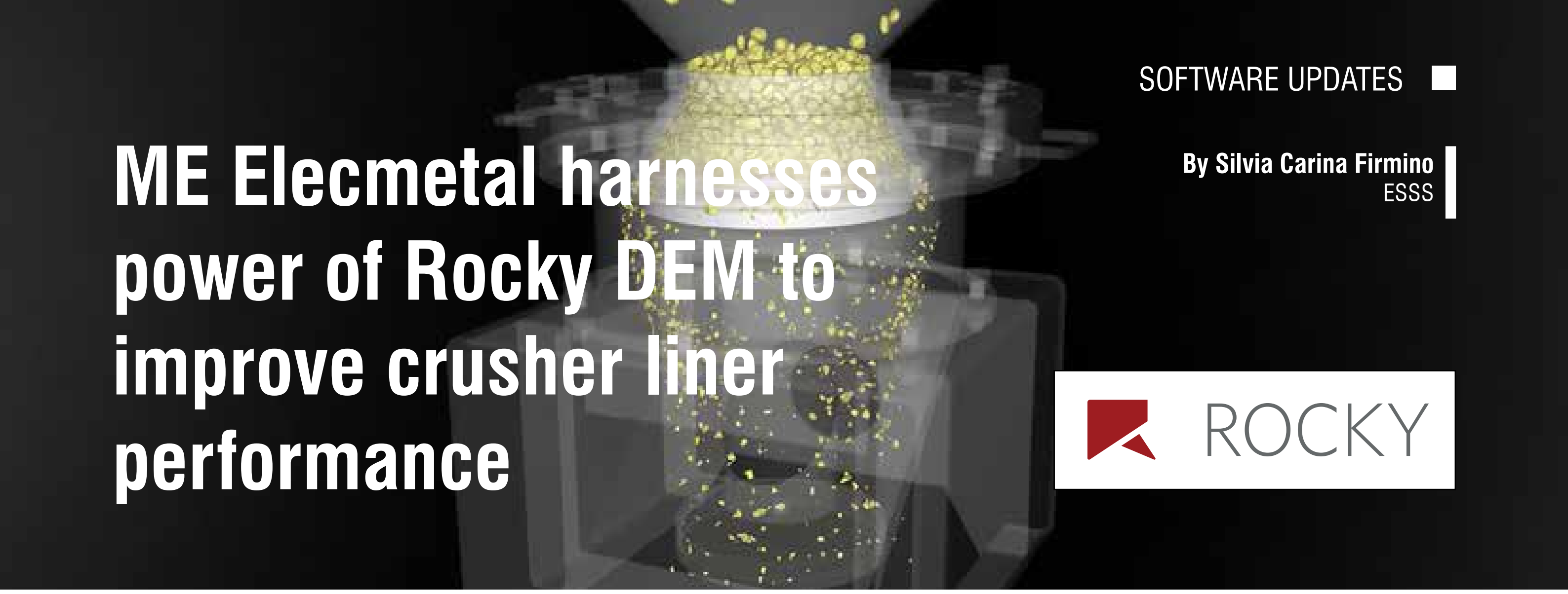


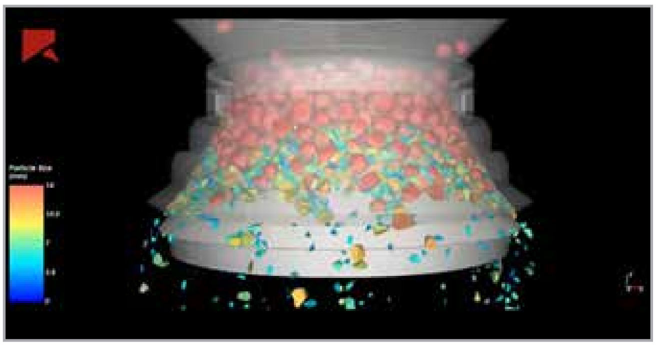
ME Elecmetal harnesses power of Rocky DEM to improve crusher liner performance

By Silvia Carina Firmino
ESSS

ME Elecmetal — a global supplier of integrated wear solutions for mining, construction and industry — is among the first companies to benefit from Rocky DEM's latest technology: the Tavares breakage model. The industrial supplier chose Rocky software specifically for this capability, which accurately shows how particle breakage affects crusher liner equipment, in an effort to improve liner longevity and, subsequently, to reduce maintenance downtime, and increase throughput.

