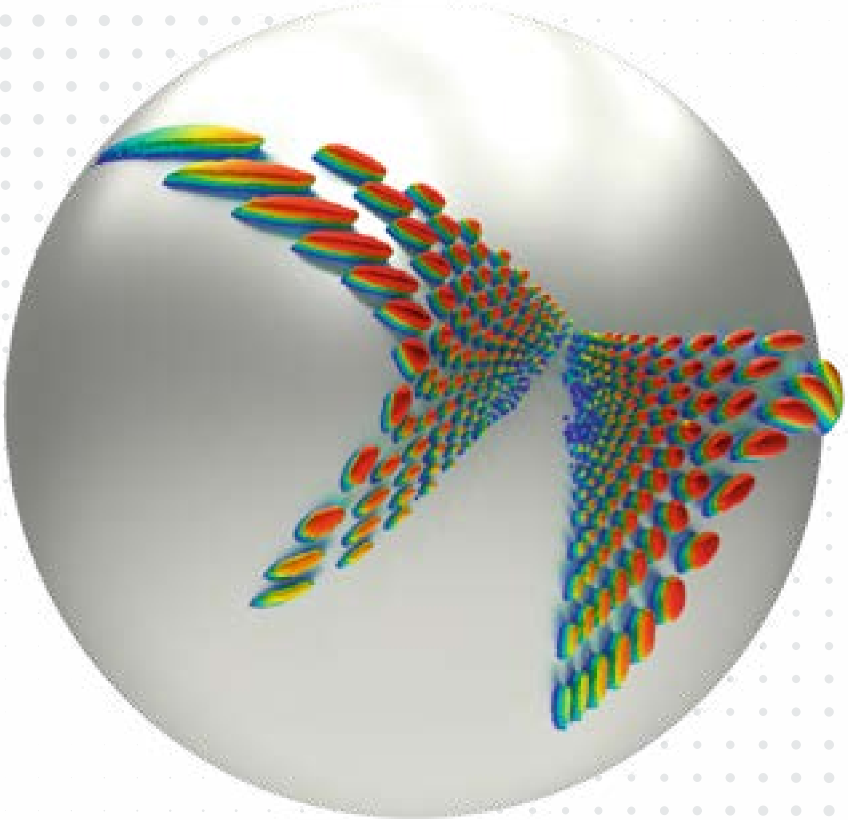
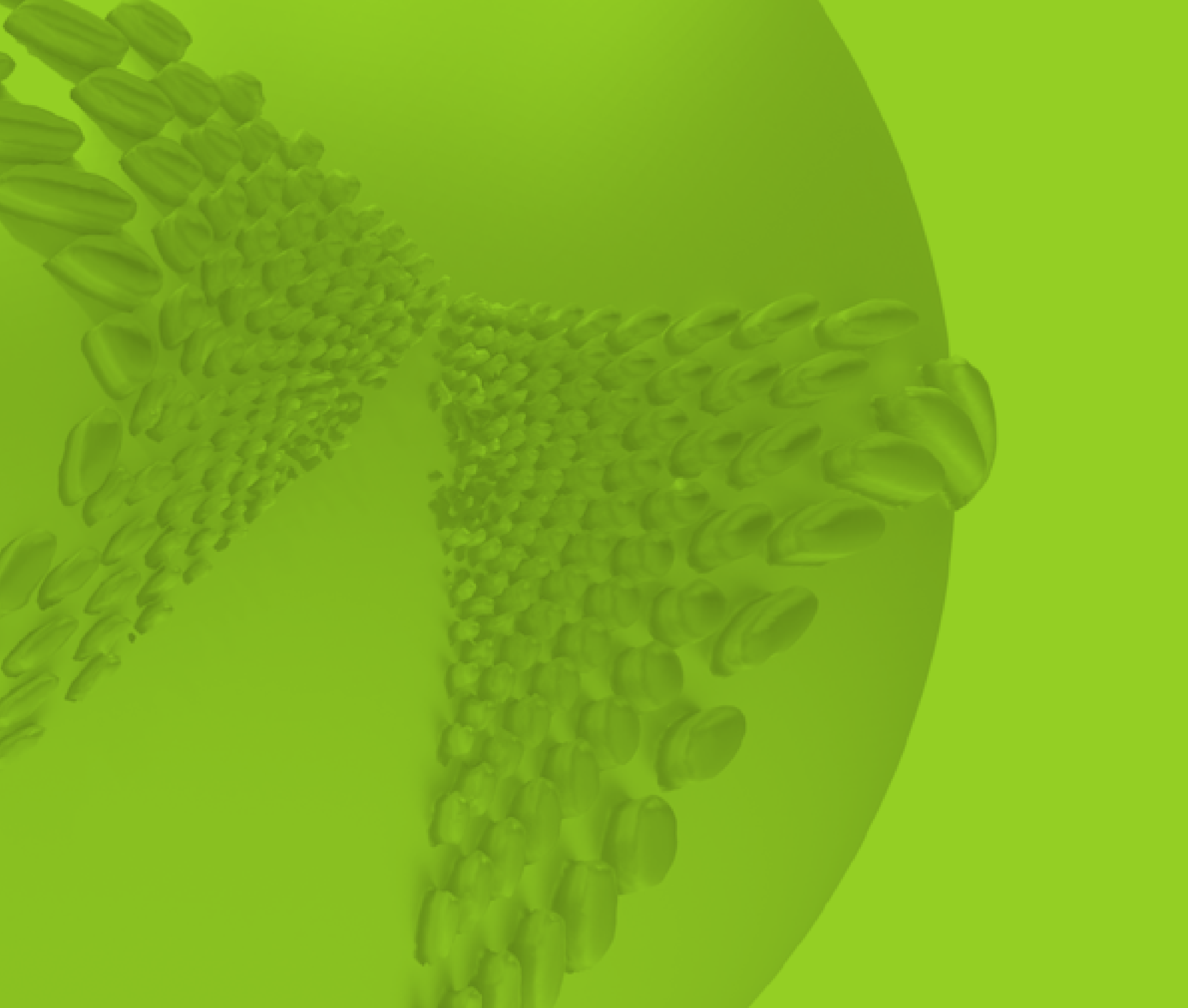
ANNUAL REPORT 2018



Cenaero



Result of a coating simulation obtained with the original Lattice Boltzmann - Level Set method developed by Cenaero for industrial coating applications on 3D objects. The simulation is based on a uniform volumetric flow rate targeting a sphere. A masking surface is used to create the butterfly shape through the shadowing capability of the Cenaero software. The color map represents the coating thickness.

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| 1 | WORD FROM THE CHAIRMAN

Throughout its 16 years of existence, 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 2018 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 some third parties' ones.

2018 revenues increased to 6.188 million euros with operating expenses of 6.066 million euros thanks to good control of main sources of expenses. Resulting operating profit has been transferred in accumulated profit.

Even though Cenaero remains focused on the aeronautical sector, its developed numerical tools and abilities are also used to serve other sectors like energy, health and buildings. This allows Cenaero to entertain relationships with approximately 40 regional SME's.

A major achievement in 2018 has been the signature in the frame of Construction 4.0 of the BUILD4WAL project with construction partners CCW and CSTC and with CETIC and Digital Wallonia.

Cenaero also continued its partnership with Numeca to better promote multi-disciplinary optimization by integrating Minamo into Numeca's software. Cenaero has renewed its long-lasting partnership with the Safran Group in several fields. Cenaero and GeonX have ended by mutual consent their partnership.

None of this could have been done without continuous support from Regional and European authorities since day one in 2002. Most important ERDF 2014-2020 portfolio projects which started in 2016 (additive manufacturing activities and bio-based composite materials) have produced their first results in 2017 and 2018.

As Chairman of the board, I thank board members for their contribution to Cenaero development and I congratulate Cenaero team for their 2018 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 aerospace (in particular turbomachinery), process engineering, energy and building sectors. 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 | 2018 HIGHLIGHTS

As illustrated by this report in the fields of additive manufacturing, coating and fuel cell, the year has seen several impressive results from the 6 Structural Funds 2014-2020 projects in which Cenaero is involved. In addition to these structuring projects, Cenaero has continued to develop and apply its expertise through a strong participation in about 30 collaborative research projects at European, French and Walloon levels. Within industrial contracts, Cenaero has been involved with about 25 Walloon companies, half of them being SMEs. Cenaero has been also very active in creating new development opportunities and was partner in 6 successful proposals, one of them allowing Cenaero to secure more than 100 million core hours at the Argonne Leadership Computing Facility. Regional and international visibility has been achieved through the participation in about 25 fairs and conferences.

At the beginning of the year, the research partnership between Cenaero and Safran has been renewed for 5 years with a focus on multi-disciplinary design optimization, assembly processes and additive manufacturing simulation and turbulence modeling. In these fields, the expertise and pro-activity of Cenaero has continued to be highly appreciated by Safran. Cenaero's activity has been showcased at the Safran Aircraft Engines R&T day held at the end of the year and Cenaero has been awarded the price for best proximity. The year has also seen a strong collaboration with the von Karman Institute for Fluids Dynamics in the field of high enthalpy flows through the joint participation in several ESA projects. At the beginning of the year, the partnership with GeonX has been ended by mutual consent. This allows Cenaero to (re)use Morfeo without any restrictions. A significant effort has been made to release by mid-year an industrial version of Morfeo without any contribution from GeonX. Finally, in the frame of the partnership with Numeca, additional advanced capabilities of Minamo have been introduced in FINE™/Design3D. Very positive feedback has been received from the market and sales have increased.

