PRACE Success Stories in Engineering

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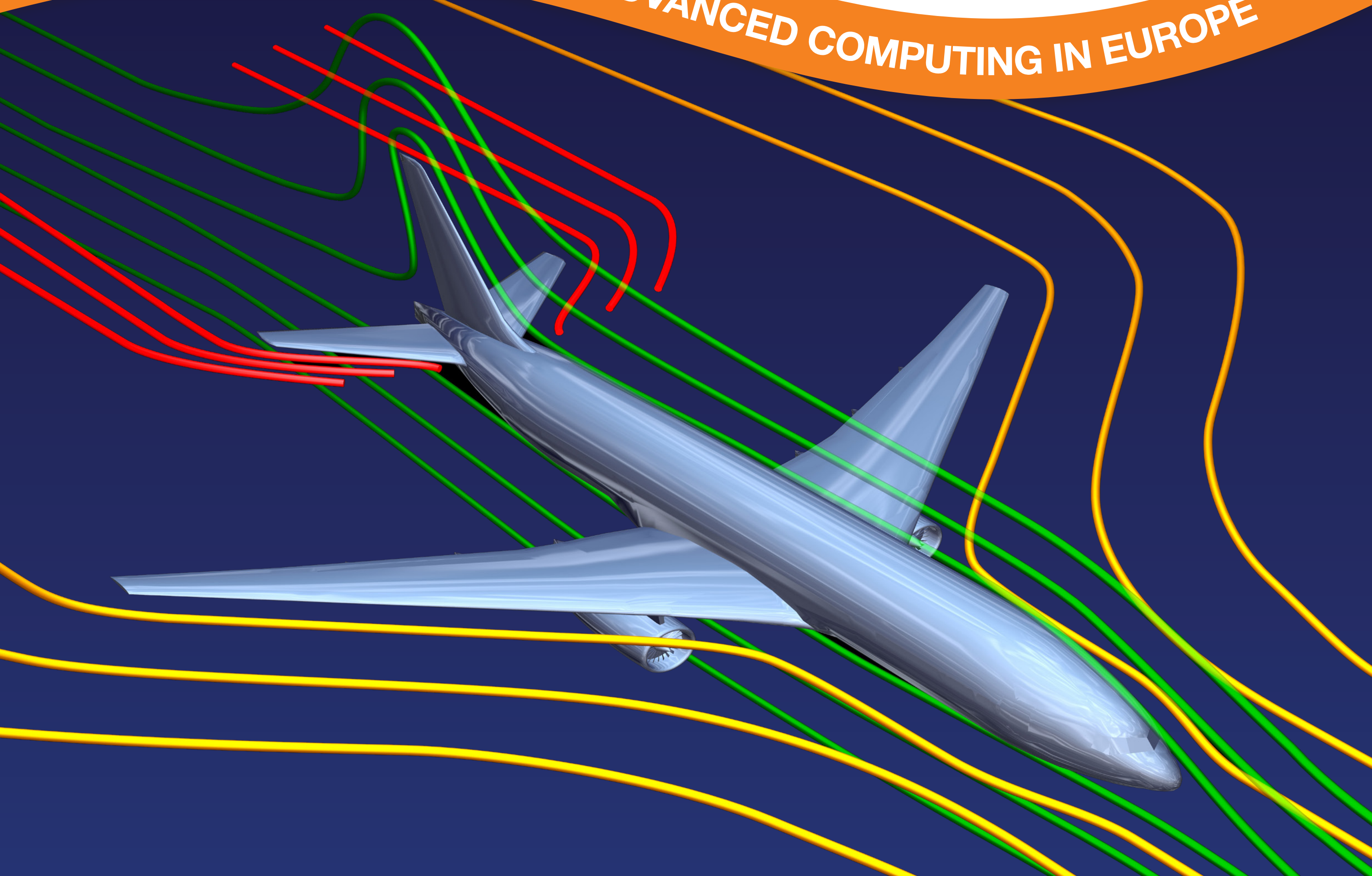

When it comes to propulsion systems and aerodynamics, experiments are extremely costly, and the knowledge scientists can gain from them is limited. High-fidelity simulations can support experimental investigation and the development of novel systems by helping to better understand and ultimately to manipulate turbulent processes — such as turbulence around aircraft wings, ship propellers and inside engines. We showcase three projects that, thanks to PRACE resources, boost the efficiency of propulsion in water, the air and in space.

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Future Aircraft Wings will Adapt their Shape Mid-flight

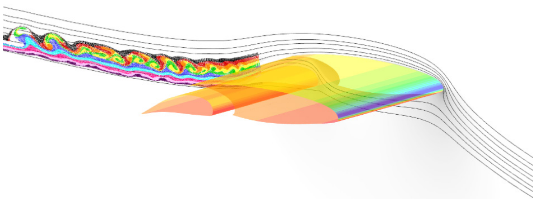
"The rigidity of today's aircraft wings has gross aerodynamic disadvantages", says Marianna Braza, CNRS director of research at the Institut de Mécanique des Fluides de Toulouse (IMFT). Within the EU-funded Smart Morphing & Sensing project, Braza and her co-workers at IMFT and the LAPLACE Laboratories developed a novel concept for aircraft wings that can adapt their shape as well as their vibratory behaviour during flight.