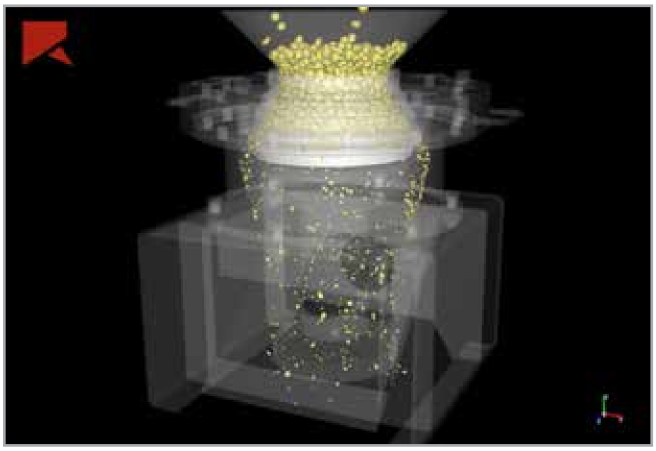
In mining companies around the globe, crusher liners are regularly used to reduce large ore chunks into smaller pieces. By nature, the crushing process is very abrasive; therefore, this equipment is outfitted with wear linings that must be replaced periodically — and downtime affects profitability. In addition, it is impossible to physically observe the specific impact that crushing has on equipment. In the past, DEM breakage simulations often produced biased results — sometimes even useless solutions.

Incorporating the latest technology, Rocky DEM extends the existing application range for modeling particle breakage, including predictive simulations that match real-world experience. The Tavares breakage model (named for Prof. L.M. Tavares' Ph.D. work at the University of Utah and further development with his group at the Federal University of Rio de Janeiro, Brazil), adds capabilities (submodels) that can make breakage modeling quite realistic in a wide variety of situations. In particular, the model is useful in describing ore degradation during handling as well as size reduction in different types of crusher liners, providing greater confidence in predicting both the proportion of broken particles and product size distribution.



Copper ore model validation.

At the outset, the Tavares model accounts for variability in particle strength: Even when particles are the same size and material, each particle has a distinct strength or fracture energy. Strength varies with particle size so that as a particle becomes smaller, its strength increases — that is, the fracture energy per unit of material mass increases. This is described using the size-dependent breakage probability submodel.



Laboratory cone crusher in operation simulated with Rocky DEM Tavares breakage model. Feed: 22.4–16 mm; closed side setting 5 mm.

"Crusher OEMs generally offer a limited choice of wear-part designs, and these are usually based on average conditions. But few crusher liner operators work under 'average' conditions," noted Tavares. *"We have been working with ME Elecmetal for about 10 years now, and we are thrilled that they want to become 'early adopters' of this virtual breakage technology."* Tavares and the Rocky DEM team are going beyond investigating liner wear and life expectancy — they are building a foundation for exploring how liner parameters interact, from performance improvements to geometry changes.

"With Rocky DEM, ME Elecmetal has confidence that simulation is the right direction, the proof needed about how crushers operate in the real world," Tavares, said.

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European Open Science Cloud: a real opportunity for European research

EOSC: a major co-design and co-creation effort... instead of reinventing the wheel every time, the intention is to recover and build on already existing structures.

By Gina Pavone and Emma Lazzeri
CNR

One often hears about EOSC in research circles: institutions are trying to understand how they will be involved, while researchers are wondering what their role will be. To begin, it is valuable to clarify what all the discussion is about: in this article we will provide an overview of the EOSC facility and its main objectives.

