第49回流体力学講演会 / 第35回航空宇宙数値シミュレーション技術シンポジウム
国立オリンピック記念青少年総合センター
Third Aerodynamics Prediction Challenge (APC-Ⅲ)

非構造格子を用いた NASA-CRMの空力解析

Computation of NASA-CRM Aerodynamics Using Unstructured Mesh

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Contents

- Subject 1-2 (APC-I) $M_\infty = 0.847, \alpha = 2.94^\circ, Re = 2.26 \times 10^6$
  - Grid convergence study for 2nd order Spectral Volume (SV) scheme using hybrid unstructured meshes
- Subject 3 (APC-III)
  - NASA-CRM buffet onset prediction at high angle of attack
  - Introduction of unsteady perturbed RANS approach
  - Preliminary results for transonic buffet onset prediction

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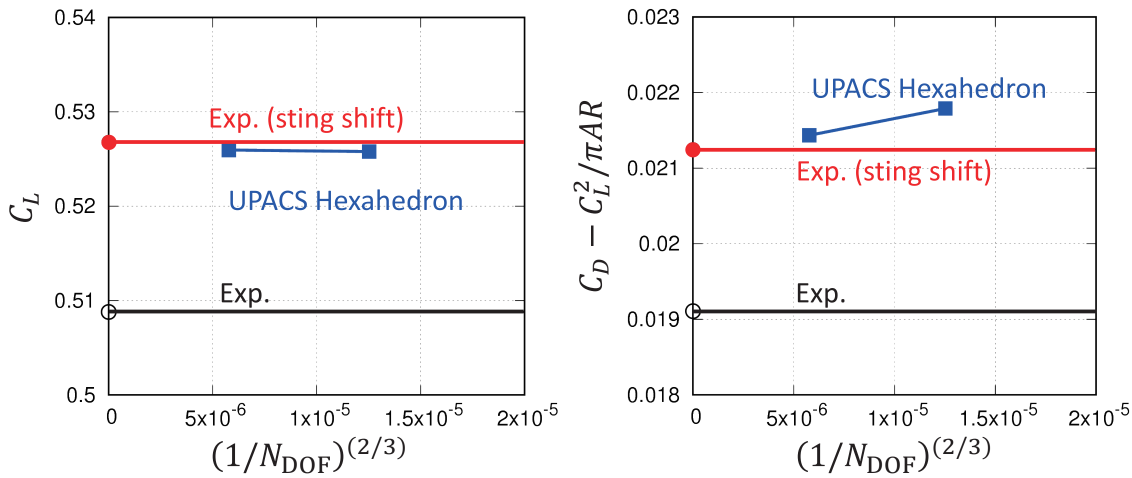
Subject 1-2 (APC-I)

◻ Previous attempts

- Grid convergence using 2nd order SV code was only confirmed using UPACS structured meshes in APC-I



Mesh Sequence for Grid Convergence Study

◻ Hybrid unstructured meshes

- Comprised of tetrahedral and prismatic cells

SV 2nd	Tetrahedron	Prism	Total Cells	Total DOF
Coarse	1,210,384	299,078	1,509,462	6,636,004
Medium	2,935,538	694,050	3,629,588	15,906,452
Fine	7,055,087	1,942,220	8,997,307	39,873,668

