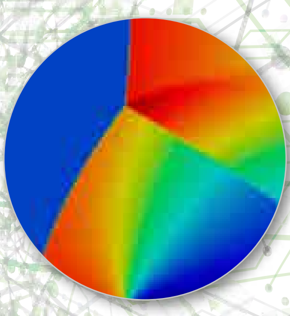
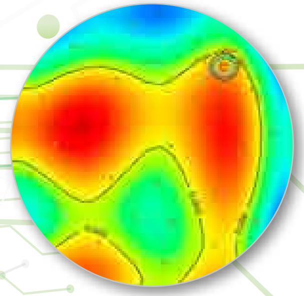
ANNUAL REPORT 2019





Cenaero

Cenaero

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| 1 | WORD FROM THE CHAIRMAN

Cenaero has become a recognized and important research center aiming at helping Walloon and European industrial organizations to keep their leading positions over world-wide competition by intensive use of sophisticated numerical simulation tools.

During 2019 Cenaero continued to demonstrate its capabilities to deliver top notch research activities in high fidelity numerical simulation using its in-house software (Argo, Minamo and Morfeo) and also some third parties' ones.

2019 revenues increased to 6.482 million euros with operating expenses of 6.482 € million euros thanks to good control of main sources of expenses.

Even though Cenaero remains focused on aeronautical sector, its developed numerical tools and abilities are also used to serve other sectors like health, energy and buildings. In the last sector, Thomas&Piron has become partner with Cenaero.

Cenaero entertains relationships with more than 40 regional companies of which half of them are SME's.

A major achievement in 2019 has been signature of 3-year strategic partnership with SAFRAN Group to develop additive manufacturing processes.

None of this could have been done without continuous support from Regional and European authorities since day one in 2002.

In May 2019, the Walloon government has agreed to support Cenaero for the renewal of regional HPC infrastructure.

ERDF 2014-2020 portfolio projects which started in 2016 (additive manufacturing activities and bio-based composite materials) have produced results in 2019.

As Chairman of the board, I thank board members for their assertiveness and I congratulate Cenaero team for their 2019 achievements, under leadership of Philippe Geuzaine, General Manager.

Michel Milecan
Chairman

| 2 | VISION & VALUES

Cenaero is a private non-profit applied research center providing to companies involved in a technology innovation process 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 design, spacecrafts, manufacturing processes, and buildings and smart cities. Cenaero operates experimental facilities in composite manufacturing and prototyping as well as 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 | 2019 HIGHLIGHTS

During the year Cenaero has continued to develop and apply its expertise through a strong participation in more than 35 collaborative research projects at European, French and Walloon levels. Within these projects and industrial contracts, Cenaero has been involved with over 40 Walloon companies, about a half of them being SMEs. Cenaero has been also very active in creating new development opportunities and was partner in five successful proposals, one of them allowing Cenaero to secure more than 40 million core hours at CINECA, the largest Italian computing center. Regional and international visibility has been achieved through the participation in about 35 fairs and conferences.

At the beginning of the year, a 3-year strategic partnership between Safran and Cenaero was signed. It is focused on the development of tools and methodologies to tackle challenges related to additive manufacturing processes. This is a genuine recognition of the quality of the research work conducted by Cenaero on this topic for the past four years. In addition, the expertise and pro-activity of Cenaero has continued to be highly appreciated by Safran in the fields of multidisciplinary design optimization and turbulence modeling. Cenaero's activity has been showcased at the Safran Aircraft Engines R&T Day Propulsion held at the end of the year and Cenaero has been awarded for the second time the price for best proximity.

New partnerships have also been developed outside the aerospace sector. In the field of energy and buildings, a partnership has been signed with Thomas & Piron Bâtiment, as well as CSTB, the Scientific and Technical Center for Building in France. Cenaero has also become part of A6K (Atelier 6000). Located next to the rail station in Charleroi, A6K is a shared multidisciplinary center dedicated to engineering sciences which co-locates in one place industrial companies, start-ups, universities, research and training centers to stimulate innovation and value creation in the field of engineering with a particular focus on energy, communication and embedded systems, and Industry 4.0.

The industrial impact of niche software developed by Cenaero has increased last year. In the frame of the partnership with Numeca, the advanced capabilities of Minamo have been coupled with the uncertainty quantification module of FINE™/Design3D allowing to find a robust design optimum which is less sensitive to operational or geometrical uncertainties. Very positive feedback has been received from the market and sales have increased. Following the release mid 2018 of an industrial version of Morfeo without any contribution from GeonX, the direct sales of Morfeo have also increased this year.

Thanks to Walloon funding, Cenaero has continued to operate to the highest standards its high-performance computing infrastructure counting about 14,000 compute cores. It maintained a remarkable effective usage rate of more than 90 % over the year. The infrastructure offers a unique working tool to researchers of the Fédération Wallonie-Bruxelles as well as a growing number of Walloon companies. A major milestone has been reached in May with the confirmation by the Walloon government to support the renewal of the infrastructure.

The challenges that await us are exiting and I am confident that we are prepared to successfully tackle them.

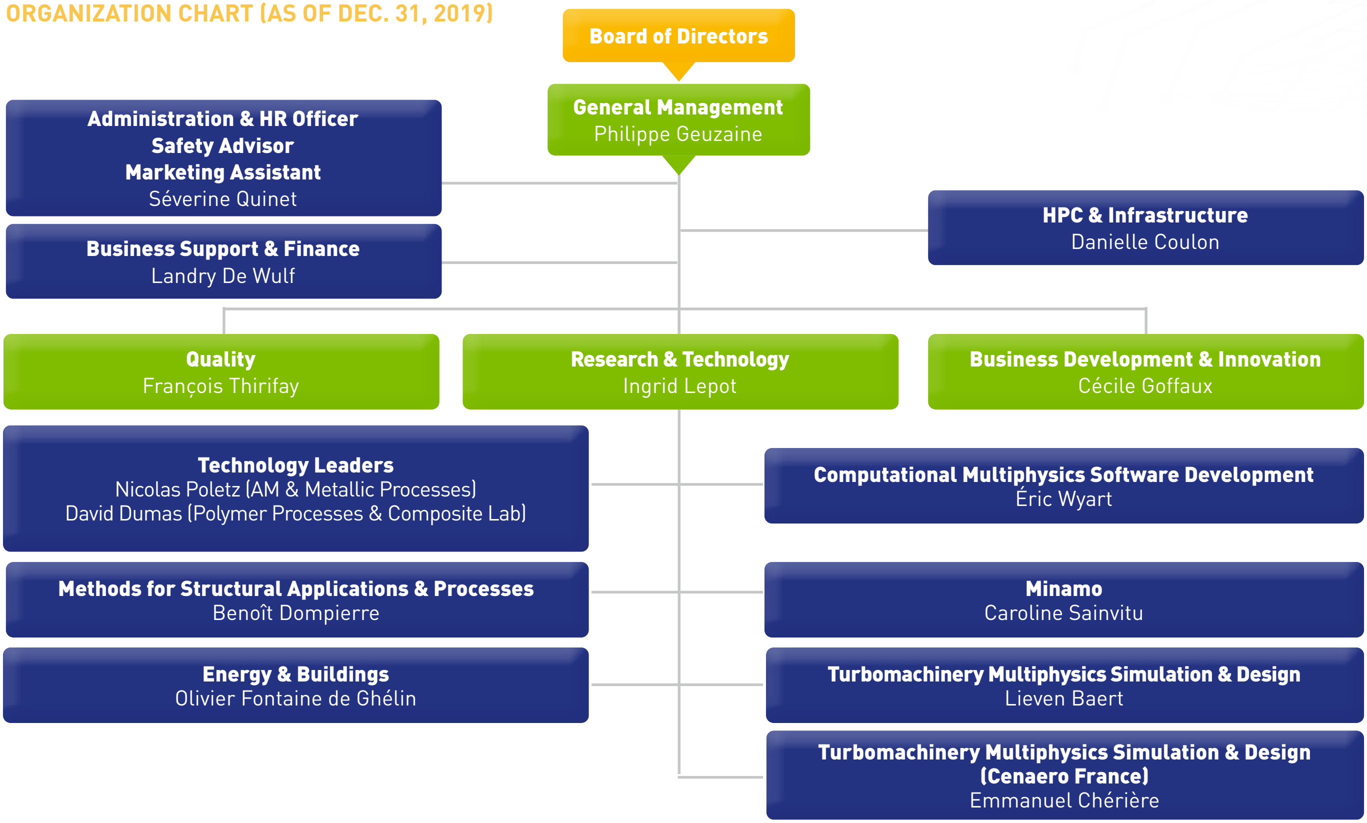
Philippe Geuzaine
General Manager

| 4 | 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 Directors are 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, 2019)



| 4 | GOVERNANCE

BOARD OF DIRECTORS (AS OF DEC. 31, 2019)

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

DESIGN SPACE EXPLORATION AND OPTIMIZATION

Minamo, our in-house platform provids design space exploration, optimization and predictive modeling tools, making the best possible use of a limited simulation budget through a user-friendly graphical user interface. The inherent surrogate-assisted paradigm allows to simultaneously acquire new knowledge exploring promising areas of the design space and further refine and exploit current designs. This strategy allows to investigate scenarios and trade-offs which may be complicated to assess only through high-fidelity simulations and/or real-world experiments, and reduces the costs associated with product and process development. Furthermore, the information provided by advanced data-analysis and visualization tools is relevant for helping and guiding designers to smartly (re)formulate their optimization objectives and constraints, and dynamically steering the search process. The Minamo platform is daily used to solve challenging engineering problems and allows pushing forward the frontiers of the capabilities in terms of design space dimensionality and complexity.