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 Walloon companies. In collaboration with the CÉCI consortium, a significant effort has been devoted to draft the request for proposal for the future public tender associated with the renewal of the infrastructure.

In the frame of Construction 4.0, the proposal submitted by Cenaero with key stakeholders of the sector for the development of a demonstration infrastructure based on Cenaero's future building has been approved by the Walloon government. This paves the way for the co-development with industry of a flexible full-scale test bench for Smart Products and a one-of-the-kind experience targeting a Cost-optimal Zero Energy Building using a collaborative Building Information Model.

A major milestone has been reached in 2018 with the successful certification of Cenaero against the EN 9100:2018 standard after successfully completing the transition audit from EN 9100:2009. The audit has highlighted amongst some other strengths that the client satisfaction is a value strongly integrated in the culture of Cenaero.

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

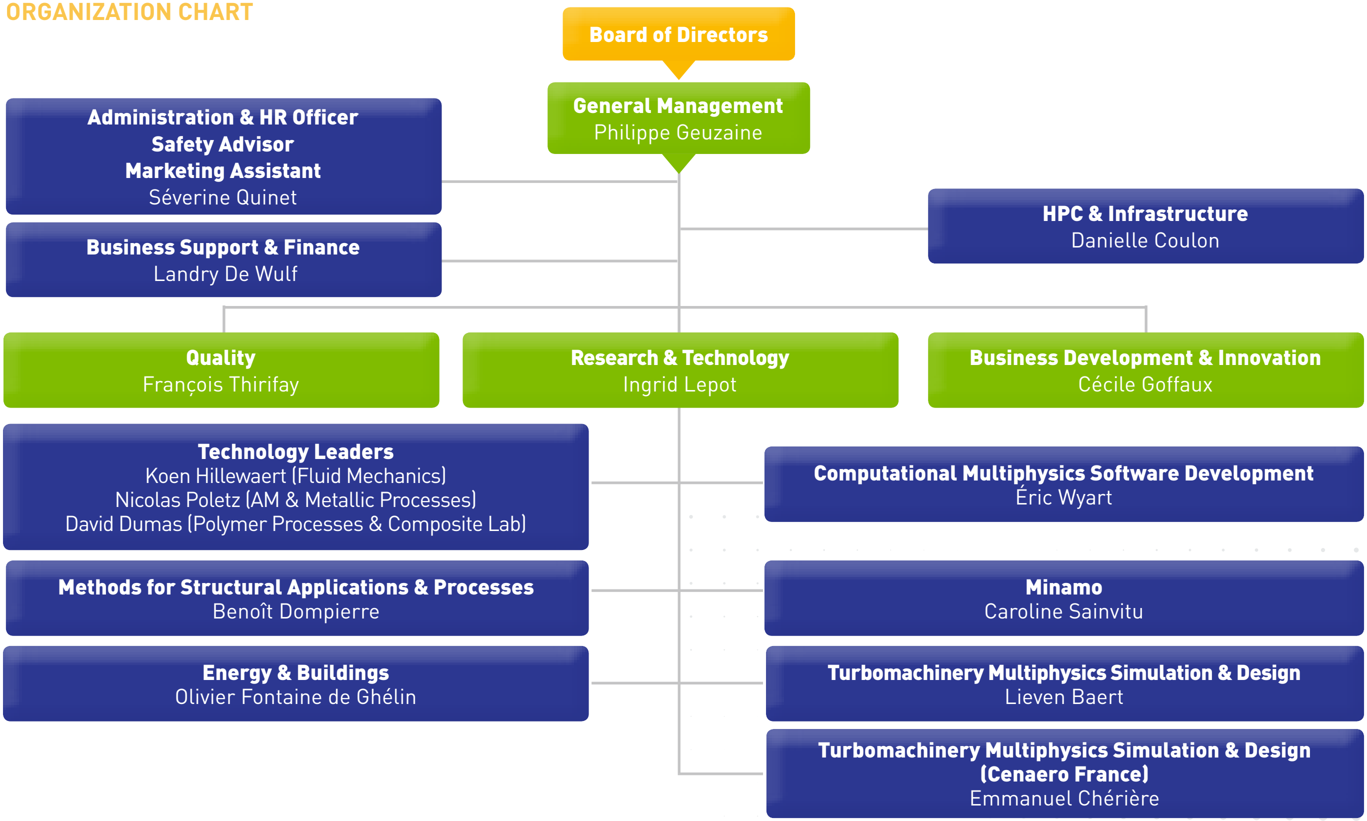
Philippe Geuzaine
General Manager

| 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



| 4 | GOVERNANCE

BOARD OF DIRECTORS

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DESIGN SPACE EXPLORATION AND OPTIMIZATION

Simulation has become an organic part of the design process of complex systems allowing to deliver better, sometimes unimagined, and more competitive products, while being subject to increasingly challenging market constraints. Minamo, Cenaero's in-house design space exploration, optimization and data analysis platform (see **Figure 1**), provides advanced tools making the best possible use of the limited computational resources and handling optimization problems based on expensive simulations in high-dimensional design spaces. The inherent surrogate-based paradigm of Minamo allows to simultaneously acquire new knowledge exploring promising areas of the design space and further refine current designs. The optimization platform is daily used at Cenaero and allows pushing forward the frontiers of our capabilities in terms of design space dimensionality, as illustrated by the aerodynamic optimization of a multistage low-pressure turbine (see section "Turbomarchinary Design").

Cenaero is continuously extending the capabilities of the Minamo platform in order to strengthen its position as key design optimization partner. Keeping in mind the surrogate-assisted paradigm, the dimensionality of the design space has a direct and significant impact on the complexity of the surrogates' training and the search process, since the design space grows exponentially. Among others, developments in the algorithmic library have been pursued in 2018 targeting the challenge related to this "curse of dimensionality" within the framework of the ORFI project and a collaboration with UNamur. Cooperative co-evolutionary algorithms, especially those able to uncover interaction structure between design

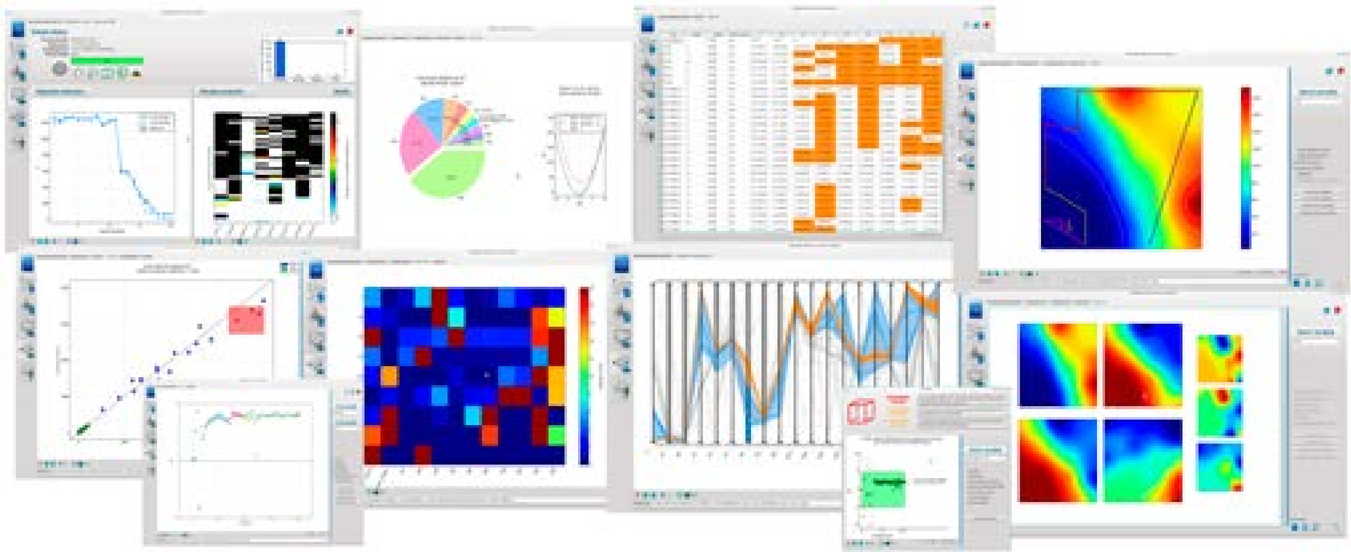


FIGURE 1 : MONITORING AND DATA-MINING TOOLS WITHIN MINAMO

parameters, have a great potential in optimizing large-scale problems. A new algorithm, taking benefit from cooperative co-evolution and surrogate modeling, has been developed in Minamo to efficiently solve high-dimensional expensive problems. This method combines a divide-and-conquer strategy to divide the initial high-dimensional search space into several lower dimensional subspaces and a recursive differential grouping to perform an accurate problem decomposition. The obtained sub-problems are optimized in a round-robin fashion with an evolutionary algorithm, while the exchange of information, called cooperation, is performed at each iteration. The algorithm shows promising results on a set of 1000-dimensional benchmark problems. This new method will be further developed in order to be able to efficiently solve constrained problems before being applied on a real industrial test case such as the optimization of a full multistage low-pressure turbine.

