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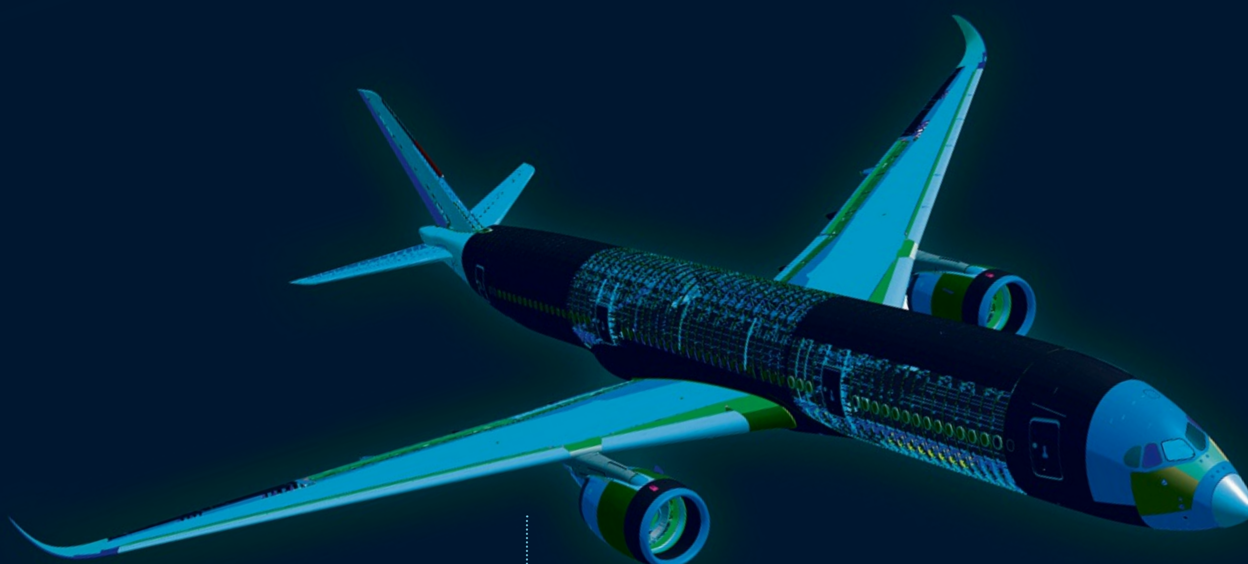

AERONAUTICS, HEALTH, DEFENSE, AUTOMOTIVE… SIMULATION, THE ERA OF DIGITAL TWINS

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CEA at the heart of innovation for extreme computing and Big Data

CEA and Atos are co-designing exascale technologies[1]

Harnessing exascale computing and data processing will open unexplored perspectives for the numerical simulation of complex physical phenomena and industrial objects, by 2020 and beyond.

In order to tackle this challenge, CEA, in partnership with Atos, is co-designing technologies to:

- Reduce energy consumption
- Process and manage massive flows of data
- Increase performance, efficiency and modularity of supercomputer architectures
- Design fault-tolerant architectures


TERA 1000, developed in partnership with Atos/Bull according to CEA requirements and installed in 2016, is foreshadowing exascale supercomputers.

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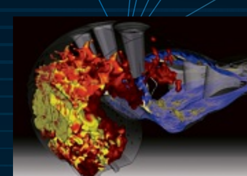
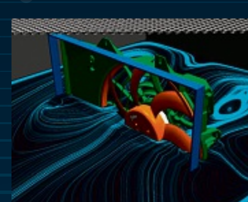
1 - *At the scale of a billion of billions of operations per second (exaFlops) and memory bytes (exaBytes).*

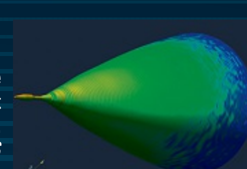
CEA boosts industrial innovation

Located at CEA Bruyères-le-Châtel site, TGCC (CEA Very Large Computing Centre) hosts CCRT (Computing Centre for Research and Technology), a shared infrastructure optimized for HPC. CCRT partners receive 2.4 Pflops of computing power, as well as services and expertise supported by CEA HPC team skills – an essential asset for their numerical simulations.

CCRT partners: *ArianeGroup, Cerfacs, EDF, IFPEN, Ingeliance, Ineris, IRSN, L'Oréal, Michelin, Onera, Safran Aero Boosters, Safran Aircraft Engines, Safran Helicopter Engines, Safran Tech, Sanofi, Synchrotron Soleil, TechnicAtome, Thales, Thales Alenia Space, Total, Valeo, CEA as well as France Génomique consortium (supported by French government PIA).*


Numerical simulation of combustion in an helicopter turbo-engine.
TURBOMECA


Motor-driven fan simulation.
VALEO


Simulation of surface currents on an aircraft nose radome.
THALES

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COVER
Digital mock-up of Airbus's A350.

On Every **Front**

It's everywhere! Numerical simulation is now everywhere in industry and the wider economy. Sometimes still seen only through the prism of supercomputing for fluid and material mechanics, it must now, in the words of Bernard Charlès [see interview page 4], be looked at "as holistically as possible": the representation of how a system changes in time and space as it interacts with its environment. This is the yardstick by which industry's current enthusiasm for digital twins is measured. Digital twins increasingly combine multiphysics modeling with field data to create virtual replicas of machines, industrial installations and living organs that change over time with their real-life twins.

Our special report shows how companies from every sector are – each in their own way – seizing on digital twins: to optimize aircraft and car production, improve maintenance of Mirage 2000 jet fighters, practice surgical operations, reduce oil-well operating expenses, speed up submarine design, and explore the impact of urban planning, etc. Nevertheless, this more accessible and revamped simulation in an era of big data, the internet of things and artificial intelligence is not wiping out traditional simulation, which uses enormous amounts of computing power to numerically solve complex equations for matter.

> Simulation is helping fight the COVID-19 pandemic.

Simulation is now helping fight the COVID-19 pandemic. For example, Summit – the USA's most powerful supercomputer – has carried out molecular dynamics simulation, virtually testing the ability of 8,000 molecules to interact with a SARS-CoV-2 coronavirus protein – called S-protein – to stop it infecting human cells. In this way, 77 molecules have been selected for further research. In Europe, the Exscalate4CoV program was launched in Italy in mid-March. It will use the Exscalate supercomputing platform and its library of 500 billion molecules to identify potential drugs for combating COVID-19. Finally, Folding@home software enables everyone to give a small part of their personal computer's computing power to speed up researchers' study of the structure and behavior of SARS-CoV-2 viral proteins. Simulation is on every front.

JULIEN BERGOUNHOUX, MARION GARREAU AND MANUEL MORAGUES

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Bernard Charlès

"WE NEED TO LOOK AT SIMULATION HOLISTICALLY"

The Chairman and CEO of Dassault Systèmes spoke to us about how increasingly commonplace and omnipresent simulation technology and its rich datasets can be applied to health.

INTERVIEW BY MARION GARREAU AND MANUEL MORAGUES
PHOTOS: PASCAL GUITTET

What is most remarkable about simulation today?
Simulation has been around for decades, but is now omnipresent and used in all sectors of the economy. Once the preserve of very high-tech industries such as nuclear and aerospace, simulation is now used to do things like study noise inside cars or air conditioning flows, for example.

Would you say that it is now central to design?
Yes. But it's important to remember that it's a kind of return to source. Many observers think that simulation has taken over from CAD (Editor's note: computer aided design) for representation and modeling. But in reality, CAD originated in simulation. Simulation software, used at the time for aerodynamic constraints, guided how forms were represented. When we designed our CATI software at Dassault, everybody thought it was to define the surface. But no, it was developed to define the basis on which the aerodynamic simulation could be calculated to replace wind tunnel tests. Make no mistake: simulation formed modeling.

The word simulation can be deceiving
For a long time, the term was associated with the finite elements method (Editor's note: method for numerically solving partial differential equations). Nowadays simulation has far broader applications than what some specialist would have you believe. Making a mechanism work, that's simulation. Developing the process for assembling a vehicle, preparing a robot's trajectory, managing flows, sequencing systems assembly, this is all simulation.

How do you define it?
We need to look at simulation as holistically as possible. It is a representation in time and space of how something behaves in its environment. We need this visual information to understand how to go further, especially when it comes to digital twins, which are not just the objects, but also about how to produce the object, how to use the object. The digital twin is an attempt to achieve the closest possible representation of reality and then to act on this virtual twin to give it life.

Democratization of the technology is a key development
The expansion of simulation is a remarkable phenomenon. The technology is far more accessible, in terms of both price and know-how. A technician or 3D designer can use the engineering capabilities in our Solidworks software to calculate the dynamics of the system they are designing and to characterize the materials they need to build a lightweight, tough structure. We've taken simulation and scientific calculation out of the specialist niche. Before, you had to be an expert in finite elements to interpret the results of stress calculations, now it's a question of "green: it works; red: it breaks". This democratization to non-experts marks a complete shift in how jobs are defined, freeing the engineer to go back to their real job: imagining.

> "A technician can use the engineering capabilities in our Solidworks software to calculate the dynamics of the system they are designing, freeing the engineer up to go back to their real job: imagining."

What next for simulation?
There are two big developments underway. The first is multiphysics simulation. Multiphysics couples many different phenomena, mechanical, magnetic, thermal, etc., to give a more complete description of how an object or system behaves. Multiphysics simulation is complex and mastered by very few. Dassault Systèmes is far and away the world leader in this area. The market is still limited, because you

> "Our goal is to create a digital twin of a human being. The challenge is to move therapeutic research and medical practice forward."

need highly developed technology to know how to use it. But it will expand at speed and coupling will become easy to use. The other major step forward is the use of observed data to readjust the intelligence of models or to learn behaviors that scientists have not been able to put in equation form.

How do you negotiate the shift in data?

There are two camps: for one data are the future; for the other equations are the future. Naturally, at Dassault Systèmes, we think both are the future. After all, it's useful to know that E = mc2! We shouldn't underestimate human capacity to come up with amazing abstract representations of phenomena. Nor should we play down the contribution of data, which is nothing new, since the ability to align theoretical representation and the real world has always been crucial. The problem of tolerancing in large systems is a practical example of the historical need to take reality into account, in the form of data.

Models learned from data are sometimes compared to black boxes, with results that are difficult to explain. What's your opinion?

I'm quite amused at the debate about how inexplicable artificial intelligence is. The question isn't new. If I were to give a full explanation of crash simulations, I would actually be handing over my intellectual property! And only a very small number of people would be able to understand the explanation in the first place. In terms of explicability, we give the area for which the simulation is valid. In other words, the application for which the real-world behavior will be consistent with the results of the simulation. The same can be done for AI models and neural networks don't change anything when it comes to explicability. The only difference is the question of how the model evolves as new data are absorbed. Here again, we are not starting from zero because the statistical models have been around for a long time in factories, and are added to and refined as production continues. In this case, explicability amounts to saying that at any point in the learning process, all adaptive systems must be able to account for the range of parameters they use to take decisions.

Dassault Systèmes' acquisition of Medidata gives you a much stronger position in the health space. What is your objective?

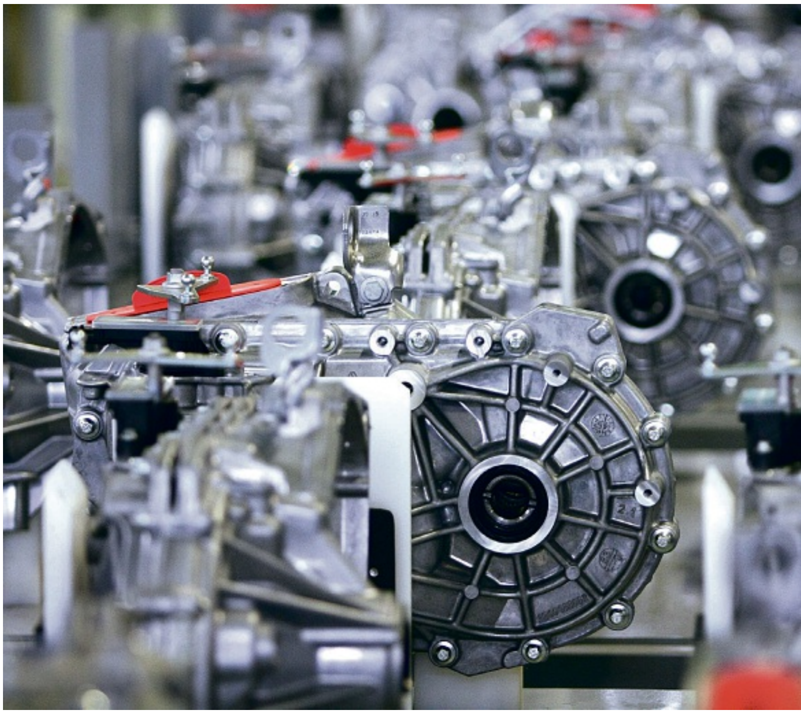
Our first forays into biotech date back 12 years or so. The $700 million acquisition of Accelrys in 2014 accelerated our work in this area. We now boast the most advanced simulation platform in both chemistry and biochemistry. With the addition of Medidata, which holds the data from half of the world's clinical trials, we want to build representations of human phenomena that are as close as possible to reality. We already have a model of the heart that includes electrical phenomena so that surgeons can determine ahead of time where to place the pacemaker's electrical signal. We're pretty much there with the human skeleton and we're also working on the brain. Our goal is to create a digital twin of a human being.

What can digital twins of organs or a human being offer medicine?

The challenge is to move therapeutic research and medical practice forward. Medical professionals are artisans, not industrialists. Of course, there is excellence, but excellence on the level of art will never surpass a large-scale industrial approach in terms of reliability and performance. I think virtual technology will bring about radical change in the world of medicine. And it will happen through the capability to simulate, to train, to observe after the fact how outcomes diverge from the expected, to remember the experience, to supplement it with learning from other interventions, and to mine all this to do better next time. Isn't this the beauty of industry?

NVIDIA
SIMULATING SELF-DRIVING

The NVIDIA DRIVE Constellation autonomous vehicle simulation platform announced in 2018 is now available. The system harnesses the computing power of two servers to create a virtual proving ground with hyperreal simulations of self-driving situations. One server generates the virtual driving world and the sensor data, while the other reproduces exactly the driving patterns of the self-driving vehicles (this is the same system NVIDIA provides to the auto industry). Toyota's TRI-AD institute (Toyota Research Institute - Advanced Development) was first off the mark to purchase the system. DRIVE Constellation is NVIDIA's solution not only for deep learning to develop the driving systems, but also for testing and validation by the regulators and safety authorities. It is used by TÜV SÜD, the German certification and risk assessment specialist. **J. B.**


PASCAL GUITTET ; D.R.

Cyberattacks
CITALID ASSESSES THE FINANCIAL RISKS

When they were cybersecurity experts at the National Cybersecurity Agency of France (ANSSI), Maxime Cartan and Alexandre Dieulangard were struck by how businesses could be on the back foot when it came to assessing the potential financial impact of a cyberattack. They found that companies didn't build this aspect into the scope of conventional cybersecurity solutions, which are more focused on technical aspects and operational risk. This led to them founding Citadil in 2018. They raised €1.2 million in seed capital in June 2019. Citadil helps information system security managers to estimate the costs of a potential attack to justify proactive investments in the right defensive systems. The start-up models the full spectrum of losses: productivity, statutory fines (for breach of the GDPR, for example), competitiveness and reputation. **J. B.**

Digital twins
RENAULT OPTIMIZES ENGINE PRODUCTION

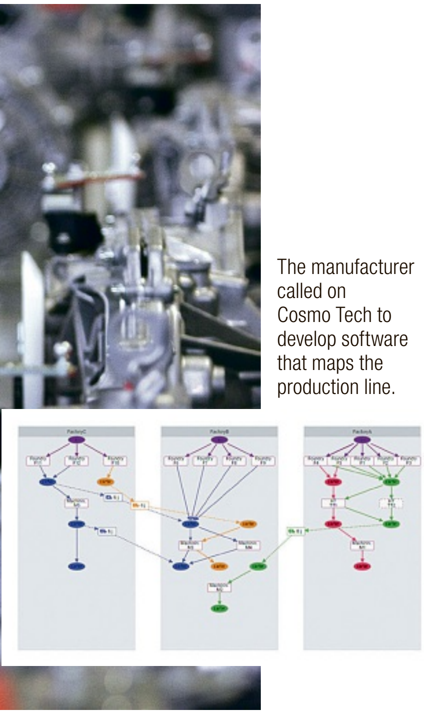
Renault presented its experience of using a digital twin of a manufacturing tool at the December Supply Chain Event in Paris. Developed by start-up Cosmo Tech, the solution maps and optimizes the carmaker's production flows. "The auto industry is currently undergoing major changes. Demand for electric vehicles has accelerated faster than expected, and we have had to boost our supply and manufacturing flows," explained Aimé-Frédéric Rosenzweig, supply chain expert at Renault. "Here's the problem: how do we produce more engines with the same capacities in a fast-changing market?"

Renault approached Cosmo Tech in 2017 to help it rise to the challenge. The start-up proposed digitizing the automaker's flows, business processes and manufacturing infrastructure, as well as its human and financial resources. Working from this data, Cosmo Tech's software maps all Renault's key positions and their interconnections in a dynamic flowchart, with the entire production chain and its flows displayed in a few clicks. "Now everyone is on the same page with the same visual of our manufacturing system. This gives us vital information to better understand any weaknesses in our operating strategy," said Aimé-Frédéric Rosenzweig.

For Michel Morvan, a former mathematician and co-founder of Cosmo Tech, this is just the first stage in the use of digital twins. "Industry gathers vast quantities of data, which we can organize to produce a visual representation of their production process. But being able to mine historical data to analyze the system's current state is not enough. What industry needs is predictive analysis, the ability to look at and question future states."

