Ansys

ADVANTAGE

EXCELLENCE IN ENGINEERING SIMULATION

ISSUE 3 / 2021

SIMULATION SAVES LIVES

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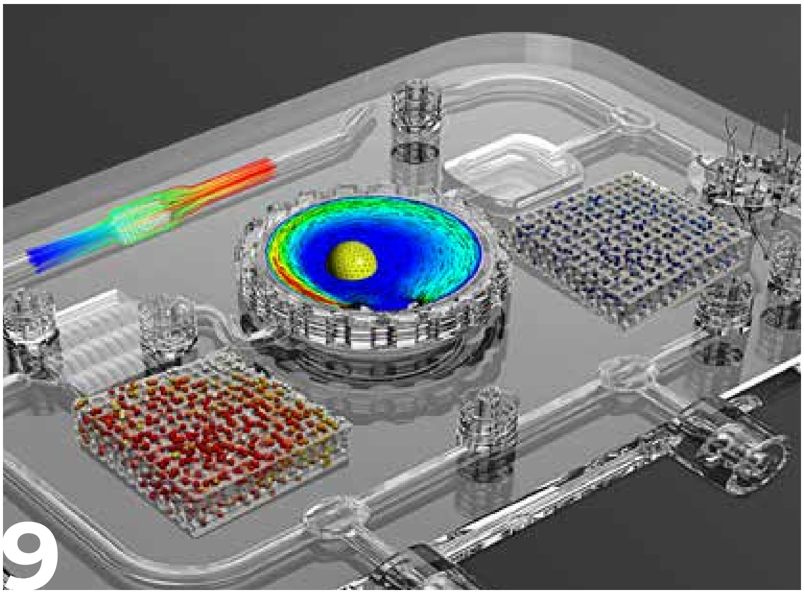

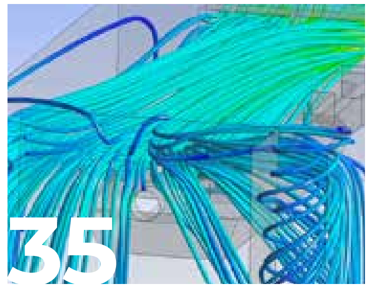

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ADVANTAGE

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ansys-advantage@ansys.com

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ANSYS, Inc.,
Southpointe, 2600 Ansys Drive, Canonsburg, PA 15317

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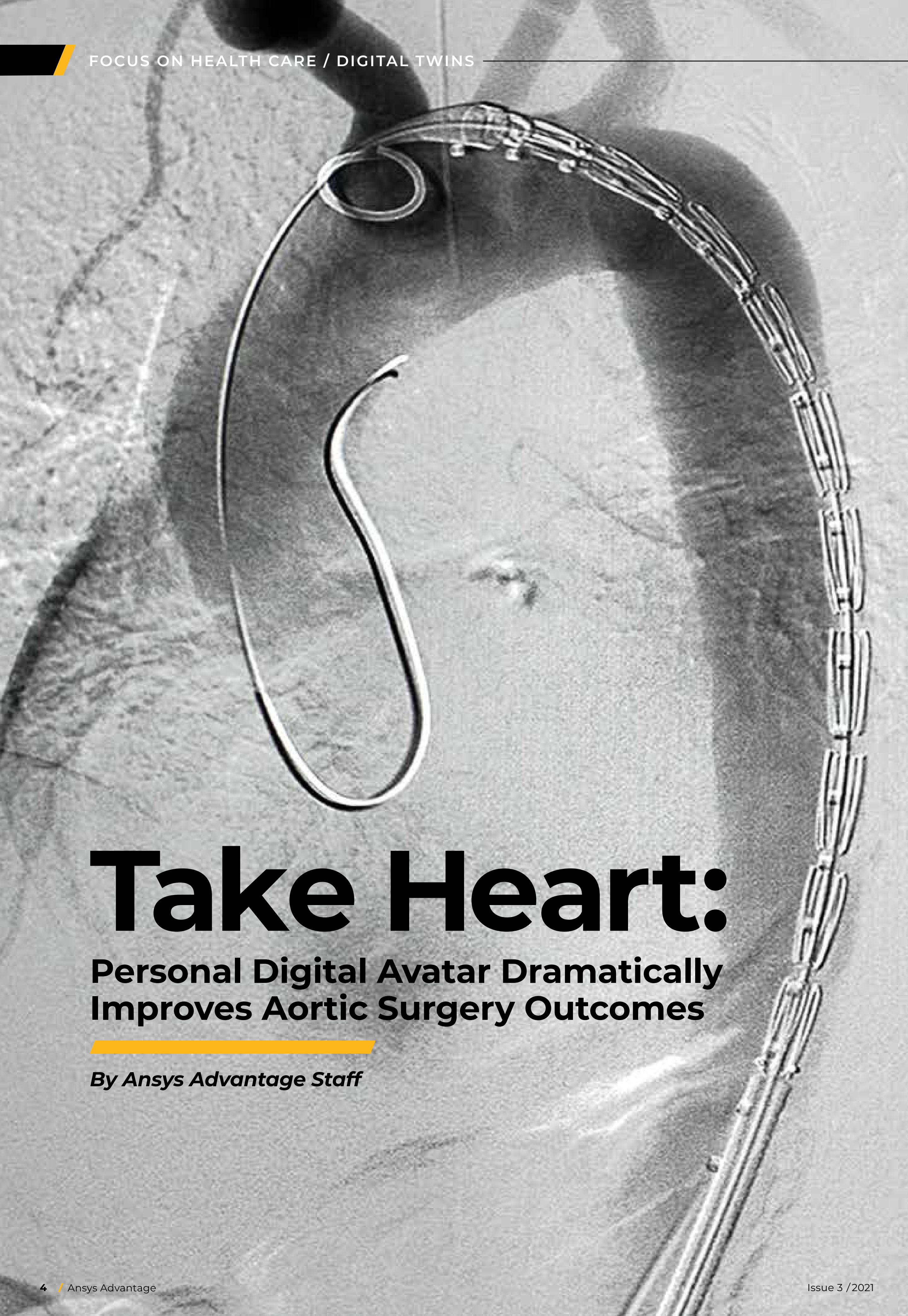


Take Heart:

Personal Digital Avatar Dramatically Improves Aortic Surgery Outcomes

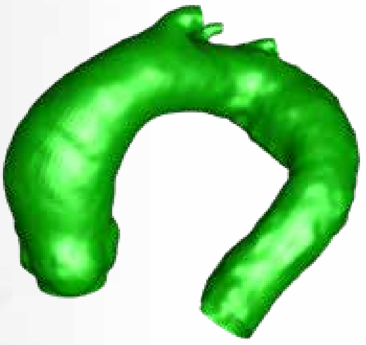
By Ansys Advantage Staff

Each year, thousands of people die as a result of aortic aneurysms — balloon-like bulges caused by weaknesses in aortas, the large artery that sends blood from the heart through the vascular system. If an aneurysm remains undetected, the aorta can eventually tear or rupture, causing uncontrolled internal bleeding.

When an aneurysm is detected before it ruptures, thoracic surgeons can intervene by repairing the aorta and eliminating the aneurysm. However, repair surgery comes with risks. If surgeons use conventional open-surgery approaches, up to 12% of patients may not survive the procedure.

A newer and less invasive technique, endovascular aneurysm repair (EVAR), has a much lower mortality rate. In this procedure, surgeons make a small incision in the groin, through which they insert a stent graft and thread it upward until it reaches the aneurysm. There, it is positioned optimally to reinforce the section of weakened tissue.

The greatest challenge of an EVAR procedure is that surgeons are operating blindly, without a detailed understanding of each patient's unique vascular geometry. While imaging tools help guide the insertion and placement of the stent, the process is characterized by real-time discovery and adaptation. Surgeons have little advanced knowledge of the patient's vascular system in three dimensions because imaging tools like computed tomography (CT) scans only reveal two dimensions.



Aneurysm model

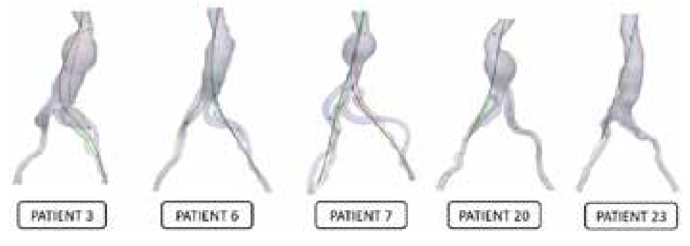
Aortic flow simulation

SIMULATION PROVIDES A CLEAR, PATIENT-SPECIFIC VIEW

Professor Jean-Philippe Verhoye is a leading global advocate for using biomedical simulations of individual patients' vascular systems to inform surgery and produce better outcomes.

Prof. Verhoye is head of cardiac and vascular thoracic surgery at Rennes University Hospital, France. He is also the president of the French Society of Thoracic, Cardiac and Vascular Surgery, and a member of the European Society of Thoracic, Cardiac and Vascular Surgery, as well as former secretary of the French College of Cardiac Surgery. He has published 190 articles and two books on cardiac and vascular surgery topics.

"By using routinely available images like CT scans and other clinical data to generate 3D virtual models of the vascular system, surgeons can 'practice' their EVAR procedures in advance, using the actual patient's specific geometry," says Prof. Verhoye. "Since no two patients' bodies or vascular systems are alike, surgeons can optimize the process of threading and positioning the stent on an individual basis. "Simulation allows the creation of a kind of digital twin — or avatar — of a given human body," explains Prof. Verhoye. "We can work on that personal digital avatar and perfect our surgical techniques without any degree of risk exposure for the patient."

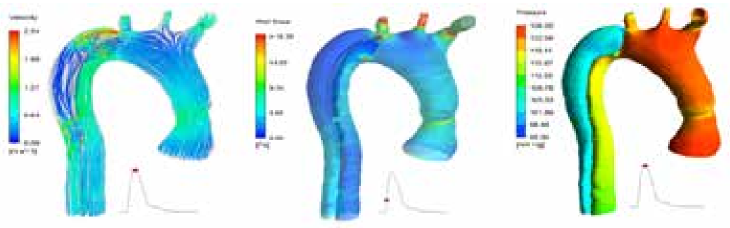


These simulations of endovascular aneurysm repair (EVAR) surgery, modeled using Ansys software, show the very different vascular geometries of five patients with an aortic aneurysm. Surgeons at Rennes University Hospital, France, were able to simulate the insertion of an aortic stent in advance (path shown in black) for an optimal, error-free outcome (path shown in red).

FROM EMERGING CONCEPT TO EVERYDAY PRACTICE

For more than seven years, Prof. Verhoye's cardiac and thoracic surgery team at Rennes University Hospital has been perfecting the use of patient modeling via Ansys LS-DYNA prior to EVAR procedures. "We have a dedicated team of researchers who perform the meshing and modeling, and they work closely with the surgical team," he notes. The resulting model not only reflects the overall vascular geometry, but also the distance between the aorta and the spinal cord — a critical boundary condition — and the properties of artery walls.

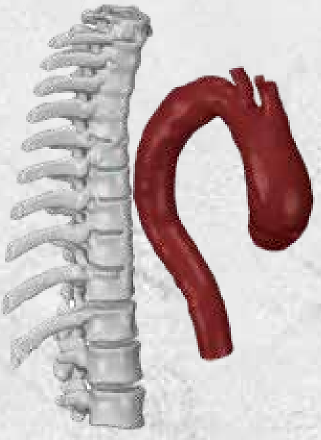
"Ansys has collaborated with us to ensure that the available data, including CT and MRI (magnetic resonance imaging) scans, feeds into the software to automatically produce a geometrically correct, finely meshed model," Prof. Verhoye continues. "Ansys has also helped us develop some specialized expertise, such as understanding what kinds of tissue deformation occur when the stent is inserted."



In modeling a specific patient's vascular system, Ansys software accurately replicates the overall organ geometry, as well as key properties such as calcification or thrombosis of the artery walls.

Prof. Verhoye and his team use the Ansys-enabled modeling approach during more than 100 successful EVAR surgeries each year. "It has taken us years to get from the initial idea to practical application," he states, "but today pre-surgery modeling is a routine procedure for aortic aneurysm patients at Rennes."

Patient-specific modeling provides Prof. Verhoye's team with three distinct capabilities. "First, simulation allows us to accurately visualize the interior of a patient's body, without opening the thoracic cavity," he says. "That in itself is revolutionary. But it also enables us to confidently predict outcomes and then communicate about surgery challenges on a case-by-case basis. We go into surgery with a shared expectation of what will happen. That's invaluable."



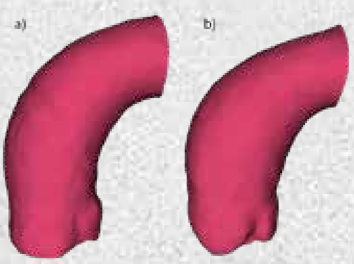
A model represents the distance between the aorta and the spine.

MODELING A MORE INNOVATIVE FUTURE

Not only is Prof. Verhoye performing simulation-driven surgery himself, but he is also training the next generation of surgeons in these advanced techniques. "I think in 10 to 15 years, pre-surgery modeling will become an industry-standard procedure," he predicts. "But we will have to undergo massive clinical trials before regulatory and insurance company approvals are gained on a large scale. Until then, we are building our own capabilities here and establishing best practices."

Beyond approvals, Prof. Verhoye points out that there are cultural and financial obstacles standing in the way of faster adoption. "We are lucky that Rennes understood the concept of simulation and its potential benefits very quickly," Prof. Verhoye points out. "We have been able to invest in proving the idea. Not every university or hospital is open to supporting this kind of radical innovation.

"We have also been given the freedom to assemble a simulation team that really understands our challenges as surgeons," Prof. Verhoye continues. "Often there is a disconnect between clinicians and engineers, but we have been able to overcome that challenge by living, eating and sleeping together. We speak the same language now. We are equally devoted to applying the best-available technologies to improve patients' outcomes and save lives. That is how real biomedical innovation takes place."



The model also shows properties of artery walls.

Promoting the Benefits of In Silico Medicine

Dr. Rebecca Bryan

When she was a doctoral student, Dr. Rebecca Bryan used statistical modeling techniques, supported by Ansys Mechanical, to design methodology to allow the evaluation of orthopedic devices across populations of femur models. The idea fascinated her.

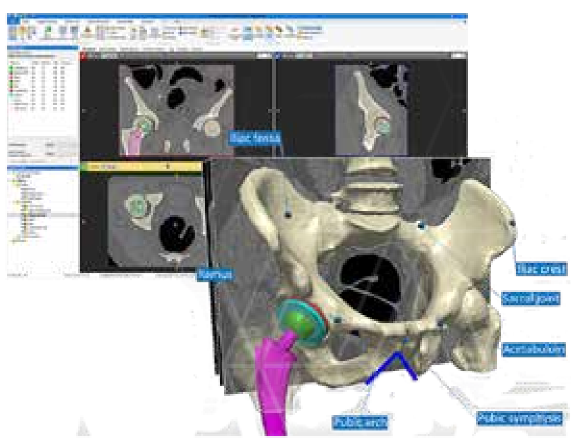
"There is so much variability between each of us. Imagine testing a new design on a young, 6-foot-6-inch commando and then expecting it to work the same way for your 90-year-old, 5-foot grandmother!" Bryan says. "It was exciting to try to capture that variability and use it to better understand how implants would perform using computational modeling. It was hard work, but I loved it."

One of the challenges was converting tens of patient data sets — typically CT images — into 3D models suitable for computational modeling. When Bryan learned that a startup company called Simpleware had created software specifically designed to do this, she applied for a job there immediately. "I turned my thesis in on Friday and started working at Simpleware as an application engineer on Monday," she says. "I was enthusiastic about the product and wanted to get right to work."

BECOMING A GLOBAL ADVOCATE FOR IN SILICO MEDICINE

Bryan has been at Simpleware for over 11 years, through its acquisition by Synopsys in 2016, and has advanced steadily through roles in alliance building, sales and business development. She has become a global advocate for using advanced computational technology to model and simulate medical outcomes, an approach known as in silico medicine.

"If we can use medical imaging to generate 3D, high-quality computational models of a patient to predict how implants will actually perform in their body or provide insight for surgical planning, then we can start to customize health care and dramatically improve outcomes," she explains.



Simpleware ScanIP Medical, combined with Ansys simulation software, helps clinicians build reliable models for pre-surgical planning.

"Equally exciting, we can use in silico approaches on a massive scale to test new devices or treatment plans in a simulated environment and help provide evidence for regulatory approvals," she continues. "Not only can in silico clinical trials be significantly faster and cheaper than traditional human or animal studies, but they pose zero risk — giving researchers freedom to innovate."

Supported by artificial intelligence and machine learning, Simpleware's solutions significantly reduce the time needed to generate simulation-ready models, supporting mass adoption of in silico approaches. 3D imaging, such as CT scans and MRIs, can be rapidly and seamlessly translated into 3D models that are ready for design and simulation studies. Via an automated process, Simpleware can accurately process images, obtain measurements and statistics, and export high-quality models in a fraction of the time required for manual processing.

Because Simpleware exports models directly to Ansys software, the two companies have formed a partnership to communicate the benefits of in silico medicine. "Working together, Ansys and Synopsys aim to eliminate the technical barriers to in silico clinical trials," Bryan points out. "Now our shared mission is to overcome cultural and educational obstacles through outreach, advocacy and example. We want to spread the word and see in silico medicine reach its full potential. I truly believe in silico medicine has the power to transform health care, and I'm happy to be part of that transformation."

Using Simulation and In Silico Models to Simulate Biological Processes

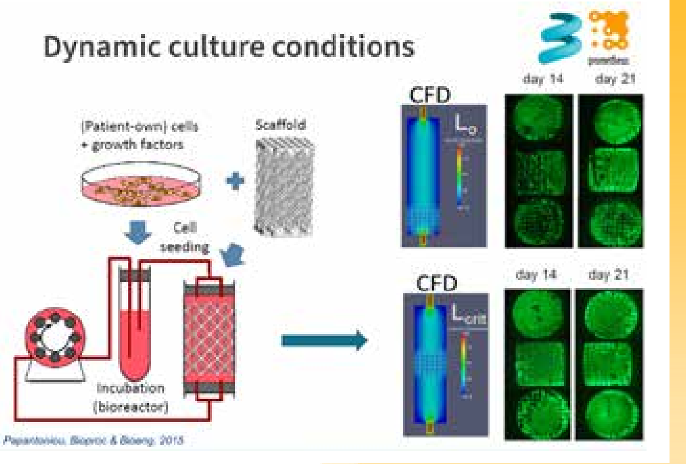
Dr. Liesbet Geris

The concept of in silico experimentation — or research performed on a computer — is capturing the imagination of the global biomedical community. By replicating disease progression, predicting surgical outcomes or studying the efficacy of various drug therapies in a simulated virtual environment, researchers can develop more effective treatment strategies and maximize patient outcomes, with no risks to human or animal subjects.

"Very soon, I believe it will be considered unethical to fail to use in silico methods for biomedical research," predicts Dr. Liesbet Geris, research professor in biomechanics and computational tissue engineering at the University of Liège and KU Leuven in Belgium. Geris is a long-time user of Ansys solutions in her research, which focuses on bone and cartilage regeneration, computational tissue engineering and the design of orthopedic implants that can be 3D printed on demand.

"Given the enormous benefits of the in silico approach and the increasing accuracy of modeling and simulation tools, there will be a reduced need to incorporate humans or animals into our experiments," Geris explains. "We will be able to move faster, more confidently and more cost-effectively toward research discoveries by using advanced simulation tools than we would using traditional in vitro and in vivo approaches."

According to Geris, one of the primary benefits of in silico experimentation is the ability to create customized models that reflect a specific patient. "Every human body is distinct in its geometry, movements and behaviors," notes Geris. "By creating a patient-specific simulation, we can predict how a proposed treatment plan will work not just in a generalized way, but in some cases also for a specific person. This is a revolutionary concept that has the potential to fundamentally change the way we treat patients in a medical setting."



Geris encourages the use of in silico models for better health care treatments.

