URANS for Predicting Resonances in Jets

Vance F. Dippold, III

Spring Acoustics Technical Working Group
Cleveland, OH
April 24, 2013
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
  - $T_0=530$ deg R
  - Quiescent freestream
  - Unsteady RANS
    - Wind-US v. 3.0
    - SST turbulence
    - $\Delta t=1e-7$ s
  - Axisymmetric grid
    - Structured
    - 10 $D_{jet}$ radially, 30 $D_{jet}$ downstream
    - 428,800 cells
    - $y^+<1$
Over-Expanded C-D Nozzle: Unsteady Results

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 \(~8.73\times10^{-4} \text{ s}, \sim 1145 \text{ Hz}\)
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 ($1D_e$) below nozzle centerline
- Inflow conditions:
  - $M_{jet}=0.99$
  - $NPR=1.8709$
  - $T_0=530$ deg F
- Quiescent freestream
- Unsteady RANS
  - Wind-US
  - $\Delta t=1.0e^{-7}$ 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 $x/D_{TE} \geq 5.66$
- Noticeable vertical spreading of jet plume; but no axis-switching
Jet and Surface Interaction: Unsteady Pressure Probe Results

**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.