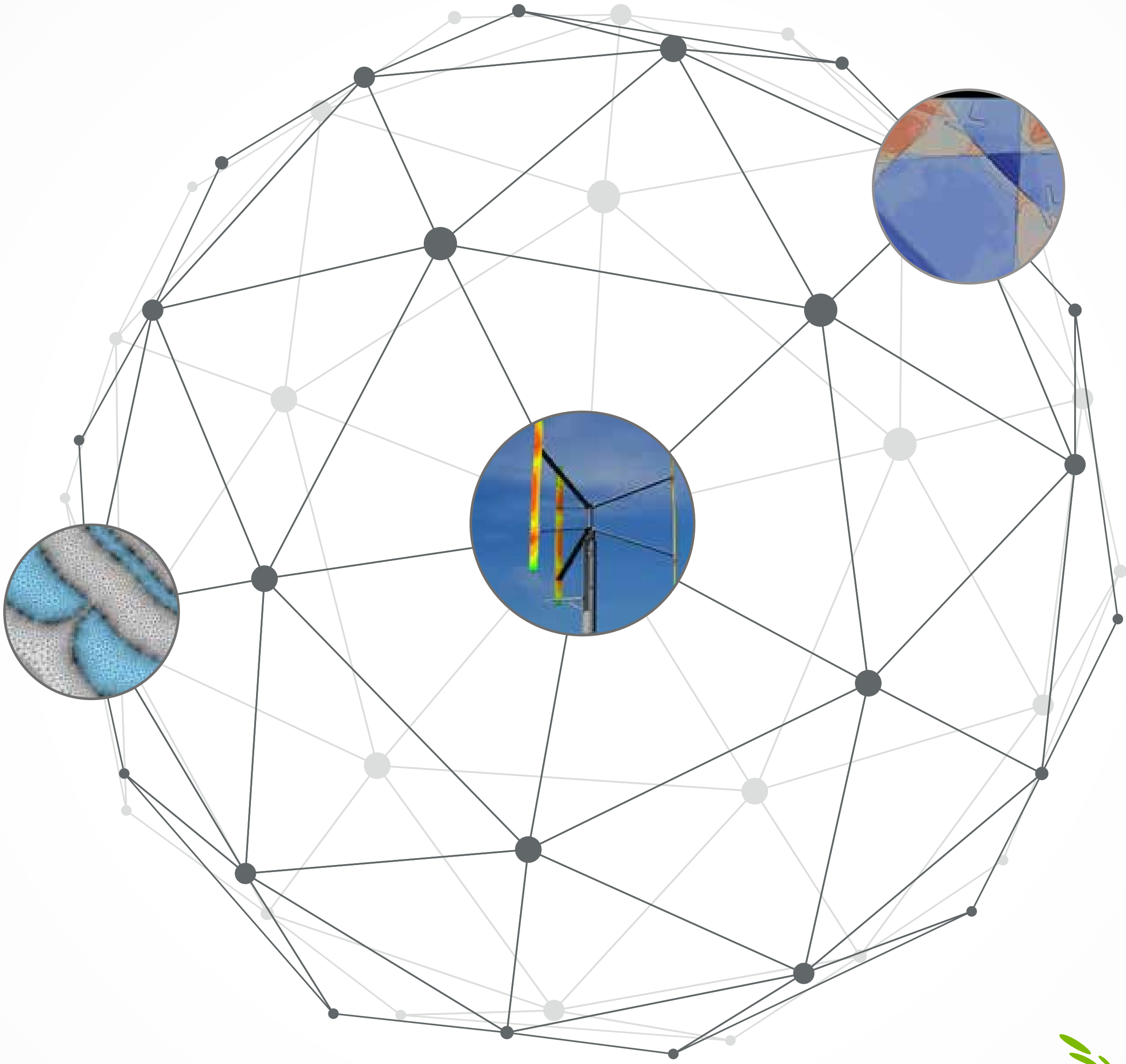
2020

ANNUAL REPORT



Cenaero

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1 Foreword

The year 2020 was marked by the evolution of the Covid-19 pandemic. Sanitary measures were implemented at all our operating sites to ensure the good health of staff and internal communication was strengthened to take into account the massive use of remote work. The pandemic has greatly accentuated the crisis in the aeronautical sector, which began in 2019 following the difficulties encountered by Boeing. From the start of the health crisis, activities were prioritized and their monitoring was reinforced both internally and with our clients. This agile management enabled us to anticipate changes in revenues and control costs.

The crisis in the aeronautical sector has generated a significant R&D opportunity through a project funded by the Walloon government. Set up during the summer and accepted in October, the WINGS (Walloon INnovations for Green Skies) project is a partnership for innovation in the aeronautical sector in the face of the crisis, bringing together nineteen partners with a total budget of 112 million euros for a period of three years. Starting in January 2021, Cenaero will welcome more than 20 engineers from Safran Aero Boosters and Sonaca to join forces in research on the ecological and digital transition of the aeronautical sector, with the aim of contributing fully to the European green deal. Besides this major project, Cenaero has been also very active in creating development opportunities and was partner in six successful research proposals, one of them allowing Cenaero to secure 30 million core hours at Jülich Supercomputing Centre, one of the largest German computing centers. During the year, Cenaero continued to develop and apply its expertise through a strong participation in 36 collaborative research projects at European, French and Walloon levels.

In February 2020, the Board of Directors has approved a 3-year action plan associated with the ambition for Cenaero to be pioneers in combining our core business, numerical simulation and high-performance computing, with artificial intelligence in the strategic areas of aerospace design, manufacturing processes, and buildings and smart cities.

During 2020, research has been organized around the following themes:

- high performance composites
- optimization and uncertainty quantification
- multidisciplinary topology optimization
- metallic manufacturing processes modeling
- high resolution computational fluid dynamics for aeronautical applications
- hypersonic flows and ablative materials
- buildings and smart cities
- turbomachinery design

The Walloon government has approved in March 2020 the renewal of the supercomputing infrastructure with a 10 million euros investment that will take place at A6K, a shared multidisciplinary center dedicated to engineering sciences located next to the rail station in Charleroi. The request for proposal has been published in November 2020 and the start of the installation of the equipment is foreseen at the end of 2021.

The activities of our composite lab have been put to a stop in July 2020. The adventure of the lab began about 10 years ago as an ERDF project. It has been a real adventure as everything had to be developed from scratch. One can be proud of what has been achieved. Unfortunately, over the years it has been a financial struggle as the amount of revenues was too limited. The shutdown of the activity will reduce the pressure on Cenaero's finances starting next year.

In September 2020, the five French-speaking universities and four research centers including Cenaero have joined forces to create the TRAIL Institute (Trusted AI Labs), dedicated to artificial intelligence, and thus jointly mobilize their resources and expertise for regional development.

