Meeting the Challenges of Defense Budget Reductions Through M&S

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Challenges

• Defense acquisition is already broken
• Reduced budgets are a fact of life
  – Fewer acquisition new starts
  – Reduced infrastructure, reduced capacity
• Over the next decade the US could lose technological superiority, economic competitiveness
• Can M&S be an enabler to overcome pending reductions and increase the output of the US aerospace industry?
Five Key Leverage Points Marked by Events – Mired by Lack of Effectiveness

1. Technology Maturity @ Milestone B
2. Design Closure @ CDR
3. Late Defects
4. IOT&E Pause Test Rate
5. Suitability

RDT&E Fraction is revealing metric
RDT&E Fraction of the DoD Budget

Is The Next Wave Starting to Break?

Discrete Jumps At Beginning Of
Periods 2 and 3
Indicative of a Repeated Dynamic,
Not a General Trend
Complexity
A Self Inflicted Wound?

Runaway cycle time not inherent to added complexity
- Architecture choices
- Processes
- Process ownership
- Lack of Accountability

Aerospace industry rampant with late defects and rework
- Design tools and processes
- Lack of feedback to key design and SE processes
- Lack of quantified risk and uncertainty at key decision points

Can M&S integrated with processes change this trend...

...and reduce late defects?
Macro-Dynamics of Acquisition
Moving From Symptoms to Systemic Causes

- Acquisition output impacted by RDT&E Fraction of acquisition costs

\[ \text{Fraction of Systems Actually Delivered} = 1 - \frac{\text{RDT&E Overrun} + \text{Proc Overrun} + \text{Delta Budget}}{\text{RDT&E Budget}} \]

- Discrete jumps in RDT&E Fraction align with “Procurement Holidays” – not a general increase attributable to complexity

- Fundamental dynamic cycle –
  - at onset of each period, procurement decreases but RDT&E stays constant because of backlog
  - At end of each period, procurement increases and so does RDT&E because of new starts added to backlog

- Correlating causative factor –
  - Capability and capacity of system reduced at beginning of each cycle but not rebuilt during the ascending end of the cycle – bathtub effect, more RDT&E coming in but less going out

**Acquisition system has passed a tipping point leading to pathological firefighting**
Impact

Next Gen Fighter?

Average Time to IOC

Time to First Flight

Orange indicates current estimate

Complex Systems + Diminished Skills => Long & Costly Development
Challenge

Offsetting Further Reductions in Capacity

Capacity of Aerospace Industry Relative to Pre 1970

Potential Future Reductions in Capacity

Historical Levels

Effective Capacity Increase To Offset Future Cuts

Effective Capacity Increase To Improve Acquisition Outcome

Challenge

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RDT&E Outlay / Acquisition Outlay
Cycle Time
Key Effectiveness Parameter

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

- **Workload** – Process driven, currently \( \sim 22,000 \) of wind tunnel testing, \( 13,000 \) of propulsion cell testing, \( 6-8,000 \) flight test hours
- **\( q \) (inverse of rework)** – Process driven, typically have 10 structural failures found in flight
- **Capacity** – Budget driven, availability \( \times \) staffing \( \times \) 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
Why Hasn’t M&S Already Fixed the Problems?

• Which M&S – LVC Simulators, Wargames, or Physics Based Models?

• Point of view
  – M&S vs testing
  – M&S leveraged with testing and statistical engineering to reduce cycle time

• M&S not an integral part of systems engineering processes – need to change processes to leverage M&S to reduce cycle time

• Requires government to act as a monopsony to assure continuity of integrated processes over entire life cycle and from program to program
Characteristics of M&S Domains

**Simulator**
- Discrete Event Simulation
- Real Time
- High Resolution Time – Space Visualization
- Event Engineering Models
- Table Look Ups

**Operational Modeling**
- Discrete Event Simulation, Agent Based Modeling
- < Real Time
- Scenario Visualization
- Event Engineering Models
- Table Look Ups

**Physics Modeling**
- Discretized Physics
- > Real Time
- Phenomena Visualization

**Common Interface**
Built on Reducing Physics Models to Light Weight Algebraic Relations

**L-V-C Interface**
CREATE
Emerging Capability for Improving Acquisition

- CREATE is a DoD program to develop and deploy multiphysics-based software for engineering design and analysis of:
  - Air Vehicles (AV)
    - Aerodynamics, structural mechanics, propulsion, control,
  - Ships
    - Shock vulnerability, hydrodynamics, concept design
  - Radio Frequency (RF) Antennas
    - RF Antenna electromagnetics and integration with platforms
  - Mesh and Geometry (MG) Generation
    - Rapid generation of mesh and geometry representations

