High-Fidelity Physics-Based Modeling in Support of Test & Evaluation

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Integrity - Service - Excellence
Objectives

• Illustrate the history, diversity and intensity of physics-based modeling in T&E

• Indicate a future vision for increased utility of physics based modeling integrated with T&E in support of weapon system development and sustainment
Brief History of Physics-Based Modeling in T&E

• 50’s and 60’s
  – MOC, Panel Methods, and Boundary Layer Theory
  – Very limited computer capability
• 70’s
  – Non-linear small disturbance equations
  – Early IBM Mainframes
• 80’s
  – Euler, Navier-Stokes, Zonal Decomposition
  – IBM 370, Cray XMP
• 90’s – today
  – Unsteady RANS Navier-Stokes, LES
  – Clusters, Massive Parallel Processing
  – CREATE-AV Scalable Architecture
Representative Advances in Physics-Based Modeling in Support of T&E

Complexity Ratio Relative to Euler F-15E

- **Euler**
  - F-15E: 1.2 x 10^5 pts., 4 weeks
  - B-2: 4 x 10^2 pts., 3 weeks
  - F-22: 1.2 x 10^5 pts., 3 days

- **Viscous**
  - UCAV: 6 x 10^5 pts., 3 days
  - F-16: 5 x 10^5 pts., 5 days
  - WASP: 25 x 10^5 pts., 14 days
  - MALD: 18.5 x 10^5 pts., 2 days
  - JSF: 16 CPU, 18 x 10^6 pts., 3 days
  - Standard Model: 64 CPU, 30 x 10^5 pts., 8 hours
  - Full Annulus Turbine: 600 CPU, 300 x 10^5 pts., 24 hours

**HPC Funded Hardware Buys**

- Complexity = [Number of CPU's] * [Number of Grid Points] * [Number of Solutions/Week]
### Early EMD JSF Applications

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<th><strong>Objective</strong></th>
<th><strong>Approach</strong></th>
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| In support of early JSF developmental T&E integrated HPC with wind tunnel testing to reduce epistemic uncertainties, support design changes to improve performance, and reduce costs. | In close coordination with Lockheed-Martin.  
- Applied high-fidelity steady and unsteady RANS CFD code  
- Performed over 1000 individual computations  
- Leveraged V&V with wind tunnel data to build confidence to cover regimes without data. |

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<th><strong>Outcome</strong></th>
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| Used computations to increase insight and knowledge into:  
- Wind Tunnel Wall Effects, Reynolds Number Scaling  
- Airframe Loads  
- Carriage Loads  
- Store Separation (Internal/External Carriage)  
- Fuel Tank Design, Loads, and Jettison  
- Aircraft lift fan/secondary inlet design. |  
- Eliminated tests for high speed data  
- Improved data quality and reduced risk  
- Computed trajectories beyond tunnel hardware movement constraints  
- Screened test configurations reducing testing costs  
- Supported OEM in improving inlet performance  
- Total savings = $ Millions. |
CREATE-AV
(Computational Research Engineering Acquisition Tools Environment for Air Vehicles)

• A rapidly maturing physics-based flight system modeling architecture enabled by large scale computing
  – Development focused on impact to acquisition by embedded subject matter experts
  – Successfully delivering a family of products supporting activities from early trade studies to detailed engineering design
  – Using pilot studies to demonstrate ability to efficiently provide better physics-based design and analysis capabilities
Cycle Time
Key Effectiveness Parameter

\[
\text{Cycle Time} \sim \frac{\text{Workload}}{q \cdot \text{Capacity}}
\]

- **Workload** – Process driven, currently \(~22,000\) of wind tunnel testing and \(13,000\) of propulsion cell testing
- **q (inverse of rework)** – Process driven, typically have \(10\) structural failures found in flight
- **Capacity** – Budget driven, availability x staffing x throughput

50% reduction in wind tunnel costs equates to just a few tenths of a percent reduction in program costs – Reducing acquisition cycle time by a month could save more than the cost of the entire wind tunnel campaign
CREATE-AV
Inserting HPC Into Key Acquisition and Sustainment Processes

