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Charles E. Tinney, Andre Hall, Mark N. Glauser
Syracuse University
Syracuse, NY 13244

Lawrence S. Ukeiley
The University of Mississippi
University, MS 38677

Tim Coughlin
C & S Engineers, Inc.
Syracuse, NY 13212

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Designing an Anechoic Chamber for the Experimental Study of High Speed Heated Jets.

Charles E. Tinney,* Andre Hall, Mark N. Glauser †
Syracuse University
Syracuse, NY 13244
Lawrence S. Ukeiley ‡§
The University of Mississippi
University, MS 38677
Tim Coughlin
C & S Engineers, Inc.
Syracuse, NY 13212

The refurbishment of the 7,300 ft³ anechoic chamber located at Syracuse University for studying aerodynamically generated noise is discussed. The purpose of the facility is to provide free field conditions for an experimental study aimed at the identification and control of the noise producing events in the shear layer of a cold (104°F), 2in. diameter, Mach 0.85 jet. The facility is updated with intentions of performing future studies at elevated temperatures near 1000°F. Safety issues are discussed because of the elevated temperatures, as well as concerns for ensuring acoustical quality in the chamber due to the addition of a new Make-Up Air unit. Several far field acoustic measurements are acquired over a range of Mach numbers and facility conditions in order to quantify the acoustic performance of the facility. Pitot-static measurements of the jet’s plume, obtained at several streamwise locations, are shown and compared with the mean statistics from a stereo PIV system. Instantaneous PIV vector maps of the $r - \theta$ plane at Mach 0.85 and $z/D = 2$ through 7 are shown to illustrate the rich turbulent character of the flow from a compressible axisymmetric jet.

Historical Overview

The large anechoic chamber located at Syracuse University’s Skytop campus was originally constructed in the early seventies under the leadership of Dosanjh et al. (1977) to study the effects of varying exit temperature and mass flow of secondary and tertiary annular jets surrounding a sonic, axisymmetric heated jet. Many of the measurements were acquired using a few far field (more than 80 diameters) acoustic microphones and shadow-graphic flow visualization techniques. Research studies continued in the early 1990’s with studies pertaining to the control of impinging high speed jet resonance; refer to Sheplak (1994). With these latter studies, the facility had primarily remained unchanged except for the replacement of the original compressor with a newer power plant.

Anechoic Chamber

The interior chamber dimensions including sound treatment (wedge tip to wedge tip) are 26ft. x 20ft. x 14ft. with exterior walls, flooring and ceiling constructed from reinforced 12in. thick single poured concrete. All interior surfaces of the chamber are acoustically treated using fibreglass wedges with a cut off frequency of 150Hz. Wedge fabrication comprises of an interior high-density fibreglass wedge covered with lower-density fibreglass matting. The eductor duct and 6 pressure balancing ducts (to be described later on) are all treated with several layers of medium-density fiberglas held in place by perforated (46% solidity) metal sheeting. This was necessary to reduce any noise emitting from a centrifugal eductor fan and any outside sound disturbances such as passing aircraft and grounds crew equipment.
Processed Airflow

The power plant that supplies air to the experimental jet rig is broken down as follows. Compressed air is supplied by a 100hp two stage (2 piston) Joy compressor at a maximum discharge of 270SCFM and 500psi. This primary compressor discharges to a single bypass after-cooler and desiccant dryer capable of reducing the compressed air to a recommended \(-40^\circ F\) dew point. Five tanks with a volumetric capacity of 1100\(ft^3\) store the compressed air to a maximum pressure based on the performance of the compressor. The tanks also function as a plenum for the compressor, as not to experience piston cycling in the experimental jet rig. The interiors of the tanks are lined to prevent corrosion. Refer to the appendix for an illustration of the facility and its various components.

A pneumatically actuated control valve with a whisper trim interior is installed downstream of the tank storage and controls flow rates to the experimental rig located in the chamber (air for actuating the valve is provided from a separate secondary compressed air system). The experimental jet rig is connected to the control valve via 150ft. of 4in. inner diameter carbon steel piping followed by 60ft. of 6in. inner diameter stainless steel 304 sch-40 piping. A safety blow off valve is inserted to prevent any air system items (located downstream of the valve) from experiencing pressures above 100psig. The junction between the smaller and larger diameter pipes is through a centrifugal filter / muffler. This is necessary both for removing any debris emanating from the carbon steel pipe, and for reducing internal noise induced by the compressor and valve.