Cenaero is continuously extending Minamo's capabilities in order to strengthen its position as key partner in terms of descriptive, diagnostic, predictive and prescriptive analytics. In particular, the predictive capabilities of surrogate models help designers in performing a wide range of analysis with an affordable number of computer simulations (see **Figure 1**).

Surrogate models are invaluable tools in engineering for performing uncertainty quantification and optimization under uncertainties. In an Uncertainty Quantification (UQ) context, the inputs and outputs are treated as random/uncertain variables instead of treating the system deterministically. Developments in the algorithmic library have been performed in 2019 (partly through the ORFI project) in order to implement a global, modular surrogate-assisted framework dedicated to

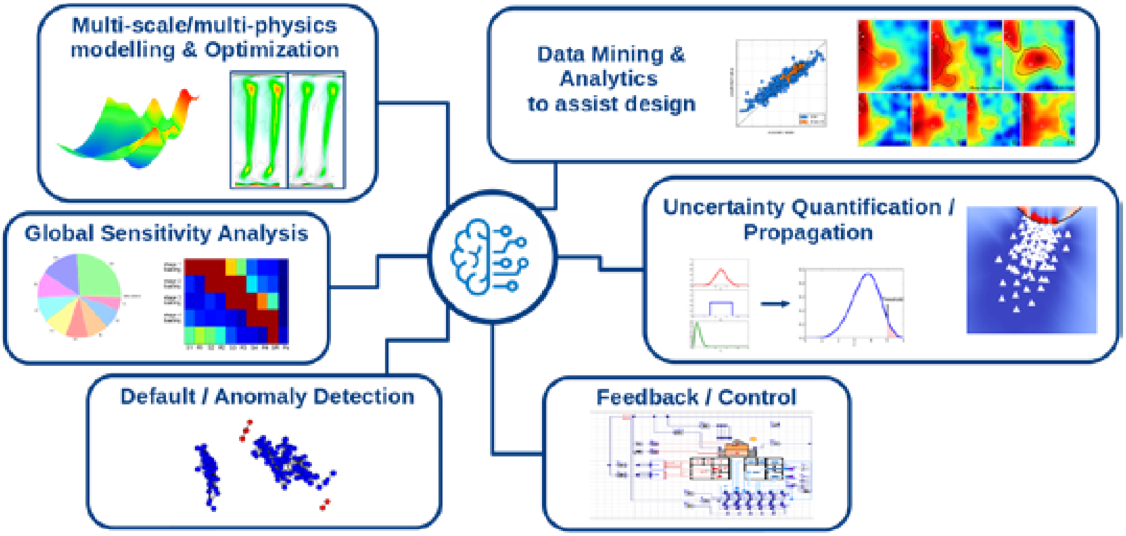


FIGURE 1 : MACHINE LEARNING EXPLOITATION AS STRATEGIC LEVERAGE FOR REAL-TIME PREDICTION AND DECISION MAKING

uncertainties management that will allow for various types of problem formulations in optimization under uncertainties. In real-world problems, uncertainties could come from variations in environmental and operational conditions (e.g. operating temperature, humidity, loads, changing material properties, ...), manufacturing tolerances, or uncertainties in the numerical simulations themselves; the design variables could also be uncertain.

Robust optimization and Reliability Based Design Optimization (RBDO) are computationally intensive processes, coupling optimization techniques, uncertainty analysis, and reliability computation. The aim of robust optimization is to find optimal solutions that are robust in presence of uncertainties, while RBDO aims to optimize performance function under reliability constraints, keeping the failure limit state sufficiently far from the optimum point.

The building blocks of the uncertainty management methodology in Minamo are hybrid surrogate modeling (smart blend of interpolation/regression and classification techniques) and active learning through dedicated online enrichment criteria. Indeed, the surrogate models are built adaptively in a single "augmented" space (combining the design and random variables into one space) in order to increase the overall efficiency. The developed strategies focus on the online training of surrogate models that should be more and more precise and reliable in the vicinity of the region(s) of interest.

For structural reliability analysis, the predictive models should be accurate near the limit state function, i.e. the boundary between the safe and failure domain, in order to efficiently compute the probability of failure. Adaptive surrogate-driven approaches have been implemented in Minamo for reliability analysis (see **Figure 2**) and for optimization under uncertainties (see **Figure 3**).

Thanks to the flexibility of its architecture, the implemented UQ framework is conducive to the development of innovative, hybrid and smart uncertainty management algorithms in

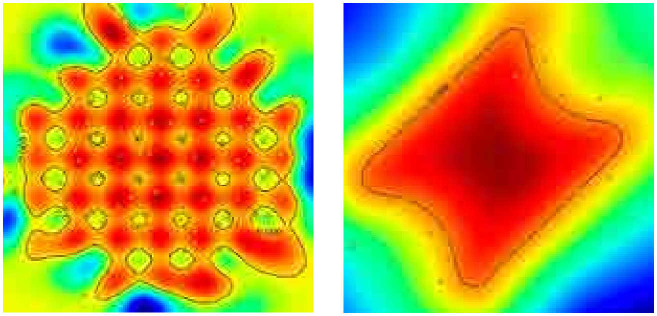


FIGURE 2 : FAILURE/SAFETY DECISION BOUNDARY IDENTIFICATION THROUGH ONLINE DEDICATED INFILL CRITERIA

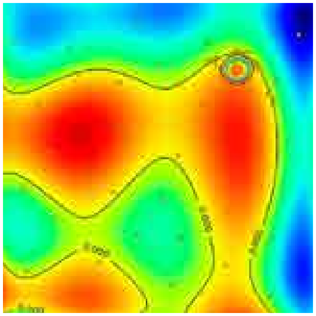


FIGURE 3 : EXPLOITATION OF SURROGATE MODELS COMBINED WITH SIMULATION TECHNIQUES AND OPTIMIZATION TO REFINE THE IDENTIFICATION OF DECISION BOUNDARY ONLY IN THE REGION OF INTEREST (RELIABLE/ROBUST OPTIMUM)

order to strengthen the position of Cenaero as key design partner.

Furthermore, in the frame of the partnership with Numeca, the advanced capabilities of Minamo have been coupled with the uncertainty quantification module of the software environment FINE™/Design3D (Release 14.2) allowing to find a robust design optimum which is less sensitive to operational or geometrical uncertainties. Very positive feedback has been received from the FINE™/Design3D users.

TURBOMACHINERY DESIGN

To reach Europe's ambitious Flightpath 2050 objectives for the aviation sector, disruptive technologies are needed. Therefore, EU research has been aligned to meet those objectives through H2020 and Clean Sky projects. Collaborative research is an accelerating vector for achieving technology readiness levels 5 and 6 for new technologies, because it often allows for a tight coupling between the exploitation of numerical modeling and the validation through wind tunnel tests.

One of the challenges that face new disruptive turbomachinery designs is the consideration of important inlet distortion. In this context, Cenaero has submitted in 2019 together with the Von Karman Institute and NUMECA the ASTORIA project proposal within the Clean Sky research program. ASTORIA aims at developing a demonstrated set of tools and methodologies in order to design and test a distortion generating device that is able to reproduce steady and unsteady distortion patterns at the fan inlet. The proposal has been accepted and the kick-off took place in October 2019 with Cenaero as coordinator and Safran Aircraft Engines as topic leader. 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 (similar to the NASA/Boeing demonstrator in **Figure 4**. As such, they contribute in paving the way for new robust integrated engine/air frame design practices.

