



User's Guide for GAA_JET_FV (V1): A Jet Noise Prediction Code Based on the Generalized Acoustic Analogy

Stewart J. Leib
HX5 Sierra, LLC, Brook Park, Ohio

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI Program provides access to the NASA Technical Report Server—Registered (NTRS Reg) and NASA Technical Report Server—Public (NTRS) thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counter-part of peer-reviewed formal professional papers, but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., “quick-release” reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.
- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>
- E-mail your question to help@sti.nasa.gov
- Fax your question to the NASA STI Information Desk at 757-864-6500
- Telephone the NASA STI Information Desk at 757-864-9658
- Write to:
NASA STI Program
Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199



User's Guide for GAA_JET_FV (V1): A Jet Noise Prediction Code Based on the Generalized Acoustic Analogy

*Stewart J. Leib
HX5 Sierra, LLC, Brook Park, Ohio*

Prepared under Contract 80GRC020D0003

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

Acknowledgments

This work has been supported over the years by the Commercial Supersonic Technology Project. The author thanks Dr. James Bridges, NASA Glenn Research Center Acoustics Branch, for his comments and suggestions on the initial release of this code and for his continuing support of this work. The author thanks Ms. Lydia Sgouros, Case Western Reserve University, for her work on the interpolation process, in particular her idea and implementation of 'sectioning' the full data file around axial slices, which greatly improved the performance. Many thanks to Mr. William Banks, HX5, LLC., for testing numerous versions of this code, making many useful suggestions for improving it and for providing the FUN3D RANS solution for the ASME nozzle case.

This report contains preliminary findings,
subject to revision as analysis proceeds.

This work was sponsored by the Advanced Air Vehicle Program
at the NASA Glenn Research Center

Trade names and trademarks are used in this report for identification
only. Their usage does not constitute an official endorsement,
either expressed or implied, by the National Aeronautics and
Space Administration.

Level of Review: This material has been technically reviewed by NASA expert reviewer(s).

Available from

NASA STI Program
Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-605-6000

This report is available in electronic form at <http://www.sti.nasa.gov/> and <http://ntrs.nasa.gov/>

Contents

Abstract.....	1
1.0 Introduction.....	1
2.0 Quick Start Guide	3
2.1 Code Package.....	3
2.2 Unpacking the Code.....	3
2.3 Compiling and Building Executables	4
2.4 Running the Code	4
2.4.1 Input Data Files.....	4
2.4.2 Code Runs	7
3.0 Interpolation of a RANS Solution Onto a Structured Grid for the Noise Computation	8
3.1 Running the Interpolation in the QUICK_START Example.....	8
3.2 General Description of the Interpolation Script and Preparation of Data File.....	10
3.3 Instructions for Running the Script.....	10
4.0 Details of the Input and Output Files and Run Instructions for the Main Noise Code	12
4.1 Input Data Files.....	12
4.2 Run Instructions.....	15
4.3 Output Data Files.....	15
5.0 Descriptions of Code Modules.....	16
6.0 Sample Test Cases	18
6.1 Unstructured SP05 Round Jet Solution—SWFS RANS	18
6.2 Unstructured SP07 Round Jet Solution—SWFS RANS	20
6.3 ASME Grandfather Nozzle—Unstructured FUN3D RANS	21
6.4 SMC001_SP7—Unstructured SWFS RANS.....	23
6.5 SMC002_SP7—Unstructured SWFS RANS.....	26
6.6 SMC004_SP7—Unstructured SWFS RANS.....	27
6.7 SMC026_SP7—Unstructured SWFS RANS.....	30
7.0 Summary and Recommendations	32
References.....	32

User's Guide for GAA_JET_FV (V1): A Jet Noise Prediction Code Based on the Generalized Acoustic Analogy

Stewart J. Leib
HX5 Sierra, LLC
Brook Park, Ohio 44142

Abstract

This document is a user's guide for the jet noise prediction code GAA_JET_FV, which can be used to make predictions of turbulent mixing noise in high-speed free jets (i.e., in the absence of any solid surfaces) of arbitrary cross section. The code requires a Reynolds-averaged Navier-Stokes (RANS) solution for the mean flow and turbulence as input. A script is provided in the code package which can be used to interpolate structured or unstructured RANS solutions onto a structured grid suitable for the noise calculations. Output file formats for two commonly used RANS solvers are currently supported by this script. The document describes how the code is unpacked and installed on a user's system. A simple test case is provided that can be run with minimal user knowledge of the code details. General instructions for running the interpolation script and the main code are given along with descriptions of the input and output data files and individual code modules. Several detailed test cases are provided which allow the user to exercise additional features of the code. This document is Version 1, Revision 0 of the User's Guide, which contains examples of round and non-axisymmetric unheated jet test cases. Future versions are planned which will include additional functionality for the code and more complex test cases.

1.0 Introduction

Acoustic analogy approaches to the analysis of flow-generated noise can provide a basis for the development of physics-based, reduced-order noise prediction methods. In their practical implementation, these methods rely on the use of Reynolds-Averaged Navier-Stokes (RANS) flow solutions for the mean velocity and temperature, to compute sound propagation through non-uniform flows, and modeling of the sound source terms, parameterized by turbulence quantities (turbulent kinetic energy and dissipation rate) from the RANS solution. These methods lie between very fast (but highly approximate) empirical methods and time-consuming (but highly resolved) simulation methods, and can be used to screen new noise reduction concepts using reasonably modest computational resources while still maintaining the essential physical effects which impact noise generation and propagation. The Generalized Acoustic Analogy (GAA) formulation (Refs. 1 and 2) provides a rigorous, self-consistent, framework on which to build a RANS-based, reduced-order, noise prediction method.

This document is a user's guide for the jet noise prediction code GAA_JET_FV, and associated routines, which is a jet mixing noise prediction code developed from several implementations of the GAA over the years. The code can be used to make predictions of turbulent mixing noise in high-speed free jets (i.e., in the absence of any solid surfaces) of arbitrary cross section. Technical details of the implementation, including the approximations made, modeling of the source terms and numerical solution of the Green's function, can be found in the references given at the end of this document (Refs. 2 to 4).

A high-level description of the run process is illustrated in the block diagram of Figure 1. The process starts with the computation of a RANS solution for the flow. This can be done using any available, structured or unstructured, flow solver. Typically the RANS solution needs to be interpolated onto a structured mesh appropriate for the noise calculation. A general routine for this interpolation,

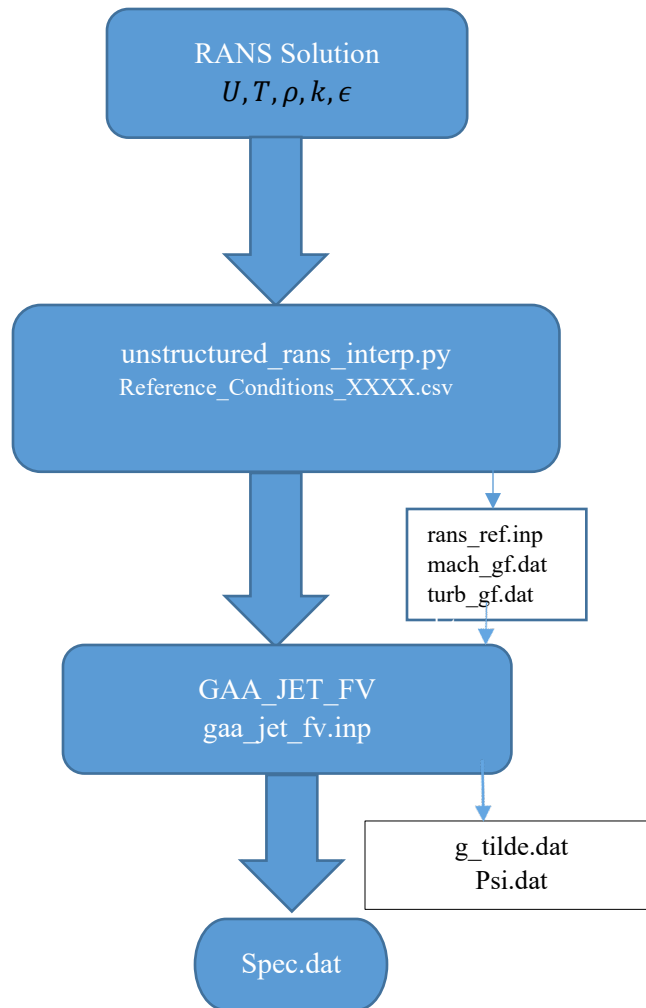


Figure 1.—Block diagram of code structure.

unstructured_rans_interp.py, which accepts RANS files exported by the SolidWorks Flow Simulation solver (Ref. 5) and the FUN3D code (Ref. 6), is provided in the code package and described in Section 3.0. The interpolation script requires the input data file, Reference_Conditions_XXXX.csv, where XXXX is SWFS or FUN3D, containing the reference flow conditions for which the mean flow was computed. The flow variables needed by the noise code from the RANS are: mean streamwise velocity, U , mean temperature, T , mean density, ρ , turbulent kinetic energy, k , and turbulence dissipation rate, ϵ .

The interpolation routine outputs two files, mach_gf.dat and turb_gf.dat, which contain, respectively, the mean flow and turbulence quantities interpolated onto the specified grid to be used in the noise calculations and a file, rans_ref.inp, in namelist format, which contains the reference flow conditions. These files are read by the main noise code, GAA_JET_FV. The input data file, gaa_jet_fv.inp, contains all the remaining input parameters needed by GAA_JET_FV. This input data file is in NAMELIST form, with the parameters organized into namelist groups according to their roles in the noise computation (Model_Constants, Options, NUMERICS, RUN_PARAMETERS). More details are provided Section 4.1. The primary result output by GAA_JET_FV is the prediction of the acoustic spectrum, i.e., the far-field fluctuating pressure power spectral density (PSD) vs. Strouhal number ($St = fD/U_j$, where f is the frequency, D the nominal nozzle diameter and U_j the jet exit velocity), at the specified observer locations (polar angle, θ , measured from the downstream jet axis and azimuthal angle, ϕ) suitable for comparison

with experimental data. The lossless PSD is expressed per unit Strouhal number, in decibels (dB) referenced to a pressure of 10^{-5} Pa at a spherical radial distance of one-hundred nozzle diameters from its exit. These results are written to the output data file Spec.dat.

Depending upon the run options selected, additional output data files can be generated containing intermediate results of the computations. The far-field Green's function can be output to the file g_tilde.dat and selected components of the sound source spectrum model to Psi.dat. These results can be used for diagnostic purposes and to study sound propagation and generation effects, respectively.

The document describes how the code is unpacked and installed on a user's system. A simple test case is provided in Section 2.0 that can be run with minimal user knowledge of the code details. General instructions for running the interpolation script are given in Section 3.0. More detailed descriptions of the input and output data files of the main noise code, and general instructions for running it, are given in Section 4.0. Descriptions of the various FORTRAN 90 modules that make up the noise code are provided in Section 5.0. In Section 6.0 details of several example test cases are provided. This document is Version 1, Revision 0 of the User's Guide, which contains examples of round and non-axisymmetric unheated jet test cases. Future versions are planned which will include additional functionality for the code and more complex test cases.

2.0 Quick Start Guide

In this section we provide a quick-start guide to the steps involved in installing and running GAA_JET_FV to obtain a prediction of the power spectral density (PSD) of the mixing noise from a turbulent jet. An initial example case, corresponding to an unheated round jet with exit acoustic Mach number of 0.7 (SP05), where the RANS solution has been obtained from SolidWorks Flow Solver, has been interpolated and processed for direct use by the main noise code. All files needed to run this case are provided in the subdirectory, QUICK_START.

2.1 Code Package

The code package is provided as a zipped tar file, GAA_JET_FV_Vx_Ry.tar.gz, where x is the current distribution version and y its most recent revision. The package includes: this document, a subdirectory, SOURCE_CODE, which contains the FORTRAN 90 source code, the makefiles used to build the executable and the python-based interpolation script, unstructured_rans_interp.py, a subdirectory TEST_CASES, which contains, in separate sub-directories, RANS solutions and input data files needed to run the sample test cases provided with the distribution. There is also a subdirectory, QUICK_START, that contains files needed to run the initial example case described in this section.

2.2 Unpacking the Code

Files are extracted from the archive in the usual way on a LINUX/UNIX/Mac system:

```
gunzip GAA_JET_FV_Vx_Ry.tar.gz
tar -xvf GAA_JET_FV_Vx_Ry.tar
```

The files will expand into a new directory, GAA_JET_HOME, with sub-structure as described above.

2.3 Compiling and Building Executables

A FORTRAN 90 compiler is needed to compile the code and produce the main executable file. The code has been tested using the Intel ifort (2018.3.222) and the open source gfortran (8.1.0) compilers. Two makefiles are found within the subdirectory SOURCE_CODE that can be used to compile and build the executable for the main noise prediction code, GAA_JET_FV. The file, `makefile`, uses the gfortran compiler, while `makefile_nas` uses the Intel compiler, ifort. The former requires that the lapack library be installed while the latter invokes the Math Kernel Library (MKL), in both cases to make use of the NETLIB routine, `zgbsv`, which solves the complex linear system of algebraic equations resulting from the finite volume discretization (Ref. 4). Typically, `makefile` would be used on a local Mac/LINUX system while `makefile_nas` would be used on the High-End Computing resources at NASA Ames Research Center (Pleiades). To access the Intel compiler on Pleiades, the relevant module must first be loaded as, for example, `module load comp-intel/2018.3.222`, or other current version (see https://www.nasa.gov/hecc/support/kb/intel-compiler_86.html).

