URANS for Predicting Resonances in Jets

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Introduction: Why Unsteady RANS?

- Two Cases:
  - Over-expanded convergent-divergent nozzles
  - Jet and surface interaction

- Both cases exhibit resonance (e.g. tones) during experiment
- Typically, these are candidates for Large Eddy Simulation
  - However, LES involves greater computational costs

- Can we predict the resonance using Unsteady Reynolds-Averaged Navier-Stokes (URANS) simulations?
- Can the URANS predictions give us further insight into the mechanisms that cause resonance? (e.g. ability to observe flowfield details)

Unsteady CFD of Over-Expanded Convergent-Divergent Nozzle

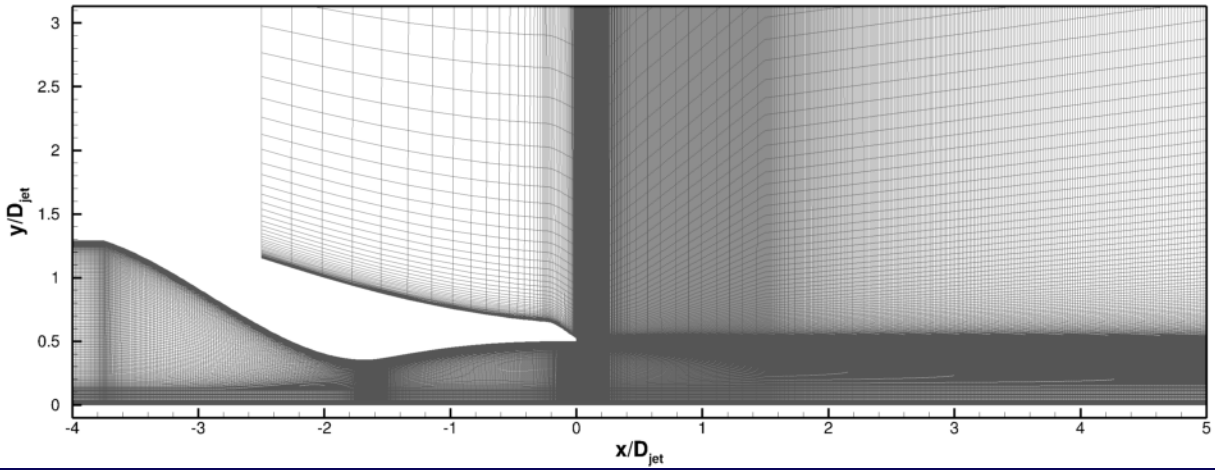
Purpose:

- Characterize turbulence and determine mechanisms that cause transonic tones and excess broadband noise (EBBN) in some convergent-divergent (C-D) nozzles at over-expanded conditions

Method:

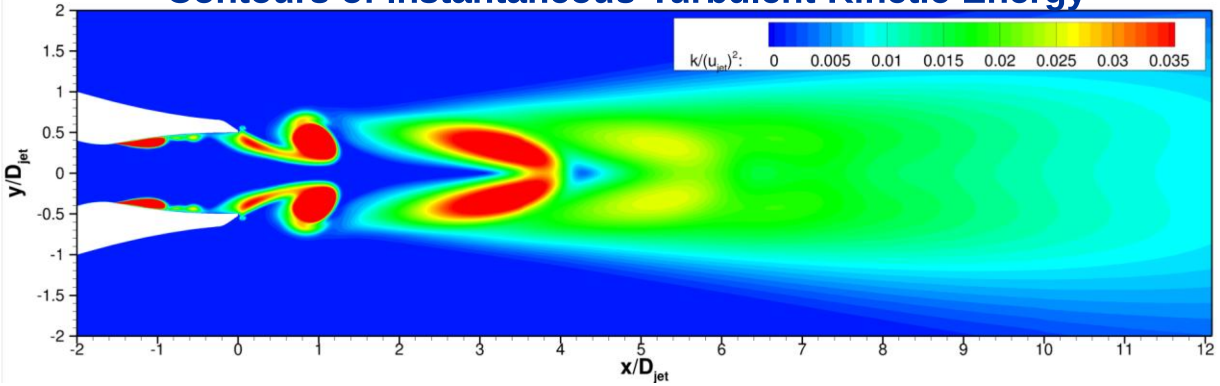
- Mach 2.2 C-D nozzle
  - D_{jet}=2 in
- Inflow:
  - M_{jet}=0.61
  - NPR=1.286
  - T0=530 deg R
- Quiescent freestream
- Unsteady RANS
  - Wind-US v. 3.0
  - SST turbulence
  - Δt=1e-7 s
- Axisymmetric grid
  - Structured
  - 10 D_{jet} radially, 30 D_{jet} dowstream
  - 428,800 cells
  - y^+<1