The team carried out extensive numerical simulations and coupled them with structural mechanics calculations in order to better understand the turbulences around airplane wings and to improve their shape shifting design. It consists of three components: First, a sensing system takes pressure measurements in real time during flight; then, electrically driven shape memory alloy actuators change the cambering of the wing, meaning its bending in the flight direction — a property that strongly affects turbulence around the wing; lastly, an array of piezo-electric elements at the rear of the wing create vibrations that alter a class of unfavourable vortices.

Within the simulations, the scientists examined different vibration modes for the piezo-electric elements and found that vibration at a frequency of 300 Hertz modifies turbulence very favourably: dragging air vortices in the wake of the wings are attenuated and, at the same time, vortices that produce lift are enhanced. The team also probed different designs and placements of the actuators that execute the cambering motion.

The overall result is convincing: The shape shifting wing components not only increase the lift of the aircraft and reduce its drag — thereby increasing flight efficiency and reducing fuel consumption and pollution — but also diminish noise during take-off and landing. As a next step, the concept will be applied on an unmanned drone with a wingspan of 6 meters to be tested for the first time in real flight.

Supercomputing Resources:
Joliot-Curie (SKL) at GENCI (France)



The novel prototype for the Airbus A320 family of aircrafts with morphing and vibration capabilities in a simulated take-off. Image Credit: A. Marouf, M. Braza.

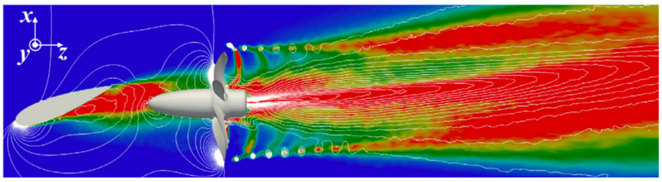
Understanding the Sneakiness of Submarines

Submarines are meant to be efficient and very quiet. One source of undesirable disturbances is the rudder used for manoeuvring, which is installed upstream of the submarine's propeller. "This means that the rudder impacts the flow into the propeller, altering noise emissions as well as propulsion efficiency", explains Riccardo Broglia, a research scientist at the Institute of Marine Engineering (INM) in Rome.

To better understand these relationships, he and his co-workers have carried out Large-Eddy Simulations (LES) of the propeller wake flow at different rudder orientations. The results showed that when the rudder is steered at a low angle, the wake from the propeller remains stable. However, when approaching a rudder angle of 20°, vortices from the rudder start to interfere with the propeller vortices, creating small-scale turbulences. According to Broglia, this may unfavourably affect propulsion efficiency, noise emission and fatigue on the material.

The team is also studying the inverse geometry, meaning a rudder in the wake of an upstream propeller, which is the typical configuration for surface ships. As before, their goal is to better understand and ultimately manipulate the propulsion turbulences.

Supercomputing Resources: MARCONI at CINECA (Italy).



At a rudder angle of 20°, the wake of the propeller becomes a turbulent affair. The red colour denotes the high kinetic energy of small-scale turbulences in the water – energy that is wasted, instead of providing propulsion. Image credit: Posa et al. Computers and Fluids, 184 (2019), Posa et al. Computers and Fluids, 192 (2019)

Re-usable Rockets Need New Engines

Future space rockets need to be re-usable to cut down on operation costs and space waste. The engines must therefore be re-ignitable and operable at variable thrust levels. That's why space flight initiatives like SpaceX and ArianeGroup are working on novel methane/oxygen rocket engines that operate in extreme thermodynamic conditions, where there is no longer any difference between the liquid and gas phase. However, in this form of combustion, instabilities can arise from the coupling between the flame and the acoustic field: The combustion creates noise that disturbs the flame, which triggers even more noise, and so on. "In extremis, this could lead to the destruction of the engine", says Laurent Selle, group head at the Institut de Mécanique des Fluides de Toulouse.

Selle and his co-workers at CERFACS used Large-Eddy Simulations to study the flame turbulences, the thermoacoustic coupling and the heat transfer between the flame and the wall of the injector — the device that is responsible for the mixing and injection of fuel and oxygen into the combustion chamber.

With their analyses, the scientists identified mechanisms for both flame stabilisation and combustion efficiency. In addition, the team is cooperating with experimentalists working on the development of such an engine. "Our findings will help with the step-by-step building of a future re-ignitable rocket engine", says Selle.

Supercomputing Resources: Joliot-Curie (SKL) at GENCI (France).

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