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SUPERSONIC JET NOISE PREDICTION USING HIGH-ORDER LARGE-EDDY SIMULATION

Allocation: Innovation and Exploration/300 Knh
PI: Zhi Jian Wang[1]

[1]University of Kansas

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EXECUTIVE SUMMARY

The environmental impact of aviation is measured in emissions and noise. The communities in the vicinity of airports bear the brunt of aircraft noise during takeoffs, climbs, flyovers, approaches, and landings. Research has shown that exposure to loud noise is harmful to human physiological and psychological health and welfare.

The research team at the University of Kansas has identified a novel and powerful means of mitigating jet noise by inducing shear layer swirl through embedded vanes near the nozzle exit lip. The team has employed a newly developed high-order (up to sixth order) Navier–Stokes solver capable of handling mixed unstructured meshes to perform computational predictions of the aero-acoustic noise using implicit large-eddy simulations. Blue Waters enables the team to accurately compute the near- and far-field supersonic jet noise. As a result, the research group can perform computational evaluations of a new concept in supersonic jet noise mitigation, which has the potential to significantly reduce the jet noise generated by military aircraft.

RESEARCH CHALLENGE

The noise generated by supersonic aircraft is deafening. The communities in the vicinity of airports bear the brunt of the noise during their takeoff, climb, flyover, approach, and landing. Human physiological and psychological health and welfare are negatively affected by exposure to this noise. The problem in the military is even greater since there are servicemen and women working near advanced supersonic jets during takeoffs and landings. The long-term health risk has created a huge problem for the Department of Defense (DOD). However, finding a solution has been a challenge. This project evaluates a promising new concept to reduce such noise.

METHODS & CODES

The research team used swirl-generating vanes placed inside the nozzle to enhance mixing in order to reduce noise [1]. The team employed a state-of-the-art unstructured mesh-based high-order Navier–Stokes solver (up to sixth order in space and fourth order in time) called hpMusic [2] in combination with large-eddy simulation to directly compute the near- and far-field jet noise. The near-field simulation was coupled with the Lighthill acoustic analogy [3] to compute the far-field jet noise.

HpMusic has been developed with support from AFOSR (Air Force Office of Scientific Research), NASA (National Aeronautics and Space Administration), and ARO (Army Research Office), and has been used to perform Implicit Large-Eddy Simulations for real-world complex configurations. The solver is based on the flux reconstruction/correction procedure via reconstruction method [4] on mixed unstructured meshes [5]. In addition, hpMusic has both explicit and implicit time-marching algorithms such as the explicit SSP Runge–Kutta scheme, an optimized second-order backward difference formula. The solver has been successfully implemented on massively parallel supercomputers such as the petascale Blue Waters. A scalability study demonstrated excellent parallel efficiency with over 10,000 cores.

RESULTS & IMPACT

The research team has completed the simulations of one baseline supersonic nozzle and one model with vanes to generate swirls to enhance turbulent mixing and mitigate jet noise. In addition, the team has performed mesh refinement and p-refinement studies to assess the sensitivity of the mesh resolution and the order of the simulation.

Based on the results of simulations and data analysis, the group will design more refined vane configurations to reduce jet noise. The team anticipates multiple iterations will be required to arrive at a nearly optimal design configuration. Extensive data analysis and comparison with other simulations and experimental data is currently being performed. So far, the computational results are very promising.

WHY BLUE WATERS

Jet noise computations using large-eddy simulation are very computationally expensive even on supercomputers because the acoustic magnitude is several orders smaller than the mean flow scales [6]. The use of Blue Waters increases the computation speed by at least a factor of 20 compared with the team's local cluster, thus enabling these very complex simulations to be carried out in a timely fashion. The DOD-funded jet noise mitigation project lasts for only one year. Access to Blue Waters is essential for the team to achieve its goals for this project along with the professional and timely support provided by the Blue Waters staff.

