The Role of CFD in Stores Certification

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Eglin AFB, Florida

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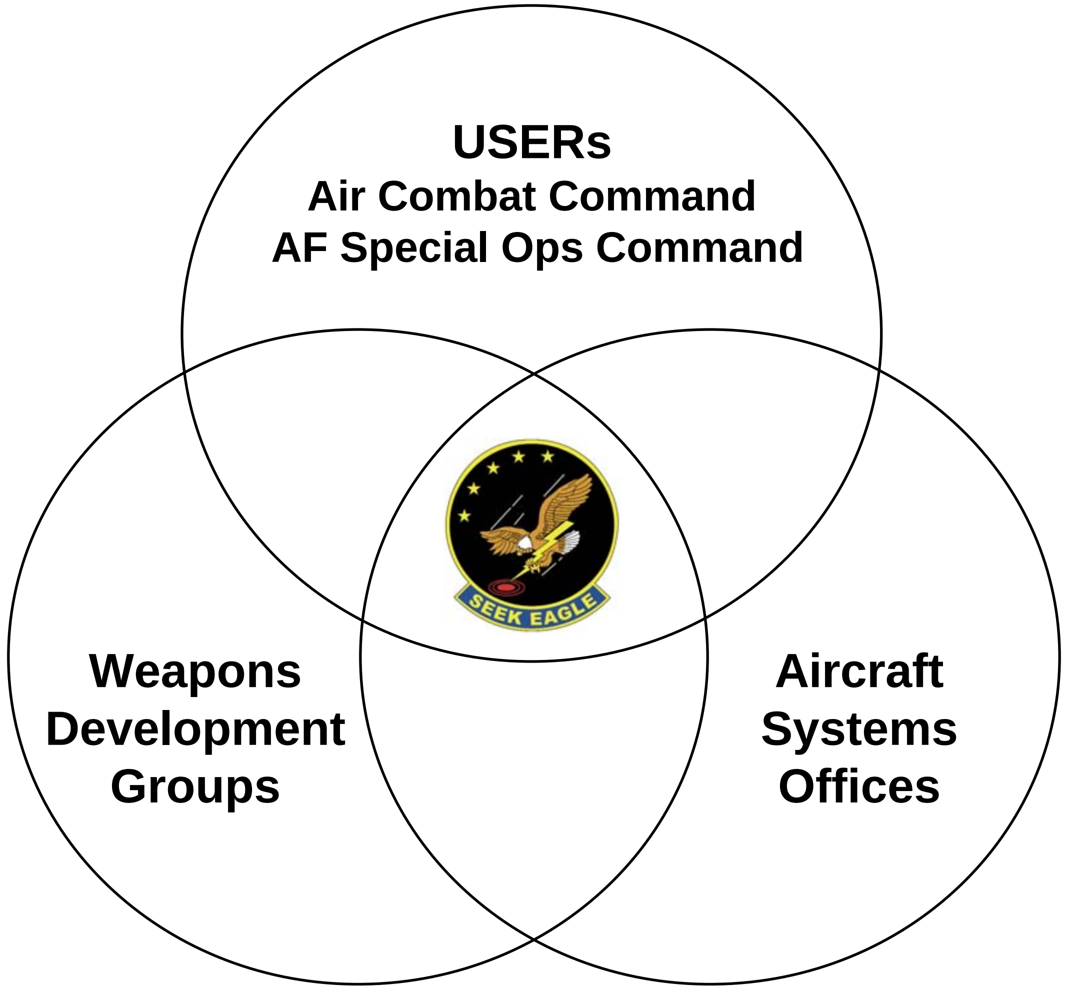
Air Force SEEK EAGLE Office

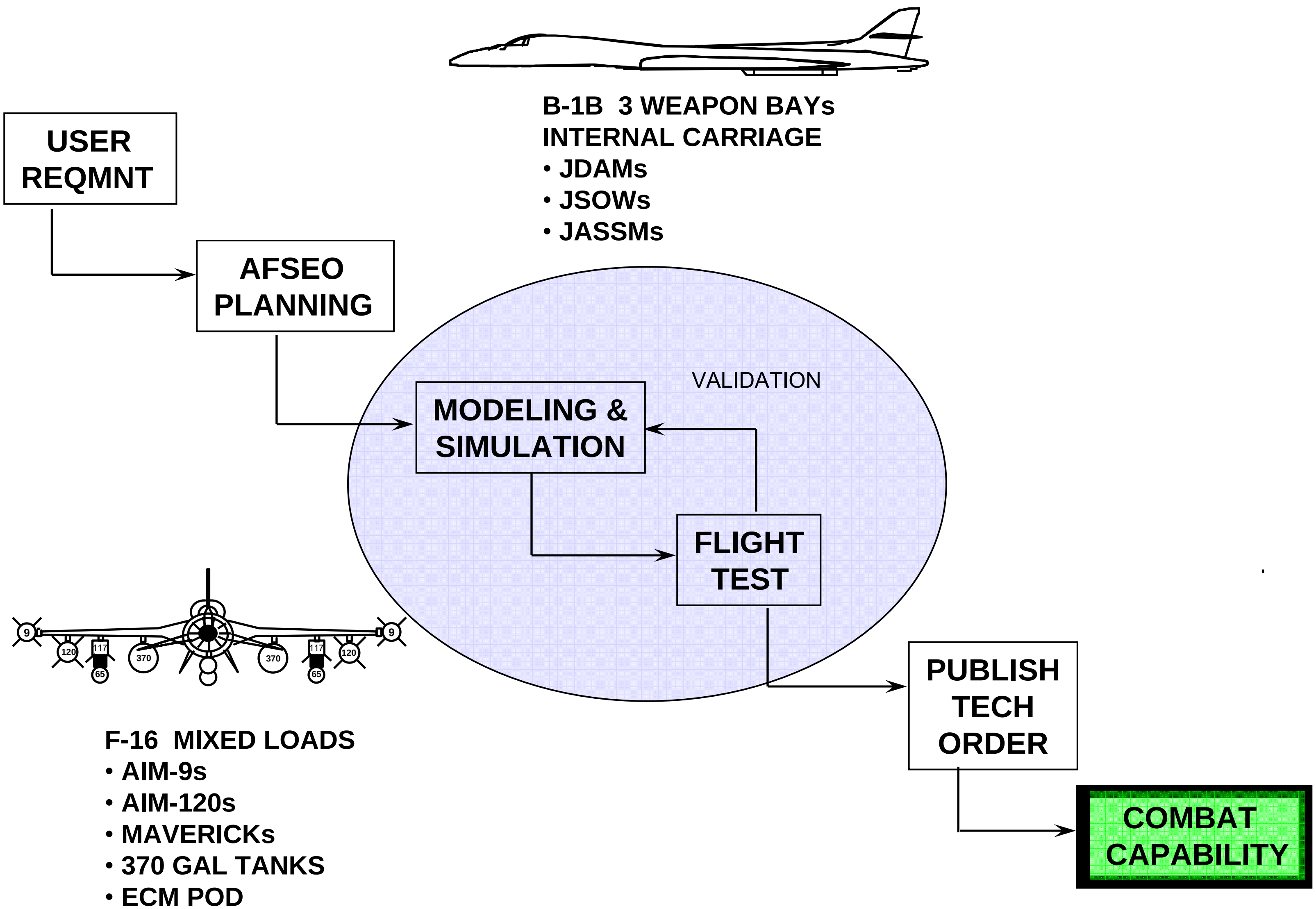
- Air Armament Center has two major components
  - Weapons System Program Offices
  - Test Wing including Flight Test and SEEK EAGLE Office
- USAF Aircraft-Store Certification Program (SEEK EAGLE Process)
  - Store loading procedures
  - Carriage loads*
  - Store separation*
  - Flutter*
  - Ballistic accuracy
  - Stability & control*
  - Safe escape
- Stores Include
  - Munitions, fuel tanks
  - Suspension equipment
  - Pods for navigating, sensing, targeting