To use the makefile to compile the code and build the executable, execute, within the subdirectory SOURCE_CODE:

MacOSX:

```
make GAA_JET_FV
```

NAS:

```
make -f makefile_nas GAA_JET_FV .
```

The makefiles also contains a rule, `make clean`, which deletes all existing object (.o), module (.mod) and executable (GAA_JET_FV) files. This allows for a fresh compile and build of the code, which is recommended when moving the code to run on a different operating system. The makefiles also contains a rule, `make tar_it`, that generates a tar file from the FORTRAN source code, which facilitates moving the code to another computer system. (The original tar distribution can also just be moved to different systems.)

2.4 Running the Code

A simple case set up for the user to run as an initial example is provided in the subdirectory, QUICK_START. Within this subdirectory are the input data files, `gaa_jet_fv.inp` and `rans_ref.inp`, and the files, `mach_gf.dat` and `turb_gf.dat`, containing the RANS solution on a grid suitable for the noise calculations and in the form read by the code, so that the interpolation step does not need to be run in this initial example.

2.4.1 Input Data Files

The main input data file is `gaa_jet_fv.inp`. This file provides values for the source model parameters, output and run options and order of accuracy options for the far-field boundary condition. Also, in this file the user can specify the parameter ranges (Strouhal number, observer polar angles, observer azimuthal angles and number of axial slices) for the noise calculations.

The input data file is in NAMELIST format, with group names organized according the variables' roles in the calculation. In this way, default values can be used for many of the parameters by including only the variables whose values are to be modified from the defaults. This is particularly recommended for the source model coefficients in the namelist group `Model_Constants`. A listing of the input datafile `gaa_jet_fv.inp` for the Quick Start example case is given below.

```

&Model_Constants ! Coefficients in the source model; Leib & Goldstein AIAAJ 2011
  Cl0_1111 = 0.7d0, Cl1_1111 = 1.2d0, ClT_1111 = 0.4d0, CCapLT_1111 = 2.0d0! Length Scale Coeffs
  Cl0_2222 = 0.7d0, Cl1_2222 = 0.8d0, ClT_2222 = 0.89d0, CCapLT_2222 = 2.0d0
  Cl0_3333 = 0.7d0, Cl1_3333 = 0.8d0, ClT_3333= 0.89d0, CCapLT_3333 = 2.0d0
  Cl0_2233 = 0.7d0, Cl1_2233 = 1.1d0, ClT_2233 = 0.4d0, CCapLT_2233 = 2.0d0
  Cl0_1212 = 1.05d0, Cl1_1212 = 1.0d0, ClT_1212 = 1.1d0, CCapLT_1212 = 0.4d0
  Cl0_1122 = 0.7d0, Cl1_1122 = 1.1d0, ClT_1122 = 1.0d0, CCapLT_1122 = 2.0d0
  Cl0_1133 = 0.7d0, Cl1_1133 = 1.1d0, ClT_1133 = 1.0d0, CCapLT_1133 = 2.0d0
  A_ret_time_1111 = 0.073d0, A_ret_time_2222 = 0.519d0, A_ret_time_3333 = 0.519d0 !Source
component series coeffs
  A_ret_time_2233 = 0.0d0, A_ret_time_1212 = 0.559d0, A_ret_time_1122 = 0.103d0, A_ret_time_1133
= 0.103d0
  A_omega_1111 = 0.0d0, A_omega_2222 = 0.0d0, A_omega_3333 = 0.0d0
  A_omega_2233 = 0.0d0, A_omega_1212 = 0.0d0, A_omega_1122 = 0.0d0, A_omega_1133 = 0.0d0
  A_11_1111 = 0.0d0, A_11_2222 = 0.0d0, A_11_3333 = 0.0d0
  A_11_2233 = 0.0d0, A_11_1212 = 0.0d0, A_11_1122 = 0.0d0, A_11_1133 = 0.0d0
  A_20_1111 = 0.070d0, A_20_2222 = 0.049d0, A_20_3333 = 0.049d0
  A_20_2233 = 0.0d0, A_20_1212 = -0.006d0, A_20_1122 = 0.079d0, A_20_1133 = 0.079d0
  A_30_1111 = -0.00085d0, A_30_2222 = -0.0097d0, A_30_3333 = -0.0097d0
  A_30_2233 = 0.0d0, A_30_1212 = -0.015d0, A_30_1122 = 0.0d0, A_30_1133 = 0.0d0
  C1111 = 1.28d0, C2222 = 0.203d0, C3333 = 0.203d0 ! Source component amplitudes
  C2233 = 0.0d0, C1212 = 0.2918d0, C1122 = 0.0616d0, C1133 = 0.0616d0
&END
&Options
  ioutput(1) = 1 ! Output spectral preiction in Spec.dat == 1
  ioutput(2) = 0 ! Output Green's function == 1
  ioutput(3) = 0 ! Output Source distribution == 1
  irun = 1 ! Run code and compute new GF == 1 ; Read exisitng GF == 2
&END
&NUMERICS
  iorder = 1 ! Order of accuracy for far-field bc: 1 for first, 2 for second
&END

&RUN_PARAMETERS
  St0 = 0.01d0 ! Initial Strouhal Number
  nSt = 32 ! Number of Strouhal numbers
  dSt = 1.25d0 ! Increment in Strouhal number. St_new = St * dSt
  theta0 = 30.0d0 ! Initial Polar Angle -- degrees, measured from jet axis
  ntheta = 1 ! Number of Polar Observer Angles
  dtheta = 30.0d0 ! Increment in Polar Angle, degrees measured from jet axis (theta_new =
theta + dtheta)
  phi0 = 0.0d0 ! Initial Azimuthal Angle, degrees
  nphi = 1 ! Number of Observer Azimuthal Angles
  dphi = 30.0d0 ! Increment in Observer Azimuthal Angle, degrees (phi_new = phi + dphi
  islice_begin = 1 ! Initial axial slice to use in computation
  islice_end = 37 ! Final axial slice to use in computation
  islice_skip = 1 ! Increment in axial slices to use in computation
&END

```

Details of the variables within the different NAMELIST groups are provided in Section 4.0.

The input data file, `rans_ref.inp`, contains information about the RANS solution: the number of grid points in the axial, radial and azimuthal directions and the reference conditions for the flow. The latter include the jet exit velocity (defined as the maximum velocity at the nozzle exit), the nozzle exit diameter

and the ambient values of the speed of sound, pressure and temperature. The file contents for the initial test case are listed here:

```
&RANS_SOLUTION

IMAX_RANS = 37 , ! Number of Axial Slices

JMAX_RANS = 301 , ! Number of Radial Grid Points

KMAX_RANS = 360 , ! Number of Azimuthal Grid Points

UJ = 240.373970000 , ! Jet exit velocity (m/s)

DIAM = 0.050800 , ! Nozzle diameter (m)

AREF = 343.114267 , ! Reference (ambient) sound speed (m/s)

PREF = 101325.000000 , ! Reference (ambient) pressure (Pa)

TREF = 293.000000 , ! Reference (ambient) temperature (K)
```

The RANS solution files are `mach_gf.dat` and `turb_gf.dat`. The former contains the radial and azimuthal grid points for selected axial slices and values for the mean streamwise velocity, normalized by the ambient sound speed (acoustic Mach number), the local sound speed squared, normalized by the jet exit velocity, and the mean density, normalized by the jet exit density. The later file contains the radial and azimuthal grid points and values for the turbulent kinetic energy, normalized by the jet exit velocity squared, and the ratio of the turbulence dissipation rate to the turbulent kinetic energy, normalized by the jet exit velocity and nozzle diameter. These files are in Tecplot format with axial slices arranged in separate ZONES. Profiles of the acoustic Mach number and the normalized turbulent kinetic energy at sample axial locations can be plotted using the Tecplot layouts `Ma_Plot.layout` and `TKE_Plot.layout` and the results compared with Figure 2 and image files `Ma_Plot.png` and `TKE_Plot.png`. The original Solid Works Flow Solver output file, `SMC000_SP5_full.txt`, is also provided in the Quick Start directory if the user would like try running the interpolation script, `unstructured_rans_interp.py`, to reproduce these RANS files. See Section 3.0 for instructions.

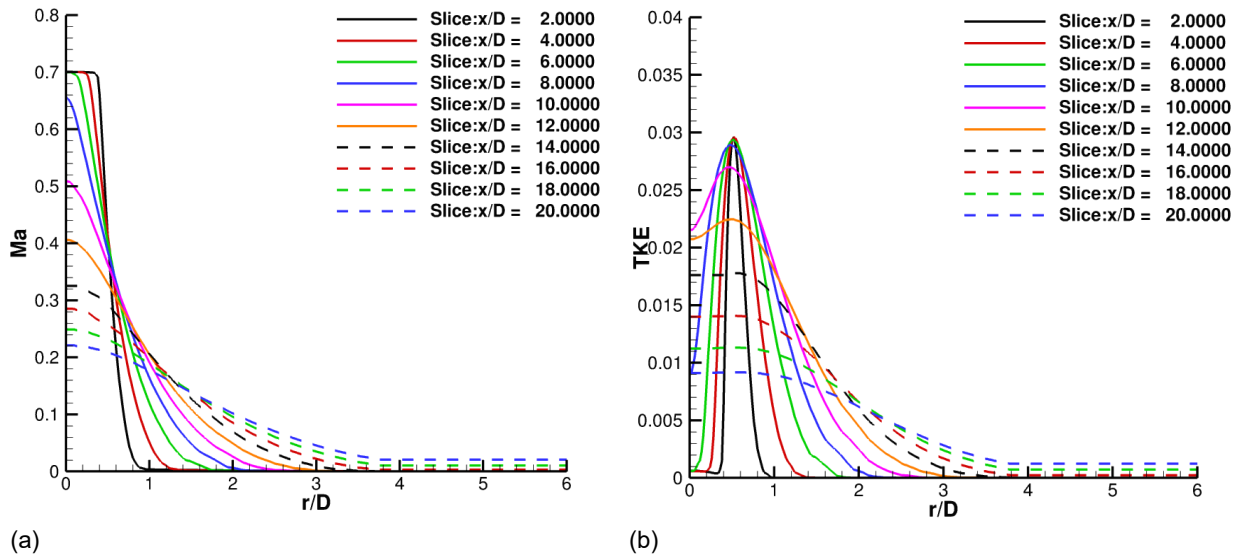


Figure 2.—Sample profiles of the (a) acoustic Mach number and (b) normalized turbulent kinetic energy vs. normalized radius for the Quick Start case.

2.4.2 Code Runs

Running the code using the input datafile provided in the QUICK_START directory produces a spectral noise prediction at an observer polar angle of thirty degrees to the jet axis at thirty-seven frequencies, ranging from $St = 0.01$ to 10.0 .

The code is run by executing the command within the QUICK_START directory:

```
../SOURCE_CODE/GAA_JET_FV .
```

If running on the NAS system (Pleiades) a batch job can be submitted using the script, RUN_GAA_JET.pbs. Edit the lines:

```
PBS -W group_list=a1486
```

```
module load comp-intel/2016.2.181
```

for the appropriate GID and compiler module loaded.

Submit the batch job as:

```
qsub RUN_GAA_JET .
```

The output, containing the spectral noise prediction at thirty degrees to the jet axis, is contained in the file Spec.dat. These results can be compared with those in the file Spec_QS.dat. They can also be plotted using the provided Tecplot layout, Plot_Spectrum.lay and compared with the image file, Plot_Spectrum.png. These results are shown in Figure 3.

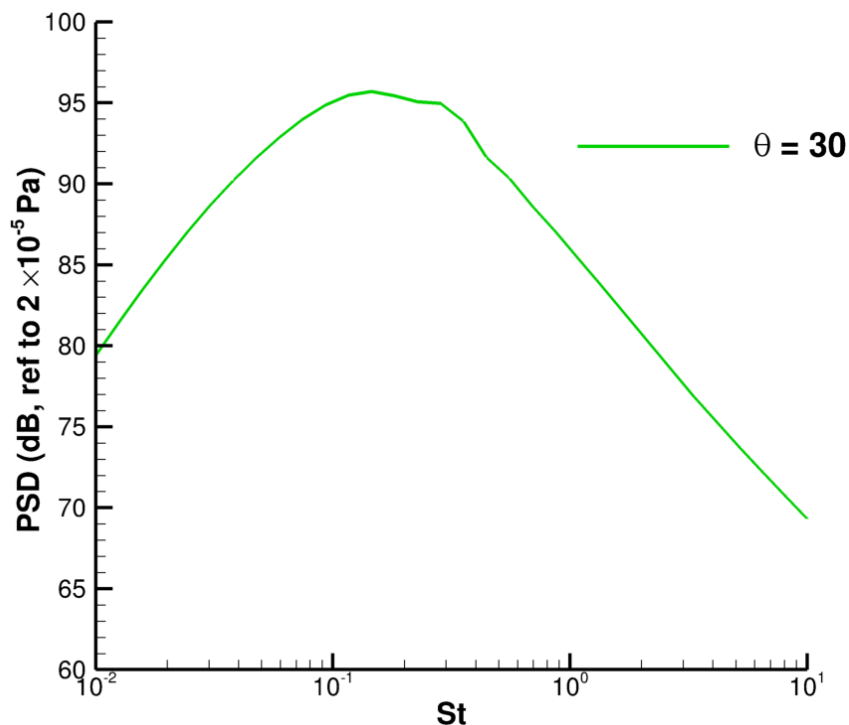


Figure 3.—Noise prediction results from the QUICK_START case. Power spectral density (per unit Strouhal number = fD/\bar{U}_j) of the far-field fluctuating pressure vs. Strouhal number.

