Numerical Computation and Experimental Measurement of Aerodynamic Noise

Present and Future

CISS
Center for Research on
Innovative Simulation Software

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Outline

CISS
Center for Research on
Innovative Simulation Software

- Background
- Numerical Prediction of Aerodynamic Noise
- Applications at Present
- Perspectives and Future Roles of Measurements

Background

Prediction and Reduction of Aerodynamic Noise

- **Aerodynamic Noise**
  - **Generated from deformation of vortices**
  - **Drastically increase with increasing flow speed**
- **Reduction of Aerodynamic Noise**
  - **Crucial in development of various fans, airplane, automobiles, etc.**
- **Expectations for Numerical Predictions**
  - **Cost and/or time reduction for prototyping**
  - **Reduction of noise by identifying essential mechanism for noise generation**
  - **Prediction of noise under installation conditions**

Numerical Prediction of Aerodynamic Noise

Direct .vs. Decoupled Methods

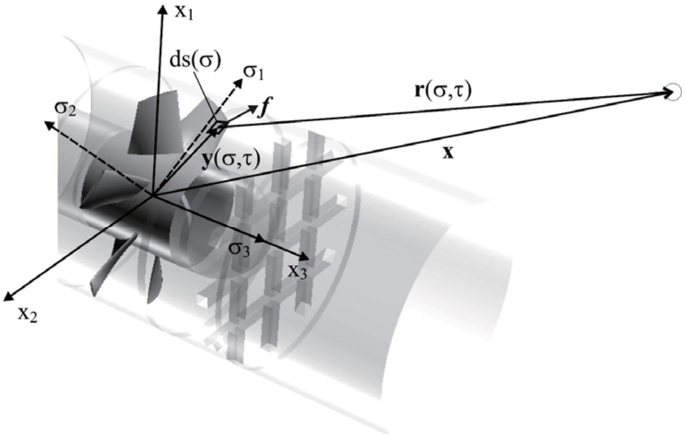
- **Direct Computation of Aerodynamic Noise**
  - **Provide information regarding detailed mechanism of noise generation**
  - **Applicable to feedback noise**
  - **Limited to simple geometries, particularly for noise from low speed flows**
- **Decoupled Methods**
  - **Based on acoustic analogy**
  - **No feedback assumed**
  - **Applicable to relatively complex geometories**
  - **Various methods have been proposed**

Applications at Present

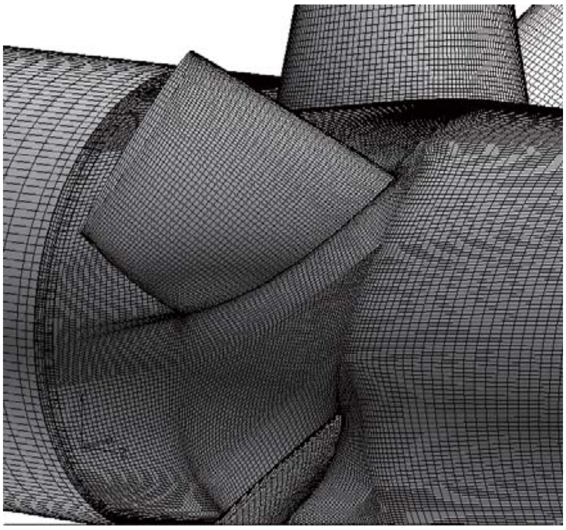
Noise Generated from an Axial-flow Fan Subjected to Inflow Turbulence

