Engineered Resilient Systems

DoD Science and Technology Priority

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Engineered Resilient Systems (ERS): A DoD Perspective

Resilience: Effective in a wide range of situations, readily adaptable to others through reconfiguration or replacement, with graceful degradation of function

ERS: a DoD Science and Technology Priority

- Established to guide FY13-17 defense investments across DoD Services and Agencies
- Ten year science and technology roadmap being developed
- Five technology enablers identified

"...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.

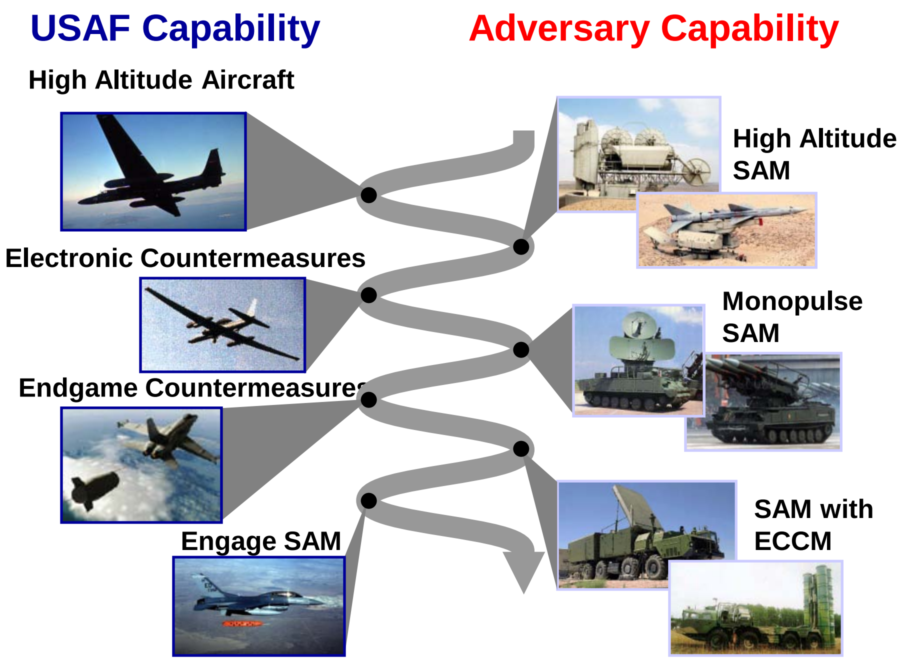
… we need to have in mind the greatest possible flexibility and versatility for the broadest range of conflict..."

The Honorable Dr. Robert M. Gates
22nd Secretary of Defense
24 May 2011

Uncertain futures, and resulting changes to missions, require adaptable and effective systems – quickly and affordably

