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
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

<table>
<thead>
<tr>
<th></th>
<th>Tetrahedron</th>
<th>Prism</th>
<th>Total Cells</th>
<th>Total DOF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>1,210,384</td>
<td>299,078</td>
<td>1,509,462</td>
<td>6,636,004</td>
</tr>
<tr>
<td>Medium</td>
<td>2,935,538</td>
<td>694,050</td>
<td>3,629,588</td>
<td>15,906,452</td>
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<tr>
<td>Fine</td>
<td>7,055,087</td>
<td>1,942,220</td>
<td>8,997,307</td>
<td>39,873,668</td>
</tr>
</tbody>
</table>
$C_L$ Convergence Sequence

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

- Compared with APC-I participants
  - Better convergence property indicated
$C_D - \frac{C_L^2}{\pi AR}$ Convergence Sequence

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

$C_D - \frac{C_L^2}{\pi AR}$ Convergence Sequence

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


Computed mean $C_L$ curves

- 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
- 4th order accuracy in prismatic layers
- Better convergence in friction drag as expected

Global-Stability Theory

- Buffet onset prediction by Crouch et al.
  - Stability limit agrees with experimentally determined buffet onset


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

\[ \theta = \theta_o \cdot \text{rand} \quad \theta_o = 0.001 \text{ [deg]} \]
\[ -1 \leq \text{rand} \leq 1 \]
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

\[ u_t = 2 \sum_{n=1}^{N} u_n \cos(k_n \cdot x + \phi_n) \sigma_n \]
\[ u_n = \sqrt{E(k_n)} \Delta k_n \]
\[ E(k_n) : \text{Energy spectrum} \]
A New Method for Numerical Perturbation

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Transonic Buffet Onset Prediction for NACA0012

- Increasing $C_L_{RMS}$
  - Buffet onset is clearly captured
  - Reasonable agreement with experiment

$M_\infty = 0.75, \ Re_c = 10^7$
Computed $C_N$ Fluctuations

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

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

- 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

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

- Buffet boundary (Exp.) : $\alpha = 3.4[\text{deg}]$