Air Force SEEK EAGLE Office Role

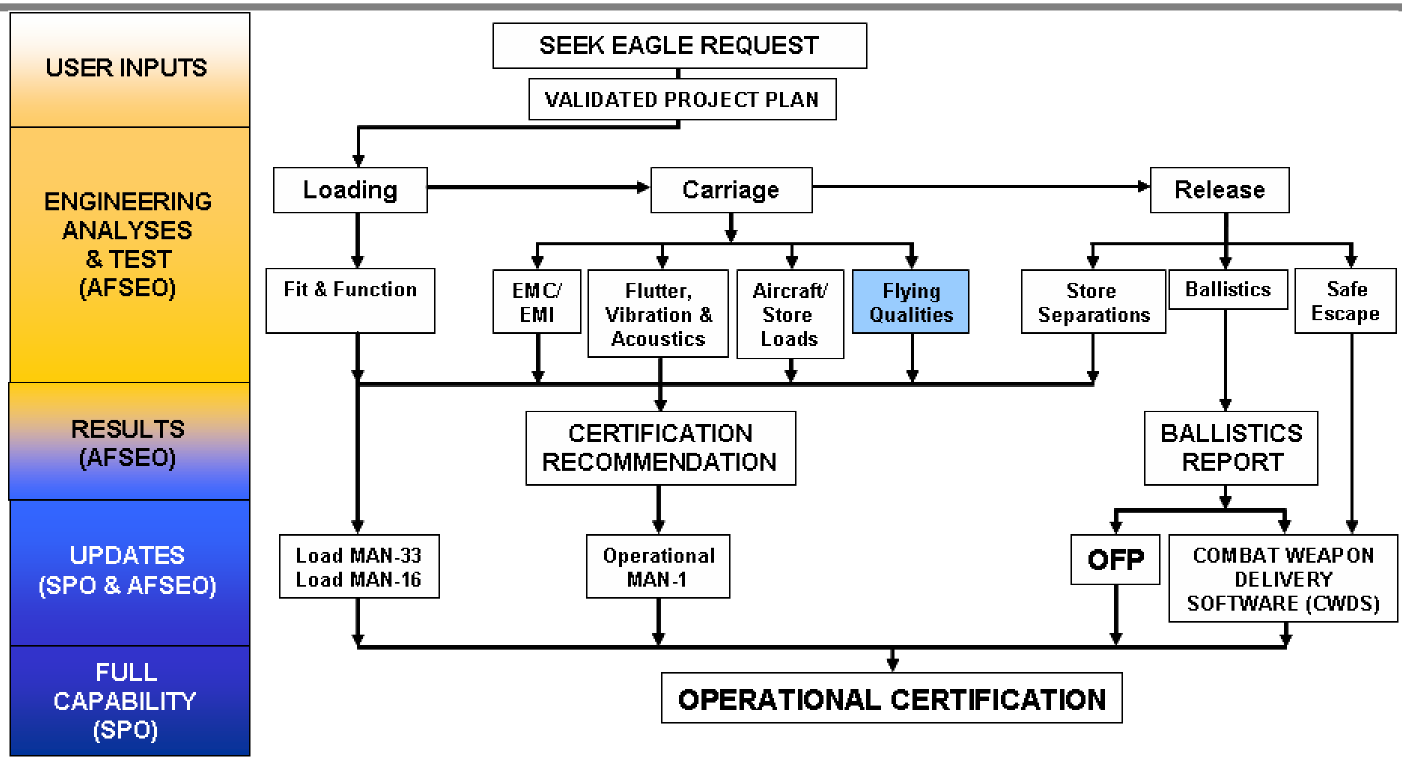


AFSEO is AF Store test and EVALUATION

Aircraft Store Certification Process



SEEK EAGLE Process



OVERVIEW

- **The SEEK EAGLE program is the standard for the aircraft-stores certification process governed by AFI 63-104 for the US Air Force**

PRODUCTS

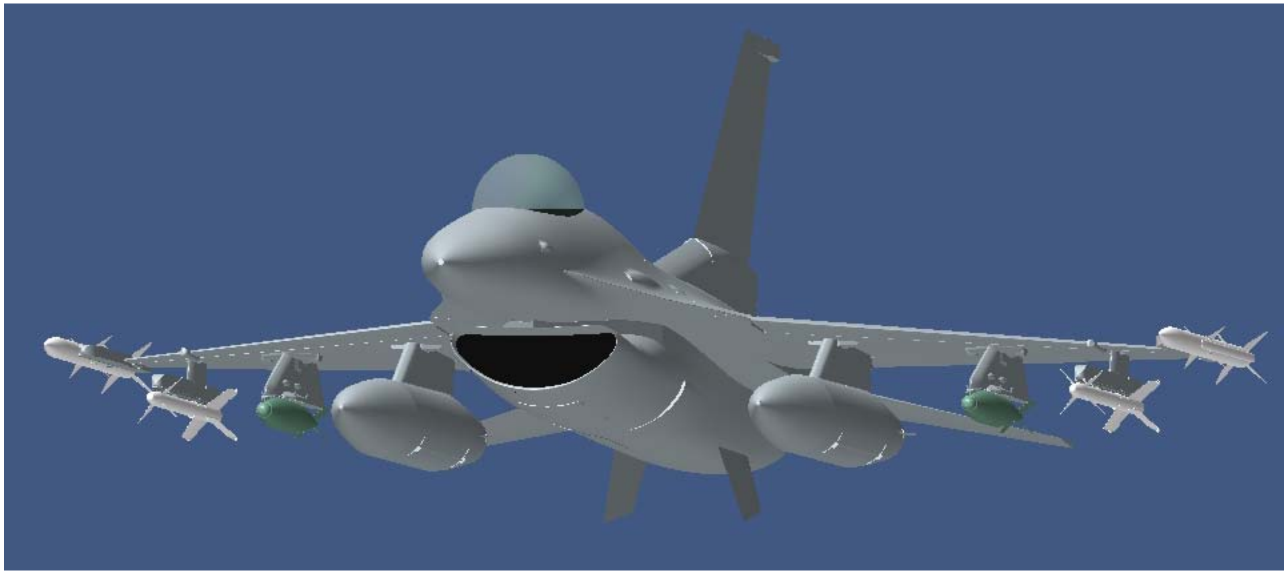
- **Quick Reaction Certification (QRC)**
- **Certification Recommendation (CR)**
- **Flight Clearance (FC)**

Disciplines Use of HPC

- **Store Separation**
  - 12 – 15 year history of CFD support to SS certification decisions
  - Steady solutions of aircraft/stores to determine interference effects
  - Time accurate 6DOF solutions of store release from aircraft
- **Stability and Control**
  - Current S&C analysis based on analogy/wind tunnel/**flight test**
  - CFD capability being developed to simulate aircraft maneuvers in captive carry for ANY configuration – capability will supplement flight test
- **Flutter**
  - Analysis primarily uses lower order methods (i.e. panel, transonic small disturbance)
  - **Flight tests** become primary clearance method for transonic conditions
  - No coupled computational method available for high fidelity analysis (Yet!)
- **Loads**
  - Occasional use of CFD to investigate anomalies
  - Loads analysis primarily based on reports and wind tunnel data of analogous configurations and **flight test**

Future Certification Challenge (Flutter Example)

Typical Store Loading - 10 years ago -

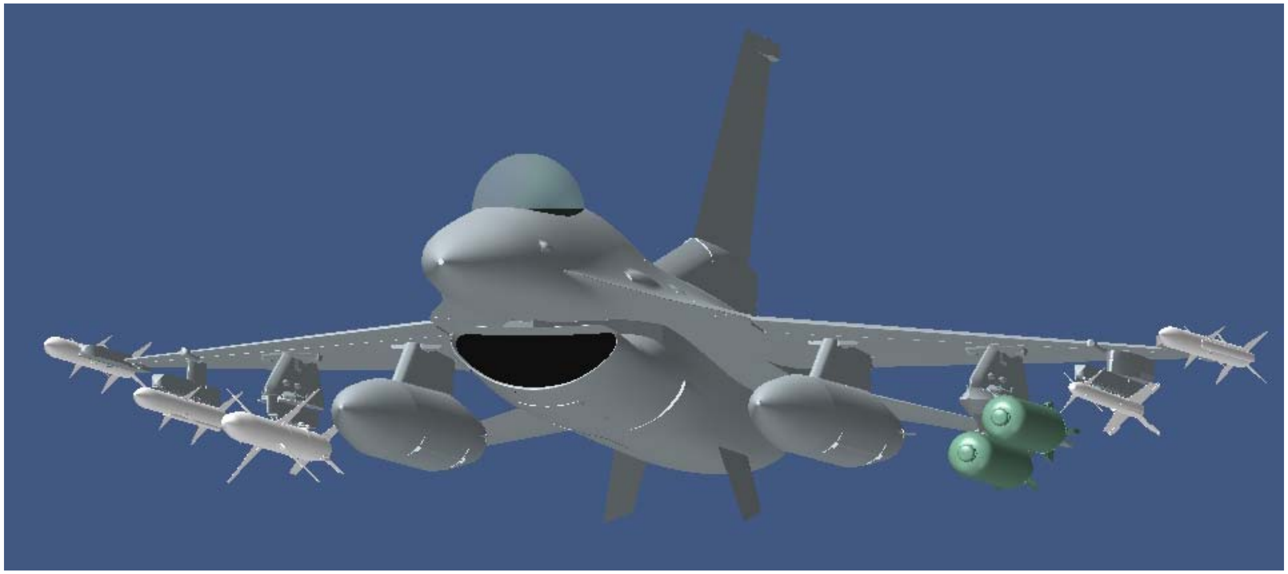


Symmetric Takeoff Configuration
Single Weapon Carriage w/std Pylons

- Download permutations = 500
- Critical analytical cases = 80
- Potential test candidates = 10
- Flight test configurations = 5

Future Certification Challenge (Flutter Example)

Typical Store Loading - 5 years ago -

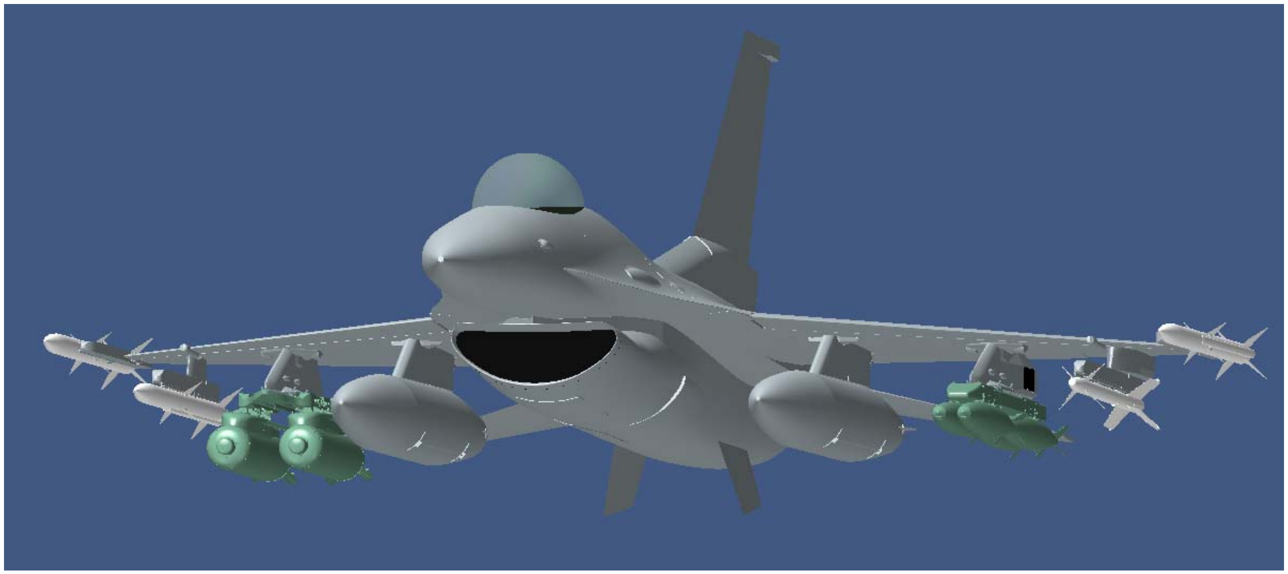


Asymmetric Takeoff Configuration
Single & Multi-Weapon Carriage w/Countermeasure Pylons

