HOKKAIDO UNIVERSITY

Overview of Our Recent Research on AePW-4 and Introduction of CFML (HU)

R. Kikuchi, S. Kuruhara, T. Miyake, H. Terashima

Computational Fluid Mechanics Laboratory

Hokkaido University

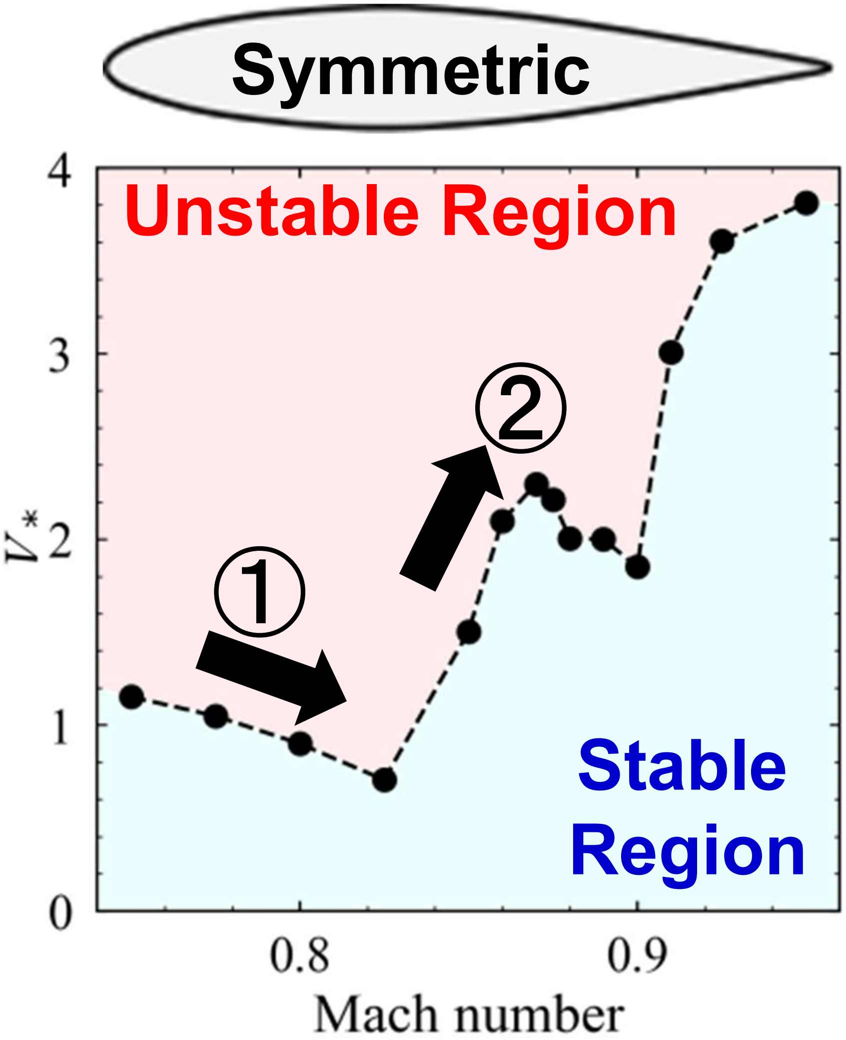
January 8th , 2026

1. Sapporo and Hokkaido university

Highlights of Our Research Achievements

- ✓ Transonic Flutter Behavior of a 2-D Symmetric Airfoil
- ✓ Transonic Flutter Behavior of a 2-D Supercritical Airfoil [1]

[1] Miyake, T., et al., *AIAA Journal*, Vol. 62, No. 12, 2023, pp. 5365-5376.



① Instability Induced by Shock Formation

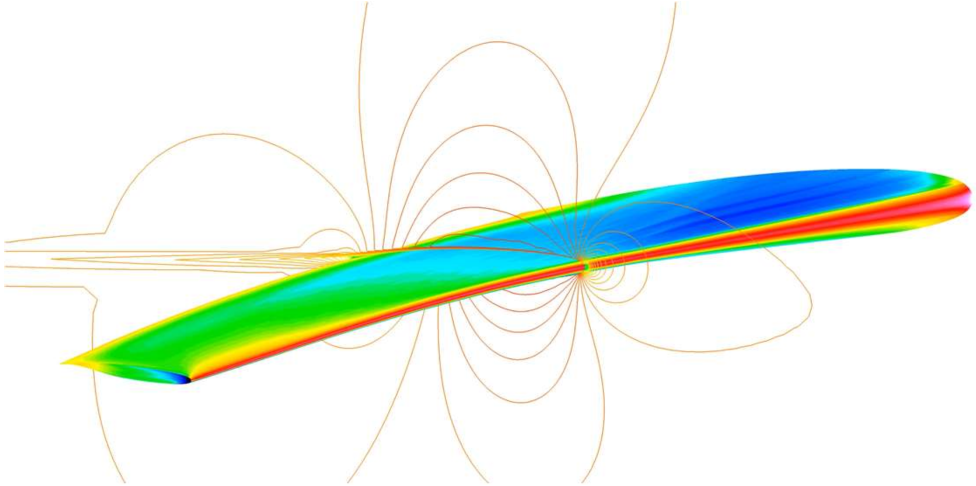
② Separation behind the Shock wave[2,3]

[2] Oyeniran, N. D et al., *AIAA Journal*., Vol. 60, No. 12, 2022, pp. 6557–6565.
[3] Selland, S., et al., *AIAA Journal*, Vol. 62, No. 12, 2024, pp. 4881-4887.

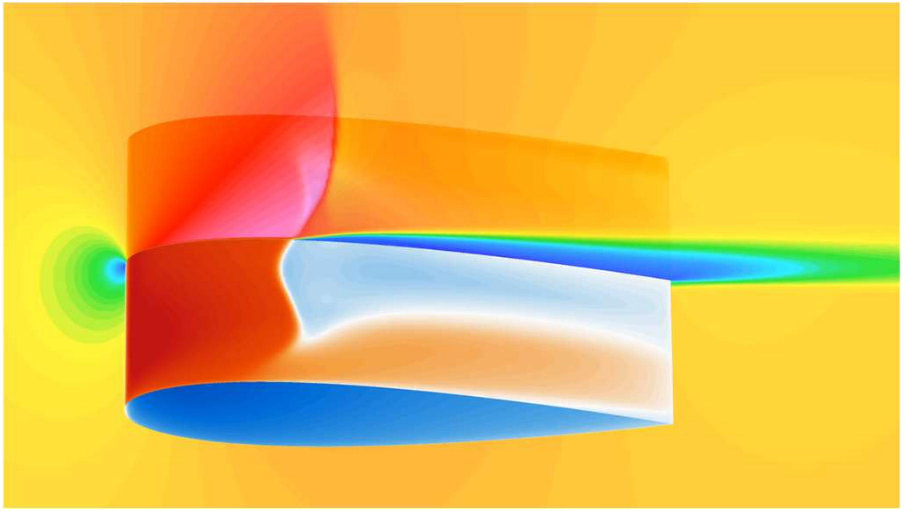
High-Fidelity Transonic Flutter Analysis of a 3-D Wing