3.0 Interpolation of a RANS Solution Onto a Structured Grid for the Noise Computation

In this section we describe the use of the python script, `unstructured_rans_interp.py`, that can be used to interpolate a structured or unstructured RANS solution onto a structured grid suitable for use with the jet noise prediction code `GAA_JET_FV`.

The python script, `unstructured_rans_interp.py`, delivered with this code package uses the Scipy routine, `griddata`, within the sub-package, `interpolate`, and is written to accept (after possibly a minimum amount of hand clean-up) RANS solution files typically output by the SolidWorks Flow Simulation solver (Ref. 5) and the FUN3D code (Ref. 6).

A sufficiently complete python distribution is needed to run this script. (The default python distribution available on Mac computers is not sufficient.) A freely available up-to-date python distribution can be downloaded from <https://www.anaconda.com/distribution/>.

The next subsection gives a quick introduction to running the interpolation script, using the example in the `QUICK_START` subdirectory. This is followed by a more detailed description of the script and general instructions for its use.

3.1 Running the Interpolation in the QUICK_START Example

For a quick introduction to using the interpolation script, the user can run it within the `QUICK_START` example subdirectory to reproduce the files `mach_gf.dat` and `turb_gf.dat` there. The steps are given in this subsection. Renamed copies of these data files, `mach_gf_SAVE.dat` and `turb_gf_SAVE.dat`, are provided for comparison with the newly created files.

The file, `Reference_Conditions_SWFS.csv`, provided within the `QUICK_START` subdirectory, contains the jet exit diameter and the reference conditions used in computing the RANS solution with the SolidWorks Flow Simulation solver. This file is read by the script and the flow condition values used to normalize the solution for use in the noise calculations. For this case this file contains:

```
D [m], Tref [K], Pref [Pa]
0.0508, 293.0, 101325.0
```

The script is run as:

```
python unstructured_rans_interp.py.
```

The script will prompt the user for several input parameters. These prompts, and the inputs needed to reproduce the files `mach_gf.dat` and `turb_gf.dat` in the `QUICK_START` example, are given below.

- [1] Enter SWFS or FUN3D: SWFS
- [2] One or Two input files ?, Enter 1 or 2: 1
- [3] Enter Input Data File Name: SMC000_SP5_full.txt
- [4] Enter Type of Flow Solution Symmetry: Half (H) or Quarter (Q) : Q
- [5] Enter the number of radial grid points: 301
- [6] Enter the number of azimuthal grid points: 360
- [7] Enter the maximum radial distance, in nozzle diameters: 6.0
- [8] Enter the number of axial slices: 37
- [9] Enter the initial axial slice, in nozzle diameters, to use in the noise calculations: 2.0
- [10] Enter the increment in axial slices, in nozzle diameters: 0.5
- [11] Enter the minimum number of points in axial sectioning to use for interpolation: 80000

The script will loop through the number of axial slices, printing to standard output the current slice being processed and the elapsed time, carry out the two-dimensional interpolation in each slice and output the results into the files `mach_gf.dat` and `turb_gf.dat`. The first few lines of these files for the QUICK_START case are given below.

mach_gf.dat:

```
VARIABLES = r/D phi Ma c2 density
ZONE T = "Slice:x/D = 2.0000" F = POINT, I = 360, J = 301
0.000000000 0.000000000 0.700410436 1.870450382 1.090359683
0.000000000 0.017453293 0.700410436 1.870450382 1.090359683
0.000000000 0.034906585 0.700410436 1.870450382 1.090359683
0.000000000 0.052359878 0.700410436 1.870450382 1.090359683
0.000000000 0.069813170 0.700410436 1.870450382 1.090359683
0.000000000 0.087266463 0.700410436 1.870450382 1.090359683
0.000000000 0.104719755 0.700410436 1.870450382 1.090359683
0.000000000 0.122173048 0.700410436 1.870450382 1.090359683
0.000000000 0.139626340 0.700410436 1.870450382 1.090359683
```

turb_gf.dat:

```
VARIABLES = r/D phi TKE EPS
ZONE T = "Slice:x/D = 2.0000" F = POINT, I = 360, J = 301
0.000000000 0.000000000 0.000631476 0.030398070
0.000000000 0.017453293 0.000631476 0.030398070
0.000000000 0.034906585 0.000631476 0.030398070
0.000000000 0.052359878 0.000631476 0.030398070
0.000000000 0.069813170 0.000631476 0.030398070
0.000000000 0.087266463 0.000631476 0.030398070
0.000000000 0.104719755 0.000631476 0.030398070
0.000000000 0.122173048 0.000631476 0.030398070
0.000000000 0.139626340 0.000631476 0.030398070
```

The script also outputs a file, `rans_ref.inp`, containing information about the RANS solution which is used by the noise code. A listing of `rans_ref.inp` for the QUICK_START case is given below.

```
&RANS SOLUTION
IMAX_RANS = 37 , ! Number of Axial Slices
JMAX_RANS = 301 , ! Number of Radial Grid Points
KMAX_RANS = 360 , ! Number of Azimuthal Grid Points
UJ = 240.373970000 , ! Jet exit velocity (m/s)
DIAM = 0.050800 , ! Nozzle diameter (m)
AREF = 343.114267 , ! Reference (ambient) sound speed (m/s)
PREF = 101325.000000 , ! Reference (ambient) pressure (Pa)
TREF = 293.000000 , ! Reference (ambient) temperature (K).
```

Sample radial profiles of the acoustic Mach number and the normalized turbulent kinetic energy, along $\varphi = 0$, for selected axial slices can be plotted using the provided Tecplot layouts, `Mach_Profiles.lay` and `Tke_Profiles.lay`, and compared with those in Figure 2.

The next subsection describes the interpolation script in more detail and provides instructions for running it for the test cases in Section 6.0 as well as new cases initiated by the user.

3.2 General Description of the Interpolation Script and Preparation of Data File

The script `unstructured_rans_interp.py` reads a RANS solution, does appropriate mirroring of the solution based on the symmetry of the flow and generates a structured grid in the cross-flow plane at axial slices from parameters provided interactively by the user. The script will then loop over the specified axial slices, extracting a 'section' of the solution around each slice (whose width is also specified by the user) and use this sub-set of the solution to interpolate the mean streamwise velocity, mean temperature, mean density, turbulent kinetic energy, and a quantity composed of the turbulent dissipation rate and turbulent kinetic energy which is used to form a turbulent length scale from the RANS solution, onto the structured grid. In the final step in the script, the interpolated profiles are scanned for the presence of 'bad' points (nans) which, if found, are replaced by values obtained by extrapolating from the last 'good' points. The interpolated profiles are then written to output data files that can be used as input to noise calculations.

The files currently supplied from SolidWorks requires a small amount of hand clean-up in order to be used by `unstructured_rans_interp.py`. The steps are:

1. Delete the extraneous dependent variable, Surface, if present.
2. Replace double tabs with single tabs.
3. Replace tab separators with commas.
4. Delete data beyond the line containing the last flow solution data point.

One input data file, `Reference_Conditions_xx.csv`, where `xx` = SWFS for a SolidWorks solution and `xx` = FUN3D for a FUN3D solution, is required to run `unstructured_rans_interp.py`. This file contains the reference conditions for which the flow solution was computed and quantities needed to non-dimensionalize the flow variables for use by the noise code.

For a SolidWorks RANS solution, an example of this file is below.

```
D [m], Tref [K], Pref [Pa]
0.0508, 293.0, 101325.0
```

The file contains a length scale, in meters (typically the nozzle [equivalent] diameter) and the reference ambient temperature, in Kelvin, and pressure, in Pascals, used in the RANS solution. The script computes additional ambient reference quantities (density and sound speed) from ideal gas relations.

For a FUN3D RANS solution, an example of this file is below.

```
D [m], Tref [K], Pref [Pa], aref [m/s], rhoref [kg/m^3], muref [Pa*s]
0.19596, 293.2, 141855.0, 343.266, 1.203879, 1.8135e-05
```

Here, in addition to the quantities input in a SWFS case, a reference velocity (ambient sound speed), density and viscosity are included. The latter is used to re-normalize the length scale parameter.

In either case, the script pulls out a jet exit velocity (the maximum velocity found in the solution) for use in normalizing the Green's function in the noise calculation.

3.3 Instructions for Running the Script

The script is run as:

```
python unstructured_rans_interp.py
```


The script will prompt the user for several input parameters. These prompts, a description of the input parameters and suggested starting values for the latter are given below.

- [1] Enter SWFS or FUN3D:
The script can treat RANS files exported from the SolidWorks Flow Simulation solver (after the preparation steps above) and the FUN3D code. Enter 'SWFS' for the former or 'FUN3D' for the latter.
- [2] One or Two input files ?, Enter 1 or 2:
The SolidWorks Flow solver can output the RANS solution in a single file or in two files, with one containing the mean flow quantities and the other the turbulence quantities. If the single-file option was used, enter '1', if the mean and turbulent quantities are in two separate files, enter '2'.
- [3] Enter Input Data File Name:
Enter the name of the file containing the RANS solution. If the two-file option is used, enter the name of the file containing the mean flow quantities first, followed by that of the file containing the turbulence.
- [4] Enter Type of Flow Solution Symmetry:
Geometrical symmetry properties are often used when computing RANS solutions to reduce computational costs. The interpolation script can treat RANS solutions where half- or quarter-symmetry was imposed on the solution. The latter is typical for axisymmetric flows and the former for some non-axisymmetric cases. Enter 'H' when half-symmetry was imposed or 'Q' for quarter-symmetry.
- [5] Enter the number of radial grid points: 301
This is the number of radial grid points, which will be distributed uniformly across the jet, to be used by GAA_JET_FV in the noise computation.
- [6] Enter the number of azimuthal grid points: 360
This is the number of azimuthal grid points, which will be distributed uniformly around the jet, to be used by GAA_JET_FV in the noise computation.
- [7] Enter the maximum radial distance, in nozzle diameters: 6.0
This is the radial location where the far-field boundary will be imposed on the Green's function and the maximum radial extent of the noise 'source region.'
- [8] Enter the number of axial slices: 37
This is the total number of axial slices to be used in the noise calculations.
- [9] Enter the initial axial slice, in nozzle diameters, to use in the noise calculations: 2.0
This is the initial axial slice location, in nozzle diameters measured relative to the nozzle exit, to be used in the noise calculations.
- [10] Enter the increment in axial slices, in nozzle diameters: 0.5
This is the increment in the axial slice, in nozzle diameters, to be used in the noise calculations.
- [11] Enter the minimum number of points in axial sectioning to use for interpolation: 80000
The script will extract a 'section' of the RANS solution about the current axial slice to limit the number of points used in the interpolation. This speeds up the interpolation process considerably. The number entered here is the minimum number of points to be included in this 'section.'

The code will create a cross-flow (radial, azimuthal) grid from the numbers of grid points and maximum radial position input above, loop through the specified axial slices and interpolate the flow solution onto this grid. The script uses the SciPy routine, `griddata`, within the sub-package, `interp` to do the two-dimensional interpolation. A final step in the process scans the interpolated results for nans and removes them in favor of extrapolated values from the last 'good' point.

The output of the code is the files, `mach_gf.dat` and `turb_gf.dat`, containing the interpolated mean flow and turbulence variables, respectively, and a file `rans_ref.inp`, containing RANS reference conditions. These files are to be used in the jet noise prediction code, `GAA_JET_FV`.

4.0 Details of the Input and Output Files and Run Instructions for the Main Noise Code

In this section we describe the parameters in the input data files used by the main noise code, provide instructions for running the code and describe the contents of the output files produced. Initiation of a new case starts with the generation of a RANS solution, which is not described here but rather assumed to be available. The first step, once a RANS solution has been obtained, is to run the interpolation script described in the last section to extract the relevant mean and turbulence quantities, put them onto a structured grid suitable for the noise calculation and output them in a format suitable for input to the main noise prediction code, `GAA_JET_FV`. The currently supported formats are .csv type files exported from the SolidWorks Flow Simulation solver and the FUN3D code.

The next subsections describe the input data files.

4.1 Input Data Files

The main noise code, `GAA_JET_FV`, reads three input data files created by the interpolation script `unstructured_rans_interp.py`. These files are named: `rans_ref.inp`, `mach_gf.dat` and `turb_gf.dat`. The first of these contains information about the grid and the reference flow conditions for which the noise predictions are computed and the last two contain the interpolated mean and turbulence quantities on this grid. An example of the contents of the file, `rans_ref.inp`, and descriptions of the parameters it contains, is given below.

