ENGINSOFT

futurities

Year 20
02
Summer
2023

The Simulation Based Engineering & Sciences Magazine

SPOTLIGHT

Engineering for renewables

- Editor's Note

First of all, allow me to take this opportunity to inform you about the creation of EnginSoft Simulation Software Italia (ESSS Italia), a new company within the EnginSoft group. ESSS Italia has been formed in a partnership with ESSS, a Brazilian multinational with a global presence in the computer simulation market and a long-term Ansys Elite Channel Partner in Latin America and Iberia. The new company will focus on developing the Ansys software business supported by significant investment from ESSS to accelerate its growth. I believe this partnership will be of significant benefit to the Ansys business and to our customers in Italy, who can now draw on the combined skills of our two highly experienced teams.

Turning our attention to the summer issue of Futurities now, we have placed the **Spotlight** on sustainability by looking at Engineering for Renewables. With ever-increasing pressure from the public, academia and scientific bodies on governments and businesses to take significant action to reduce carbon emissions and convert to renewable energy sources to mitigate the effects of climate change and reduce the various kinds of pollution, there is more pressure than ever on engineers to create the solutions – either by developing better methods to use and store energy from renewable sources more efficiently and effectively, or by reducing the impact of the existing, traditional energy sources by making their use cleaner, more efficient and less harmful. Among other pieces, our Spotlight looks at a solution from SAER Elettropompe to modify turbines to generate low-cost electricity from existing piping systems as well as a study by ESTECO to ensure the stability and functionality of offshore wind turbines even in hurricane-force winds.

This issue also features an in-depth **Face to Face** interview with Paul Stewart, a long-time design process leader and consultant in the automotive sector, having participated in production design projects for almost every automotive and heavy truck OEM worldwide. We interviewed him about his thoughts on the evolution of simulation in the automotive industry and the likely impact of new technologies.

In our **Know-how** section, where we explore different challenges and share the approaches and methodologies engineers have undertaken to overcome them, we have an article from ISEO Serrature who discuss how they have been introducing a new approach to calculating tolerance chains when designing new products in their sector of mechanical and connected solutions for intelligent access control. Our other article in this section looks at how EMAK, which manufactures machines for gardening, small-scale agriculture, and civil construction, was able to reduce the design time of a two-stroke engine for handheld applications such as chainsaws, brush cutters, and blowers by automating the generation of the CAD model to be used as a reference for the designers as much as possible.

The **Research & Innovation** section includes some more of the success stories from the EU's FF4EuroHPC initiative to promote the uptake of advanced HPC technologies and services by funding business-oriented experiments for European SMBs, and a discussion of a virtual approach adopted to design the component and optimize the additive printing process of CuCr1Zr copper alloy using laser powder bed fusion technology. The component is intended for use as a "cold crucible" for the controlled melting of metal with the objective of saving energy and reducing power consumption compared to traditional cold crucibles.

This edition's **Product Peeks** look at the latest release 6.0 of MAGMA, complex battery system storage modelling with Ansys Twin Builder and Ansys Fluent, and look in detail at the use of Ansys Actuator-Designer to predict the operating performance of a solenoid valve.

Our next issue will be a special edition focused on Additive Manufacturing.

In the meantime, I wish you an informative read.

Stefano Odorizzi

Editor in chief

"Engineering is fundamental to the achievement of sustainability overall because of the impact that industrial activities and construction have on the planet.

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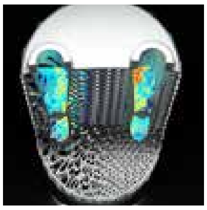

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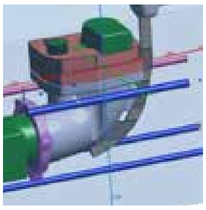
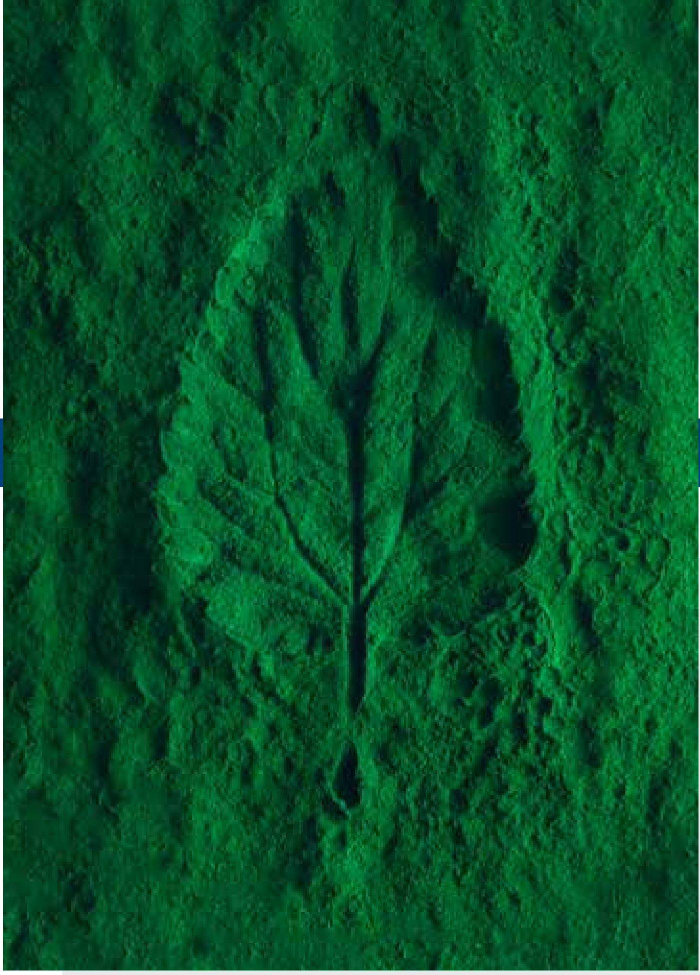


SPOTLIGHT



SPOTLIGHT

Engineering for Renewables

Contriving more sustainable energy systems

The focus on sustainability in recent years has seen the development of many sources of renewable energy, including more "traditional" sources, such as wind; the sun; rivers, lakes, and the sea; and the heat generated by the earth, as well as newer approaches like biofuels, recycling of certain parts of waste, or the capture of environmental heat using specific pumps. According to the International Energy Agency, "Renewables play a key role in clean energy transitions and the deployment of renewable power is one of the main enablers of keeping the rise in average global temperatures below 1.5°C."

The International Renewable Energy Agency (IRENA) announced that 83% of all power capacity added in 2022 was produced by renewables, "By the end of 2022, global renewable generation capacity amounted to 3,372GW, growing the stock of renewable power by a record 295GW or by 9.6%," it stated in a press release. However, IRENA's Director-General Francesco La Camera, cautions that annual additions of renewable power capacity must grow three times the current level by 2030 to stay on a pathway limiting global warming to 1.5°C.

IRENA's research shows that hydropower accounts for 1,250GW – the majority – of the total renewable generation capacity, but that solar and wind collectively contributed 90% to the share of all new renewable capacity last year.

Engineering is fundamental to the achievement of sustainability overall because of the impact that industrial activities and construction have on the planet. On the one hand it can drive the optimization and/or overhauling of existing infrastructure and extraction, production and waste disposal or recycling processes to become more energy efficient and sustainable, while it is also playing a key role in optimizing new sustainable forms of energy generation, as well as innovative approaches to a range of industrial activities to minimize their environmental impact and increase their social and economic contributions.

We turn the **Spotlight** of *Futurities* onto the topic of renewable energy in this issue, and explore a small portion of the activities being undertaken by engineers across the spectrum to address the urgent need to reduce our impact on the environment and make better use of the finite resources on the planet for the good of all. These activities may take the form of refitting existing equipment such as is explored in the article from SAER Elettropompe who have repurposed turbines to generate low-cost electricity; and ESTECO's article on the optimization of offshore wind turbines to enable them to better withstand hurricane-force winds during the increasing number of extreme weather events; or it may involve the fine-tuning of energy storage, discussed in the article from Ansys on digital twins for battery packs, and efforts to "green" aviation, as explored in a couple of articles reprinted from the *Horizon Magazine.*

Bibliography

IEA 2022, "Renewable Electricity - Analysis and key findings. A report by the International Energy Agency", published online September 2022, www.iea.org/reports/renewable-electricity, License: CC BY 4.0, accessed 30 May 2023.

IRENA 2023, "Record Growth in Renewables Achieved Despite Energy Crisis", published online 21 Mar. 2023, www.irena.org/News/pressreleases/2023/Mar/Record-9-point-6-Percentage-Growth-in-Renewables-Achieved-Despite-Energy-Crisis, accessed 30 May 2023.

From saving energy to creating energy

Use pumps as turbines to generate low-cost electricity from existing piping systems

by Marco Favella
SAER Elettropompe

SAER has been using Ansys CFX to study pump fluid dynamics since 2006. One of the company's key objectives has always been to improve the efficiency, and reduce the energy consumption of its pump designs. This article describes how SAER ELETTROPOMPE used Ansys CFX to transform "standard" pumps into pumps to be used as turbines.

Hydroelectric energy recovery is an effective response to rising energy prices and the requirement to lower CO_2 emissions. Pumps as turbines (PATs) can transform excess water energy into power and the newly generated electricity can be used for own consumption or fed into the grid. With low investment and maintenance costs, PATs enable the recovery of the energy from existing pipe networks and provide significant energy savings.

As a result, the demand for PATs, a recognized use of pumps, has grown significantly in recent years as the focus has moved from the concept of energy saving to that of energy creation: that is, using pumps as turbines to generate cheap electricity from existing pipeline systems without any associated environmental impact.

However, even in this type of use, it is essential to ensure that the theoretical design data corresponds to actual data in the field.

Thanks to the experience accumulated by SAER engineers over almost 20 years of using CFD systems, the reliability of fluid-dynamic simulations and SAER tests systems, and the knowledge gained from more than 70 years of experience in the pumping sector, it was a natural for the company to extend its know-how to the design of PATs.

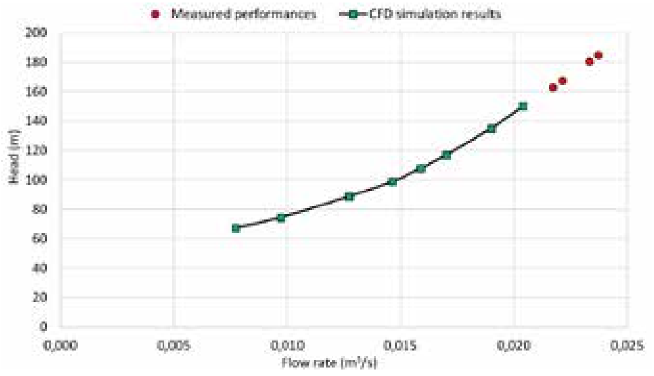


Fig. 1. Characteristic flow/prevalence curve (black-green) modelled by CFD analysis v. experimental measurements taken after installation (red).

SAER has developed a wide range of pumps for use as PATs, specifically small and medium-sized modular hydroelectric generator sets suitable for sites up to 500kW of nominal power. Instead of a specially designed conventional turbine, SAER offers a standard water pump designed for reverse operation and CFD verified, which is easy to maintain and offers a low life cycle cost.

PAT simulation with Ansys CFX

A mathematical model of the turbine was created with Ansys meshing and then used to calculate the different sizes of pump to be used as a turbine for each INPUT set (the different pressures given by the different jumps in potential energy): the range of flow rates, the efficiency and the power generated in kW.

The simulation, carried out with Ansys CFX 2022 R2, made it possible to calculate the power generated by the thrust received by the impeller and transmitted from the pump shaft to the generator. In the end, SAER was able to verify that a large part of its range of centrifugal electric pumps, multistage centrifugal pumps, and split-case pumps, noted for their characteristic flexibility and versatility, can be easily adapted for use as a turbine. According to Eng. Marco Favella, Quality Manager at SAER, these characteristics are important identifying traits that the company strives for in its production. He continues, “Ansys CFX has enabled us to confirm deviations between actual and theoretical data of less than 3% – even in this type of application.”

Benefits of PATs

- Hydroelectric energy recovery is an effective response to rising energy prices.
- Pumps used as turbines can transform excess water energy into electrical energy.
- The turbines are optimised to operate reliably and fail-safe.
- The newly generated electricity can be self-consumed or exported to the grid.
- Negligible environmental impacts, minimal water. requirements and no need for reservoirs.
- Rapid return on investment and simplified maintenance due to ready availability of spare parts.

SOFTWARE: ANSYS CFX 2022 R2
ANALYSIS TYPE: Steady state. Global Number of Elements = 44,209,579
PARALLEL ENVIRONMENT: 64 Processors
HARDWARE: AMD Ryzen Threadripper PRO 5975WX 32-Core 3.60GHz processor with 256GB RAM installed.

Case study: Pilot energy-recovery installation in an underground mine in Ireland

The project, one of the first involving a PAT application inside an operating mine, was developed in collaboration with Easy Hydro which is a spinout of Trinity College Dublin and SAER’s partner in the supply of PAT installations. The PAT was designed and installed to recover energy in parallel with an existing pressure reducing valve station on a DN150 pipeline that carries freshwater from the surface down to the depths of the mine. The turbine is located 300m underground, and the project aimed to allow the mine operator to generate its own power and reduce the import

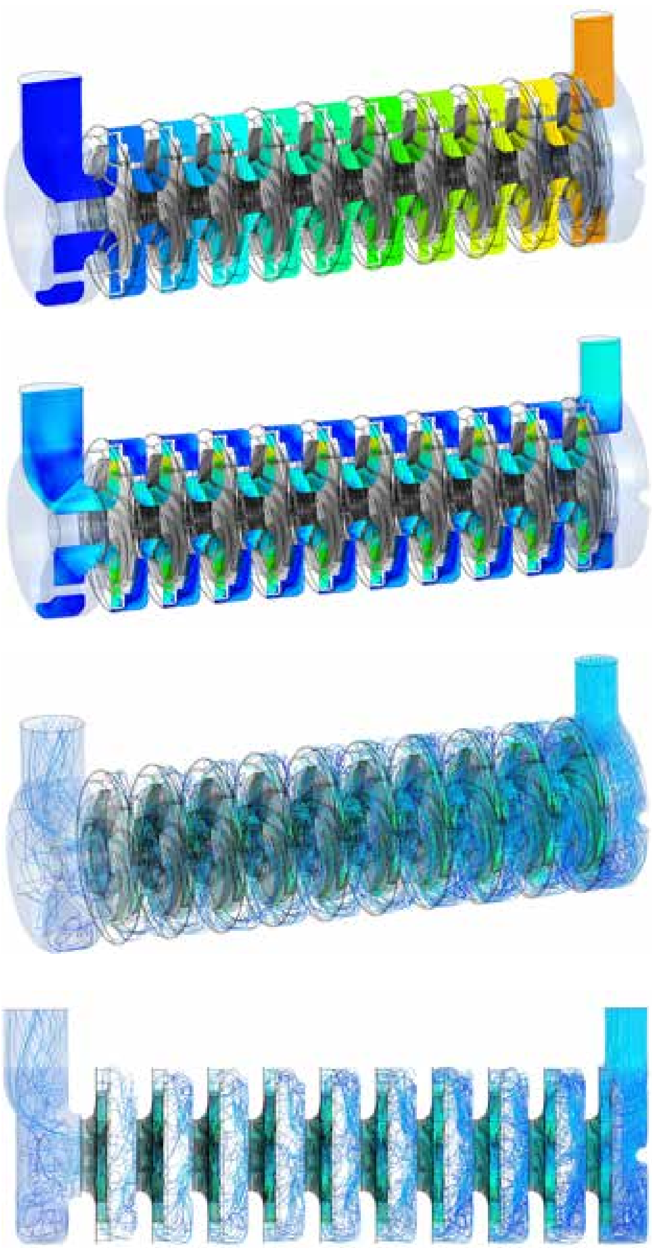


Fig. 2. SAER multistage turbine model E-TMZ-4P-50-80. Top: during manufacture; bottom: after installation.

of electricity from the grid as opposed to simply dissipating the water pressure as heat and noise through the use of pressure reduction valves.

Based on the site data (hydraulic head 210m and flow rate 15-25l/s), a multistage pump from the SAER TMZ range was selected to operate as a turbine. Then, in order to confirm the exact number of stages of the unit, a CFD simulation was performed to model the flow/head performance curve.

As shown in the graph above, the simulation was carried out between 7.7 and 20.4l/s and the simulated performance curve matched very well with the operating conditions measured in the field after installation. The final PAT selection consisted of a SAER model E-TMZ-4P-50-80 multistage unit with 10 impellers, connected to a 37kW SAER generator.

With an average flow rate of 22l/s and a pressure drop of 21 bar, the turbine produces up to 30kW of clean renewable energy, saving more than 200MWh of electricity that would otherwise be imported from the grid each year. This corresponds to the annual energy consumption of almost 50 average Irish households.

The proposed installation will directly offset over 60 tons of CO_2 per year and this technology, if replicated in a number of other similar locations within the same mine, has the potential to significantly reduce the current carbon footprint of the mine.

The technology allows water-intensive organizations to conveniently exploit an untapped source of energy in a cost-eff effective manner, all with negligible environmental impact, due to the use of the existing infrastructure.

To develop this project, Easy Hydro received a booster grant from the EU EIT Raw Materials consortium, which highlights the growing interest in hydroelectric energy recovery solutions from the mining sector.

For more information:
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About SAER Elettropompe

SAER Elettropompe is one of Italy's leading manufacturers and suppliers of surface and submersible pumps and motors, with over 70 years of experience in the Italian and international markets. A specialist in the clear water sector, where it offers 360° solutions, SAER offers its customers and partners maximum flexibility and innovation thanks to an advanced in-house design department and its constant research and development that allow the company to offer highly customized products in short timescales, with all the guarantees of Made-in-Italy quality. For more information, visit: www.saerelettropompe.com/en/home

About Easy Hydro

Easy Hydro, based in the campus of Trinity College Dublin, is a spinout born from the experience of the Dwr Uisce and REDAWN research projects. Its members have accumulated unique expertise in the design, selection, and installation of hydraulic pumps operating as turbines for energy recovery in water networks or for small-scale hydropower schemes. For more information, visit: easyhydrosolutions.com/

Optimizing an offshore wind turbine monopile for hurricane-prone regions

by Matteo Bucchini[1], Gabriele Degrassi[2]
1. Blom Maritime - 2. ESTECO

The offshore wind energy sector is developing rapidly in the United States. Several new wind farms that use turbines supported on fixed foundations are at various stages of development, especially off the northeast coast. Indeed, there are no plans for floating installations primarily because the continental shelf extends a considerable distance from the shore and so the waters are relatively shallow.

One of the key technical aspects to consider when designing monopile foundations for offshore wind turbines in the US is the occurrence of tropical cyclones along its east coast. The maximum wind speeds of hurricanes can exceed the design limits of wind turbines, making them vulnerable to blade loss, while the supporting monopile foundations can also deform. To tackle this challenge, the goal is to design a wind turbine monopile system that functions even when it is subjected to a critical load such as a strong storm.

Traditionally, the process of developing a design to meet these criteria is iterative and relies on the engineers' skill and project experience. However, modern simulation and numerical analysis techniques were developed to assist engineers to optimize designs according to their set of criteria in less time, which is why we used ESTECO's modeFRONTIER process automation and design optimization software to demonstrate how the design of a monopile for a 15MW turbine can be optimized to survive hurricane conditions.

Investigating the monopile's structural design and response under different environmental conditions

As with any large-scale investment in a project such as an offshore wind turbine farm, numerous factors need to be considered:

- Environment (wind and marine conditions, seabed movement and scour, and conditions such as air temperature, solar radiation, seismicity, maritime traffic, and so on)
- Structure (rotor-nacelle assembly, support structure, energy production and transfer, operation, maintenance, and emergencies)
- Actions/loads (gravitation/inertia, aerodynamics, hydrodynamics, actuation, wake loads, impact loads, tsunamis)

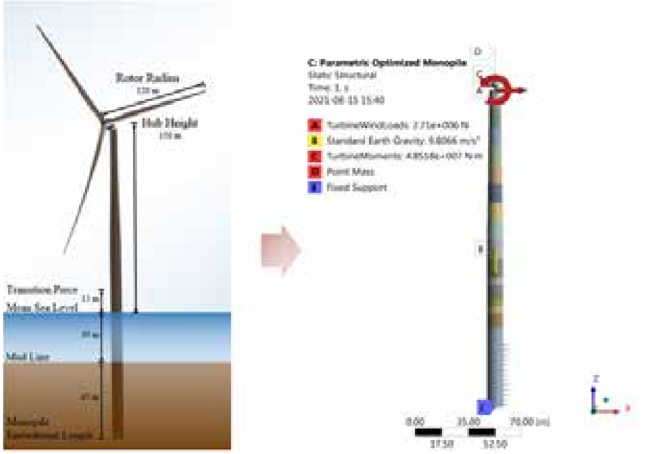

Fig. 1. Structural design of a single wind turbine on a monopile foundation.

The scope of this project is limited to the structural design of a single wind turbine on a monopile foundation. For this study, we used the NREL IEA 15-megawatt offshore reference wind turbine as a starting point. This monopile, which is circular in cross-sections, is 10m in diameter and about 75m long; the thickest segment is the wall thickness, which exceeds 55mm. Based on these considerations we transformed the monopile design into a finite element (FE) model using Ansys Workbench.

Five connected Ansys Workbench blocks form the core of the analysis:

- Three static, structural-analysis blocks cover loads, boundary conditions, and deformation-stress results. Each block covers one load case.
- A modal-analysis block, which is connected to the solution step of the previous block and covers the extrapolation of the natural frequencies from the constrained geometry.
- Additionally, an Excel block is used to incorporate the characteristics of the sandy floor that vary with the depth of the monopile. This block is linked to the parameter set and provides information to the nonlinear springs that are used to represent the soil behaviour.

With regard to the design loads, the monopile foundation is subject to the forces of the waves, ocean currents, winds, and more. Structurally, the wind turbine is designed to cut out at a specific wind speed. In hurricane conditions, the blades are feathered to stop turbine rotation and reduce the loads. Wind loads are calculated for the following conditions using NREL's OpenFAST software:

- Wind speed from max thrust: 11m/s
- Max operational wind speed: 25m/s
- Hurricane conditions: 50m/s

Design optimization process for an NREL 15-MW offshore wind turbine monopile

The optimization-driven process was created and automated in a modeFRONTIER workflow by integrating the Ansys FEA (finite element analysis) model and the NREL OpenFAST software to extract the loads from the operating conditions. The overall aim was to minimize the offshore wind turbine monopile's mass because this parameter is one of the most important influences on the cost, affecting the quantity of material used and the fabrication cost.

Focusing on the overall structural geometry, the primary input design variables considered are the diameters of the base of the monopile and the top of the tower; and the discrete distribution of wall thickness along the height. The main output variables considered are the mass of the monopile, transition piece and tower; the maximum stress experienced; and the natural frequencies of the structure. The design constraints in this problem include the maximum stress experienced by the monopile, buckling checks, and the natural frequencies.

Once the simulation process workflow had been set up, we performed design of experiments (DoE) studies using the uniform Latin hypercube (ULH) algorithm in the modeFRONTIER Planner environment to create 42 configurations of the monopile.

The aim was to minimize the correlations between the input variables and maximize the distance between generated designs

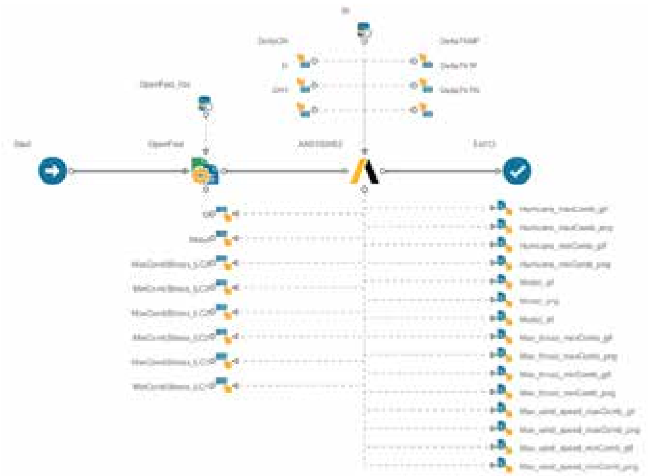

Fig. 2. Automated workflow in modeFRONTIER to minimize the mass of the offshore wind turbine monopile.

Fig. 3. modeFRONTIER cluster parallel coordinates chart: best cluster selected for virtual optimization.

to explore which areas presented feasible designs before starting the optimization process.