Cosmo Tech's digital twin is built on "20 years of algorithm research" led by Michel Morvan during his tenure as professor at the École Normale Supérieure de Lyon. The technology simulates scenarios to achieve specific goals and to devise an action plan to cope with the unexpected.

There are two types of scenarios: "what if" and "how to". The "what if" simulation is a predictive tool used to plan and manage the consequences of certain decisions and identify the strengths



The manufacturer called on Cosmo Tech to develop software that maps the production line.

and weaknesses of an operational strategy. "How to" is prescriptive. It helps manufacturers to prepare action plans aimed at harnessing the best optimization levers.
The system seems to have won over the Renault Group. Aimé-Frédéric Rosenzweig again: "Cosmo Tech's solution identified bottlenecks in our flows and helped us to make the necessary adjustments. We were able to model different iterations, without impacting the role of our operating teams. The machine shows up the problems and the teams can then quickly simulate the potential solutions." Renault wants go further and achieve deeper integration of Cosmo Tech's digital twin by automating real-time capture of manufacturing data. **ALEXANDRE COUTO**

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Aviation

SEMAXONE GETS INSIDE PILOTS' HEADS

Augmented intelligence is Semaxone's area of expertise. Founded in mid-2018 through the business incubator at the IMT Mines Alès engineering school and based in Le Gard, the start-up made the cut for the 2019 "Companies on Campus" program launched by the Montpellier Université d'Excellence i-Site (MUSE i-Site). We spoke to Guilhem Belda, chairman and founder of Semaxone: "Being selected for this program gives us new opportunities. We will collaborate intensely with EuroMov and use the iMose full-body motion simulator (housed in EuroMov) to configure real situations and study pilots' mental workload. This robotic arm places the subjects (either seated or standing) in two detachable "gondolas" and presents them with various trial scenarios." Sensors analyze their heart rhythm, brain activity and eye movements, and a microphone captures their voice. We then use the data to determine their cognitive load, or in other words, to "gain insight into the operator's mental state". Semaxone also works with the LGI2P IT and Production Engineering Lab at IMT Mines Alès. The tools being developed by the lab use natural language processing. The goal is to compensate for overload, highlight certain information, add stimuli, etc. "Our originality, our added value is that we propose a convergence between the sensors and information sciences to capture the subject's cognitive state in a single psychological-IT model," outlined Guilhem Belda, adding that Semaxone is set to hire an IT specialist. Its goal is to produce a prototype within a year. The company recently submitted a bid for the second round of the Man Machine Teaming (MMT) call for proposals issued by the French Ministry of the Armed Forces in 2018. The project is part of the army's tilt to AI and the development of next-generation combat aircraft. The results are expected in nine months. Looking to the longer term, Semaxone will target other sectors where the human factor plays an important role and where people are exposed to risk, including the aerospace and nuclear industries. "Some companies are already asking about their employees' cognitive load," said Guilhem Belda. **SYLVIE BROUILLET**

Benoît Bardy, the director of EuroMov, housed in iMose. This simulator allows pilots to test all flight scenarios. Their stress levels are analyzed using sensors.

SIPA

EDF/ GUILLAUME MURAT

Energy transition
DALKIA DEVELOPS A WASTE-TO-ENERGY TWIN

Producing energy from waste to generate heat and electricity is a growing imperative. All too aware of what is at stake, Dalkia Wastenergy, a subsidiary of Dalkia (EDF) headquartered at La Défense, has turned to digital twins to convert readily-available waste into an energy resource. "Three years ago, we decided to digitally clone our plants to improve how we harness waste to generate energy," explained Christophe Roulot, Chief Technology and Engineering Officer.

The company drew on the expertise of its 1,200 staff in thermodynamics to develop a digital tool in-house, known as Twin. Designed for Dalkia's heat engineers, the software incorporates all the functional elements of waste treatment, from the composition and calorific power of the feedstock to treating the fumes. "We've created a digital twin of each of our waste treatment sites using algorithms that can reproduce the site's entire energy profile in seconds. We then work on the clone to adjust parts of the facility's configuration and test solutions to churn out more energy with the same quantity of waste," he went on.

Twin boosted Dalkia Wastenergy's energy production by 4.8% in just over a year. No two of its sites are alike, as the volume, composition and supply frequency of the waste feedstock vary from one location to another. In addition to optimizing energy generation across its own sites, Twin also streamlines management of partnership projects with customers, primarily urban district communities and waste treatment syndicates.

In Perpignan, the company developed an urban heat network with the local authority that heats both the local hospital and a chocolate manufacturer. Christophe Roulot again: "we simulate the customer's energy needs to test a range of energy transfer scenarios, making decisions about temperature and delivery method that must hold up over distances of a few dozen

Plastics manufacturing
SIMULATION IN PRODUCTION

At last October's K 2019 trade fair in Germany, software maker Autodesk announced a partnership with Engel, which manufactures injection molding machines, to link injection simulation with real production processes. This year both companies will release Sim Link, a software extension to Engel's CC300 control unit, which converts the rheological simulations produced in Autodesk's Moldflow into a set of configuration data that can be used directly by the injection molding machine. "This functionality guarantees data consistency and eliminates the need for time-consuming and error-prone manual inputs," explained Engel. In addition, Sim Link sends information on current production back to Moldflow to check conformity with the digital model, optimize processes and feed precise production values into the simulation engine. Engel and Autodesk will start marketing the software to SMEs in the plastics space this year to offer them "a competitive advantage". **A. C.**

Aeronautics
SAFRAN AND DAHER EMBRACE VIRTUAL REALITY

ESI Group attracted a lot of attention at last June's International Paris Air Show at Le Bourget with its demonstrations of IC.IDO, the virtual reality solution developed for Safran Nacelles and Daher. Initially applied in its services to the nuclear industry, Daher is expanding its range and now incorporates IC.IDO "in all project chains," says Tangi Meyer, IC.IDO engineer at ESI France. The demos at Le Bourget were for Daher's TBM 900 assembly lines.

The Safran demonstration centered on use cases trialled to train personnel in maintenance of aircraft engine nacelle systems. Safran is increasingly embracing virtual reality, including for validation of design stages before starting production. "It's a must in our

The Twin tool enabled Dalkia Wastenergy to increase production by 4.8% at its facilities in just over a year.

kilometers. Twin not only improves how we communicate with our customers, but also gives them the ability to project their needs into the future. Projects move faster, since we have the tool to jointly assess the project's potential value, without the need for separate impact assessments." All of which leads to more and increasingly efficient energy generation and distribution. **MARION GARREAU**

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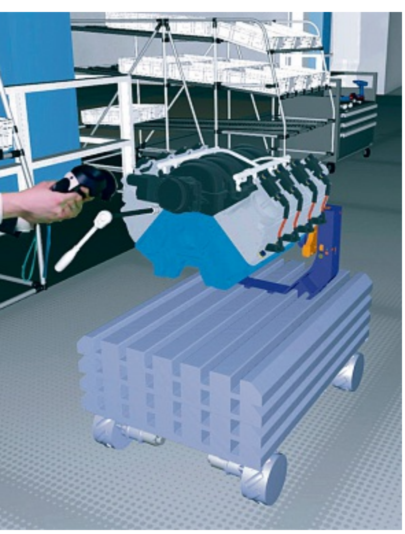
GAUTIER VIROL

The International Conference for Multi-Area Simulation in Angers wants to build bridges between medicine and industry in simulation.

Trade fair
ANGERS PUSHES THE ENVELOP

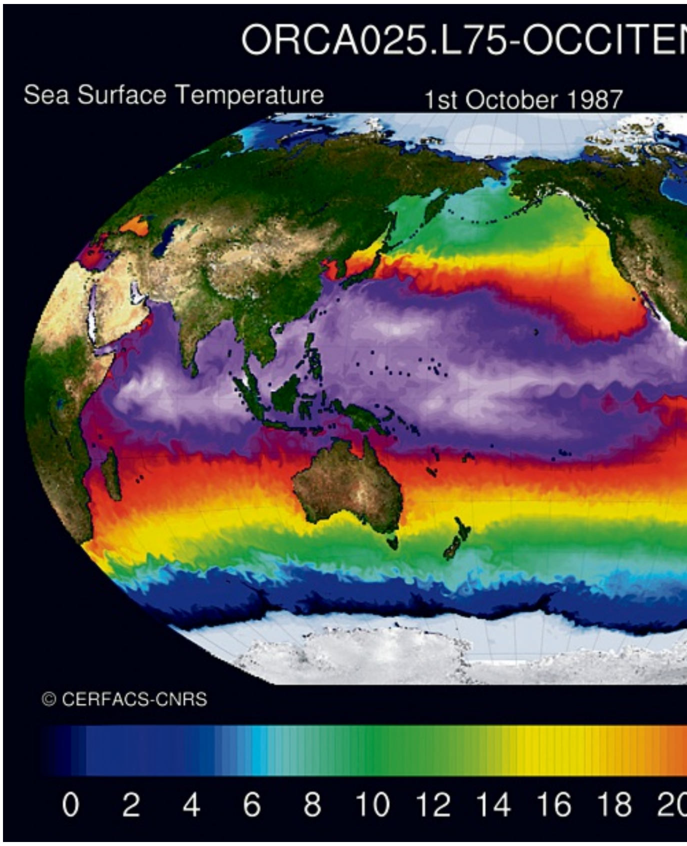
Jean-Luc Grandry, professor of anesthesia and resuscitation at Angers University Hospital (CHU), founded one of the first simulation centers in France in 2007. His ambition is a bold one: break down silos and pool research in medical and industrial simulation. And he has the perfect tool: the International Conference for Multi-Area Simulation, held in Angers last October. Simulation techniques break through the barriers between industries in training, crisis management and product or process enhancement. "Digital calls for sharing," he remarked. "We've made strides in promoting collaboration, not just in health, but in industry 4.0, self-driving cars, and more." He cites the example of Simulation Australasia, an international, multidisciplinary collaborative hub focused on simulation. The Australian-based hub organizes conferences, empowers collaboration and arranges financing to advance research.
Although the health sector was overrepresented at the conference, it also attracted manufacturing companies, urban planning and virtual reality specialists to the Angers Palais des Congrès. Orange Labs was there with its 3D urban visualization project. So too was DPS, which is working on mechanical, thermal and electromagnetic simulation of manufactured parts, and 1001rues, the start-up that uses simulation to survey people's opinions on urban redevelopment projects. The synergies may not be apparent yet, but these are inspiring initiatives. Don't miss the second Conference to see where these exciting developments lead. **G. V.**



BARA MURATOLU

Aerospace manufacturers use ESI Group's iC.iDo software for prototyping, assembly lines and maintenance.

processes. No assembly line adjustments are made without first running a virtual reality simulation to check the ergonomics or tool layout," says Tangi Meyer.
ESI Group, a virtual prototyping specialist, took over IC.IDO in 2011. Traditionally used to drive projection systems (Powerwalls and Cave), the software has had a makeover to ride the virtual reality headset wave. The development will accelerate roll-out and help to push beyond proof-of-concept to application in actual operations. Besides the solutions demonstrated at the Paris show, IC.IDO is firmly established with Boeing. Airbus also has a few licenses and Expleo, which provides consulting and engineering services, uses the solution for workstation design studies in plants in the south of France. **J. B.**



Model developed by Cerfacs reproducing the behavior of the atmosphere and the oceans on a large temporal scale in order to establish climate projections.

Virtual planet

CLIMATE SIMULATION IN FRANCE

French scientists have developed two climate simulation models. Their projections will be included in the next IPCC report, due in 2021.

SYLVAIN ARNULF

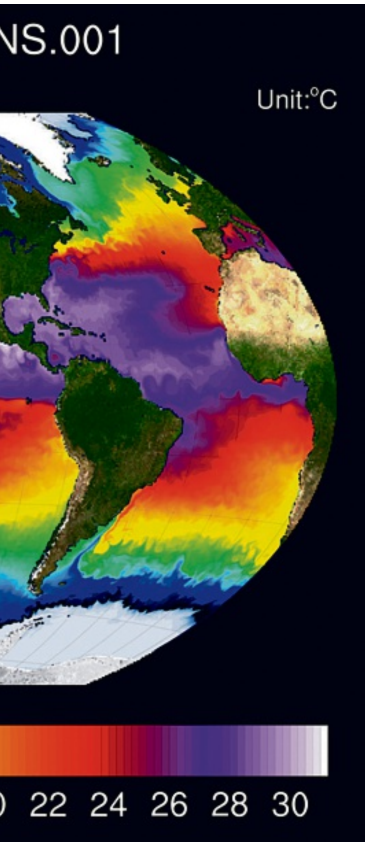
"There is no Plan B, because there is no Planet B," said French president Emmanuel Macron in June 2017, after the United States had announced it would withdraw from the Paris Climate Agreement. This is a statement of the obvious in the real world... but not in the virtual world. Computer simulation can be used to create digital doubles of the Earth, in order to better understand how the planet functions and reacts. This approach was launched over 20 years ago under the World Climate Research Programme, and France has been one of the driving forces in its progress.

Projections made by French scientists and engineers in the most recent simulation cycle (generation 6 of the Coupled Model Intercomparison Project, CMIP6) will be the basis of the sixth evaluation report by the Intergovernmental Panel on Climate Change (IPCC) that is due to be published in February 2021. These projections are the fruit of four years of work involving about a hundred experts. Five hundred million hours of intensive calculations were required to produce these projections.

Among the 30 or so simulation models developed around the world are two French models, one developed at the Pierre-Simon Laplace Institute (IPSL) in Guyancourt (Yvelines), and the other at the National Center for Meteorological Research run by the French National Center for Scientific Research (CNRS) and Météo-France in Toulouse (Haute-Garonne). These two poles aggregate the research of dozens of other specialized laboratories.

20 PETABYTES OF DATA

Their models are "virtual planets from which we can create a broad range of samples to address many scientific issues," explains Pascale Braconnot, climate scientist and research director at the French Alternative Energies and Atomic Energy Commission (CEA). These simulators reproduce the parameters of the "Earth system" – its atmosphere, oceans, land masses, vegetation, marine biochemistry, sea ice, the chemistry of the troposphere and the stratosphere. Each of these components is studied in its own right in French laboratories. For example, the Météo-France model includes the Arpege atmosphere simulator (which is used to make weather forecasts), the Surfex continental land surface model, the oceans simulator developed by the Nemo research consortium, the Gelato ice model and others. Couplers most also be devised to simulate interaction between environmental compartments. Oasis is a tool used to simulate exchanges between the ocean and the atmosphere; it was designed by the European Center for Research and Advanced Training in Scientific Calculation (Cerfacs) in Toulouse. Other building blocks, such as the carbon cycle and aerosol behavior (liquid and solid particles), are integrated into the model. The output



CERFACS

GLOBAL WARMING, DROUGHT AND HEAT WAVES ARE JUST THE BEGINNING

Will the type of drought seen in France in the summer of 2019, with the water table at historically low levels, be the new normal? Are heat waves going to come more frequently? These outcomes are suggested by French climate simulation models. In the most alarming scenario, heat waves such as the one experienced in France in 2003, exceptionally long and intense, could become habitual occurrences by the end of the century. "No matter what we do, the number of days of heat-wave conditions will continue to rise up to the years 2040-2050, and so will temperature spikes," says Olivier Boucher, research director at CNRS, in charge of the IPSL Climate Modelling Centre (IPSL-CMC). "It will be possible to stabilize these phenomena starting only in 2050, at the earliest," he adds. In the most pessimistic scenario envisaged by French researchers, i.e. fossil fuel consumption continuing at current levels, the average global temperature could rise by 6 to 7°C by 2100. In the most optimistic scenario estimated global warming would still exceed the target set by the Paris Agreement, an increase limited to 1.5°C. French experts expect the global temperature to increase by 2 to 2.5°C.

is roughly 3,000 units of data (temperature, humidity, wind, etc) for a section of the globe (the size depending on the desired resolution) for a given time increment (15 minutes, 1 hour, 3 hours, depending on available computing power). By modeling the interaction between all these systems it is possible to simulate past and current climate conditions and build projections of future climate.

The IPSL model went through a year of testing and some 15 intermediate versions before the CIMP6 simulations were launched. This calibration phase necessitated 32 simulations of past climate (for the period 1850-2014). In all, 80,000 years of cumulative climate evolution were recreated, with the help of calculators running around the clock seven days a week for over a year. The calculators generated 20 petabytes of data (1 petabyte is equal to 1 million billion bytes). Five socioeconomic scenarios – from the status quo to a carbon neutral system with sequestration of CO_2 – were "injected" into the system and run with the multiple integrated parameters. Under the five sets of projections produced, average global temperature would increase by 2 to 7°C, depending on the climate policies implemented.

MORE PRECISE MODELING

Simulation models have gained in precision and in robustness with each successive generation. The most recent IPSL model harnessed 1,000 processor cores per simulation, compared to 32 for the preceding generation. The new models have been refined and provide more pertinent information on some aspects of the simulation, such as atmospheric physics. It is now possible to "zoom in" on certain areas, with a resolution of up to 50 km for land masses and 25 km for oceans. This means that regional phenomena such as cyclones around the islands of Réunion and Mayotte can be more precisely simulated. It is also possible to calculate the probability of occurrence of extreme events, and better prepare for them. It is not possible, however, to accurately predict where or when such events will occur. To make progress in these simulations increasingly detailed data must be gathered. "To understand how clouds interact with climate change, we will have to make very close observations all around the world, based on field studies, aerial and satellite observation," says Marie-Alice Foujols, former deputy director of IPSL in charge of intensive computing. Simulation and field work will continue to be the inseparable partners of progress in research. "Only digital models can give us a full picture of the Earth, despite the fact that there are good observation systems. Some zones cannot be accessed in all their points, for example deep sea beds," reiterates Sébastien Denvil, a research engineer at IPSL who works in data management for climate modeling.