Current Research Topic

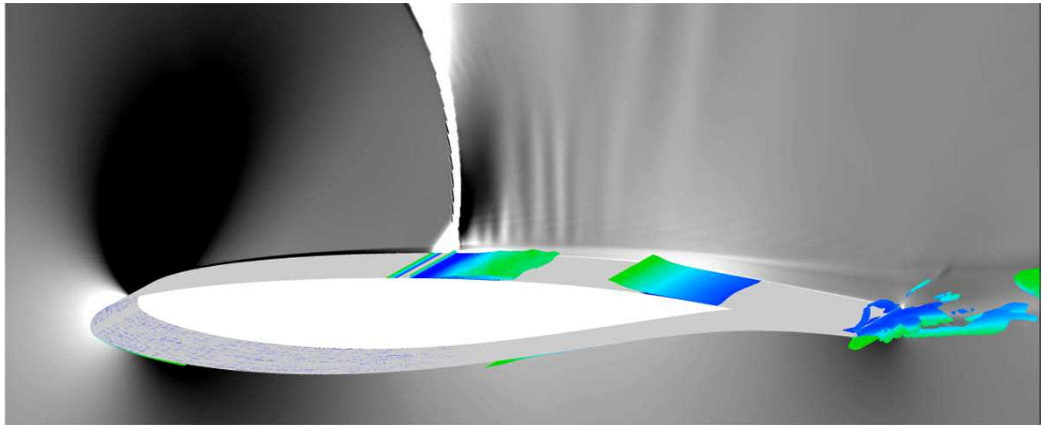
Flutter Analysis of an Elastic Wing



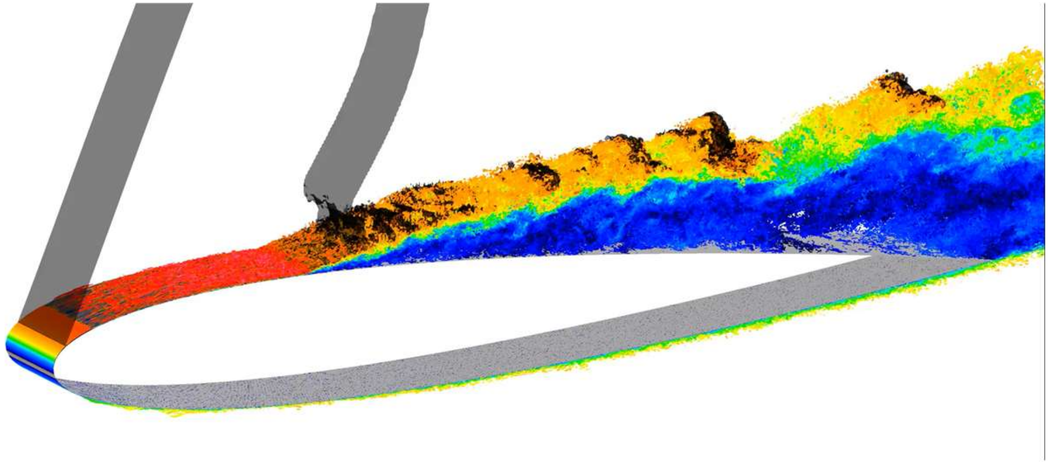
Modeling of wing-root wall



RANS/LES Hybrid (Transonic buffet)



Flutter simulation using WRLES



Flutter Suppression Using Plasma Actuators (PA)

Cartesian Grid Method for moving-boundary problems

3-D Flutter Code

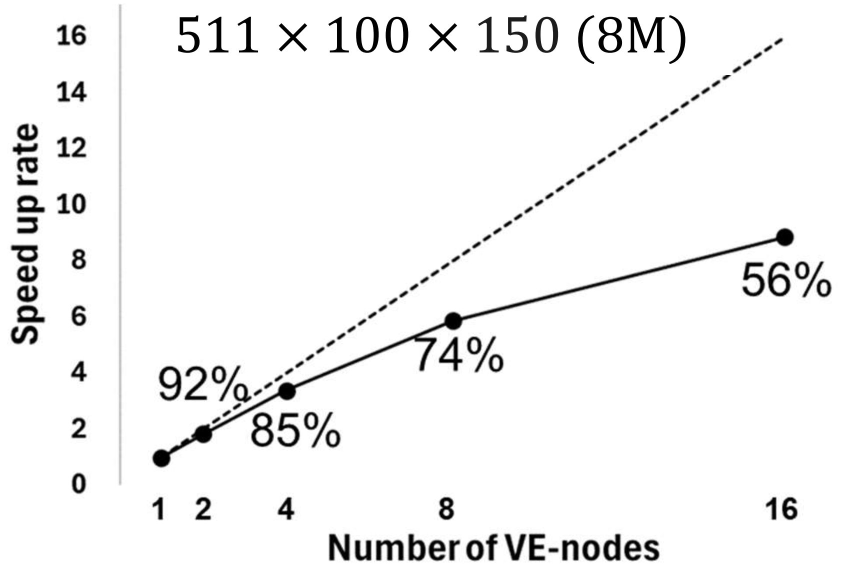
Fluid computation method

Governing Eq	3D compressible NS
Turbulence model	SA, SST (QCR2000, 2024, DDES)
Inviscid flux	SHUS (3^{rd}–order MUSCL) KEEP/Upwind Hybrid
Time integration	implicit DP–LUR method

Computation environment

Supercomputer	NEC SX–Aurora (Vector Machine)
MPI	8
OpenMP	16
Peak performance	16–20%