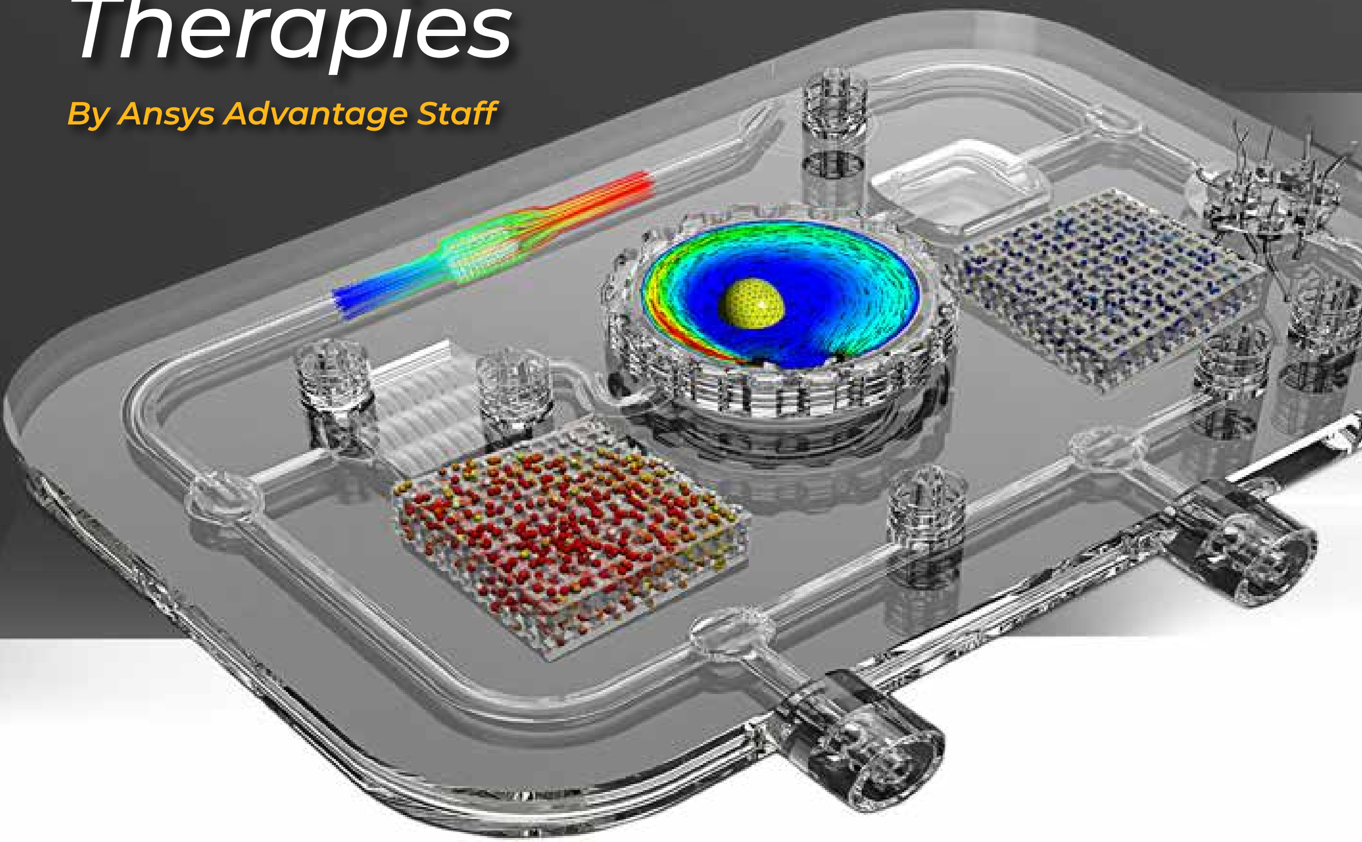
Geris, who is the executive director of the Virtual Physiological Human Institute (VPHi), is at the forefront of this revolution. In her position with VPHi, she proactively advocates the use of in silico modeling in health care through collaboration with the clinical community, the European Commission and Parliament, and regulatory agencies such as the European Medicines Agency (EMA) and the U.S. Food and Drug Administration (FDA). Geris is the youngest-ever executive director of VPHi, and the first woman to hold this position.

Ongoing advances in Ansys simulation software are making it much easier for Geris and her research team to replicate biological processes, such as medium flows through scaffolds in bioreactors, that are critical to her work. "We are getting closer and closer to ensuring that every research team and every clinical team is using simulation and in silico models to simulate biological processes, predict patients' biological responses to treatment and significantly improve outcomes. I'm proud to take a leadership role in encouraging the adoption of computer simulation in the global medical community."

"We are getting closer and closer to ensuring that every research team and every clinical team is using simulation and in silico models to simulate biological processes, predict patients' biological responses to treatment and significantly improve outcomes."

Digital Twins Help Bioreactors to Produce Personalized, Cell-Based Therapies

By Ansys Advantage Staff



While a few big pharma companies produced amazing results in developing and manufacturing massive amounts of COVID-19 vaccines in under a year, many pharma challenges exist on a smaller scale — that of an individual patient or small group of patients with a rare disease. This "personalized medicine" approach has led companies like Antleron in Leuven, Belgium, to redefine the concept of a bioreactor, using Ansys simulation solutions and digital twins to optimize and customize the growth of cells for therapeutic purposes.

"Though we still use the word 'bioreactor,' I think a better description is 'customized factory,'" says Jan Schrooten, co-founder and CEO of Antleron. "It looks like a chemical plant in miniature, and the output might be 1 milligram of end product, instead of thousands of liters in a large pharma plant."

Schrooten founded Antleron in 2014 after working in academia for 25 years trying to build living implants and experimenting with tissue engineering. Being an engineer and faced with the limitations of academia in translating lab work into real-world solutions, he quit his university position and founded a startup company. After much thought, he and his colleagues decided to call the company Antleron after the way deer antlers grow from nothing to a meter or more in length every year — one of the most impressive regenerative biological processes in nature. The name fits their mission of "Enabling living therapies: turning cells into personalized therapies, tissues and organs."

HELP FROM THE ANSYS STARTUP PROGRAM

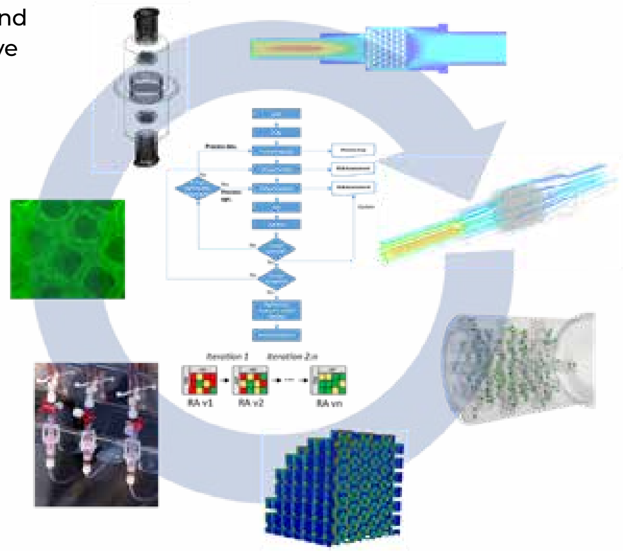
Schrooten was no stranger to Ansys simulation products, having worked with them for about 25 years, and he recognized that simulations would be essential to engineering and monitoring the bioreactors he had in mind. But, like most startups, funds were not exactly plentiful at the beginning. So, he

> *“Though we still use the word ‘bioreactor,’ I think a better description is ‘customized factory.’ It looks like a chemical plant in miniature, and the output might be 1 milligram of end product, instead of thousands of liters in a large pharma plant.”*

contacted Ansys and learned about the Ansys Startup Program, which provided him with simulation software at a fraction of the list price. But he sees more than just financial value in the program.

“Even if we could have paid for a full software license, it wouldn’t have been as helpful as going through the Ansys Startup Program,” Schrooten says. “Exploring the software with Ansys experts and getting their feedback about how best to do what we were attempting is the key. The program provided a framework for our companies to learn from each other and develop a strong relationship that benefits both of us. By engaging in similar collaborations with other partners, we are able to merge the potential of various core computational and experimental techniques and integrate them to enable engineering of innovative cell-based therapy manufacturing solutions.”

Using Ansys solutions, Antleron has been able to design custom bioreactors that place living cells in the best environment for growth and modification. They use Quality By Design, digital twins, additive manufacturing and other engineering technologies to achieve success.



Digital twins are part of Antleron’s Quality-by-Design approach to fast-track development of optimized and scalable bioreactor designs. In an iterative risk-based development process loop, designs are first tested in silico by CFD simulations. Then promising designs are additively manufactured and experimentally tested, resulting in optimized, robust and scalable bioreactor designs at a minimal time and cost.

SIMULATING THE COMPLEXITIES OF BIOREACTORS

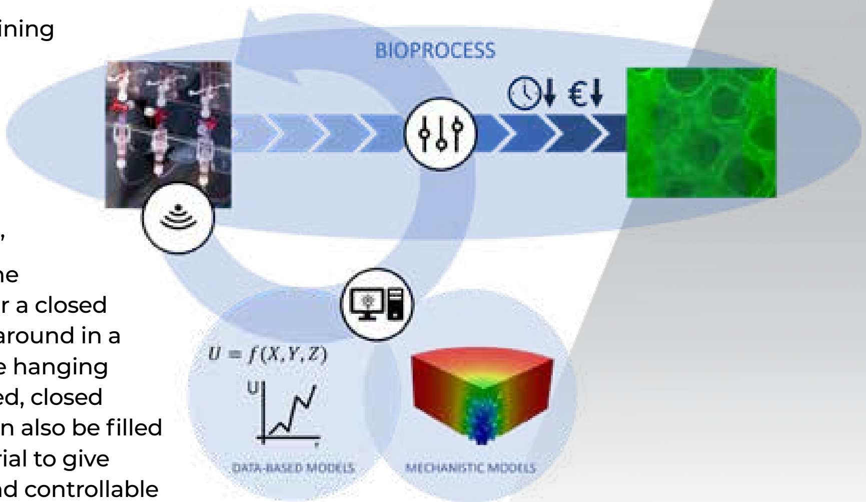
A quick internet search of images of bioreactors yields a series of tanks, stirrers, piping, valves and more that resemble any generic chemical plant and reveal very little about the complex inner workings of a bioreactor. When you add living cells to the equation, with the inherent complexity and variability of biological processes, things can quickly get out of hand.

“One cell by itself is much more complex than the whole bioreactor that we are working on,” says Tommy Heck, who leads the digital twin and modeling efforts at Antleron. “Inside the cell, you have numerous signaling pathways, consisting of various molecules, that all are affected by the nutrients that the cell receives and the mechanical conditions that the cell experiences. So that’s just too complex to describe with a simple model. Since we don’t know exactly what’s going on there, it’s better to simulate the process in a hybrid simulation approach.”

The process starts with a cell source. This source can be an individual patient whose cells are extracted, grown and modified in a bioreactor and then returned to the patient, or it can be a bank containing lots of cells from different donors. These cells are accustomed to grow under specific conditions (e.g., temperature, pH and mechanical rigidity) provided by the human body. However, often the environment for cells in in vitro experiments resembles a plastic petri dish open to the air, which is not optimal.

“Putting cells in a more physiological environment that they recognize improves the situation,” Schrooten says. "The key is defining that environment. We create a three-dimensional — even four-dimensional, because time is important — controlled, closed environment that we monitor and customize for best results."

Instead of cells sticking to the bottom of an open petri dish, or a closed stirred tank with cells floating around in a fluid suspension medium while hanging on to microbeads, the controlled, closed environment of a bioreactor can also be filled with a high-surface-area material to give the cells a more customized and controllable surface on which to grow. This internal material could be a highly porous structure or a more engineered 3D pathway designed for optimal fluid flow and cell growth conditions.



Hybrid digital twins, combining data-based and mechanistic computer models, facilitate real-time monitoring and control of closed bioprocesses, enabling optimized process outcomes and minimized process time and cost.

"You can often build up the internal bioreactor structure out of geometrical units," says Heck. "You can perhaps have a repeated cubic shape, or maybe some convex and concave shapes in there, with some larger channels to distribute the fluid flow. Ansys Fluent is great for predicting the flow through these complex paths. By including computational fluid dynamics (CFD) simulations in an iterative loop of design, additive manufacturing and experimentation, we are able to quickly screen and compare various designs. This significantly decreases the time and cost to develop a bioreactor, while its performance is optimized."

The goal of the combined custom bioreactor with its internal structure is to give the cells a surface to connect to, to provide optimal flow conditions at the same time, and also to ensure efficient supply of the added glucose and oxygen nutrients that feed the cells and make them grow. But inserting flow meters, thermocouples and glucose sensors throughout such a complicated 3D structure is difficult, and therefore the local conditions inside the bioreactor can't be measured. So Antleron has developed an in silico approach to accommodate co-development of hybrid modeling, with the goal of enabling a digital twin of the bioreactor powered by a combined use of mechanistic, physics-based simulations and a data-based simulation approach.

A BIOREACTOR DIGITAL TWIN BASED ON DATA AND SIMULATIONS

"Once you have designed a more optimized bioreactor, you want to be able to know what's happening during cell culture, so you have to monitor and control the process," Schrooten says. "But you can't take the biology out of the bioreactor and perform invasive measurements. You need to put intelligence into the bioreactor and find a way to maximize the use of data. We use digital twins — models that can connect the in silico know-how with the actual experiments — to monitor and control the system in a scalable way."

The mechanistic simulations in the digital twin, overseen by Heck, are the physics-based simulations of flow rate, flow direction, shear, nutrient concentration and other fluid properties typically done by Fluent. Working on the other half of the digital twin solution, Evan Claes, who is in charge of the advanced therapy medicinal products (ATMP) bioprocess and data-based modeling at Antleron, collects data from sensors inside the bioreactor or from noninvasive sampling to effectively "learn" how the cells in the bioreactor respond to different conditions. "Much like how food intake is monitored for infants or young animals, data on the cells' nutrient uptake can be used to infer their growth rate — something which would be impossible to directly measure in the bioreactor," Claes says.

While these data-based models accurately predict cell growth in a "simple" bioreactor, the presence of an engineered internal structure makes the situation more complex. Claes explains: "If you have an internal structure providing a high surface area for the cells to grow on, you may not be able to get a lot of nutrients to the center of this structure — they are consumed by the cells on the outside of the scaffold before they reach the center. But it is almost impossible to gather data on this because you can't put a sensor inside the structure. However, with Fluent we can simulate the concentration inside the structure from knowledge of the concentration outside the structure, which we can measure."

Working together, the mechanistic and data-based simulation approaches provide data to feed the digital twin of the bioreactor. The digital twin gives Antleron engineers and scientists a better idea of what is happening in the real bioreactor at a given time, so they can adjust the amount of nutrients, determine how many cells are in the system and know when to stop the process.

DEVELOPING BIOLOGIC THERAPIES AND GROWING LIVING TISSUE

Besides just increasing the number of cells in a bioreactor, biotech companies can also modify the cells to produce cell-based therapeutics. For example, the starting point can be a sample of induced pluripotent stem cells (iPSCs), which are derived from skin or blood cells that have been reprogrammed back into an embryonic-like pluripotent state. From the iPSCs, an unlimited source of any type of human cell needed for therapeutic purposes can be developed.

"Once I have the number of cells that I need, I can transform them into another cell type, or I can combine them with yet another cell type to form a tissue," Schrooten says. "If I have cells that can form liver or, let's say, soft tissue, I can give them cues in the bioreactor by combining them with a certain material to be transformed into the end product — in this case, liver."

HARVESTING CELLS FROM BIOREACTORS

Once the cells are finished growing and have been modified, if necessary, they must be harvested efficiently from the bioreactor. Because each cell is a discrete unit, Rocky DEM, a discrete element

"By including computational fluid dynamics (CFD) simulations in an iterative loop of design, additive manufacturing and experimentation, we are able to quickly screen and compare various designs. This significantly decreases the time and cost to develop a bioreactor, while its performance is optimized."

software coupled to Ansys Fluent, can help in this process. Rocky DEM can show how changing the flow or adding some enzymes or proteins to the bioreactor can loosen the cells from the substrate they are attached to so they can detach and be harvested.

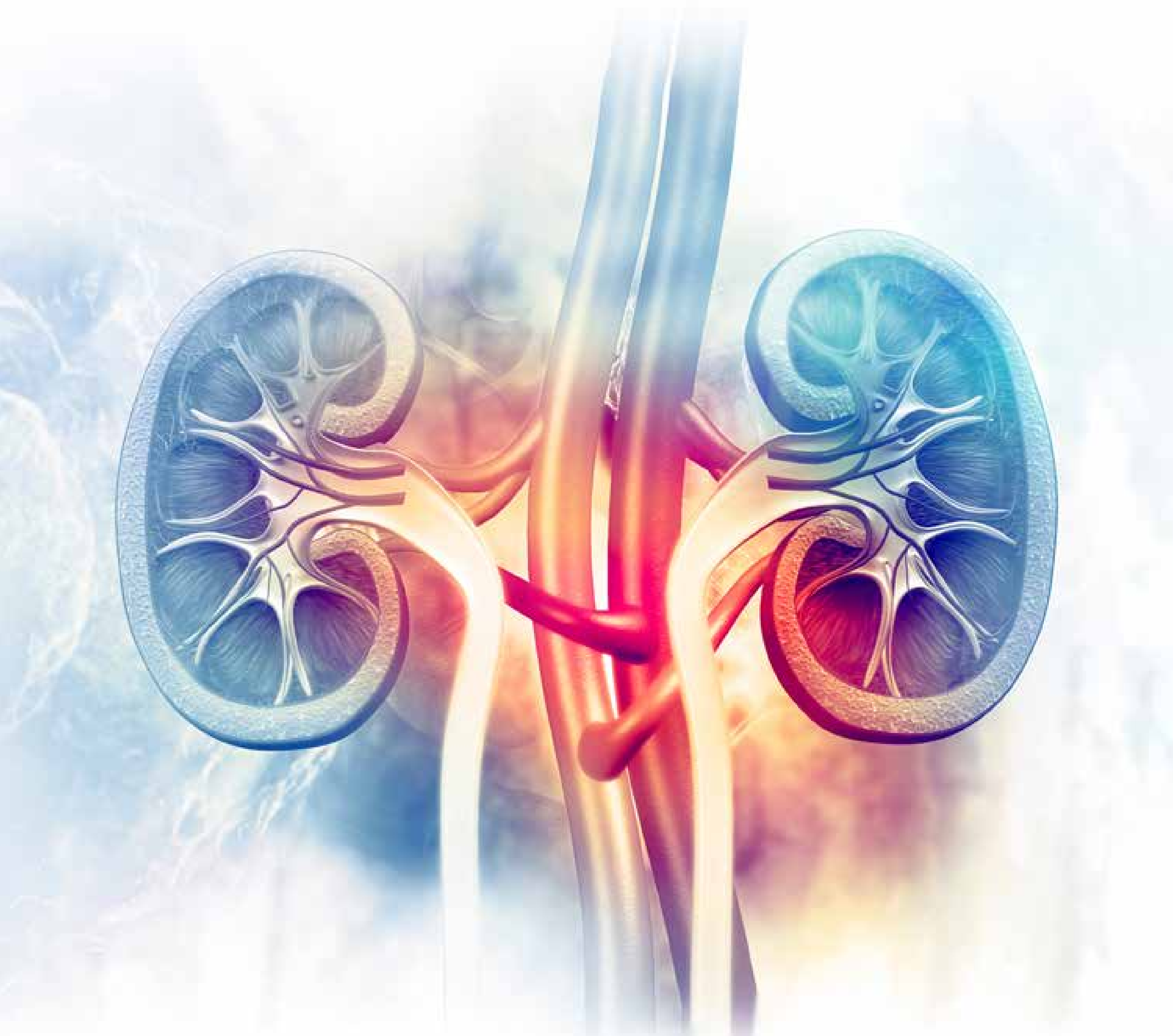
"You have millions of cells in a bioreactor, but they are separate particles, so you want to treat them as such rather than as a continuous material," Heck says. "Simulation using Rocky DEM helps us to optimize the conditions for the seeding and harvesting of these cells."

CURRENT AND FUTURE WORK

One of Antleron's current projects involves investigating the potential of immunotherapy to kill cancer cells. Instead of using radiation or chemotherapy, immunotherapy delivers specific proteins that attack the cancer via their attachment to specific cells that are injected into the patient. In this case, the starting point is the patient's own dendritic cells that are part of their immune system. These cells are multiplied and loaded with the active protein in a bioreactor. Then they are returned to the patient to, hopefully, kill the cancer.

In the long run, Antleron wants to go beyond personalized cell therapies to create living organs that can be transplanted into humans to extend their lives when the original organ fails due to a disease or injury. Despite the number of potential human organ donors, only a small fraction of people actually consent to donating their organs should they die in an accident, and more opportunities are lost because loved ones are not aware of the deceased's desire to donate organs. Artificial organs could help the supply get closer to the demand, but a lot of challenges remain to reach this lofty goal.

"We see a lot of tools and technologies — for example, additive manufacturing and the power of simulation — being used in other industries that we believe can be helpful in health care," Schrooten says. "With Ansys simulations, we can do a lot of the development already in silico before we do it in vitro, and then, finally, in vivo. That's why we say: 'If we know how a bioprocess works, by simulations and by experiments, we can build the ideal bioreactor around it.'"



Building a Bioartificial Kidney

By Ansys Advantage Staff

Ansys Fluent is helping researchers involved with The Kidney Project create a small, surgically implanted, self-sustaining bioartificial kidney that could deliver a quantum improvement in the quality of life for tens of thousands of people currently on dialysis and awaiting kidney transplants.

Most people don't appreciate their kidneys — until they fail. These small organs are responsible for filtering toxins from the blood and regulating electrolytes and blood pressure. They produce urine and critical hormones, and they help maintain the body's pH balance. But in stage 5 kidney disease — also known as end stage renal disease (ESRD) — an individual's kidneys have failed. They can no longer perform these critical functions adequately. Without intervention, death inevitably follows.

