Visualizing Jet Plume Noise Using Helmholtz Equation Least Squares Method

Outlines

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2. Challenges
3. Tasks
4. Experiments
5. Validations and Prediction
6. Discussions
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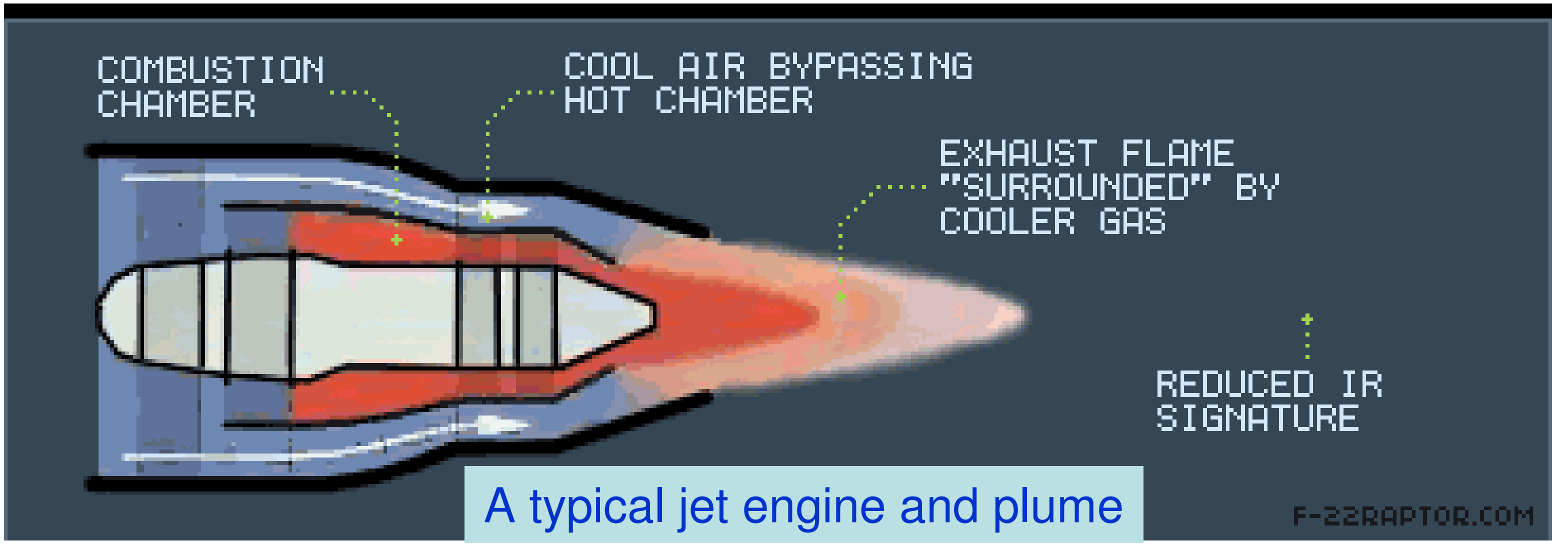
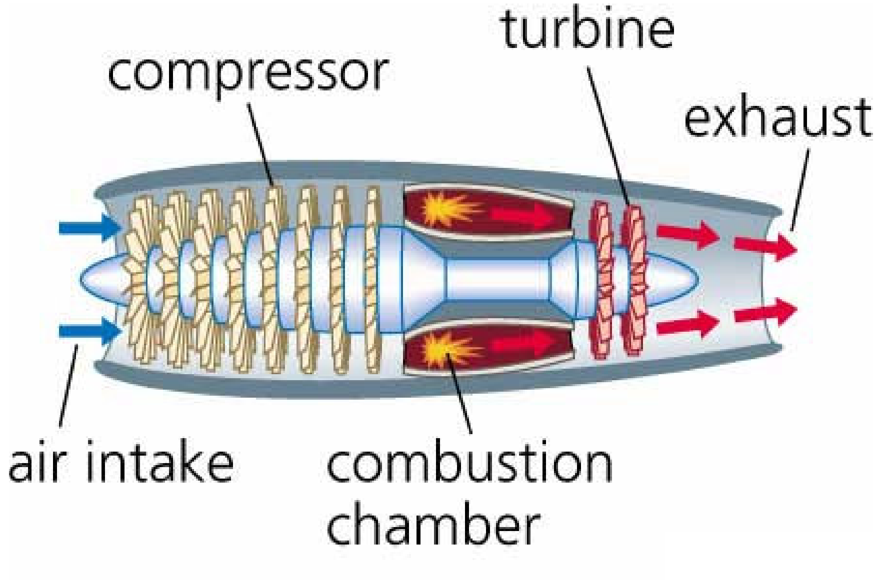
Objectives:

- **Examine the robustness and effectiveness of HELS-method to reconstruct the acoustic characteristics of supersonic jet plumes.**
  - **sound source frequency dependent spatial distribution**
  - **3D diagram of a reconstructed sound field in a jet plume**
  - **radiation angles and strengths of jet plumes**



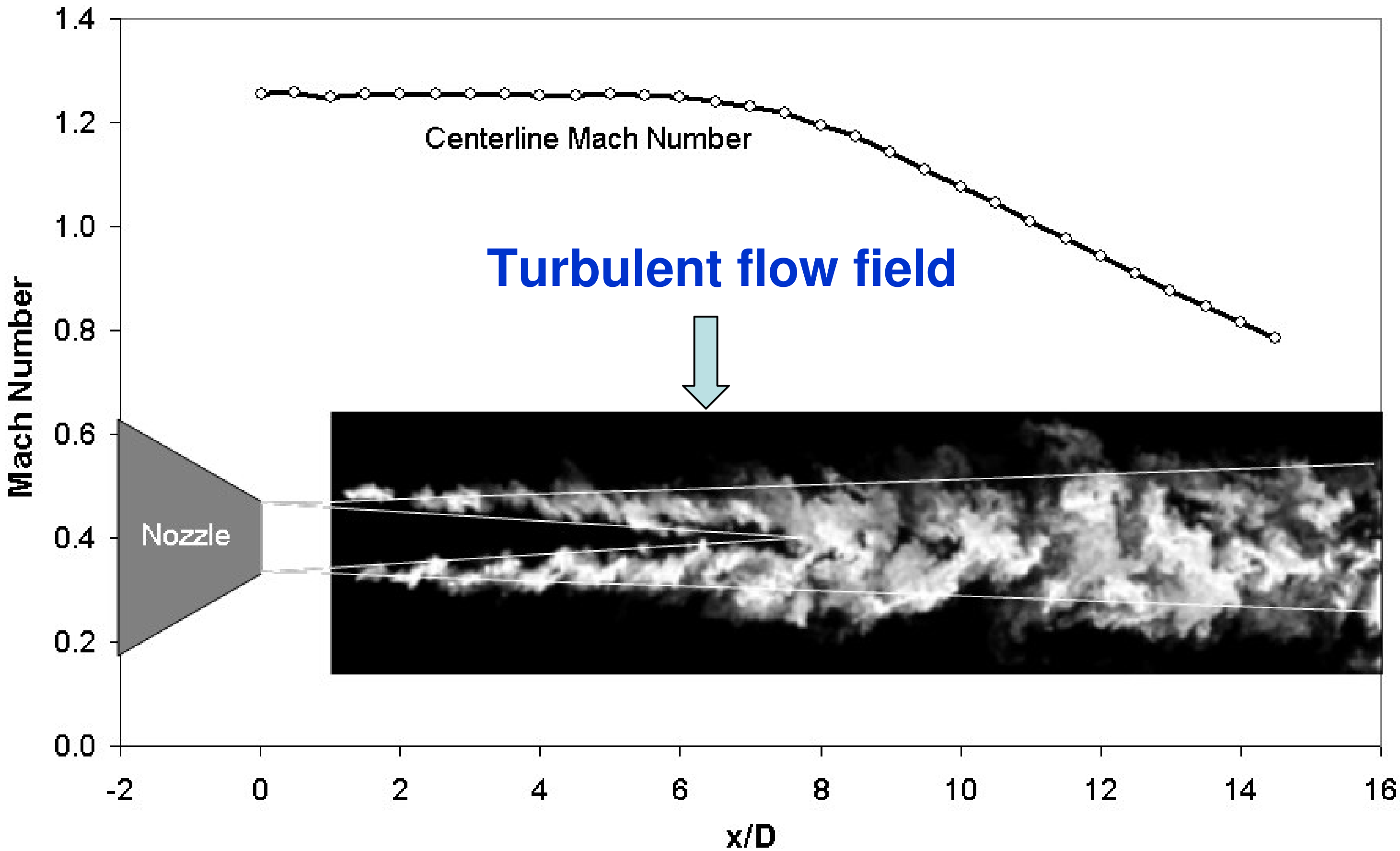
A typical jet engine and plume

Challenges



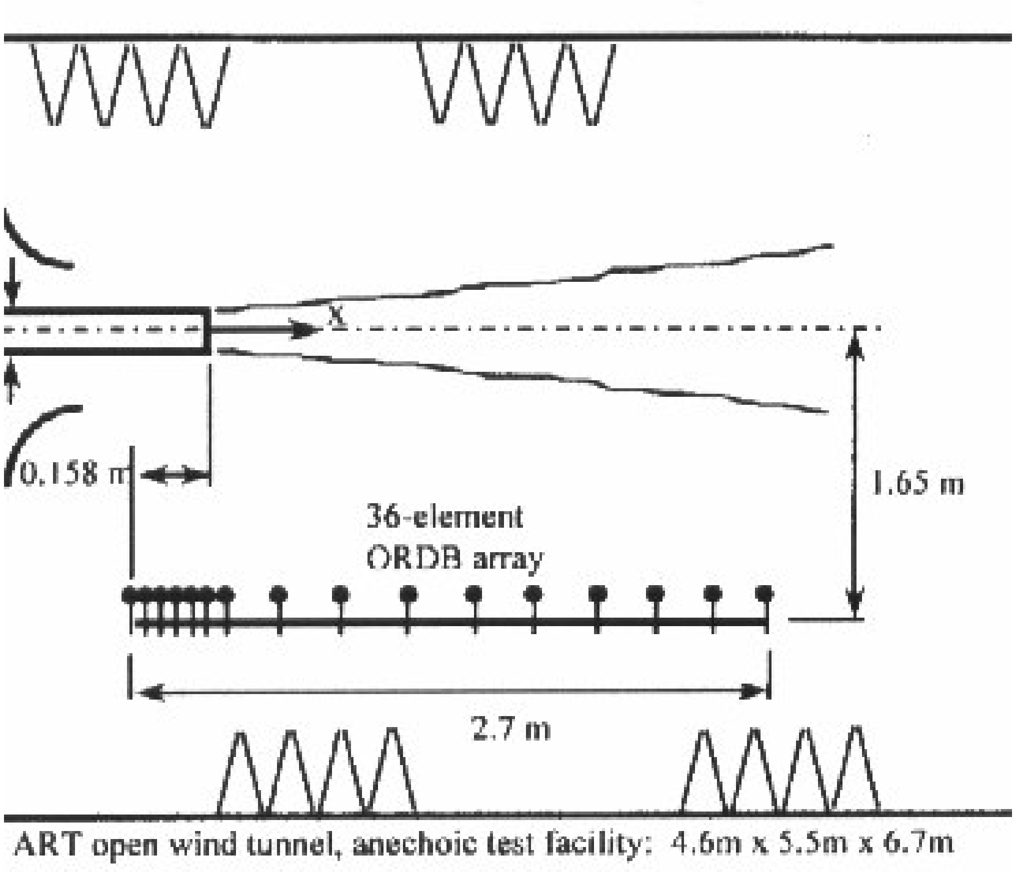
- High-speed flows from an exhaust nozzle can produce extremely high jet noise.
- Closed-form solutions for high-speed jet flow through an arbitrarily shaped nozzle and those for a turbulence sound field do not exist.

Challenges



- Turbulent flow can be measured by PIV, hot-wire, and pressure transducers, and visualized by CCD camera.

Challenges



- Jet noise was measured by microphones placed in the far field, not helpful to gain insight into jet noise.

Challenges

- However, the turbulent flow measured or visualized by traditional methods cannot be correlated to the sound field measured by microphones placed in the far field.
- As a result, not much insight into jet plume noise can be gained from these studies.

Task: Visualizing Jet Plume Noise

Use the HELS method to describe sound radiation from high speed turbulent flow

$$p(\mathbf{x};\omega)=\sum_{n=1}^{n_{\max}} D_{nl} h_{|l|}(kr_n) Y_n^{|l|}(\theta_n,\phi_n)$$

where $n_{\max}$ represents the total number of virtual sources at $x_n \equiv (r_n, \theta_n, \phi_n)$, $n = 1$ to $n_{\max}$, and r_n is the radial distance of the nth virtual source to any point $x \equiv (r, \theta, \phi)$ in space, $h_l(kr)$ and $Y_n(\theta_n, \phi_n)$ denote the spherical Hankel functions and spherical harmonics, respectively.

Test Object

- Because of lack of accesses to a supersonic jet, we could only conduct tests on a subsonic jet.