- **`rans_ref.inp`**

```
&RANS SOLUTION
IMAX_RANS = 37 , ! Number of Axial Slices
JMAX_RANS = 301 , ! Number of Radial Grid Points
KMAX_RANS = 360 , ! Number of Azimuthal Grid Points
UJ = 240.373970000 , ! Jet exit velocity (m/s)
DIAM = 0.050800 , ! Nozzle diameter (m)
AREF = 343.114267 , ! Reference (ambient) sound speed (m/s)
PREF = 101325.000000 , ! Reference (ambient) pressure (Pa)
TREF = 293.000000 , ! Reference (ambient) temperature (K).
```

The first three entries are the numbers of grid points in the axial (slices), radial and azimuthal directions used for the noise computation. The next two, `UJ` and `DIAM`, are the jet exit velocity (in m/s) and the nominal nozzle exit diameter (in m), respectively. The last three are the ambient values of the sound speed (in m/s), pressure (in Pascals) and temperature (K), respectively.

- **`mach_gf.dat`**

This file contains the grid points and interpolated values for the acoustic Mach number, sound speed squared (normalized with the jet exit velocity) and density (normalized by the jet exit density). The first few lines of a typical example of this file is given in Section 3.0.

- **`turb_gf.dat`**

This file contains the grid points and interpolated values for the turbulent kinetic energy, k , (normalized with the jet exit velocity, U_j) and the ratio of the turbulence dissipation rate, ϵ , to k

(normalized with U_j and the nozzle diameter, D). The first few lines of a typical example of this file is also given in Section 3.0.

- **gaa_jet_fv.inp**

This is the main input data file for GAA_JET_FV. This file provides values for the source model parameters, output and run options and information on the grid to be used in the noise calculation. Also, in this file the user can specify the parameter ranges (Strouhal number, observer polar and azimuthal angles) for the noise calculations.

The input data file is in NAMELIST format, with group names organized according the variables' role in the calculation. In this way, default values can be used for many of the parameters by including only the variables whose values are to be modified from the defaults. This is particularly recommended for the source model coefficients in the namelist group Model_Constants. An example of a complete input datafile, `gaa_jet_fv.inp`, with the default values for the input variables, is listed below.

```
&Model_Constants ! Coefficients in the source model; Leib & Goldstein AIAAJ 2011
  Cl0_1111 = 0.7d0, Cl1_1111 = 1.2d0, ClT_1111 = 0.4d0, CCapLT_1111 = 2.0d0! Length Scale Coeffs
  Cl0_2222 = 0.7d0, Cl1_2222 = 0.8d0, ClT_2222 = 0.89d0, CCapLT_2222 = 2.0d0
  Cl0_3333 = 0.7d0, Cl1_3333 = 0.8d0, ClT_3333 = 0.89d0, CCapLT_3333 = 2.0d0
  Cl0_2233 = 0.7d0, Cl1_2233 = 1.1d0, ClT_2233 = 0.4d0, CCapLT_2233 = 2.0d0
  Cl0_1212 = 1.05d0, Cl1_1212 = 1.0d0, ClT_1212 = 1.1d0, CCapLT_1212 = 0.4d0
  Cl0_1122 = 0.7d0, Cl1_1122 = 1.1d0, ClT_1122 = 1.0d0, CCapLT_1122 = 2.0d0
  Cl0_1133 = 0.7d0, Cl1_1133 = 1.1d0, ClT_1133 = 1.0d0, CCapLT_1133 = 2.0d0
  A_ret_time_1111 = 0.073d0, A_ret_time_2222 = 0.519d0, A_ret_time_3333 = 0.519d0 !Source
component series coeffs
  A_ret_time_2233 = 0.0d0, A_ret_time_1212 = 0.559d0, A_ret_time_1122 = 0.103d0, A_ret_time_1133
= 0.103d0
  A_omega_1111 = 0.0d0, A_omega_2222 = 0.0d0, A_omega_3333 = 0.0d0
  A_omega_2233 = 0.0d0, A_omega_1212 = 0.0d0, A_omega_1122 = 0.0d0, A_omega_1133 = 0.0d0
  A_11_1111 = 0.0d0, A_11_2222 = 0.0d0, A_11_3333 = 0.0d0
  A_11_2233 = 0.0d0, A_11_1212 = 0.0d0, A_11_1122 = 0.0d0, A_11_1133 = 0.0d0
  A_20_1111 = 0.070d0, A_20_2222 = 0.049d0, A_20_3333 = 0.049d0
  A_20_2233 = 0.0d0, A_20_1212 = -0.006d0, A_20_1122 = 0.079d0, A_20_1133 = 0.079d0
  A_30_1111 = -0.00085d0, A_30_2222 = -0.0097d0, A_30_3333 = -0.0097d0
  A_30_2233 = 0.0d0, A_30_1212 = -0.015d0, A_30_1122 = 0.0d0, A_30_1133 = 0.0d0
  C1111 = 1.28d0, C2222 = 0.203d0, C3333 = 0.203d0 ! Source component amplitudes
  C2233 = 0.0d0, C1212 = 0.2918d0, C1122 = 0.0616d0, C1133 = 0.0616d0
&END

&Options
  ioutput(1) = 1 ! Output spectral preiction in Spec.dat == 1
  ioutput(2) = 0 ! Output Green's function == 1
  ioutput(3) = 0 ! Output Source distribution == 1
  irun = 1 ! Run code and compute new GF == 1 ; Read exisitng GF == 2
&END

&NUMERICS
  iorder = 1 ! Order of accuracy for far-field bc: 1 for first, 2 for second
&END

&RUN_PARAMETERS
  St0 = 0.01d0 ! Initial Strouhal Number
  nSt = 17 ! Number of Strouhal numbers
  dSt = 1.25d0 ! Increment in Strouhal number. St_new = St * dSt
  theta0 = 90.0d0 ! Initial Polar Angle -- degrees, measured from jet axis
```

```

ntheta = 1          ! Number of Polar Observer Angles
dtheta = 30.0d0     ! Increment in Polar Angle, degrees measured from jet axis (theta_new =
theta + dtheta)
phi0 = 0.0d0        ! Initial Azimuthal Angle, degrees
nphi = 1            ! Number of Observer Azimuthal Angles
dphi = 30.0d0       ! Increment in Observer Azimuthal Angle, degrees (phi_new = phi + dphi
islice_begin = 1     ! Initial axial slice to use in computation
islice_end = 37      ! Final axial slice to use in computation
islice_skip = 1      ! Increment in axial slices to use in computation
&END

```

We next describe the input parameters in each namelist group in `gaa_jet_fv.inp`.

Model_Constants:

The coefficients, Clx_{ijkl} , are the parameters in the length scale definitions, $l_\alpha = Cl\alpha_{ijkl} \left(k^{3/2}/\epsilon \right)$, where $\alpha = 0, 1, T$ for the convective, streamwise and transverse turbulent length scales and $ijkl$ refers to the component of the Reynolds stress auto-covariance (Refs. 2 and 3). The coefficients $CCapT_{ijkl}$ are not used in the current code version. The coefficients A_x_{ijkl} are the amplitudes of the terms in the truncated series representation of the turbulence source spectrum for the $ijkl$ component (Ref. 3). The coefficients, C_{ijkl} , are scaling parameters for the Reynolds stress auto-covariance component amplitudes, determined from a quasi-normal turbulence approximation (Ref. 3).

Options:

The parameters in this namelist group specify the run and output options. Not all options are available in this initial release. The three-element, one-dimensional integer vector, `ioutput(3)`, specifies the code output options: `ioutput(1) = 1` to output the spectral predictions in a file `Spec.dat`, `ioutput(2) = 1` to output the Green's function to a file `g_tilde.dat` and `ioutput(3) = 1` to output selected components of the source model distribution. Any other integer values input for these quantities will suppress the respective output. If the `ioutput(2)` or `ioutput(3)` options are set, it is recommended that the frequencies and observer locations requested be limited to very small numbers, as these files can become quite large otherwise. These latter two options can be used for diagnostic and analysis purposes to study mean flow interaction effects, such as the effect of the mean flow on sound propagation including preferential shielding in non-axisymmetric cases, and examine the model source distribution. The parameter `irun` specifies whether a run will compute a new Green's function (`irun = 1`) or will read in an existing one (`irun = 2`). Currently the only option is to compute a new Green's function (`irun = 1`).

NUMERICS:

The only variable in this namelist group is a parameter, `iorder`, which specifies the order of accuracy of the numerical approximation for the far-field boundary condition imposed on the Green's function; `iorder = 1` for first-order, `iorder = 2` for second-order. First-order has generally been found to be sufficient.

RUN_PARAMETERS:

The variables in this namelist group allow the user to specify the ranges of parameters (frequency, observer location, number of axial locations used) for which spectral predictions are obtained. The variables: `St0`, `dSt` and `nSt`, set the initial Stouhal number ($St = fD/U_j$, where f is frequency (Hz), D is the nozzle (equivalent) diameter (ft) and U_j is the jet exit velocity (ft/sec)), the Strouhal number increment

and the number of Strouhal numbers in the computation, respectively. The variables: `theta0`, `ntheta` and `dtheta` set the initial observer polar angle (in degrees measured from the downstream jet axis), the number of polar angles and the increment in polar angle (in degrees), respectively. The variables: `phi0`, `nphi` and `dphi` set the initial observer azimuthal angle (in degrees), the number of azimuthal angles and the increment in azimuthal angle (in degrees), respectively. The variables: `islice_begin`, `islice_end`, set the index of the initial and final, respectively, axial locations to use in the noise calculation and `islice_skip` is the increment in the slice index. In this release version, `islice_begin = islice_skip = 1` and `islice_end` must equal `IMAX_RANS` in the file `rans_ref.inp`. Future releases will include the capability to choose different axial slice ranges, including skipping some for quicker turn-around, without re-running the interpolator.

4.2 Run Instructions

To run the main noise prediction code, once the files produced by the interpolator are available, prepare the input data file, `gaa_jet_fv.inp`, as described above. As stated above, it is only necessary to specify in this file input parameters whose values are to be changed from their default ones. Then, from the `SOURCE_CODE` sub-directory, execute the makefile to produce the executable file for the main code, `GAA_JET_FV`:

MacOSX:

```
make GAA_JET_FV
```

NAS:

```
make -f makefile_nas GAA_JET_FV .
```

Run the code from a directory containing the required input data files (`mach_gf.dat`, `turb_gf.dat` and `gaa_jet_fv.inp`) as:

```
../.. /SOURCE_CODE/GAA_JET_FV
```

4.3 Output Data Files

A run of `GAA_JET_FV`, with `ioutput(1) = 1`, produces the main output data file, `Spec.dat`, which contains predictions for the acoustic spectrum, i.e., the far-field fluctuating pressure power spectral density (PSD) vs. Strouhal number ($St = fD/U_j$), at the specified observer angles (polar angle, `theta`, measured from the downstream jet axis, azimuthal angle, `phi`) suitable for comparison with experimental data. The lossless, one-sided, PSD is expressed per unit Strouhal number, in decibels (dB) referenced to a pressure of 10^{-5} Pa at a spherical radial distance of one-hundred nozzle diameters from its exit. Below are the first few lines of an example of the file `Spec.dat`.

```
TITLE = "Spectral Data "
VARIABLES = "St" "phi" "theta" "PSD" "Quad SPL" "Di SPL"
ZONE T = " Azimuthal " F = POINT, I = 32 J = 1 K = 3
0.10000E-01 0.00000E+00 0.30000E+02 0.79417E+02 0.00000E+00 0.69531-309
0.12500E-01 0.00000E+00 0.30000E+02 0.81439E+02 0.00000E+00 0.69531-309
0.15625E-01 0.00000E+00 0.30000E+02 0.83406E+02 0.00000E+00 0.69531-309
0.19531E-01 0.00000E+00 0.30000E+02 0.85287E+02 0.00000E+00 0.69531-309
```

The output variables are the Strouhal number (`St`), the observer azimuthal (`phi`) and polar (`theta`, measured from the jet axis) angles and the power spectral density. The last two output variables are placeholders for the contributions to the PSD from the so-called quadrupole and dipole components of the source (see Refs. 3 and 4) which are not active in this version release.

A run of GAA_JET_FV, with `ioutput(2) = 1`, produces the output data file, `g_tilde.dat`, which contains results for the far-field Green's function. The latter can be used for diagnostic and analysis purposes to study mean flow interaction effects, such as effect of the mean flow on sound propagation including preferential shielding in non-axisymmetric cases. The first few lines of a typical example of this file is given below.

```
TITLE = "Greens Function - Polar Coords "
VARIABLES = "r" "phi_0" "Real(g_tilde)" "Imag(g_tilde)" "|g_tilde|"
ZONE T = " phi = 0.00 theta = 60.00 St = 0.20 X/D = 0.00 "F=POINT I = , 300 J = 360
0.20000E-01 0.00000E+00 0.45081E-02 0.32021E-02 0.55296E-02
0.40000E-01 0.00000E+00 0.45474E-02 0.31585E-02 0.55367E-02
0.60000E-01 0.00000E+00 0.45832E-02 0.31119E-02 0.55398E-02
0.80000E-01 0.00000E+00 0.46175E-02 0.30640E-02 0.55416E-02
0.10000E+00 0.00000E+00 0.46509E-02 0.30153E-02 0.55429E-02
0.12000E+00 0.00000E+00 0.46836E-02 0.29659E-02 0.55437E-02
```

Cross-flow distributions of the real and imaginary parts and the magnitude of the normalized far-field Green's function (see Refs. 2 to 4) at fixed frequency, observer location and axial position in the jet are output into separate zones in Tecplot format for plotting.

