Jet Noise Modeling and Prediction using Steady RANS Solutions

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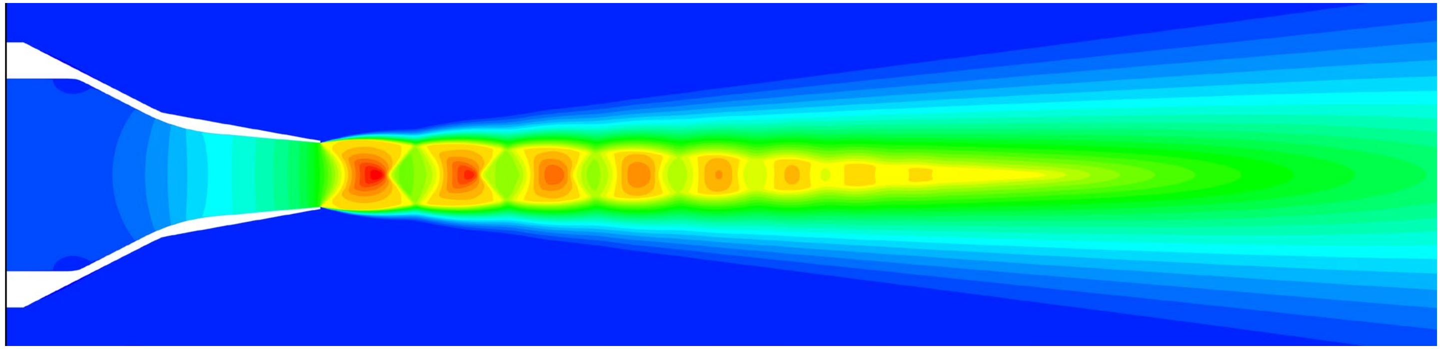
Target

Implement a computational procedure to evaluate the noise disturbance caused by aircraft's jets using high order models



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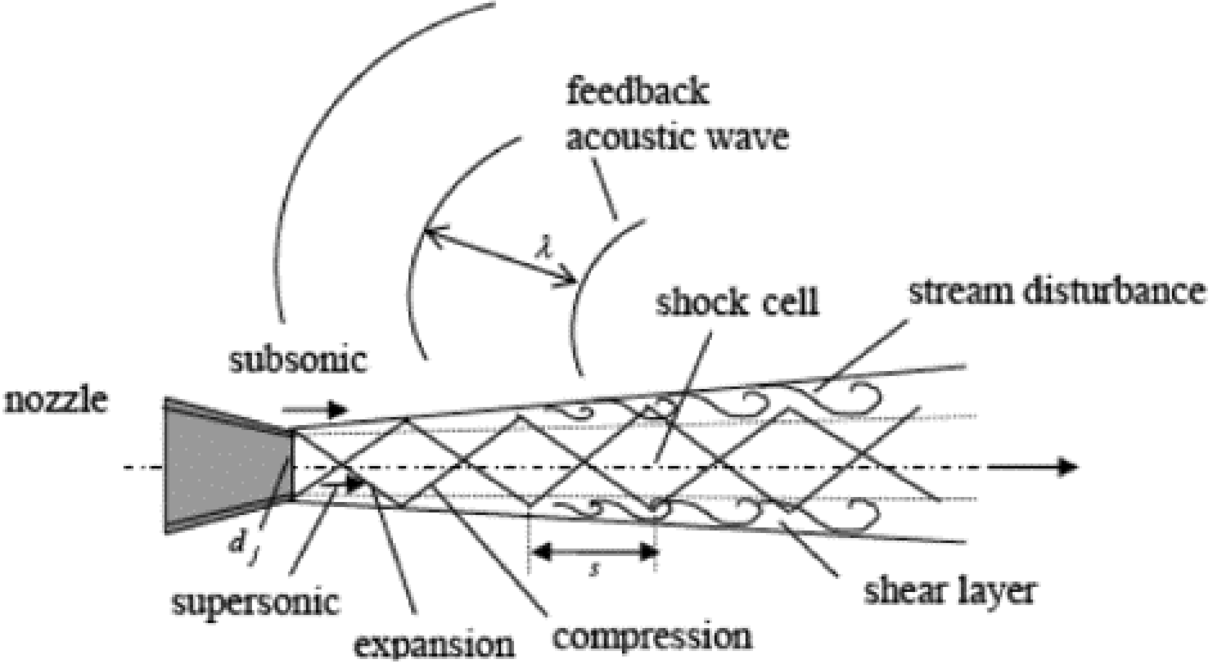
Jet Noise Description



- **Mixing Noise**
  - Large-Scale Coherent Noise
  - Fine-Scale Inchoerent Noise
- **Shock Associated Noise**
  - Broad-Band Shock-Associated Noise
  - Screech

Acoustic Analogy Model

Model Features

- Acoustic analogy model based on the linearized Euler equations (LEE)
- Ability to separate source terms from propagation terms
- Full compatibility with both components of 'noise' considered
  - Mixing noise
  - BBSAN

Working Assumptions

- Observer far from the jet
- Absence of a mean flow field
- Proudman hypothesis for isotropic turbulence

Model governing equations

$$\frac{\partial \pi'}{\partial t} + \bar{u}_j \frac{\partial \pi'}{\partial x_j} + \frac{\partial u_i'}{\partial x_i} = \theta$$

$$\frac{\partial u_i'}{\partial t} + \bar{u}_j \frac{\partial u_i'}{\partial x_j} + u_j' \frac{\partial \bar{u}_i}{\partial x_j} + \bar{a}^2 \frac{\partial \pi'}{\partial x_i} = f_i$$

