Oral presentation | Aero-acoustics

Aero-acoustics-I

Mon. Jul 15, 2024 10:45 AM - 12:15 PM Room B

[1-B-02] Sound Generation and Shock Wave Deformation in Shock Wave - Vortex Ring Interaction

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Keywords: Vortex ring shock wave interaction, Compressible ring vortex, Naturally generated vortex ring

Sound Generation and Shock Wave Deformation in Shock Wave - Vortex Ring Interaction

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Outline

Introduction

- Shock wave vortex ring interaction → noise generation
- Noise in supersonic jets
  - Turbulent mixing noise
  - Screech noise
  - Broadband shock noise

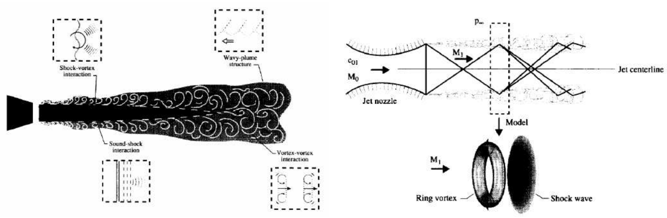

Figure: Schematics of noise generation from report[1]

[1] Meadows, K.R., 1997. A study of fundamental shock noise mechanisms, NASA Technical Report (No. NASA-TP-3605).

Shock Wave Interaction with a Naturally Generated Vortex Ring

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Motivation

- Commonly used Vortex ring models → incompressible[1] [2]
- Meadow's model[1] → high vortex ring radius to vortex c/s radius ratio
- Inoue's model[2] → complicated far-field conditions
- Naturally generated vortex ring → compressible

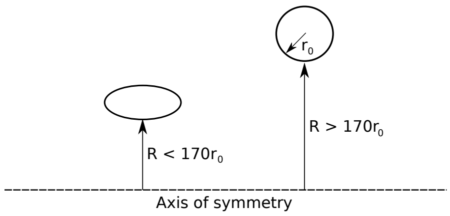


Figure: Meadows K.R[1] Vortex Ring model

[1] Meadows, K.R., 1997. A study of fundamental shock noise mechanisms, NASA Technical Report (No. NASA-TP-3605).
[2] Inoue, O. et. al, 2000. Successive generation of sounds by shock–strong vortex interaction. Physics of Fluids, 12(12)

Computational Domain

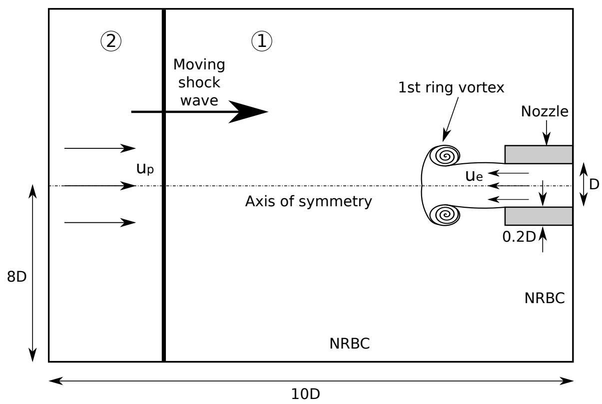


Figure: Computational Domain

Numerical Method

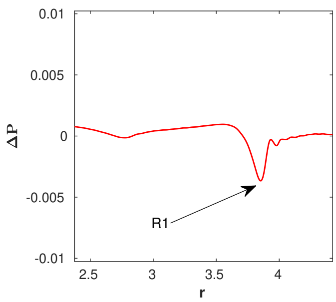
Unsteady axisymmetric Navier-Stokes equations are solved to model the viscous flow [1],

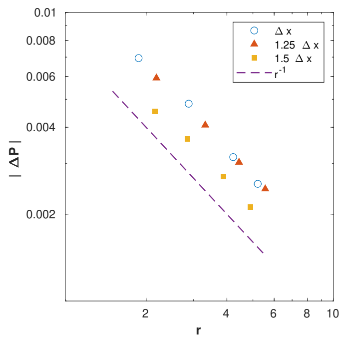
$$\boldsymbol{U}_t + \boldsymbol{F}_x + \boldsymbol{G}_y = \boldsymbol{Q} \quad (1)$$

- Closure is done with γ, Pr, μ (laminar) and R
- Fifth order WENO is used to discretize convective fluxes
- Time advancement by TVD - Runge-Kutta second order scheme
- Non-reflective boundary conditions (NRBC) are imposed at boundaries

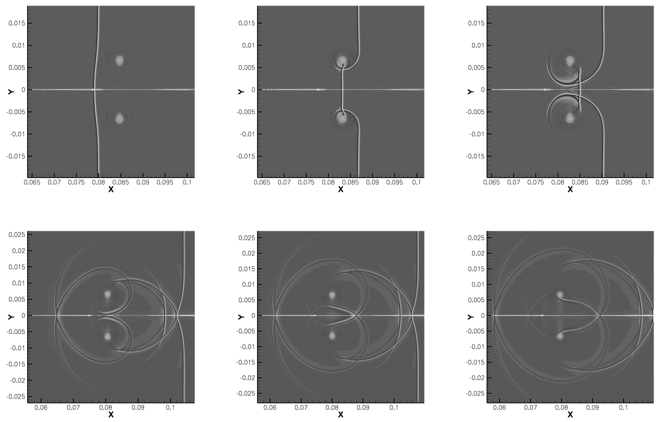
[1] Avijit Chatterjee et. al Screech frequency prediction in underexpanded axisymmetric screeching jets. International Journal of Aeroacoustics, 8(5):499–510, 2009

