Recent & Upcoming Features in STAR-CCM+ for Aerospace Applications

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Outline

- **Introduction**
- **Aerospace Applications Summary**
- **New Capabilities for Aerospace**
  - Continuity Convergence Accelerator
  - Overset Mesh
  - Honorable Mentions
    - Fluid Film Enhancements
    - Turbulence Model Enhancements
- **Upcoming Aerospace Capabilities**
Typical Use of CFD in Aerodynamics

Classical / Semi-Empirical Methods
- Feasibility studies
- Bound the problem
- Perform initial sizing/trades

CFD
- Refined performance estimates
- Identify possible trouble areas and important flow phenomena
- Determine interference/installation effects
- Down-select for wind tunnel testing
- Determine expected wind tunnel loads (instrumentation selection)

Wind tunnel tests
- Final design selection
- Final aerodynamic performance

Expanding CFD in the design process:
- Reduces the time and money spent on wind tunnel tests
- Provides insight to improve the design
- Reduces the number of design iterations
- Shortens the development process

This necessitates:
- Faster turnaround times (initial and subsequent design modifications)
- Accurate physics modeling
Native CAD Geometry

Geometry Cleanup

Robust Unstructured Meshing

Advanced Physics Solution

Reduce overall CAD-to-solution time while maintaining high-end advanced physics
Keys to Successful Simulations

⊕ Quality Meshes
- Polyhedral or Trim-Cell
- Proper surface & volume refinements
- Quality prism layer regions

⊕ Proper Physics & Numerics
- Pressure & Density-based solvers
- RANS, DES, LES turbulence models
- Boundary layer transition models
- Multiple Physics
  - Aeroacoustics
  - Aerothermal / CHT
  - Combustion
  - Fluid-structure Interaction
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Upcoming Aerospace Capabilities
Aerospace Application Areas

- Aircraft Systems / Thermal Management
  - Mechanical Systems (APU’s, undercowling, etc.)
  - Ice Protection
  - Avionics / Electronics Systems
  - Fuel systems
  - Heat Exchangers
  - Other Conjugate Heat Transfer

Eulerian Multiphase
Lagrangian Multiphase
Liquid Film

Surface Wrapping
Robust Prism Layers
In-plane Conduction

Engine Thermal Management

Ice Protection / Collection Efficiency

Avionics Cooling

Conjugate Heat Transfer
Automatic Imprinting
Fan Models
Aerospace Application Areas

Propulsion Systems
- Pumps
- Rocket Motor, Ramjet, & Scramjet
- Compressors, Fans, Turbines
- Combustion, sprays, chemistry
- Inlets & nozzles
- Fuel systems, sloshing

Automatic Conformal Meshes
Motion Models
Harmonic Balance

Turbomachinery

Cartesian Trim-Cell Meshes
AUSM+ FVS
Continuity Convergence Accelerator

Gas, Particle, Surface Reactions
Erosion Models
Morphing Boundaries

Supersonic Combustion
Solid Rocket Motors
Aerospace Application Areas

**Aerodynamics**
- Subsonic Through Hypersonic
- Aeroacoustics
- Store Release
- Stage Separation
- High-Lift Devices
- Plume Effects

**High-Speed Aerodynamics**

**GSI / Solution Driver**
- Overset Mesh
- Mesh Adaptation

**Polyhedral Mesh**
- Turbulence Models
- Transition Models

**High-Lift Aerodynamics**
- Tightly-Coupled FSI
- Mesh Morphing
- Solution Mapping

**Fluid-Structure Interaction**
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High-Speed Flow Solution Approach

Density-Based Coupled Solver

Implicit Formulation
AUSM+ inviscid flux scheme
MUSCL + Venkata limiter

Grid Sequencing Initialization

Expert Solution Driver

Continuity Convergence Accelerator

Proper numerical formulation for high-speed flows

Robustness and convergence at initial iterations

Automatic convergence control

Faster convergence
Expert Option for the Density-Based Coupled Solver

- Sub-solver to accelerate mass conservation
  - Solves an elliptic equation for pressure corrections
  - Updates the cell pressures (w/underrelaxation)
  - Corrects the face mass fluxes and cell velocities
  - Updates density, total enthalpy, etc. appropriately

Improves convergence for stiff problems

- Temperature-dependent gas properties
- Mix of high/low Mach numbers
- Combustion
- Internal compressible flows