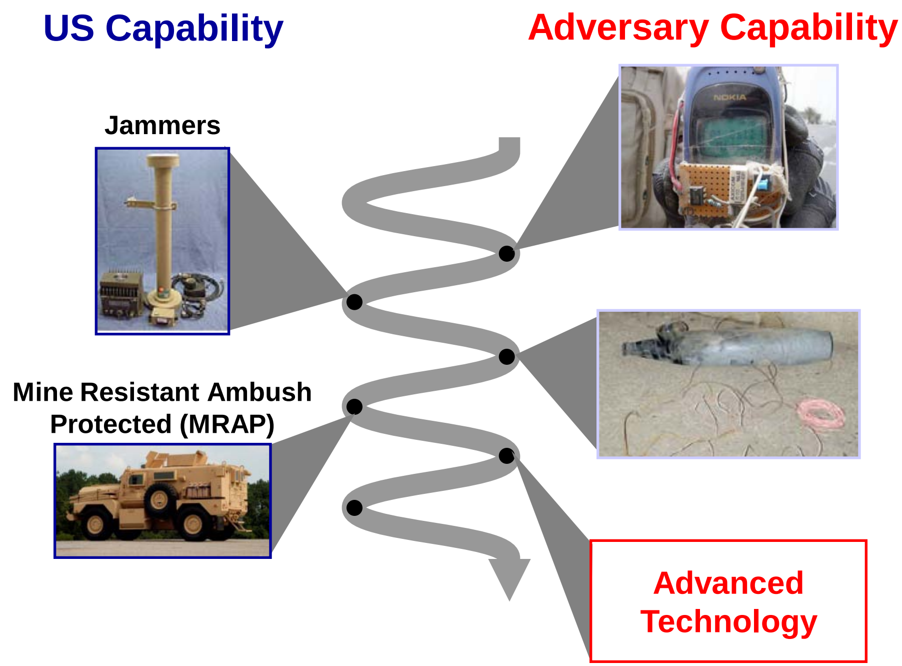
The Timeline has Collapsed

Conventional Warfare



Response loop measured in years

Counter-Insurgency Warfare



Response loop measured in months or weeks

Resilient Systems?
Adaptable Systems?

Apache Revolver / Knife / Brass Knuckles

SPECIFICATIONS	
Country of Origin:	France
Date:	1869
Calibre:	7mm (.275in)
Operation:	Revolver
Weight:	.362kg (.8lb)
Overall Length:	105mm (4.3in) folded; 200mm (7.8in) unfolded
Barrel Length:	N/A
Muzzle Velocity:	N/A
Feed/Magazine:	Detachable cylinder
Range:	3m (10ft)

Swiss Army Knife

Specifications
- 85 tools
- 8.75” x 2.75”
- 2 lbs, 11 oz
- $1,300
- Lifetime warranty

Train Transportation

A system that complies with thousands of specifications is not necessarily resilient

We need to be able to manage and design to frequent changes in requirements

The Problem Goes Beyond Process

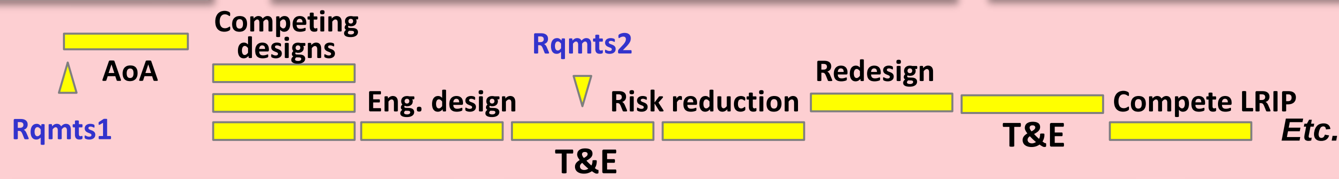
Need New Technologies, Broader Community

Today

Rapidly necks down alternatives

Decisions made w/o info

50 years of process reforms haven't controlled time, cost and performance



Sequential and slow

Information lost at every step

Ad hoc reqmts refinement

The Future

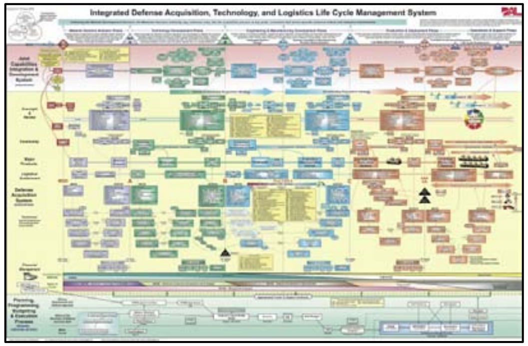
Fast, easy, inexpensive up-front engineering:

- Automatically consider many variations
- Propagate changes, maintain constraints
- Introduce and evaluate many usage scenarios
- Explore technical & operational tradeoffs
- Iteratively refine requirements
- Adapt, and build in adaptivity
- Learn and update

New tools to help Engineers & Users understand interactions, identify implications, manage consequences

Systems Engineering and Development of Resilient Systems

- **Product-line approaches to address a dynamic environment are available today**
  - Not without challenges…
- **What is the role of systems engineering?**
  - Process oversight, hierarchical decomposition of requirements, consideration of all design constraints?
  - Enabling a team to design and build a system that is responsive to current needs?

