Engineered Resilient Systems (ERS):
Insights and Achievements within the ERS Secretary of Defense Science and Technology (S&T) Priority

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Office of the Deputy Assistant Secretary of Defense
for Systems Engineering

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Coming Attractions

Jeff Holland Speaks Next on ERS' Current State and Future Directions

Key Concepts of ERS

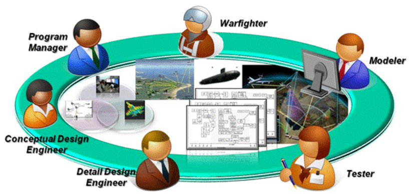
Consistent system and contextual info represented in many form

Mission effectiveness proven wrt operational context

Large scale managed collaborative environmen

Exploration and analysis of appropriately sized tradesp

Coupling of know across engineerin disciplines, acqui activities and representations



Major ERS Technical Areas

- Integrating Architecture
- Data/Knowledge Management and Training
- Virtual Collaborative Environment
- Interoperable Models, Simulations, and Data
- Usable Mission Context
- Risk/Opportunity, Reliability, and Trustworthiness
- Decision Support Technologies

Validation, Verification, and Demonstration for components, systems

Capabilities Delivered by the ERS

Acquisition Challenges (Gov't as Smart Buyer)
- Increase the speed and agility of system development
- Improve the effectiveness and quality of fielded systems
- Minimize the lifecycle costs, including the cost of redesign

Secretary of Defense, Dr. Robert Gates:
"… we need to have in mind the greatest possible flexibility and versatility for the broadest range of conflict …"

VISION: Transform the acquisition process through risk mitigation, opportunity identification, productivity enhancement, and knowledge management

FAR TERM (FY 18+)
- Explicitly consider evolving TTPs in design
- Living, adaptive repository of 100,000's of alternative designs, operational/mission contexts, value
- Semantic search and large-scale data mining
- Direct assessment of the producibility (manufacturability) of proposed alternatives
- Incorporate lifecycle costs of design alternatives
- Fully incorporate training modules into collaborative tools

MID TERM (FY 16 - 18)
- Extend ERS to ground vehicles, weapons and software systems
- Embed ERS developers on Ships, Air Vehicle, and Sensor Acquisition Teams
- Integrate models, simulations, experimental data design tools
- Quantify uncertainty of experimental outputs
- Field capability to evaluate and buy-down risk through acquisition process

NEAR-TERM (FY 13 - 15)
- Capture and model essential components of the DoD acquisition and operational analysis processes
- Integrate models, simulations, collaborative tools, tradespace analysis, engineering design processes into single architecture
- Incorporate lessons learned and create communities of interest through DoD social media exploitation
- Demonstrate ERS for Ships, Air Vehicles, and Sensors
- Provide technical basis for improvements to DoD policy

Leap Ahead S&T: Integrate Producibility and Lifecycle concepts formally across the acquisition process

Revolutionary Capabilities
- 75% time savings via reduction of rework
- 100-fold increase in number of operational scenarios considered prior to Milestone A
- Quantification of risk for proposed systems

ERS Timeline

	FY 13	FY22		FY16	
Architecture	♦	♦	♦		♦
Knowledge Management	♦		♦		♦
VCE	♦	♦	♦		♦
Interoperable M&S / Data	♦	♦	♦	♦	♦
Mission Context			♦		♦
Risk, Reliability and Trust			♦		♦
Decision Support			♦	♦	♦
Versions	V1		V2		V3

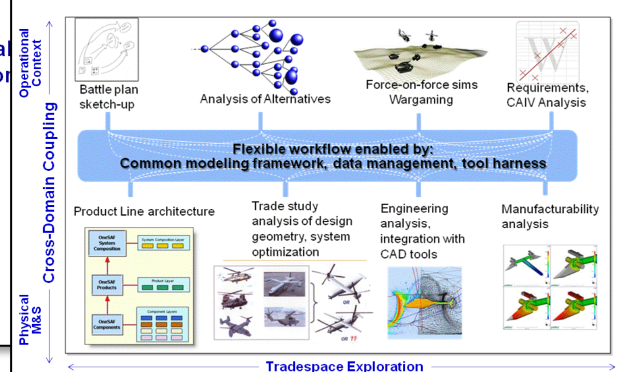
Versions:
- V1: Demo ERS Concept; Integrate VCE & HPC; Exploit Social Media; Capture Acquisition Process
- V2: Extend Demo Projects; Automate Requirements; Initial DS Tools; Prototype Risk Tools
- V3: Manufact…; Tradespa…; Uncertain…; Quantific…

