Engineers turn to Argonne's Mira supercomputer to study supersonic turbulence

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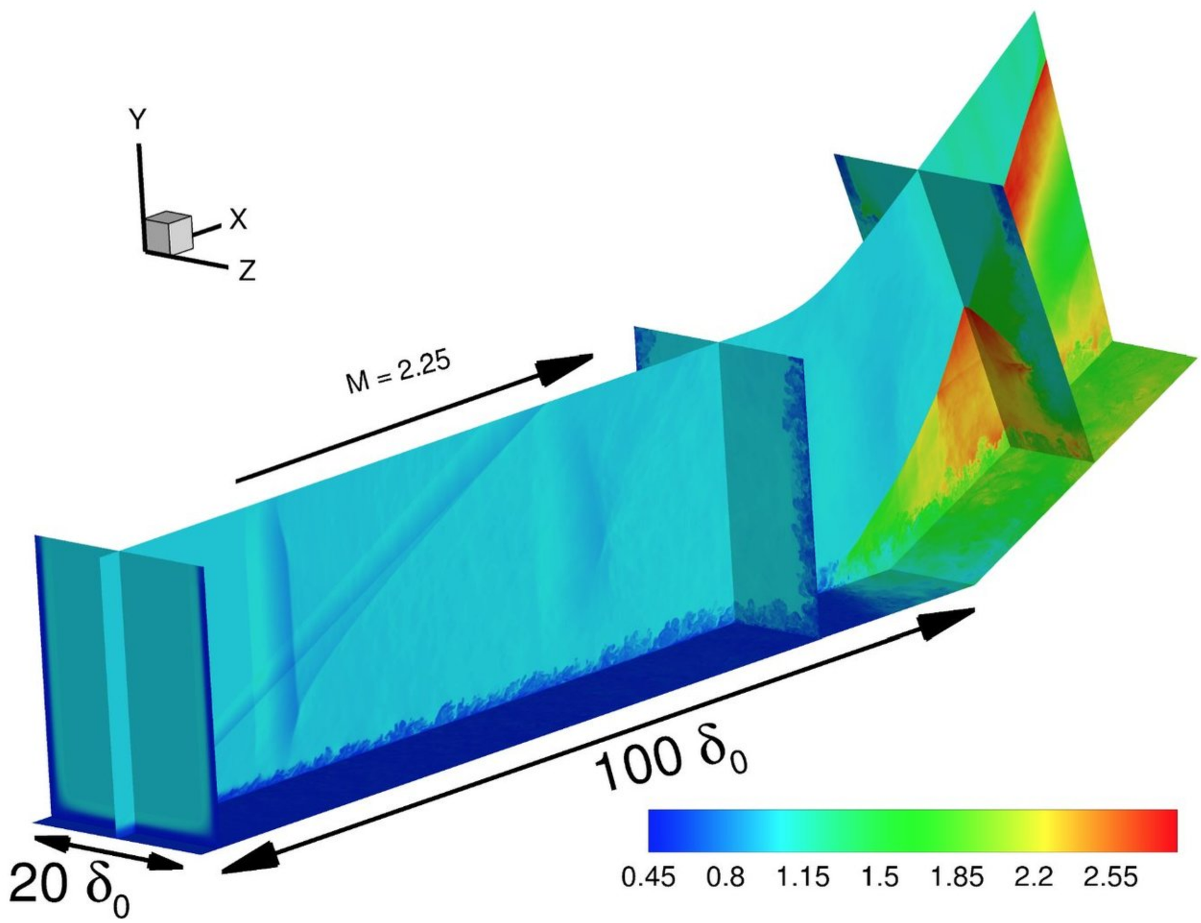

A simulation of supersonic turbulent flow on a ramp. Sharp lines show shock waves; irregular, smudged boundaries represent turbulent flow. Credit: Jonathan Poggie, Purdue University.

Aviation's frontier is supersonic. The military is seeking ever-faster aircraft, planes that can fly five times the speed of sound. Fifteen years after the Concorde's last transatlantic flight, Japan Airlines and the Virgin Group are investing in jets that could slash overseas travel time by more than half.