A run with `ioutput(3) = 1` produces the output data file `Psi.dat`, which contains the values of selected (currently 1111, 2222 and 1212, see Refs. 2 and 3) components of the model for the source spectrum. The latter can also be used for diagnostic purposes to study the relative source distributions of different mean flow fields. The first few lines of a typical example of this file is given below.

```
TITLE = "Source Distribution "
VARIABLES = "x/D" "r" "phi_0" "Psi_1111" "Psi_2222" "Psi_1212"
ZONE T = "St = 0.60 X/D = 5.90 "F=POINT I = , 300 J = 360
0.59000E+01 0.20000E-01 0.00000E+00 0.40328E-08 0.12979E-09 0.11862E-09
0.59000E+01 0.40000E-01 0.00000E+00 0.60763E-08 0.19179E-09 0.17356E-09
0.59000E+01 0.60000E-01 0.00000E+00 0.75595E-08 0.23433E-09 0.21059E-09
0.59000E+01 0.80000E-01 0.00000E+00 0.93868E-08 0.28522E-09 0.25485E-09
0.59000E+01 0.10000E+00 0.00000E+00 0.11677E-07 0.34676E-09 0.30854E-09
```

Cross-flow distributions of these components at fixed frequency, observer location and axial position in the jet are output into separate zones in Tecplot format for plotting.

In the next section the various FORTRAN 90 modules that make up the noise code are described.

5.0 Descriptions of Code Modules

In this section we describe the various FORTRAN modules that make up the noise prediction code.

GAA_JET_FV.f90:

This module contains the main program, `gaa_jet`. It allocates arrays needed by the code, calls a sub-routine (`Read_Input`) that reads the input data files and loops over the specified ranges of observer polar and azimuthal angles and frequencies (Strouhal number). Within these loops, it loops over the number of axial slices, calling the Green's function solver and source model modules, and evaluates terms in the formula for the acoustic spectrum at each point in the jet. It then integrates the latter over the source volume to obtain the complete power spectral density. The main program outputs results for the power spectral density (PSD) vs. Strouhal number for the specified observer angles. Depending upon the output options, it may also generate files containing the Green's function and/or specified components of the sound sources.

Read_Input_GAA.f90:

This module contains the subroutine Read_Input, which defines the default values for the input parameters and reads, in NAMELIST format, values contained in the input data file gaa_jet_fv.inp specified by the user. It then reads the file, rans_ref.inp, containing the reference conditions for the RANS solution.

GF_Solve.f90:

This module contains the subroutine, GFSolve, which computes the Green's function at a particular axial slice for a given observer location and frequency. It calls a number of internal subroutines.

Banded_Storage (**A_Banded.f90**):

This subroutine puts the coefficient matrix into banded format for use with the linear system solver,

right_hand_side (**In_homog.f90**):

This routine assembles the right hand-side of the linear system of equations.

zgbsv:

This is a NETLIB routine which solves a complex sparse system of simultaneous linear algebraic equations. It is included in the code build using the -llapack or -lmkl library options in the makefile.

GFExtract: (**GF_Extract.f90**):

This routine extracts the solution vector from the array output by zgbsv.

Phi_Functions.f90:

This module contains function subprograms that compute the components of the source spectrum, Φ_{ijkl} , appearing in the formula for the acoustic spectrum (Ref. 2). It calls function subprograms within the module, **Psi_Functions.f90**, which evaluate the source spectral functions, Ψ_{ijkl} , which are the Fourier transforms of the corresponding fourth-order space-time correlations of the turbulent velocity fluctuations (Ref. 2). The later, in turn, calls function subprograms within the module, **Master_Spectra.f90**, which evaluates the functional forms of the terms in the source model as given in Reference 3.

PSD_Calculations.f90:

The module computes the lossless Power Spectral Density (PSD) of the fluctuating far-field pressure, per unit Strouhal number, in decibels (dB) referenced to a pressure of 10^{-5} Pa at a spherical radial distance of one-hundred nozzle diameters from its exit.

GF_Write.f90:

This module contains the subroutine GFWrite, which outputs the Green's function to the file, g_tilde.dat and at the specified frequency and observer locations, when the output option ioutput(2) = 1 is set.

Source_Write.f90:

This module contains the subroutine SourceWrite, which outputs the dominant source spectra components to the file Psi.dat, at the specified frequency and observer locations, when the output option ioutput(3) = 1 is set.

modules.f90:

This file contains the modules for the code which make common variables available to various routines by use association.

In the next section, the sample test cases supplied with this distribution are described. Instructions for running these cases are provided along with results that can be used for comparison with those obtained in users' runs.

6.0 Sample Test Cases

In this section we describe the sample test cases provided in this distribution that can be run by the user to test the code. In this (V1) version of the guide, three axisymmetric cases, two using RANS solutions from the SolidWorks Flow Simulation solver and one using the FUN3D code, and four non-axisymmetric cases, corresponding to jets from ‘chevron’ nozzles of different azimuthal modal orders with RANS from SWFS (Ref. 7), all unheated, are given. It is hoped that these relatively simple cases can be exercised by new users to see how the code is run and to provide feedback for use in further releases and code development.

6.1 Unstructured SP05 Round Jet Solution—SWFS RANS

This test case is contained in the subdirectory, TEST_CASES/ROUND_SP05_SWFS. It corresponds to the jet from the round, SMC000, nozzle with NPR = 1.43 and NTR = 1.0, for an exit acoustic Mach number of 0.7 and exit temperature ratio of 0.906 (SP05). This is the same case provided in the QUICK_START directory but here the interpolation script, unstructured_rans_interp.py, must first be run before the noise code can be executed.

The following files are found in this subdirectory:

- SMC000_SP5_full.txt - The RANS flow solution exported from SolidWorks Flow solver, stripped of extraneous variable names and converted to .csv format
- Reference_Conditions_SWFS.csv - The file containing the reference conditions for the RANS solution
- Ma_Plot.layout (.png) and TKE_Plot.layout (.png) - Tecplot layouts (resulting image files) for plotting interpolated profiles of acoustic Mach number and normalized turbulent kinetic energy
- gaa_jet_fv.inp - Input data file for the noise code
- RUN_GAA_JET.pbs - A Portable Batch System script that can be used to run GAA_JET_FV on the HPC system, Pleiades
- Plot_Spectrum.layout (.png) - Tecplot layout (resulting image file) to plot the spectral noise predictions

The first step is to run the interpolation script as:

```
python ../../SOURCE_CODE/unstructured_rans_interp.py.
```

The script will prompt the user for several input parameters. These prompts, and the inputs needed to reproduce the plots in the image files in this directory, are given in the Section 3.1 and repeated here for convenience.

- [1] Enter SWFS or FUN3D: SWFS
- [2] One or Two input files ?, Enter 1 or 2: 1
- [3] Enter Input Data File Name: SMC000_SP5_full.txt
- [4] Enter Type of Flow Solution Symmetry: Half (H) or Quarter (Q): Q
- [5] Enter the number of radial grid points: 301
- [6] Enter the number of azimuthal grid points: 360
- [7] Enter the maximum radial distance, in nozzle diameters: 6.0
- [8] Enter the number of axial slices: 37

- [9] Enter the initial axial slice, in nozzle diameters, to use in the noise calculations: 2.0
- [10] Enter the increment in axial slices, in nozzle diameters: 0.5
- [11] Enter the minimum number of points in axial sectioning to use for interpolation: 80000

Upon completion of the script run, the files, `mach_gf.dat` and `turb_gf.dat`, containing the interpolated flow solution, and `rans_ref.inp`, containing the reference conditions for the RANS solution for use by the noise code, should appear in this subdirectory. These can be plotted using the Tecplot layouts, `Ma_Plot.lay` and `TKE_Plot.lay`, and the results compared with the image files, `Ma_Plot.png` and `TKE_Plot.png`, and also with Figure 2.

Once the executable has been produced by executing the `makefile`, the main noise prediction code can be run as:

```
../../../../SOURCE_CODE/GAA_JET_FV .
```

The output from this run is the data file, `Spec.dat`, containing the noise prediction results. These results can be plotted using the Tecplot layout, `Plot_Spectrum.lay`, and the plots compared with Figure 4 and the image file `Plot_Spectrum.png`.

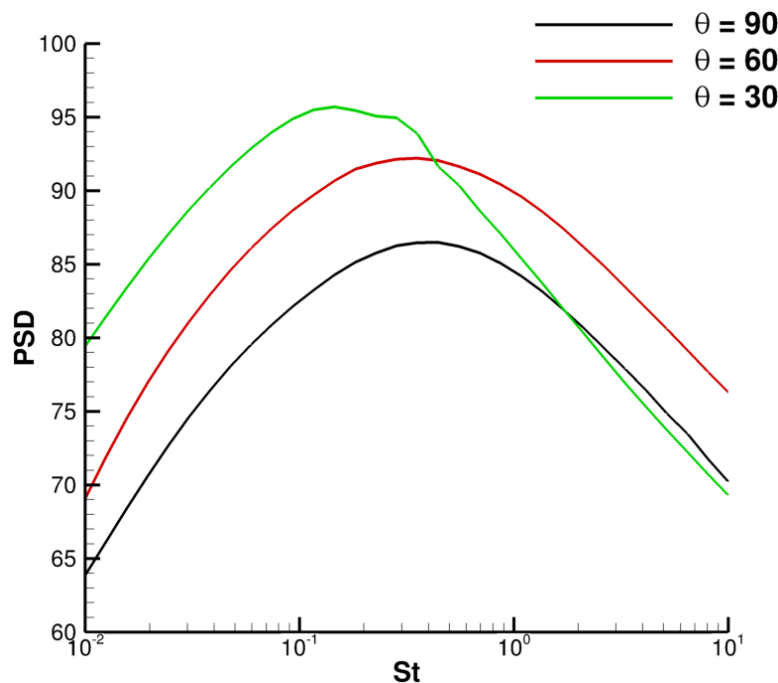


Figure 4.—Spectral noise prediction results from the ROUND_SP05_SWFS case. Power spectral density (per unit Strouhal number = fD/U_j) of the far-field fluctuating pressure vs. Strouhal number.

6.2 Unstructured SP07 Round Jet Solution—SWFS RANS

This test case is contained in the subdirectory, TEST_CASES/ROUND_SP07_SWFS. It corresponds to the jet from the round, SMC000, nozzle with NPR = 1.86 and NTR = 1.0, for an exit acoustic Mach number of 0.9 and exit temperature ratio of 0.835 (SP07).

The following files are found in this subdirectory:

- SMC000+SP7bigfull.txt – The RANS flow solution as exported from SolidWorks Flow solver
- Reference_Conditions_SWFS.csv – The file containing the reference conditions for the RANS solution
- Ma_Plot.lay (.png) and TKE_Plot.lay (.png) – Tecplot layouts (resulting image files) for plotting interpolated profiles of acoustic Mach number and normalized turbulent kinetic energy
- gaa_jet_fv.inp – Input data file for the noise code
- RUN_GAA_JET.pbs – A Portable Batch System script that can be used to run GAA_JET_FV on the HPC system, Pleiades
- Plot_Spectrum.lay (.png) – Tecplot layout (resulting image file) to plot the spectral noise predictions

In this case the steps given in Section 3.2 must be followed to edit the file, SMC000+SP7bigfull.txt, before running the interpolation script. Then the interpolation script can be run as:

```
python ../../SOURCE_CODE/unstructured_rans_interp.py .
```

The inputs for the script prompts in this case are the same as for the SP5 case in Section 6.1, except for the RANS file name, SMC000+SP7big_full.txt.

Upon completion of the script run, the files, mach_gf.dat and turb_gf.dat, containing the interpolated flow solution, and rans_ref.inp, containing the reference conditions for the RANS solution for use by the noise code, should appear in this subdirectory. These can be plotted using the Tecplot layouts, Ma_Plot.lay and TKE_Plot.lay, and the results compared with the image files, Ma_Plot.png and TKE_Plot.png, and also with Figure 5.

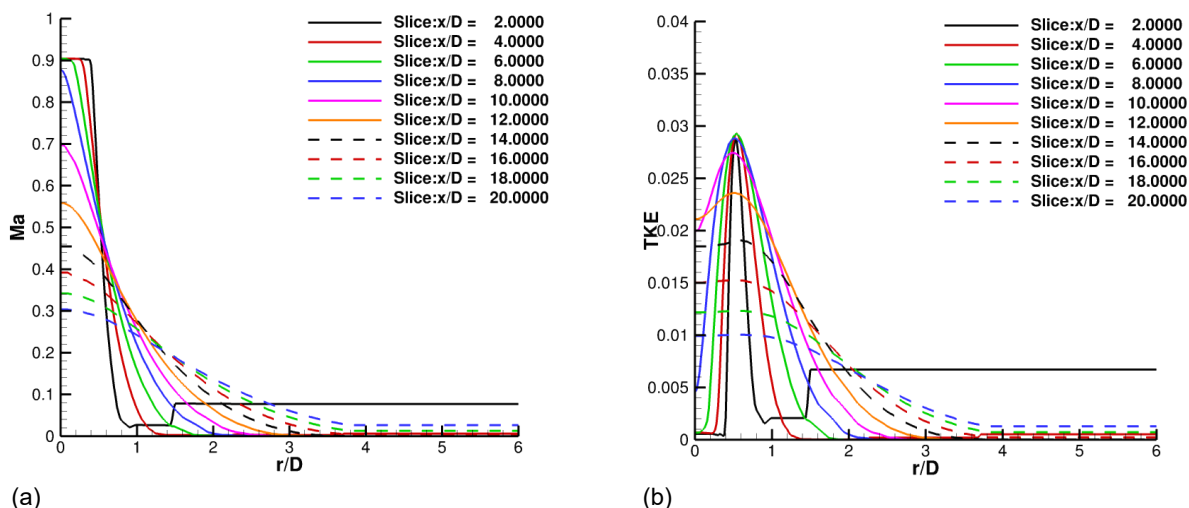


Figure 5.—Sample profiles of the (a) acoustic Mach number and (b) normalized turbulent kinetic energy vs. normalized radius for the Round SP07 SWFS case.