Demos & Transitions:
- V1: Demo with Ships, AV, & Sensors
- V2: Demos to GV, Weapons, & Software Systems; Embed Demo Projects with Acquisition Teams

Major Goals of ERS by 2022

- 75% time savings via reduction of rework, with resultant reductions in overall RDT&E costs
- 100-fold increase in number of parameters and operational scenarios considered in setting system requirements prior to Milestone A
- Quantification of risk of failure to meet changing mission requirements, in operationally relevant contexts, for systems under development
- Integration of Producibility, Lifecycle and cost estimating concepts continuously across the acquisition process
- Transformation of the acquisition process through risk mitigation, opportunity identification, productivity enhancement, and knowledge management

Architectural Concepts



This Presentation

The Prequel: How we got here....

- **A brief description of ERS' process and products**
- **How that process has refined DoD's thinking**
- **Key points from an OSD perspective**
- **Ongoing need to foster a ERS community of interest**

Engineered Resilient Systems: Why

The country – literally – can't afford not to

- **Uncertain futures: engagements and mission needs change quickly and unexpectedly**
  - Ties back to supporting Key Mission Areas in Quadrennial Defense Review
- **Pace and availability of technology**
  - Nation/state and transnational opponents can leverage the latest to constantly morph asymmetric threats – we must keep up
- **Cost**
  - Our opponents ~~can~~ ***will*** get us to bankrupt ourselves if we don't spend wisely

Secretary of Defense Guidance on Science & Technology (S&T) Priorities FY13-17

SECRETARY OF DEFENSE
1000 DEFENSE PENTAGON
WASHINGTON, DC 20301-1000

APR 19 2011

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY AND LOGISTICS
ASSISTANT SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING
DIRECTORS OF THE DEFENSE AGENCIES

SUBJECT: Science and Technology (S&T) Priorities for Fiscal Years 2013-17 Planning

The Department's S&T leadership, led by the Assistant Secretary of Defense for Research and Engineering, in close coordination with leadership from the Under Secretary of Defense for Policy, the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense, the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy, and the Joint Staff, has identified seven strategic investment priorities. These S&T priorities derive from a comprehensive analysis of recommendations resulting from the Quadrennial Defense Review mission architecture studies directed in the FY12-16 Defense Planning Programming Guidance.

The priority S&T investment areas in the FY13-17 Program Objective Memorandum are:

(1) **Data to Decisions** – science and applications to reduce the cycle time and manpower requirements for analysis and use of large data sets.
(2) **Engineered Resilient Systems** – engineering concepts, science, and design tools to protect against malicious compromise of weapon systems and to develop agile manufacturing for trusted and assured defense systems.
(3) **Cyber Science and Technology** – science and technology for efficient, effective cyber capabilities across the spectrum of joint operations.
(4) **Electronic Warfare / Electronic Protection** – new concepts and technology to protect systems and extend capabilities across the electro-magnetic spectrum.
(5) **Counter Weapons of Mass Destruction (WMD)** – advances in DoD's ability to locate, secure, monitor, tag, track, interdict, eliminate and attribute WMD weapons and materials.
(6) **Autonomy** – science and technology to achieve autonomous systems that reliably and safely accomplish complex tasks, in all environments.
(7) **Human Systems** – science and technology to enhance human-machine interfaces to

The Assistant Secretary of Defense for Research and Engineering, with the Department's S&T Executive Committee and other stakeholders, will oversee the development of implementation roadmaps for each priority area. These roadmaps will coordinate Component investments in the priority areas to accelerate the development and delivery of capabilities consistent with these priorities.

Priority S&T Investment Areas:

1. Data to Decisions
2. Engineered Resilient Systems
3. Cyber Science and Technology
4. Electronic Warfare / Electronic Protection
5. Counter Weapons of Mass Destruction
6. Autonomy
7. Human Systems

