DoD’s Engineered Resilient Systems (ERS) S&T Priority

PoC: Dr. Robert Neches
Director, Advanced Engineering Initiatives
ODASD - SE

Presenter: Dr. Randy Avent
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A Quote from the former Secretary of Defense, Dr. Robert Gates

...our record of predicting where we will use military force since Vietnam is perfect. We have never once gotten it right.

There isn't a single instance ... where we knew and planned for such a conflict six months in advance, or knew that we would be involved as early as six months ahead of time.

So my mantra actually has been for the last several years in the department that, as we train and as we equip, we need to have in mind the greatest possible flexibility and versatility for the broadest range of conflict....
Engineered Resilient Systems
Problem Statement

Uncertain futures & threats outpace our ability to create & field affordable, effective systems

Change happens – we need to design for it.
But, today, instead...

• **Adaptability, trustability and affordability are not sufficiently considered** when making tradeoffs
  • ...and are also not maintained when modifications occur during design, manufacturing, and fielding

• **Effective design is hobbled**: engineers hear too little about warfighters’ / stakeholders’ needs; and too little information about design feasibilities and opportunities gets fed back

• **Cost/schedule slip is highly likely when problems arise, requirements change, or adaption is needed**: Too few alternative designs are considered in depth, nor are they kept active very long

• **Uncertainties compound when planning horizons grow**: long design-test-build-field-adapt lead-times exacerbate uncertain futures problems, overload designs, and lock out new technologies
21st Century Dynamics Require New Design Constraints

Trustability

Adaptability (Modifiability)

Adaptability (Fit)

Capability

Feasibility

Manufacturability

Rapidly Adapting to User Needs

Leveraging the Global Supply Chain

Facing Uncertain Futures
ERS: Tools and Technologies to Facilitate Adaptability & Trustability

ERS Technology Toolbox

1. Trustability: design patterns, analytic tools
2. Platform-Based analysis & architecting
3. Model-Based tools: analysis and simulation
4. Tying design, physical and computational testing
5. Tradespace exploration
6. Instrumented virtual and live environments

ERS Environment

Accelerated Design-to-Build: Capability Engineering

Warfighter / Engineer Information Exchange

Accelerated needs exploration: Conceptual Design

Manufacturing

ERS Technology Toolbox
ERS delivers science, engineering concepts, processes, and design tools to:

- Continuously coordinate design, testing, and production with warfighter review to facilitate earliest possible safe field use of needed capabilities
- Generate an efficient set of design points spanning the design space
- Ensure that tradeoffs among alternative designs are better understood, and that tradeoffs bearing on time, cost, trust and adaptability get appropriate consideration
- Facilitate adaptability via both reconfigurable product families and design diversity
- Consider a wide range of conditions and ConOps during design and testing
- Protect against unintentional or malicious compromise of weapon systems through the supply chain
- Reduce the time needed to reconfigure, substitute or otherwise adapt systems to rapidly changing conditions or operational concepts
- Provide a distributed collaborative engineering environment with seamless two-way transfer of data between tools enabling design, engineering, production/manufacturing, and operational evaluation
Enabling Technologies for Making Informed Decisions about Systems Designed for Trustability and Adaptability – with Timely and Affordable Results

Synthetic Environments for Assessment
(Mission Centric Design Support)

Early Warning Systems for Downstream Issues:
- Tradespaces
- Testing sufficiency
- Computational Test and Validation of Process Plans (e.g., Manufacturability, Supply Chain Risk,...)

Cross-level consistency / interoperability of models (scale, physics)

Efficient, sufficiently veridical Physical & Engineering (product, environmental) Models
(System Centric Design Support)

(Distributed Infrastructure Support)
Configurable Collaborative Engineering Environments and Processes
Human-provided Guidance and Coordination Mechanisms
Emerging Technical Opportunities

1. **Trustability: design patterns and tools**
   *Adapt/extend reliability-inspired methods*
   - Integrating reliability and cost approaches
   - Reasoning about risk and uncertainty
   - New sensitivity localization algorithms

2. **Platform-Based analysis & architecting:**
   *New analysis tools for designing platforms, rapidly adapting systems*
   - Identifying high-impact variables, and likelihoods of emergent interactions
   - Algorithms for measuring adaptability
   - Risk-based cost-benefit analysis tools for platforms and designs, “uncertainty bars”

3. **Model-based tools: analysis & simulation**
   *New products / product line options*
   - On-demand composition of models and simulation/analysis workflows
   - Maintaining consistency across hybrid models (not unintelligible monolithic models)
   - Using semantic features to create and repair mappings between modeling systems

4. **Tying design, physical/computer tests**
   *Linked temporal & physical models*
   - Simulations combining live and virtual elements
   - Acquisition and cross-integration of physics-based vs. statistical models
   - Critical new models: e.g., deformable and moving objects