Researchers will have to take some fundamental constraints into account: the number of climate specialists is tapering off, and data processing power and storage space are not unlimited. These resources must be intelligently managed to keep financial and energy costs under control.

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"Only digital models can give us a full picture of the Earth, despite the fact that there are good observation systems."

SÉBASTIEN DENVIL, RESEARCH ENGINEER, IPSL

PASCAL GUITTET

Daniel Verwaerde

"AI WILL BE WRITTEN INTO PROCESSORS"

The president of Teratec and former administrator general of the French Alternative Energies and Atomic Energy Commission (CEA) talks about the challenges and transformation of high-level calculation in the coming decade.

CONVERSATION WITH JULIEN BERGOUNHOUX

At the dawn of the age of exaflops, what are the stakes for simulation in the decade to come?

My feeling is that as we pursue today's technologies – CMOS, processor and network architectures – we have reached an asymptote with exaflops. To improve performance levels by a factor of 10, or 100, as we have done in the past, there will have to be technological breakthroughs. We are facing two obstacles. The first is energy. Extrapolating from our current energy needs, the superprocessor of the future will consume hundreds of megawatts. That is not sustainable. The second obstacle is the cost of foundries. When I started in this business, the unit cost of a foundry was one billion dollars. Today, to produce processors measuring seven nanometers, the investment cost is 20 billion dollars.

How can we overcome these obstacles?

From a technological viewpoint, I think that the key will be better integration of graphics processors – GPUs – in our systems. They are still controlled by central processors – CPUs – and the way they work together is not coherent. Their interaction has to be managed manually. By 2023 the use of GPUs will be transparent. This is absolutely necessary, if we don't achieve this we will be able to make processors that rank high in the top 500, but they won't be good. Another direction for exploration is quantum accelerators. There are significant challenges to be met, but I believe we will see the first functional quantum computers in the course of the next decade.

> "The proper scale today for developing high-performance computing and its supply chain is Europe. France no longer has sufficient resources."

Will we see an evolution in microarchitecture design itself?

I'm sure of it. With artificial intelligence (AI) the demand for computing power is growing very quickly, and businesses involved in simulation must integrate this into their thinking. AI will ultimately be built into processors, and players in simulation will have to choose – either just suffer the consequences, or make the most of it. Future architecture designs will be specified for the biggest customers, that is for mass consumer uses, in which AI plays a significant role. In practice, this means smartphones. In France 5,000 people use a supercomputer and 50 million use a smartphone... Simulation will have to adapt. We experienced a similar revolution 20 years ago, moving from dedicated vector processors, that were very expensive, to scalar processors designed from the outset for the general public.

And what about networks?

Communication capacities are very important, and will be even more vital with the development of the Internet of Things (IoT) and smart cities, which will generate enormous amounts of data. This is perhaps the real driver of this transition. Teratec grew out of a strategy to develop high-performance computing (HPC) using a very large processor. But uses will not be limited to this model in the future. It will be necessary to run different processors together, along with edge computing that will handle a large share of the data locally, and the whole system will be linked together by high-capacity networks. We will have to move beyond the paradigm of the large central computer.

You mentioned manufacturing costs earlier. The same applies to computers…

That's right. The appropriate scale today for developing high-performance computing and its supply chain is Europe. France no longer has sufficient resources. It costs between five and ten billion dollars to develop an exaflop computer. The answer? The EuroHPC project, in which Teratec participates. In this framework we are a candidate to become the pole of HPC competence in France, and to work on the Fortissimo project, which aims to help companies use HPC. The Commission has also asked us to structure users' requests and ideas. With the High-Performance Computing Center (HLRS) at the University of Stuttgart we are going to create an EU non-profit group bringing together users across the industry. This group will develop proposals for the future EuroHPC supercomputers. Users will be able to do R&D, and we are going to look at ways for them to contract to use EuroHPC equipment for commercial operations. S

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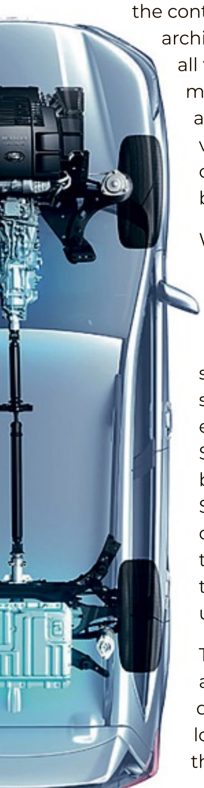
Automotive systems under control

One of the greatest challenges for electric and hybrid vehicle designers is creating accurate control systems that balance safety, performance and energy efficiency. For nearly a decade, Subaru has relied on Ansys SCADE solutions to develop the software code that underlies the electronic control units (ECUs) for its electric car program.

Critical systems like propulsion, acceleration and braking are now complemented by infotainment systems, customized heating and cooling options, and other electronics that add to the driving experience. Bringing all these sophisticated systems together, safely and seamlessly, means establishing a flawless system of controls. Maintaining and managing all these systems is the job of the electronic control unit (ECU) that lies at the heart of every hybrid and electric vehicle. Supported by millions of lines of underlying embedded software code — and subject to strict regulatory oversight — the ECU is one of the most crucial elements of any electric car.



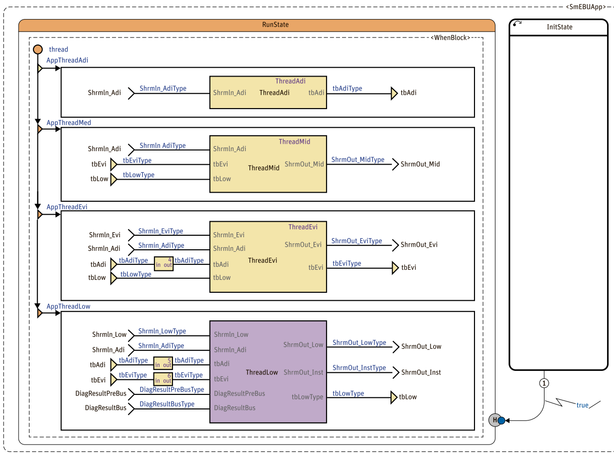
The process of generating software code for the ECU begins by defining the control logic for bringing all the parts of the car's electronics architecture together. This set of logic-based rules ensures that all the car's electronics are integrated safely and securely. It manages the system interactions, sends alerts when needed and can also shut down systems in an emergency. It controls vehicle dynamics, engine function, the vehicle's energy consumption and the load management of the electric battery.

While many other automotive engineering teams rely on manual methods to accomplish these tasks, Kawakami leads Subaru's effort to significantly accelerate this process by applying SCADE software. "First, Subaru engineers convert the control logic into a SCADE model of the overall system architecture, using SCADE Suite Simulink Gateway," said Yuji Kawakami, senior engineer in Subaru's electronics engineering department. "Then our engineers apply SCADE Suite KCG Code Generator to create implementation code based on this model. In generating control software code for Subaru's first hybrid vehicle, the Subaru XV, about 80% of the development work was automated. As Subaru's engineering team improved its internal processes by using Ansys SCADE, the amount of automation increased to 95% for the code underlying the e-BOXER."

Today, it only takes Subaru engineers half a day to implement a model for an ECU once the Simulink control logic has been defined. This enables Subaru's developers to modify the ECU's logic and architecture much more frequently and easily as they explore continuing design innovations.

Unlike generic tools, SCADE is a specialized tool for developing embedded software code. Its model-based environment and tight scripting language eliminate the potential for human error as it translates the control logic for the ECU.

Because the SCADE Suite KCG Code Generator meets automotive industry standards such as ISO 26262 at the highest levels of safety (ASIL D in that case), the resulting code is automatically in compliance with strict regulations — dramatically reducing the time, effort and documentation required for final code verification. SCADE is a key tool not only for



meeting regulatory standards, but for supporting Subaru's commitment to passenger safety.

In addition, the use of SCADE facilitates a closed-loop software engineering process. In the event that the overall ECU control logic is modified in Simulink at a later date by Subaru engineers, SCADE solutions automatically and universally reflect these changes in the system model and embedded software code, eliminating costly rework and manual updates.

By leveraging SCADE, Subaru engineers can quickly and accurately generate the mission-critical code that keeps electric vehicles running safely and smoothly, no matter how complex their technology architecture.

Yuji Kawakami
senior engineer in Subaru's electronics engineering department

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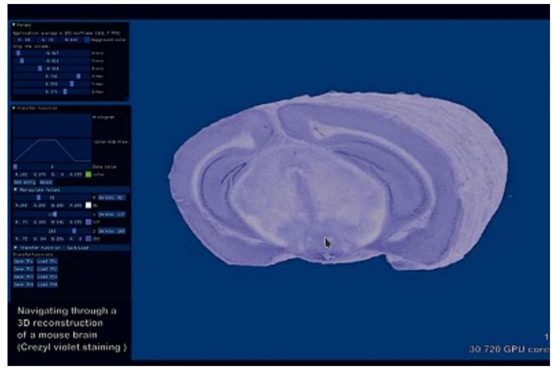
Health
FIGHTING ALZHEIMER'S USING 3D MODELING OF THE BRAIN



3DNS

The 3DNs platform can model the brain of a mouse in 3D at a resolution of 0.2µm.

The 3D NeuroSecure (3DNS) project, completed in June 2019, has developed a platform capable of modeling a mouse's brain in 3D at a resolution of 0.2 µm, a dimension that is 20 times smaller than the size of a neuron. "The idea was to acquire tools to analyze very large 2D and 3D images in order to produce medical imaging with resolutions at the cellular scale," explains Gilles Mergoil, chief executive and founder of Neoxia, a small company of about a hundred people that is coordinating the project.

The difficulty in obtaining a 3D model at this level of resolution is the mass of data to be processed. "This was the technological barrier to be addressed," says Mergoil. "At the present time laboratories do not have software capable of doing this." At a resolution of 0.2 µm a 3D scan of a mouse's brain, 2 to 3 mm long, represents 1.5 terabytes (Tb) of data, for just one imaging modality. And several different modalities are required for a medical study, producing images obtained with different markers to highlight the desired information, number of neurons, inflammation, etc. By comparing the images correlations can be made. "Four or five imaging modalities are required for each brain that is studied," explains Gilles Mergoil. "And a serious study includes data from several mice. So we are quickly looking at about a hundred terabytes for a study." This must not be an obstacle. "We can run our code on a supercomputer, but also in a public cloud, such as Amazon's, which enables us to make it accessible to all types of entities," explains the founder of Neoxia. The 3DNS platform aims to provide assistance to biologists, in particular in research on neurodegenerative diseases such as Alzheimer's and Parkinson's. Neoxia is also looking farther ahead, with its sights on molecular simulation to design drugs before starting in vivo analysis. **XAVIER BOIVINET**

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Nuclear industry
FORTUM USES VIRTUAL REALITY TO TRAIN STAFF

VARJO / JANI YLINEN

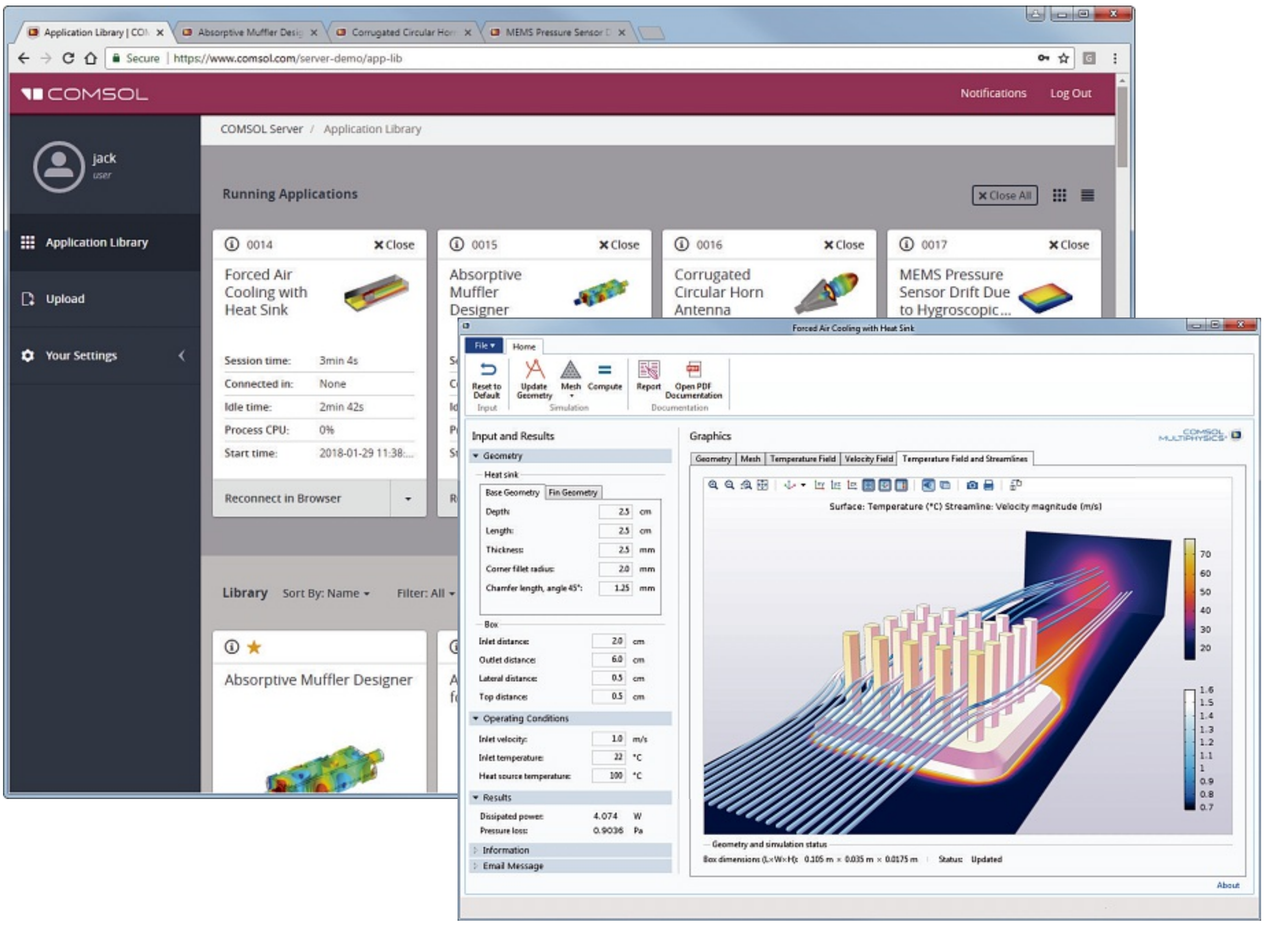
The Finnish energy company has trained 90% of the employees at its Loviisa site.

The Finnish energy company Fortum is innovating in staff training at its nuclear power plants. The company has devised a virtual reality simulator that perfectly reproduces a control room. This interactive control room has been tested by 90% of employees at the pilot site located in Loviisa in Finland. The technology is now part of the basic training course. Development work is ensured by Fortum eSite, a subsidiary dedicated to virtual reality for industrial training, and supervised by Joakim Bergroth, a specialist in the human factor who has ten years of experience in the nuclear power industry.

According to Joakim Bergroth, virtual reality simulators can be developed for one-tenth of the cost of a physical simulator, which costs millions of Euros to build. They can be easily and less expensively deployed later at other sites, whereas physical simulators are few in number and are in great demand.

The uses of virtual simulators are not limited to training. They can also be used to test and validate new equipment and new procedures before they are installed or implemented at plant sites. Previously validation occurred in the final phase of a project, and the slightest design error could be costly and difficult to correct. In a worst-case scenario, says Bergroth, a project could be delayed for an entire year. Very early testing of design changes can save hours of work and hundreds of thousands of Euros, according to Bergroth. This highlights another advantage of virtual simulation. **J. B.**

Develop better products — faster.



An example of a simulation application in the COMSOL Server™ application library. Application users can find an optimal heat sink design without having any knowledge of the underlying mathematical model.

Industry engineers and researchers are accelerating product development by building numerical simulation applications and deploying them throughout their organizations. COMSOL Multiphysics® enables you to build specialized applications, and COMSOL Server™ and COMSOL Compiler™ help you distribute them to the right contributors at the right time in your product development workflow.

The COMSOL Multiphysics® software is used for simulating designs, devices, and processes in all fields of engineering, manufacturing, and scientific research. See how you can apply it to product development.