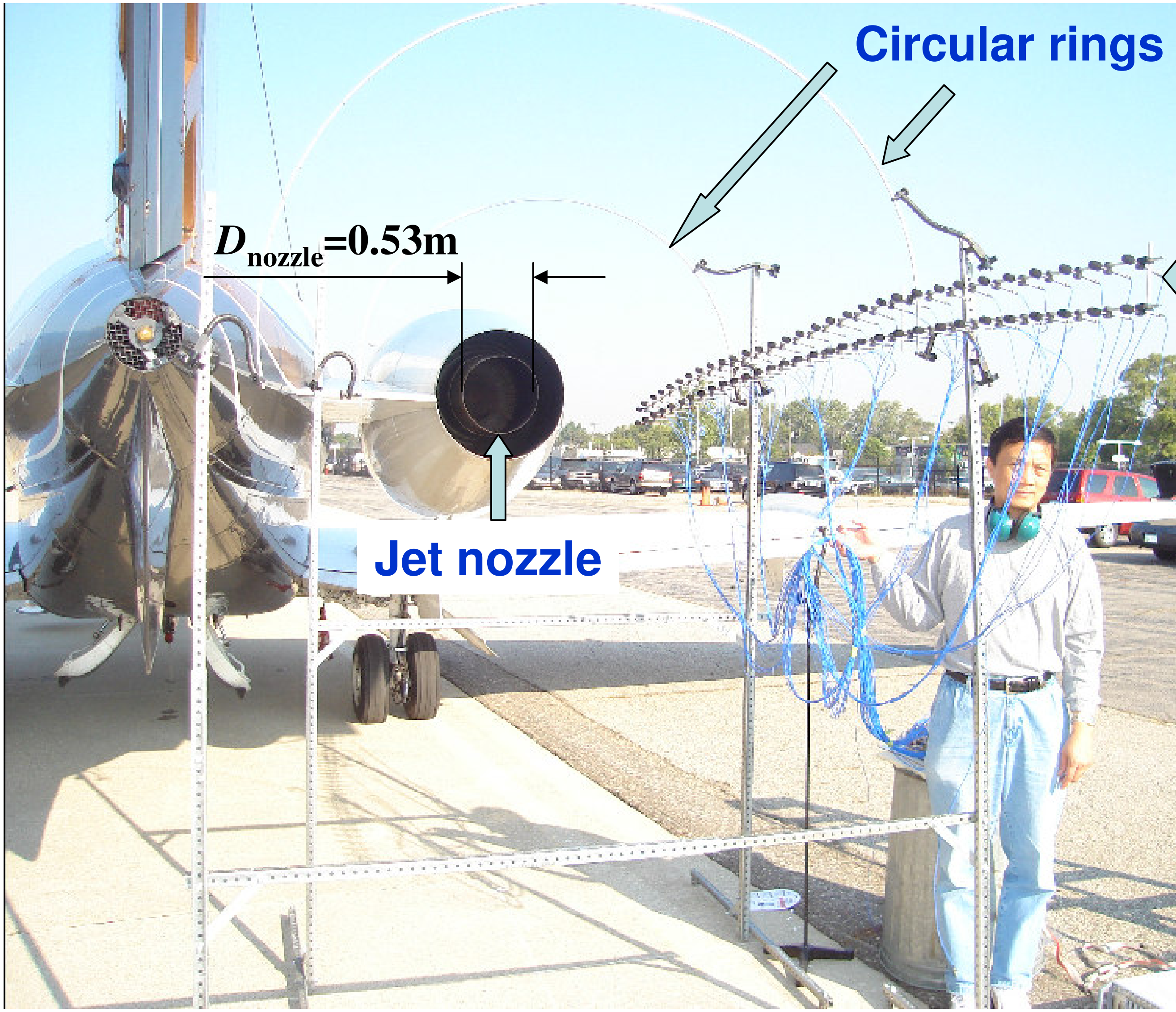
Microphones

- Moreover, our measurement microphones have limited dynamic ranges (40 – 122dB overall).
- As a result, we were able to run the subsonic jet at idle speed only in order to take near-field measurements of the acoustic pressures.
- The sound field produced by this low-speed turbulent flow was shown to be adequately described by using a multiple expansion of a single source.
- There is no need to use a distributed virtual sources because the source region was relatively compact.

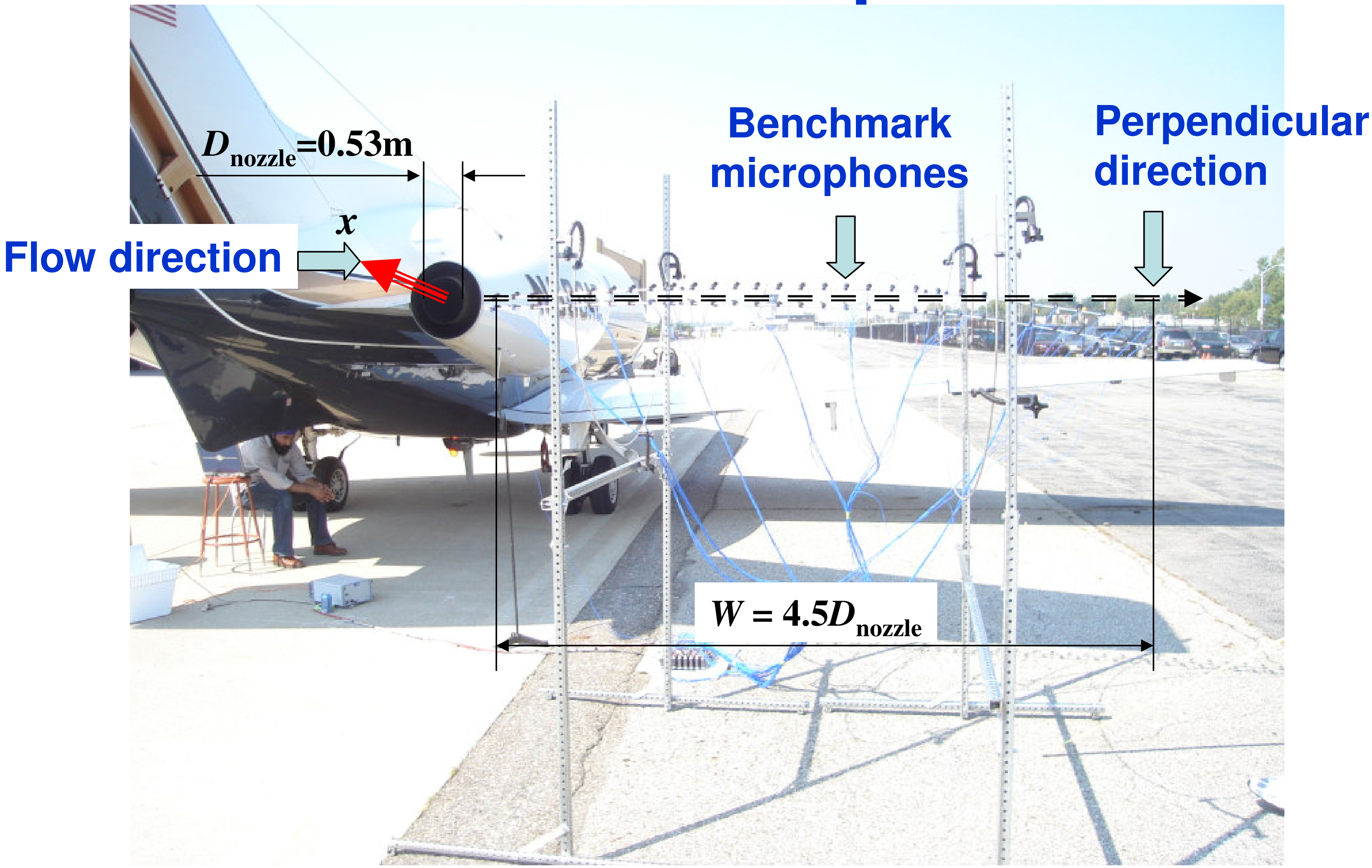
Test Setup

- Arrays of microphones and stands were designed and built so that conformal measurements of sound pressures could be taken around the jet plume.
- Two rings were designed to hold microphone arrays.
- Diameters of these rings were carefully determined so that microphones could be placed as close to the jet plume as possible, yet without contaminations by turbulent flow from the jet nozzle.
- Microphones were spaced at 0.077m and rotated along the rings at every 5.6^0 over 360^0 range.
- To validate the reconstructed acoustic pressures, benchmark pressures perpendicular to the jet flow direction were taken as well.

Test Setup



Test Setup

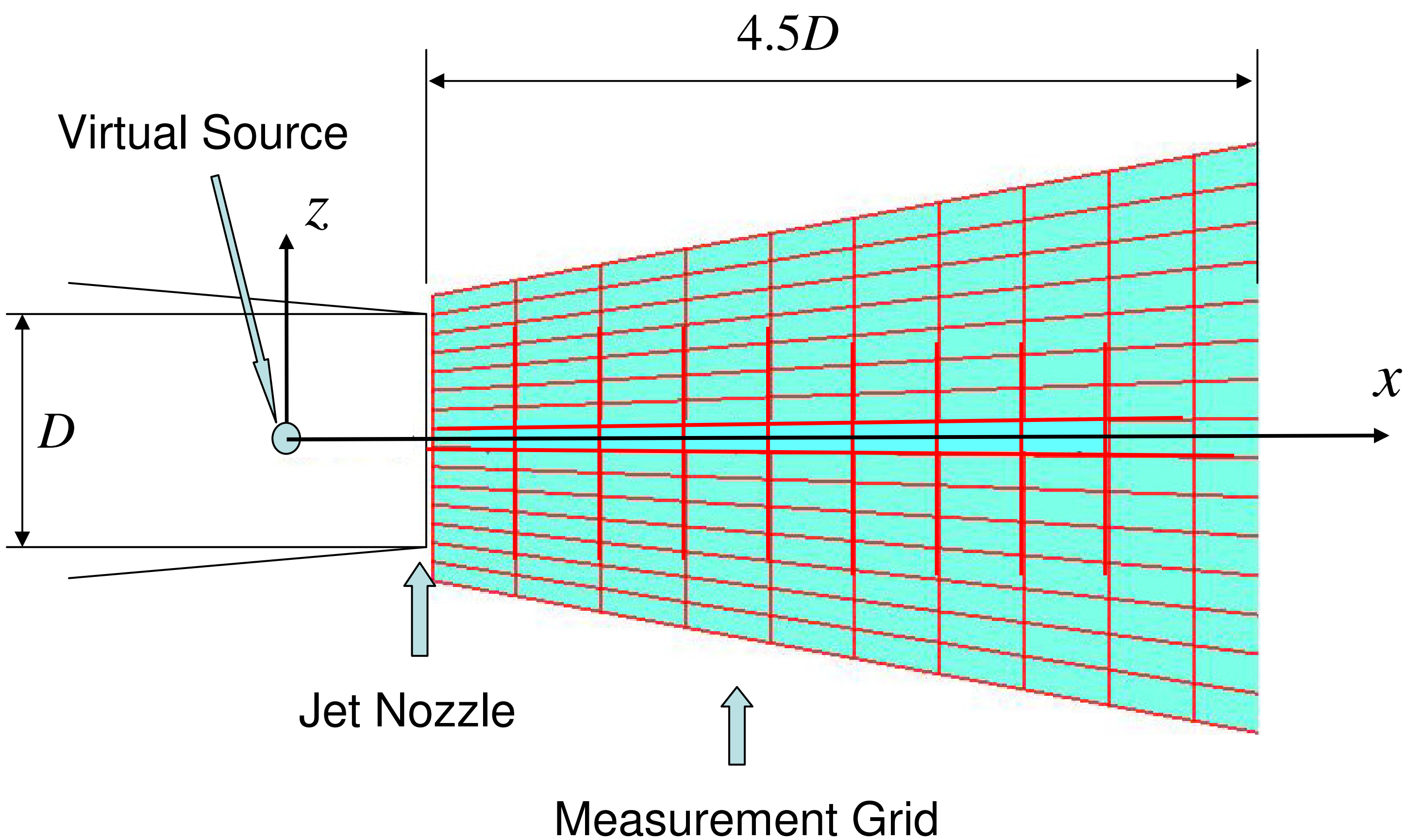


D_{nozzle}=0.53m
x
Flow direction
Benchmark microphones
Perpendicular direction
$W = 4.5D_{nozzle}$

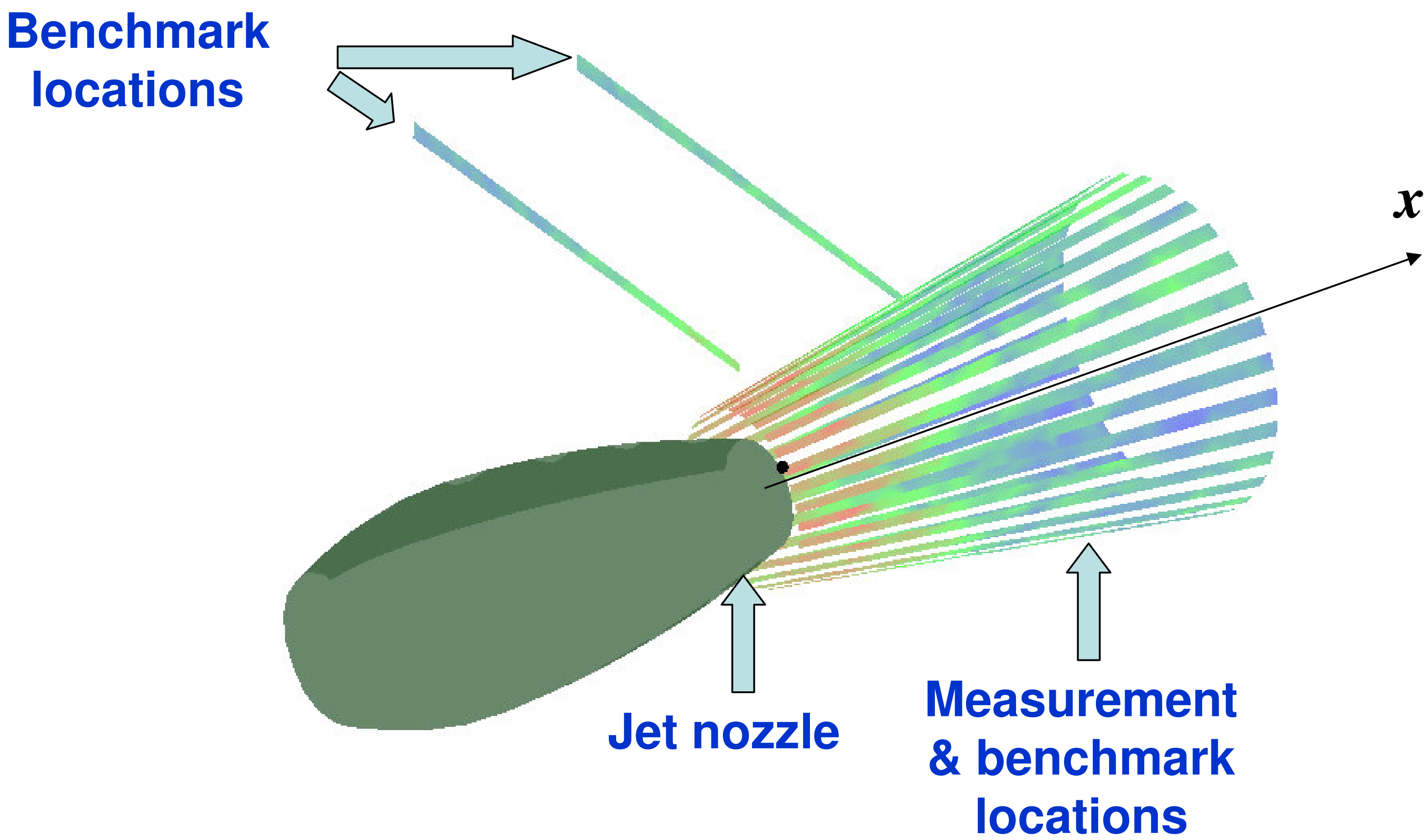
Test Procedures

- Jet engine was operated at idle speed.
- 31 microphones were mounted on a straight rod with spacing of 0.077cm.
- This rod was rotated along two supporting rings at every 5.6^0 over 360^0 range.
- This resulted in 1984 measurement points around the jet plume.
- The diameters of these two rings were 0.9m and 1.69m, respectively, whereas that of jet nozzle was 0.53m.
- Measurements were taken continuously one after another while the jet engine was running.

