REPORT DOCUMENTATION PAGE AFRL-SR-BL-TR-00-

0537

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	10/13/00	Final Report - 01 Oct 98 To 30 Sep 99

4. TITLE AND SUBTITLE
JET NOISE AND MIXING IN HIGH SPEED AXISYMMETRIC JETS

5. FUNDING NUMBERS
F49620-99-1-0097

6. AUTHOR(S)
Mohammad Samimy

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ohio State University Research Foundation
Grants and Contract Management
1960 Kenny Road
Columbus OH 43210-1063

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NA
801 N. Randolph St. Room 732
Arlington VA 22203-1977

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT

Unclassified Unlimited Distribution

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
A coaxial jet facility and a modular, full anechoic chamber, which has extensive optical access windows, have been designed to investigate mixing and acoustic radiation, especially interrelation between mixing and noise, in high speed jets. The facility will enable us to simultaneously measure acoustic radiation via microphones and flow parameters using advanced optical techniques such as planar Doppler velocimetry (PDV). The primary and secondary jet diameters are 2.54 cm and 5.08 cm. The jet facility is equipped with a 100 kW heater to provide jet temperatures up to 800 K. The anechoic chamber is designed with fiber glass cloth covered wedges to handle even higher temperature. Currently we are in the process of carrying out flow visualizations and acoustic measurements both separately and simultaneously. The primary jet Mach numbers are 0.9 and 1.3. No secondary flow is utilized. Very preliminary sample results will be presented.

20001024 105

14. SUBJECT TERMS
Investigate Mixing, Acoustic Radiation, Mixing and Noise

15. NUMBER OF PAGES
7

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASS	UNCLASS	UNCLASS	UL

JET NOISE AND MIXING IN HIGH SPEED AXISYMMETRIC JETS

F49620-99-1-0097

M. Samimy
Department of Mechanical Engineering
The Ohio State University

Abstract

A coaxial jet facility and a modular, full anechoic chamber, which has extensive optical access windows, have been designed to investigate mixing and acoustic radiation, especially interrelation between mixing and noise, in high speed jets. The facility will enable us to simultaneously measure acoustic radiation via microphones and flow parameters using advanced optical techniques such as planar Doppler velocimetry (PDV). The primary and secondary jet diameters are 2.54 cm and 5.08 cm. The jet facility is equipped with a 100 kW heater to provide jet temperatures up to 800 K. The anechoic chamber is designed with fiber glass cloth covered wedges to handle even higher temperature. Currently we are in the process of carrying out flow visualizations and acoustic measurements both separately and simultaneously. The primary jet Mach numbers are 0.9 and 1.3. No secondary flow is utilized. Very preliminary sample results will be presented.

Introduction

The main objective of the current research is to advance our understanding of the fundamentals of infrared radiation and acoustic noise in high speed flows, particularly the interrelation between the two. In this abstract, a brief description of the jet facility and the anechoic chamber will be provided followed by a brief discussion of the evaluation of the anechoic chamber. Very preliminary results will be presented and discussed at the end.

Jet Facility

The air, supplied by two four-stage compressors, is filtered, dried, and stored in two cylindrical tanks with a total capacity of 42.5 m^3 at 16.5 MPa (1600 ft^3 at 2500 psi) pressure. The air is delivered to the laboratory through a 4 inch diameter main line. A 2 inch diameter line is tapped into this line to provide air to the primary jet. Only the primary jet will be discussed here. This line passes through a pressure control valve, where air pressure is stepped down from tank pressure to a remotely controlled pressure selected by the user. The air then either passes through a 100 kW electric heater, or directly into the primary stagnation chamber. In the primary stagnation chamber, the air is expanded from the 2 inch line to a 9.5 inch diameter pipe that is 36 inches long for flow conditioning. The air passes through a perforated plate (1/4" holes, 37% porosity), coarse mesh screen, fine mesh screen, and finally converges to a 2.35 inch pipe that is 16 inches long. After passing through this pipe, it enters a nozzle with an exit diameter of 1.0 inch. Figure 1 shows a schematic of the jet facility.

