Improving Phased Array Measurement Techniques and Jet Noise Understanding

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Improving Phased Array Measurement Techniques and Jet Noise Understanding

1st INTERIM REPORT

21 May 2012

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Executive Summary

This first interim report summarizes the progress made toward advancing "synthetic phased array" technology to improve understanding of noise in hot supersonic jets. This technology, initially developed in a previous NASA SBIR project for trailing edge noise, will be applied to improve beamforming analysis methods, facilitate the design of more effective microphone arrays, and significantly enhance the understanding and characterization of noise sources from supersonic jets.

The work accomplished this period is primarily of a foundational nature for our future efforts:

- Contracts have been put in place to allow all of our collaborators to participate in the work.
- Accounts have been obtained on a number of DoD HPC resources and computer time allocated for use on this project.
- An initial run of an over-expanded jet issuing from a military-style nozzle has been conducted in order to provide verification that ITAC's version of the CHOPA solver, when run on the HPC systems, is obtaining consistent results to those obtained earlier by Penn State.
- Data has been obtained from Prof. Morris's group at Penn State from earlier simulations of both a nearly perfectly expanded jet and the over-expanded jet case.

- A new version of the PSU-WOPWOP Ffowcs Williams-Hawkings solver has been obtained from Prof. Brentner. This version requires much less memory, fixes important bugs, and runs faster than previous versions.

As a result of the above efforts, the project is in a good position to make significant progress in the next period.

Introduction

As mentioned above, the objective of this program is the advancement of "synthetic array technique" to improve both the tools for investigating noise in hot supersonic jets and the fundamental understanding of that noise. This approach, initially developed in a previous NASA SBIR project for trailing edge noise, will be applied to improve beamforming analysis methods, facilitate the design of more effective microphone arrays, and significantly enhance the understanding and characterization of noise sources from supersonic jets.

This work involves the use of Large Eddy Simulation (LES) to generate data on the nearfield unsteadiness in jet flows. The nearfield noise is then numerically propagated to the farfield phased array microphone locations. Beamforming analysis methods are used to predict noise source locations, and these predictions can then be compared with the original LES results. Discrepancies between the phased array prediction and the LES flowfield results can then be used to guide development of new and improved phased array source models and analysis techniques. This ONR effort leverages jet noise LES results that have been generated in a NAVAIR-sponsored, ITAC-led, Phase II STTR effort. These results include data for both a baseline military-style nozzle as well as the nozzle with chevrons attached. Data is available for over-expanded, nearly perfectly expanded, and under-expanded nozzle conditions.

When fully developed, this synthetic array technique offers the potential for significant benefits. First, it will empower experimental aeroacoustics researchers to customize the layout of microphone arrays for a given experimental configuration. Similarly, this approach offers the potential for experimentalists to customize the analysis of the recorded data they take for optimum accuracy. Beyond this, the improved beamforming methods that will be developed using this technique will benefit any experiment which makes use of phased arrays of microphones. Finally, the work will add to the overall understanding of jet noise sources.

Technical Objectives

This work has two primary inter-related goals. The first is to advance “synthetic phased array” technology with specific application to supersonic hot jets. With this advanced technology available, the second goal is to use the “synthetic phase array” approach to develop an improved understanding of hot supersonic jets, better analysis techniques for them, and deeper insight into noise reduction methods.

To accomplish these goals, the effort is pursuing the following research objectives:

- Generate detailed unsteady flowfield and acoustical data in the jet nearfield using a computational aeroacoustics solver for nozzles both with and without chevrons.
- Numerically propagate the nearfield noise to the microphone locations of “virtual” phased arrays positioned in the farfield.
- Use experimental data reduction methods (such as beamforming) on the data from the virtual phased arrays to predict the jet noise source locations.
- Compare predicted source locations with the detailed flowfields from the unsteady simulations.
- Use the insights gained from the above to develop new and improved source models which can be incorporated into the analysis of phased microphone array measurements.
- Compare the findings from the cases with chevrons and those without to derive new insights into how chevrons work to reduce jet noise.

Progress to Date

Following the initiation of the contract on February 21, 2012, the ITAC-led team began assembling the resources needed to conduct the effort. This included putting formal sub-contracts in place with each of our partners: Prof. Morris, Prof. Brentner, and Dr. Dougherty. This has now been accomplished.

Given the highly computational nature of this work, another important resource to obtain was sufficient computing resources for the numerous simulations we will need to perform. To this end, we have established a project for this work with the DoD High Performance Computing Modernization Program and obtained time on a number of their DoD Supercomputing Resource Centers.

We have also ported our computational aeroacoustics solver, CHOPA, to several of these systems ('jade' at the Army's Engineer Research and Development Center—ERDC—and 'einstein' at the Navy DoD Supercomputing Resource Centers—NAVO), and have initiated check runs to ensure that the results we obtain are consistent with the high quality data obtained in previous simulations on other systems.