- Download permutations = 2900
- Critical analytical cases = 600
- Potential test candidates = 50
- Flight test configurations = 20

Future Certification Challenge (Flutter Example)

Typical Store Loading - Now -

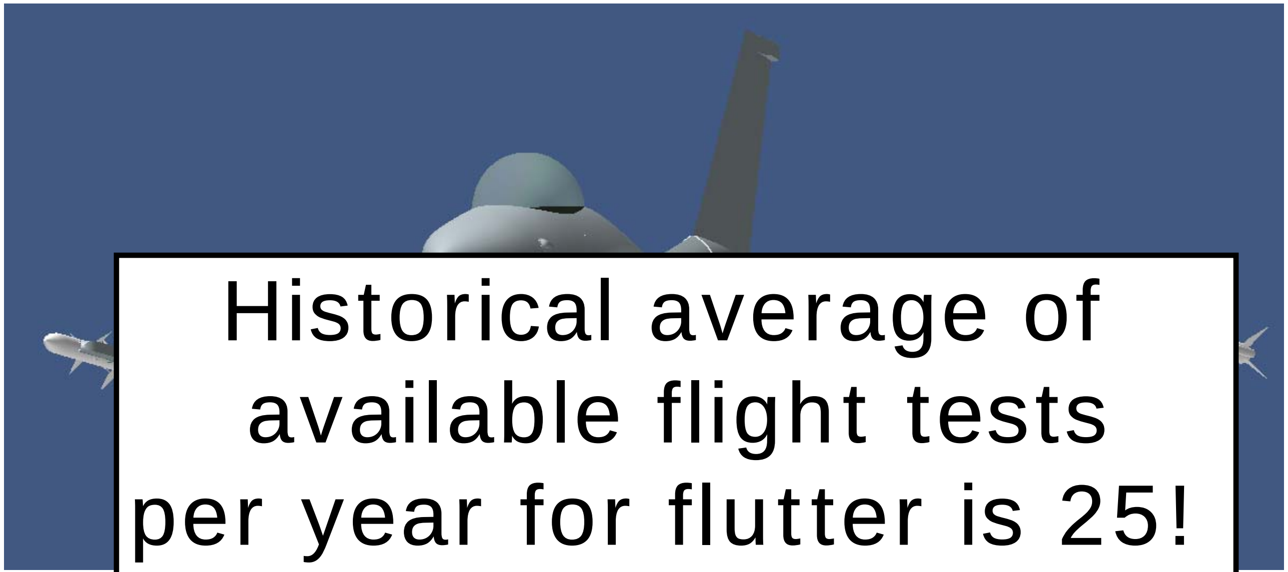


Complex Asymmetric Takeoff Configuration
Multi-Place Weapons Racks & Multiple Countermeasures Pylons

- Download permutations = 25000
- Critical analytical cases = 6200
- Potential test candidates = 250
- Flight test configurations = 75

Future Certification Challenge (Flutter Example)

Typical Store Loading - Now -



Multi-Plac[...] [...]Pylons

Historical average of available flight tests per year for flutter is 25! No expected increase for the out years.

- Download permutations = 25000
- Critical analytical cases = 6200
- Potential test candidates = 250
- Flight test configurations = 75

Current Store Separation Use of CFD

- Complicated flow physics – transonic, high α cases
  - Compressibility, interference, shear/boundary layer effects
  - Viscous, flow separation, choked flow, shock waves
  - Multi-body motion, autopilot control, parachutes
- Rapid response – typically 2-6 weeks
  - Time-critical support of flight test
  - Quick turn-around for external customers (warfighter)
- Analysis includes combination of wind tunnel data, CFD solutions, Monte Carlo analysis of sensitivity parameters
- Complex geometry requires large number of CFD grid points (15-60 million)
  - Full or symmetric aircraft
  - Pylons, launchers, etc. – level of detail
  - Store grid

AFSEO CFD Project Summary

FY01

F-16/MA-31
F-16/Mk-82 fin crack
F-15/GBU-27

F-16/JASSM

Captured JASSM jettison!

FY02

F-111/SSB
F-16/CBU89/JSOW
F-16/PPB
B-52G/JASSM
F-15E/SLV
JDAM FZU Sim

FY03

F-15E/JDAM
F-15E/SATIRS
F-16/SNIPER
F-15E/SNIPER
F-15E/LITENING
F-16/BRU/CBU89
B-52H/X-37
F-15E WT Support
GBU Aero Data
F-16/ARGUS
F-16/MALD

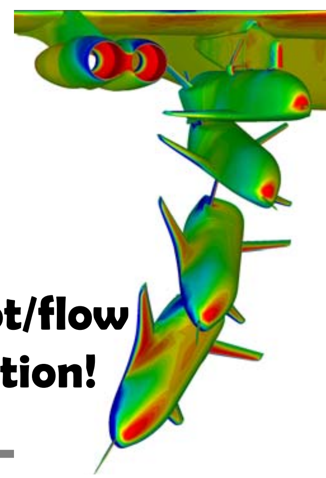
F-15E/WCMD

Realistic fin deployment!

FY04

B-52H/Mailbox
Predator/GBU-12
Predator unsteady flow
SDB-FTS (GBU-39B)
B-52H/JASSM validation
BQM-167 rocket plume
FZU-55 on MQ-9/GBU-38
MALD design studies
B-1B/Mk-82/GBU-38
F-15E S&C w/CBU-104
F-16/600-gal tank
B-52H/MALD
F-16/MALD
F-15E/GBU-28
F-16/WCMD-ER

B-52H/X-37

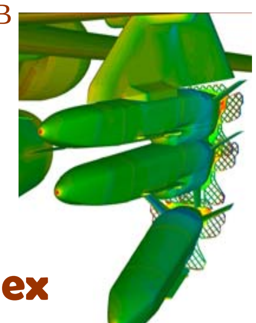


Autopilot/flow interaction!

FY05

B-1B/Mk-82/GBU-38
B-1B/IHAAA - turbulence study
BQM-167A rocket plume
BQM-167A RATO separation
MALD design studies
B-52H/MALD
F-15E S&C w/CBU-104
F-15E/GBU-31
F-16 w/active control surfaces
F-16/600-gal tank
F-16/WCMD-ER
F-16/ECIPS/MA-31
F/A-18C/GBU-12
C-130/Store deployment
Condensation predictions
B-1B/SNIPER/GBU-38
F-15E/GBU-28B/B
F-15E/SNIPER/GBU-38
F-15E/BRU61/GBU-39/B (SDB)
B-52/GBU-12 SafetyIB
B-2A/GBU-28
JSF-CTOL/AIM-9X
JSF-CV/AIM-9X

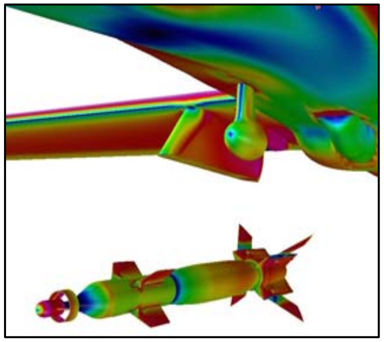
F-16/MALD

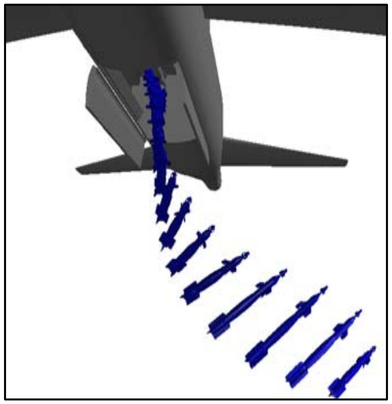


Complex grid fins!

AFSEO CFD Project Summary (Cont.)

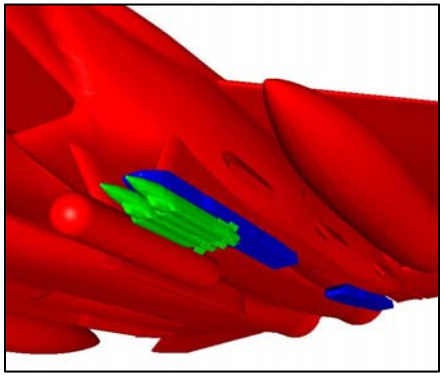
FY06

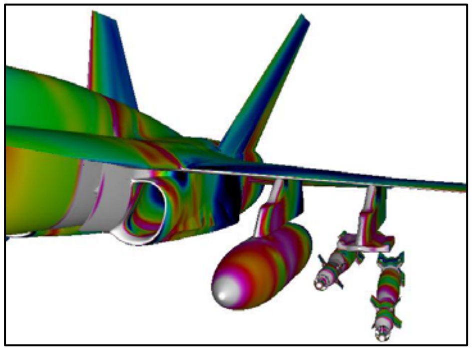


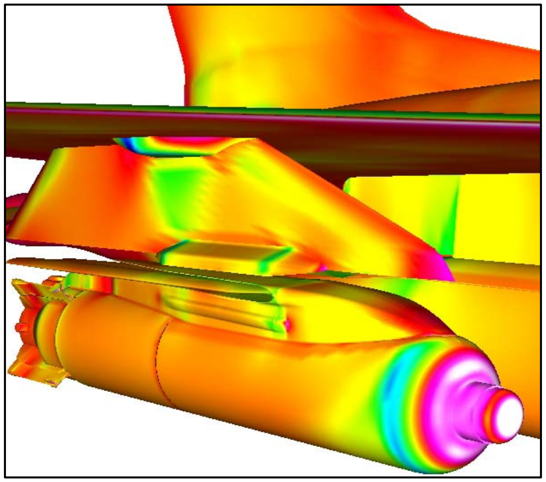


F-16/WCMD-ER
GBU-38 WT
F-15E/GBU-38 Condensation
F-16/AIM9X-9L Flutter
B-52/GBU-38
B-52/GBU-12B
F-18/GBU-12B
JSF-CTOL/Aim-9X
BQM-167/AFSAT
F-15E/SDB
MK-82 WT
F-15E/AGM-158
B-1 Cavity study
F-16/JSOW