Source Location for SenHELS

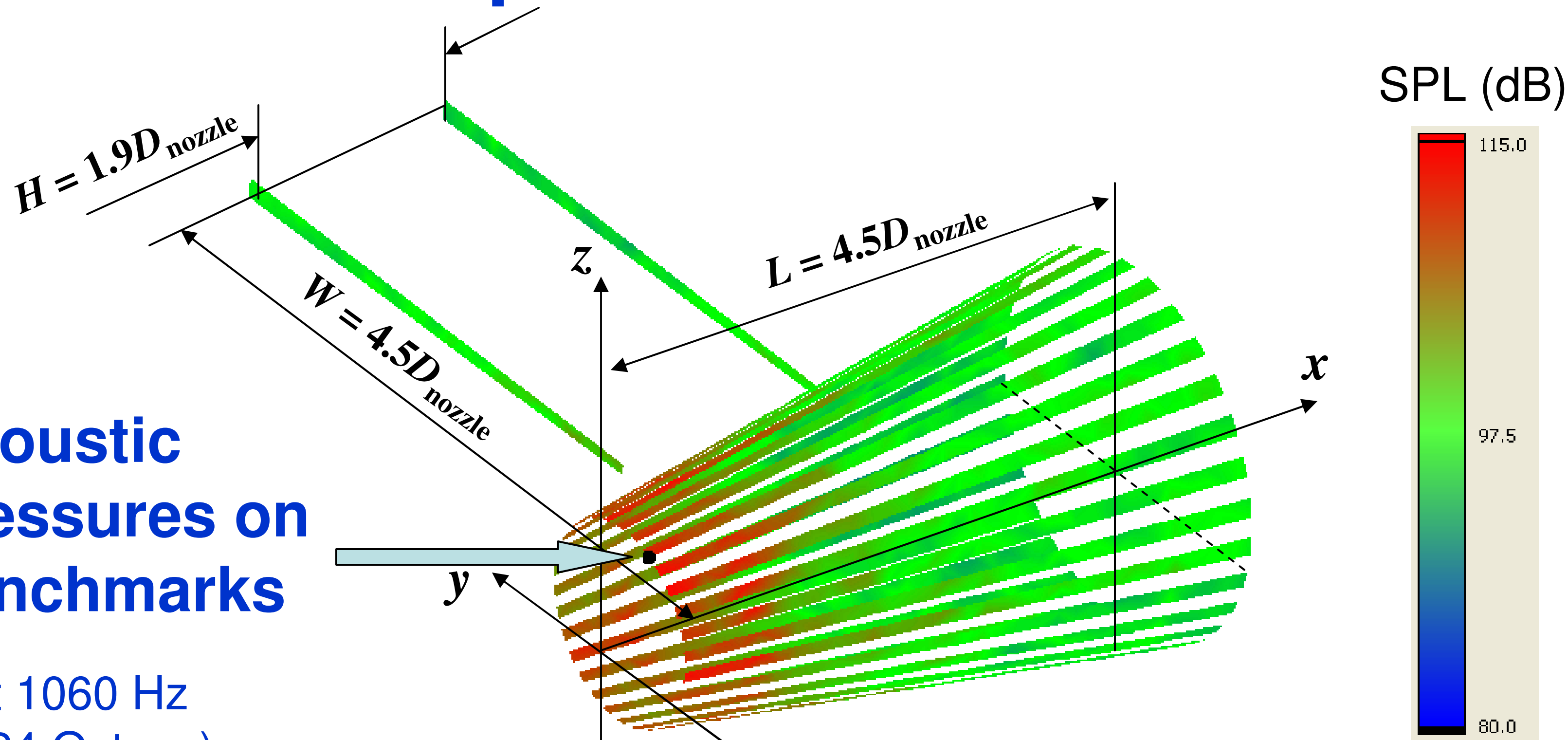


Comparison of Results



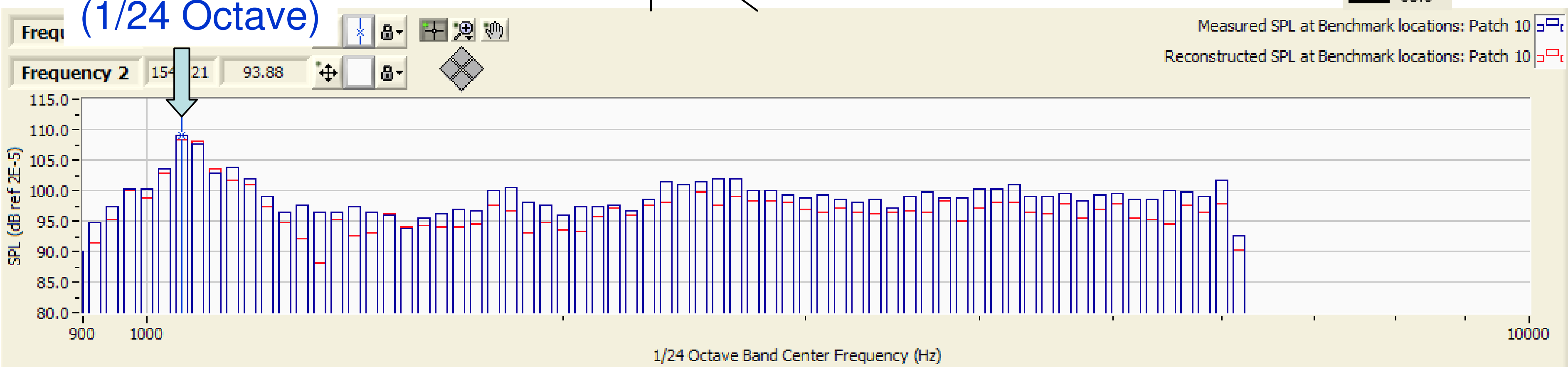
Schematic of test measurement and validation process

Comparison of Results



Acoustic pressures on benchmarks

At 1060 Hz (1/24 Octave)



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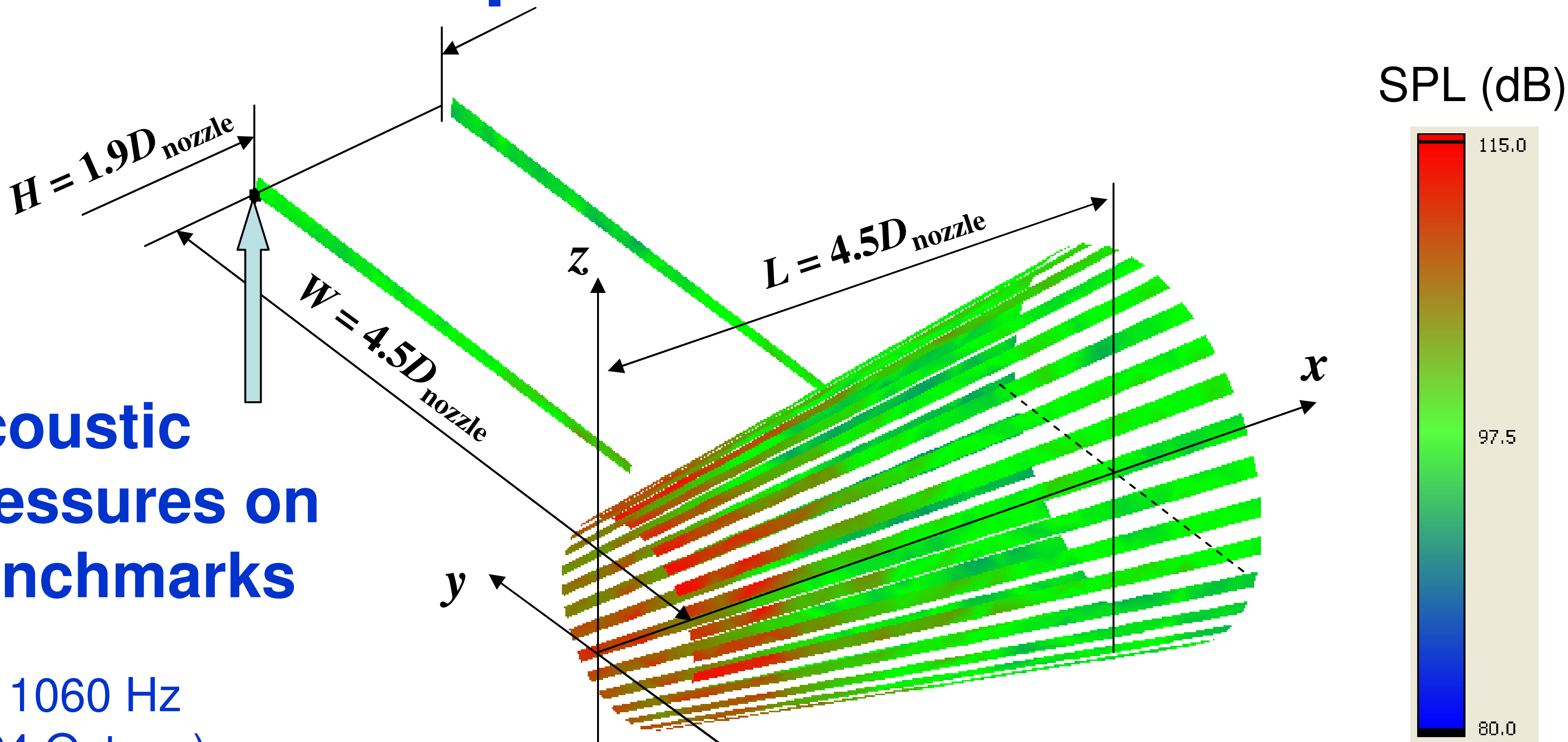

Acoustic pressures on benchmarks

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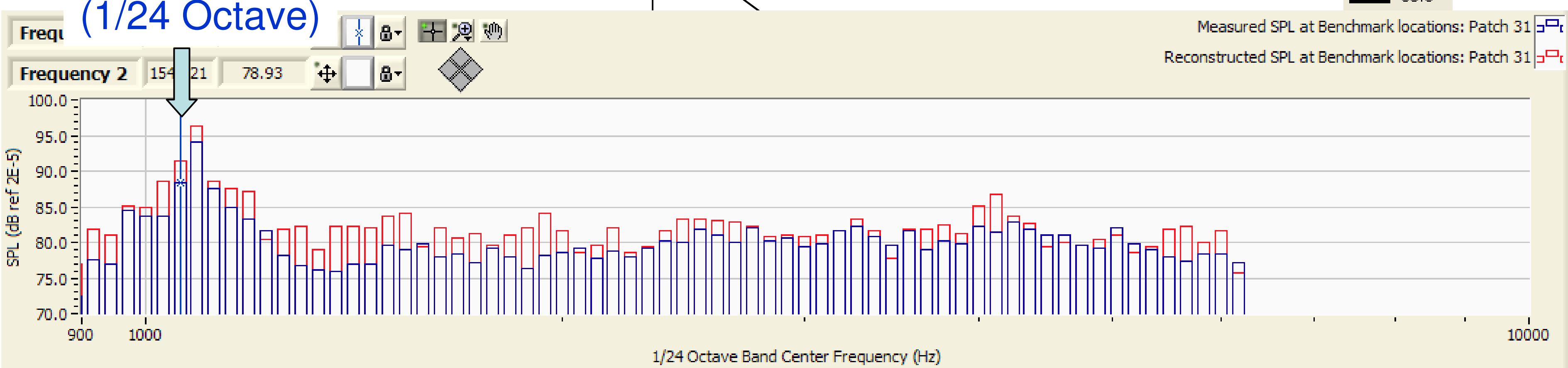
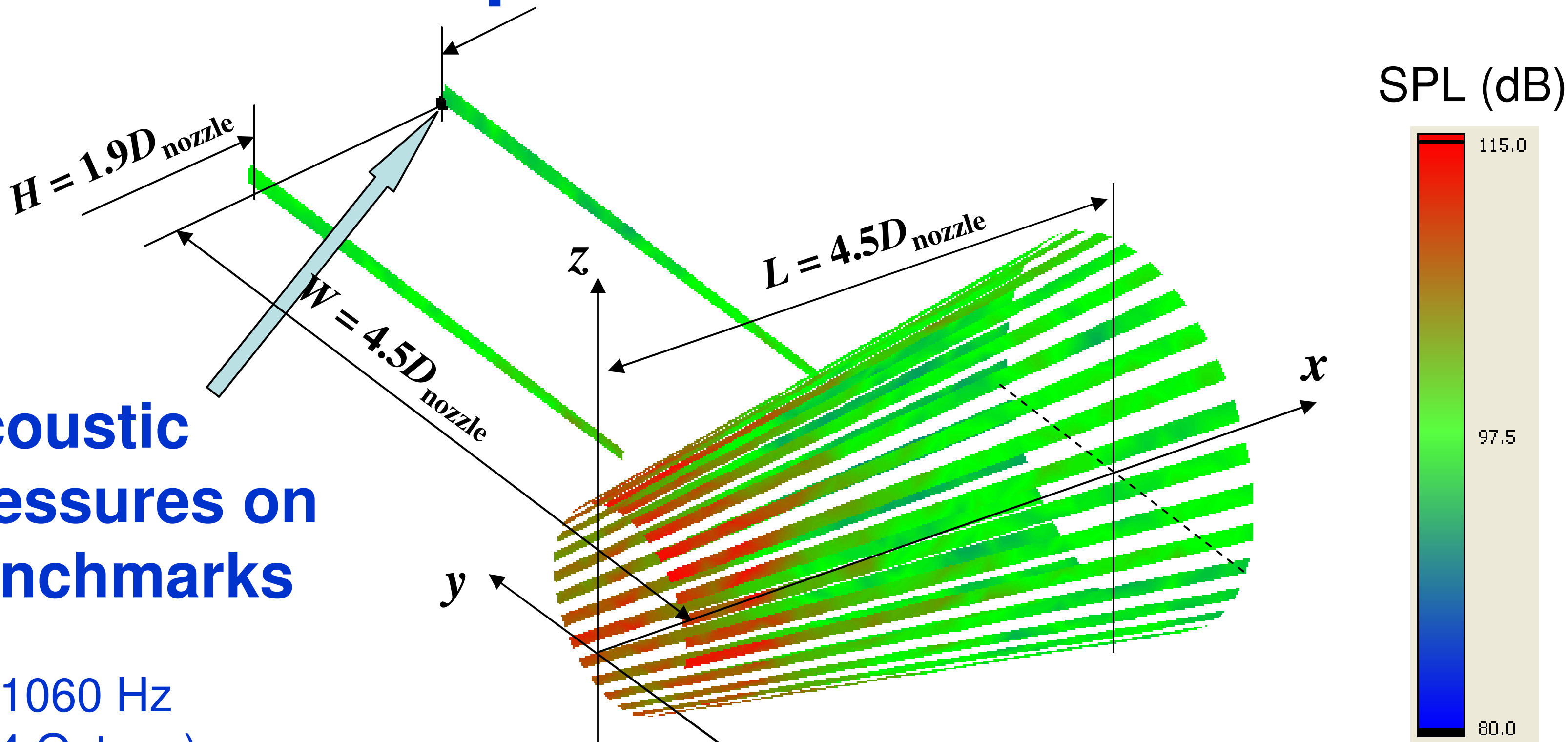