For purposes of running experimental studies at elevated temperatures, the facility is equipped with a 470kW Chromalox electric circulation heater. The heater consists of 144 incoloy-800 sheathed rods that turn on and off, as needed, to achieve the desired output temperature. The output temperature is measured by an ungrounded thermocouple located in the flow stream before the experimental rig. The heater’s construction and electrical input requirements were designed using a flow rate of 1460SCFM and a nozzle exit temperature of 1000°F. Because of the difference in the discharge rate between the experimental rig and the compressor (nearly 1200SCFM), the facility is employed as a blow down system, as is the primary function of the large air storage mentioned earlier. The operational time of the jet rig when discharging at a rate of 1460SCFM (Mach 0.85 for a 2in. nozzle) yields nearly a 20-minute window, therefore in the time scales of the flow this is essentially a continuous facility.

Chamber Eductor and Co-Flow Air

The additional source of air supply needed to balance the pressure deficit induced by the Eductor fan is provided by the installation of an industrial variable Make-Up Air (MUA) unit capable of supplying 7kSCFM to 14kSCFM, (50% to 100% fan speed) of air at a maximum exit temperature of 90°F. This MUA unit consists of a fan controlled by a variable frequency drive (VFD) that heats outside air as it is drawn through an 85% filter, to the desirable temperature through the firing of a gas burner.

The treated air is then ducted into a large plenum located behind the back wall of the anechoic chamber with dimensions 13ft. x 10ft. x 22ft. The treated air travels from the plenum to the chamber through an axisymmetric, 15ft, acoustically treated duct with a cross sectional area of 0.16\(ft^2\). Given the discharge rate of the MUA unit, the bulk velocity of the co-flow air can range between 13\(ft/s\) and 25\(ft/s\). The duct contains several mesh grid inserts and honeycomb for preventing large eddies from entering into the chamber, and is centered on the same axis as the jet rig. The velocity of the MUA is at several orders of magnitude smaller than the jet’s core exit speed. Refer to figure 1 for a theoretical relationship between the bulk co-flow air velocity and the Jet’s core exit Mach number for a range of MUA discharge rates. This co-flow will also be crucial when operating the experimental jet rig at elevated temperatures, thus preventing the chamber from heating up and exposing any instrumentation to temperature conditions detrimental to their performance and reliability.

Experimental Jet Rig

The experimental jet rig located in the anechoic chamber was designed with intentions of using optics based measurement tools (PIV, LDA) for performing velocity measurements. Therefore the jet rig design employs two azimuthal arrays of seeder injection ports. The first array is utilized for cold experiments and uses an olive oil seed (for any temperatures that may pro-

Fig. 1 Relationship between MUA co-flow air jet core flow under standard atmospheric conditions.

(Efan)
vide consistency in particle size, phase state and light scattering), whereas the second array is for appropriate particle injection during heated experiments.

The interior profile of the jet rig is axisymmetric and comprises of two custom machined members constructed entirely of 304 Stainless Steel, refer to figure 2 for a cutaway view. A custom flange houses a honeycomb flow straightening ceramic substrate and joins the two members. The substrate has a density of 400 cells per square inch and is capable of operating in temperatures of up to 2600°F with minimal growth. The pressure drop through a 3.2in. substrate (over half the diameter of the pipe) at 1460SCFM is negligible at 0.53psi. With fear of eroding the ceramic substrate, the 6 seeding injection ports are located downstream from the substrate and have been found to have negligible little effect on the quality of the acoustics and the flow.

The jet nozzle’s interior profile utilizes a matched 5th order polynomial contraction with a ratio of 3:1, for a 2in. exit diameter, and screws onto the experimental rig for capability of interchanging different nozzles in the future. The surface roughness of the experimental rig including the jet nozzle end piece is of order 30µm. The nozzle’s contraction shape was based on a ratio of length to steepness using guidelines from Morel (1975)\(^{12}\) and Chmielewski (1974).\(^{4}\) For a contraction that is too steep, the flow experiences separation at the exit of the contraction, whereas a contraction that is too gradual experiences unwanted growth in the boundary layer. A compromise was found between the two phenomena.