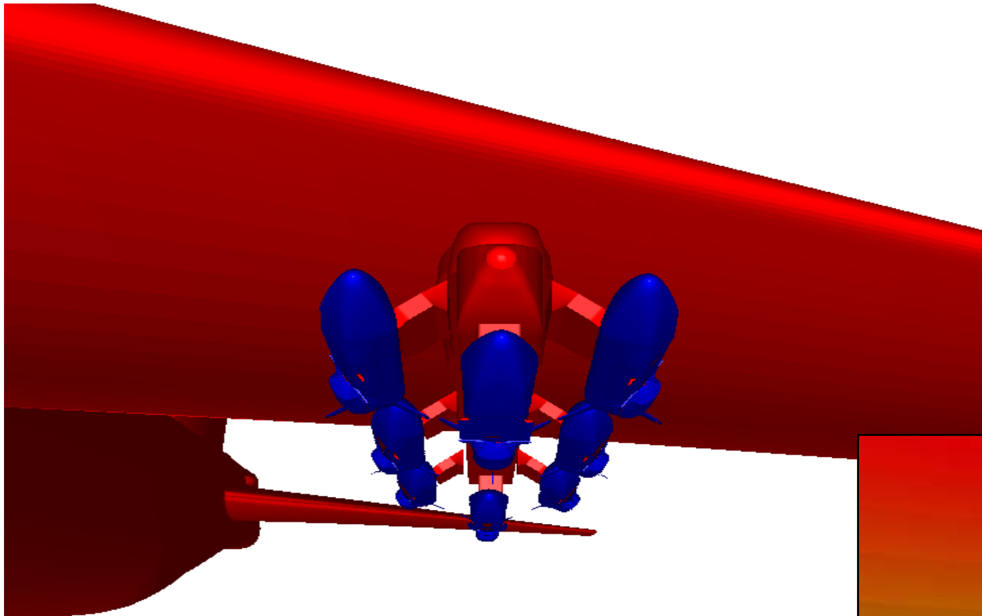
F-15E/GBU-38
YMQ-9A/GBU-12B
F-15E/GBU-31 Condensation
F-16/Tanks S&C
B-2/GBU-28
F-15E/GBU-28C/B
F-16/MALD
JSF Bay Study
B-52/MALD
F-15E/SNIPER/GBU38
F-16/MA-31
B-1/GBU38-MK82
F-15C/AIM-54C
F-16/GBU-39







Store Separation Example – B-52 / MALD

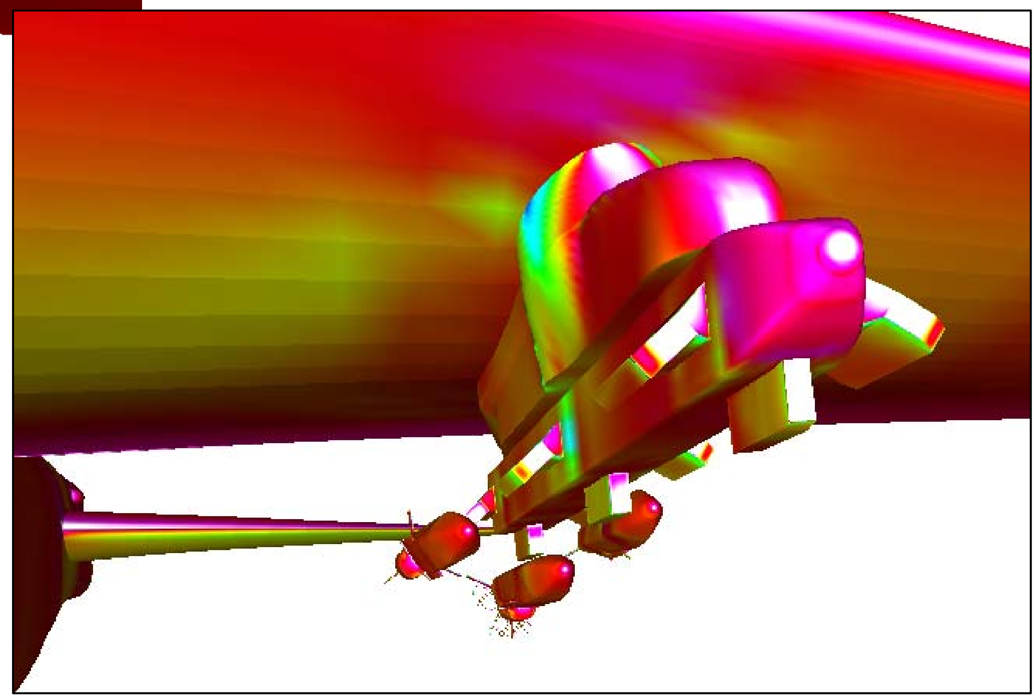


MALD Separation CFD

- **13 carriage solutions**
- **20 separation trajectories**
- **6,992 CFD Solution Points**

Case Management Software

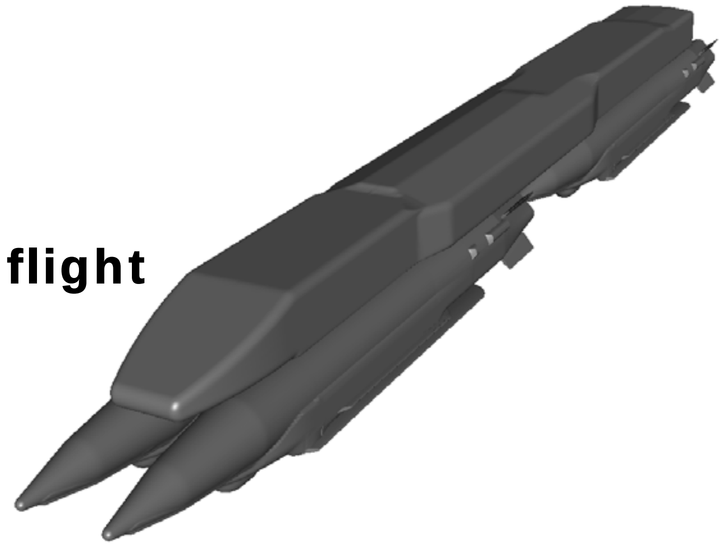
- **Tower at ERDC, ARL**
- **~2.5 million CPU-hours**
- **Project not possible w/out HPC support**

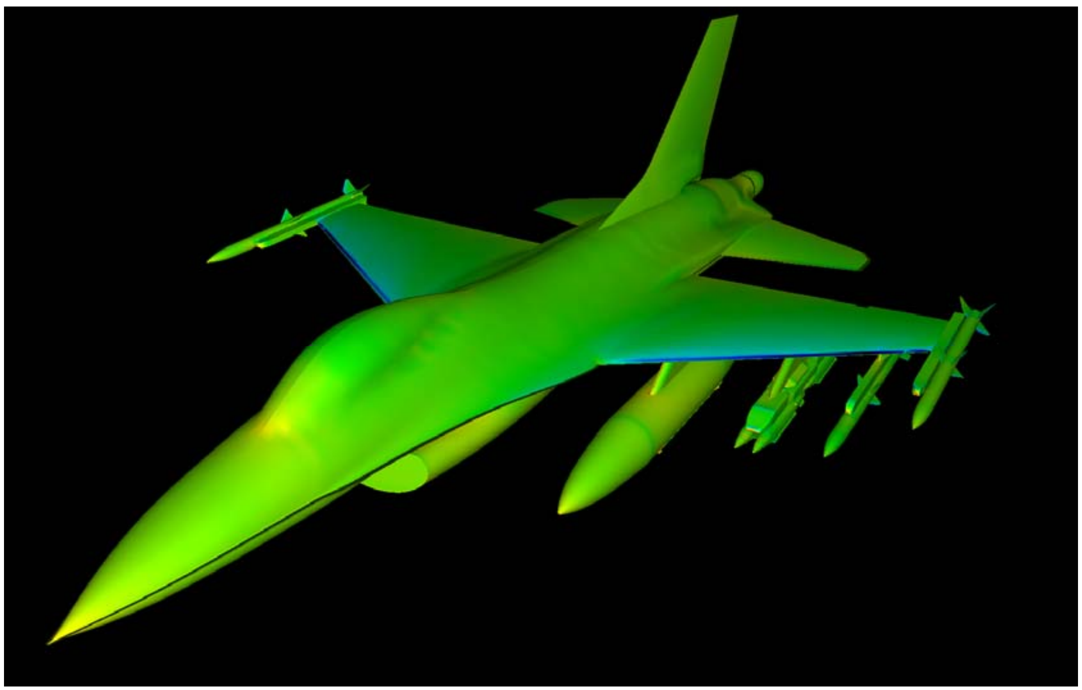


Store Separation Example – F-16 / GBU-39

F-16/BRU-61/SDB integration and certification effort

- **15-35 million cell problem**
- **33 trajectories in total**
- **Led to initial flight clearance for flutter flight testing**





Over 10,000 CFD Solutions required to perform the analysis of the Small Diameter Bomb!