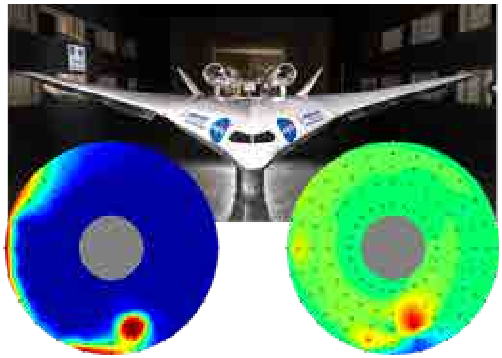


FIGURE 4 : INLET DISTORTION FOR THE NASA/BOEING HYBRID WING BODY DEMONSTRATOR (CARTER ET. ALL, AIAA 2016-0010, 2016)

Again in the framework of Clean Sky, Cenaero has contributed to the design of a disruptive low-noise propeller within the IRON project. A baseline geometry has been provided by Dowty Propellers, and the work of all partners (CIRA, Cenaero, GE Deutschland, NLR, ONERA, and UNINA) has resulted in the design of six low-noise concepts.To efficiently handle the multi-disciplinary features inherent to this design, Cenaero has developed a multi-fidelity design methodology leveraging on acoustic drivers. The Calypso package contains a noise propagation routine dedicated to the prediction of near-field cabin noise and far-field community noise of isolated propellers, based either on the outputs of a low-fidelity steady lifting-surface computation also integrated in Calypso, or on the outputs of a high-fidelity Reynolds-averaged Navier-Stokes simulation. The design methodology deployed by Cenaero exploited both Calypso's capabilities as well as Minamo's data mining features, optimization kernel, and machine learning techniques. This has allowed for an efficient exploration of a large design space and the consideration of a gradual increment of the design space to locally fine tune the propeller geometry. The obtained geometry, characterized by a high sweep and proplet-like features, achieved a 6dB near-field noise reduction (see **Figure 5** and **Figure 6**). The mechanical viability of this pronounced 3D shape has been

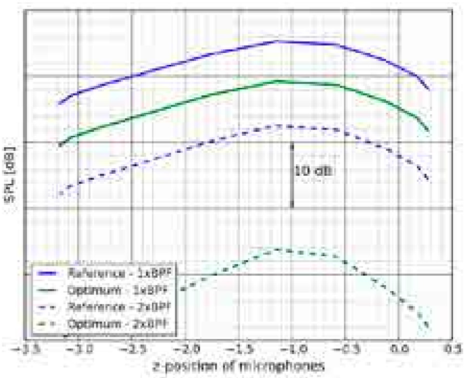


FIGURE 5 : NEAR-FIELD SPL NOISE LEVELS FOR MICROPHONES IN THE PROPELLER PLANE FOR THE FIRST AND SECOND BLADE PASSING FREQUENCIES (CRUISE FLIGHT CONDITION). COMPARISON BETWEEN THE BASELINE AND OPTIMIZED PROPELLER

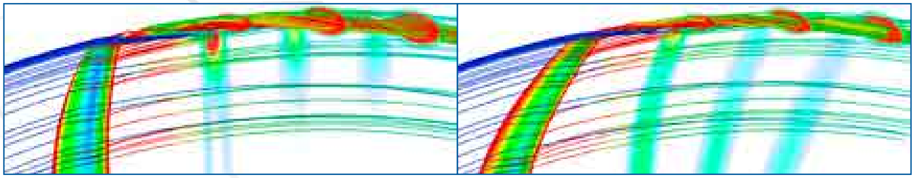


FIGURE 6 : ILLUSTRATION OF THE FLOW NEAR THE PROPELLER TIP FOR THE BASELINE PROPELLER AND THE OPTIMIZED PROPELLER AT CRUISE FLIGHT CONDITION (PROPELLER BLADE COLOURED BY STATIC PRESSURE, STREAM LINES BY ENTROPY)

assessed and the impact of a full hot-to-cold and cold-to-hot loop on the blade deformation and performance has been investigated. Among the six concepts submitted by the partners, the innovative geometries produced by Cenaero and GE Deutschland met the 6dB target noise reduction and have been selected for wind tunnel testing in 2021.

ADVANCED STRUCTURAL DESIGN

The TRACTION 2020 project aims to create a technological breakthrough in the railway sector by revisiting the traditional equipment of the train traction chain. The increase in the operating speed of trains, their reliability as well as their energy performance depend mainly on the so-called traction chain. The choices of power converters and traction motors made twenty years ago, although both conceptually and technologically groundbreaking at that time, are no longer effective. The aim of this project is threefold:

1/ make a complete break with the traditional technological solutions of traction chain equipment by introducing the latest developments in motors, converters, gearboxes and even boxes;

2/ improve the efficiency by at least 5%;

3/ reduce the Life Cycle Cost in a drastic way by introducing magnetic reducers and natural ventilation.

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 recent years, synchronous reluctance motors have been receiving increasing interest in industry as well as in automotive applications. When compared to conventional induction machines and permanent magnet assisted synchronous machines of the same power rating, reluctance machines can provide similar performances without expensive rare-earth magnets. Because of their robustness and efficiency over a wide speed range, they are a valuable alternative to induction and permanent magnet machines in a variety of applications, including hybrid and electric vehicles.

The purpose of Cenaero's work is twofold. On one hand, to confirm the potential of reluctance machines over current induction machines, in terms of average torque level and mechanical robustness, by replacing the rotor core of an existing induction machine used in a railway application (provided by Alstom). On the other hand, to enrich the existing mechanical model by including the stresses resulting from the manufacturing process of the rotor core, submitted to a centrifugal loading.

The rotor integrity of modern synchronous reluctance machines is highly dependent on the so-called iron bridges also known as "ribs" (see **Figure 7**). As the speed increases, these bridges are made to be wider for the sake of the rotor robustness but at the cost of a reduction in torque and power factor. Usually, motor manufacturers directly use thin lamination sheets punched by stamping machines or laser cut to give them the desired pattern. The rotor assembly is achieved when the shaft is fitted into the rotor core. The fitting operation is essential to ensure reliable motor operation and a correct transmission of torque to the external load. Improper fitting may lead to rotor core loosening during motor operation. Rotor assembly by shrinkage of laminations onto the shaft induces however significant mechanical stresses in the laminations, which increase with the interference (i.e. the difference between the shaft diameter and the inner diameter

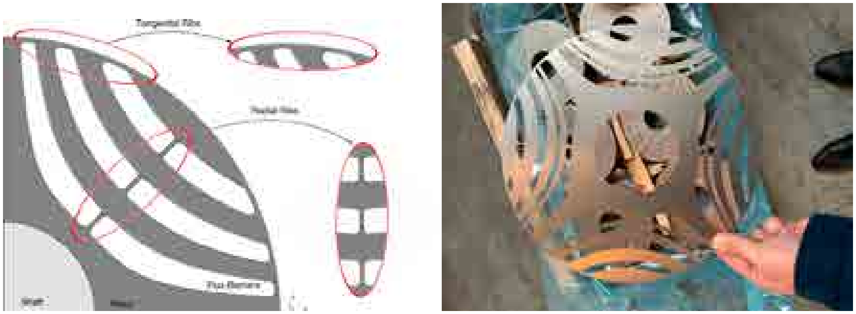


FIGURE 7 : LAMINATION OF A SYNCHRONOUS RELUCTANCE MACHINE WITH FLUX-BARRIERS, (LEFT) INCLUDING RADIAL AS WELL AS TANGENTIAL IRON BRIDGES; AND MANUFACTURED OPTIMIZED LAMINATION BY LASER CUT (RIGHT, COURTESY OF ALM).

of the laminations before shrink-fitting). If the interference value is too large, the laminations may plasticize in the vicinity of the shaft during assembly, which is not desirable.

Several attempts have been made over the years in order to identify guidelines based on analytical rules to design the iron bridge dimensions. However, such analytical models consider only the effect of centrifugal loading, assuming a virgin initial state of stress in the laminations. The overstress resulting from the assembly process, which is predominant for a hollow rotor structure, is not taken into account accurately, which leads to a lack of accuracy of current models. Cenaero developed a significantly more complex model, based on the finite element method, than the existing analytical guidelines due to the introduction of a contact condition between the shaft and the lamination. This model takes into account the interference such as the difference between the diameter of the shaft and the inside diameter of the magnetic laminations before shrinking. Improvements to the mechanical model make it possible to account for the distortions induced by the centrifugal loading as well as the maximum transmissible torque for all operating speed range. The numerical experiments highlighted the relevance of using an accurate contact model for the design optimization of the synchronous reluctance machine.

Cenaero's design strategy relies on a workflow based on in-house (Minamo, Morfeo) and open-source software (Gmsh, GetDP), and was successfully tested in 2019 with the design of a rotor core with flux barriers, achieving torque levels comparable to that of an induction machine under the same supply conditions.

