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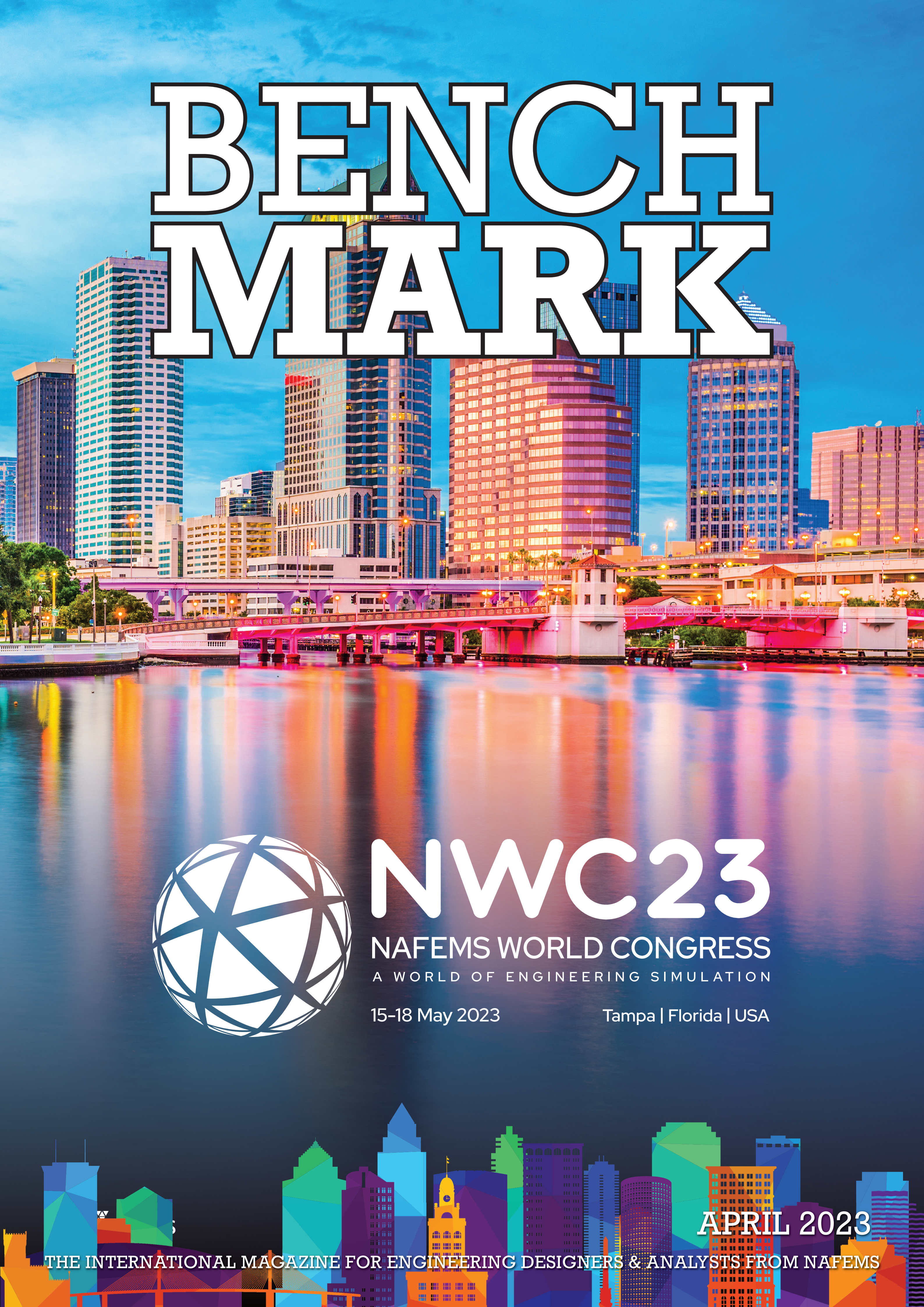

# NWC23

## NAFEMS WORLD CONGRESS

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# Making HPC Technologies Accessible for SMEs

**Alessandro Alaia | Nikola Blažević | Tina Črnigoj Marc**
**Francisco Ramirez-Javega | Andrea Antonio Russo**

The FF4EuroHPC project is funded by the European Commission under the H2020 EU Framework Programme for Research and Innovation with a total budget of €9.9 million. The project, scheduled to run for 36 months, was initiated in August 2020 and is coordinated by the University of Stuttgart (Germany) and supported by 5 other core partners: Arctur (Slovenia), CINECA (Italy), Galicia Supercomputing Center (CESGA, Spain), scapos AG (Germany) and Teratec (France).