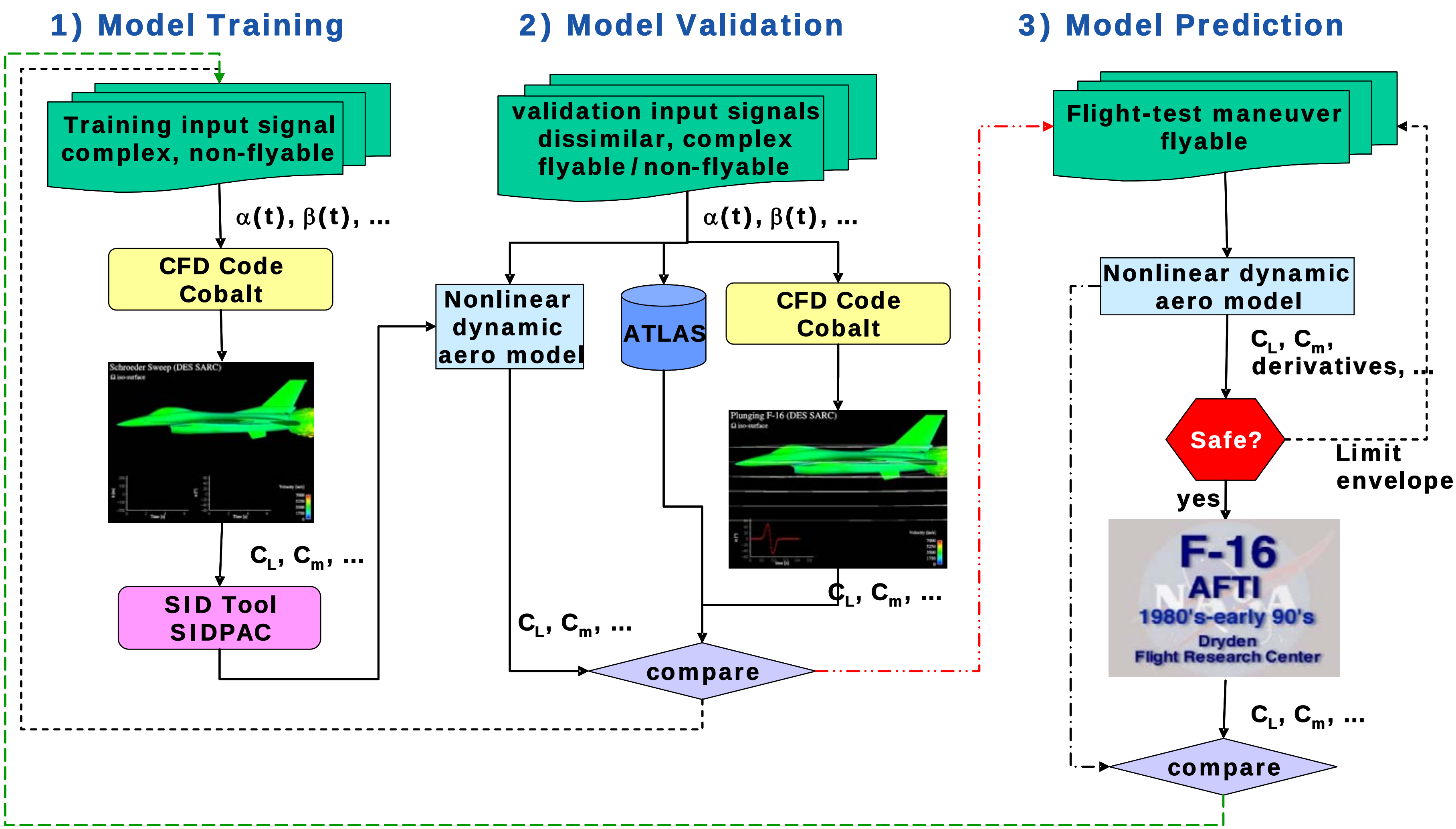
Current Stability & Control Challenges

- **Determine the impact external stores have on aircraft flying qualities**
- **Ensure all configurations meet weight and balance requirements**
- **Three methods to clear a configuration—analogy, wind tunnel test, and flight test**
- **Analogy**
  - Most stores are similar in aerodynamics and mass properties
  - Small changes can also be analyzed this way
- **Wind tunnel testing**
  - Static stability only
  - Expensive and time consuming for good answers
- **Flight testing**
  - Most expensive, but most robust
  - Fully-instrumented, quantitative, monitored test
  - Un-instrumented, qualitative, captive flight profile test → pilot assessment, Cooper-Harper/PIO rating system

Current Stability & Control Challenges

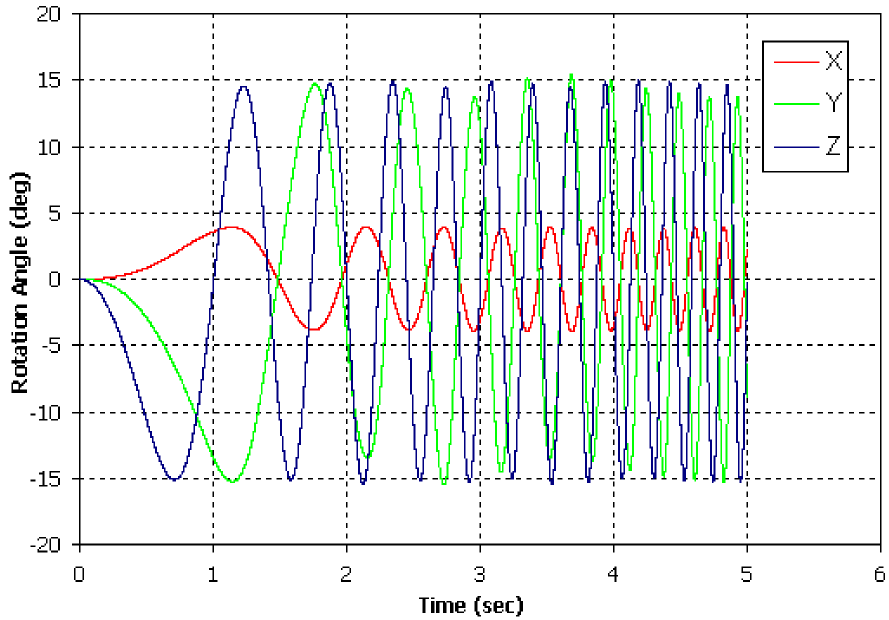
- **No computational S&C capability (static or dynamic)**
- **F-16 and F-22 ATLAS aerodynamic database limitations:**
  - Limited in the number of configurations
  - Only symmetric configurations available
    - Many S&C problems arise when asymmetries present
  - No data for modern stores and suspension equipment
    - TGP (LANTIRN only)
    - Multi-carriage rack systems
    - Guided weapons w/ wing & tail kits, odd shapes, etc.
- **Unable to accurately predict where instabilities occur in the flight envelope and their nature, if they occur at all**
- **Unable to accurately predict departure resistance and boundary layer separation for high AOA testing of new configurations**