Collaborator: Siegen University in Germany

Computational Model

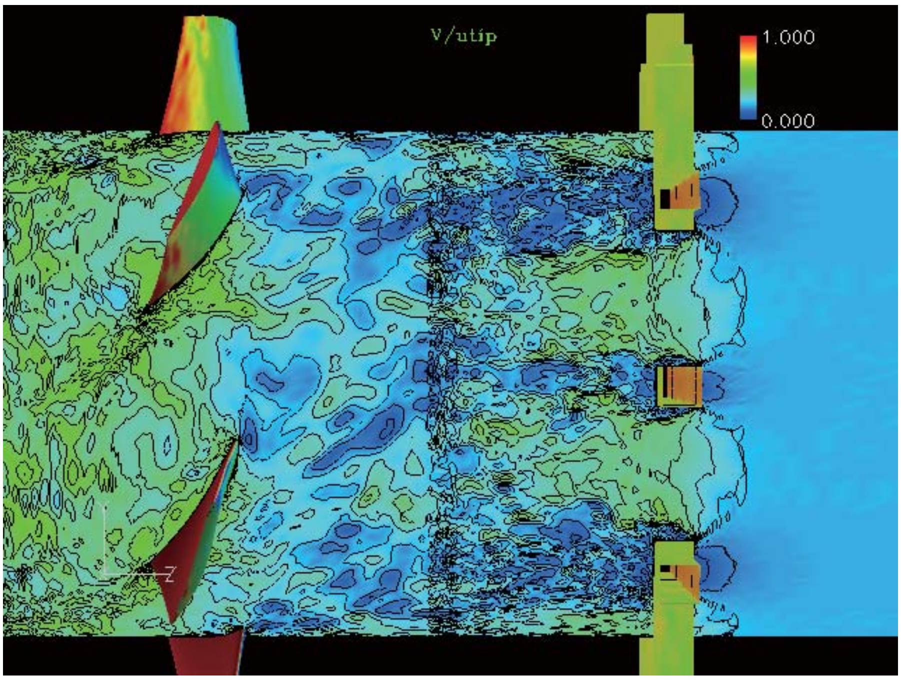


Ducted Fan Subjected to Turbulence Ingestion

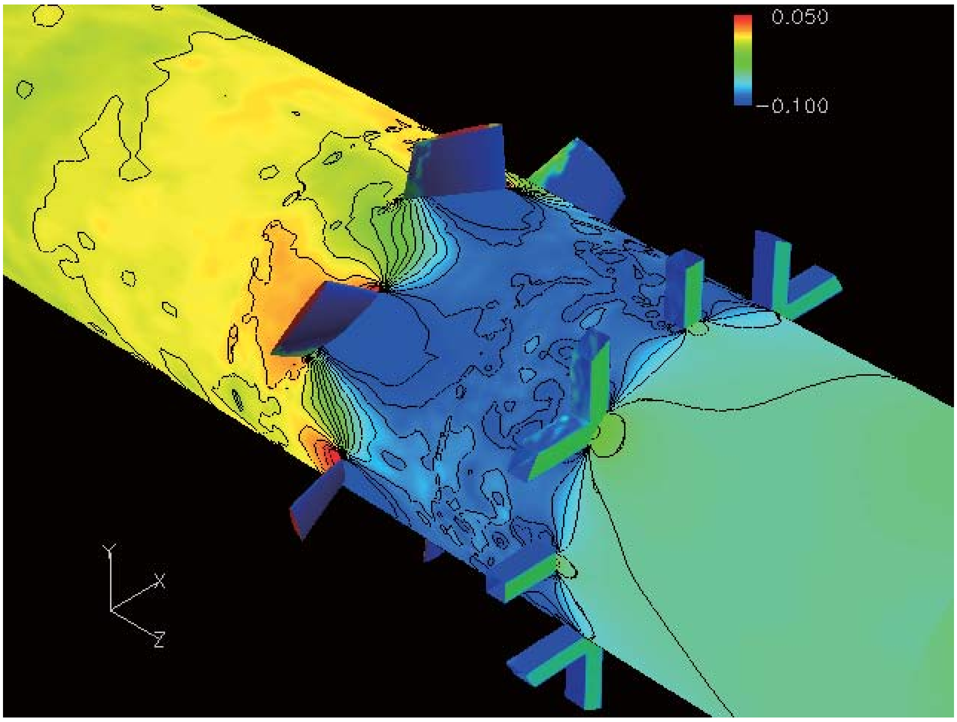


Computational Grids on Blade Surface

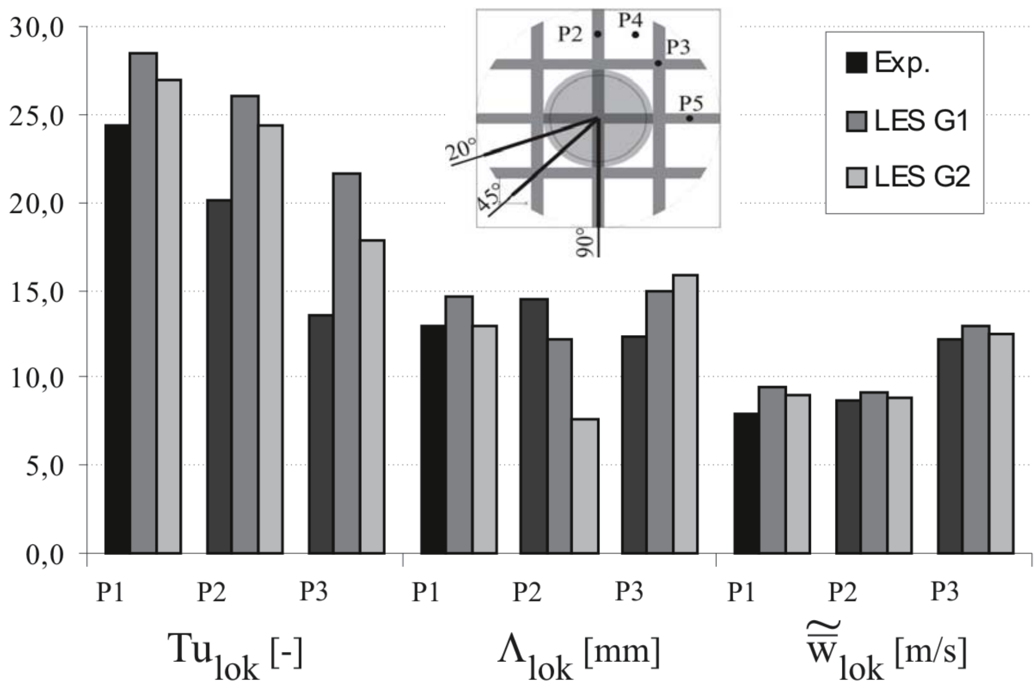
Fluctuations of Instantaneous Streamwise Velocity