**Project Aim**

FF4EuroHPC helps facilitate access to High Performance Computing-related technologies for European Small & Medium Enterprises (SMEs) and thus increases the innovation potential of European industry. Whether the SME is running high-resolution simulations, doing large-scale data analyses, or incorporating AI applications into its business or service workflows, FF4EuroHPC assists SMEs to connect their business with cutting-edge technologies.

**SME Participation**

Two open calls targeting the highest quality experiments involving innovative, agile SMEs were offered through the project. The focus was on key European industrial sectors, particularly SMEs from the manufacturing and engineering sectors. Each experiment centred on an end-user SME (or consulting SME) with technology or service providers such as Independent Software Vendors (ISVs), technology and domain experts, and HPC providers completing the partnership. The partners identified and addressed a specific business challenge for the SME, linked to a specific industrial sector or, in some cases, multiple industrial sectors. By implementing HPC, Artificial Intelligence (AI), Machine Learning (ML), High-Performance Data Analytics (HPDA), and other state-of-the-art technologies, the partners were able to develop unique products, innovative business opportunities, and become more competitive.

**Experiments and Success Stories**

42 experiments met the open call requirements, successfully passed the evaluation process, and were selected for funding. During the 15-month duration of the experiment, the partners jointly worked on the relevant use case and strove to overcome the challenges with the help of HPC. In the first open call, 16 experiments were run involving 53 partners from 22 European countries. All 16 experiments from that open call were successfully concluded and are presented in this booklet.

Each experiment had to address SME business challenges by using HPC and complementary technologies such as HPDA and AI. Therefore, each was an end-user relevant case study demonstrating the use of cloud-based HPC and the benefits it brings to the value chain from the end-user to the HPC infrastructure provider. As soon as the experiment was successfully concluded, it generated a success story, which highlights the expected business benefits for the participating SMEs. The success story also presents the potential impact of the experiment's results in economic terms, as well as with regard to societal or environmental challenges. Thus, it provides an inspiration to the broader industrial community.

The research leading to these results 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 the governments of Germany, Italy, Slovenia, France and Spain.

For further information about FF4EuroHPC, please visit:

**Website:** ff4eurohpc.eu

**LinkedIn:** linkedin.com/company/43366020

**Twitter:** twitter.com/ff4eurohpc

**YouTube:** youtube.com/@ff4eurohpc744

In the following, the challenges and results of four different experiments are presented showing how FF4EuroHPC helped SMEs to use HPC technologies to solve concrete business problems.

## Multiphysics and Multiscale Modelling of Aeronautical Components (MULCOM)

### The Partnership

**SME- Manta Group** is an Italian SME that operates in the aeronautical field and specializes in the production of composite parts of aircraft. It is also one of the strategic suppliers of Leonardo Spa.

**Technology partner- CETMA**, a private Research and Technology organization, which has acquired skills and know-how focused on composite materials and numerical modelling of these advanced materials and their manufacturing processes through over 25 years of applied research.

**HPC infrastructure partner- CINECA** (part of the National Competence Center (NCC) Italy). The largest Italian supercomputing centre with an HPC environment equipped with cutting-edge technology and highly qualified personnel which cooperates with academia and industrial partners.

### The Challenge

The autoclave moulding process – where composite layers are placed on a mould based on a lamination sequence and cured inside an autoclave using a vacuum, heat, and pressure – is the main fabrication method for composites used in the aerospace field. This process involves both mechanical and chemical phenomena, and a correspondingly high number of variables affect the final result.

Working with innovative materials and geometries leads to an increased number of defects and voids in the finished components which are then rejected. During the curing process, the mechanical stresses in the various materials rise, and this can lead to undesirable consequences. For example, during the cooling phase the different thermal expansion coefficients of the fibre, matrix, and mould materials generate high residual stresses which can lead to defects in the finished composite parts. Given the expense of the autoclave process, it is important to minimize defects in the finished components.

Currently, an expensive trial-and-error approach is used to find the optimal process parameters to produce complex-shaped components while minimizing the risk of voids or geometric distortions. This leads to long development times and high costs.

Manta Group's aim is to find a more effective manufacturing process for its products: finding the optimal process parameters by multi-scale and multi-physics numerical simulations. Compared to the current trial-and-error approach, this would significantly reduce the necessary development time and cost.