Strong scaling



Flutter of an Elastic Wing

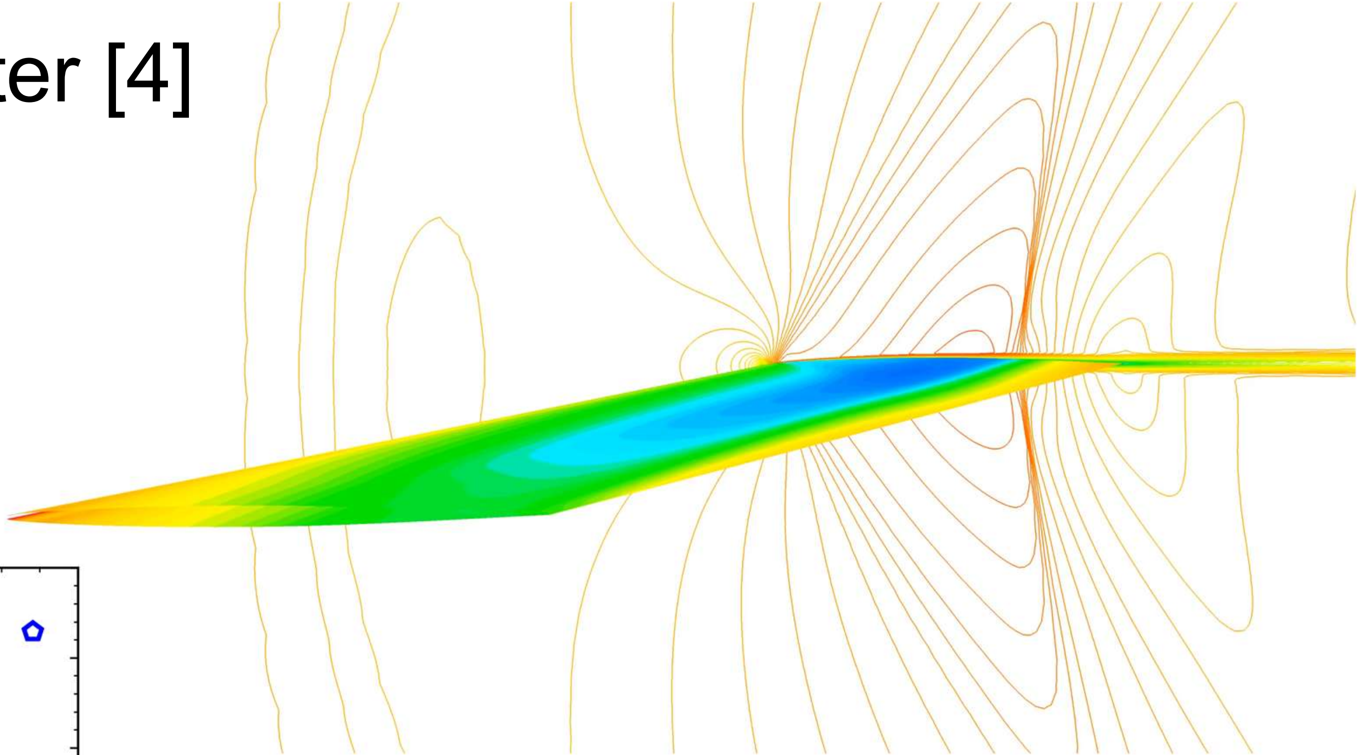
AGARD445.6 Flutter [4]

