FaSTAR results with Various Grids and Turbulence models

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Task1 Computational Method

• Flow solver: FaSTAR
  – Grid: HexaGrid, BOXFUN, UPACS, MEGG3D
  – Turbulence model: 3 SST models,
    3 EARSM models,
    + 1 SA model (APC2 result)
  – Discretization
    • Cell-Vertex: MEGG3D
    • Cell-Center: HexaGrid, UPACS, BOXFUN
  – Inviscid flux: HLLEW
  – Reconstruction: U-MUSCL (\(\chi=0.5\))
  – Gradient: GLSQ
  – Slope limiter: Hishida (van Leer-type)
  – Time integration: LU-SGS (Local time stepping)
Turbulence models (1)

- **SAQCR**: SA-noft2-R-QCR2000
  - This is used for APC-I and APC-II.
  - No Ft2 term, rotation correction, nonlinear QCR model

  \[
  \tau_{ij,QCR} = \tau_{ij} - C_{cr1}[O_{ik}T_{jk} + O_{jk}T_{ik}]
  \]

  \(\text{Linear} \quad \text{Nonlinear (QCR model)}\)

- **SST**: SST2003
  - Menter’s SST proposed in 2003

- **SSTsust**: SST-2003-sust
  - \(k\) and \(\omega\) do not decay in free stream (controlled decay)

- **SSTsustQCR**: SST-2003-sust-QCR2000
  - Add QCR model to the above SSTsust model

The destruction terms are canceled when \(k=k_{amb}\), \(\omega=\omega_{amb}\)

\[
\tau_{ij} = \frac{M_{\infty}}{Re}\mu_t \left( S_{ij} - \frac{1}{3} \frac{\partial u_k}{\partial x_k} \delta_{ij} \right) - \frac{1}{3} \rho k \delta_{ij} - a_{ij}(\text{ex}) \rho k
\]

Nonlinear term

\[
a_{ij}(\text{ex}) = \beta_3 \left( W_{ij}^* - \frac{1}{3} H_{ij} \delta_{ij} \right) + \beta_4 \left( S_{ij} W_{ij}^* - W_{ij}^* S_{ij} \right) + \beta_5 \left( S_{ij} W_{ij}^* - W_{ij}^* S_{ij} \right) - \frac{2}{3} \frac{1}{3} IV \delta_{ij}
\]

\[
S_{ij}^* = \frac{1}{\beta^* \omega} \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right), \quad W_{ij}^* = \frac{1}{\beta^* \omega} \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i} \right)
\]

- **EARSMS**: EARSMSko2005a
  - Hellsten’s \(k\)-\(\omega\) based explicit algebraic Reynolds stress model

- **EARSMMmod**: EARSMMmod
  - The nonlinear term \(a_{ij}(\text{ex})\) is deleted from the above model
  - This is a linear \(k\)-\(\omega\) model, but this is different form the Wilcox’s \(k\)-\(\omega\) model

- **EARSMMmodQCR**: EARSMMmodQCR
  - Add QCR model to the above EARSMMmod
• Low AoA - Cruise AoA: Almost same
• High AoA: Considerable variations

Aerodynamics Coef. at 2.94deg (MEGG3D)

• CD: EARS model > SA model > SST model
• The similar trend for the other grids.
Pressure and Viscous Drag at 2.94deg (MEGG3D)

- Viscous Drag: EARSM model > SA model > SST model

CL-α at High Angles of Attack

- High AoA: HexaGrid and BOXFUN results are similar trend.
- UPACS and MEGG3D results are similar trend.
SurfaceFlow of AoA 5.72deg

- Shock wave location is changed by turbulence models.
- BOXFUN: There is no SOB (Side of Body) separation.
- MEGG3D: The size of SOB separation is changed by turbulence models.

Cp and CL of AoA 5.72deg (BOXFUN)

- There is a relationship between Cp of Section C and CL.
- The vortex appears near the Section C.
The Most Corresponding Case with the EXP at AoA5.72deg

- Best CL prediction ⇒ MEGG3D+EARSMod
- Best Shock wave location ⇒ BOXFUN+EARSModQCR
- There are no cases which correspond with both of CL and Shock wave location?

Task2 Whole Wind Tunnel CFD

- We computed the wall interferences
  - to investigate the difference between EXP and CFD at the low angles of attack
  - to validate the amount of wall correction

- Grid: BOXFUN
- Turbulence model: SA-noft2-R-QCR2000

Computational Conditions

<table>
<thead>
<tr>
<th></th>
<th>w/o wall</th>
<th>w/ wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mach number</td>
<td>0.847 (corrected)</td>
<td>0.85 (uncorrected)</td>
</tr>
<tr>
<td>Angle of attack</td>
<td>0 deg</td>
<td>0 deg</td>
</tr>
<tr>
<td>EXP</td>
<td>All corrected</td>
<td>Only corrected for upflow angle</td>
</tr>
</tbody>
</table>

Without wall

Uniform flow

30 million cells

With wall

Porous wall

P_0, T_0

80 million cells
## Task 3 Computational Method

- **Flow solver:** FaSTAR
- Grid: HexaGrid (80 million cells)
- Discrezation: Cell-Center
- Inviscid flux: HLLEW
- Reconstruction: MUSCL
- Gradient: GLSQ
- Slope limiter: Hishida (van Leer-type)
- Time integration: LU-SGS (Dual Time Stepping)
- Turbulence model: Zonal-DES (SA-noft2-R-QCR2000)

### About “t”

- **Lift**
  CFD results are still overestimated.
  The wall interference (the difference between the two cases with and without wall) is almost same between CFD and EXP
- **Drag**
  Wall interference is opposite
- **Pitching moment**
  Wall interference is small

We change the RANS thickness in the spanwise direction.

- **x1:** Thickness which calculated from the previous RANS computation.
- **x6:** Six times thickness of x1.
Average and RMS of $C_p$ at AoA4.87deg

- Section E: Spanwise x1 get close to the EXP.
- Section F: Spanwise x6 get close to the EXP.

Time history of $C_p$ at AoA4.87deg (Section E)

- Time history of $C_p$ is similar to the EXP.
Summary

• Task 1
  – We computed with 4 grids and 6 turbulence models.
  – Low AoA – Cruise AoA
    • Computed forces are almost same.
    • Viscous Drag: EARSM model > SA model > SST model
  – High AoA
    • Computed forces show considerable variations.
    • Shock wave location is changed by turbulence models.
    • The SOB separation is affected by the grids.
    • There is the relationship between Cp of Section C and CL.
    • There are no cases which correspond with both of CL and Shock wave location

• Shock wave location: Almost same
• Q criteria: Small vortex are found at BOXFUN.
Summary

• Task 2
  – We computed the wall interferences.
  – Lift
    • The CFD result is still overestimated.
    • The wall interference is almost same between CFD and EXP.

• Task 3
  – We computed Zonal-DES for the two spanwise cases.
  – Average and RMS of Cp
    • The shock wave locations are not predicted well.
  – Time history of Cp
    • CFD is similar trend to the EXP.
  – Result of BOXFUN
    • The resolution near the wall is improved.