Validation of an Unstructured Overset Mesh Method for CFD Analysis of Store Separation

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Stores Separation – Introduction

Flight Test
- Expensive, high-risk, sometimes catastrophic loss of aircraft

Wind Tunnel
- Captive Trajectory (CTS) methods developed in 1960's
- Expensive, require very small scale models
- Difficulty in bays and multiple-stores releases

CFD
- CFD-Generated Aerodynamic Database
  - Database of steady-state CFD solutions (1000s)
  - "Grid" approach to build interference aerodynamics database
  - Database lookup within 6DOF model
  - 1000’s of Monte-Carlo runs once model is constructed
- CFD-in-the-Loop
  - Couples CFD with the 6DOF solver
  - Typically used to verify behavior of aerodynamic database + 6DOF
Stores Separation – CFD

**CFD Approaches**

- **Block-structured overset mesh**
  - Difficult, complicated meshing
  - Many overset boundaries leads to significant interpolation

- **Dynamic morphing/remesh**
  - Issues controlling volume mesh density during motion
  - Does not work well for “shearing” motions
  - High computational cost (~20-30%)
  - No benefit for “grid” approach

- **Unstructured overset mesh**
  - Best of both worlds: ease of meshing / fewer overset boundaries
  - As implemented in STAR-CCM+
Many Industries
- Aerospace, Marine, Automotive, Manufacturing, etc.

Aero Applications
- Parametric Studies
  - Fewer meshes to build
  - Same mesh quality in important regions
- Same bodies at different relative positions / orientations
  - Stores separation “grid” approach
  - Control surface deflections
  - High-lift configurations
  - Rotorcraft
  - Tube/Silo launches
- Bodies with complicated motion pattern
  - Prescribed or coupled 6DOF
Arbitrary Unstructured Meshes

- 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
- Improved convergence
Control volumes are labeled as:

- **Active cells (may be donors)**
  - Regular discretized equations are solved

- **Coupling (acceptors)**
  - Algebraic equations are solved – values are expressed via variables at a certain number of donor cells on other grid
  - Many possibilities, currently use linear shape functions

- **Passive**
  - These cells are temporarily or permanently de-activated
Each region (“grid”) meshed independently
- Can use different mesh topologies
- Cells should be similar sized at interface

Multiple-select regions, select Create Interface → Overset Mesh

Position and orient foreground region(s) as desired

Cell types (active, coupling, passive, etc.) determined automatically as needed.
Wing/Pylon/Store Benchmark Case

Geometry
- Clipped delta wing with pylon
- Standard 4-fin store ~10ft in length

Benchmark wind tunnel data available at Mach 1.2
- Trajectory information
- Surface pressure

<table>
<thead>
<tr>
<th>Store and ejector properties</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>$M$</td>
<td>2,000 lb</td>
</tr>
<tr>
<td>$x_{CG}$</td>
<td>4.65 ft</td>
</tr>
<tr>
<td>$I_{xx}$</td>
<td>20 slug-ft²</td>
</tr>
<tr>
<td>$I_{yy}$</td>
<td>360 slug-ft²</td>
</tr>
<tr>
<td>Forward ejector location</td>
<td>4.06 ft aft of store nose</td>
</tr>
<tr>
<td>Aft ejector location</td>
<td>5.73 ft aft of store nose</td>
</tr>
<tr>
<td>Forward ejector force</td>
<td>2,400 lb</td>
</tr>
<tr>
<td>Aft ejector force</td>
<td>9,600 lb</td>
</tr>
<tr>
<td>Ejector stroke length</td>
<td>0.33 ft</td>
</tr>
</tbody>
</table>
Computational Mesh

- **Unstructured Cartesian Trim Cell**
  - Cells refined in region of expected store travel
  - Cell refined around store (nose, tips, wake)
  - Minimum of 4 cells across the small 1.4” gap between pylon and store

- **3.8M Cells Overall**
  - 3.0M Farfield/Wing/Pylon
  - 0.8M Store

- **Lateral extents located at approximately 100 diameters**
Solver Settings

Density-based Coupled Solver

Inviscid Flow
- Previous studies have shown this is sufficient for trajectory calculation

2\textsuperscript{nd}-Order upwind spatial discretization

2\textsuperscript{nd}-Order implicit temporal discretization
- Implicitly-coupled 6DOF motion
- $\Delta t = 0.01s$ nominal, and and $0.002s$ fine
Ejector Forces Definition

- Modeled as arbitrary point loads
  - Defined through the GUI
  - Custom functional relationships to match ejector force and stroke length
- Visualize loads real-time
  - Note that initial motion is dominated by ejector forces
Visualization – Overall Trajectory

- Initial nose-up motion due to ejector forces
- Store rolls and yaws outboard
Overset domain initially overlaps pylon
Overset domain falls through refined region in background grid
Shock structures can be seen
Visualization – Small Gap

- Flow within the small pylon/store gap is resolved
- Automatic activation/de-activation of cells is seen
Surface Pressures

- t = 0.00
- t = 0.16
- t = 0.37
Results are nearly identical for nominal and fine time step
Y- and Z-position and velocity are in excellent agreement
Aft-ward X-movement is underpredicted
- Common for this benchmark case
- NOT due to viscous effects
- Likely due to wind tunnel sting corrections
Fine time step shows improved results, but only slightly
Pitch and roll are in good agreement
Initial outward yaw rate is underpredicted
   - Initial rates are dominated by ejector forces
   - Further investigation is needed to determine difference between CFD and WT ejector force definition
STAR-CCM+ unstructured overset mesh approach shown to be effective and successful for transonic stores separation

- Trajectories are predicted well
- Surface pressures are in excellent agreement
- Quick turn-around time
  - Meshing: ~ 1 hour from raw CAD model
  - Solution: 2 hrs on 6-core workstation for nominal $\Delta t$

Future Work
- Multiple moving bodies (ripple-release)
- Constrained relative motion
- Automatic mesh adaption
- Collision modeling
Questions?