Air Force SEEK EAGLE Office

Capability via Compatibility

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

October 2012

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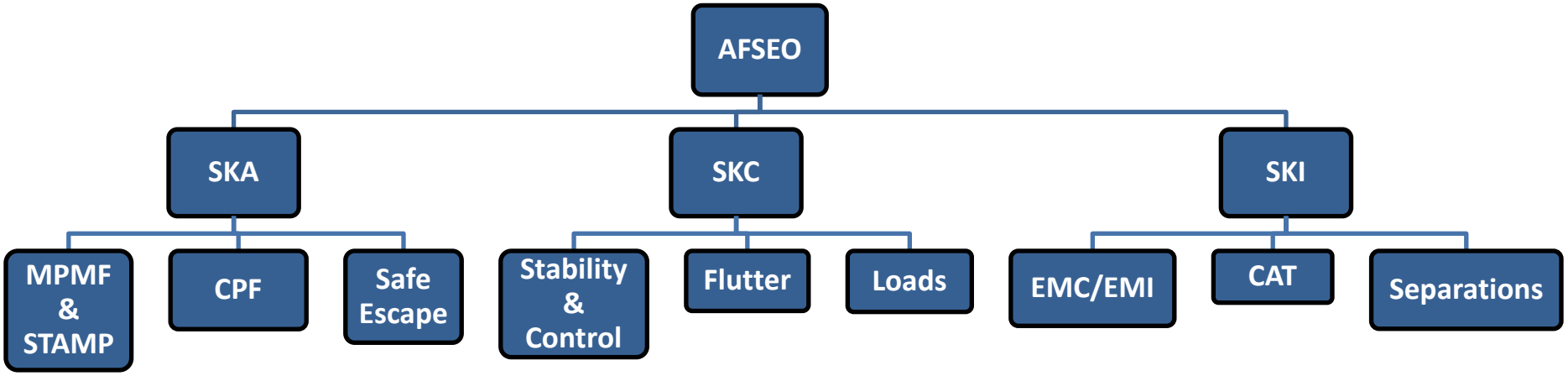
Computational **A**eromechanics **T**eam

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)