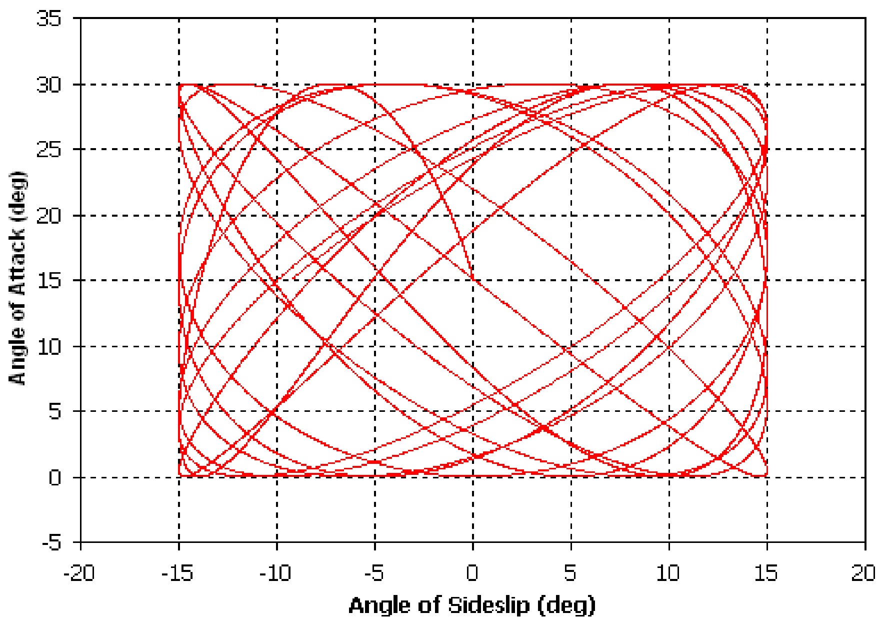
Developing New Approach for S&C



Composite Pitch-Yaw DC Chirp

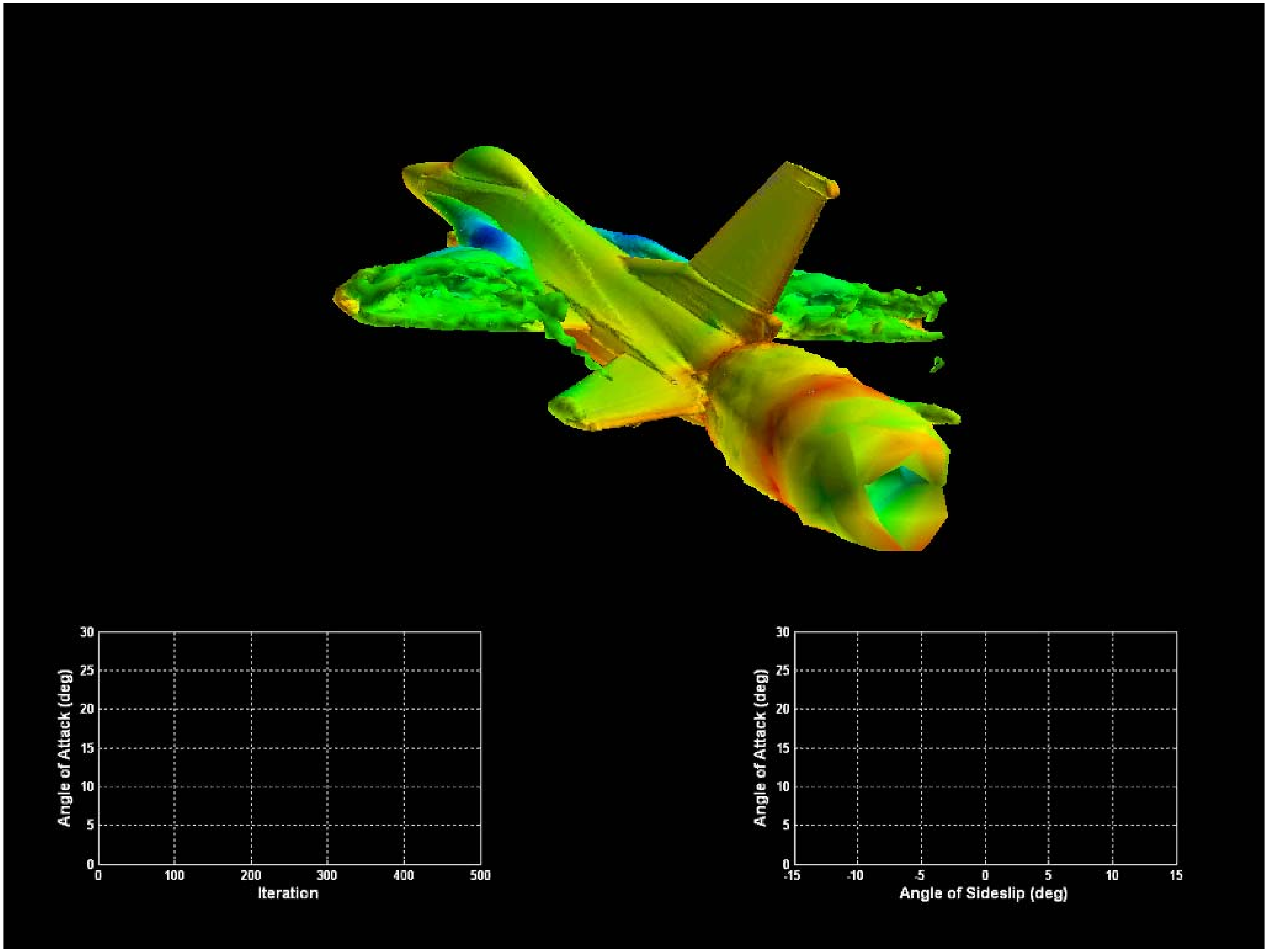
- Composite PitchYaw DC Chirp manuever allows a single motion input to create a model including motion about two axes
  - $\alpha = 15 \pm 15$ deg, $\beta = 0 \pm 15$ deg
- Input signal is made orthogonal by setting λ to 1.0 for pitch and varying λ until dot product of the two signals is zero resulting in λ of 1.47 for yaw signal
- Requires full span F-16C grid





Composite Pitch-Yaw Chirp

Simulation run at M=0.6 and h=5,000 ft with full span grid



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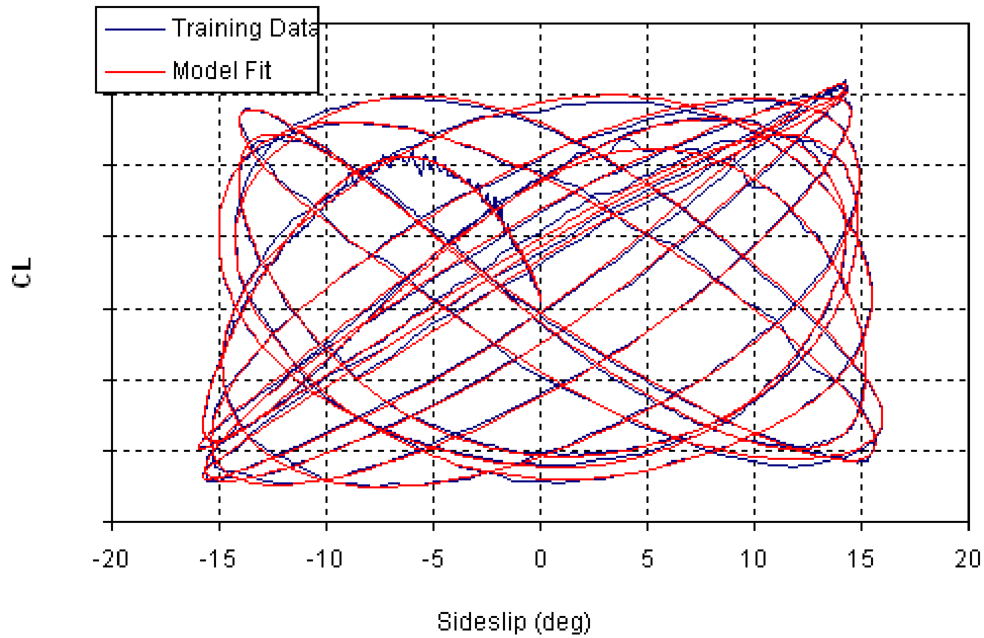
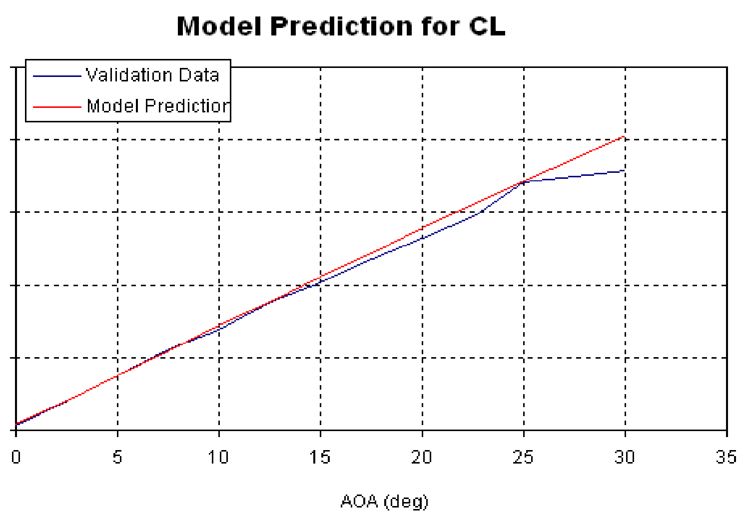
System ID of Pitch-Yaw Chirp

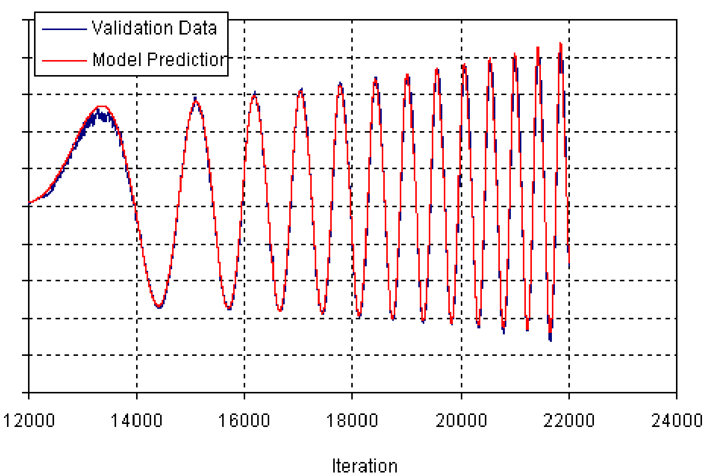
- SIDPAC Model:

$$C_L(\alpha,\beta,p,q,r)=C_1+C_2\alpha+C_3q+C_4p^2+C_5\alpha q^2+C_6\beta pq$$
$$C_7\beta p+C_8\alpha^2q+C_9r+C_{10}\alpha\beta^2+C_{11}\alpha^3+C_{12}pr+$$
$$C_{13}\beta^2p+C_{14}\beta^2q+C_{15}p+C_{16}\beta^2$$

- Validated against static C_L-α data and single axis motion pitch chirp

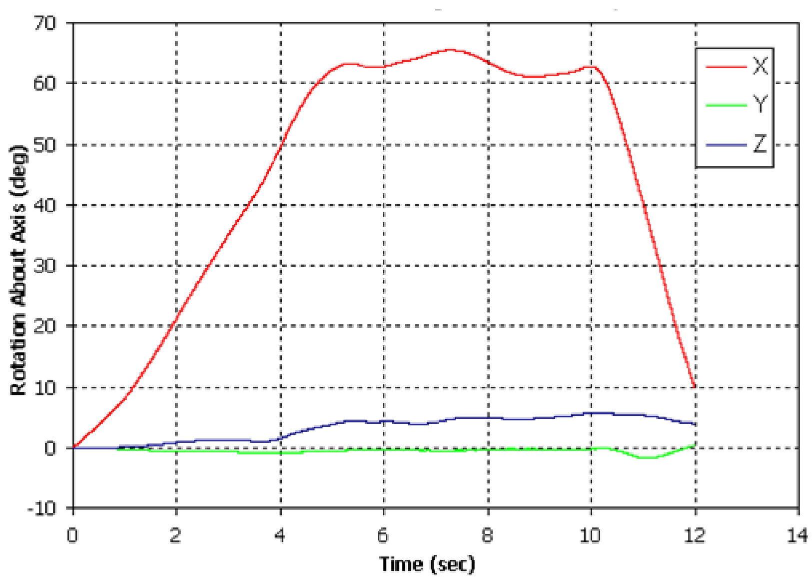


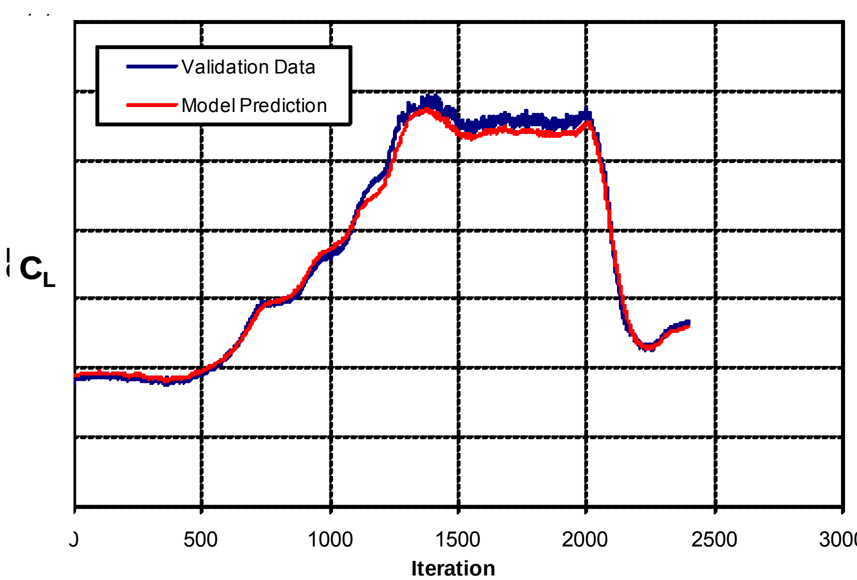




2.5g Wind Up Turn Flight Test Maneuver

- Gathered actual strip chart data from a flight test
- Created the motion file that forces the F-16C through translations and rotations resulting in the Wind Up Turn observed in flight
- Also used the reduced order loads model to perform the maneuver and compared them