Acoustic Analogy Model: Final Equations

Mixing Noise

$$S(\mathbf{x},\omega) = \rho_\infty^2 a_\infty^4 \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{2\pi^{3/2} a_\infty^2 l_x l_y l_z x^2 \tau_s}{a_\infty^2 x^2 + (a_\infty x + \bar{u} x_1 + \bar{v} x_2 + \bar{w} x_3)^2 \tau_s^2 \omega^2} \Bigg\{ \left[\pi_g^{*0}(\mathbf{x},\mathbf{y},\omega) \pi_g^0(\mathbf{x},\mathbf{y},\omega) A_s^2 \frac{(u_s/a_\infty)^4}{\tau_s^2} \right] +$$

$$+ \sum_{n=1}^{3}\sum_{m=1}^{3} \pi_g^{*n}(\mathbf{x},\mathbf{y},\omega) \pi_g^m(\mathbf{x},\mathbf{y},\omega) B_s^2 \frac{(u_s/a_\infty)^2 u_s^2}{l_x^2} \Bigg\} \exp\left[-\frac{\omega^2 (l_x^2 x_1^2 + l_y^2 x_2^2 + l_z^2 x_3^2)}{4 a_\infty^2 x^2} \right] d\mathbf{y}$$

Broad-Band Shock-Associated Noise

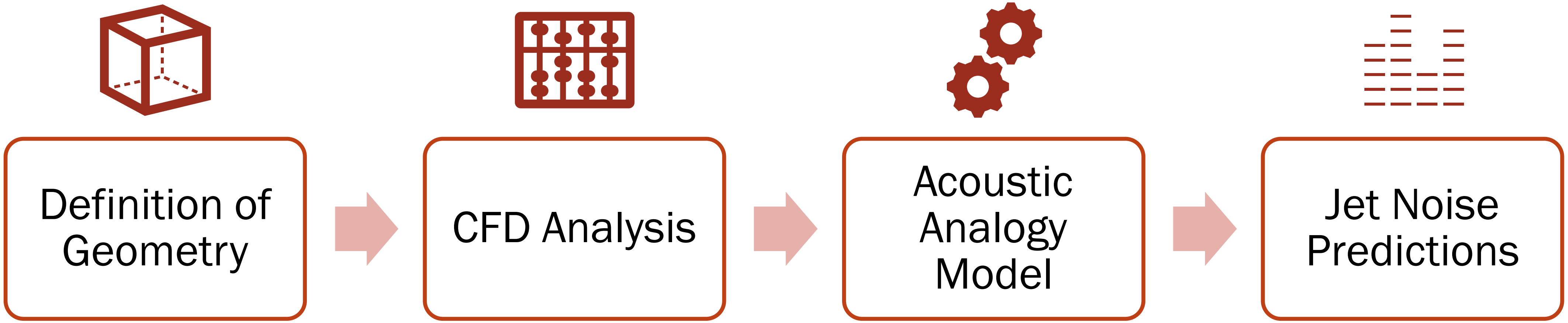
$$S(\mathbf{x},\omega) = \pi^{1/2} \rho_\infty^2 a_\infty^4 \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} \left\{ \sum_{n=1}^{3}\sum_{m=1}^{3} \pi_g^{*n}(\mathbf{x},\mathbf{y},\omega) \pi_g^m(\mathbf{x},\mathbf{y},\omega) \frac{x^2}{x_n x_m} \frac{2K(\mathbf{y}) l_y l_z \tau_s}{3 \bar{\rho}^2 \bar{u}^2 l_x} p_s(\mathbf{y}) \tilde{p}_s(k_1, y_2, y_3) \right\} \times$$

$$\times \frac{1}{\left[1 + \left(1 - \frac{\bar{u}}{a_\infty}\cos\theta + \frac{\bar{u} k_1}{\omega} \right)^2 \omega^2 \tau_s^2 \right]} \exp\left[-\frac{l_x^2}{4} \left(\frac{\omega}{a_\infty}\cos\theta - k_1 \right)^2 - \frac{\omega^2 l_y l_z}{4 a_\infty^2} \sin^2\theta \right] dk_1 d\mathbf{y}$$