A sensitivity analysis was performed on the results of the DoE, which highlighted the important influence of the t1 (thickness of the first section) and OR1 (outer radius of the first section) parameters on all the outputs. We then applied the FAST RSM-based algorithm to run the design optimization study in modeFRONTIER. This allowed us to concurrently evaluate 202 designs, finding the best feasible design after 150 evaluations.

Starting from the optimization results, modeFRONTIER's clustering tool was used to find the best cluster and this subset was used as the starting point for a virtual optimization on a reduced design space.

The process led to three different designs with apparently better mass values, but validation revealed that they were not, in fact, better than the original best point.

Post-process offshore wind turbine monopile model results in an SPDM framework for collaborative design optimization

To enable us to improve collaboration between the different subject-matter experts involved in this project, the simulation results were uploaded to ESTECO VOLTA – an enterprise platform for simulation process and data management (SPDM) and design optimization.

Thanks to VOLTA Advisor, the advanced web-based data analysis environment, we could collaborate to compare and evaluate the different design results in real time from an interactive dashboard.

In summary, the reduction in mass for the multi-case scenario is lower than for the hurricane condition itself. The result is still significant. By including more loading conditions and design criteria, the result is an increase in the optimized mass value. The weight of the structure has been reduced by more than three percent,

Fig. 4. VOLTA Advisor enables different subject matter experts to collaboratively decide on the best design solution for the NREL 15-MW offshore wind turbine monopile

Name	Initial value	Best Design just LC3	Best Design Common Optimum
Mass [kg]	2.01E+06	1.64E+06	2.01E+06
Δmass%	0.0%	-18.5%	-3.4%

Table 1. Reduction in mass for the multi-case scenario and for the hurricane condition.

however, with an associated reduction in the cost of construction.

The simulation workflow in the VOLTA SPDM platform is impressively powerful: we ran hundreds of designs in half a day, finding the best ones. The VOLTA working environment also provides all the design exploration tools in the same place, which is available via browser from any computer. This is both flexible and powerful.

This research project was undertaken by the HS-03 SNAME panel consisting of the following members and supporting companies: Matteo Bucchini (BLOM Martine); Zhiyong Yang (7C Engineering); Roger I. Basu (Roger Basu & Associates); Aimin Wang (EXMAR Offshore); Won Ho Lee (Lloyd's Register); Gail Baxter (consultant); Robert Sielski (consultant); Raffaele Frontera (HMC); and Gabriele Degrassi (ESTECO).

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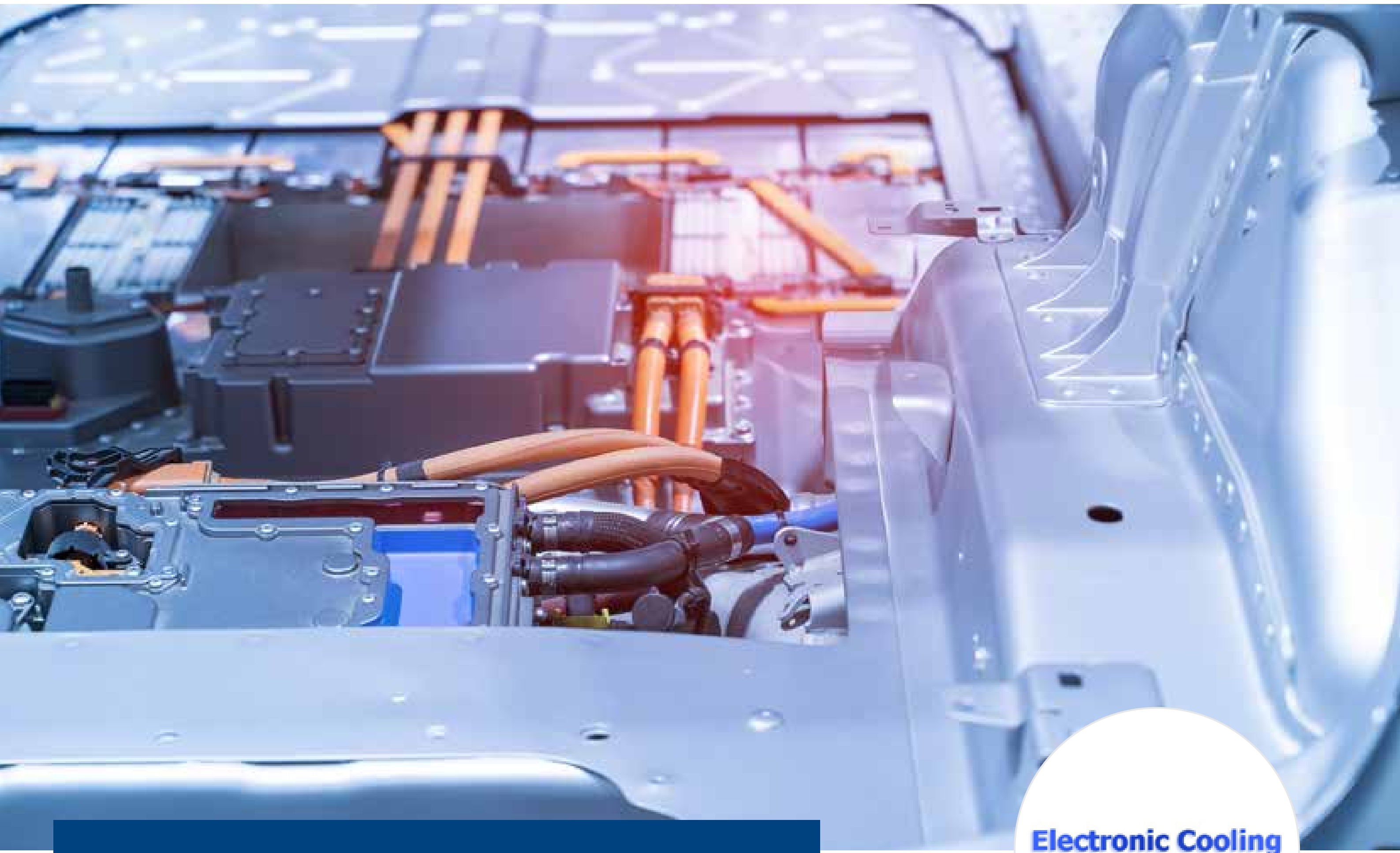
The University of New Orleans (UNO), the Louisiana Wind Energy Hub, and DNV held a technical workshop entitled "Expanding Engineering Knowledge for Floating Offshore Wind" at the UNO on April 12, 2023. At the event industry experts from DNV, Principle Power, UNO, Gulf Wind Technology, TAI Engineers, CONVERGE CFD, EXMAR Offshore, and 7C Engineering shared their knowledge about the various aspects of offshore wind ranging from design and manufacturing to supply chain and economics.

The HS-03 panel of the Society of Naval Architect and Marine Engineers (SNAME) reviewed its recent research activities including the forthcoming publication of "Guidelines for Structural Finite Element Analysis of Marine Structures", and the SNAME research paper "Optimum Design of Large Wind Turbine Monopile".

It also announced a new Joint Industry Project (JIP) proposal on Structural Sizing and Load Selection for Early-Stage Design.



Digital twin prevents drain on battery pack simulation time

by Azita Soleymani
Electronic Cooling Solutions

The global shift to electric vehicles (EVs) is coming, and unless alternative technology emerges, it will be fuelled by high-capacity lithium-ion (Li-ion) batteries. Making the hundreds of millions of Li-ion batteries the world will eventually need for electric mobility is a massive undertaking full of technical challenges. Concerns about battery pack size, weight, cost, and sustainability have to be resolved before there can be a mass rollout of "green" cars; so do issues about battery life span and safety, which can be affected by thermal conditions.

Among other benefits, regulating cell and battery pack temperature within a given range can increase the number of cycles a battery can achieve, making performance more dependable. More importantly, an effective thermal solution can reduce the possibility of catastrophic battery failure. US-based Electronic Cooling Solutions provides thermal management expertise to the electronics industry, rapidly identifying and resolving thermal questions using analytic and optimization tools, including Ansys simulation software. Recently, the company used Ansys Fluent and Ansys Twin Builder to investigate design optimization of a battery pack thermal system.

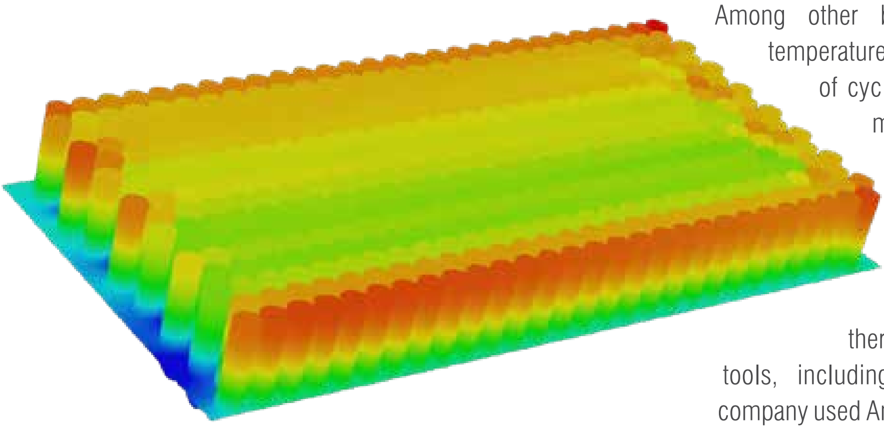


Fig. 1. A temperature profile of a battery module.

Simulation enabled Electronic Cooling Solutions to:

- Develop and validate the best operating setup for user comfort and safety
- Validate the design for aggressive scenarios such as fast driving, cold start and fast charging
- Conduct troubleshooting
- Predict performance decay with age

Monitoring battery packs for preventive maintenance

Operating an EV requires an enormous amount of energy, which is why the battery is such an important — and expensive — component. It is not unusual for the battery to represent as much as 50% of the total cost of the EV.

There are two main types of Li-ion battery cells: cylindrical and prismatic. Cylindrical cells are small, typically measuring 2cm in diameter and 7cm in height, and there can easily be thousands of them in an average battery pack. Typically, the cells are organized into clusters called modules. Multiple modules form a pack.

Unlike most electronic integrated circuits and microchips in electronic devices, the optimal temperature range for Li-ion battery packs is quite narrow and varies depending upon cell supplier, charge and discharge mode, and other factors. To ensure performance — and to avoid irreversible damage — the average temperature of the cells and the temperature difference among them should be within a target range.

Battery packs are designed with separators to keep electrodes from touching one another and generating heat. Unfortunately, separators can fail for a number of reasons: a side-impact collision can tear them; an electrical shock can pierce or puncture them; and extreme temperatures, either ambient or related to the car's operation, can cause the separator to collapse. If any of these events occur, it can lead to thermal runaway. As a result, the battery begins smoking, catches on fire or even explodes. As for the car, it can be a total write-off.

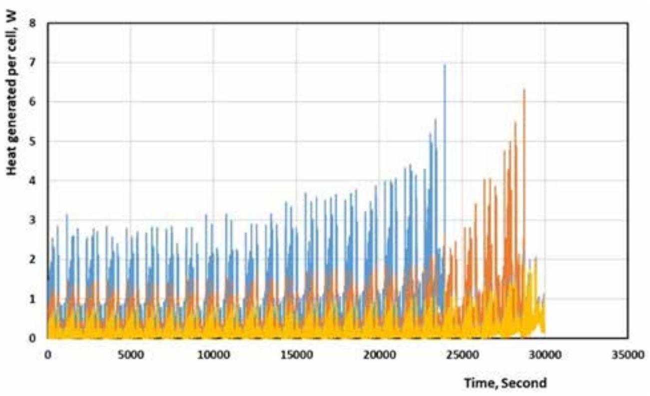


Fig. 2. This graph shows the typical heat-generation data from an equivalent circuit model of Li-ion cells. Colour indicates the impact of operating temperature on the rate of heat generation.

To prevent these problems, Electronic Cooling Solutions characterized a robust, reliable and cost-efficient battery pack temperature monitoring system. Because a Li-ion battery pack is a highly convoluted multiphysics system, the company had to consider a variety of key factors, such as analysing in transient fashion:

- Heat generation as a function of the design of the battery pack's busbars, which are used for local high current power distribution, and the speed of electrochemical reactions, which is dependent upon temperature, state of charge (SoC), electric current, and the electrochemistry properties of the cell
- Heat removal rate as a function of coolant flow rate, design of cooling system, and change of the coolant's physical properties with temperature
- Three-dimensional spread of dissipated heat

A design of experiment (DoE) approach had to incorporate a range of conditions to ensure that all thermal requirements were met: fast charging, cold start, charging at low temperature, discharging when the charge was low, and different drive cycles.

Using conventional computational fluid dynamics (CFD) to validate design is not practical because of the large number of cases that have to be considered. Although it is possible to perform and link 1D and 3D simulations, each method has limitations that could cause design problems.

For example, although 1D simulation is fast and allows for multiphysics analysis, it doesn't include 3D visualization of the problem. On the other hand, 3D transient simulation can be computationally expensive, considering the large number of cases.

To overcome those issues, Electronic Cooling Solutions developed a digital twin that provided the accuracy and reliability of 3D simulations and the computational speed of 1D.

Digital twin enables real-time analyses

The company used Twin Builder to capture live sensor data and develop a digital twin model of the Li-ion battery packs that captured real-time behaviour in a real-time environment. This allowed engineers to conduct in-depth root cause analyses on various inputs and operating conditions, including initial SoC, temperature, coolant flow rate, and different charge and discharge profiles.

To generate the digital twin, engineers began by characterizing battery cell performance. Considering the highly convoluted multiphysics nature of Li-ion battery cells, the thermal load of each battery cell at one instant in time depends on the cell type (manufacturing parameters), SoC, cell temperature, charge/discharge mode, magnitude of electric current extracted from cells and aging. Typically, each cell is represented by a 2RC model

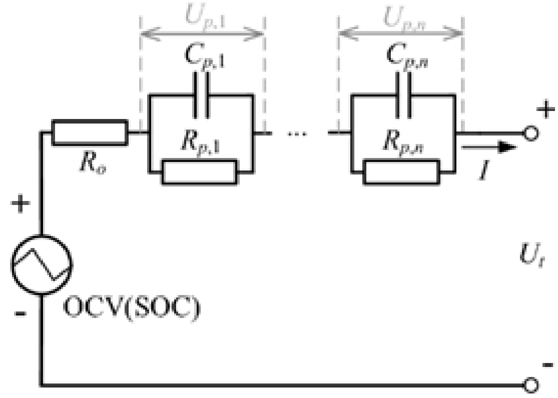


Fig. 3. The 2RC model representing the Li-ion battery cells' temporal thermal and electrical performance.

(with one resistance and voltage source in series). Engineers also conducted hybrid pulse power characterization (HPPC) tests to characterize and estimate the cell parameters.

Next, they used Twin Builder to create an equivalent circuit model (ECM) of a battery cell that accounted for all electrochemistry behaviour, and then applied the model to real-time heat generation. The ECM approach is based on the battery cell's impedance response — that is, its resistance to alternating current — under different external conditions.

Engineers then performed transient 3D simulation using Fluent to generate response curves at the battery pack level. They fed the response curves into the reduced order model (ROM) application of Fluent to create the ROM of the battery pack. Linking the ROM and ECM of the battery cell in Twin Builder produced a digital twin model of the battery pack. It has the accuracy of conventional 3D analysis and the speed of 1D system-level analysis.

Electronic Cooling Solutions validated the developed model by comparing results against available test data. They then used the model to evaluate design feasibility for various operations and to optimize and troubleshoot the design.

Thermal management critical for mainstream electric vehicles

Thermal management of Li-ion batteries is a daunting task that can be computationally expensive and time-consuming. But with more than half of the new cars on the road expected to be all-electric by 2040 vehicle reliability and driver safety depend on it.

By relying on Ansys' results-driven software, Electronic Cooling Solutions was able to consider the critical design elements required for an effective thermal monitoring system and significantly reduce the calculation time from weeks to hours compared to other approaches. This resulted in significant time-to-market reduction. Electronic Cooling Solutions provided their client with recommendations for a high-performance product designed to help bring EVs into the mainstream — and bring the future closer to reality.

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About Electronic Cooling Solutions, (ECS)

Electronic Cooling Solutions (ECS) was founded in 1998. The company was formed with the vision of providing the best thermal management consulting services to the electronics industry world-wide. This vision continues to be the driving force for the company and its team.

ECS provides services for companies in a wide variety of industries and applications. Our customers develop products for the avionics, consumer, computing, medical, networking and telecommunications industries. Special needs can also be addressed, such as cooling the electronics for a unique telescope, and the thermal issues in manufacturing processes.

Since its founding, ECS has established a reputation for excellent service to its customers, providing high-quality and cost-effective solutions. Each member of the team is customer-driven and brings a combination of design, analysis and test skills to the issues faced by our customers. Several members of the team have 15 or more years of experience solving thermal problems in a product development or research environment.

The quest for hypersonic and hydrogen-fuelled air travel

While flying is a major contributor to the climate crisis, behind the scenes scientists are designing cleaner and faster airliners.

By Tom Cassauwers

What if we could get from Paris to New York by plane in less than one hour?

An EU-funded project is dreaming big about the future of sustainable – and fast! – aviation, proposing of a revolutionary aircraft design that could take 300 passengers from Paris to New York in record time.

The aircraft would be hypersonic, powered by hydrogen, and fly in the stratosphere, 30km up in the air.

The passenger planes of today are based on designs that have been fundamentally the same for decades. This means that flight times have also changed very little. But what if people could get from Paris to New York in less than one hour?

Sky-high ambitions

That's what the EU-funded STRATOFLY project proposed: a Mach 8 airliner – a hypersonic aircraft that can go at least 9,500km per hour, or about eight times the speed of sound.

"It's going to be a real challenge," says Nicole Viola, who coordinated STRATOFLY and is a professor at the Polytechnic University of Turin in Italy. "Maybe we're not ready yet for Mach 8 right now. But I'm sure that I will see a hypersonic airliner in my lifetime."

A three-year initiative that began in 2018, STRATOFLY designed a prototype for a hydrogen-powered hypersonic aircraft able to carry 300 passengers.

Ambitious ideas like this one are entering the world of civil aviation once again. New designs, technologies and fuels are being explored to make aeroplanes fly faster, soar higher and have a smaller environmental footprint. While these technologies might take decades to enter service, it's important to dream big now, according to scientists.

> I'm sure that I will see a hypersonic airliner in my lifetime.
>
> Professor Nicole Viola,
> STRATOFLY

Not so fast

The STRATOFLY design came with plenty of technological challenges. But one of the biggest sticking points was not so much to create an aircraft that could fly fast, but rather to design one that could also fly slowly. "The challenge isn't in the hypersonic phase," says Viola.

The hypersonic airliner that Viola and her colleagues dreamed up would need not only to fly at high speeds but also to take off and land at much lower velocities. This produces design challenges. An engine capable of hypersonic speeds, for example, is not the best option for lower speeds.

A hypersonic engine also needs a huge inlet to "breathe in" air, which gets mixed with hydrogen. "As the speed grows, the inlet grows as well," says Viola. But at a lower speed, less air needs to get sucked into the engine. This requires scientists to make a compromise in the design.

The 94-metre aircraft contains a massive inlet in the nose, with sliding doors to regulate the air intake. From take-off to a speed of around 5,000km/hour, six smaller engines do all the work. Above that velocity, one massive engine extending along the tail thrusts the aircraft forward.

Back to the future

The STRATOFLY proposal is only a concept designed to demonstrate what a hypersonic airliner could look like. It allows researchers to test and think about new technologies that might take decades to build successfully.

Today, however, the aviation industry might be returning to supersonic airliners like the famed Concorde, which was in service for more than 30 years before being retired in 2003. Used by Air France and British Airways, the Concorde was best known for its Paris-New York and London-New York routes featuring one-way travel times of three to three-and-a-half hours.

Boom Aerospace, a US company, has already signed contracts on supersonic design with United Airlines and American Airlines. And hypersonic flight is attracting attention beyond civil aviation. The space industry is eyeing the technology to build craft that can take off like a plane, a development that could reduce the need for expensive rocket launches. "Hypersonic is somewhere between aviation and space," says Viola. "So, eventually, we will see one of those fields take up the technology."

Clearing the air

If such high-speed flying eventually becomes possible, a related goal is to limit the environmental impact. Today, aviation accounts for around 2.5% of global CO_2 emissions, a percentage that risks rising with faster flights.

Hydrogen might be the solution here, according to Professor Bobby Sethi of Cranfield University in the UK. "We have been researching hydrogen for aviation for a long time," Sethi says. "The costs, however, have long dampened enthusiasm. But its introduction is a question of when, not if."

He coordinated the EU-funded project ENABLEH2, which examined the potential of hydrogen in aviation over four years through last November. There is much to like about hydrogen, according to Sethi. It is one of the most abundant elements on Earth and, if generated with renewable energy, emits no CO_2. In addition, the ENABLEH2 research showed that hydrogen combustion systems will deliver lower emissions of NO_x, another greenhouse gas, than kerosene. Furthermore, aircraft powered by hydrogen can fly longer distances than electrified planes, which will likely be used only for short to medium-range flights.

Transition routes

But then there are the costs. Hydrogen behaves differently than regular aviation fuel, so planes and some airports would need to be completely redesigned – a transition that could take around 20 to 30 years, according to Sethi.

"We could technically redesign an existing aircraft, like an Airbus A380, to use hydrogen," he says. "But you would need to install hydrogen tanks in the aircraft. We can't just store the fuel in the wings as is done now, which makes the model uncompetitive with regular fuel or sustainable aviation fuels."

> "Invest aggressively in hydrogen to reduce the transition time.
>
> Professor Bobby Sethi, ENABLEH2

That is why most predictions foresee an intermediate period when the industry will use alternative sustainable aviation fuels (SAF), which are generally made from sources such as biomass or waste and produce less life-cycle CO_2 compared with regular jet fuel.

According to Sethi, however, that might not be the right way to go. He says SAF could delay investments in hydrogen. It would be better, according to him, to focus on carbon capture of aviation emissions in the intermediate period and "invest aggressively in hydrogen to reduce the transition time".

Regardless of the path taken, the key for Sethi is a long-term and sustainable future for the industry. "Aviation has enormous social and economic benefits," he says. "It has lowered transport times across the globe drastically and has been a driver of economic growth through, for example, tourism. We can't let that be destroyed."

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ec.europa.eu/research-and-innovation/en/horizon-magazine/quest-hypersonic-and-hydrogen-fuelled-air-travel

The first flight of the P2010 H3PS hybrid aircraft. ©Tecnam, 2021/22

Horizon
The EU Research & Innovation Magazine

Green aviation takes wing with electric aircraft designs

With the overall rapid growth of air travel, aircraft design is ripe for decarbonisation, but widespread electric flight requires better batteries and lightweight systems.

by Gareth Willmer

As the aviation industry emerges from the impact of the COVID-19 pandemic, when passenger numbers plummeted, the number of flights is increasing again. The industry is recovering to pre-pandemic levels of air passenger journeys, with some estimates forecasting over 40% growth by 2050.

In general, crises aside, air passenger travel tends to double every 15 years, with the aviation sector also proving one of the fastest-growing sources of greenhouse gas (GHG) emissions. It currently accounts for 2% of global GHG emissions, but this is forecast to potentially triple by 2050 from 2015 levels on its existing trajectory.

Given that the European Green Deal calls for climate-neutrality by 2050, a green reset is called for to improve the sustainability of aviation. Follow the link to learn more about the measures the EU is advocating to reduce aviation emissions. Aviation is becoming more efficient with engine improvements, but decarbonisaton calls for alternatives to today's fossil fuel-hungry aircraft.

Hybrid-electric and full-electric propulsion systems offer one answer. Such powertrains are already gaining traction on the ground, with global sales of electric cars doubling last year to 6.6 million.

Numerous projects are under way for aviation to follow suit, but they face many challenges, not least of which is the sheer weight of batteries. Follow the link to read more about sustainable aircraft design in Horizon Magazine.

"Yet finding environmentally friendly alternatives that are simultaneously high-performance and profitable is of 'paramount importance", said Fabio Russo, head of research and development at aircraft manufacturer Tecnam in Capua, Italy.

Scalability

Russo led the H3PS (High Power High Scalability Aircraft Hybrid Powertrain) project, which investigated the potential of hybrid-electric systems in so-called 'general aviation' (GA) aircraft.

Covering more than 400 000 civilian aircraft around the world, this category includes private planes, business jets, helicopters and more, but not commercial airliners.