Fluctuations of Instantaneous Static Pressure

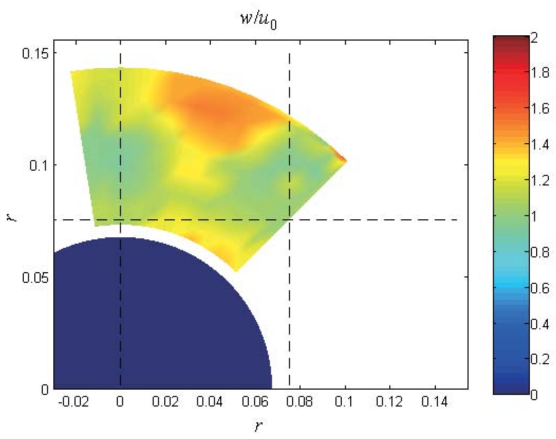


Comparisons of Turbulence Statistics behind Grid

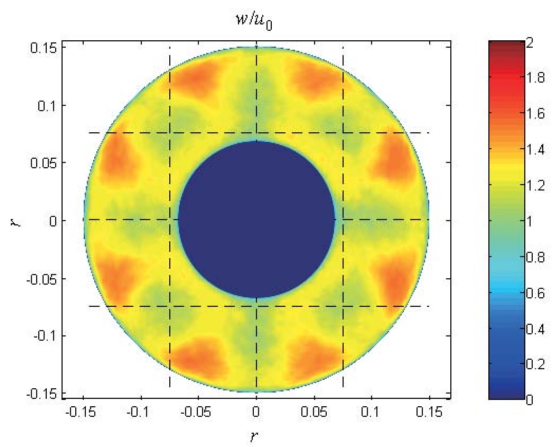


Comparison of Turbulence Intensity behind Grid

■ Incoming Turbulence Intensity



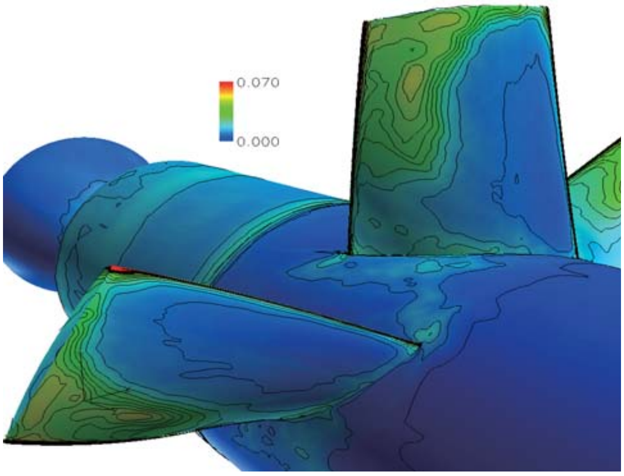
Measured by Hot Wire



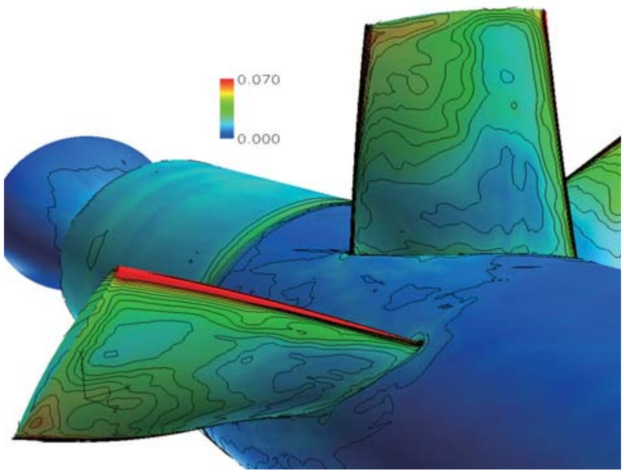
Computed by LES

Comparison of Surface Pressure Fluctuations

Root-mean-square Value of C_P



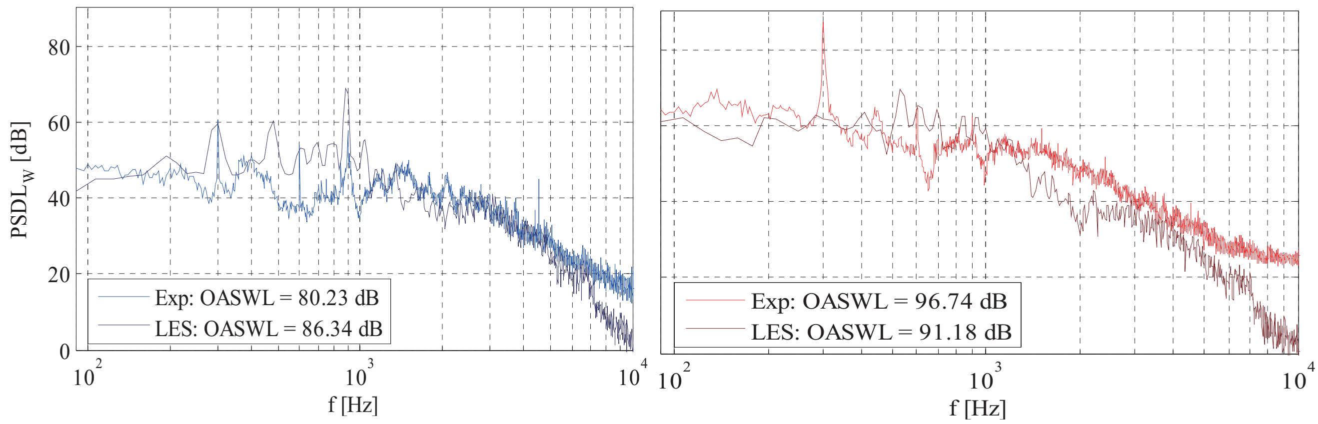
Clean Inflow Case



Turbulent Inflow Case

Comparison of Radiated Sound Pressure Levels

■ Far-field Sound Pressure Level

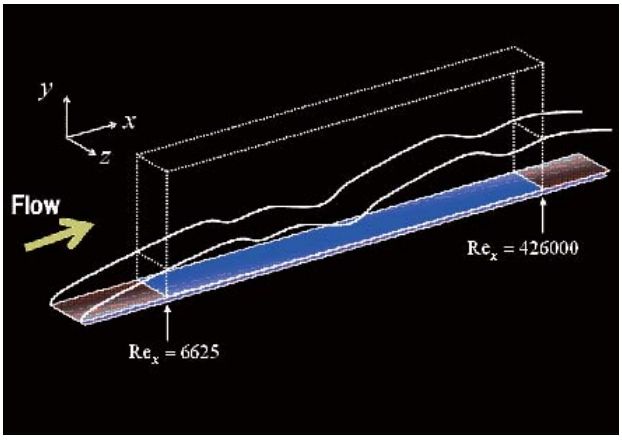


Clean Inflow

Turbulent Inflow

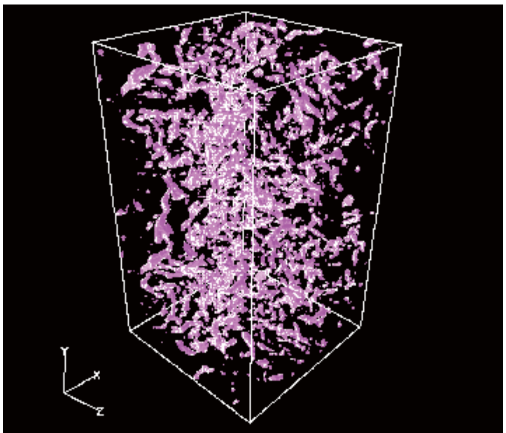
Bypass Transition of Flat Boundary Layer and Resulting Sound