The options for intervention, though, are limited. A patient with ESRD can undergo dialysis, a clinical procedure in which a machine filters the blood and removes what toxins it can. Unfortunately, dialysis is only about 10% as effective as a kidney at detoxifying blood, and it provides none of the kidney's metabolic benefits. Furthermore, dialysis comes at a price. The three- to four-hour procedure is expensive, and it can be so exhausting that patients tethered to a dialysis machine effectively lose the entire day. Nor is it just one day: Individuals on dialysis must undergo the procedure three times per week.

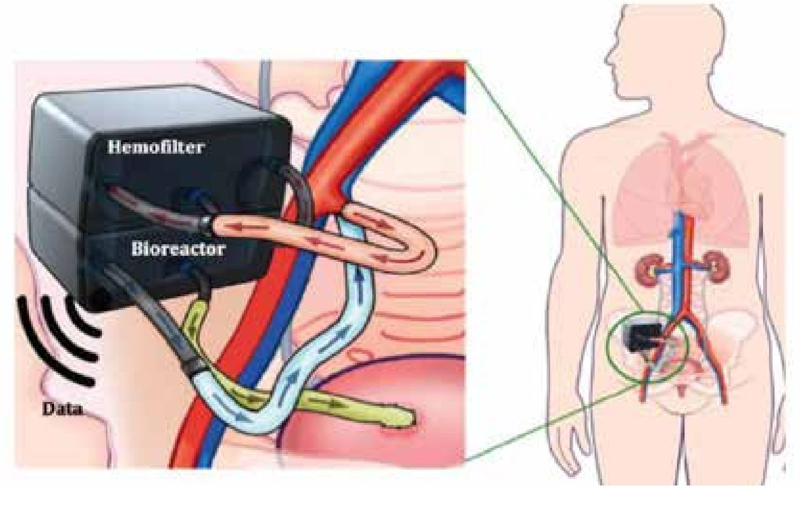
A kidney transplant offers a far greater benefit, as a transplanted kidney can perform all the functions of the patient's original kidney. But too few kidneys are donated each year to meet the demand for transplants. At any given time, there may be more than 100,000 individuals on the kidney transplant waiting list, but only enough viable donated kidneys to perform around 20,000 transplants each year.

CREATING THE KIDNEY PROJECT

All of these factors inspired The Kidney Project, a national research project involving engineers, scientists and clinicians headquartered at the University of California, San Francisco (UCSF) along with collaborators at the University of Michigan, Vanderbilt University Medical Center, and other institutions. The project's goal has been to create a surgically implantable, self-sustaining bioartificial kidney that will perform as many of the functions of a healthy human kidney as possible.

One part of this tiny device — the hemocartridge — is designed to perform the blood filtration functions of the kidney. A second part — the biocartridge or bioreactor — is designed to house lab-grown cells from a human kidney that will deliver the metabolic benefits that a healthy human kidney would. In the first version of the bioartificial kidney, these embedded kidney cells (derived from human cadaver kidneys that were not viable for transplantation but whose tubule cells could be preserved, isolated and then replicated) are expected to support the regulation of electrolytes. In future versions, researchers working on The Kidney Project expect that other embedded kidney cells will add support for the regulation of pH and blood pressure as well as provide other hormonal benefits.

As designed, this tiny, surgically implanted device would operate continuously, powered not by batteries but entirely by the force of an individual's blood pressure. Because toxin filtration would be ongoing, patients with a bioartificial kidney would not need to be connected to a dialysis machine three times a week. Nor would they experience the exhaustion that arises from dialysis. Such



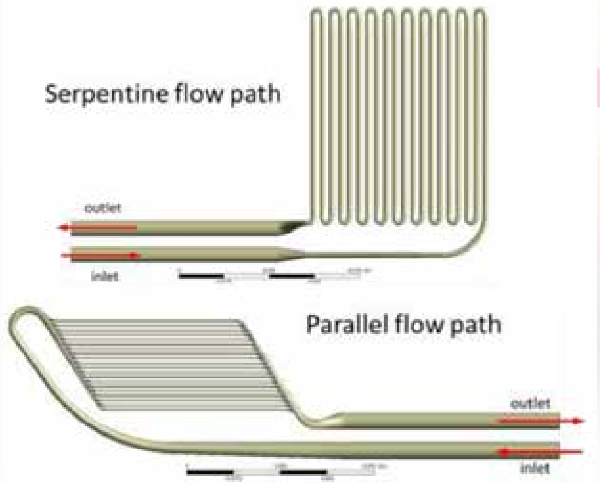
Representation of the implantable bioartificial kidney device showing the two-compartment structure. The patient's blood passes through the hemofilter, where toxins are removed. The blood then redirects to the bioreactor where renal cells ensure proper reabsorption of water and salts from the ultrafiltrate back into the patient's blood.

enhancements would have a powerful impact on an ESRD patient's quality of life. Moreover, they would have a significant impact on Medicare spending. Medicare is US federal health insurance for certain people. ESRD is the only condition where the treatment is fully covered by Medicare regardless of the patient's age. Today, Medicare spends more than $40 billion per year covering the cost of ESRD care. That's around 7% of its annual budget, yet those funds care for only 1% of the Medicare population. No other single disease has this kind of disproportionate impact.

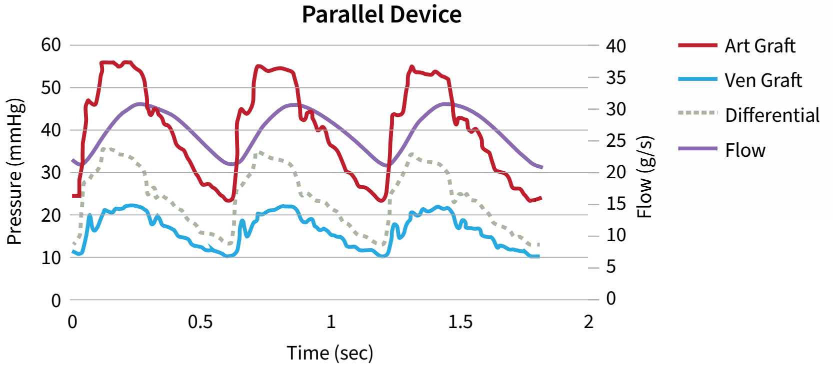
BUILDING A BIOARTIFICIAL KIDNEY

Using Ansys Mechanical, designers working with The Kidney Project created and refined detailed models of all the physical components of the bioartificial kidney, including the

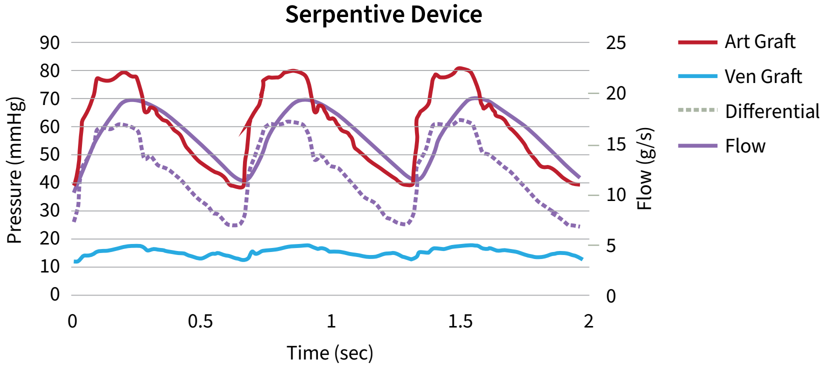
By refining designs and significantly reducing low shear regions, clot development was eliminated. The device on the bottom showed no clot formation after 30 days of implantation in an animal.



Candidate flow paths within the hemofilter compartment.



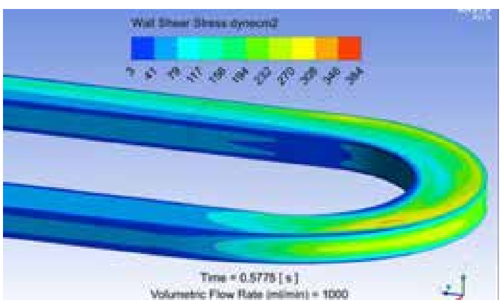
Measuring boundary conditions in vivo for candidate hemofilter flow paths with the computational fluid dynamics (CFD) output flow path indicated in purple



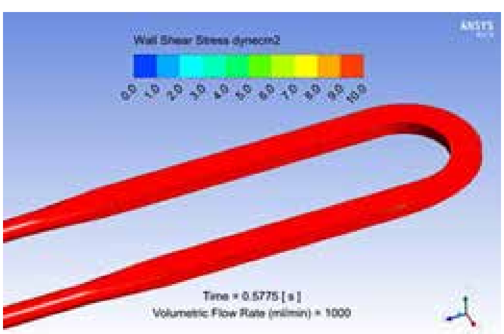
Using Ansys Mechanical, designers working with The Kidney Project created and refined detailed models of all the physical components of the bioartificial kidney, including the breakthrough silicon nanopore membrane technology that makes much of the bioartificial kidney operationally feasible.

breakthrough silicon nanopore membrane technology that makes much of the bioartificial kidney operationally feasible. These membranes, created by The Kidney Project, encapsulate the lab-grown human kidney cells embedded in the device's biocartridge. As blood flows across the membranes, the embedded kidney cells perform the same metabolic functions that the same cells would perform in a normal healthy kidney. After extensive stress simulations in Mechanical, the designers found the ideal balance of thickness, pore size and pore distribution for use in their design. The membrane's micromachined pores are only 10 nm wide — too narrow for blood cells associated with the body's immune system to penetrate the membrane and discover these "foreign" kidney cells, which could result in the body rejecting the bioartificial kidney. At the same time, the membrane's pores are large enough to filter out the toxins, salts and water from the blood. Blood pressure continuously forces those filtrates through the hemocartridge and onto the biocartridge, which reabsorbs the necessary salt and water back into the blood, thereby concentrating the toxins into urine, which is directed onto the bladder.

Given the need to flow blood across these membranes and through the channels within the device, researchers working with The Kidney Project knew that the device had to be designed to minimize the potential for blood clot formation. Clots can form when the chemistry of the blood reacts with a surface or when blood flow is disrupted and blood platelets congregate to form a nucleation site for a clot. Researchers knew that they could treat the surface of the silicon membrane with biologically friendly chemistries to prevent clotting caused by a chemical reaction, but needed a way to optimize and streamline blood flow though the device to avoid disruptions and ensure that blood flow remained laminar.

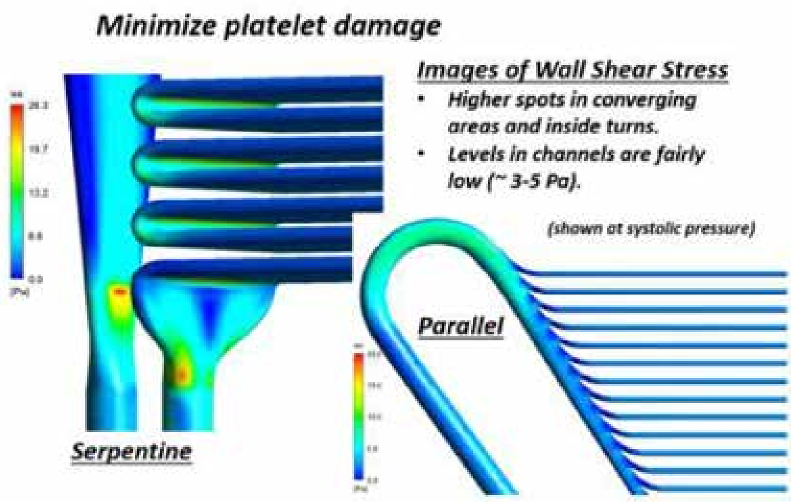


Full range wall shear stress contour plot from Ansys Fluent for a candidate bioreactor blood flow path.



Limited range wall shear stress contour plot from Ansys Fluent for a candidate bioreactor blood flow path. The range is limited here to 10 dynes/cm2 (or 1 Pa), which corresponds to the threshold clot nucleation value.

To accomplish this, engineers working with The Kidney Project teamed up with experts in computational fluid dynamics (CFD) at SimuTech Group, who used Ansys Fluent and Ansys CFX to simulate and analyze the flow of blood into, through and out of numerous bioartificial kidney designs. Researchers needed to understand where zones of blood recirculation might create clotting opportunities within a given design. They needed to tune the design of the filtration cartridge to keep the wall shear stress forces low enough to prevent red blood cells from exploding and becoming nucleation sites for clots. At the same time, they needed to ensure that design refinements did not reduce the low wall shear stress forces to a level so low (below 1 Pascal) that it could cause blood cells to congregate — in turn creating a nucleation site and conditions conducive to clot formation.



Ansys Fluent results of wall shear stress showing both low wall shear stress regions and high wall shear regions, which may lead to platelet damage or activation

By simulating the flow of blood through the different designs in Fluent and visualizing the outcomes in CFX, the researchers at The Kidney Project could measure blood flow velocity precisely, identify areas where clots were likely to form, understand why those spots created opportunities for clotting, and then incorporate and test design adjustments.

SIMULATION FACILITATES DESIGN FILTRATION

Bringing the designs created in Mechanical into Fluent and then running blood flow simulations in Fluent made it easy for The Kidney Project team to assess and refine — to filter, as it were — a large number of design options. They could have created physical prototypes of each design from Mechanical, but testing each physical prototype would have been unfeasible. Such an approach would have taken far longer, incurred much higher costs and raised ethical issues because of the potentially high number of animals that would have been required to validate the effectiveness of the different prototypes.

By simulating the flow of blood through the different designs in Fluent and visualizing the outcomes in CFX, the researchers at The Kidney Project could measure blood flow velocity precisely, identify areas where clots were likely to form, understand why those spots created opportunities for clotting and then incorporate and test design adjustments. They could refine prototype designs quickly in Mechanical and then quickly run new simulations on the refined designs. This minimized the need to build and test prototypes on animals. Indeed, when the researchers at The Kidney Project did build and test a prototype of a promising design, they quickly discovered that blood clots formed in precisely the locations that Fluent had indicated they would — which prompted them to focus even more on refining the designs using Fluent prior to prototyping a promising candidate. They could see that there was strong correlation between the simulations and real-world outcomes.

AIMING FOR INCREMENTAL IMPROVEMENTS

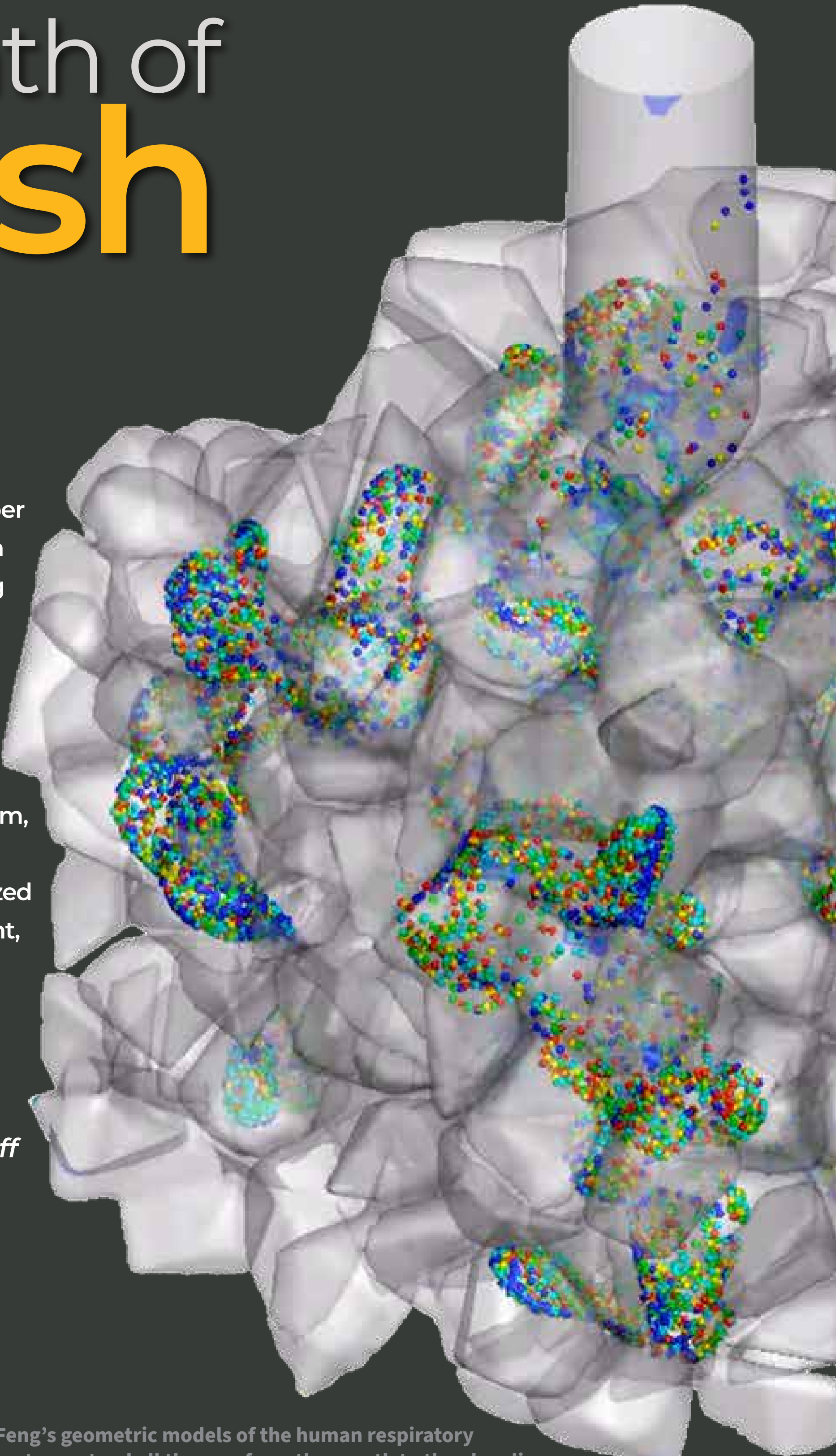
While the goal of creating a bioartificial kidney may seem lofty, researchers at The Kidney Project understand that the device does not need to replicate the full functionality of a healthy human kidney perfectly. If it can provide patients with the level of kidney functionality that they had experienced at stage 4, it would change lives because many people with stage 4 kidney disease don't even feel the downsides of kidney disease. They travel, they eat normally, they exercise; they live life in much the manner anyone else does. That all stops when dialysis begins and the long wait for a kidney transplant commences.

With help from Fluent and CFX, researchers at The Kidney Project are well on their way to delivering a bioartificial kidney that will fulfill its design goals — quickly, efficiently and far more cost-effectively than would otherwise be possible.

A Breath of Fresh Air

Dr. Yu Feng, a faculty member and researcher at Oklahoma State University, is leveraging simulation to create customized models of the pulmonary systems of individual patients. By creating a digital twin of the human respiratory system, Feng is helping health care teams deliver personalized treatments, patient by patient, that increase the effectiveness of medical therapies and support better outcomes.

By Ansys Advantage Staff



Feng's geometric models of the human respiratory system extend all the way from the mouth to the alveoli, the tiny fluid-filled sacs in the lung that support gas exchange. His work is elucidating how both toxic and therapeutic particles are absorbed via fluid-structure interactions. (Thank you to Dr. Kenichiro Koshiyama, Tokushima University, Tokushima, Japan, for the code generating the alveoli geometry.)

As an engineering mechanics student at China's Zhejiang University, Dr. Yu Feng developed an early, and unusual, interest in health care applications.

"Most of my fellow students were fascinated by turbines and aerospace science," he recalls. "But I was more intrigued by the mechanics of the human body, particularly the respiratory system." As early as 2007, Feng was using Ansys Fluent to perform computational fluid dynamics (CFD) simulations of air trajectories inside the lungs as part of his undergraduate research. He continued this work while earning his master's and doctoral degrees in mechanical engineering at North Carolina State University.

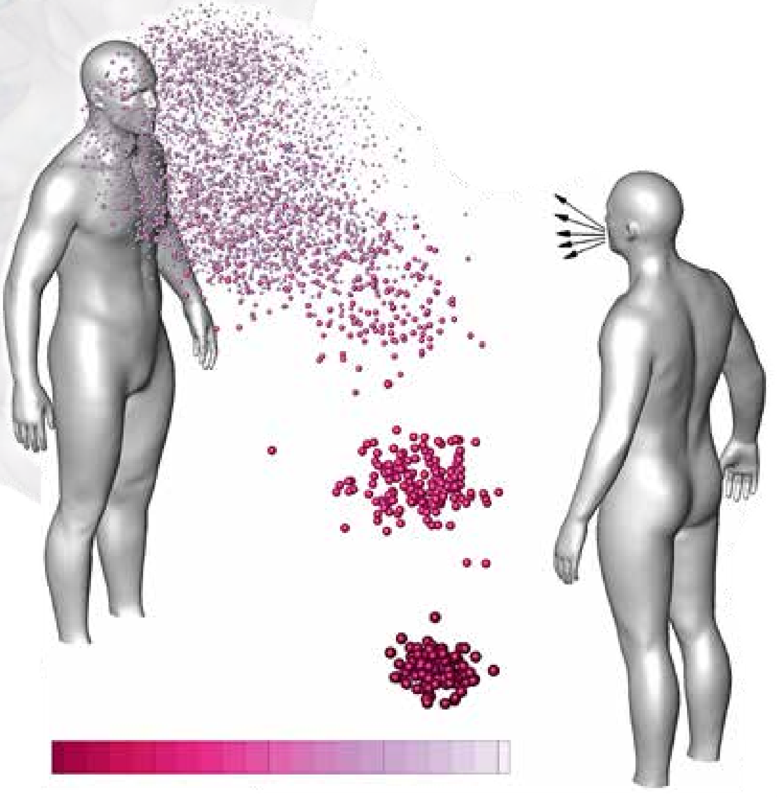
Fast forward to 2021, when Feng has become a pioneer of using engineering simulation — including both CFD and structural modeling — to create digital twins of the respiratory systems of individual human patients. His team at the Computational Biofluidics and Biomechanics Laboratory at Oklahoma State University is working to gain a more in-depth understanding of respiratory processes and improve pulmonary health outcomes, a topic that's gained global attention today.