As aircraft that tend to be relatively small, the H3PS initiative views them as a first step towards developing electric propulsion systems for widerflights. "We need environmental solutions today, and the H3PS project was done to prove an efficient, low-weight and scalable solution," said Russo. "Scalable means you can move this concept from a four-seater aircraft up to an 11-seater or, eventually, more-seater aircraft."

Hybrid powertrain

The project also involved Rolls-Royce and engine manufacturer Rotax. One of its objectives was to fly a four-seater aircraft powered by what's known as a 'parallel hybrid powertrain' – combining both a traditional internal combustion engine and an electric motor.

The hybrid propulsion system can give a power 'boost' to the aircraft during flight phases such as take-off and climb, says Russo. With a hybrid, you can, for example, use a fuel engine with a lower power than normal and fill the gap for the aircraft to take off and climb with an electric motor. "You can therefore have access to a lower-consumption fuel engine," said Russo.

This approach enables a reduced engine size and weight, allowing the battery for the electric motor to be included without adding significant weight to the system.

Late last year, the project succeeded in taking to the skies with its Tecnam P2010 H3PS aircraft. As the first four-seater to do this using a parallel hybrid system, H3PS highlighted the achievement as 'a major milestone on the aviation industry's journey towards decarbonisation and R&D on alternative powertrains.

> "At the end of the flight, when we measured the fuel we consumed, the difference was remarkable.
>
> Fabio Russo,
> H3PS

Battery economy

Nevertheless, Russo emphasised that the project was about demonstrating the feasibility for such aircraft rather than creating a product for market. There is some way to go to make them a reality on a wide scale, he said.

"There are still quite a lot of limits in terms of economics behind developing this kind of engine and aircraft," said Russo. One key limiting factor is how the batteries deteriorate as they cycle through recharges. This means there is a high cost to keep replacing them on timescales that, at present, Russo estimates may be as little as a few months.

He believes improvements rest on a real drive, backed by support from the battery-manufacturing industry, to boost battery technology, while reducing shipping and decommissioning costs, and enhancing the circular economy.

"A local economy for battery manufacturing is essential", said Russo. "This will also mean that CO2 is not saved only during operation, but well before and after the battery's use in an aircraft." He added that for aircraft components as a whole, focus is required on the full end-to-end lifecycle and impact of products.

Viable hybrids

Russo believes such hybrid aircraft could become more economically viable by about 2030, with the potential to save significantly on emissions in certain flight phases. One test his team performed indicated a potential 50% reduction in carbon emissions during take-off and initial climb, and 20% during the whole three-hour journey, suggested by the lower amount of fuel used.

"At the end of the flight, when we measured the fuel we consumed, the difference was remarkable," said Russo. Other projects are investigating how to optimise different components for future electric propulsion aviation systems to make them as lightweight as possible, as well as safe and efficient.

Electromagnetic interference

For example, the EASIER project has been designing systems to limit electromagnetic interference (EMI) between components that may affect an aircraft's functioning.

The team is also investigating thermal methods to better dissipate heat generated by electrical components. That is all while trying to ensure the aircraft remain lightweight, taking the size and weight of current batteries into account.

Dr Ignacio Castro, a senior principal engineer at Collins Aerospace, based in Cork, Ireland, is the coordinator for EASIER. He said the project has been looking into EMI filtering and wiring options with lower volume and weight for electrical powertrains in aircraft, plus "two-phase" cooling systems and methods to improve rates of heat transfer to an aircraft's exterior. He explained that there's a need to

> Any change that we make to an aircraft to make it greener could potentially increase its weight (which) also increases the amount of fuel consumed (...) We need to make things smaller.
>
> Dr Ignacio Castro,
> EASIER

prepare now for the longterm future of electric systems. "Any change that we make to an aircraft to make it greener could potentially increase the weight of the aircraft," said Dr Castro. "That also increases the amount of fuel consumed, so we might not have an aircraft that is fully ready for flight. We need to make things smaller."

Some of EASIER's upcoming work involves more investigation of the trade-offs between methods. "The idea is that we will see how the thermal systems are affecting the EMI and vice versa, to see what the implications are," said Dr Castro.

Trade-offs

There are all kinds of other trade-offs to understand when it comes to manufacturing electric aircraft. For example, while making things smaller decreases weight, it can cause things to heat up faster too – much like a small house warms up quicker when heated. "That's the kind of trade-off with weight, size and efficiency, and it's not that simple," said Dr Castro.

He added that integrating all the individual technologies into a wellfunctioning overall aircraft system will be key in future research. "It's about understanding what the architectures should look like to be made as efficient as possible," said Dr Castro. Comparing it to construction, he stressed that you can't just throw bricks together in any way to make a building. "You need to put things together in a way that's smart in the context of power delivery," he said.

Right direction

Though there are many complex issues to resolve in electric aviation, Dr Castro believes things are starting to move in the right direction. "I think we're taking the right paths towards hybrid-electric aviation, and there's a lot of interest and many programmes," he said. "That would be the first step to start reducing carbon emissions."

Ensuring these new systems run smoothly and safely is also essential. Safety is paramount and a single crash is enough to generate big headlines and plenty of fear.

That means a need to take significant care with developments. "There's a risk saying things are going to be great, particularly when things need to be extremely reliable for aircraft," pointed out Dr Castro. "It's a paradigm shift in technology." There is also much investment needed and many questions to address in the coming decades, he said. "The challenge towards net-zero emissions in the EU by 2050 is a huge challenge, and I don't think at the moment anyone has a definite answer," said Dr Castro. "It's the one-million-dollar question."

European Commission

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ec.europa.eu/research-and-innovation/en/horizon-magazine/green-aviation-takes-wing-electric-aircraft-designs

As the aviation industry recovers to pre-pandemic levels, innovators are exploring solutions to reduce aircraft's carbon footprint. Image credit: John McArthur via Unsplash

face to face with Paul Stewart

Design process leader and consultant

A perspective on simulation in the automotive industry

by Kathleen Grant
EnginSoft

From his studies in Systems Design Engineering and Naval Architecture Dr Paul Stewart has an extensive background in CAD surface mathematics and fluid dynamics as they relate to the design process. He began working at the Ford Research Lab where he was the first to apply shape morphing to automotive CFD (computational fluid dynamics) and then continued on with EXA and eventually Altair, creating virtual design technologies involving advanced surface modelling, response analytics, and advanced visualization. During this time he has worked on production design projects and processes with almost every automotive and heavy truck manufacturer worldwide.

Paul is currently consulting with CAE providers looking to find their place in the design process and Design and Engineering companies looking to take their design process to the next level. Futurities interviewed him about his thoughts on the evolution of simulation in the automotive industry and the likely impact of new technologies.

The roles of design and engineering in automotive

The sinuous lines of a sand dune, the poetic simplicity of the curve of a feather, the power and adrenaline of a galloping stallion - these are the sources of inspiration for car designers. The design has to evoke an experience or make an identity statement for the eventual car buyer … and the car's shape captures the essence of that theme.

Yet it is also just the beginning of the automotive design process with the emphasis being on "Design" and not "Art" because the vehicle manufacturers set a large number of rigid objectives for the final product, thousands of which constrain the designers. These are fixed numbers to be achieved in multiple areas, such as aerodynamics where their design shape must satisfy a specific drag count to achieve the fuel economy necessary to be able to sell the vehicle model. Since an automotive company will cancel a programme rather than manufacture a product that does not meet its numbers, this places great pressure on the designers and engineers to meet these constraints.

According to Stewart, this is where a lot of the friction between designers and engineers arises: "Designers and engineers both think of themselves as the designers of the car. However, engineers generally concentrate on the specific technical constraints - thermal problems, aerodynamics, emissions, manufacturability, and so on - while studio designers are the group in the company tasked with creating a shape that meets or facilitates almost all the 5,000+ constraints that any car design must achieve for commercial viability.

Beyond that, to truly succeed the studio designers must do this with a shape that that the client loves," states Stewart. "Engineers often talk in terms of optimization, but vehicle programme management will tell you it's all about compromise. What's good for aerodynamics is bad for thermal cooling, what's good for thermal cooling is bad for crash-ability, and so on. Optimizing for any single engineering requirement will certainly degrade others. The studio designer has to weave a solution among all the constraints while simultaneously satisfying the aesthetics required for the vehicle."

Stewart views the designer's role as somewhat similar to an orchestra conductor's – combining all the elements in harmony where each element or instrument succeeds, and their combination captures and conveys the brand image that they set out to create originally. "While an orchestra conductor is likely to be an expert in most instruments, the designer must rely on the individual engineers for their expertise. That creates friction and explains why the designer's job is so challenging," he says.

> "Automobile design is about achieving an acceptable compromise between all the constraints while satisfying the aesthetic requirement for the vehicle.

According to Stewart, CFD engineers may often have the tendency to run some simulations, identify changes to the car design to correct the aerodynamics, and propose the modified design to the design team as "the fix" to their problems. This generally causes frustration and irritation among design teams: "In fact, parts of the studio design process are built as an obstacle to engineers' attempts to tamper with their design language."

Changing perceptions

Stewart's perception of the roles of the automotive designer in the studio and the automotive engineer have evolved significantly over his career.

In the 11 years he spent in Ford Research Lab (FRL) he was able to observe the automotive design process first-hand and develop design technology from the automotive company's perspective, particularly the design studio. His next 20 years were spent with software companies supplying CFD design process technology to the industry and participating in production design projects.

"In the beginning I viewed both engineers and studio designers as 'designers', each with their individual design tasks to complete. While they naturally needed to work in partnership, each had their own design responsibility. Over time and with the help of a few studio mentors, I came to understand the unique, central role of the designer and my perception evolved to view the engineer's role as being to support the designers by helping them to understand how and why air interacts with the surface they're designing," he explains.

"If engineers can guide designers to intuitively understand how air works over the surface, the designers can integrate that knowledge into their design language as they go through their creative process," he says, specifying that guidance by the engineer is the critical step in the process. "Designers do not need to understand air flow mathematically (Bernoulli's equation, pressure gradients on the surface, etc.), but rather instinctively, so they can anticipate its behaviour as it moves over their surface."

The evolution of CAD and CAE with free-form deformation

Historically, another barrier between design and engineering was the amount of time it would take engineers to respond with a design analysis: "In the past, it would take a CFD department two weeks or more to turn the designer's outer body geometry into something that could be simulated and analysed, by which time the designers would have moved in a different direction," he says. This meant early CFD was used primarily in the late stages of design, after the intensive studio work, when the body shape was more or less final but still needed testing to meet its performance targets.

This use of CFD was faster to react to ad hoc tests than the wind tunnel, but it meant simulation was only being used for testing, as a score card to measure pass/fail and improvement, rather than for actual design. According to Stewart, this is where the studio designer's frustration would reach its peak: "At this late stage meeting performance targets is critical, and "fixes" proposed by engineering most often take priority over the aesthetics of the design. Once the manufacturing tooling process is underway, all changes are expensive and the designer has very little flexibility left to save their design," Stewart says.

He believes CAE can only contribute its potential value to automotive design if it keeps pace with the speed of the design process at its earliest stages. "The design process is very rigid to allow the myriad of related dependencies to be resolved in the correct order from the outset. The timing of every milestone is marked out years in advance, and missed deadlines are measured in millions of dollars per day.

> "This type of volumetric morphing allowed us to keep pace with the design team and marked the transition of CFD from testing to design.

Your assigned task may have a six-week window to begin and complete a particular design decision and if the CAE can't keep up, it can't add value. The decision will be made on deadline with whatever information is available," he says, explaining that this leads to overly conservative decisions being made. "The vehicle must perform and be safe, certainly, but conservative, conventional, and over-designed is not a winning approach in a style-driven industry with small profit margins."

In his last few years at Ford in the late 1990s, Stewart saw an opportunity to bring simulation turnaround times closer to automotive design's pace. The Ford CFD department had approached him with a typical problem to solve: adjust the CAD model to tilt a windscreen and adjust the wrap radius (the curve of the windscreen as it moves outboard to the A pillar). "This was simple enough - until they explained that they wanted to perform a design of experiments (DoE) with 30 different models, and they needed the 30 models in less than a day to have the time to run the simulations and still meet their design process milestone! We believed it was impossible, especially if we worked directly on the NURBS of the CAD model," he says.

The enormity of the problem forced what was, for that time, a radical solution: the mathematics modelling literature at the time was covering new methods of shape modelling, many of which were the first seeds of the development of CGI animation at companies like Pixar. One method in particular, from Thomas Sederberg, professor of Computer Science at Brigham Young University in Utah in the USA, warped rigid curves by encasing them in a lattice which was then bent to "morph" the curve into a new shape without constraint from the mathematical form of the original curve.

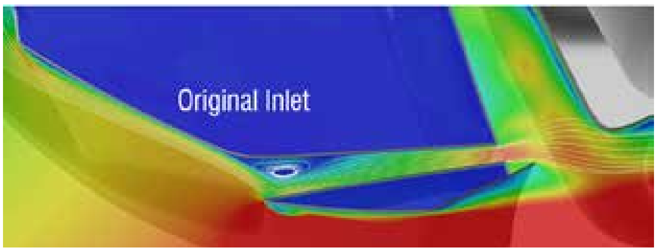
This inspired Stewart to rethink the approach to modelling: "We abandoned the CAD model or, rather, converted the baseline model to a CAE mesh, and we used this as a baseline that was then morphed into derivative shapes.

We enhanced the early morphing work by creating individual lattices for each DoE design element and parameterizing the lattice morphing from 0-100%. Once the individual morphing lattices were complete (a few hours work) we could take the baseline mesh model, apply the three windscreen design parameters automatically, according to a DoE table, and create the 30 simulation-ready CAE models - all in about 10 minutes," he explains.

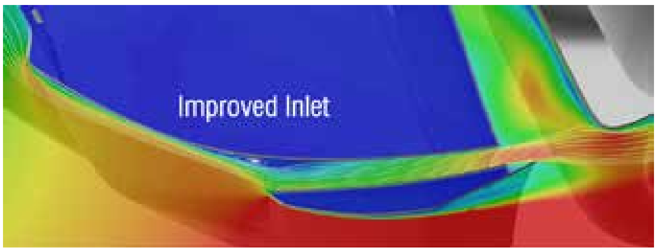
"This type of volumetric morphing allowed us to keep pace with the design team and marked the transition of CFD from testing to design. A CFD department could generate large numbers of complex shapes in a small fraction of the time, change and add design parameters without having to manually rework the geometry, and perform a more reasoned study of performance than they could using the previous approach of trial and error," he says. "Even if a DoE wasn't being applied, we could morph significant design changes to all parts of the car in half a day and produce a new design analysis each morning instead of the two weeks required to work from CAD. This approach provided significant value to the design team and changed the business significantly. It was ground-breaking to apply Sederberg's science in that way," he states.

Arc SUV design courtesy of Francesco Di Giuseppe

The interior surfaces of ducts are usually tuned to optimize air flow during the later stages of design. However, maximum duct potential is governed by the visible shape of the inlet and frozen in the early stages of design.



Most ducts inlets have significant recirculation. But if the designer understands the flow paths over the fascia while creating the design concept shape the result can be a duct with twice the flow potential.



The interior of this improved duct was later tuned with a parametric design space analytics resulting in more than twice the performance possible with the original.

Shortly after this first project, EXA, who supplied their flagship CAE product, PowerFLOW, to the simulation department, realized the value and licensed all the morphing technology from Ford, and in the early 2000s Stewart joined the company to produce what became PowerCLAY, "the first parametric morphing tool applied to CAE". This work eventually expanded to include template-based meshing, response surface analysis, and adaptive sampling to reduce the number of simulations required by 50-70% v. a DoE.

Over time, engineers at all automotive manufacturers began applying these techniques while other CAE meshing tools adopted similar morphing technology, culminating in a perhaps unfortunate effect: all cars started looking the same. Since the morphing tools were applied primarily by the engineers whose primary goal was to meet their specific performance criteria, they all carefully rounded the front fenders and tuned boat tails and applied all the shape changes known to have worked in the past, smoothing away anything that might interfere with the flow. In a short time, car manufacturers' designs started to converge.

My journey with aerodynamics and design began when learning to sail at 10 years old. At first imagining the wind moving through the sails to make the boat go forward and later, when teaching racing, helping students think about the air moving over the shape of the sail surfaces as we learned to trim them to maximize boat speed. Yes, the mathematics and physics are important, but ultimately good design comes from a natural understanding of behavior. This is what we, as engineers, should provide.

Stewart believes two things are missing in the design-engineer partnership: "First, engineers need to 'teach, not tell' and explain to designers how and why flow moves as it does over a design shape; in other words, describe what engineers try to achieve with flow, but in intuitive and spatial terms designers can relate to. This puts the designer back in the central position of creating a shape that integrates all needs, including aesthetics. Armed with this knowledge, it's been my experience that they can offer much more creative shape solutions than engineers - and definitely alternatives that capture not only the needs of the physics, but also fit coherently into the design language of the vehicle," he says.

The second missing piece is a design tool that allows designers to rapidly create parametric shape alternatives, similar to morphing parameters, but with a mathematical elegance more closely related to the character lines and design language of their vehicle. "These tools aren't there today, but the need is great because designers are introducing more distinguishing forms back into design. There are many regions in cars where a very smooth form only improves drag very slightly.

With this knowledge, designers can explore shapes with more character such as using aggressive details in the stagnation regions (where flow stagnates regardless of shape) and along the sides (where the flow is already turbulent from the wheel wakes and may not be significantly affected). We're getting back to focusing on the aesthetics. But better design tools are needed to complete this step," comments Stewart.

When Dassault acquired EXA, Stewart joined Altair where he re-built his parametric-design process vision including the volumetric morphing, and added a significant new piece based on the subdivision surfacing mathematics of Inspire Studio. Sub-division surfaces, sometimes referred to as polygonal modelling, are an alternative to conventional NURBS surfacing mathematics and, as mentioned earlier, are extensively used in CGI software to create shapes for movie animation and gaming. Although not as precise as NURBS for tight tolerance manufacturing, designers can directly use sub-division surfaces to create and modify detailed concept shapes in significantly less time. This makes them ideal as a design format to feed early-stage CAE analysis, according to Stewart.

His process could take a proverbial sketch on a napkin to a fully detailed, open-grille vehicle model, including all the gaps and fillets necessary for accurate CFD, in one day; present an aero analysis the next morning; and then follow up with a re-design and analysis the morning after.

This was further augmented by directly adding parametric control of the designer's character lines, thus almost completely eliminating the need for the more complex volumetric morphing. "This approach is the next step to moving CAE all the way forward into the concept and even pre-concept design stages," he says.

How are the evolution of CAD and CAE intertwined?

"As an undergrad, I didn't understand how pervasive surface mathematics were," Stewart says, "But in my graduate research in CAD mathematics I soon realized that we live our lives in and around objects defined this way. Virtually everything we touch every day was described with a mathematical surface at some point, starting back with shoe companies that had to produce the same shoe for all foot sizes," he says. Applied research into surface mathematics really flourished in the automotive and manufacturing sectors.

"Automotive companies had the budgets for such work and the extremely difficult problem of transferring complex, freeform designs from paper to mass production where high volumes and tight tolerances make customized manufacturing prohibitive," Stewart explains, "A science was needed to faithfully translate the design idea quickly and accurately for manufacturing, which led to the creation of CAD."

> "This approach is the next step to moving CAE all the way forward into the concept and even pre-concept design stages.

Ultimately two types of CAD emerged: constructive solid geometry (CSG) to describe parts with Boolean combinations of solid primitives, and boundary representations (B-Reps) to describe complex and freeform shapes by stitching together individual patches, usually NURBS, into a quilt describing the surface boundary of a volume. "A B-Rep NURBS has a more versatile shape that can be faired to a few thousandths of an inch to achieve the near-perfect continuities required for smooth surfaces, as well as elegant highlight or reflection lines," says Stewart. "However, while the B-Rep is great for describing an abstract design idea, its construction and design-change process can be very labour intensive for manufacturing."

He continues, "Consider class-A surfaces. These free-form surfaces of cars, such as the stamped sheet metal and plastic body parts, are both aesthetic and critical to many of the vehicle's physical performance criteria. Expertly skilled math-modelers (a new profession, similar to a clay modeller, that evolved just to create these shapes) can create a reasonable outer skin of vehicle hood (or bonnet) in about half a day.

This painstaking process proceeds one NURBS patch at a time, with each depending on its neighbours in a critical and complex hierarchy such that an entire vehicle can take up to two weeks to be fully stitched with all of the critical details necessary for accurate simulation. Any design changes further compound this problem because even a small change may cascade to many layers of surrounding surfaces, requiring extensive re-work. These time delays make it impossible for CAE to keep pace with a rapidly evolving design and for this reason CAE was initially applied at a relatively later stage in the design process once the design was stable when it helped to avoid significant physical testing costs and rescued programmes with critical corrections," Stewart explains.

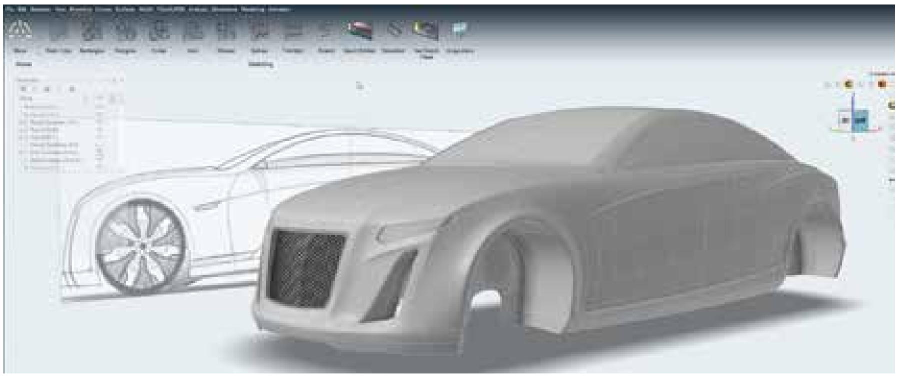
"A typical new vehicle programme may start with seven or more alternatives that quickly explore aesthetic themes and technologies. Over a matter of months, these are narrowed down until one design theme is then perfected in the studio," he says. "This early pace is simply too rapid for CAE that depends on a complete model description in CAD - even with the significant efforts to automate and reduce the time to create a simulation-ready mesh from CAD, the time required to create the CAD is still prohibitive and unnecessary considering that the manufacturing-quality CAD only becomes important once the final theme is selected," says Stewart.

"However, that's not to say applying CAE once the final theme has been selected is without value. On the contrary, avoiding a problem during intensive studio work on the selected theme can be one or two orders of magnitude cheaper to correct than a problem found late in the programme when corrections often cascade to surrounding parts and include expensive re-tooling costs," he comments.

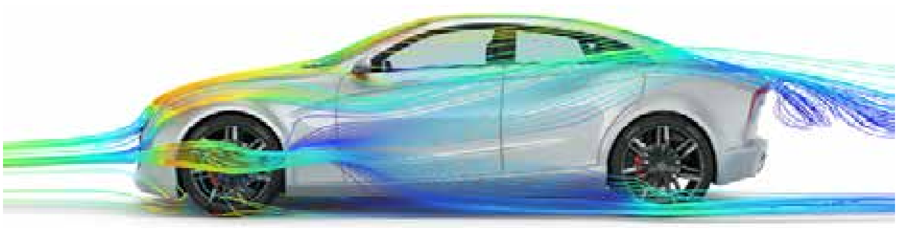
He believes that CAE has still greater potential if it can move even further upstream in design: "The guiding principle of successful design is to manage risk. As I already mentioned, to be noticed, a new vehicle or any product, must introduce bold customer-visible advancements. But manufacturers cannot afford to commit to any unsuccessful idea that may prevent the product from reaching the market.

These bold risks are evaluated during the earliest stages of design and, unless they can

CX1 Sedan design courtesy of Darren Chilton



When sub-division surface modeling software is tailored for CAE a detailed open grille vehicle model can go from an idea on paper to a fully detailed simulation mesh in one business day.



This time advantage allows the designer to review an interactive, animated flow study the next morning while the design concepts are still relevant.

be proven to be very likely to succeed, they will be removed from the programme. It is here, when the concepts themselves are still vague, that CAE, at its best, can add enormous value - by allowing radical new concepts to be explored and refined to an acceptable level of risk."

According to Stewart this was the vision for simulation to fulfil its long-held promise: "To achieve it we required a new mathematical shape model capable of capturing form specifically for simulation - at the point when the idea was still only an image on a wall or a pencil sketch on a notepad. The success of PowerCLAY and volumetric morphing demonstrated the value of a modelling technique specifically for simulation that avoided significant portions of the meshing process and facilitated parametric-shape studies.