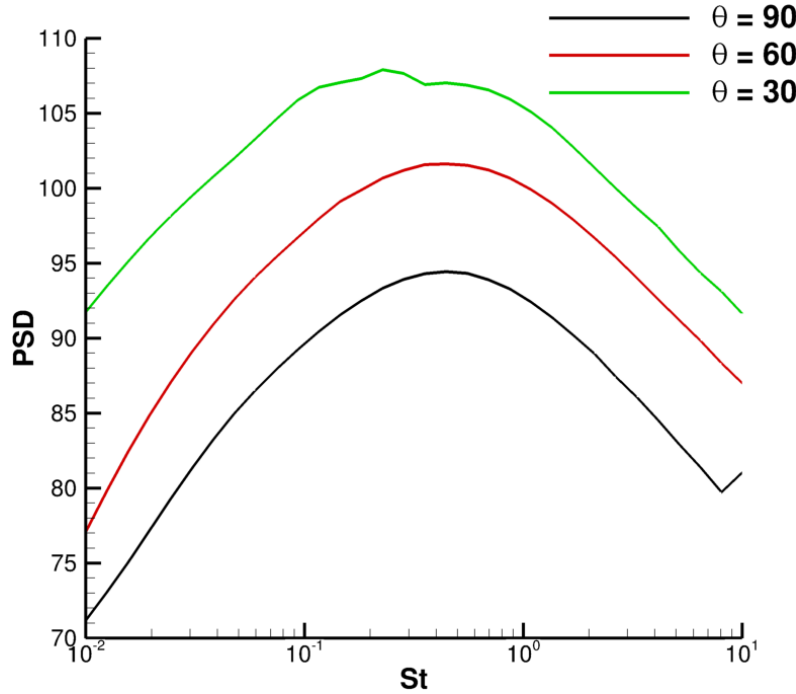


Figure 6.—Results from the SMC000_SP7 test case. Power spectral density (per unit Strouhal number = fD/U_j) of the far-field fluctuating pressure vs. Strouhal number.

Once the executable produced by executing the makefile, the main noise prediction code can be run as:

```
../../SOURCE_CODE/GAA_JET_FV .
```

The output from this run is the data file, Spec.dat, containing the noise prediction results. These results can be plotted using the Tecplot layout, Plot_Spectrum.lay, and the results compared with Figure 6 and the image file Plot_Spectrum.png.

6.3 ASME Grandfather Nozzle—Unstructured FUN3D RANS

This test case is contained in the subdirectory, TEST_CASES/ASME_GRANDFATHER. It corresponds to a jet from the axisymmetric ASME Grandfather nozzle with NPR = 1.8 and NTR = 1.0. This case is an example where the RANS solution is obtained from the FUN3D code.

The following files are found in this subdirectory:

- ASE_Nozzle_volume.tec – The RANS flow solution as exported from FUN3D
- Reference_Conditions_FUN3D.csv – The file containing the reference conditions for the RANS solution
- Ma_Plot.lay (.png) and TKE_Plot.lay (.png) – Tecplot layouts (resulting image files) for plotting interpolated profiles of acoustic Mach number and normalized turbulent kinetic energy
- gaa_jet_fv.inp – Input data file for the noise code
- RUN_GAA_JET.pbs – A Portable Batch System script that can be used to run GAA_JET_FV on the HPC system, Pleiades
- Plot_Spectrum.lay (.png) – Tecplot layout (resulting image file) to plot the spectral noise predictions

The first step is to run the interpolation script as:

```
python ../../SOURCE_CODE/unstructured_rans_interp.py .
```

The same inputs for the script prompts can be used for this as in the SP5 SolidWorks RANS case in Section 6.1, except that the file type is `FUN3D` and the RANS file name is `ASE_Nozzle_volume.tec`.

When complete the files, `mach_gf.dat` and `turb_gf.dat`, containing the interpolated flow solution, and `rans_ref.inp`, containing the reference conditions for the RANS solution for use by the noise code, should appear in this subdirectory. Example plots of the profiles of the mean acoustic Mach number and normalized (with the jet exit velocity) turbulent kinetic energy are shown in Figure 7. The Tecplot layouts, `Ma_Plot.lay` and `TKE_Plot.lay` can be used to make these profile plots.

Once the executable produced by executing the makefile, the main noise prediction code can be run as:

```
../../SOURCE_CODE/GAA_JET_FV .
```

The output from this run is the data file, `Spec.dat`, containing the noise prediction results. These results can be plotted using the Tecplot layout, `Plot_Spectrum.lay`, and the results compared with Figure 8 and the image file `Plot_Spectrum.png`.

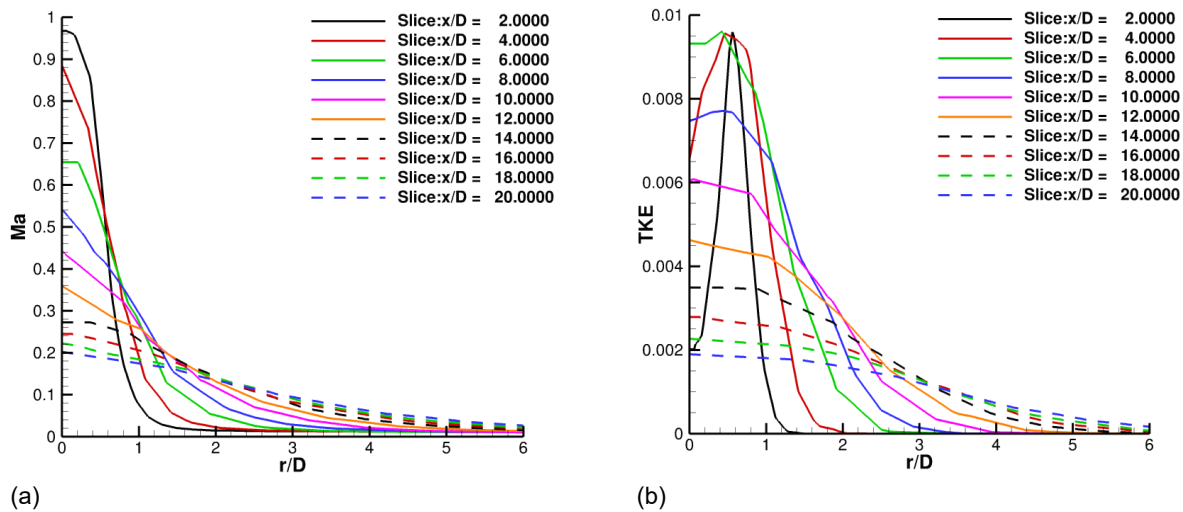


Figure 7.—Radial profiles of: (a) acoustic Mach number and (b) normalized turbulent kinetic energy output by the interpolation script for the ASME Grandfather nozzle case.

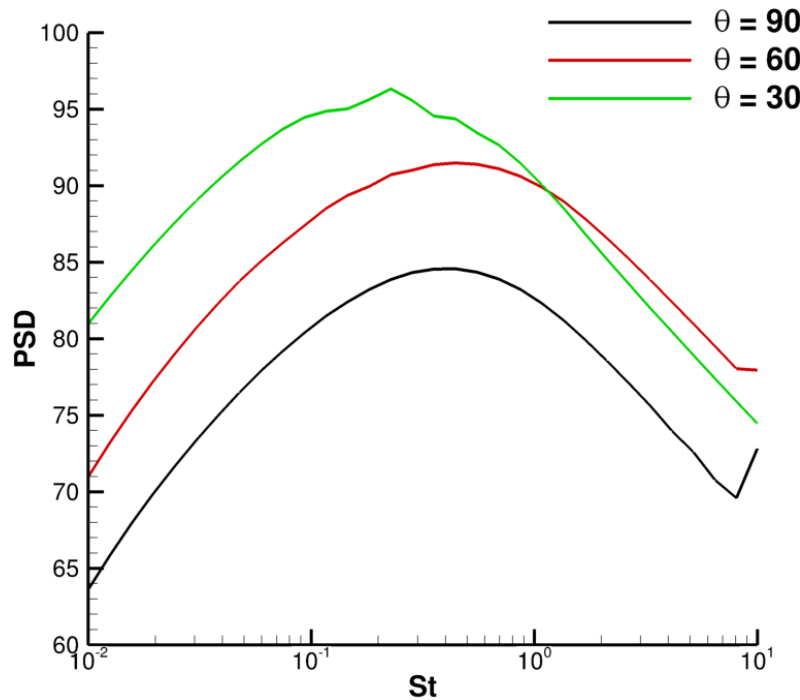


Figure 8.—Results from the ASME Grandfather nozzle test case. Power spectral density (per unit Strouhal number = fD/U_j) of the far-field fluctuating pressure vs. Strouhal number.

6.4 SMC001_SP7—Unstructured SWFS RANS

This test case is contained in the subdirectory, TEST_CASES/SMC001_SP7. It corresponds to the jet from six-chevron nozzle, SMC001, nozzle, pictured in Figure 9, with NPR = 1.86 and NTR = 1.0, for an exit acoustic Mach number of 0.9 and exit temperature ratio of 0.835 (SP07). In this case, the mean and turbulence quantities from the SolidWorks Flow solver are contained in separate files.

The following files are found in this subdirectory:

- SMC001_SP7_q.dat and SMC001_SP7_k.dat – Files containing the mean and turbulence quantities, respectively, from the RANS flow solution as exported from SolidWorks Flow solver
- Reference_Conditions_SWFS.csv – The file containing the reference conditions for the RANS solution
- Mach_X5.lay (.png) and Tke_X5.lay (.png) – Tecplot layouts (resulting image files) for plotting contours of the interpolated profiles of acoustic Mach number and normalized turbulent kinetic energy in the cross-flow plane at $x/D = 5.0$
- gaa_jet_fv.inp – Input data file for the noise code
- RUN_GAA_JET.pbs – A Portable Batch System script that can be used to run GAA_JET_FV on the HPC system, Pleiades
- Plot_Spectrum.lay (.png) – Tecplot layout (resulting image file) to plot the spectral noise predictions

In this case the steps given in Section 3.2 must be followed to edit the files, SMC001_SP7_q.dat and SMC001_SP7_k.dat, before running the interpolation script. Then the interpolation script can be run as:

```
python ../../SOURCE_CODE/unstructured_rans_interp.py .
```



Figure 9.—SMC001 nozzle.

The only differences in the inputs for the script prompts from the previous cases using the SolidWorks Flow solver RANS is that there are now two input data files and the solution in this non-axisymmetric case is provide with half-symmetry.

- [1] Enter SWFS or FUN3D: *SWFS*
- [2] One or Two input files ?, Enter 1 or 2: *2*
- [3] Enter First Input Data File Name: *SMC001_SP7_q.txt*
- [4] Enter Second Input Data File Name: *SMC001_SP7_k.txt*
- [5] Enter Type of Flow Solution Symmetry: : Half (H) or Quarter (Q): *H*
- [6] Enter the number of radial grid points: *301*
- [7] Enter the number of azimuthal grid points: *360*
- [8] Enter the maximum radial distance, in nozzle diameters: *6.0*
- [9] Enter the number of axial slices: *37*
- [10] Enter the initial axial slice, in nozzle diameters, to use in the noise calculations: *2.0*
- [11] Enter the increment in axial slices, in nozzle diameters: *0.5*
- [12] Enter the minimum number of points in axial sectioning to use for interpolation: *80000*

Once the interpolation script run is complete, the files, *mach_gf.dat* and *turb_gf.dat*, containing the interpolated flow solution, and *rans_ref.inp*, containing the reference conditions for the RANS solution for use by the noise code, should appear in this subdirectory. Example plots of contours of the mean acoustic Mach number and normalized turbulent kinetic energy (with the jet exit velocity) at an axial slice five diameters from the nozzle exit are shown in Figure 10. The Tecplot layouts, *Mach_X5.lay* and *Tke_X5.lay* can be used to make these plots and the image files are contained in *Mach_X5.png* and *Tke_X5.png*.

Once the executable for the main noise prediction code has been produced by executing the makefile, it can be run as:

```
../SOURCE_CODE/GAA_JET_FV.
```

The input data file, `gaa_jet_fv.inp`, for this case specifies a polar angle of sixty degrees to the jet axis and azimuthal angles of zero and twenty-nine degrees (see Figure 10), corresponding to the thickest and thinnest sides of the mean flow. The output from this run is the data file, `Spec.dat`. The results can be plotted using the Tecplot layout, `Plot_Spectrum.lay`, and the results compared with Figure 11 and the image file `Plot_Spectrum.png`.