### The Solution

To optimize the autoclave process parameters (e.g., the lamination sequence, the maximum temperature, the soaking times, the times of heating, the maximum pressure), the different phenomena during the curing process need to be simulated to predict the parameters' effects on the quality of the components to be manufactured. To this end, two separate multi-physics and multi-scale numerical models

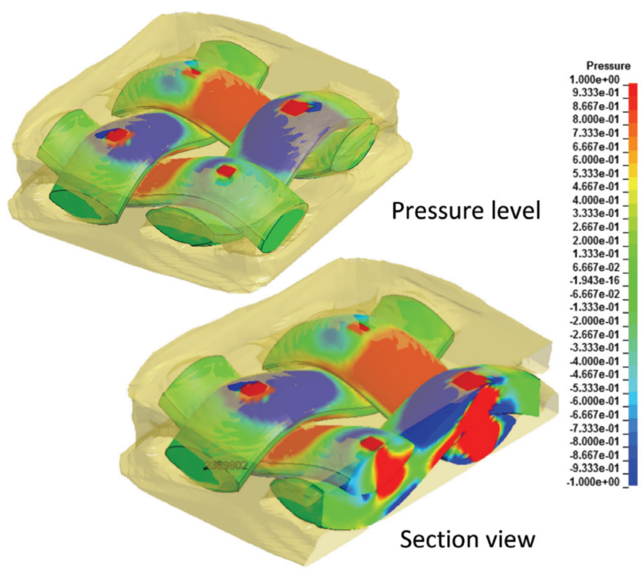


Figure 1: Pressure distribution in a composite part.

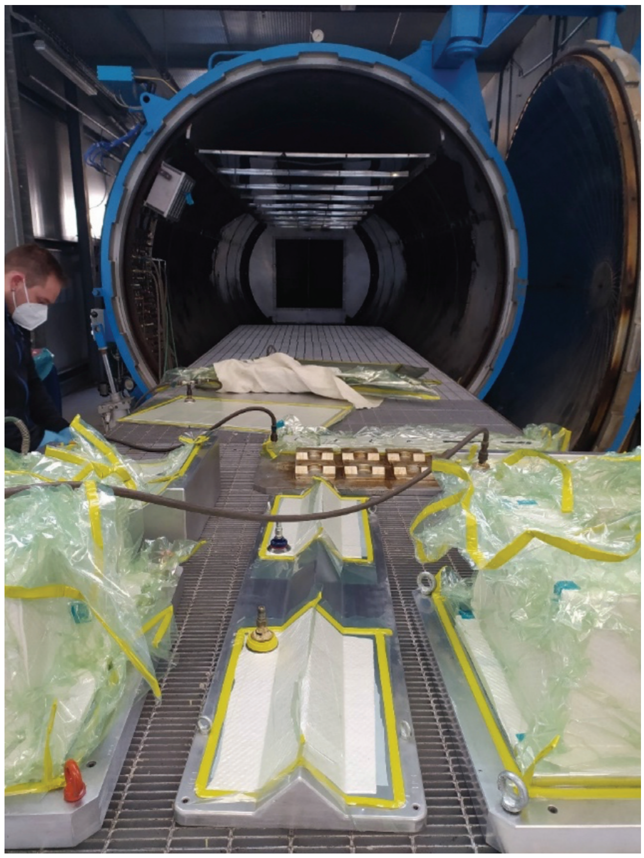

Figure 2: Autoclave for big composite parts.

were set up, employing HPC resources. In detail, these are (a) a thermo-mechanical model (on the macro scale) to predict the dimensional variations of the laminates due to the residual stresses generated during the autoclave process, and (b) a fluid-structure model (on the micro-scale) to simulate the resin flow during the pressure application. Both numerical models were validated by comparison with results of experimental tests done by Manta Group. To reduce the computing times, the scalability of the simulations and the use of HPC resources were improved substantially with the help of CINECA.

Using the material properties, the lamination sequence, the geometry of the parts, and the specification of the autoclave curing cycle as input parameters, the HPC simulations set up in the first step were able to provide the required information about the resulting part distortion and possible defects in the finished part in a very short amount of time. This HPC-backed simulation workflow now enables Manta Group to easily find the optimal parameters for the manufacturing process within a matter of minutes, thereby cutting down development times and significantly minimizing the number of physical tests.

**Business Impact**

Thanks to the MULCOM experiment, MANTA now uses HPC-based simulations to produce high-quality composite components, reducing development time and costs while increasing its competitiveness. Since autoclave moulding remains the main manufacturing technology of aerospace structures, at least for the next 10 years, this significantly strengthens Manta Group's business position.

In addition, the improved autoclave process know-how enables MANTA to profitably enter many other sectors besides aerospace (e.g., luxury boats, automotive, sport). All this helps to attract new customers by offering a full service, from design to production of the component. The expected business impact has been quantified at €1million three years after the end of MULCOM (September 30th, 2022).

**Benefits**

- MANTA (End-user) expects to reduce design costs by 50% (about €100,000 saving per year), material waste by 70% (about €60,000 saving per year), and raw materials usage by 15% (about €150,000 saving per year).
- CETMA expects the success story will lead to new R&D projects and consultancy services with an increase in its turnover of about €50,000 per year.
- CINECA aims to become MANTA's provider of HPC resources estimating its related increased turnover to €20,000 per year and to exploit the success story to attract new customers with an additional increase of turnover of the same order.