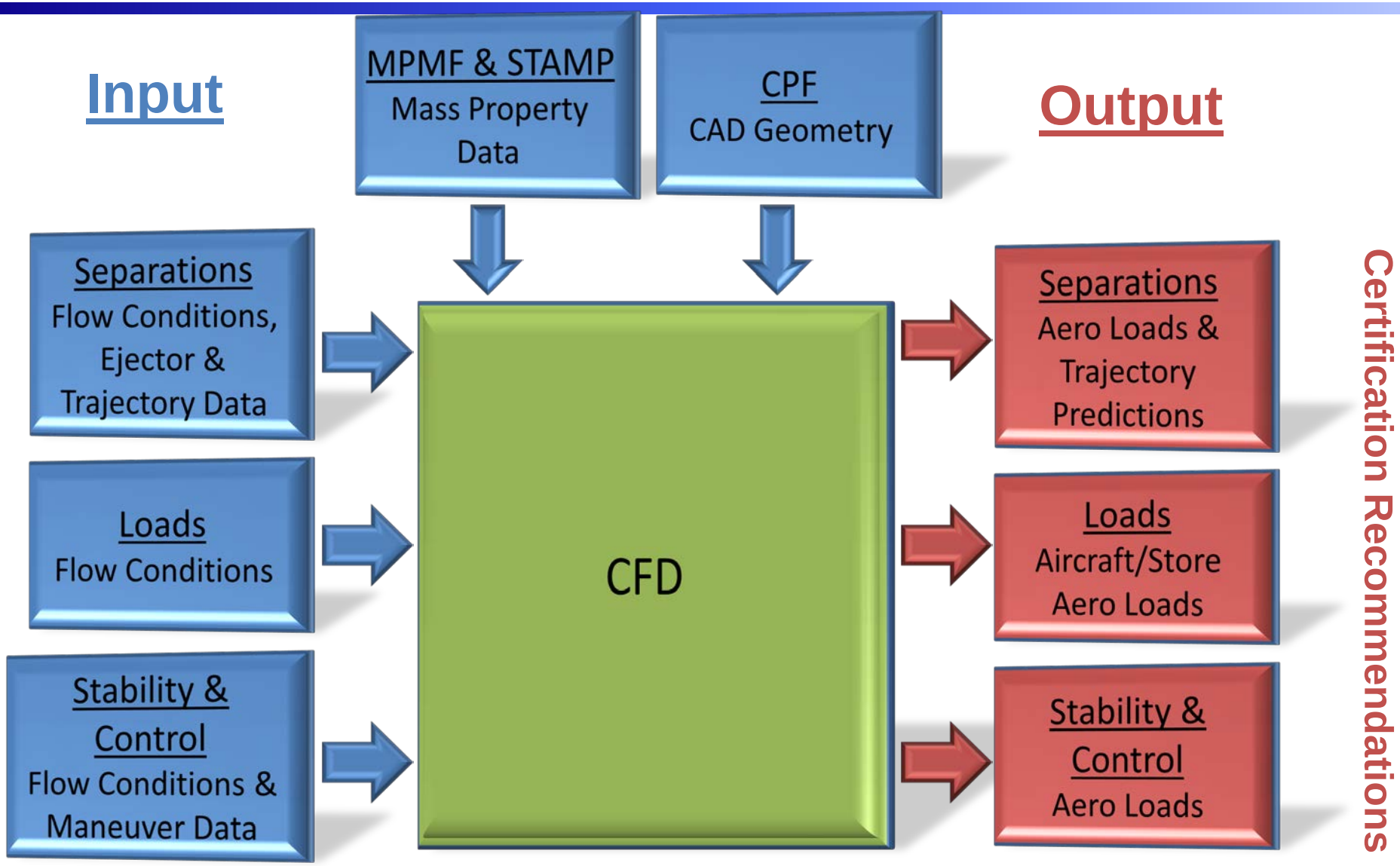
Introduction

- 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

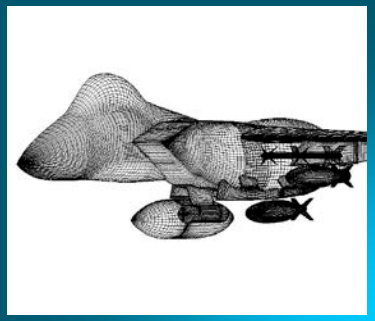
Introduction



Introduction

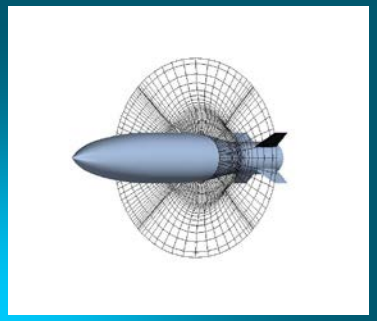
The Overset CFD Process

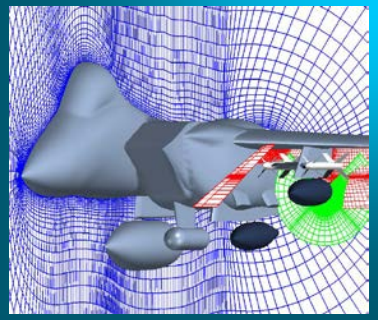
Geometry Definition



Grid Generation

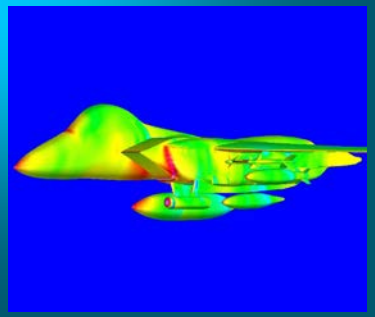
Volume Grids





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

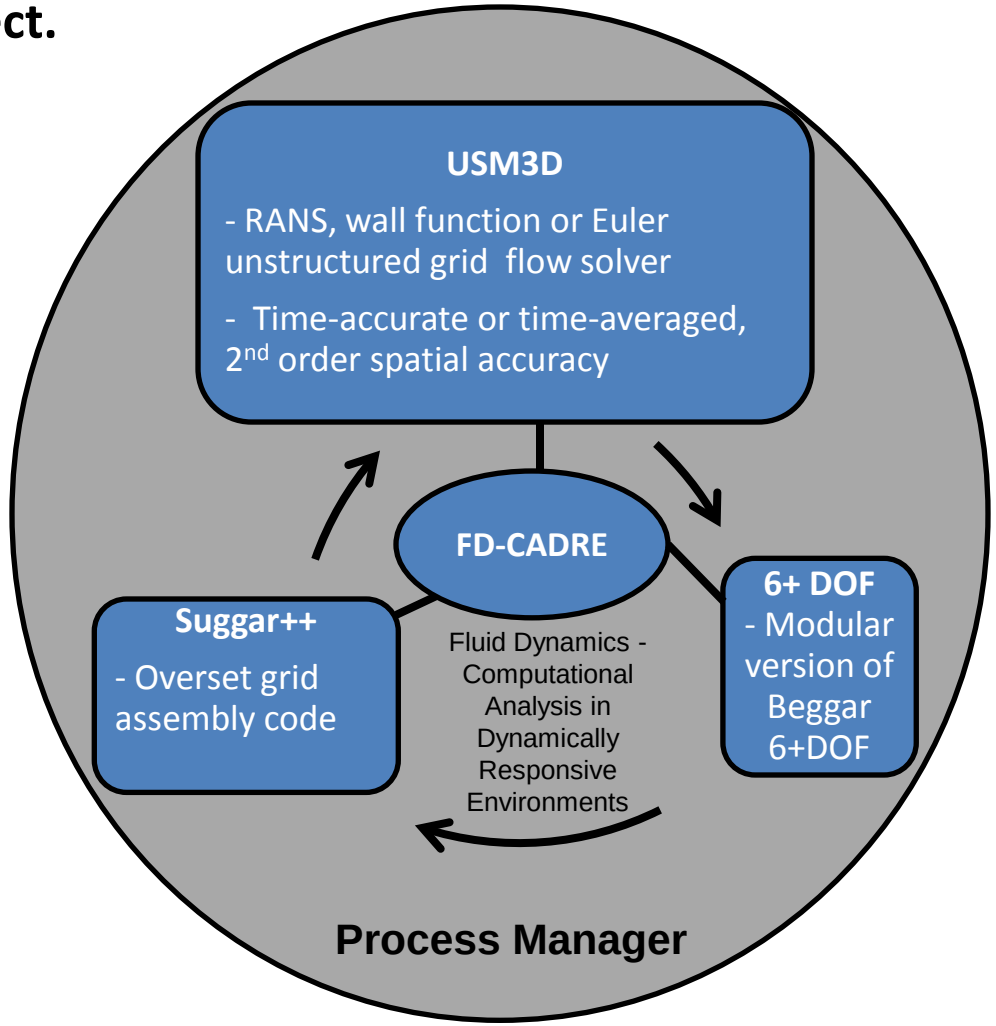
- Cell-centered, finite-volume, upwind, implicit Roe scheme
- Time-accurate or time-averaged, 2nd order spatial accuracy

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…

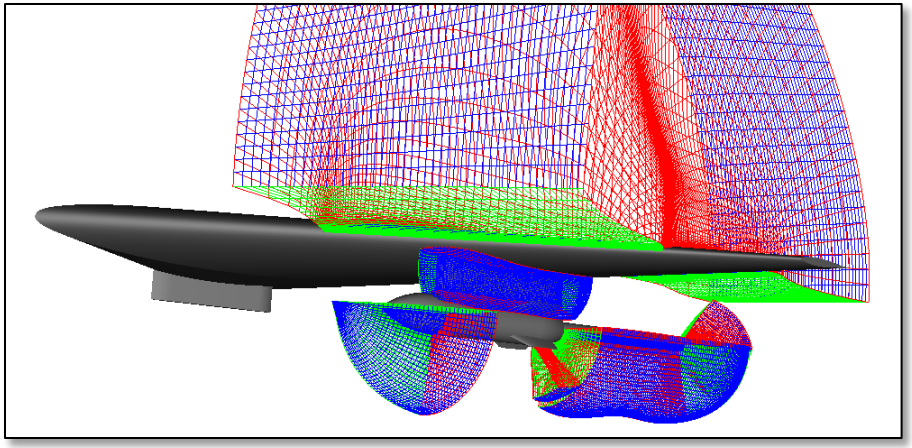


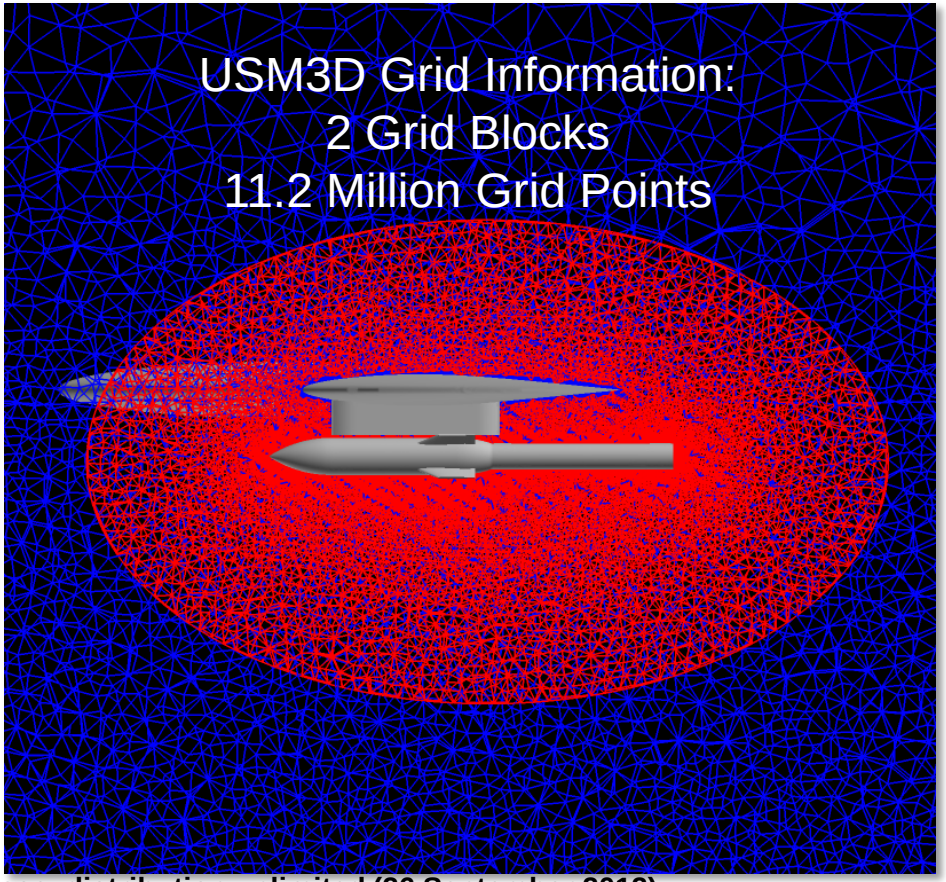
Application Efforts
Wing-Pylon-Store Separation