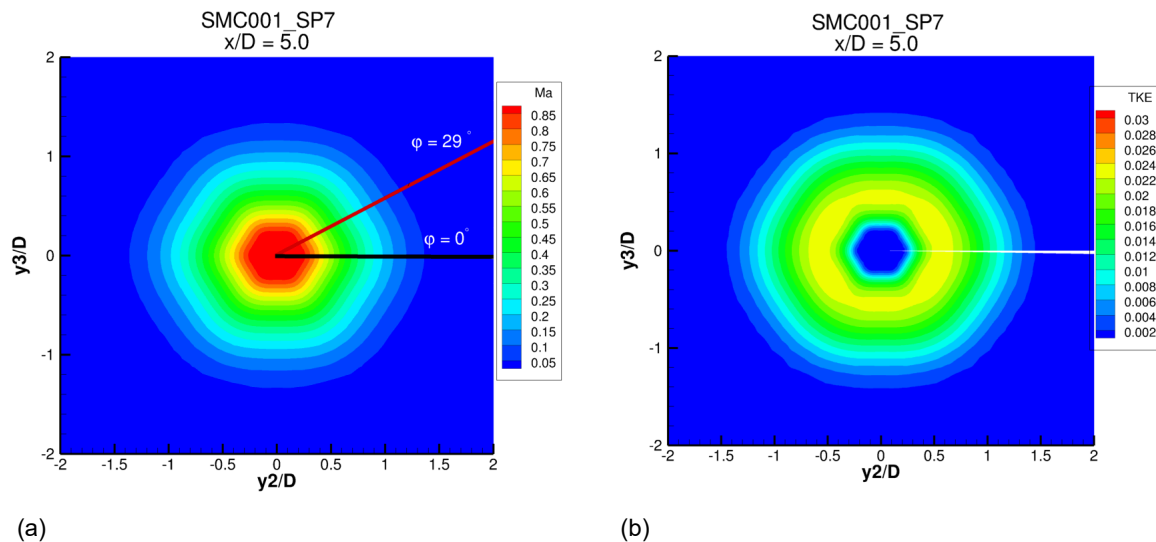


Figure 10.—Contours of the (a) mean acoustic Mach number and (b) normalized (with the jet exit velocity) turbulent kinetic energy at an axial slice five diameters from the nozzle exit. SMC001.

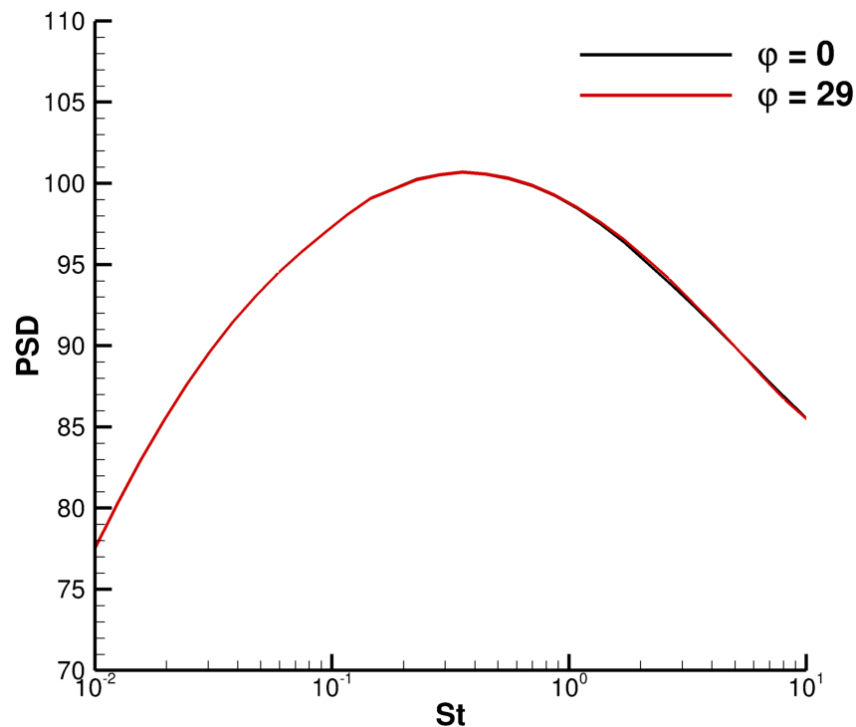


Figure 11.—Noise prediction results for the SMC001_SP7 chevron nozzle test case. Power spectral density (per unit Strouhal number = fD/U_j) of the far-field fluctuating pressure vs. Strouhal number.

6.5 SMC002_SP7—Unstructured SWFS RANS

This test case is contained in the subdirectory, TEST_CASES/SMC002_SP7. It corresponds to the jet from four-chevron nozzle, SMC002, nozzle shown in Figure 12, with NPR = 1.86 and NTR = 1.0, for an exit acoustic Mach number of 0.9 and exit temperature ratio of 0.835 (SP07). In this case, the mean and turbulence quantities from the SolidWorks Flow solver are contained in separate files.

The following files are found in this subdirectory:

- SMC002_SP7_q.dat and SMC002_SP7_k.dat – Files containing the mean and turbulence quantities, respectively, from the RANS flow solution as exported from SolidWorks Flow solver
- Reference_Conditions_SWFS.csv – The file containing the reference conditions for the RANS solution
- Mach_X5.lay (.png) and Tke_X5.lay (.png) – Tecplot layouts (resulting image files) for plotting contours of the interpolated profiles of acoustic Mach number and normalized turbulent kinetic energy in the cross-flow plane at $x/D = 5.0$
- gaa_jet_fv.inp – Input data file for the noise code
- RUN_GAA_JET.pbs – A Portable Batch System script that can be use to run GAA_JET_FV on the HPC system, Pleiades
- Plot_Spectrum.lay (.png) – Tecplot layout (resulting image file) to plot the spectral noise predictions

To generate the interpolated RANS files, mach_gf.dat and turb_gf.dat, for this case follow the same steps as for the last non-axisymmetric case, using the Solid Works option in the interpolations script on the files, SMC002_SP7_q.dat and SMC002_SP7_k.dat.



Figure 12.—SMC002 nozzle.

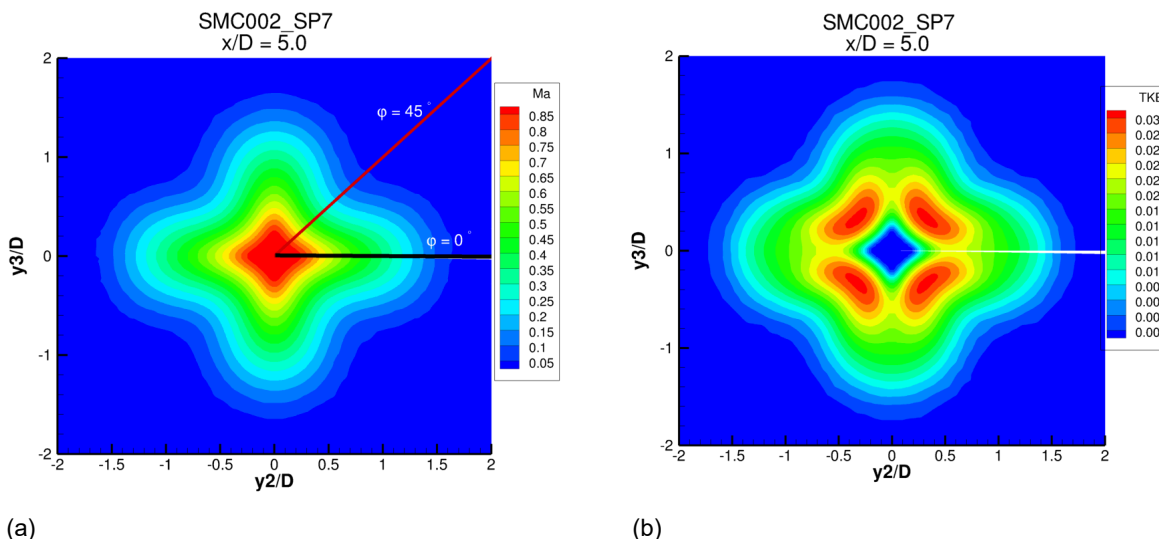


Figure 13.—Contours of the (a) mean acoustic Mach number and (b) normalized (with the jet exit velocity) turbulent kinetic energy at an axial slice five diameters from the nozzle exit. SMC002_SP7.

When complete the files, mach_gf.dat and turb_gf.dat, containing the interpolated flow solution, and rans_ref.inp, containing the reference conditions for the RANS solution for use by the noise code, should appear in this subdirectory. Example plots of the contours of the mean acoustic Mach number and normalized (with the jet exit velocity) turbulent kinetic energy at an axial slice five diameters from the nozzle exit are shown in Figure 13. The Tecplot layouts, Mach_X5.lay and Tke_X5.lay can be used to make these profile plots.

Once the executable is produced by executing the makefile, the main noise prediction code can be run as:

```
../SOURCE_CODE/GAA_JET_FV.
```

The input data file, gaa_jet_fv.inp, for this case specifies a polar angle of sixty degrees to the jet axis and azimuthal angles of zero and forty-five degrees (see Figure 13).

The output from this run is the data file, Spec.dat, containing the noise prediction results at one polar angle and the two azimuthal angles. These results can be plotted using the Tecplot layout, Plot_Spectrum.lay, and the results compared with Figure 14 and the image file Plot_Spectrum.png.

6.6 SMC004_SP7—Unstructured SWFS RANS

This test case is contained in the subdirectory, TEST_CASES/SMC004_SP7. It corresponds to the jet from five-chevron nozzle, SMC004, nozzle, shown in Figure 15, with NPR = 1.86 and NTR = 1.0, for an exit acoustic Mach number of 0.9 and exit temperature ratio of 0.835 (SP07). In this case, the mean and turbulence quantities from the SolidWorks Flow solver are contained in separate files.

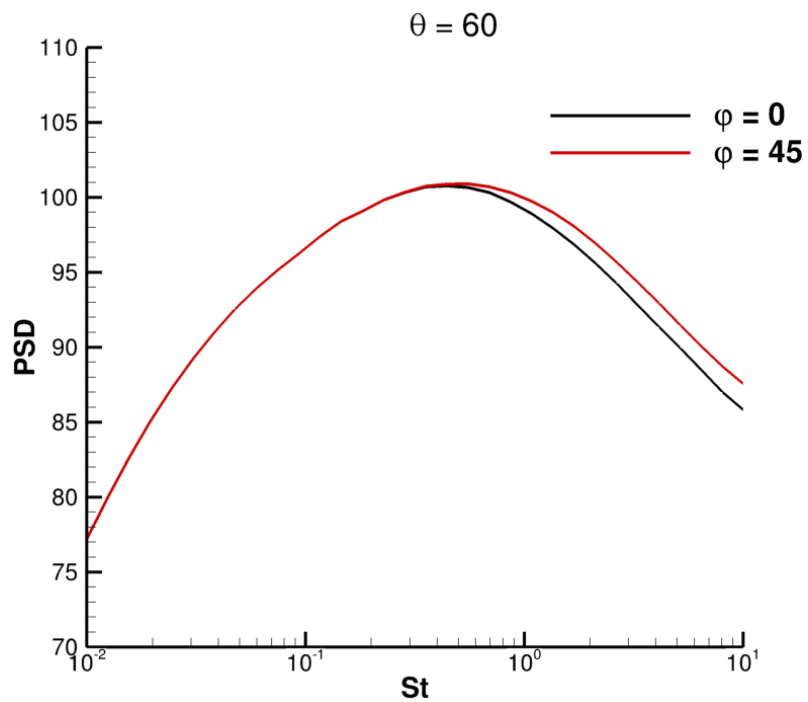


Figure 14.—Noise prediction results from the SMC002_SP7 nozzle test case. Power spectral density (per unit Strouhal number = fD/U_j) of the far-field fluctuating pressure vs. Strouhal number.



Figure 15.—SMC004 nozzle.

The following files are found in this subdirectory:

- SMC004_SP7_q.dat and SMC004_SP7_k.dat – Files containing the mean and turbulence quantities, respectively, from the RANS flow solution as exported from SolidWorks Flow solver
- Reference_Conditions_SWFS.csv – The file containing the reference conditions for the RANS solution
- Mach_X5.lay (.png) and Tke_X5.lay (.png) – Tecplot layouts (resulting image files) for plotting contours of the interpolated profiles of acoustic Mach number and normalized turbulent kinetic energy in the cross-flow plane at $x/D = 5.0$
- gaa_jet_fv.inp – Input data file for the noise code
- RUN_GAA_JET.pbs – A Portable Batch System script that can be use to run GAA_JET_FV on the HPC system, Pleiades
- Plot_Spectrum.lay (.png) – Tecplot layout (resulting image file) to plot the spectral noise predictions

The same steps can be followed as in the previous chevron nozzles cases with the only differences in the inputs for the script prompts from the previous chevron nozzle case are the names of the RANS datafiles, SMC004_SP7_q.dat and SMC004_SP7_k.dat, here.

Example plots of the contours of the mean acoustic Mach number and normalized (with the jet exit velocity) turbulent kinetic energy at an axial slice five diameters from the nozzle exit for this case are shown in Figure 16. The Tecplot layouts, Mach_X5.lay and Tke_X5.lay can be used to make these plots and the image files are in Mach_X5.png and Tke_X5.png.