Mach 2.2 Nozzle Grid

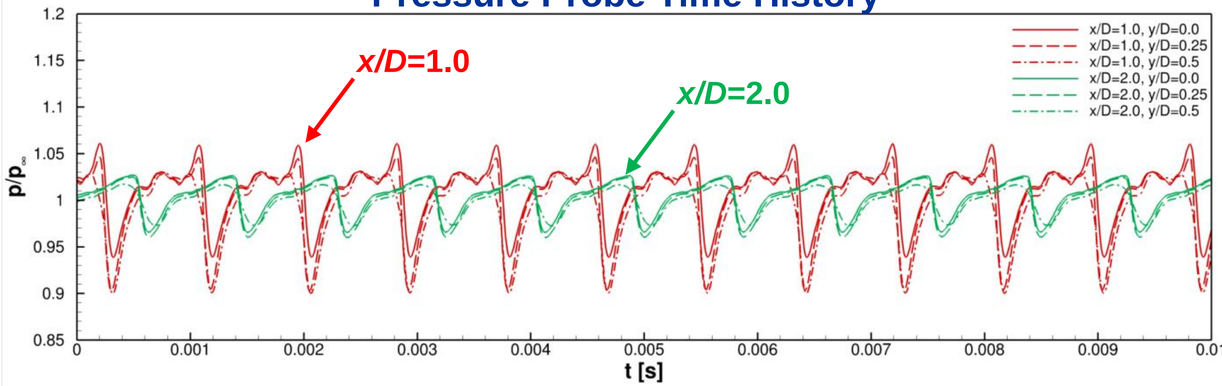


Over-Expanded C-D Nozzle: Unsteady Results

Contours of Instantaneous Turbulent Kinetic Energy



Pressure Probe Time History

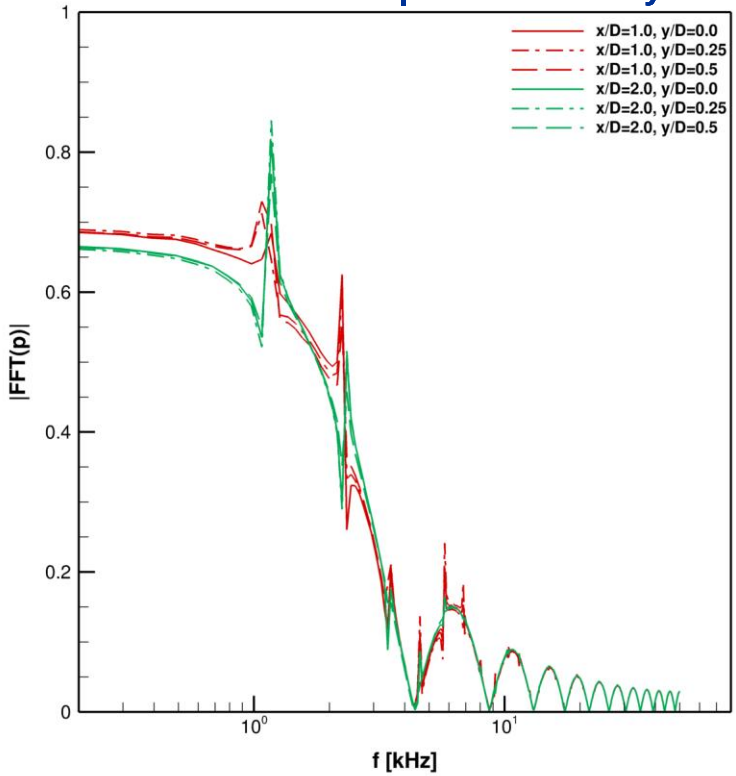


Observations:

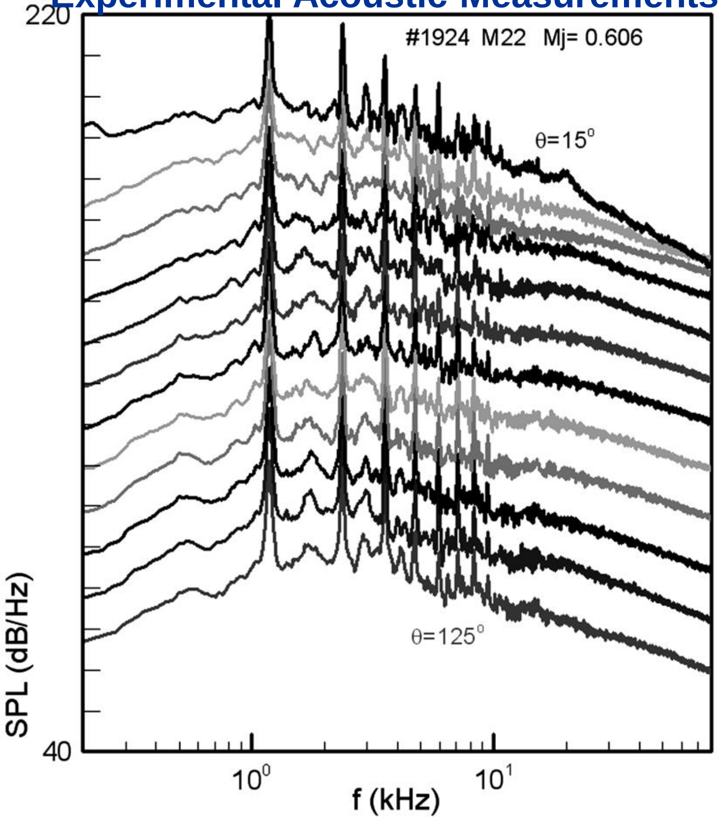
- Evidence of periodic unsteady flow present in instantaneous flow contours
- Shock and separation region inside nozzle oscillate axially
- Unsteady pressure probe shows period of ~8.73e-4 s, ~1145 Hz

Over-Expanded C-D Nozzle: URANS vs Experimental Resonances

URANS Power Spectral Density



Experimental Acoustic Measurements



(Zaman, Bridges, Brown, *AIAA Journal*, Jan 2010)

Observations:

- Power spectral density (PSD) analysis shows resonance of ~1175 Hz
- Zaman observed resonant frequency of ~1130 Hz

Over-Expanded C-D Nozzle: Conclusions

- Unsteady RANS can predict resonance for jet flows with clear/strong resonance
  - Close prediction of resonance frequency observed experimentally
- With Unsteady RANS, we observe what is happening inside the nozzle
  - The shock and separation region move axially, causing vortices to roll out of the nozzle

Future:

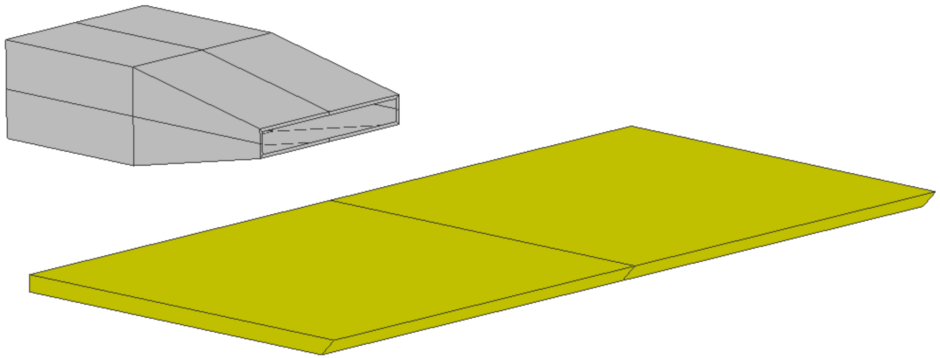
- Conduct experiment in CW17 to fill out data set for M2.2 nozzle to characterize turbulence field for EBBN found in over-expanded C-D nozzles
- Run further Unsteady RANS simulations of other over-expanded C-D nozzles/conditions to verify approach

This work was supported by High Speed, Airport Noise Project.