Computational Model



	# of nodes	Grid size
x	1134	Δ+=14-38
y	70	Δ+=1-76
z	76	Δ+=15

Grid Resolution

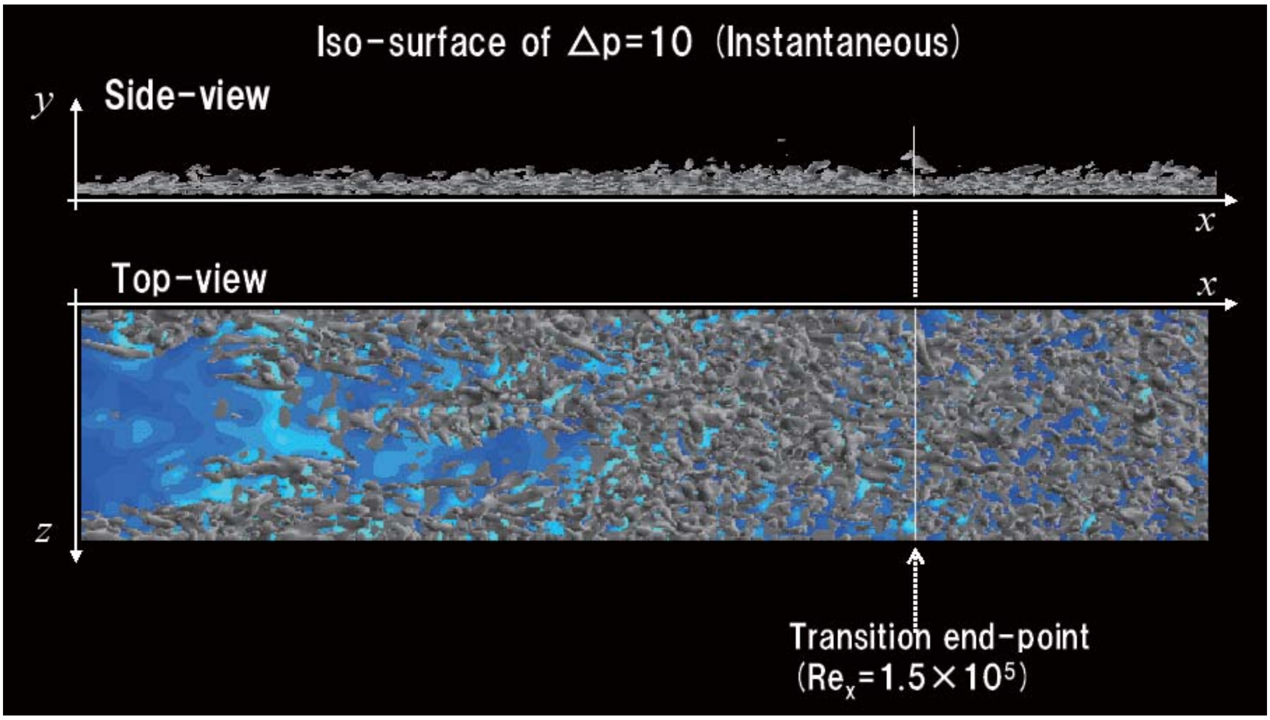


$$E(k)=\frac{\Lambda_f^5 k^4}{\left(1+\Lambda_f^2 k^2\right)^3} \qquad \frac{\Lambda_f}{L_z}=0.326$$

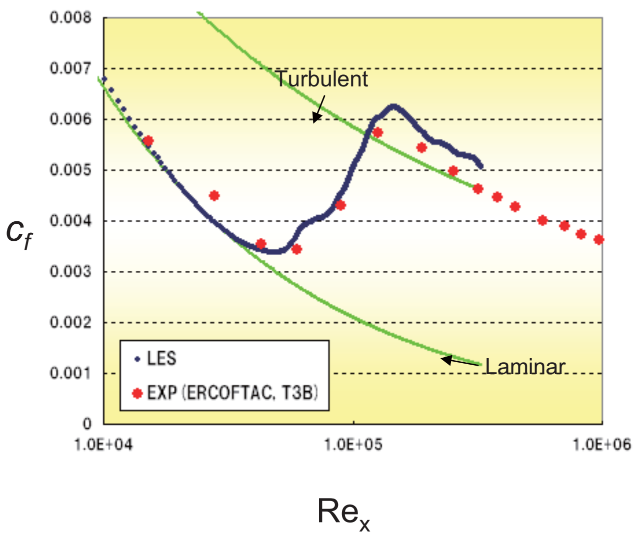
$$\Gamma u=\frac{\sqrt{\left(u_{rms}^2+v_{rms}^2+w_{rms}^2\right)/3}}{U_0}=6\%$$