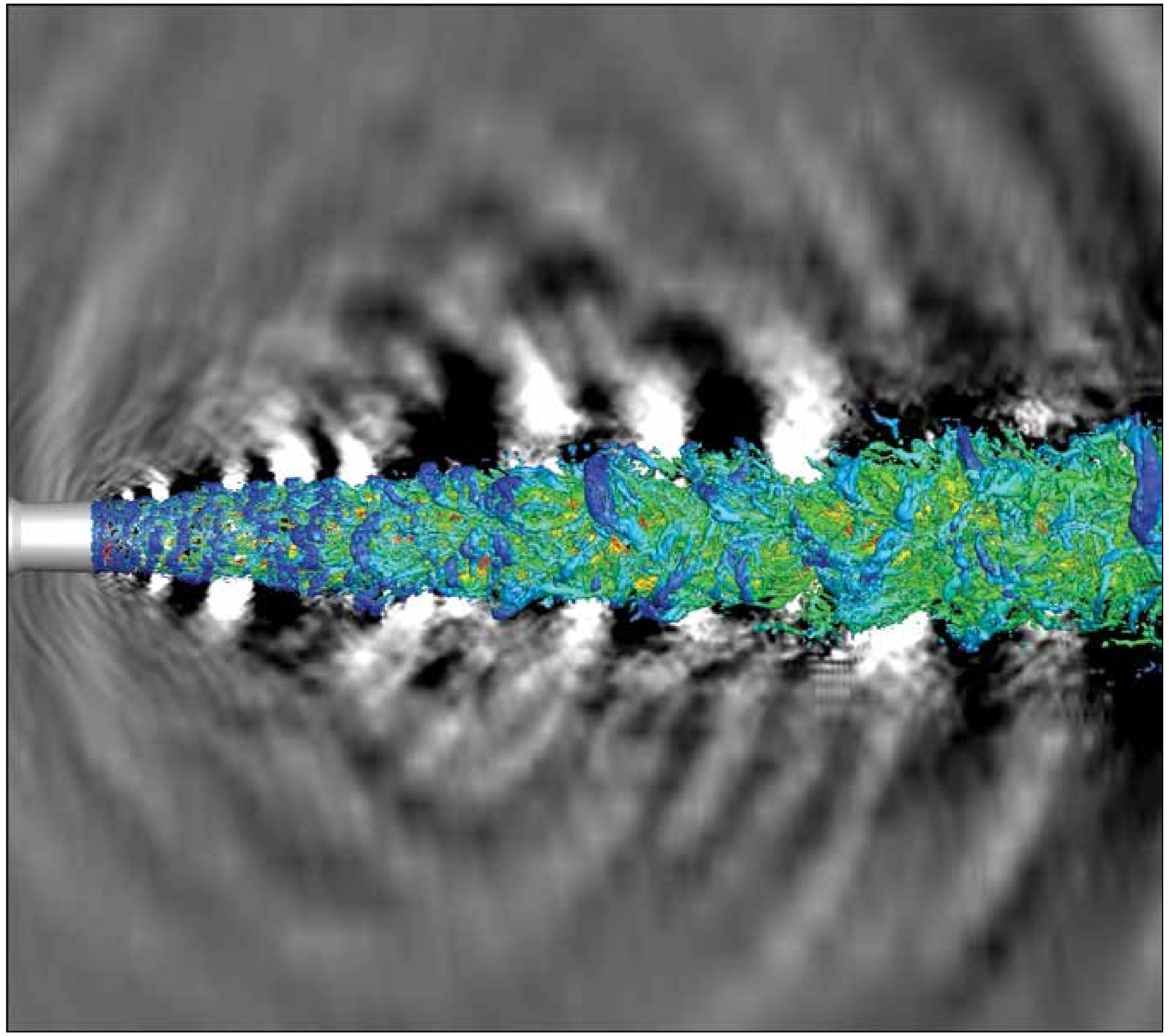

Figure 1: Key flow structures and acoustic waves captured in a large-eddy simulation of a supersonic jet (iso-surfaces of the Q-criterion colored by the streamwise velocity, with acoustic waves shown on the symmetry plane).