We have found, unfortunately, that while the code runs well on some systems, significant problems have been encountered on others. We have been able to work around some of these issues and have now successfully run test cases on one of the systems ("harold" at the Army Research Laboratory—ARL) where we previously had problems, but continue to experience difficulties with other systems (e.g. "garnet" at ERDC). We continue to work with system support personnel to understand and overcome these issues. Recently, a code modification was developed which may alleviate some of the issues limiting the code's portability, but this has not yet been tested on the HPC systems.

Aside from the above efforts, progress has been made toward accomplishing several of the specific tasks in the Work Plan. The Work Plan for the base contract period effort is as follows:

1. Perform Unsteady Simulations of Hot, Supersonic, Nearly Perfectly Expanded Jet Flow Using a Military-Style Nozzle
2. Perform Unsteady Simulations of Hot, Supersonic, Nearly Perfectly Expanded Jet Flow Using a Military-Style Nozzle with Chevrons
3. Propagate Noise to the Far-Field Array Location
4. Predict Noise Source Locations
5. Predict Far-Field Sound Pressure Levels with Generalized Inverse Method Beamforming
6. Compare Flow-Field and Acoustic Results
7. Perform Unsteady Simulations of Hot, Supersonic, Over-Expanded Jet Flow Using a Military-Style Nozzle
8. Perform Unsteady Simulations of Hot, Supersonic, Over-Expanded Jet Flow Using a Military-Style Nozzle with Chevrons
9. Propagate Noise to the Far-Field Array Location for the Over-Expanded Jet Flow
10. Predict Noise Source Locations for the Over-Expanded Jet Flow

11. Predict Far-Field Sound Pressure Levels with Generalized Inverse Method Beamforming for the Over-Expanded Jet Flow
12. Compare Flow-Field and Acoustic Results for the Over-Expanded Jet Flow
13. Implement and Evaluate New Noise Source Models in the Beamform Interactive Software
14. Prepare Quarterly Reports
15. Present Results at Annual Review Meetings
16. Prepare Final Report

The following sections detail the accomplishments thus far on a task by task basis.

Task 1 – Perform Unsteady Simulations of Hot, Supersonic, Nearly Perfectly Expanded Jet Flow Using a Military-Style Nozzle

Data from earlier simulations using CHOPA of a military-style style faceted nozzle were obtained from Prof. Morris's group at Penn State. Figure 1 shows the baseline geometry (without chevrons) of this nozzle, which is to be used for the current work.

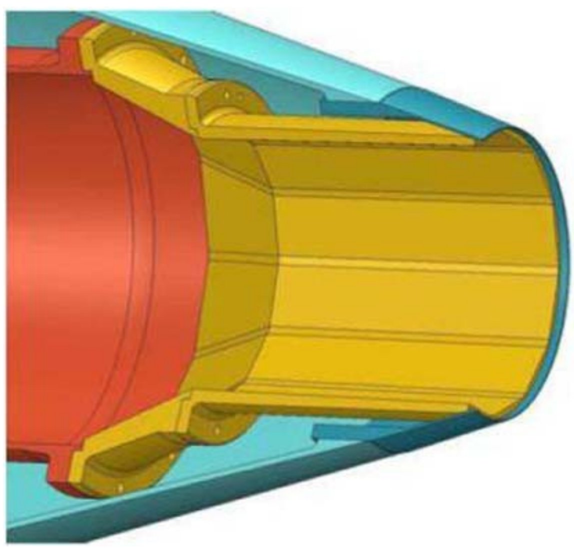

Figure 1: Baseline military-style faceted nozzle geometry

This nozzle can be configured both with and without chevrons. The design Mach number for the nozzle is 1.5. The total temperature ratio for all these simulations is 3.0. The nozzle throat has a diameter of 4.45 inches. To faithfully simulate the jet noise from this configuration, all the geometric details, including the faceted inner contours, and the finite nozzle thickness, are captured in the computational mesh.

As part of earlier NAVAIR-sponsored work, supersonic hot jet noise simulations have been performed to predict the noise emanating from the nozzle at three different operating conditions (with and without chevrons), which correspond to exit Mach numbers of 1.36, 1.47, and 1.56. For Task 1 (and Task 2), the Mach 1.47 case is the relevant one.

The baseline computational mesh created for this configuration contained 5.89M grid points. Several views of the mesh are shown in Figure 2. Figure 2 (a) shows the center-line cross-section of the entire mesh. Figure 2 (b) shows a cut through the mesh at the trailing edge of the nozzle. As is usual with CHOPA, the mesh has been designed to avoid having a singular axis at the center-line. Figure 2 (c) shows a close-up of the nozzle region in a center-line cross-section. The finite thickness of the nozzle lip is resolved on the grid, as illustrated by Figure 2 (d).