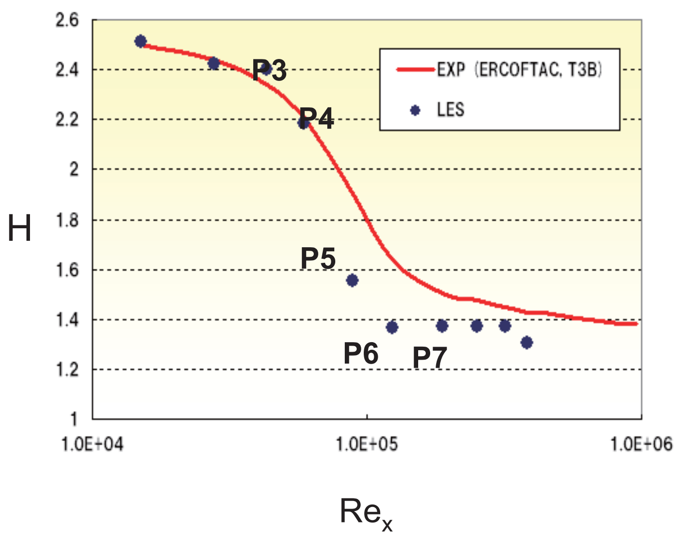
Inflow Turbulence

Instantaneous Vortical structure



Comparison of Skin Friction and Shape Factor

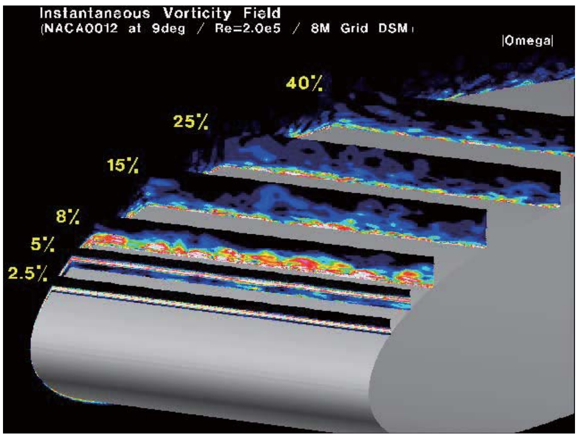


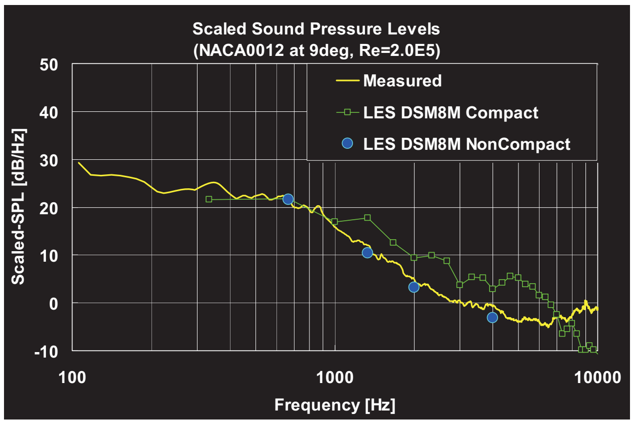


Skin Friction Coefficient **Shape faction**

Prediction of Transitional Boundary Layer and Resulting Sound

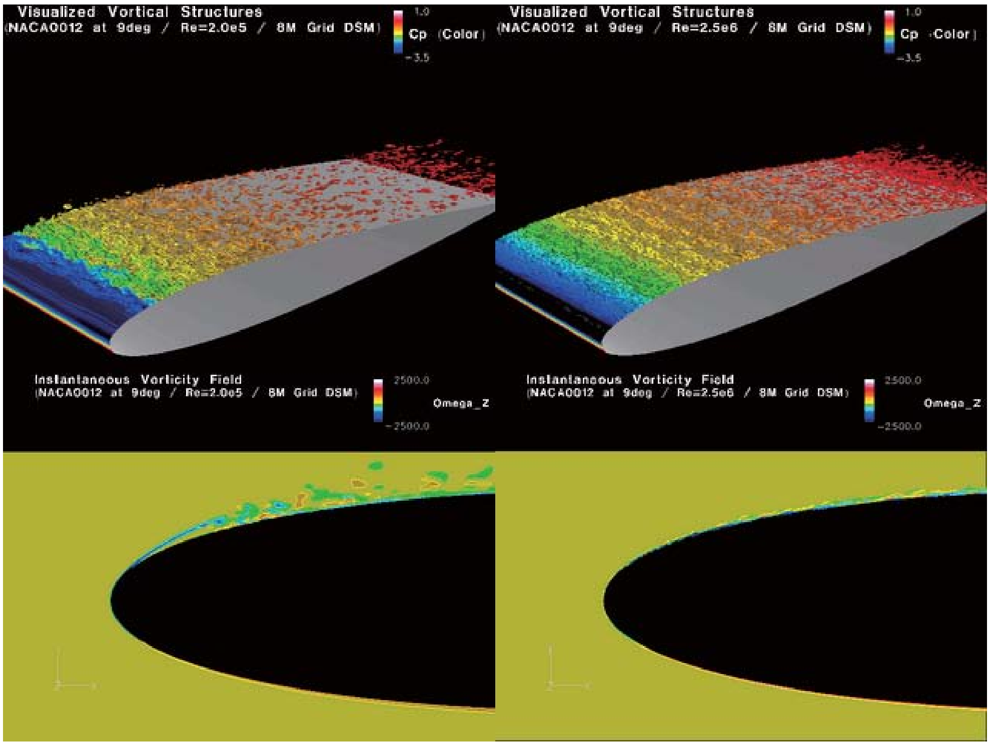
NACA0012: Angle of attack=9 deg, Re=2.0x10^5





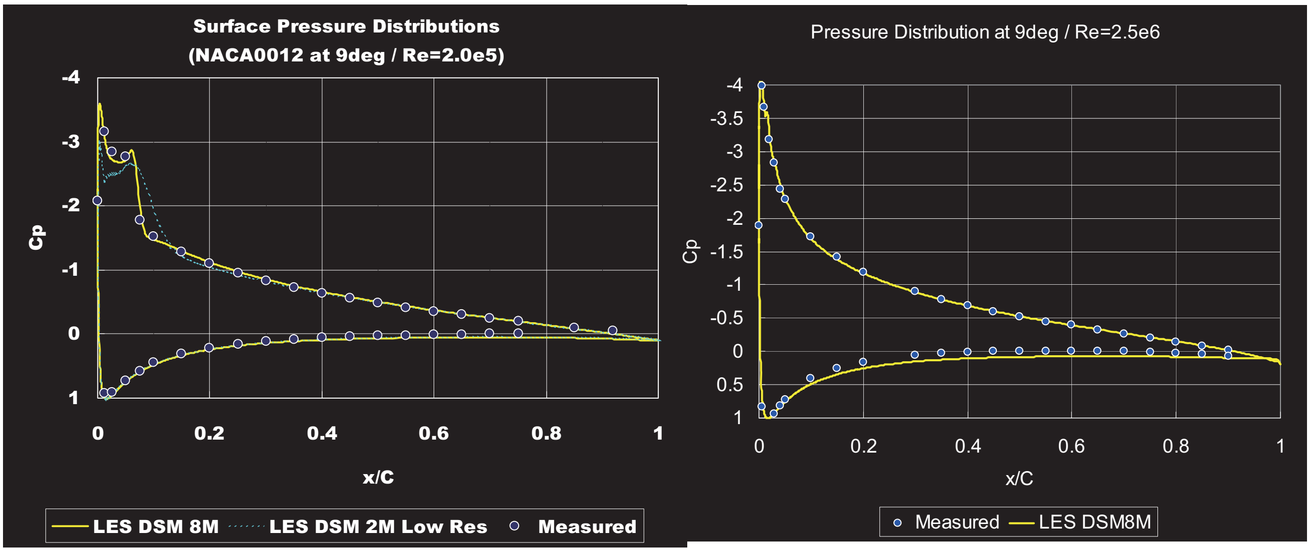
Vortical Structure near L. E. **Comparison of Far-field Sound Pressure Level**

Effects of Reynolds Number on Transition Process (left: 2.0 x 10^5, right: 2.0 x 10^6)



Effects of Reynolds Number on Surface Pressure Distributions

NACA0012: Angle of Attack = 9 deg.

