Challenges to the use of CFD in the Military Aircraft Industry

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Overview

• Industrial environment
• Types of problems that need to be addressed
• Challenge areas
• Summary
Environment

- Diverse problem set
  - Incompressible through hypersonic
  - External aerodynamic and internal (inlet, nozzle) flows
  - Range of aircraft (subsonic transport, transonic, fighters, ISR, hypersonic...)
  - Range of complexity: components, conceptual, final design
- Large number of users with range of CFD competence
- Computational resources are often restricted – difficult to use massive parallel resources
  - Need to protect proprietary data
  - Small, compartmentalized programs
- CFD must buy its way into program application
  - Accurate enough to be relied on for design
  - Cost effective
  - Meet schedules
Diverse CFD Applications on Programs

• New Concepts
  – Radical new designs
  – Flow control (example: sweeping jets, synthetic jets)
• Design
  – Preliminary design – screen a design space
• Optimization
  – Optimize outer mold line for cruise conditions
  – Meet performance requirements
• Development
  – Off design
  – Databases: loads, S&C
  – Store separation
• Analysis of special cases
  – Ground test and flight test anomalies
  – Improvements and modifications
Conceptual Design Requires Tools that Can Rapidly Simulate Multiple Configurations

- Conceptual design methods for fast turnaround analysis
  - Many configurations need to be analyzed
  - Highest fidelity may not be required at this stage
  - Focus is frequently on cruise design points

- A variety of methods can be applied depending on speed regime and accuracy desired
- Methods with automated grid generation can be extremely valuable for these applications

Vortex Lattice
Full Potential
Euler
RANS

LM Aero Employs Splitflow for Conceptual Design
Optimization Requires Specialized Methods for Efficient Application

- Optimization requires methods for automated geometry changes
  - Unstructured meshes
  - Cut cell methods
- Moderate levels of accuracy
- Computational efficiency is critical

High Fidelity Simulations Required to Analyze Flows with Complex Phenomena

• Some cases require capturing flow physics as accurately as possible
  – Critical flight conditions where an aircraft problem is identified
  – Complex, interacting flow phenomena
    • Shocks
    • Separated flows
    • Vortices
  – Capture of unsteady flow phenomena is required for some problems
    • Aero-optics
    • Aero-acoustics
    • Flow control
• For RANS, need highly accurate models and numerics
  – Explicit algebraic stress or RS closure turbulence models for RANS
  – Extensive model validation
• For unsteady simulations, high order, low dissipation methods
  – Hybrid RANS/LES
For Program Support, Accurate and Efficient Methods Needed

- Program demands high accuracy
- Configuration not changing rapidly
- Many solutions required – database generation – loads, S&C
  - Man-in-the-loop grid generation may be desirable
  - Accurate physical modeling

Physical Models are Critical to CFD Accuracy

- We are decades away from being able to use large eddy simulation for routine design applications
- Physical models, and efficient algorithms to solve models, are essential to expanded application of CFD
  - Transition prediction
  - Turbulence modeling – separated flows, compressibility
  - Combustion modeling
  - Real gas reactions for hypersonic flow
  - Flow control actuation
  - Icing
  - Ablation
  - ...
Computational Methods Have Improved, Modeling Issues now Leading Error Term

- Propulsion Aerodynamics Workshop found turbulence models to be largest source of differences between predictions
  - Next pages show results for different turbulence models and different flow solvers with a range of grid densities and solutions algorithms
  - Results show the total pressure recovery near the exit plane

From Domel, Baruzzini and Tworek, “Inlet CFD Results: Comparison of Solver, Turbulence Model, Grid Density and Topology,” AIAA 2013-3793
Results: Solver 1, 2-eq

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<th>Hex (Coarse)</th>
<th>Hex (Medium)</th>
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<tr>
<td>% DPCP40 ave</td>
<td>+0.38</td>
<td>+0.39</td>
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<table>
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<td>% DPCP40 ave</td>
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Results: Solver 1, 1-eq