## AI-Aided Wind Flow and Gas Dispersion Simulations in Cities

**The Partnership**

**SME- Bettair Cities** S.L., a Spanish SME focused on deploying hyper-local real-time air quality monitoring networks that identify the sources of pollution street by street in cities and providing actionable information to the different stakeholders.

**Technology and HPC partner - Barcelona Supercomputing Center (part of the NCC Spain)**, established in 2005 and serves as the national supercomputing facility. Its mission is to research, develop, and manage information technologies to facilitate scientific progress.

**The Challenge**

Air pollution is the single largest environmental health risk in Europe and a major cause of premature death and disease. Thanks to advances in research on the human health impacts of air pollution, now reflected in the 2021 WHO Air Quality Guidelines, we know that adverse effects begin at much lower concentrations than previously assumed.

Urban air quality is influenced by complex atmospheric dynamics, urban geometry, land use, and traffic patterns, resulting in very different pollutant distributions at microscales. Some air pollution is windblown from outside the city, but most urban air quality problems are hyper-local, i.e., at street level and within meters of their source. As a consequence, any high-accuracy air quality map needs to use either a very dense network of sensors that measures pollution in real-time (which is very expensive) and/or high computational resources to process the data and model the distribution of pollutants with high spatial and temporal resolution.

The goal of this experiment was to reduce the computational cost of air quality simulations in urban environments and to give Bettair Cities access to affordable and accurate state-of-the-art real-time air quality modelling tools.

**The Solution**

Using 30 3D models of 1km$^2$ areas of real urban geometries from European capitals as a basis, a dataset of approximately 30,000 256m x 256m areas was built. These urban geometries were then used to perform CFD simulations of the wind flow for three different wind directions and the pollutant dispersion generated by traffic with a high spatial resolution.

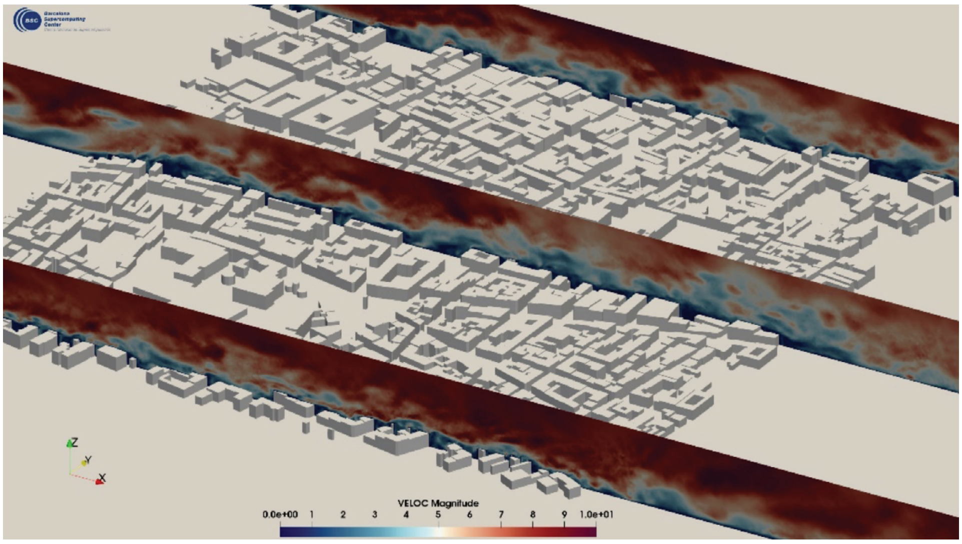


Figure 3: CFD simulation of a city geometry.

Deep Neural Networks were then trained to learn the results of these simulations at different heights. Using these AI models, simulations of new urban geometries can now be performed instantaneously with high precision and fewer computational resources. These models have been added to Bettair's platform to provide information about air quality and local emissions in real time.

**Business, Social, and Environmental Impact**

Bettair's ultimate aim is to help improve the air quality in local communities by providing accurate and actionable information. They want to raise awareness and work together with stakeholders to create policies and push initiatives that improve air quality everywhere. As a result of this experiment, Bettair has created an energy and computationally efficient low-cost AI solution to model air quality in cities with up to 1m$^2$ resolution, in near real-time. This type of precision and resolution is currently out of reach for any competitor due to the computational requirements of the CFD simulations with scientific software. The cost of the service provided by Bettair is up to 95% lower than that of competitors with similar spatial resolution and runs in real-time. The expected revenue for 2022 will be two or three times higher than previously expected, than previously expected because of the new service, and the turnover for 2023 will increase by – at least – a factor of two.