The refactoring of Minamo towards a modular and flexible integrative algorithmic platform has been achieved by the connection of the new kernel to the graphical user interface within the release of Minamo 3.0.4 in July 2018. The new architecture allows to quickly embed any in-house, user-developed algorithms, enabling rapid prototyping and R&T capitalization in an industry-proven platform.

Among others, developments in the algorithmic library have been performed in 2018 in order to jointly and smartly exploit several surrogate models, resulting in a more reliable modeling. Indeed, one of the key enablers for efficient simulation-driven optimization approaches relies on how the surrogate models are combined with and exploited by the search process. For the surrogate modeling phase, a wide variety of techniques are available, such as Kriging, radial basis function networks or support vector regression, with their own strengths and weaknesses. Unfortunately, it is rarely possible to determine the optimal type of surrogate model upfront as the behavior of the quantities of interest is often poorly understood or even unknown. Therefore, automatic strategies that can help to select the "best" surrogate model, or to aggregate several surrogate models by weighting them with a "quality" factor have been investigated. These developments, made possible thanks to the flexible new code architecture, enable to select a surrogate model or aggregate several ones for each response at each iteration. Either in selective or combined approaches, it is important to define adequate measures of the quality of surrogate models. Cross-validation techniques and ranking preservation have been used. The numerical results reveal that both strategies give globally better results in terms of convergence than a static surrogate model that would be chosen a priori for all responses of interest, yielding robustness and efficiency of the overall optimization process.

With the availability of parallel computing becoming commonplace, multi-point strategies based on varied surrogate models and infill sampling criteria exploited by multiple instances of evolutionary algorithms have also been pursued in 2018. This kind of hybrid strategies is promising as benefiting from complementary information of the surrogate models and infill criteria for an enhanced balance between exploitation, exploration and feasibility, which may be considered as the Graal quest in surrogate-assisted optimization.

In the frame of the partnership with Numeca, the advanced capability of Minamo in terms of simulation failures handling has been introduced in FINE™/Design3D v13.2 allowing for a maximal exploitation of the available simulation data, resulting in more accurate surrogate models and a faster convergence of the search process.

FINE™/Design3D powered by Minamo has been successfully used by Concepts NREC during the year 2018 for the optimization of a radial compressor (see **Figure 2**) with vaneless diffuser for two operating conditions. Results have been presented at the 2018 Numeca User Meeting.

FIGURE 2 : A RADIAL COMPRESSOR (COURTESY OF CONCEPTS NREC)

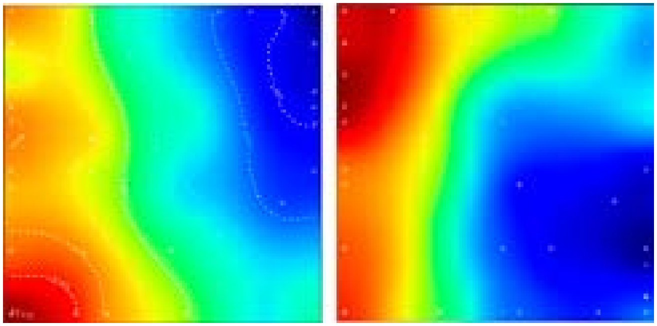


FIGURE 3 : SELF ORGANIZING MAPS – LEFT : RATIO OF EXIT STATIC PRESSURE TO INLET TOTAL PRESSURE AT HIGH-FLOW RATES - RIGHT : IMPELLER EXIT RADIUS (COURTESY OF CONCEPTS NREC)

The sophisticated data analysis and visualization tools of Minamo, such as analysis of variance, self-organizing maps or parallel coordinates plots, help to identify key factors and trends, to visualize and discover patterns and correlations within the data and to better understand the impact of antagonistic goals on the search process. Understanding the relations between parameters and/or responses of interest is crucial for making the right design decisions, especially with complex problems including a high number of conflicting objectives and/or active constraints. For instance, in the frame of the radial compressor optimized by Concept NREC, the impeller radius exit has been identified through an analysis of variance as a key, influential parameter for the response corresponding to the ratio of exit static pressure to inlet total pressure at the high mass flow conditions. The self-organizing maps of **Figure 3** show that the targeted high values for this response (at the bottom left on the first map) correspond to higher (but not maximum) values of the impeller radius exit (second map).

The information provided by these advanced data-analysis tools is relevant for helping and guiding designers to smartly (re)formulate their optimization goals and constraints.

TURBOMACHINERY DESIGN

Aspired by legal regulations on emissions, and even more by economical and competitive considerations, aero-engine designs are continuously challenged to have an increased efficiency to further reduce the Specific Fuel Consumption (SFC). For a simulation-driven design process, this implies that more detailed and complex models, together with a tighter coupling of the different high-fidelity models, are key enablers to sustain further innovative or even radical design choices. The capabilities and performance of the optimization platform Minamo help our industrial partners to integrate these complex models in an industrial design context where the computing resources are limited and the turnaround time of the design optimization is important. In 2018, the turbomachinery design activities have been focused among others on the booster and the low pressure turbine.

Non-axisymmetric endwall contouring can be applied on the blade rows to improve the aerodynamic performance of the booster. By locally changing the endwall shape, the stall behaviour can be postponed. In close collaboration with Safran Aero Boosters, the design methodology for endwall contouring has been further developed and refined. The results of both steady and unsteady Reynolds Averaged Navier Stokes (RANS) simulations of the full booster have been exploited for the setup of an accurate but efficient computation setup. A part of this work has been supported by the ORFI project, in which Safran Aero Boosters is one of the industrial sponsors.

The low pressure (LP) turbine of an aircraft engine has a direct impact on the SFC. An increase of 1 percent in LP polytropic efficiency can improve the fuel consumption by 0.5 to 1.0 %. With state-of-the-art low pressure turbines achieving to push the efficiency well above 90 %, further improvement has however become progressively more and more difficult.

Classical design approaches for the LP turbine consider a process where each stage is optimized sequentially. The potential of a single design space for the entire LP turbine module is presented in a copublication with Safran Aircraft

Engines. Despite the high-dimensional design space (350 design parameters), the optimization problem is efficiently handled by Minamo. An increase of 0.5pt has been obtained for the global LP turbine design space, offering almost 50 % gain with respect to the performance achieved after a sequential stage optimization. At the same time, the turnaround time is compatible with the critical requirements of a design cycle in an industrial context and with a relatively modest computational budget (less than five times the number of design parameters).

In the framework of the IPANEMA project, an aerodynamic study of the Inlet Particle Separator (IPS) has been performed. The purpose of this study is to support the design of the test bench and the experimental campaign that will be performed at the von Karman Institute (VKI). Subsequent resolution studies have been performed to investigate the turbulence specifications of the inlet conditions in detail.

ADVANCED STRUCTURAL DESIGN

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 structures and processes through innovative design methodologies and tools applied in topics as diverse as lightweight composite materials, additive manufacturing, metal and construction materials. Through simulation, we aim to ensure positive synergy between industrial design practices and experience, and multi-disciplinary design space exploration capabilities.

To decrease the weight of critical or large elements such as those found in fuselage and wings, composite materials made from carbon fibers and thermosetting polymers have been introduced. Thanks to their increased specific stiffness (ratio between stiffness and density) they can successfully impact the resulting weight of a part. A leading aero-structure manufacturer such as Sonaca has successfully introduced these materials into slats, flaps and other wing elements. The underlying design constraints and material behavior have nonetheless required adapted models and sizing tools taking specific processes (see **Figure 4**) specificity and constraints into account.

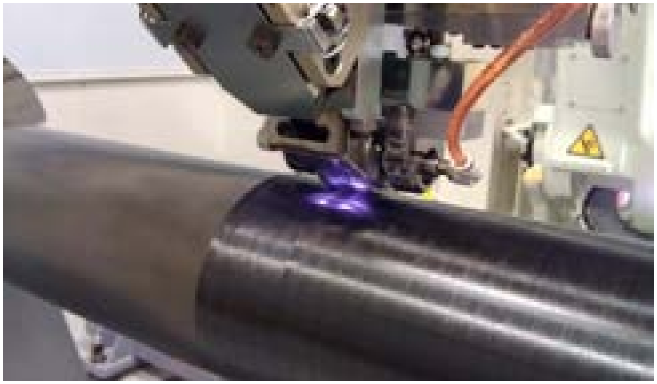


FIGURE 4 : AUTOMATIC TAPE LAYING FOR CURVED COMPOSITE PARTS

Cenaero successfully proved in 2018, using new design methodologies, that it was possible to perform an effective design space exploration to find acceptable composite material configurations and further optimize a concept to reduce the structural weight by over 10%. To do this, Cenaero, together with Sonaca's numerical methods department setup a simple workflow comprising of:

- Cenaero's optimization suite: Minamo;
- The stacking sequence generator tool developed by Cenaero: Cossmo;
- Sonaca's aero structure sizing system used for certification based on Virtual Testing SONIA.

Starting from a basic description of a structure in terms of zoning (areas in which different thicknesses of composite material are going to be used), and design rules taken from rulebooks (HDBK-17) and in-house specifications, the definition of a structurally sound and lightweight configuration of composite plies is defined (see **Figure 5**).

Cossmo has been developed over recent years to systematize and enhance past tools and scripts to explore stacking sequences. When a structure comprises of over 30 different zones, each with a thickness that can vary from as little as 8 plies to over 50, the number of combinations and probability that transitions between ply thicknesses do not respect design rules becomes so high, one has to either rely on simple repetitive stacks or use an elaborate stacking generator.