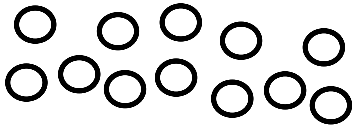


- **Can tools and technologies make systems engineering more relevant?**

vs.

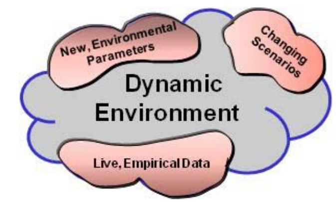
Engineered Resilient Systems Key Technical Thrusts

Systems Representation and Modeling



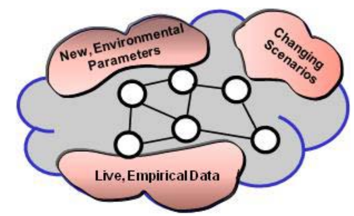
- Capturing physical and logical structures, behavior, interaction with the environment, interoperability with other systems

Characterizing Changing Operational Contexts



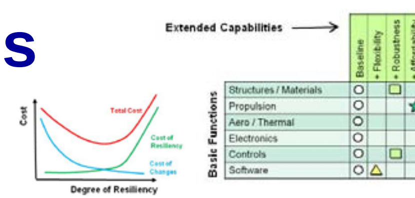
- Deeper understanding of warfighter needs, directly gathering operational data, better understanding operational impacts of alternative designs

Cross-Domain Coupling



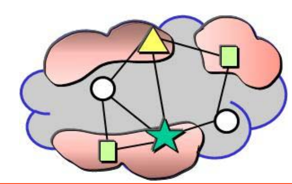
- Better interchange between "incommensurate" models
- Resolving temporal, multi-scale, multi-physics issues across engineering disciplines

Data-driven Tradespace Exploration and Analysis



- Efficiently generating and evaluating alternative designs, evaluating options in multi-dimensional tradespaces

Collaborative Design and Decision Support



- Enabling well-informed, low-overhead discussion, analysis, and assessment among engineers and decision-makers

Tradespace Analysis: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Efficiently generating and evaluating alternative designs ***Evaluating options in multi-dimensional tradespaces***	**Trade analyses over *very large* condition sets**	• Guided automated searches, selective search algorithms • Ubiquitous computing for generating/evaluating options • Identifying high-impact variables and likely interactions • New sensitivity localization algorithms • Algorithms for measuring adaptability • Risk-based cost-benefit analysis tools, presentations • Integrating reliability and cost into acquisition decisions • Cost-and time-sensitive uncertainty management via experimental design and activity planning

Exploring more options and keeping them open longer, by managing complexity and leveraging greater computational testing capabilities

System Representation and Modeling: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Capturing • ***Physical and logical structures*** • ***Behavior*** • ***Interaction with the environment and other systems***	**Model 95% of a complex weapons system**	• Combining live and virtual worlds • Bi-directional linking of physics-based & statistical models • Key multidisciplinary, multiscale models • Automated and semi-automated acquisition techniques • Techniques for adaptable models

We need to create and manage many classes (*executable, depictional, statistical...*) and many types (*device and environmental physics, comms, sensors, effectors, software, systems ...*) of models

Cross-Domain Coupling: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps

Better interchange between incommensurate models
 	
Resolving temporal, multi-scale, multi-physics issues
	Weapons system modeled fully across domains	• Dynamic modeling/analysis workflow
		• Consistency across hybrid models
		• Automatically generated surrogates
		• Semantic mappings and repairs
		• Program interface extensions that:
		  • Automate parameterization and boundary conditions
		  • Coordinate cross-phenomena simulations
		  • Tie to decision support
		  • Couple to virtual worlds