CREATE tools support all stages of acquisition from rapid early stage design to full life-cycle sustainment
Recent Breakthrough
CREATE-AV

Game Changing Engineering Process Improvement that creates lightweight algebraic models from hi-fi simulations

Scalable to 1000’s of processors

High Performance Computing

System Identification

Conceptual Design
- Early discovery of nonlinear aerodynamic issues
- Nonlinear aero surface loads for conceptual structural design
- Nonlinear aero loads for flight control law development

Detailed Design
- Evaluation of aerodynamics from outer mold line (OML) changes
- Updated nonlinear aerodynamic surface loads for changed OML to evaluate structural design
- Nonlinear loads for flight control law refinement with detailed control surfaces

Flight Test
- Pre-flight maneuvers planned for test with any store loadout
- Eliminate benign flight tests

Modular architecture for multi-discipline, multi-fidelity physics modeling – not a one size fits all CSE model

Interchangeable analog and digital inputs
• Compute a maneuver at a particular flight condition (only need OML)
• Knowing input angles, rates and output loads, allows an algebraic model to fit to the data

\[ C_L(\alpha, q, \dot{q}) = C_0 + C_1\alpha + C_2q + C_3q^2\alpha + C_4\dot{q}\alpha + C_5q^4 + C_6\dot{q}q^2 + C_7q\alpha^2 + C_8\ddot{q} + C_9\alpha^3 + C_{10}\dot{q} + C_{11}\dot{q}^2 + C_{12}q^2 + C_{13}q\dot{q} + C_{14}\dot{q}\alpha \]

• Sys ID model gives dynamic behavior for ANY maneuver inside the regressor space AND static lift curve slope \textit{before a wind tunnel or flight test article exists}
Streamlining Testing at the Campaign Level
New T&E Tools + DOE

Common Thread
System ID Techniques

“Fly the Mission”
Ground Testing

Flight Testing

Computational Science
and Engineering Dynamic Trajectories

Estimation Theory
Quantify Effectiveness of Testing

Using Estimation Theory variance reduction is proportional to the effectiveness of resources used and resources applied

\[ p(t_{in}) = p(t)/(1 + pt) u \Delta t, \]

\[ u = \text{resource effectiveness} \]

\[ u(t) = (p(t)/p(t_{in})) - 1/p(t_{in}) \]

Which can be estimated using the SEMP, TEMP, and KPP values pre- and post-test.

Value of T&E

**DOE**
- Data Merge/Data Mine
- Response Surface Analysis
- Variance Reduction Strategy

Interfaced Operations and Physics Based Models for Enhanced Analysis
Use of Validated Models to Assess Readiness at Milestone B
Cycle Time and Design Uncertainty Reduction

Materal Solution Analysis

Technology Development

Engineering & Manufacturing Development

Production & Deployment

Response Surface 1.0 -> Response Surface 2.0 -> Response Surface 3.0

Dynamic State Model

Integrated System Design With Quantified Uncertainty

Range = V X (1/5FC) X (L/D) X In (We/Wf)

Design of Experiments

Multi-Disciplined Probability Based Design

KPP’s

Reduced Cycle Time

Post-PDR A

Risk Assessment

Post-CDR A

Design Closure

Merged modeling and testing response surfaces minimize total testing, focuses on regions of uncertainty, quantifies residual risks

Response Surface Uncertainty Map

Rig and Component Tests

Optimized Test Points

Common Thread System Identification

Measurement Facilities

System Integration Labs

Hardware-in-The-Loop Facilities

Installed Systems Test Facilities

Open Air Ranges

Cost Tradespace For Uncertainty Reduction

Through More Testing

Using Estimation Theory variance reduction is proportional to effectiveness of resources used and resources applied

\[ \text{Probability Density} = \frac{1}{(2\pi)^{n/2}|\mathbf{A}|} \left| \mathbf{A} \right| \text{exp} \left( -\frac{1}{2} \mathbf{x}^T \mathbf{A}^{-1} \mathbf{x} \right) \]

Which can be estimated using the SERP, TEMP, and KPP values pre- and post-test

Statistical Engineering

Estimation Theory Quantify Effectiveness of Testing
Summary

• The DoD is facing a critical challenge to improve acquisition in an era of reduced budgets
• M&S can be an enabler for offsetting budget reductions and improving acquisition outcome
• Challenges
  – Technologies are attainable, but will require focused efforts to validate and implement
  – Process changes to use new technologies and increased discipline at key decision points very challenging
  – Process and data/model ownership critical to success – will require collaborative government and industry approach
• NDIA Members represent key industry process owners – need to collaborate with government to help lead acquisition process changes