REDUCING JET AIRCRAFT NOISE

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EXECUTIVE SUMMARY

Developing quieter, more fuel-efficient jet aircraft has been a goal since the 1950s. The movement of engine designs from the original turbojet to today's high-to-ultra-high-bypass-ratio turbofans has sustained noise and fuel-use reduction goals. However, future growth in aircraft utilization and more stringent requirements on acceptable noise suggest further demand on noise reduction. This requires detailed understanding of the turbulent flow in the fan stage of the engine that gives rise to the dominant broadband component of the fan noise, which cannot be provided by current reduced order models. Therefore, it is essential to utilize high-fidelity numerical tools to predict the turbulence and its radiated noise.

RESEARCH CHALLENGE

The dominant noise source of jet engines has changed as engines have evolved. Large bypass-ratio fans (Fig. 1, upper-left inset image) produce noise that predominantly originates from the fan itself, rather than from the exhaust streams from the core and fan. Fan noise is mostly due to the interaction of small unsteady flow perturbations with the fan (rotor) and stationary guide vane (stator) blade rows. Depending on the nature of these sources, they are categorized as tonal noise and broadband noise.

Broadband noise contains a wide range of frequencies and is associated with the interaction of a turbulent flow with a solid boundary (Fig. 1, main image). The prediction of the broadband component of fan noise (Fig. 1, lower-right inset image) is more complicated than tonal noise predictions since it arises from an inhomogeneous and anisotropic turbulence interacting with fan blades. Although the methods developed to predict rotor–stator interaction tonal noise can, in practice, also be applied to the broadband component prediction, representing a collection of random incident disturbances in the time domain or a wide range of frequencies in the frequency domain—the ensemble of which represents a turbulent flow—requires a highly resolved computational domain with a significant computational cost.