The entire experimental jet rig is mounted to a stand designed to allow the jet and piping to grow naturally at elevated temperatures and is shown in the chamber in figure 3. The piping is 24ft. in length and is constructed using the same stainless steel piping mentioned earlier. This was recommended for purposes of reducing internal noise generated by an alternative method that fixes the nozzle head and uses several pipe bends that flex under heating loads. The stand compensates for this growth using several high strength linear rails providing a rigid single degree of freedom system in the axial direction only (z-axis). A commercial software package (COADE Caesar II v. 4.30) aided in the piping design to determine the response of the system under thermal loads.

The placement of the nozzle’s lip is crucial to ensure that the growth of the shear layer does not extend beyond the dimensions of the plume catcher (eductor). An angle of 15° with respect to the jet’s axis is used to estimate this location. This is necessary to prevent unwanted re-circulations from occurring inside the chamber. This is even more of a problem for the Syracuse University facility because of the asymmetric location of the chamber walls with respect to the jet axis.

**Process Control**

The process for controlling the air supplied by the compressor / storage tanks to the experimental rig in the chamber is of immense importance especially for experimental studies at elevated temperatures. This is because the electric heater requires a bypass flow (air from the primary compressor) during all stages of its operation (including heat up and cool down) to prevent risk of destroying heater rods. The entire process is controlled using an Allen Bradley, Pro-Logix Control (PLC) based system. The choice of control systems resulted in an industrial grade, hardware system that is more robust than other software controlled type systems (laboratory type instruments) and utilizes an arrangement of input sources as follows:

1. P1: Tank pressure.
2. P2: Static pressure in nozzle.
3. P3: Total pressure in nozzle.
5. P5: Chamber pressure, Barometric.
6. T1: Nozzle temperature (exit temperature of core flow).
7. T2: Chamber temperature.
8. FS: Flow switch on/off, binary output

The process for running cold experiments (no electrical heating) begins with the sensing of the tank pressure from P1. When the desired tank pressure is achieved, i.e. 400psig, the control valve is throttled open in order to achieve a pressure ratio between P2 / P5 corresponding to a PLC-input experimental condition, i.e. Mach 0.85 jet core exit speed. The relationship between P2 and P5 is based on a calibration performed before hand that determines the relationship between the total pressure at the center of the
Fig. 3 Experimental jet rig located in Syracuse University’s high-speed jet-noise lab.

jet’s exit measured by P3 (a total pressure probe is temporarily placed for this), and the static pressure in the pipe measured by P2 and is exhibited in figure 17. The relationship between P3 and P2 are also independent of ambient conditions and can be used reliably for remaining experiments.

For all jet exit conditions, the MUA and Efan are activated and provide temperature controlled air through the co-flow duct. When the tank pressure drops below a certain level, the control valve is throttled shut and the compressor continues to recharge the tanks for the next experiment.

The alternative process for running heated experiments is more crucial and involves bypass flow through the heater for reasons mentioned earlier. With the tanks fully charged, and the compressor still running, the control valve is opened and a bypass air is provided to the heater at a rate equal to the compressor’s output. This prevents the tanks from deflating and provides adequate cooling needed to maintain safe operation of the electric heater during the heat up stage. Also the bypass air activates a flow switch, FS in the piping thus giving permission to the PLC to activate the heater. Output temperature is sensed by T1, whereas the chamber temperature is sensed by T2. Knowledge of the latter is crucial to ensure a safe environment for the delicate instruments. The sensing of T1, T2, P1, P2 and P5 is continuously monitored and displayed using a dedicated PC. PID control loops are incorporated in the PLC feedback algorithms and are tuned for accurate throttling of the valve. The output temperature of the MUA unit is self-monitoring. For experiments exceeding the discharge rate of the compressor, (anything above M = 0.25 for the 2 inch nozzle), the heater is shut down prematurely in order to ensure an ample supply of bypass air necessary to remove heat from the rods during cool down.