Engineered Resilient Systems: A DoD-wide Activity

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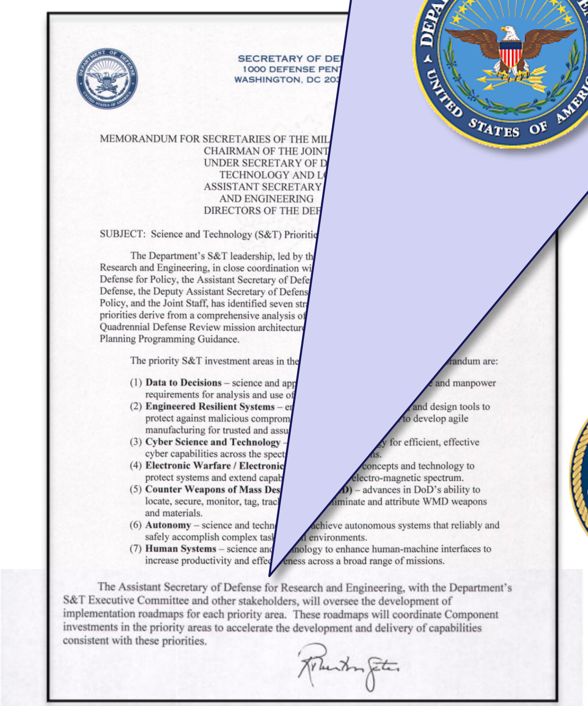
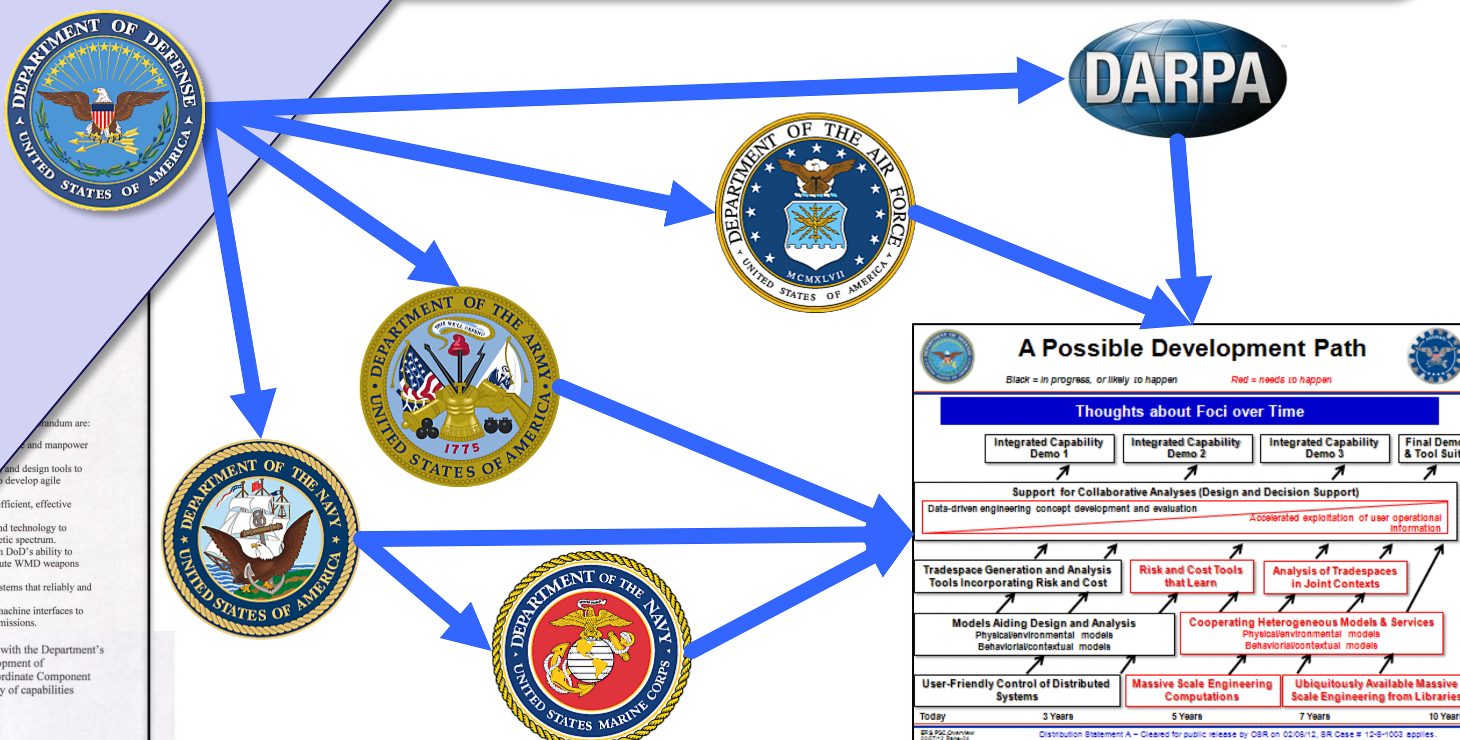