Comparison of Results



Acoustic pressures on benchmarks

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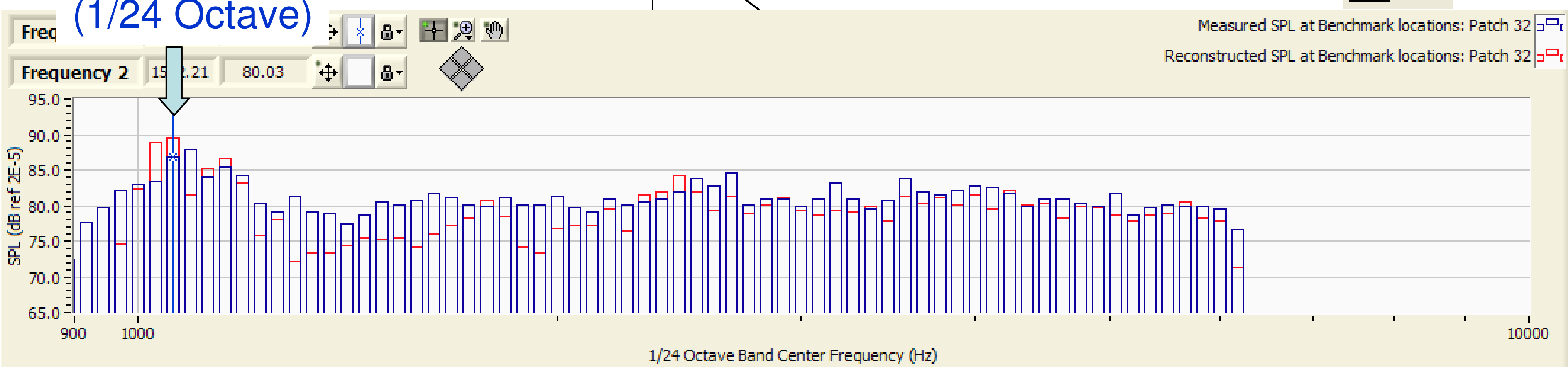
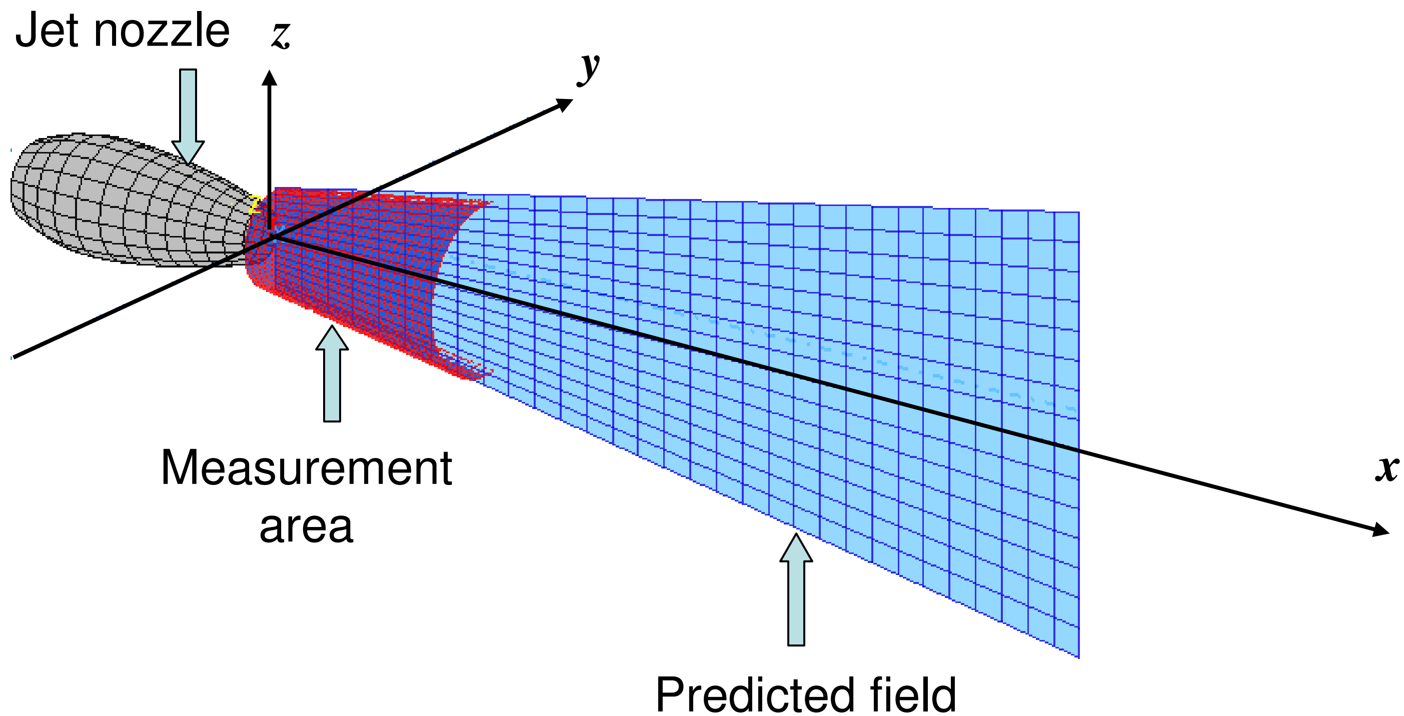


Visualization of Jet Plume Noise

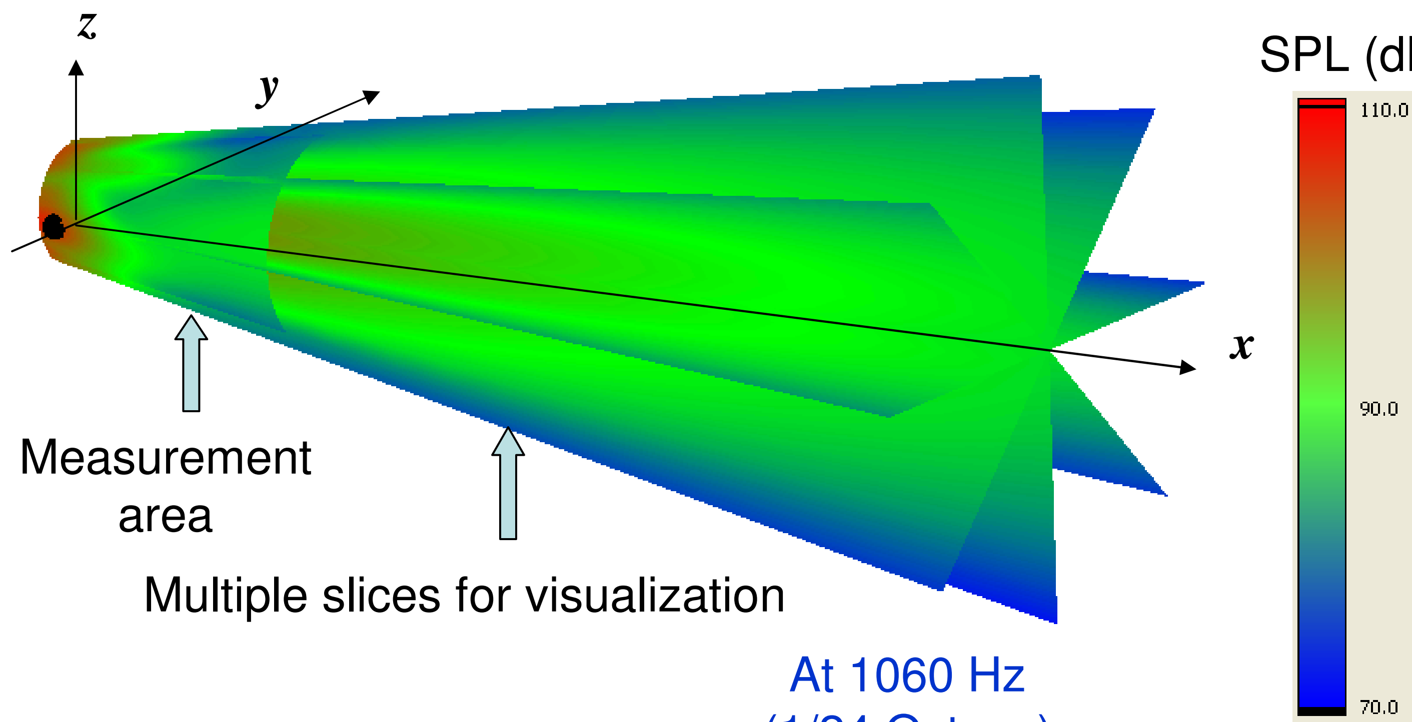
- Once the HELS-based NAH technique was validated, the sound field inside and outside the jet plume in the downstream direction were calculated.
- In this case, we covered the sound field to 17 times the diameter of the jet nozzle, consistent with most studies in turbulent flows even for a supersonic jet.
- In particular, we sliced across the jet plume to visualize the source strength distributions inside the jet plume.
- Note that we can slice across the jet plume at any angle with any increment in the azimuthal direction.
- This enables us to acquire a better understanding of the acoustic characteristics of the jet plume and their source strength distributions.

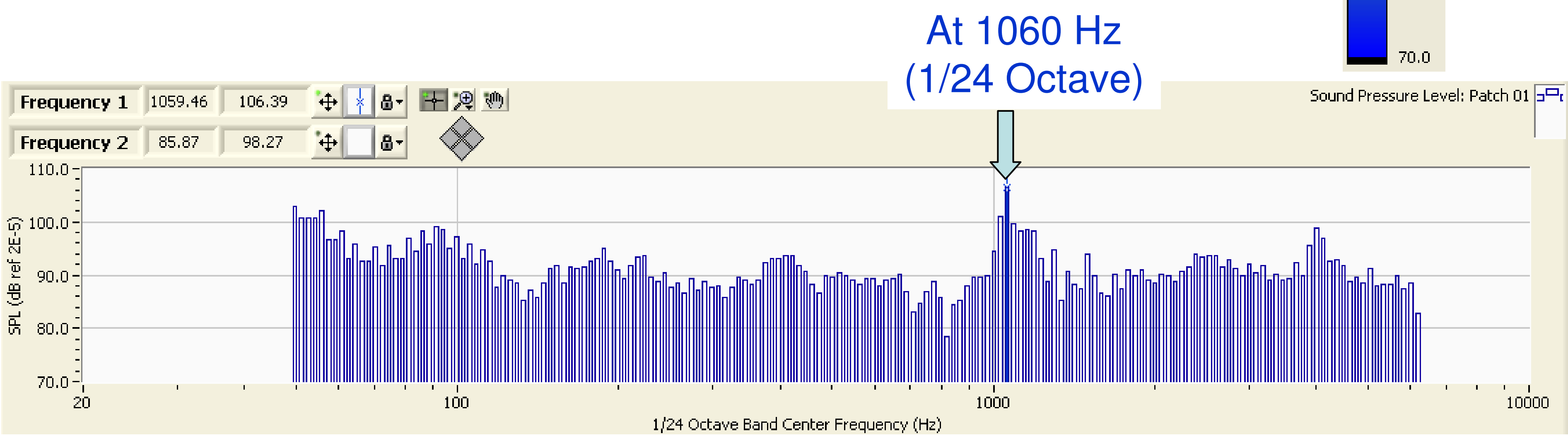
Visualization of Jet Plume Sound Field



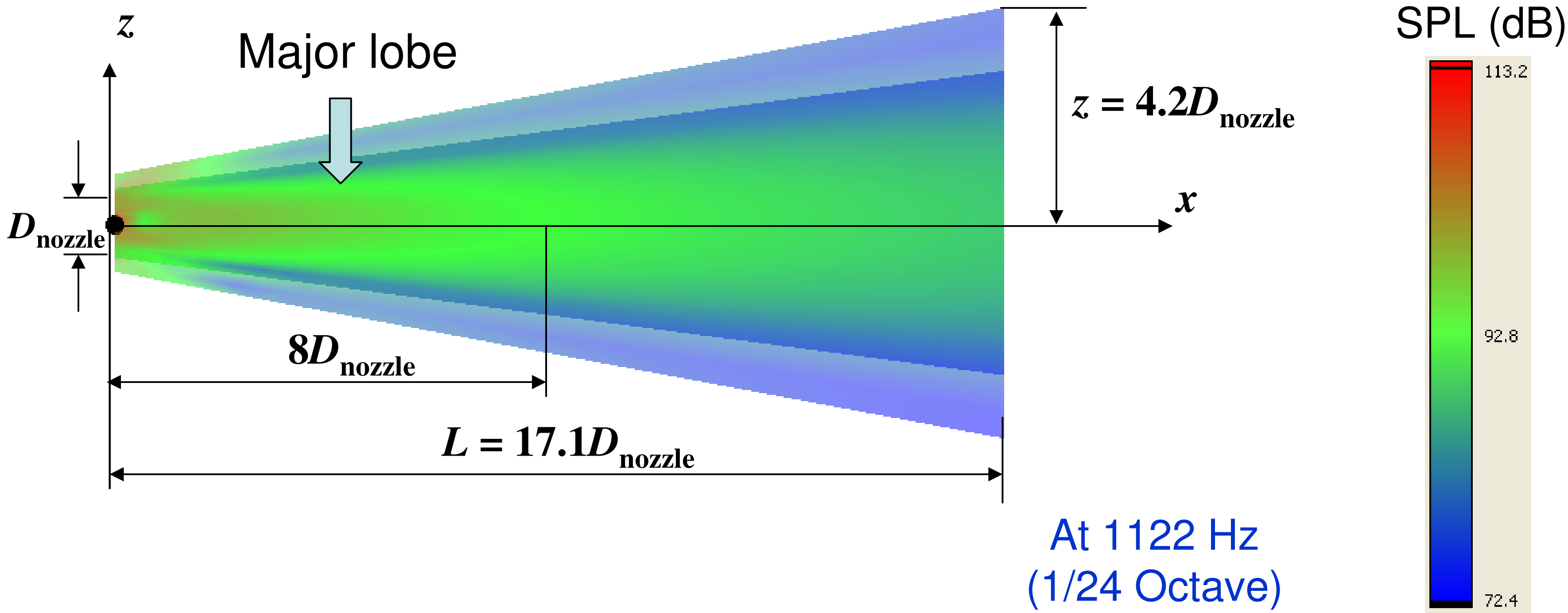
Schematic of jet nozzle, measurement and prediction regions.