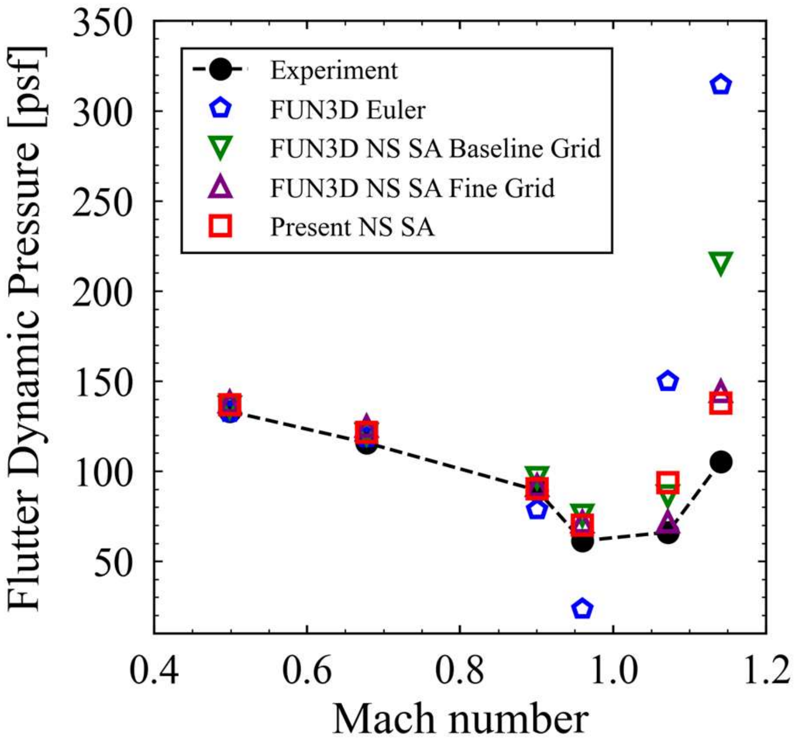
Wing : NACA65A004

Sweep Angle : 45 deg

Aspect ratio : 1.6525

Taper ratio : 0.6



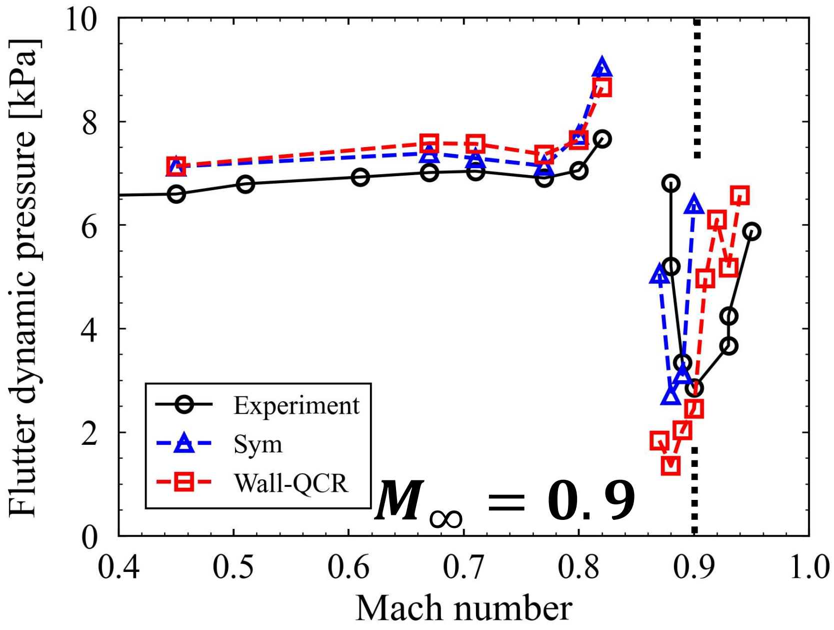


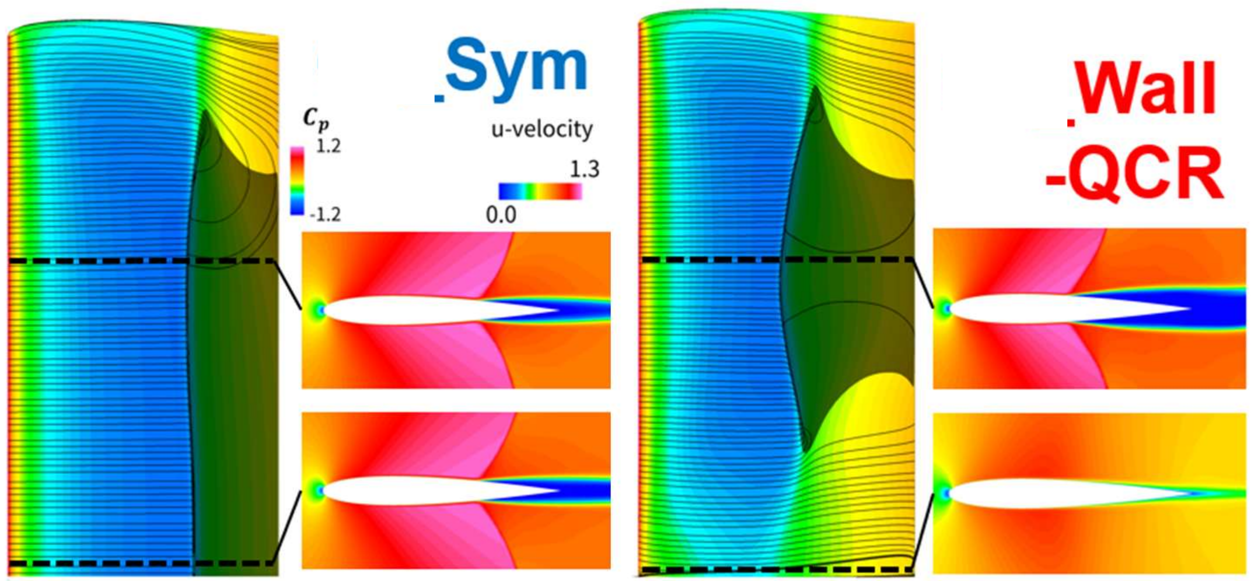
- 5.4 Million Grid Points
- 30 min for 1case

[4] Yates, E. C., AGARD report, No. 765, 1988.

NACA0012 Transonic Flutter

- **High-Fidelity 3-D Flutter Analysis in Complex Flows with Shock-Induced Separation**



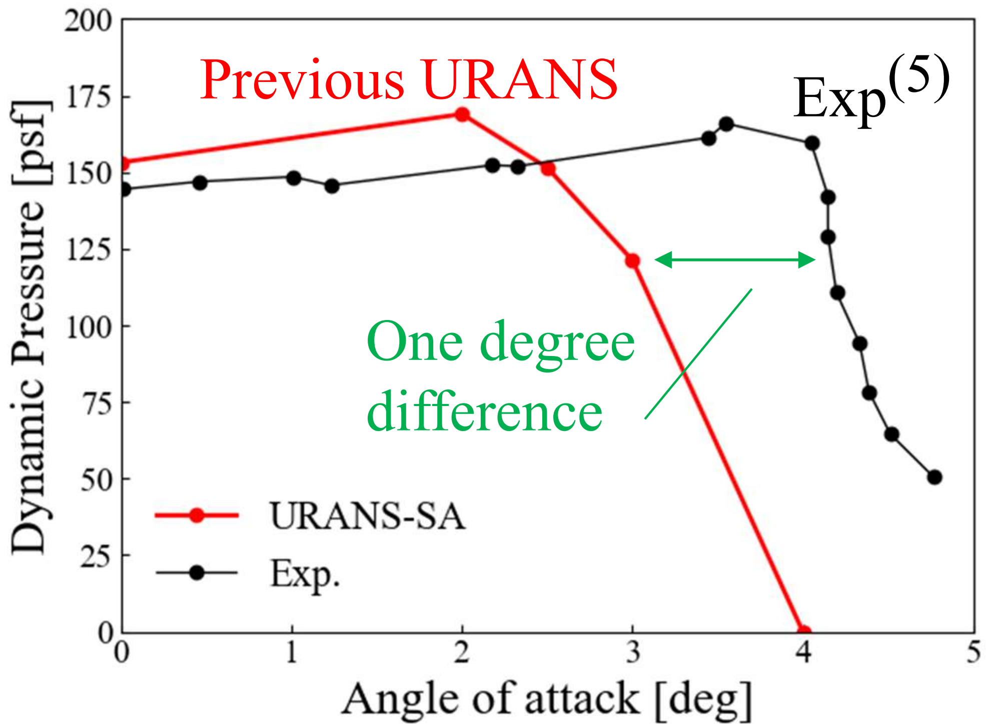


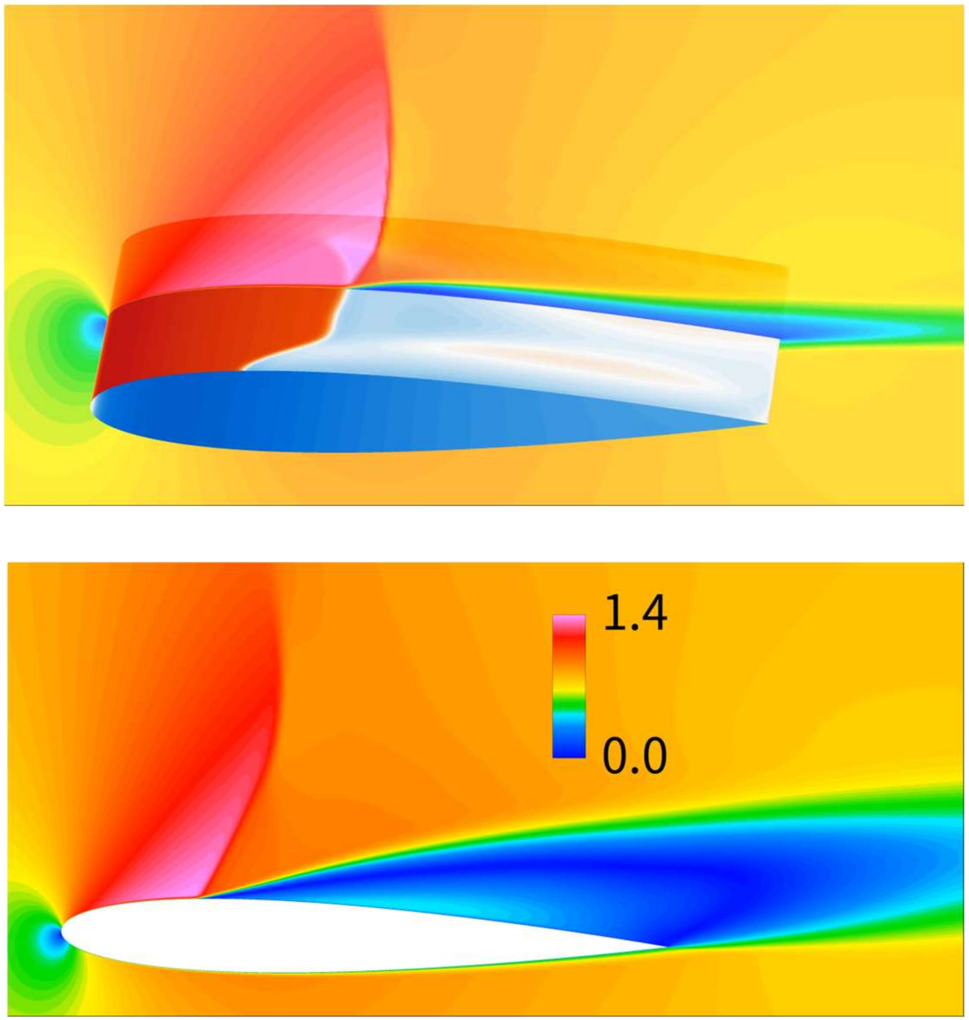
➢ Improving the Prediction Accuracy of Shock-Induced Separation Flutter Using an Anisotropic Turbulence Model