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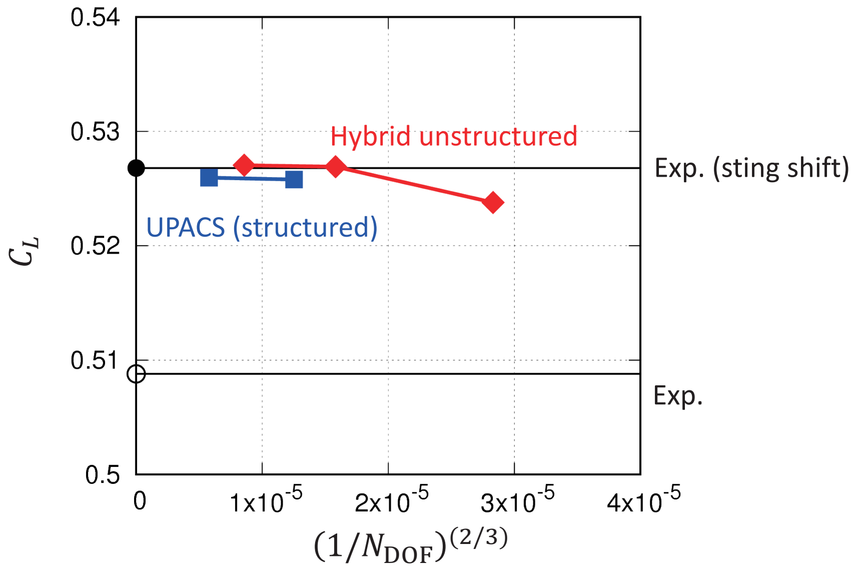
C_L Convergence Sequence