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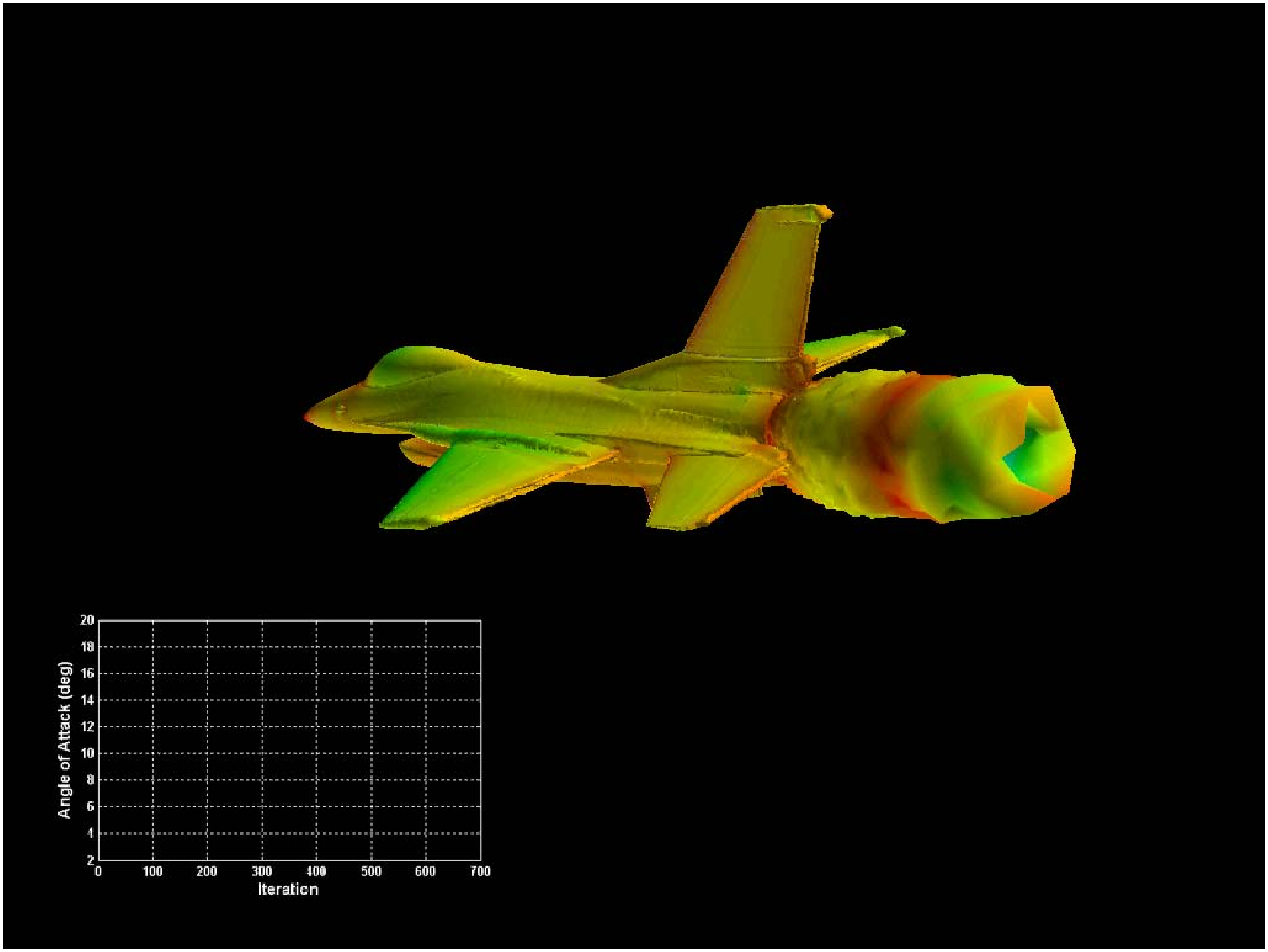
2.5g Wind UpTurn Flight Test Maneuver

Simulation run at M=0.6 and h=5,000 ft with full span grid



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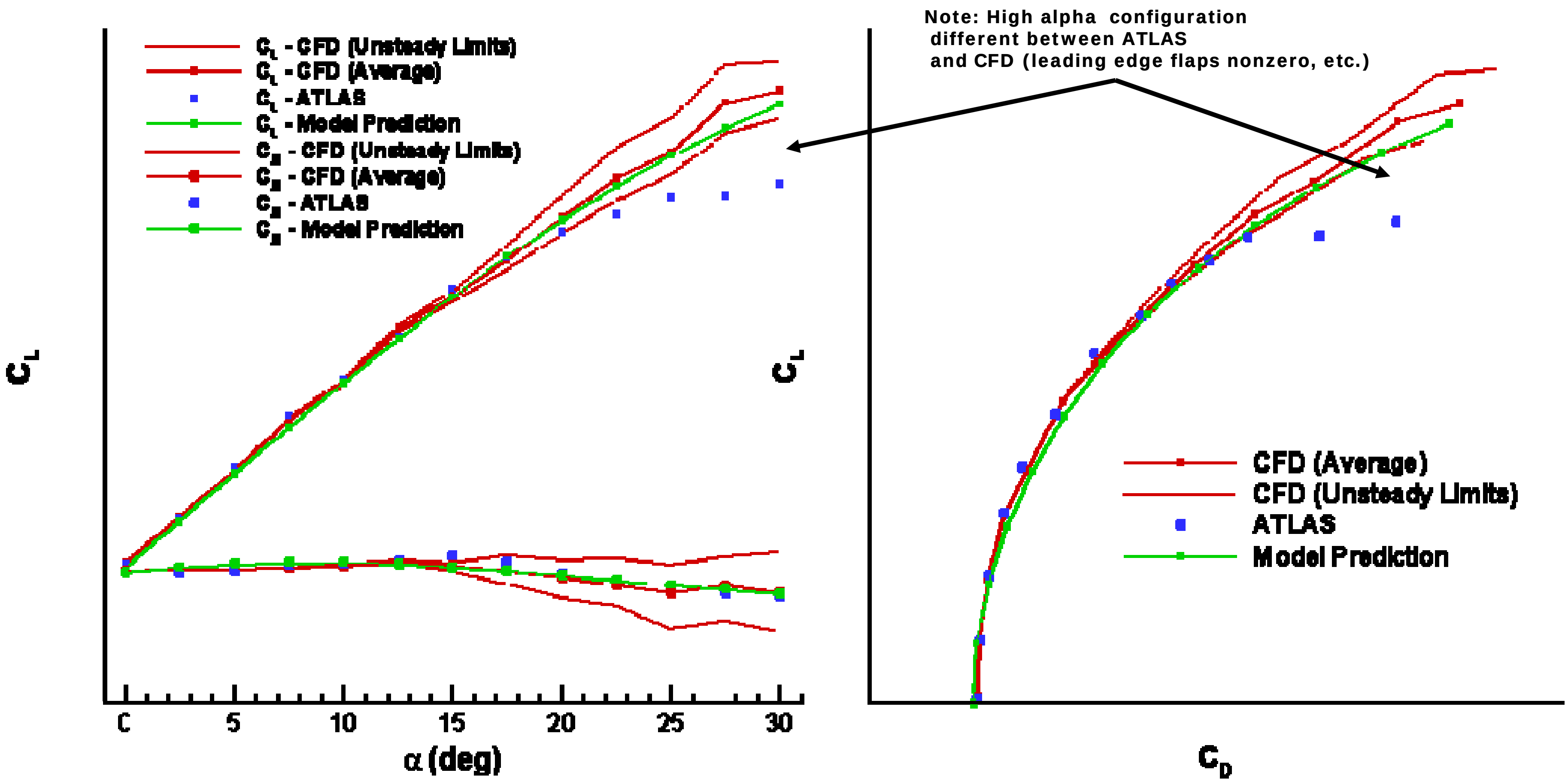
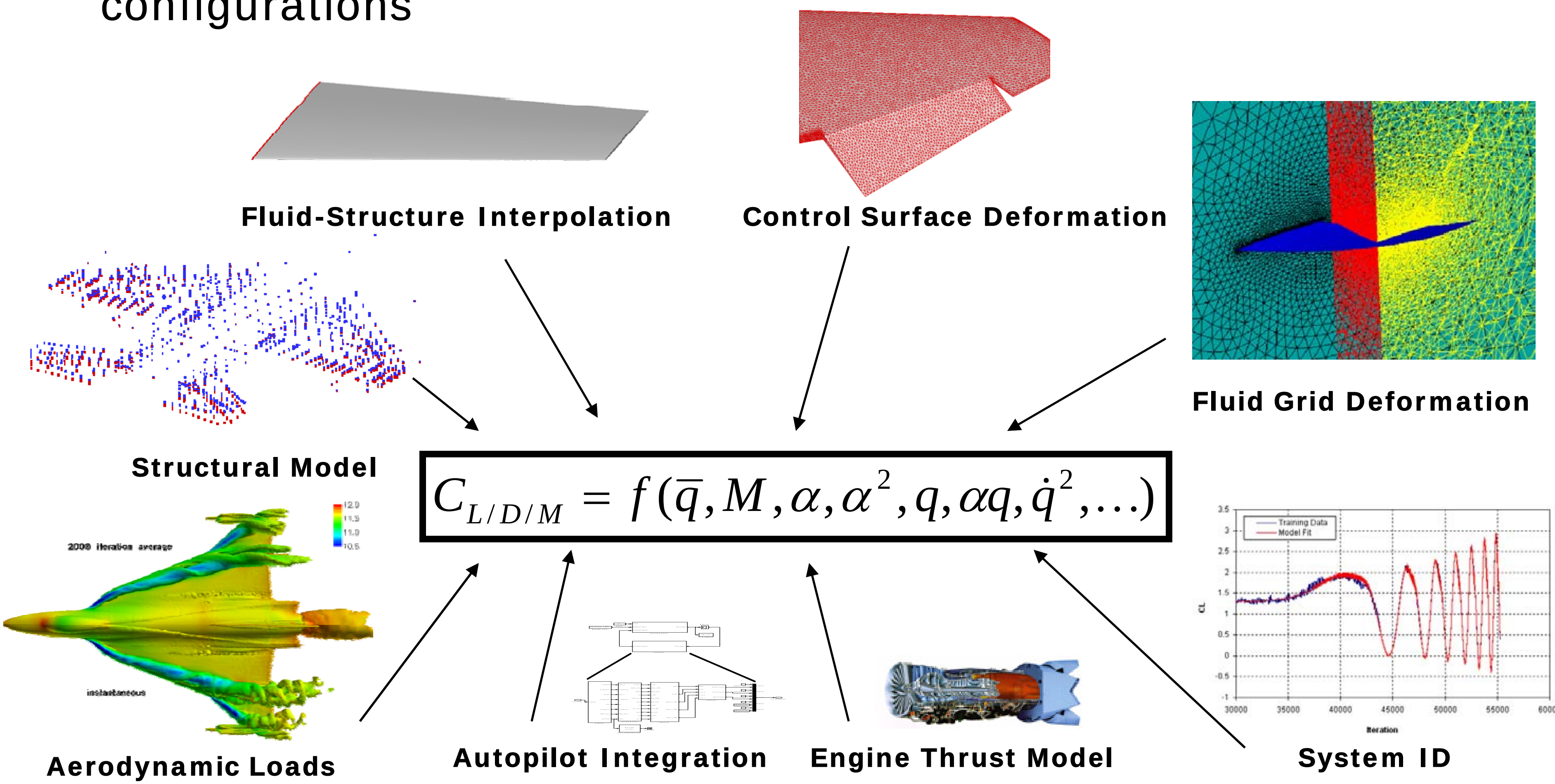
Static Validation vs. CFD / ATLAS