In addition, the first natural frequency of the optimized rotating machine (obtained by a simplified Jeffcott model) showed an increase compared to the induction machine. Since the reference induction machine had no vibration problems, the optimized synchronous machine should not have any either. We demonstrated through the developments, the relevance of accounting for the mechanical stress due to the assembly process in the design loop of an electrical machine and the importance, especially for a variable speed application, of considering several operating points (rather than a complete time consuming life analysis conducted over the drive cycle) in the optimization. This strategy has led to the manufacture of the laminations of the machine, while the tests will be conducted in 2020.

Many short- and medium-term perspectives for future works exist. This strategy paves the way for more comprehensive design analyses that would also involve stator parameters, and for enhanced modeling taking into account further effects like fatigue and magnetic losses. While the current design approach uses selected geometrical parameters of the CAD description as optimization design variables, we are now developing topology optimization methods based on a Level-Set approach, where design variables are the presence or absence of materials at each point where it is applied, thus introducing more flexibility and allowing to explore novel designs without any a-priori guess. Finally, our approach can also potentially be extended to the aerospace industry where the electric and hybrid-electric aircraft are expected to disruptively change aviation in the next decades.

MANUFACTURING PROCESSES MODELING FOR METALLIC PARTS

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 will be acquired by a joint modeling and experimental research effort. The experimental data are used to formulate the most appropriate simulation hypotheses and methodologies as well as to feed and validate the models. This facilitates checking the processes for a given part beforehand, and eventually feeding a robust design tool which incorporates manufacturing constraints to optimize the process, the material and the product.

Our multi-scale smart inherent strain methodology developed in Morfeo in the framework of the ANYSHAPE 4.0 and IAWATHA projects was further investigated and assessed with respect to a macro-scale thermo-mechanical approach. It has been shown that accurate inherent strain mapping techniques provide good results with respect to thermo-mechanical modelling, while commonly used global averaging techniques do not provide satisfactory results on all geometries. However, the original smart averaging technique can provide distortion results comparable to most accurate mapping techniques at reduced cost. The results are summarized in **Figure 8** and were presented at the Second International Conference on Simulation for Additive Manufacturing (Sim-AM 2019). This strategy opens up a range of new possibilities in terms of artificial intelligence assisted parametric inherent strain data base generation and evaluation.

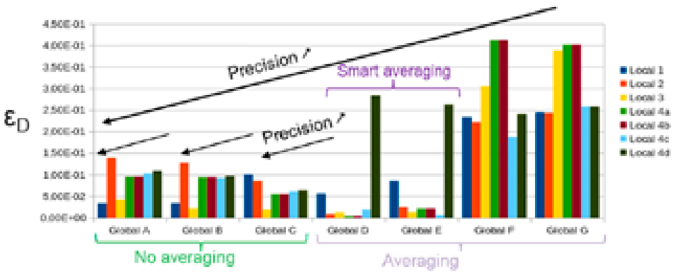


FIGURE 8 : DISTORTION ERROR EVALUATION USING VARIOUS LOCAL INHERENT STRAIN EXTRACTION AND MAPPING TECHNIQUES. THE ORIGINAL SMART AVERAGING TECHNIQUE SHOWS SAME ACCURACY AS THE NON-AVERAGED RESULTS WHILE GLOBAL AVERAGING FAILS TO PREDICT THE CORRECT DISTORTIONS

Morfeo's capacity to simulate the distortion of an industrial component in the same condition as commercial solutions has been demonstrated on an antenna support designed by Sirris as part of an ESA project. The overall deformation modes and maximum deformation zones obtained with Morfeo (see **Figure 9**) are consistent with the experimental observations. Efforts were dedicated to the simplification of the model preparation to foster the dissemination of this tool to our partners.

FIGURE 9 : DISPLACEMENT FILED COMPUTED USING MORFEO ON AN ANTENNA SUPPORT (DESIGNED BY SIRRIS AS PART OF AN ESA PROJECT)

In parallel with our work at the macro scale, a significant effort has been devoted to high-fidelity simulation activities with our in-house software Argo. On one hand, we carried out a first coupling between immersed boundary method and mechanical model in the framework of linear elastic hypothesis. On the other hand, we have extended the capabilities of our immersed boundary hydro-dynamic model. The model was verified with respect to existing conforming approach for non-deformable free surfaces (see **Figure 10**) and with respect to continuum surface force approach for deformable free surfaces.

Finally, for laser metal deposition simulation, Morfeo provides an implicit free surface tracking strategy based on a level-set to model filler material. Conventional techniques like birth and death method cannot easily handle process parameters dependency of the bead shape. This strategy overcomes this limitation. It is currently being investigated in the framework of the FAFIL project for LMD-wire process. Material flow and heat source distributions are specific to the process. Effort was put in 2019 on modeling the material flow distribution. Objective is to make the link with the process parameters (e.g. wire velocity, advancing velocity). This will be achieved based on experimental data provided by the partners of the project. In addition, the implementation has been parallelized with MPI to address large size industrial structures.

THERMO-FLUID PROCESSES MODELING

The need for innovation in the field of building energy systems requires the industry to develop new products faster while ensuring a good quality of the products. Prototypes and later the final product must be developed and tested. The annual performance of the systems has to be estimated. Although several modeling and simulation techniques can be used to evaluate the performance of Heating, Ventilation and Air Conditioning (HVAC) equipment, experimental validation is almost always required to determine the actual system performance. As the operating conditions for HVAC equipment are so varied, characterizing performance by field testing is both impractical and unrealistic. To overcome this issue, hardware-in-the loop (HIL) simulation, also called emulation technique, can be used. Indeed, the HIL simulation is frequently used in the development and testing of complex real-time embedded systems to reduce testing cost and provide a more flexible and controlled testing environment. The great advantage of this technique is to be able to test different devices under real operating conditions without having to physically have the building in which these devices are installed. The behavior of the building environment and its interactions with the equipment to be tested are reproduced virtually by numerical simulation. Different situations and parameters can thus be assessed such as the impact of the building's characteristics (type, energy class), the influence of weather conditions (season, month, time of day), the influence of the occupancy rate and the building usage mode.

In addition, the emulation also relates to the other equipment of the buildings which could interact with the equipment to be tested such as solar (photo-voltaic or thermal) panels, heating circuits (radiators, storage tank, etc.), ventilation, etc. It will therefore be possible with the semi-virtual bench to assess the energy performance and robustness of the equipment in a controlled, rapid and inexpensive manner and in various phases of development of the equipment. Many laboratories are currently employing the emulation technique to evaluate the performance of energy system/equipment in buildings.

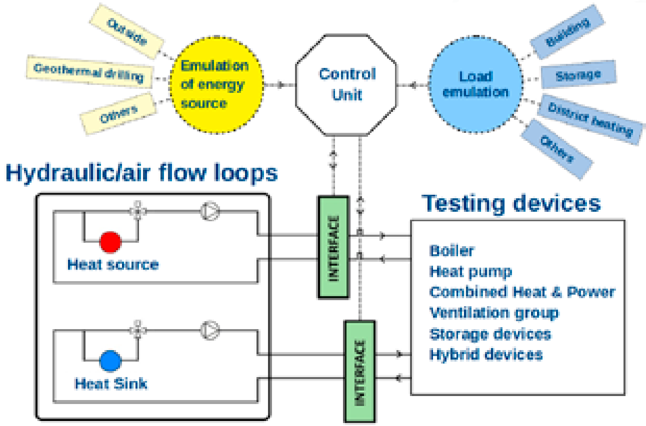


FIGURE 11 : PEPSE CONCEPT

Within this context, the PEPSE project whose research partners include CSTC, UMons, ULiège and Cenaero, aims at designing, developing and setting up the infrastructure and the equipment of a laboratory for evaluating the energy performance of heating and cooling production, storage and distribution systems in buildings. The platform is semi-virtual, i.e. energy sources and loads can be real or simulated (see **Figure 11**).