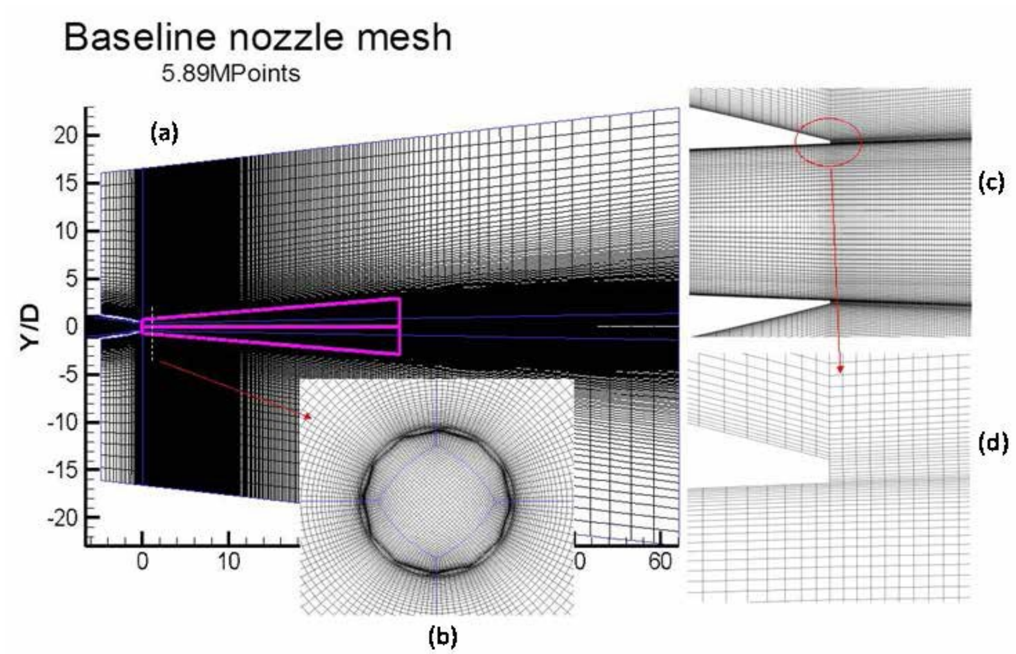

Figure 2: Computational mesh for the baseline nozzle without chevrons

The magenta lines in Figure 2 (a) indicate the location of data collection surfaces on which the solution has been saved for later processing with a Ffowcs Williams-Hawkings solver.

To date, we have obtained the data for previously run solutions for this case. This data must now be converted to a form which can be read by the PSU-WOPWOP Ffowcs Williams-Hawkings solver for Task 3

In addition, a denser grid, with twice the resolution in the streamwise and radial directions, has been created. The azimuthal resolution was already consistent with meshes used successfully by other researchers, and was thus not changed. Our previous work has indicated that the resolution of the initial mixing layer development aft of the jet exit can be very important, and this mesh should allow for better results in this area. This will allow better resolution of higher frequencies. Once the check case being run on the HPC system is successfully completed, the nearly perfectly expanded jet case will be re-run on the new mesh.

Task 2 – Perform Unsteady Simulations of Hot, Supersonic, Nearly Perfectly Expanded Jet Flow Using a Military-Style Nozzle with Chevrons

As mentioned above, the data from previous runs of the military-style nozzle (with chevrons) at nearly perfectly expanded conditions has been obtained. This data will be converted to a form usable by PSU-WOPWOP for use in Task 3.

Task 3 – Propagate Noise to the Far-Field Array Location

A new version of the PSU-WOPWOP Ffowcs Williams-Hawkings solver has been obtained from Prof. Brentner. This new version fixes several important bugs which hindered previous efforts to apply the synthetic array technique to other configurations. In addition, the code has been reworked such that much less memory is required to perform the same analysis. Thus, for example, a previous case which used to require a dedicated system with 128GB of memory can now be run on a laptop with only 8 GB of memory.

Task 7 – Perform Unsteady Simulations of Hot, Supersonic, Over-Expanded Jet Flow Using a Military-Style Nozzle

Similar to Task 1 and Task 2 above, data from previous runs of the military-style nozzle at over-expanded conditions has been obtained. This data must now be converted to a form readable by the PSU-WOPWOP solver.

Also, these conditions are being used for the test case being run on the 'einstein' HPC system to verify that the current version of CHOPA runs properly on the HPC machines and matches the results of the previous runs.

Task 8 – Perform Unsteady Simulations of Hot, Supersonic, Over-Expanded Jet Flow Using a Military-Style Nozzle with Chevrons

As with Task 7, the results from earlier simulations have been obtained and will be processed using the PSU-WOPWOP solver.

Future Plans

The existing data for both the nearly perfectly expanded case and the over-expanded case will be converted to a format readable by PSU-WOPWOP for use in Task 3. ITAC has already written conversion codes to do this for the output from the Wind-US and OVERFLOW solvers. These tools will be used as the basis for the new conversion tool.

Also, once the check case on the 'einstein' HPC system is complete, new solutions will be sought for these cases using the higher resolution mesh which has been created.

Beyond this, PSU-WOPWOP will be used to generate the acoustic 'measurements' at the virtual microphone array, and the results will be handed over to our partners so that they can being working with them on the other Tasks.

Finally, we also plan to compare the output of the PSU-WOPWOP FW-H solver with that of the similar PSJFWH solver, which has been used previously in conjunction with CHOPA. This will provide a good check to ensure that these Ffowcs Williams-Hawkings solvers are correctly propagating the acoustic field.