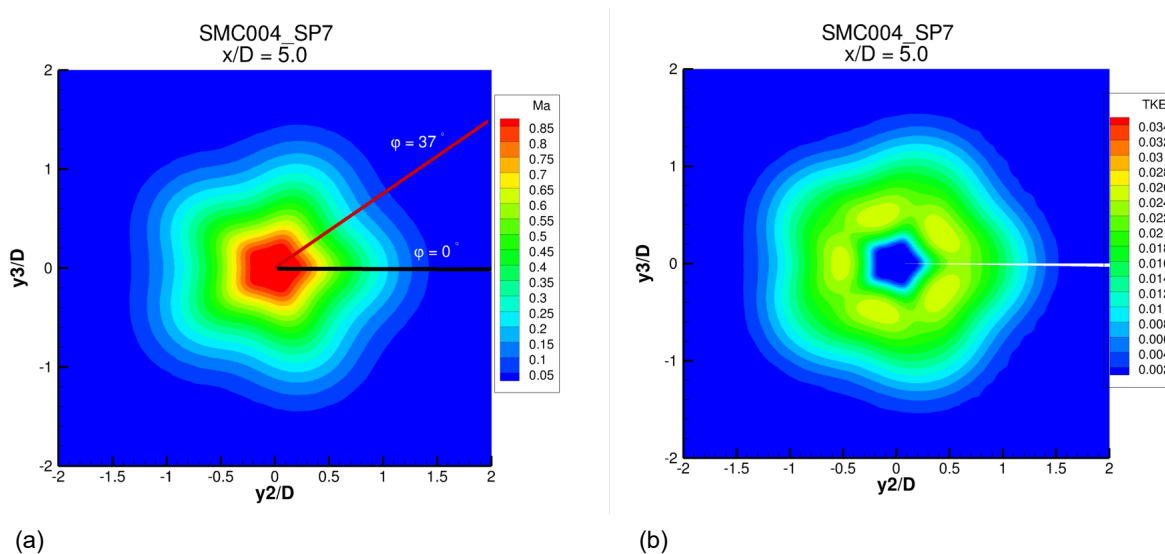


Figure 16.—Contours of the (a) mean acoustic Mach number and (b) normalized (with the jet exit velocity) turbulent kinetic energy at an axial slice five diameters from the nozzle exit. SMC004_SP7.

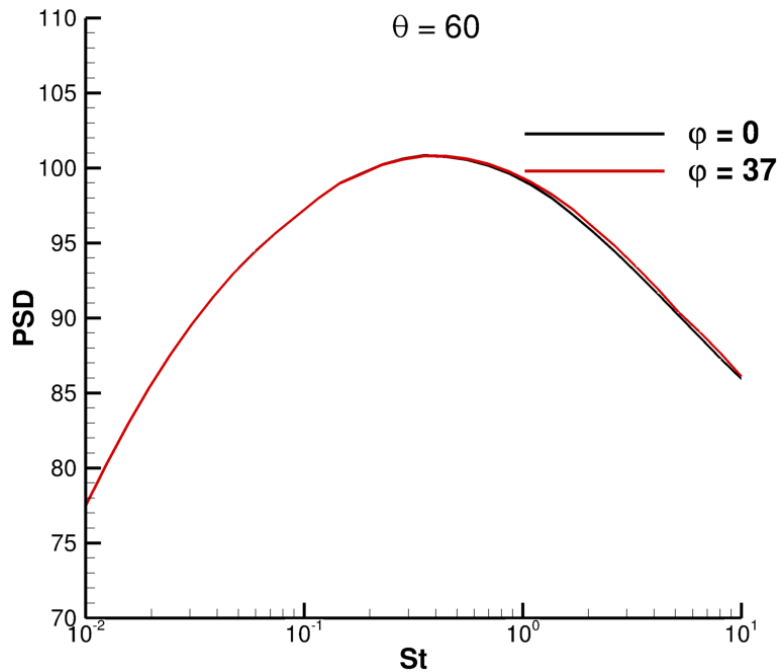


Figure 17.—Noise prediction results from the SMC004_SP7 test case.

Once the executable is produced by executing the makefile, the main noise prediction code can be run as:

```
../../SOURCE_CODE/GAA_JET_FV.
```

The input data file, `gaa_jet_fv.inp`, for this case specifies a polar angle of sixty degrees to the jet axis and azimuthal angles of zero and thirty-seven degrees (see Figure 16).

The output from this run is the data file, `Spec.dat`, containing the noise prediction results at one polar angle and the two azimuthal angles. These results can be plotted using the Tecplot layout, `Plot_Spectrum.lay`, and the results compared with see Figure 17 and the image file `Plot_Spectrum.png`.

6.7 SMC026_SP7—Unstructured SWFS RANS

This test case is contained in the subdirectory, `TEST_CASES/SMC026_SP7`. It corresponds to the jet from five-chevron nozzle, SMC004, nozzle, shown in Figure 18, with $NPR = 1.86$ and $NTR = 1.0$, for an exit acoustic Mach number of 0.9 and exit temperature ratio of 0.835 (SP07). In this case, the mean and turbulence quantities from the SolidWorks Flow solver are contained in separate files.

The following files are found in this subdirectory:

- `SMC026_SP7_q.dat` and `SMC026_SP7_k.dat` – Files containing the mean and turbulence quantities, respectively, from the RANS flow solution as exported from SolidWorks Flow solver
- `Reference_Conditions_SWFS.csv` – The file containing the reference conditions for the RANS solution
- `Mach_X5.lay` (.png) and `Tke_X5.lay` (.png) – Tecplot layouts (resulting image files) for plotting contours of the interpolated profiles of acoustic Mach number and normalized turbulent kinetic energy in the cross-flow plane at $x/D = 5.0$
- `gaa_jet_fv.inp` – Input data file for the noise code

- RUN_GAA_JET.pbs – A Portable Batch System script that can be used to run GAA_JET_FV on the HPC system, Pleiades
- Plot_Spectrum.lay (.png) – Tecplot layout (resulting image file) to plot the spectral noise predictions

Follow the same steps as for the other non-axisymmetric cases, using the RANS files, SMC026_SP7_q.dat, to generate the interpolated RANS files, mach_gf.dat and turb_gf.dat, for this case. Example plots of the contours of the mean acoustic Mach number and normalized (with the jet exit velocity) turbulent kinetic energy at an axial slice five diameters from the nozzle exit for this case are shown in Figure 19. The Tecplot layouts, Mach_X5.lay and Tke_X5.lay can be used to make these profile plots.

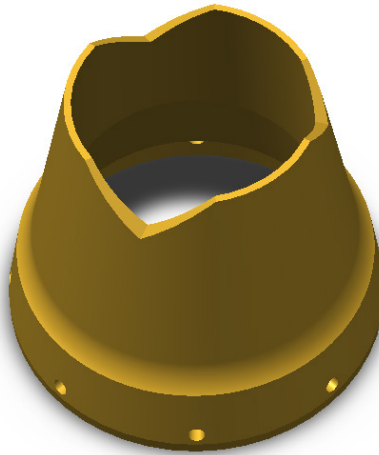


Figure 18.—SMC0026 nozzle.

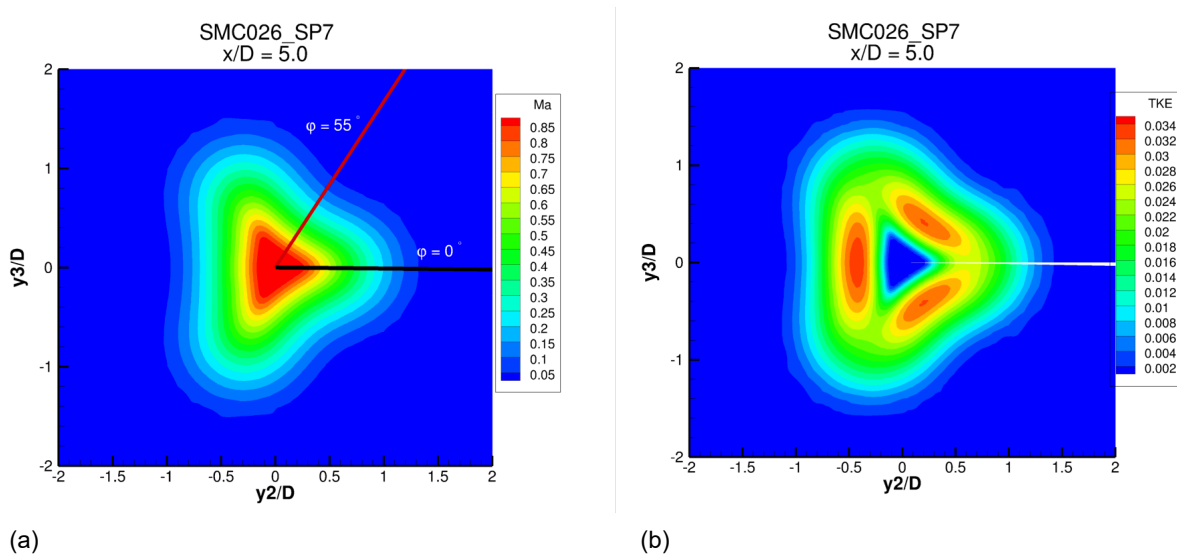


Figure 19.—Contours of the (a) mean acoustic Mach number and (b) normalized (with the jet exit velocity) turbulent kinetic energy at an axial slice five diameters from the nozzle exit. SMC026_SP7.

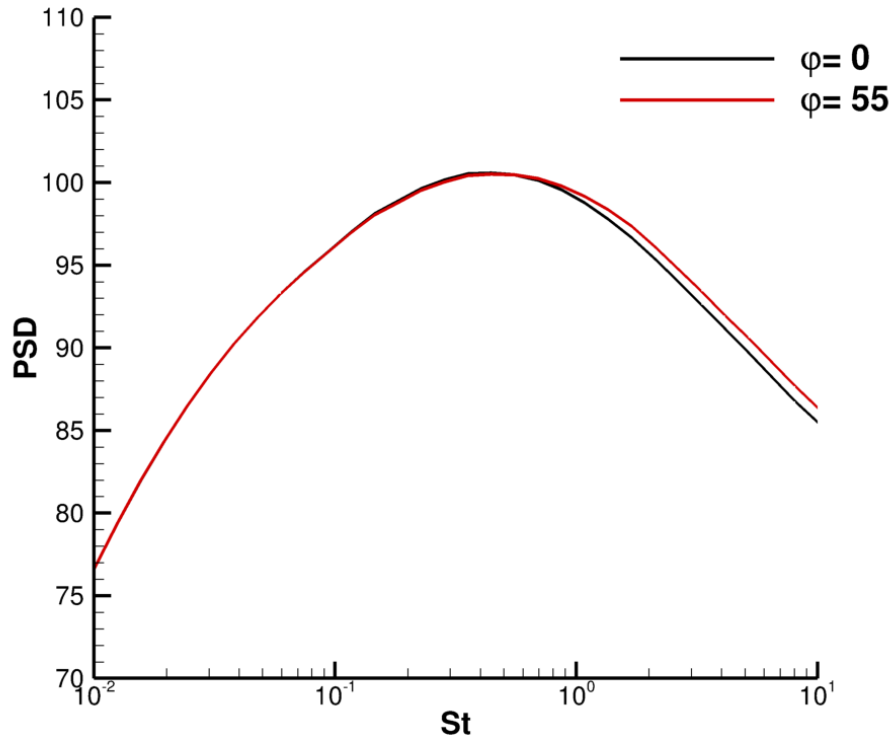


Figure 20.—Noise prediction results from the SMC026_SP7 test case.

Run the noise code as before to generate the output data file, Spec.dat, containing the noise prediction results at one polar angle and the two azimuthal angles. These results can be plotted using the Tecplot layout, Plot_Spectrum.lay, and the results compared with Figure 20 and the image file Plot_Spectrum.png.

7.0 Summary and Recommendations

This document describes the V1 release of the code package for the noise prediction code, GAA_JET_FV. The code is a RANS-based noise prediction tool based on the Generalized Acoustic Analogy formulation. Although it is the result of many years of work on the theoretical, physical and computational modeling aspects of the development of a reduced-order jet noise prediction code, it is the first of an expected series of releases to provide a ‘user-friendly’ tool for jet noise prediction that can be used by other researchers. Input provided by users testing this release version will be used to improve the workflow and processes in future releases.

References

1. Goldstein, M.E., “A Generalized Acoustic Analogy,” *Journal of Fluid Mechanics*, Vol. 488, pp. 315–333, 2003.
2. Goldstein, M.E. and Leib, S.J., “The Aeroacoustics of Slowly Diverging Supersonic Jets,” *Journal of Fluid Mechanics* Vol. 600, pp. 291–337, 2008.
3. Leib, S.J. and Goldstein, M.E., “Hybrid Source Model for Predicting High-Speed Jet Noise, *AIAA Journal*, 49, No. 7. pp. 1324–1335.

4. Leib, S.J., “Toward a Finite Volume/Unstructured Grid Approach to Jet Noise Prediction Using the Generalized Acoustic Analogy,” NASA Acoustics Technical Working Group Meeting, October, 2017, Cleveland, Ohio.
5. <https://www.solidworks.com/product/solidworks-flow-simulation>.
6. Biedron, R.T., Carlson, J.R., Derlaga, J.M., et al., “FUN3D Manual: 13.4,” NASA/TM—2018-220096. October 2018.
7. Bridges, J., Khairul Zaman, K. and Podboy, G., “Experiments to Challenge Jet Noise Prediction,” NASA Acoustics Technical Working Group Meeting, April 7, 2020, Hampton, Virginia.