Cenaero focused on the second that combines fast exploration methods and repair techniques to find, if possible the right stacking for each zones before performing a finite element evaluation.

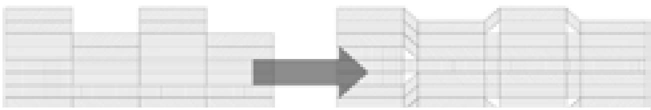


FIGURE 5 : BLENDING OF STACKING SEQUENCES FOR FOUR DIFFERENT ORIENTATION OVER SEVERAL CONNECTED REGIONS

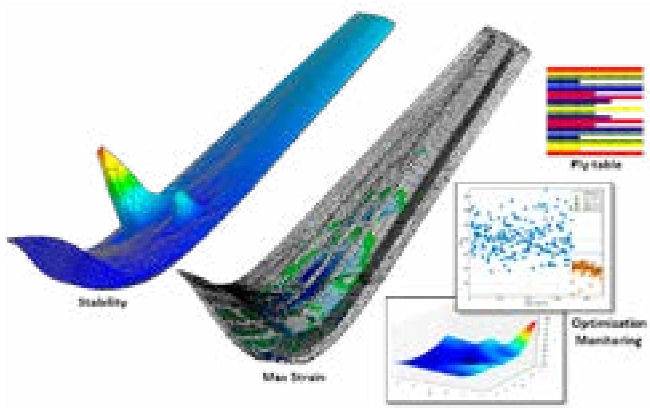


FIGURE 6 : GEOMETRY AND STRUCTURAL OPTIMIZATION OF THE WINGLET THROUGH STACKING SEQUENCE GENERATION

Cossmo is combined with the in-house optimization software Minamo to perform a design space exploration. Response surfaces are built with the information collected from Cossmo and the stressing skill tool that was specifically developed by the client (making the optimization process a very generic one that could be adapted to any other project/client). With this, the inherently discontinuous design space can be controlled and most promising configurations defined. The design of a winglet skin based on a decomposition into 28 zones was completed to reach a 10% decrease in weight compared to conventional design methods (see **Figure 6**).

This can hopefully lead to a more competitive and interesting solution for the aerospace industry as well as other fields where cost of materials are a significant part of the total cost of ownership or where the gains in materials/weight can significantly impact the overall performance and edge of a structural concept.

MANUFACTURING PROCESSES MODELING FOR METALLIC AND COMPOSITE PARTS

Understanding and mastering 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, and 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.

A level-set based strategy accounting for filler material with fusion welding process was initiated in 2015. Additional features (e.g. shadowing) were implemented in 2017 when investigating this approach for coating-like processes. The implementation was further improved (e.g. new algorithms allowing for speed-up) this year in the framework of the 3DCoater project to address 3D parts of industrial scale with complex coating kinematics. These developments were tested on an aerospace industrial test case illustrated on **Figure 7**. The new features and algorithms are directly applicable for Direct Metal Deposition processes.

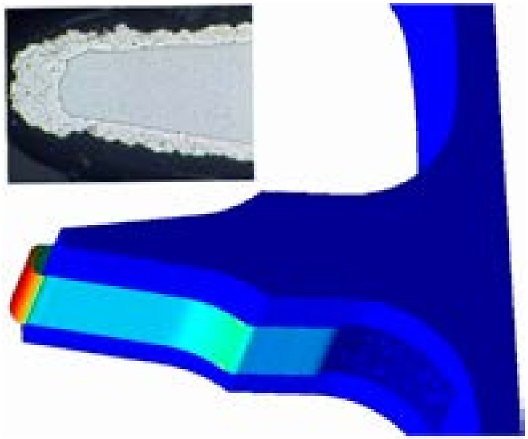


FIGURE 7 : THERMAL SPRAY COATING OF A PART OF AIRCRAFT ENGINE (EXPERIMENTAL VS NUMERICAL) – COURTESY OF SAFRAN

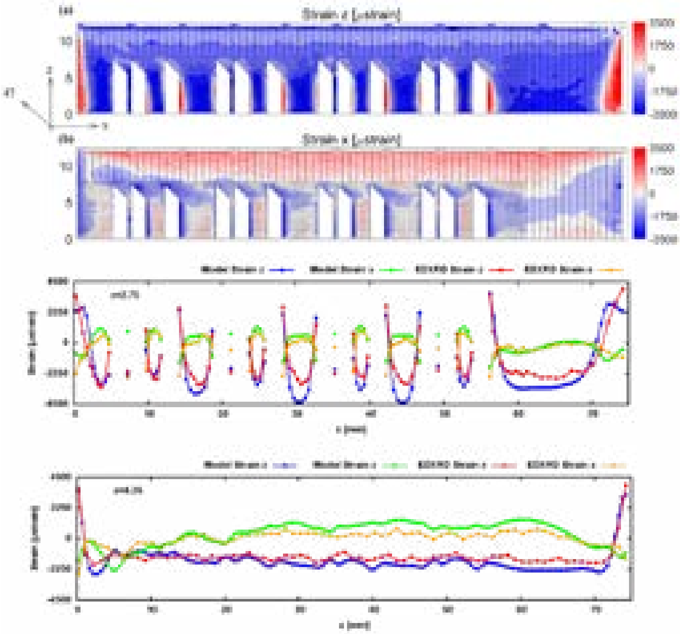


FIGURE 8 : COMPARISON OF CENAERO RESIDUAL STRAIN RESULTS (MODEL 6) WITH EXPERIMENTAL DATA

In terms of thermo-mechanical modeling of selective melting processes, two complementary approaches were investigated during 2018 in the framework of the IAWATHA project. On one hand, algorithmic developments were carried out to perform thermo-mechanical simulation using a variable order discontinuous Galerkin approach. This allows fully resolved evolution of the stresses during the process at the layer scale. On the other hand, the macro scale methodologies developed during the past two years were further improved and validated. This approach was assessed when participating to the Additive Manufacturing (AM) modeling benchmark organized by the National Institute of Standards and Technology (NIST), USA. The tests are designed to compare numerical simulations against rigorous and highly controlled AM experimental data (https://www.nist.gov/ambench). The simulated residual strains are compared to measured strains in **Figure 8**. During the AM Benchmark 2018 Conference held at NIST, Cenaero was awarded 1st place (tie) for the Best modeling results predicting the residual stresses within an as-built IN625 bridge structure by the 2018 AM-Bench Organizing Committee.

Finally, based on our multi-scale high fidelity Additive Manufacturing modeling capacities and methodologies, a smart inherent strain approach has been developed. It is based on two different aspects. First, a part and process dependent relevant feature analysis combined with a voxel mesh generation of the component and its supporting structure is performed. Second, thermo-mechanical analyses on equivalent configurations are conducted. Third, resulting inherent strains are smartly mapped on the component to predict post build distortions. This approach was developed in collaboration with Any-Shape, a Walloon SME, and a first application on an industrial component was tested as illustrated in **Figure 9**.

FIGURE 9 : POST BUILD DISTORTIONS OF A 3D PRINTED BRAKE CALIPER - COURTESY OF ANY-SHAPE

THERMO-FLUID PROCESSES MODELING

The year has seen an increased involvement of Cenaero in the development of fuel cells technology.

Fuel cells are attracting an increasing attention as one of the most promising technologies for heat and electricity generation in buildings, not to mention their well-known potential application in the automotive industry.

For heating and electricity supply in buildings, the polymer electrode membrane fuel cell (PEMFC) is the most appropriate type, since it:

- can be operated at relatively low temperatures;
- is less sensitive to the CO_2 produced during the fuel reforming process;
- is simple to maintain;
- offers high electrical efficiency.

A typical PEMFC system for combined heat and power (CHP) generation consists of three major subsystems: (i) a fuel processor; (ii) the fuel cell itself; and (iii) a heat recovery system. Due to the complexity of the configurations involved in the design, numerical simulations are critical to the improvement of the performance and efficiency of the combined PEMFC and CHP system.

FIGURE 10 : (LEFT) PEMFC OF THE PROJECT AND (RIGHT) A TOP VIEW OF ONE OF ITS BIPOLAR PLATES

| 5 | RESEARCH AND TECHNOLOGY

Following earlier work on fuel cell application to heating households and buildings, Cenaero is involved in the LOOPFC project, which aims to develop with Calyos, a Walloon SME, a two-phase loop system on the surface of the fuel cell stack for recovering the heat losses from the PEMFC, and thereby to ultimately increase overall efficiency, estimated to be at least of 2%. **Figure 10** depicts the fuel cell to be studied within the project, and the accompanying bipolar plate (graphite structure containing the gas channels).

An important point to mention in this project is the presence of internal, water-cooling channels inside the bipolar plates, which help to avoid high temperatures and contribute to ensure a uniform temperature field over the stack, two parameters directly correlated to fuel cell performance. The challenge for the simulations comes from the fact that detailed information concerning these channels has not been provided by the fuel cell supplier, so the assumption of straight and parallel channels is an issue to be studied in the simulations.

First, sensitivity analyses of the parameters directly affecting the temperature field over the fuel cell stack were made for a model with a more realistic design of bipolar plate; i.e. one with internal cooling channels. **Figure 11** shows the predicted temperature field over the bipolar plate for the fuel cell under investigation. The numerical results will eventually be validated against experimental data to be provided by the Université Libre de Bruxelles (ULB).