(Under review)

NACA0012 Shock-Stall Flutter

- 20million Grid Points
- 15h for 1case



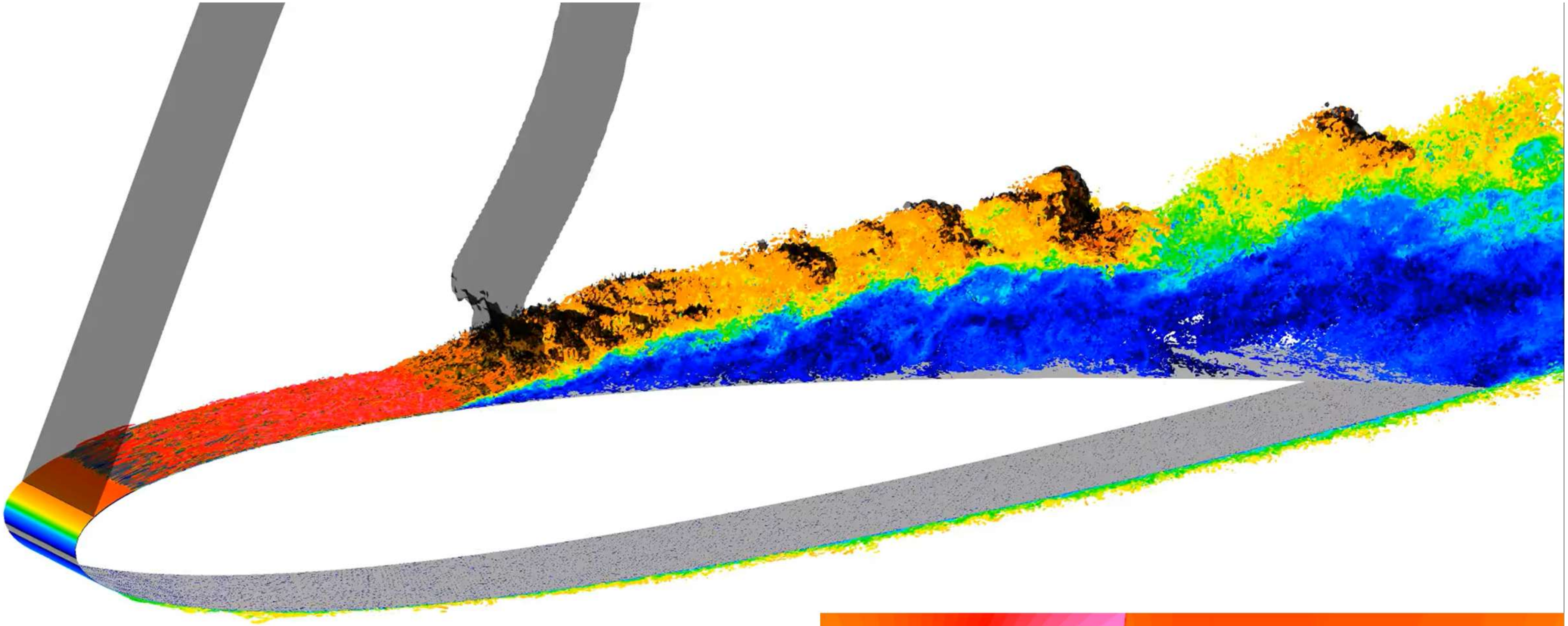


Strong Shock + Large boundary Separation

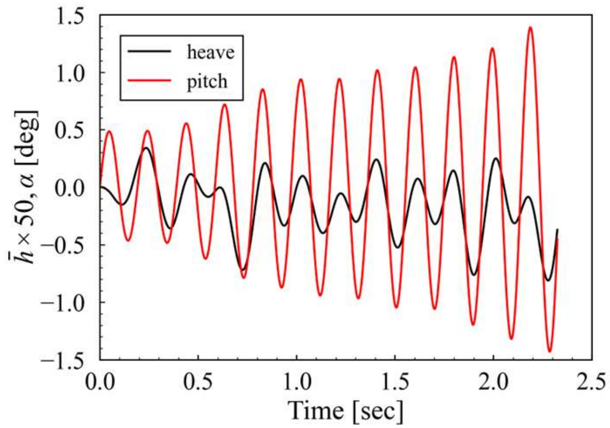
[5] Rivera J., et al., "NACA 0012 Benchmark Model Experimental Flutter Results with Unsteady Pressure Distributions," AIAA Paper, 1992-2396-CP, 1992.

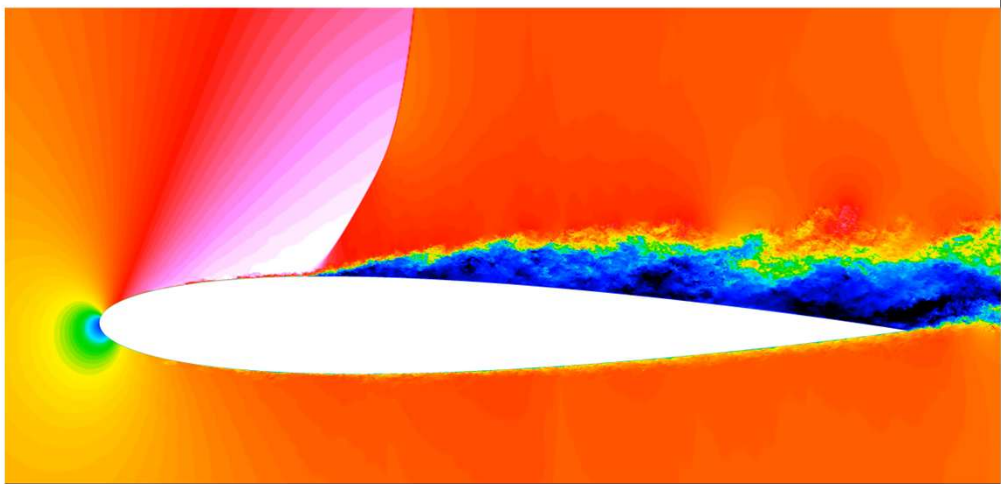
Wall-Resolved LES for the shock-stall flutter