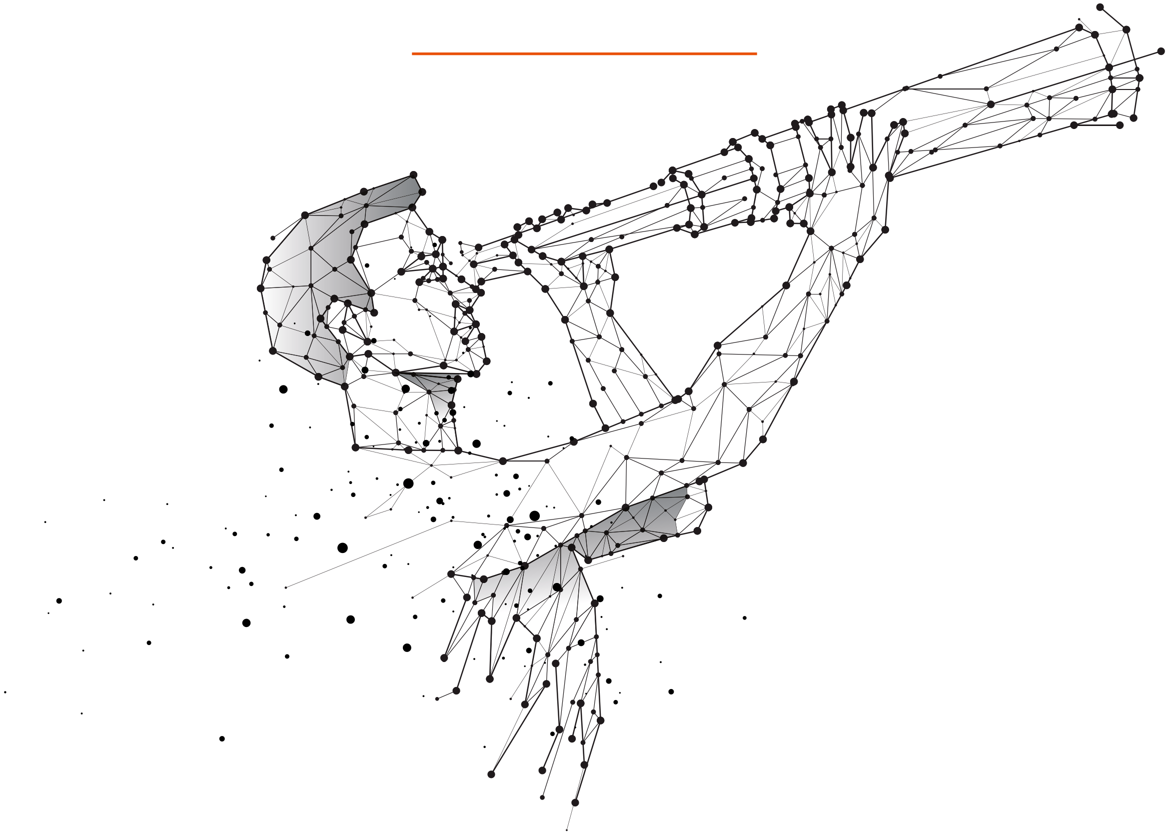
Main research achievements of the year 2020 are highlighted in the present report.

Philippe Geuzaine
General Manager

Michel Milecan
Chairman

Cenaero ASBL and its subsidiary Cenaero France provide companies involved in a technology innovation process with numerical simulation methods and tools to invent and design more competitive products. Our ambition is to be internationally recognized as a technology leader in modeling and numerical simulation, to be a strategic partner of large global industries as well as a real support to regional companies including SMEs. Cenaero is mainly active in the fields of aeronautical and space design, manufacturing processes, and buildings and smart cities. Cenaero operates the Tier-1 Walloon supercomputing infrastructure.

Passion drives us. The technological challenges of our partners and customers stimulate our creativity and our envy to continuously improve ourselves. Scientific rigor and intellectual curiosity nourish our passion for high-quality work. We make it a priority to establish a trustworthy long-term relationship with our partners and customers, as well as within the Cenaero team. Boldness moves us forward to ambitious projects. We solve these challenges by mobilizing our willingness, our competences, our organization and our capability to master risks. We believe our team is the source of our success. Therefore, we care for the personal development of our collaborators and seek to make them harmoniously progress.

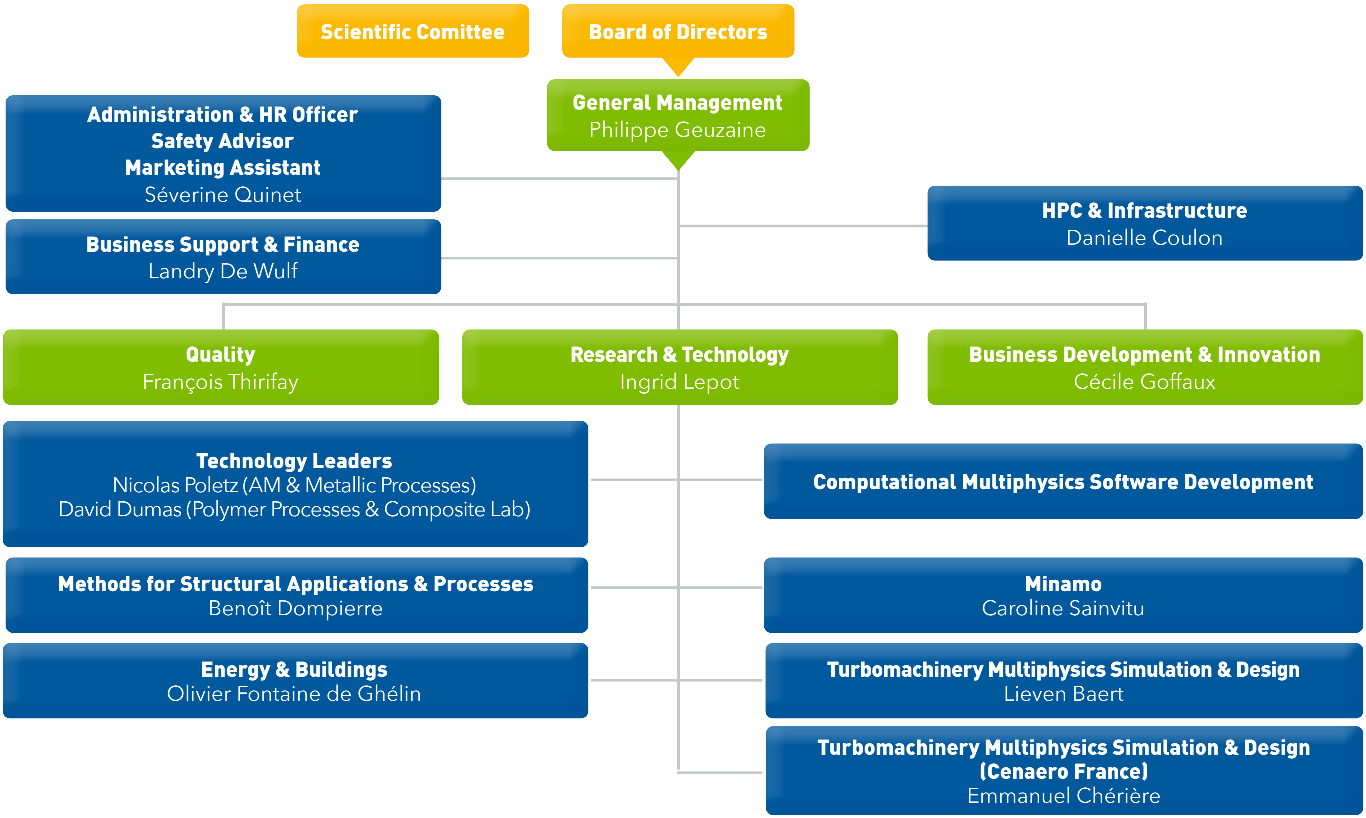


3 Governance

Following its legal establishment, Cenaero ASBL is a Belgian non-profit research center administered by a Board of Directors with representatives of the members of the association. The Board of Directors involves representatives of seven companies representing the Walloon Aeronautics Association (EWA), six representatives of university members, two representatives of IGRETEC and one representative of the Von Karman Institute, the University of Namur and the Walloon Region as observers. The Board of Directors is nominated by the General meeting of the association for a period of six years. The Board of Directors elects its Chairman and vice-chairmen. The Board of Directors is currently chaired by Mr. Michel Milecan. The Board of Directors entrusts the General Manager, together with the Management Committee, with the daily management of Cenaero. The Management Committee is composed of three managers (Business Development & Innovation, Quality, Research & Technology) and the General Manager. The Remuneration Committee is appointed by the Board of Directors for a period of three years and is composed of the President, the General Manager and two Board Directors. It assists the Board of Directors in defining a consistent and balanced salary policy.

Established in 2009 and located in Moissy-Cramayel, Cenaero France SASU is a 100 % subsidiary of Cenaero ASBL and is geared mainly to perform collaborative research and industrial services.