☐ Compared with UPACS (structured) case

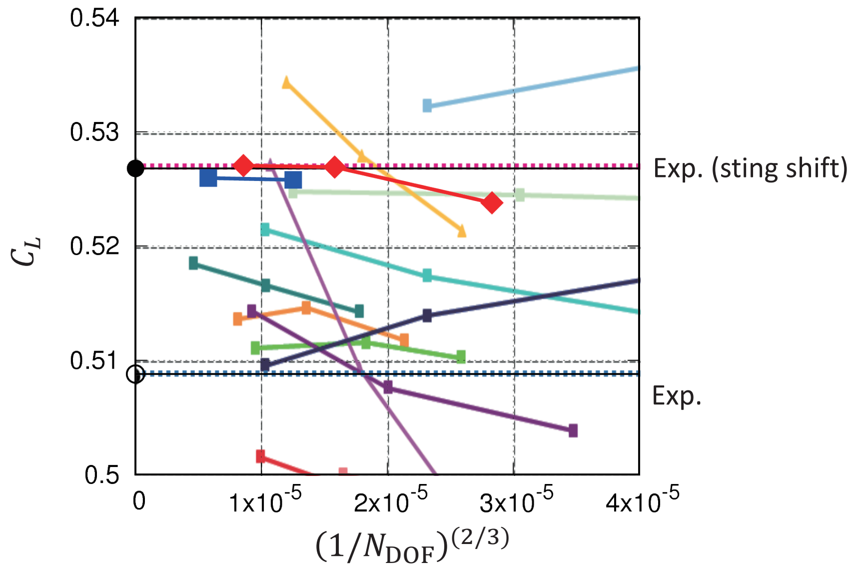
- Better convergence property indicated



C_L Convergence Sequence

☐ Compared with APC-I participants

- Better convergence property indicated



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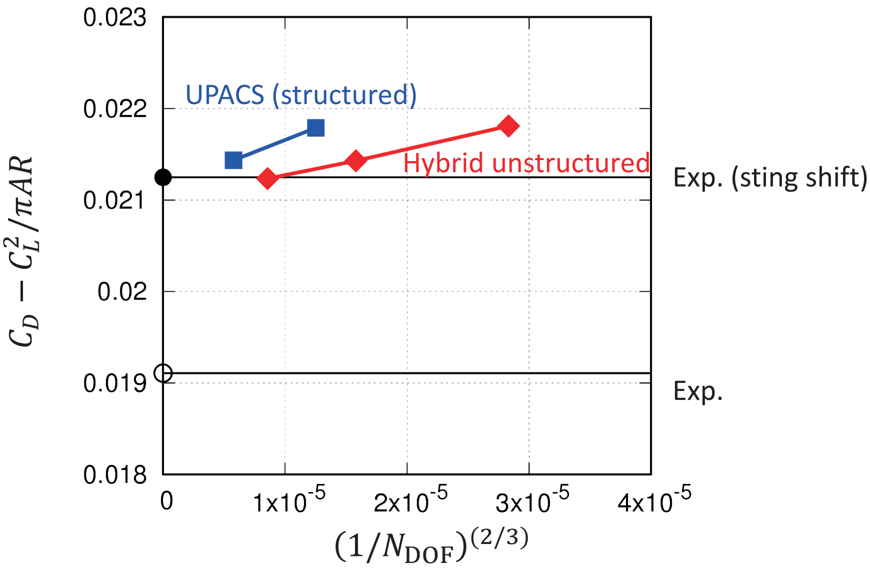
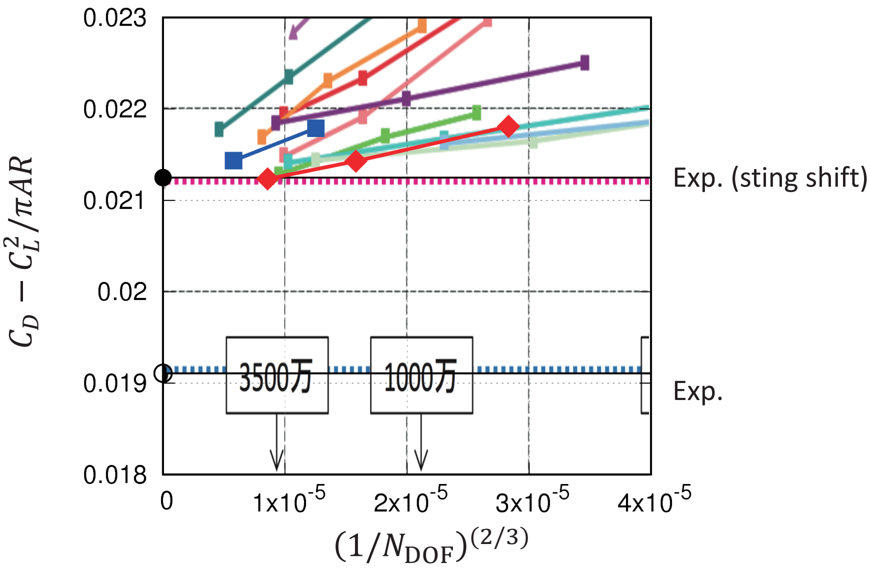
$C_D - C_L^2/\pi AR$ Convergence Sequence

- Compared with UPACS (structured) case
  - Better convergence property indicated



$C_D - C_L^2/\pi AR$ Convergence Sequence

- Compared with APC-I participants
  - Better convergence property indicated



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Summary for Subject 1-2 (APC-I)

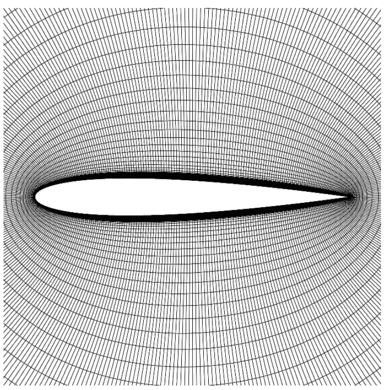
☐ Grid convergence study

- SV method successfully gives reasonable mesh convergence property for hybrid unstructured mesh sequence
- Better convergence property of hybrid unstructured mesh than that for UPACS structured mesh sequence

Subject 3 (APC-III)

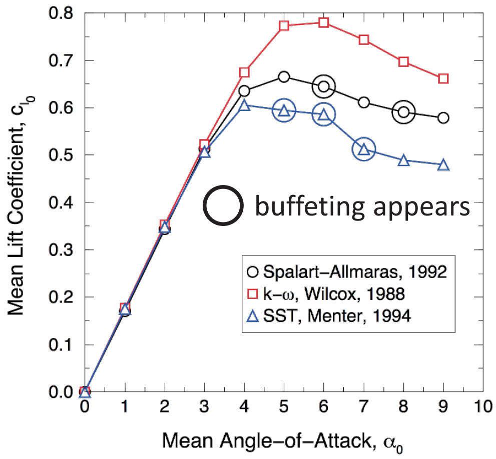
☐ Buffet onset prediction using RANS

- Practical method at industries in terms of cost
- Depends on choice of schemes, computational meshes and turbulence model