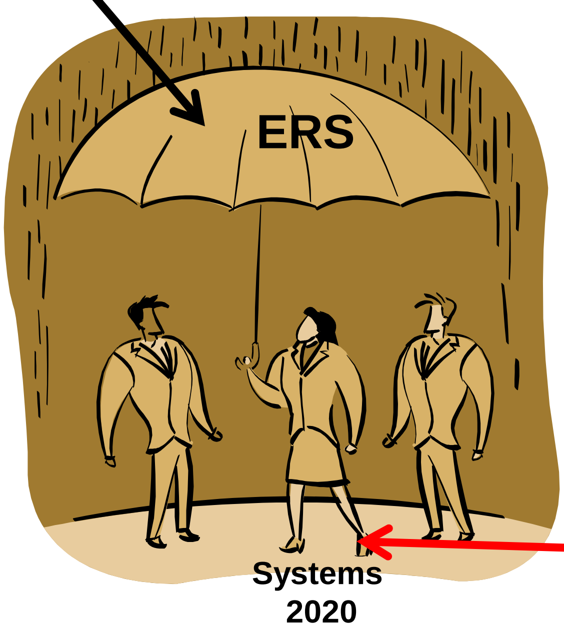
Working Toward A DoD-Wide Roadmap

Engineered Resilient Systems vs. Systems 2020

Engineered Resilient Systems

An Early View of ERS

- A science and technology *priority*
- Spans over 50 OSD, DARPA, Air Force, Army, and Naval programs
- Ten year plan
- Budget is all – and only – the sum of the program budgets
- Coordination makes it more than the sum of its parts



Systems 2020

- A specific *program*
- One of a number participating in ERS
- Five year span: GFY12-GFY16
- Has its own budget
- Executed by service labs and contractors

Engineered Resilient Systems (ERS)

An Early View of ERS

GOALS

- To transform the engineering design and development of defense systems by providing the technical methods, processes, technologies and tools to
  - Reinvigorate engineering science and technology to enable timely, affordable delivery of complex and adaptive systems
  - Develop advanced engineering tools for efficient, integrated design and development across the full range of product life cycles (from rapid fielding to traditional acquisitions)
  - Advance collaborative design and engineering capabilities for today's environment where technologists and engineers span a diverse set of technical specialties often geographically distributed
  - Increase the efficiency and effectiveness of system design, test and transition to production of trustworthy systems

TECHNICAL PROGRAM

- **Technologies and tools for engineering, design and development of cyber physical systems in key areas**
  - **Systems Analysis Techniques** to address a wide range of system architecture and design drivers
  - **Concept Engineering** techniques and environments to allow for rapid conception, visualization and assessment of new material approaches designed and analyzed in a realistic operational context
  - **Architecture and Design Analysis Techniques and Tools** to allow for automated assessment of a wide range of architecture alternatives and platforms, for optimal design across multiple missions
  - **Integrated Modeling Environments** which enable integrated, virtual analysis to leverage technology to reduce cost/increase productivity
  - **Security Engineering** including scientific and engineering principles, methods and tools to identify vulnerabilities and minimize risks in hardware, software and firmware, incorporating and evaluating security as part of the system design

IMPACT

- Transforming engineering practices to efficiently create, field and evolve trusted defense systems which can readily adapt to the inevitable changes in threat, technology, and mission environments
- Advancing productivity of US industrial base to develop and adapt defense systems within the rapid time cycle of technology and mission changes
- Improving DoD responsiveness to user needs by developing and deploying new concepts, tools ,and techniques for defense systems
- Developing trusted systems from untrusted components

METRICS

1. **Improved engineering and design**
   - **Development Agility:** Quality, timely development with an incomplete and changing set of system requirements
   - **Design Integration:** Concurrent assessment across design dimensions and trades, reducing time and surprise
   - **Productivity:** Design iteration and resolution within shorter design time
2. **Improved systems**
   - **Adaptive:** The ability to expand and enhance capabilities for future growth without having to make major changes in the infrastructure
   - **Effective**: Address the needs of the warfighters reliably and robustly
   - **Trusted**: Designed with resilience against current and emerging threats

Engineered Resilient Systems: What

Reshaping engineering from design through production to face 21st Century Challenges

- **Ensure that we're building the right things**
- **Minimize time and cost from design to delivery**
- **Embrace shifting requirements and manage them**