EOSC is an acronym for the European Open Science Cloud. It originates from the idea of building a European research infrastructure to facilitate the research process, connections between working groups, and the sharing of experiences and services related to knowledge and scientific work in order to fully benefit from an advanced and integrated management of research data. This infrastructure will be used to fully implement open science in Europe, creating a virtual environment to access, analyze, manage, store and/or reuse research results across the boundaries of scientific disciplines. It will provide a set of open and free services for the 1.7 million researchers and 70 million science and technology professionals, according to the estimate provided by the European Commission in its "Communication on the European Cloud Initiative".
EOSC is not just a simple cloud for data sharing, as its name may erroneously suggest. Nor is it yet another bureaucratic undertaking. Instead, the intention is to create a single access point to the working groups and to the results of all public research conducted in Europe, thereby facilitating the sharing and collaboration required by open science. This will benefit not only researchers, but also funding bodies and institutions.

At present, researchers may require data that has already been produced by other public research institutions, but they are likely to be unaware of its existence. If they spend time identifying it, they may possibly subsequently discover that they cannot use the data because, even though it may have been reported in a paper, the data is not stored in a repository where it can be easily found, or, in the case of sensitive data for example, the data may only be consulted and used after a specific request. In essence, a lot of resources are currently being spent on recollecting the same data, while the full potential of data that has already been collected, for example through multidisciplinary analysis, is not being exploited.

With EOSC, on the other hand, all data (and in general all digital products - publications, software, etc.) from public research will be traceable and accessible from a single access point online, which will also serve as a point for content sharing, meeting and exchange between researchers and European working groups. For funding bodies this means multiplying the impact of the resources deployed: facilitating the reuse of research and its results, the creation of new projects, international and interdisciplinary collaboration, and the associated social opportunities in terms of applications and new products, technology transfer and market opportunities.
A keyword for EOSC is co-creation: the various stakeholders, people and entities that are or will be affected by it currently have a great opportunity to become involved and participate. Indeed, this infrastructure cannot simply be imposed "from above" but rather has

to be designed and implemented together with the people who will use it and the other stakeholders, in a collective effort of co-design and co-creation. In order to avoid reinventing the wheel every time, the intention is to recover and build on pre-existing structures and understand how to combine them to enhance their potential.

The EOSC was officially launched in 2018 with a provisional governance structure to foster dialogue with the scientific communities in order to collect information on how to finally create the overall infrastructure. EOSC is currently composed of three constituent bodies: the Stakeholder Forum, a group of organizations, projects and initiatives involved in the co-design effort; the Governance Board, made up of representatives from each member state; and the Executive Board, composed of experts tasked with implementing a reliable infrastructure.

The work of the Executive Board is supported by working groups responsible for collecting information, suggestions, requests, and ideas from various stakeholders regarding partially predefined topics. These working groups are working on: architecture, defined as the structure to be given to the federated infrastructure; FAIR (an acronym for the characteristics required - in whole or in part - for the data and, increasingly, for all scientific products, i.e. that they are findable, accessible, interoperable and reusable) data and services; "context" analysis (or landscape analysis, the purpose of which is to map existing infrastructures in order to understand how to bring them into EOSC); "rules of participation", namely the regulatory framework for EOSC, in which the rights and obligations of users and service providers will be defined; and last but not least, sustainability, i.e. the financial structure within which the work will continue following the start provided by the European Commission with its funding for the various projects related to EOSC.

One of these projects is the EOSCSecretariat.eu, which is intended to act as a bridge between the Stakeholder Forum and the Executive and Governance Boards, and to manage the mechanisms set up for co-creation. On one hand, these mechanisms are designed to facilitate stakeholder involvement while on the other hand they will provide resources for co-creation activities. For example, the EOSC Liaison platform, an open online forum designed to collect feedback and input from users, provides a tool for participation by allowing users to upload content, consult official documents and the calendar of events, participate in existing discussions or create new ones.