Visualization of Jet Plume Sound Field

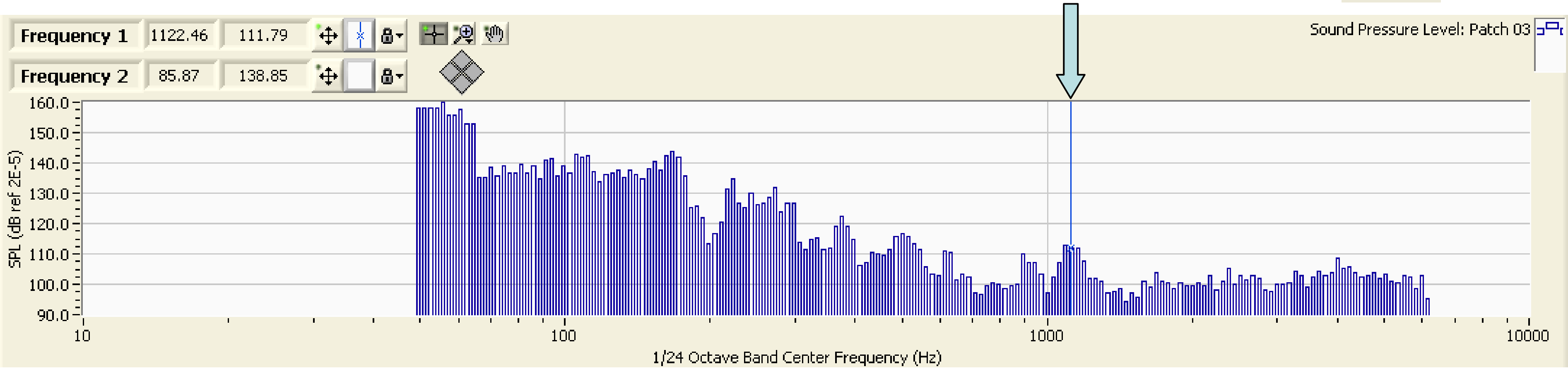




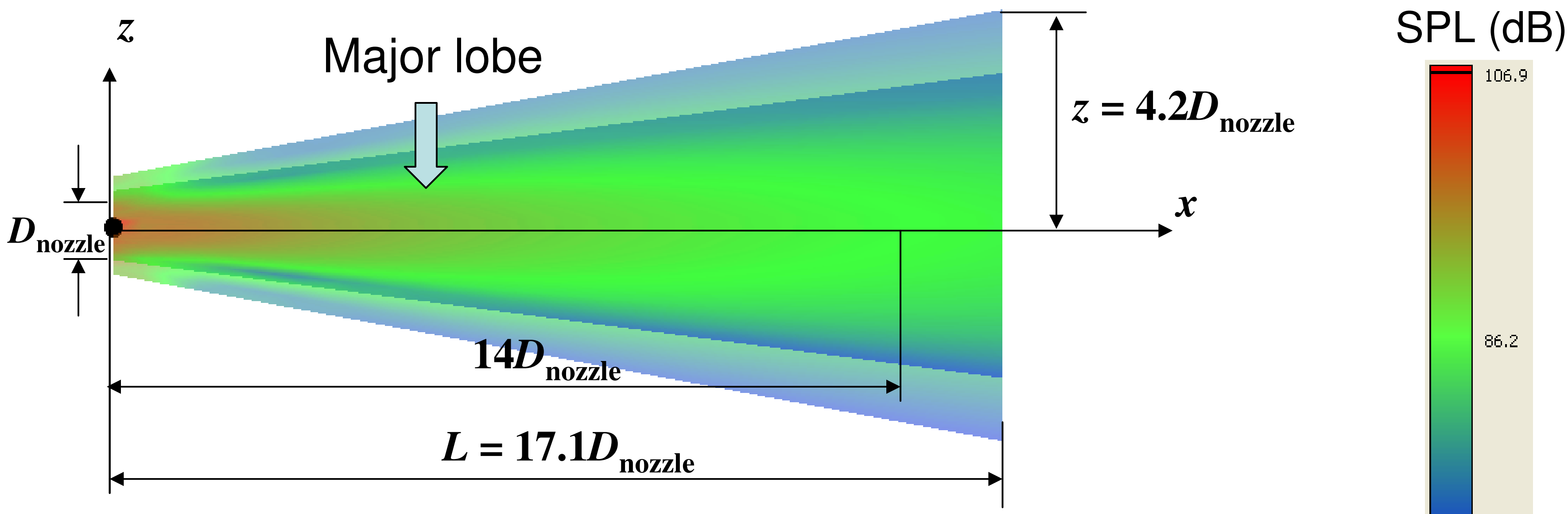
Visualization of Jet Plume Sound Field



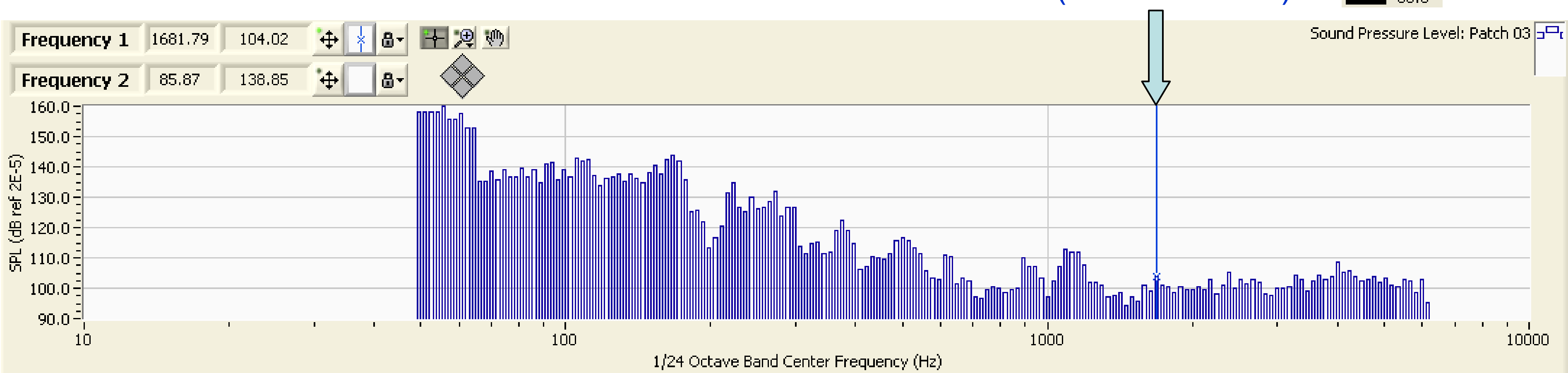
At 1122 Hz
(1/24 Octave)



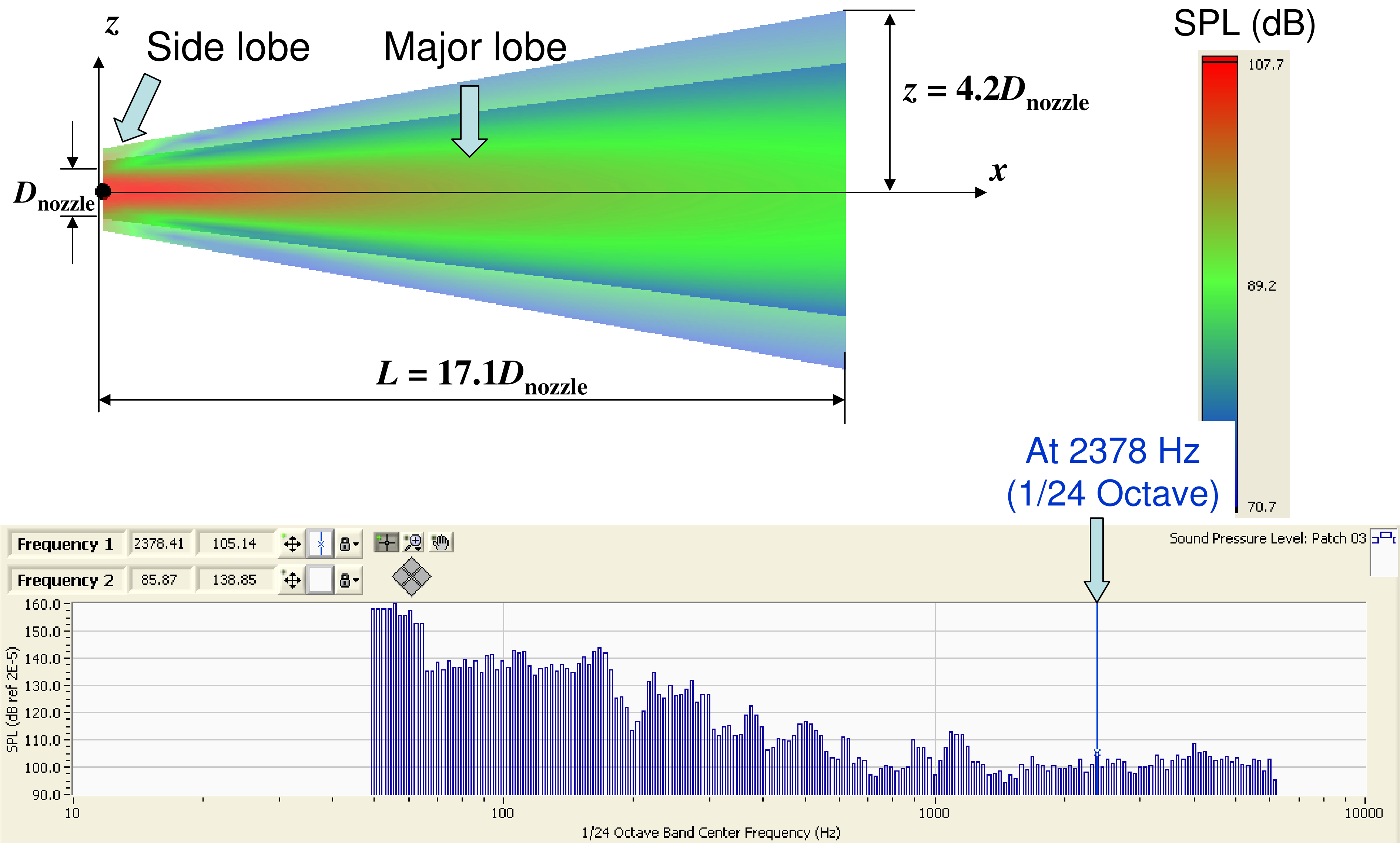
Visualization of Jet Plume Sound Field



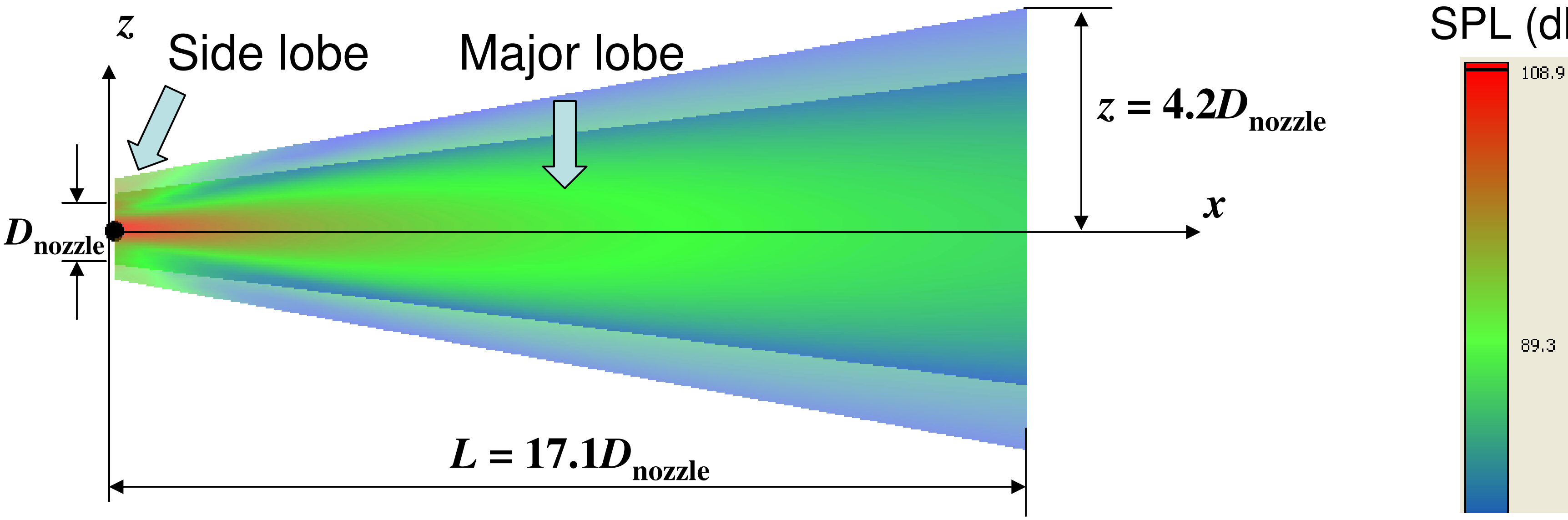
At 1682 Hz
(1/24 Octave)