Organization chart (as of Dec. 31, 2020)



Board of Directors (as of Dec. 31, 2020)

Tony Arts	Observer	The von Karman Institute for Fluid Dynamics
Jérôme Bonini	Director	Safran Aircraft Engines
Nathalie Burteau	Director	Université catholique de Louvain
Jean-François Cortequisse	Director	Safran Aero Boosters
Grégory Coussement	Director	Université de Mons
Michel Coulon	Observer	Université Libre de Bruxelles
Didier Descamps	Director	Sabca
Pierre Galland	Director	Université Libre de Bruxelles
Olivier Gillieaux	Director	Université de Liège
André Grégoire	Director	Sonaca
Guy Janssen	Director	GDTech
Benoît Champagne	Observer	Université de Namur
Fabian Lapierre	Observer	Région wallonne
Michel Milecan	Chairman	EWA (Entreprises Wallonnes de l'Aéronautique)
Jean-Philippe Ponthot	Director	Université de Liège
Michel Tilmant	Director	Samtech
Stéphanie Toussaint	Director	Igretec
Grégoire Winckelmans	Director	Université catholique de Louvain

4 Research and Technology

High Performance Composites

The design of structures is fundamental to ensure safety, performance, and manufacturability of elements whatever the materials they may be made of. Cenaero aims to be at the forefront of the research field in composite structures in the development of renewable energies while moreover positioning regional companies as leaders in a specific market niche enabled by innovative products. Through simulation, we aim to ensure positive synergy between industrial design practices and experience, and multidisciplinary design space exploration capabilities.

COMP2BLADES is a regional project combining expertise that Walloon partners have in vertical wind turbines, composite materials (fibers), and manufacturing technologies. The project aims to develop a structural solution to allow for lightweight composite blade profiles that will increase the production window of medium-sized vertical wind turbines.

As bending stresses coming from the rotation of the turbine around its central axis vary over one full rotation, the fatigue life of the material is critical and high-performance reinforcement solutions are sought. The consortium set out to find a solution based on basalt reinforcement fibers and potentially automated manufacturing routes such as braiding and pultrusion. A NACA airfoil profile made up of two skins, co-cured on a braided central beam can lead to a good load distribution and minimal weight. The modeling tools developed in the first part of the project focused on predicting the material properties of a braided profile wound on a complex mandrel. These tools are combined with a classical finite element analysis approach and brought together in an optimization workflow using Minamo that looks to reduce the weight since the highest loaded sections will be close to fixation points while the extremities will undergo lower stress levels.

Starting from an aluminum reference profile featured at 17 kg per linear meter of blade, the structural optimization allowed for a composite solution at 13 kg/m to be found. This allows us to significantly increase the surface area covered by the blades, while keeping the same bearings and support structures. This brings a huge gain for productivity and the possibility to expand the market share and exploitable locations where the wind turbine will produce sufficient energy.

Figure 1: Vertical wind turbine.

The optimization was made possible with the use of Cossmo, a stacking sequence generator specifically developed at Cenaero for optimization purposes in composite structural design (see Figure 2). Cossmo ensures that the layers of composite selected for different thickness zones will lead to a manufacturable solution that respects different rules defined to reduce any risk of premature cracks/deformations in the composite (alternating plies, symmetry, …).

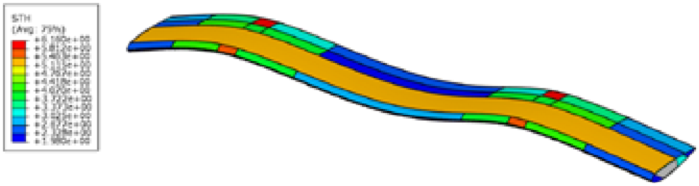


Figure 2: Optimization of the composite layers of the vertical wind turbine blade.

The solution proposed by structural optimization will further be adapted (fixation zones are studied separately) and tested for manufacturing using a combination of composite braiding and liquid resin infusion on the composite skins.

Machine Learning for Modelling, Optimization, Data Mining, Monitoring & Control

Machine Learning (ML) is a key ingredient of the design space exploration, optimization, monitoring and control strategies at Cenaero. Minamo, the in-house platform providing optimization, predictive modeling and data-mining tools, exploits machine learning-based techniques as a strategic leverage to speed up design processes. Our optimization strategy incorporates ML rationale to perform smart balance between exploration and exploitation. The Minamo platform is used daily to solve challenging engineering problems and allows investigating trade-offs which may be complicated to assess only through numerical simulations and/or real-world experiments. Cenaero is continuously extending its capabilities to strengthen its position as key partner in terms of predictive and prescriptive analytics.

The process anomaly detection can greatly benefit from ML techniques. In the last few years, Cenaero has collaborated with Vallourec to predict the occurrence of galling in OCTG (Oil Country Tubular Goods) connections. In the constant quest for efficiency and well integrity in the oil and gas industry, the reliable detection of galling during the make-up process of premium tubular connections remains an active challenge. The friction between pin and box seals under high

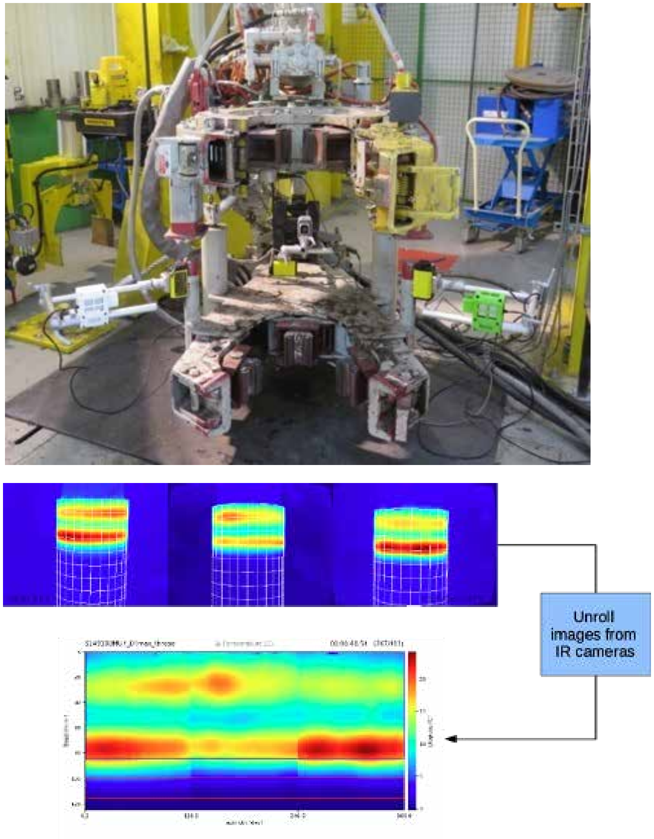


Figure 3: Experimental setup dedicated to OCTG investigations in the Vallourec Research Center Connection with three infrared cameras (left) and the reconstructed connection temperature map (right), from the three cameras.

metal-to-metal contact pressures could potentially cause galling and, in worst cases, creating the seizure and grooving of the metal surfaces. Galled internal surfaces significantly reduce the sealing of premium connections, which brings safety issues and economic penalties as well. Cenaero has developed a reliable real-time galling detection toolkit based on machine learning techniques trained on thermal signatures collected with infrared cameras positioned around the connection, see Figure 3.

4 Research and Technology

The complex 3D representation space along with the small training database due to the limited number of experiments are major challenges. On the one hand, we mitigate the dimensionality of representation issue by setting up a Proper Orthogonal Decomposition representation of the IR images at the price of a reasonable loss of information. Furthermore, a careful filtering of outliers' images, combined with a probabilistic support vector machine decision algorithm, implemented in Minamo, resulted in a considerable gain in reliability of galling prediction. A GUI application embedding Minamo (see Figure 4) has been developed allowing to perform live galling prediction with a confidence level.

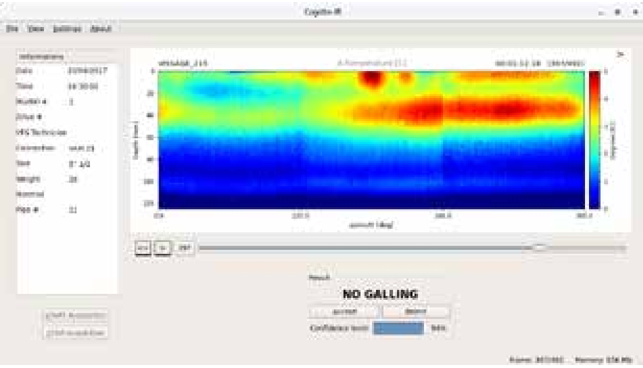


Figure 4: GUI for galling prediction with machine learning based on thermal acquisition.