Within the framework of this project, Cenaero is in charge of developing the platform's virtual environment, which is a numerical program for simulating energy sources and loads,

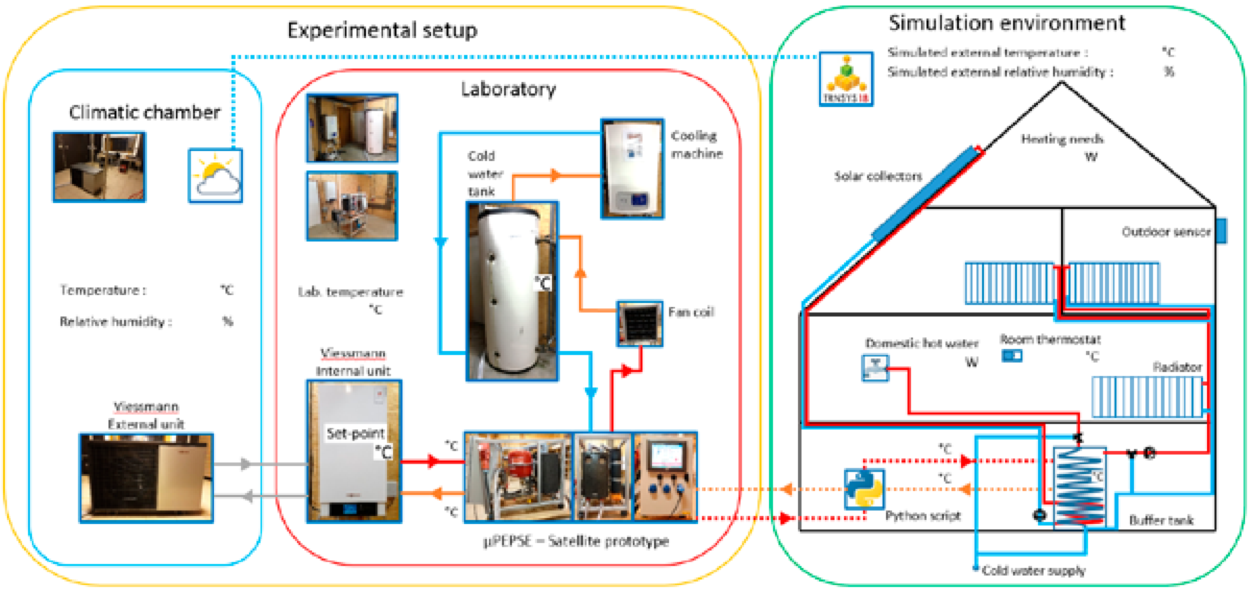


FIGURE 12 : IMPLEMENTATION OF MPEPSE FOR TESTING AN AIR-WATER HEAT PUMP

as well as the communication between the virtual environment and the real part (e.g. satellite units, energy production and distribution systems, etc.) of the platform. The virtual environment controls the inlet conditions and the operation of tested device by means of one or several satellite units (i.e. physical interfaces) located on the distribution and return lines of the hydraulic/air-flow loops. The equipment outlet conditions are also sent back towards the simulation program by these interfaces. The latter are supplied with hot and cold water by two principal energy production, distribution systems. The maximum power of devices to be tested could be up to 200 kW (heating or cooling). This capacity allows the laboratory to test a relatively wide range of devices from the heating or cooling appliances of a single-family house to the energy equipment/system of multi-family residential building or the equipment for district heating system, etc. The semi-virtual platform PEPSE would be designed as a modern and efficient tool intended to be made available to internal and external research teams of the laboratory as well as companies in the sector for testing or developing new products.

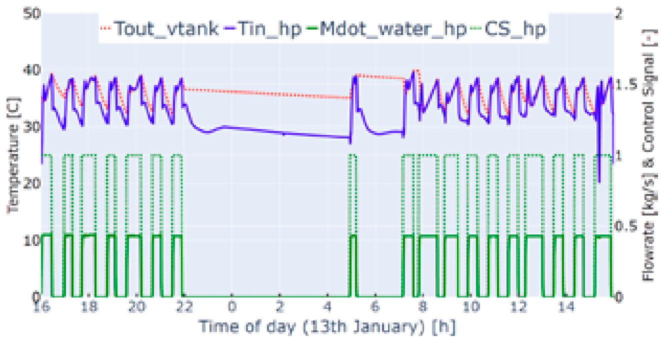


FIGURE 13 : REAL HEAT PUMP ON/OFF & INLET TEMPERATURE AND THEIR VIRTUAL CORRESPONDING VALUES

To demonstrate the validity of the platform concept, it has been decided to develop a satellite module at a reduced scale of 10 kW (called µPEPSE) and to operate this module in an existing laboratory of the University of Liège. This µPEPSE is then used to evaluate the performance of a 10-kW air-water heat pump for space heating and Domestic Hot Water (DHW) preparation of a single-family house (see **Figure 12**). The test is carried out for 24 hours of a winter day. The weather data come from the typical meteorological year data of Uccle in Belgium. The test results show that the platform concept works well. As found in **Figure 13**, the (real) ON/OFF of the heat pump, corresponding to the (real) water flow rate (in continuous green), follows well the control ON/OFF (in dotted green) coming from the simulation environment. A positive water flow rate means that the heat pump is ON and a zero-flow rate, the heat pump is OFF. When the heat pump is ON, the temperature, regulated by the satellite module, of the water (in continuous blue) entering the heat pump is in good agreement with the value of the water temperature (in dotted red) coming out of the house's (virtual) storage tank. This good result of µPEPSE demonstration is the premise for the implementation of the full-scale platform PEPSE in the future. Many feedback and lessons learnt from this demo day were capitalized and would be useful for the development of the virtual part as well as the real part of the platform.

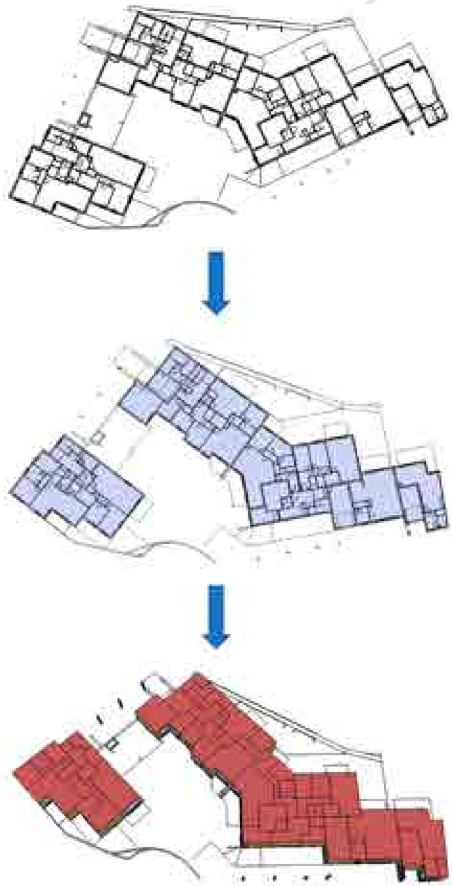


FIGURE 14 : MODELLING STEPS FROM 2D PLANS

BUILDINGS AND SMART CITIES

Within the WAL-E-CITIES project, which aims to develop digital technologies for smart cities and to create demonstrators in collaboration with private and public actors, Cenaero develops digital tools in the "Energy & Environment" theme. One of the sought targets is the use of data specific to existing buildings in order to improve, through feedback, the quality of projects delivered on the criteria "energy, health, comfort", while providing new predictive maintenance capabilities. In 2019, the development and experimentation of a prototype digital platform and energy data exploitation services, applied to Thomas & Piron's

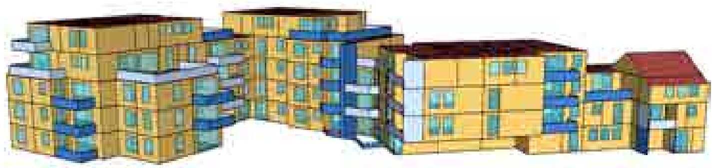


FIGURE 15 : FINAL 3D MODEL OF THE T&P RESIDENCE

| 5 | RESEARCH AND TECHNOLOGY

FIGURE 16 : PROTOTYPE OF THE ENERGY SERVICES PLATFORM DEVELOPED: ENERGY ANNUAL BALANCE FOR ONE APARTMENT OF THE RESIDENCE

(T&P) multi-residential projects, has been started Several T&P residences will be studied as proofs of concept for the developed platform which will provide the following "functionalities" through the user interface:

- Production of dynamic graphs in a "Dashboard" on key measured data such as system performance, consumption, comfort, air quality, occupancy, climate. These are raw data from sensors (not processed).
- Generation of statistical analyses of "Overall Performance": trends on measured data, comparisons of performance, consumption balances, statistical analyses.
- Support to "Operation & Maintenance". This involves providing key monitoring indicators and analyses to the technical teams, mainly on common installations (boiler room) or even individualized technical installations. The solution will be mainly based on weekly a priori projection (prediction) and a posteriori comparison between actual data and data predicted by the thermal model, with identification of the origin of the systems failure. It will be based on the so-called Fault Detection and Diagnosis (FDD) methods in a top-down diagnostic approach. Eventually, the tool will allow to optimize the instructions in the Building Management System or to anticipate maintenance interventions or equipment replacement.

To meet the platform requirements, an energy model of the building must be developed from different data sources, such as 2D plans or preferably Building Information Modelling files if available. To model and run the energy simulations, the opensource toolchain OpenStudio/EnergyPlus was chosen due to its performance and interoperability possibilities with other tools. A step of model calibration, based on advanced optimization techniques, is then necessary to ensure the accuracy of the energy model and the relevance of the FDD methods.