Thanks to this experiment, Bettair is able to combine sensor measurements with AI simulations and extract precise information about the local emissions and pollutant concentrations in the cities. This information is then made available in Bettair's platform and enables individuals and communities to take collective action to improve air quality for everyone. These solutions are already being tested in big cities like Rome, as well as in smaller cities like El Prat de Llobregat (population of 65,000) in Barcelona.

**Benefits**

- The simulation cost per km2 is reduced from €1,850 to less than €1.
- The spatial resolution of the real-time modeling capabilities is enhanced from 100 m2 to 1 m2.
- The experimental setup time for new cities is reduced by 80% from 3 weeks to 4 days.
- Access to new markets as cost barrier for municipalities and regional governments that could not afford classical modeling before is significantly reduced.
- Bettair's expected turnover for 2023 set to increase by a factor of at least two.

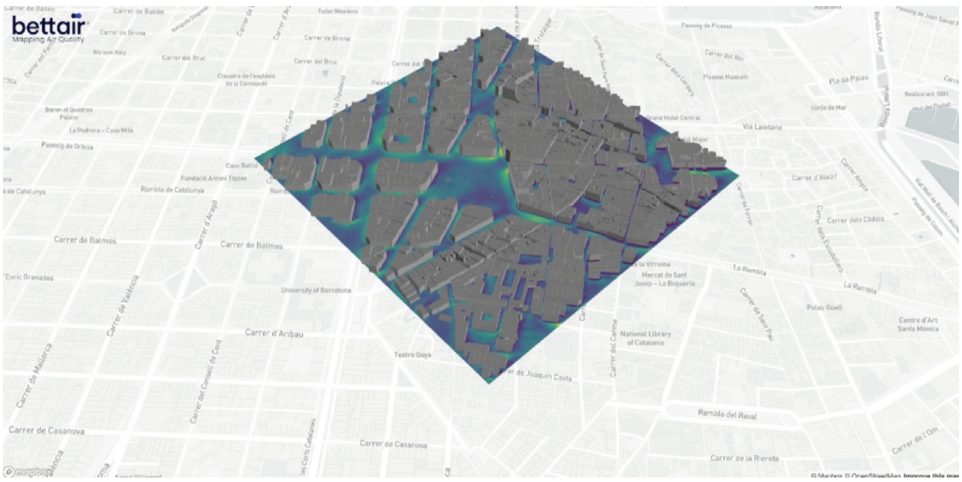


Figure 4: Finished software product: map with information about air quality.

# Multi-head Additive Manufacturing with Optimal HPC Thermal Stabilization

**The Partnership**

**SME -Mikrotvornica Ltd**., a Croatian SME that has a lot of experience with different additive and digital manufacturing technologies and sells 3D printers to its customers.

**Technology and HPC partner -Ruđer Bošković Institute (part of the NCC Croatia)** is regarded as Croatia's leading scientific institute in the natural and biomedical sciences as well as marine and environmental research.

**The Challenge**

When using industrial machines for additive manufacturing, heat and its dissipation to individual structural elements of the machine play a major role. A heated workspace inside a 3D printer is important because most materials used in industries such as those of the automotive and aerospace sectors require heated work chambers to work with. Problems with the heat distribution inside the 3D printer can lead to void formation, geometrical deformation, or poor interlayer bonding in the printed pieces.

The high temperature inside the chamber can be generated either passively – i.e., using a heated working plate only – or actively with an additional heater pushing hot air into the chamber. Mikrotvornica's aim was to understand what effect the temperature distribution and the different ways of generating the high temperature inside the chamber have on the printer itself, e.g., on aluminum profiles or transmission systems, and on the final 3D printed pieces.

**The Solution**

The solution was to predict the impact of heat on the structure and motion system of the 3D printer using a numerical simulation model for the 3D printer that was built from scratch. First, the 3D geometry files for the different parts were generated and boundary conditions and material parameters were set up. To avoid high costs for HPC licenses, the open-source CFD simulation code OpenFOAM was used for scaling. Different simulations were performed incorporating the unsteady process while the printer chamber heats up and the different parts move.

The final CFD simulations that were performed on the HPC architecture had a run time of 3-4 days. This means that they can be used in the development and production process of new machines or to find the correct temperature setting.

Additionally, several tests on 3D printers were performed to validate the numerical simulations. During these tests, the exact temperature values inside the chamber were measured and then compared with the results of the numerical simulations.

**Business Impact**

By using HPC and numerical simulations, delivery times can be shortened significantly by 30-50% leading to a reduction of 15-30% in production costs. This amounts to savings of €150,000 over a period of three years.

Through the usage of numerical simulations, the accuracy of the 3D printing process is increased and Mikrotvornica can be more competitive on the market with the improved 3D printers. Therefore, it is possible for Mikrotvornica to achieve an increase in sales by 20-30% which can generate €600,000 more in turnover over a period of 3 years.