Acoustic Measurements and Chamber Characterization

The acoustic instruments selected for this study were based primarily on bandwidth and dynamic range capabilities from previous investigations in similar facilities. Aluja (1973) illustrated using 1/3 octave spectra of noise from a 1.52 inch diameter nozzle at roughly 50 diameters and 30° to the jet axis, a dynamic peak near 100dB at 2kHz. More recently, Callender et al. (2002) showed from a radial arc of 30 equivalent diameters (3.125 inch diameter nozzle) at 50° relative to a positive streamwise jet axis over a range of Mach numbers (0.5 to 1.0), a dynamic response near 95dB with moderate energy in frequencies up to 50kHz. Jansson et al. (2002) showed from a Mach 0.9, cold jet, 83.5 diameters away and 90° from the positive jet axis, a dynamic response above 80dB, peaking between 10^3 and 10^4 Hz.

Using these findings as a guide, 6 - G.R.A.S. type 40BE 1/4 inch pre-polarized free field condenser microphones are chosen. Excitation is provided by G.R.A.S. type 26CB 1/4 inch preamplifiers. Advantages to these instruments is in their ICP capabilities, thus allowing several hundred feet of coaxial lines between the preamplifier and the digitization equipment, without attenuation in the signal. Enabling this characteristic requires a 2mA to 20mA power supply and is generally built into the A/D converter. The frequency response and dynamic range of the type 40BE microphones are 10Hz-40kHz (+/- 1dB), or 4Hz to 100kHz (+/- 2dB), and 166dB re. 20µPa (30dB re. 20µPa thermal noise), respectively. Sensitivity for these front-vented microphones are around 4mV/Pa with capabilities of operating in temperatures ranging from −40°F to 250°F.

Signals from these microphones are acquired using two United Electronics Industries PD2MFS8 boards. The board’s characteristics include a 500kHz multiplexed A/D converter over 8 differential channels (with gains), 16 bit resolution per channel and multi-board synchronization; as is important for any simultaneous sampling. Acquisition delay between channels is of order 15ns and is truly simultaneous. Because the A/D boards do not have filtering characteristics, the signals from the microphones are feed appropriately to several external Krohn-Hite model 34 filters. The filters attenuate at a rate of 24dB/octave and have a maximally flat (Butterworth) amplitude response. For all acoustic measurements shown, the microphones are sampled...
at 150kHz, and band pass filtered between 500Hz and 75kHz. 200 blocks of 8192 samples are acquired thus providing a spectral frequency resolution $\delta f$ of 18.3Hz and a total acquisition time of 5.46s.

The microphone arrangement in the anechoic chamber is shown in figure 4. The boom array is placed 85 diameters from the center of the jet exit plane and the microphone array is located 75 diameters. Each microphone is supported by a 3/8 inch diameter threaded rod extending from the boom towards the jet as to increase the distance between the microphones and the boom (intended to help reduce reflecting sound sources in and around the microphone). While some surfaces from flat/non-porous and acoustically untreated surfaces may reflect high frequency sound pressure waves; similarly treated surfaces may then reflect low frequency sound pressure waves, due to an increase in surface area caused by the acoustic treatment. This is always a concern to the acoustician when deciding to treat items in the chamber or not. The jet axis ($z$) defines the abscissa of the microphone arc array starting with microphone 6 located $15^\circ$ from the jet axis. With increments of $15^\circ$ between each microphone; microphone 1 is then perpendicular to the jet axis.

To properly identify potential sources of contaminating sound in the facility, several experiments were performed before running the compressor and jet. The two potential sources are the eductor fan and the newly installed MUA unit. Since the Efan is powered by a constant drive, it is referred being in either an on or off state. Contrarily, the MUA is capable of operating at various speeds (50% [7kSCFM] to 100% [14kSCFM] fan blade speed) and temperatures for reasons described earlier. Sound quantification of the MUA unit is performed at 10% fan blade speed increments. The true base noise measurements of the facility as recorded from microphones 1 and 6 at $90^\circ$ and $0^\circ$ respectively, are shown in figure 5 and represent conditions under which all equipment in the facility are turned off.