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<th>Mesh Type</th>
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<th>DPCP40 ave (ave)</th>
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<td>Unstructured Tet Prism (Fine)</td>
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<td>+1.59</td>
</tr>
</tbody>
</table>
Results: Solver 2, K-KL

- **Hex (Coarse)**
  - Δ % Recovery: +0.10
  - Δ % DPCP40 ave: +0.98

- **Hex (Medium)**
  - Δ % Recovery: +0.06
  - Δ % DPCP40 ave: +0.73

- **Hex (Fine)**
  - Δ % Recovery: +0.07
  - Δ % DPCP40 ave: +0.74

- **Tet Prism (Very Coarse)**
  - Δ % Recovery: -0.16
  - Δ % DPCP40 ave: +0.79

- **Tet Prism (Medium)**
  - Δ % Recovery: +0.07
  - Δ % DPCP40 ave: +0.83

- **Tet Prism (Fine)**
  - Δ % Recovery: +0.06
  - Δ % DPCP40 ave: +0.84
Results: Solver 2, ASM

Structured

Hex (Coarse)

Δ % Recovery: -0.28
Δ % DPCP40 ave: +0.99

Hex (Medium)

Δ % Recovery: -0.28
Δ % DPCP40 ave: +0.98

Hex (Fine)

Δ % Recovery: -0.13
Δ % DPCP40 ave: +0.65

Unstructured

Tet Prism (Very Coarse)

Δ % Recovery: -0.60
Δ % DPCP40 ave: +1.14

Tet Prism (Medium)

Δ % Recovery: -0.40
Δ % DPCP40 ave: +1.12

Tet Prism (Fine)

Δ % Recovery: -0.39
Δ % DPCP40 ave: +1.09
Standard Turbulence Models do not Capture Many Simple Flows Well

- Results from AIAATurbulence Model Benchmarking Working Group website for subsonic jet centerline velocity
- If these simple flows are not predicted well, what should we expect for complex jet flows?
Transonic Flow over an Axisymmetric Bump – Separated Flows Remain a Challenge

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Velocity and Turbulence Profiles not Predicted Well for Transonic Flow over Axisymmetric Bump

- SST predicts pressure on bump reasonably well
- Velocity and shear stress profiles are poorly predicted
- Results from Turbulence Model Benchmarking Working Group website
Industry has a Need for a Diverse Set of Tools to Meet Diverse Requirements

• Automated methods needed for preliminary design and optimization
• Accurate methods needed for system development and maturation
• Common thread – bigger computers alone insufficient to meet needs!
  – Increased automation requires investment in software and algorithms for grid generation, flow solution and post processing
  – Improved accuracy requires investment in improved physical models of turbulence, and robust high order accurate numerical methods.
Wind Tunnel vs CFD on Programs

• Project development efforts have extensive experience using wind tunnel data to develop databases
  – Errors in wind tunnel data have been quantified, corrections developed
  – Process is well defined, results are generally repeatable
• Less experience base with CFD
  – Many error sources not well understood by users or program managers
  – Results can be sensitive to CFD software, grid, models
  – User expertise factor in result quality
• Once a design is matured, wind tunnel based generation of some data bases is more competitive in accuracy and cost
  – Minimal model changes
  – Large data sets can be generated rapidly
  – Off design conditions can be relatively accurate
• Large numbers of CFD runs with a fixed model can require significant computational resources
  – Off design cases may be less accurate (high lift, high angle of attack maneuvers)
  – A requirement for a large database generated using unsteady CFD (hybrid RANS/LES methods) may not be feasible computationally
Key Factors for CFD for Military Aircraft Environment

• Computational efficiency is important
• Accurate modeling of turbulence, transition, combustion: currently lacking
• CFD methods and physical models have to be selected for each application to obtain acceptable accuracy and performance
• Calibration and validation are an essential part of industrial application for complex flow problems
• Results are dependent on
  – Code
  – Models
  – User competency
Summary

• Increasing computer power at reduced costs provides opportunities for increased application of CFD
• Industrial applications are diverse in terms of level of accuracy and efficiency that are required
• Significant improvement in CFD methods is required to harness increased computer power