By using simulations in development and production Mikrotvornica can create jobs for new highly skilled employees, in order to generate even better results in the future.

Benefits

- Shortening of product delivery time to the customer by 30-50%.
- Cutting costs in production by 15-30%.
- Greater accuracy of 3D printers expected to increase sales by 20-30%.
- Creation of jobs for new highly skilled employees performing simulations for even better results.

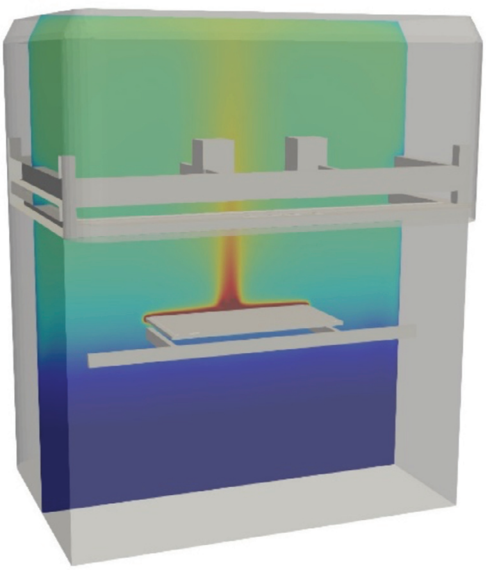

Figure 5: CFD model of 3D Printing Machine with temperature distribution.


Figure 6: Experimental temperature measurement in 3d printer.

## Topology Optimization of Micro-Channel Heat Exchangers (TOLOMHE)

**The Partnership**

**SME – Aidro Srl.**, an Italian high-tech SME specializing in the design and manufacture of hydraulic parts and metal devices by both traditional technologies and Additive Manufacturing.

**Technology partner -OPTIMAD** was founded in 2006 as a Spin-Off company of the Department of Mechanical and Aerospace Engineering of the Politecnico di Torino and specializes in the development of numerical simulation codes for scientific computing.

**HPC partner – CINECA (part of NCC Italy)**

**The Challenge**

Micro Channel Heat Exchangers (MCHX) are heat exchangers in which the fluid flows in lateral confinements with dimensions of millimetres (usually used in the aeronautic, aerospace and oil & gas sectors). Thanks to their high volumetric heat flux, compactness, and efficient flow distribution, they offer improved performance over standard exchangers. The design of MCHX requires balancing many competing design constraints, including weight reduction and manufacturability. Topology Optimization (TO) is a promising design paradigm for finding an optimal design which meets all these requirements. However, geometries resulting from TO are impossible to manufacture using standard techniques such as Computerized Numerical Control machining or vacuum casting. Instead, the design and production paradigm of combining Topology Optimization with Additive Manufacturing (AM) has enormous potential but requires the solution of key technical challenges to provide accurate results at speeds consistent with industrial design cycles. These challenges arise from both the business and engineering contexts. The former generates the need for reduced design costs and shorter design cycles leading to a shorter time-to-market for new products. In turn, the engineering context requires innovative new solutions or improved existing solutions enabled through automated design exploration. Lastly, the accuracy requirement maps directly to the need for accurate multi-scale models and robust automated computational pipelines to be executed on high-performance computing resources.

From the end-user perspective, the challenge is to deliver innovative, high performing, and customized MCHX to the market. They must be able to differentiate the offer with respect to standard solutions (tube or plate-fin heat exchangers) and leverage in-house design and manufacturing capabilities in AM to gain profitability. The target customers are from the aerospace and oil & gas industries, who are highly demanding from a regulatory point of view (e.g., certification processes), but willing to pay for added-value solutions in terms of weight saving, improved thermal performance, and higher compactness. Since 2019, Aidro has received several specific requests for MCHX in AM from these types of customers, but the design process with the tools available was too demanding in terms of effort. The experiment's technical challenge was therefore to develop a solution that would help Aidro respond to such requests.

**The Solution**

The TOLOMHE platform developed in the FF4EuroHPC experiment was conceptualized and developed as a SaaS platform, which integrates a set of computational tools for topology optimization of MCHX in an HPC-centric framework. TOLOMHE represents the first step towards cloud services for topology optimization and generative design offered to SMEs specialized in AM for MCHX. This