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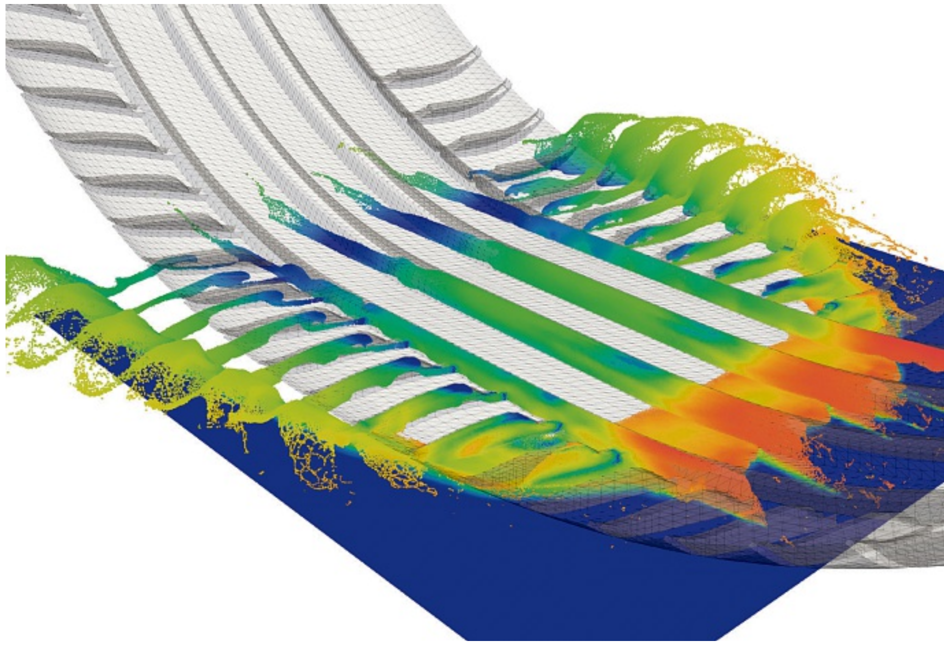


Automotive

HOW MICHELIN SIMULATES AQUAPLANING

Nothing could be more basic than tires when it comes to cars, right? Yet, the humble tire has a long history of innovation, and the newest are based largely on digital simulation. Michelin, the French industry pioneer, invests heavily in R&D in this area. "We want to produce the best possible products in a fiercely competitive environment. To do this, we need the ability to incorporate the latest innovations in tire materials, sculpting and architecture," said Yohan Le Chenadec, Research Team Manager responsible for grip performance at Michelin's Technology Center. "And digital simulation is the only way to do this effectively, by constantly testing and improving our tire design."

The tire giant works with the Nantes-based start-up Nextflow Software, a specialist in simulation applied to fluid mechanics. It was founded in 2015 as an offshoot of the École Centrale de Nantes research lab. Michelin uses Nextflow's SPH-flow software (Smoothed Particle Hydrodynamics), which represents fluid flows as particles.

"The model means we were able to dispense with a complicated and cumbersome stage required by other methods, namely fluid-structure interaction meshing. We normally have to specify the 3D operating environment, especially the fluid volume. But a mesh method doesn't have the ability to simulate the complex environment of a deformed, moving tire, or a tire in a given volume of water," explained Vincent Perrier, CEO of Nextflow Software.

Michelin's solid tire model coupled with Nextflow's fluid mechanics model, which deals with the interaction of water on the road, can produce a simulation in the space of an hour, compared to meshing which takes a week. Above all, it's now possible to simulate far more complex scenarios.

TECHNOLOGY SAVES TIME

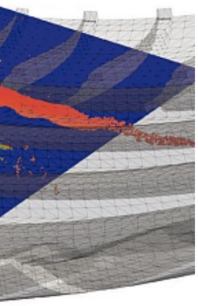
"Nextflow's technology overcomes limits we previously faced when simulating aquaplaning," continued Yohan Le Chenadec. "For instance, we can simulate the roughness of stones on the road, something we couldn't do before." Another benefit of the software is a more detailed view of the tire that takes the complexity of the grooves into account. This high fidelity yields a more accurate simulation. These methods are key to Michelin's ability to pro-

VIRTUAL IT

CES 2020

VIRTUAL IT, SAFER ON-SITE OPERATIONS

Virtual IT, a start-up based in Toulouse, had its first outing to CES Las Vegas where it presented a solution that combines digital modeling and precision geolocation to help operators in real-world situations. The principle is to couple two complementary tools using a 3D connected digital model. The first (e-monitoring) remotely monitors the source stations. The second (e-marking) accurately flags areas at risk at the site. The location of the operator, wearing a helmet equipped with a sensor, is pinpointed with extreme accuracy (to within a few meters) using triangulation and radio waves. Working from a tablet, the operator tracks his or her movements and the at-risk areas on a digital model. The goal is to make working on site safer. The solution was tested by Enedis at two source stations in the Greater Toulouse Area and is set to be rolled out nationwide in France. Virtual IT employs around 20 people, including a team of seven hosted in the Airbus Defence and Space 3D Space Lab in Toulouse. The company aims to develop solutions to plan on-site operations (maintenance and training). Its targets are high-risk industries, including energy, chemicals, transport and rescue. **M. A.**



MICHELIN/NEXTLOW SOFTWARE CNRS/LH

duce tires that deliver unrivaled long-lasting performance. “The possible void volume to store and eliminate water in a hydroplaning situation diminishes with wear,” Yohan Le Chenadec pointed out. “But we want the tire to continue to perform well on the wet surface. Therefore we designed hidden hollows or grooves that open up gradually so that the tire can still evacuate the water. This innovation is already on the market.”
Naturally, Michelin is still producing physical prototypes to confirm the accuracy of the simulations before moving on to the production stage. But one of the boons of digital technology is the ability to test more, better and earlier, eliminating the need for prototypes until the final design stages. “We use more than 400 simulation tools when we design our tires to minimize trial-and-error and get it right first time,” summarized Yohan Le Chenadec. Technology that saves time and money, all of which gets the products to market faster. The trend is also gaining ground with carmakers. “The initial stages in vehicle tire design are now completely virtual. We send digital models to the car manufacturers, instead of sending physical prototypes,” said Yohan Le Chenadec. **JULIEN BERGOUNHOUX**

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CES 2020
NUMIX, SERIOUS GAMES FOR TRAINING

“Flooding at a hydroelectric dam, a major alarm at a nuclear power plant, fire or explosion at a chemical plant, short circuits on power grids: these are some of the scenarios used in our virtual reality solutions to give staff the opportunity to grapple with crisis situations that are difficult to reproduce in the real world,” explains Jeff Sebrechts, who co-founded Numix with Amélie Raffenaud. The company has 12 employees and is based in Gaillac, France. It already boasts several key accounts in the energy sector for its custom serious games. Numix was at CES 2020 to showcase its new simulation engine, Industry Simulator VR, designed as a comprehensive, generic and agile solution. “We want to move into developing standard solutions with tools to monitor and analyze training programs and resources. This way, each client can create their own library of objects and scenarios,” stressed Jeff Sebrechts. Numix is developing the simulator with the Institut de Recherche en Informatique de Toulouse (IRIT) and the Serious Game Research Lab (SGRL) at INU Champollion in Albi. **M. A.**

DIGITAL TWINS

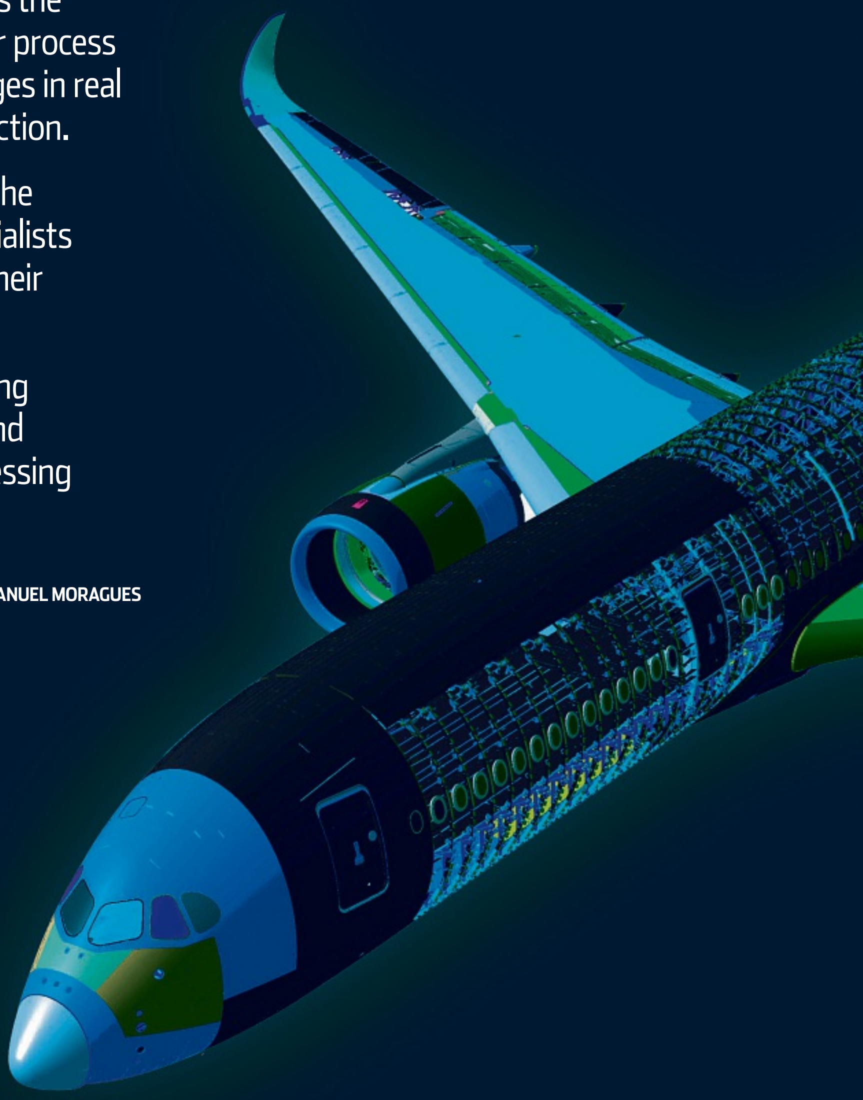
ONE FOOT IN THE REAL V IN **VIRTUAL REALITY**

CONCEPT A digital twin is the virtual replica of an object or process designed to reflect its changes in real time, from design to destruction.

USES Many variations of the concept are used by industrialists in every sector to improve their operations.

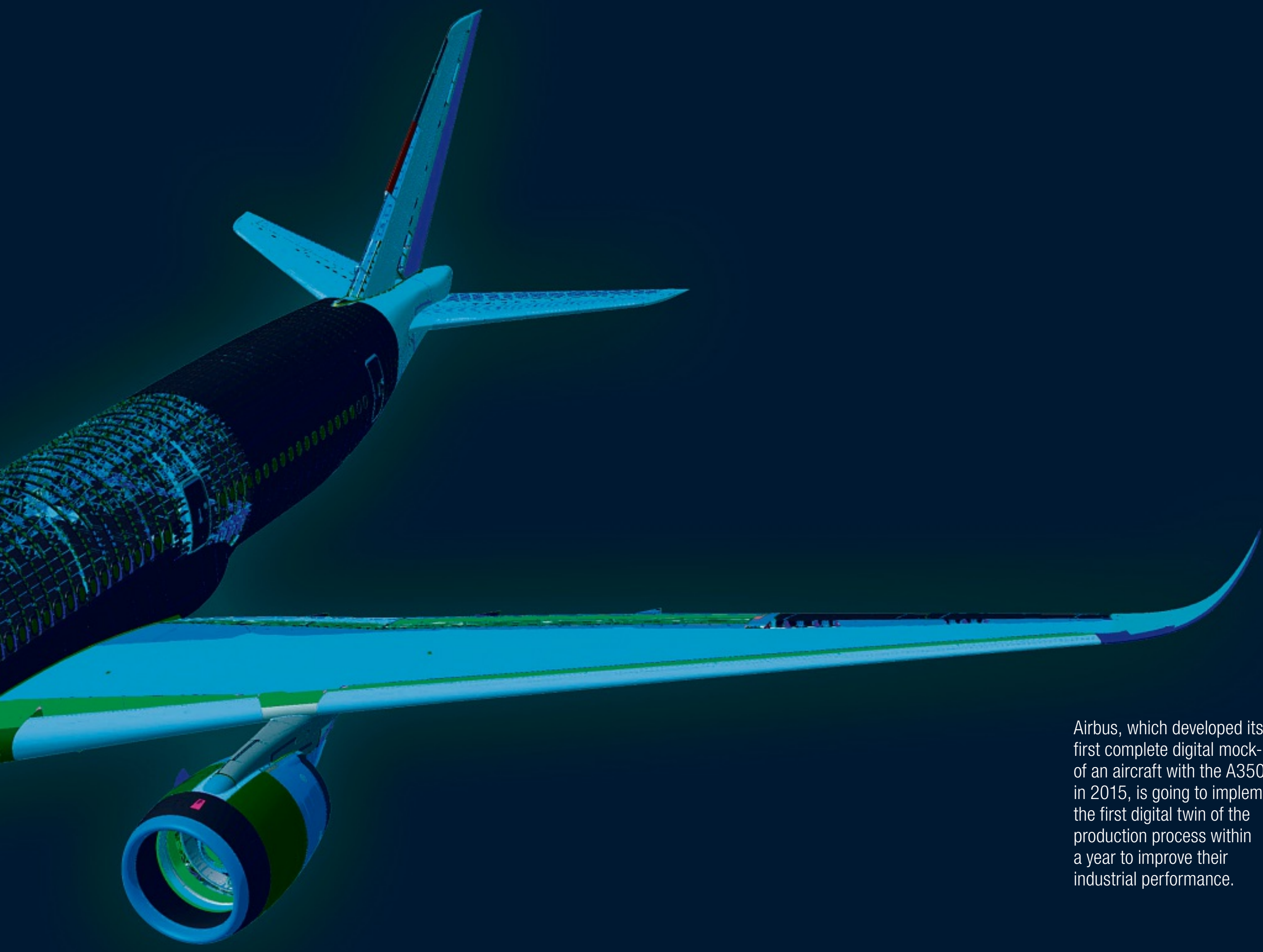
TECHNOLOGY Combining simulation with field data and the need for real-time processing relies on new technology.

SPECIAL REPORT COORDINATED BY MANUEL MORAGUES



AIRBUS

WORLD, THE OTHER



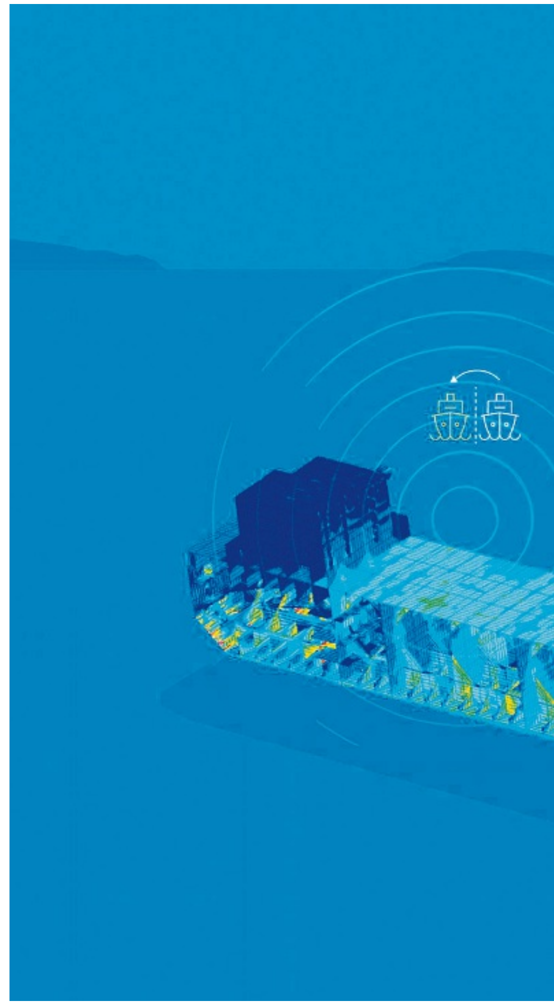
Airbus, which developed its first complete digital mock-up of an aircraft with the A350 in 2015, is going to implement the first digital twin of the production process within a year to improve their industrial performance.

STRATEGY

DIGITAL TWINS BREATHE NEW LIFE INTO INDUSTRY 4.0

Harnessing the power of simulation and data, digital twins aim to closely replicate the real systems they model. They offer industry compelling tools to supervise, maintain and optimize machines and products.

FLORIANE LECLERC



French start-up Akselos has developed software for the predictive maintenance of technical infrastructures, such as oil rigs.

Cited by Gartner as one of the Top 10 strategic technology trends, digital twins are gradually entering the global industrial mainstream. It may be true that only a few companies are currently using the technology in production, but two-thirds of firms with an Internet of Things (IoT) strategy plan to do so by 2022, according to the consulting firm. Since researcher Michael Grieves (University of Michigan, USA) first formulated the concept in 2002, digital twin technology has evolved in all sorts of ways to meet all kinds of needs. Gartner gives a fairly generic definition of the concept as a digital representation of a process or real object, given dynamic form by the data from this process or object. It is not just a simple virtual copy of a part or a generic process, "but a real individual twin, designed to mirror the transformations of the object or process in real time across its entire life cycle, from design through to disposal", asserted Éric Martin, Director of the École Nationale Supérieure d'Ingénieurs de Bretagne Sud (ENSIBS), in Lorient, which has just established a Digital Twin Chair.

Accelerate decisions

The basis of any digital twin is a set of physical models used to perform simulations to digitally solve physics equations and predict how the actual system will behave. What makes the digital twin unique is that the data captured by sensors in the real-world system or from the most recent inspection will be continuously input to these models. Digital twin models never stop – unlike conventional simulations. They provide a constant flow of information on the current state of the actual system it is linked to. It can also give real-time predictions within seconds, minutes, hours or weeks on what will happen in the system [see sidebar].

It's easy to see the technology's value for closer monitoring or to anticipate potential breakdowns. "Take the example of a wind turbine twin: the most recent data can be used to

D.R.

Éric Martin, Director of École Nationale Supérieure d'Ingénieurs de Bretagne Sud (ENSIBS)

"The digital twin is designed to mirror the transformations of an object or process in real time across its entire life cycle, from design through to disposal."