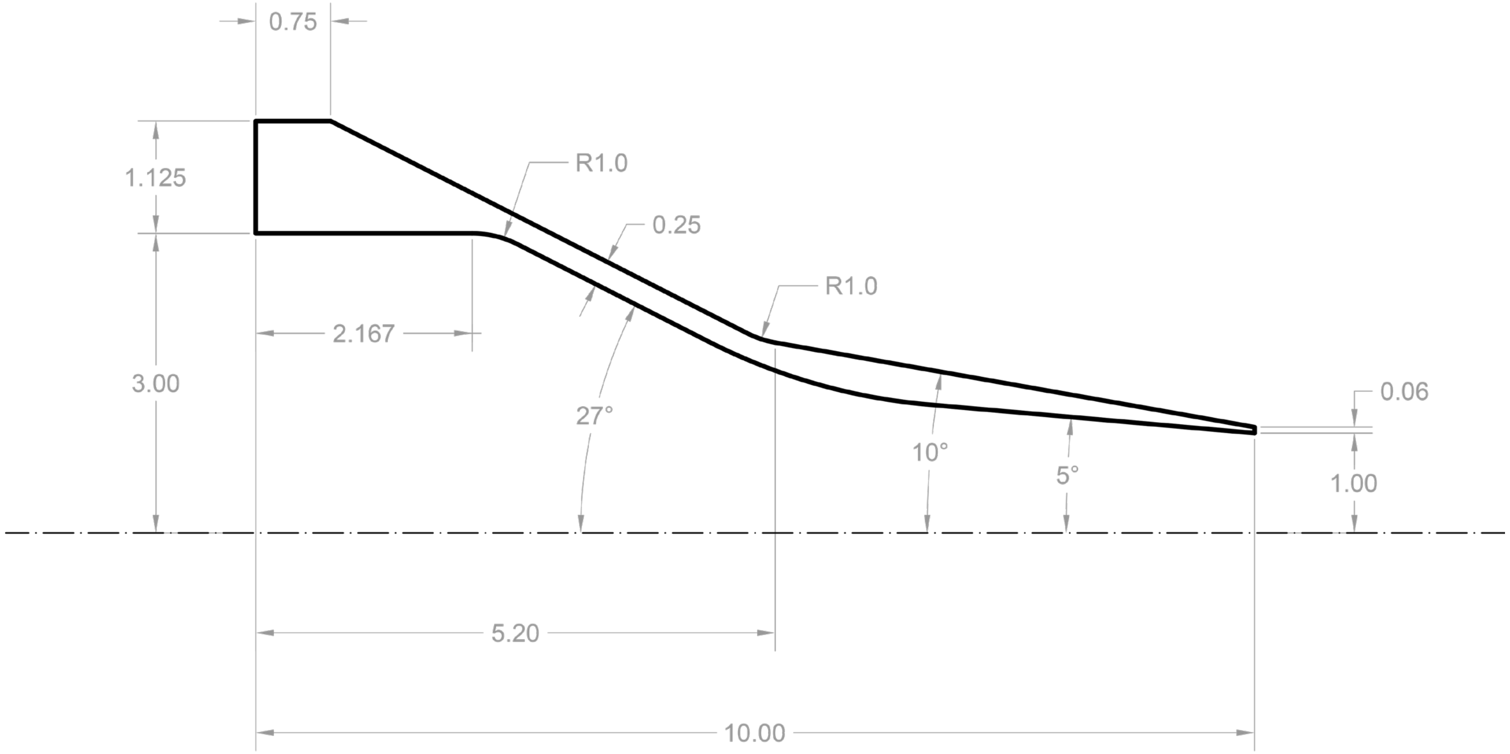
Green's Function

$$\pi_g^n(\mathbf{x},\mathbf{y},\omega) = \frac{i\omega x_n}{4\pi a_\infty^3 x^2} \exp\left[\frac{-i\omega x}{a_\infty} \right] \delta_{in} + \frac{i\omega}{4\pi a_\infty^2 x} \exp\left[\frac{-i\omega x}{a_\infty} \right] \delta_{0n}$$

Overview of the Process



Definition of Geometry: SMC000 Nozzle



Geometric Dimensions

- Axial Symmetry
- $L = 0.254\ \mathrm{m}$
- $D_1 = 0.1524\ \mathrm{m}$
- $D_2 = 0.0508\ \mathrm{m}$
- $\frac{A_1}{A_2} = 9$

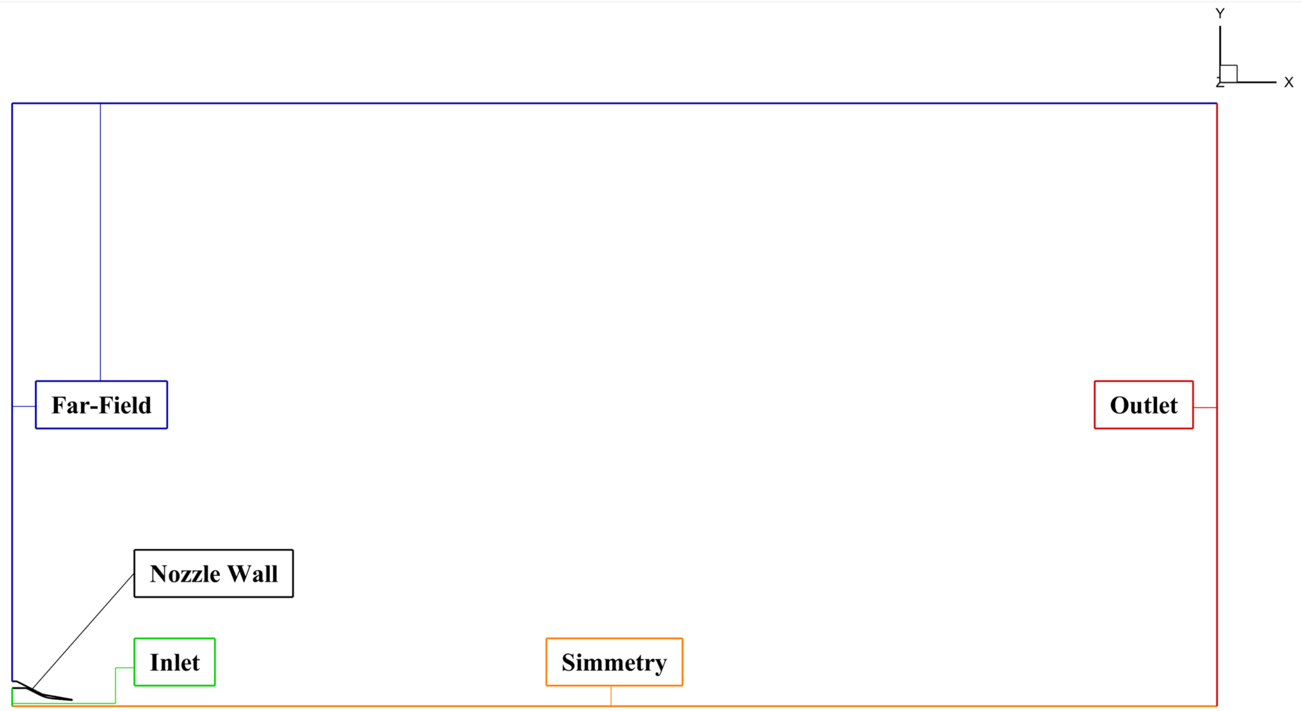
Definition of the Computational Domain

Dimensions:

- $L_x = 100 \cdot D_2$
- $L_y = 50 \cdot D_2$

Boundary Conditions:

- Inlet
- Far-Field
- Axis of symmetry
- Nozzle Walls
- Outlet



Test Case and Computational Grid

Type of Simulation

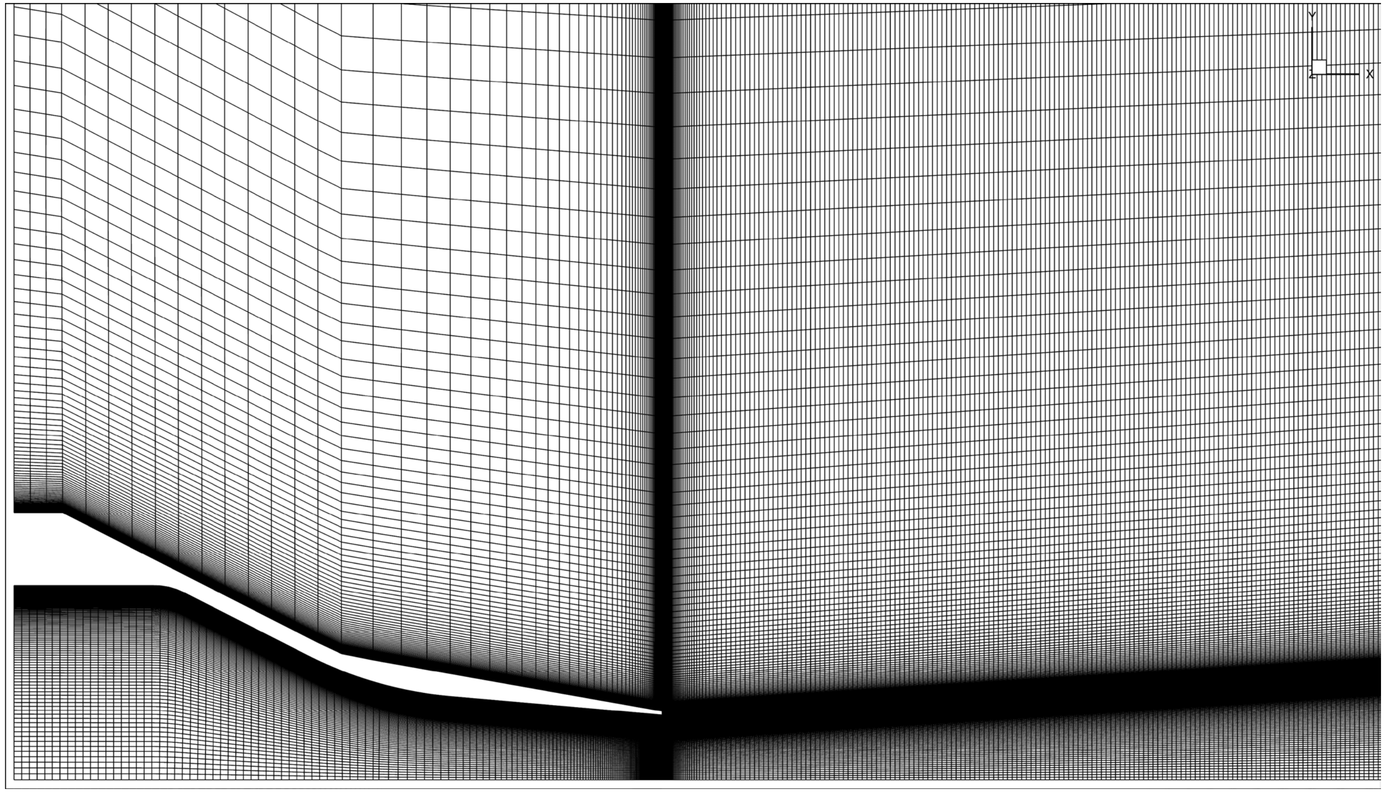
- Steady RANS with $k - \omega$ SST closure model

Operating Conditions

- $M_j = 1.47$
- $M_d = 1.00$
- $TTR = 1.00$

Free-stream Conditions

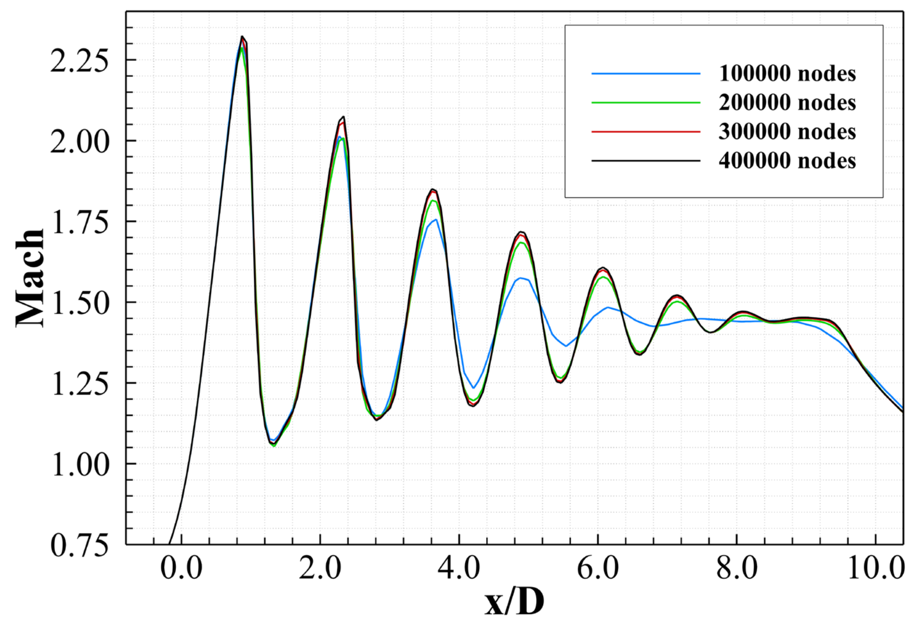
- $p_\infty = 101325$ Pa
- $T_\infty = 293.15$ K