"Simulation provides a noninvasive way to understand the geometry and mechanics of each patient's respiratory tract, making treatments more targeted and more effective," he notes. "My entire academic and professional career has been based on using simulation to improve human respiratory health, and the COVID-19 pandemic has only increased my commitment."

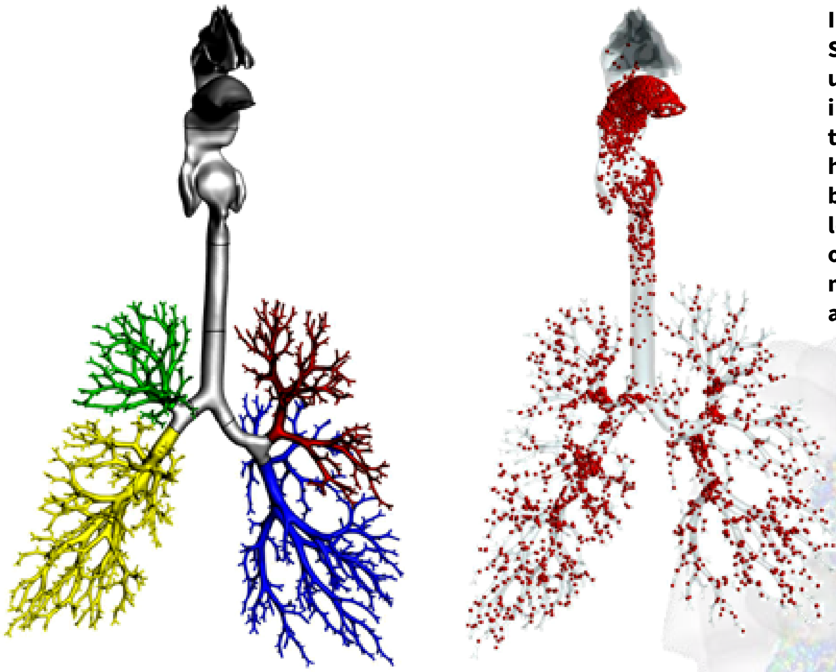
MORE ACCURATE TRACKING OF TOXIC AND THERAPEUTIC PARTICLES

In his research group in the School of Chemical Engineering at Oklahoma State, Feng uses Fluent and Ansys Mechanical to construct a subject-specific complete respiratory model, covering the entire lung-conducting zone that begins with the mouth. Feng's simulations incorporate computational fluid-particle dynamics (CFPD) and physiologically based pharmacokinetic/toxicokinetic (PBPK/TK) models to capture the transportation, deposition, translocation and clearance of inhaled aerosols in the pulmonary system. Feng's dynamic simulations are among the first to capture the complex workings of the human respiratory tract as it is exposed to airborne particles.

By modeling the whole-lung geometry and then creating a dynamic digital simulation, Feng can gather high-resolution data and perform parametric studies that show how particles are distributed and absorbed over time. Not only can this advanced research improve the effectiveness of inhalers and other respiratory therapies, but it can also help illuminate how the coronavirus and other airborne diseases enter the lungs.



By using simulation to model the pathways of airborne particulates following a cough, Feng and his research team are increasing the collective understanding of how COVID-19 and other airborne diseases are transmitted.



In his lab at Oklahoma State, Yu Feng is using fluid-structure-interaction simulations to understand how the human airway is impacted by obstructions in various locations — and how each of those obstructions might affect air flows and treatment plans.

"Pulmonary modeling via Ansys software can help clinicians better understand and visualize particle flows, so they can design more effective devices and treatment plans for delivering drug therapies to the lungs, no matter the patient's respiratory condition," explains Feng. "In terms of combatting COVID-19 and other airborne illnesses, these simulations can also help elucidate how viruses attach to the lung, grow and trigger an immune-system reaction."

Feng's research team at Oklahoma State is also using dynamic simulations to increase the collective understanding of how the coronavirus is transmitted in both indoor and outdoor environments. By revealing how airborne particles travel, and the effects of ventilation systems on their pathways, Feng hopes to protect health care workers and the general public from airborne infections and pollution.

> ***"Simulation provides a noninvasive way to understand the geometry and mechanics of each patient's respiratory tract, making treatments more targeted and more effective."***

PATIENT-SPECIFIC DIGITAL TWINS: AN EMERGING CONCEPT

According to Thierry Marchal, program director for Healthcare Solutions at Ansys, one of the most exciting aspects of Feng's models is the fact that they can be customized to reflect the exact geometries of a specific patient.

"Dr. Feng's work on customized human-body simulation is at the forefront of medical research and development today," Marchal emphasizes. "The global health care community is recognizing that a personalized approach to drug delivery, surgery and other medical interventions can deliver dramatically improved outcomes."

How exactly does Feng's modeling approach impact patient results? Consider a patient with a very specific deformity in the respiratory tract, such as a scarred glottis that partially impedes the airway. By using inputs from CT images, MRI scans or other imaging methods to create a base geometry in Ansys Mechanical, Feng can model this very specific deformity. Then he can add Fluent to build a digital twin that dynamically replicates real-world airflows, all the way from the mouth to the alveoli, the tiny sacs in the lungs. Expanding Fluent capabilities by

"Pulmonary modeling via Ansys software can help clinicians better understand and visualize particle flows, so they can design more effective devices and treatment plans for delivering drug therapies to the lungs, no matter the patient's respiratory condition."

adding PBPK/TK models, Feng can next predict how the particles are absorbed through the alveola wall and distributed through the organs.

Clinicians can study fluid-structural interactions (FSIs) in the digital twin to see how this patient-specific feature affects the individual's overall breathing process, as well as the delivery of therapeutic drugs to the lungs. Then they can modify their treatment plans accordingly.

"In improving medical outcomes for all patients, the question is not, 'How can we make a better one-size-fits-all inhaler or ventilator?'" says Feng. "The question is, 'How can we engineer an inhaler or ventilator, and associated best practices, that work more effectively for specific patients?' Dynamic, multiphysics simulations are the most noninvasive and cost-effective way to accomplish that goal."

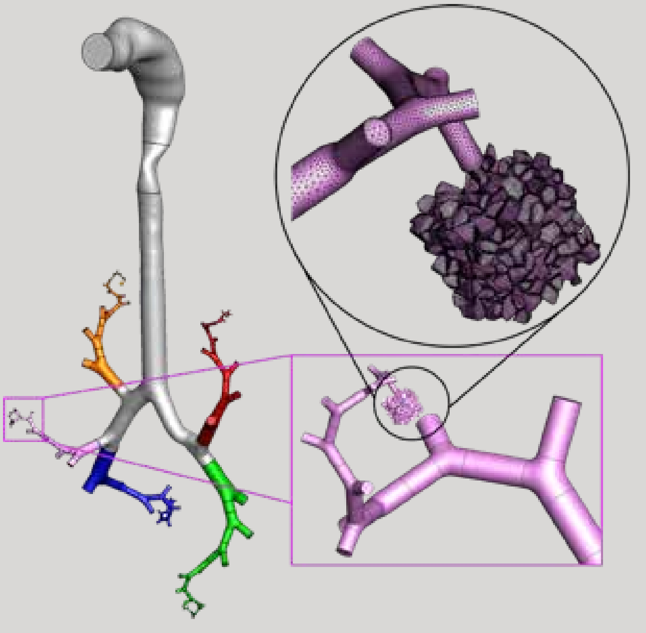
While the concept of human digital twins is not widely deployed today, Feng's research is creating a foundation for broader adoption. He is collaborating with doctors at the University of Oklahoma Health Sciences Center to perfect the simulation models and algorithms that underlie his digital twins so they can eventually be commercialized and launched on a large scale.

BREATHING NEW LIFE INTO RESPIRATORY THERAPIES

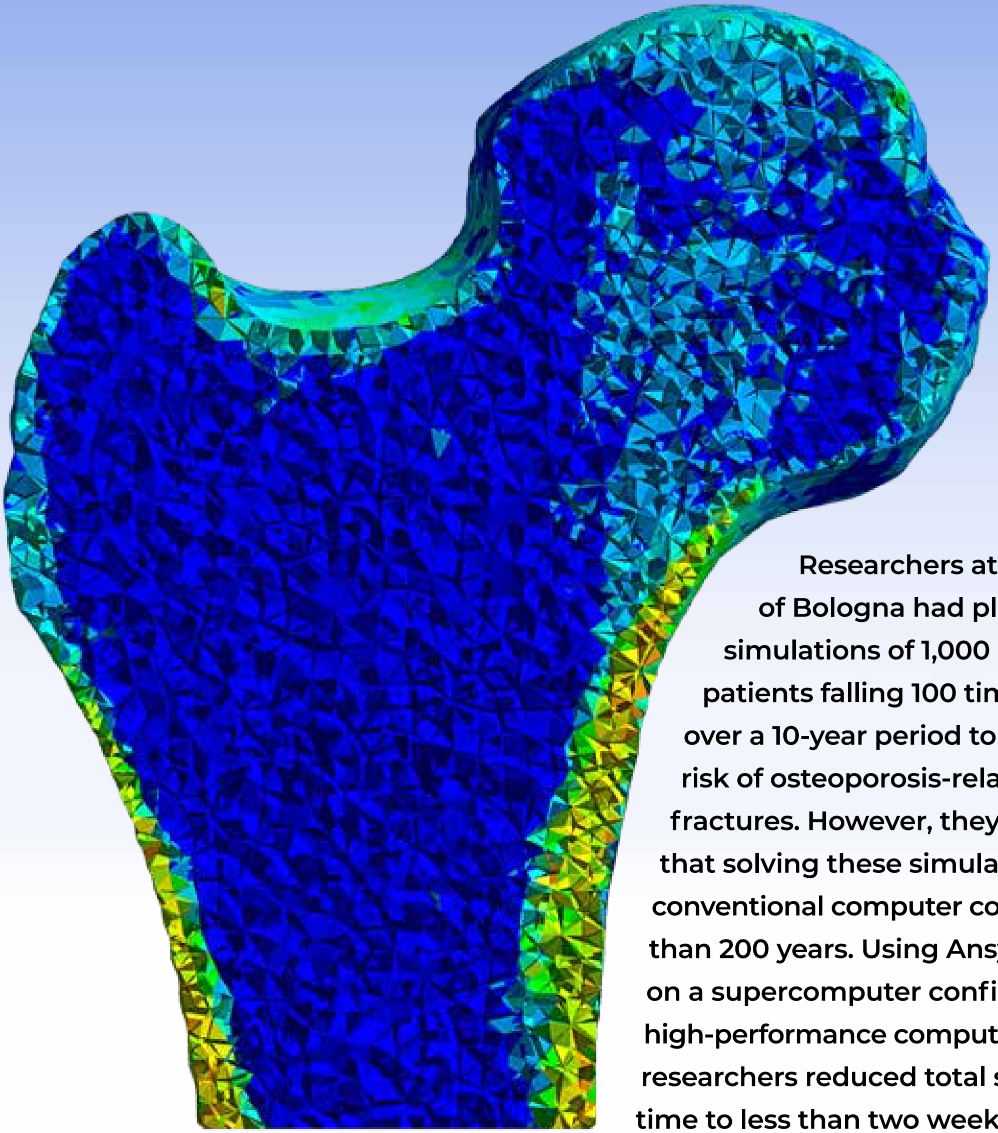
A 13-year user of Ansys simulation software, Feng points out that today's dynamic digital twins would not be practical without significant advances in processing speeds, parametric studies and computational algorithms that deliver faster solve times. Because the human respiratory tract is geometrically complex, and dynamic particulate-based airflows are equally complex, Feng's work involves solving problems that are extremely large numerically.

"From the development of Ansys Workbench for data management, which allows my team to apply machine-learning algorithms to an enormous database, to the emergence of cloud hosting, Ansys has supported my research as it's grown in complexity," states Feng. "Everything Ansys has done to improve its software has directly benefited my modeling capabilities and increased the likelihood that they can be launched into the global health care market."

Dr. Yu Feng has come a long way from his early days as an engineering mechanics undergraduate who was fascinated by the human respiratory system. Today he is leading the development of innovative diagnostic and therapeutic approaches that have the potential to transform health care — and help the world win its battle against COVID-19 and other airborne illnesses.



Feng's work is advancing clinicians' ability to develop patient-specific treatment plans. Here, Feng models a glottis that is deformed. By creating a digital twin that includes this deformity, Feng reveals how it will impact the lungs' ability to absorb medications or oxygen when administered in a health care setting.



Researchers at the University of Bologna had planned to run simulations of 1,000 osteoporosis patients falling 100 times per year over a 10-year period to quantify the risk of osteoporosis-related bone fractures. However, they calculated that solving these simulations on a conventional computer could take more than 200 years. Using Ansys Mechanical on a supercomputer configured for high-performance computing (HPC), the researchers reduced total simulation time to less than two weeks.

Simulation and High-Performance Computing

Reduce Fracture Risk in Osteoporotic Patients

By **Marco Viceconti,** Professor of Industrial Engineering, University of Bologna, Bologna, Italy

"Because Ansys Mechanical is optimized for HPC, UNIBO researchers could run it on thousands of compute cores simultaneously … What could have taken 200 years if executed serially took less than two weeks."

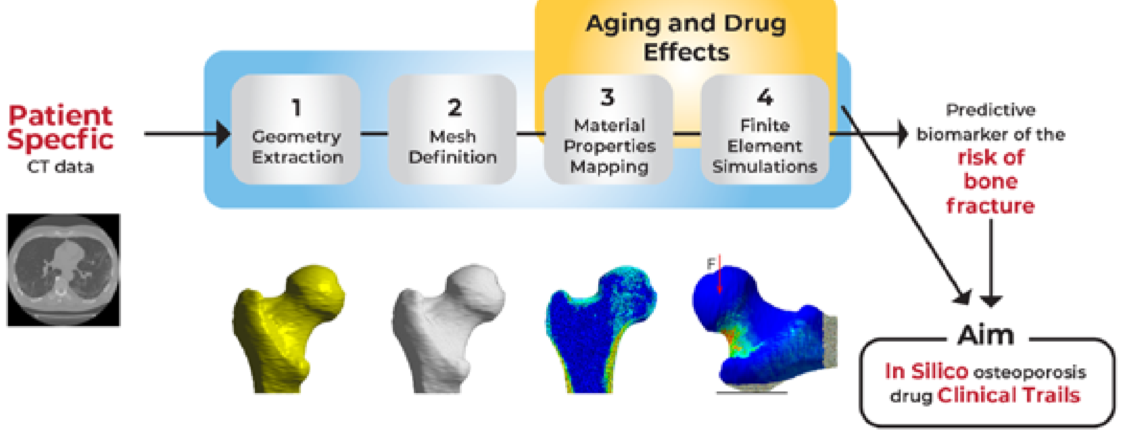
Pharmaceutical companies have a problem when it comes to developing drugs to help reduce the number of bone fractures arising from osteoporosis, a disease that weakens the bones of millions of primarily elderly women. It's not that the companies can't discover medicines that might help reduce fractures; it's that they can't conduct clinical trials that identify fracture reduction as the primary endpoint showing the efficacy of the drug under investigation. The problems are manifold: Such a trial would involve observing more than 1,000 osteoporotic patients fall — repeatedly — for five to 10 years or until they experienced a fracture. Even if there were no ethical concerns about watching Grandma fall down over and over for 10 years, the cost of conducting such a trial would be prohibitive.

As a consequence of these difficulties, pharmaceutical companies don't run trials that focus on fracture reduction. Instead, they focus on a surrogate endpoint, such as an increase in bone mineral density, to show the efficacy of a drug. Such trials can involve far smaller numbers of participants and need to run for only a few months. But such surrogate endpoints have their own problems. An increase in bone mineral density by itself does not guarantee fewer bone fractures. Bone strength is a function of both the anatomy of the bone and the distribution of bone minerals, and bone strength is the key to reducing fractures. Yet without a five- to 10-year clinical trial involving thousands of osteoporosis patients — repeatedly falling down and not breaking bones — it would be impossible to correlate changes in bone strength to a reduction in bone fractures.

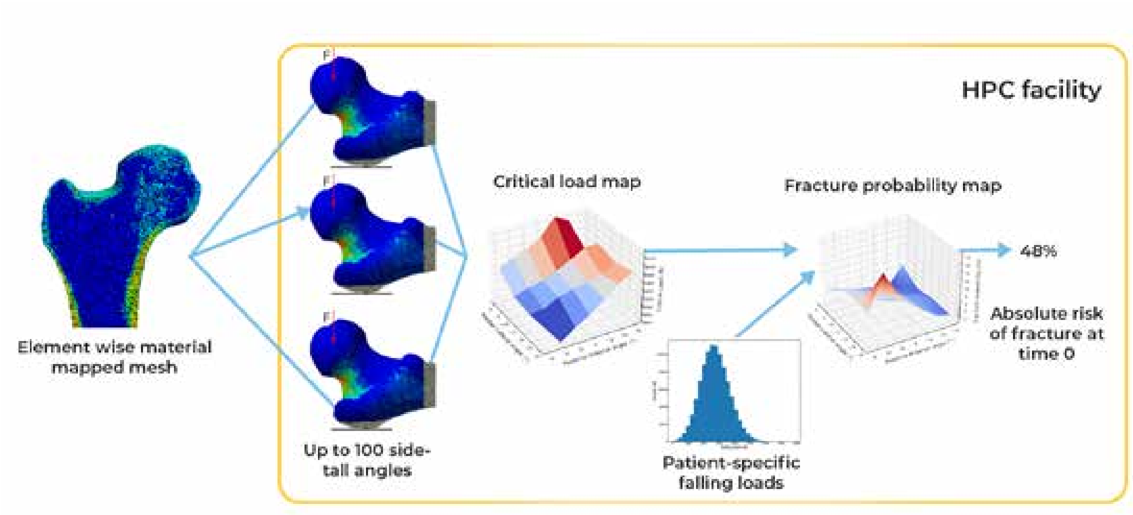
But what if such a correlation could be shown without real people and real bones? Or, for that matter, real time?

UNDERSTANDING AN UNDERLYING ENGINEERING PROBLEM

At the University of Bologna (UNIBO), biomechanical researchers in the Department of Industrial Engineering have been working closely with the Medical Technology Laboratory at Rizzoli Hospital, the leading orthopedic hospital in Italy, to explore the complexities of the underlying biophysics associated with osteoporosis and falls. Fundamentally, when an individual falls, the skeletal bones are subjected to a physical force. Different types of falls will result in different types and directions of force. Depending on the strength of the force and the strength of the bone, a fall may or may not result in a fracture. Over time, though, osteoporosis will change both the architecture of the bone and density and the distribution of bone mineral in the bone, decreasing bone strength and increasing the risk that a fall will result in a fracture.



Moving from computer tomography imaging data to a finite element model in Ansys Mechanical



Simulation pipeline for a single patient simulation

Viewed this way, the question of whether a fall will lead to a fracture at any given time is, in the purest sense, an engineering problem — one that UNIBO researchers believed could be solved with the right tools and the right inputs.

The team at UNIBO obtained computer tomography–generated images of femurs from 100 individuals. They analyzed these images using principal component analysis techniques to understand both the anatomical variations and their frequency among the 100 femurs but also the frequency of bone mineral density variations among these femurs. Other internally developed tools enabled the researchers to see exactly how bone mineral deposits were distributed throughout the anatomical architecture of each femur.

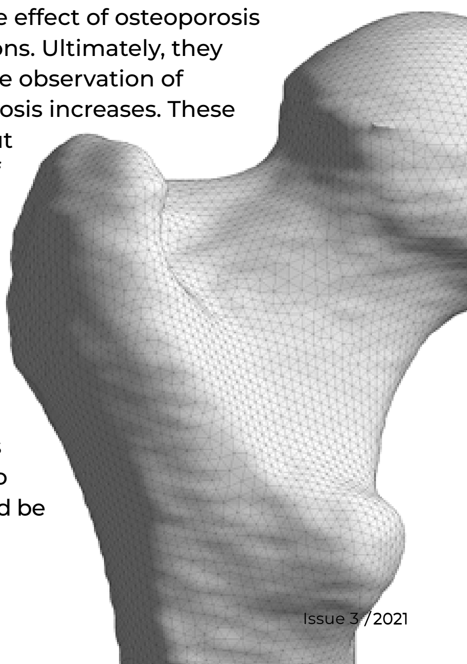
Using Ansys Mechanical, the researchers created finite element (FE) models from the CT scans of these 100 real-world femurs. The mesh in each model not only mapped the unique architecture of each femur but it also mapped the distribution of bone minerals throughout each bone. They then replicated and resampled these 100 models to create a total of 1,000 FE models. This cohort precisely reflected the distribution of anatomical and bone mineral density variations that researchers would have expected to find in 1,000 humans with osteoporosis.