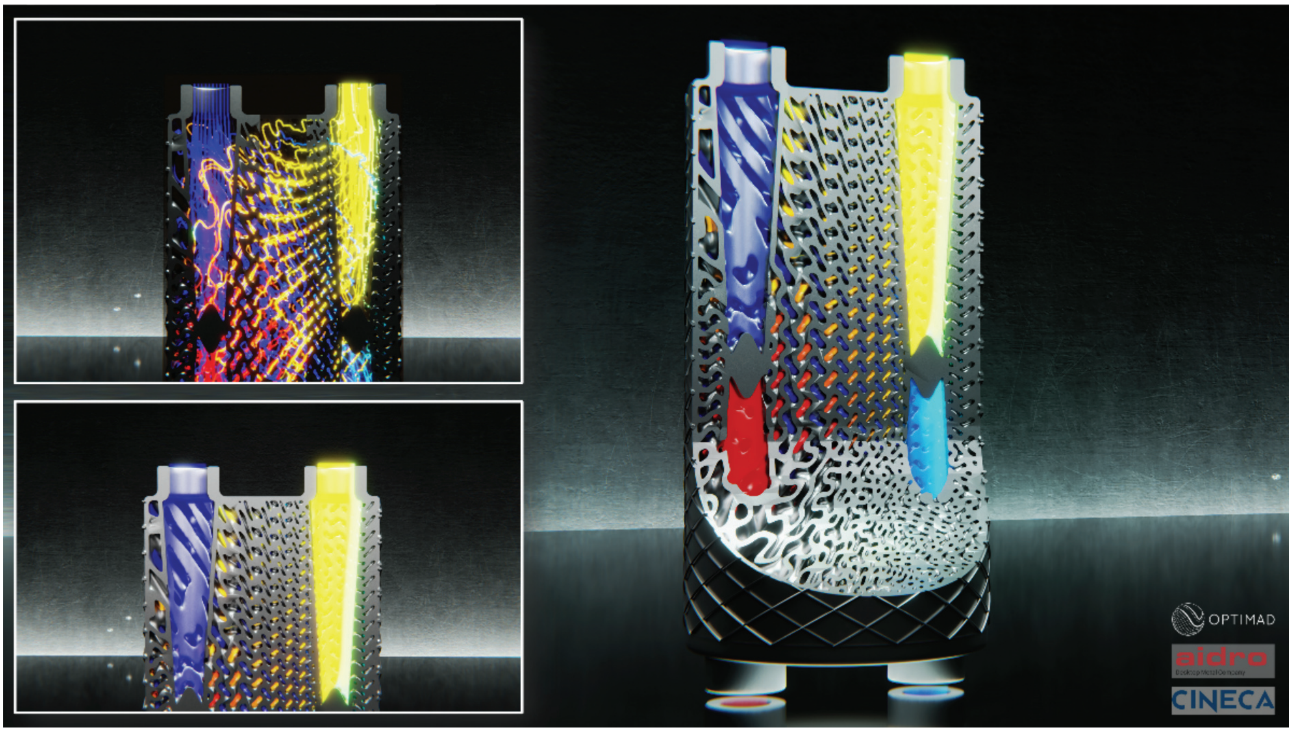

Figure 7: CFD model of a Micro Channel Heat Exchanger.