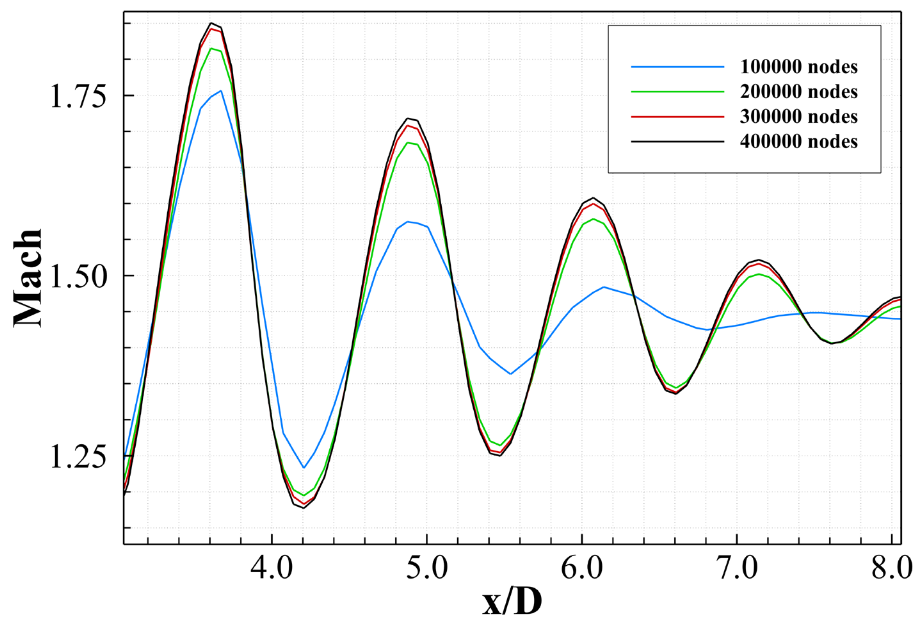


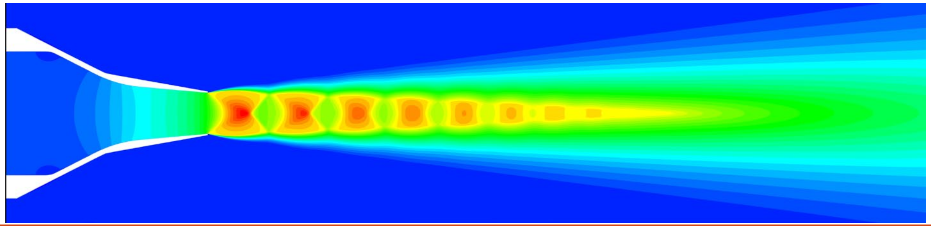
Grid Convergence Study

1. Generation of a first try mesh
2. Generation of increasingly refined mesh
3. Comparison of solutions of different meshes
4. Choice of the best computational grid

Grid Convergence Study







CFD Solution Validation

Reference solution performed with

FUN3D

- Turbulence closure model: $k - \omega$ SST
- With compressibility correction

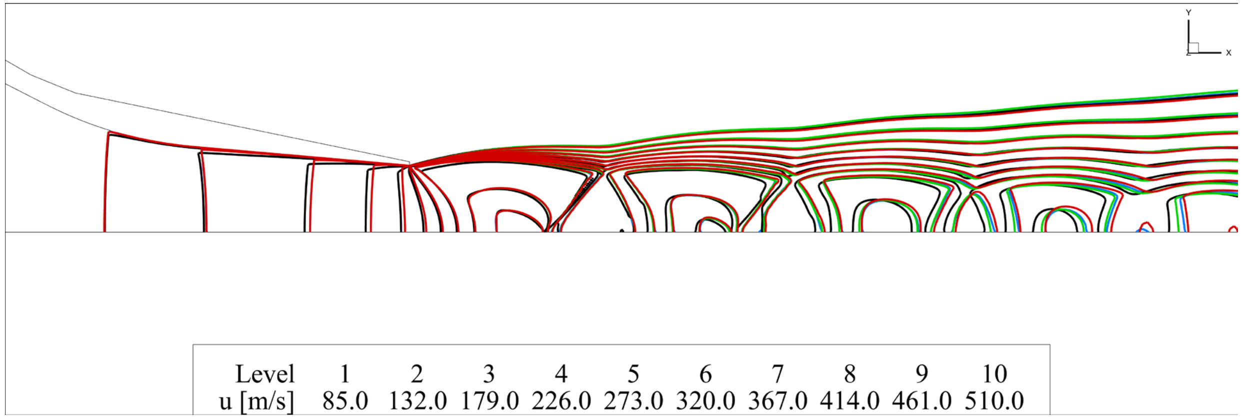
CFD simulations performed with

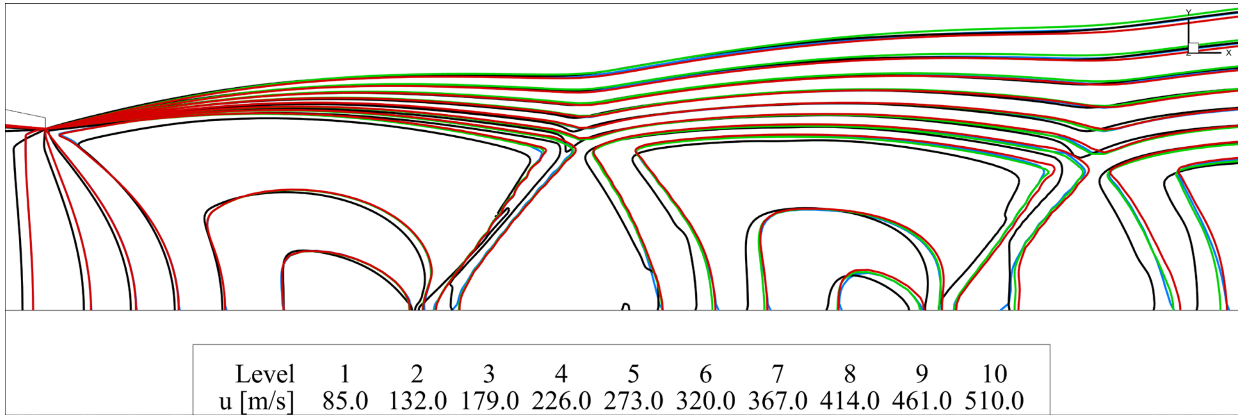
Ansys Fluent

- Turbulence closure model: $k - \omega$ SST
- With compressibility correction
- Without compressibility correction