PAUL LANGROCK/LAIF-REA

REAL TIME IS A VARIABLE MEASURE

"Real time can mean different time scales. We should really talk about quasi-real time. Faults on a wind turbine don't happen in a matter of seconds, but over several days. The data uploaded to the digital twin might be captured once a day on average. But some processes, like aircraft gas turbine engines, need to be monitored every single second," explained Sébastien Kawka, Applications Manager at software provider Comsol. What's more the models used will be very different. "For a wind turbine, simulating complex models can take hours. But for a plane engine, the digital models have to be simplified to interact at speed with the physical system."

model blade fatigue, based on rotation speed or wind pressure, to continuously predict wear and tear. When the first signs of wear appear, the information is sent to the operator to stop the turbine for preventive maintenance," explained Sébastien Kawka, Applications Manager at software provider Comsol. "When we replicate the entire wind farm and simulate trends, we can predict precisely when and how you should start repairs to minimize the impact on wind generation and maximize efficiency. Simulations are a tool to visualize what happens if I adjust one or other parameter and, by comparing different scenarios, to calculate the best ways to optimize production and the best action plan," added Michel Morvan, chairman of the Lyon-based start-up Cosmo Tech, which rolled out its digital twin solution at Renault.
Decisions on wind turbines must be made quickly, within the space of a day. But decisions in the world of self-driving cars are made a lightning speed, in a fraction of second. To produce predictions at this pace, some firms reworked their simulation software code to increase processing speed. "How efficient the calculation is largely depends on the algorithms. In the course of 12 years of research, we've managed to refine them to produce faster simulation technology. We're now at the stage where our algorithms can execute thousands of simulations in less than an hour. Nowadays, we can produce reports in 24 hours that took anywhere from four to six months before. But the physics underpinning our technology is relatively simple," explained Thomas Leurent, CEO of the Swiss start-up Akselos, which develops software for the maintenance of complex infrastructure assets. "Others simplified to gain speed by stripping back the number of parameters to a few key ones," added Sébastien Kawka.

Harnessing the power of AI to anticipate all the what-ifs

And still others use digital abacuses, an approach based on a table with a huge range of ready-to-use calculations to speed up processing. When data is input, the system searches in the table for existing similar calculations and directly interpolates a result.
AI is the other option for faster simulation technology. Here, a great many simulations will have been performed on the models to anticipate all possible what-ifs (breakdown, collision, fatigue, etc.). Working from this library "that also includes all the past scenarios, AI tools (deep learning, neural networks) mine this data to quickly produce

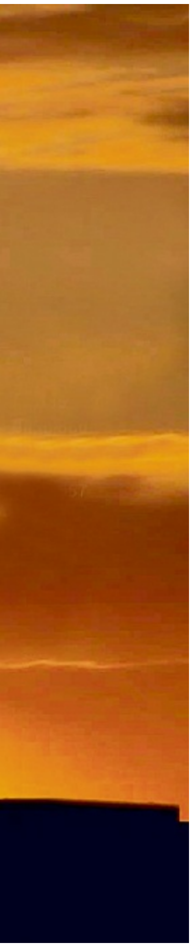
D.R.

predictions, based on the equipment operating conditions or if the slightest fault is detected," said Elie Hachem, Professor at Mines ParisTech and leader of the MINDS project aimed at "creating a digital R&D platform that harnesses the power of digital simulation and AI to offer accurate and comprehensive solutions for industry".

The very diverse range of digital twin solutions on offer is multi-modal and multi-scale. Applications vary from simulating a single part to a sub-system or an entire system. "The possibilities are exciting. For example, we could develop enterprise-wide digital twins built around very different components: machines, production processes, human resources and even financial inputs," Michel Morvan of Cosmo Tech pointed out. In Singapore, Dassault Systèmes' 3DExperience combines data on the city's building construction and management, energy and transport infrastructures to create a dynamic model for the city's government. Long the preserve of aerospace, the technology has captured the interest of many other industries keen for a solution to monitor complex, high-stakes assets. Éric Bantegnie, chairman of

VIRTUAL AND AUGMENTED REALITY: THE INTERFACES OF THE FUTURE

A digital twin lets you send many types of data on the system to many different users. Nowadays, it's common for simulation results to be displayed on a 3D dashboard showing operators what is happening inside the object they're doing maintenance on. "But we're seeing the emergence of virtual or augmented reality solutions that make complex information from digital twins easier to understand and more readily available," explained Olivier Sappin, Catia CEO (Dassault Systèmes). "Kitted out with my virtual reality headset, I can get a complete representation of the passenger compartment of a vehicle and visualize the air flows circulating in the space. This data can give a deeper understanding and help to design a more comfortable climate control system for the car." "In the interfaces of the future, for a more direct man-twin interface, we should be able to use all of our senses, sight, touch even smell. Of course, this brings up psychological, cognitive and ergonomic issues," stressed Francisco Chinesta, CNRS Professor and Researcher and advanced simulation specialist.



Ansys' Twin Builder solution is winning over heavy industry, aeronautics and energy players. Applied to an eolian wind farm, it keeps track of blade conditions and plans repairs.

D.R.

"A digital twin for all seasons"

PATRICE HAURET
R&D manager at Michelin

How would you define the digital twin?
In the broad sense of the term, it is the virtual replica of a real-life system to predict how it will work, optimize it and deliver sophisticated services around this system. Developed by NASA to better understand and control remote systems, the concept now extends to a very broad range of applications.

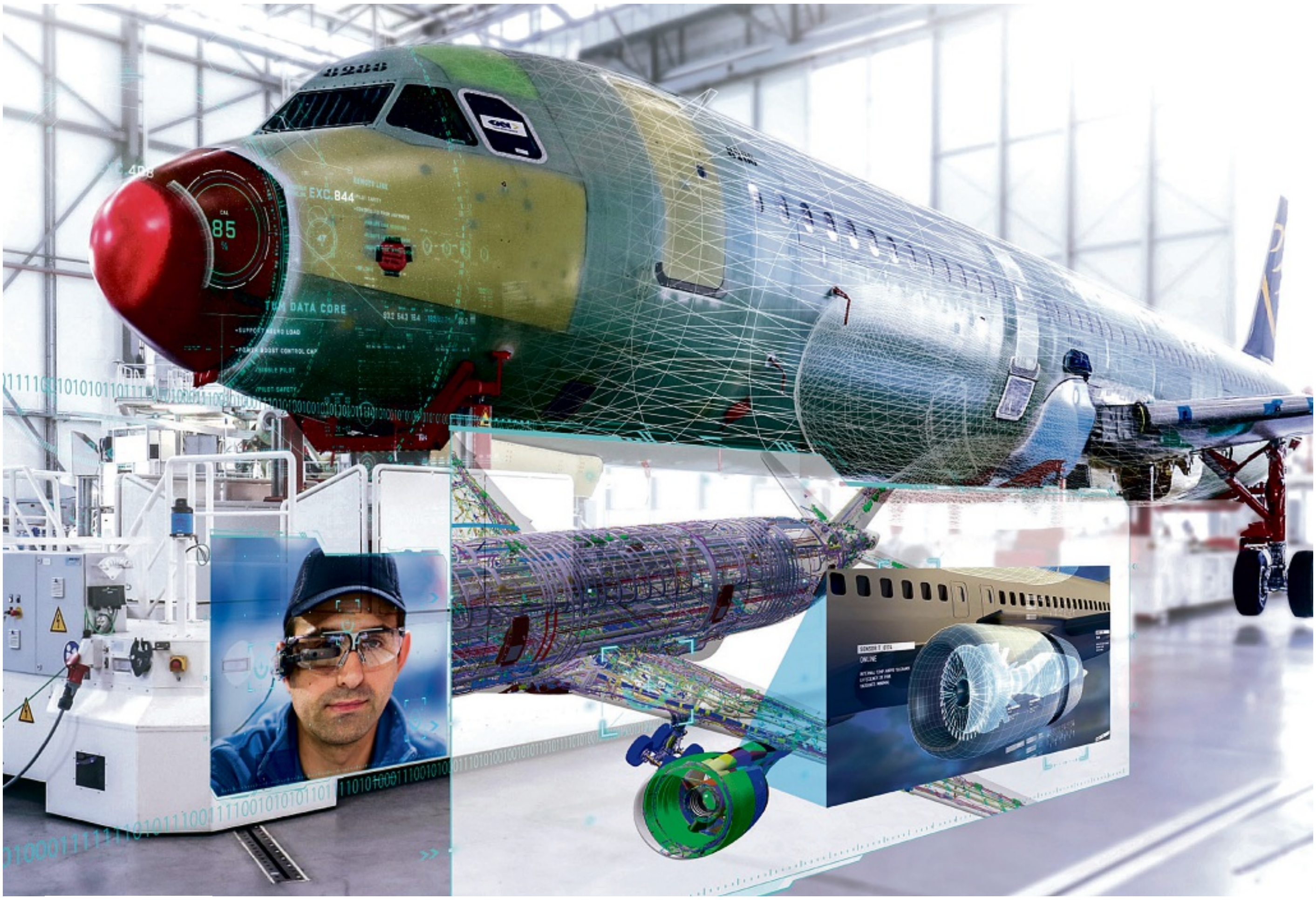
How does Michelin use the concept?
At Michelin we use digital twins to provide connected services to feed information to the motorist or the vehicle on the condition of the tires, about wear or grip for example. The technology means we're constantly adding real-world data to our tire model. A second increasingly commonplace application of digital twins is in industry 4.0. The production tool is modeled and input with data that describes the state of the production line. Operators then have the information to make decisions, such as when to adjust the settings on the machine or when to schedule maintenance.

How does digital twinning improve design?
The third application of digital twin technology is virtual co-design of the latest-generation tires with carmakers. Digital twins of the vehicle and tire are combined to predict overall performance, delivering better and more agile development. Processes are more predictive with less need for testing. Our target is to reduce the cycle time by 50% by halving the number of vehicle and tire prototypes used.

Ansys told us more: "we launched our Twin Builder platform in May 2018 and already have 500 customers around the world. Initial demand was from heavy industry and energy sectors. The second wave was from aerospace and defense. For example, we use digital twins to make sure that the landing gear on drones is working properly to prevent breakage." Electric vehicles are another growth driver. Ansys signed a partnership with Volkswagen in December 2019 to validate all components of its engines (from batteries to the control software).

Data processed close to source

"Deploying digital twins in very large numbers requires hosting capacities and the ability to manage and administer vast quantities of data," stressed the executive. With tens of thousands of digital twins in operation, Ansys has just teamed up with Microsoft. The software giant's Azure Digital Twins can be used to create comprehensive models of physical environments that are compatible with edge computing and can process data closer to source. "Our digital twins run externally in computing centers right now, but down the line they could be embedded in systems enabling auto-surveillance. When critical decisions come up, the development would eliminate the latency period to send and retrieve data to and from the data centers. Security is also tightened by keeping the data in the same place," said Éric Bantegnie. The partnership should also improve interoperability so that each digital twin of a machine or system can communicate with its counterparts. The aim being to develop a common language for digital twin definition so that industries that manufacture different parts of a system or thing (car, plant, etc.) will be able to express these data models in a language everyone can understand, which will make the task of integrators a lot easier.
The final challenge is to be able to explain the predictions AI produces. "It's true that the physical models underpinning conventional simulation have been certified, but we now have new protagonists: data and AI," said Francisco Chinesta, French National Centre for Scientific Research (CNRS) Professor and Researcher and advanced simulation specialist."



AIRBUS

Airbus's Hamburg site is a testing ground for digital twins.

AERONAUTICS

AIRCRAFT MANUFACTURERS MOVE INTO ACTION

As with engine manufacturers, the digital twin concept is enjoying great success with aircraft manufacturers, both for developing and operating aircraft.

OLIVIER JAMES

Digital twins are becoming increasingly prevalent, as proved by the fact that they are now regarded as one of the main levers to improve military aircraft availability, a strategic issue, in France. The digital twin concept is at the heart of the RAVEL, or VErticaLIsed RAfale, maintenance contract signed for ten years between Dassault Aviation and the French ministry for the armed forces' department of aeronautical maintenance in May 2019. This contract is now entering its implementation phase. Dassault Aviation is now using digital twins for all equipment, apart from engines and ejector seats, which come under separate contracts – in the 152 Rafale aircraft belonging to the French air force and navy. This is to improve their maintenance in operational condition (MOC).

"With RAVEL, Dassault Aviation is making a long-term commitment on fleet availability performance, in an expanded scope and at a flat-rate, thus giving visibility to the French state and our industrial partners," says Jean Sass, the company's executive vice-president responsible for digital transformation. In detail, this involves collecting fleet maintenance data, integrating it into each plane's digital twin via

ELECTRONICS ENGINEERS ON THE SIDELINES

Electronics and digital twins do not go well together. "Implementing digital twins to model how electronic equipment ages is currently inconceivable due to their technical feasibility and economic interest," says Olivier Saint-Esprit, a partner at the consulting company IAC Partners. The reason is that, unlike the wear and tear of mechanical components, it is still very difficult to digitally model the wear and tear of electronics components. In particular, limits have been encountered by Thales in the aeronautics sector. In detail, a metal mechanical component follows a linear wear and tear curve up to a certain threshold, beyond which its wear and tear speeds up until it breaks completely. For electronics components, there is almost no wear and tear, which is why their failure is extremely rare. "Following how an electronics component ages is beyond our reach," sums up Saint-Esprit. "Although there are tests to establish mathematical rules for wear and tear in different types of component, it's still very complicated."

Dassault Systèmes' 3DExperience platform and then analyzing it. At stake is reduced intervention time and predictive maintenance. "This platform is also intended to establish an industrial processing standard for the future Eurofighter plane, which is at the heart of the FCAS," says Sass.
To capitalize on this commitment, aircraft manufacturers can learn from engine manufacturers. For example, General Electric, Rolls-Royce and Safran, which generate up to half of their services income from plane engines based partly on the digital twin concept. These companies produce and maintain the most critical and heavily used part of a plane. They are still seeking to diversify: in partnership with Infosys, General Electric recently established that by placing 34 sensors on aircraft landing gear feeding into a digital twin, it was possible to significantly reduce maintenance times by also taking operational data into account.

Coping with faster pace

"Historically, the first digital twin of an aircraft in the commercial aviation sector dates back to the Boeing 777, which came into service in 1995. This was a physical representation mock-up," recalls David Ziegler, vice-president for industry aerospace and defense at Dassault Systèmes. Then as now, this tool enables a prime contractor's design office to work jointly with the sub-contractors in a virtual environment. Aircraft manufacturers now want to go further. First, by creating true digital twins specific to each aircraft, which will be updated by integrating operational data, and secondly by constructing digital twins of production processes. This will encompass the entire life cycle of aircraft and thus meet the challenges linked to increased production rates, improved aircraft quality and hence security, increased aircraft customization, and optimized fleet management by airlines.
In 2018, Dennis Muilenburg, the CEO of Boeing at the time, stated that by using digital twins Boeing had improved by 40% the quality of parts and systems needed to assemble aircraft. Muilenburg announced that this concept would be one of the key factors for Boeing's industrial efficiency during the decade starting in 2020. "It's going to become widespread throughout the sector, enabling every plane to have an exact digital twin in its production configuration," predicts Ziegler. This will improve our understanding of each aircraft's specific performance level and enable the best operating conditions to be derived from it. Aircraft manufacturers will also be able to offer the best services associated with their production."

Drawing on aircraft operational data

At Airbus, which developed its first complete digital mock-up of an aircraft with the A350 that came into service in 2015, the time has also come to extend digital twins to aircraft production. "We're going to implement the first digital twin of the production process within a year. This is to improve our industrial performance, especially by using simulation to anticipate solutions in the event of disruption," says Alain Tropis, head of Airbus's DDMS program, which aims to ensure digital continuity throughout the group's activities. The digital twin is being implemented on the Hamburg site (Germany) for pre-assembly of the A321 fuselage. In this way, Airbus can virtually test interactions between the equipment and the parts to be assembled, and check that the robots carry out their tasks correctly. "This is a digital twin and not just simulation since we can integrate observed data into the model," points out Tropis.
Airbus then plans to deploy this system on all its industrial sites. The next stage will be to link digital twins to processes and products. "If these models share a 'common language'

AIRBUS

"Within a year, we're going to implement the first industrial digital twin to improve our industrial performance."

Alain Tropis, head of the DDMS program at Airbus for modeling and structuring, we'll be able to make them interact iteratively and ensure that each modification made to one of them modifies the other," explains Tropis. Although product digital twins have reached maturity at Airbus, as evidenced by their use to assess the impact of modifying a physical product on the industrial system and to improve maintenance, and although a digital twin linked to processes is currently being deployed, overall integration remains to be done. "This is our objective for our forthcoming programs," says Tropis.

The Holy Grail that Airbus intends to reach is for aircraft operational data to be fed into the digital twins of processes and products. Currently, Dassault Systèmes' 3DExperience platform – acclaimed by Airbus and all other major stakeholders in this sector, such as Boeing, Safran, Lockheed Martin, etc. – aims to ensure digital continuity between product design and industrial production. But Airbus, which also turned to the US company Palentir to develop the flight operational data platform Skywise, has its sights set on overall integration of the various digital environments. "This will be the 'cornerstone' of our digital transformation," claims Tropis.

Extending the concept ever further downstream

Dassault Aviation, which has long relied on its cousin Dassault Systèmes, wants to deploy this concept at every stage. Although digital mock-ups were extended to civil aviation processes in the early 2000s, the Falcon 7X being the first aircraft to benefit from them, Dassault Aviation now has its eye on services. "Digital twins are currently used in phases further downstream to monitor a plane once it has been delivered to a customer," says Sass. As well as for Rafale aircraft, Dassault Aviation also intends to do the same thing in civil aviation: the 3DExperience platform can process data from Falcon fleets and put together what the group calls 'individual health records' of aircraft in service. "The standard approach consists of accumulating data via big data and analyzing it to offer fleet management optimization services," says Sass. "At Dassault Aviation, we have the same approach, except that we match this operational data with data from the aircraft's representation, its digital twin."