Acquisition Process

CREATE-AV – Technology Enabler to Affect Process

Labs, COCOMS
Labs, Industry, COCOMS
Labs, Industry, DT
Industry, Programs, DT
Industry, Programs, OT
COCOMS SEEK Eagle Tiger Teams
- Labs
- T&E

Quantified Technology Assessment
Ground Test Force Accounting
Airframe Certification
Airworthiness Qualification
Flight Clearance
SEEK EAGLE Certification
Mishap Investigation
Aerodynamic Data Base
Development Process

Aerodynamic Test Effects
- Aerodynamic Test Increment
- NAB Sting Distortion Model
- Dummy Sting
- Undistorted Aft End
- Distorted Aft End

Aerodynamic Loads
- Aero Loads Pressure Model

Increase Quality
- Protruberance & Surface Quality Adjustment to Full Scale (f/A) @ C=0
- Thrust Independent Propulsion Drags: Nag, Bay Vent EEX Spool Bleed (f/A) @ C=0
- Roughness & R/N Adjustment
- Wind Tunnel to Full Scale @ 30,908 ft
- To Operation Altitude (f/A)

Decrease Workload
- Stability & Control
  - Primary Aerodynamics Force & Moment Model
  - Inlet Drag Model
  - Engine Cycle Deck with Derivatives for Recovery, Bleed, & I/OX
  - Inlet Performance

Increase Capacity
- Propulsion Aero-Integration Inlet Model
- Propulsion Aero-Integration NAB Model

Predicted Aircraft Performance
- CG Effects (f/A, Cl, CD)
- Critical Inlet Spill Drag (f/A, Cl, CD)
- Subcritical Inlet Spill Drag (f/A, MFR)
- Inlet End Bleed & E/E Heat Exchanger Drag
- Net Thrust
- Net Propulsive Force (f/A, AR, PL)
- Store Separation CTS & Bay Acoustic Model
- Captive Trajectory Store Effects (Grid & Trajectory)
- Tail and Panel Loads
- Aerodynamic Database (CL, CD, EM, CD, EM)
Reducing Workload/Increasing Capacity
Streamlining Testing at the Campaign Level
New T&E Tools + DOE

Common Thread
System ID
Techniques

"Fly the Mission"
Ground Testing

"Kestrel + System ID"
Response Surface

Computational Science
and Engineering Dynamic Trajectories

Estimation Theory
Quantify Effectiveness of Testing

Value of T&E

DOE
• Data Merge/Data Mine
• Response Surface Analysis
• Variance Reduction Strategy

Increasing Quality
Late Structural Defect Discoveries

- Major Fundamental Causes
  - Inadequate Loads Analysis
  - Aero loads data base
  - Dynamic structural modeling
  - Inadequate Loads Environment
  - Inadequate estimation of non-linear local phenomena (shock, buffet, burst vortex, etc.) – gets worse for high performance aircraft

Aero load data base obtained very early in development program, loft lines not yet frozen – requires faster dynamic structural modeling capability
Reducing Late Defect Discovery
New Technologies Enhance Fluid / Structure Interactions

• Advanced PSP test technologies permit acquiring loads data more frequently during development
• Efficient nodal structural models could be updated more frequently
• Embedded finite element modeling future update to Kestrel
Increasing Quality

Early Airframe / Propulsion Integration

- Improved Inlet Performance
- Focused Testing
- Lowered Risk for Advanced Inlet Concepts

Inlet Design

- CFD Resolution
- Equivalent 40-Probe Rake

Wind Tunnel Validation

- Embedded in Maneuvering A/C

Engine Design

- Firebolt + Kestrel
- Full Annulus Modeling

Engine Testing

- Data Merging / Data Mining
- Distortion Generator
Summary

• High-fidelity physics based modeling has been an integral part of aeronautical T&E for over 25 years

• CREATE-AV is an enabler to accelerate the acquisition process

• Focus needs to be on processes changes, not just the science of high performance computing