Computational mesh (NACA0012)[1]

Computed mean C_L curves [1]



[1] JP. Thomas and EH. Dowell, AIAA 2011-2077

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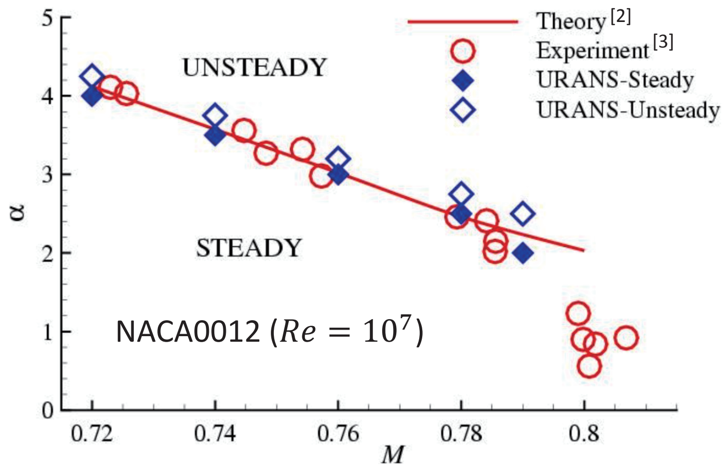
Global-Stability Theory

☐ Buffet onset prediction by Crouch et al.

- Stability limit agrees with experimentally determined buffet onset

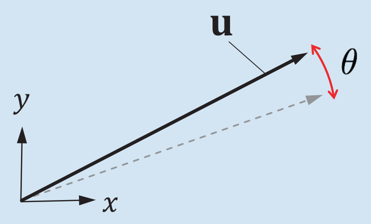


[2] Crouch et al, AIAA Paper 4233, 2008
[3] McDevitt et al, NASA Technical Paper 1985-2485

Unsteady Perturbed RANS Approach

☐ Introduction of numerical perturbation

- Velocity vector is perturbed by rotating for small angle
- Numerical perturbations are applied to all computational domain



$$\theta = \theta_o \cdot \mathrm{rand} \qquad \theta_o = 0.001\ [\mathrm{deg}]$$

$$-1 \leq \mathrm{rand} \leq 1$$

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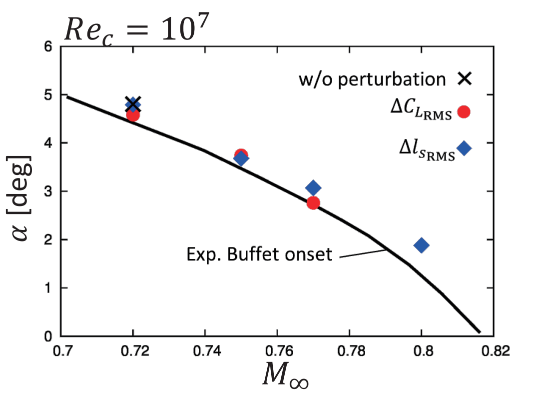
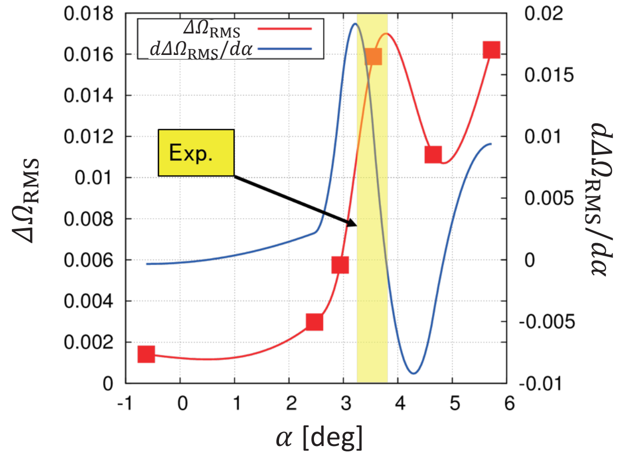
Transonic Buffet Onset Prediction