- 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



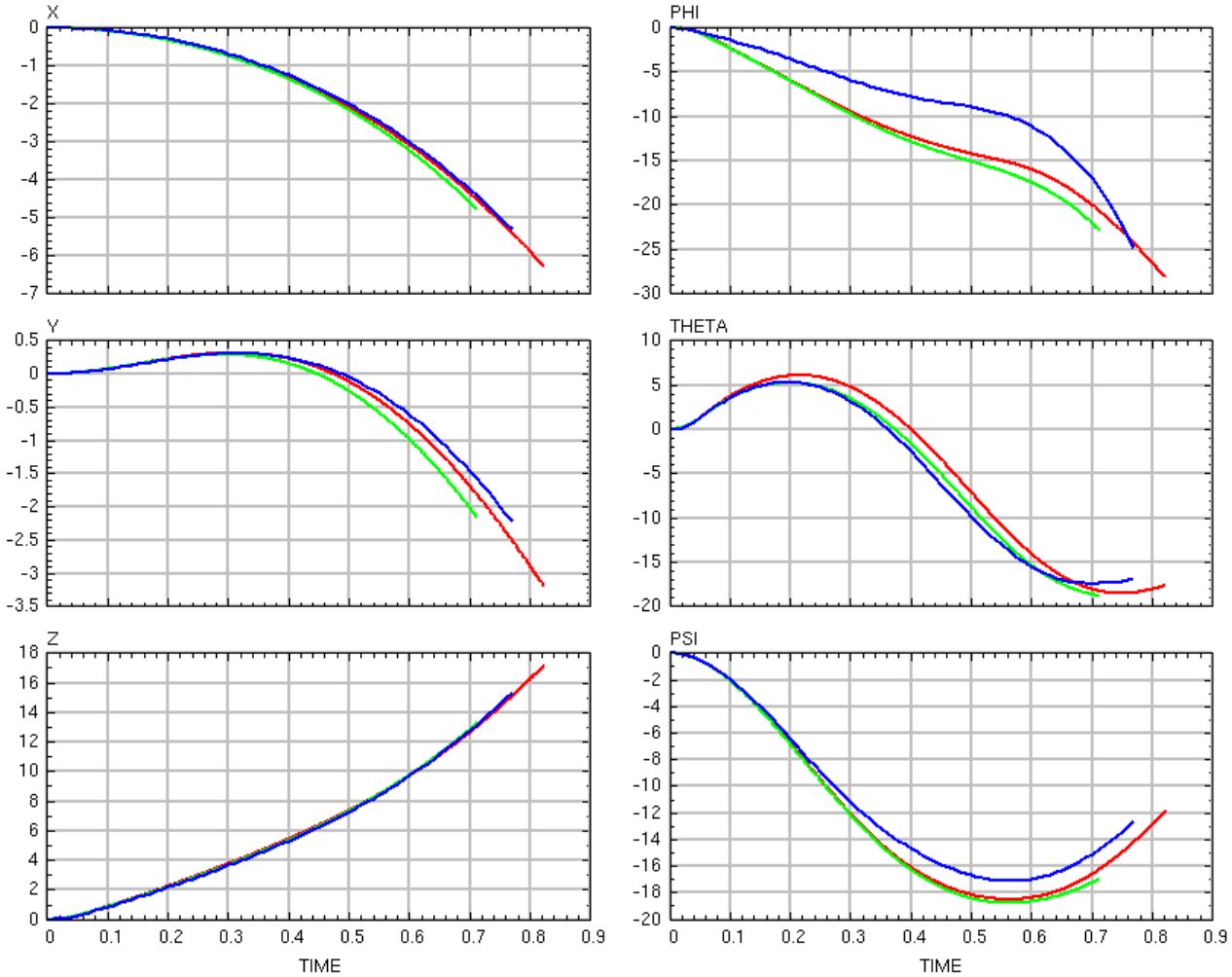


Application Efforts
Wing-Pylon-Store Separation

Mach 0.95

WT
Beggar
USM3D

- 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)

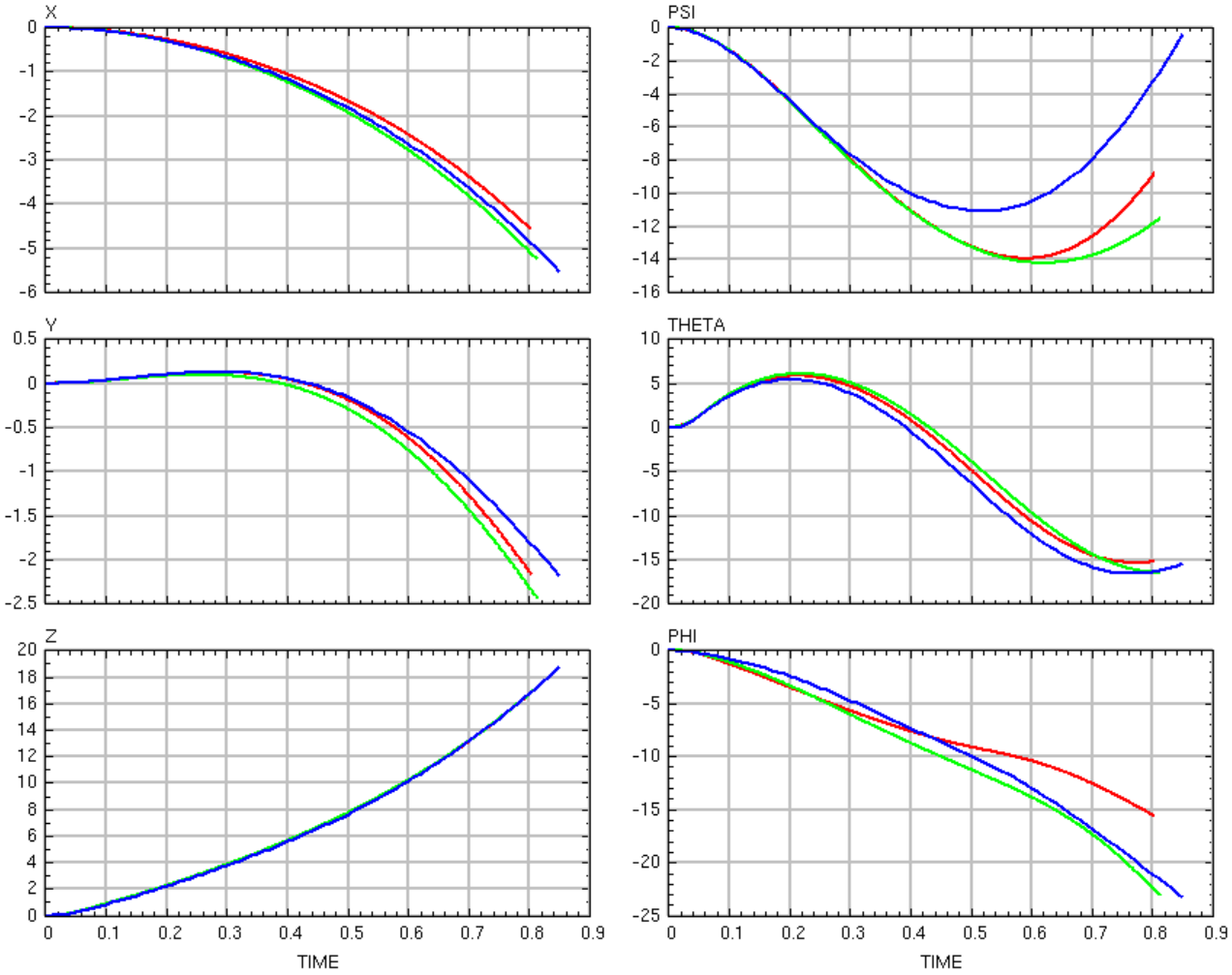


Application Efforts
Wing-Pylon-Store Separation

Mach 1.2

WT
Beggar
USM3D

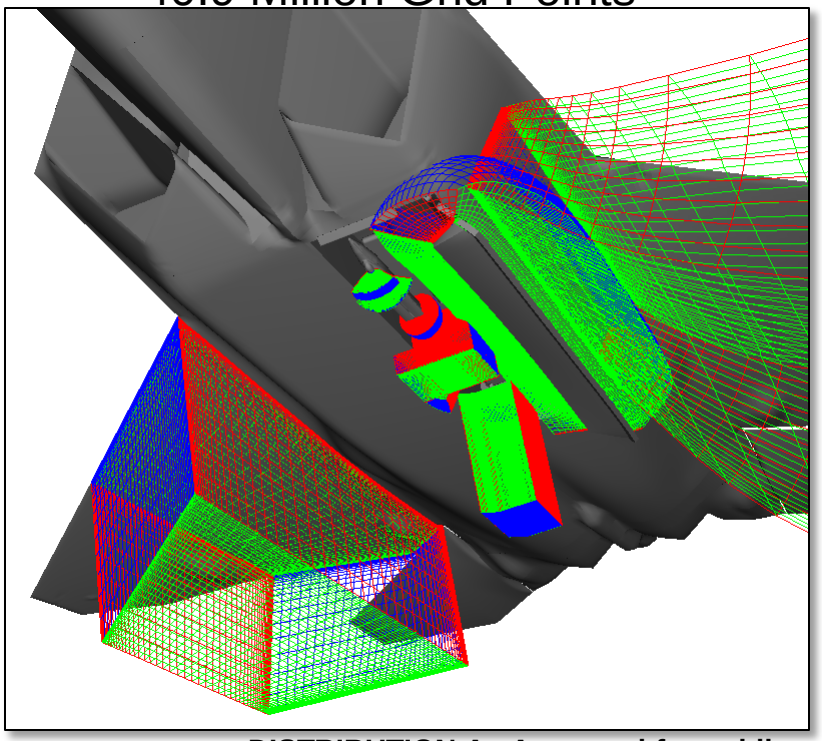
- X Translation (+X – forward)
- Y Translation (+Y – right)
- Z Translation (+Z – down)
- Yawing Orientation – PSI (+PSI – nose right)
- Pitching Orientation – THETA (+THETA – nose up)
- Rolling Orientation – PHI (+PHI – right wing down)