Working directly on the simulation mesh created a general-purpose approach that allowed CAE to significantly contribute to design. Yet that technique had drawbacks too because the baseline mesh still came from CAD, and morphing skills are not commonplace for either designers or engineers," he says. He continues, "Automotive design required a tool that could capture shape fast, run a simulation, and revert quickly to designers with the required feedback. In other words, a mathematical format that allowed designers to easily ideate a shape that was already (or very close to) a simulation-ready mesh. As mentioned, Hollywood provided inspiration for the answer."

The sub-division surfacing techniques of movie CGI have been incorporated into effective concept design tools like MAYA from Alias, which Stewart and his team experimented with successfully at EXA. In his time at Altair, Stewart was able to further improve on this by introducing parameterized shape features into Inspire Studio, which allowed a designer to create a fully detailed vehicle including open grille and fully filleted edges from scratch in a day (math modeler not required); this could then be simulated in CFD overnight and the same vehicle could be parameterized the following day to drive a complete parametric analysis by the end of the week.

> “ CAE, at its best, can add enormous value - by allowing radical new concepts to be explored and refined to an acceptable level of risk.

Stewart acknowledges that sub-division surfaces are generally not precise enough to be considered manufacturing quality but says they can capture the significant design details required for analysis: "Coupled with easy and rapid shape iteration and direct input into CAE it offers a significant advantage over traditional CAD modelling." Ultimately, he believes the design process will evolve to perform thousands of design iterations for concept evaluation and engineering design using sub-division surfaces and that the finalized shapes will then be transferred to traditional CAD modelling to prepare for manufacturing. "Beyond that new manufacturing techniques like additive manufacturing can completely skip the CAD model to create components," he says, "We need to prepare for that by creating models that are suited to CAE right away to allow CAE to add significantly more value in the design industry."

What role does and can artificial intelligence play?

"The latest hype around AI is over-extended compared to what it can deliver," says Stewart, emphasizing that it is still extremely valuable to the design process, "however, it is not going to replace the important human aspect of innovation." Stewart says that AI was called pattern recognition when he was an undergraduate, and that he considers it a more accurate description of the initial forays into deep learning and neural nets, etc. "The algorithms were 'trained' by being fed a lot of data from past experiences in which they identified various relationships and behaviour patterns. These behaviour models could then be used to predict expected behaviours, or searched to identify optimum behaviours."

> “ We need to prepare for that by creating models that are suited to CAE right away to allow CAE to add significantly more value in the design industry.

He comments, "In that project at Ford where a DoE was used to study the effects of three shape parameters on the windscreen using 30 vehicle design-combination simulations to understand the sensitivity of those shape parameters and how to arrange them to optimize drag, you could say there were two core problems with our initial approach, namely the cost, and the scope of the design space or selection of shape parameters."

Explaining, he says, "Consider cost: 30 simulations to understand three shape parameters is far too expensive. An experienced aerodynamicist could probably achieve a similar answer by trial and error using around a quarter of the simulations, maybe fewer. Then consider that a typical production upper-body aero-design task actually involves from 10 to as many as 25 or 30 parameters for which a DoE would require hundreds of simulations. However, this problem is solvable: at EXA my group did research into AI including adaptive sampling and progressive shape parameter selection which allowed accurate response models to be built at ratios closer to three simulations per design parameter."

Regarding the scope of the design space, however, Stewart contends that it is not solvable with AI. Citing the windscreen design-space problem again, he asks, "What if there were a fourth parameter that was even more effective at improving drag than the three that had been selected? Or a fifth? There is nothing in the machine learning approach that will detect whether effective parameters are missing in the learning, let alone identify them. This is because AI builds its understanding of the universe based on what it's been taught; it fundamentally lacks the ability to create," he states, "It can propose combinations of

Understanding specific flow behaviors at the earliest stages of concept ideation allows the designer to evolve their entire design language coherently in few hours before it is set in stone. Three concept evolutions produced the vehicle on the right with drag reduced by 15%. Notice how the character lines from the hood have all shifted inward one feature on the fascia to accommodate a rounder fender while maintaining an aggressive look. A significant improvement over simply bending the collective surface.

parameters that have never been tried before, and thus appear to be 'creating' something new, but it cannot propose a new dimension of exploration."

He hurries to clarify however that he sees AI as "a powerful tool for performing a task that is extremely difficult for humans, namely modelling and predicting the complex integrated behaviour of multiple shape parameters without a preconceived notion of good and bad combinations. A project with dozens of individual parameters can be like solving a 25-dimensional Rubik's cube: every time you change the value of one parameter, the behaviour of all the others changes."

Stewart describes his favourite part of each production project which he came to call it the "Aha!" moment: "At some point the response model would uncover a combination of design parameters that the experts 'knew' by intuition beforehand was not worth exploring because their experience suggested it would not work. Unencumbered by this bias and with the logical ability to pursue a myriad of potentially viable combinations of the design parameters, the process would almost always uncover a successful combination of parameter settings that caused us to re-think our understanding of the physical behaviour."

He says that this phenomenon of experience bias is even more true when the timeframe for finding a solution is tight and inflexible: "People tend to become more conservative and follow what they already know when they're under time pressure," he says. "Between this bias and the engineers' tendency to stop when they reach the target improvement, I feel like we routinely left 10-20% or more of the performance potential behind when we didn't use analytics."

Returning to the perceived threat of AI to many jobs, Stewart reiterates that creativity and innovation - and not intuition - are our differentiators over advanced AI. "With our creativity, humans can change the structure of a problem or change the problem altogether. Take Formula One design for example. While AI can help refine body shapes, it won't propose re-purposing the front-end foils to also provide an air curtain over the front wheels or adding small tabs around the vehicle to generate vortices and improve intake performance, underbody down force, or even disrupt the air for a following competitor.

Those come from a human who saw that the team was solving the wrong problem and could get better overall performance by changing the objective of the problem or the scope of the solution." He says that this is where his understanding of the roles of designer, engineer, and technology have changed yet again: "The engineer must identify the fundamental design objective and work with the designer to create a set of shape parameters (a design space) they believe will have a strong influence on that objective with the goal of building the most active design space with the greatest potential to improve performance. This will offer the most flexibility for crafting an aesthetic solution that meets all the design criteria."

> "[AI is] a powerful tool for performing a task that is extremely difficult for humans, that is modelling and predicting the integrated behaviour of multiple shape parameters and without a preconceived notion of what will and what won't work.

"That relegates AI to the role of exploring and learning about a given design space, analysing the unique value of individual parameters and the potential of their most effective combinations. Once engineers understand, without their knowledge bias, which shape combinations work best, they can re-examine the physics to determine why. Armed with this improved understanding, they can then either change the design space to increase its potential or even change the problem altogether," he continues.

"Combined with the improved modelling processes I described earlier, this further clarifies the relationship between engineer and designer. When engineers can explain to designers how shapes create flow structures and which flow structures are most beneficial, the designers, who are naturally creative spatial thinkers, can use this understanding to create a design language and a shape that will also satisfy the aerodynamic needs," he concludes.

Optimization of a brush cutter using knowledge-based engineering

by Paolo Verziagi
Emak

Emak manufactures machines for gardening, small-scale agriculture, and civil construction. It develops its two-stroke engines for handheld applications such as chainsaws, brush cutters, and blowers. The aim of the project was to automate as much as possible the generation of a CAD model to be used as a reference for designers during the whole industrialization phase. By implementing and harnessing an advanced process integration workflow, it was possible to reduce design time and obtain a broad view of all potential critical aspects of the machine.

Brush cutter architecture

A brush cutter essentially consists of a motor (in this case an endothermic, single-cylinder two-stroke engine), a transmission system, and a cutting device. A large part of the design work concerns the endothermic unit, which was developed directly in-house, while the transmission system and the cutting device allow less leeway at the design level. As a result, the CAD for the drive unit is far more detailed and complex than the CAD for the transmission system; the cutting device was modelled.

Technical situation at Emak at the start of the project

The company began producing brush cutters in 1972, but only introduced the position of calculation specialist – previously left to more experienced designers – into the technical management team in 2012. It was then that the company began developing spreadsheets to try to prevent individual problems in the various functional groups while taking advantage of past experience.

Over the years, the spreadsheets have been refined and enriched with new features, including the ability to perform Monte Carlo analyses based on the tolerances used in established manufacturing processes.

At the start of the project, the following spreadsheets were being used:

- CAE1402D02: screw tightening analysis
- CAE1402D03: crank gear cages and bearings analysis
- CAE1402D04: starting unit analysis
- CAE1402D06: flywheel-cylinder system analysis
- CAE1402D09: clutch-transmission system analysis
- CAE1402D10: cylinder layout analysis
- CAE1402D11: cutting force analysis

The disadvantage of these spreadsheets is that they do not interact with each other and therefore, every time a new machine is introduced, the same data must be copied across the various sheets, wasting unnecessary time, and possibly leading to typographical errors on the part of the calculation specialist.

Reorganization of the spreadsheets

It was therefore necessary to modify the spreadsheets so that they interacted with each other; spreadsheet CAE1402D01 functions as a collector, distributing the variables necessary for the calculations, and distributing the ensuing results to the other spreadsheets tasked with checking specific issues.

In addition, the flow of data generation was analysed in depth, starting with the limited data representing market demand.

The underlying idea is that all these variables can be used to construct a parametric CAD model capable of providing the designer with a starting point for any new machine to be designed.

Keeping the CAD model up to date across an increasing number of configurations required considerable effort. It was also necessary to introduce some spreadsheet constraints that did not exist before. This initial phase of work lasted approximately six months. Only three pieces of data are necessary to start the calculation (see Fig. 1):

- the maximum power
- the maximum power speed
- the maximum torque speed

modeFRONTIER methodology

In order to manage the large number of activities required to characterize a particular brush cutter design, it was decided to organize the workflow according to nested processes. We therefore created a MAIN process which launches the following activity-specific processes in sequence (Fig.2):

- INNER1: performs the actual optimization using the previously mentioned spreadsheets; we use the pilOPT algorithm here because it has proven to be effective and is able to produce a sufficiently populated Pareto front that can be used for further considerations.
- INNER2: automatically creates a CAD drawing from each Pareto front design. The CAD drawings are then numbered sequentially to allow them to be simultaneously opened by the user (see Fig.5).
- INNER3: prepares and launches the multi-body model needed to calculate the excitants; a folder containing all the necessary information is created for each Pareto front design (see Fig.6).

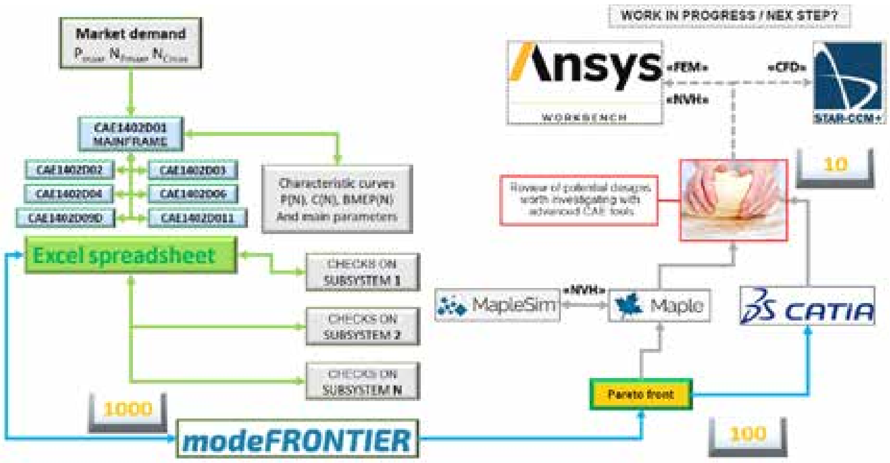


Fig. 1. The workflow created to generate and analyse the best brush cutter designs.

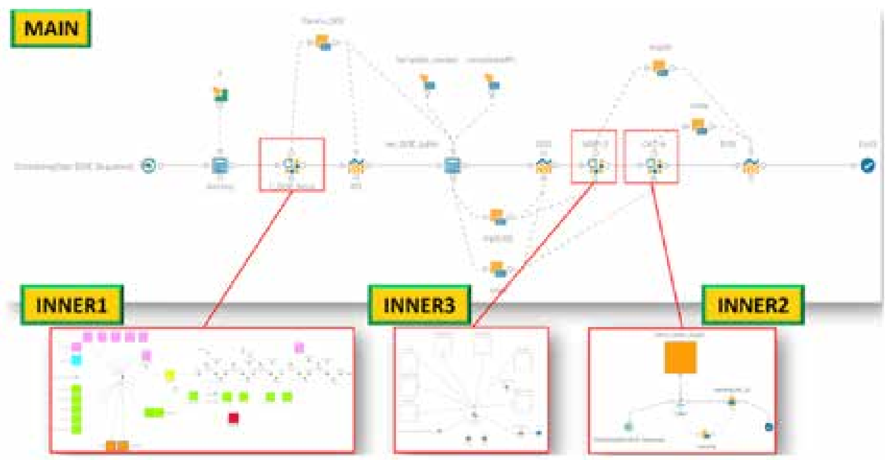


Fig. 2. The nested workflow used in modeFRONTIER.

As can be seen in Fig. 1, while the pilOPT process is capable of analysing around 1,000 designs overnight, the Pareto front that is generally extracted is an order of magnitude less (around 100 designs). A subsequent "manual" review of the data reduces the number of feasible designs by a further order of magnitude (around 10 designs). The design engineer can then choose the most suitable design for the case according to other selection criteria that have not been codified within the workflow.

The post-processing phase of the Pareto front takes a morning to complete. As a result, the CAD upon which to develop and industrialize the new brush cutter can be generated within a single working day, from the moment the calculation is begun.

Optimization strategy

The following objectives were set for optimizing the brush cutter:

- min {total mass M_tot}
- min {alternate mass M_alt}
- min {height ING_H}
- min [cross sectional dimension ING_tra}
- min {axial dimension ING_ass}

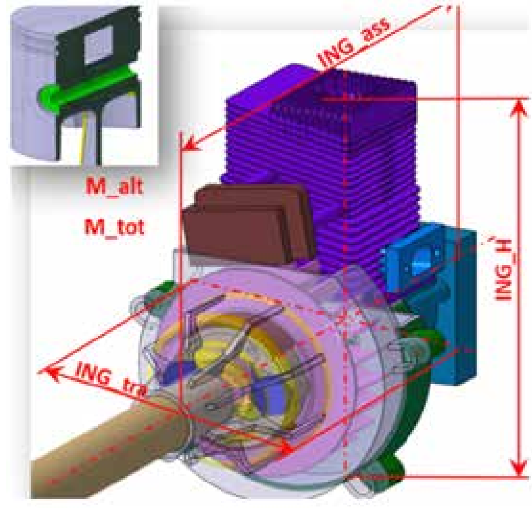


Fig. 3. The objectives defined for the INNER1 process

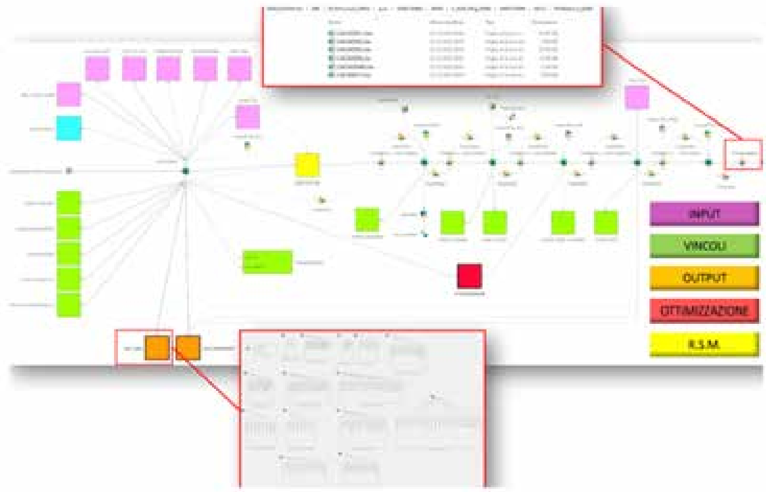


Fig. 4. The INNER1 workflow that optimizes the brush cutter.

Obviously, this refers to the representative values of the machine and not to the real ones (Fig. 3); in fact, many components such as intake filter, carburetor, muffler, ignition system, handles, etc. are not included in the calculation of total mass, nor are they managed at CAD level. At the end of the process of the INNER1 workflow (see Fig. 4), the full set of spreadsheets containing all the specific variables of the analysed design, whether feasible or unfeasible, is saved.

Feasible or unfeasible? Monte Carlo analysis

According to modeFRONTIER, a design is feasible when it satisfies all the imposed constraints. These constraints are nothing more than verifications of component safety coefficients, compliance with certain type-approval standards, geometric verifications to ensure functionality and CAD updates of components. All these constraints are estimated for nominal conditions of the design, without any knowledge of the potential consequences of compliance with the constraints if the production process is at the specification limit.

For this purpose, Monte Carlo analysis is used. It basically consists of introducing the usual manufacturing process tolerances for the input variables, associating a statistical model for data variations (not necessarily a Gaussian distribution), and establishing a reference population (that intercepts a 0.1% defect). The calculation of the results is, therefore, subject to a certain variability resulting from the tolerances imposed as input.

To ensure that a constraint is respected in practice as well as in theory, it is necessary to require at least 95% of the resulting population to respect the constraint. All this translates into a doubling of the number of constraints required for a design to be considered feasible. In total, 70 constraints are imposed in the system.

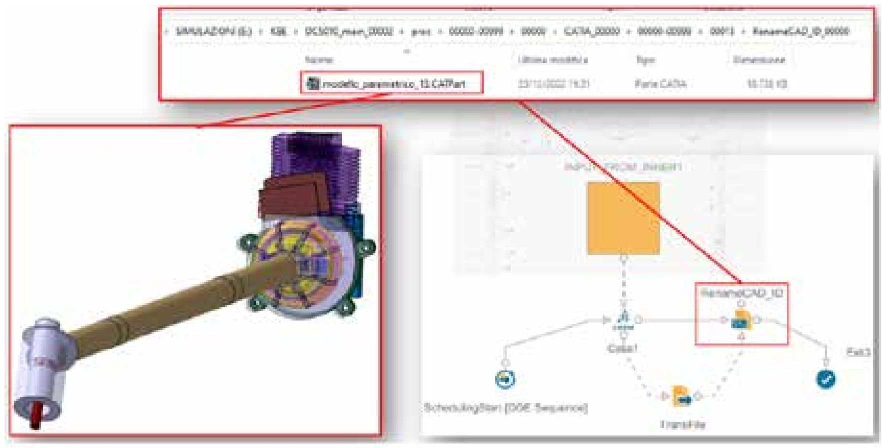


Fig. 5. The INNER2 workflow to automatically generate the CAD drawings.

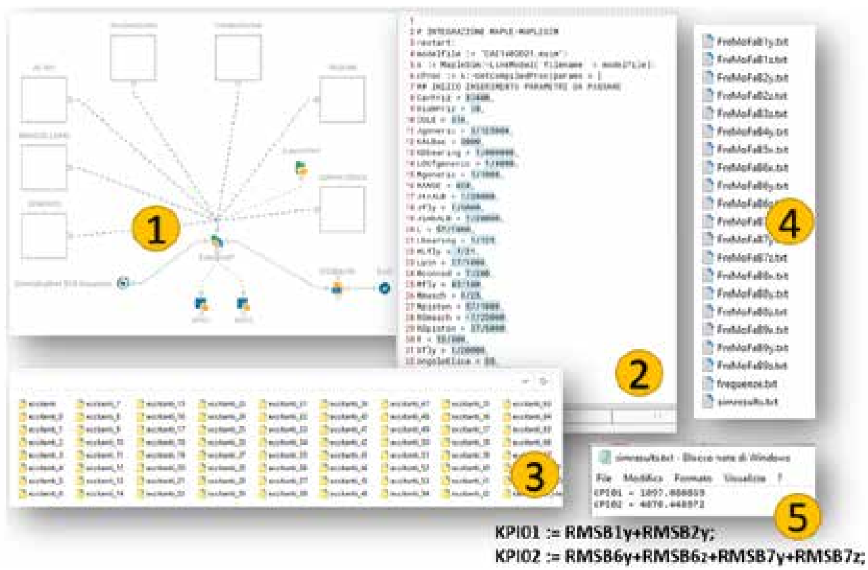


Fig. 6. The INNER3 process qualifies the Pareto designs from a vibrational point of view.

The use of RSM (response surface modelling)

modeFRONTIER initially interpreted the attempt to reduce the alternate mass of the single-cylinder endothermic engine as a reduction of the die-casting thickness to the lower limit of the assigned variation range. To remedy this, it was necessary to include a check on the piston deformation, which can be calculated by means of a thermo-structural finite element simulation. It was therefore necessary to create a parametric CAD model of only the piston-pin-rod system, run it through Ansys Workbench, and perform the calculation by extracting the necessary information. At this point, we asked modeFRONTIER to create a response surface on approximately 300 designs of the piston deformation, enabling us to greatly reduce the calculation time for the INNER1 process.

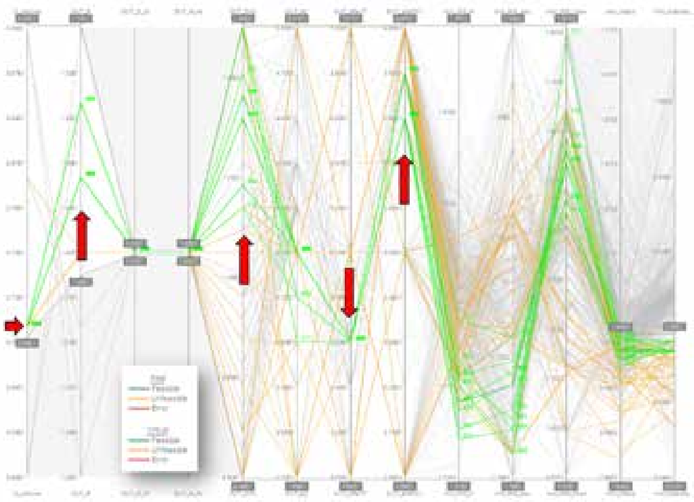


Fig. 7. Analysis of results using a parallel chart.

An initial look at vibration

Single-cylinder endothermic engines are susceptible to vibration due to the impossibility of balancing alternating and rotating forces. However, partial balancing of the crankshaft is possible, and is factored into the complex calculation system.

However, it is not possible to balance all the static imbalances that accumulate randomly on the inside of the rotor, in particular the flywheel, clutch and tool. Without going into detail, we can state that the lower the exciters acting on the machine structure, the lower the resulting vibrations will be. Therefore, the INNER3 process extracts all the forces that the rotor side exerts on the structure and uses them to summarize certain qualitative indices of the vibration level: in particular, the transverse vibrations in mean effective value (RMS) measured on the bench bearings and tool-side bearings (KPI01 and KPI02) are evaluated (see Fig. 6).

modeFRONTIER manages the multi-body parametric model realized in MAPLESIM with a MAPLE script to which the input variables are passed; the resulting time histories, calculated over a normalized one-second cycle, are then post-processed via MAPLE and transformed into frequencies for potential use with FEM codes (fatigue analysis).

Results

The most efficient way to analyse the solutions generated is to highlight the Pareto front in a parallel chart, concentrating on the input and output variables of greatest interest (Fig. 7). This allows the main trends in the input variables that allow for Pareto optimal designs to be identified. Furthermore, by filtering down the values of total mass and alternate mass, one can further filter out those few designs (<10) that constitute the "best of the best".

Compared to the designs currently in production, the objectives are being achieved with a different engine bore and, in general, a different stroke-to-size ratio than the existing architectures. This aspect would never have emerged had we not also included an assessment of the machine's potential vibratory aspects in a preliminary analysis. This was made possible by using the created workflow, which provides a 360° view of all critical aspects of the machine before even producing any CAD model.

Compared to the reference case, the process estimates an approximate 7% mass reduction, which we consider to be overstated compared to what can actually be achieved, specifically because it does not consider all the surrounding components and only evaluates the components over which we have the most control.

About Emak

For the past 25 years, Emak has been one of the leading names associated with the care and maintenance of parks, gardens, and green spaces. Our brands — Efco, Oleo-Mac, Bertolini and Nibbi — are known and valued by professional and hobby users the world over. With four brands and as many production facilities to its name, plus seven branches and 22 product families, our company is constantly expanding. The quality and excellence in design of our products have won us many international awards, and we are regarded as setting the benchmark for internal combustion engine technology and its applications in our chosen sector. We are a leading global player, offering innovative solutions for gardening, agriculture, forestry, and industry. We manufacture and distribute machines, components, and accessories of high technological value, designed to render the activity of our customers easier and more efficient. We have a flexible manufacturing model focused on the high added-value aspects of engineering, industrialization, and assembly. Our production systems are geared to "lean manufacturing" and involve supply chains as part of an extended factory model.