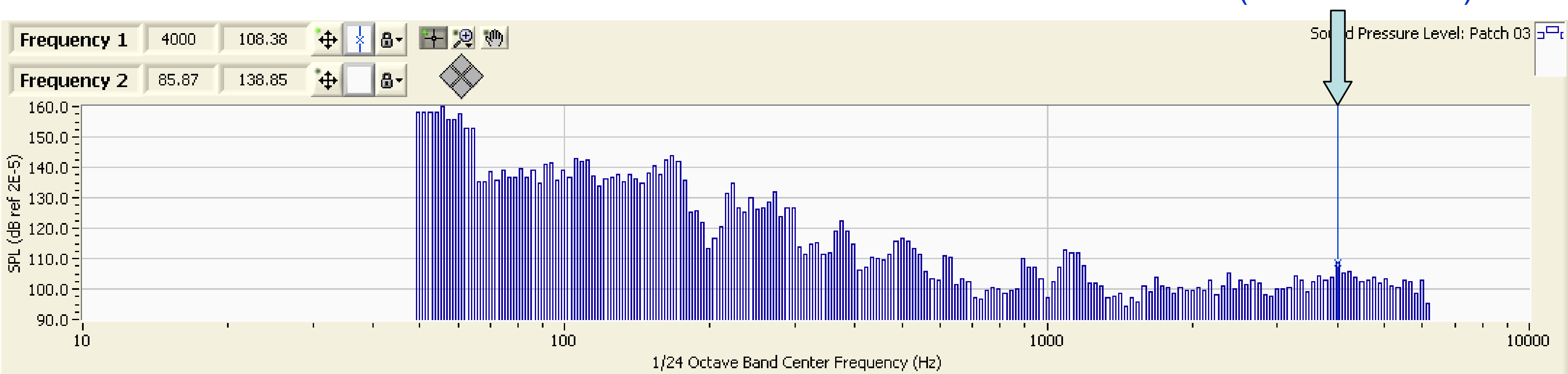
Visualization of Jet Plume Sound Field



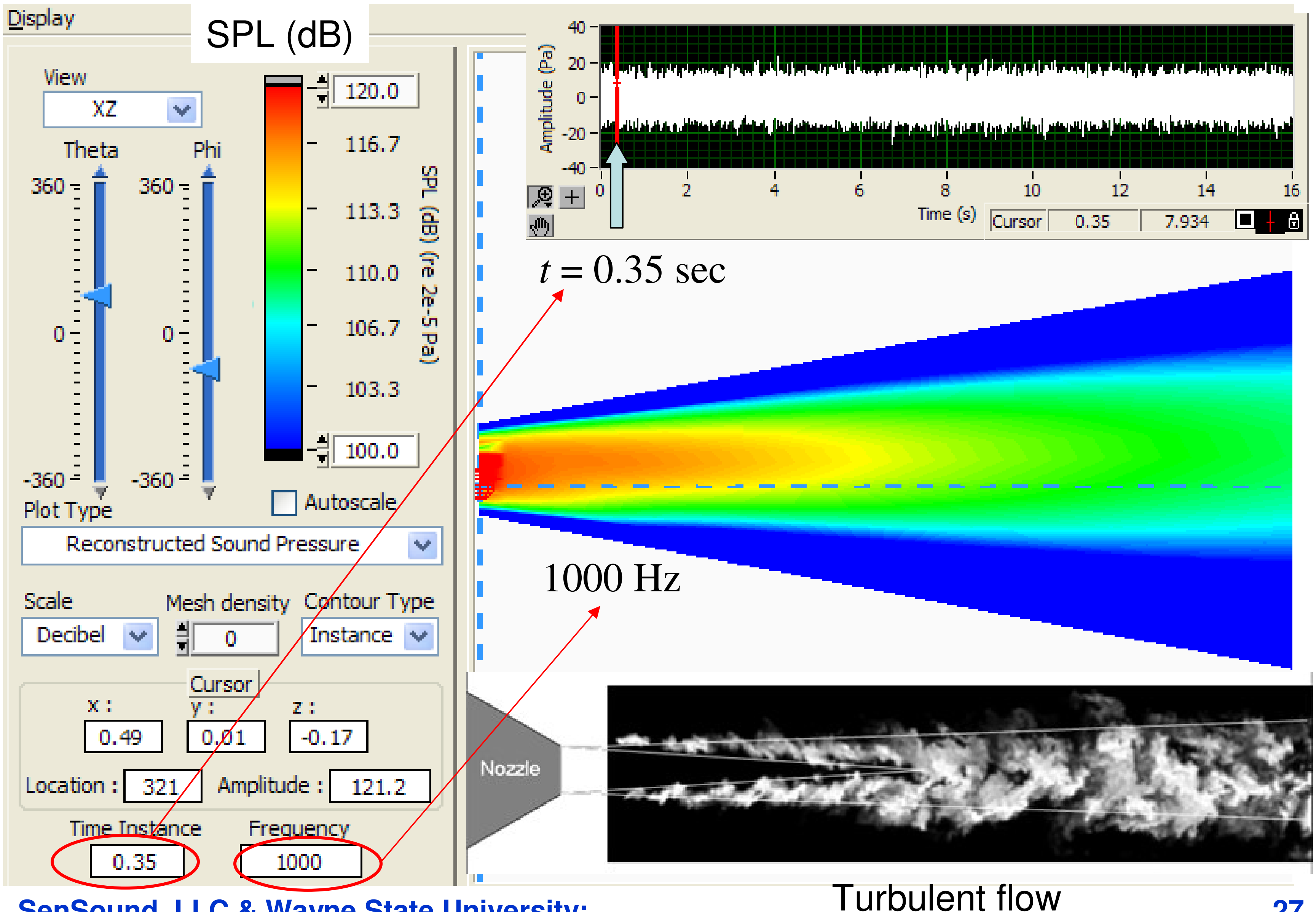
Visualization of Jet Plume Sound Field



At 4000 Hz
(1/24 Octave)

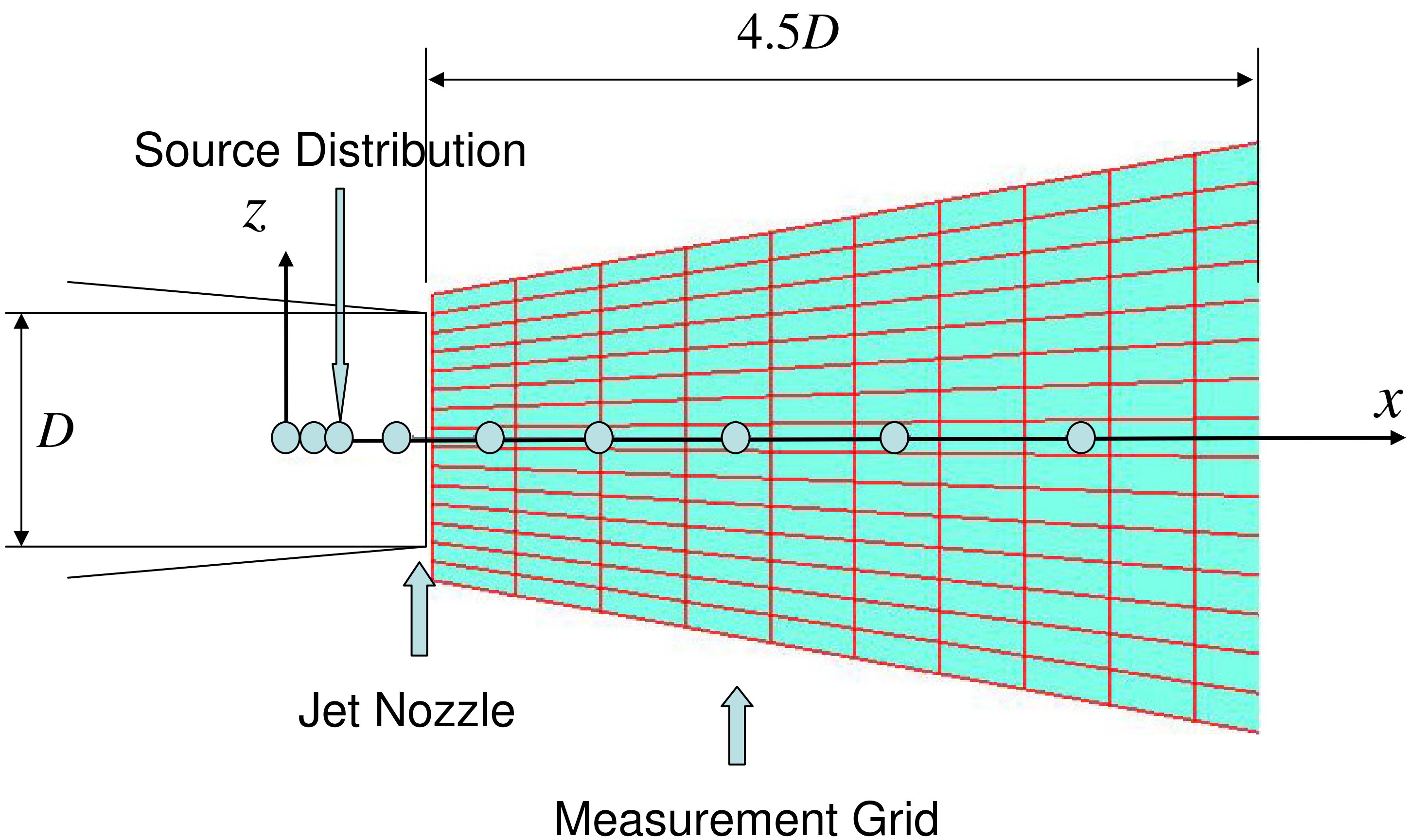


Visualization in Real Time

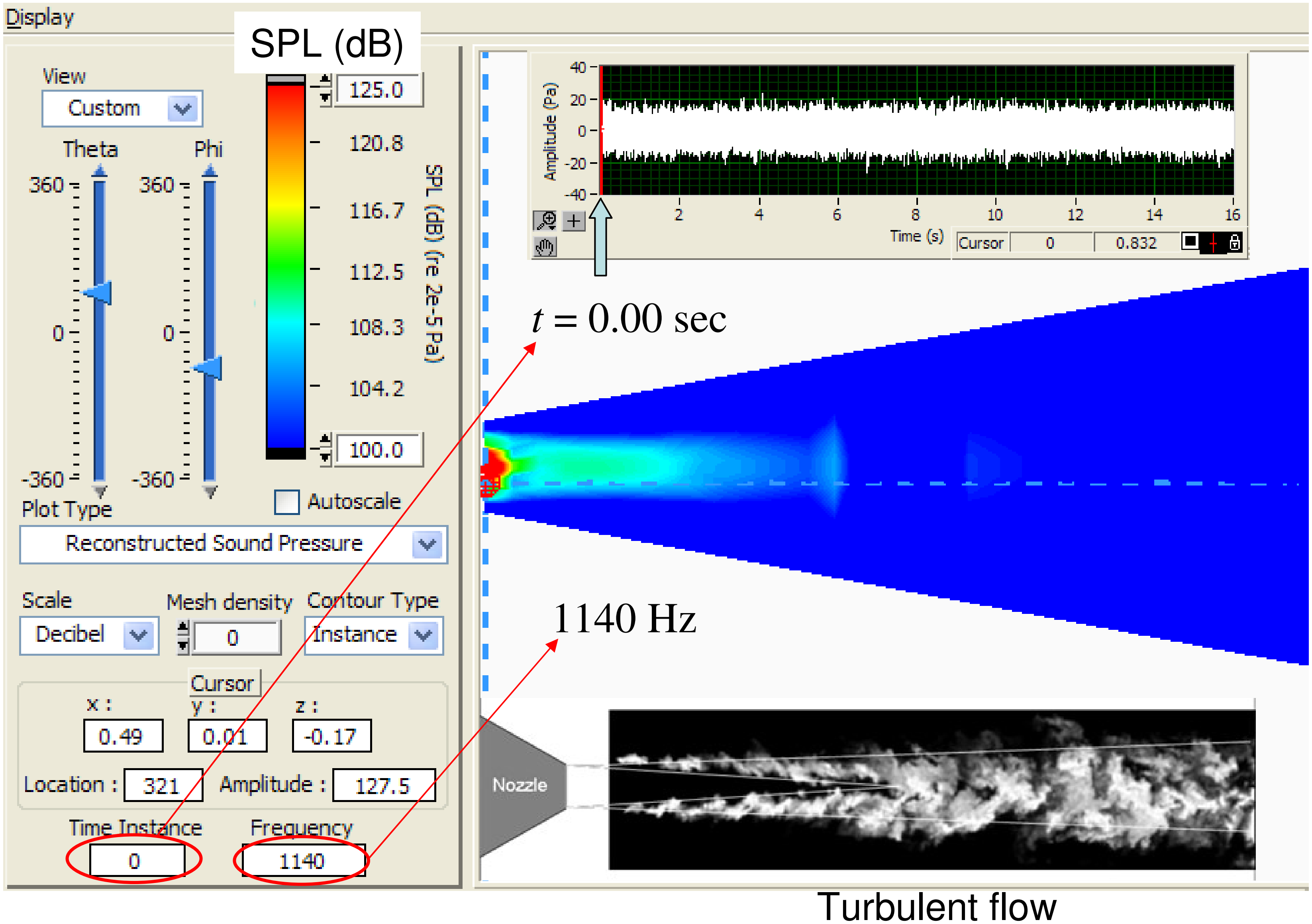


A Modified HELS Method

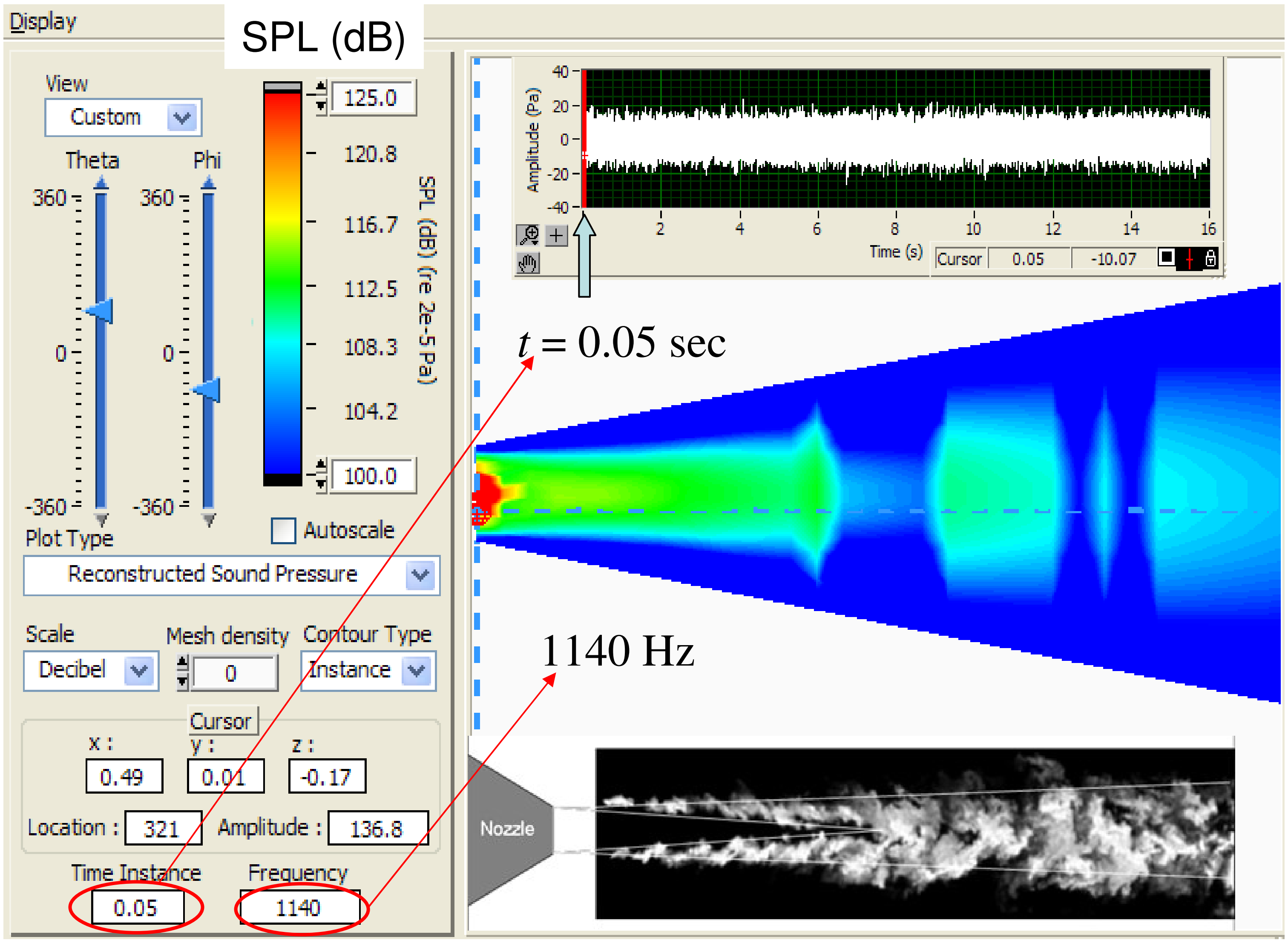
A sound field is described by multiple expansions with respect to many virtual sources distributed inside the jet plume.