Making the wide range of model classes and types work together effectively requires new computing techniques (not just standards)

Characterizing Changing Operational Environments: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Deeper understanding of warfighter needs ***Directly gathering operational data*** ***Understanding operational impacts of alternatives***	**Military Effectiveness Breadth Assessment Capability**	• Learning from live and virtual operational systems • Synthetic environments for experimentation and learning • Creating operational context models (missions, environments, threats, tactics, and ConOps) • Generating meaningful tests and use cases from operational data • Synthesis & application of models

"Ensuring adaptability and effectiveness requires evaluating and storing results *from many, many scenarios* (including those presently considered unlikely) *for consideration earlier* in the acquisition process."

Collaborative Design & Decision Support: Technical Gaps and Challenges

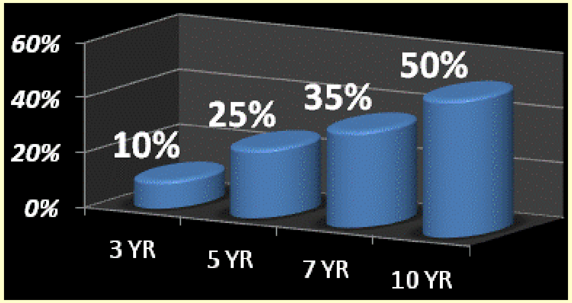
Technology	10-Yr Goal	Gaps
Well-informed, low-overhead collaborative decision making	**Computational / physical models bridged by 3D printing** ***Data-driven* trade decisions executed and recorded**	• Usable multi-dimensional tradespaces • Rationale capture • Aids for prioritizing tradeoffs, explaining decisions • Accessible systems engineering, acquisition, physics and behavioral models • Access controls • Information push-pull without flooding

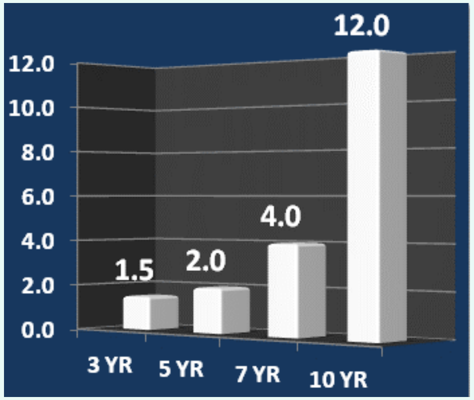
ERS requires the transparency for many stakeholders to be able to understand and contribute, with low overhead for participating

What Constitutes Success?

Adaptable (and thus robust) designs

– Diverse system models, easily accessed and modified
– Potential for modular design, re-use, replacement, interoperability
– Continuous analysis of performance, vulnerabilities, trust, cost
– ***Target: 50% of system is modifiable to new mission***