An Early View of ERS

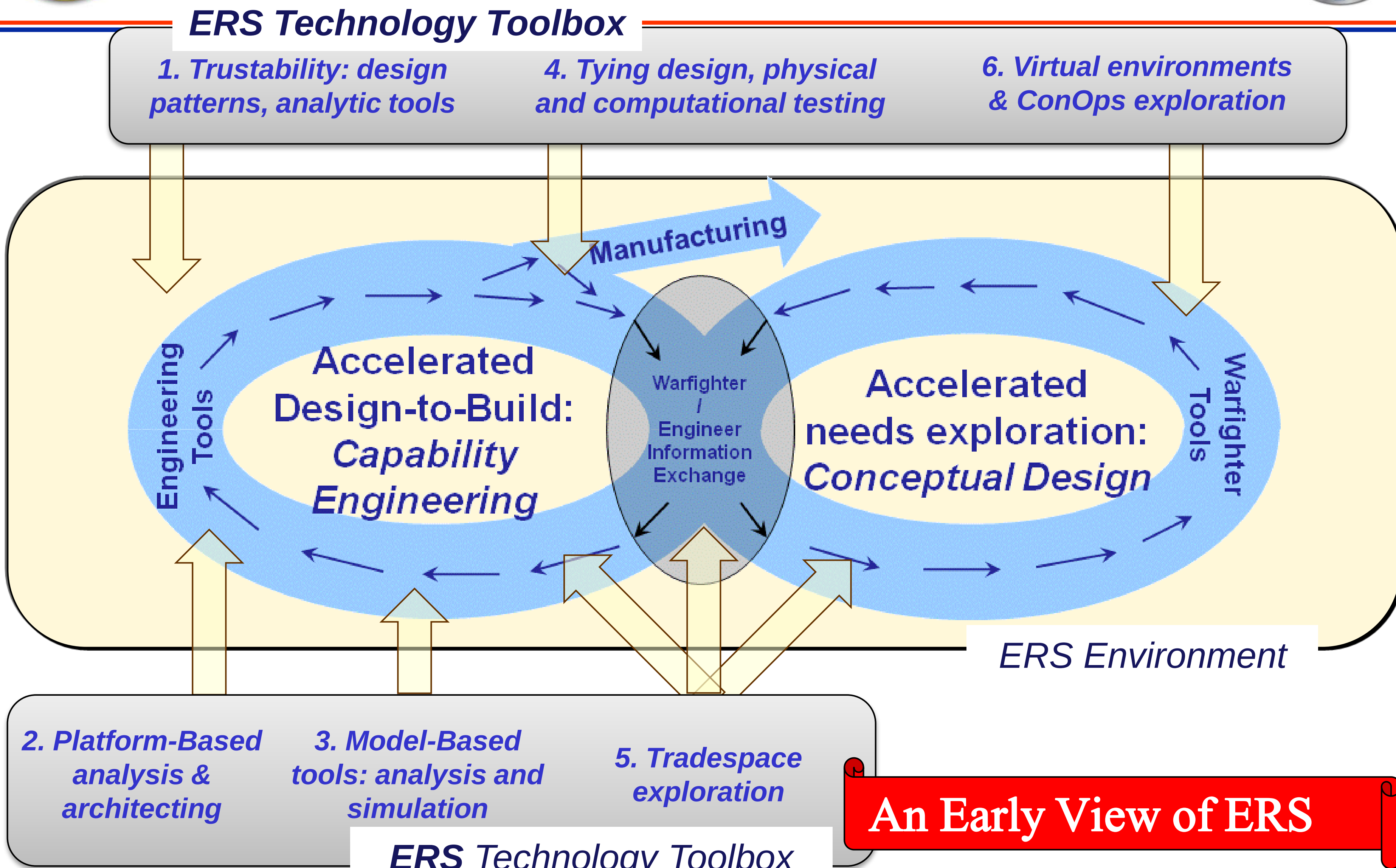
Engineered Resilient Systems: How

Breaking away from lockstep processes to enable creative systems and ConOps solutions

- **Do analysis of alternatives, requirements definition, and initial prototyping as collaborative, concurrent, iterative processes**
  - Reduced time, with more opportunities to learn from efforts
- **Enable larger tradespaces, keep alternative design options open longer, design and test for flexibility**
  - Increased computing power & ubiquity allows trying more ideas
- **Do the right tests -- at the right time -- to reduce risk**
  - Ruling out infeasible approaches early frees up time and money

An Early View of ERS

ERS: Tools and Technologies to Facilitate Adaptability & Trustability



Resilient Systems, Defined

A resilient system is trusted and effective out of the box in a wide range of contexts, easily adapted to many others through reconfiguration or replacement, with graceful and detectable degradation of function.