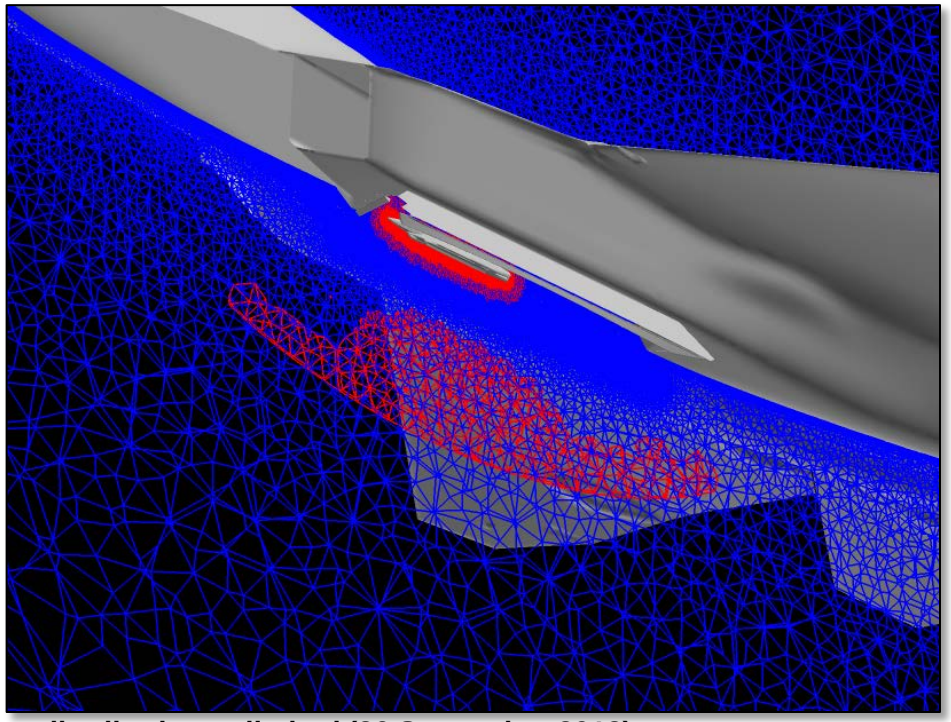
Application Efforts
F-22/GBU-39 Separation