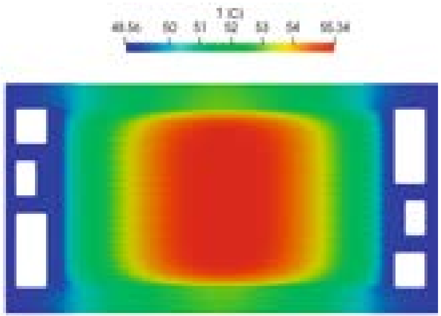


FIGURE 11 : TEMPERATURE FIELD OVER A COMPLETE BIPOLAR PLATE

FIGURE 12 : KART CAR FOR THE LAST TESTS WITH THE FUEL CELL DESIGN PROPOSED BY INOXYPEM PROJECT

Concerning projected automotive usage, which is one of the best-known applications of fuel cell technology, Cenaero is involved in the INOXYPEM project. It aims to develop a platform featuring high-fidelity tools for the improvement of the design of a coated, stainless-steel, bipolar plate for a PEMFC, including realistic modeling of the multi-physics phenomena, together with the development of an associated optimization procedure. The modeling challenge comes from the presence of multi-component, multi-phase, and multi-dimensional flow, heat and mass transfer, in the presence of electrochemical reactions.

The final part of the model testing will involve the installation of the proposed fuel cell in a hybrid Go-Kart, of the form shown in **Figure 12**. Results from initial simulations performed using the OpenFOAM software, and incorporating a specific solver developed within the openfuelcell project, are displayed in **Figure 13.** As can be seen, air consumption and water production profiles are well predicted. A comprehensive validation exercise will subsequently be undertaken based on measurements taken by the Nanomaterials, Catalysis and Electrochemistry (NCE) laboratory of the Université de Liège.

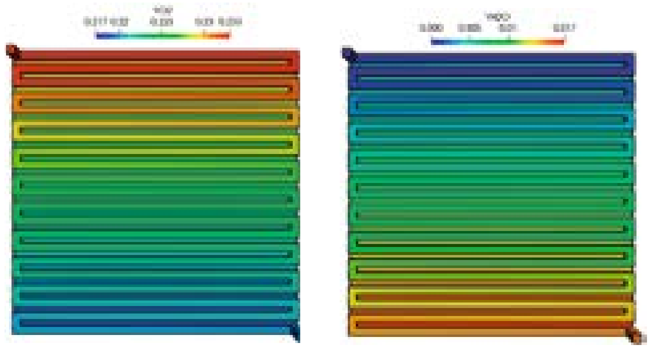


FIGURE 13 : MASS FRACTION FIELDS OF THE SPECIES CONSUMED (LEFT) AIR AND PRODUCED (RIGHT) WATER

BUILDINGS AND SMART CITIES

Nowadays, together with CFD simulation, dynamic building simulation becomes an essential tool for the reliable design of appropriate system solution that suits the demands of specific buildings, since it is capable to describe the dynamic interactions among building, energy systems, occupant and outdoor environment. The analysis of the building, coupled with its heating system, provides key information for not only sizing but also controlling the system's components in order to ensure comfort conditions in the house for the whole studied period. Many parameters such as occupancy patterns, internal heat gains, solar heat gains and building fabric characteristics that affect the building energy system performance are taken into consideration in a 3D model of the building. In the framework of the PCC80 project, led by the Walloon SME Stûv, developing a wood-pellet boiler-stove, a dynamic thermal simulation approach is used to assess the behavior and the performance of a residential pellet-based heating system as well as the occupant thermal comfort in a transient condition.

Within this context, Cenaero is in charge of virtually (numerically) integrating the product (i.e. wood-pellet boiler-stove) into a single-family detached house for space heating and Domestic Hot Water (DHW) preparation. Indeed, from available results of high-fidelity simulation (i.e. detail 3D CFD simulation) and the experimental data, a simplified (0D) model of boiler-stove was developed and calibrated. This numerical model is then used within TRNSYS (software environment used to simulate the behavior of transient system) to perform the thermal dynamic simulation of the boiler-stove and its surrounding (i.e. single-family house) (see **Figure 14**).

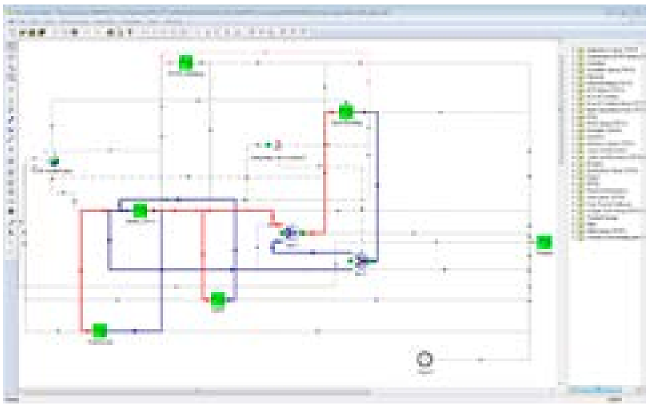


FIGURE 14 : A TRNSYS MODEL FOR PCC80 PROJECT

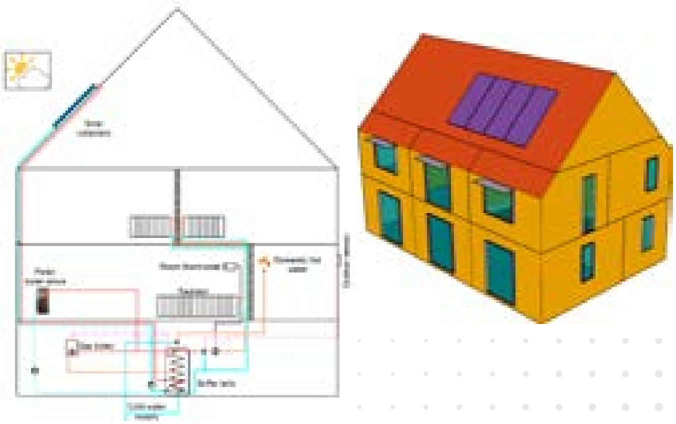


FIGURE 15 : BUILDING ENERGY SYSTEM FOR SPACE HEATING & DHW PREPARATION

In the PCC80 project, the wood pellet-based system is not designed as a monolithic closed and frozen system but as a preponderant element of a global and evolutionary heating solution, allowing an optimal usage of the different sources of energy available in a house. In this respect, the regulation of system, its opened characteristics and the possibilities of the communication with other systems such as solar collectors, gas boiler and with outside world (weather database) will be a significant part of the development effort (see **Figure 15**).

With the developed transient system model, it is now possible for Stûv to evaluate the performance gain (see **Figure 16**) on the annual basis using the wood boiler-stove. Different combinations of wood boiler-stove with other heating devices (gas boiler, solar thermal collectors, heat pump, ...) can be studied for space heating and DHW preparation. The influence of different parameters can be also investigated: global heating system concept, control strategy, building energy performance level. Another important result concerns the evaluation of the thermal comfort along the year in function of the retained concepts and control strategies.

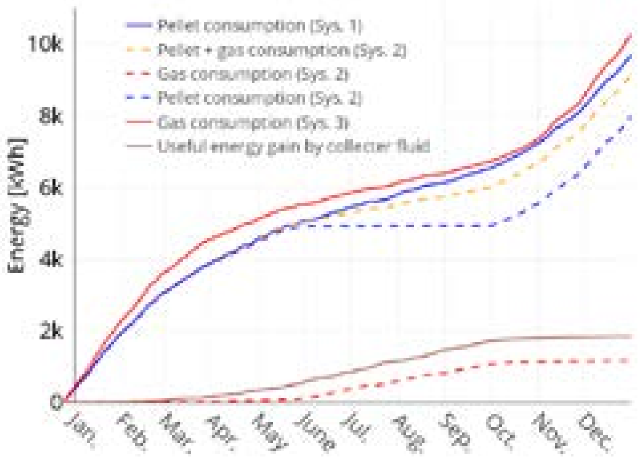


FIGURE 16 : ANNUAL ENERGY CONSUMPTION AND SOLAR GAIN FOR DIFFERENT CONFIGURATIONS

HIGH RESOLUTION CFD FOR AERONAUTICS

An important part of the development of the high order solver Argo for Large Eddy Simulation (LES) of turbomachinery flows has been targeted on the integration in an industrial simulation environment in collaboration with the R&T center of Safran. This involves developments of the core in terms of robustness and functionality, as well as the extension of peripheral tools and their integration in the code.

In 2018, this collaboration has led to a common project on the computation of the 3-stage compressor Create2bis in the framework of the LES_Turbomach project. The computation of this ambitious case on the Mira BG/Q supercomputer at the Argonne Leadership Computational Facility required a large number of numerical developments. On the high performance computing side, this includes the upscaling of all functionalities of the code to a quarter of Mira, in casu 131k cores. This included I/O functionality, the non-matching connections and the interpolation of a Reynolds Averaged Navier-Stokes (RANS) based solution from a CFD General Notation System (CGNS) checkpoint. The sharp transient and complex physics also required the correction of unphysical interpolated solutions and the improvement of the robustness of wall models and shock capturing strategies. A large effort was also dedicated to the deployment of the co-visualization tools on Mira, however without success due to compilation issues of the Catalyst suite. **Figure 17** shows a representative sample of the computation, through a cut of the entropy contours approximately at mid-span.