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ISEO adopts Cetol 6σ for a global approach to dimensional management

Technical collaboration and support from EnginSoft key to achieving maximum benefit from the solution

ISEO ULTIMATE ACCESS TECHNOLOGIES is Europe's leading Italian multinational company in mechanical and connected solutions for intelligent access control. The company produces products that cover the full range of market demand for access technologies: from residential buildings to large commercial and financial sites, hospitality and transport facilities and critical infrastructure.

Over the past two years, ISEO has been working with EnginSoft to introduce a new approach to calculating tolerance chains when designing a new product. "Working with EnginSoft is of paramount importance for increasing the technical level of ISEO's R&D team, with active and dynamic support guaranteed whenever necessary – and not only during the theoretical training period," states Matteo Calzaferri, Mechanical Design Engineer at ISEO.

The challenge

ISEO has stringent requirements with regard to tolerance management in the development of its products. Calzaferri explains, "Our main requirement is to be able to design locks and cylinders using tools that enable us to conduct tolerance chain analyses of at least five or more components. The calculation and management of tolerances is crucial for us during the design phase because it can have significant effects on production reliability and repeatability."

A further requirement is the need for a tool that enables potentially out-of-specification components and their impact to be assessed quickly and accurately so that operators can quickly decide whether to reject a batch of components with certain unsuitable specifications.

Traditional methods limited production performance

ISEO's R&D department required tools that would allow it to perform the overall analysis of the product assemblies and sub-assemblies that the company develops. Prior to the decision to introduce

Cetol 6σ, the company's R&D department used a traditional numerical spreadsheet for the analysis of tolerance chains, which required the dimensions and dimensional tolerances to be inserted manually.

Calzaferri comments, "This method has major limitations, especially when it is necessary to analyse complex assemblies consisting of several components in which both the dimensional and geometric tolerances of the components themselves must be considered. As the number of parts constituting the assembly increases, the tolerance chain becomes more complicated. It is almost impossible to manually calculate these chains in a way that considers all the elements involved." He continues, "The traditional method also doesn't enable engineers to identify which elements have the greatest impact on the tolerance chains and therefore they are not in a position to determine how and where to intervene."

Another aspect that affected the choice for the R&D department was the tendency to perform these calculations from a "worst case scenario" perspective, aiming to achieve greater quality and security, with the result that they always risked specifying tighter tolerances on the drawings than necessary.

Cetol 6σ is comprehensive 3-D model-based tolerance analysis solution that works directly with the CAD definition to help companies build better products through mechanical variation management. It provides product development teams with the insight required to confidently release designs to manufacturing. Precise calculation of surface sensitivities exposes the critical-to-quality dimensions in the assembly. Utilizing advanced mathematical solutions, Cetol 6σ accelerates tolerance optimization to achieve robust designs ready for manufacturing.

Cetol 6σ and a global approach to dimensional management

Early in 2022, ISEO's R&D team attended a course hosted by EnginSoft on Dimensional Management, Geometrical Product Specification (ISO-GPS) and tolerance analysis. "Shortly afterwards, ISEO decided to introduce the Cetol 6σ software into our R&D process, and the functional approach to mechanical variation management revolutionized our product development methodology," states Calzaferri. He says that EnginSoft played a key role in the development of the software and its use within ISEO: "In addition to the initial course, EnginSoft also provides ongoing technical and theoretical assistance to all the designers in our R&D team, enabling them to increase their skills by applying them to practical cases during product development at ISEO."

The direct interface between ISEO's CAD software and the Cetol 6σ software allows designers to perform an advanced tolerance chain analysis on the entire model that is under development during the detailed product modelling phase. Calzaferri explains, "The introduction of the new software had quite a heavy, transversal impact that initially involved all the designers in the R&D team, and then also affected the departments of industrialization, production and quality control. This gave rise to the need for the development of a global dimensional management approach, which is still ongoing, and which is enabling the relevant ISEO users to acquire important skills in product development, production, and control."

EnginSoft has been supporting this internal development process. "Meetings involving several corporate entities are often held where technical drawings are analysed, and design, process, and dimensional control are discussed to find the best product configurations," says Calzaferri, "EnginSoft plays a key role in these meetings by providing the theoretical support needed to understand the designer's requirements and convert them into clear, understandable instructions for the production and quality control teams."

ISEO's global dimensional management approach starts from the product concept phase and includes design development and prototyping that are addressed through the creation of interdisciplinary working groups; it then covers all other phases of production through to the finished product.

While the implementation of this new approach is still in its infancy in the company, the first results have already been seen in R&D where the use

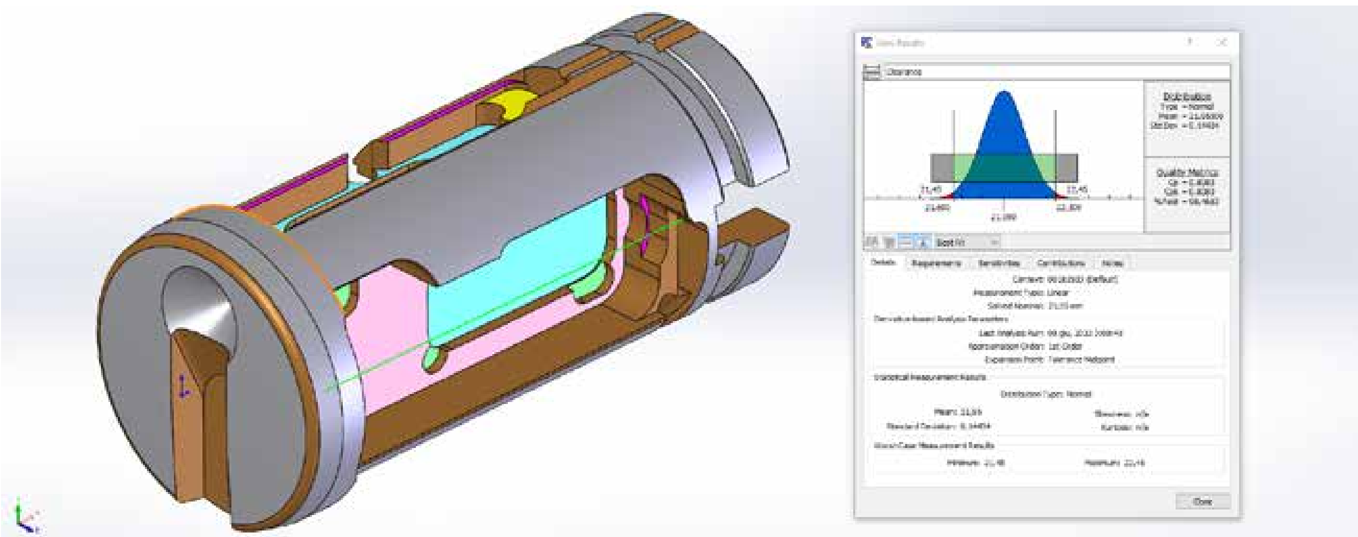

Fig. 1. Tolerance chain to assess the variation of Clearance in ensuring the assemblage of the sub-system in the cylinder.

of Cetol 6σ has reduced the time required to analyse tolerance chains and guaranteed full control of the internal 3D model. By aligning the full product development process with the ISO-GPS approach, the company expects to reduce flow time (design, manufacturing, and dimensional control) and scrap.

Tolerancing analysis of ISEO's flagship F9000 mechatronic cylinder

One of the very first studies that ISEO conducted with the Cetol 6σ software concerned the company's F9000 mechatronic cylinder, a classic mechanical encryption cylinder combined with an advanced electronic access control system in which energy is transmitted between the key and cylinder inductively without any type of electrical contact. The F9000 mechatronic cylinder is one of ISEO's flagship products and is already available on the market.

ISEO's R&D team used Cetol 6σ to study the sub-assembly of the electronic module with the aim of optimizing the geometry of an existing component in order to improve the coupling between the housing and the actuator, and to reduce waste production during sub-assembly. Cetol 6σ allowed the sub-assembly of the initial product, which was already in production, and which consisted of nine different components to be analysed in detail. The analysis highlighted the critical points and the dimensions and tolerances with the greatest impact on the positioning of the motor in relation to the housing.

The analysis results enabled the company to accelerate the development of a new geometry to minimize the impact on the coupling of the housing and motor of the components' geometric variations. Cetol 6σ was then used again to analyse the new design in detail, which allowed the designer to produce drawings in which the tolerances and dimensions with the most significant impact were tightened. The company has found model analysis with Cetol 6σ easy to implement because the study is set up directly in the GUI of ISEO's CAD software by applying the contact constraints and tolerances. Calzaferri states, "Here again, EnginSoft's support was crucial because, in uncertain situations, it allowed us to find the correct Cetol 6σ model configuration that reflected the reality of the assembly."

He continues, "Compared to the traditional use of spreadsheets, it has reduced the time to build the model and increased the number of simultaneous variables in our analyses. We were able to analyse the assembly as a whole, something we had never been able to do with spreadsheets due to the complexity of the model and the large number of variables that were impossible to handle simultaneously with a manual calculation method."

Calzaferri states that EnginSoft's support is fundamental, both because his company is new to using the software and because the Dimensional management and ISO-GPS topics are very broad and complex and EnginSoft's theoretical experience is key in being able to apply the method correctly and use the Cetol 6σ software in the best possible way. "We interface with EnginSoft's technicians who are always available to make technical support calls in a manner consistent with our development needs," says Calzaferri, adding: "In the past, due to the complexity of this product, we repeatedly performed two or three rounds of prototyping before correctly defining the geometric configuration. With the introduction of Cetol 6σ we have reduced the prototyping rounds to one, and the newly defined geometry was correct first time and immediately validated."

According to Calzaferri, the goal for the near future is to extend the use of Cetol 6σ to all the designers in ISEO's R&D team in order to reduce development times and costs, and guarantee greater reliability of the products produced. He concludes, "The work of disseminating the Dimensional management and ISO-GPS methods outside R&D will also continue, and will increasingly involve in-house production of the components, the semi-finished and finished products, quality control, and external suppliers."

About ISEO Serrature

ISEO ULTIMATE ACCESS TECHNOLOGIES is Europe's leading Italian multinational company in mechanical and connected solutions for intelligent access control. Located in Pisogne (Brescia), it has been working for over 50 years to evolve the concept of security, developing the concept of "UNLOCK YOUR FREEDOM TO MOVE" which brings the value of security into a new dimension: the freedom to move, ensured by the most advanced access technologies.
Embodying the "Made in Italy" label, with approximately 1,200 employees worldwide, the brand operates through four production sites and 14 companies, and distributes products in Europe, Asia, the Middle East, South Africa, and South America that cover the full range of market demand: from residential buildings to large commercial and financial sites, hospitality and transport facilities and critical infrastructure.

About Cetol 6σ

Cetol 6σ enables designers and engineers to easily address multi-dimensional problems, using their native CAD geometry. This unique method provides immediate analytical feedback via the easy-to-use modelling, analysis, and reporting components. The user is guided through the tolerance analysis and optimization process whilst being informed about missing or erroneous data. Unlike simple 1D stack-up analysis or Monte Carlo simulation, Cetol 6σ pursues a statistical approach employing advanced and precise constraint technology which is displayed in an intuitive graphical user interface. This approach accelerates the ability to identify and illustrate dimensional sensitivities and the tolerances that have the most significant contribution to the component's variation.

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L-PBF additive manufacturing simulation of a “cold crucible” in copper alloy

by Nicola Gramegna[1], Antonio Rossi[2]
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Introduction

The TEMART project was approved by Italy’s Veneto Region under the POR-FESR 2014-2020 program under Axis 1 and Action 1.1.4, namely "Support for collaborative R&D activities for the development of new sustainable technologies, new products and services".

The four Regional Innovative Networks (or Reti Innovativi Regionali – RIRs) that participated in the TEMART project, namely M3NERT, EUTEKNOS, VHC and VSL, operate in three different areas of Smart Specialization representing some of the most significant and distinctive domains and industrial sectors in the industry and artisanship of the Veneto region. The region’s four universities, coordinated by the Univeneto Foundation, also participated in the project as partners, making complementary contributions that reflect the specific character of their research and training specializations. As a result, the TEMART project has become highly significant industrially, economically, socially, and culturally. The project involved the development of several case studies concerning the creative use of technologies and processes to produce innovative, competitive, aesthetically pleasing, high quality items. New manufacturing technologies, in particular additive manufacturing (AM) technologies, make it possible to design and produce new shapes with a broad range of materials e.g. polymers, composites, or metallics and even to combine these in the same item/object. As an example, one of the project goals was to integrate different CAE tools into a single intelligent design process for the AM environment. This integration created competitive advantages such as reduced design times with the maximum reduction, for example, in weight and a maximum increase in the part’s functional reliability. With regard to the specific project areas, the case study on crucibles made of refractory metal was a prime example of the reduction in weight and increase in functionality.

After a brief introduction about the implementation objectives of the “cold crucible”, this article describes the virtual approach adopted to design the component and optimize the manufacturing process for CuCr1Zr copper alloy. The partners listed in the acknowledgments played a key role in characterizing the material and fine-tuning the machine parameters for manufacturing the part, which helped confirm the excellent design, and the modelling of the AM process.

Objectives

Officina dei Materiali, a consulting company in the field of materials science and engineering, first launched the idea of next-generation cold crucibles in 2015. The idea quickly gained momentum thanks to the first funded projects which aimed to use simulation software to model the physical phenomena at play during levitative metal melting, and to optimize the technological process of additive manufacturing with pure copper.

The main objective of this study is to demonstrate how additive technologies combined with simulation methods can enable continuous progress in the creation of innovative and efficient products.

The component being studied is a crucible for the controlled melting of metal. Conventional crucibles are usually made of ceramic material with the obvious limitations of high cost relative to service life, and the contamination of the molten metal by the ceramic material itself. Such contamination affects and sometimes impairs the mechanical, electrical, and magnetic properties of many reactive metal alloys.

A "cold crucible", on the other hand, is made of a metal alloy with high thermal and electrical conductivity. This crucible, when suitably cooled and designed, can concentrate its electromagnetic energy to melt the metal contained in the crucible. It does not contaminate the melt in the crucible and also, conceptually, does not use consumables because, if properly designed, it never comes into contact with the molten metal.

Some prototypes demonstrated the cold crucible's potential, but also its limitations compared to production using traditional manufacturing technologies. Furthermore, during validation, some operating efficiency limitations emerged regarding the transfer of electromagnetic energy internally, and heat dissipation.

Using additive technologies enables radically new shapes and geometries to be created. L-PBF (laser powder bed fusion) technology is probably the most versatile of the additive technologies for metal parts in terms of its potential to produce complex geometries in combination with ad-hoc microstructures [1]. More specifically, such technologies can enable the production of more thermally and electromagnetically efficient parts by realizing complex geometries and designing appropriate channels for controlled conformal cooling.

The aspects to consider in producing an object that meets the design specifications as studied and confirmed through the use of additive manufacturing process simulations include optimized complex internal channels, thin walls, and thickness transitions.

Part design for additive processing

In recent years, simulation tools have continuously evolved to support design, or more specifically to complete the virtual workflow of Design for Additive Manufacturing (DfAM), in order to drastically reduce the number of iterative experimental tests, which are very costly and time-consuming. However, there continue to be well-known challenges not least of which are the simulation methods used and the associated computational times. Some of these have been highlighted in the literature by various authors [3]. The main sources of complexity relate to the numerous physical phenomena involved, some of which are difficult to model; the spatial and temporal discretization; and finally, the experimental validation of the results.

This study aims to simulate the L-PBF additive manufacturing process at a macro scale with the goal of determining the residual stresses, distortions and defects related directly to the process itself. The macro-scale simulation uses continuous models in which the material layers are merged into layers of finite elements,

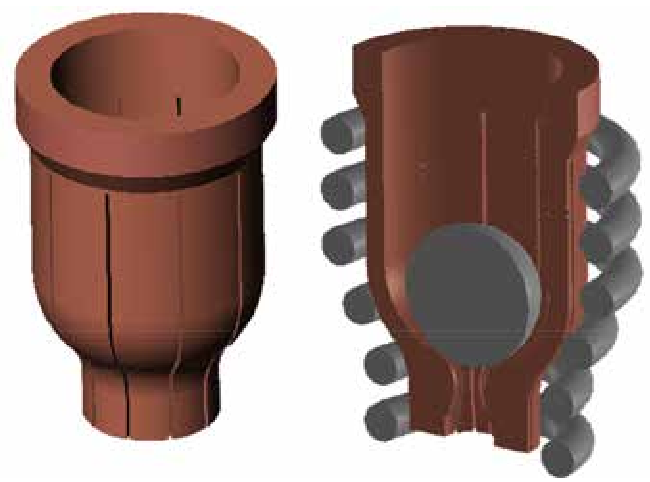


Fig. 1. View of the crucible (courtesy of Officina dei Materiali).

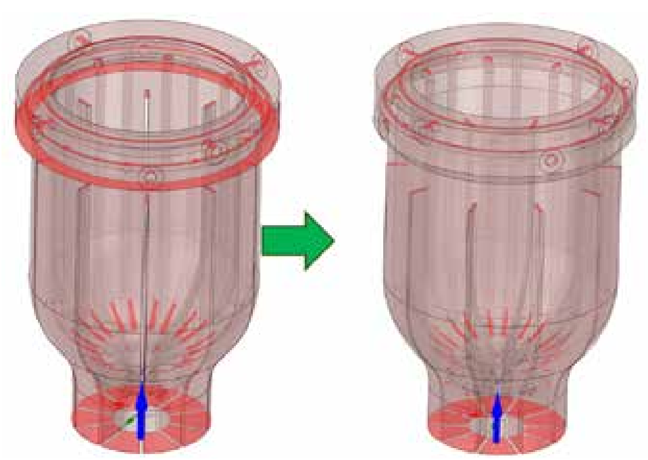
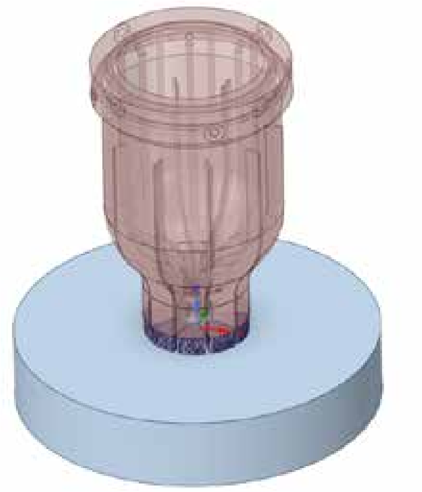


Fig. 2. Geometric analysis of the CAD in terms of a 45° overhang angle relative to the direction of material growth (Z-axis print direction).



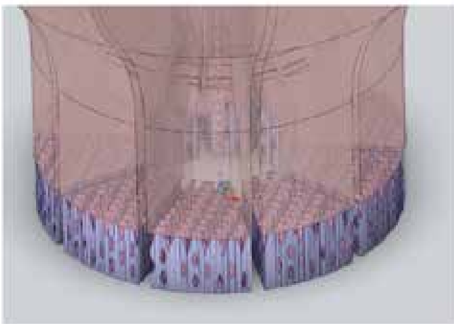


Fig. 3. Support structures built with Ansys Additive Prep for process simulation.

thereby partially foregoing resolution on actual thermal gradients and micro-scale phenomena. Rather than progressively adding material along the laser path, an entire layer is deposited. This only requires the specification of the direction of material accretion and the height of the simulated layer, which greatly reduces the complexity of the simulation setup.

The design of the part required several steps leading up to the analysis of the geometric models in terms of printability by using an analysis of the regions that require supporting structures and that are potentially critical to realize. In Fig. 2, those areas with an "overhang angle" greater than 45° (in red) that require support are highlighted and minimized.

Fig. 3 shows the print setup with the supporting structures that connect the part to the platform.

Simulation of the L-PBF manufacturing process

Similar to conventional welding simulation, the inherent strain approach provides a computationally efficient method to simulate the production of complex metal additive parts on a macroscopic scale. The aim is to predict residual stresses and distortions in the part. This approach simulates a build-up of thermal stress by activating the macro-layers sequentially and applying inherent strain.

Inherent strain is a permanent plastic deformation of the material that subsists in the Heat Affected Zone (HAZ) of the weld, and it is this region which causes the overall deformations and residual stresses.

As this region is an accumulation of various physical phenomena, it is necessary to use a calibration procedure to determine the average total inherent strain, which is only valid for a specific machine model, material and set of process parameters. The accuracy of the material model therefore hinges directly upon the calibration. Such simulations can be conducted with the bare minimum of material property information, that being the mechanical properties at room temperature.

Calibration of the material model

Cantilever beam specimens are now standard for determining inherent strain value as the distortion measurements are simple. Once the test specimens were printed (using the same setup as for the manufacture of the object), they were partially cut from the manufacturing platform near the base, leaving intact the thicker section of the cantilever beam connecting it to the platform. The distortion was measured at three positions (M1, M2, M3) before and after cutting, and the average value was used for the calibration procedure (Figs. 4 and 5).

Essentially, the goal is to identify the calibration parameter (Strain Scaling Factor, or SFF) of the intrinsic strain which matches the measured experimental distortion with the virtual distortion of the simulation.

Process simulation setup

Despite the fact that intrinsic strain values are anisotropic according to the direction of the scanning vectors in relation to the scanning strategy, which is caused by a greater contraction along the scanning direction rather than orthogonally to it,

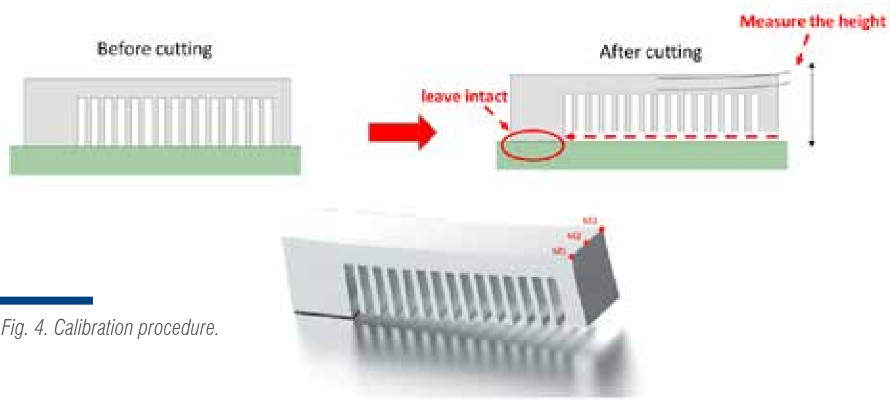


Fig. 4. Calibration procedure.

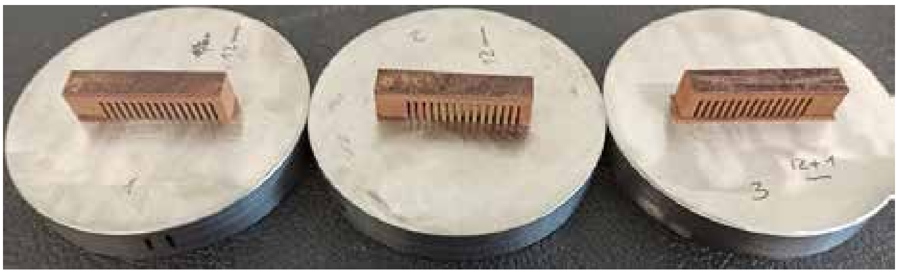


Fig. 5. SLM additive manufacturing specimens for calibration (courtesy of ECOR).

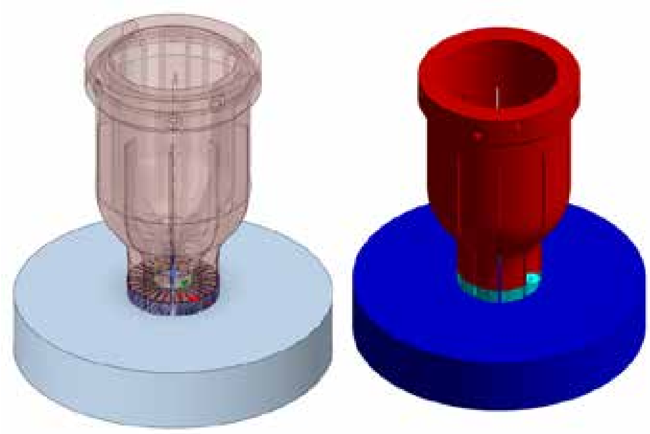


Fig. 6. Setup for manufacturing, and setup in Ansys for LPBF additive process simulation.

they are essentially isotropic when the different powder layers are averaged into a finite element layer that incorporates *n* layers of material (macro-scale approach). The crucible was discretized with tetrahedral FEM (finite element method) elements measuring 0.5mm, which provide a good representation of the geometric features, especially for the cooling channels.