- 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

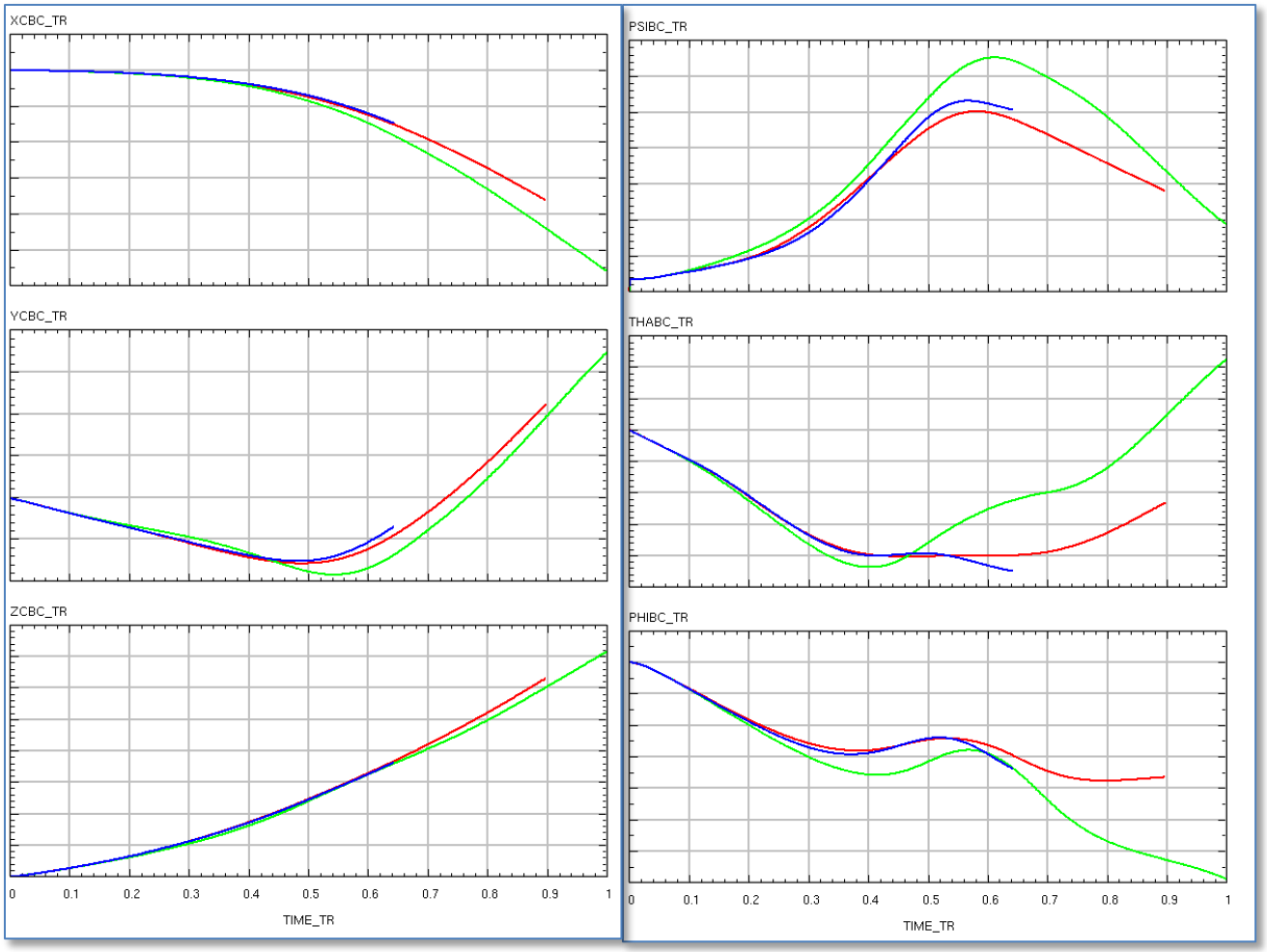


USM3D Grid Information:
2 Grid Blocks
41.2 Million Grid Points



Application Efforts
F-22/GBU-39 Separation

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

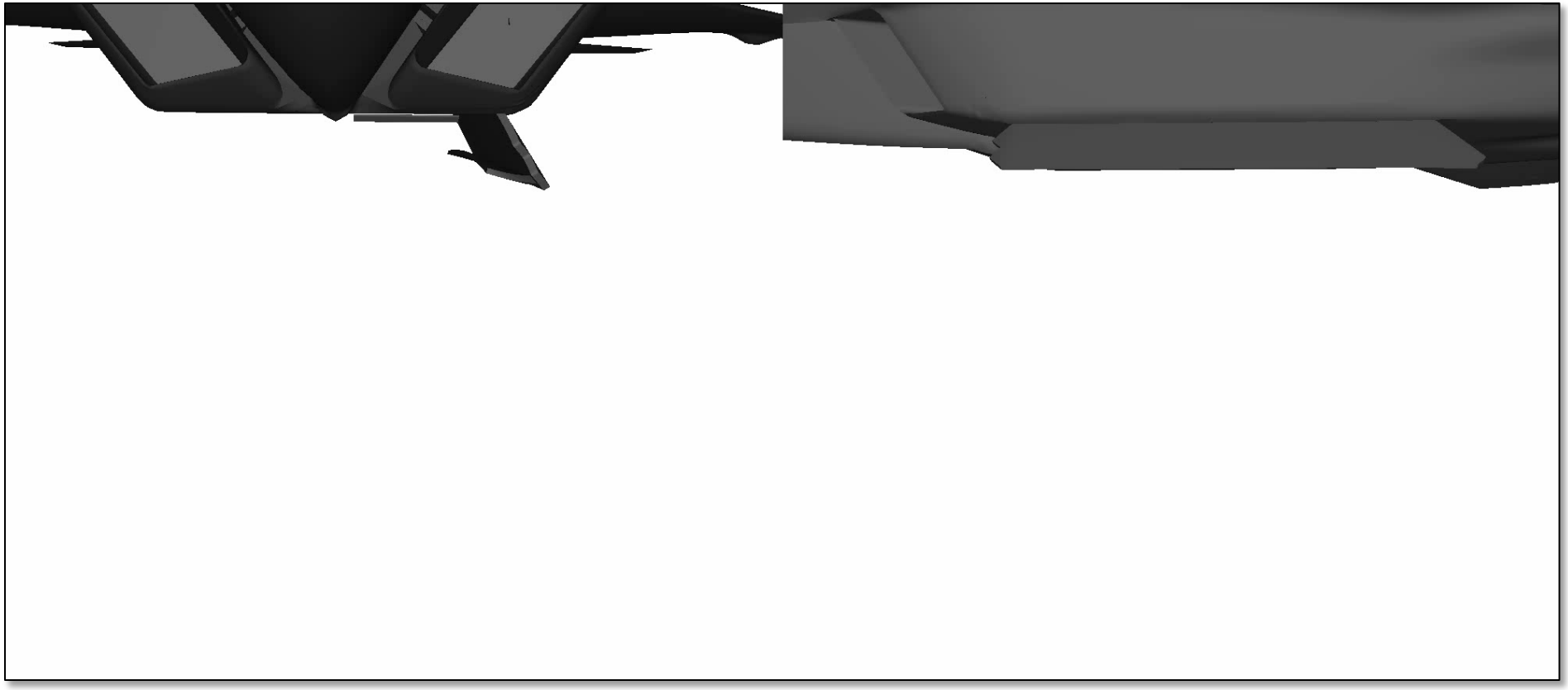


- X Translation (+XCBC_TR – forward)
- Y Translation (+YCBC_TR – right)
- Z Translation (+ZCBC_TR – down)
- Yawing Orientation – PSIBC_TR (+PSI – nose right)
- Pitching Orientation – THETABC_TR (+THETA – nose up)
- Rolling Orientation – PHIBC_TR (+PHI – right wing down)

Application Efforts
F-22/GBU-39 Separation

GBU-39 Trajectory Comparison

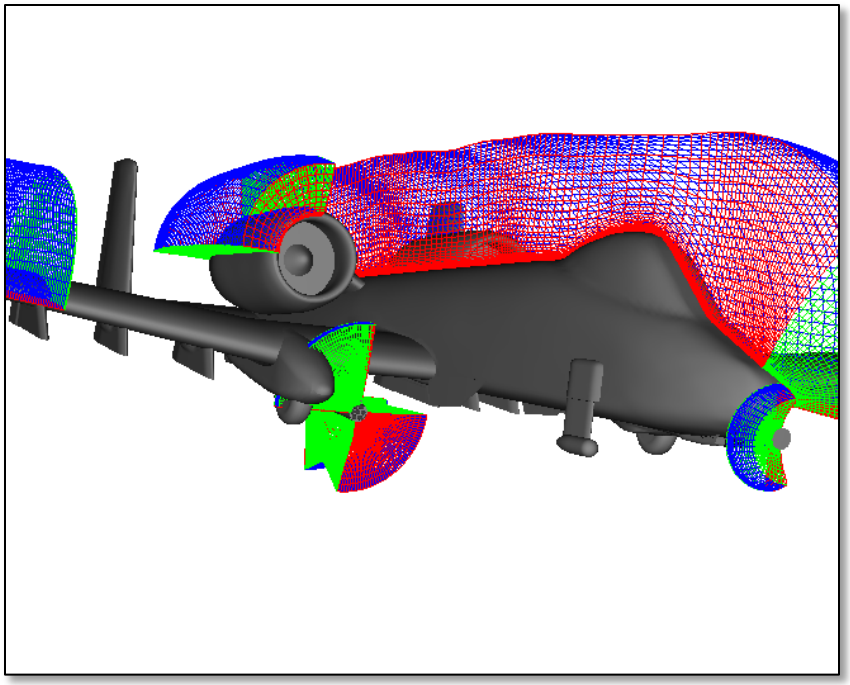
Green – Flight Test
Red – Beggar CFD
Blue – USM3D CFD



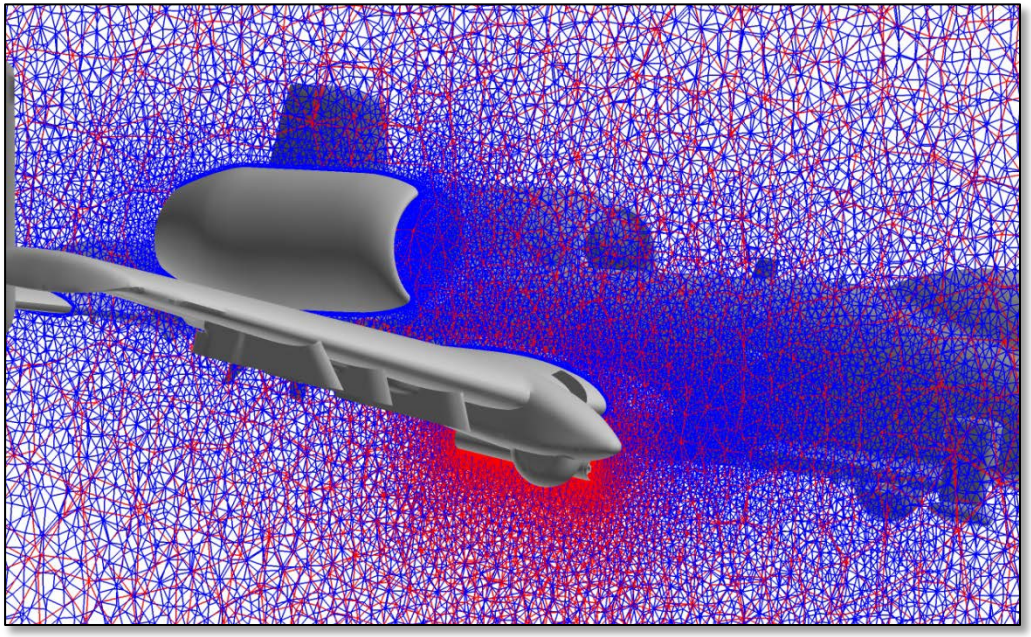
Application Efforts
A-10/LAU-131 Separation

- 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



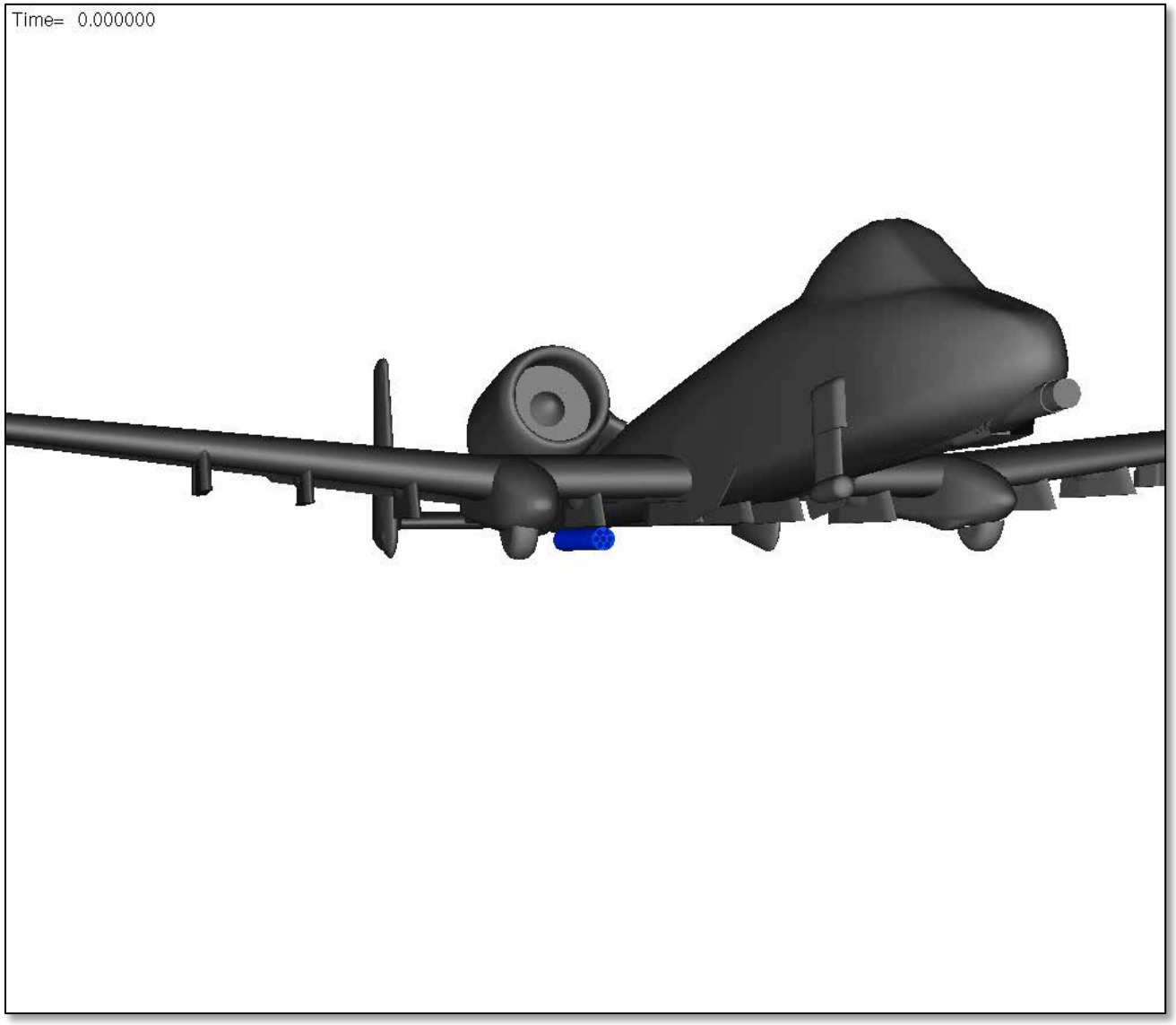
USM3D Grid Information:
2 Grid Blocks
42.4 Million Grid Points



