Computer simulations could lead to better cardiac pump for children with heart defects

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Alison Marsden, a professor of mechanical and aerospace engineering, examines some of the simulations her research group developped in the StarCAVE imaging space on the UC San Diego campus. Credit: Erik Jepsen, UC San Diego Publications

Structural and mechanical engineers at the University of California, San Diego, are working together to create blood flow simulations that could lead to improvements in the design of a cardiac pump for children born with heart defects. They hope that the design changes will improve young patients' outcomes.

The Berlin Heart is currently the only FDA-approved cardiac pump for young children who can't be outfitted with an adult-sized pump. The device is used to extend a patient's life until a transplant becomes available. Accurate simulations of the way blood flows inside the pump are important because the device is associated with a 40 percent risk of developing blood clots, which can lead to strokes or embolisms. This in turn can have devastating consequences on the children using the pump, who can be anywhere from just a few months old to about 9 years of age. Simulations can be used to make design changes that would lower these risks.

Two researchers at the Jacobs School of Engineering at UC San Diego have combined their strengths to solve this problem. Alison Marsden, a professor of mechanical and aerospace engineering, focuses on the development of blood flow simulation tools that can be used to test and optimize new heart surgery designs on the computer before trying them on patients. Yuri Bazilevs, a professor of structural engineering, focuses on computational science and engineering to develop methods for large-scale, high-performance computing applications.

"This works saves a tremendous amount of time, money and risk," said Dr. Jeff Feinstein, a pediatric cardiologist at Stanford University, who has been working closely with the Jacobs School researchers.

Marsden, Bazilevs and their teams have successfully simulated blood flow within the device. They are now trying to understand how blood clots form inside the pump. The next step is to figure out, through simulations, what design changes are needed to reduce that risk.

The Berlin Heart, a pediatric heart pump, seen on the side where the blood chamber is located. Credit: Jacobs School of Engineering at UC San Diego

"Yuri has been essential in training my team in complex mathematical methods, such as finite element methods, and providing expertise in the development of cutting-edge computational methods," Marsden said. "I interface with the clinical people to identify high-impact applications, and combined we make a great team."

The pump has two chambers: one for blood, another for air, separated by a flexible membrane. The air chamber is pressurized, which drives the membrane to pump the blood. But blood flow created by the device is difficult to simulate because of the interaction of blood, membrane and air.

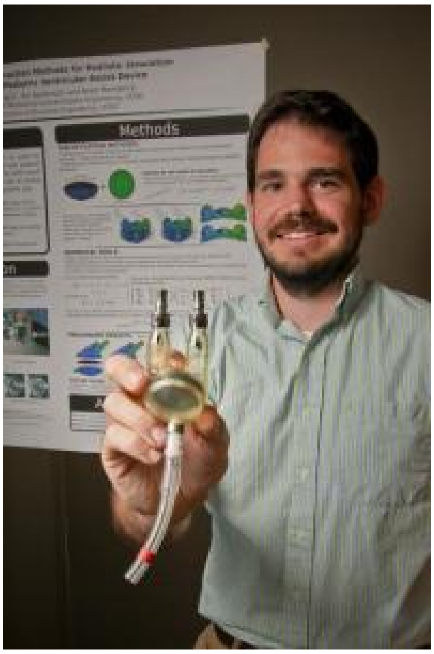
"Blood vessels are complicated," said Bazilevs, the structural engineer.

He specializes in complex simulations depicting the interaction of several elements. His lab has produced simulations of everything from airflow for wind turbine blades to air flow and water interacting with the hulls of high-speed ships.

"Simulating the heart pump is not simple," Bazilevs said. "Current commercially available codes are not capable of handling such problems, which necessitate the development and implementation of advanced procedures for the interaction of fluid and structure for this class of applications."

"Alison's expertise in applications of computational methods to pediatric cardiology complements my expertise in the formulation and implementation of advanced computational fluid-structure interaction techniques," Bazilevs added. "It is the fact that our skill sets complement each other and Alison's great personality that fuels this collaboration."

Marsden's work focuses on the development of blood flow simulation tools that can be used to test and optimize new heart surgery designs on the computer before trying them on patients. Her group uses patient imaging data, such as CT or MRI scans, to build personalized computer models of the arteries and veins, simulate blood flow and design surgeries that are customized to the patient. Many of the simulation tools used in this research are similar to those originally developed for aircraft design.



Chris Long, a PhD student is working on simulations of blood flow in the Berlin Heart. Credit: Jacobs School of Engineering at UC San Diego

Some of the designs developed in Marsden's lab have been used by pediatric heart surgeons at Stanford to treat children born with only one functioning heart ventricle. She and her students also have developed models of heart damage occurring in Kawasaki Disease in collaboration with physicians at the UC San Diego Medical Center and Rady Children's Hospital.

The collaboration between Marsden and Bazilevs illustrates the inter-disciplinary thinking that is one of the strengths of the Jacobs School.

The new Structural and Materials Engineering building, where both Marsden and Bazilevs are based, is designed to encourage such thinking. It is home to structural, mechanical, aerospace and nanoengineers, as well as visual artists.

"Yuri and I have been co-advising a student, and he is looking forward—for better or worse!—to having both his advisors in the same building," Marsden said.

Provided by University of California - San Diego