Research in Engineered Resilient Systems focuses on agile and cost-effective design, development, testing, manufacturing, and fielding of trusted, assured, easily- modified systems

Transforming Engineering of Complex Systems

Engineering for resilience: *robust* systems with *broad utility*

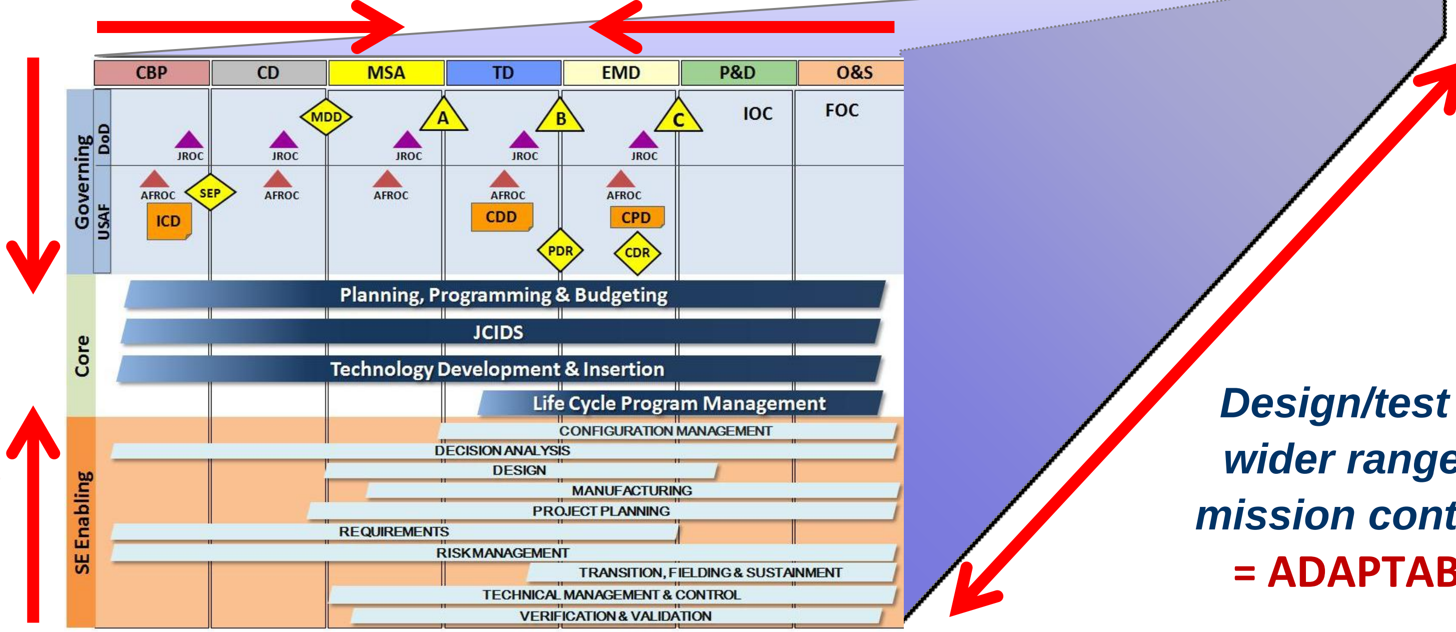
- *In a wide range of joint operations*
- *Across many potential alternative futures*

Faster engineering, less rework

= AFFORDABLE

Better informed decision-making

= EFFECTIVE



Design/test for wider range of mission contexts

= ADAPTABLE

Adaptable? Affordable? Effective? Designing for Change Reasonably

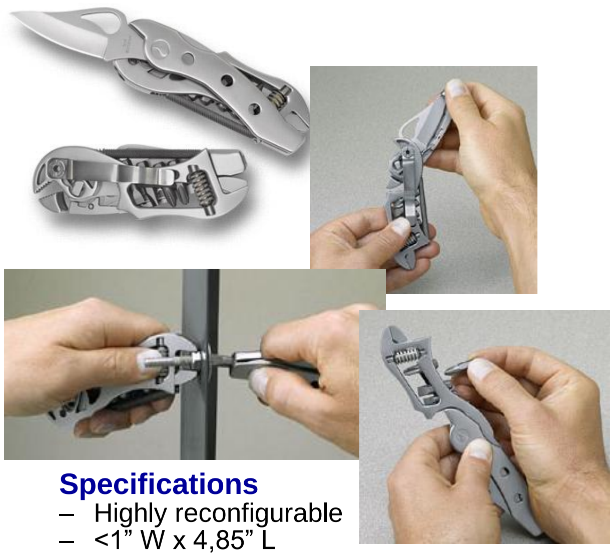
A system that complies with thousands of specifications is not necessarily resilient

Each tool individually maximally effective, jointly inconvenient and unaffordable

Specifications
- Highly reconfigurable
- 7" W x 12" L
- 3 lbs, 8 oz for the bag alone
- $53 for the bag alone
- Still have to pay for the tools
- Which tools do you take along?