Unsteady CFD of Rectangular Jet and Surface Interaction

Purpose:

- Better understand the mechanisms that cause resonances for rectangular jets interacting with a flat surface

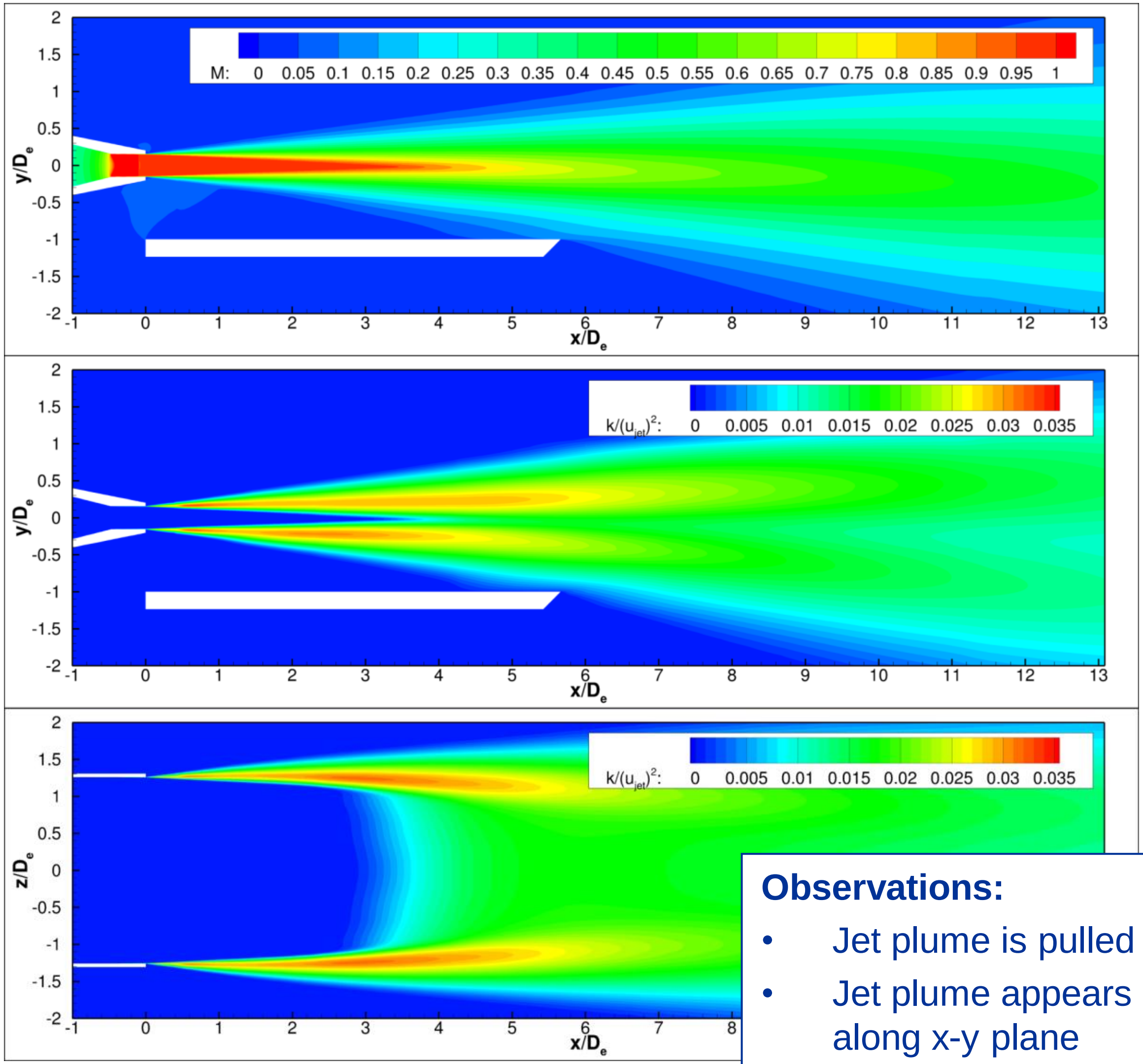


Method:

- Rectangular, convergent nozzle
  - AR=8
  - D_e=2.12 in
- Jet exhausts over flat plate, 24 in W x 12 in L
  - Plate LE in-line with nozzle exit plane (x_{TE}/D_e=5.66)
  - Plate located 2.12 in (1 D_e) below nozzle centerline
- Inflow conditions:
  - M_{jet}=0.99
  - NPR=1.8709
  - T_0=530 deg F
- Quiescent freestream

- Unsteady RANS
  - Wind-US
  - Δt=1.0e-7 s
  - SST Turbulence
- Full 3D grid
  - Structured
  - 89 million cells
  - 10 D_e vertically, 50 D_e spanwise, 80 D_e downstream