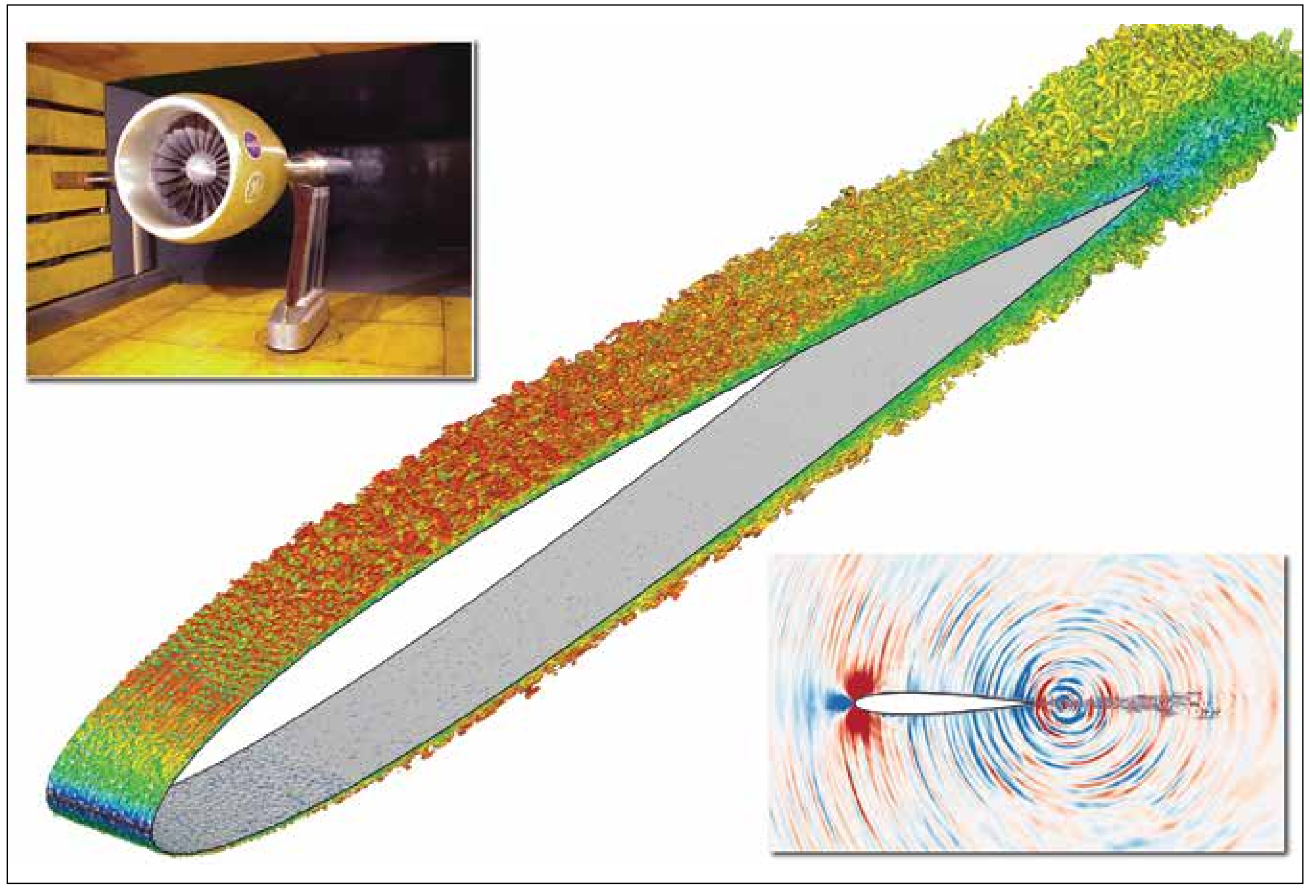

Figure 1: (Upper-left inset image) NASA/GE Source Diagnostic Test Fan whose geometry and flow measurements provide the validation dataset. (Main image) Iso-surface plot of Q-criterion for a transitional boundary layer over a NACA0012 airfoil. (Lower-right inset image) turbulence-generated noise from the NACA0012 airfoil visualized using the divergence of the velocity field.

METHODS & CODES

The turbulence and its radiated sound are governed by the compressible Navier-Stokes equations that are solved using a high-order, finite difference code written by the PI, capable of describing complex geometries using multiple, overset meshes. From fan airfoil geometry, including small roughness elements near the leading edge (Fig. 1, main image), a computational grid is designed which sufficiently resolves the flow around the blade as well as the radiated field far away from it (Fig. 1, lower-right inset image). The resulting mesh contains 2.5 billion degrees of freedom, which are saved in HDF5 format on the file system using a new, scalable, collective MPI-IO-based infrastructure (Fig. 2).

RESULTS & IMPACT

The direct numerical simulation of sound generated by an idealized blade shown in Fig. 1 requires 2.5 billion degrees of freedom and generates a database on the order of 1 terabyte. While useful for generating reduced-order models for broadband sound generation from isolated blades, the simulation domain shown in the main image of Fig. 1 is only a fraction of that needed to predict the noise from the entire fan shown in the upper-left inset image of Fig. 1. Thus, the main results of the simulation are being used to develop a wall-modeled large-eddy simulation (WMLES) approach to broadband noise prediction wherein the inner boundary layer dynamics (below the log layer) are modeled using a less expensive model while the outer boundary layer dynamics and external flow field are modeled using traditional LES techniques. Determining the accuracy of the WMLES simulation for on-blade and acoustic field predictions is the primary impact of the simulations. If successful, using WMLES for broadband noise prediction enables the aeroacoustic community to predict and, ultimately, reduce the environmental impact from most aircraft noise sources.

WHY BLUE WATERS

Blue Waters is critical to the research because of the system's scale, the performance of its I/O system, and the capability its software teams have in improving code performance, including I/O performance. These runs would not be feasible on any XSEDE computer.

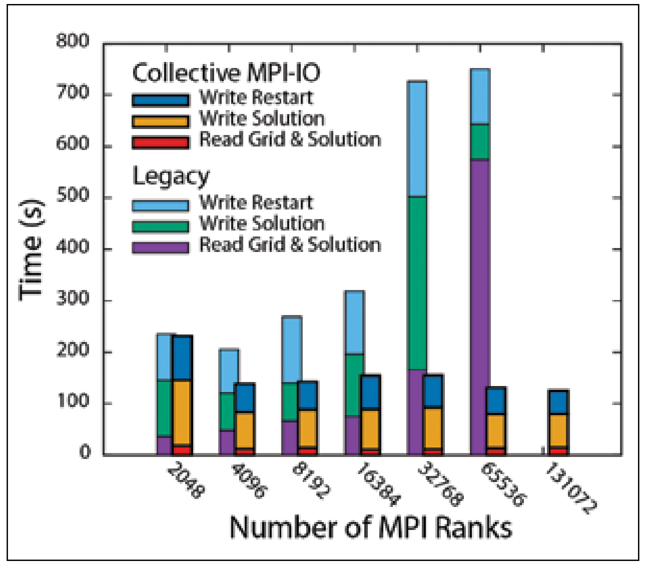

Figure 2: Blue Waters I/O performance using a new collective, MPI-I/O infrastructure.