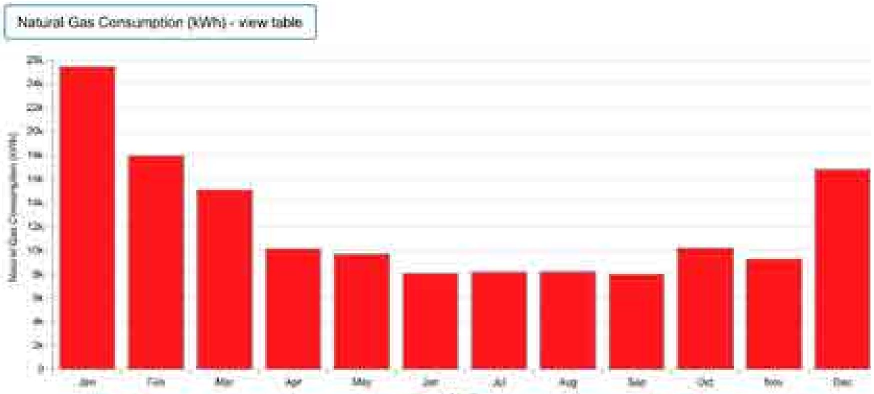


FIGURE 17 : EXAMPLE OF ENERGY SIMULATION RESULTS: MONTHLY GAS CONSUMPTION FOR THE RESIDENCE

HIGH RESOLUTION CFD FOR AERONAUTICS

In 2019, the development of high-order numerical technologies for large-eddy simulations within Argo has been carried on in collaboration with industry. In addition to the continuous improvement of Argo in terms of robustness, performance and functionality, a strong focus has been put on interoperability and on integration in industrial simulation platforms.

The CFD General Notation System (CGNS) is both a set of specifications and a software library that provide a standardized format for the exchange of CFD data. In 2019, Cenaero has finalized a proposal for the extension of the standard to generic high-order meshes and solutions, which has been accepted by the CGNS steering committee. Cenaero has then implemented the high-order functionalities, along with their set of unit tests, in the official CGNS mid-level library. The capability of reading and writing in CGNS files meshes and solutions of arbitrary, potentially non-uniform order is now easily available to the CFD community at large. In a second step, the whole computational chain centered on Argo has been upgraded to take advantage of the new features of the CGNS library. This work entails improvements to the open-source mesh generation, adaptation and manipulation packages Gmsh and MAdLib, as well as Argo itself. A significant part of the effort has been dedicated to defining a consistent specification of the parallel partitioning and to properly handle the topology of the mesh in relation with computer aided design (CAD) entities, which is particularly important for the correct application of periodic boundary conditions commonly used in turbomachinery simulations.

Beyond the exchange of data through standardized file formats, another vector of integration of Argo in industrial simulation chains is the capability to couple the code with others simulation software packages in a multi-physics setting. Significant progress towards this objective has been achieved in 2019 in the framework of the ICARUS project, with the integration of the open-source CWIPI library developed by ONERA. First demonstrations consisting in coupling several instances of Argo have been performed.

Robust and efficient mesh generation is a prerequisite for the simulation of flows around industrial configurations. In 2019, Cenaero has carried on the development of its tool Toro that handles the meshing and simulation processes in a workflow-centric manner, with new capabilities in terms of hybrid meshing and mesh size field specification, as well as CAD parsing and cleaning features. The mesh adaptation library MAdLib is now able to automatically produce anisotropic meshes that minimize the approximation error with respect to given high-order solutions, thanks to both fundamental mathematical work and practical algorithmic improvements carried out over the last year.

Finally, Cenaero is deeply involved in the development of next-generation turbulence models through its participation in the HIFITURB project, that has started in 2019. In this project, Cenaero oversees the generation of high-quality reference Direct Numerical Simulation (DNS) data for reproducible benchmarks of industrial relevance. The resulting DNS databases will be subsequently processed by Machine Learning algorithms to identify important correlations between turbulent quantities. One of the considered test cases is the Bachalo-Johnson axisymmetric bump, that features complex phenomena representative of the flow over transonic wings, and for which Cenaero has obtained first results with Argo, as illustrated in **Figure 18**.

FIGURE 18 : PRESSURE DISTRIBUTION AROUND THE BACHALO-JOHNSON AXISYMMETRIC TRANSONIC BUMP, HIGHLIGHTING A SHOCK-BOUNDARY LAYER INTERACTION AND SHOCK-INDUCED SEPARATION

HYPERSONIC FLOWS & ABLATIVE MATERIALS

Hypersonic flights are encountered during access and return to space but hypersonic aircraft could revolutionize commercial aviation and defense industry. Hypersonic flight is a very difficult endeavor and involves complex physico-chemical phenomena still not fully understood today. Among which, one can cite shock waves and chemistry, shock-boundary layers interaction, turbulence and ablation. The experimental reproduction of relevant flight conditions on ground is very difficult to achieve which renders numerical tools crucial to study those phenomena. Nonetheless, hypersonic flows are also challenging to simulate numerically due to the combination of high Mach numbers and low pressure. Most Computational Fluid Dynamics (CFD) codes used today rely on finite volume schemes. On one hand, these have shown to provide accurate evaluation of the heat flux required for the design of hypersonic vehicle. But on the other hand, Finitie Volume (FV) methods suffer from high sensitivity to the mesh alignment with the shock and the choice of the inviscid flux function. Cenaero is involved in several research projects to look for alternatives to classical methods to simulate high Mach number flows. Two methods are investigated, the Discontinuous Galerkin Method (DGM) and Lattice Boltzmann Method (LBM). **Figure 19** shows the comparison of the two methods for the flow past a forward facing step.

First, the DGM Argo code is currently extended to simulate supersonic and hypersonic flows. High order schemes such as DGM are promising because they provide high order accuracy on unstructured meshes, geometric flexibility, easy local adaptation in mesh size and polynomial interpolation order and are efficiently parallelized. The method is quite sensitive to capture under-resolved features of the problem such as shocks or strong gradients hence an artificial viscosity method has been implemented. This technique smears the discontinuities by adding artificial diffusion in the shock regions. Those development will be used within an ESA project which tries to reproduce Plasmatron experiments simulating the atmospheric entry of space debris.

Second, LBM devoted historically to the simulation of incompressible fluid flows can have several advantages over conventional CFD methods thanks to its kinetic theory background. The underlying Boltzmann equation allows to describe all fluid regimes, the method involves two local operations which allow for efficient implementation, multiphase and multispecies flows can be easily tackled, and the method is able to treat easily and efficiently complex geometries. The stability conditions of the original LBM limit its use for weakly compressible flows. Cenaero is involved in an ESA research project with the von Karman Institute for fluid dynamics, Université Paris Sud and Ecole Polytechnique Paris to develop a Lattice Boltzmann method that would be able to simulate high Mach number flows. Different schemes are investigated and tested using the pyLBM software showing promising results without artificial viscosity as could be observed in **Figure 19**. The computational efficiency of LBM and the ease to treat immersed boundaries with this method could be the keys to simulate complex geometries re-entering our atmosphere. This could help for the demise prediction of space debris. Nowadays, to simulate the uncontrolled atmospheric entry of a satellite, engineering tools are using simplified correlations to simulate the complex multi-physics problem. The use of LBM could enable better heat flux predictions to feed those engineering software.

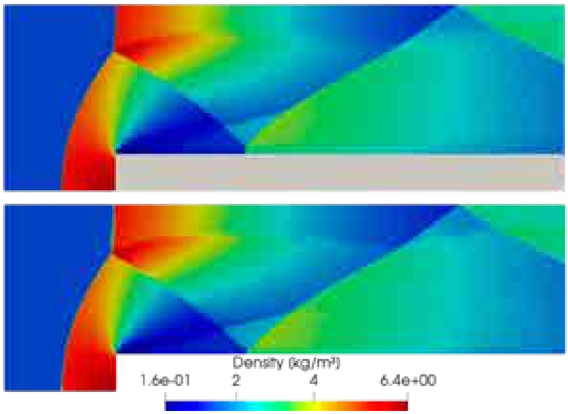


FIGURE 19 : INVISCID FLOW AT 4 [S] PAST A FORWARD FACING STEP AT MACH 3, COMPARISON BETWEEN LATTICE BOLTZMANN DISCRETIZATION WITH 786K POINTS (TOP) AND DISCONTINUOUS GALERKIN METHOD WITH 81K POINTS (BOTTOM). ARGO (DGM) IS ABLE TO CAPTURE SMALL FEATURES WITH ACCURACY BUT REQUIRES HOURS IN COMPUTATION TIME WHILE PYLBM CAPTURES MAIN FEATURES OF THE FLOW IN ONLY SEVERAL MINUTES

HIGH PERFORMANCE COMPUTING FACILITIES

The Walloon Tier-1 supercomputer operated by Cenaero entered its sixth year of operation. The supercomputer counts more than 14,000 compute cores delivering a compute capacity of more than 400 TFlop/s (Rpeak). It maintained in 2019 a remarkable effective usage rate of more than 90% and it delivered about 107 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 20** shows the computing time used on the Tier-1 in 2019 by scientific field.

