Laying the foundations to model physical problems

The rapid development of numerical methods over the last ten years holds important implications for modelling systems in engineering and applied sciences. **Professor Gianluigi Rozza** tells us about the AROMA-CFD project's work in developing reduced order modelling techniques, which could help overcome current limitations

The idea of using reduced order modelling techniques in numerical simulations to reduce complexity and computational times is not entirely new, dating back around thirty years, but they are still not widely applied in engineering and applied sciences problems. Part of the reason in the past was a lack of devices with sufficient computational resources, and more difficult problems had not been addressed yet by numerical analysts and computational scientists, while Professor Gianluigi Rozza of the AROMA-CFD project says the application of model order reduction techniques to practical industrial problems is also still relatively limited. "The research community has historically been more devoted to numerical analysis research than to exporting the methodology and exploiting it in computational science and engineering," he explains.

Reynolds number

This is an issue the AROMA-CFD project aims to address by further developing reduced order modelling techniques, with a particular focus on computational fluid dynamics. A large part of this work relates to the application of model order reduction to a specific class of physical problems involving fluids, such as gases, liquids, as well as cardiovascular flows. "There is a strong limitation in this related to the fact that we are not able to simulate what we call a high Reynolds number, which is a non-dimensional quantity in fluid dynamics. It relates to the ratio between inertial forces and viscous forces," continues Professor Rozza. "A high Reynolds number roughly means that there is a higher velocity, whereas a low Reynolds number means that more of a viscous effect is involved."

A high Reynolds number would be used to simulate the fluid dynamics around an aircraft in flight for example, while a lower Reynolds number would be used for a problem like modelling blood flow in the human body. These are very different problems, with very different shapes and dimensions, but Professor Rozza says they can be unified within a single paradigm, improving efficiency. "At the moment, when someone does a numerical simulation, they don't have a parametric design. So every time that you change the shape or the configuration of your problem or your system, you have to re-do almost everything," he explains. "We are now preparing a reference configuration, a reference shape that is properly parametrized."

This configuration can be changed for specific industrial problems, providing the foundation for model development. The same paradigm can be used for medical problems, including modelling blood flow in certain parts of the cardiovascular system. "We know about specific shapes in the cardiovascular system, like the aortic arch and the carotid bifurcation," says Professor Rozza. Everybody's cardiovascular system is different, yet with good parameterisation a reference configuration can be developed, again providing the basis for accurate models. "We can build all possible configurations, using the same paradigm and the same kind of parameterisation," stresses Professor Rozza.

This approach could potentially be applied in other contexts as well, with researchers testing its potential in automotive design and construction. In future, researchers plan to move towards a proof-of-concept and to demonstrate the versatility of this methodology. "We would like to develop a more unified framework," says Professor Rozza. The next step will be to further develop a multi-physics approach, which Professor Rozza says will be central to applying this research more widely. "This research could be an integral part of the new industrial design paradigm. We are integrating computer-aided design with research and development, optimization and control, and exporting supercomputing to industry and to hospitals thanks to reduced order methods and modern devices, like smartphones and tablets." he says.

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Advanced Reduced Order Methods with Applications in Computational Fluid Dynamics (AROMA-CFD)

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