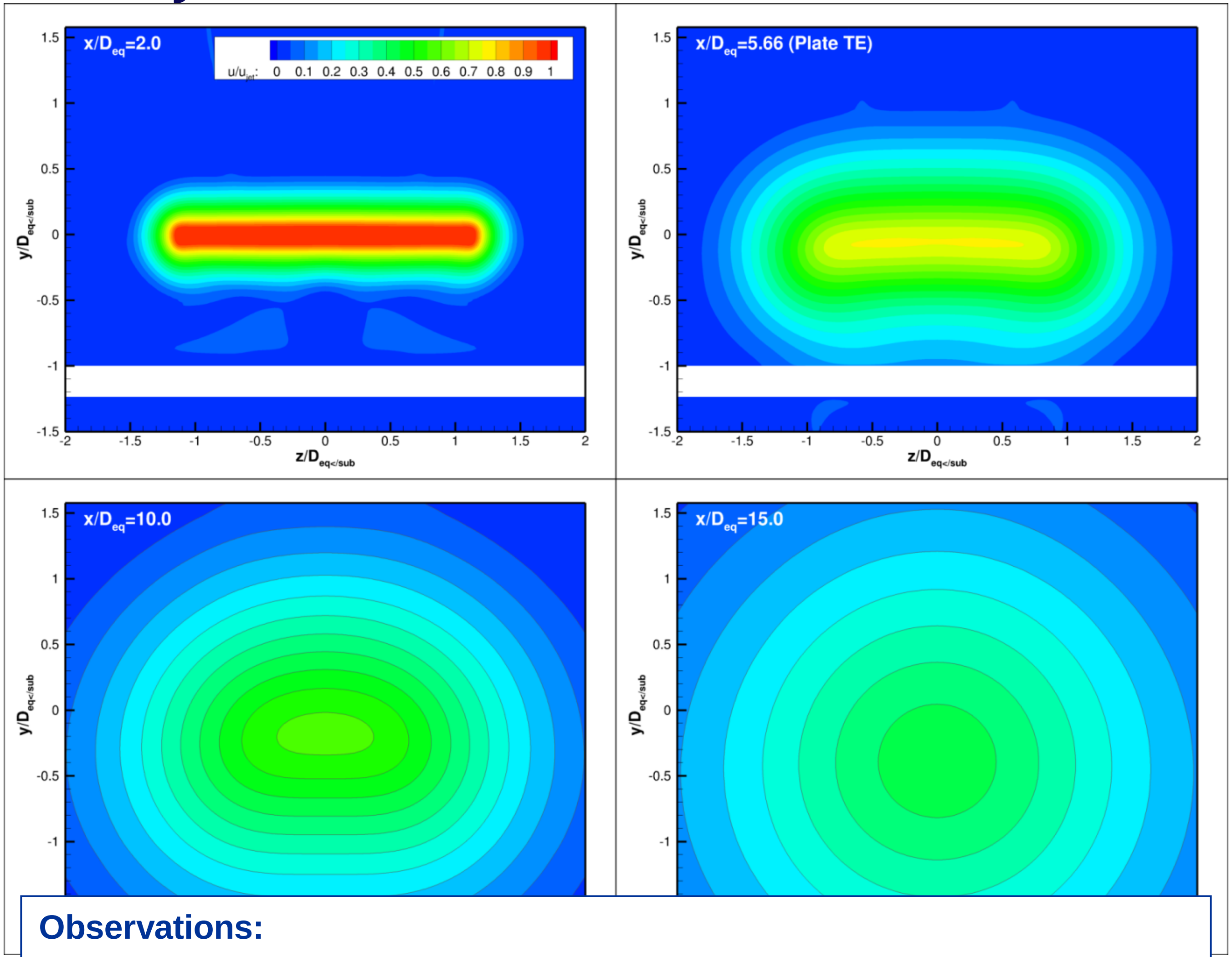
Jet and Surface Interaction: Contours of Instantaneous Flow



Observations:

- Jet plume is pulled towards plate
- Jet plume appears to be symmetric along x-y plane