Application Efforts
A-10/LAU-131 Separation

LAU-131 Trajectory Comparison

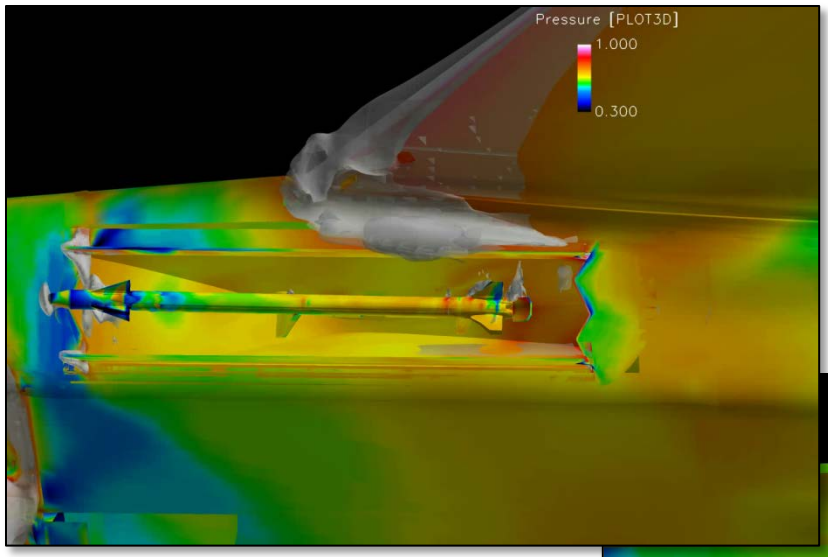
Blue – USM3D CFD
Red – Beggar CFD

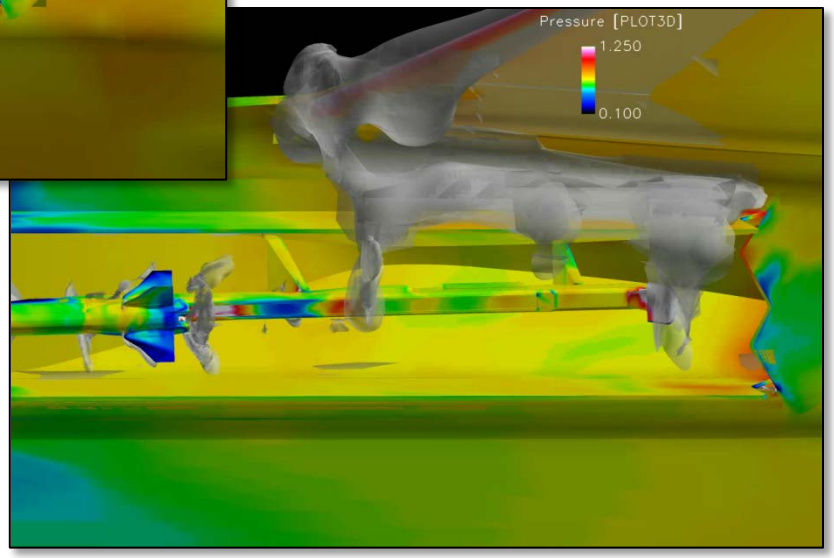


Application Efforts
F-22/AIM-9X Separation Analysis

- 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

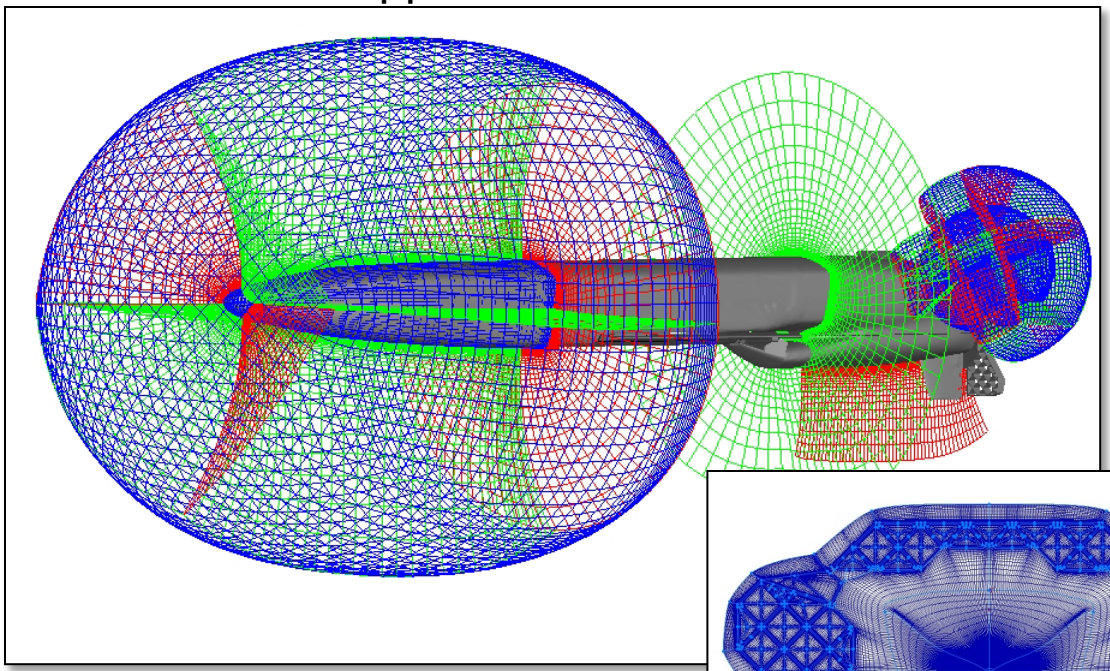
Beggar Grid Information:
1140 Grid Blocks
31.3 Million Grid Points



