HPC Goes into the Wild Blue Yonder

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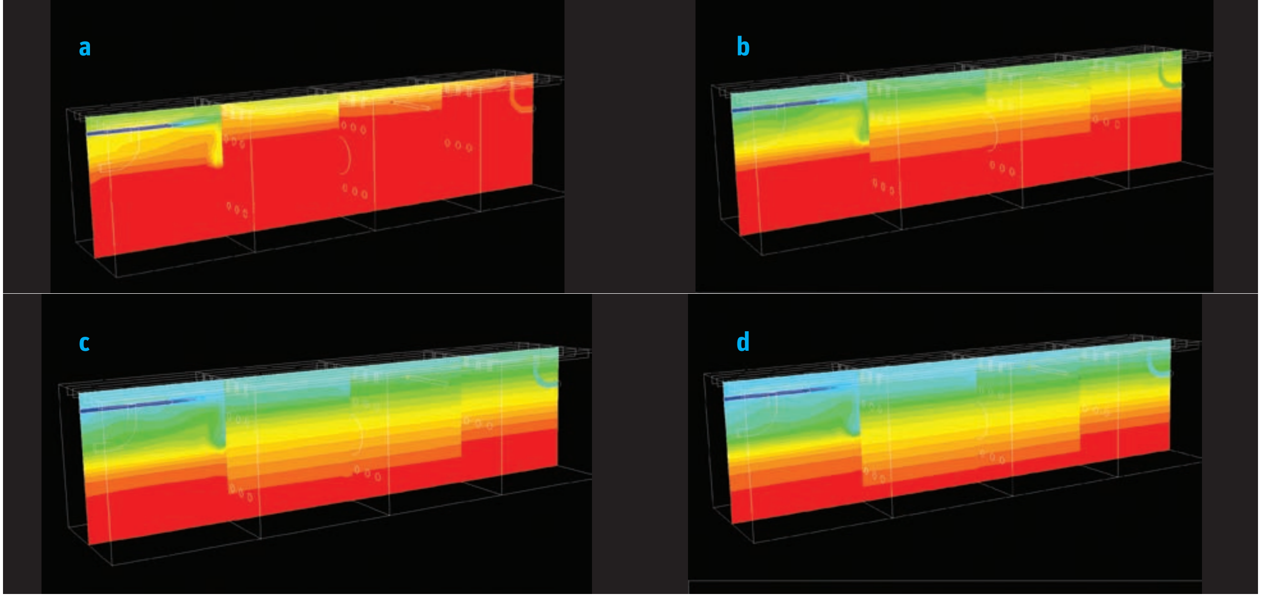
Scaled-up flow simulation enables cost-effective aircraft design optimization.

In commercial aircraft design, numerous mechanical, electrical, chemical and pneumatic systems must interact seamlessly to provide for the safety and comfort of passengers and crew. These systems must function predictably, since more efficient and reliable systems result in lower operational and maintenance costs. When bringing a new commercial aircraft design to market, it can often take several years of testing and optimization, and flow simulation software has become a vital tool in the design arsenal for modeling aircraft subsystems. As desktop computational speeds have increased, so has the ability to consider more candidate designs with increasingly complex physics. State-of-the-art high-performance computing (HPC) capabilities for engineering simulation now allow designers to throttle up simulation fidelity and deliver reliable and optimized designs.

At Airbus in the U.K., a team of fluid engineers has been using HPC in safety investigations of fluid behavior within the fuel tank. To achieve compliance with recent U.S. Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) regulations, the central fuel tanks on several families of Airbus planes must include, or be retrofitted with, inerting systems for the purpose of reducing flammability. An inerting system is mainly an air separation module that takes a portion of the engine bleed air and reduces oxygen content from 21 percent to between 10 percent and 15 percent. The system then feeds the nitrogen-enriched air continuously into the fuel tank to ensure that the oxygen level in the ullage — the space above the liquid fuel — is maintained below the threshold for combustion.