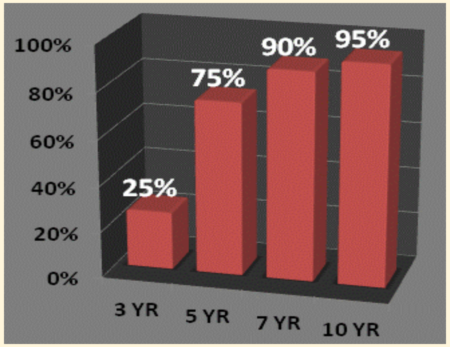


Faster, more efficient engineering iterations

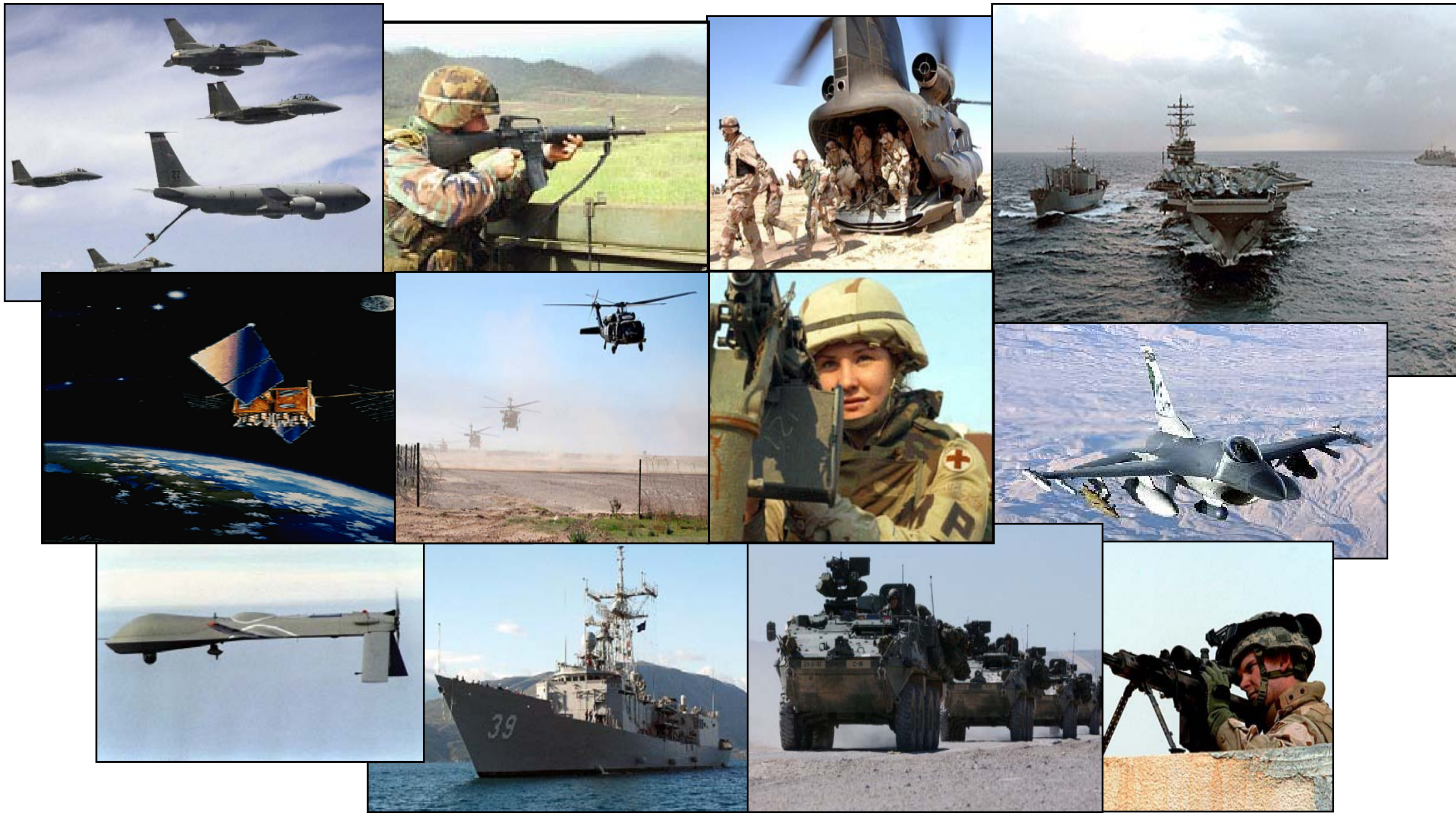
– Virtual design – integrating 3D geometry, electronics, software
– Find problems early
– Shorter risk reduction phases with prototypes
– Fewer, easier redesigns
– Accelerated design/test/build cycles
– ***Target: 12x speed-up in development time***

Decisions informed by mission needs

– More options considered deeply, broader trade space analysis
– Interaction and iterative design among collaborative groups
– Ability to simulate & experiment in synthetic operational environments
– ***Target: 95% of system informed by trades across ConOps/env.***



Engineering: Critical to Capability Delivery



Innovation, Speed, and Agility

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