OVERFLOW Analysis of the NASA Common Research Model Using WENO and MUSCL Schemes

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Dr. Jim Coder
Research Associate, Computational Mechanics
Geometry

WB

WBNP
Common Overset Grid System

WB Grid Sizes

- **T:** 7,398,176
- **C:** 14,355,678
- **M:** 24,698,828
- **F:** 39,098,858
- **X:** 58,227,000
- **U:** 82,754,486

WBNP Grid Sizes

- **T:** 11,865,177
- **C:** 22,999,565
- **M:** 39,542,953
- **F:** 62,566,221
- **X:** 93,176,522
- **U:** 132,381,764

- Generated by Boeing (Long Beach) and provided by DPW organizing committee
Objectives and Strategy

• Goal: Assess benefits of using higher-order convective fluxes for cruise drag prediction

• Solver: OVERFLOW 2.2l
  – Structured, overset solver developed by NASA

• Cases: 2 and 3
  – WB and WBNP grid convergence, nacelle-pylon drag increment
  – Alpha sweep with static aeroelastic deflections, buffet study
Objectives and Strategy

• 5\textsuperscript{th}-order WENO vs. 3\textsuperscript{rd}-order MUSCL with Roe fluxes
  – 2\textsuperscript{nd}-order viscous fluxes for both

• ARC3D scalar pentadiagonal LHS for first 5000 iterations
  – Grid sequencing and multigrid for convergence acceleration

• Switch to SSOR left-hand side until convergence
  – No artificial dissipation (DIS2 = 0, DIS4 = 0)
  – No multigrid

• USURP force/moment integration

• OVERFLOW’s $C_L$ driver used to update AoA during solution
Objectives and Strategy

- SSOR + multigrid did not lead to favorable results
Turbulence Modeling

• Spalart-Allmaras model with Spalart-Shur rotation/curvature correction and the quadratic constitutive relation (‘SA-RC-QCR2000’)
  – RC correction beneficial in tip region
  – QCR improves predictions in wing-body junctures (side-of-body separation) by introducing turbulence anisotropy

• Case are assumed a priori to be fully attached (or nearly so) with an attainable and meaningful steady RANS solution
Quadratic Constitutive Relation

• Non-linear Reynolds-stress closure

\[
\tau_{ij} = \tau_{ij}^{linear} - C_{nl1} \left[ O_{ik} \tau_{jk}^{linear} + O_{jk} \tau_{ik}^{linear} \right]
\]

\[
\tau_{ij}^{linear} = 2\mu_t \left[ S_{ij} - \frac{1}{3} \frac{\partial u_k}{\partial x_k} \delta_{ij} \right] - \frac{2}{3} \rho k \delta_{ij}
\]

\[
O_{ij} = \frac{\Omega_{ij}}{\left( \frac{\partial u_m}{\partial x_n} \frac{\partial u_m}{\partial x_n} \right)}
\]

• Promotes 4:2:3 principal stress ratio in planar shear layers
  – Accepted value: \( C_{nl1} = 0.3 \) (used here)
  – ‘True’ values: \( C_{nl1} = 0.358 \) (\( a_1 = 0.31 \)); \( C_{nl1} = 0.370 \) (\( a_1 = 0.30 \))
Case 2: CRM Nacelle-Pylon Drag Increment
Case 2: Drag Convergence

WB

WBNP
Case 2: $\Delta C_D$ Convergence
Case 2: Alpha and Pitching-Moment Convergences

Angle of Attack

Pitching-Moment Coefficient
Case 2: $C_p$ Comparisons (Medium Grid)
Case 2: CRM-WBNP Surface Streamlines (Medium Grid)

3rd-order Roe

5th-order WENO
Case 3: CRM-WB Static Aero-Elastic Effect
Strategy

• Same solver parameters as Case 2(a)
  – 3\textsuperscript{rd}-order Roe vs. 5\textsuperscript{th}-order WENO, SSOR LHS, no dissipation

• Restart from lower alphas
  – Converge $\alpha = 2.50^\circ$ first
  – Start $\alpha = 2.75^\circ$ from $\alpha = 2.50^\circ$ solution, etc.

• Run until force/moment convergence
Case 3: Force and Moment Comparisons

5th-order WENO
\( \alpha = 4^\circ \)
Observations and Conclusions
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• Higher-order convective fluxes had no impact on formal order of accuracy
  – Two fringe layers (PEGASUS connectivity)
  – Viscous terms and grid metrics remain 2\textsuperscript{nd}-order
  – SA convective terms are 1\textsuperscript{st} order

• WENO and Roe solutions are not converging to the same continuum values
  – Similar convergence qualities, small (< 1 ct) offset in drag values
  – Requires further investigation
Observations and Conclusions

• WENO solutions showed oscillations around the shockwave
  – WENOM limiter used, perhaps not effective enough
  – Alternative may be to set DIS2 ≠ 0

• Lift and pitching-moment polar comparisons imply too much lift predicted outboard
  – Need to compare predicted and measured lift distributions
  – Sting not modeled

• SSOR solutions are slow
  – D3ADI showed promise for upwind RHS and DIS4 = 0
Questions?