About 72% of the computing time was used for academic research while 11% was used for applied research and 17% for industry. **Figure 21** shows the computing time usage by the number of cores used per computation.

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. This framework also involves coordination of involvement of all interested parties in HPC in Belgium. Cenaero has also been involved in the EuroHPC initiative that aims to develop a pan-European High-Performance Computing and data infrastructure. In June 2019, eight sites were selected in the European Union to establish centers that will host European supercomputers. Three of these sites will host pre-exascale performance systems (> 250 PFlop/s). Belgium is a member of a consortium for a pre-exascale machine to be installed in Finland. In this context, the Brussels, Flemish and Walloon Regions as well as the Federal state will contribute 15 million euros. This will provide a guaranteed access for research activity in Belgium on this machine which will be put into production during 2021.

COMPOSITE LABORATORY

As the composite lab continues to increase process developments and prototyping activities, Cenaero has gained new experience on composites materials including high performance materials (using carbon fiber and Resin Transfer Moulding injection processes) and low carbon foot print materials (using natural fibers and bio-sourced resins).

The lab, organized around several key activities and processes covers the main transformation steps to evolve from fiber preforms to full scale prototypes:

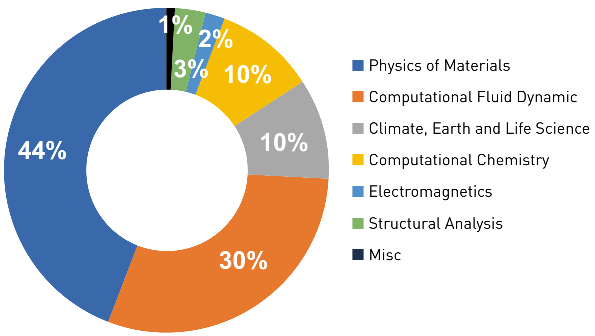


FIGURE 20 : COMPUTING TIME USED IN 2019 ON THE WALLOON TIER-1 BY SCIENTIFIC FIELD

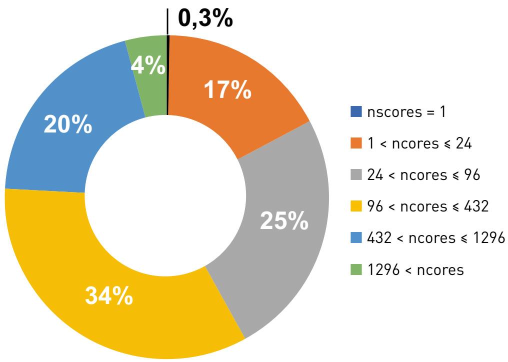


FIGURE 21 : COMPUTING TIME USED IN 2019 ON THE WALLOON TIER-1 BY THE NUMBER OF CORES USED PER COMPUTATION

| 6 | INFRASTRUCTURES

- Tooling design and manufacturing;
- Dry fiber and prepreg layup for resin infusion, resin injection or pressure consolidation using vacuum and hydraulic presses;
- Dimensional control and ultrasonic inspection;
- Machining, assembly (bonding) and finishing operations.

Molds designed and developed in the lab are used to manufacturing test plates of various dimensions. A new tooling was developed to work on plates up to 1100x700mm, possibly separated into four zones of different thicknesses ranging from 1 to 10mm. Successful campaigns were made on carbon, basalt and linen continuous reinforced composites to extract test specimens for mechanical testing.

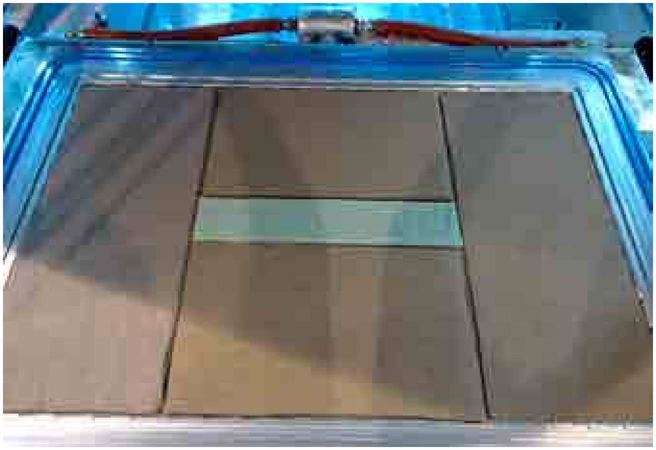


FIGURE 22 : FIBER LAYUP OF VARIOUS THICKNESSES THE LARGE FLAT MOLD

This increased manufacturing capability was done at the same time as the acquisition of a higher performance piston heating system that is capable of maintaining resin temperatures throughout the resin injection process. This is especially important with highly reactive resins and slow injection processes.

Demonstrator parts manufactured during the last period were focused around robust analysis (taking variability into account)

FIGURE 23 : DEMOLDING OF A CFRP COMPOSITE PLATE

of manufacturing and mechanical performance of bio-sourced composites. One of the functional demonstrators was optimized "pick-and-place" of flax reinforcements and cork core materials. Reducing the amount of materials, this part was manufactured to the same global stiffness (compliance) while reducing material weight by 10% compared to a similar glass fiber reinforced. A monolithic plywood solution taken as another reference was over 90% heavier. All chairs complied to the ISO7173 norm for a 200kg load.

FIGURE 24 : SETUP OF FLAX PLIES ON A CURVED SURFACE

FIGURE 25 : CHAIR SEAT DEMONSTRATOR OPTIMIZED WITH RESPECT TO WEIGH

Finishing operations are an important part of the activities at Cenaero to obtain highest quality test specimens as well as clean finishing during trimming and drilling operations. Using the 5 axis Computer Numerical Control machine, trimming of complex 3D shapes is performed to address the difficulties of fiber pull-out and surface roughness. Correct tooling selection and finishing parameters were studied to reach a correct quality in continuous fiber reinforced composite edges as shown in **Figure 28** the for Natural Fiber Reinforced Composites (NFRP).

FIGURE 26 : RTM INJECTION PISTON HEATING ELEMENT

FIGURE 27 : TRIMMING OF NFRP SHOWING FIBER PULL-OUT

FIGURE 28 : CLEAN TRIMMING OF NFRP PARTS

| 7 | QUALITY MANAGEMENT SYSTEM

The certification of Cenaero against the EN 9100 standard initially obtained in June 2013 has been successfully renewed after the 2019 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 besides pursued. For instance, the risk-based thinking initiated in 2018 has been extended to all our processes.

Moreover, operational risk management has been improved through the extension of the risk analysis to our research projects and HPC&I activities. The control of production and service provision after each HPC maintenance has been reinforced.

Lastly, a periodical review of the external provider performance has been initiated.

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.

| 8 | FAIRS & EVENTS

JEC World (mission AWEX)	12-14 March	Paris, France
Hannover Messe (mission AWEX)	1-5 April	Hannover, Germany
Bourget (mission AWEX)	17-23 June	Paris, France
Salon Métamorphoses	5 November	Marche-en-Famenne, Belgium
Formnext	19-22 November	Frankfurt, Germany
Mission Transition & efficacité énergétiques des bâtiments (mission cluster TWEED/pôle Greenwin/AWEX/WBI)	27-29 November	Genève & Sion, Switzerland

| 9 | PUBLICLY FUNDED RESEARCH PROJECTS

3DCOATER	Plateforme combinée d'outils de revêtement par voie humide et par voie sèche d'objets 3D à l'échelle pilote pré-industrielle (3D COmbined wet and dry CoATERs)	ERDF 2014-2020 (WAL)	ULG (BE)
ASTORIA	Advanced Steady and unsTeady distORsion sImulAtor	H2020 (EU)	CENAERO (BE)
BUILD4WAL	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)
CIMEDE2	Construction Industrielle de Maisons Evolutives, Durables et Economiques 2	Plan Marshall (WAL)	ATELIER DE L'AVENIR (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)
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)

| 9 | PUBLICLY FUNDED RESEARCH PROJECTS

MACHCOMP	Optimization of machining of composites and stacks with dedicated cutting tools	MANUNET (WAL)	SOBELCOMP (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)
MICROLAB	Lab-On-Chip laser Micro-manufacturing	Plan Marshall (WAL)	LASEA (BE)
NEWA	New European Wind Atlas	ERA-NET (WAL)	DTU (DEN)
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)
PRACE	PRACE Supercalculateur Tier-1	ESFRI (WAL)	CENAERO (BE)
PRACE-5IP	PRACE 5th Implementation Phase Project	H2020 (EU)	JUELICH (DE)
PSIDESC	Predictive Simulation of Defects in Structural Composites	CleanSky (EU)	CENAERO (BE)
SILENTHALPIC	Ventilation décentralisé silencieuse & intelligente avec récupération de chaleur sensible et latente	Plan Marshall (WAL)	AIRRIA (BE)
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)