Multidisciplinary Topology Optimization

To create innovative design permitted additive manufacturing, Cenaero develops differentiating topology optimization capabilities in its finite element solver, Morfeo, initially oriented towards manufacturing process simulation. Two topology optimization strategies are available in Morfeo and combined: the SIMP method which parametrizes the design by material densities, and an explicit Level Set method. This approach uses the extended finite element method to ensure a clean interface between the solid and void phases. More specifically for the optimization of designs containing lattice structures, Cenaero has developed an innovative method that combines these two approaches (density and Level Set) through a multi-scale homogenized model.

The TRACTION2020 project revisits the traditional equipment of the train traction chain. This project is led by Alstom, a worldwide railway manufacturer, and brings together partners from both industry (CoExpair, Ateliers de la Meuse) and universities (ULiège, UCLouvain). In this context, synchronous reluctance motors are a valuable alternative to traditional induction machines of the same power rating due to their robustness and efficiency. Cenaero performed in 2019 a first successful shape optimization of the underlying CAD model of a rotor core with flux barriers, achieving torque levels comparable to that of the current induction machine under the same supply conditions, meeting hence the requirements on the rotor integrity as well as the assembly process. This strategy has led to the manufacture of the laminations of the machine and the successful tests in 2020.

The initial choice of design variables among the CAD model parameters, inherent to shape optimization, may limit the ability of this approach to bring innovative layouts that would lead to better performance. Cenaero moved therefore towards topology optimization which allows to easily handle large shape modifications, or merging geometric entities such as holes, without degenerating the model.

An alternative level set topology optimization method using body-fitted mesh discretization has been successfully applied to electromagnetic design for which the accuracy of the physical response in the vicinity of the boundaries is a major concern. The ability of this method to use the FEM solver as it is, i.e. without requiring any modification of the physical equations, regardless of the physics, along with the simplified handling of manufacturability constraints makes it a valuable alternative to the classical approaches.

The optimization results in a rotor with two flux-barriers (holes shown in blue in Figure 5) and several radial ribs determined automatically in each flux-barrier. The complexity of the holes pattern requires a fine mesh for the accurate FEM analysis.

The design shows the ability of the method to recover similar layouts to those of the first design obtained by imposing design rules. The topology optimized rotor exhibits the same level of average torque with less than 10% torque ripples, meeting hence the expected requirements.

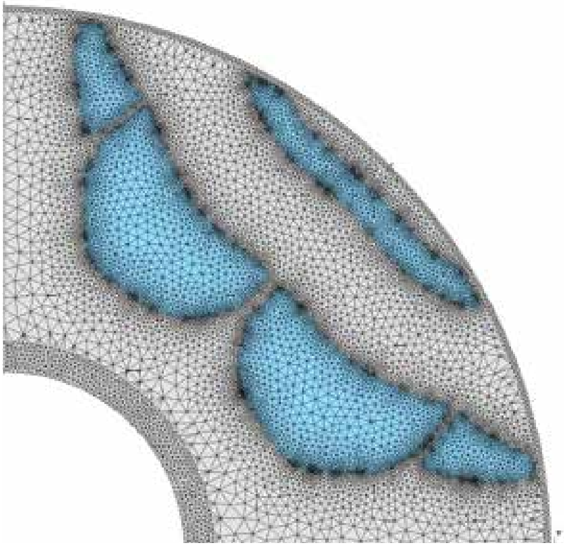


Figure 5: Topological optimization result of a synchronous reluctance motor.

Metallic Manufacturing Processes Modeling

Understanding and mastering of the physical phenomena involved during manufacturing processes of metallic structures are major challenges to move towards improved components quality and optimized products/processes. This is acquired by a joint modeling and experimental research effort.

The implicit free surface tracking strategy developed in Morfeo for laser metal deposition simulations has been investigated in the framework of the FAFIL project for the LMD-wire process. The flow of material is modeled with the help of a level-set. This allows to better represent the shape of the beads and offers more freedom to handle process parameters dependency compared to conventional techniques (e.g. birth and death method). A 10-layers single-bead wall of Inconel 718 was built by CRM Group, partner of project, using the LMD-wire process. An infrared camera was used to obtain temperature measurements on the wall during the construction process. The parameters (e.g. material flow and heat source distributions) of a numerical model were calibrated against the experimental data. The numerical results are in good agreement with the measurements, as illustrated in Figure 6. Cooling rate may be improved by accounting for heat dissipation between the base plate and its support.

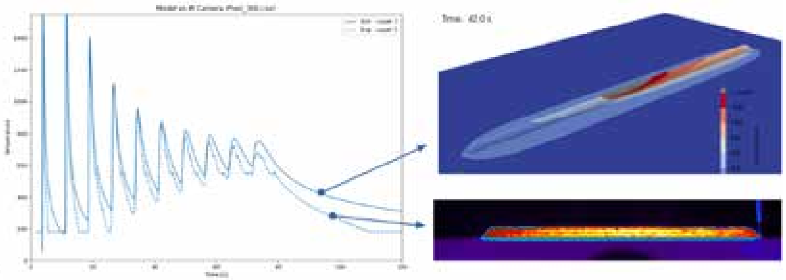


Figure 6: Estimated (solid line) vs measured (dashed line) temperature at the center of layer 1 during the construction of the wall.

High Resolution CFD for Aeronautical Applications

Computational Fluid Dynamics (CFD) technologies are now routinely used in engineering for the design of industrial products and processes, particularly in the aeronautical sector. However, further optimization of aerodynamic designs calls for a better understanding and prediction of complex flow phenomena, including turbulence and laminar-turbulent transition, which in turn requires specific numerical methods. Cenaero has a widely recognized expertise in the development and application of CFD numerical tools for turbulent and transitional flows, which has been further extended in 2020.

The increasing computational power of supercomputers combined with new efficient numerical algorithms allow Direct Numerical Simulations (DNS) to be nowadays recognized by the scientific community as a valuable data source on par with wind tunnel experiments, under the condition that the different sources of uncertainty are properly assessed and controlled. Estimators that quantify statistical uncertainty related to the time sampling of numerical results exist in the literature, but they are based on the storage of the entire time series, which is intractable when dealing with entire numerical solutions such as those obtained with the Argo-DG code developed at Cenaero. In the framework a PhD project, funded by Safran Tech and co-supervised by ULiège and UCLouvain, three asymptotically unbiased estimators for the variance of mean quantities have been developed. Their reduced memory footprint makes them computationally affordable in the context of DNS. For industrial applications such as high-Reynolds number flows in compressor or turbine components of aero engines however, DNS and even Large Eddy Simulations (LES) are still often considered too costly in practice, because of the resolution imposed by

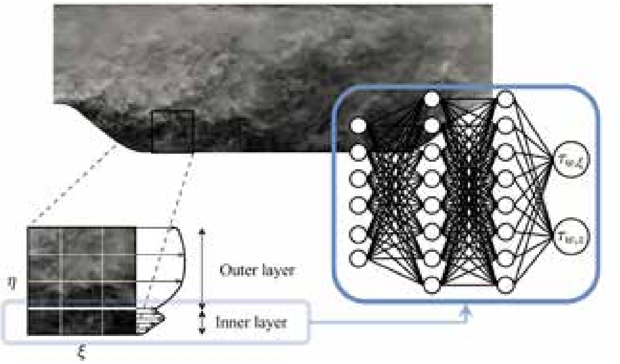


Figure 7: Turbulent flow over a 2D periodic hill geometry used to train a neural network modelling the inner region of the boundary layer.

the inner part of the boundary layer. Wall models can replace the inner layer to save computational resources, but they usually assume that the flow is at equilibrium, attached and turbulent, which is rarely the case in real-life applications. The main objective of the thesis consists in developing new wall models, that can be applied to separated and transitional flows, using deep learning techniques. In 2020, an LES of the well-documented 2D periodic hill case has been performed (see Figure 7), and the results have been carefully studied using advanced statistical treatments. This allowed to determine the most relevant input data for the neural networks to be implemented in the next stage, which will maximize their performance in general cases.