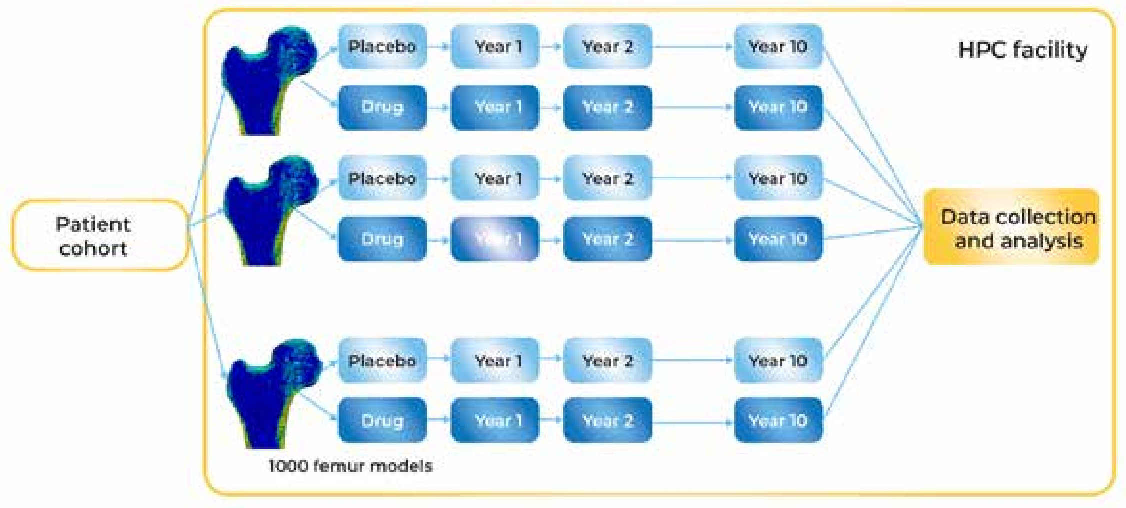
The researchers subsequently developed a stochastic model of a fall, with parameters that could take into consideration the patient weight, the amount of soft tissue that might absorb the impact, direction and distance of a fall and more. The UNIBO researchers intended to use Mechanical to put each of these 1,000 models through 100 different fall simulations to correlate bone strength to fracture risk. They then intended to modify the bone mineral composition of each of the 1,000 models in a manner that mirrored the degenerative effect of osteoporosis over the course of a year, whereupon they would rerun all the simulations. Ultimately, they would rerun all these simulations 10 times over, effectively mirroring the observation of 1,000 individuals falling 100 times per year for 10 years as their osteoporosis increases. These simulations would provide the long-sought-after clinical insight without anyone's actual grandmother having to suffer the indignity and pain of falling and fracturing a hip.

SOLVING AN OVERARCHING TIME PROBLEM

But researchers soon encountered a problem. A single fall simulation took approximately 1.8 hours to solve on the computing resources available at UNIBO. Solving one million simulations, which is what 1,000 virtual patients falling 100 times per year for 10 years amounts to, would take 1.8 million hours — more than 205 years.

That would not do, particularly because the practical application of this silico clinical trial would eventually involve using these same techniques to model the effect of potential osteoporosis drugs to see whether they could be shown to reduce fractures over time.

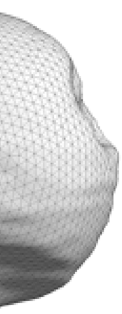




Comparing the effect of a prospective drug to the progression of the placebo cohort

Working with Ansys, the researchers at UNIBO used Ansys Mechanical software with the Cartesius supercomputer hosted by SURF in The Netherlands and the Galileo supercomputer hosted by CINECA in Italy. Cartesius is configured as a high-performance computing (HPC) system with more than 1,900 central processing units (CPUs) each with between 16 and 64 compute cores (for a total of more than 47,000 cores). Each CPU is configured with between 64 and 256 GB of memory. Galileo is also configured as an HPC system with 2,044 18-core CPUs (for a total of nearly 36,800 cores), and each CPU is configured with 128 GB of memory. Both Cartesius and Galileo have access to petabytes of storage capacity and ultra-high-performance interconnects that ensure that system resources are used in a highly efficient, highly parallelized manner.

Because Ansys Mechanical is optimized for HPC, UNIBO researchers could run it on thousands of compute cores simultaneously — which dramatically accelerated the completion of the million simulations. What could have taken 200 years if executed serially took less than two weeks when run on Cartesius and Galileo.



ON THE ROAD TO IN SILICO TRIALS

The researchers at UNIBO are well on the way to creating an opportunity for true in silico clinical trials whose endpoint is the reduction of fractures in osteoporotic patients. The initial findings form the basis for what would, with regulatory approval (itself a goal involving many hurdles yet to be encountered), be considered the placebo arm of a clinical trial. What the researchers have modeled using Mechanical and HPC systems represents risk of fractures among a cohort of 1,000 individuals whose osteoporosis has evolved unimpeded over the course of 10 years. Against this, clinical researchers could analyze new FE models to simulate the effect of an investigative osteoporosis drug over the course of 10 years to see whether the drug increases bone strength and decreases the risk of fractures in comparison to the placebo group.

But more work remains for the researchers at UNIBO. They need to learn how to model the effects of prospective osteoporosis drugs in their FE models, which involves learning how to take data showing the effect of an investigative agent on an animal population and scaling that properly to model the effect of the drug in a human population — a task that poses its own challenges. Then they have to simulate the effect of those potential drugs in the cohort of 1,000 virtualized participants (falling 100 times during each of 10 simulated years). Ultimately, that means solving another million simulations in which the investigational agent now plays a modifying role each year. Does the bone grow stronger? Does the risk of fracture decline as a consequence of prolonged medication use?

All of these questions remain to be answered, but at least the researchers at UNIBO know that by running Ansys Mechanical on highly parallelized HPC systems they should ultimately be able to answer many of these questions in a matter of weeks — not a matter of centuries.

Repairing Bone Loss with Simulation-Generated, Patient-Specific Implants

By Ansys Advantage Staff

When a person loses bone structure due to an accident or a disease, it's important for a surgeon to be able to reconstruct the lost bone as quickly as possible. Until recently, the surgeon might have a few titanium or plastic implants in different sizes to choose from, and they had to make them work, even if the sizing was not ideal. In the case of mechanical joints like the lower mandible (jaw), a good fit determines the functionality and quality of life of the patient.

Now Techfit Digital Surgery of Daytona Beach, Florida, has developed a patient-specific way of 3D-printing medical devices using computerized tomography (CT) and magnetic resonance imaging (MRI) scans of the patient to determine the perfect geometry for each implant. They use Ansys Discovery 3D design software to quickly develop the implant's optimal design. Then they manufacture the implants, mostly using metal or plastic additive manufacturing, and deliver them for surgery within 10 working days.

"With Discovery, we know that our digital models will behave anatomically and mechanically like the patient will," says Mauricio Toro, cofounder and CEO of Techfit. "It allows us to do very rapid iterations and improve the surgical product and surgical outcome."

Custom surgeries are possible with new technologies.

"Ansys Discovery's mechanical solver turns out a design within hours as opposed to days or weeks, which we don't have because a patient is waiting for that implant."

A THREE-STEP PROCESS FOR 3D PRINTING MEDICAL DEVICES

1. Acquiring Data

The first step in the surgical implantation process is to acquire data, which involves obtaining CT and MRI scans of the affected area. These scans are the starting geometry for the design. But as every engineer knows, geometries have to be cleaned up and modified before they can be useful.

Toro's first big challenge was to find software that could input the STL file created from the scans and enable him to edit the geometry. He started using Ansys SpaceClaim first, with good results. But then along came Ansys Discovery.

"Ansys Discovery is a perfect match because it can process the STL files, which not every CAD package can handle, and mesh the geometry and make alterations in near real-time," Toro says. "Discovery's mechanical solver turns out a design within hours as opposed to days or weeks, which we don't have because a patient is waiting for that implant."

2. Co-creation and Validation

This second step in the process starts with the physician. Toro and his team meet with the surgeon to learn about his or her needs for a particular patient. They often take Discovery along with them for these meetings to show the surgeon their preliminary design based on the scans and make modifications from there.

"Especially if I have a case where I'm uncertain about the mechanical behavior of the bone or the implant, in a meeting with the surgeon I can start tweaking the model using Discovery," Toro says. He explains that any implant design is always a compromise between the space you have and the implant's mechanical properties. In many nonbiological applications, you can just add more material to increase the factor of safety. But when you are implanting something in a human body, your packaging requirements are very strict.

"So, being able to perform simulations live with the surgeon and interact with them in a very fast feedback loop to understand where the sweet spot lies between mechanical performance and packaging is key to providing the best results achievable," he says.

Toro finds this rapid feedback loop to be of critical importance.

"The saying goes that 'practice makes perfect,'" he says. "But without a good feedback loop you can actually practice the wrong thing and become very good at doing something wrong. That's why we'd rather say 'iteration makes perfection.'"

Simulation is helping cranial reconstructions happen after accidents or head trauma.

Techfit uses simulation to manufacture custom implants.

3. Manufacturing

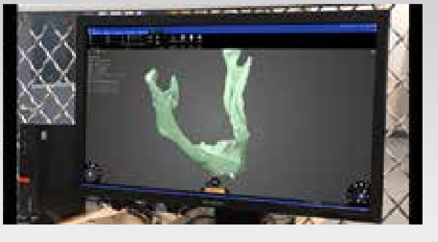
Techfit currently manufactures all of its implants at company headquarters in Daytona Beach. They have all the standard machine tools needed for conventional manufacturing, along with additive manufacturing capabilities for more exotic implant shapes. Titanium alloys are most commonly used for metal implants. Plastic implants use PEEK for load-bearing applications and ultrahigh molecular weight polyethylene for tribological surfaces like joint replacements, where friction and wear can be a concern. Each implant is delivered with a mechanical validation analysis report so the surgeon has the utmost confidence in the surgical outcome.

The future of manufacturing at Techfit will include an additive manufacturing network distributed around the world, as Toro envisions it. A major reason for such a network is to deliver implants faster. If you make an implant in the United States for a patient in Saudi Arabia, that's two days lost to shipping and another two days clearing customs, Toro explains. "If we have 10 days from CT scan to surgery, this means we are already four days late or our design time is crunched down into six days. Knowing a print is going to work on a machine across the world by sending an STL file is going to be critical."

HEALING PEOPLE AROUND THE WORLD

To date, Techfit has provided implants for several thousand patients.

"We have helped in some very incredible surgeries," Toro says. These include hemi-mandibulectomies, where patients have lost half of their jaws because of tumors or accidents; a sternum replacement using a plastic implant fixed to the ribs with titanium plates; and, most commonly, thousands of cranial reconstructions required because of motorcycle accidents, tumors or head traumas.



Simulation models can be tweaked after meeting with the surgeon.

Techfit also publishes papers in medical journals, presents results at conferences and even holds its own digital surgery conference annually.

"Custom surgery is actually a new field, so it's not only a matter of making the implants but also a matter of evangelizing and ensuring adoption of the technologies," Toro says. "Our goal is to make custom treatments the new standard for every patient around the world."

Ansys simulation will continue to play a major role in achieving this goal.

"Having Ansys Discovery in our workflow allows us to validate our products faster, helps people get their surgeries faster and helps them recover faster," Toro says. "One of the most rewarding things is you can actually see people's lives get better every time."

A structural analysis of the AdvenChair frame in Ansys Discovery

The AdvenChair is equipped with various adjustment mechanisms to accommodate riders of varying sizes and weights.

Isaac Shannon takes to the trails, thanks to AdvenChair.

AdvenChair Rolls Boldly Into Adventure With Off-Road Wheelchair Design

Geoff Babb is an outdoor adventurer. He has enjoyed mountain biking, skiing and hiking in rugged terrain with friends over the years. He wasn't about to let a stroke in 2005 stop him from enjoying his passions, or even a second stroke 12 years later. By then he was the founder of a company called The Onward Project, maker of the AdvenChair, dedicated to inspiring and enabling those with mobility challenges to visit wild places. The company's motto: Roll Boldly.

You can see Geoff doing just that in a YouTube video featuring him in a prototype of the AdvenChair in the woods, on the beach and in the snow, accompanied by a group of friends who push and pull the AdvenChair using a set of handlebars in back and ropes in front.

"We're sometimes asked about an electric-assist version, but honestly we're not really thinking about it at this stage, primarily because we see the group dynamics of teamwork as a key tenet of the AdvenChair," Babb says. "AdvenChairing is a team sport."

“I quickly learned that it was so much easier to make design tweaks in Discovery in Explore mode and get a solution almost instantly to see that you are trending in the right direction.”

ON THE ROAD TO AN OFF-ROAD WHEELCHAIR DESIGN

When the idea of hiking in a wheelchair came to him in 2006, it quickly became apparent that the standard wheelchair, designed for floors in buildings and paved roads outside, was not up to the challenge of more rugged surfaces.

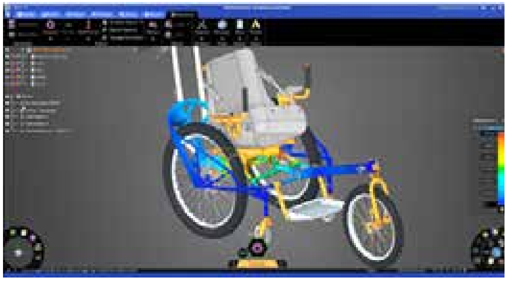
“I wanted to make a chair that would benefit not only me but so many people who want to be outside,” Geoff says. “We tinkered with a standard wheelchair but that didn’t work.” The stresses and strains on the chair would be too great and the jolts experienced by the rider too jarring.

So Geoff turned to his mountain biking experience and began developing ideas for what would become the AdvenChair. It would be a three-wheeler — two large wheels in back for strength and stability and a smaller wheel out front for balance and maneuverability. It would incorporate the materials and components of a mountain bike that suit the terrain, including suspension, disc brakes and a lightweight but strong frame.

In 2017, Jack Arnold, an engineer with experience in product development, sheet metal and machinery, joined Geoff’s group. Together they decided it was time to scrap the early designs and build something new from the ground up.

ENGINEERING A NEW WHEELCHAIR DESIGN

Jack brought an engineer’s knowledge of simulation to the group. Before the first design review meeting, he used an engineering software package to simulate the stresses and strains on a prototype design that could hold a 250-pound rider with a safety factor of 3, for a total load of 750 pounds. He knew they wouldn’t end up building this design but he wanted to get the ideas flowing, and to let the team know that this was going to be an iterative process.



Using Ansys Discovery, an engineer ran simulations with the seat in different positions.

“I wanted to go into the meeting with the ‘warm and fuzzy’ feeling of knowing that the structure was sound from the start,” Jack says. “You really need to use simulation upfront so you know that your first prototype is at least in the ballpark.”

A fortunate series of events brought Ansys simulations into the picture. In 2018, a reporter at a local radio station did a story on Geoff and the AdvenChair team. “After that story aired, we had a number of people reach out to us to provide service, and Ansys was one of them,” Geoff says. “Next thing I knew Ansys was offering to help us with the analysis. I asked Jack what he thought, and he said we definitely should follow up on that.”

Soon Jack was working with Ansys Discovery as part of the Ansys Startup Program to verify the frame simulation he had done with the other software package. He ran several different simulations with the seat in different positions and with different loadings to see how these changes affected the frame.

“I quickly learned that it was so much easier to make design tweaks in Discovery in Explore mode and get a solution almost instantly to see that you are trending in the right direction,” Jack says. “I really love the brilliant use of onboard memory on video cards to make nearly instant updates possible.”

But what he loves the most about Discovery is the generative design feature. “Watching it iterate, removing material in the unstressed areas and then suggesting a final shape — that is really cool,” Jack says. “Our current AdvenChair is heavier than our design goal, so we are going to use generative design to eliminate material where it’s not needed. That will reduce the weight and translate into material and cost savings as well.”

The AdvenChair 1.0 early prototype at the Grand Canyon
Photo credit: Pat Addabbo

"You really need to use simulation upfront so you know that your first prototype is at least in the ballpark."

HEADING TO MARKET

Somewhere along the way, the team came up with what Geoff calls the "Swiss Army" approach. This meant adding adjustability and scalability to the AdvenChair so it could be used throughout a person's lifetime for various purposes. An important feature of this approach is that the front wheel is removable so the AdvenChair can be used as a standard wheelchair to go into buildings, fit under tables and allow transfers in and out of vehicles.

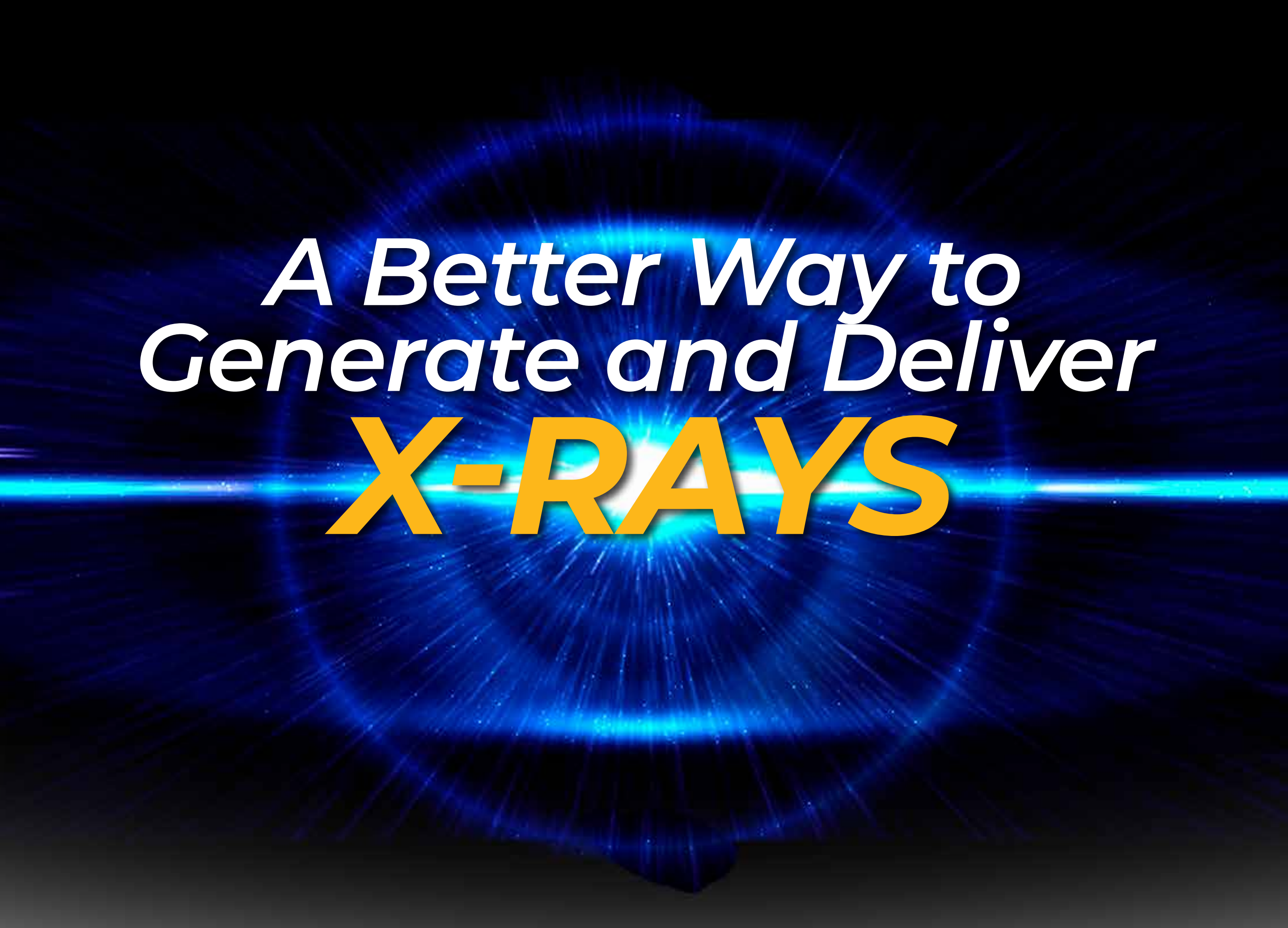
Much of what Jack and the design team have been doing these last two years has been working on the adjustability of components. They want the rider to be able to adjust the seat position fore and aft, to adjust the inclination angle of the seat, and to set the footrest in the most comfortable position. Moving these components around in Discovery and seeing how they change the loads on the chair and its performance was easy.

"With Discovery, we've designed a scalable platform that can handle anyone from a small child to an adult," Jack says. "This includes three different seat sizes that can be swapped out when needed. The idea is that a family can buy this for a child and it can be a lifetime chair for them."

In the bigger scheme of things, Geoff sees the AdvenChair as a way of helping people of all ages with different abilities enjoy the outdoors again.