Supersonic Combustion
Converges in < 1/10th iterations

See our paper/presentation at the AIAA Fluid Dynamics Conference, 24 - 27 June 2013, San Diego, CA

“Continuity Convergence Acceleration of a Density-Based Coupled Algorithm,” Caraeni et al.
V7.06: Continuity Convergence Accelerator
Solid Rocket Motor / Nozzle

- Freestream Mach = 0.6
- Pressure Ratio = 10.0
- TCombustion = 3000K
- Steady-State, SST k-\omega turbulence model
V7.06: Continuity Convergence Accelerator
Hypersonic Shock/Boundary Layer Interaction

- Freestream Mach = 5.0
- Steady-State, SST $k-\omega$ turbulence model
- Iterations to fully develop separated region:
  - No CCA: 12,500 iterations
  - With CCA: 3,500 iterations
- With CCA, 67% reduction in wall-clock time
V7.06: Continuity Convergence Accelerator
High-Pressure Bleed Line / Butterfly Valve

- Stagnation conditions provided at inlet
- Steady-State, SST $k-\omega$ turbulence model
- Engineering items of interest
  - Mass Flow Rate
  - Outflow Total Pressure
- No CCA = 3500 iterations
- CCA = 1250 Iterations
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**Overset Mesh**

**Aerospace Applications**
- Parametric Studies
- Same bodies at different relative positions / orientations
  - Aerodynamic databases
- Bodies with complicated motion pattern
  - Control surface deflections
  - Tube/Silo launches
  - Transient stores separation
    - Pylon / Weapons Bay
  - Rotorcraft blades

**Unique implementation features in STAR-CCM+**
Arbitrary Unstructured Meshes

**Advantages**

- Complex geometries need not be broken down into simpler shapes
- Reduces number of interfaces / interpolations
- Any combination of mesh topologies (hex, tet, poly, etc.)
Implicit Grid Coupling

- Solution is computed on all grids simultaneously
- Interpolation factors are included in the linear system(s)
- Improved robustness
  - Especially in regions of sharp gradients (shocks, plumes)
- Improved convergence behavior
Automatic Grid Assembly / Hole-Cutting
- Robustness improvements with each release
- 8.02 includes ability to handle some “orphan” cells

Loads Visualized in Real-Time
- Aerodynamic, Gravity, User-Specified, etc.
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Upcoming Aerospace Capabilities
Fluid Film Enhancements

- Fluid film melting/solidification/evaporation models
- Fluid film compatible with the Coupled Solver
- Fluid film compatible with MRF moving reference frames
Curvature correction terms added to $k-\omega$ models (baseline & SST)

- Improves accuracy for flows with significant streamline curvature:
  - Separated flows
  - Cavity flows
  - Flows with strong swirl

- More efficient and robust than DRSM approach
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Altitude-based freestream boundary conditions

- Altitude & Mach Number
- Altitude & Reynolds Number
Virtual Blade Model
- Model rotors / propellers via momentum source disks
- Has been available as a JAVA macro for some time

Blade Element Method
- Requires blade-level information
  - # of blades, chord, twist, airfoil section data, etc.
  - Trimmmable

Body Force Propeller Method
- Requires disk-level information
  (i.e. performance curves as a function of advance ratio)
  - \( \eta, K_T, K_A = f(J) \)
Upcoming

**Overset: Multiple Overlapping Grids**

- Same setup approach: additional overset interface between foreground regions
- New, more robust hole-cutting algorithm
Ice Accretion with Build-Up Geometries
- Utilizes fluid film melting and solidification
- Morpher distorts mesh to capture ice shape

Supplementary Capabilities Development Ongoing
- Film + Eulerian Multiphase
- Specialized Eulerian Multiphase
- Interface with Lewice3D
STAR-CCM+ provides a unique integrated CAD-to-solution process that significantly reduces pre-processing time, but maintains high-fidelity physics models.

- **Wide range of Aerospace Industry applications**
  - Aircraft Systems
  - Propulsion
  - Aerodynamics

- **New features improve productivity and accuracy**
  - Overset mesh with coupled 6DOF solver (V7)
  - Continuity Convergence Accelerator (V7)
  - Fluid Film Enhancements (V8)
  - Turbulence Models: Curvature Correction (V8)

- **Continued improvements to capabilities and interface for aerospace applications**