Another important numerical development taking place in 2020 has been the introduction of a fully automatic solution-based mesh adaptation capability in Cenaero's Argo-DG platform through coupling with the MAdLib mesh adaptation library, that is also developed at Cenaero. Given a solution field, such as the pressure or the Mach number, MAdLib can automatically modify the mesh so that it minimizes the interpolation error induced by Finite Elements approximations. An innovative aspect of this feature is the ability to use high-order solutions from the Discontinuous Galerkin method (DG), on which Argo-DG is based, in the adaptation procedure. The new capability has been tested on numerous cases, involving steady subsonic and hypersonic flows, but also unsteady hydrodynamic simulations. These simulations confirmed that solution-based mesh adaptation helps minimize the computational cost, but also the user-friendliness and the robustness of the overall simulation workflow, as the user does not need to guess where to refine or coarsen the mesh.

Hypersonic Flows & Ablative Materials

Highly compressible flows are encountered during hypersonic flights. This flow regime is difficult to study since it involves complex physico-chemical phenomena. Hypersonic flows are also challenging to simulate numerically due to the combination of high Mach numbers and low pressure. Nowadays, most commercial tools rely on Finite Volume (FV) schemes. Those have shown to provide accurate evaluation of the heat flux required for the design of hypersonic vehicles. But on the other hand, FV methods suffer from high sensitivity to mesh alignment with the shock and the choice of the inviscid flux function. Lattice Boltzmann Method (LBM) exhibits many interesting advantages for simulating industrial applications. This method is simple to implement, deals easily with complex geometries, presents highly parallel computing efficiency and allows to tackle multi-physics problems. The computational efficiency of LBM and its ease to treat immersed boundaries could be the keys to simulate complex geometries re-entering our atmosphere. This could help for the demise prediction of space debris to improve correlation for the heat flux computation currently used in engineering code. However, the main limitation of LBM is the restriction to low velocity/weakly compressible flows which is incompatible with the hypersonic flow regime. LBM is based on a bottom-up multi-scale approach where the macroscopic quantities and their driving equations do not appear explicitly in the numerical scheme. In other words, the study of the relationships between the (microscopic) LBM scheme and the (macroscopic) flow behavior is not straightforward and requests the use of advanced mathematical and numerical tools. The ESA LBMHYPE project proposes to investigate and push further the limitations of pure LBM schemes to simulate highly compressible flow behaviors.

In this framework, the consortium conducted by Cenaero and involving the von Karman Institute, Université Paris Sud and Ecole Polytechnique Paris, developed a numerical tool exploiting vectorial LBM schemes to simulate successfully inviscid hypersonic flows. The opensource platform (available at https://github.com/pylbm/pylbm_ui.git) has been developed to gather in a catalog all schemes and relevant test cases investigated. The platform provides a user interface with an intuitive workflow to guide new users for several theoretical and practical information to ease the definition, run and post-treatment of LBM simulations. Experienced users can benefit from the advanced LBM scheme analysis features proposed during the project to further investigate the relationships between the LBM scheme definition and the behavior of the simulated flow.

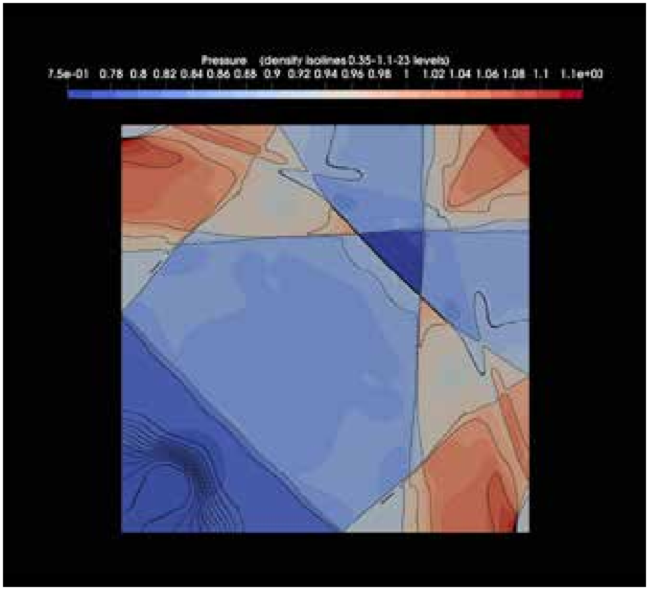


Figure 8: Hydrodynamical implosion test. Pressure field at time 2.5 [s] and density isolines are shown for this 2D Sod shock test case. The LBM simulation uses a cartesian grid with 1601x1601 nodes.

Moreover, a systematic analysis method has been developed to ease the study of the influence of LBM parameters on the stability and accuracy of LBM simulations. The parametric study database is compatible with the Minamo software to provide advanced data analysis tools. The advanced infill and optimization features provided by the Minamo coupling showed that the optimal scheme parameter values vary with the selected test case and that multiple relaxation scheme do not provide clear advantage comparing to single relaxation time mode. The resulting compressible LBM code has been compared to state-of-the-art hypersonic software showing very good quality results. The comparison also highlights the high computational efficiency of LBM, with a CPU time several orders of magnitudes smaller for similar time and space resolutions. Moreover, the setup of LBM simulations is significantly shorter and easier, mainly due to the absence of preliminary meshing procedure.

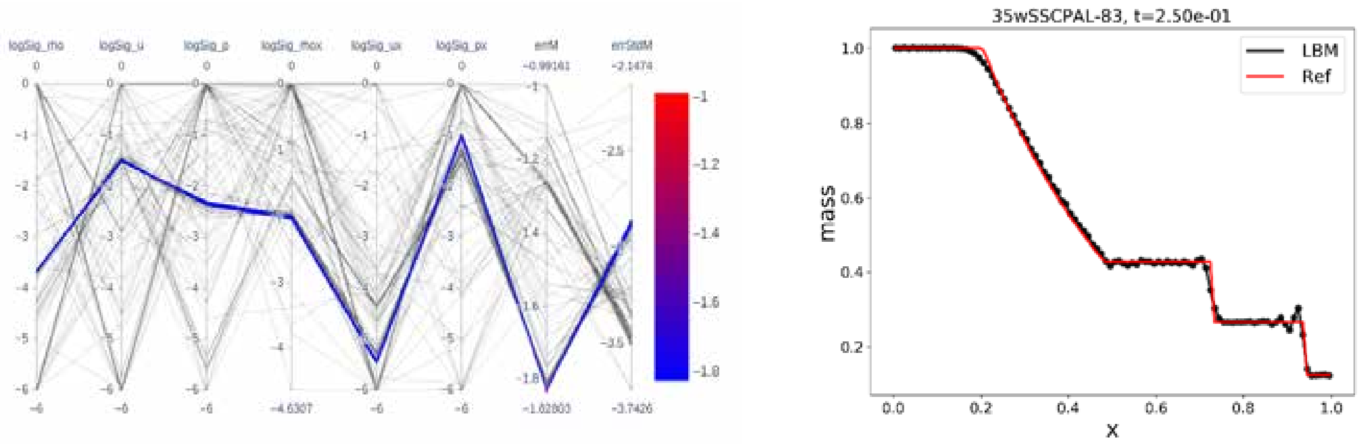


Figure 9: Optimization of the relaxation rates for the D1Q333 LBM scheme applied to the Sod shock tube problem using Minamo platform.

Buildings and Smart Cities

The Buildings and Smart Cities theme has taken an increasing importance in the last few years, with projects at component (energy production and storage systems), building and district scales. Considering the interactions between different research domains, from thermodynamics to artificial intelligence, the challenges are diverse and with high potential to improve the energy performances of individual and global systems. Through its expertise in numerical simulation, optimization and data analysis Cenaero is extending its network and projects portfolio in the field of design and renovation, energy management, model predictive control and predictive maintenance for energy systems and buildings.