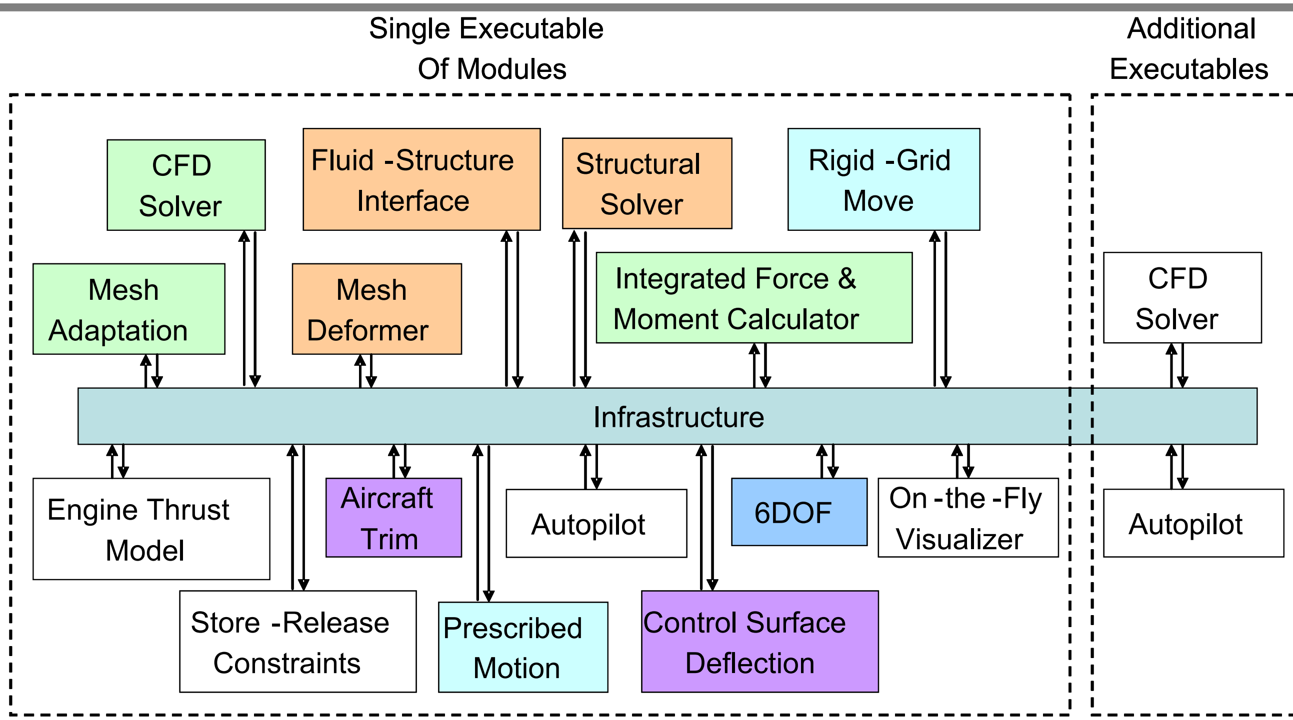


Ultimate Goal

- Integrate all modules into high-fidelity tool capable of accurately modeling full elastic aircraft/armament configurations



DoD HPC CREATE-AV Product



Kestrel Fixed Wing Virtual Aircraft Description

- **Cross-over between aerodynamics, stability and control, structures, propulsion, store separation**
- **Improved performance on parallel architectures with from 10^4 to 10^6 cores (giga-flop to peta-flop)**
- **Fixed wing vehicle in the subsonic, transonic, and supersonic flight conditions**
- **Manuevering aircraft, multiple aircraft tracked, in operations of refueling, carrier landings, etc.**

- **KIE Infrastructure and Executive in Python, KUI Graphical User Interface in wxPython**
- **Components programmed in F90/95/03 and C**
- **All APIs and data structures for components consistent across CREATE-AV products**

Notional Delivery Schedule

KIE Design Complete – End of 2Q FY08
KUI Design Complete – End of 2Q FY08

Spiral One Phase One – End of 2Q FY09

- **Static Rigid Body Aircraft & Captive Store**
  - Single Grid, Multiple Grids Stitched
- **Dynamic Rigid Body Aircraft & Captive Store**
  - Single Grid with Prescribed Motion
- **Flexible Aircraft**
  - Static Position Single Grid Aeroelastic
- **Regression Test Implementation for Spiral 1 Phase 1**

Spiral One Phase Two – End of 4Q FY09

- **Static Rigid Body Aircraft & Captive Store**
  - Single Grid Control Surface Move, Multiple Grids
- **Dynamic Rigid Body Aircraft & Captive Store**
  - Single Grid with 6DOF Motion
- **Static Rigid Body Aircraft & Dynamic Store**
  - Multiple Grids with Prescribed Store Motion
- **Flexible Aircraft**
  - Flexible Aircraft and Captive Store Motion

Notional Delivery Schedule

Spiral One Phase Three – End of 2Q FY10

- **Dynamic Rigid Body Aircraft & Captive Store**
    - Single Grid with Autopilot, 6DOF Store Motion
    - Single Grid with Dynamic Propulsion, Autopilot, 6DOF, and Trim
- **Static Rigid Body Aircraft & Dynamic Store**
    - Multiple Grids with 6DOF Store Motion
    - Multiple Grids with 6DOF Store Control Surfaces

Spiral One Phase Four – End of 2Q FY11

- **Dynamic Rigid Body Aircraft & Captive Store**
    - Multiple Grids with Dynamic Propulsion, Autopilot, 6DOF, and Trim
- **Dynamic Rigid Body Aircraft & Dynamic Store**
    - Multiple Grids Prescribed Aircraft Motion, and 6DOF Stores
    - Multiple Grids, 6DOF Aircraft Motion, and 6DOF Stores
- **Flexible Aircraft**
    - Dynamic Flexible Aircraft and Captive Stores
    - Dynamic Flexible Aircraft and Dynamic Stores

Spiral Two Phases focus on Performance on Peta-flop machines and code development for maintainability – FY10 – FY18

Summary

- **AFSEO has been using HPC for 12 – 15 years in Store Separation Certification**
  - Exponential growth in configurations
  - Case management as important as performance

- **AFSEO changing workflows in Stability and Control, Loads, and Flutter to include HPC in certification decisions**
  - New process for S&C and Loads using reduced order loads model
  - New software needed for Flutter

- **DoD HPCMP CREATE Program**
  - Kestrel Fixed Wing Virtual Aircraft Software Product
  - Full capability being developed in prototype over first 3 years
  - Performance and scalability over the life of the program (12 years +)

Questions?