A flat noise level over the entire measurement spectrum is experienced around 41dB, with an integrated noise floor of 78dB. Microphones 1 and 6 are selected because of there broad location between one another. Figures 6 and 7 illustrate the Efan alone, and the Efan & MUA at 100%, respectively, with an integrated noise level for both units of 78dB. Therefore, it is conclusive from these findings that the potential sources of contaminating noise pose negligible change to the true base noise in the facility.

The next order of presentation is to illustrate the acoustical performance of the new jet for a range of Mach numbers: 0.30, 0.40, 0.50, 0.60, 0.70, 0.85 and 1.10. The final supersonic measurement was a result of left over pressure in the tanks. However, it does pose some discussion as to the tonal peaks emanating from the existence of shock cells, otherwise absent in the subsonic, transonic measurements.

For the purposes of matching flow conditions from the Taylor et al.\textsuperscript{18} investigation of the compressible turbulent shear layer of a Mach 0.3, 0.6 and 0.85 jet, figures 8, 9 and 10 are focused on the acoustic characteristics of the S.U. jet under these conditions. Figure 10 displays the findings for the supersonic condition ($M=1.10$). Figures 12 and 13 display the full range of Mach number conditions as observed by microphones 1 and 6, respectively.

According to the results shown in figure 8, the acoustical energy from a Mach 0.3 jet under these conditions is difficult to characterize aside from the corrected base noise of the facility as well as the thermal character-
Fig. 6 Eductor Fan noise: Efan (on), MUA (0%), Compressor off.

Fig. 7 MUA unit (100%) and Efan (on) noise, \( T_{bp} = 75^\circ F \), compressor off.

Fig. 8 Jet noise at \( r/D=80 \), Mach 0.30, MUA (85%), Efan (on), \( T_{bp} = 75^\circ F, T_{jet} = 55^\circ \).

Fig. 9 Jet noise at \( r/D=80 \), Mach 0.60, MUA (85%), Efan (on), \( T_{bp} = 75^\circ F, T_{jet} = 55^\circ \).

The characteristics of the microphones. This was also observed by Jansson et al. (2002).\(^9\) For the Mach 0.6 and 0.85 case, the spectral characteristics of the jet are more pronounced with an increase in sound pressure with increasing Mach number. For all microphones and Mach numbers, there is a broad sound pressure peak between 1kHz and 2kHz. Additionally, one can see a higher amplitude in the lower bandwidth frequencies and a relative attenuation in the higher bandwidth frequencies as the microphone angle reduces.

Resultant spectral trends of microphones 1 through 5 (90\(^\circ\) to 30\(^\circ\), respectively) illustrate a noticeable gap in amplitude of the higher frequency scales with respect to microphone 6 (15\(^\circ\)). This is occurring for two possible reasons: the orientation of the microphone’s angle of incidence with respect to the jet’s cone of silence as described by Tam (1998),\(^17\) and the placement of microphone 6 inside the jet plume thus saturating higher frequency waves due to hydrodynamic forces. The latter is shown to be unlikely by measurements illustrated in figure 14 taken with a 5e\(^{-4}\)mm Hg accurate manometer traversed along several radial points at \( z/D = 80 \). From this illustration (figure 14) the width of the jet’s shear layer at this streamwise location does not extend beyond \( r/D = 16 \) whereas the location of microphone 6 is around \( r/D = 25 \) at \( z/D = 75 \). From this profile, one can estimate the growth of the jet’s shear layer to be of order 0.2\( x \) at an angle of 11\(^\circ\).

A rippling effect is seen in the higher frequencies and is a result of reflections from the microphone’s holder. The holders have since been more streamlined to minimize these reflections. Referring to the supersonic measurements in figure 11, one can see the existence of discrete tones around 4kHz and 8kHz. The second 8kHz tone is not experienced by microphone 6 in
frequency [Hz], (f_s = 150kHz, n=4096, N=100, BP Filter: 500Hz to 75kHz)

Fig. 10 Jet noise at r/D=80, Mach 0.85, MUA (85%), Efan (on), T_bp = 75°F, T_jet = 55°.

Fig. 12 Jet noise at r/D=80, microphone 1 (90°), MUA (85%), Efan (on), T_bp = 75°F, T_jet = 55°.