Energy Management Systems in the form of applications and web-based platforms are under development in different projects, using data processing based on monitoring systems and results from energy production systems and building simulations. Cenaero is collaborating with Thomas&Piron Bâtiment to develop a tool for monitoring energy consumption and thermal comfort and for predictive maintenance services for multi-residential residences. This tool requires a robust modeling and reliable data analysis and predictive algorithms. To this end, Machine Learning techniques and our internal multi-disciplinary optimization tool Minamo have been used during the calibration process of the detailed multi-zone building energy model: in a first step, clustering techniques were used to cluster apartments with similar physical and architectural characteristics (see Figure 10). A sensitivity analysis was then carried out on representative apartments from each cluster in order to determine in a cost-efficient way the most important parameters that should be calibrated.

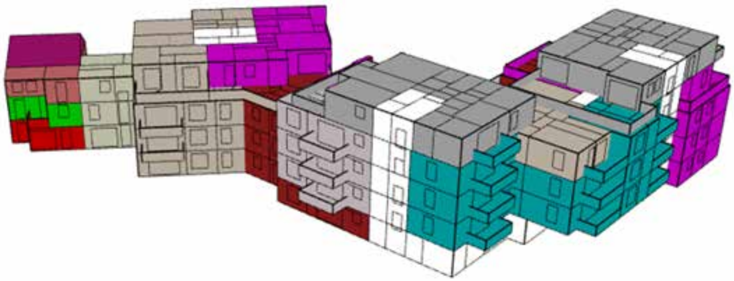


Figure 10: 3D geometry of a multi-residential energy building model (colors represent clusters of apartments).

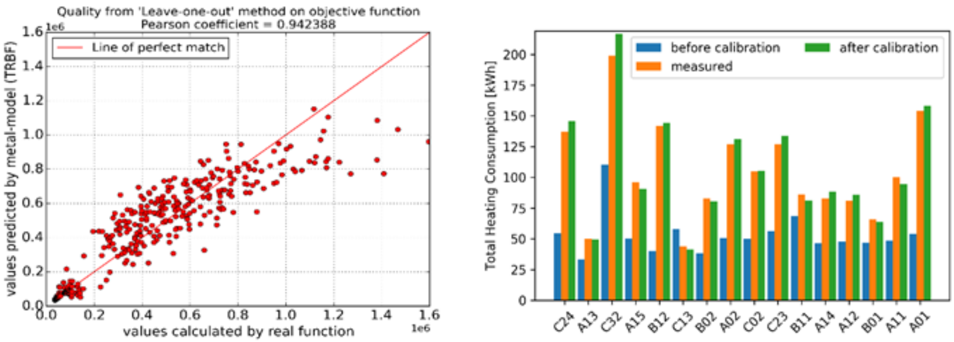


Figure 11: LEFT: Quality of surrogate model (TRBF) representing the objective function at the end of the SBO process. RIGHT: Heating consumption for the investigated apartments (on a winter week).

In a second step, the building energy model (BEM) was calibrated through two Surrogate-Based Optimisation processes using a Kriging and a TRBF surrogate models. Both strategies had a good quality of surrogate models and gave similar results. The calibration improves substantially the precision of the model results in terms of heating energy consumption.

The Fault Detection and Diagnosis methodology being developed is a hybrid data-driven and model-based methodology based on a large amount of monitored data and simulation results. The comparison between simulation results and measurements allows to detect faulty behavior of energy systems. Then additional simulations using varying input parameters allow to diagnose the problem.

Turbomachinery Design

Technology advancements in the aircraft engine industry over the last several decades have been driven by a relentless focus on reducing fuel burn, emissions and noise. Specific targets for these drivers have been defined in Europe's ambitious Flightpath 2050 along with the launch of H2020 Clean Sky 2 programme to develop and mature technologies to meet these targets.

Cenaero started, in collaboration with NUMECA (now Cadence) and the Von Karman Institute (VKI), the Clean Sky 2 ASTORIA project in October 2019 to develop a set of tools and methodologies, and to and experimentally validate them, for the design of devices replicating complex, steady and unsteady, combined total pressure and swirl distortion patterns. In the first year of the project a literature survey has been performed to prepare and set up the design methodology, and a first low-fidelity tool has been developed for the preliminary design of the total pressure distortion screen. This tool will be integrated in a fully automated design tool that exploits Minamo's optimisation kernel for the preliminary design of the total pressure distortion screen, and it will then be exploited for the design of four different screens in 2021. The design methodologies developed within ASTORIA will be directly applied on specific fan designs for the SA²FIR test rig, as well as for the Boundary Layer Ingestion demonstrator. As such, they contribute to paving the way for new robust integrated engine/air frame design practices.

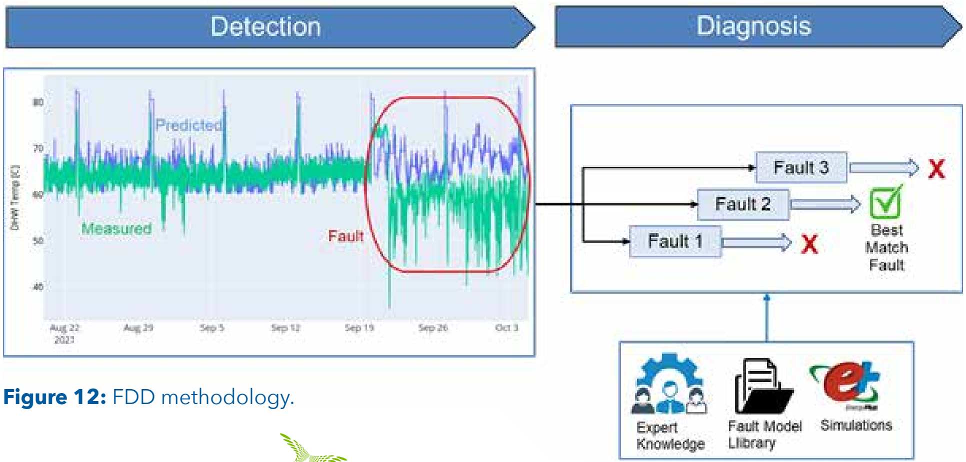


Figure 12: FDD methodology.

5 Infrastructures

High Performance Computing Facilities

The Walloon Tier-1 supercomputer operated by Cenaero entered its seventh year of operation. The supercomputer counts more than 14,000 compute cores delivering a compute capacity of more than 330 TFlop/s (Rmax). It maintained in 2020 a remarkable effective usage rate of more than 90 % and it delivered about 102 million core hours. The efficient operation of the machine has been continuously monitored by the steering committee gathering the interested parties, namely the Walloon Region, Universities – through the CÉCI consortium – and Cenaero. Figure 13 shows the computing time used on the Tier-1 in 2020 by scientific field. About 74% of the computing time was used for academic research while 14% was used for applied research and 12% for industry. Figure 14 shows the computing time usage by the number of cores used per computation.

Following the approval in March 2020 by the Walloon government of the renewal of the infrastructure, work has started to identify different hosting possibilities within A6K, a shared multidisciplinary center dedicated to engineering sciences located next to the rail station in Charleroi. Several meetings were organized to define the technical specifications of the machine by collecting the current and future needs, both from academic representatives and research centers as well as from industrial users. In the frame of a competitive procedure with negotiation, the call for applications has been published in November and the start of the installation of the equipment is foreseen end of 2021.

Besides, Cenaero remained actively involved in the follow up of the participation of Belgium to the PRACE (Partnership for Advanced Computing in Europe) initiative which provides large-scale HPC resources in Europe.