But supersonic speeds bring a slew of design challenges. For one thing, unsteady air-flow patterns can generate aircraft panel-damaging shock waves. Engineers must put safety first, but they also want to keep structures as light as possible to maintain energy efficiency that cuts fuel costs.

Researchers hope to understand what causes these erratic flows by modeling strategies for preventing or eliminating them. "It was not possible until the last few years to really simulate this kind of unsteadiness because we lacked the computing power," says Jonathan Poggie, an associate professor with Purdue University's School of Aeronautics and Astronautics.

But with support from the Department of Energy's (DOE) INCITE program (Innovative and Novel Computational Impact on Theory and Experiment), Poggie and his Air Force Research Laboratory collaborators have tackled these turbulent systems. Their INCITE allocation includes 200 million processor hours on the Mira IBM Blue Gene/Q supercomputer at Argonne Leadership Computing Facility, a DOE Office of Science user facility.

As an airplane wing moves through the atmosphere, gases flow around it. When air movement is smooth around the plane's contours, it's called attached flow. Drag is low, Poggie notes, and the craft is easy to control.

But aircraft can undergo separated flow, particularly at supersonic speeds. This happens when air moving along the surface detaches and forms a vortex, a complicated, unsteady three-dimensional flow pattern. These fluctuations sometimes occur at a low frequency that can resonate with aircraft panels. Supersonic speeds can generate shock waves that repeatedly hammer an airplane's structure. "There's a very serious problem when you get this type of separation in that it causes incredible flow fluctuations," Poggie says.

The problem isn't unique to the fastest military jets. Supersonic flow can form around even a commercial jet, such as a 747 flying at 85 percent of the speed of sound. "We'd like to be able to predict that, control it and improve the situation on airplanes," Poggie says.

Like other fluid-dynamics problems, separation unsteadiness presents big computational challenges. Tiny turbulent eddies might measure fractions of a millimeter and last only thousandths of a second while aircraft-size flow structures – up to 10 meters – might last a second or more. "To fully capture turbulence," Poggie says, "we need to capture both scales."

As the proportions increase, computational intensity also grows. Calculating turbulence on a lab bench might require only a desktop computer. Move up to a 747, Poggie says, and it was impossible until recently to resolve all the scales.

With their INCITE allotment, Poggie and his team initially modeled a classic separation case, using a ramp-like structure with a moderate incline and an area resembling a wing flap. The simulation offered a comparison to wind tunnel experiments that test flows around an airplane wing.

To tackle the problem, the team first had to optimize algorithms to efficiently handle large quantities of information in parallel on multiple processors. "We were dealing with terabytes of data rather than gigabytes," Poggie says.

With the new code, graduate student Kevin Porter could examine flow as the separation bubble moved. The simulations revealed patterns that occur just before separation. The low-frequency unsteadiness – with features about the same size as the aircraft – was connected to incoming flow-related events. We now have a clue as to why low frequency unsteadiness occurs, Poggie says. That knowledge could allow them to control the behavior.

But they realized that the simplified ramp also was misleading, even in tests. A wind tunnel has sides, Poggie notes, and vortices form in the corners. Researchers had wondered if those vortices were important; they do appear to be.

Such a vortex can slow the flow, even to subsonic speeds. Crossing that critical threshold alters sound-wave movement. At supersonic speeds, sound waves flow downstream only, but subsonic sound can travel upstream or downstream. That situation also creates disturbances and unsteadiness in the flow.

Researchers have developed two models of how turbulence interacts with separation unsteadiness, Poggie says. In one scenario the flow itself can be an oscillator, excited by fluctuations that grow. In another scenario, the flow amplifies constant incoming fluctuations but can't oscillate on its own. "It turns out that in the last few years we've found that there's a combination of those two effects," Poggie says.

Their work is now teasing out when each individual situation is important, which will be critical for controlling these disturbances. For amplifiers, adding disturbances would only make the situation worse, Poggie says. But with oscillators, they could incorporate actuators or actuator arrays to counteract the flows that excite the disturbance.

The group plans to also model the separation flows around a more complex shape: a fin that mimics an airplane's tail, he says. "A fin calculation will give us a contrasting flow that will have a subtly different behavior."

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