$$M_\infty = 0.78, Re_\infty = 1.0 \times 10^6, \alpha = 6\ \mathrm{deg}$$



- 570M grid
- 160h/case





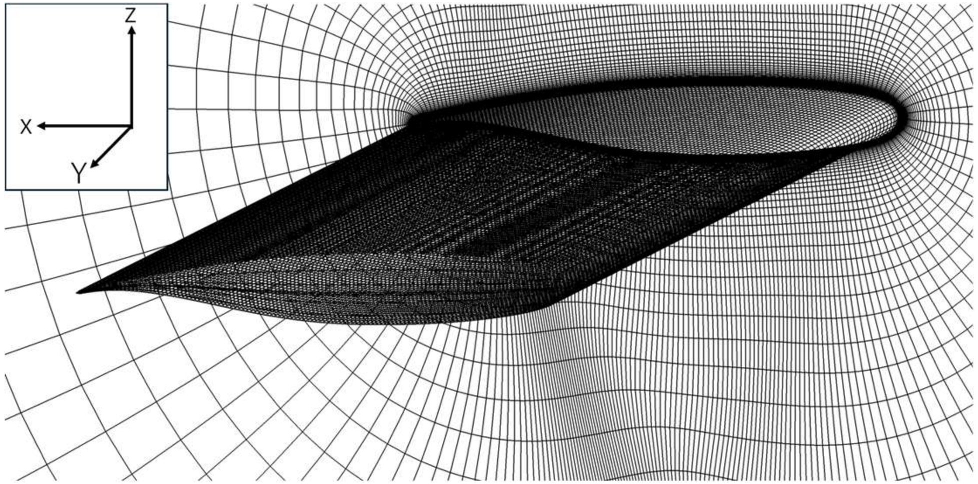
AePW-4

Flutter prediction at $M_\infty = 0.80, AoA = 0 - 6\ \mathrm{deg}$

Numerical setup

3D compressive N-S

$$\frac{\partial \boldsymbol{Q}}{\partial t} + \frac{\partial \boldsymbol{F}_j}{\partial x_j} = 0$$



$503 \times 211 \times 200 = 21.2$ M

Weakly coupling

Equation of motion

$$[M]\{\ddot{q}\} + [D]\{\dot{q}\} + [K]\{q\} = \{Q\}$$

Structural damping

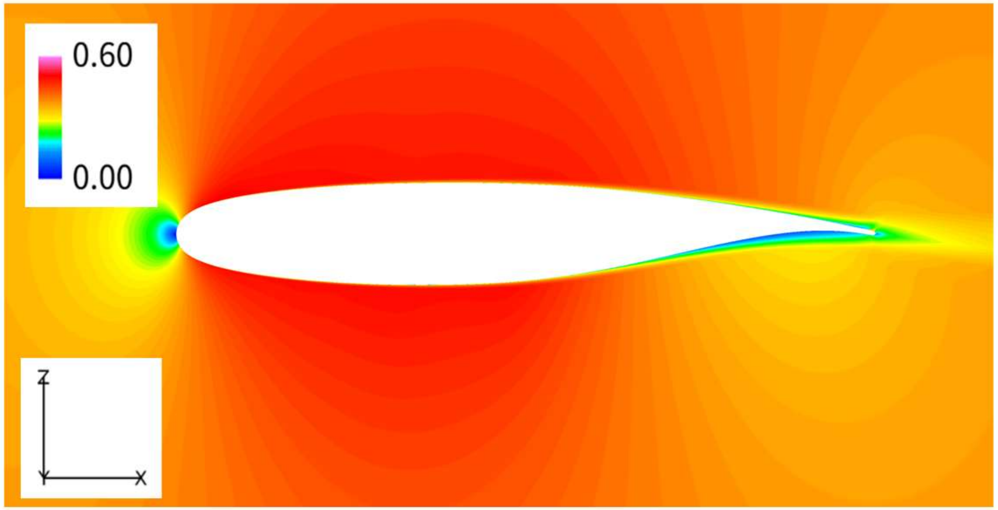
$g_h = 0.0020 \qquad g_\alpha = 0.0020$

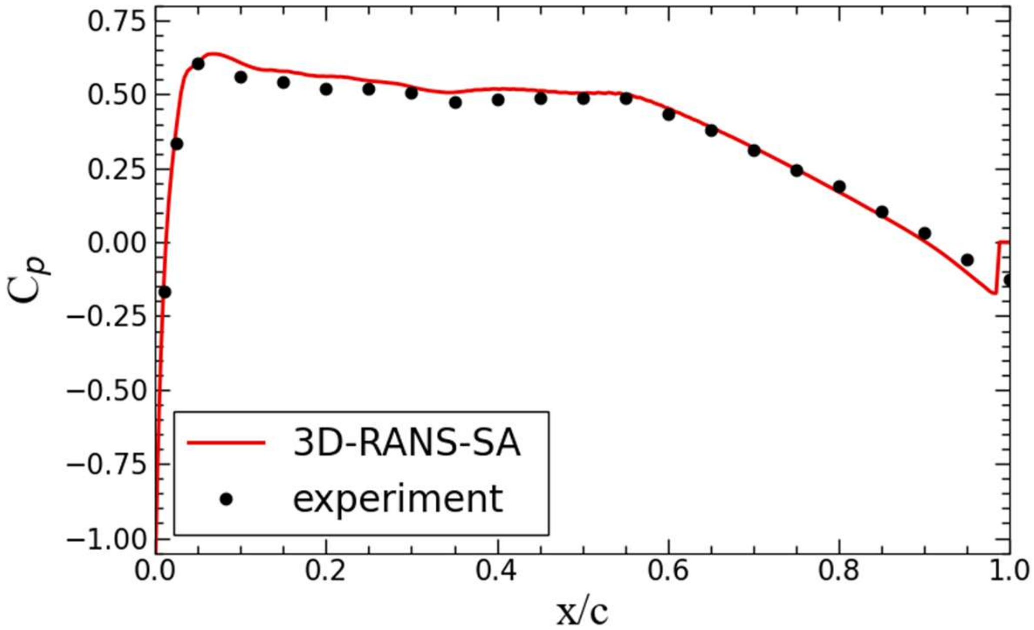
Method and Condition

Turbulence model	**Spalart-Allmaras**
Inviscid flux	**SHUS(3rd MUSCL)**
Inner iteration	5 times
Time step size	5×10^{-3} (1.3×10^{-5} s)