Fig. 13 Jet noise at r/D=80, microphone 6 (15°), MUA (85%), Efan (on), T_bp = 75°F, T_jet = 55°.

Velocity Field Measurements & Shear Layer Characterization

Before employing optical based measuring tools (PIV), pitot-static measurements are acquired at several streamwise locations. This provides a basis to compare the mean statistics of the PIV measurements. The pitot-static tube employs a 1/16 diameter hole...
and is traversed perpendicular (horizontal) to the jet’s axis at several streamwise locations. Vertical profile measurements were initiated at \( z/D = 0.0 \) and 7.0 to ensure the proper location of the pitot tube with respect to the jet’s true axis. The spacing between measurements in the cross-stream direction is chosen based on the shape of the shear layer; thus for large gradients, the incremental spacing is reduced.

Two Pressure Systems 0.05% of full scale (FS), 0-25psig transducers are digitized using a National Instruments PXI-4472 board installed in a National Instruments PXI chassis. The NI-4472 board contains 8 single and differential channels with 24 bit resolution, and is capable of sampling up to 102.4 kHz. The additional features are the 8 independent Delta-sigma A/D converters (1 for each channel for simultaneous sampling) and the built in low pass filters. Selection of appropriate transducers for the above mentioned task, and for accurately controlling the flow valve, was based on the uncertainty analysis illustrated in figure 16 for a 25 [psig] transducer with different FS accuracies. It is shown that the 0.05% of FS-transducer greatly reduces the uncertainty of the low Mach number studies and should be considered when operating at these flow speeds. The uncertainty in the jet’s core flow at Mach 0.3, using this transducer is under 2% and falls below 0.5% with flows above Mach 0.85.

In order to operate the nozzle under accurate and consistent exit conditions, the exit nozzle total pressure had to be estimated from the static pressure in the pipe. This requires a calibration of the nozzle and is shown in figure 17 where the substitution for the total pressure from the pipe static pressure is shown to exhibit a linear behavior and is very small. Under subsonic conditions, the static pressure at the lip (P5) is taken to be barometric and is acquired using a barometric transducer (2.5% accuracy of FS).

The profile measurements obtained with the pitot

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**Fig. 15** Acoustic energy at \( r/D=80 \), MUA (85%), Efan (on).

**Fig. 16** Uncertainty in Mach number based on transducer accuracy.

**Fig. 17** Relationship between nozzle total pressure and nozzle static pressure.

**Fig. 18** Pitot-static profile of S.U. jet at Mach 0.30, \( Re \approx 3.5e^5 \)
tube are shown in figures 18 through 20 and characterize the symmetric profile of the plume from this jet. The potential core is found to collapse for different Mach numbers near 4, 5 and 6 diameters for the Mach 0.3, 0.6 and 0.85 respectively, and was shown similarly in the subsonic axisymmetric jet by Glauser (1987). Additional pitot-static measurements are performed using the 5e^{-4}mmHg, accurate manometer mentioned earlier and exhibit the jet plume’s downstream development, (figure 21). These measurements employed a relatively course grid with the smallest radial spacing being of order \( \delta r / D = 0.5 \). The symmetry of the jet’s far field plume is characterized by these measurements at \( z / D = 20 \) to \( z / D = 80 \).

Figure 22 presents an illustration of the secondary velocity components (via. PIV) at an instant in time along the \( r \theta \) plane at Mach 0.30, and 4 diameters downstream of the jet lip. The mean profile is removed to illustrate the richness of the jet’s turbulent shear layer. Figures 23, 24 and 25 are snap shots at Mach 0.85 of the same secondary velocity components at \( z / D = 3 \), 4 and 4, respectively. From these vector maps, the rich azimuthal structures in the turbulent shear layer are clearly illustrated, consistent with previous work (v. Taylor et al. (2001), Glauser & George (1987), Citriniti & George (2000)) thus suggesting the low dimensional character of this complex evolving flow.