- Unsteady perturbed RANS approach gives reasonable transonic buffet onset for NACA0012 and NASA-CRM

NACA0012 wing section (2D)



NASA-CRM wing-body (3D)



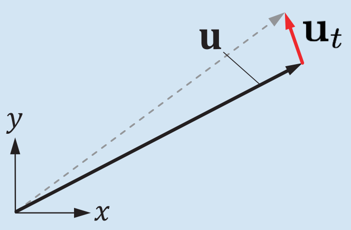
Exp. :3.39 [deg], URANS : 3.2 [deg]

Δl_S : Separation length

$\Delta\Omega$: Separation area

A New Method for Numerical Perturbation

- Perturbation is determined by turbulent kinetic energy
  - Numerical perturbation is introduced where turbulent fluctuation becomes significant
  - Rotation angle is determined based on SNGR
  - Appropriate portion of wave number range above Kolmogorov wave number is chosen



$$\mathbf{u}_t = 2\sum_{n=1}^{N} u_n \cos(\mathbf{k}_n \cdot \boldsymbol{x} + \psi_n)\boldsymbol{\sigma}_n$$

$$u_n = \sqrt{E(k_n)\Delta k_n}$$

$E(k_n)$: Energy spectrum

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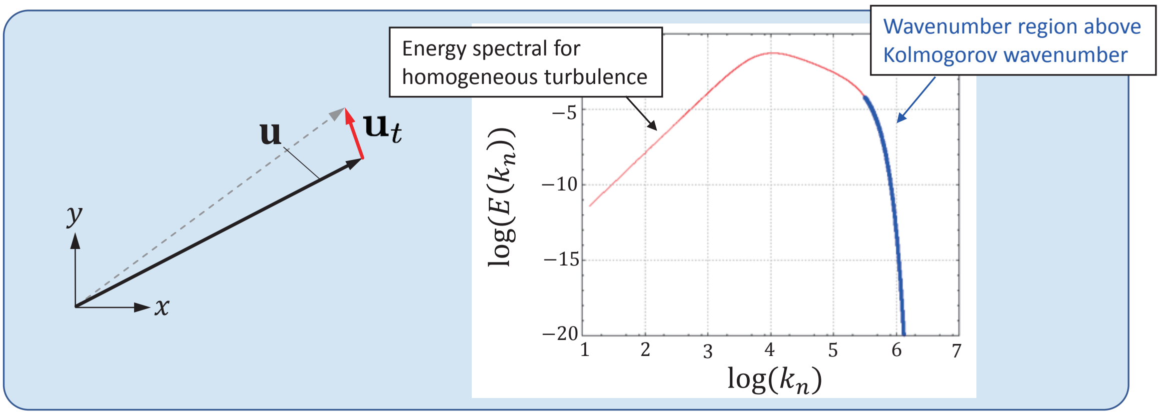
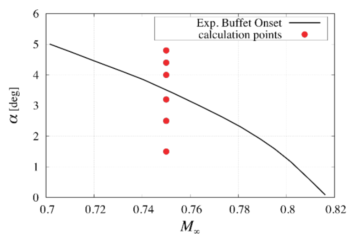
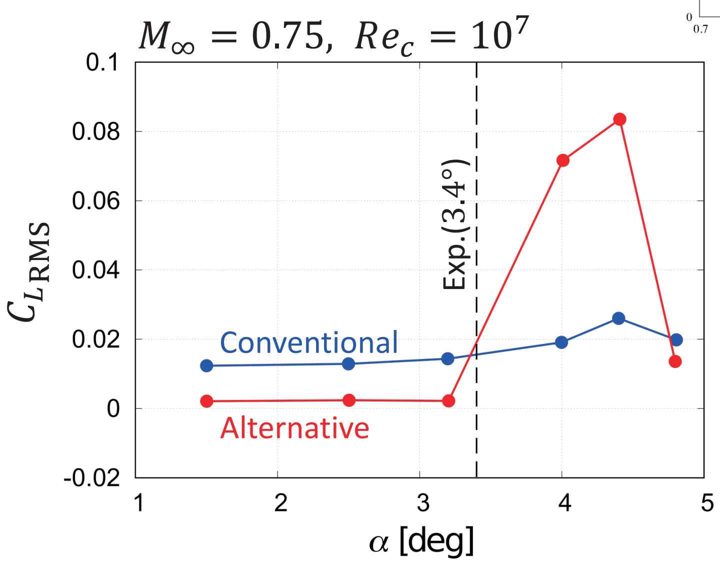