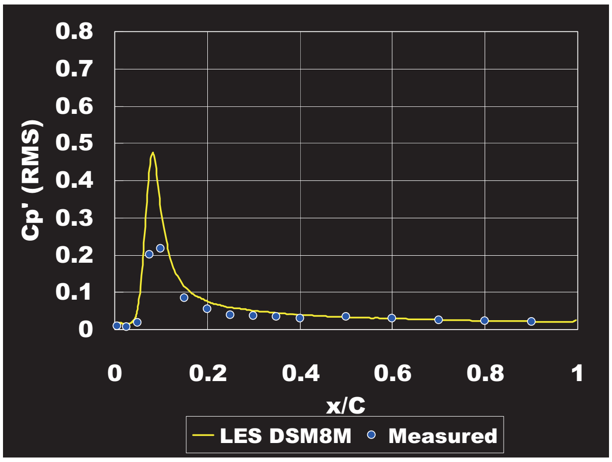


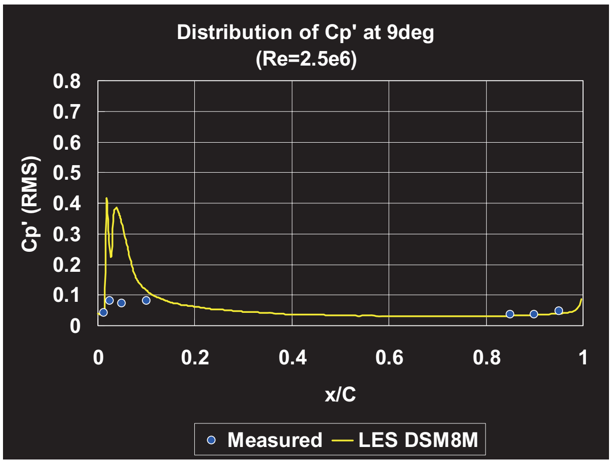
■ Re = 2.0 x 10^5
(U_0=20m/s, C=0.15m)

■ Re = 2.5 x 10^6
(U_0=50m/s, C=0.75m)

Comparison of Surface Pressure Fluctuations

Angle of Attack: 9 degrees



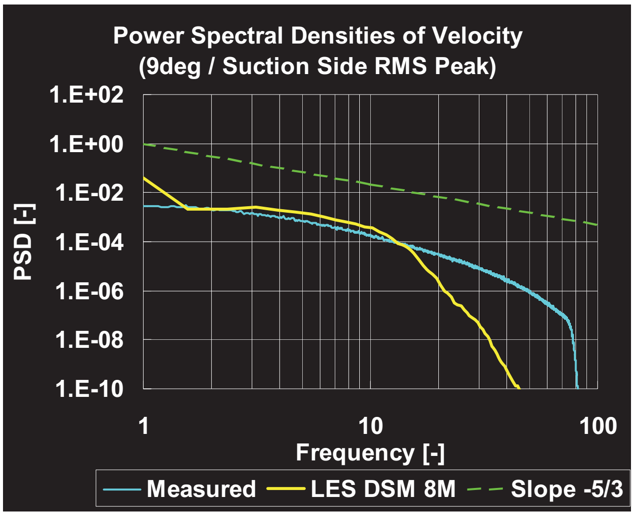


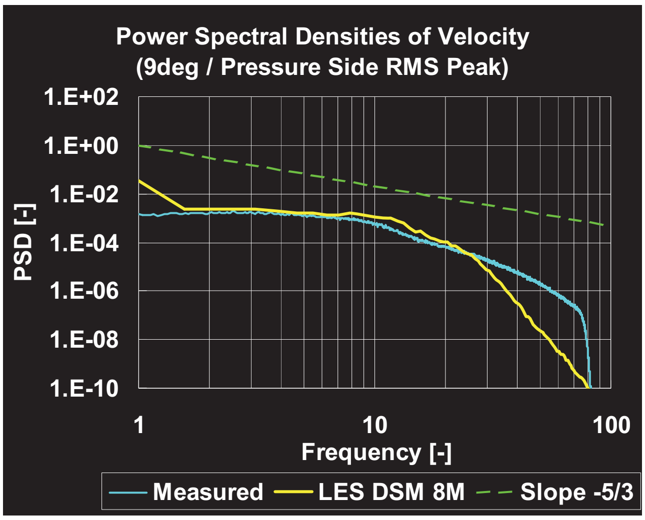
■ Re = 2.0 x 10^5
(U_0=20m/s, C=0.15m)

■ Re = 2.5 x 10^6
(U_0=50m/s, C=0.75m)