Jet and Surface Interaction: Velocity Contours at Plume Cross Sections

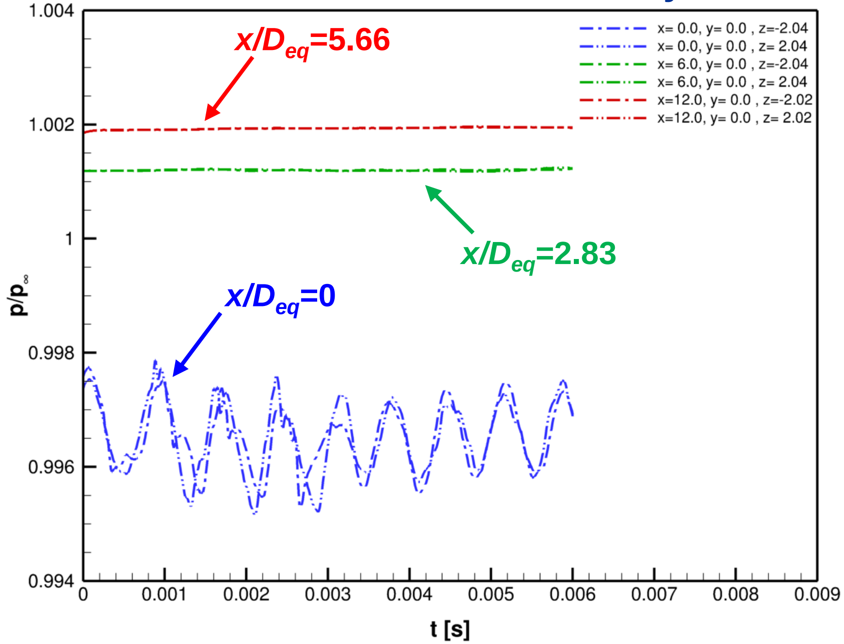


Observations:

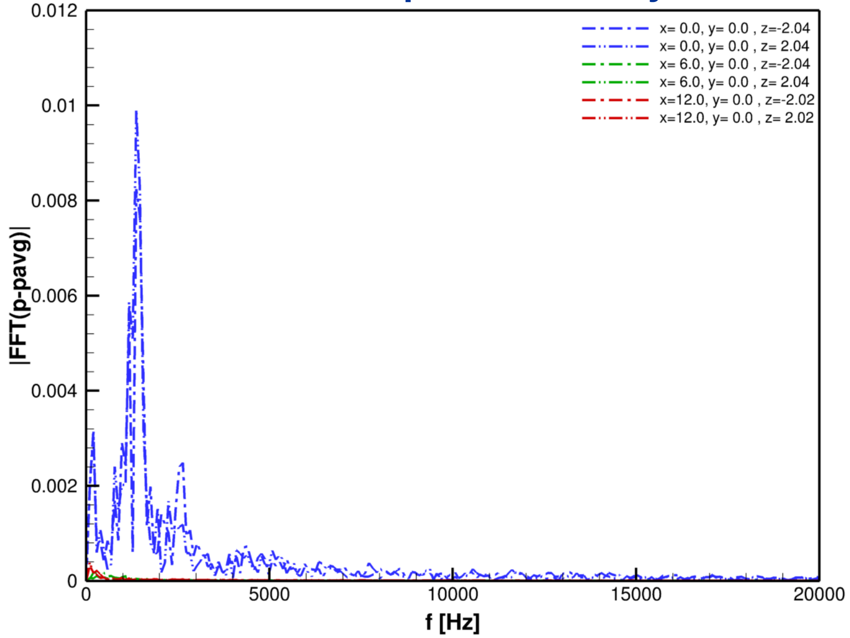
- Jet plume is subtly pulled down towards the plate, visible at x/D_{TE}≥5.66
- Noticeable vertical spreading of jet plume; but no axis-switching

Jet and Surface Interaction: Unsteady Pressure Probe Results

Pressure Probe Time History



URANS Power Spectral Density Plot



Observations:

- Pressure is unsteady and apparently periodic near the nozzle exit
- PSD shows resonant frequency of ~1350 Hz
- Zaman saw resonant frequency of ~1100 Hz

Jet and Surface Interaction: Conclusions

- Unsteady RANS can predict resonance for jet flows with strong resonance
  - Gives a reasonable “ball-park” prediction of resonance frequency observed experimentally

Future:

- Simulate configurations for which Zaman has observed stronger resonances experimentally
- Simulate configurations for which axes-switching was observed experimentally
- Coordinate with Zaman for comparison to experiments
  - Plans to use time-accurate pressure-sensitive paint on the plate; would be easy to pull this data from URANS simulations

This work was supported by Fixed-Wing, Quiet Performance Project.