Transonic Buffet Onset Prediction for NACA0012

- Increasing $C_{L_{\mathrm{RMS}}}$
  - Buffet onset is clearly captured
  - Reasonable agreement with experiment





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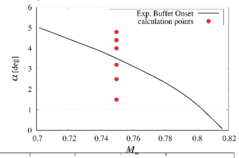
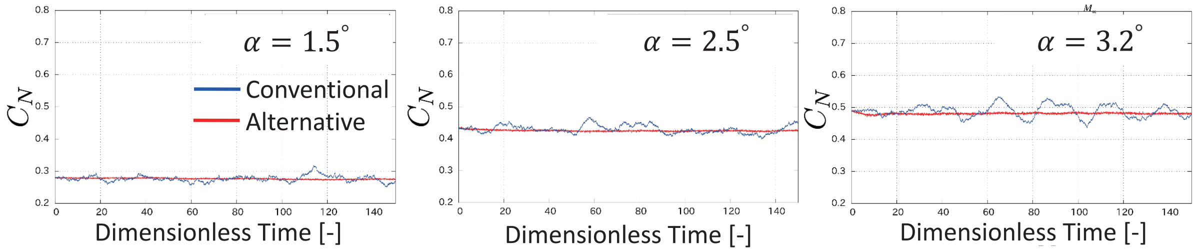
Computed C_N Fluctuations

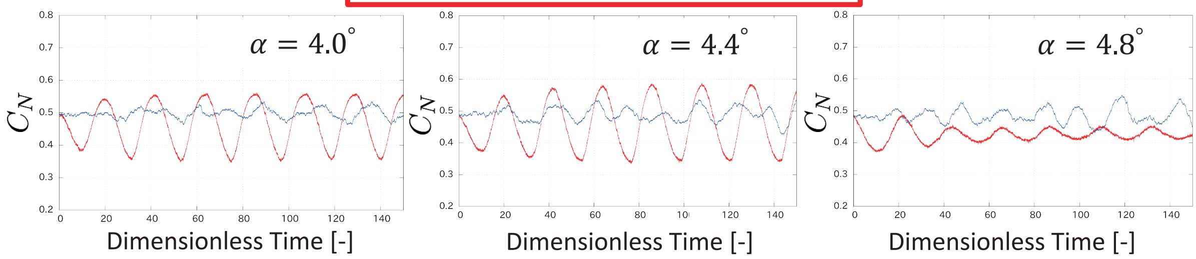
- New approach determines buffeting range clearly
  - C_N fluctuation is absent below $\alpha = 3.2^\circ$



NACA0012 (2D) : $M = 0.75, Re = 10^7$



Buffet boundary (Exp.) : α =3.4[deg]



Summary for Subject 3 (APC-III)

- Preliminary results for transonic buffet onset prediction are shown for 2D wing section and NASA-CRM wing-body
  - Unsteady perturbed RANS simulation is capable of predicting transonic buffet onset reasonably well
  - New method seems promising which can determine buffet onset clearly

- Computed result of transonic buffet onset for NASA-CRM using new method will be reported elsewhere

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