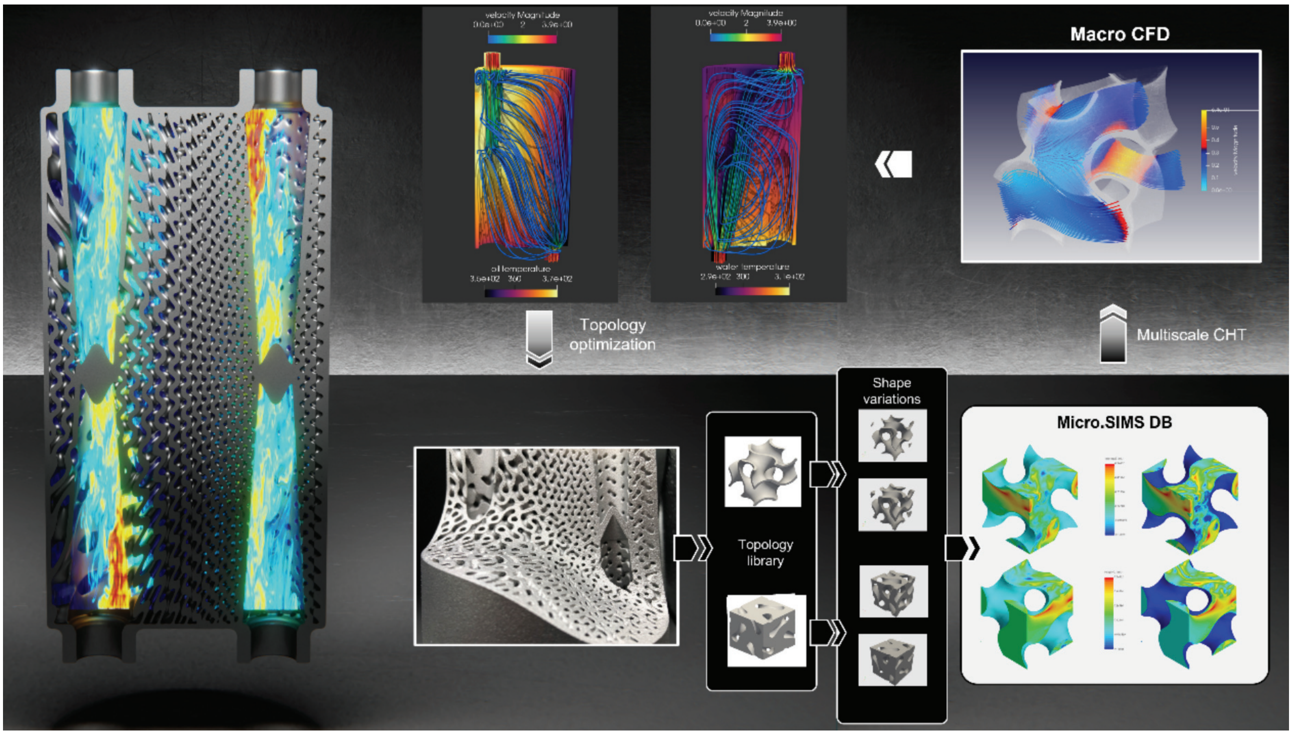


Figure 8: Workflow in TOLOMHE experiment.

innovative solution is based on coupling a standard CFD solver (immerFLOW by Optimad), an ML model and a parametrized topology (mimic by Optimad). Thanks to the synergic deployment of the ML model and the CFD solver, multiscale CHT simulations can be performed without the burden of simulating high-resolution models during the online (optimization) phase. TOLOMHE is deployed on the CINECA HPC infrastructure to fully leverage the high scalability of genetic algorithms during topology optimization to guarantee a short time to solution.

**Business Impact**
TOLOMHE represents an easy-to-use platform for generative design and product optimization. The ultimate goal is to alleviate problems and barriers encountered by SMEs specialized in the design of high-performance MCHX.

All involved organisations will directly benefit from TOLOMHE: Aidro with a shorter development time - not only increasing competitiveness but also reducing development and design costs - and Optimad with a new tool and know-how in this manufacturing area. TOLOMHE has the potential to become a technology enabler and will allow a potential user to target high-value applications, improve the design of existing products, and ultimately increase market competitiveness. Thanks to the adoption of TOLOMHE, the end-users are expected to accelerate the transition from a build-to-print to a build-to-spec business model by reducing R&D costs and time-to-market for new products.

The first applications at Aidro foreseen for the TOLOMHE platform are an oil-air heat exchanger project for the transmission system of helicopters, which is a sea water-natural gas heat exchanger project for off-shore gas platforms.

**Benefits**

- Automation of the design workflow has the potential to shorten the time-to-offer by 90%, and time-to-market by 50%.
- For Aidro, savings can potentially add up to €100,000 million by redirecting skilled labour to other added-value activities.
- For OPTIMAD, TOLOMHE can generate a stream of revenue of approximately €250,000-500,000 in the first 36 months.
- For CINECA, sales of CPU cycles can generate up to €40,000 per year.

**Alessandro Alaia** received his master's degree in aerospace engineering in 2006, and his PhD in Applied Mathematics at Politecnico di Torino in 2011. He is heading the R&D Department at Optimad, focusing on the development of numerical methods for computational flow dynamics and hybridization of standard numerical models with machine learning.

**Nikola Blažević** is the founder and CEO of Mikrotvornica Ltd, a company focussing on additive manufacturing technologies. He made his first robust 3D printer in 2016, as a part of a graduate thesis on a Faculty of Mechanical Engineering in Zagreb.

**Tina Črnigoj** Marc is a project manager at hi-tech company Arctur and has extensive experiences in working in European R&D projects, especially on communication, dissemination and exploitation tasks. She is a digital communication expert, introducing new ideas and creativity into corporate and R&D communication activities.

**Francisco Ramirez** received a PhD degree in telecommunications engineering from Universitat Politecnica de Catalunya in 2016.  He leads Bettair Cities' multidisciplinary research team on air quality monitoring and modelling.

**Andrea Antonio Russo** is a Management Engineer with a master degree from Politecnico di Bari, Italy. After years of experience as Program Manager in military and civilian aerospace programs, he has been working as consultant in research and business development for Manta Group since 2020.

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**Additional Contributors:** Pasquale Bene (CETMA), Jaime Bustillo (Bettair Cities), Joan Calafell (BSC), David Matas (Bettair Cities), Samuel Gomez (BSC), Oriol Lehmkuhl (BSC), Edoardo Lombardi (Optimad Engineering, Tommaso Tirelli (AIDRO), Antonio Memmolo (CINECA).