The non-linear material used for the calibration procedure was also used to simulate the part (job).

Simulation results

This article describes the important results of the manufacturing configuration considered optimal for manufacturing the CuCr1Zr copper alloy crucible.

The following images of the simulation results show the distributions of distortions induced by the manufacturing process, layer by layer until the end of the process. The thermo-mechanical equilibrium induces a state of residual tension and deformation of the part attached to the base platform by the supports (Figs. 7a and 8a). The same observations, using cross-sectional or external surface views, are made following the detachment of the part from the platform and the removal of the supports (Figs. 7b and 8b).

Preliminary analysis of the results shows that in the as-built condition, i.e. still anchored to the platform, the part is not subject to such distortion as to impair its operational functionality. However, when analysing the distortions after the post-processing steps of

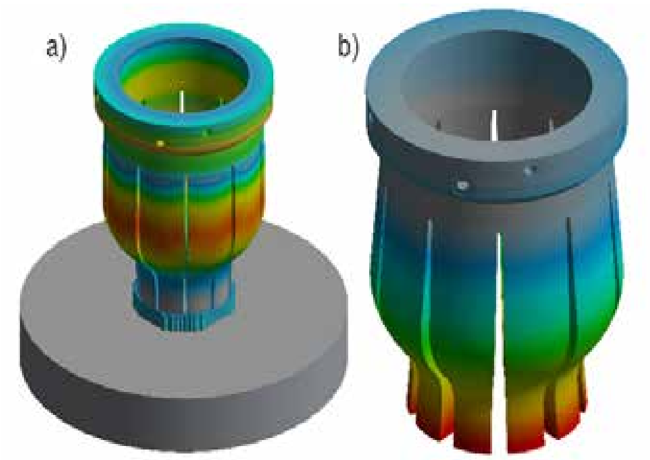


Fig. 7. Part distortions in as-built conditions after process simulation. Left) job anchored to platform. Right) after detachment from platform and removal of supports.

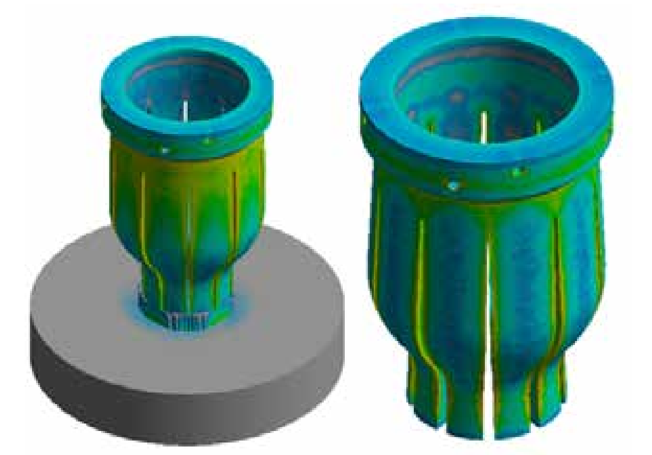


Fig. 9. Stress on the part in the as-built condition after process simulation Right) job anchored to the platform. Left) after detachment of the part from the platform and the removal of supports.

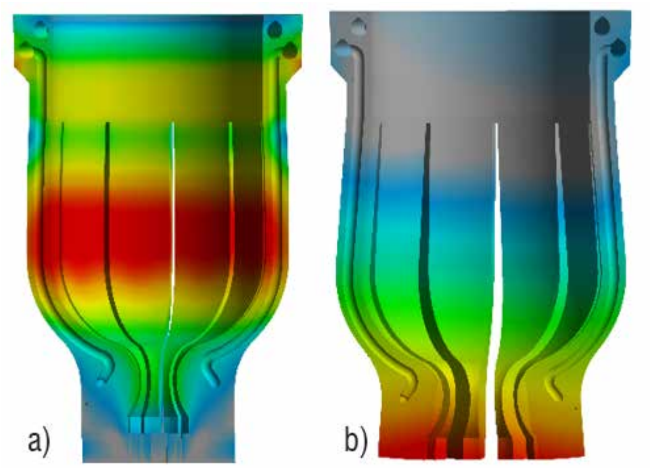


Fig. 8. Cross-sectional view of part distortions in as-built conditions after process simulation Left) job anchored to platform. Right) after detachment from platform and removal of supports.

Fig. 10. Cross-sectional view of the stresses on the part in the as-built condition after process simulation Left) job anchored to the platform. Right) after detachment of the part from the platform and removal of supports.

removing the part from the platform and removing its supporting structures, a substantial increase in distortion can be seen. This indicates that heat treatment to relieve residual stresses and avoid subsequent distortions is necessary to obtain a component that deviates as little as possible from the nominal geometry.

The maximum value in terms of residual stresses exceeds the fracture stress but is limited to very narrow areas and is due to the peculiarities of certain mesh nodes. Further investigation is needed to verify the above observations.

Remarks and conclusions

The TEMART project's intended objectives were successfully achieved in this industrial case where the virtual approach to the design of the copper alloy crucible made it possible to produce the object successfully at the first attempt (right first time). The first prototype's material density and final shape matched expectations.

By designing the component according to DfAM (Design for Additive Manufacturing), the geometry was studied from the perspective of the production process, allowing us to identify the potential critical areas during the design phase even before producing the part, and therefore determine how to modify them. The process simulation made it possible to predict tension and deformation values in order to assess the component's compliance with the design specifications and to take countermeasures in the event of non-conformity thus eliminating the iterative process in the field.

Upon completion of the project in early 2021, the first example of a new-generation cold crucible designed to melt metals and metal alloys with a high melting point was produced and tested. Internally, the shape of the funnel and the number of cuts were optimized to produce a gradual variation in levitating force (in order to accommodate alloys of different densities) while retaining a conveniently sized nozzle for tapping melt that can be controlled electromagnetically; the production by additive manufacturing adhered faithfully to the optimized complex shape.

Apart from numerous advantages over traditional crucibles, the new crucible demonstrated a considerable energy-saving capability, reducing the power consumption required to melt metals by a factor of 3-4 compared to traditional cold crucibles.

Addtoshape was created in 2022 from a meeting between Seitron, an industrial production company that has operated on Italian and foreign markets for over 40 years, and Officina dei Materiali.

Addtoshape was established on the foundations of Seitron's strong spirit of innovation and modern industrial production capacity, Officina dei Materiali's decades of experience in national research facilities, and a registered patent (no. 102021000024227 (filing date 21/09/2021)) protecting the new-generation crucible. Seitron, ever attentive to the evolution of technologies and to the challenges posed by new processes and new markets, has decided to take on the adventure offered by additive metal manufacturing of pure copper, in order to support the production of new-generation cold crucibles.

Acknowledgements

We would like to thank the M3NET Consortium, project leader of the TEMART ("Tecnologie e materiali per la manifattura artistica, i beni culturali, l'arredo, il decoro architettonico e urbano e il design del futuro" or technologies and materials for artistic manufacturing, cultural heritage, interior design, architectural and urban decoration, and the design of the future) project and all the project partners – with particular reference to Officina dei Materiali, Ecor International, and the Department of Industrial Engineering (DII) of the University of Padua.

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References

[1] C. Meier, R. W. Penny, Y. Zou, J. S. Gibbs, and A. J. Hart, "Thermophysical Phenomena in Metal Additive Manufacturing by Selective Laser Melting: Fundamentals, Modeling, Simulation, and Experimentation", *Annual Review of Heat Transfer*, vol. 20, no. 1, pp. 241–316, 2018.

[2] BSI Standards Publication, BS EN ISO / ASTM 52911-1:2019 *Additive manufacturing - Design Part 1: Laser-based powder bed fusion of metals,* October 2019.

[3] W. J. Sames, F. A. List, S. Pannala, R. R. Dehoff, and S. S. Babu, "The metallurgy and processing science of metal additive manufacturing", *International Materials Review,* vol. 61, no. 5, pp. 315–360, 2016.

[4] L. Bertini, F. Bucchi, F. Frendo, M. Moda, and B. D. Monelli, "Residual stress prediction in selective laser melting: A critical review of simulation strategies", *The International Journal of Advanced Manufacturing Technology,* vol. 105, no. 1–4, pp. 609–636, Nov. 2019.

About Addtoshape

Addtoshape designs and manufactures, through additive manufacturing, innovative windings in pure copper for high performance electric motors. Complex geometries, otherwise not achievable with traditional, round or flat copper wire, are now achievable without limits, allowing maximum freedom of expression in terms of shape, function and performance. Despite large-scale production capacities and high efficiency achieved by traditional windings, the growing pressure from environmental policies is pushing the electric motor sector to a leading role in the fight to reduce global greenhouse gases. To achieve this, it is necessary to reduce the carbon footprint of electric motors by further increasing their efficiency and power density.

Courtesy of Leonardo Geronzi, Early Stage Researcher of Meditate Project (meditate-project.eu). University of Rome "Tor Vergata".

Copernicus: A cloud-based HPC platform to support systemic-pulmonary shunting procedures

by Simona Celi[1], Emanuele Vignali[1], Dorela Haxhiademi[1], Margherita Cioffi[2], Alessia Baretta[3], Stefano Porziani[4], Andrea Chiappa[4], Marco Evangelos Biancolini[4]
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Congenital heart diseases (CHDs) account for nearly one-third of all congenital birth defects. Since the prevalence of CHDs cannot be altered, interventions and resources must be focused to improve survival and quality of life. The modified Blalock Taussig shunt (mBTS), a common palliative operation performed on patients with cyanotic heart diseases, is unfortunately associated with significant mortality with the most threatening complications being over-shunting and shunt thrombosis. The proposed experiment aims to realize an application to support surgical planning using advanced numerical means, presented in an interactive and effective manner.

The challenge: creating innovative solutions to support surgery for congenital heart disease

InSilicoTrials Technologies and RBF Morph are innovative SMEs that offer a portfolio of software and services to clinics and medical research. To expand their business, the SMEs joined forces under the FF4EuroHPC project with RINA Consulting, CINECA and Fondazione Toscana Gabriele Monasterio to tackle the challenging field of CHDs. CHDs are a significant health problem, being the seventh leading cause of death for children under one year of age in 2017. Although the prevalence of CHDs cannot be changed, interventions and resources can focus on improving the survival rates and quality of life of those affected.

A common palliative operation for CHD is mBTS, which provides blood flow from the systemic circulation to the lungs. However, despite its simple concept, the mBTS procedure is associated with significant morbidity and mortality, with over-shunting and shunt thrombosis being the most serious and life-threatening complications. The criteria for determining shunt size, length, and position remain a matter of debate, as a shunt diameter that is too small can lead to shunt thrombosis due to high wall shear stress, while a shunt that is too large may cause pulmonary overflow, decreased diastolic pressure, and reduced systemic perfusion.

Computational simulation can help support medical decisions and improve surgical outcomes by modelling the effects of different shunt sizes and positions. However, it requires considerable computing power and expertise to provide accurate results in a short time. By combining the expertise of all organizations involved, and with the fundamental tools provided by the HPC environment, this FF4EuroHPC experiment creates an opportunity to generate new business opportunities for the partners in the sphere of advanced medical modelling.

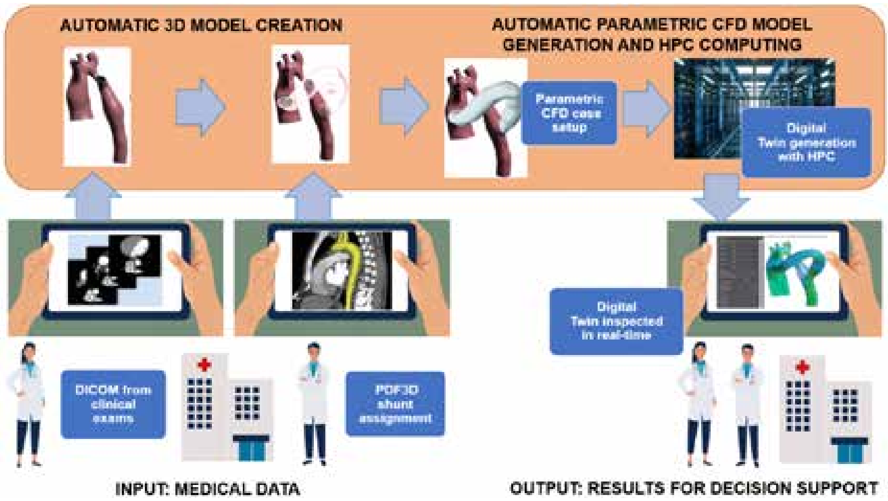

Fig. 1. The Copernicus concept: the process starts and ends in the hands of the medical staff. The creation of the medical digital twin is powered by high fidelity CAE, mesh morphing, and HPC.

The solution: development of a medical digital twin to simulate the surgical intervention

This experiment faced a significant challenge in creating a cost-effective decision support web application called "Copernicus" to assist surgeons in their approach to mBTS medical interventions. Simulating the impact of such surgery on blood flow requires complex computational fluid dynamics calculations on high-performance systems. However, these calculations are still far from being used in clinical practice during preoperative planning due to the specialized knowledge required to perform them.

To overcome these problems, Copernicus generates a medical digital twin (MDT) of the patient's vascular district through a reduced order model (ROM), which condenses the complex and expensive preloaded calculations. This allows the size and positioning of the shunt implant to be varied interactively in a geometrically parameterized process. Medical personnel can thus inspect the patient's MDT and observe how the planned intervention will affect the fluid dynamics of the impacted area.

The platform's dedicated user interface enables the medical team to make surgical decisions more efficiently. By using the HPC, the time required to perform the demanding preloaded analysis that supports the MDT is significantly reduced. This acceleration is crucial as important decisions regarding mBTS preparations have to be made in a short time, usually within two days, in the case of complicated morphologies. Validation through retrospective clinical data has improved the readiness level of the Copernicus platform, enabling business exploitation with minimal additional effort. By harnessing HPC, ROM, and the power of interactive visualization, the Copernicus platform provides an innovative and effective tool to improve medical decision making in the treatment of CHDs.

The Copernicus concept is explained in Fig. 1 with the medical part shown in green at the bottom of the diagram, and the CAE shown in orange at the top. Using a tablet, medical personnel inspect the image data stored in DICOM, the data interchange standard for biomedical imaging. Once approved, the geometry enters the computer aided engineering (CAE) part where automatic AI-powered segmentation allows the aortic arch district to be extracted. The segmentation results are then displayed to the surgeon who assigns an initial shunt placement according to current best practice.

The CAE part defines the prosthetic geometrical model with the shunt placement and lateral parameterization. This parametric model is then used to define hundreds of variations (i.e. possible surgical scenarios). Thanks to HPC all variations are calculated and then distilled into a reduced order model that is the engine of the interactive surgery MDT. The MDT can be inspected by the medical team so that the initial assumption provided for placement can be refined to achieve the best compromise for the patient. It is worth noting that, from the perspective of the medical personnel, this approach is displayed as an augmentation of the data available on the original patient image data.

The technical implementation of Copernicus is depicted in Fig. 2. The orange section summarizes the pre-processing steps. The starting point is the segmentation of the CT image stored in the DICOM file. The aortic arch is automatically extracted and is ready to be displayed to the surgeon. It will be used in CAE as the surface of the relevant vessels. Once the surgeon's input is received (an automatic process), the CAD SpaceClaim tool allows the input data to be transformed into a CAD Boundary Representation (BRep) model of the patient's vascular district with the shunt positioned according to the proposed hypothesis solution.

The CAE model, i.e. a CFD model, is then generated using the Ansys Fluent meshing with watertight geometry technology. RBF Morph software is then used to make the geometry and positioning of the shunt parametric (Fig. 3). The positions of the insertion points on the vessels can be changed along with their angles and the size and length of the shunt. The configuration of the RBP (ROM builder preprocessing)

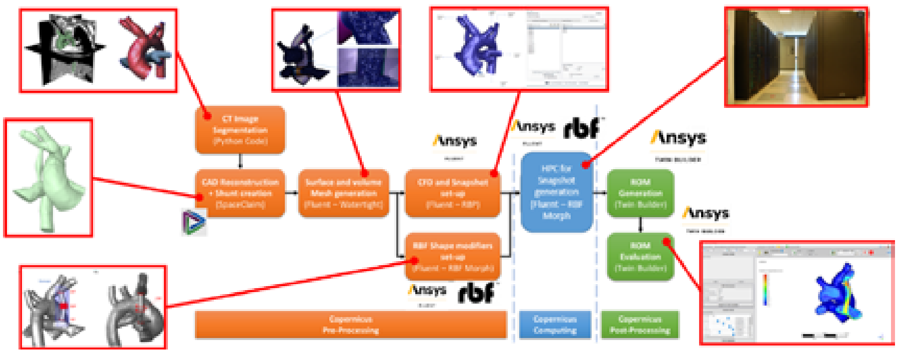

Fig. 2. The implementation of the Copernicus solution in detail: from the DICOM medical image to the interactive medical digital twin.

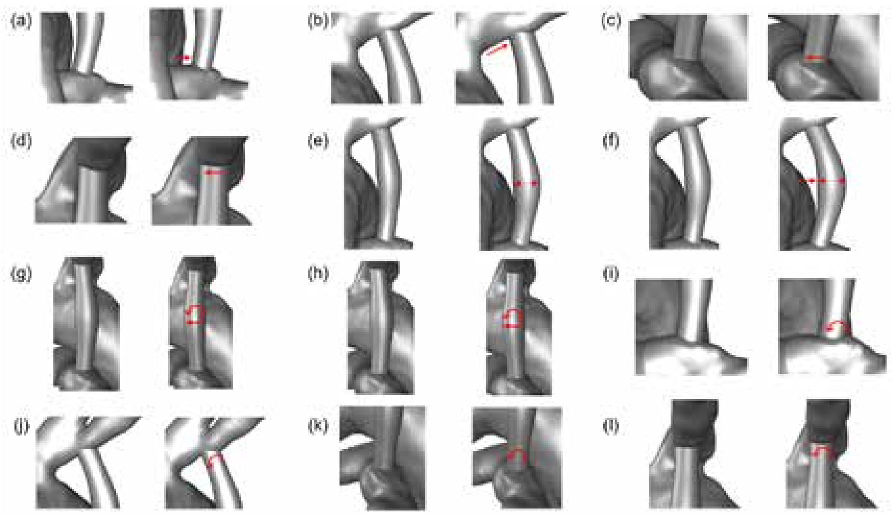

Fig. 3. Shunt shape and placement.

extension to the Fluent solver is conducted so that the solver, coupled with RBF Morph, is ready to calculate and store the CFD simulation results as snapshots, ready to be processed for data compression. The next step is performed on the HPC cluster where Ansys Fluent in combination with RBF Morph enables the creation, solution, and storage of all required snapshots (150 in the current workflow). Once the HPC runs are complete the post-processing phase can begin (Fig. 2).

Ansys Twin Builder is used to generate reduced order models from the snapshots; both geometry variation and flow solutions are captured by using POD (proper orthogonal decomposition); the number of modes stored allows the prescribed accuracy to be achieved.

The interactive ROM representative of the MDT is now ready to be inspected by the medical team using Twin Builder's ROM visualization tool.

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

A solution with the potential to disrupt the medical field and save lives

The proposed Copernicus solution has the potential to have a significant impact on the clinical field by enabling surgeons to make informed decisions about CHD treatment with greater accuracy and speed, leading to a reduction in post-operative complications and recurrences, and ultimately a reduction in hospitalization costs.

The Copernicus solution represents a promising opportunity for the partners involved to expand their activities and contribute to the advancement of medical modelling.

In the era of the precision medicine, the ability to more accurately provide the biomarkers of patients, using more clinical data, imaging, and other variables enables the healthcare system to guide diagnosis and treatment more precisely. The concept of the medical digital twin, and its related virtual representation of a patient, therefore, is the approach to achieve this. In fact, such an approach is able to reduce the costs to the health system and increase the safety of interventions for the operators and the patients by developing ad-hoc, patient-specific procedures with the added benefit of also safely harnessing different virtual therapeutic and treatment scenarios.

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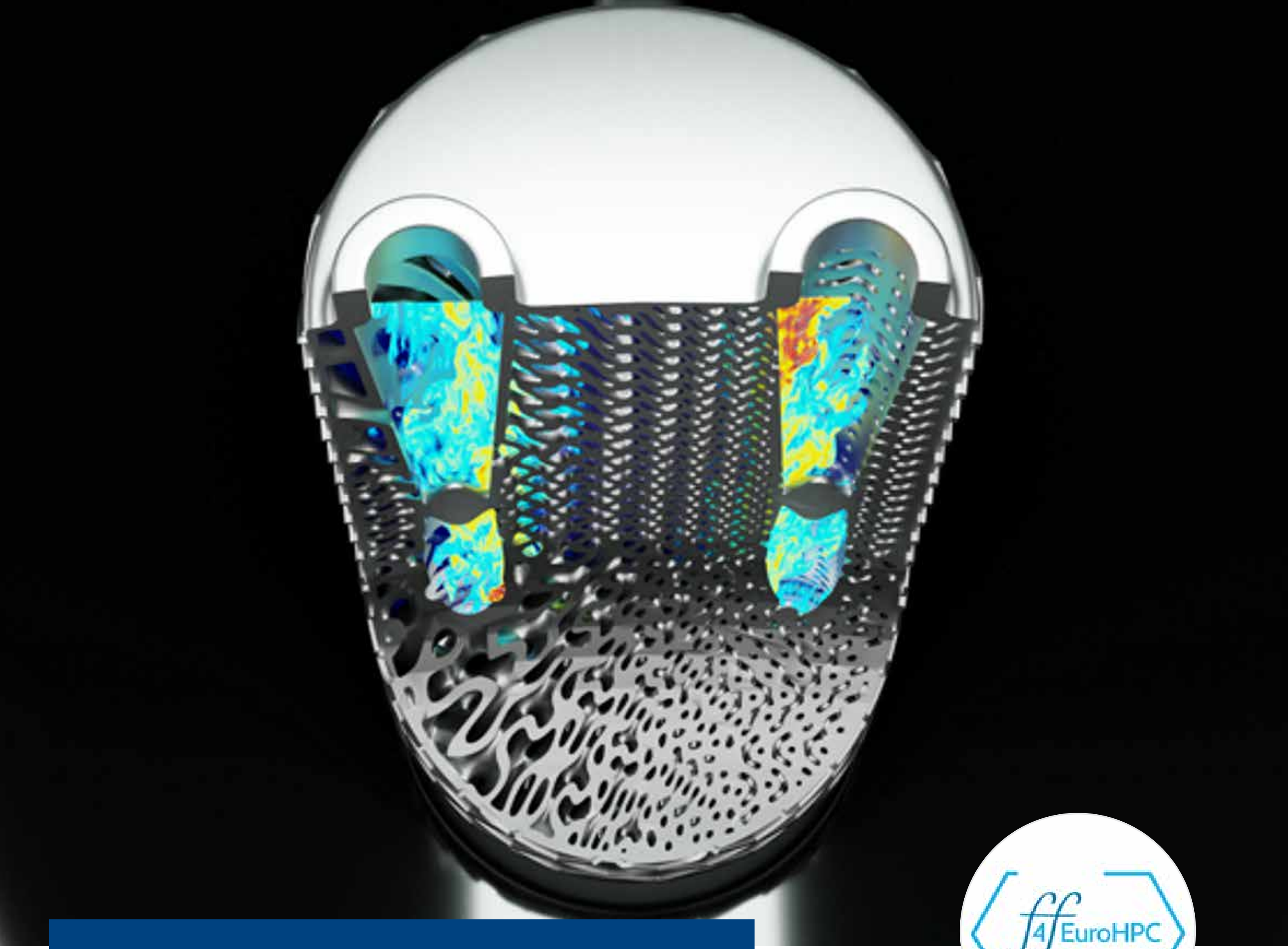

Topology optimization of micro-channel heat exchangers

by Alessandro Alaia[1], Edoardo Lombardi[1], Marco Cisternino[1], Giacomo Uffreduzzi[1], Antonio Memmolo[2], Claudio Domenico Arlandini[2], Tommaso Tirelli[3], Alberto Tacconelli[3], Paolo Ambrogiani[3]
1. Optimad - 2. Cineca - 3. Aidro

The success story presented in this article was developed during the first tranche of the FF4EuroHPC project. Partners Optimad, Aidro and CINECA teamed up to address a specific business challenge in the manufacturing sector and overcome it with the help of high-performance computing.