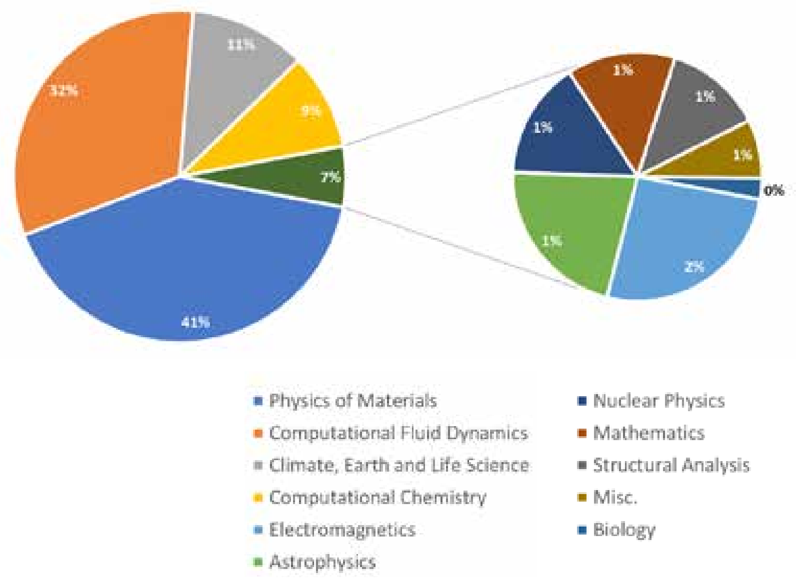


Figure 13: Computing time used in 2020 on the Walloon Tier-1 by scientific field.

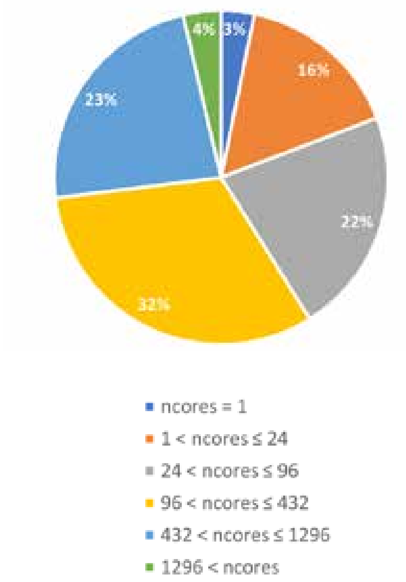


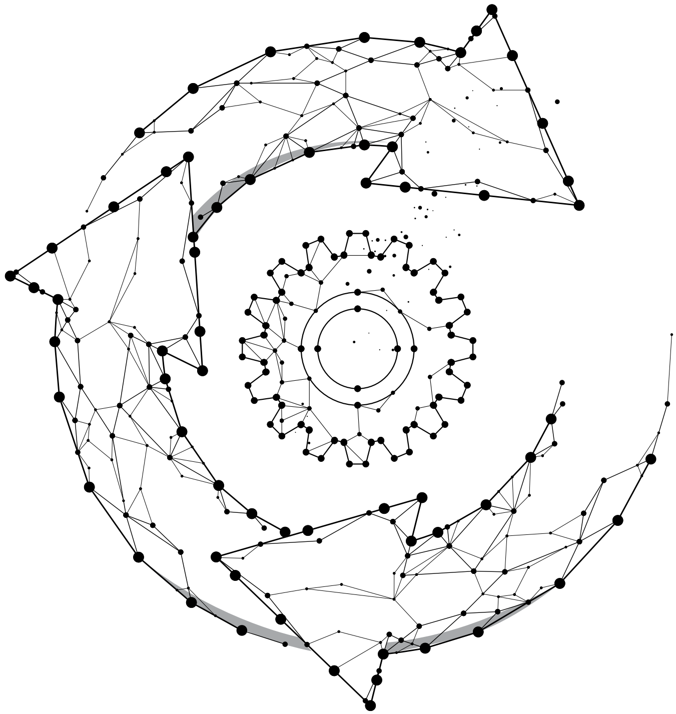
Figure 14: Computing time used in 2020 on the Walloon Tier-1 by the number of cores used per computation.

The certification of Cenaero against the EN 9100 standard initially obtained in June 2013 has been successfully renewed after the 2020 external audit performed by Bureau Veritas certification. The audit highlighted, amongst some other strengths, that client satisfaction is a value strongly integrated in Cenaero's culture and that the teams' reactivity contributes to its improvement. The audit also confirmed our ability, recognized by the clients, to supply services which meet relevant technical requirements and the underlying competence and expertise of the employees of Cenaero.

The continuous improvement of the organization, and its performance, was pursued. For instance, the Business Continuity Plan has been successfully exploited and further developed in the context of the pandemic situation.

Moreover, the release of products and service has been improved through a clear definition of the approval process. Our General Sales Conditions and the Intellectual Property have been improved in our offers.
Lastly, a fine grained recording of the time spent on our activities has been deployed at the corporate level aiming for the improvement of the efficiency of our processes.

Globally, the different evolutions of our Quality Management System (QMS) have been addressed and turned into actions. The follow up of these actions and their results has been reviewed systematically by Cenaero's Quality Steering Committee, ensuring that the planned improvements are effectively being considered and then implemented.



7 Publicly funded research projects

ANY-SHAPE 4.0	Développement d'un démonstrateur industriel dédié à l'additive manufacturing sur base des compétences wallonnes déjà présentes	Plan Marshall (WAL)	ANY-SHAPE (BE)
ARIAS	Advanced Research Into Aeromechanical Solutions	H2020 (EU)	KTH (SE)
ASTORIA	Advanced Steady and unsTeady distORsion sImulAtor	H2020 (EU)	CENAERO (BE)
BUILD4WAL-Anim	Démonstrateur Construction 4.0	Financement Equipements (WAL)	CSTC (BE)
CALFDM	Méthodologie de calcul de pièces mécaniques produites par fabrication additive FDM et optimisation des techniques de fabrication	Plan Marshall (WAL)	MSC SOFTWARE (BE)
COMP2BLADES	Composite à architecture complexe pour pales d'éoliennes	Plan Marshall (WAL)	FAIRWIND (BE)
ECOCITYTOOLS	Plate-forme d'aide à la décision en matière de développement durable des villes et éco-quartiers	Plan Marshall (WAL)	1SPATIAL (BE)
EUROCC	National Competence Centres in the framework of EuroHPC	H2020 (EU)	UNIVERSITAET STUTTGART (GER)
FabricAr3v	FabricAr3v : vers la fabrication additive métallique pour tous	INTERREG (WAL)	CNRS (FR)
FAFIL	Fabrication additive par dépôt de fil	INTERREG (WAL)	INSTITUT DE SOUDURE (FR)
HiFiTurb	High-Fidelity LES/DNS data for innovative TURBulence models	H2020 (EU)	NUMECA (BE)
IAWATHA	InnovAtion en Wallonie pas les TecHnologies Additives	ERDF 2014-2020 (WAL)	SIRRIS (BE)
ICARUS	Intensive Calculation for AeRo and automotive engines Unsteady Simulations	FUI (FR)	SAFRAN HE (FR)
INJECTEUR	Etude, dimensionnement et prototypage d'un injecteur de vapeur dans un écoulement de liquide sous-refroidi afin d'assurer le bon fonctionnement d'une boucle de refroidissement diphasique	CWALity (WAL)	CALYOS (BE)
INOXYPEM	Prototypage de plaques bipolaires en acier revêtu pour piles à combustible PEM	ERDF 2014-2020 (WAL)	ULG (BE)
IPANEMA	Inlet PArticle Separator Numerical & ExperiMental Assessment	CleanSky (EU)	CENAERO (BE)
IRON	Innovative turbopROp configuratioN	CleanSky (EU)	CIRA (IT)
LAWITECS	LAminar WIngs TEChnologies for Aircraft fuel Savings	Plan Marshall (WAL)	SONACA (BE)