Visualization in Real Time

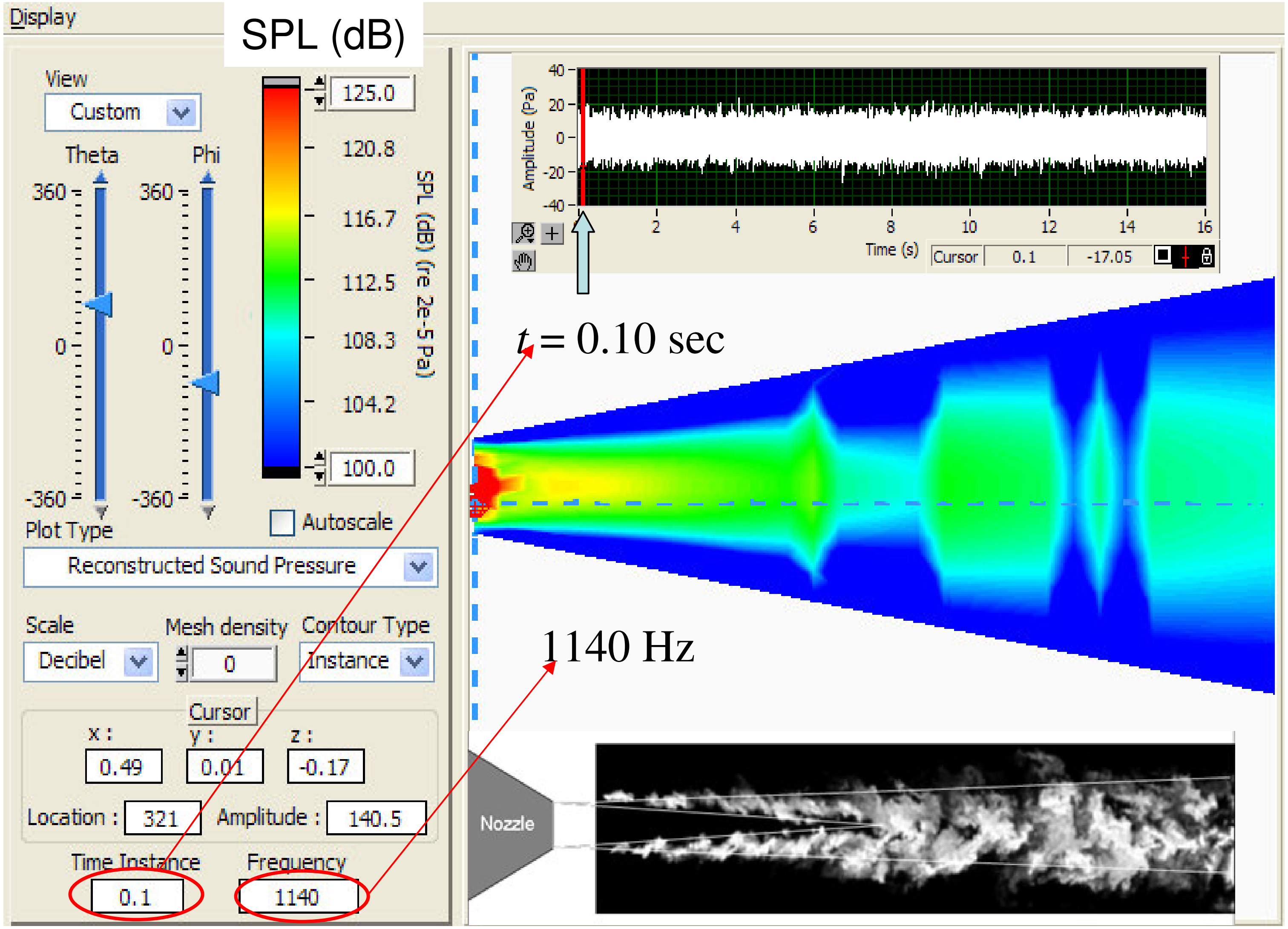


Visualization in Real Time



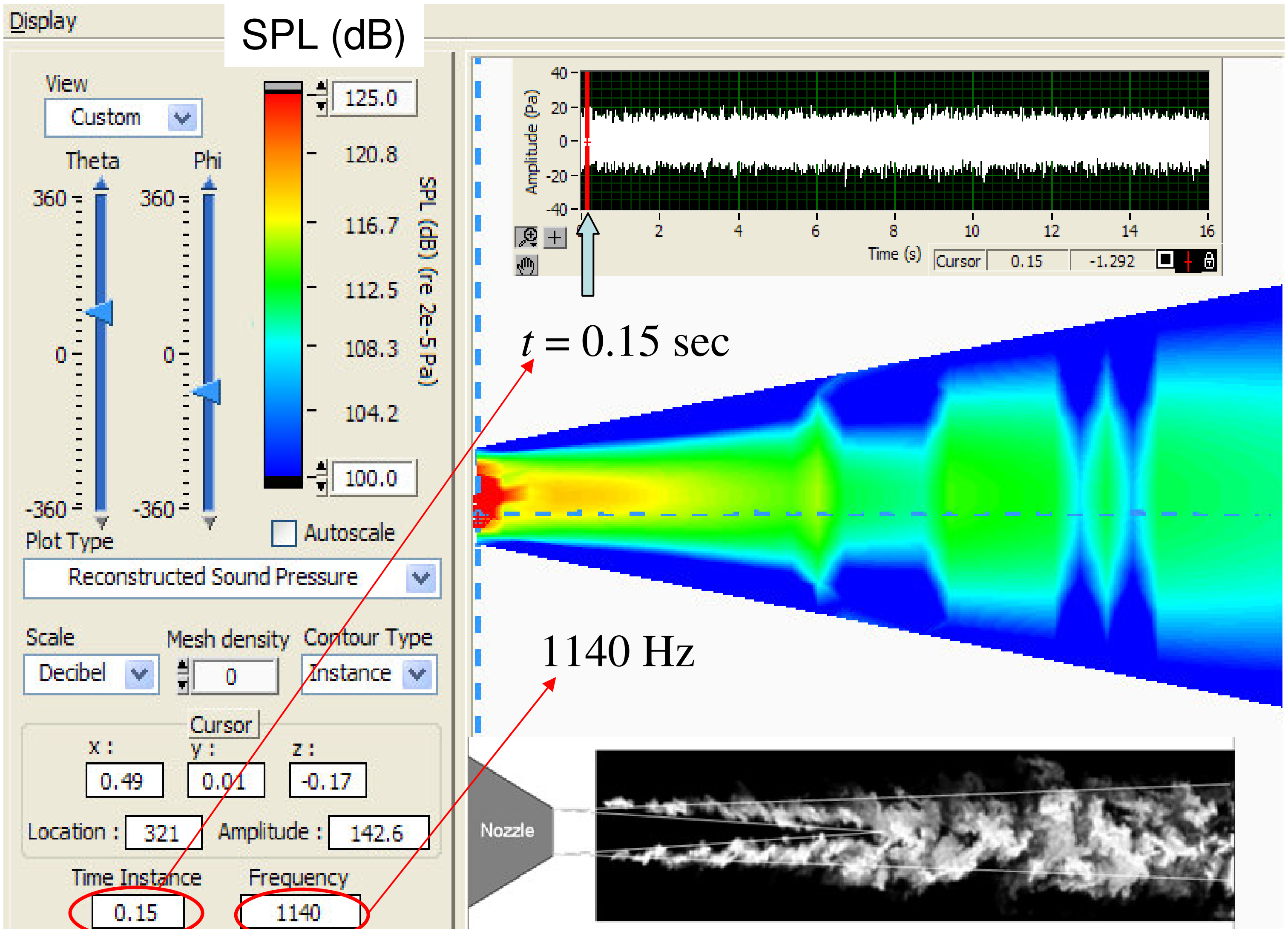
Turbulent flow

Visualization in Real Time



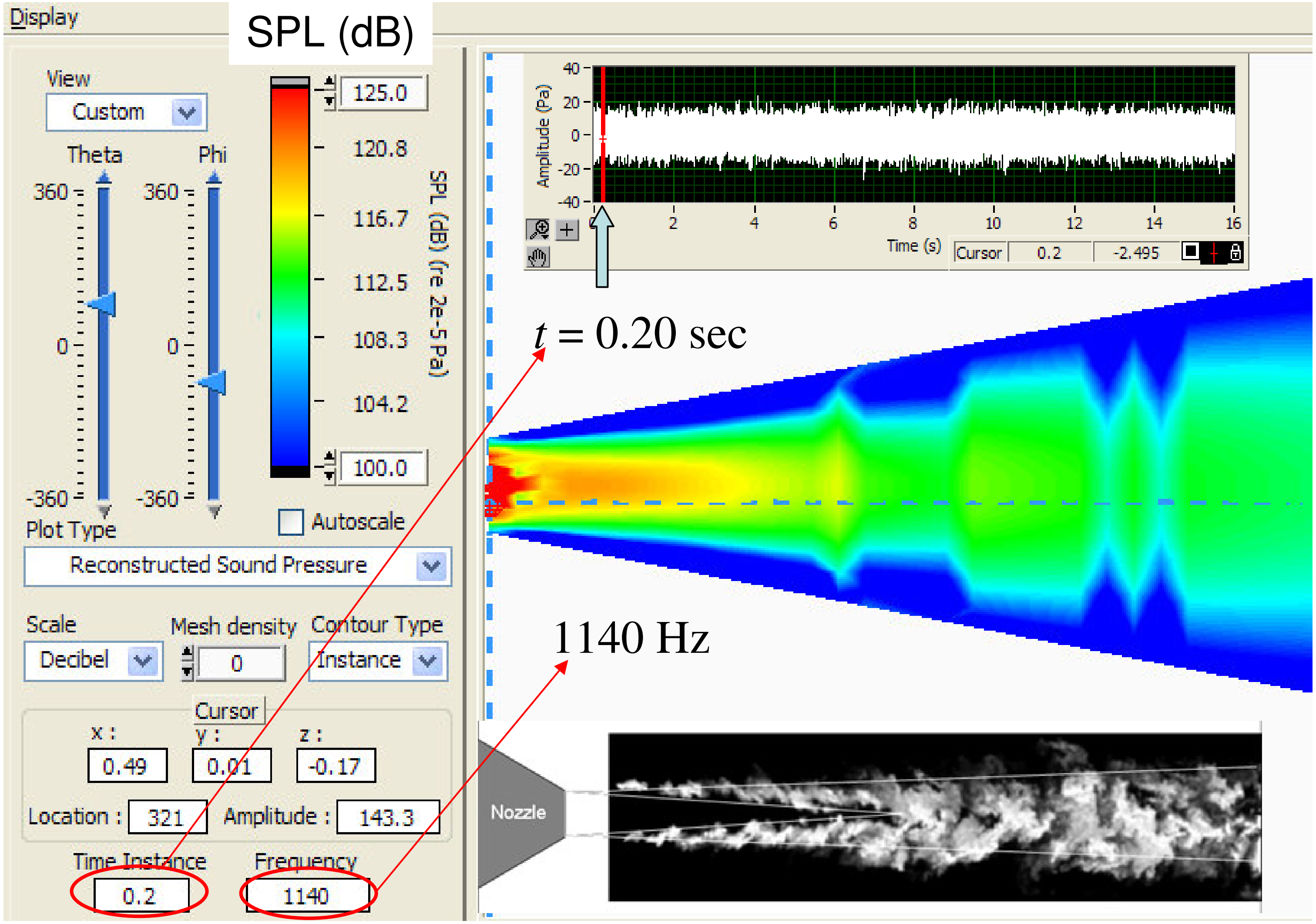
Turbulent flow

Visualization in Real Time



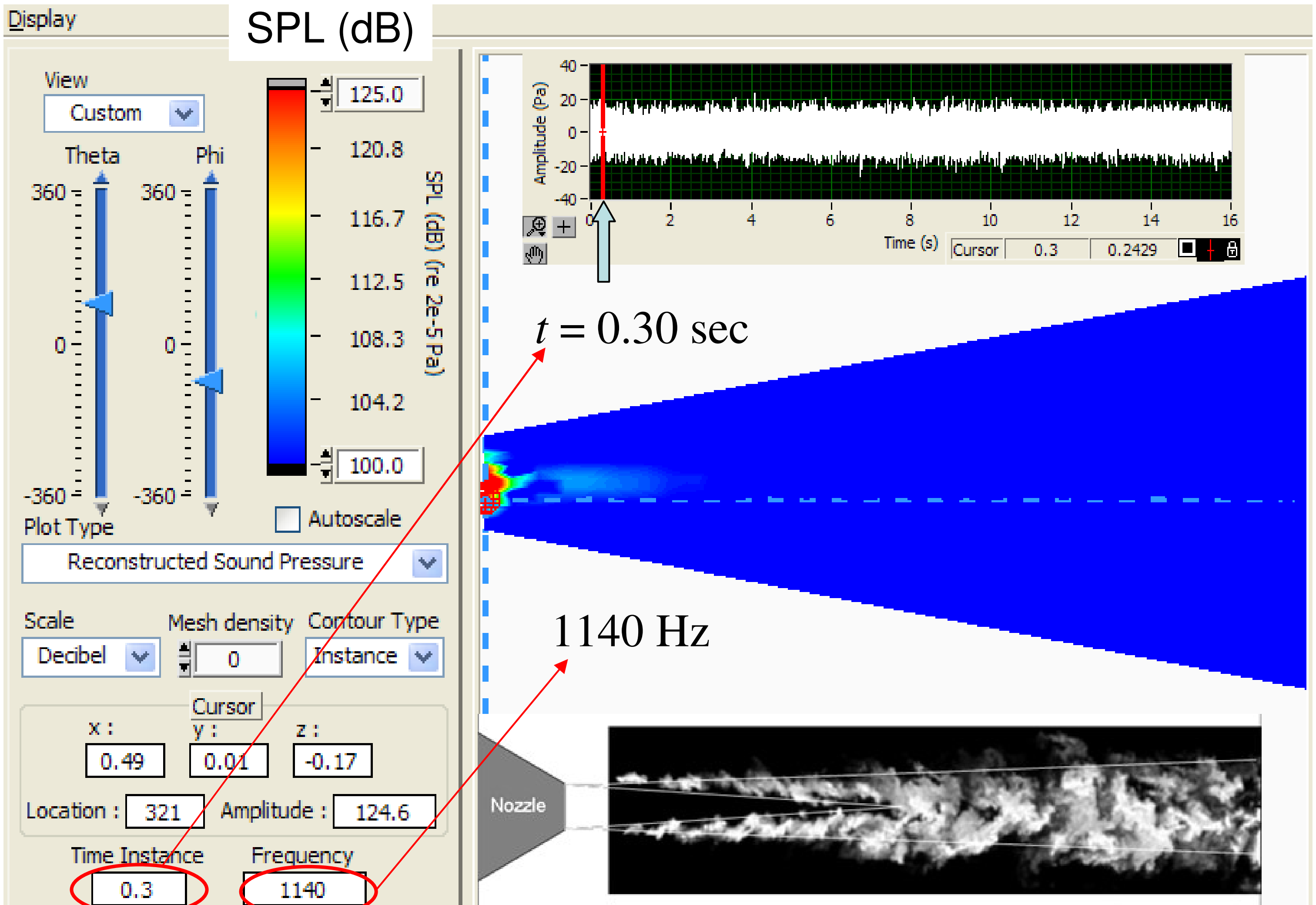
Turbulent flow

Visualization in Real Time



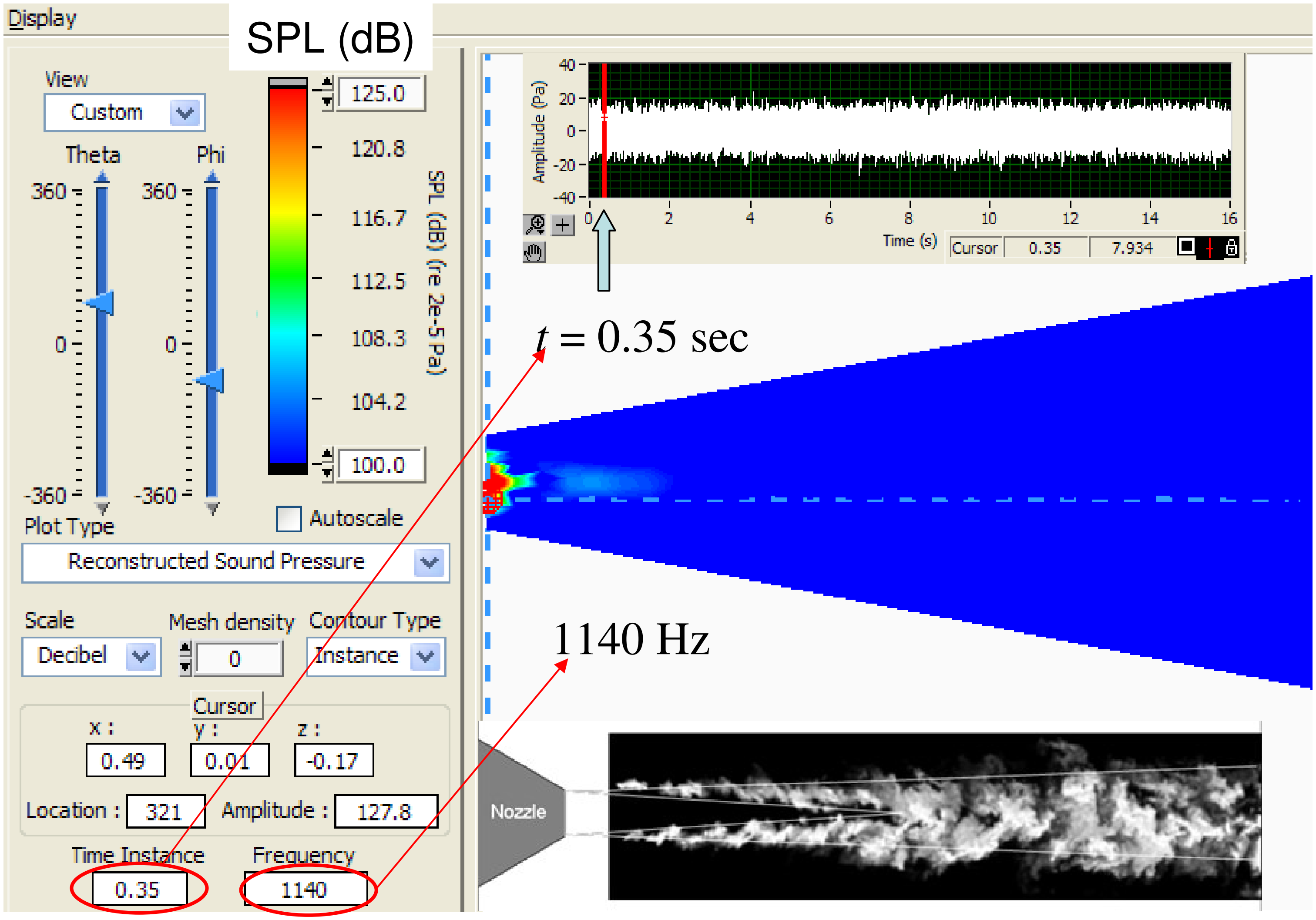
Turbulent flow

Visualization in Real Time



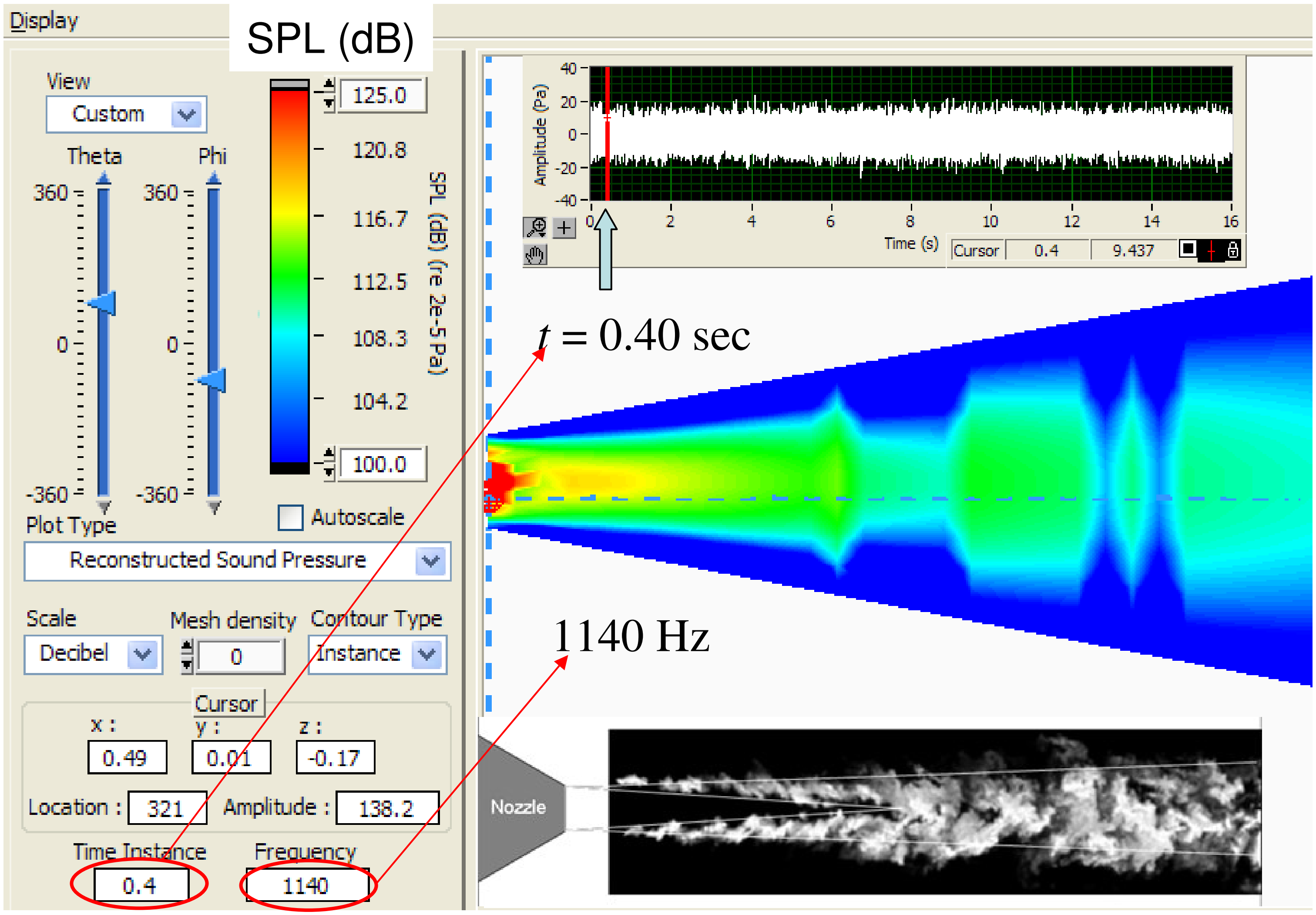
Turbulent flow

Visualization in Real Time



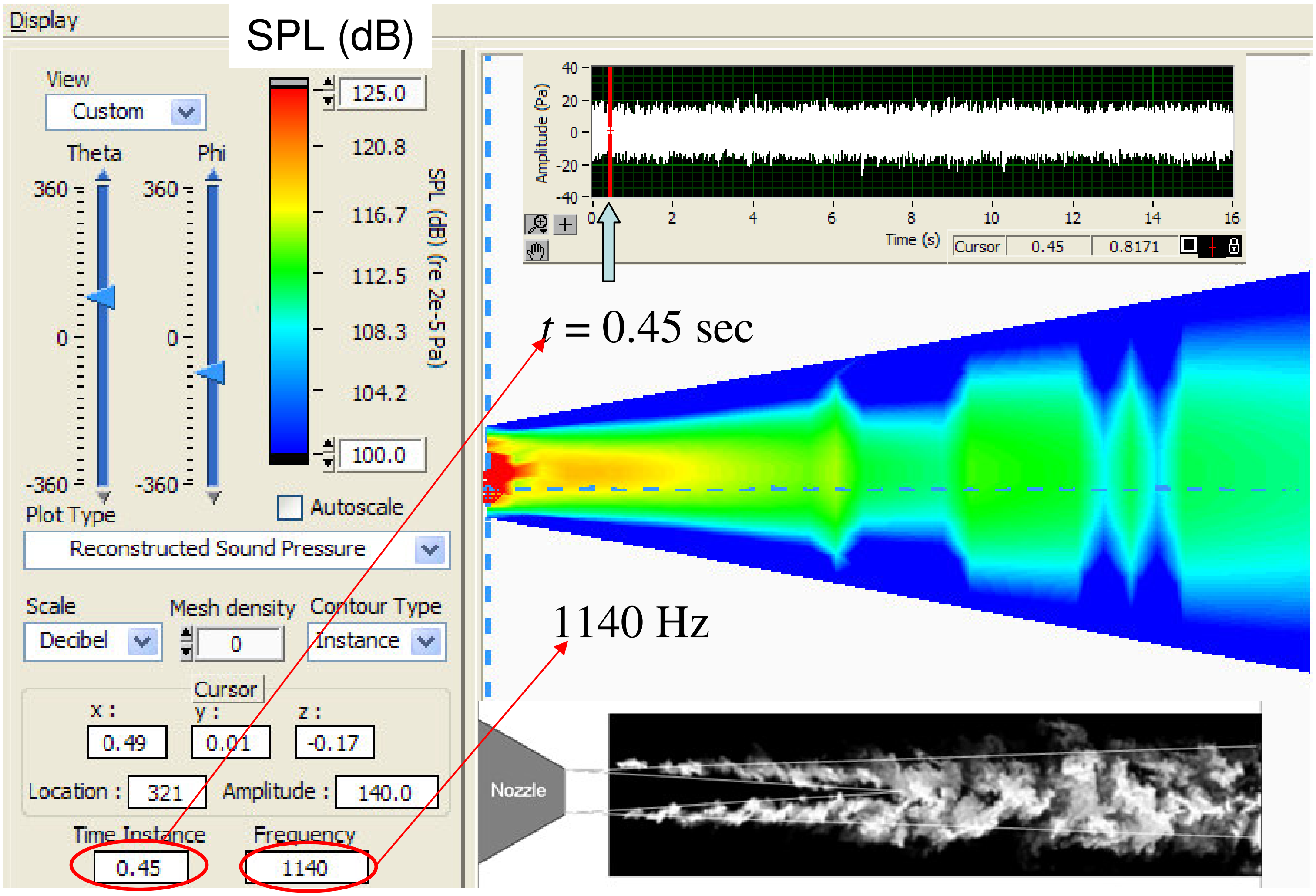
Turbulent flow

Visualization in Real Time



Turbulent flow

Visualization in Real Time



Turbulent flow

Results Discussion

- Although SenHELS and SenFANS employ very different acoustic models, the main feature, namely, the main lobe of acoustic radiation inside the jet plume is the same.
- This implies that there is a high possibility of an existence of strong radiation in the asymmetric axis of the jet nozzle at this subsonic jet flow speed.
- However, the acoustic field reconstructed by SenHELS is smooth and continuous as waves travel in downstream; whereas the acoustic field reconstructed by SenFANS consists of packets of waves in the downstream direction.
- The acoustic field reconstructed by SenFANS seems to be more consistent with the turbulent flow ejected from a nozzle than that reconstructed by SenHELS.

Current Limitations

- In this Phase I investigation, we used probe microphones with relatively low dynamic ranges. This restricted us to a subsonic jet only. Therefore, no information regarding the feasibility of the proposed software for a supersonic jet flow is available.
- The acoustic pressures were measured separated, but not simultaneously around the jet plume. This may cause distortions in the reconstructed acoustic images in the azimuthal direction.