The airflow for the primary flow jet is controlled by the primary pressure regulator. This regulator works by having a sensing element monitor the total pressure in the primary stagnation chamber, and then comparing it with a user selected pressure. The regulator controller sends air to the pneumatic actuator of the pressure control valve, as necessary, to maintain the prescribed pressure. Air used for this control is brought from a separate line branched off of the 4 inch main line and regulated to 30 psig. The facility incorporates digital displays for the key flow parameters, i.e., total pressure and temperature. Pressure is measured by a pressure transducer, teed into the line for the pressure regulator and displayed in an electronic display housed in the main control panel. A pitot tube is used within the chamber to measure total pressure. The temperature is monitored via a type K thermocouple mounted into the stagnation chamber and display unit incorporated into the main control panel.

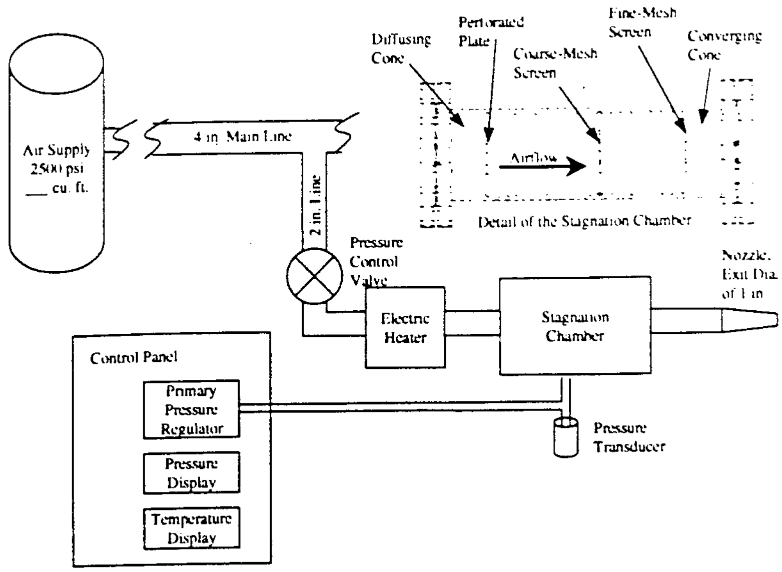


Figure 1 Schematic of the jet facility

Optically Accessed Anechoic Chamber

A modular, full, anechoic chamber with extensive optical access has been designed and constructed to investigate acoustic radiation from high-speed jets (Fig. 2). This anechoic chamber will enable us to simultaneously measure acoustic radiation via microphones and flow parameters using simple flow visualizations (e.g. Kim and Samimy, 1999) and advanced optical diagnostic techniques such as PDV (Clancy and Samimy 1997 and Clancy et al. 1999). A brief description of the chamber and some evaluation results will be presented below.

The anechoic chamber was designed to be fully compliant with the ANSI Standard S12.35 for performance, and to allow optical access for flow measurements with and without simultaneous sound measurements. The material of the chamber also needed to withstand the temperatures from a hot jet, operating from 300° K up to 800° K. To meet the first requirements, the chamber is designed to be fully anechoic, meaning that all surfaces of the chamber are covered with sound absorbing material. To meet the second requirement, windows were added to all sides of the chamber to allow for laser access and camera placement outside of the chamber.