AePW-2: $M_\infty = 0.74, \ \ \mathrm{AoA} = 0 \ \mathrm{deg}$

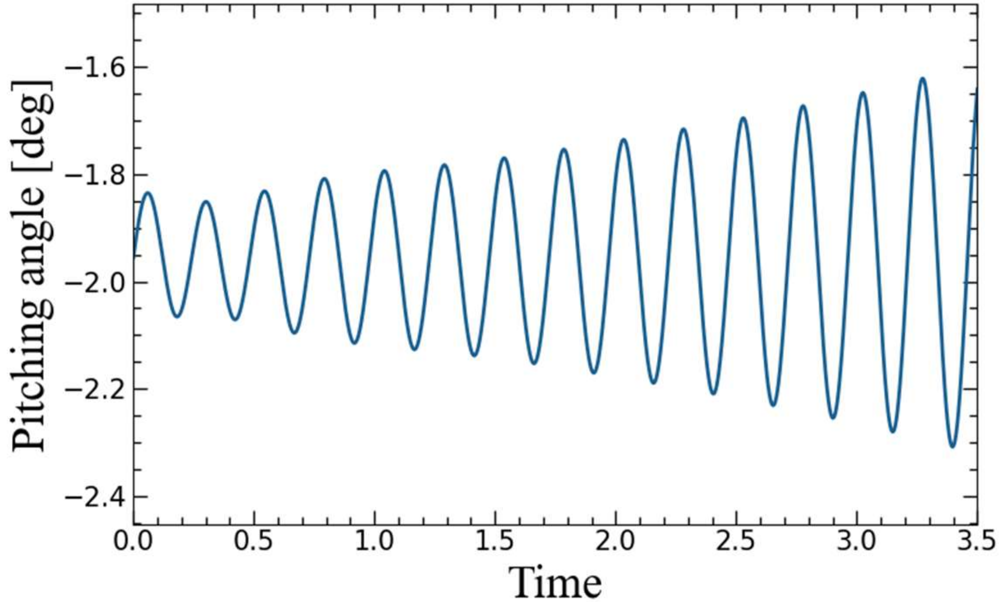
Steady condition





60% Upper surface

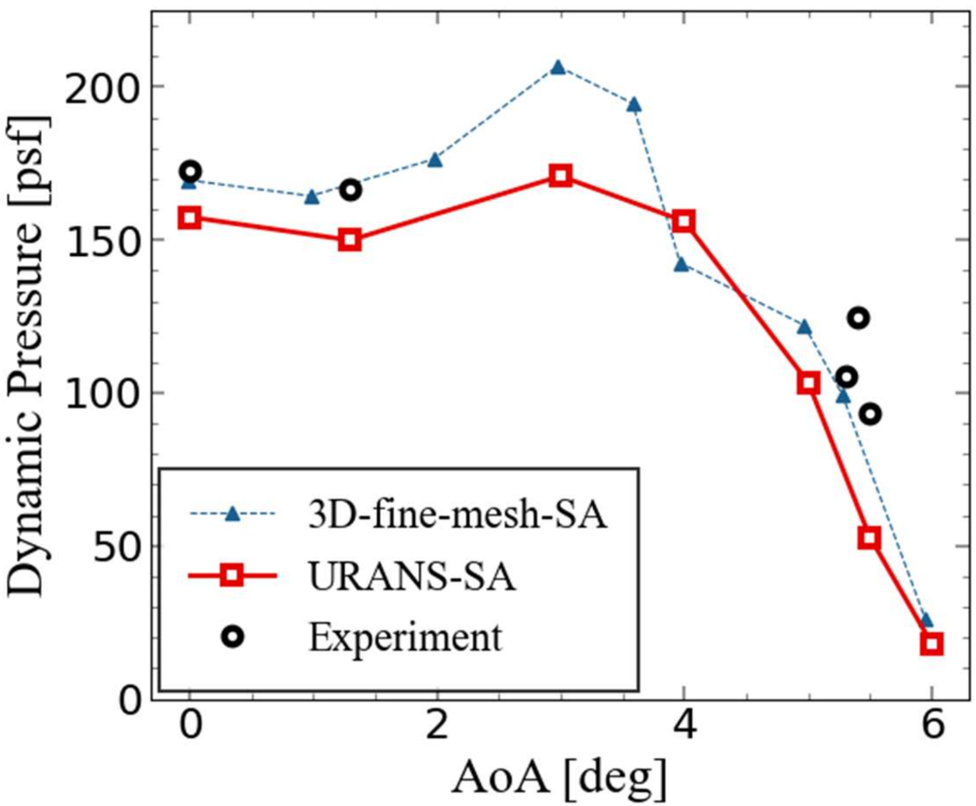
Flutter condition

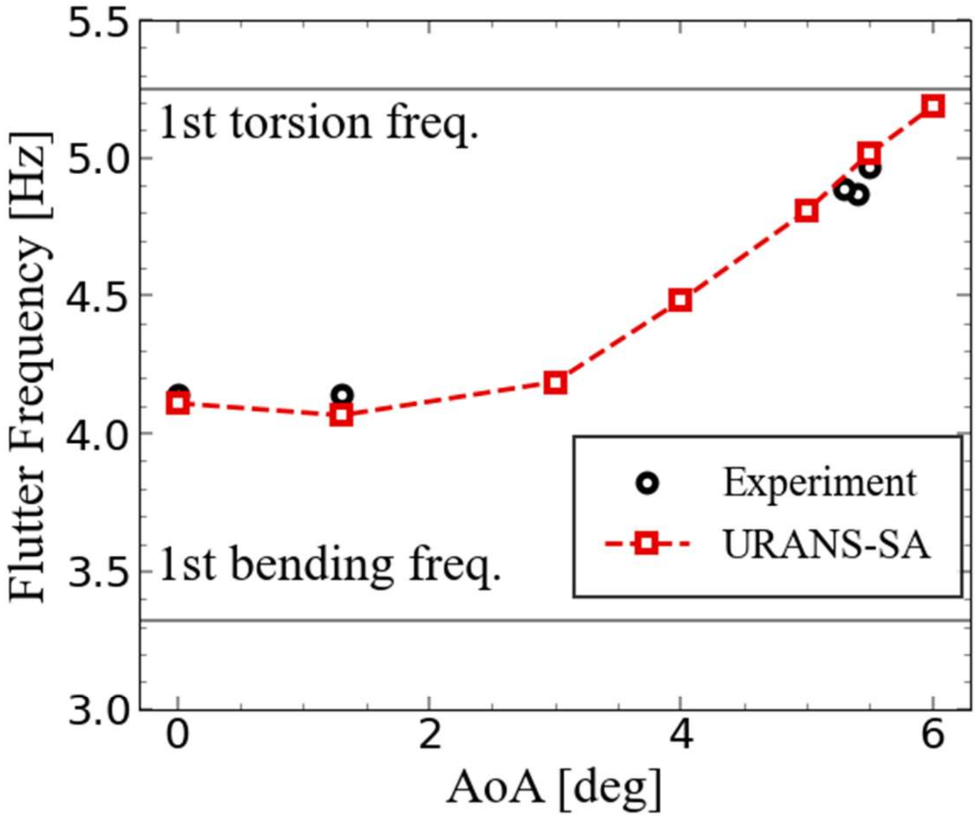


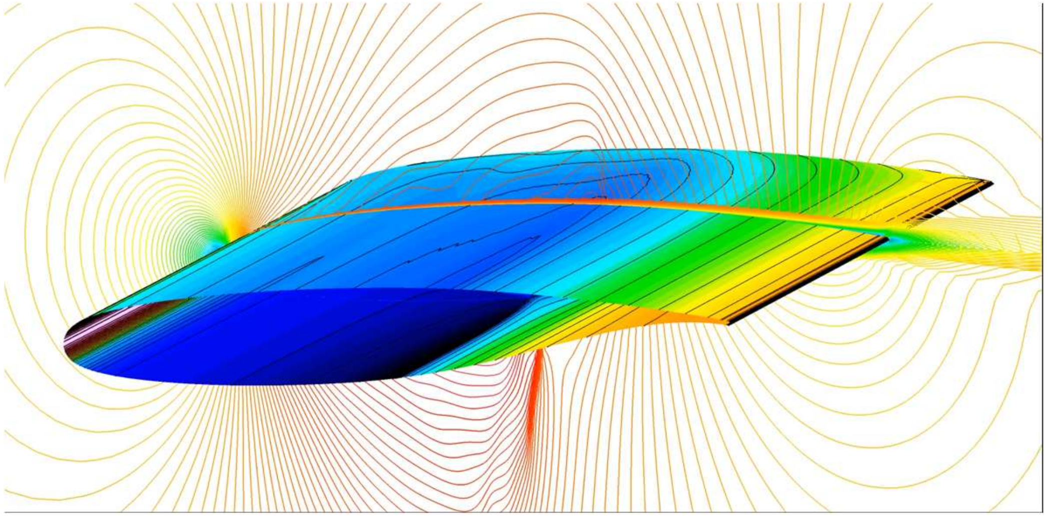
	Flutter boundary [psf]
Experiment	168.8
3D-RANS-SA	168.14

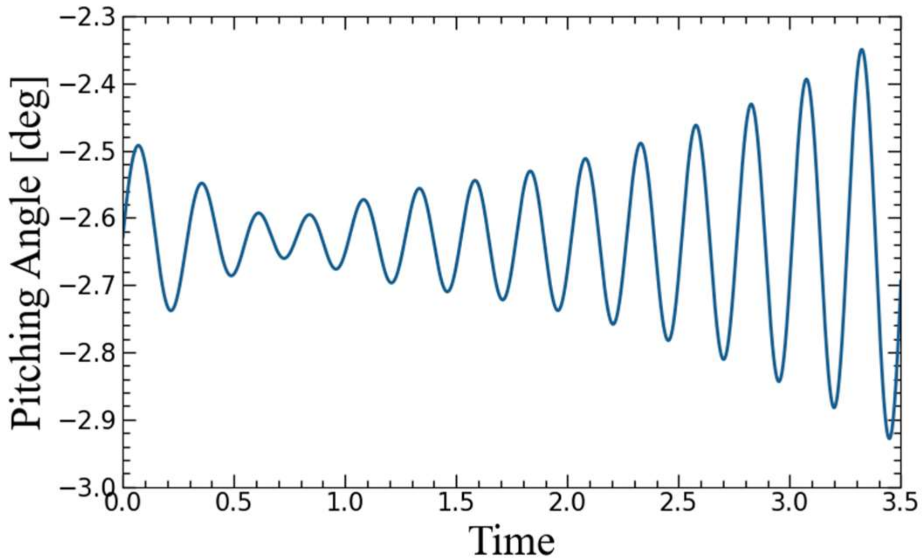
⇨ Precious prediction

AePW-4: $M_\infty = 0.80, \quad \mathrm{AoA} = 0 - 6\,\mathrm{deg}$

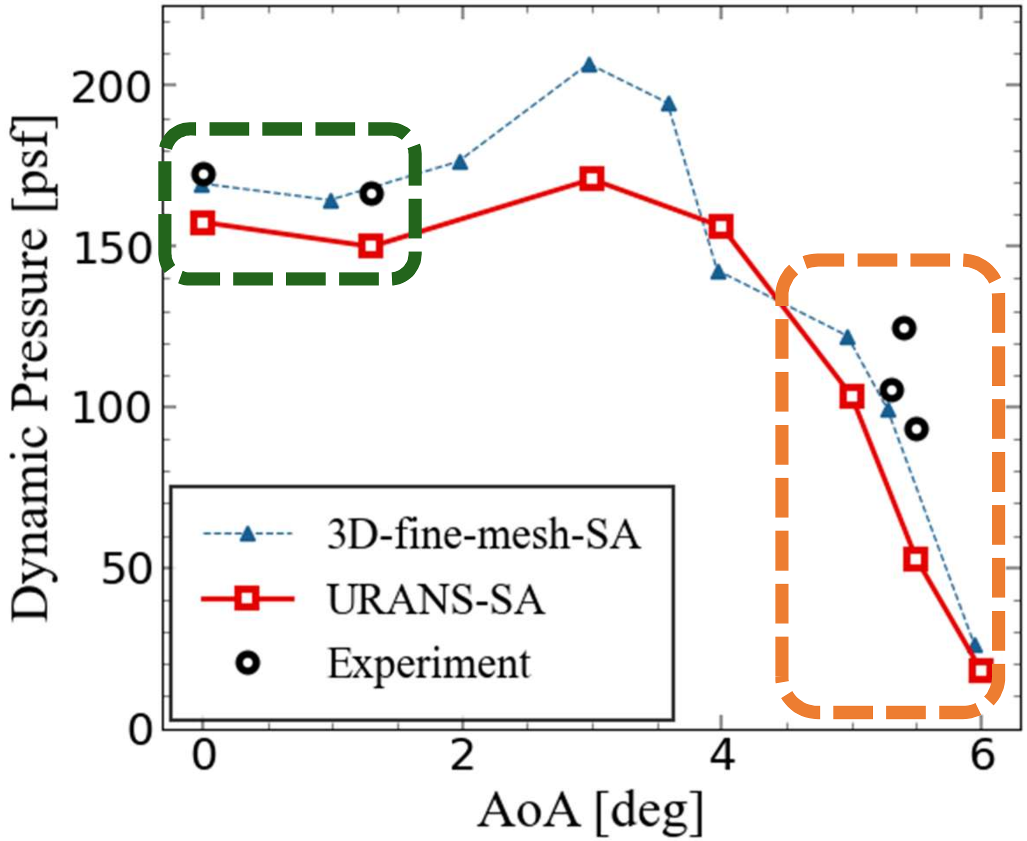








AePW-4: $M_\infty = 0.80, \quad \text{AoA} = 0 - 6\ \text{deg}$



Low AoA regime : 10% discrepancy in dynamic pressure

High AoA regime : stall flutter occurs earlier

Plan1 : Make grid with accurate airfoil data

Plan2 : Wing root : symmetric → Non-slip

Conclusion

Results

- Qualitative capture of the flutter boundary was successful under the condition of AePW-4
- At low AoA, 10% discrepancy exists compared to experimental data
- At high AoA, there was a difference of about 0.5 degrees in the AoA at which stall flutter occurred.

Future Works

- Apply non-slip condition to the wing root
- Make new grid with accurate wing data