Benchmark Supercritical Wing Results using NSU3D

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NSU3D Description

- Unstructured RANS solver
- Widely used for fixed wing (steady) and rotorcraft (unsteady)
  - Vertex-based discretization
  - Mixed elements (prisms in boundary layer)
  - Matrix artificial dissipation
    - Option for Roe scheme with gradient reconstruction
  - No cross derivative viscous terms
    - \( \nabla (\mu \nabla v) \) (Similar to incompressible Full NS)
    - Option for full Navier-Stokes terms
      - Extended stencil with edge-based normal derivatives
Solver Description (cont’d)

• Spalart-Allmaras turbulence model
  – (original published form)
  – Used exclusively in AePW calculations

• Options for
  – Wilcox k-omega model
  – Mentor SST Model
  – Not exercised in AePW
Solution Strategy

- Steady or BDF2 Implicit Time-stepping
  - Deforming meshes with GCL
- Jacobi/Line Preconditioning
  - Line solves in boundary layer regions
    - Relieves aspect ratio stiffness
- Agglomeration multigrid
  - Fast grid independent convergence
- Parallel implementation
  - MPI/OpenMP hybrid model
    - MPI only on local 512 core cluster
Cases Run

- Steady State
  - Coarse mesh
  - Medium mesh (steady and time-dependent)

- Time dependent runs
  - No mesh deformation (mesh rotated as solid body)
  - f=1hz and f=10hz
  - Coarse and medium meshes
  - Time step and convergence study
    - 180, 360, 720 time steps per period
    - 20 and 50 multigrid cycles per time step
    - 4 periods of simulation time
Sample Run Characteristics

• Use workshop meshes
  – Coarse, Medium (mixed NC unstructured)

• Steady-state runs
  – 500 to 1000 multigrid cycles
  – Coarse mesh converged
  – Medium mesh :incomplete convergence
    • Ran also in time dependent mode

• Run on in house 512 core cluster
  – Coarse grid: 128 cores: 1.08 secs/MG cycle
  – Medium grid: 256 cores, 1.85 secs/ MG cycle
BSCW Steady State Convergence

- Coarse mesh converged well
- Medium mesh did not produce steady solution
  - Run as time dependent case
  - Required resolving period of oscillation with small enough time step
BSCW Steady State Convergence

- Coarse mesh converged well
- Medium mesh did not produce steady solution
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  - Required resolving period of oscillation with small enough time step
For f=1Hz, significant variation with $C_L$ and $C_M$ with:

- Time step size
- Number of subiterations
- Mesh size
BSCW Time Dependent Results
(f=10Hz)

For f=10Hz:
- Time step size has little effect
- Effect due to mesh size
- Temporal convergence well behaved
  - Time steps small enough to resolve unsteady flow phenomena
BSCW Time Dependent Results
(f=1Hz)

- Density correction converged 1.5 orders of magnitude at each time step (not residual)
- Forces well converged at each time step
- Convergence is variable for low frequency case
• Density correction converged 2 to 3 orders of magnitude at each time step (not residual)
• Forces well converged at each time step
• Convergence more uniform for high frequency case
  – Smaller physical time step (compared to shock instability)
BSCW Steady/Mean Cp Distribution

Steady
• Reasonable agreement with experimental data

Mean at f=1Hz
BSCW Steady/Mean Cp Distribution

Mean at f=10Hz
- Reasonable agreement with experimental data

Mean at f=1Hz
BSCW Unsteady Pressures

(f=1hz)

Upper Surface

Lower Surface

magnitude/deg

X/C

magnitude/deg

X/C

phase(deg)

phase(deg)

BSCW Experiment
BSCW Coarse Mesh, Δt = T/180, 20MG
BSCW Coarse Mesh, Δt = T/360, 20MG
BSCW Coarse Mesh, Δt = T/720, 20MG
BSCW Coarse Mesh, Δt = T/720, 50MG
BSCW Medium Mesh, Δt = T/720, 50MG
BSCW Unsteady Pressures

(f=1hz)
BSCW Unsteady Pressures (f=10hz)
BSCW Unsteady Pressures

(f=10hz)
Conclusions and Future Work

• f=1hz results sensitive in some locations to:
  – Time step size
  – Level of implicit time step convergence
• f=10hz insensitive to time step size
• Both f=1Hz,10Hz sensitive to grid size
• SA turb model well known deficiencies for shock-boundary-layer separation
• Future work to investigate finer meshes, time steps using tight convergence tolerances, SST model