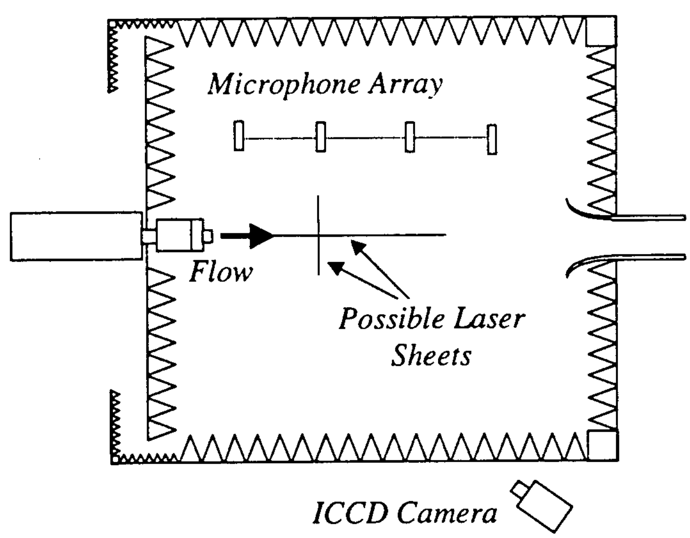


Figure 2 Schematic of the optically accessed anechoic chamber

Finally, the building materials were chosen to meet or exceed the testing temperatures.

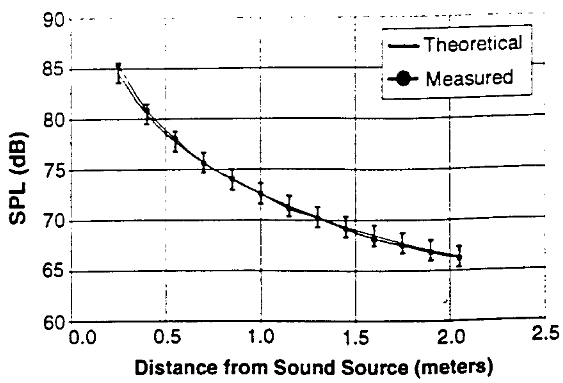
The wedges used in the chamber were manufactured by Eckel Industries. The wedges were designed and tested for compliance by the manufacturer to a cutoff frequency of 250Hz. The wedge dimensions are 8 x 24 inches at the base, with a height of 17 inches. There are three wedges per group, which are mounted on a frame to allow for a 1-inch air gap behind the wedges once placed on the wall. The total dimensions of a wedge group is 24 x 24 x 18 inches. Due to the high temperature requirement, the wedges are made of a special fiberglass material that can withstand sustained temperatures of up to 800 °K.

The chamber was constructed out of extruded aluminum beams manufactured by Item Products. This material was chosen for its ease of assembly and flexibility. The walls of the chamber are made of 1/8-inch thick aluminum sheets. The overall dimensions of the chamber are 4.11 meters wide by 4.71 meters long and 3.683 meters high. Because of the flexibility of the structural beams, windows were placed on all four walls of the chamber. To simplify the camera placement, the centerline of these windows coincides with the centerline of the jet. Also, two windows were place above the jet nozzle on the ceiling to allow for laser access from above. Two doors were placed in the chamber. The main door is on the front of the chamber, the side that the jet enters. The other door is on the right side of the chamber and allows for increased access. The floor was designed to be completely removable. This allows for easier experimental and camera setup when acoustic testing is not taking place. The floor was divided into five sections of five wedge groups each. Each section, as needed, can be removed through the main door.

The jet enters the chamber through an open window on the center of the front wall. Directly downstream from the jet, a bellmouth is placed in the back wall to capture the exhaust and channel it out of the building (see Fig. 2). The bellmouth is 1.2 meters in diameter and contracts down to 60 centimeters in diameter. The front face of the bellmouth has been covered with sound-absorbing material. Air vents were built into the front wall of the chamber to allow for adequate entrainment of air by the jet. These vents are covered by a hood, which extends over the openings, and is completely lined with acoustical foam. This simple design allows for the smooth flow of air into the chamber as well as impeding outside noise from entering the chamber. Inside dimensions of the chamber from wedge tip to wedge tip, measure 3.12 meters in width and length, and 2.69 meter in height, which creates the free field for acoustic measurements. Four B and K Model 4135, quarter inch microphones are used to measure the sound pressure levels in the chamber during testing.