Comparisons of Frequency Spectra of Velocity Fluctuations in Near Wake

Angle of Attack: 9 degrees, Re = 2.0 x 10^5

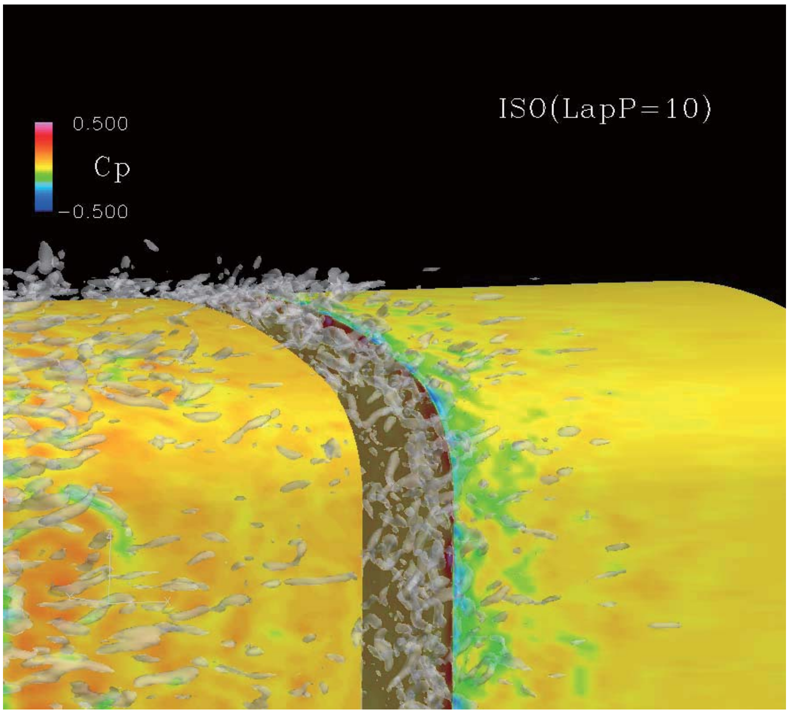




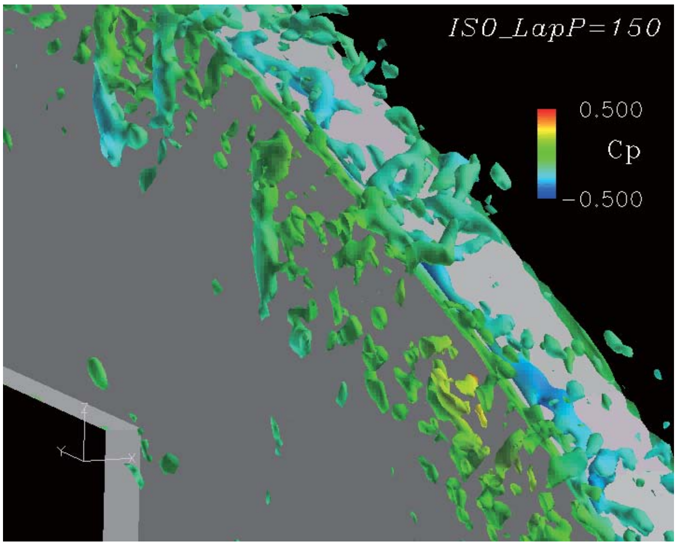
■ x/C=1.1
(suction side)

■ x/C=1.1
(pressure side)

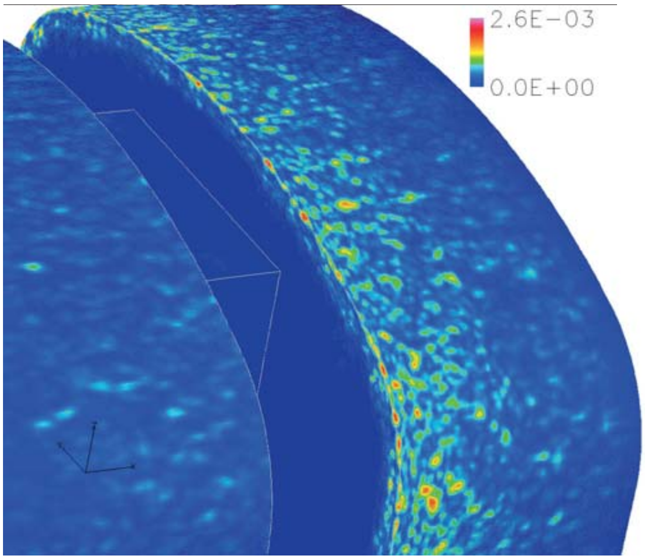
Approaching TBL and Flow in Actual Car Gap



Stretching of Vortices and Acoustical Source on Surface



Stretching of Vortices at the Edge

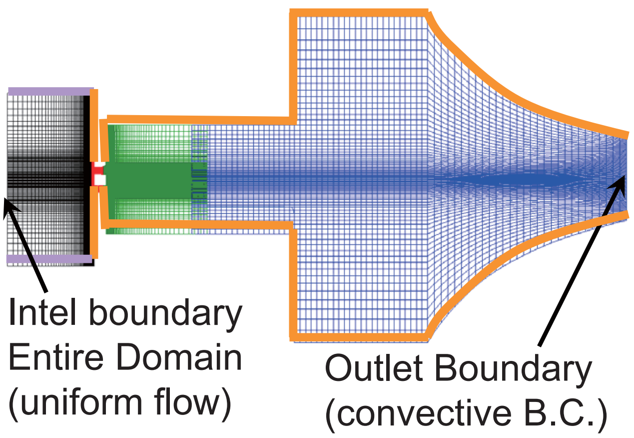


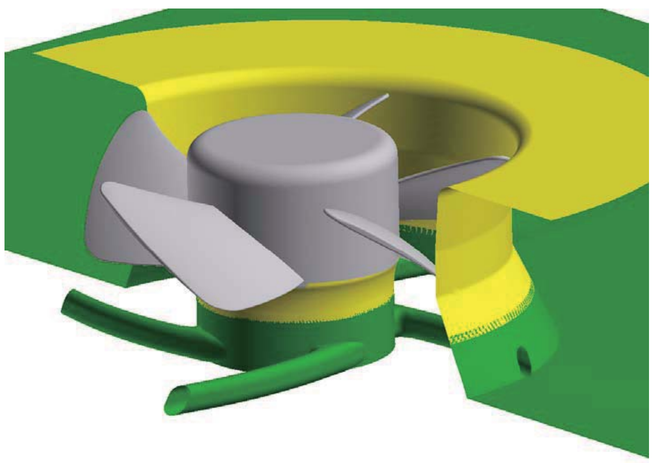
Aeroacoutsical Sources at 4. 8 Hz

26

Sound Radiated from a Small Propeller Fan

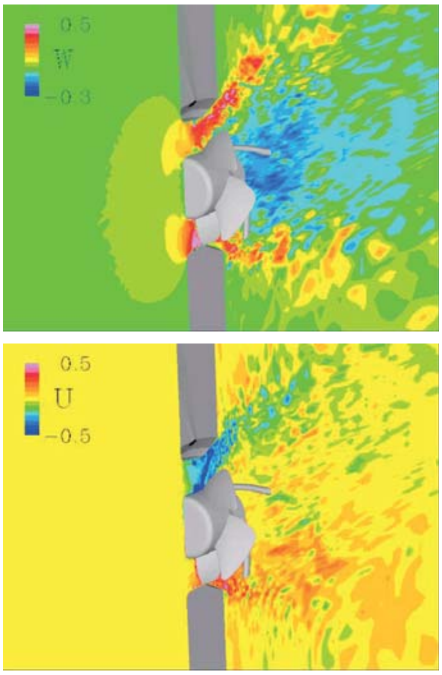
Computational Model and Boundary Conditions