Cenaero has also continued the investment in the industrialization. The first activity concerns the uptake of CGNS as the main vector for storing and exchanging the data associated to a computation. In this context, Cenaero has proposed extensions to the standard, elaborated colloquially with academic and industrial partners, for storage of high order solutions and a generalization of the storage of meshes in CGNS databases. These extensions have been accepted and the formal aspects are currently under final review for adoption in 2019.

FIGURE 17 : ENTROPY CONTOURS PROGRESSING THROUGH THE 3-STAGE COMPRESSOR CREATE2BIS

An important point in terms of industrialization concerns curved mesh capabilities. In the ICARUS project, the curved adaptation routines were consolidated, and a first curved grid generation chain was developed in collaboration with the French SME Distene. At the same time, the CGNS interface of the Gmsh sotware was improved to enable the curving of linear meshes stored in CGNS format to the Computer Aided Design (CAD) model. This involves the reconstruction of the full topology of the CAD model from the boundary condition specification and mapping of mesh elements.

Finally, also the co-processing capabilities were developed further with the inclusion of the in-situ computation of statistical data, including spatial correlations and a standardized set of flow correlations.

HYPERSONIC FLOWS & ABLATIVE MATERIALS

Space debris are a growing concern for low Earth orbit space activities. According to the European Space Agency (ESA), the number of space debris objects in orbit larger than 10 cm is estimated to be more than 34 000. The awareness of the threat for population on ground caused by the atmospheric entry of these debris has raised in the past few years. During the uncontrolled atmospheric entry of a satellite, its structural components are exposed to significant aerodynamic heating and forces. This triggers the breakup of the spacecraft into several parts which are then degraded mostly by thermo-chemical processes and shear stresses. Some of these components may survive the re-entry reaching the ground and threatening to cause casualties. Currently, engineering tools are used to predict the demisability of space objects. These software tools use simplified correlations to simulate the complex multi-physics problem. Dedicated experiments, high-fidelity models and numerical simulations are necessary to improve the accuracy of those tools.

The research activities at Cenaero regarding the development of high-fidelity numerical tools for demise prediction are broken down into two main axes:

- Computational Fluid Dynamics methods to capture the hypersonic flow surrounding the space object
- Numerical methods to study the degradation of metallic and composite materials and their interactions with the flow

To tackle the first challenge, Cenaero has worked in 2018 on upgrading the capabilities of the Argo software to capture strong shocks inherent to hypersonic flow. This requires discretization efforts to ensure stability of high-order schemes and mesh adaptation to capture the phenomena.

The second axis deals with the thermal response of the materials subjected to high enthalpy flows. Among space components presenting on-ground risk, composite overwrapped pressure vessels, metallic tanks and reaction

| 5 | RESEARCH AND TECHNOLOGY

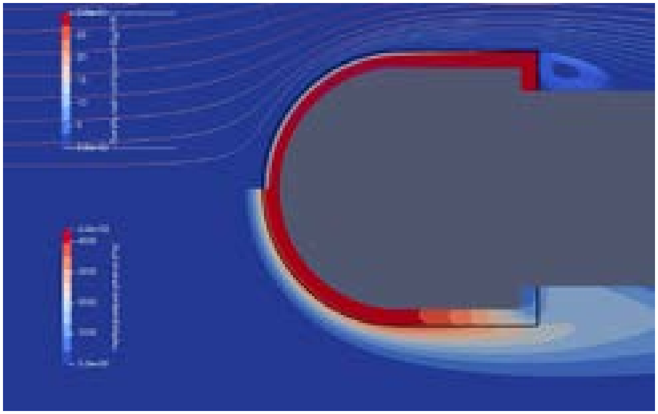


FIGURE 18 : AXI-SYMMETRIC SIMULATION OF THE ABLATION OF A CHARRING MATERIAL IN PLASMATRON CONDITIONS AFTER 1 SECOND. TOP VIEW SHOWS THE STREAMLINES SURROUNDING AND WITHIN THE POROUS COMPOSITE AS WELL AS THE DENSITY OF A RESIN COMPONENT. BOTTOM VIEW SHOWS THE PRODUCTION OF A PYROLYSIS PRODUCT DUE TO THE DECOMPOSITION OF THIS RESIN COMPONENT. BLACK LINES ON BOTH VIEWS IDENTIFY THE POROUS/FLUID INTERFACE

wheels have been shown to survive the atmospheric re-entry. In order to study those materials, Cenaero is involved with the von Karman Institute for fluid dynamics (VKI) in two ESA projects dedicated to the experimental and numerical study of the demisability of composite and metallic materials.

For composite materials, carbon fibers and resin are the main components, and these are very similar to those used to design thermal protection shields for re-entry vehicles. High-fidelity models have been developed and implemented in the Argo software in recent years to predict the response of light porous ablative thermal protection materials. There is a growing interest in exploring the possible extension of those models to predict the demisability of space debris composite materials. During the re-entry, this type of material is progressively heated up by the high-enthalpy flow, the resin degrades into pyrolysis gases which flow through the porous composite. The remaining carbonaceous residue is physically and chemically eroded by the surrounding flow. A unified method which allows to capture with accuracy the porous material and the surrounding flow has been developed within the high order multi-physics platform. The method allows to capture with accuracy the gas-material interactions. Recently, Cenaero has enriched its high-order software Argo to simulate the ablation of charring materials in atmospheric entry conditions. **Figure 18** shows the simulation of the degradation of a charring material in Plasmatron conditions using Argo.

The process for the degradation of metallic materials is very different. The component will progressively melt creating a flowing liquid layer over the solid surface, which will be removed progressively by evaporation and by the shear forces due to the surrounding flow. The study of the degradation of metallic material with the Argo tool will exploit the synergies between this thematic and the additive manufacturing research on the hydrodynamics of the melt pool.

HIGH PERFORMANCE COMPUTING FACILITIES

The Walloon Tier-1 supercomputer operated by Cenaero entered its fifth 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 2018 a remarkable effective usage rate of more than 90 % and it delivered about 108 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 19** shows the computing time used on the Tier-1 in 2018 by scientific field.

About 78% of the computing time was used for fundamental research while 8% was used for applied research and 14% for industry. **Figure 20** 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 implies 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.

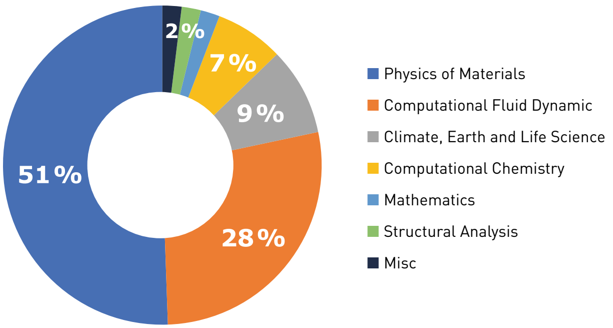


FIGURE 19 : COMPUTING TIME USED IN 2018 ON THE WALLOON TIER-1 BY SCIENTIFIC FIELD

COMPOSITE LABORATORY

A combined numerical and experimental approach on designs and processes takes place in composites activities at Cenaero through efforts to study better ways to manufacture and design composites. The Composites Innovation Lab was used over the past year in different research projects.

Composites tend to show better specific stiffness and strength compared to metals and could therefore be potentially used in many applications. Costs, process quality and automation remain key hurdles to introduce them into various applications. Also, depending on the manufacturing process and conditions, the properties may vary and it is critical to be able to ensure repeatability and validate a process as soon as first prototypes can be manufactured.

In the Comp2Blades project, led by the Walloon SME Fairwind active in the production of vertical axis wind turbines, Cenaero focused in the first half of the project on improving prediction of material properties of braided reinforced composite blades and completing a fist series of prototype blade extensions to test in operating conditions. The current extruded aluminum profile of this vertical axis wind turbine could be replaced by a full composite section made with high performance fibers produced in the Walloon region. A braiding process is developed to allow for high volume production and acceptable manufacturing costs on the long run (see **Figure 21**). This

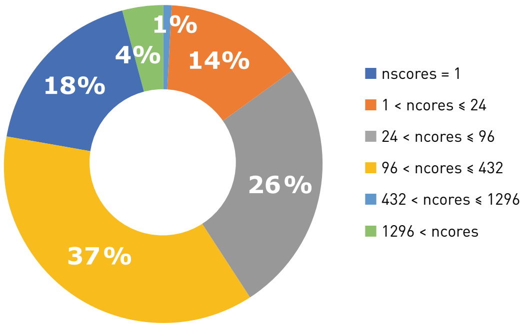


FIGURE 20 : COMPUTING TIME USED IN 2018 ON THE WALLOON TIER-1 BY THE NUMBER OF CORES USED PER COMPUTATION

FIGURE 21 : BRAIDING PROCESS OF THE BLADE

would allow to improve the blade area and allow operation over a larger range of wind speeds.

Initial manufacturing of beams allowed to properly identify the fiber configurations in the profile and compare these to simulations. These high fidelity simulations can predict the final stiffness and strength of a full composite blade profile (as shown in **Figure 22**). The proper design can then be defined in terms of orientations and strength for a full composite blade.