The chamber was tested for compliance to the ANSI Standard S12.35. This entailed measuring the decay of the sound pressure level (SPL) generated by a source suspended in the center of the room in eight radial directions or microphone paths, and the comparing the data to the theoretical inverse r squared law for SPL decay in a free field. The sound generator was set to generate white (broad band) noise for all measurements. Results from the test were in good agreement with the theory within the required tolerance over most of the distance along the microphone paths. Figure 3 gives sample results for the decay of the SPL along a path perpendicular to one of the walls in the chamber. The error bars show the maximum deviation from theory allowed by the ANSI standard.

For flow visualization, a laser beam is directed into the chamber through one of the windows. The optics are mounted on a framework connected to the ceiling, which is constructed out of the same material as the chamber structure. The framework allows for laser sheet placement, in spanwise or streamwise directions, at a distance of up to 1.2 meters from the nozzle exit.



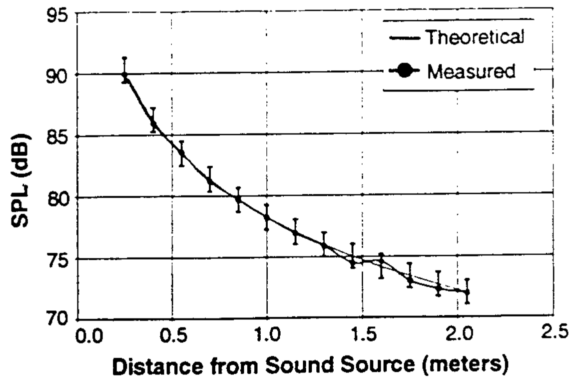


Figure 3 Comparison of the $1/r^2$ law with the measured SPL at 1 kHz (left) and 5 kHz (right) frequencies.

Preliminary Results

Flow Visualizations A sheet of light, created by a Nd:YAG laser, passed through the jet centerline, thus illuminating the flow in the streamwise direction. A Princeton Instruments ICCD camera was placed perpendicular to the laser sheet to capture images of the flow structure. Different seeding techniques were employed for visualizations of the Mach number 0.9 and 1.3 jets. For the Mach 1.3 case, the jet temperature was sufficiently low to condense the moisture in the ambient air in the mixing region of the jet thus providing light scattering particles for visualizations. This technique has been used extensively in the literature for supersonic flow visualizations (e.g. Samimy et al. 1998). Figure 4 shows a sample instantaneous streamwise image (9 ns exposure time) of the M = 1.3 jet case. The flow is from left to right, and the numbered vertical lines show the distance in jet diameters from the jet exit. Structures of various sizes and shapes can be seen in the mixing layers of the jet, and the jet does not seem to be axially symmetric beyond about 5 diameters downstream. The structures from both sides start interacting between 6 & 7 jet diameters downstream indicating the end of the potential core.

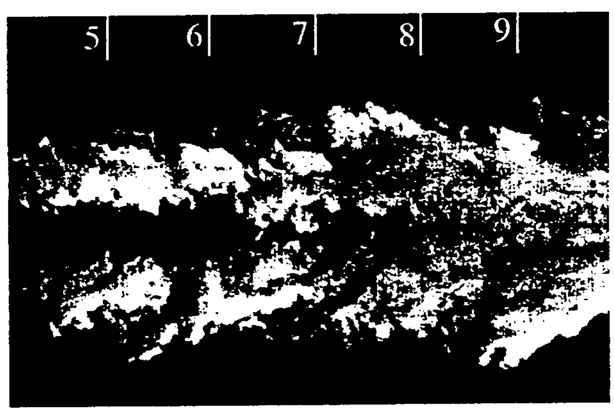


Figure 4 An instantaneous image of Mach 1.3 jet.