"We want to reach out to veterans to get their buddies out on the trail using teamwork," he says. "Children with cerebral palsy. Elderly folks who just can't easily hike anymore and people with Parkinson's disease who want to visit their favorite lake again." He talks about how he received a call from a man whose daughter was in hospice and wanted to revisit her favorite spots on the family farm one last time. He loaned them an AdvenChair and one week before she passed she got her wish.

In this way and many others, the AdvenChair team is already fulfilling its dream of helping people who love the wild outdoors to hit the trails throughout their lifetimes, no matter what challenges life throws at them. They took orders until Feb. 15 for the first production run of AdvenChairs and shipped their first 10 units in the second quarter of 2021. In the meantime, they are continuing to use Ansys Discovery to reduce the overall weight of the AdvenChair, particularly in the seat, and are developing a lighter-duty, less expensive urban version for those who find the city wild enough.



A Better Way to Generate and Deliver X-RAYS

By Ansys Advantage Staff

LUMITRON TECHNOLOGIES INC., A MEMBER OF THE ANSYS STARTUP PROGRAM, Is using Ansys HFSS and Ansys Fluent to design a new X-ray technology that combines accelerators with lasers to create higher-energy, higher-resolution X-ray beams that can be used simultaneously for imaging and treatment. The X-rays could be tuned to a narrow range of energies with small source size to provide greater contrast and resolution for imaging, while enabling novel treatment methods for radiosurgery.

When the company was founded by Chris Barty in 2018 in Irvine, California, they used Ansys HFSS because most of the initial employees were familiar with the product. "Then, when we learned about the deal that the Ansys Startup Program offered — combining thermal simulation and electromagnetic simulation in a single package at a low price — that's a deal we couldn't refuse," says Yoonwoo Hwang, an accelerator physicist at Lumitron who started working on the new X-ray technology as part of his Ph.D. research project while at UC Irvine.

WAYS TO MAKE X-RAYS

The standard way that X-rays are created in a hospital is by aiming an electron beam at a metal target. The electrons slow down upon penetrating the metal and emit X-rays in the process. This produces a broadband radiation, most of which is filtered out. Some of the wavelengths that are not filtered out are absorbed by the tissues of your body without helping to make an image, so you might be getting more radiation than is necessary.

For scientific applications like crystallography, a synchrotron accelerates the electrons to high speeds to produce X-rays. If this radiation passes through a periodic magnetic field, the electron beam undulates or wiggles, creating higher–energy X-rays. But a synchrotron can be a huge device consisting of a ring many kilometers long.

To bring the system down to a more manageable size for clinical applications, in recent years researchers have been experimenting with lasers in place of the periodic magnetic field undulators. A laser beam is an oscillating electric field with a much shorter wavelength than the magnetic undulators at synchrotron facilities. If you collide a laser with an electron beam, the electrons wiggle. In doing so, they emit higher energy X-rays in a much more compact footprint, in the range of a few meters, suitable for hospitals.

Hwang explains the physics involved: To make electron beams for radiography, you need X-ray energies in the range of 10 kV to 100 kV. Using the synchrotron method, you would have to accelerate the electrons up to giga-electron-volt (GeV) levels, which would require an accelerator ring hundreds of meters long. "But in the laser collision method that we are developing, to make that same X-ray energy (10 kV–100 kV), you only need about 50 MeV (mega-electron volts), not GeV," Hwang says. "And a 50 MeV electron accelerator is actually very small — just a few meters long."

Lumitron's HyperVIEW X-ray system.

WHY SIMULATION IS NEEDED FOR X-RAY DESIGN

Precise RF design and controlling temperature to maintain resonance in the accelerator are key. Lumitron uses copper microwave cavities containing electromagnetic fields. "You can set up the field so that the electrons will ride only on the accelerating parts of the cavity," Hwang says. But this requires very precise design to tune the cavities for optimal operation.

After they generate the proper electromagnetic fields from Ansys HFSS, Lumitron engineers then look at where and how much the structure deforms and use Ansys Fluent to stimulate what kind of cooling is necessary.

The cavities heat up due to the electromagnetic fields, which can distort the copper. Lumitron uses HFSS to simulate the RF structures and Fluent to simulate thermal deformations to be expected for various conditions. If the temperature of the cavities is slightly off, even by only 0.5 degrees, the RF source is not matched to the cavity. This will cause all the power to be reflected and damage the power source.

It's a careful balance between the heating caused by the electromagnetic field and any artificial cooling solution you apply. Excessive cooling can distort the cavities too. So, after they generate the proper electromagnetic fields from HFSS, Lumitron engineers then look at where and how much the structure deforms and use Fluent to stimulate what kind of cooling is necessary. Recent improvements in the accelerator design have pushed the

"The ability to do these things with one instrument while enhancing the contrast and delivering a lot lower X-ray dose to the patient — that is unique. And the Ansys Startup Program played a big role in making this research and development possible."

operating parameters by a factor of 1,000. "We had to redesign the entire cooling structure, and to do that, we have to carefully simulate the effects of the new cooling manifolds and other apparatus," Hwang says.

HEALTH BENEFITS OF THE LUMITRON X-RAY DESIGN

The Lumitron design is an improvement over existing X-ray machines in several ways:

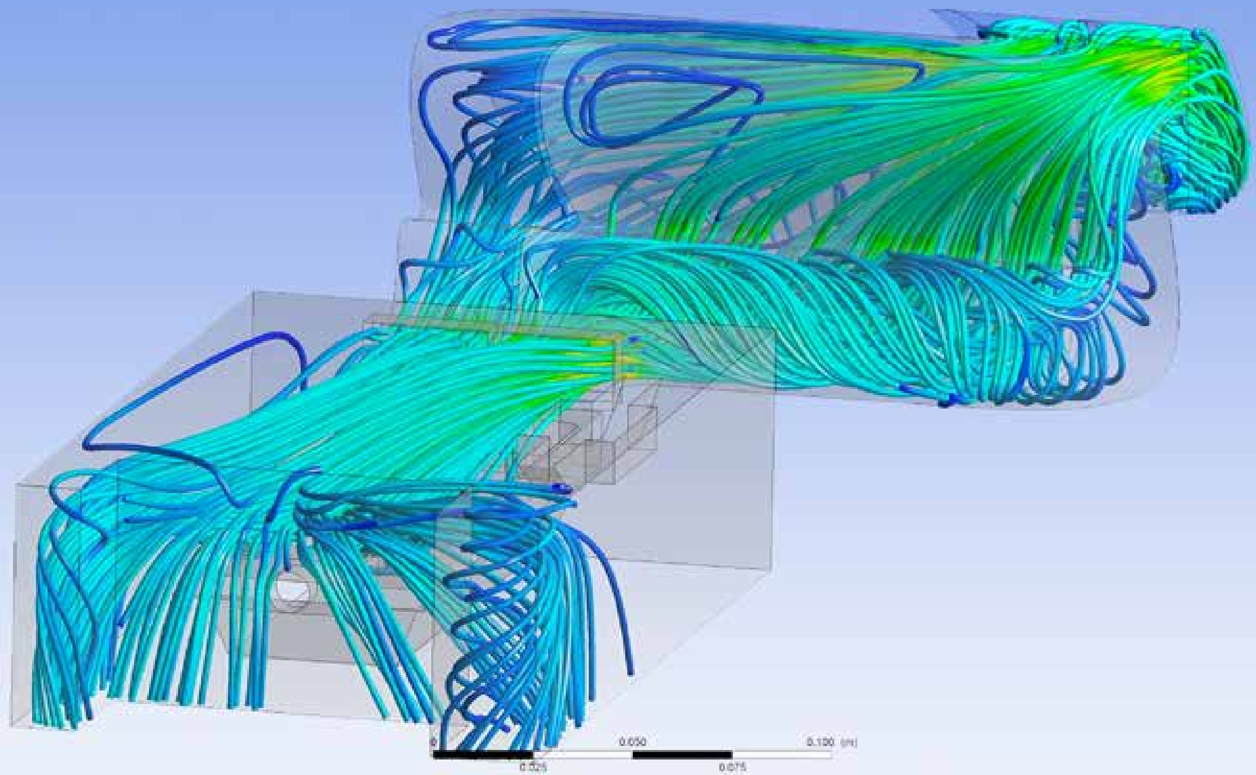
- **A single energy beam.** Unlike the broadband X-ray radiation that emanates from modern clinical machines, Lumitron's design can finely tune the output to a single wavelength of X-rays. "If you want 50 kV X-rays, you will just have 50 kV X-rays," Hwang says. "Your imaging system will be tuned to the most efficient energy. This will enable a lot of new imaging techniques."
- **A smaller spot size for higher resolution.** Lumitron is able to focus the electron beam and the laser beam on a very tiny spot, 10 microns or smaller. And that essentially becomes the source size of the X-rays, which determines how small a thing you can resolve in your image.
- **Combined imaging and therapy.** Tuning the accelerator to a higher energy can be done in a matter of minutes. So, you can use one instrument to image a tumor at low energy and then increase the X-ray energy to that spot to begin killing cells in the tumor immediately.
- **A more targeted, effective therapy region.** Using a metal-based contrast agent, like gadolinium, helps to locate a tumor more clearly. But there is another advantage of these metal particles: If you irradiate the region with X-rays having an energy just above the K-edge (sudden increase in X-ray absorption) for the metal, they release a lot of radiation locally. "This starts the cascade of thousands of electrons leaving the atom," Hwang explains. "But these electrons are at a much lower energy, usually a kV or less, so they really can't travel very far — nanometers at most. So, if the metal particles are located in the center of the cancer cells, this cascade will kill only the nearby cancer cells without damaging the rest of the healthy tissue."

A small section of a building-sized synchrotron

IMPROVING HEALTH CARE THROUGH SIMULATION

The Lumitron X-ray design improvements could pave the way for combining medical diagnosis and therapy. The company's technology has been called a new frontier for medicine.

"We are very devoted to imaging, diagnostics and therapy," Hwang says. "The ability to do these things with one instrument while enhancing the contrast and delivering a lot lower X-ray dose to the patient — that is unique. And the Ansys Startup Program played a big role in making this research and development possible."



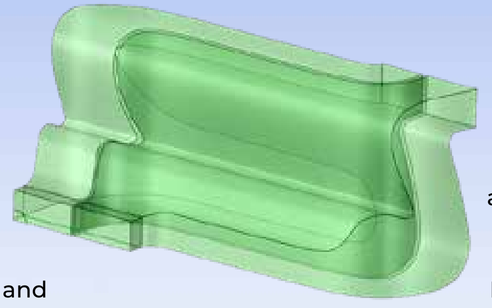
Fluid Dynamic Simulations Advance Appliance Designs

By **Manilka Abeysuriya**, Senior Product Development Engineer,
Fisher & Paykel Appliances, Auckland, New Zealand

In the competitive world of home appliance design, particularly refrigeration, cooking, laundry, dishwashing and range hoods, pushing performance boundaries means grasping a deeper understanding of how these products operate. Tighter environmental regulations coupled with more sophisticated user experience requirements push the designs into territories where subtle physical behavior starts to play a more prominent role. This can mean lengthy and expensive development and testing phases.

> ***"Simulations are also used extensively throughout the development process, especially when various design changes pop up as the designs of related systems mature."***

For instance, the moisture management inside refrigeration compartments is one area where understanding condensation, heat transfer and airflow is crucial to developing a better-performing product.



The optimized design

New Zealand–based appliance designer Fisher & Paykel uses Ansys software to carry out simulations at the early stages of product development to identify and rectify potential issues, as well as optimize designs to meet various performance criteria. They had particular success using Ansys Fluent and computational fluid dynamics (CFD) to improve ice-making in their refrigeration products.

Simulations are also used extensively throughout the development process, especially when various design changes pop up as the designs of related systems mature. These analyses tend to be a case of assessing multiple solutions to prioritize those that are most promising. Because of subtle differences between some of these solutions and experimental uncertainty, CFD has become the most reliable means of their assessment.

UNDERSTANDING ICE-MAKING CHALLENGES

Fisher & Paykel's goal was to develop a higher performance ice maker, which requires increasing airflow over the ice tray to improve the ice-making rate. This meant creating an air delivery system that is capable of channeling even flow over the ice tray.

This was no easy feat, since the company had to redirect some of the primary air that feeds into the freezer compartment into the ice maker. The challenges: dealing with the abrupt changes in flow direction and developing a design that could work with a range of different refrigerator models.

In initial discussions, the company realized multiple baffles wouldn't work due to the chaotic, swirling airflow at the source. The solution is a zone that allows the flow to buffer sufficiently in a controlled manner before releasing into the ice maker.

IMPROVING ICE-MAKING PERFORMANCE

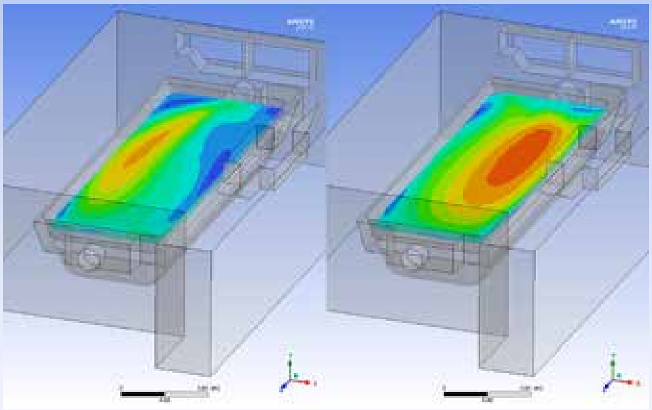
Fisher & Paykel engineers created initial designs using end-to-end, simple swept profiles and relatively convoluted flow paths because of the need for air to make drastic directional changes in two orthogonal transverse directions over a short length.

The solution was a redesign of the duct profile using a single baffle to better

Air redirection improves ice making.

"When hunting for an organic shape to achieve the given performance criteria, the shape-morphing ability of the Fluent Adjoint solver was a superior approach."

control diffusion across the two orthogonal planes independently. This resulted in a 67% decrease in pressure loss compared to the initial design. Inspired by the swirling motion of ground surface water navigating around an obstacle — and with the help of Fluent's Adjoint solver — the company optimized the design to produce a flow with primary direction aligned with the ice tray. This resulted in an average velocity increase of over 50% and produced a more symmetric flow profile over the ice maker tray, which helps significantly improve ice-making performance.



Simulation shows the final (right) design improves velocity distribution over the ice maker tray compared to the initial design (left).

HOW THE FLOW FIELD WAS DESIGNED

Flow entering the duct gets drawn down into a cylindrical chamber, encouraging a swirling motion with an axis in the transverse direction to the primary flow at the duct's entry. This allows the lateral translation of the primary flow, while minimizing losses. The flow then releases behind the ice maker through a short straight duct segment. Here, the bulge/cylindrical feature upstream of the duct outlet encourages and facilitates the transverse swirl motion, which is key when attempting to produce unidirectional flow over the ice tray.

Throughout this process, Fluent CFD simulations were used extensively. This use of simulation was much more cost– and time–effective compared to producing and testing 3D–printed designs, which required three days per design iteration. The company could turn CFD simulations around in a single day. Additionally, when hunting for an organic shape to achieve the given performance criteria, the shape-morphing ability of the Fluent Adjoint solver was a superior approach compared to manually creating discrete design iterations.

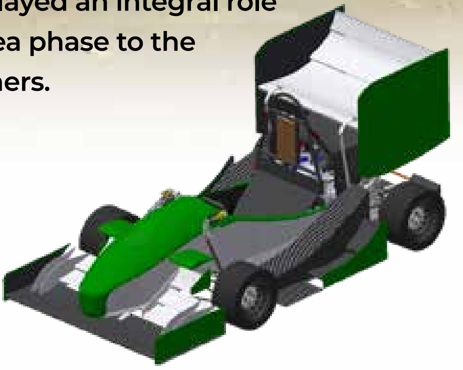
CFD simulations also revealed an extensive description of the flow field, which enhanced the engineers' understanding of the flow behavior. Compared to physical testing, the ability to have greater control of the test environment in a virtual model also helped Fisher & Paykel refine the product design. As well as looking at the airflow behaviors, it was paramount that any aerodynamically generated noises were also kept to a minimum in order to produce a quiet refrigerator. For this, the company used Fluent aeroacoustics simulations to assure that noise–level requirements were met within the CFD analysis and physical tests for assessing the final design.

A FORMULA FOR SUCCESS

By Ansys Advantage Staff

IIT Bombay Racing's E-12 electric vehicle, winner of the Formula Student 2020 Engineering Design competition.

Student auto racing competitions have a long history at universities worldwide. Over that history, as professional racing teams have integrated physics-based simulation software into their workflows, the student teams have adopted the same tools for their competitions. Ansys simulation software has played an integral role in helping get student design concepts from the idea phase to the final product for teams, including many recent winners.



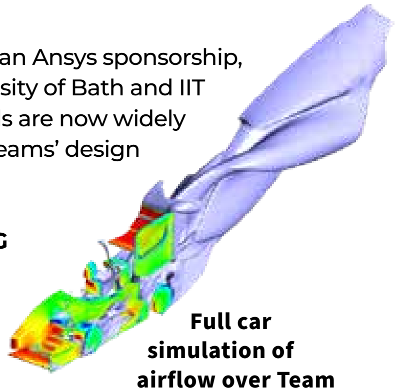
CAD model of the Team Bath Racing's 2021 entry highlighting the updated aerodynamics package.

The first automobiles appeared in the 1880s, and enthusiasts soon began modifying them for racing. Open-wheel racing became a sanctioned professional sport quickly. The cars came from years of engineering by teams trying to wring horsepower and downforce out of their machines while staying within design rules and budget caps.

STUDENT COMPETITION HISTORY

For many aspiring engineers, one avenue toward pursuing a career in the auto industry has been through their participation in the main international open-wheel competitions targeted to university students. In North America, Formula SAE began its competitions in 1981, and is organized by SAE International – formerly the Society of Automotive Engineers. SAE now hosts multiple Formula SAE events globally with its main showcase at the Michigan International Speedway near Detroit. Student teams design and fabricate a new vehicle for each competition year. In a typical year, the teams square off in three static events, including cost analysis, business presentation and engineering design, and five dynamic events, including skidpad, acceleration, autocross, endurance and efficiency. The UK-based Formula Student competition emerged in 1998 with very similar rules as Formula SAE and hosts its main event at the Silverstone Circuit in central England.

The use of Ansys simulation software by student teams debuted in the 1990s, with early adopters first using the Ansys structural analysis package to model the stresses, stiffness and vibration modes on different elements of the vehicle chassis. Beginning in 2012, Ansys began officially sponsoring student teams by providing no-cost access to its suite of structural, fluids electromagnetics and high-performance computing tools. Additionally, the teams have access to free software training courses and to the Ansys Learning Forum for technical support. Of the several hundred teams from universities around the world competing in Formula SAE and Formula Student events, more than 150 of those teams are benefiting from an Ansys sponsorship, including the University of Bath and IIT Bombay, as CAE tools are now widely used as part of the teams' design processes.

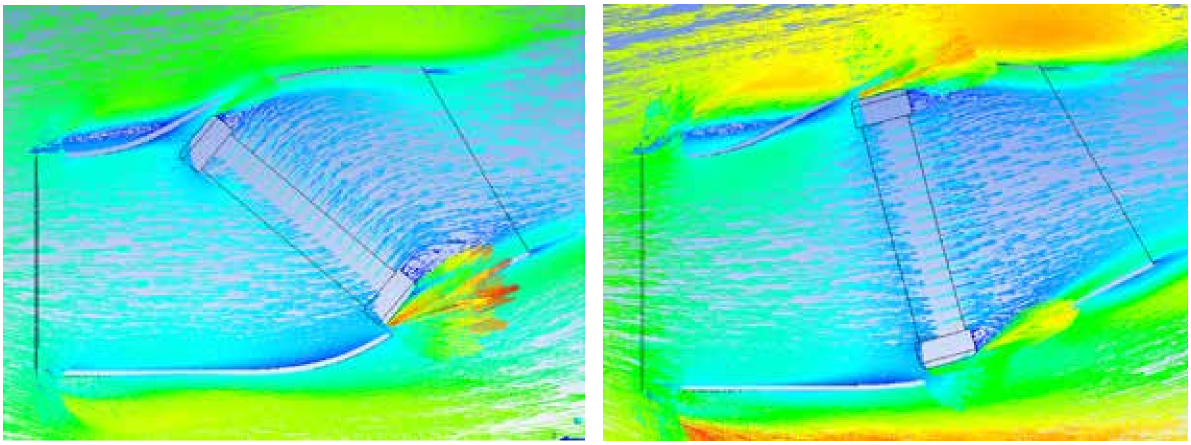


Full car simulation of airflow over Team Bath Racing's 2021 car using Ansys Fluent

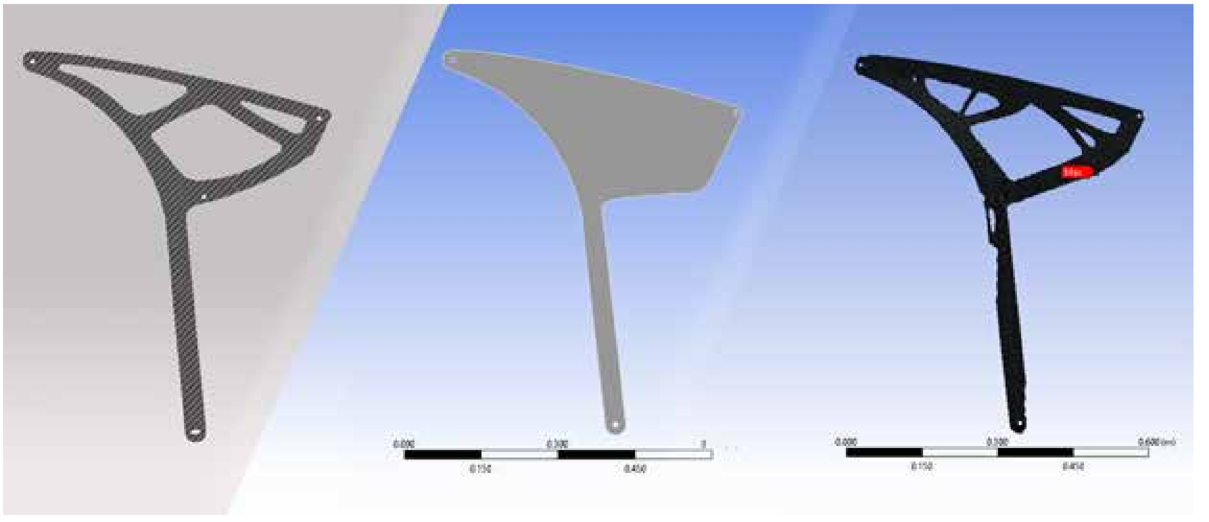
TEAM BATH RACING

In the internal combustion category, Team Bath Racing from the University of Bath has been competing in Formula Student events since 2000 and has been consistently ranked as the top UK team for many of those campaigns. By having to create a brand-new vehicle from scratch each year, the team is limited by both the available time and funding. It has been crucial that any simulation software be easy to use and capable of producing accurate results – no matter the size of the component or model.