Development of the inerting system at Airbus commenced in 2004. In the beginning, the team used ANSYS Fluent computational fluid dynamics (CFD) software to evaluate design variations under a variety of flight conditions. Mesh sizes for the fuel tank at that time contained 8 million cells. Capturing jet impingement and low-speed mixing phenomena inside the tanks while also accounting for species transport and turbulence required the highly resolved domains. The large mesh sizes provide for a finer analysis of localized variations in ullage oxygen concentration during routine and extreme flight conditions. To perform a transient analysis of the tank during taxiing, takeoff, climbing, cruising, descent and landing — equivalent to hours of real-time flight — formerly required simulation times of three months using a top-of-the-line cluster of 16 processes. Physical testing was still necessary at that time because the high computational cost would not allow simulation-based optimization studies.

Today, however, those types of simulation barriers are being knocked down. HPC technology provides computational horsepower that would have been unimaginable a decade ago. Airbus leases 10,000 CPUs from Hewlett-Packard for general CAE use, housed in mobile data centers in France and Germany. The inerting system team in the U.K. performs pre-processing and post-processing by transferring mesh and solution files between local desktop machines and the remote clusters, with the aim of eventually doing the entire pre–solve–post simulation process remotely. More important is that access to these CPU clusters



Contours of oxygen volume fraction on a center plane cut of a fuel inerting test rig under simulated cruising conditions at time equal to (a) 4 minutes, (b) 20 minutes, (c) 38 minutes, (d) 50 minutes. Nitrogen gas is injected at the upper left and gradually displaces the air in the rig's four compartment bays; the gas is then vented through an exhaust opening at the upper right.

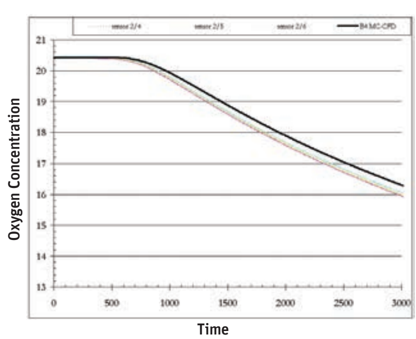
has allowed the U.K. team to remotely run its CFD simulations overnight while considering larger tanks with even more complex physics along with mesh sizes greater than 100 million cells. This enormous acceleration in solution time leveraged the Infiniband® communications link to connect the many Intel® Xeon™ processors running Linux® architecture. The ANSYS HPC Pack license model has enabled the Airbus scaleup to massively parallel simulation. In 2004, such aggressive HPC would have been cost-prohibitive; with the HPC Packs, the inerting system team can run cost-effective calculations on hundreds or even thousands of cores.

Airbus gained confidence in the HPC-powered CFD flow simulations based on comparison with experimental data from the early years of the project. The team was satisfied that data from in-flight testing of the inerting system using 10 oxygen sensors could be reproduced using simulation to within 10 percent accuracy, which they considered to be reasonable.

Beyond the solution accuracy, Airbus engineers depend on the overall robustness of the commercial CFD solver for modeling different physical phenomena across many aircraft subsystems as well as the accessibility of the user interface. Other subsystems that Airbus analysts have modeled with fluid dynamics technology from ANSYS include changes in fuel tank temperature during flight, ventilation of the aircraft cabin and thermal comfort of passengers, and heat transfer flows in the engine nacelle. This work is done in company locations in France and Germany, and it is part of the interdependent process of modeling different aspects of a large aircraft. For example, because bleed air from the engine is used for both fuel tank inerting and cabin pressurization, heat exchangers operating on compressed hot air from the engine have to be modeled upstream of these other two subsystems so that proper boundary conditions can be applied.

In the end, the Airbus team's use of HPC simulation in the inerting system design has been so successful that it has enabled the elimination of building more-expensive physical testing rigs. Many more simulation runs are completed in the time available, which has facilitated improved system design optimization and, thus, lowered the risk to Airbus of the overall aircraft design programs. The inerting systems staff members noted that they are "light years" from where they were seven years ago with regard to the business value achieved by using the current generation of ANSYS HPC solutions. The team looks forward to integrating ANSYS CFD with other software tools to give further thrust to HPC simulation capabilities.

Airbus fuel inerting test rig



Fluid flow simulation results of the changing oxygen concentration over time (black line) showed consistent close agreement with experimental data taken from multiple oxygen sensors placed inside the inerting test rig.

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