For the Mach 0.9 jet, on the other hand, the jet temperature was not cold enough to condense the moisture in the ambient air, thus seed particles had to be introduced into the jet. This was done with two different types of particles: condensed acetone and silica particles. A sample instantaneous image of the flow using condensed acetone particles is shown in Fig. 5. Liquid acetone was atomized and injected into the air flow several meters before the stagnation chamber for this case. Acetone then was evaporated before entering the nozzle. For a supersonic nozzle, the acetone would completely condense and form submicron particles during the expansion process in the nozzle

(Clancy et al. 1999). However, for a Mach 0.9 nozzle only a very small fraction of the acetone was condensed. These particles acted as nuclei for the moisture in the ambient air to condense. This is the reason for the appearance of a thin jet up to about five jet diameter downstream, beyond which the jet appears to be asymmetric.

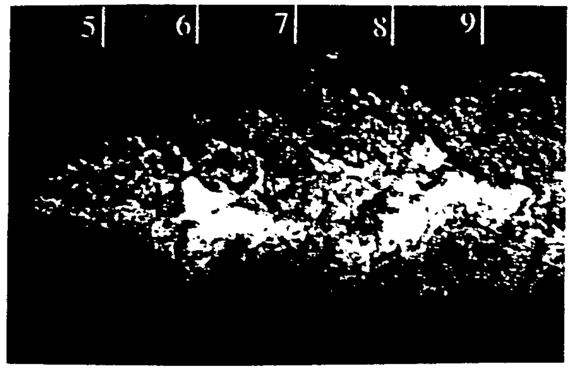


Figure 5 An instantaneous image of Mach 0.9 jet using acetone particles

Generating acetone particles is simple and economical; however, these particles cannot be used in heated jets. Therefore, solid particles will be used with the heated jet. The particles used in this research are aerosil R972 and manufactured by Degussa Corporation. Aerosil, as it will be referred to in the rest of the text, is highly hydrophobic and is loosely bound into interwoven chains 500 microns in length (Smith 1998). It is considered an amorphous synthetic silica. A supersonic shearing nozzle is used to break these chains apart prior to injection. Once broken, the aerosil particles are approximately 0.3 microns in size. A large supply of the particles is available for extended experiments thanks to a storage tank that holds the particles and feeds them through the shearing nozzle and into the pressure line that supplies the stagnation chamber.

Figure 6 shows an instantaneous streamwise image of the Mach 0.9 jet using aerosil particles. The aerosil particles were injected at the same location as the acetone. Therefore, the aerosil particles are well mixed in the jet and exist from the beginning of the jet. That is why the jet appears thicker in this case, as compared to the condensed acetone seeding case shown in Fig. 5. Interestingly, both images in Figs. 5 and 6 show helical structures around the centerline of the jet, and the jet appears to be asymmetric beyond about 6 jet diameters.

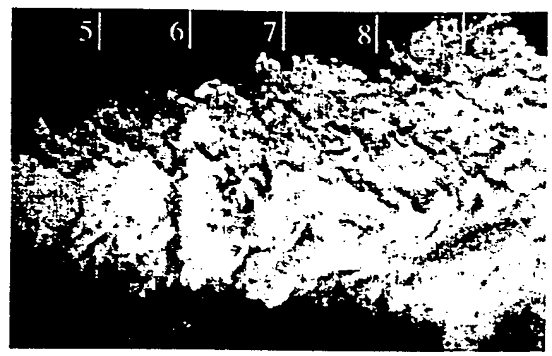


Figure 6 An instantaneous image of Mach 0.9 jet using silica particles.

<u>Simultaneous Flow visualizations and Noise Measurements</u> In an attempt to understand the noise generation process in a jet and the interrelations between noise and mixing we have initiated research to first look at simultaneous flow visualizations and noise measurements and eventually simultaneous quantitative flow measurements and noise measurements. The newly designed optical access anechoic chamber will be used for this purpose. As an initial attempt four B&K model 4135 microphones were placed along a line that was 30 inches from and parallel to the jet axis. The microphones covered a range of observation angles from 20 to 90 degrees with respect to the jet centerline. The 90 degrees position is perpendicular to the jet exit and located on the plane of the jet exit, while the other measurements were taken at downstream angles. For the Mach 1.3 case, only the 30-degree spectra has a prominent peak. The peak is located around 2 kHz, and as reported by many in the literature is due to the turbulent mixing noise from the large scale structures within the jet. Flow images were also taken simultaneously with the sound measurements.