For financing, there is a " co-creation budget" made available for activities not already covered by EOSC related projects or funded already by the commission. This budget can be accessed in two ways: passively, i.e. by responding to open calls for proposals that are managed by EOSC Governance; or actively, by proposing a study or an activity to the Governance Board.

The current construction phase therefore represents a unique opportunity for participation for all potential stakeholders and interested parties to benefit by ensuring that this extensive infrastructure is not constructed on top of them but together with them.

To accomplish this, and to prepare for the actual EOSC, there is something for all the various stakeholders to do. Researchers can inform themselves about the opportunities and ways in which they can contribute to the co-creation phase, e.g. by helping now to establish the list of requisites for and services by the infrastructure that is being built. Institutions can develop appropriate support services and undertake initiatives to facilitate the participation of their researchers. Content providers can follow the current processes underway to understand how to become part of the catalogue of services that will be federated in EOSC.

More generally, people involved in the Open Science world are invited to actively participate now, at this stage, to avoid being unprepared for the future developments to come.

The article was firstly published in Italian on APRE Magazine N.12 - January 2020

For further information, visit:
www.eosc-portal.eu/ and
www.eosc-hub.eu/

How EnginSoft transforms funded research into cutting-edge innovation

Announcing "The transformative power of research"

Published in June 2020, EnginSoft's projects collection, titled "The transformative power of research" documents the path EnginSoft has taken (and continues to pursue) in converting funded industrial research into state-of-the-art innovation. Innovation is impossible without research insofar as knowledge is essential for any development process, which is why EnginSoft places research at the core of its business.

Stefano Odorizzi, president and CEO of EnginSoft, explains, "EnginSoft has always believed in research and it is this conviction that has allowed us to remain at the forefront of the various technological sectors in which we specialize. Research projects are an excellent way for us to gain cutting-edge know-how, to deepen and extend the knowledge and expertise we already have, to access new sectors and, last but not least, to create and test new tools and platforms in the SBES field."

EnginSoft has actively contributed to innovation in European industry since 2003 by participating in almost 90 international research projects and contributing its expertise in Simulation Based Engineering Science (SBES). "The transformative power of research" illustrates the variety of contexts and sectors in which SBES can be applied, including Smart Manufacturing, Aerospace and Defense, Aeronautics, Materials, Energy, Marine, HPC, Biomedical, Construction, Geomechanics and Consumer goods.

EnginSoft's active participation in research projects also extends to various European research bodies, such as the European Factories of the Future Research Association (EFFRA), the European Materials Modelling Council (EMMC), the European Platform for High-Performance Computing (ETP4HPC), and the European Institute of Innovation and Technology (EIT)'s Raw Materials consortium.

"This publication is a testimonial to how and when research can be applied to benefit industry. It not only highlights the capacity that EnginSoft has developed as a facilitator and coordinator of different research consortia but demonstrates the depth and continuity of the company's involvement in pan-European bodies and projects," states Carla Baldasso, EnginSoft's Chief of International Research.

EnginSoft USA and MotionPort announce merger

Combined company will provide national coverage in Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD) and Multibody Dynamics (MBD)

EnginSoft USA and MotionPort, both leading providers of computer aided engineering (CAE) solutions, have announced the merger of the two companies to create a nationwide CAE services and software provider. MotionPort has over 25 years of experience in the field of mechanical computer-aided engineering (MCAE), with both the theoretical background and the practical skills to apply simulation technology to design challenges.

"We celebrate a new milestone today by merging with our highly-regarded peer, EnginSoft USA," said Brant Ross, owner of MotionPort, "Together under the EnginSoft umbrella, we can leverage our decades of experience to push the boundaries of multibody dynamics and CFD technology innovation while focusing on delivering outstanding technology, capabilities and service."

"We are thrilled to join forces with MotionPort," said Chris Wilkes, CEO of EnginSoft USA. "MotionPort has been on the leading edge of multibody dynamics and CFD research and application as testified by their extensive list of customers, commercial consulting engagements, and multiple government-funded research projects with NASA and the US Army. As a combined company, we expect to increase both the commercial and research parts of the business."