How far can the concept be extended? "We're now moving towards a complete digital twin of the company," predicts Ziegler. "For example, this would include the positioning of a new program in relation to market conditions or even social data in data models. We can now simulate the impact of a new factory in a production system. In the future, we'll be able to check the relevance of research programs according to their impact on sustainable development." Where digital twins are concerned, the sky's the limit.


CS/CAPA PICTURES

"We're observing the ability of our vehicle-environment system to react correctly"

NICOLAS FOUQUET
Head of the autonomous vehicle R&T laboratory at Safran

What are the most recent applications for digital twins at Safran?
The digital twin concept has been deployed in military and civil aviation at Safran for many years. It's now at the heart of our developments on autonomous land vehicles. We've modeled the environment of our Saclay research center site up to an 8km radius, with an accuracy of around 5cm. Anything that an autonomous vehicle could encounter as it moves around has been modeled: roads, pavements, road-markings, plants, etc. We then inserted the vehicle's digital twin into this environment.

What is the purpose?
We're not observing how the system ages but rather its ability to react correctly in a wide range of scenarios, such as heavy traffic, type of driving, different sorts of obstacles, etc. Real data from tests is regularly added to the simulator. We've proved the system's reliability in a clearly defined setting. The goal now is to develop this digital twin in an uncontrolled environment. Simulation results may eventually be acceptable ways to ensure compliance during the certification process.

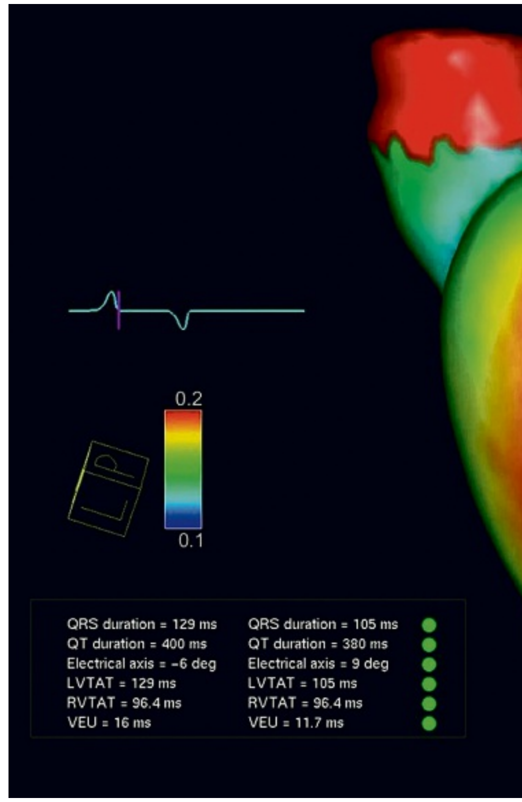
Is your work feeding into research on autonomous aircraft?
Most of the technology we're developing can be used in the aviation sector. We've reused sensors, concepts and algorithms for applications linked to commercial aircraft VTOL and taxiing. It's easier to conduct real experiments on land vehicles than on aircraft.

SURGERY

HEART FIRST: VIRTUAL SIMULATION OF ORGANS

Virtual human organs are the latest application of digital twin technology, and it begins with the heart. The goal is to customize prostheses, target treatment more accurately and enhance surgery preparation.

GAUTIER VIROL



Produced by Siemens Healthineers, this digital twin of a patient's heart simulates how the patient will react during surgery.

Digital twins are not just for machines and production lines. The latest innovations seek to tackle that most complex of machinery, the human body. "Taking the concept of digital twins into medicine means simulating a treatment or surgical procedure, organ by organ," according to Agnès Malgouyres, Head of Artificial Intelligence (AI) at Siemens Healthineers.

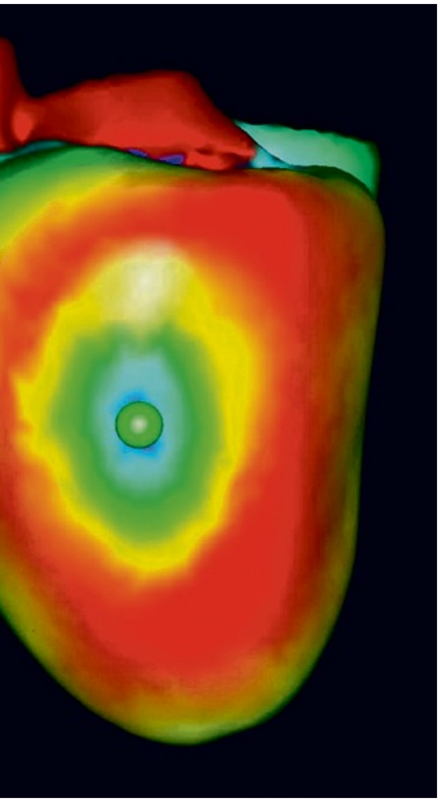
This specialist medical technology division of Siemens successfully simulated a heart to prepare for a cardiac resynchronization procedure. "This operation entails placing electrodes on the heart of a patient with arrhythmia to regulate the rhythm," explains Agnès Malgouyres. "The surgeon feels his way somewhat, looking for the optimum response by placing the electrodes in different locations." Enter digital solutions to eliminate the need for this type of trial-and-error approach. By creating a model of the patient's heart, the surgeon can identify the ideal position for the electrodes, before the procedure. "The clinical trial conducted at Bordeaux University Hospital (CHU) demonstrated that the simulated heart responded in the same way as the patient's heart," she is pleased to report.

Guillaume Kerboul, consultant at Dassault Systèmes

"When you make a machine, the User Guide always explains how it works. But it's different with the human body; we don't know exactly."

Siemens Healthineers is also conducting research into liver simulation to maximize responses to cancer treatments. As well as pre-operative planning, the objectives include customizing treatments to individual needs. Agnès Malgouyres again: "Siemens wants to develop the principle of non-invasive procedures. The idea is to have as much information available as possible, before a procedure."

PrediSurge harbors similar ambitions. A French start-up founded in 2017 in Saint Etienne, PrediSurge is working on recreating the aorta of patients with aortic aneurysm. The goal is to design a patient-specific stent perfectly tailored to the individual's pathology and prepare to implant it. "Cardiac prostheses are very complex, especially when the aneurysm affects the area where the aorta branches down into the arteries feeding the liver, spleen, intestines and kidneys," explains Jean-Noël Albertini, surgeon and chairman of the young start-up. A stent that previously took one month to design now takes two days using simulation technology. It took three years for PrediSurge to develop a digital aorta.



SIEMENS HEALTHINEERS

INRIA

"We have to improve life models at all scales"

NICOLAS AYACHE
Digital Patient Research Director, at Inria, the French National Institute for Research in Digital Science and Technology

How is the digital twin of a patient's organ created?
First we have to develop the algorithms capable of reproducing the anatomy and physiology of the organ with the patient's specific characteristics. The models we use are structural (the shape of the organ and tissue) and functional (how the organ functions). These are developed from geometric, statistical and biophysical modeling of the living organism to build a standard digital organ, which is then personalized.

How is it personalized?
Personalization algorithms use all the data available on an individual patient (medical images, clinical and biological data) to adjust the standard parameters and create a personalized digital organ, which is the digital twin of the patient's organ. We use this digital twin to quantify the seriousness of the pathology, predict how it might evolve and plan treatment therapies, thus covering the three pillars of digital medicine: diagnosis, prognosis and treatment.

What are the major priorities for research?
We need to keep on improving life models at all scales, from the molecular to the entire organ or even the body, and develop more powerful personalization algorithms. Access to massive quantities of patient data should help to guide new personalization algorithms and help make them more effective and more robust in the future, drawing on modern AI methods, especially machine learning.

The cardiac surgeon explains: "To build a digital twin, you have to calculate the geometry of the organ using medical imaging technology. But the geometric model is only the first step. Then you need to calculate the—very precise and specific— mechanical properties." Siemens Healthineers also grappled with this challenge. "Training the electrophysiological model of the heart, which is the building block for digital twins for different patients, is quite a complex problem," according to Guillaume Chabin, AI researcher. "We solved it with a 20-petaflop supercomputer and AI."

Vast data and computing power needs

Creating this model is the main difference between the digital twin of a machine and that of an organ. "When you make a machine, the User Guide always explains how it works. But it's different with the human body; we don't know exactly. And we have to factor in the environmental impact and patient differences," says Guillaume Kerboul, consultant at Dassault Systèmes. This is partly why the Dassault Aviation spin-off, Dassault Systèmes, acquired Medidata at the close of 2019. "Our scientific model is to use the greatest number of patients to observe their similarities and differences," explains the consultant. The Medidata start-up—the single biggest investment in Dassault Systèmes' history—specializes in processing medical data. Yet, the software company lost no time and launched its organ simulation program before the deal was tied up. Its human heart simulation was used by a surgeon in the pre-op planning for surgery on a young female patient with a cardiac malformation. It also kicked off research projects aimed at improving treatments for colon cancer and is working on modeling the regions of the brain responsible for epilepsy in a patient with drug-resistant epilepsy. In a nutshell, "our goal is to plan for the surgery and predict its impacts," says Claire Biot, VP of Life Sciences Industry at Dassault Systèmes.
Almost science fiction? Siemens Healthineers and Dassault Systèmes have bold ambitions: to extend digital twin technology beyond organ simulation to recreate the entire body. Understanding the human body is not the only hurdle. The vast quantities of data and computing power needed to create a virtual patient mean this lofty aim is still out of reach.

DEFENSE

NAVAL GROUP SPEEDS UP **SHIP DESIGN**

The first Barracuda nuclear attack submarine was in part designed using a digital twin, cutting down on testing time.

Thanks to digital twin technology, the ship builder Naval Group can study a broad range of possibilities in the design phase of manufacturing and choose the best options early on.

HASSAN MEDDAH

The first sea trials of the Suffren submarine are slated to take place this year. This vessel is the first in the Barracuda series of new nuclear attack submarines to be built for the French Navy. Its nuclear-powered boiler is one of the assets of this formidable predator of the seas, giving it an action range and capacity for discretion that surpass the performance of the preceding generation of submarines. The vessel's characteristics were validated on the basis of a digital twin developed by the design teams at Naval Group and its partner TechnicAtome. "We developed a digital twin for the entire functional chain of the vessel's propulsion system, by modeling all its components. We were able to combine these models to work simultaneously, and simulate the overall functioning of the Barracuda propulsion system," says Yves Dubreuil-Chambardel, coordinator of digital transformation R&D programs and supervisor of the Twin Ship program for Naval Group. This major development confirms the potential of this new simulation tool, and has considerably accelerated the design phase for this supplier of the French Navy. "The digital twin optimizes design decisions by reviewing a large number of architectural options. It would be very difficult to achieve this manually without this tool that predicts the performance of each configuration tested." The time devoted to bench-scale testing was cut from eighteen to three months.

Given these time gains, is Naval Group going to develop the digital twin for the entire ship? "It would not be technically impossible, but simulating the global operations of a ship could be costly. That's why we want to take a pragmatic approach. We set ourselves partial objectives, for the short term, each of which has its benefits, and yields a return on investment," explains the head of the Twin Ship program. In other words, the ship builder will focus first on the design of the most critical equipment. The manufacturer's library of fundamental simulation models will grow over time, and in the distant future will eventually include all the pieces of the digital puzzle.

Meanwhile, Naval Group has other plans for the digital twin, which it aims to use to develop new services for its customers, naval forces around the world. The Holy Grail of these ser-

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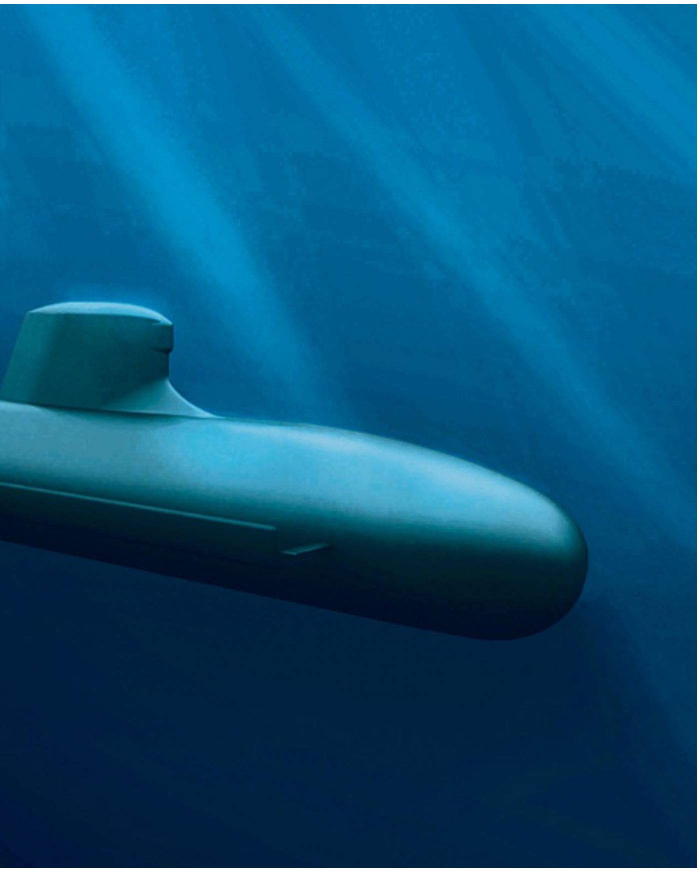
Yves Dubreuil-Chambardel
Coordinator of digital transformation R&D programs

"We developed a digital twin for the entire functional chain of the vessel's propulsion system, by modeling all its components."



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BENOIT TESSIER/REUTERS

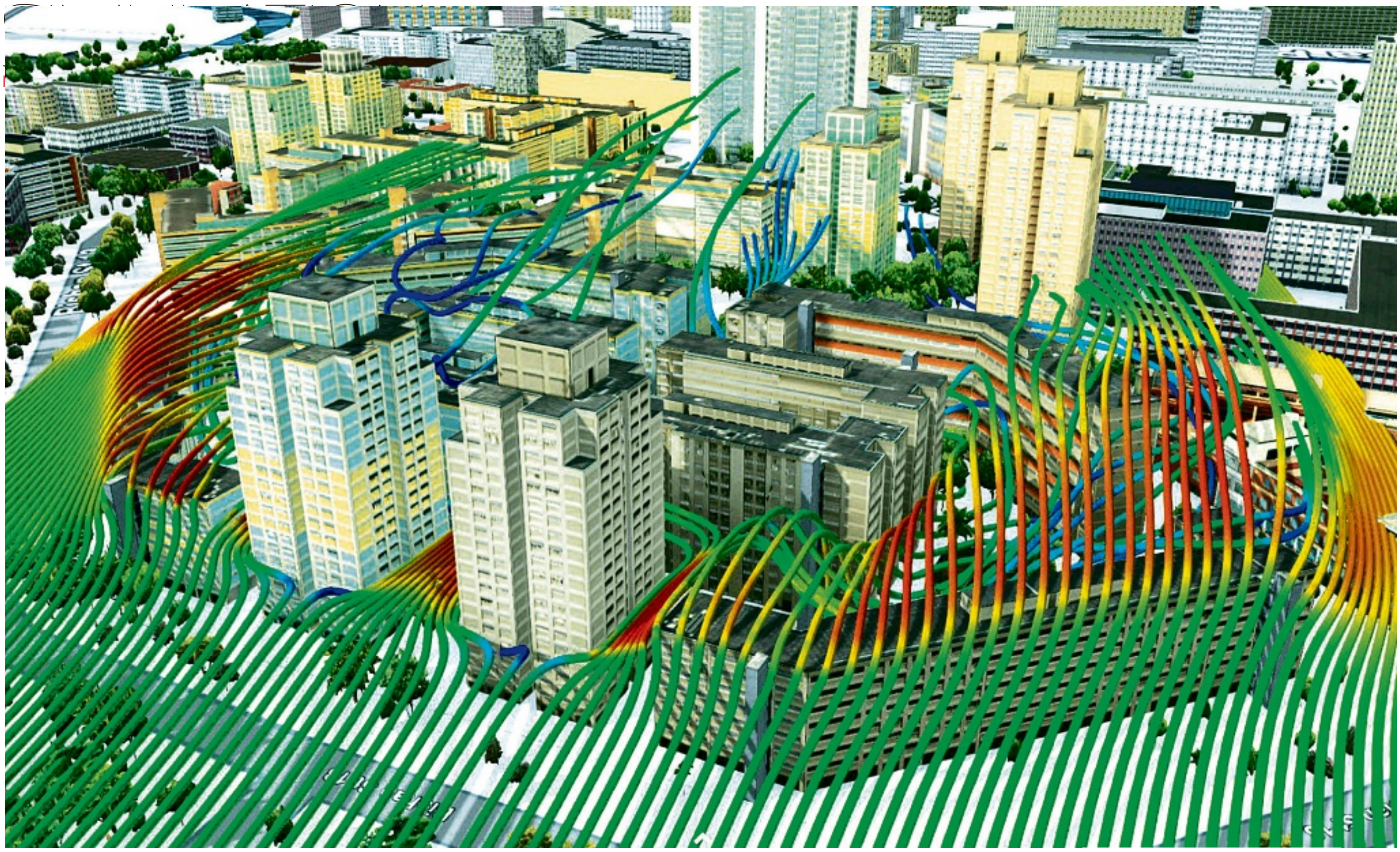
The Suffren leaving the Naval Group construction hangar in Cherbourg in July 2019.

vices is predictive maintenance capable of warning the crew of a foreseeable malfunction in a piece of equipment. The digital twin has emerged as a better tool than a big data approach, which has shown its limitations when it comes to ship building. Ships are built in such small numbers that data series are not significant. Furthermore the vessels can embark only so much computing power. The digital twin addresses both of these constraints. "We compare readings from a piece of equipment with those predicted by its digital twin, in real time. If there is a discrepancy, the equipment is malfunctioning," explains Yves Dubreuil-Chambardel. Naval Group is testing its first predictive maintenance services on equipment aboard the latest generation of frigates that accompany the Charles de Gaulle aircraft carrier. A warning system alerts the crew if certain devices show degraded performance that could lead to a breakdown.