5. **Tradespace exploration:**
   *Collaborative options exploration*
   - Guiding automated searches
   - Advanced algorithms and massive computing for exploring alternative options
   - Envisionment of multi-dimensional tradespaces

6. **Instrumented live and virtual environments for ConOps Exploration**
   - Game and scenario writing tools
   - Discussion, annotation, collaboration in augmented reality environments
   - Visualization and explanation tools to assist in prioritizing tradeoffs, explaining decisions
Basic Science Issues

- **Scale and Complexity mean that humans cannot do the job unassisted**
  - Algorithms for selective search of intractably large spaces are needed to manage the combinatorial explosion
  - Human-guided search, and social networking techniques will also play a role

- **New challenges for large distributed architectures**
  - Efficient execution and coordination of large processing that is widely distributed and highly stochastic but partly parallel

- **New technology of interchange between discrete event, process and mathematical models will be needed to further manage tractability**
  - Models will need to be learned and refined from instrumenting physical tests and live systems

- **New human interface tools and approaches for decision support**
  - How do we help people understand the extent of coverage of mission possibilities?
  - How do we help people understand impact of requested design features/properties/capabilities and their interactions on affordability, delivery time, cost, and mission range?

- **New mathematical and statistical approaches to testing complexity and model validation**
  - Uncertainty representation and analysis (risk and confidence intervals)
  - Game theoretic approaches to finding design tradeoff win-wins

- **Physics and engineering disciplines**
  - Understanding the actual phenomena we want to capture in multi-scale, multi-physics models
  - Validating multi-scale, multi-physics models
Novel Elements of Approach

- **Focus on re-design:** retrofit/upgrade/adapt faster and cheaper

- **Selectively explore feasible variations, reconfigurations, extensions**

- **Three lines of defense against change and uncertainty:**
  - Mission-oriented design for adaptability, with testing against broad range of missions and environments, prepares for the “known unknowns”
  - Diversity from *longer retention* of *multiple* designs avoids fragility of *monoculture*
    - Increases chances of having options that will address any “unknown unknowns”
    - Forcing the entire process to be open to alternatives, architects the engineering process to facilitate as rapid and agile a response as possible -- even in the worst case
  - Reduced engineering times enable tighter (therefore less uncertain) planning horizons

- **Focus on design and testing *in context, with stakeholders***
  - Model more of the operating environment
  - Explore and evaluate current and future scenarios, jointly with associated CONOPS
  - Design and evaluate for *mission capability* rather than disjoint technical parameters
The Path to Achieving, “Agile and cost effective design, development, testing, manufacturing, and fielding of trusted, assured, easily modified defense systems”

Timely & Affordable
via selective search, design-driven testing

Adaptable & Trustworthy
via longer-lived options, contextual analysis and testing

Informed Decisions
via larger tradespaces (designs, constraints)

Advanced Design & Engineering Capability

Better conceptual design

Better deep design

Better coordination between them
Key ERS Goals, Concepts and Notional Roadmaps

**Informed Decisionmaking**
- Increasing the availability of engineering choices and the ability to assess consequences of those choices

**Trustworthy and Adaptable Design**
- Encouraging design for reliability, testing designs across many contexts (including degraded functioning), keeping options open, and learning from inspecting alternatives

**Affordable and Timely**
- As fast as possible for the problem addressed – minimizing unnecessary effort both reduces time and the cost of standing armies of engineers

**Metrics**
- **Informed Decisionmaking**
  - Distance from “Point Designs”
  - # contexts, effectiveness testing
- **Trustworthy and Adaptable**
  - Metrics: # of contexts tested, # of designs considered, depth into engineering process that options are preserved
- **Affordable and Timely**
  - Metrics: reduced time to conceive-design-build-test-adapt, increased ratio of design-to-development, reduced ratio of rework to design/test
- **Engineering Efficiency**
  - Reduced time to conceive-design-build-test-adapt, increased ratio of design-to-development, reduced ratio of rework to design/test
  - Ten-year time frames, tens of billions of $ regarded as ill-spent

**Cost-justified**
- Systems fielded in 50-75% time taken for today’s high-cost systems

**Choices made, options preserved, based on millions of mission-driven tests on hundreds of alternatives**

**Single design, aimed at individual reqmts -- trust and adaptability quality not considered**

**No designing for trust and adaption, no testing for it, no metrics of quality**

**Systems designed, tested, and rated based on thousands of variations on hundreds of mission cases**

**Informed Decisionmaking**
- Metrics (distance from a single design):
  - # options developed, # of “-ilities” assessed for each option, # of mission use cases tested, # of participants in the process