Preliminary sample results of the simultaneous flow visualization/sound measurements are shown in Figure 7 and 8 for the Mach 1.3 jet. Figure 7 shows the normalized pressure recorded by a microphone located at 30 degrees. The corresponding flow visualization is shown in Figure 8. The amplitude of a 114 dB, 1 kHz reference signal was used to normalize the raw acoustic pressure voltage as recorded by the B&K microphone. The normalized sound pressure is plotted versus time. The time range was selected based on the amount of time it would take an acoustic wave to reach the microphone from a fixed location within the visualized region in the jet. For example, if a structure that produced a sound wave were located on the jet centerline, 6 inches from the jet exit, it would take 4.1 milliseconds for the wave to reach the microphone located at 30 degrees. This assumes a speed of sound of 340 m/s, and negligible refraction effects within the mixing layer. Thus, if a large scale structure, as seen in a flow visualization, is centered on the jet centerline 6 inches from the jet exit, its sound wave should reach the 30 degree microphone in 4.1 milliseconds. We have not had time to analyze the data, and are running out of space. So please stay tuned for more to come.

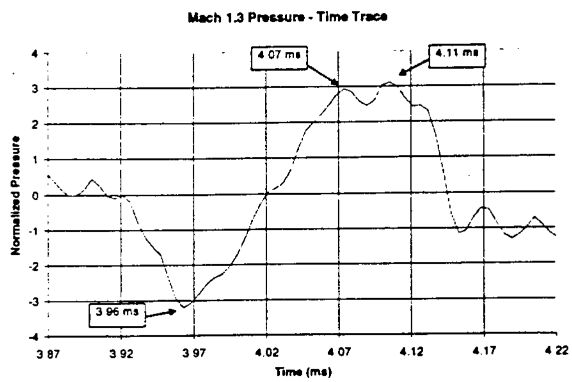


Figure 7 Acoustic pressure traces for Mach 1.3 jet with simultaneous flow vis.

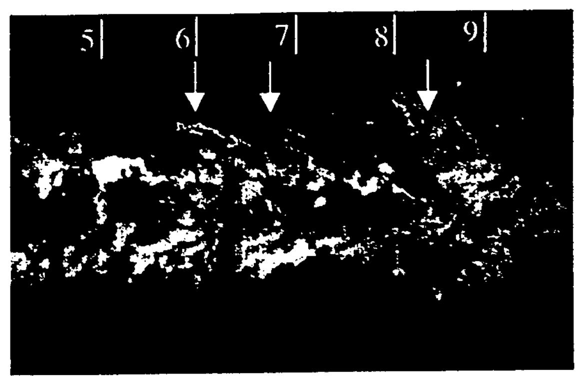


Figure 8 Simultaneous instantaneous flow vis for Mach 1.3 jet.

Acknowledgment/Disclaimer

This work was sponsored in part by the Air Force Office of Scientific Research, USAF, under grant/contract number F49620-99-1-0097. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the Air Force Office of Scientific Research or the U.S. Government.

References

Clancy, P., Samimy, M., and Erskine, W.R., "Planar Doppler Velocimetry: Three-Component Velocimetry in Supersonic Jets," AIAA Journal, Vol. 37, No. 6, pp. 700-707, 1999.

Clancy, P. And Samimy, M., "Two-Dimensional Planar Doppler Velocimetry Technique in High Speed Flows," AIAA Journal, Vol. 35, No. 11, pp. 1729-1738, 1997.

Kim, J.-H. and Samimy, M., "On the Streamwise Vortices in Trailing Edge Modified Supersonic Nozzles," Physics of Fluids, Vol. 11, No. 9, 1999.

Samimy, M., Kim, J.-H., Clancy, P., and Martens, S., "Passive Control of Supersonic Rectangular Jets via Trailing Edge Modifications," AIAA Journal, Vol. 36, No. 7, pp. 1230-1239, 1998.