A micro channel heat exchanger (MCHX) is a heat exchanger in which fluid flows in millimetre-sized lateral confinements. Due to their high specific properties, efficient flow distribution, and light weight, they are gaining popularity in various industries, including aerospace, bioengineering, electronics, and oil & gas.

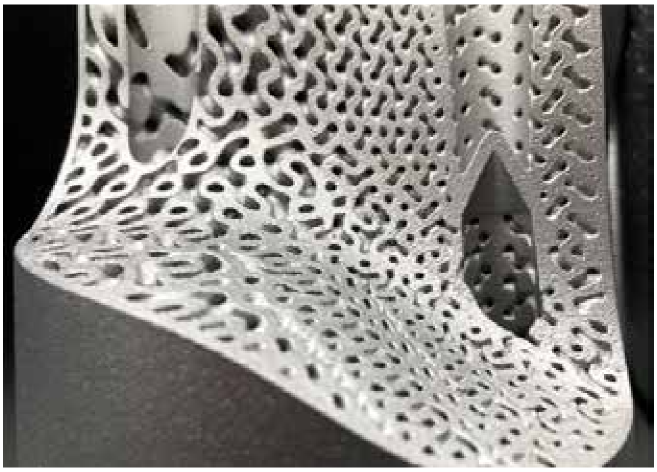

Fig. 1. An example of MCHX (3DHX, courtesy of Aidro). The internal lattice structure is obtained using a TPMS (gyroid) with variable frequency and wall thickness.

The challenge:
to develop an advanced design methodology to generate innovative micro channel heat exchanger configurations

The performance of MCHX is strongly influenced by the design (shape and topology) of the micro-channels. Design approaches based on experimental campaigns require many iterations, resulting in significant R&D costs and long times to market. In practice, due to budget and time constraints, only a few configurations are evaluated leading to sub-optimal solutions. On the other hand, a simulation-centred design approach poses several challenges including modelling, software integration, and robustness. Furthermore, due to the inherent multiscale nature of the problem, conjugate heat transfer (CHT) simulations of MCHX require high-resolution computational models to resolve fluid dynamics well at the smallest space-time scale of microchannels.

Consequently, the costs associated with these calculations severely restrict the comprehensive exploration of the design space. Optimization is also a fundamental requirement for any ICT infrastructure. In-house HPC solutions are generally under-dimensioned for these tasks, especially for small and medium-sized enterprises.

As a result, some shortcuts are taken to accommodate the limited computational resources (e.g. the feasible design space is limited heuristically in advance, or simplified models are developed on an ad-hoc basis for a single use case) leading to workflow entropy, further increases in R&D costs, and ultimately poorer market competitiveness. Therefore, it becomes imperative to use parallel computing to maintain development times that are compatible with industrial turnarounds.

Topology optimization (TO) is an advanced design methodology used to generate innovative configurations that are difficult to achieve with conventional design techniques. The complex shapes resulting from TO are not easily produced by established techniques such as computer numerical control machining, injection moulding, or vacuum casting. The technology readiness level (TRL) of different types of additive manufacturing (AM), e.g. laser-sintering, has soared over the past decade, making these technologies key to new business models in the manufacturing industry. AM offers several advantages such as a faster production cycle and flexible design, and creates possibilities that traditional manufacturing technologies could not by enabling the production of components with complex geometries at relatively low costs. Therefore, the combination of TO with AM is a promising application for MCHX design. Notwithstanding the enormous potential, however, MCHX manufacturers are prevented from taking advantage of the freedom provided by the TO+AM paradigm due to the difficulties mentioned previously.

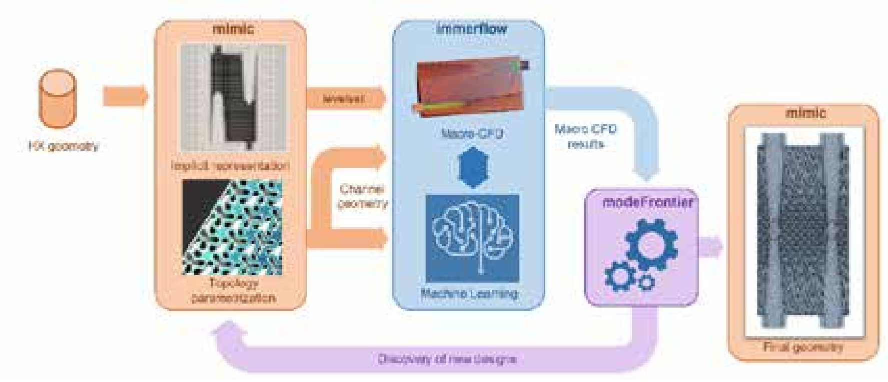

Fig. 2. Schematic representation of the TOLOMHE optimization workflow. New designs are discovered by the optimizer based on the results of CFD simulations performed at the macroscale. Macroscale simulations use an ML model to infer the local permeability and heat exchange coefficients based on local flow field and channel topology. At the end of the optimization loop, the optimal geometry is calculated by merging the HX layout geometry with the optimal channel topology discovered by the optimizer.

The solution:
TOLOMHE framework for topology optimization

TOLOMHE is a high-performance computing (HPC)-centric platform developed for MCHX topology optimization. Combining advanced optimization, simulation, machine learning, and deployment on an HPC infrastructure, the TOLOMHE platform aims to: 1) increase the competitiveness of MCHX manufacturers by providing a cost-effective design tool for MCHX; and 2) validate an innovative business model for the independent software vendor based on the "Optimization-as-a-Service" paradigm.

Fig. 3. Example of microscale simulation performed on "prototype" lattice topologies. The simulations are used to train an offline ML model to predict local permeability and heat transfer coefficient given local flow conditions and lattice topology.

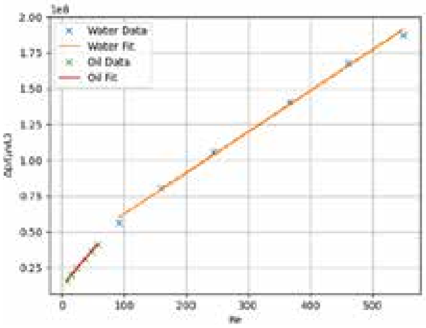

Fig. 4. Comparison between pressure gradient estimated by our ML model and numerical results of high-fidelity simulations at different Reynolds numbers for a gyroid cell.

The building blocks of TOLOMHE are a solver-independent optimizer (modeFRONTIER), a multiscale multi-physics solver for CHT simulation (immerFLOW), and geometry manipulation software (mimic). modeFRONTIER (ESTECO) is an industry-leading tool for multi-disciplinary design optimization; immerFlow (Optimad) is a high-throughput CFD (computational fluid dynamics) solver based on an immersed boundary paradigm that is particularly well-suited to automated workflows with complex geometries; mimic (Optimad) is a tool for computer-aided manipulation of geometry with implicit geometry topology parametrization.

The multiscale nature of fluid dynamic/thermal coupling in MCHX is addressed through a machine learning (ML) model. The resulting approach is characterized by three nested mathematical/numerical models:

1. **A Micro-scale model.** This consists of a deep neural network that estimates the local permeability and heat transfer coefficients from the (local) channel topology and flow conditions. The (synthetic) dataset used for offline training was created on an HPC cluster (Galileo100, CINECA's infrastructure with 528 computing nodes, each with two Intel Cascade Lake 8260 CPUs with 24 cores each). Each data point corresponds to a high-resolution simulation performed on a single cell of a "prototype" lattice topology.
2. **A Macro-scale model.** This is used to simulate the macro-scale flow field for a given heat exchanger layout. The microscale effect is incorporated in terms of local permeability and heat transfer coefficients. These are calculated through inexpensive feed-forward evaluations performed by the ML model. The computational cost of a simulation for the entire heat exchanger is drastically reduced as a result.
3. **Evolutionary optimization.** This framework is used to explore the entire design space and improve the initial design. Genetic algorithms require the evaluation of a large number of models during the initial exploration of the design space (from a few hundred to several thousand, depending on the specific problem). To achieve this exploration in an acceptable amount of time, the optimization is performed on the HPC infrastructure, thereby harnessing the high scalability of the genetic algorithms. Furthermore, genetic algorithms are well suited to multi-objective and multi-constraint optimizations. A hybrid strategy combining SQP (sequential quadratic programming) and the NSGA-II (non-dominated sorting genetic algorithm) was selected as the optimization algorithm within modeFRONTIER. During topology optimization the design of the MCHX is implicitly described in terms of a level set function to avoid costly (and error-prone) remeshing cycles. At the end of the optimization, an explicit representation of the overall geometry of the heat exchanger is returned to the user in terms of the surface tessellation provided by mimic.

TOLOMHE business benefits and impact

TOLOMHE's value proposition revolves around three main concepts:

- Implementation on the HPC infrastructure, which guarantees access to an adequate computing infrastructure.
- No previous knowledge is required to use the HPC or optimization, which helps remove the barrier to entry for first-time HPC users.
- All the necessary tools are integrated into a single platform, which

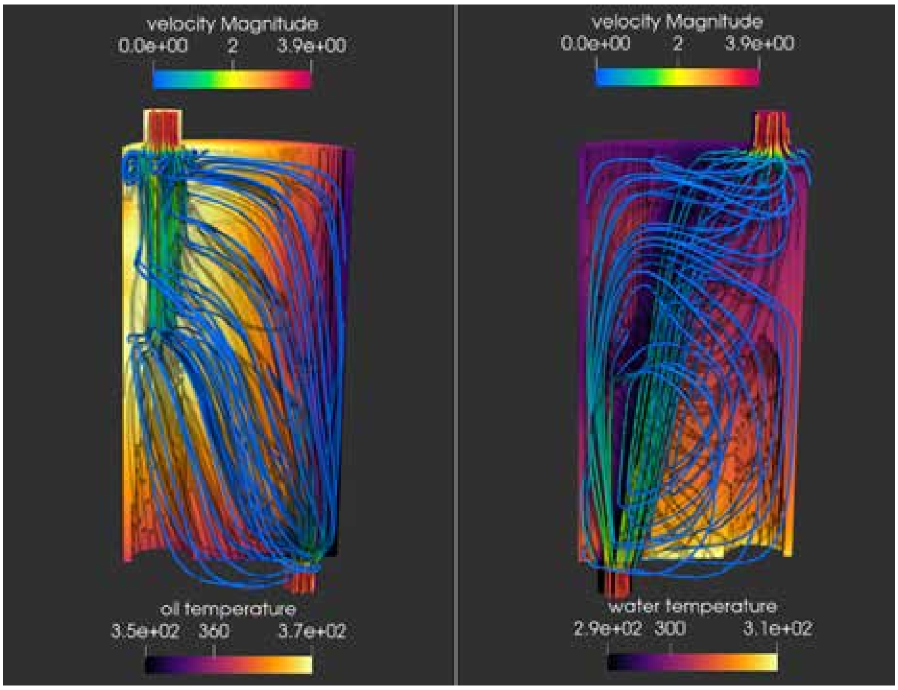

Fig. 5. Examples of results from a CHT simulation performed on an MCHX at macroscopic scale. The flow lines are coloured by the velocity and temperature fields for both hot fluid (left) and cold fluid (right). Microscale effects on both fluid perfusion and heat transfer are incorporated in terms of non-linear, spatially variable permeability and heat exchange coefficients. These coefficients are calculated on the fly by the ML model, thus achieving the bi-directional coupling between macro- and micro-scale.

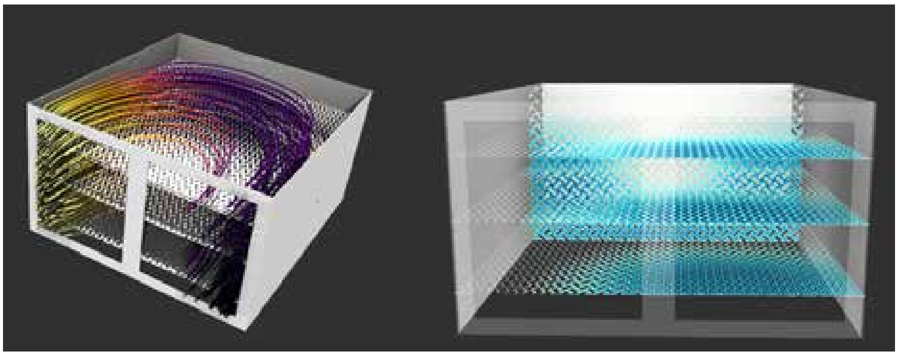

Fig. 6. Different sections of the optimized geometry for the ACOC heat exchanger. The optimized heat load (greater than 30kW) was calculated with an air inlet temperature of 50°C, an air mass flow of 0.5kg/s, an oil inlet temperature of 130°C, and a volumetric flow rate of 54l/min. The maximum pressure drop allowed was set to 130 kPa for oil.

eliminates all the problems related to the integration of different (CAE/CAD) tools and the related licenses.

By adopting TOLOMHE the end user should accelerate their transition from a build-to-print business model to a build-to-spec business model and reduce R&D costs and time-to-market for new products.

The work done in the TOLOMHE experiment provides further commercial benefits to the end user:

- Design workflow automation has the potential to reduce time-to-offer by 90%, and time-to-market by 50% (from a few months to a one month).
- By redirecting skilled labour to other value-added activities, the end user can potentially save up to €100,000 per year.

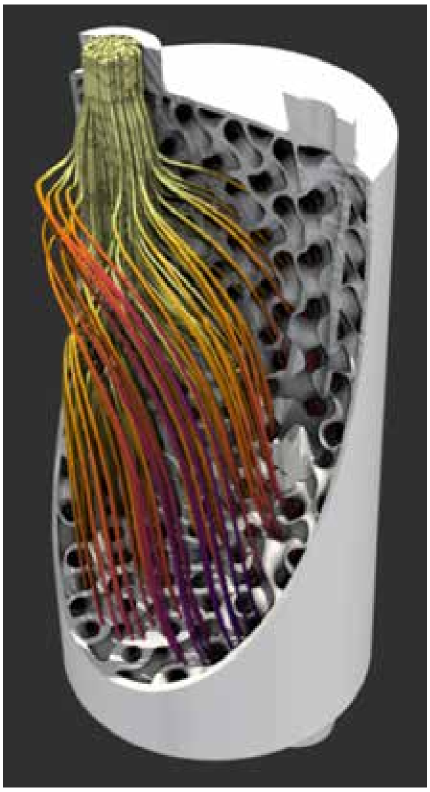

Fig. 7. Cropped view of the inner channel of an optimized two-fluid oil-water 3DHX (Aidro). Flow lines for the hot fluid (oil) are colored according to temperature. The objective of the optimization was to maximize the heat exchange by modulating the solid wall thickness within the design volume. Fixed mass flow rate and temperatures were prescribed at the flow inlets. A maximum 20kPa pressure drop constraint was imposed.

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

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

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MAGMA 6.0: Casting process simulation made easy

A little more than a year after release 5.5, MAGMASOFT has released version 6.0 with a brand-new livery which allows users to reach their objectives even faster, thanks to the special focus on ease-of-use and time-to-answer.

This version, which covers all foundry processes, features significant improvements to ease-of-use while the intuitive user interface accelerates the process of setting up simulations. The toolbars and menus have been simplified, making configuration of a simulation easier and more intuitive, while new keyboard shortcuts save time and simplify work processes.

The new CAD is more streamlined and intuitive, allowing both imported and internally modelled 3D files to be handled more quickly in the software. Projects also load in 80% less time, allowing users to save further time, or switch more quickly between different projects, or different versions of projects.

The composite solver mesh, previously available for HPDC (high pressure die casting) processes only, has now also been extended to gravity die casting processes, thus significantly reducing the number of elements needed to define the computational grid. A new control system for filling dynamics, which builds on the functionality of version 5.5, allows the user

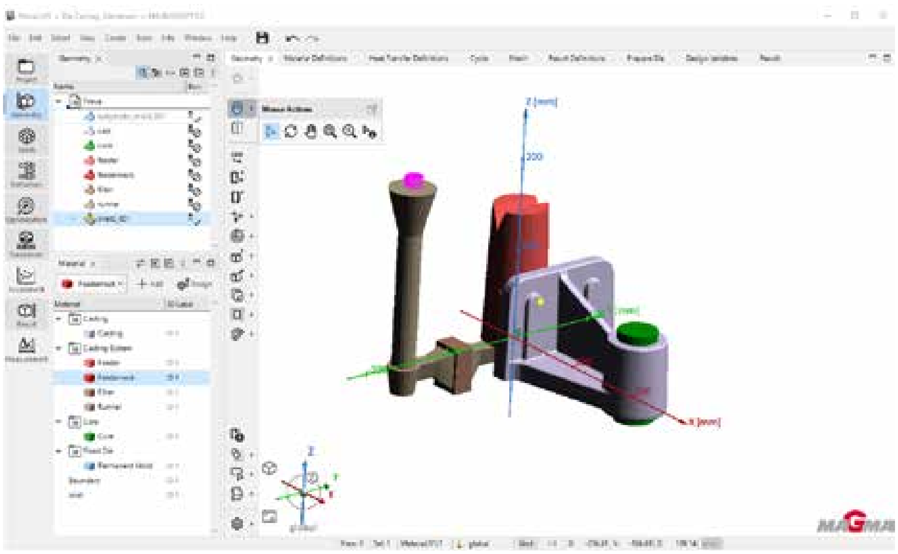

Fig. 1. MAGMASOFT 6.0's new CAD.

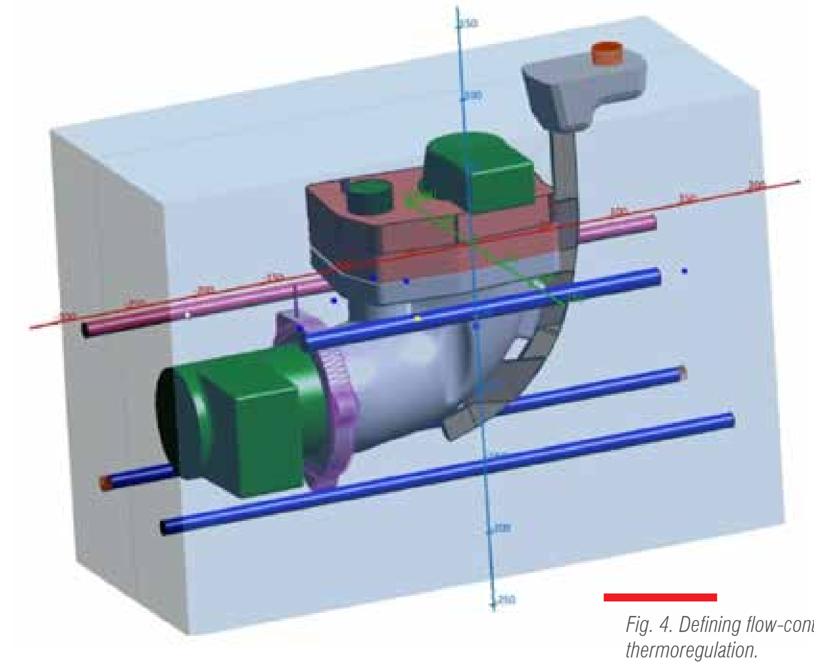

Fig. 4. Defining flow-controlled thermoregulation.

to define whether a mould should be filled completely or only up to a certain level. This functionality allows the true dynamics of the process to be represented more accurately.

MAGMASOFT Ver. 6 has been extensively updated and extended for gravity die casting processes. The permanent mould gravity casting model now integrates fluid dynamics for temperature control circuits, derived from the HPDC module. This allows designers to monitor the efficacy of the temperature control system and the efficiency of the circuits in terms of sudden increases in the temperature of the control medium, the pressures and speeds involved, as well as the relative zones of highest exchange per single circuit, and the heat transfer coefficients per single zone. This helps designers more accurately calculate the heat balance in the mold and to predict the presence of shrinkage porosities, to improve the quality of die casting results.

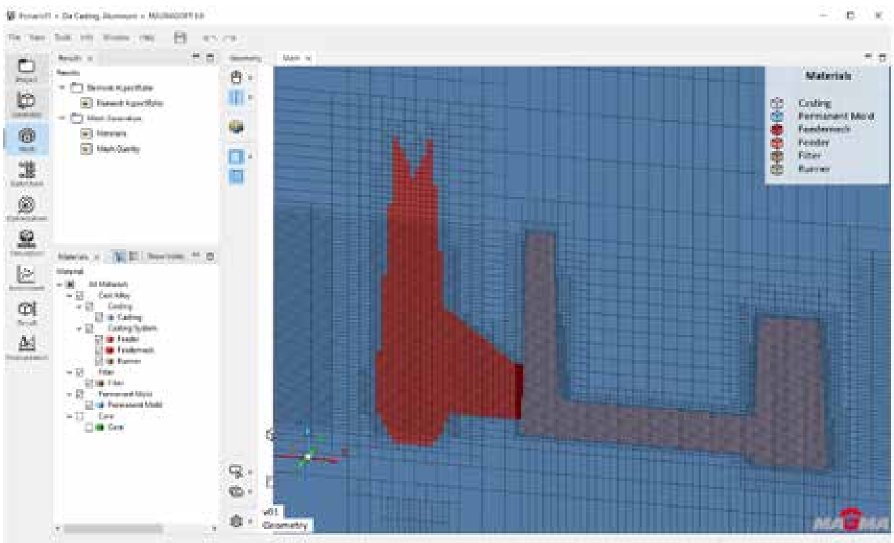

Fig. 2. New MAGMASOFT 6.0 composite mesh.

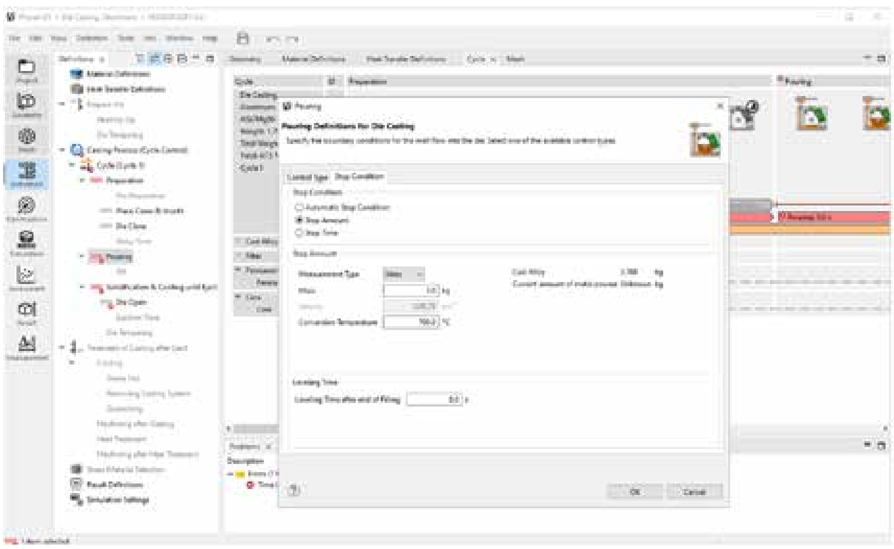

Fig. 3. New control system for filling dynamics.

Release 6.0 allows users to define the settings of the heaters independently and separately from the temperature control circuits.

For process optimization purposes, MAGMASOFT Ver. 6.0's new preheating phase allows users to calculate and simulate the preheating of the mould or printer in preparation for production.

This release builds on the previous version's automatic optimizer that allows the optimal system configuration to be identified thanks to the introduction of geometric and process variables and the MOGA (Multi Objective Genetic Algorithm) solver.

Release 6.0 is available for 64-bit Windows and Linux operating systems.

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Complex battery system storage modelling with Ansys Twin Builder and Ansys Fluent

"We're designing a fully integrated energy storage system for ease of deployment and sustainable energy optimization for use across solar, wind farm, and power plant applications. Every system component is pre-assembled before it is shipped to the customer site, so it is ready for immediate implementation. Ansys solutions enable us to simulate and build a fully optimized, low-maintenance, shelf-ready product with a 20-year design life that delivers high energy efficiency.

