Production Use of Overset Grid Technology in the US Air Force Aircraft/Store Compatibility Enterprise

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Overview

- Introduction
- Application Efforts
  - Wing-Pylon-Store Separation Analysis
  - F-22/GBU-39 Separation Analysis
  - A-10/LAU-131 Separation Analysis
  - F-22/AIM-9X Separation Analysis
  - MALD Separation Analysis
  - Delta Coefficient Approach and Grid Freezing Analysis
  - Notable Application Efforts
  - Future Application Efforts
- Development Efforts – Past & Future Upgrades
  - Beggar
  - FD-CADRE
  - USM3D
  - Case Manager (TOWER)
Introduction

- The SEEK EAGLE program is the USAF aircraft/store certification process established by AFI 63-104
- The Air Force SEEK EAGLE Office (AFSEO) is the organization established to aid aircraft/store program offices with certification
- AFSEO has 9 technical engineering divisions

**AFSEO Mission Statement:**
Ensure new warfighter capabilities through the application and transfer of aircraft-store compatibility expertise
Introduction

**Input**

- MPMF & STAMP
  - Mass Property Data
- CPF
  - CAD Geometry

**Output**

- Separations
  - Aero Loads & Trajectory Predictions
- Loads
  - Aircraft/Store Aero Loads
- Stability & Control
  - Aero Loads

**Certification Recommendations**

Separations
Flow Conditions, Ejector & Trajectory Data

Loads
Flow Conditions

Stability & Control
Flow Conditions & Maneuver Data

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Introduction

The Overset CFD Process

- Geometry Definition
- Volume Grids
- Grid Generation
- Grid Integration
- Flow Solution
- Post Processing
Introduction

The CAT uses two CFD codes to support the certification process, running tens to thousands of simulations per project.

**Beggar**

- 3-D RANS or Euler Structured Grid Flow Solver
  - Cell-centered, finite-volume, upwind, implicit Roe scheme
  - Time-accurate or time-averaged, 2nd order spatial accuracy

- Coupled Automatic Overlap Detection & Grid Assembly
  - Uses blocked/overlapping structured grids
  - Auto-detects overlapping, far-field, singularity, block-to-block boundaries

- Coupled 6+ Degrees of Freedom (DOF)
  - Ejector, hinge, pivot point (parachute), spring/damper, rate-control autopilot models, variable properties, etc...

**USM3D**

- RANS, wall function or Euler unstructured grid flow solver
- Time-accurate or time-averaged, 2nd order spatial accuracy

**FD-CADRE**

**Suggar++**

- Overset grid assembly code

**6+ DOF**

- Modular version of Beggar 6+DOF

**Process Manager**

**Fluid Dynamics - Computational Analysis in Dynamically Responsive Environments**

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Application Efforts  
Wing-Pylon-Store Separation

• Classic dynamic motion case; wind tunnel test was conducted at Arnold Engineering Development Center (AEDC) in September 1990

• Tested at two flow conditions: Mach 0.95 & 1.2.

Beggar Grid Information:  
113 Grid Blocks  
5.4 Million Grid Points

USM3D Grid Information:  
2 Grid Blocks  
11.2 Million Grid Points
Application Efforts
Wing-Pylon-Store Separation

Mach 0.95

- X Translation (+X – forward)
- Y Translation (+Y – right)
- Z Translation (+Z – down)
- Rolling Orientation – PHI (+PHI – right wing down)
- Pitching Orientation – THETA (+THETA – nose up)
- Yawing Orientation – PSI (+PSI – nose right)
Application Efforts
Wing-Pylon-Store Separation

Mach 1.2

- X Translation (+X – forward)
- Y Translation (+Y – right)
- Z Translation (+Z – down)
- Yawing Orientation – PSI (+PSI – nose right)
- Pitching Orientation – THETA (+THETA – nose up)
- Rolling Orientation – PHI (+PHI – right wing down)
Application Efforts
F-22/GBU-39 Separation

• Supported the first flight test of GBU-39 release from the F-22 Main Weapons Bay
• Performed eight validation simulations (after flight testing) and one prediction simulation (before flight test) at subsonic, transonic, and supersonic flight conditions

Beggar Grid Information:
  1043 Grid Blocks
  40.9 Million Grid Points

USM3D Grid Information:
  2 Grid Blocks
  41.2 Million Grid Points
Application Efforts
F-22/GBU-39 Separation

Green – Flight Test
Red – Beggar CFD
Blue – USM3D CFD

• X Translation (+XCBC_TR – forward)
• Y Translation (+YCBC_TR – right)
• Z Translation (+ZCBC_TR – down)
• Yawing Orientation – PSIBC_TR (+PSI – nose right)
• Pitching Orientation – THETABC_TR (+THETA – nose up)
• Rolling Orientation – PHIBC_TR (+PHI – right wing down)
GBU-39 Trajectory Comparison

Green – Flight Test
Red – Beggar CFD
Blue – USM3D CFD
Application Efforts
A-10/LAU-131 Separation

- Supported flight certification for the LAU-131 on the A-10
- Performed 12 trajectory simulations for varying configurations using USM3D and Beggar

Beggar Grid Information:
1044 Grid Blocks
23.8 Million Grid Points

USM3D Grid Information:
2 Grid Blocks
42.4 Million Grid Points
Application Efforts
A-10/LAU-131 Separation