FIGURE 22 : SIMULATION OF BRAIDED REPRESENTATIVE SECTIONS

In the Composites Innovation Lab, several 1.5m blade section were manufactured to connect to existing aluminum profiles and test for mechanical performances. To reduce development costs, a first lightweight mold (see **Figure 23**) was prepared that nevertheless allowed a full section of the blade to be infused in one shot, therefore reducing further assembly steps and eliminating any weak spots due to adhesive bonding.

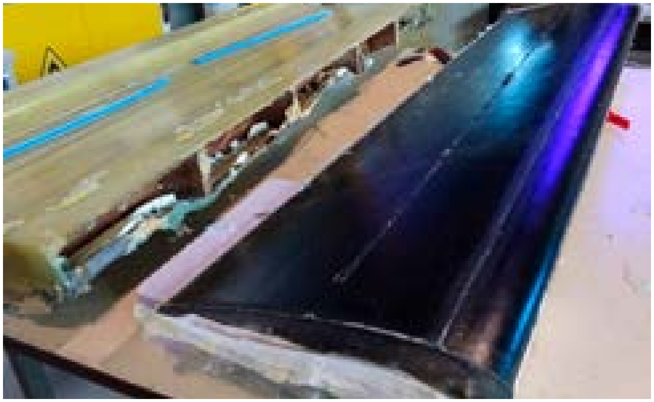


FIGURE 23 : COMPOSITE BLADES MANUFACTURED IN THE LIGHT MOLD

The mechanical tests (see **Figure 24**) have proven to be satisfactory, showing higher performance for the composite blade than the aluminum profile under bending. While damage mechanism can further be studied and fatigue behavior will be explored, the encouraging results in the first half of this project show how innovative design and manufacturing techniques can be introduced through research being carried out by engineers and technicians in the Composites Innovation Lab.

FIGURE 24 : MECHANICAL TESTING OF EXTENSION

| 7 | QUALITY MANAGEMENT SYSTEM

The certification of Cenaero against the EN 9100 standard firstly obtained in June 2013 has been successfully renewed after the 2018 external audit performed by Bureau Veritas certification. Cenaero has been awarded EN 9100:2018 after successfully completing the transition audit from EN 9100:2009.

The audit highlighted amongst some other strengths that the client satisfaction is a value strongly integrated in the company culture and that the teams'reactivity contributes to its improvement.

The audit also confirmed our ability – recognized by the clients – to supply services satisfying relevant technical requirements and the underlying competence and expertise of the employees of Cenaero.

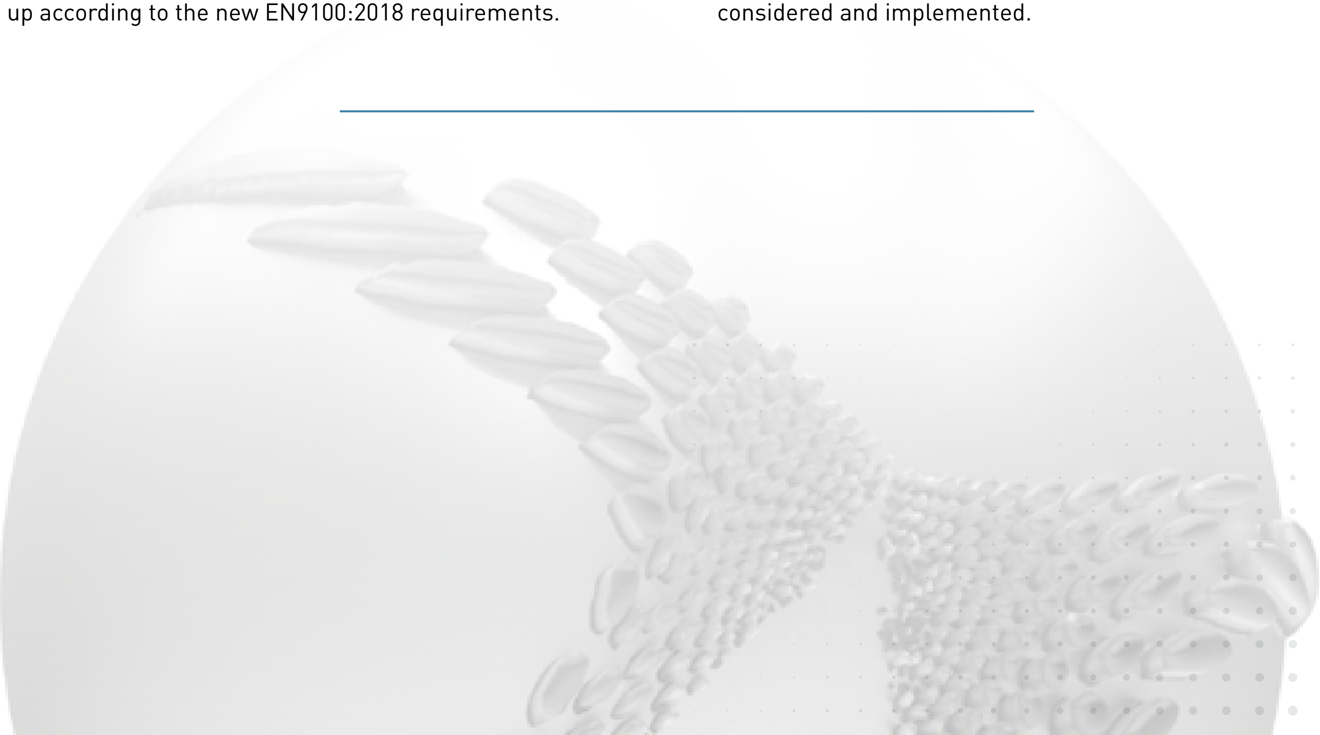
The continuous improvement of the organization and its performance was besides pursued.

Information provided to our external providers has been set up according to the new EN9100:2018 requirements.

The project management has been improved by a better exploitation of our Customer Relationship Management (CRM) projects database. Adjustments in our Quality Management System (QMS) forms have been conducted to introduce CRM connectivity capabilities. Accesses to the CRM have been provided to the whole organization and dedicated workshops have been organized to explain and support the move towards this new way of project management.

Information about software used, required input data, deliverables and actions of our projects are now centralized and easily accessible by the project teams in order to improve our processes' efficiency.

The different evolutions of our QMS have been turned into actions in order to allow for a smooth transition. The follow up of these actions and their results has been reviewed systematically by our Quality Steering Committee ensuring that the planned improvements are effectively being considered and implemented.



| 8 | FAIRS & EVENTS

Journée des Entreprises	February 21, 2018	Mons, Belgium
Job Day, UNamur	February 26, 2018	Namur, Belgium
JEC World (mission AWEX)	March 6-8, 2018	Paris, France
Journées de l'Industrie, Université catholique de Louvain	March 7, 2018	Louvain-la-Neuve, Belgium
Job Fair Engineers, Université Libre de Bruxelles	March 7, 2018	Bruxelles, Belgium
Forum Entreprises, Université de Liège	March 14, 2018	Liège, Belgium
Hannover Messe (mission AWEX)	April 23-27, 2018	Hannover, Germany
Smart Cities (mission AWEX)	May 7-11, 2018	New York, USA
formnext	November 13-16, 2018	Frankfurt, Germany

| 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)
ATALANTA	Accurate, adaptive Large Eddy Simulations for Aerodynamics and Wind Turbines Applications	BEWARE (WAL)	CENAERO (BE)
CAFEINE	Développement d'outil d'aide à la conception pour la fabrication Additive	FSN (FR)	CENAERO (FR)
CALFDM	Méthodologie de calcul de pièces mécaniques produites par fabrication additive FDM et optimisation des techniques de fabrication	Plan Marshall (WAL)	MSC SOFTWARE (BE)
CASCADE	Concentré de technologies d'avenir	FSN (FR)	SAFRAN HE (FR)
CEMDAM	Computation of structural EleMents with DAMage and fracture	BEWARE (WAL)	CENAERO (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)
ELCI	Environnement Logiciel pour le Calcul Intensif	FSN (FR)	BULL SAS (FR)
FAFIL	Fabrication additive par dépôt de fil	INTERREG (WAL)	INSTITUT DE SOUDURE (FR)
HPC4WE	High Performance Computing for Walloon Enterprises	Plan Marshall (WAL)	GDTECH (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)
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)
LES_TURBOMACH	High Accuracy LES of a Multistage Compressor using Discontinuous Galerkin	INCITE (USA)	CENAERO (BE)

| 9 | PUBLICLY FUNDED RESEARCH PROJECTS

LOOP-FC	Amélioration des rendements d'une pile à combustible par l'intégration d'une boucle diphasique	Energie DGO4 (WAL)	EHP (BE)
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)
MICROLAB	Lab-On-Chip laser Micro-manufacturing	Plan Marshall (WAL)	LASEA (BE)
NEWA	New European Wind Atlas	ERA-NET (WAL)	DTU (DEN)
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)