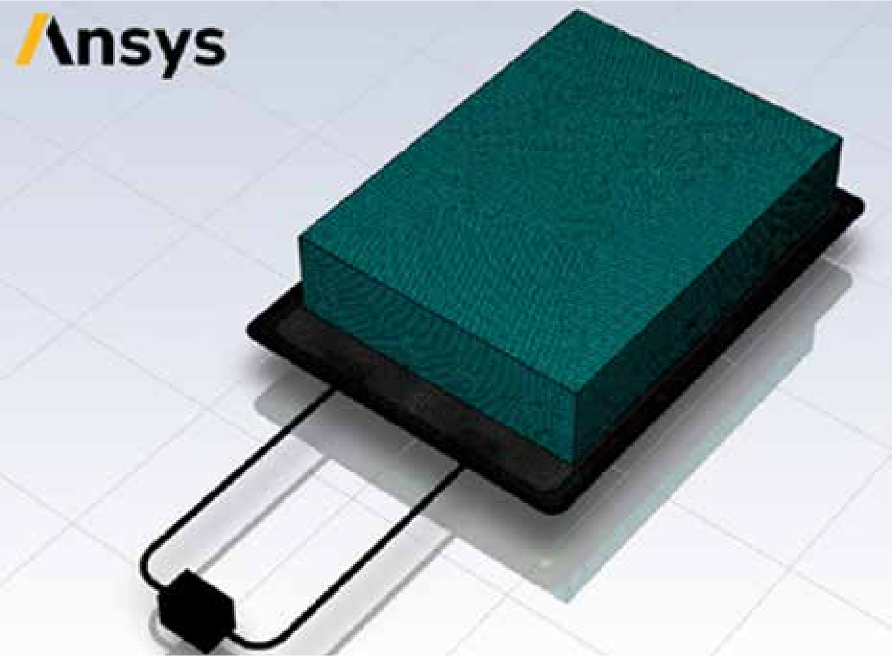
Wärtsilä uses Ansys software for complex battery storage system modelling to accurately test and make predictions about the life expectancy of our energy storage systems. With the help of Ansys simulation software, we were able to layer and build an accurate representation of our system that we can use to understand thermal management performance. Simulation also saved the team six months of development time and reduced the number of physical prototypes by three.

Dewei Guan
Energy Storage & Optimization - Wärtsilä

CHALLENGES

Designing an entirely new energy storage system requires building a complex system model that can simulate and capture the thermoelectric and electrochemical behaviour of the battery and the complicated transient heat transfer between multiple system components.

The model must be able to accurately predict battery module temperature change in transient analysis (the calculation of a circuit's response over a defined time period). Successful simulation depends on seamless data exchange between the system model and a unique software environment.



TECHNOLOGY USED

- Ansys Twin Builder
- Ansys Fluent

ENGINEERING SOLUTION

- Input battery dynamic performance data to calculate and build a six-parameter battery cell model based on the electric circuit model (ECM)
- Build a chiller model to calculate power consumption and cooling capacity based on battery and coolant temperatures
- Generate and validate a reduced order model (ROM) from a fully converged computational fluid dynamics (CFD) model of the cold plate to solve conflicts between accuracy and computational speed
- Combine the ECM and ROM models into a battery module to understand state of charge (SOC) as a function of power, coolant, and ambient temperatures to control battery charge and discharge rates
- Combine model components, to create an accurate battery storage system model for testing and validation

BENEFITS

Simulation enables the team to deliver an accurate, reliable model of the storage system that can be used for testing and validation of overall system performance over the life of the battery. With Ansys solutions, we can easily predict what is going to happen over the next five years. The simulation software provides intuitive, user-friendly tools that address system development and validation from every perspective. We use this comprehensive set of solvers at every stage during validation, whether working at the system level or capturing a specific electrical response. Twin Builder's ROM technology also enables us to reduce simulation time from one day to 10 minutes with a high-fidelity representation of the CFD model, resulting in faster product development.

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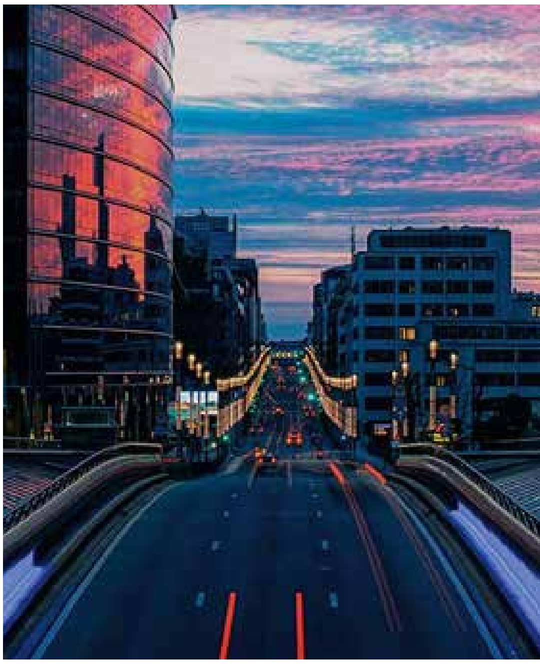
About Wärtsilä

Wärtsilä is a global leader with innovative technologies and life cycle solutions for the energy and marine markets. Wärtsilä Energy leads the transition towards a 100% renewable energy future.

We help our customers with decarbonization by developing market-leading technologies. These cover future fuel-enabled balancing power plants, hybrid solutions, energy storage, and optimization technology, including the GEMS Digital Energy Platform. Wärtsilä life cycle services are designed to increase efficiency, promote reliability, and guarantee operational performance. Our track record comprises 76GW of power plant capacity and more than 110 energy storage systems delivered to 180 countries around the world.



Multiphysics system simulation of solenoid valves

by Gi Tae Kweon
TAE SUNG S&E

Solenoid valves are devices used to shut off or control the flow of a fluid in response to an electrical signal. The magnetic finite element method is mainly used to predict the magnetic force when designing a solenoid valve. However, the movement of the plunger, which is an important inspection item for solenoid valves, cannot be directly predicted by magnetic force simulation alone. To solve this problem, solenoid valve developers try to directly predict the plunger's movement using multiphysics simulation and including the magnetic field of the magnetic finite element method. In this article, we created a system simulation model for each internal element of a solenoid valve based on a multiphysics system in the Ansys AEDT environment. The simulation models of each element were then combined to create a full simulation model for the solenoid valve.

Introduction

When current flows through a solenoid valve coil, it creates a magnetic force on the internal plunger. The magnetic force generated moves the plunger and valve spool together to close or control the fluid. Solenoid valves are multiphysical systems that operate through the interaction of various physical elements such as electricity, heat, mechanical movement, and fluid dynamics as well as magnetic forces. In this article, we created a system simulation model for each internal element and then, by combining the individual simulation models for each element, we created a total simulation model for the solenoid valve. Using the system model created, it is possible to simulate and predict the same items that are tested in performance tests by solenoid valve inspection equipment.

The multiphysics system of solenoid valves

Fig. 1 shows the internal elements of a solenoid valve. A solenoid valve is a system that combines various physical elements and operates as a result of the interaction between these elements.

A solenoid valve operates as follows:

- When voltage is applied to the coil of the drive circuit, magnetic flux is generated in the magnetic circuit and magnetic force is generated in the plunger.
- When the magnetic force exceeds the sum of the spring force and the

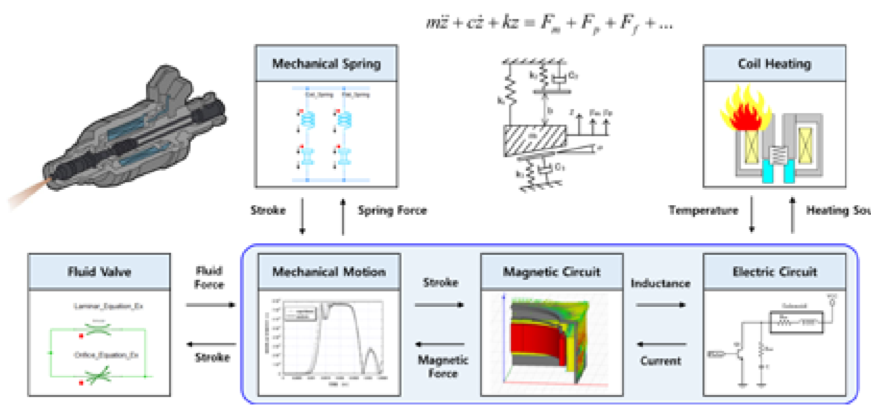


Fig. 1. Model of solenoid valve system.

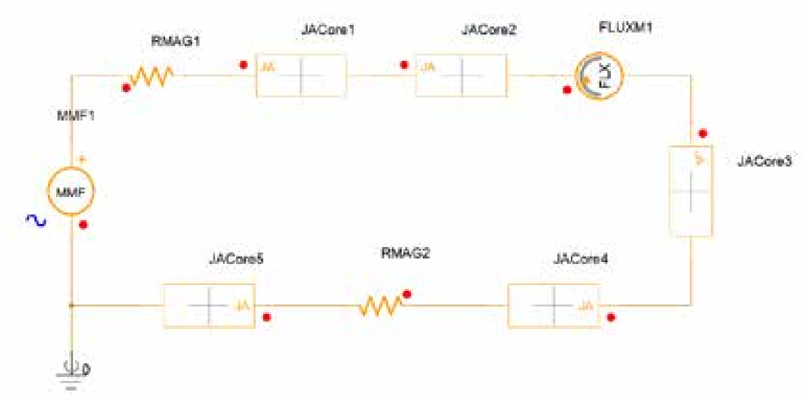


Fig. 2. Equivalent magnetic circuit of a solenoid valve.

fluid force on the valve, the internal plunger starts to move.

- When the plunger moves, the magnetic resistance of the solenoid decreases and the inductance value increases, so the current value of the coil temporarily decreases.
- In this process, the current heats the coil causing its temperature to rise.
- As the coil's temperature increases, the coil's resistance increases, so the current in the coil decreases at the same voltage.
- As the resistance of the solenoid valve increases, the current at the same voltage decreases and the magnetic force of the solenoid valve also decreases.

As described above, a solenoid valve is a system that operates through the interaction of their internal physical elements.

Simulation modelling of various physical elements

(A) Magnetic circuit

The generation of magnetic flux by the current applied to a solenoid coil can be represented as an equivalent magnetic circuit in a similar way to an electrical circuit. Fig. 2 shows the equivalent magnetic circuit of a solenoid valve. The equivalent magnetic circuit method has the advantage of being easy to understand and fast to simulate. However, this approach uses mathematical approximations for the nonlinear properties of the magnetic materials, which results in inaccurate predictions of the magnetic forces; it also doesn't allow study of the detailed shape of the magnetic circuit. For this article, we used the finite element method (FEM) with Ansys Maxwell to predict magnetic force

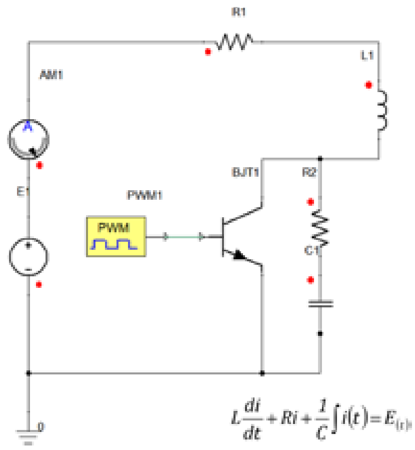


Fig. 3. The electric drive circuit of a solenoid value.

accurately. The magnetic simulation model generated is added as a co-simulation block within the Ansys Simplorer system simulation program, as shown in Fig. 3. This method makes it possible to predict magnetic forces with great accuracy because the magnetic FEM simulation can be conducted concurrently with the system simulation.

(B) Electric drive circuit

The drive circuit of the solenoid valve is simply composed of a power transistor (TR) and a surge protection circuit. It can be simplified as shown in Fig. 3, and the system simulation model can consist of a single Bipolar Junction Transistor (BJT), a resistor-inductor (RL) surge protection circuit, and a pulse-width modulation (PWM) block for on/off control.

(C) Coil heating

When the solenoid valve is energized, heat is generated in the coil. This heat causes the temperature in the coil to rise, which increases the electrical resistance of the solenoid coil, and decreases the coil

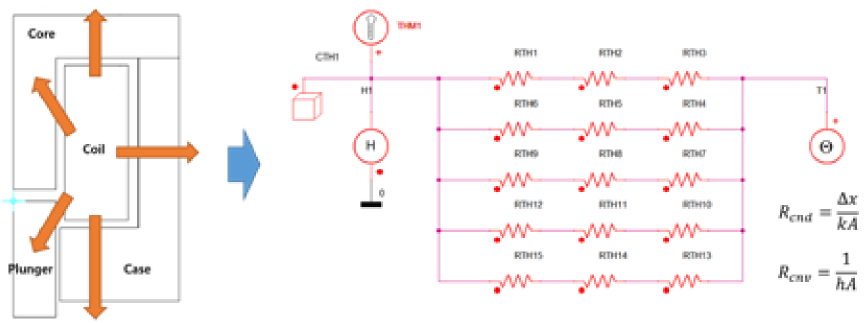


Fig. 4. Thermal network of solenoid values.

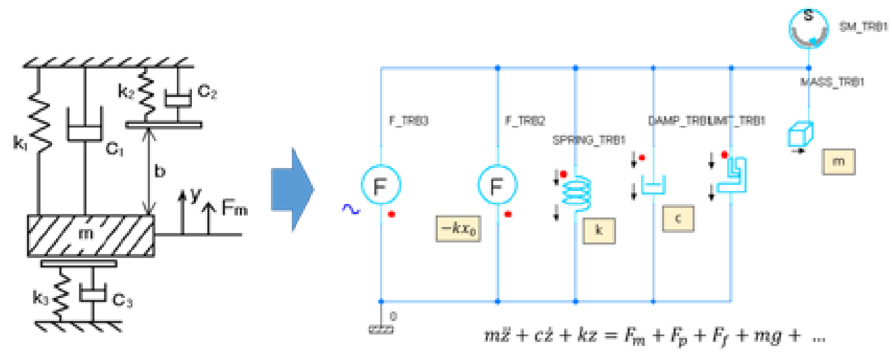


Fig. 5. Modelling the mechanical movement system.

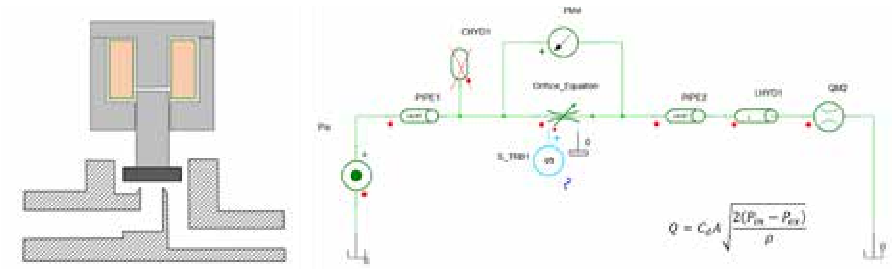


Fig. 6. System modelling of a fluid valve.

current and solenoid's magnetic force together. Therefore, when simulating a solenoid valve system, it is essential to predict the temperature change in the coil due to heat generation.

In general, 3D thermal simulation is used to predict the heating of solenoid coils. Another approach is thermal system simulation modelling of the thermal networks, where heat transfer is expressed as a combination of thermal resistance by conduction and convection, as shown in Fig. 4.

(D) Mechanical movement

The solenoid valve moves the plunger, which is an internal component, to control or shut off the fluid. Therefore, the solenoid valve's performance is determined by the movement of the plunger, so mechanical movement directly affects the product's performance. The motion of the plunger can be expressed as a linear motion equation of one degree of freedom and can be predicted through mechanical motion simulation.

Fig. 5 shows a system simulation model for the mechanical motion of the solenoid valve. It consists of blocks for mass, damping and stiffness of linear motion equation with one degree of freedom. The limit block also defines the equivalent stiffness and damping of the collision at both ends and limits the range of motion.

(E) Fluid value

Solenoid valve is divided into solenoid part and valve part. The solenoid plunger and the valve's spool are joined together like a single piece. So the flow of the valve is controlled by the magnetic force of the solenoid, and the fluid force applied to the spool affects the mechanical movement of the solenoid valve. The fluid in the valve is calculated by the hydraulic equation shown in Fig. 6, and the system simulation model is created by a combination of orifices and pipe blocks.

Integrated system simulation model

In the previous section, we created a system simulation model for each component within the solenoid valve. The full system simulation model in Fig. 7 was constructed by incorporating the individual system simulation models created of the various components. The combined system simulation model can be used to predict the operational characteristics of solenoid valves.

Fig. 9 shows the plunger and spool stroke in time series and Fig. 10 shows the current applied to the solenoid coil. The solenoid valve plunger does not move for about 2.5ms after excitation due to the initial spring force. In the period from 2.5-6.5ms, when the plunger operates, the current temporarily decreases due to the increase in inductance. This operating characteristic is also observed during the operational tests of the solenoid valve. By combining mechanical movement, magnetic circuits, and electrical circuits into one system, system simulation can be used to predict not only magnetic forces but also experiments on the operational behaviour of solenoid valves.

Automated system simulation

Predicting the performance characteristics of solenoid valves requires multiphysics system simulations.

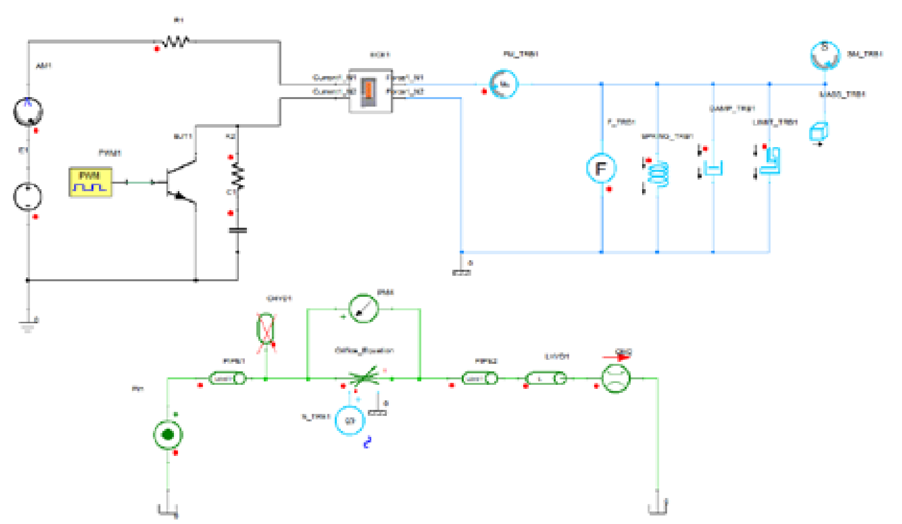


Fig. 7. Solenoid valve system simulation model.

Categories	Design factors & Function
Magnetic circuit	Magnetic force, Magnetic density saturation, Inductance by time
Electric circuit	Control type (voltage, current, PWM, peak&hold), Reverse voltage protection circuit
Mechanical motion	Plunger stroke, Two spring, Plunger gravity, Frictional force due to lateral magnetic force
Fluid valve	Flow rate, Fluid force, Viscous force between seat and disk of water valve

Table 1. Functions and design factors provided by Actuator-Designer.

However, multiphysics system simulation is only available to simulation experts who can understand the mathematical models of various physical systems, such as electric, magnetic, thermal, fluid and mechanical movement, and who can directly generate system models for each physical domain. In particular, product designers who need to predict the performance parameters of solenoid valves may not be simulation experts, which makes it difficult for them to implement and use system simulation models.

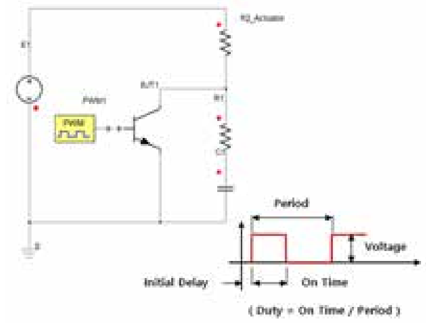
To solve this problem, we propose an automation program that automatically generates a system simulation model of solenoid valves. Actuator-Designer is a design program that allows designers to easily predict the performance characteristics of solenoid and voice coil motors.
Actuator-Designer helps designers automatically generate system simulation models by allowing them to simply enter design values for each familiar physical domain, as shown in Fig. 8. These models can be used to predict magnetic forces and the performance characteristics for the various design factors of the solenoid valves in Table 1.

The program workflow is similar to the product development process. The designer first creates the shape of the magnetic circuit, then inserts the magnetic material and the specifications of the coils and springs. Then the designer enters the test conditions like an experiment and runs the simulation. The program uses the input information to automatically generate a simulation model in Ansys Maxwell and Simplorer, which are used as internal solvers, and performs the calculations.

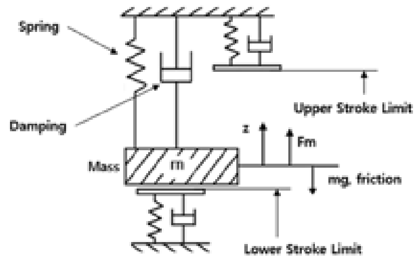
After the simulation, the program displays the results of the performance characteristics on screen or saves them to a file.

Conclusion

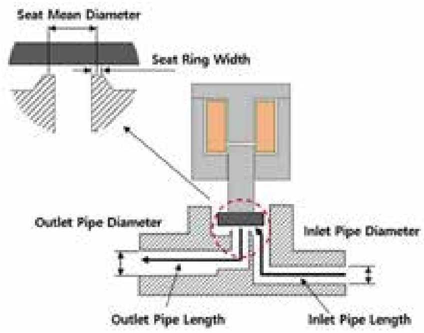
To predict the operating performance of a solenoid valve, Ansys Maxwell and Simplorer were used to create a system simulation model for each internal element and these element models were combined to generate a full system simulation model of the solenoid valve. Using the solenoid valve system simulation model, we were able to predict results such as the operational characteristics of the real product over time that could not be achieved by the magnetic finite element method alone.



(a) Electric drive circuit.



(b) Mechanical motion.



c) Fluid valve.

Fig. 8. Automation program for solenoids and voice coil motors.

However, multiphysics system simulations are complex and difficult to use for product designers who need to predict the performance of solenoid design factors. To solve this problem, a design program has been introduced that can predict the performance characteristics of solenoids by automatically generating and calculating system simulation models by simply entering the design values.

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About TSNE

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

PRESS RELEASE

ESSS & EnginSoft join forces to boost Ansys businessin Italy

Partnership increases ESSS' presence in southern Europe and strengthens EnginSoft's position as a world-class simulation solution provider

ESSS is a Brazilian multinational headquartered in Florianópolis, Santa Catarina, Brazil. It offers advanced computational simulation and Computer-Aided Engineering (CAE) tools, and customized software. ESSS has earned an international reputation for offering a full range of numerical simulation solutions to the market, accompanied by superior customer support and related engineering services. These capabilities enable customers to take full advantage of the Ansys multiphysics portfolio while exposing simulation to all levels of the engineering organization.

EnginSoft is one of the leading technology transfer companies in the field of Simulation Based Engineering Science (SBES). Since its foundation in 1984, through its expansion in the sector in the mid-Seventies, to today with a global presence, EnginSoft has always been at the forefront of technological innovation. The company is present in Italy, France, Germany, the UK, Türkiye and the USA and partners closely with synergetic companies in Greece, Spain, Israel, Portugal, Brazil, Japan, Korea and the USA.

JUNE 6th, 2023

ESSS, a Brazilian multinational with a global presence in the computer simulation market and a long-term Ansys Elite Channel Partner in Latin America and Iberia, today announced an unprecedented partnership with **EnginSoft**, an Italian multinational and long-term Ansys Elite Channel Partner with more than 30 years of experience in providing complete engineering simulation solutions across a wide range of software and services.

Together, they are starting **EnginSoft Simulation Software Italia (ESSS Italia)**, a new company within the EnginSoft ecosystem, to focus on developing the Ansys software business supported by significant investment from ESSS to accelerate its growth.

Stefano Odorizzi, EnginSoft's Founder and President, said: *"It gives us great pleasure to announce this partnership, which will be of significant benefit to the Ansys business and to our customers in Italy, who can draw on the united skills of these two highly experienced teams."*

He explained that EnginSoft, which has been one of the leading technology transfer companies in the field of Simulation Based Engineering Science (SBES) for about 40 years, will continue to operate independently with its existing international partners and customers, focusing on the development of leading-edge design process innovation for Industry 4.0 and the emerging Internet of Things (IoT).

He concludes, *"EnginSoft has always focused on high-value services, and extensive collaboration with academia and the R&D centers of major industrial groups working on European and Italian innovation and development projects. We will continue to deliver the technology innovation and skills transfer that have become our hallmark and will become stronger than ever."*

Clovis Maliska Junior, Global CEO of ESSS said, *"We are confident that the synergy between our teams, our similar business culture and operational visions will offer many benefits not only to the market, but to our team and Ansys as well. This is a very important step in our international expansion strategy."*

Jim Chiamardas, Vice-President for EMEA at Ansys stated, *"We are happy to see two of our capable, long-term partners joining forces to accelerate the growth of the Ansys business in Italy and we look forward to a successful future with ESSS Italia."*

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