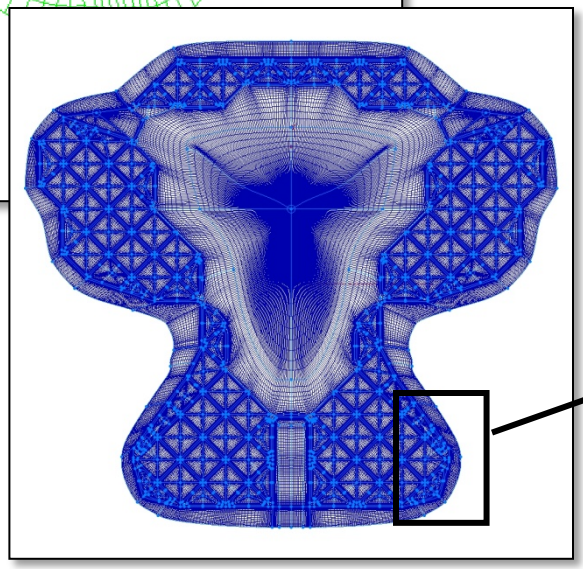


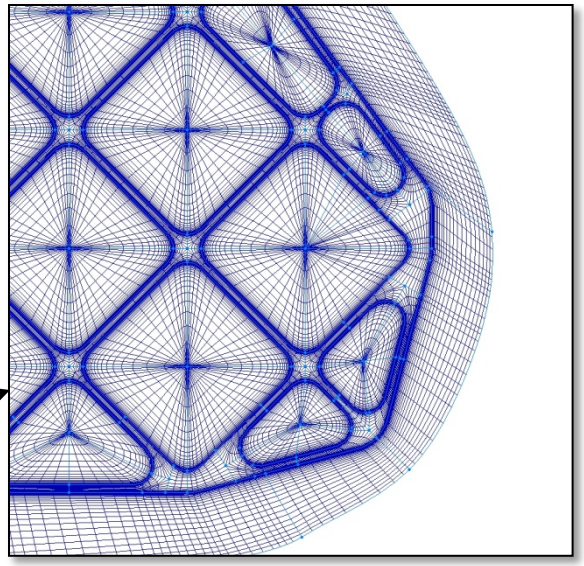
Application Efforts
MALD Separation Analysis

- 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



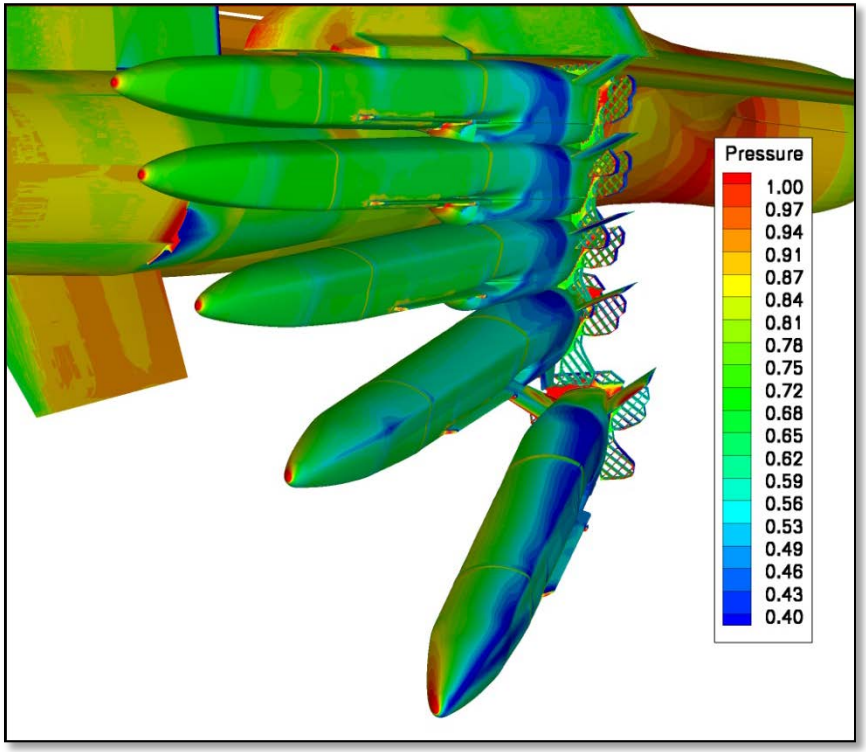
Beggar Grid Information:
16.5 Million Grid Points in MALD Overall Grid
10.5 Million Grid Points in the Grid Fin Alone