Grid Independence Study





Numerical Shadowgraphs



Shock Wave Interaction with a Naturally Generated Vortex Ring

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Characteristics based Filter (CBF)

Riemann invariants [1] for 1-D linear acoustics in laminar flow are,

$$f_a = \frac{1}{2}\left(\frac{p_a}{\rho a} + u_a\right) \rightarrow \text{in downstream direction} \quad (2)$$

$$g_a = \frac{1}{2}\left(\frac{p_a}{\rho a} - u_a\right) \rightarrow \text{in upstream direction} \quad (3)$$

where,
Pressure fluctuation,
$p_a = p - p_m$
Velocity fluctuation,
$u_a = u - u_m$

Feature of Riemann invariants,

$$\boxed{g_a(x + \Delta x, t + \Delta t) = g_a(x, t)}$$

if $\Delta x = (a - u_m)\Delta t$

[1] Kopitz, J. et. al 2005, July. Characteristics-based filter for identification of planar acoustic waves in numerical simulation of turbulent compressible flow. In 12th international congress of sound and vibration.

Characteristics based Filter example

Summerized as,

$$\hat{g}_a(x,t) = \frac{1}{m+1}\sum_{i=0}^{m} g(x - ia\Delta t, t - i\Delta t)$$

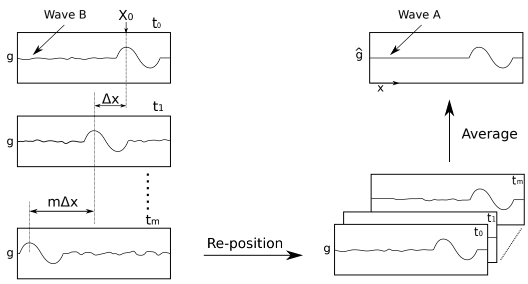


Figure: $\Delta x = a\Delta t$, $\Delta t = t_m - t_0$

Characteristics based Filter on SVI

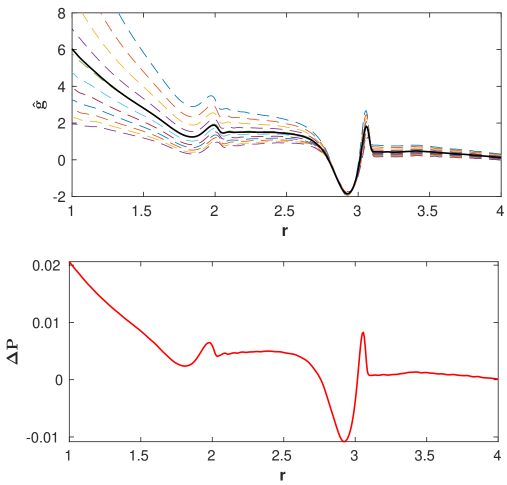
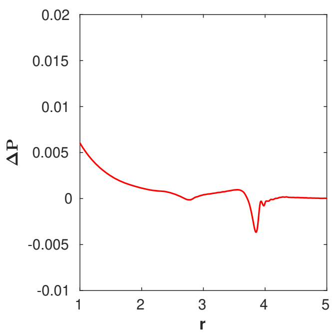


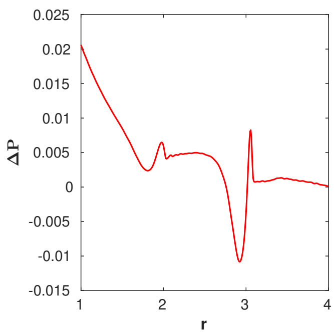
Figure: CBF on implemented for SVI

CFD Results (1/2)

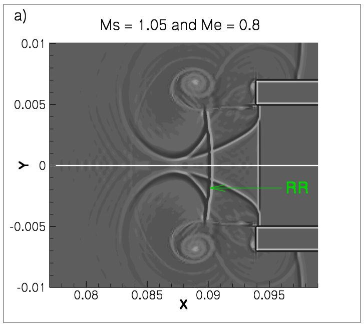
$M_s = 1.05$ and $M_e = 0.4$

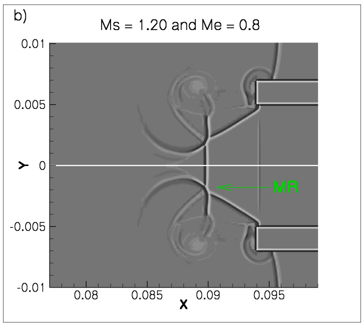


$M_s = 1.05$ and $M_e = 0.6$



CFD Results (2/2)





Summary

- Proposed a new method to study vortex ring and shock interaction
- Compressible Vortex ring $\rightarrow$ No limitation on vortex ring Mach number
- Characteristic based filtering (CBF) is used to separate hydrodynamic and acoustic fluctuations
- Results found to be in agreement with observations reported by Inoue et al.[1]

[1] Inoue, O. et. al, 2000. Successive generation of sounds by shock–strong vortex interaction. Physics of Fluids, 12(12)

Thank you !!

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