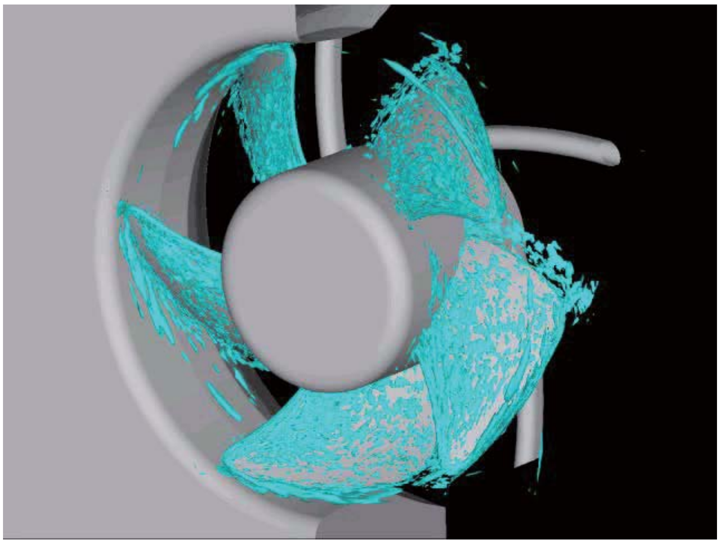




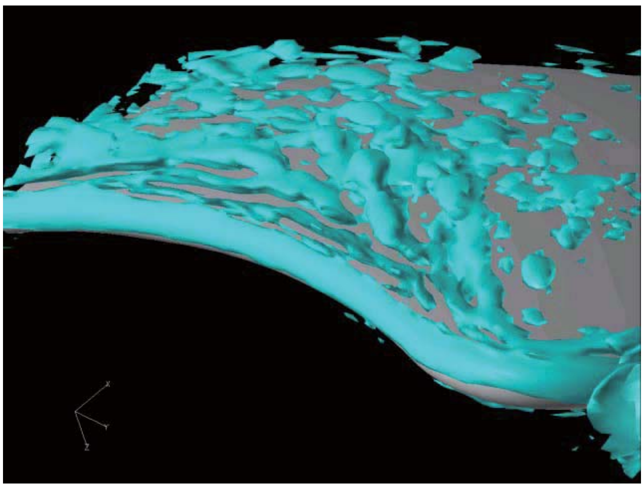
Entire Domain **Near Fan Blades**

Instantaneous Flow Fields

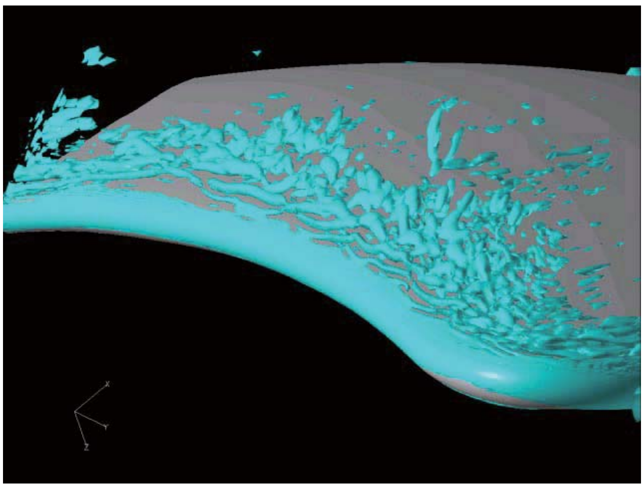




Effects of Grid Resolutions



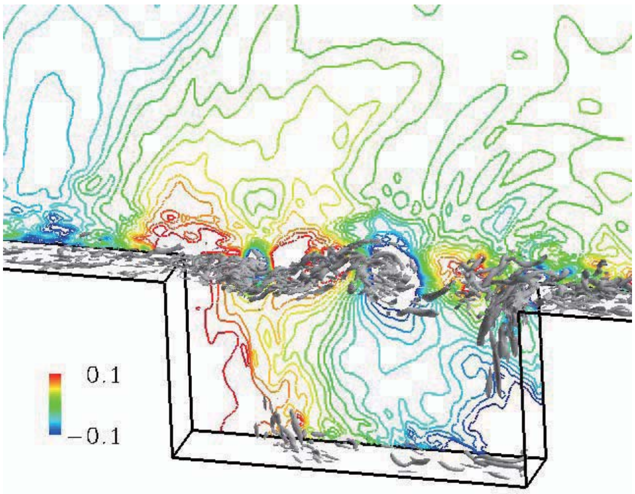
Coarse Mesh



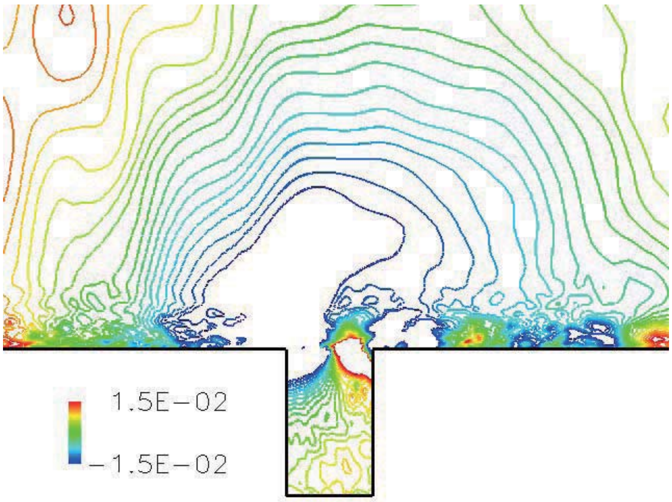
Fine Mesh

キャビティ音の直接数値解析

■ フィードバック機構の詳細解明



D/L = 0.5 (St = 0.8)



D/L = 1.7 (St = 0.4)

Perspectives and Future Roles of Measurements

Summary

- **Numerical Predictions of Aerodynamic Noise**
  - will partially replace protoryping and/or model tests up to Reynolds number O(10^6)

- **Future Role of Measurements**
  - Provide accurate and detailed data for validating numerical methods
  - Extract Essential Physical Phemomena