LOOP-FC	Amélioration des rendements d'une pile à combustible par l'intégration d'une boucle diphasique	Energie DGO4 (WAL)	EHP (BE)
MACOBIO	Matériaux composites biosourcés	ERDF 2014-2020 (WAL)	UMONS (BE)
MARIETTA	MAîtRIsE Technico-économique des Tolérances de fAbrication	Plan Marshall (WAL)	SAFRAN AERO BOOSTER (BE)
Meta4SAM	Metamodèle pour Schéma d'Activation Musculaire	CWALity (WAL)	Digital Orthopaedics (BE)
NUMSCROLL	Développement et Fabrication à l'échelle industrielle d'une gamme de compresseurs à fluide réfrigérant « LOW GWP » utilisant des techniques de simulation multiphysiques	CWALity (WAL)	Emerson (BE)
ORFI	(Simulation) Optimisation Robuste et Fiabiliste	Plan Marshall (WAL)	NUMFLO (BE)
PCC80	Mise au point d'une nouvelle génération de poêle-chaudière à condensation avec taux de récupération supérieur à 80% et ballon tampon intégré	Plan Marshall (WAL)	STUV (BE)
PEPSE	Boucle hydraulique : conception, développement, validation et mise en service d'un poste d'essai « semi-virtuel » pour les systèmes de production, de stockage et de distribution de chaleur et de froid	ERDF 2014-2020 (WAL)	IGRETEC (BE)
PIT-AERONAUTIQUE	PIT aéronautique – pour une industrie aéronautique wallonne ambitieuse et durable	PIT (WAL)	SAB (BE)
PRACE	PRACE Supercalculateur Tier-1	ESFRI (WAL)	CENAERO (BE)
PRACE-6IP	PRACE 6th Implementation Phase Project	H2020 (EU)	JUELICH (DE)
PSIDESC	Predictive Simulation of Defects in Structural Composites	CleanSky (EU)	CENAERO (BE)
R-EVOL	Evolutionary - Revolutionary processes	IRT (FR)	IRT Saint Exupery (FR)
TECCOMA	Technologies avancées pour pièces complexes et intégrées	Plan Marshall (WAL)	SONACA (BE)
TRACTION 2020	High Efficiency and Reliability of a Traction Chain	Plan Marshall (WAL)	ALSTOM CHARLEROI (BE)
WAL-E-CITIES ECO	Évaluation économique et transfert vers le tissu économique wallon	ERDF 2014-2020 (WAL)	MULTITEL (BE)
WAL-E-CITIES ENR	Développement et application à l'échelle wallonne d'une boîte à outils numérique pour la gestion intégrée de l'énergie et de l'eau dans les villes 4.0	ERDF 2014-2020 (WAL)	MULTITEL (BE)

- S. Thomas1, V-L. Lê, R. Baiwir1, P. André, O. Fontaine de Ghélin, M. Beeckmans, R. Lepore, M. Frère, X. Kuborn, "Hardware-in-the-Loop Platform for Performance Evaluation of Energy Production, Storage and Distribution Systems for Buildings", IBPSA 2020, 13-14 May 2020, Reims, France

- E. Kuci, F. Henrotte, C. Geuzaine, B. Dehez, C. De Greef, C. Versele, C. Friebel, «Design Optimization of Synchronous Reluctance Machines for Traction Application Including Assembly Process Constraints», XXIVth International Conference on Electrical Machines (ICEM 2020), 23-26 August 2020, Gothenburg, Sweden

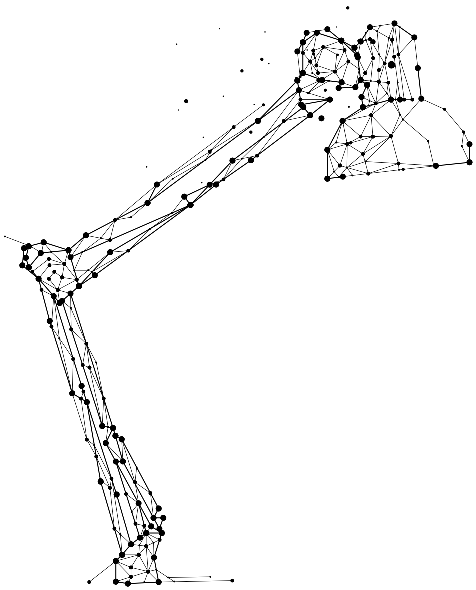
- L. Baert, C. Dumont, C. Beauthier, C. Sainvitu, I. Lepot, J. Blanchard, "Multidisciplinary Design of a Low-Noise Propeller - Part II: Efficient Aero-Acoustic-Mechanical Design Methodology Exploiting Surrogate Models in an Adaptive Design Space", ASME TurboExpo 2020, 21-25 September 2020, Virtual Conference, Online

- P. Schrooyen, A. Turchi, B. Helber, T.E. Magin, L. Walpot, "Demise of CFRP materials in atmospheric entry conditions", 5th International Space Debris Re-entry Workshop, 2 December 2020, Online

- C. Dumont, L. Baert, I. Lepot, "Multidisciplinary Design of a Low-Noise Propeller - Part I: Multi-Fidelity Design Methodology Leveraging on Acoustic Drivers", ASME TurboExpo 2020, 21-25 September 2020, Virtual Conference, Online

- L. Baert, M. Boxho, L. Cadet, E. Chérière, O. Coulaud, J. Grondin, K. Hillewaert, M. Leborgne, I. Lepot, E. Lorriaux, M. Rasquin, P. Schrooyen, A. Surti, T. Toulorge, T. Van Hoof "2020 Highlights at Cenaero", JDD HAIDA Safran, 13 October 2020, Online

- C. Marguerite, C. Goffaux, « Charl-e-district : développement d'une plateforme d'aide à la décision à l'échelle du quartier. Webinaire Smart Region : smartenergy & smartICT projects. 17 November 2020, Online.



ASSET	DE BILAN	DE BILAN
	31-12-20	31-12-19
Fixed Assets	**191.573**	**169.950**
Intangible fixed assets	**0**	**2.664**
Tangible fixed assets	**105.993**	**121.851**
A - Land and buildings		
B - Plant, machinery and equipment	51.082	41.546
C - Furniture and vehicles	8.897	12.265
D - Leases and similar rights		
E - Other tangible fixed assets	46.014	68.040
F - Assets under construction and advance payments		
Financial assets	**85.580**	**45.435**
Financial assets receivable after one year		
Current Assets	**15.489.243**	**6.717.674**
Ongoing work	**672.036**	**467.297**
Amounts receivable within one year	**4.593.960**	**3.926.603**
A - Trade debtors	379.451	750.623
B - Other receivables	4.214.509	3.175.980
Short term deposit		**0**
Cash and cash equivalents	**10.016.189**	**2.181.790**
Accruals	**207.058**	**141.984**
Total	**15.680.816**	**6.887.624**

9 Financial Results of Cenaero ASBL

LIABILITIES		
	31-12-20	**31-12-19**
Equities	**1.942.221**	**2.262.923**
Capital	**422.128**	**422.128**
Reserves	**120.840**	**120.840**
Accumulated Profit/Loss	**1.358.833**	**1.661.907**
Investment grants	**40.420**	**58.048**
Provisions and differed taxes		
A - provision for risks and charges	**0**	**0**
Debts	**13.738.595**	**4.624.701**
Amounts payable after one year	**12.381.432**	**3.436.975**
Amounts payable within one year	**1.252.549**	**904.052**
A - Current portion of long term debts		
B - Loans		
C - Trade debts	352.642	358.765
D -	309.191	
E - Taxes, remuneration and social security	569.467	524.038
F - Other debt	21.249	21.249
Accruals	**104.614**	**283.674**
Total	**15.680.816**	**6.887.624**

INCOME STATEMENT		
	31-12-20	**31-12-19**
Revenues	**5.880.664**	**6.482.449**
A - Turnover	1.898.924	2.143.694
Ongoing work	-297	136.570
D - Subsidies	3.349.865	3.525.103
E - Other operating income	632.172	677.082
Operating expenses	**5.886.133**	**6.482.413**
A - Raw materials, consumables and goods for resale	352.444	445.542
B - Services and other goods	1.218.533	1.446.924
C - Remuneration, social security and pension	4.239.734	4.360.376
D - Depreciation	73.643	227.024
E - Value reduction on stocks and receivables	0	0
G - Other operating expenses	961	2.547
H - Tax	818	
Operating profit	**-5.469**	**36**
Financial income	598	3.219
Financial expenses	3.447	1
Profit before extraordinary items	**-8.318**	**3.254**
Exceptional revenues		0
Exceptional expenses	294.756	270
Profit for the period	**-303.074**	**2.984**

Cenaero

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Wallonie

LE FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL
ET LA WALLONIE INVESTISSENT DANS VOTRE AVENIR