Michael Jang, President of FunctionBay, commented, "I have worked with Dr. Ross and his colleagues at MotionPort and with the team at EnginSoft for many years. It is a great pleasure to see this combination of talent and resources that will add capacity and focus to the market. This merger has our full support."

"The Prometech team is excited about this merger," stated Tsuyoshi Sumiya, COO of Prometech Software, Inc. "We have been working closely with EnginSoft for several years and are confident that the addition of MotionPort will provide greater resources for our Particleworks and Granuleworks customers."

About EnginSoft USA

EnginSoft USA supports companies in design process innovation, with extensive skills and highly qualified staff. We provide a wide range of software and services including effective, high-quality consulting, advanced training, development of ad hoc custom software, and research. www.enginsoftusa.com

About FunctionBay

FunctionBay, Inc. is a developer of RecurDyn – a computer aided engineering (CAE) simulation software for the simulation of both flexible and rigid body dynamics. We are the world leaders in the development of simulation technology. Our customers (including more than 500 corporate clients) cover a wide range of engineering disciplines, including automotive, shipbuilding, railway, office equipment, robots, heavy industry, and military vehicles and equipment.

About Prometech

Prometech Software was founded by experienced professionals and researchers at the University of Tokyo in 2004 and is the author of Particleworks and Granuleworks software. With the company's unique technology based on the moving particle simulation (MPS) and multi-GPU acceleration, Prometech provides simulation software and solutions to support engineering industries including chemical, rubber, steel, process manufacturing.

Save the date for the ASSESS 2020 Congress

ASSESS: Analysis, Simulation, and Systems Engineering Software Strategies to enable a significant increase in usage and benefit of these technologies

The ASSESS Initiative is a broad reaching multi-industry undertaking to facilitate a revolution in enablement to vastly increase the availability and effectiveness of engineering simulation. The Initiative has just announced that its ASSESS 2020 Congress dates and location have been confirmed. The ASSESS 2020 Congress will be held at the Chateau Elan Winery and Resort, 80.46km (50 miles) Northeast of Atlanta, from 2-4 November 2020.

The ASSESS 2020 Congress is the 5th annual congress for ASSESS, which is organized to "enable" both the strategies and relationships related to significantly increasing the use and benefit of engineering simulation. Key business drivers are forcing a "simulation revolution" to overcome the challenge of required expertise which is limiting the expansion of engineering simulation usage. The theme of the 2020 event is "Leading the engineering simulation revolution."

Registration for the ASSESS 2020 Congress is by invitation only and is limited to 110 attendees. Registration will close either when all the available seats are taken but no later than October 28, 2020.

"The ASSESS Congress is an advanced simulation-related event that is vendor neutral. It brings together a number of visionary professionals to share perspectives, build community, and propose solutions to the challenges that our industry faces," says Andreas Vlahinos, CTO at Advanced Engineering Solutions.

The ASSESS Initiative was formed to bring together key players, both users and developers of simulation software, to guide and influence the software strategies for performing model-based

analysis, simulation, and systems engineering with the intent "To significantly expand the use and benefit of software tools for model-based analysis, simulation, and systems engineering in the engineering applications domain".

The ASSESS Initiative Membership program enables the ASSESS Initiative to expand its efforts and community benefits beyond the annual congress. The ASSESS Membership Program is appropriate for all organizations engaged in analysis, simulation, and systems engineering activities related to engineered products and processes. Both individual and group memberships are available. Active members can access members-only content on the ASSESS website and receive a discount on the ASSESS Congress registration fee.

About the ASSESS Initiative

ASSESS Initiative LLC was formed in mid-2016 for bringing together the key players to guide and influence the software development and implementation strategies related to model-based analysis, simulation, and systems engineering, with the primary objective of expanding the use and business benefit of engineering simulation. ASSESS Initiative LLC is based in Clarkesville, GA, USA. Please the website www.assessinitiative.com and the following brief summary "What is the ASSESS Initiative and why is it important?" for more information.

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