With both Ansys Mechanical and Ansys Fluent in its arsenal, the Bath students have been able to use the software's wide range of simulation features to develop and test ideas effectively and reliably while reducing costs by reducing the need for prototyping and wind tunnel testing. Analysis in Mechanical ensures that the vehicle components comply with the Formula Student rules and can withstand the stresses and conditions of the competitions. Fluent simulations have enabled the team to produce year-over-year improvements in the aerodynamics package. Most recently, this was showcased through the development of new



Visualization of airflow through the radiator at higher (left) and lower (right) angles of inclination. Porous media modeling was used to compute the flow rate through the radiator core and the drag at the different inclination angles.



Initial design of IIT Bombay's wing mounting structure in Ansys Workbench (left), followed by results from topology optimization (center) and the final design (right) reducing weight by 40%.

chassis winglets that redirect flow back towards the ground, increasing the rear- and side-wing downforce by 11% and helping propel Bath to win the overall static events at Formula Student 2020.

IIT BOMBAY RACING

At the Indian Institute of Technology (IIT) Bombay, student teams have been competing in the Formula SAE and Formula Student events since 2007. For the Formula Student 2020 competition, the team's entry was in the electric vehicle division, and they used both Mechanical and Fluent to help optimize different aspects of the design.

On the structural side, the development of a lightweight mounting structure for the rear wing was a challenge due to the position of the wing relative to the chassis. With Ansys Mechanical, the IIT Bombay team performed a static structural simulation on the first design iterations to visualize the stress contours on the wing mounts.

The 2018 Formula Student car from Team Bath Racing

The next step was a topology optimization analysis, where the students defined the targeted exclusion areas and weight-reduction goals. After making geometry changes based on an optimization study, the final design ended up being 40% lighter than the initial design while still meeting the required safety factor.

For fluid dynamics analysis, the team found Fluent to be indispensable to the process of designing the cooling system for the vehicle's battery cells. The students wanted to find the best angle of inclination of the radiators to balance the airflow through the core and the resultant drag on the vehicle. Another challenge was uneven airflow within the accumulator leading to the creation of local hot spots. The IIT Bombay team was able to assess the flow rate and drag at different angles of inclination. They used Fluent's porous media simulation capability to accurately model the radiators and the flow rate through them. With their final design, the team reduced the overall size and weight of the radiators by about 25% and reduced the cell temperature by 15%. Combined with the results from the structural analysis, these design improvements helped IIT Bombay Racing win the Engineering Design event at Formula Student 2020 and place fourth overall among electric vehicles.

FORMULA STUDENT UK CHAMPION

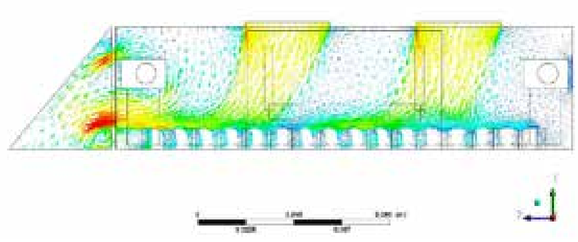
"We are currently manufacturing and testing our latest car E-12," says Saksham Garg, chief mechanical officer, IIT Bombay Racing, "the design of which won the FSUK 2021 overall championship title, the Engineering Design Competition at both FSUK 2021 and FSUK 2020, and the FSEV Concept Challenge 2021."

Garg credits Ansys for playing a pivotal role in these wins by providing a comprehensive suite of engineering tools.

"With the use of Ansys software, our team was able to reduce the weight of the rear wing mounting structure by 40%, reduce the weight of our radiators by over 24% and cell temperature by 15%," Garg says. "This improved our team's overall race car for the Formula Student competition. Using Ansys software not only helped the team overall but also improved our technical skillset and practical experience, preparing our graduates for their future careers in industry and academia."

LOOKING AHEAD

In the 2020 events, the governing bodies made the competitions virtual to accommodate COVID-19 global travel restrictions. For 2021, dynamic events returned to the tracks in July for both



Velocity vectors of airflow used by the IIT Bombay team to identify problems in the accumulator cooling system.

Formula SAE and Formula Student. Adjusting to a virtual format with limited abilities to meet in person further highlighted how critical simulation software is to the design process when physical testing is limited or not available. Through these competitions, the IIT Bombay and Bath students, along with the Ansys-sponsored teams, are gaining valuable experience on real-world projects, which is particularly sought after in the auto industry, as they make their way into professional engineering and design communities.

"With the use of Ansys software, our team was able to reduce the weight of the rear wing mounting structure by 40%, reduce the weight of our radiators by over 24% and cell temperature by 15%. This improved our team's overall race car for the Formula Student competition."

Designing the World's Fastest Bike

By Ansys Advantage Staff

In the hyper-competitive world of professional cycling, the slimmest of margins — a mere matter of seconds — can be the difference between winning and winding up out of medal contention. Getting to the finish line at all often comes down to being a fraction of a second faster during individual time trials than hundreds of other competitors.

It's no wonder then that road cycling teams are looking for any ethical way possible to shave even milliseconds off of their performance.

For France's Equipe Cycliste Groupama-FDJ, their plans to outpace the competition are riding in part on aerodynamic simulation.

Led by physiologist and Director of Performance Dr. Fred Grappe — an expert on aerodynamics in cycling and author of important research on improving training and performance capacity through science — Groupama-FDJ set out in 2019 to design what they believe will prove to be the fastest racing bicycle ever, the Aerostorm DRS. Working with partners Lapierre Bikes and professor Bert Blocken, scientific director of the University of Eindhoven wind tunnel and Professor at Technology University of Eindhoven and KU Leuven, their efforts included airflow modeling using Ansys Fluent to understand the aerodynamics of the bicycle's lightweight carbon frame tubes. Simulation helped designers streamline the frame to reduce drag. The speed-slowing, aerodynamic force that the cyclist needs to counter to move faster, drag can keep even the best trained athlete from the podium.

LESS DRAG, FASTER FINISHES

Eighty percent of the drag on a bicycle comes from the human body. Because it is not possible to change the shape of an athlete, at best we can optimize his or her position. However, we can modify the shape of the bicycle to reduce drag. Small gains can make big differences.

For the casual bike rider pedaling through the park, drag might not be terribly meaningful, but

Stefan Kung, photo credit: Presse Sports

the faster someone cycles, the more pronounced the effect becomes. Countering drag at world-class cycling speeds requires tremendous stamina and exertion. It's generally thought that a cyclist pedaling 48 km per hour (29.8 mph, which is slower than the typical Tour de France effort) will spend 90% of his or her power just trying to overcome aerodynamic drag. Though the bicycle produces less drag than the rider, even incremental reductions in drag can make a significant difference in how much energy the athlete has to expend over the entire racecourse. Better aerodynamics mean the cyclist can conserve energy throughout the race for a bigger kick at a crucial moment.

For Groupama-FDJ and Lapierre, using Fluent to quantify the drag originating from every component of the Aerostorm DRS frame allowed them to modify the geometry of the bike's components and optimize the shape of certain frame tubes. Those modifications led to a nearly 7% drag reduction compared to previous bikes.

MODIFYING FRAME TUBES TO REDUCE DRAG

Frame tubes — the components that comprise the frame of a racing bike — can essentially be thought of as cylinders. This sounds fairly unimportant until you consider that airflows around cylinders are extremely complicated: they're unstable, somewhat counterintuitive and can redirect airflow to unexpected parts of the bike or the athlete. Add in the fact that bicycle frame components negatively affect the aerodynamics of one another— a problem that's especially noticeable on the diagonal downtube — and it makes studying aerodynamic phenomena even more challenging. To properly capture these complex flow patterns, the quality of the mesh is essential; the thickness of the cells close to the tube is much smaller than a mm. Furthermore, high-resolution CFD simulations are performed with the 3D Reynolds averaged Navier-Stokes (RANS) equations and the Transition SST k-ω model; these computer models have been validated by numerous wind tunnel tests.

"It is essential to find the right compromise between components optimization and global drag reduction — what only simulation can do in a cost- and time-effective way."

By simulating every frame tube in Fluent, the Aerostorm DRS design team was able to overcome those obstacles. Modeling the laminar, transitional and turbulent airflows around the components at speeds from about 32 km per hour to 99 km per hour (20 mph to 62 mph) helped them to understand airflow resistance and circulation, and to quantify drag on different places on the bike. Indeed, it is essential to focus on the parts of the bike that contribute the most to the global drag to maximize the gain; on the other end, local improvements of the aerodynamics of some components may have negative effect on the global drag because they are modifying the airflow driving more air to drag generator sections. It is essential to find the right compromise between components optimization and global drag reduction — what only simulation can do in a cost- and time-effective way. That could never be accomplished in the wind tunnel or the velodrome.

WINNING A CLOSE GAME

That's not to suggest that simulation is now the only tool in the bike designer's kit. Simulation hasn't replaced wind tunnel or ground testing, but works hand in hand with them. It allows faster and more confident prototyping and less of the trial-and-error that went into creating new products the "old" way. Still, a prototype of every Lapierre Bikes model is road-tested by a professional cyclist whose feedback goes into the next iteration.

In fact, when it comes to using modeling, the Groupama-FDJ team's status of being early adopters makes them somewhat of an outlier in their sport. Motor sports, including Formula One, have embraced simulation, and America's Cup racers are using it as well. But the cycling world has been slower to catch onto its benefits. That could change, however, once Aerostorm DRS riders start finishing in the top spots. After all, bicycle racing is a close game, with cyclists looking for every second they can find on the road. If simulation can help uncover a second here and a second there, it's likely to be seen as essential to bike design and, eventually, racing success.

Cool, Compact *and* Comfortable: Podbike FRIKAR Redefines the Velomobile

By Ansys Advantage Staff

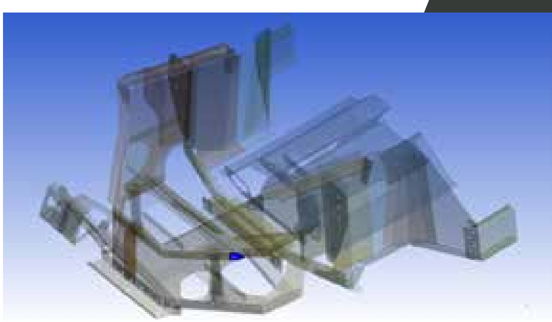
The idea for the Podbike FRIKAR e-bike began, quite literally, with a bang.

Podbike founder and product developer Per Hassel Sørensen was riding a conventional two-wheeled bike along the streets of Sandnes, Norway, when he had what he described as a "kinetic exchange with a car at three meters per second."

In other words, he was involved in a low-speed collision.

But at any speed, a bike is no match for a car in a crash. The accident nearly broke his neck. It also left him with a steel rod in his leg and a fear of riding a bike in mixed traffic.

Rather than retreat to a life of driving a car — particularly unlikely given that Sørensen is an inveterate cyclist with a master's degree in sustainable energy — he spent the next six years using a kit-built, three-wheel (and slightly souped-up) velomobile as his daily mode of transportation. But in the back of his mind, he knew he could come up with something better.



Ansys Mechanical structural fatigue simulation of the front of the chassis

Velomobiles are electric-assisted bicycle-cars especially valued in Europe's bike culture where they provide transportation and exercise yet use little energy. They have limitations, though, especially in Nordic weather, where the lack of a roof or windshield exposes riders to the elements.

That was just one of the issues Sørensen set out to overcome by developing a different kind of e-bike from the ground up.

The final product would be safer than conventional velomobiles, easy to spot on crowded roads, provide year-round comfort and have mass market appeal.

Using Ansys Discovery, Ansys Mechanical and Ansys Fluent, Sørensen and his four-person team developed the Podbike FRIKAR, a fully encapsulated, energy-efficient, all-weather, four-wheel e-bike. The FRIKAR

> ***"Given the complex geometries involved, especially regarding fatigue, it would be too time consuming and costly to do a lot of lab tests and prototypes. You need numeric simulation to be able to make a product like the FRIKAR."***

is lightweight yet strong, "acting as a cocoon," Sørensen said, to protect the rider (and any youngster in the optional child seat). Electric assist gives the rider more pedal power but doesn't propel the vehicle on its own.

Ansys provided both simulation software products through the Ansys Startup Program, which helps promising new companies who have limited funding for product development.

"It's a struggle to fund a new business in the beginning," Sørensen said. "Ansys enabled us to use first-class software at a discount. That was a huge help."

DESIGNING A VELOMOBILE WITH OUTSIZED PERFORMANCE

Designing the aerodynamic body of the FRIKAR e-bike meant balancing cost and ease of assembly with strength and safety — not only did the vehicle need to be safe, the rider needed to feel safe inside.

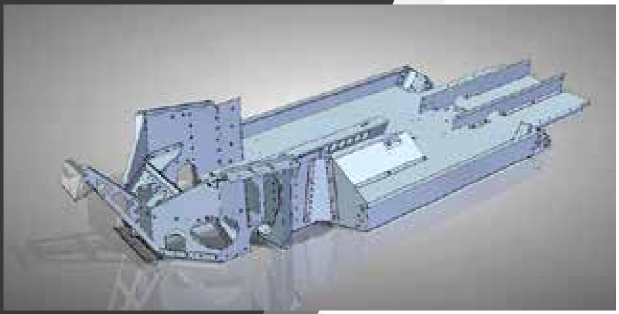
The Podbike FRIKAR takes velomobile safety to a new level.

With four wheels instead of three, the FRIKAR is more stable than traditional velobikes, especially when cornering. Protective zones absorb and distribute impact energy in case of collision. In fact, the FRIKAR is designed to bounce off any slow-moving or stationary object it contacts.

Yet to make it truly appealing to riders, the FRIKAR also had to be stylish. Some might even call it cool, which was what Sørensen was going for.

A typical velomobile resembles a three-wheeled go-cart or kiddie carnival ride. It's topless and has a Flintstone-like opening underneath the pedals. But the weatherproof Podbike FRIKAR is completely enclosed — canopy, sides and bottom —and has the streamlined good looks of a jet cockpit, only in compact form.

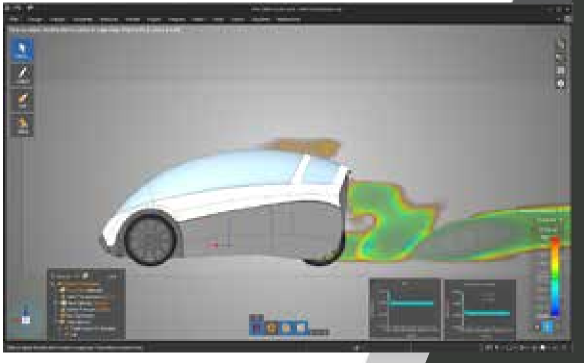
At 7.5 feet long and 2.75 feet wide, it's about the same size as a bike trailer. And though its low profile is meant to help prevent rollovers, the FRIKAR is actually taller than a Lamborghini Countach or Miura. The FRIKAR seats one adult with room to spare. There's also a cargo area ample enough for groceries, camping gear or a couple of dogs.



Screenshot of a CAD model production version of the FRIKAR structural platform, jointed using structural adhesives and speed fasteners

With its sleek styling, the FRIKAR looks like it's built for speed and, at least in the e-bike world, it is. It's built on a recumbent chassis with motors in the two back wheels and a pedal generator in each of the front wheels. Top speed with electric assist is 15.5 mph. Any faster, and it would no longer qualify as an e-bike in the EU. That would keep it from traveling in dedicated bike lanes and would also require a driver's license and registration to operate.

The FRIKAR is also built for distance. The chassis can accommodate multiple traction batteries — they provide the power — with an electric range of 37 to 55 miles each. The batteries also provide electric assist, which improves pedal power without actually propelling the e-bike on its own, helping the rider go farther while expending less energy.



The turbulence from the abrupt end of vehicle illustrates the compromise between low drag and practical features.

AN AIR OF COMFORT

Not every rider uses electric assistance, of course. To allow pedaling without it, design considerations include how to restrain the FRIKAR's overall weight (the current model is 198 pounds).

Although carbon fiber would have substantially reduced the FRIKAR's weight, it didn't meet Podbike's green requirements. Because the material can't be recycled or reused, it was taken out of the running.

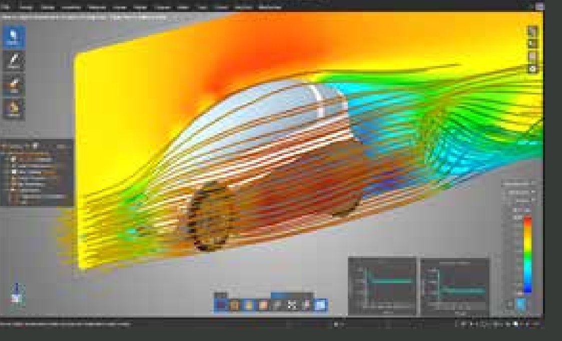
The team ultimately chose a more environmentally friendly, corrosion-resistant aluminum alloy plus stainless steel for parts subjected to higher fatigue cycles. Using Mechanical to model material fatigue, load and vibration helped the team understand how the FRIKAR would perform under different operating conditions, including bumpy roads. It also provided insight into the e-bike's response to impact.

Ansys CFD turbulence models enabled drag calculations that provided what Sørensen called "a hint" of what the e-bike's shape should be. To reduce drag as much as practically possible, the Podbike team refined the body geometry over multiple iterations.

Sørensen also used Ansys CFD to perform thermal simulation and calculate air velocity for interior ventilation, making the FRIKAR cool in an entirely different sense.

"As with any pedal-powered device, the rider generates heat that has to be dispersed," Sørensen said. "However, because a FRIKAR rider is fully enclosed, there's no automatic cooling from moving air, making airflow via blowers and ventilation ports a key design challenge."

Without sufficient cooling mechanisms, extreme exertion could cause overheating or force the rider to slow down. Calculating total heat load on ventilation also had to account for some other small heat sources, including headlights and even the rider's moist breath that could fog up the window.