Demonstration of PIV Capabilities
The facility is instrumented with a Dantec, 3 component 2-D Particle Image Velocimetry (PIV) system and is currently arranged for capturing all three components of the streamwise velocity field about the \( r \theta \) plane. The two HiSense, 8 bit resolution CCD cameras (1280 x 1024 pixels) as well as a pair of pulsed New Wave Research 200mJ Nd:YAG lasers and optical laser sheet generator are positioned upon a single degree of freedom Dantec traverse. This allows one to move the cameras and laser sheet plane along the jet’s streamwise direction without having to reposition and recalibrate the PIV system’s optical components. Seeding to the jet is provided by a PIVTEC, 12 laskin nozzle, seeder unit because of its ability to withstand pressures above that of the jet’s piping where it is injected into, (up to 10bar). Co-flow seeding is provided by a TSI model 9307 oil droplet generator and is injected into the exhaust duct of the MUA unit. Both seeders use olive oil as the seeding medium and produce mean particle sizes of order 1\( \mu \)m. Refer to Melling (1997) and Meyers (1991) for a discussion on issues concerning particle generation and tracking using optics based tools.

Figure 21 Manometer measurements of the jet’s far-field plume, MUA (85%), Efan (ON).
equipped with a Dantec LDA/PDA system. The system employs a 3Watt Argon-Ion Laser and a 40mHz Bragg Cell, and uses a back scattering technique capable of measuring all 3 components of velocity from 3 laser pairs. The receptacle head is mounted on an optics bench with a 2D traverse. The head and receiver are capable of traversing in all three dimensions using different traverse arrangements.

With the intention of employing low dimensional techniques (i.e. Modified Complementary Techniques have been demonstrated by Taylor & Glauser (2002)\textsuperscript{19} and Schmit \textit{et al.} (2003)\textsuperscript{15} to estimate flow field events), the jet’s nozzle is equipped with 15 Kulite XCE-093 model, 5psig pressure transducers with a DC to 50kHz frequency response range. Excitation is provided from five: model 136 Endevco signal conditioners (3 channels per unit). These pressure signals are digitized using the National Instruments PXI system mentioned earlier. The small Kulite transducers are placed along an azimuthal array at the lip of the jet and sample the fluctuating pressure at the jet’s exit. A spectral plot of a single Kulite transducer’s response under three Mach number conditions (0.30, 0.60 and 0.85) are shown, (figure 26) and shows the frequency characteristics of the fluctuating pressure at the jet’s lip.

Conclusions

The newly refurbished anechoic chamber on Syracuse University’s Skytop campus has been discussed. The chamber incorporates 150Hz wedges and has interior dimensions of 26ft. x 20ft. x 14ft. from wedge tip to wedge tip. An industrial Make-Up-Air unit is installed to provide co-flow air around the jet at controlled speeds (13ft/s to 15ft/s via. Variable Frequency Drive control) and temperatures (max exit
Fig. 26 Lip-pressure spectra from Kulite transducer located at r/R=1 and z/D=0.

temperature of 90°F throughout the full calendar year. A 470kW electric heater is installed to provide a 1000°F exit temperature from the 2 inch nozzle at Mach 0.85. To ensure safety and reliability at these extreme conditions a PLC unit is employed.

Acoustic measurements of the newly refurbished chamber are shown. The true base noise (without anything operating in the skytop lab) as measured by an array of 6 microphones in the chamber, is found to be 41dB with an integrated noise level of 78dB. With the make up air unit, exhaust fan and compressor running, the overall spectral and integrated noise levels remain at 41dB and 78dB, respectively. Acoustic measurements are taken at various Mach numbers (0.3 through 1.1) and illustrate typical sound behaviors of jet noise with a peak sound level at 1kHz, (Ahuja (1973)).1 Several pitot-static measurements illustrate the symmetric character of the jet plume’s mean profile and indicate that the jet spreads at a rate 0.2x or (11°). Stereo PIV measurements are shown at Mach 0.3 and 0.85 and z/D = 3 & 4 to illustrate the richness of the azimuthal structure in the jet’s turbulent shear layer. The facility is also equipped with an LDA/PDA system and several sensitive pressure transducers for future experimental studies aimed at identifying the noise generating events in the turbulent shear layer of a Mach 0.85, 2inch diameter jet using low-dimensional techniques.

Acknowledgments

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References

Fig. 27 Facility instrumentation and process diagram.

Appendix