SU2

- Turbulence closure model: $k - \omega$ SST
- Without compressibility correction

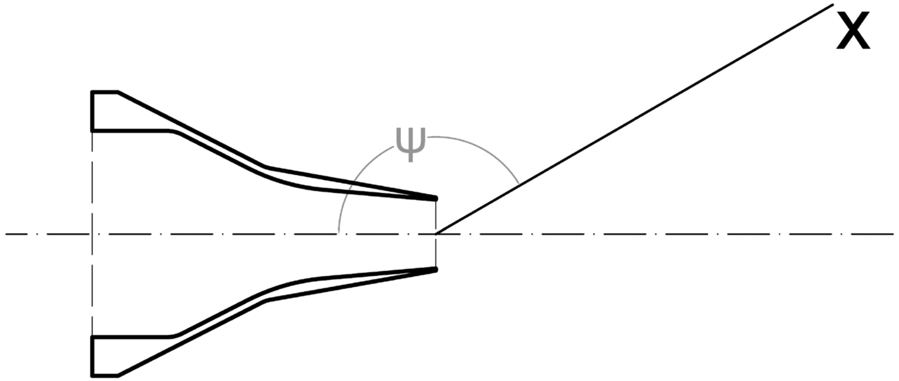


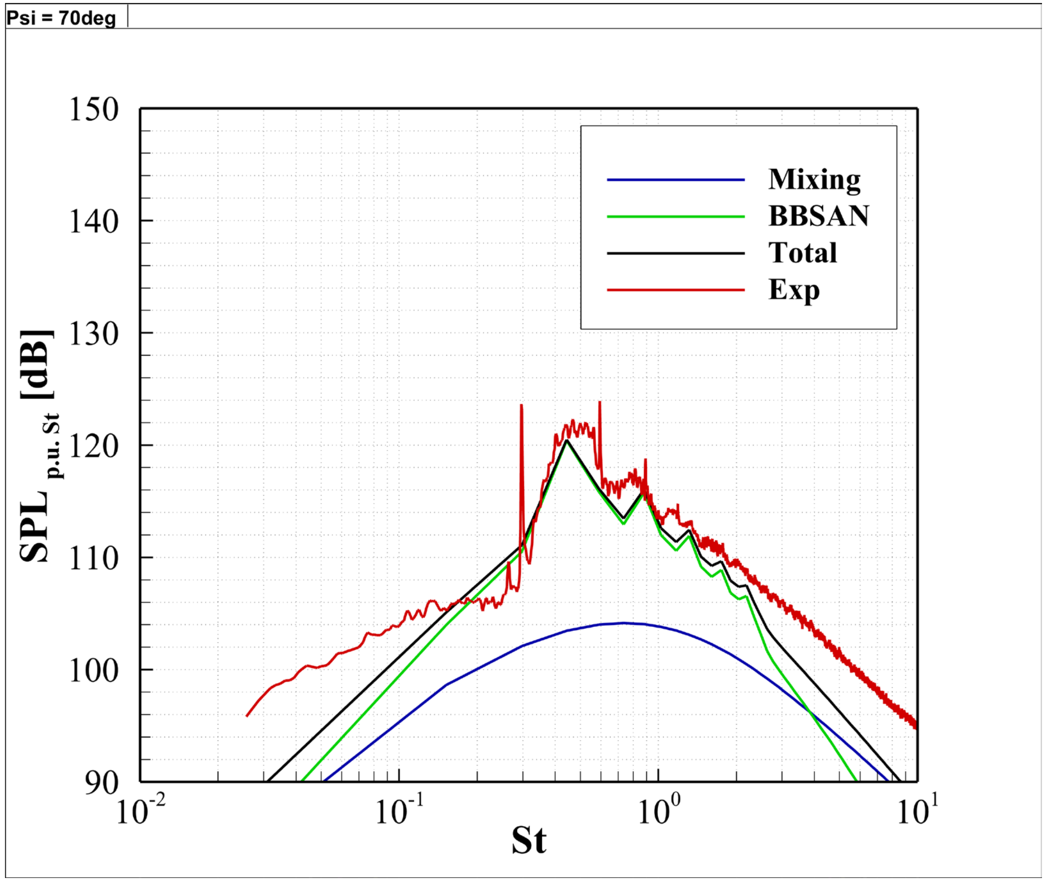


Results: Test case SMC0003

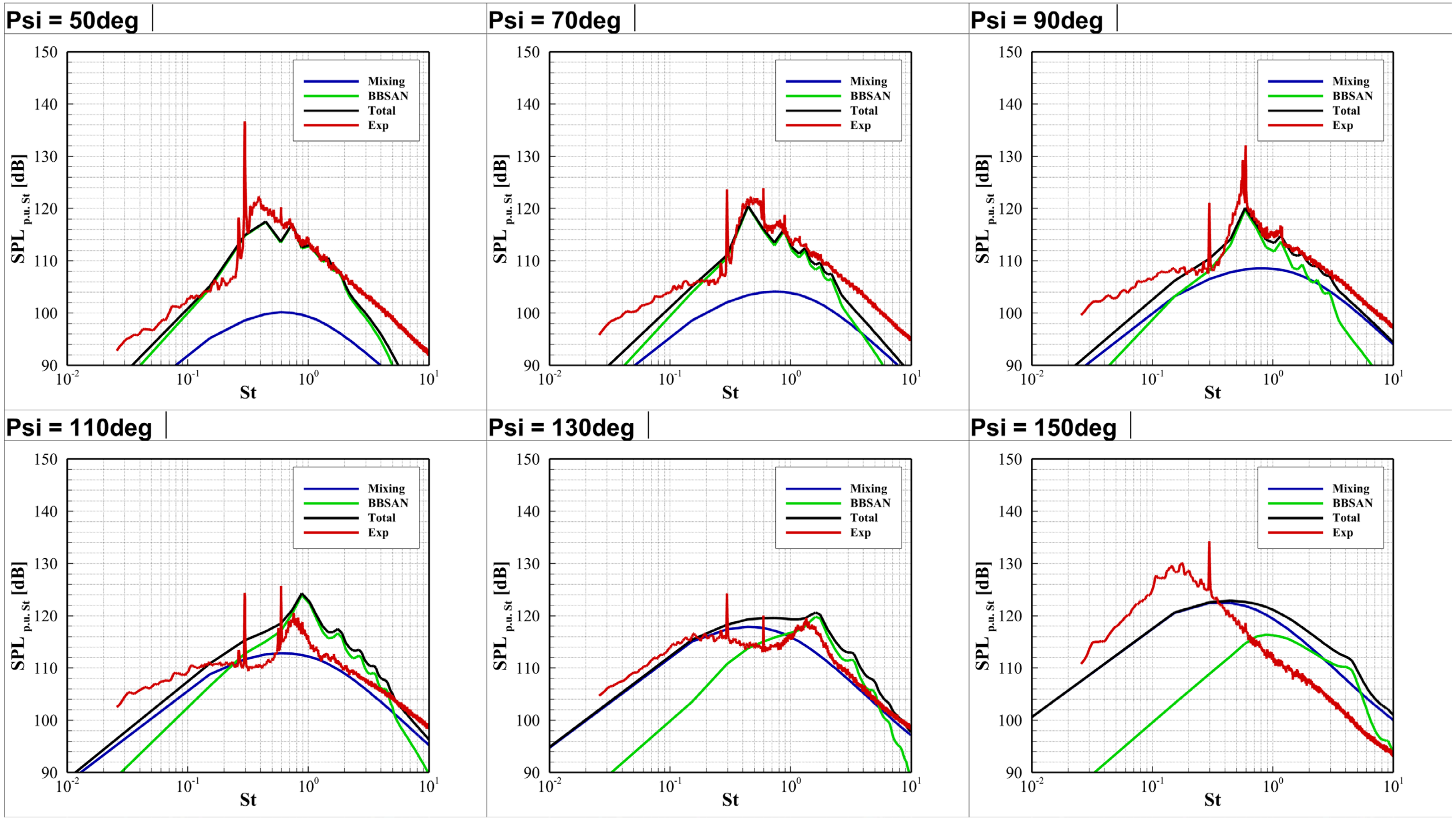
Operating Conditions

$M_j = 1.47; \quad M_d = 1.00; \quad TTR = 1.00$

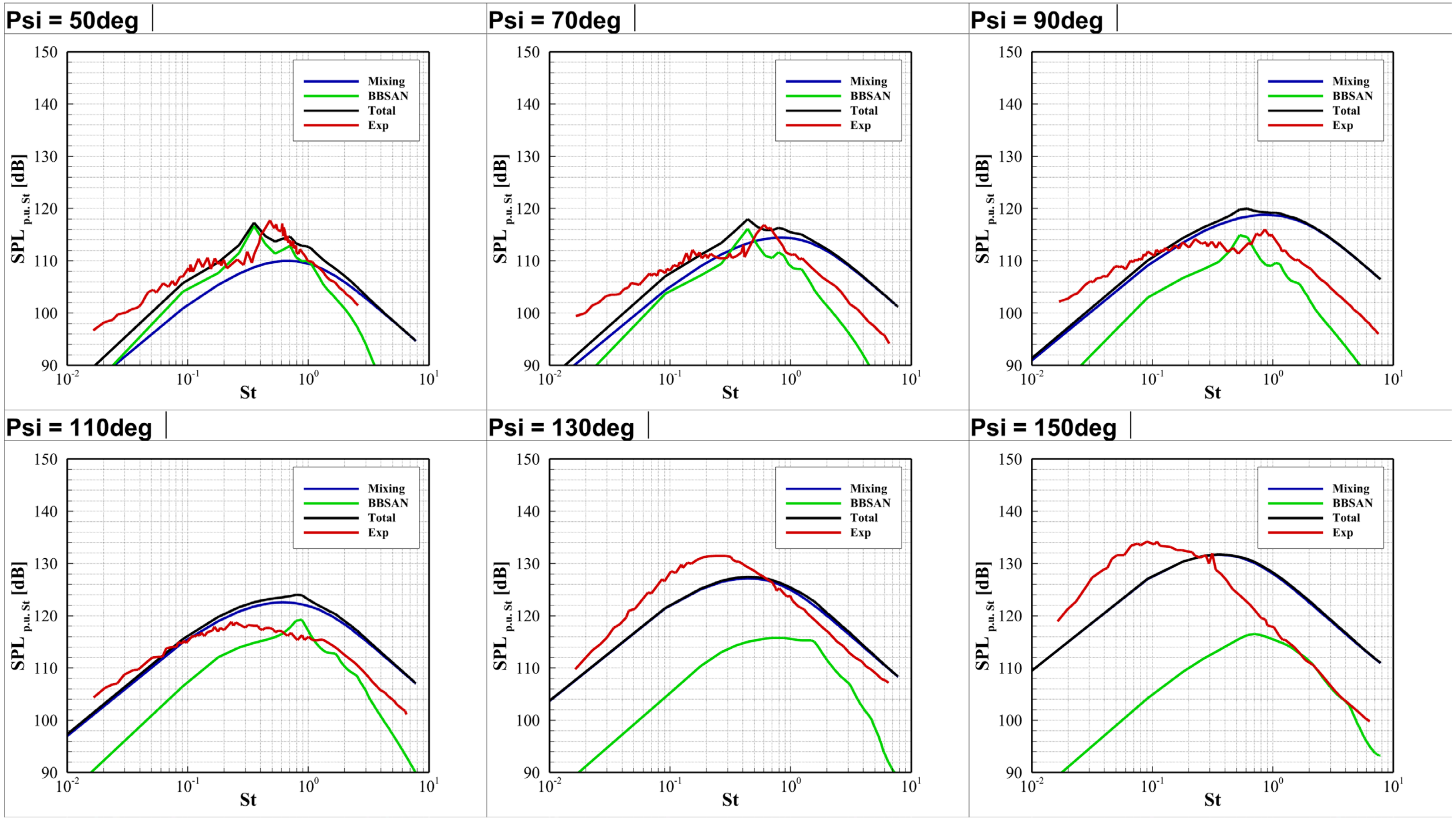




Results: Test case SMC0003



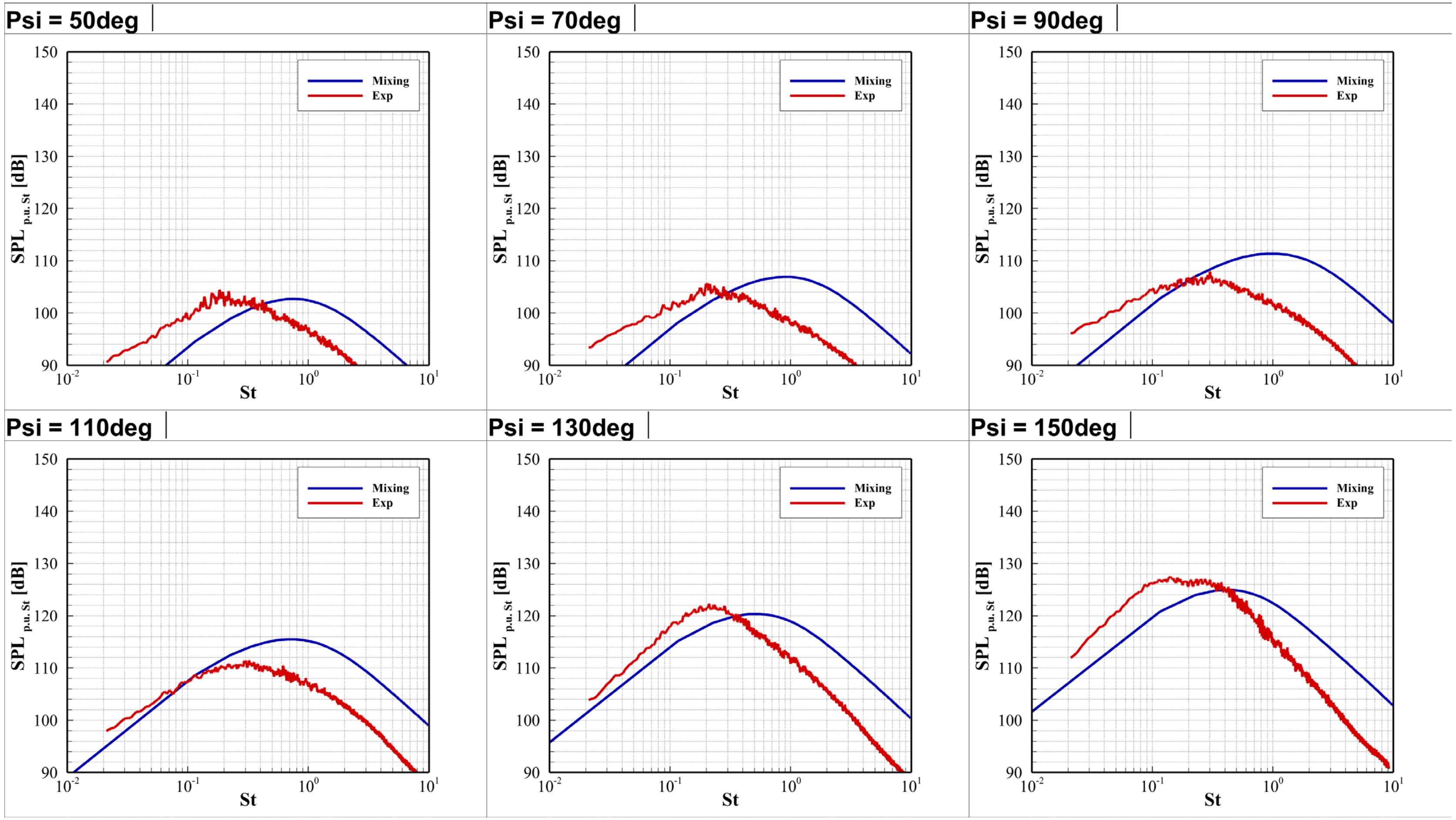
Results: Test case SMC0008



Operating Conditions

- $M_j = 1.24$
- $M_d = 1.00$
- $TTR = 3.20$

Results: Test case SMC0004



Operating Conditions

- $M_j = 1.00$
- $M_d = 1.00$
- $TTR = 2.70$

Conclusions

- Study of different aeroacoustics models
- Implementation of the acoustic model based on LEE
- Calculation of CFD solutions to be provided to the acoustic solver
- Comparison of the fluid dynamics solution with reference data
- Validation of the acoustic solver on experimental test cases

Future Developments

- Develop a solver for calculating more complex Green's functions of linearized Euler equations
- Test different closure models for the turbulence equations
- Test different compressibility correction models related to the turbulence closure equations
- Integrate into the solver different source models
- Optimize the acoustic solver to improve computation time
- Use this tool to optimize nozzle geometry

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Reference Acoustic Models

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Thank you for your attention