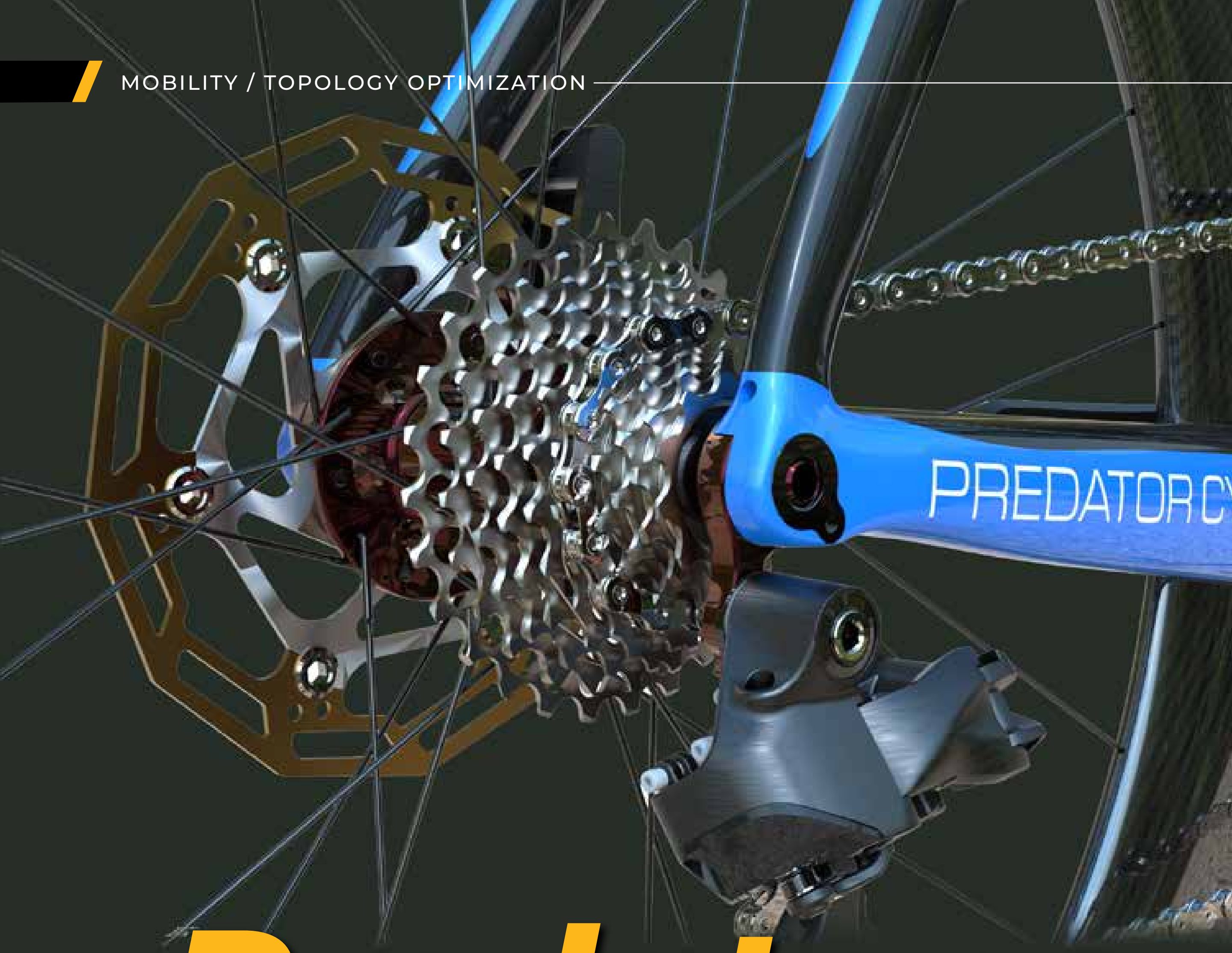
Velocity graph showing air velocity streamers at 10 m/s and the convergence of drag and lift calculations

GETTING UP TO SPEED WITH SIMULATION

While the inspiration for the Podbike FRIKAR started with an accident, every step Sørensen and his small team have made to bring it to limited production has been deliberate and well-considered. That includes using Ansys simulation to guide important design decisions. In fact, Sorensen said that without simulation, it would have been difficult to get this far.

"Given the complex geometries involved, especially regarding fatigue, it would be too time consuming and costly to do a lot of lab tests and prototypes," he said. "You need numeric simulation to be able to make a product like the FRIKAR. It's not doable without it, at least within a reasonable timescale and budget."

Podbike, the Podbike logo and FRIKAR are trademarks of Podbike AS, registered in Norway and other countries. Used with permission.



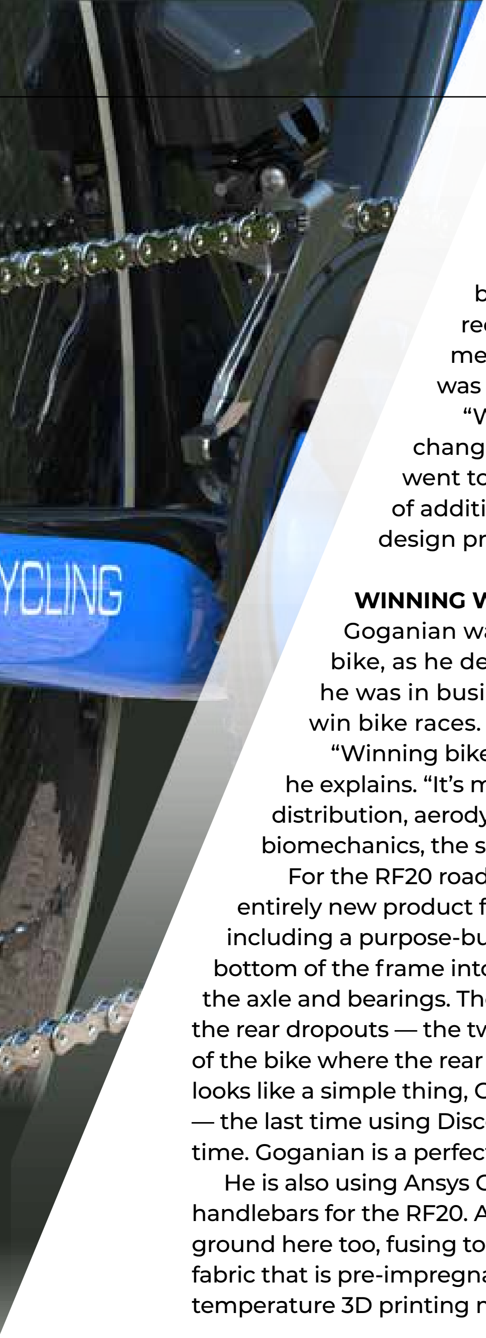
Predator Cycling

Optimizes the Cycling Experience With Simulation

By Ansys Advantage Staff

When Aram Goganian was an avid 14-year-old bike racer, he became impatient with a company that he felt was taking too long to produce a new time trial bike.

"I told them it's not that complicated," Goganian recalls. "That they should hurry up and do it. The company owner said, 'If it's that simple, you should do it.'" So he did. Twenty-two years later, he is still designing unique bikes and accessories at his company Predator Cycling, only now he's using Ansys Discovery, Ansys Mechanical, topology optimization and Ansys Composite PrepPost to produce everything from his latest carbon fiber-based bike, the RF20, to 3D-printed water bottle cages that securely hold



a water bottle in place on even the wildest mountain bike rides. He uses the new Lenovo ThinkStation P620 equipped with the NVIDIA RTX A6000 GPU and a 64-core Threadripper Pro processor built on the new Ampere architecture to run the simulations in record time. Goganian started using Ansys simulation solutions as a member of the Ansys Startup Program in early 2020, right when he was having some trouble with the design of the RF20.

"We started using Ansys simulation, and it was a huge game changer because we could actually simulate so many things before we went to prototyping," he says. "We saved at least seven or eight months of additional R&D by being able to simulate so much earlier on in the design process."

WINNING WITH SIMULATION OF THE RF20 BIKE

Goganian was only 15 when he produced his first "gnarly-looking" prototype bike, as he describes it. Other racers saw it and wanted to buy one. Suddenly, he was in business. From the start, his idea was to build the fastest bike and win bike races.

"Winning bike races doesn't always mean that you have the lightest bike," he explains. "It's more of a balancing act between total weight, weight distribution, aerodynamics, frame stiffness, impact tolerance, bike fit, biomechanics, the shortest chain stays and other factors."

For the RF20 road bike, the Predator Cycling team designed and built an entirely new product from the frame to the smallest detailed components, including a purpose-built bottom bracket system — a hollow cylinder at the bottom of the frame into which the bike's cranks fit, along with the axle and bearings. They also spent a lot of time designing the rear dropouts — the two small hanger notches in the back of the bike where the rear wheel goes. Although a dropout looks like a simple thing, Goganian redesigned it three times — the last time using Discovery — to ensure it would last a long time. Goganian is a perfectionist with his products.

He is also using Ansys Composite PrepPost to design new handlebars for the RF20. As you might expect, he is breaking new ground here too, fusing together a prepreg carbon fiber (a reinforcing fabric that is pre-impregnated with a resin system) and a high-temperature 3D printing material into a single part.

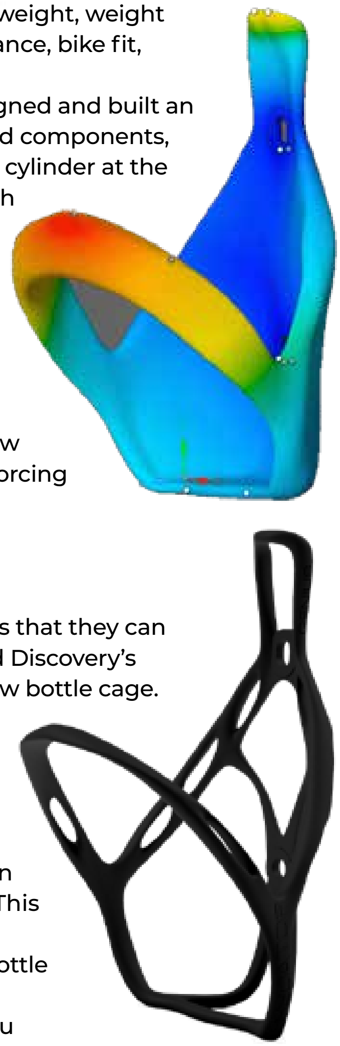
SIMULATING THE GENIUS WATER BOTTLE CAGE

With a goal of having a complete line of cycling-related products that they can 3D-print in-house and sell directly to consumers, Goganian used Discovery's topology optimization functionality to design a revolutionary new bottle cage. While a device that attaches to the frame of a bike to hold a water bottle doesn't seem like it should require much in the way of engineering innovation, it does if you work for Predator Cycling. Goganian wanted it to be the most efficient, durable and easy-to-use bottle cage on the market.

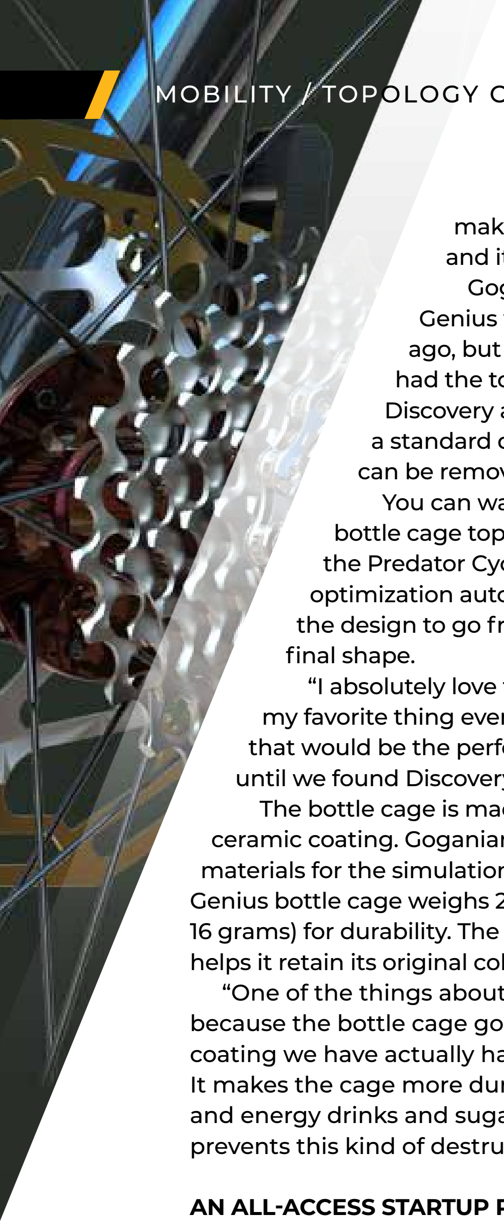
"Bottles are ejected from cages all the time, especially when you are mountain biking over rough terrain," Goganian says. "This can be dangerous and inconvenient, and it slows you down."

The entry angle is one important parameter. How does the bottle enter the cage? At what angle?

"Traditionally, you couldn't go in on the side," he explains. "You had to come in straight from the top. We designed ours with a mouth that looks like a shark mouth opening. The idea was that you could come in from almost a 45-degree angle and insert the bottle. You can come in from the top almost straight down and access it. It makes it easy. The material properties of the cage



Top to bottom: Initial and completed versions of Predator Bicycle's Genius water bottle holder, which was optimized with Ansys Discovery.



make it super flexible. You can actually bend and twist it and it will just grab the bottle."

Goganian came up with the idea for the Genius water bottle cage about three years ago, but he wasn't able to build it until he had the topology optimization feature of Discovery at his fingertips, which starts with a standard design and analyzes where material can be removed without reducing performance.

You can watch an animation of the Genius bottle cage topology automation using Discovery on the Predator Cycling website, showing how topology optimization automatically removes material from the design to go from the starting shape to the nearly final shape.

The Genius water bottle cage has a ceramic coating.

"I absolutely love topology optimization," he says. "It's my favorite thing ever. We had this idea for a bottle cage that would be the perfect thing to 3D print, but we could never figure out how to do it until we found Discovery."

The bottle cage is made of a UV-activated resin that is then post-cured with a thin ceramic coating. Goganian liked that Discovery allowed him to import his own custom materials for the simulations. By adding a ceramic coating, he was trading some weight (the Genius bottle cage weighs 20 grams, while the lightest cage on the market weighs around 16 grams) for durability. The ceramic coating protects the cage from damaging UV rays and helps it retain its original color.

"One of the things about cages that drives me nuts is they change color over time because the bottle cage goes in and out of it and it rubs against the cage. The ceramic coating we have actually has a lubricating property to it to help the cage go in and out. It makes the cage more durable. Also, in cycling, you're dealing a lot with sweat and salt and energy drinks and sugar, which just eat through and destroy everything. The ceramic prevents this kind of destruction."

AN ALL-ACCESS STARTUP PROGRAM

Besides the attractive price point of the Ansys Startup Program, Goganian loves that it gives him instant access to complete Ansys products in an approach that he describes as, "Here's everything. Use whatever you want and figure it out. We'll help you if you need it." Having a complete package meant that he didn't have to worry that he would get halfway through a design project and find that he didn't have access to some software that would prevent him from completing it.

He also likes being part of the larger engineering community. "I'm using the same simulation software to build bicycles that aerospace companies are using to build rockets," Goganian says. "That's pretty cool."

Predator Bicycle used Ansys Discovery to help design its RF20 bike.

Motorizing the Bike You Love with Bimotal and **Ansys Simulations**

All your mountain biking friends are buying e-bikes, and, even though you are considering joining them, you have a problem: You like your current bike too much to trade it in. Your bike has just the right weight and feel, and you've been through a lot together.

If none of the available e-bikes or retrofit kits have the perfect combination of features for you, check out the Elevate portable electric motor assembly from Bimotal. Designed using Ansys Motor-CAD simulation software that Bimotal obtained as part of the Ansys Startup Program, Elevate is a lightweight device that can be installed in seconds using a quick-connect cam lever on the brake rotor of the back wheel of your current bike. A throttle control on your handlebar lets you decide when to turn on the motor for a quick burst of power to help you get up that hill in front of you. And, if you are getting ready for a rocky downhill run and would like to reduce the unsprung weight, you can just as easily disconnect it and put it in your backpack for the ride down.

Bimotal says the Elevate motor and battery can be removed in 20 seconds.

“In our mission to reduce barriers to car-free mobility, we are en route to becoming motor, gearbox, battery and electronics experts. The motor and gearbox optimizations are made faster and more efficient with the help of Ansys tools.”

Elevate is the brainchild of Toby Ricco, founder and CEO of Bimotal, and “Motor Expert” (that’s his official title) Chad Furey, an electrical engineer with a focus on motor design, who had worked together at Tesla a few years back. Jason Roesslein and Matt Rounds, also former colleagues of Ricco and Furey, joined the team in the summer of 2020. When Ricco mangled his knee in a skiing accident in 2018, he was worried that he might not be able to enjoy mountain biking again, because his knee lacked the power to push up some of the hills.

The Bimotal Elevate is a removable, lightweight e-bike motor that mounts to your bike’s disc brakes.

“I started looking for full e-bikes as well as e-bike retrofit systems and found that both were still super heavy, expensive and clunky,” Ricco says. “I wanted a way to put a motor on a bike that was super light and something I could take on and off. So that’s how the system and company was born.”

FINDING A BETTER WAY TO E-BIKE

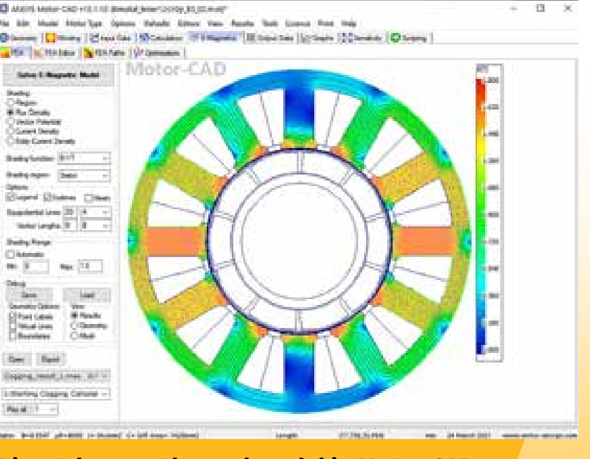
The knee took a long time to heal, which gave Ricco the space to look at e-bike design in a new way.

“It was literally me with an injured knee staring at my bike every evening after work for an hour,” Ricco says. “I thought, ‘There’s got to be a better way.’ And this went on for months … I just kept looking.”

For reference, typical mid-drive e-bikes have the motor in the bottom bracket in front of the crankshaft where the pedals are located. For most speeds (anything above 5, maybe 8 mph), the motor is geared down to the user’s cadence at the pedals and then geared back up through the bike chain and cogs mounted on the rear wheel hub. Thus, the motor is operating at a lower total motor-to-wheel gear ratio, which requires more motor torque and is inherently less efficient or heavier for the same power. Other common e-bikes are powered by hub motors that transfer torque directly to the wheel, usually with limited-to-no gear reduction, which again leads to a heavier motor for a given torque and efficiency at the wheel.

“I kept thinking, ‘How can I get torque to the wheel?’” Ricco says. “And eventually it came to me: The brakes can take a lot of torque. A motor gearbox driving a wheel didn’t exist in the e-bike world at that time, even though that’s how every single electric-powered car does it.”

Having settled upon the basic idea, the challenge was to make it simple. In Ricco’s mind it had to be this easy: Fasten the Elevate motor to a bracket on the brake post mounts and start cycling.



Bimotal uses a thermal model in Motor-CAD to understand the temperature rise in the motor under various operating conditions.

MAKING THE E-BIKE IDEA WORK THROUGH SIMULATION

With the idea of the Elevate motor established, and Bimotal launched as a company in July 2019, the real work began. While Ricco worked on the motor mount design, quick-connect system

Toby Ricco, founder and CEO of Bimotal

and gearing to drive through a bike's brake rotor, Furey got busy simulating every aspect of the battery-powered motor to make the Elevate system the lightest, quietest and most efficient, with the highest power density possible.

As a startup with very little funding, Bimotal had to do design and engineering as economically as possible. "When you start looking around at simulation software and you ask Ansys if they have a better deal for startups, you quickly learn about the Ansys Startup Program," Furey says. "We were excited that we could use Ansys software at such a low price." Soon Furey was using his own, well-established process of using MATLAB with custom scripts he wrote to automatically assess tens of thousands to a hundred thousand designs at a time, followed by Ansys Motor-CAD on the best candidates. This huge number of models piles up quickly with just a few tweaks to the design.

"I want to determine if the magnet should be this big or this big, or if the rotor should be this big or this big," Furey says. "You take 10 magnet variations and 10 rotor variations and 10 thermal variations, and soon you're at 1,000 iterations. So the thing in motor design is that with 100 parameters to adjust, the number of iterations just explodes."

Using this brute force approach, Furey can quickly assess the fundamental viability of all these combinations, and then take a closer look at the 10 or 15 most viable candidates using Motor-CAD.

"I refine the good candidates and use Motor-CAD to make sure everything's lining up nicely," Furey says.

He uses a thermal model in Motor-CAD to get a good feel for the temperature rise in the motor under various operating conditions. The software generates efficiency maps that can help him determine the drive profile and the loss at key points in the motor's design. Motor-CAD also helped with the decision to use surface permanent magnets or interior permanent magnets.

"Those are very simple things to try in Motor-CAD," Furey says. "I can experiment to see 'Hey, can I get the torque density up any higher?'"

OPTIMIZING THE SYSTEM

Ricco designed one of the smallest cam lever connector systems available, with a clamping power of 1,000 Newtons of force to make sure the Elevate package stays on the bike on rough rides.

In the end, even though the Elevate motor is a small system that you can hold in one hand, there was a lot of engineering to do. "It's a whole system optimization challenge," Ricco says. "How much power do we really want? How much does a bike need? And then, basically, how much heat do we need to reject or can we reject? How small can we make the heat sink? How small can we make the motor and still have this really punchy system?"

Motor-CAD had a part to play in answering all these questions and more. The resulting Elevate motor weighs only 2 pounds and can generate up to 750 W of power. With the help of Ansys simulation, they stayed true to their motto, helping people to "Keep Riding the Bike You Love."

"In our mission to reduce barriers to car-free mobility, we are en route to becoming motor, gearbox, battery and electronics experts," Ricco says. "The motor and gearbox optimizations are made faster and more efficient with the help of Ansys tools."