- The locations of measurement microphones were not specified accurately, which is the main reason for the errors in the amplitudes of the reconstructed acoustic pressures.

Current Limitations

- Contributions from the jet engine and turbulence flow were mixed together in reconstruction. Hence, there is no way of knowing the exact acoustic characteristics of jet plume.
- Because tests were conducted for a subsonic jet, there is no information available from this Phase I investigation about the shock wave structure inside jet plume and the space-time-frequency dependence of the acoustic field generated by a supersonic jet plume.

Next Steps

- Need high-performance probe microphones with much larger dynamic ranges so that they are applicable for a supersonic jet.
- Need better front-end data acquisition system so that much wider frequency range signals can be obtained. This is especially important for a supersonic jet.
- Need to design and fabricate much stronger test stands and to acquire corresponding control devices to facilitate automatic or semi-automatic data acquisition.
- This type of data acquisition system is critical for carrying out tests on a supersonic jet plume, since it is dangerous to expose a human being under very high SPL values.

Expected Results

- With high-performance probe microphones, better front-end data acquisition system, better test stands and more efficient data acquisition process, we will examine the feasibility of using SenFANS to describe the acoustic characteristics of a supersonic jet plume.
- The proposed tests are expected to yield new insight into the acoustic characteristics, shock wave structure, sound radiation angles, and space-time-frequency dependence of a supersonic jet plume that has never before been made available.