Simulation of Unsteady Flows around the 30P30N High-Lift System using UTCart

The University of Tokyo Cartesian grid based automatic flow solver

- Platform for aerodynamic designing
- Completely automatic grid generation using quad/oct-tree structure (complex geometry)
- Immersed Boundary Method + Wall function
Immersed boundary method

- Boundary condition is extrapolated from IP
- Wall function is used to determine the wall shear stress

Objectives

- Case 3-1 (Near-field unsteadiness)
- Demonstrate potential capability of Cartesian grid with Immersed Boundary method in unsteady flow simulation
  - Easy resolution control (cove, propagation region, etc.)
  - Use of explicit time integration method
Computational Grid

- Oct-tree Cartesian grid
  - $\Delta x_{wall} / c = 5.0 \times 10^{-4}$ (y$^+$<50)
  - Span : 0.128c (2.3 inch), 256 cells ($\Delta z / c = 5.0 \times 10^{-4}$)
  - 14,700,179 cells, 288 domain MPI

Methodology (1/2)

- Time Integration
  - 3rd order TVD-RK (Explicit time integration)
  - $\Delta t a_{\infty} / c = 2.0 \times 10^{-4}$
- Spatial accuracy
  - 4th order upwind-biased scheme for advection term
Methodology (2/2)

- **SA-DDES-p**
  - Modification for DDES
  - RANS region is protected even when the stream-wise grid size is very small (suitable for Cartesian grid)

\[
f_d' \equiv 1 - \tanh((8r_d')^3), \quad r_d' \equiv \frac{v + v_t}{S_{k_2}d_{DDES}}
\]

\[
l_{DDES}' \equiv (1 - \min(f_d, 0.5))l_{RANS} + \min(f_d, 0.5)l_{DES}
\]

*Original DDES length scale*

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**Time Averaged flow**

- \( Cl = 2.822 \, (5.5 \, \text{deg}), \, 3.233 \, (9.5 \, \text{deg}) \)
DDES-p Switching

- Correctly switched to LES in the separated region (cf. cove)

Switching between RANS and LES
fdes distribution

Eddy viscosity distribution

Instantaneous flow

Span-wise vorticity

\( \alpha = 5.5 \text{ deg} \)

\( \alpha = 9.5 \text{ deg} \)
PSD of surface pressure (5.5 deg)

- PSD level at around $f=1000\text{Hz}$ shows good agreement with experimental data

PSD of surface pressure (9.5 deg)

- Impingement point moves upstream
  $\Rightarrow$ PSD levels decrease
Conclusions

- Unsteady flow simulation was conducted by UTCart
  - Isotropic uniform grid in cove
  - Explicit time integration, high-order scheme
  - DDES-p turbulence model

- PSD levels decrease at the higher angle (5.5° → 9.5°)
  - Fair agreement with experimental data at S12
  - Lower pressure fluctuation in the cove