LAU-131 Trajectory Comparison

Blue – USM3D CFD
Red – Beggar CFD
Application Efforts

F-22/AIM-9X Separation Analysis

- Performed several simulations of the AIM-9X separating from the F-22; capability development effort geared toward support of future flight certifications
- The AIM-9X model has moving fins and tab deflectors; rocket motor model is used to propel the store down the rail

Beggar Grid Information:

1140 Grid Blocks
31.3 Million Grid Points
Application Efforts
MALD Separation Analysis

- Performed 40 trajectory simulations on the F-16 and 7000 grid data simulations on the B-52 to support the MALD SPO evaluation of Raytheon’s design concept

Beggar Grid Information:
16.5 Million Grid Points in MALD
Overall Grid
10.5 Million Grid Points in the Grid Fin Alone

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Application Efforts
MALD Separation Analysis

- Stability issues (store tumbling during separation from the aircraft) were discovered using CFD before flight testing began.
- An unscheduled flight test was performed and the predicted store behavior was confirmed.
- A $700K+ WT test was canceled; designer made adjustments to improve stability issues.
Application Efforts
Delta Coefficient Approach & Grid Freezing Analysis

• Customer Need:
  – Quickly generate 20-100K CFD grid data points
  – Calculate thousands of trajectories quickly using CFD

• Two Techniques to Speed Up the CFD Analysis:
  – Delta coefficient approach
  – Grid Freezing

• Delta Coefficient Approach:
  – High quality store freestream data (large scale WT or fully viscous detailed CFD data) required
  – The combination of the high quality freestream data and influence effect data yields high quality grid or trajectory data.

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• Grid Freezing
  – Solve A/C flow only once
  – Solve store, pylon, and box grids continuously
  – Store grids integrate with box grid only once
  – Store box grid integrates with drop grid and pylon/interface grids during the solution
  – A/C grids integrate only once
F-16/GBU-39 Project – 20K+ grid data simulations & hundreds of store freestream simulations completed in two weeks

• Much Faster Solution:
  – Fully viscous (A/C & store) simulation runtime ~ 4-6 hrs
  – Coarse inviscid store grid with grid freezing simulation runtime ~ 0.5 hrs

• Accuracy Approaching that of Viscous Solution
Notable Application Efforts

• F-22/AIM-9X Down-the-Rail Grid Data Analysis – Performed 600+ grid data simulations using Beggar over 4 month period; resulted in $500K WT test cost savings

• Subscale Aerial Target (AFSAT)/ Rocket Assisted Takeoff (RATO) Separation Analysis – Flight test revealed contact between the AFSAT and the RATO; performed trajectory analysis on proposed fixes

• B-52/X-51 Separation Analysis – Performed trajectory analysis as part of flight certification

• AGM-158 (JASSM) Separation Analysis – Performed trajectory analyses on various aircraft platforms; JASSM wing/tail deployment motion modeled
Future Application Efforts

• Maneuvering Aircraft with Moving Control Surfaces - Loads analysis on the ac/store

• Maneuvering Aircraft with Store Separation

• F-35 Store Separation Capability Testing

• F-22 Store Flight Certification

• USM3D Multi-Body Dynamic Testing
Development Efforts
BEGGAR: Past & Future Upgrades

• Previous Upgrades

  – Beggar grid freezing: Ability to freeze solution in specified grid blocks; optimized with dynamic load balancing

  – Beggar dynamic loading: 25% wall clock time reduction for a dynamic test case consisting of 1044 grid blocks and 23.8 million grid points running on 64 processors; more in-depth study is needed to determine expected average speed up value; has grid freezing optimization

  – Numerous constraint models added

  – Tecplot output: export surface data in Tecplot format

• Future Upgrades

  – AUSM+ Schemes (AUSM+up; SLAU)
Development Efforts
FD-CADRE: Past & Future Upgrades

• Previous Upgrades
  – Runtime Input: Manipulate and schedule parameter changes in real time while code is executing
  – Revised restart system: Folder based restart system; generically saves and restores restart data

• Future Upgrades
  – Tighter plug-in integration: Exploit “C” binary ABI:
    – Easier to debug & maintain
    – Increase communication speed and throughput
  – Support multiple MPI Tasks
Development Efforts
USM3D: Past & Future Upgrades

• Previous Upgrades
  – FDCADRE integration: Steady state support; increased shared information
  – Autoconf: Revised build system

• Future Upgrades
  – Newton solver: Address stability issues
  – Cell Freezing: Dynamically freeze globs of cells; similar to Beggar Grid Freezing
  – Dynamic Load Balancing: Fully exploit/optimize cell freezing
  – Streamline Process: Streamline preprocessing and code startup
  – Partial solution output: Only output data associated with specified volumes
Development Efforts
TOWER: Past & Future Upgrades

- TOWER is an in-house developed case manager for CFD simulations; key necessity when running hundreds or thousands of simulations

- TOWER is written in Python and can be installed on local machines and High Performance Computing resources; supports Beggar, USM3D, and FDCADRE

- TOWER performs the following functions:
  - Automatic simulation setup (a folder is assigned to each simulation)
  - Manages simulations (begins and stops jobs)
  - Restarts failed simulations (if a job fails because of a negative flow parameter it will decrease the CFL or time step before it restarts)
  - Folder cleanup (deletes all unwanted files from the simulation folder)
  - Limits the number of concurrently running simulations

- Future Enhancements:
  - Faster asynchronous core
  - “C” library for solvers (for generic support and manipulation)

- TOWER success story: 20,000 grid data simulations were run in approximately two weeks using TOWER
QUESTIONS?