- C. Beauthier, C. Sainvitu, "Automatic selection and aggregation of surrogate models for surrogate-based optimization", International Workshop on Optimization and Learning: Challenges and Applications (OLA 2018), 26-28 February 2018, Alicante, Spain
- R. Chocat, P. Beaucaire, L. Debeugny, J.-P. Lefebvre, C. Sainvitu, P. Brietkopf, E. Wyart, "Damage tolerance reliability assessment combining adaptive kriging and support vector machine", ICVRAM ISUMA UNCERTAINTIES conference 2018, 8-11 April 2018, Florianopolis, Brazil
- R. Chocat, P. Beaucaire, L. Debeugny, C. Sainvitu, P. Brietkopf, E. Wyart, "Damage tolerance reliability method for aerospace structures", 7th edition of the International Symposium on Air/Craft Materials (ACMA), 24 April 2018, Compiègne, France
- A. François, L. Arbaoui, P. Schrooyen, N. Poletz, "Thermal analysis of the laser beam melting process: comparison between numerical simulations and infrared camera measurements", 3rd Workshop on Metal Additive Manufacturing, 28-29 May 2018, Liège, Belgium
- M. Jansen, E. Wyart, "Overhang limitation in a level-set topology optimization framework by means of geometric constraints", 3rd Workshop on Metal Additive Manufacturing, 28-29 May 2018, Liège, Belgium
- K. Hillewaert, "Using high order DGM for generating DNS and LES databases in complex geometry", PRACE Days 2018, 29 May – 1 June 2018, Ljubljana, Slovenia
- A. François, "Numerical Challenges in Additive Manufacturing process simulations", iMdc Consortium Meeting, 13-15 June 2018, Worcerter, USA
- P. Schrooyen , L. Arbaoui, J.-S. Cagnone, N. Poletz and K. Hillewaert, "A High-order Extended Discontinuous Galerkin Method to Treat Hydrodynamics Problems", ECCM-ECFD Conference, 11-15 June 2018, Glasgow, United Kingdom
- processing of high order polynomial solutions on massively parallel systems", ECCM-ECFD Conference, June 11-15 2018, Glasgow, United Kingdom
- L. Baert, C. Dumeunier, M. Leborgne, C. Sainvitu, I. Lepot, "Agile SBO Framework Exploiting Multi-simulation Data: Optimising Efficiency and Stall Margin of a Transonic Compressor", ASME 2018, 11-15 June 2018, Oslo, Norway
- E. Wyart, "Damage tolerant analysis in turbomachinery, from basic concept to industrial application", ASME 2018, 11-15 June 2018, Oslo, Norway
- K. Hillewaert, M. Rasquin, R.-D. Baier, P. Bechlars, M. Franke, "Full span scale resolving simulations of transitional flow in an LP turbine cascade using a high order DGM solver", ECCM-ECFD Conference, 11-15 June 2018, Glasgow, United Kingdom
- A. François, "Numerical model for thermal analysis of the Laser Beam Melting process", Conference ESMC, 2-6 July 2018, Bologna, Italy
- A. Frère, M. Rasquin, K. Hillewaert, "Using a high order flow solver for generating DNS and LES reference data bases for the development of turbulence models", PASC, 2-4 July 2018, Basel, Switzerland
- M. Moonens, E. Wyart, M. Hinderdael, D. De Baere, P. Guillaume, "Numerical Simulation of Fatigue Crack Growth in Straight Lugs Equipped with Efficient Structural Health Monitoring", European Conference on Fracture 22 (ECF 22), 26-31 August 2018, Belgrade, Serbia
- C. Beauthier, C. Sainvitu, "Surrogate-assisted optimization with online selection or aggregation of models", 6th International Conference on Engineering Optimization (EngOpt 2018), 17-19 September 2018, Lisbon, Portugal
- R. Nakhoul, O. Pierard, "Modeling Restrained Shrinkage-Induced Cracking in concrete elliptical ring specimens using the Thick Level Set", 6th International Conference on Crack Paths (CP 2018), 19-21 September 2018, Verona, Italy

| 10 | SCIENTIFIC & TECHNICAL DISSEMINATION

- O. Pierard, R. Nakhoul, "Damage initiation and crack path simulation of pre-stressed concrete sleepers with the Thick Level Set model", 6th International Conference on Crack Paths (CP 2018), 19-21 September 2018, Verona, Italy
- S. Zein, D. Dumas, "Design of a composite structure with manufacturing constraints", 6th International Conference on Engineering Optimization, 17-19 September 2018, Lisbon, Portugal
- K. Hillewaert, M. Rasquin, "In situ processing techniques for high order DGM and application to full span LP turbine cascade", 12th international Ercoftac Symposium on Engineering Turbulence Modeling and Measurements, 26-29 September 2018, Montpellier, France
- D. Dumas, A. Parmentier, "Cure simulation, residual stresses and spring back analysis", 1st International Composites Conferences, 2-3 October 2018, Liège, Belgium
- A. Frère, "Towards wall-modeled Large-Eddy Simulations of high Reynolds number airfoils using a discontinuous Galerkin method", Journée des doctorants Safran, 18 October 2018, Paris, France
- P. Schrooyen, K. Hillewaert, I. Lepot, A. Turchi, B. Helber, T.E. Magin, L. Walpot, "Towards the use of ablative TPS high-fidelity models for the prediction of space debris demisability", Clean Space Industrial Days, 23-25 October 2018, Noordwijk, The Netherlands
- G. Hernandez, WORKSHOP Call PRACE Tier0 – 4 October 2018, Gosselies, Belgium
- K. Hillewaert, M. Rasquin, "DNS studies of a full span LP turbine cascade including end walls", HiFiLED Symposium, 16-19 November 2018, Brussels, Belgium
- 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, 2-4 September 2018, Rome, Italy
- L. Van Long, A. Candaele, O. Fontaine de Ghélin, "Dynamic modelling and control strategy of a heating system based on wood pellet boiler-stove", 10th International Conference on System Simulation in Buildings (SSB2018) 10-12 December 2018, Liège, Belgium
- K. Hillewaert, "Discontinuous Galerkin Methods - HPC aspects and application to LES of turbomachinery flows, HPC methods for Computational Fluid Dynamics and Astrophysics", PATC organized by Cineca, 3-5 December 2018, Roma, Italy
- J. Fang, K.E. Jansen, P. Schlatter, R. Vinuesa, A. Frere, M. Rasquin, K. Hillewaert, R. Balakrishnan, Assessment of detached eddy simulation in predicting separated flow over airfoils at moderate Reynolds number, PASC, 2-4 July 2018, Basel, Switzerland
- T. Benamara, H. Khatouri, C. Sainvitu, C. Beauthier, P. Breitkopf, "Full-field multi-fidelity surrogate assisted optimization and their application to the optimal design of turbomachines", 6th International Conference on Engineering Optimization (EngOpt 2018), 17-19 September 2018, Lisbon, Portugal

| 11 | FINANCIAL RESULTS OF CENAERO ASBL

Asset		
	31-12-18	31-12-17
Fixed Assets	361,853	914,319
Intangible fixed assets	**5,329**	**0**
Tangible fixed assets	**311,101**	**887,646**
A - Land and buildings	0	0
B - Plant, machinery and equipment	203,684	775,408
C - Furniture and vehicles	16,353	12,751
D - Leases and similar rights	0	0
E - Other tangible fixed assets	91,064	99,487
F - Assets under construction and advance payments	0	0
Financial assets	**45,423**	**26,673**
Financial assets receivable after one year	**0**	**0**
Current Assets	6,565,820	7,236,452
Ongoing work	**577,528**	**218,179**
Amounts receivable within one year	**4,535,053**	**4,976,331**
A - Trade debtors	641,982	1,260,064
B - Other receivables	3,893,071	3,716,267
Short term deposit	**0**	**0**
Cash and cash equivalents	**1,299,796**	**1,920,843**
Accruals	**153,443**	**121,099**
TOTAL	6,927,673	8,150,771

| 11 | FINANCIAL RESULTS OF CENAERO ASBL

Liabilities		
	31-12-18	31-12-17
Equities	2,399,690	2,854,359
Capital	**422,128**	**422,128**
Reserves	**120,840**	**120,840**
Accumulated Profit/Loss	**1,658,923**	**1,541,085**
Investment grants	**197,799**	**770,306**
Provisions and differed taxes		
A - provision for risks and charges	**0**	**0**
Debts	4,527,983	5,296,412
Amounts payable after one year	**3,101,083**	**3,983,312**
Amounts payable within one year	**1,008,465**	**1,010,268**
A - Current portion of long term debts	0	0
B - Loans	0	0
C - Trade debts	449,390	326,150
E - Taxes, remuneration and social security	537,826	662,869
F - Other debt	21,249	21,249
Accruals	**418,435**	**302,832**
TOTAL	6,927,673	8,150,771

| 11 | FINANCIAL RESULTS OF CENAERO ASBL

Income statement		
	31-12-18	31-12-17
Revenues	**6,187,875**	**5,990,351**
A - Turnover	2,236,866	2,363,227
Ongoing work	-117,008	-240,717
D - Subsidies	3,931,608	3,731,229
E - Other operating income	136,409	136,612
Operating expenses	**6,065,760**	**5,910,079**
A - Raw materials, consumables and goods for resale	349,600	280,205
B - Services and other goods	1,420,361	1,375,150
C - Remuneration, social security and pension	3,639,542	3,449,198
D - Depreciation	651,974	714,111
E - Value reduction on stocks and receivables	0	87,272
G - Other operating expenses	4,283	4,143
Operating profit	**122,115**	**80,272**
Financial income	**258**	**1,065**
Financial expenses	**3,646**	**4,334**
Profit before extraordinary items	**118,727**	**77,003**
Exceptional revenues	**0**	**0**
Exceptional expenses	**890**	**8,400**
Profit for the period	**117,838**	**68,602**

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FEDER

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