Highly demanding data synchronization

This simulation tool calls for a high degree of expertise. Even with 20 years of experience with digital tools (digital 3D models, 3D CAD, crew training simulators, virtual reality, etc) Naval Group advances step by step. "We make a distinction between the digital 3D model, which is a geometric representation of the ship and its components, and the digital twin, which is a representation of the functioning of the ship and its equipment. The two complement each other," explains Dubreuil-Chambardel. A high level of precision is also required when using the digital twin. The calculations must be properly chained to limit propagation of uncertainties. Data must be very carefully synchronized, especially considering that a ship may have more than one digital twin, one onboard the ship for use by the crew, and one stored in a data center for use in equipment design and upgrading work. Configuration management must ensure that these different ensembles are updated so that each twin accurately represents the ship as it is.

The greatest challenge is real-time use. In the future naval crews would like to be able to use the digital twin in the event of a military engagement, such as a torpedo attack. Decision-making tools will use the vessel's digital twin to determine the best response. "This means getting answers in a very short time. There is a lot of work needed to optimize simulation codes so that they can run in real time on onboard computer systems," underscores Naval Group. This new simulation tool also has implications for the company's industrial and commercial partners. Naval Group now expects its suppliers to deliver their components with digital twins. Closely negotiated talks are underway to establish who will own the data generated. The digital twin era is only just beginning.



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Virtual Singapore enables planners to simulate wind circulation, as seen here.

URBAN PLANNING

LARGE-SCALE VIRTUAL TESTING OF SMART CITIES

Cities are just beginning to explore the uses of digital twins: optimizing urban network grids, simulating infrastructure, and anticipating the consequences of flooding.

JULIEN BERGOUNHOUX

It is hard to imagine a system more complex than a big city. Buildings, roads, public spaces, energy grids, water supply and sanitation networks, public transit – all of these interconnected components mean that the consequences of choices cannot be fully anticipated, posing problems for infrastructure planning and decision-making. To address these issues cities around the world have created their own virtual replicas. These XXL-sized digital twins faithfully reproduce the city in 3D representation, from building height to bus shelters and the trees lining the streets. The models are supported by data from urban infrastructure, building energy consumption, road traffic, CO_2 emissions that measure activity in real time via sensors. The virtual replica can be used to simulate and better prepare for various events: medical emergencies, street demonstrations, peak pollution episodes, flooding, etc. The twin also gives planners a way to experiment before implementing changes, such as rehabilitating a neighborhood, closing a road, creating a round-about or building a tramway line.

Singapore, a laboratory for experimentation

The city-state of Singapore is conducting one of the most far-reaching experiments in this domain. The city's digital twin, Virtual Singapore, was launched in 2014, at a cost of 73 million dollars. It has been used by telecoms operators to optimize the coverage of wireless networks by building owners to identify the best locations for solar panels, and by city planners to improve park design and traffic flows.

By simulating modifications in the digital twin before implementation their costs and feasibility can be analyzed, and unforeseen consequences avoided. This simulation also facilitates project coordination involving different entities,

such as installing handrails for people with reduced mobility at the same time that green areas are renovated. The Singapore government also plans to use the virtual replica to test the use of self-driving cars in the city's dense traffic.
The metropolitan area of Rennes is a pioneer of digital urban modeling in France. The city launched a project in 2017 to construct a digital twin covering the entire urban area. Like Singapore, Rennes turned to Dassault Systèmes and its 3DExperiencity solution for this project. As in other cities the prime motivation is to share data – demographic, topographic, economic – between different urban entities to make public policy more efficient. The economic impact of new infrastructure in a neighborhood can be simulated using different variables for building space allocated to housing, commercial space or tertiary uses.

A 3D model of Ile-de-France to offer more services

This work naturally involves collaboration with companies, such as the SNCF railway operator. SNCF created a digital twin for the Rennes train station in 2019 as part of renovation work on the building. This twin is the first in what will be a long series, as SNCF plans to create digital models of 3,000 stations in France. What are the benefits of this concept when applied to a train station? Decision-makers can test various configurations of retail space, passenger waiting rooms and other areas, to determine their feasibility and impact on customers. The virtual replica is enhanced by real-time information from electrical equipment to optimize building management. Escalators, elevators, air-conditioning units, lighting, automatic doors can be visualized and centrally controlled.
The Ile-de-France region has also entered the digital age. In October 2019 the regional government contracted with Siradel, a Rennes-based company specialized in digital twins for cities (now a subsidiary of Engie). Siradel is modeling the entire territory in 3D, first aggregating and qualifying existing data sets, and then supplementing them with its own data. In all, over 10,000 data series covering a period of six months have been compiled in a repository, and 2.5 million buildings have been modeled in 3D. Vehicles equipped with cameras and sensors to measure humidity, pollution and other conditions are deployed in the streets to complete the picture and provide the most comprehensive overview possible of the metro area. On the basis of this modeling a service called My solar potential will be offered to residents this year. Users will be able to simulate the solar radiation received on a roof, square meter by square meter, and determine its energy and economic potential before installing solar panels. Another service that will be offered in 2020 is Smart Works, a platform listing all the work spaces available in Ile-de-France – coworking spaces, libraries, universities – whether for 15 minutes, four hours or several days.
The use of digital twins is expanding with smart cities around the world. This is a slow but inexorable process, varying with the global region, and the needs of metropolitan areas. In the United States urban modeling focuses on mobility. The city of Philadelphia, for instance, has used 3D modeling to simulate the bus and tramway stops of its public transit system, in order to optimize service to residential areas while holding down the costs of extension of the tramway line. In June 2019 the Open Mobility Foundation was created by 13 American cities. Among other things these cities are interested in setting up connected infrastructure to optimize traffic management, and in establishing common standards in anticipation of the next step, which will be to link the digital twins of several cities. In the framework of its Smart Cities Network the Association of Southeast Asian Nations is exploring the concept of digitally twinned smart cities in a pilot project launched in 2019, involving Singapore of course, Djakarta (Indonesia) and Cauayan City (Philippines).

MORE SMART CITY PROJECTS TO COME

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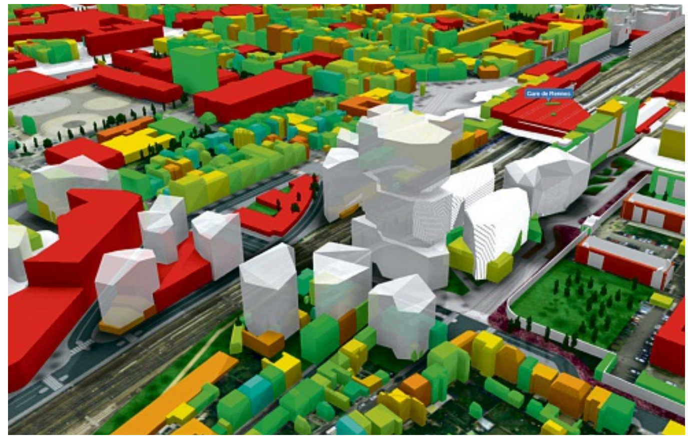
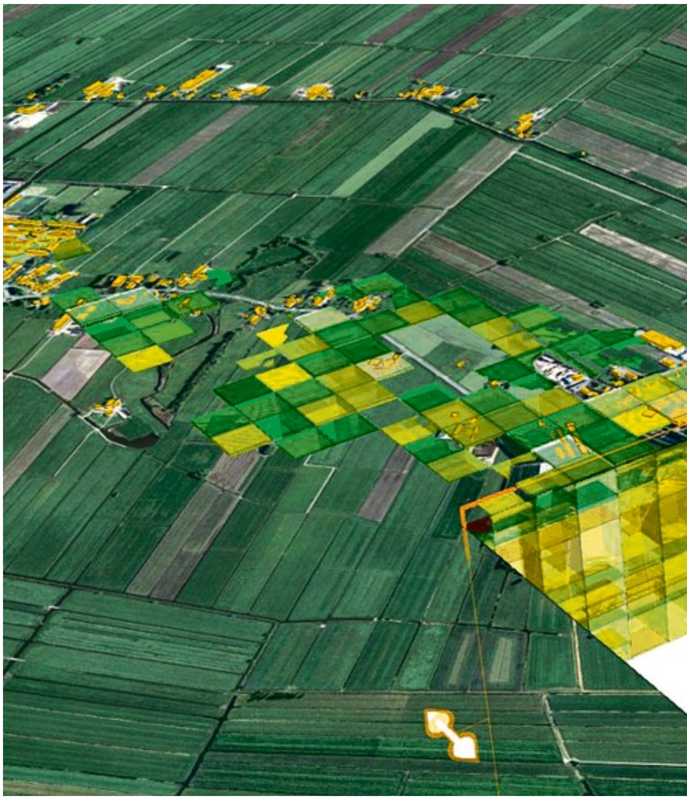


The number of digital twins for cities will rise rapidly in the next five years, according to a study published by ABI Research in September 2019. From just a handful of instances in 2019, the number of operational implementations is expected to exceed 500 by 2025. The market advisory firm anticipates that most of these will be models of specific system subcomponents (electricity grid, roadways, connected buildings, etc) that will be aggregated, rather than one single large model. This research also points to the substantial investment needed to make the most of simulation projects. Simply adding a few sensors to existing infrastructure will not be enough. The leading players in this field are Dassault Systèmes, developer of the 3DExperiencity solution deployed in Rennes (see photo), Microsoft and Siemens, followed by Bentley Systems, CityZenith and IES.



All companies that dig or explore underground in the Netherlands must submit their data to the national subterranean environment register BRO.

THE SUBTERRANEAN ENVIRONMENT

TWINS OF THE **INVISIBLE**

Replicating underground structures is a complex process, whether to represent geological formations or subsurface infrastructure foundations. Examples from the oil industry and from below-ground city planning.

MYRTILLE DELAMARCHE

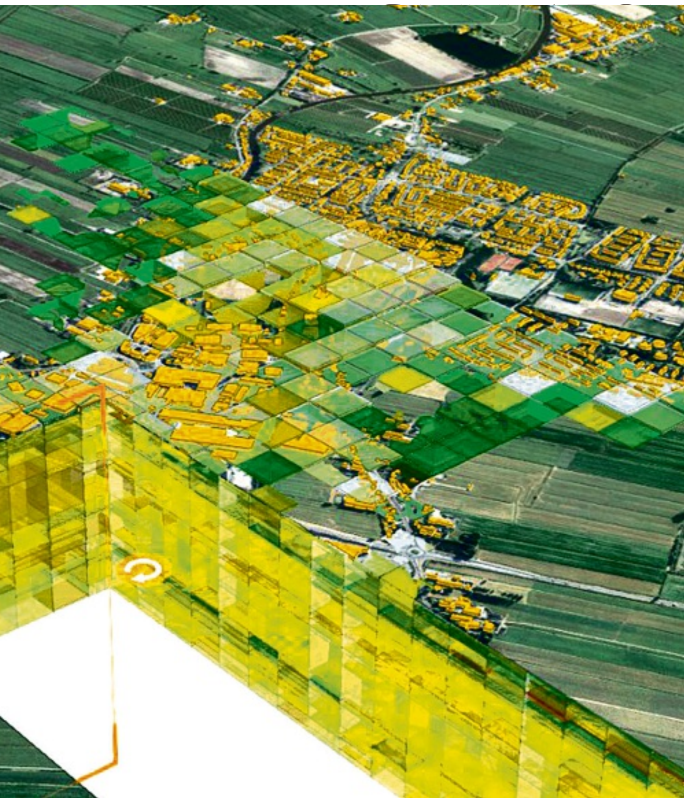
Extractive industries are accustomed to working with huge amounts of seismic data and large production figures. For years they have integrated these data in 3D models that support simulations using a great deal of computing power. In this way these companies create 3D models of oil fields, but "I wouldn't call them twins, they are never totally predictive," recognizes Dominique Janodet, director of R&D for exploration and production at the group Total, which recently inaugurated its Pangea III superprocessor. Halliburton offers a digital twin of oil wells as part of its Landmark service, used during construction as well as in the operational phase, to obtain maximum returns on investment. An oil field is more than simply a pocket containing a homogenous fluid, however. Taken in its entirety, it is more like an immense sponge, and is very difficult to model. Some specialists have attempted this. The American company Chevron plans to equip all its fields with sensors by 2024. Total is even deploying biodegradable sensors underground. BP reports that, working with WorleyParsons, it has created a digital twin of the Clair Ridge oil field in the North Sea.

Digital twinning is emerging as a powerful cost-cutting tool for oil companies that have been under increasing financial pressure since oil prices dropped in late 2014. "TechnipFMC has supplied its customers with over 700 subsea production systems that are monitored around the clock. These are digital twins in activity," explains Julie Cranga, vice-president for subsea digital operations at the group. In September 2019 TechnipFMC signed a partnership agreement with DNV GL to develop the first methodology for application of digital twin technology in the oil and gas sector. This methodology is currently being tested by a customer of TechnipFMC, and will be unveiled in the second quarter of 2020. The Quantum program is one aspect of the digital transformation at Total. The program goal is to install digital twins at all strategic assets, starting with the Culzean platform in the North Sea in June 2019.

According to analysts at Boston Consulting Group (BCG), "Despite the number of projects, organizations are failing to capture the potential value of digital twins for three reasons:

MINES TOO CAN BE REPLICATED

Although the digital transition of the mining industry progresses slowly, some pioneering companies are developing digital twins, by modeling mines, placing sensors on equipment and linking production data to the model. This solution is proposed by Swiss manufacturer ABB, specialized in automation equipment. French company Eramet is working to develop digital twins of its assets, from mines to metallurgy furnaces. Eramet has digitized its mines in Gabon and New Caledonia using Delair drones. The topographic information gathered by the drones will be exploited to monitor production volume, ore demand and quantities of ore loaded on trains and boats. The aim is to reduce costs. Analysis of the drone data using artificial intelligence should also enable the company to continually update its knowledge of surface area, volumes and land slopes, ensuring greater security for topographers.



D.R.

They prioritize use cases for digital twins on the basis of what the technology can do, rather than what generates the most value. They do not secure proper buy-in and commitment from the end users in the business. They underestimate the extent of the changes to the ways people work that are necessary to realize value."

From real-life cases to forward-looking scenarios

The BCG study also cites some success stories. "A leading international oil company wanted to reduce instances of gas compressor failures. It formed a multidisciplinary team to develop an MVP [minimum viable product] that collected data from 1,500 sensors. Then, using advanced analytics, the team established the health of 12 key systems affecting compressor performance. The solution was deployed in the company's onshore and offshore operations. The digital twin is now on track to reduce compressor failures by more than 40%." According to BCG digital twin projects should be selected for their capacity to reduce investment costs, to speed up the start of production, to increase output, to hold down operating costs and to improve security and safety. To achieve this the twin demands high-frequency data. "For example, optimizing valve controls often involves sampling data at frequencies below one second."

In addition to observation of current equipment status, a digital 3D replica of an installation, in its environment and updated in real time with data collected at the physical site, can be used to simulate forward-looking scenarios. These prospective studies will also be highly useful for carbon storage in depleted hydrocarbon formations. "When the time comes to inject CO_2 into old oil wells, we will have to be able to model the future activity of these sites for a period much longer than the 20 or 30 years of extraction," warned Dominique Janodet at a round-table discussion on predictive geosciences, part of a colloquium held to celebrate 60 years of work at the French Geological Survey (Bureau de Recherches Géologiques et Minières, BRGM).

Modeling the Netherlands, top to bottom

Far from the business of extractive industry, digital twins of underground installations are also employed in urban areas. Under legislation passed in 2015 all the municipalities of the Netherlands are required to create and update digital twins of their buildings (in coordination with building information modeling (BIM) for 3D modeling and building management) and of their underground infrastructure. Building foundations and parking garages, subway tunnels, telecoms cables, water conduits, gas pipes, etc, all sectors of activity that depend on underground installations are affected. Starting in January 2018 all companies that dig or explore underground are required to submit their data to the Netherlands national subterranean environment register (Basisregistratie Ondergrond, BRO). This database is publicly accessible via the PDOK open-data portal. What is the purpose of this unusual legislation? “To enable our towns and cities to face coming climate challenges. Close to two-thirds of our country is below sea level, and we invest 7 billion Euros each year in structures to hold back the water,” explains Martin Peersman, subsurface program manager at the Dutch Ministry of the Interior. In addition, “it is indispensable that we plan for our subterranean domain, which is already over-occupied. We have the third-highest population density in the world.”