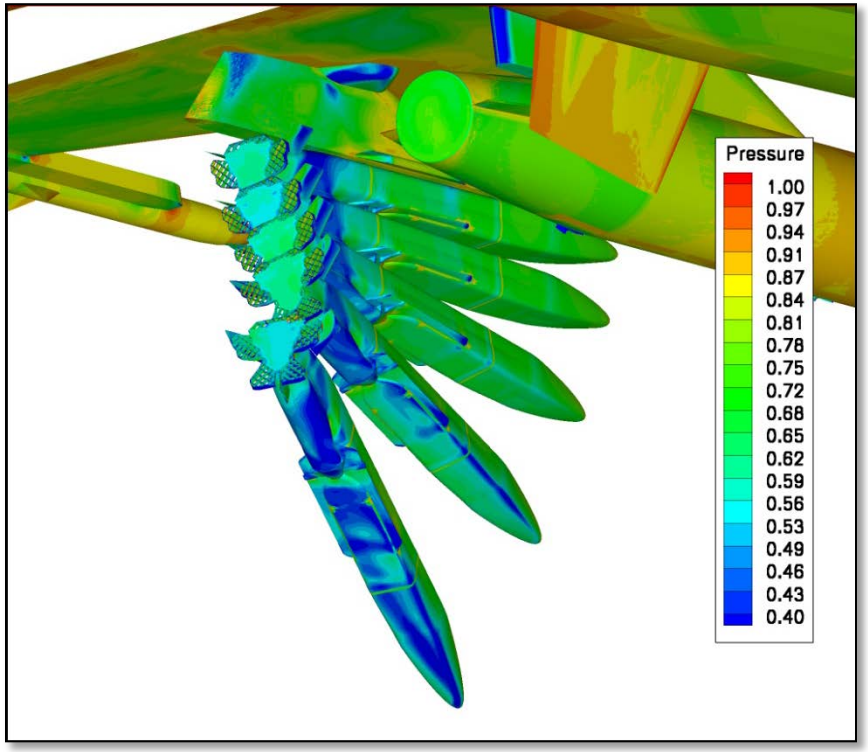




Application Efforts
MALD Separation Analysis

- 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





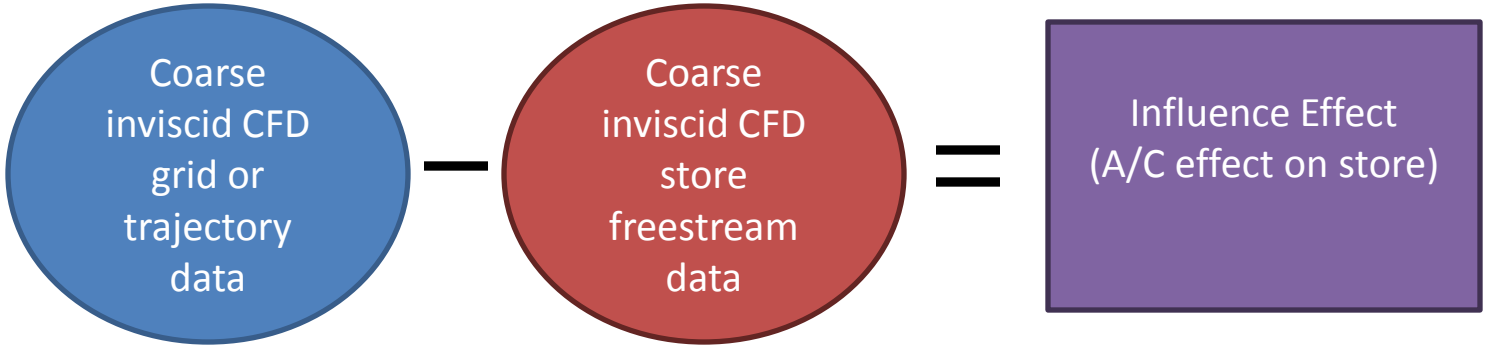
Application Efforts

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

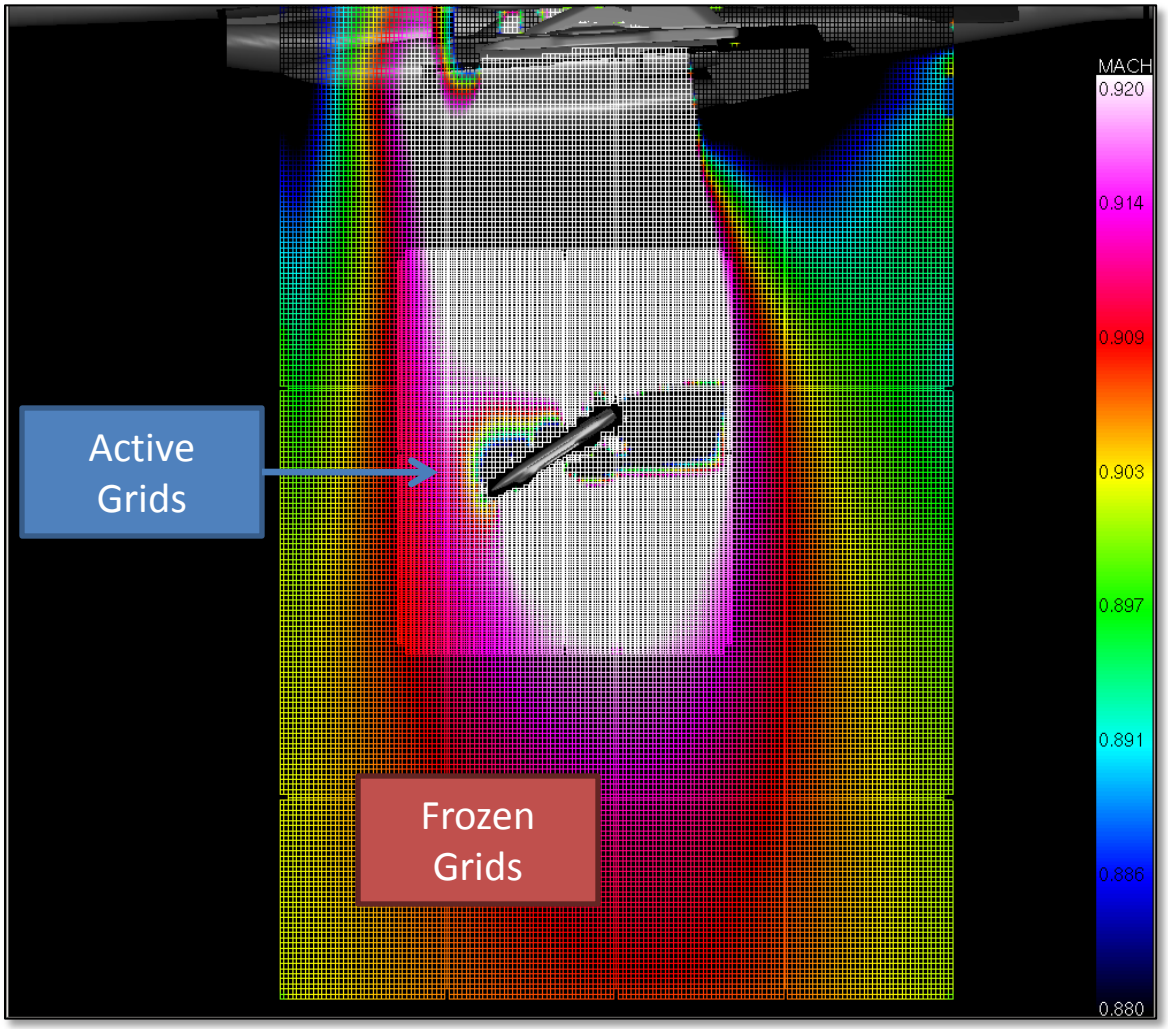


  - The combination of the high quality freestream data and influence effect data yields high quality grid or trajectory data.

Application Efforts

Delta Coefficient Approach & Grid Freezing Analysis

- **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



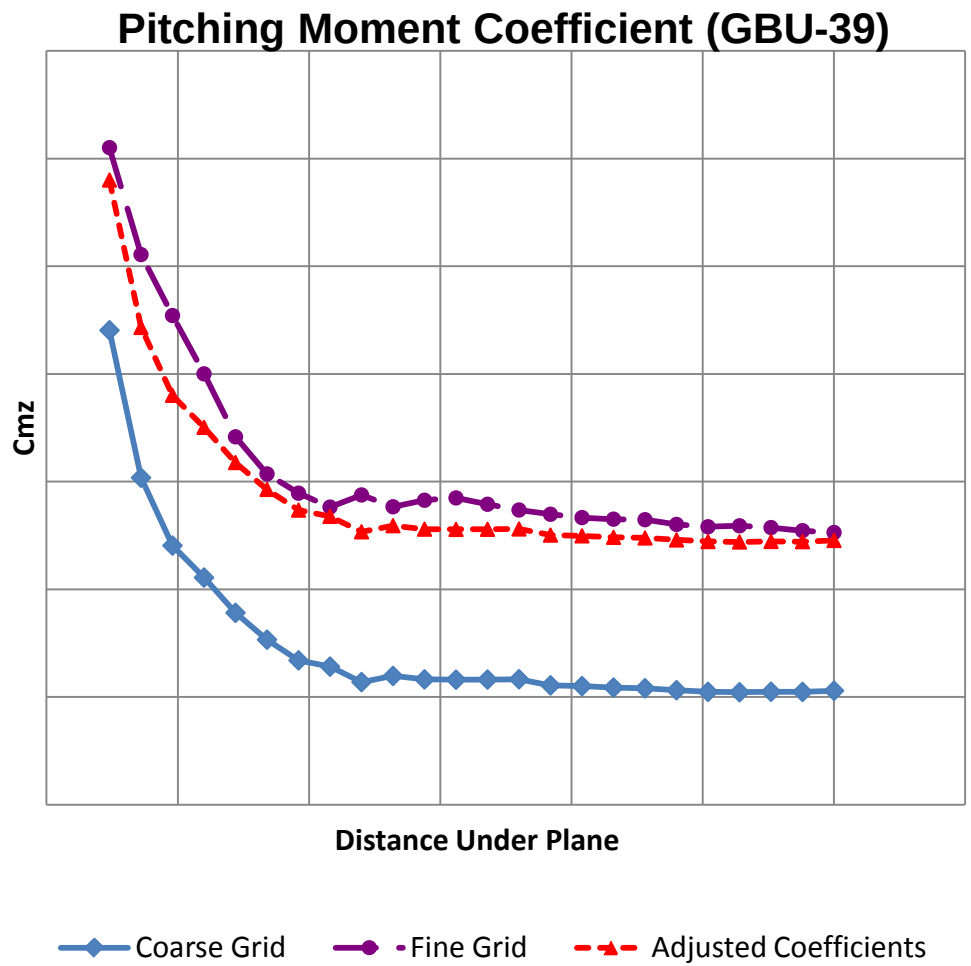
Application Efforts

Delta Coefficient Approach & Grid Freezing Analysis

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**



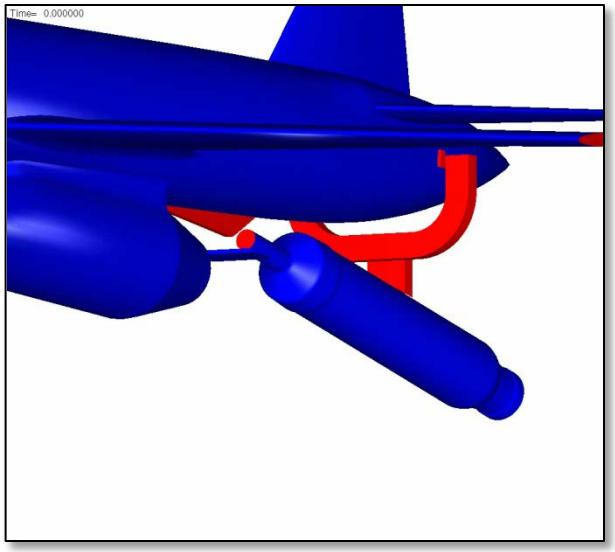
Notable Application Efforts

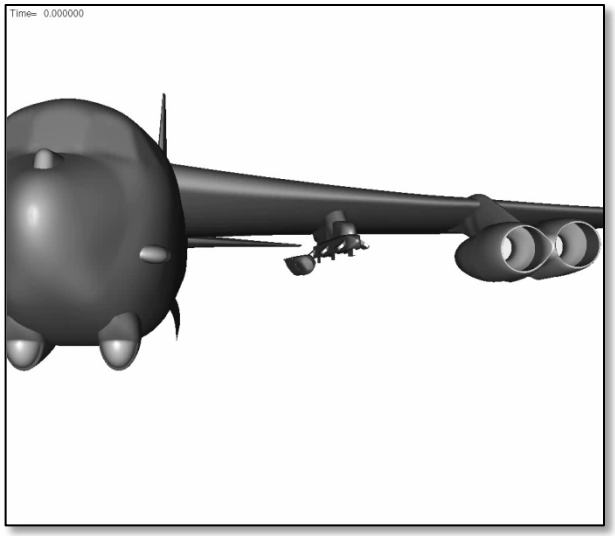
- F-22/AIM-9X Down-the-Rail Grid Data Analysis – Performed 600+ grid data simulations using Beggar over 4 month period; resulted in $500K WT test cost savings

- 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?