| 10 | SCIENTIFIC & TECHNICAL DISSEMINATION

- E. Wyart, "Fracture Mechanics from deterministic to probabilistic approach", Séminaire Twinning-Driven, Université du Luxembourg, Esch-Sur-Alzette, Luxembourg, 12 - 13 January 2019
- M. Rasquin, K. Hillewaert, "Advanced in situ analysis of high-order DG solutions with application to scale-resolving simulations of complex turbulent flow", SIAM-CSE 2019, Washington, USA, 25 February - 01 March 2019
- P. Beaucaire, R. Chocat, L. Debeugny, C. Sainvitu, E. Wyart, P. Breitkopf, "Damage tolerance reliability assessment combining adaptive kriging and support vector machine.", UQOP 2019 - Uncertainty Quantification and Optimization, Paris, France, 18-20 March 2019
- K. Hillewaert, T. Toulorge, M. Rasquin, "Development of high-resolution schemes for industrially-relevant LES and DNS", ERCOFTAC Spring Festival, von Karman Institute, Rhode-Saint-Genèse, Belgium, 15 April 2019
- P. Schrooyen, "Development of a high order numerical tool to simulate aerothermal flows and ablative porous materials.", Pyrolysis phenomena in porous media- von Karman Institute Lecture series, Rhode-Saint-Genèse, Belgium, 01-04 April 2019
- A. Parmentier, D. Dumas, "Numerical predictions of the cure-induced deformations of composite parts manufactured using closed mould processes", 12th International Conference on Composite Science and Technology (ICCST12), Sorrento, Italy, 8-10 May 2019
- E. Wyart, "20 years of XFEM, a success story?", 1st Benelux Network Meeting and Workshop on Damage and Fracture Mechanics (BDFM -2019), Antwerp, Belgium, 13 May 2019
- T. Benamara, H. Khatouri, C. Sainvitu, V. Marguin, P. Breitkopf, "Infill procedure for multi-fidelity non-intrusive POD based surrogates applied to the design of turbomachinery components", WCSMO13 - World Congress of Structural and Multidisciplinary Optimization, Beijing, China, 20-24 May 2019
- O. Coulaud, "High-order anisotropic metric-based mesh adaptation", ADMOS 2019, El Campello, Spain, 27-29 May 2019
- S. Florez, T. Toulorge, M. Bernacki, "Impact of body-fitted Finite Element discretizations for moving interfaces applied to microstructural evolution", ADMOS 2019, El Campello, Spain, 27-29 May 2019
- J. Blanchard, C. Beauthier, T. Carletti, "A Surrogate-Assisted Cooperative Co-evolutionary Algorithm Using Recursive Differential Grouping as Decomposition Strategy", 2019 IEEE Congress On Evolutionary Computation (CEC 2019), Wellington, New-Zealand, 10-13 June 2019
- L. Baert, E. Chérière, I. Lepot, C. Sainvitu, A. Nouvellon, V. Leonardon, "Aerodynamic Optimisation of the Low Pressure Turbine Module: Exploiting Surrogate Modelsin a High-Dimensional Design Space", ASME TurboExpo 2019, Phoenix, Arizona, USA, 22-26 June 2019
- P. Beaucaire, C. Beauthier, C. Sainvitu, "Multi-Point Infill Sampling Strategies Exploiting Multiple Surrogate Models", The Genetic and Evolutionary Computation Conference (GECCO 2019), Praha, Czech Republic, 13-17 July 2019
- C. Marguerite, K. Siau, C. Beauthier, "Optimization of flexible electricity loads of a buildings cluster using distributed model predictive control", Smart Energy Systems Conference, Copenhagen, Denmark, 10-11 September 2019
- Y. Bouyer, D. Dumas, "Development of composites with complex architecture for wind turbine blades", Sampe Europe Conference, Nantes, France, 17-19 September 2019
- A. Francois, L. Arbaoui, B. Wucher, N. Poletz, "Efficient strategy for distortion and residual stress prediction in Additive Manufacturing", SIM-AM 2019 (Simulation in Additive Manufacturing), Pavia, Italy, 11-13 September 2019

- S. Zein, D. Dumas, "Numerical assessment of porosity defect in composite structures", COMPOSITES 2019, Girona, Spain, 18-20 September 2019
- P. Beaucaire, C. Beauthier, C. Sainvitu, "Surrogate-based Optimization Exploiting Multiple Surrogate Models", EUROGEN 2019 : Evolutionary and Deterministic Computing for Industrial Applications, Guimaraes, Portugal, 12-14 September 2019
- L. Van Long, A. Candaele, Kevin Siau, O. Fontaine de Ghélin, "Combination of a Wood-Pellet Boiler Stove with other Conventional and Renewable Heating System for Space Heating and Domestic Hot Water within A Passive House in Belgium", 16th IBPSA International Conference and exhibition, Rome, Italy, 2-4 September 2019
- B. Wucher, C. Metton, A. Charles, N. Poletz, "Advanced inherent strain for distortion prediction in additive manufacturing", SIM-AM 2019 (Simulation in Additive Manufacturing), Pavia, Italy, 11-13 September 2019
- L. Arbaoui, P. Schrooyen, N. Poletz, "Hydrodynamic model based on extended Discontinuous Galerkin method for powder-bed fusion numerical simulation", SIM-AM 2019 (Simulation in Additive Manufacturing), Pavia, Italy, 11-13 September 2019
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| 11 | FINANCIAL RESULTS OF CENAERO ASBL

Asset		
	31-12-19	**31-12-18**
Fixed Assets	**169.950**	**361.853**
Intangible fixed assets	**2.664**	**5.329**
Tangible fixed assets	**121.851**	**311.101**
A - Land and buildings	0	0
B - Plant, machinery and equipment	41.546	203.684
C - Furniture and vehicles	12.265	16.353
D - Leases and similar rights	0	0
E - Other tangible fixed assets	68.040	91.064
F - Assets under construction and advance payments	0	0
Financial assets	**45.435**	**45.423**
Financial assets receivable after one year	0	0
Current Assets	**6.717.674**	**6.565.820**
Ongoing work	**467.297**	**577.528**
Amounts receivable within one year	**3.926.603**	**4.535.053**
A - Trade debtors	750.623	641.982
B - Other receivables	3.175.980	3.893.071
Short term deposit	**0**	**0**
Cash and cash equivalents	**2.181.790**	**1.299.796**
Accruals	**141.984**	**153.443**
TOTAL	**6.887.624**	**6.927.673**

| 11 | FINANCIAL RESULTS OF CENAERO ASBL

Liabilities		
	31-12-19	31-12-18
Equities	**2.262.923**	**2.399.690**
Capital	**422.128**	**422.128**
Reserves	**120.840**	**120.840**
Accumulated Profit/Loss	**1.661.907**	**1.658.923**
Investment grants	**58.048**	**197.799**
Provisions and differed taxes		
A - Provision for risks and charges	**0**	**0**
Debts	**4.624.701**	**4.527.983**
Amounts payable after one year	**3.436.975**	**3.101.083**
Amounts payable within one year	**904.052**	**1.008.465**
A - Current portion of long term debts		0
B - Loans		0
C - Trade debts	358.765	449.390
E - Taxes, remuneration and social security	524.038	537.826
F - Other debt	21.249	21.249
Accruals	**283.674**	**418.435**
TOTAL	**6.887.624**	**6.927.673**

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| 11 | FINANCIAL RESULTS OF CENAERO ASBL

Income statement		
	31-12-19	**31-12-18**
Revenues	**6.482.449**	**6.187.875**
A - Turnover	2.143.694	2.236.866
Ongoing work	136.570	-117.008
D - Subsidies	3.525.103	3.931.608
E - Other operating income	677.082	136.409
Operating expenses	**6.482.413**	**6.065.760**
A - Raw materials, consumables and goods for resale	445.542	349.600
B - Services and other goods	1.446.924	1.420.361
C - Remuneration, social security and pension	4.360.376	3.639.542
D - Depreciation	227.024	651.974
E - Value reduction on stocks and receivables	0	0
G - Other operating expenses	2.547	4.283
Operating profit	**36**	**122.115**
Financial income	3.219	258
Financial expenses	1	3.646
Profit before extraordinary items	**3.254**	**118.727**
Exceptional revenues	0	0
Exceptional expenses	270	890
Profit for the period	**2.984**	**117.838**

NOTES

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NOTES

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