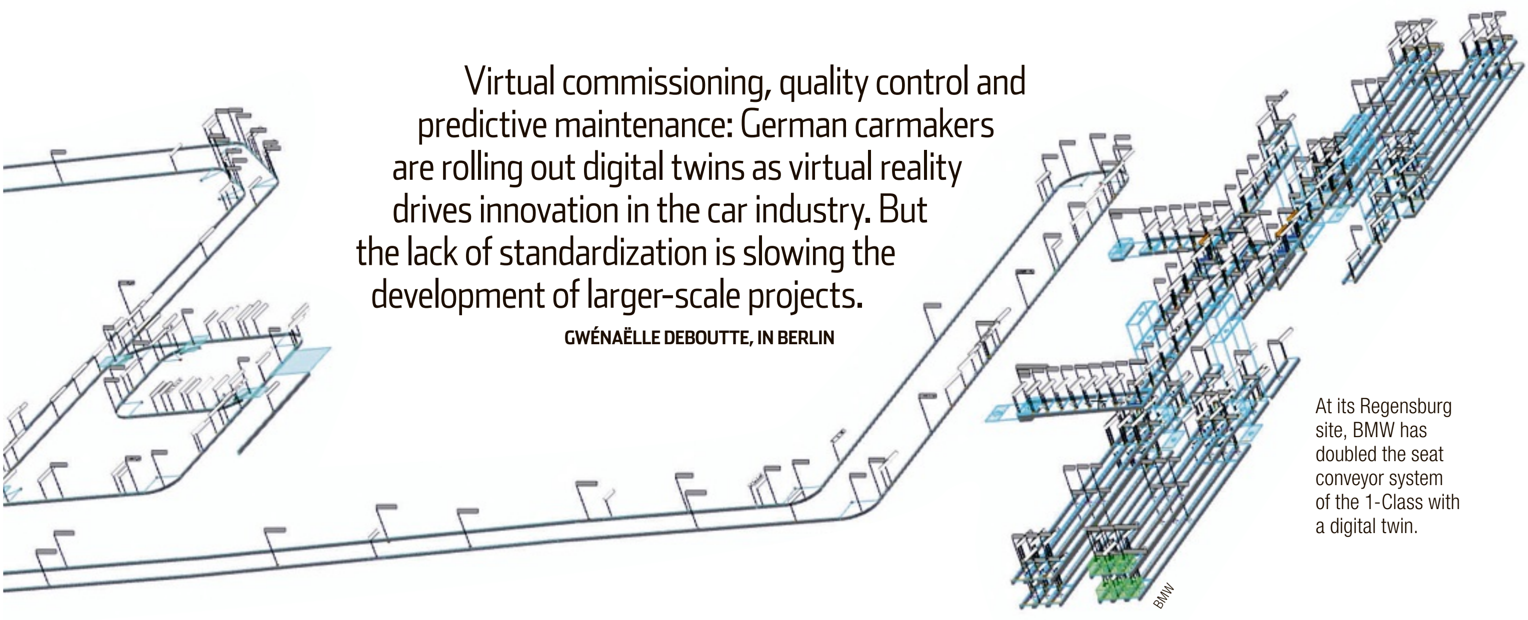
In Portugal the Aguas do Porto company turned to Bentley Systems to create a digital twin of its drinking water supply, rainwater and sewage networks in order to make the city of Porto more resilient in the face of flooding. In addition to its OpenFlowsWaterOPS solution for district hydraulic services management, Bentley offers geotechnical tools such as Plaxis, SoilVision, Keynetix (acquired in 2019) and gINT, among others. In France a program to survey sensitive underground installations is underway, and will be completed by 2026. The city of Paris is considering created a digital model of its labyrinthine sewer system. This is just the first step towards a digital twin.

AUTOMOTIVE

TWINS ON THE PRODUCTION LINES

Virtual commissioning, quality control and predictive maintenance: German carmakers are rolling out digital twins as virtual reality drives innovation in the car industry. But the lack of standardization is slowing the development of larger-scale projects.

GWÉNAËLLE DEBOUTTE, IN BERLIN



At its Regensburg site, BMW has doubled the seat conveyor system of the 1-Class with a digital twin.

Digital twin technology boosted reliability by 20% on the robotic line that fits door seals at the Volkswagen plant in Zwickau, raising it to more than 90%. Instability had been a feature of the line up to that point caused by poor correlation between the robot's rotation speed and the pressure applied to the seals. Result? Seal defects, manual interventions and waste of time. Rising to the challenge in 2018/2019, the team tasked with digitizing the plant created a virtual duplicate of the operation to improve efficiency. Everything is digitized: from the robot rotation speed and seal temperature to application pressure and door model. Combined and updated in real time, the system mines the information to calculate the optimum configuration for the robots for each type of door. "Our fault rate dropped to zero and productivity increased 30%," enthused Frank Göller, Head of Digital Production.

Volkswagen is not alone. All German carmakers now use digital twins in their plants. "There are so many applications, from twinning the car itself, the spare parts, or the on-board computer to improve the experience on the road. In production, the applications include predictive quality control of the press, welding, soldering and in the paint shop," reeled off Olaf Sauer, Head of Automation at the Fraunhofer Institute for Optronics, System Technology and Image Exploitation (IOSB). For BMW Group, digital twins applied to virtual commissioning are a powerful time-saving tool. "Each time we introduce a new model or change part of an installation, we have to stop the line and test with pilot runs to prevent programming errors and collisions between the robots before gradually stepping production back up", explained Markus Baumann, Head of Virtual Commissioning at BMW. This all takes time and the slightest delay is costly".

Targeted deployment

Equipment is tested virtually using digital twins before starting real-world production or making changes to the infrastructure. The twin is configured with a 3D model of the line, its kinematics and the entire mechanical, mechatronic, electrical, IT and software infrastructure. Then the model is put in motion to see where the problems might occur and correct them in advance. "Although the process can take anything from a year to two years, it saves us a lot of time in the end", according to Martin Langosch, digital expert on the virtual commissioning team. In the space of two weeks during the holidays in December 2019, BMW successfully replaced

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EUROPA VILLAGE
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D.R.

"We need a standardized data exchange format"

ARNDT LÜDER
Director of the Production Systems and Automation Chair at the Institute for the Science of Work and Plant Automation at Otto von Guericke University in Magdeburg

How are German manufacturers investing in digital twins?
This is a huge challenge and the auto industry is pouring considerable technical, human and financial resources into it. On the one hand, carmakers have initiated their own projects to get experience and identify obstacles. At the same time, there is growing demand to exchange skills, which is in all their interests, since their core business is to produce cars, not to master the latest in digital twin technology.

What's the state of play?
All players in the industry are in phase one for the past few years, i.e. all their engineering data is being centralized to give a consistent description of a process. Phase two involves automating real-time access to the data needed for modeling. We'll see the first automotive production lines using digital twins in five years max.

What obstacles remain?
We need a standardized data exchange format. And there are several task forces working on this. For example, the administration shell, which is a key concept of Industry 4.0, is used to define how the data should be described and structured in the digital twin. Then there's AutomationML, which is a different approach that aims to develop a standard for use in the communication protocols, based on the OPC-UA model.

all the suspended bodywork conveyor frames in the assembly hall at its Leipzig plant – a process that would have taken months without the digital twin.
Although the gains are significant, the investment required to install the digital twins and their complexity are big constraints. "The idea is to target how we deploy them," continued Markus Baumann. "We analyze how valuable they are: is this stage critical for quality, productivity, for avoiding a bottleneck?" BMW twinned the seat conveyor system for the BMW 1 series at the Ratisbonne plant. "All the seats go through a single lane," said Martin Langosch. "We analyzed the cost-benefit ratio and concluded that it was worthwhile using a virtual twin to increase reliability." The degree of sophistication also varies. BMW systematically inputs engineering data to its digital twins, but doesn't systematically capture and input real-time production data. "We haven't yet put our virtual commissioning models in motion, input with data such as displacement, speed, temperature, pressure, etc.," conceded Markus Baumann.

Simplify IT infrastructure

The picture is similar at Volkswagen, where the strategy is targeted and dynamic twins updated in real time are not yet commonplace. They are deployed as needed, for instance on the press at Wolfsburg and to install windshields at Audi's Ingolstadt plant. The Group doesn't yet have full chains where all equipment, operators and material flows would be simulated and predicted in real time. It has also chosen to limit the amount of data. «Potentially, the sensors provide us with an enormous amount of information, but we only select the most relevant data. Some processes measure air humidity, for example, which we don't yet need. In future, we plan to add in more data to increase the accuracy of our twins, as IT interfaces improve and become simpler," explained Frank Göller.
But, there are challenges ahead, starting with standardization. Martin Langosch again: "we buy data from our suppliers to feed into our 3D models. But, since the quality and format differ, we have to use an assist system to convert the data to a format compatible with our virtual planning tools." The aim is to develop a universal format to produce data with a standard level of detail and execution pattern (see above). What's more, changing the existing IT infrastructure from a monolithic to a modular and dynamic structure is complex. Volkswagen brought Amazon Web Services on board to develop its cloud architecture and uses Siemens' solutions for its applications. "The problem is that we can't stop our current IT system without stopping production, which is not an option," said Frank Göller. «The complexity comes from the fact that the algorithms are so interlinked. They have to be carefully extracted, cut, re-written and moved to the new application infrastructure." This painstaking task started in 2018 and is expected to take from three to five years.

VIDEO GAME

FLIGHT SIMULATOR IS EXTENDING THE BOUNDARIES OF REALISM

The Bordeaux-based company Asobo has developed the latest version of Microsoft's flight simulator game. Cloud-stored data has made it impressively realistic.

JULIEN BERGOUNHOUX


MICROSOFT

The cockpits are copied perfectly, even glass cockpits.

FLIGHT SIMULATOR'S KEY DATES

- **1978** First version of the software
- **1988** First 3D graphics
- **2006** Release of Flight Simulator X
- **2019** Announcement of the new project

In 1976, Bruce Artwick, a student at the University of Illinois, showed in his Master's thesis that aircraft flight could be modeled on an 8-bit microprocessor: Motorola 6800. Three years later, he released Flight Simulator, a program that was to become a best-seller on Apple II. To prove the superiority of the new 16-chip computers, including the famous IBM PC, Microsoft obtained the software license in 1981 and launched the first version of Microsoft Flight Simulator the following year. Many things have changed since then. Flight Simulator has emerged as the most famous and complete flight simulator game in the world. The next episode promises to provide revolutionary realism.

The new Flight Simulator project Flight Simulator X was announced in June 2019, thirteen years after the previous episode was released. This is the thirteenth title in the series and is being developed by the Bordeaux-based company Asobo Studio, supervised by Microsoft. "We had the idea for this following our collaboration with Asobo Studio on the HoloTour application for our HoloLens augmented reality helmet," recounts Jörg Neumann, director of the Flight Simulator project at Microsoft.

"Asobo recreated the Machu Picchu using Bing Maps' data and the result was very realistic. Asobo owns this excellent proprietary 3D engine, and I was curious to know if it would be able to do the same thing on a very large scale. So four years ago I rang its CEO and co-founder, Sebastian Wloch, to ask him if we could try with Seattle. Within a few weeks, a small Cessna plane was flying over this city. That's when I knew we were onto something."

Simulating the entire planet

This decision also reflects a change of strategy at Microsoft, which has decided to step up its production for the video game market. The watchword is to take maximum advantage of in-house technology to create an experience impossible to achieve elsewhere. The Flight Simulator project is therefore using the Azure cloud infrastructure and map data from the Bing search engine to recreate the entire planet, with an unusual degree of graphical fidelity. This represents more than 2 petabytes (2,000 terabytes) of aerial photos and satellite data. "We're constantly receiving new data from Bing. Today, for example, we obtained data from the polar regions. It's a continuous process and the Azure infrastructure enables us to integrate data quickly," explains Neumann.

Asobo's 3D engine has proved decisive for this since it can display items in real time even though they are stored in the cloud. It can also add realistic textures and light effects to them and locally manage a plane's 3D rendering. "We've been working on this engine for years and use it for all our games. It can display very large environments, which is very difficult due to issues concerning accuracy, object density,

The cities are copied so accurately you can recognize them at a glance. Here, on board an Icon A5, is a view over Bay Bridge and the Fisherman's Wharf neighborhood of San Francisco.

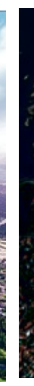
and memory management. In 2009, we even earned a Guinness record for our Fuel game," says Wloch. This hybrid approach also includes procedural generation of ground, vegetation and buildings in the two million cities containing the simulator. They are created automatically from map data by following a set of complex algorithms.

More realistic weather conditions than nature

The most important human structures for a flight simulator are obviously airports. There are 44,000 of them throughout the world, and Flight Simulator's teams plan to include all of them in the software. It already contains 37,000 airports, which have been created or edited manually to make them as realistic as possible. They are filled with travelers and workers (generated procedurally), who bustle around realistically in the terminals and on the runways. "Of the 200 people working on the project throughout the world, 50 are almost completely devoted to creating and modifying the environment, especially airport traffic lanes and runways. The runway surfaces and materials (tarmac, high or low-lying grass, earth, etc.) are also taken into account to give pilots the most accurate possible sensations when they are at the controls. "We can manage different types of static and dynamic friction on varyingly uneven surfaces," says Wloch.

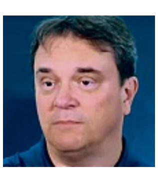
Although the ground is important, most of the time spent in the flight simulator is in the sky. Here too the new Flight Simulator has achieved a level of accuracy and realism that bears no comparison to its predecessors. Starting with its simulation of the atmosphere, from sea level to high altitude: "We simulate 60 different vertical layers," says Wloch.

Display of how air currents interact with land topography.



Atmospheric pressure, wind speed and direction, and air humidity data is all taken into account. Jet streams and turbulence are present, and are accurately reproduced in accordance with the simulator's physical model. "If I'm flying in a valley or along a mountain ridge, ascending currents are present where they would be in reality since we simulate the wind's interaction with the ground," continues Wloch. The wind even moves the grass and the leaves on trees.

The atmosphere is simulated on a local computer, but weather conditions are cloud-managed. The clouds in the sky are volumetric, which means you can fly through them, and their density varies according to location. All cloud types are represented, and their formation and dissolution depends on



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Jörg Neumann, director of the Flight Simulator project at Microsoft

"We will continue to develop Flight Simulator. We're going to fine-tune our representation of planet Earth until we come close to a digital twin."

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Cloud opacity varies according to density, as in real life.

A PILOT TRAINING TOOL

At the end of 2007, Aces Game Studio, which was then responsible for the Flight Simulator series, announced the creation of Microsoft Enterprise Simulation Platform (ESP), a simulation platform for companies that is based on Flight Simulator X. After Aces Game Studio closed in 2009, the US defense giant Lockheed Martin purchased the source code and intellectual property of this project to create Prepar3D, a flight simulator to train professional pilots. It is regularly updated and is still used, even though it is rudimentary compared to this new version of Flight Simulator, which uses modern technology. Could Microsoft adapt it for pilot training? «Our simulator is intended for players rather than training," says Jörg Neumann, director of the Flight Simulator project. Nevertheless, we receive this type of request every day and are attentive to what people are saying. We're aware that there's a worldwide shortage of pilots. For the time being, our priority is to complete our simulator, but it's possible that we'll do something in this area in the future."

air currents, as in reality. They are visible up to 600 kilometers away. They may be heavy with rain, which is itself volumetric, enabling accurate reproduction of how rain drops impact on a plane windscreen, even how they trickle over it according to the aircraft's speed and direction. The same is true for fog, snow and frost, which form in real time.
The combination of weather data and a physical model also enables light to be managed much more accurately, which significantly contributes to the overall visual quality. The clouds create shadows, both on the ground and on one another, and their opacity fluctuates according to their composition. The mountains cast their shadow on the ground and on low-altitude clouds. The sea and lakes reflect the sunlight. Light diffusion takes account of these parameters, as well as atmospheric conditions (temperature, humidity, density, air pollution, etc.), to give a very realistic result. Even rainbows can form. The cycle of day and night is also reproduced: the clouds are lit up by airport, road and city lights, while the moon and stars illuminate the ground. The show-stopping feature, however, is that users can not only set whatever time of day or weather conditions they want, but also receive real-time weather data from the cloud to fly in real conditions. "The spatial resolution varies and can be 3 or 10 kilometers, depending on where you are on the planet. Overall, it's very accurate. We also extrapolate developments in the weather, so even if we collect data that is thirty minutes old, it is still very accurate," adds Neumann.

Heavy air traffic

The game's physical model and all this data help make the flight model realistic. Microsoft is so confident that last September it arranged for some journalists to be flown over Seattle in a Cessna plane after first organizing their initiation on Flight Simulator, with a Saitek Pro Flight yoke and Thrustmaster TPR rudder. The verdict was unanimous: very similar sensations to reality, heightened by the perfectly copied cockpit and instruments. One criticism made of simulators

The simulator is just as well-suited to small aircraft...

...as airliners, in this case the A320neo.

MICROSOFT

in the past was their empty sky. A maximum of 16-24 people could fly on a dedicated server at the same time, whereas tens of thousands of planes fly every day. Here too, the cloud has enabled a paradigm shift. The developers have created a simple system that you can activate or deactivate, without adjustments, and which enables you to see all the other players at the same time. "When I'm flying over Bordeaux, there are always four or five other planes in the vicinity. We wanted to recreate this camaraderie," says Wloch.

Flight Simulator is currently in the Alpha version and its release date has not been announced. Nevertheless, thousands of dedicated users are spending hours on it, providing invaluable feedback for the development team. A dozen or so aircraft are available, including Cessna 172, Robin DR400, Daher TBM 930, and Airbus A320neo and have been copied down to the tiniest detail. Microsoft has also joined forces with Boeing, Diamond Aircraft, and Icon Aircraft. "We're going to introduce some representative aircraft, but we're leaving room for third-party developers, who will take care of modifications for the software. They're an integral part of the ecosystem and we're in touch with hundreds of them. We provide them with a very comprehensive development kit. The goal is to have hundreds of aircraft," stresses Neumann. This modularity and scalability are an essential aspect of the project. "Flight Simulator isn't a typical game that you finish developing before selling it. We've concentrated on various relevant priorities for a flight simulator, especially in the light of our testers' feedback, but we will continue to develop it. For example, we're going to fine-tune our representation of planet Earth by adding road and sea traffic, forest fires and animal migrations until we come close to a digital twin. But that will take years."

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