A Bag of Tools

A fairly adaptable system, effective in many situations, affordable enough to enable buying other tools as well



Specifications
- Highly reconfigurable
- <1" W x 4,85" L
- 8 oz
- $109

Spyderco ByrdRench

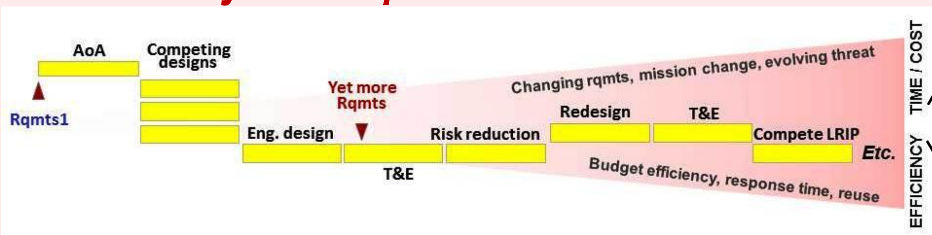
Adaptable, not affordable, not effective

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

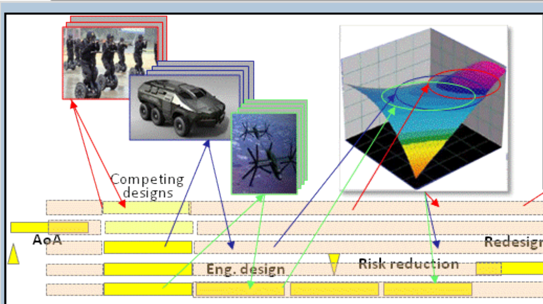
Swiss Army Knife

Engineered Resilient Systems: *We No Longer have Time or Money to Handle Threats Without Making Systems More Effective, Affordable, & Adaptable*

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



- Prematurely reduces alternatives
- Decisions made with incomplete information
- Sequential, slow
- Information lost at every step
- Ad hoc requirements refinement



Alternatives Kept Longer, Explored Deeper

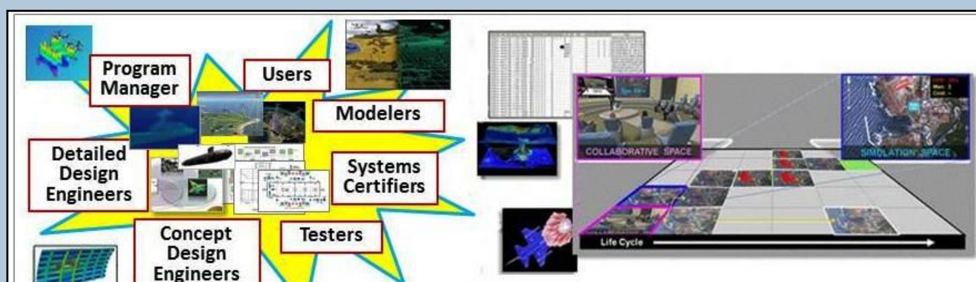
New tools help engineers & users:

- *Understand interactions*
- *Identify implications*
- *Manage consequences*

Refinement in Context of Operational Missions

Effective
- ***Better informed***

Affordable
- ***Faster engineering***



Collaborative Analysis of Engineering Issues and Impacts

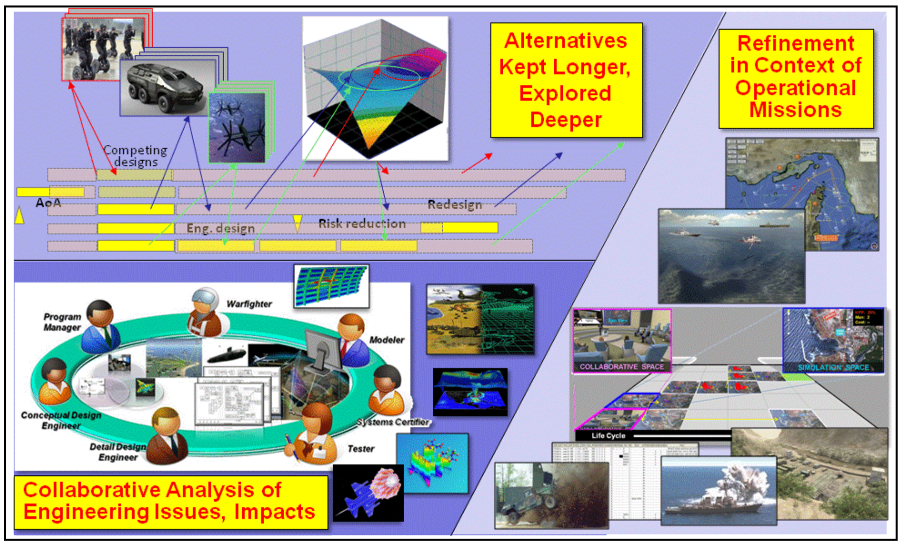
Adaptable
- ***Wider range of mission contexts***

Increased computational power and availability allow more flexibility in data exploitation and application of services

Key Technical Implications

System and environmental information represented in many forms

Mission effectiveness derived and tested wrt operational context



Coupling of knowledge across disciplines and representations

Exploration and analysis of huge tradespaces

Very-large-scale managed collaborative environment

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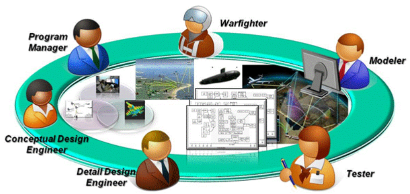

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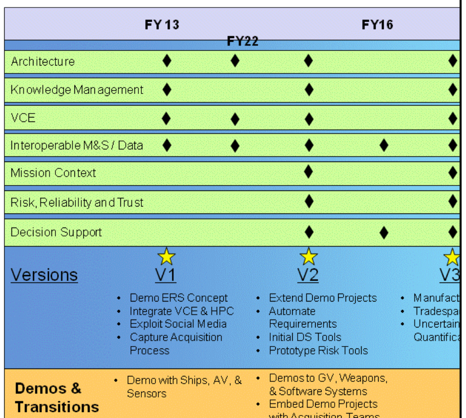
ERS Timeline



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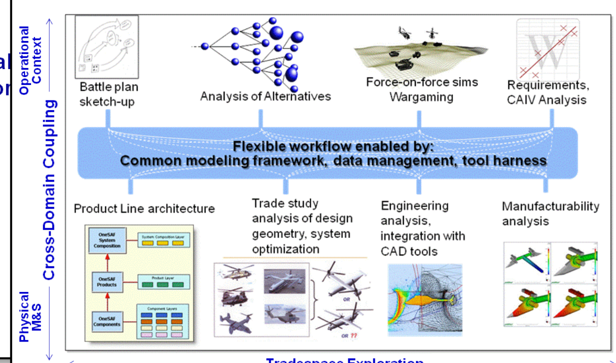
Architectural Concepts



An OSD View: Some Background

Analysis of Technology Planning Guidance FY13 and POM14 Data Call

- **Analysis and conclusions based on review of programs identified via TPG Data Call, classified against current ERS technical thrust definitions**
  - Classification performed by the author
  - Binning against topics is subjective and preliminary
- **Total dollar value of programs identified by Services, DARPA and OSD is significant**

Programs' Centers of Gravity wrt ERS

(Binning Based on Most Recent Proposal for Technical Building Blocks)

	Army	Navy	Air Force	DARPA	OSD
Decision Support					• Systems 2020
Risk and Reliability / Trustworthiness			• Engineered Resilient Systems Basic Research • Information and Complex Networks • Trustworthy Electronics Assessment	• Meta / iFAB • Self-Healing Mixed Signal Integrated Circuits (HEALICS)	
Mission Context	• C4ISR & Network Modernization • Prognostics & Diagnostics for the Future Force • Geo-Environmental Tactical Sensor Simulation				

Interoperability Modeling and Simulation / Data Feeds	• Computational Research for Distributed Ground Vehicle		• Engineered Resilient Systems Basic Research
			  • Dynamical Systems, Optimization & Control
			  • Aero-Structure Interactions and Control
			• Munition Aerodynamics, GN&C Advanced Weapons Systems Platform Integration
			• Integrated Vehicle Energy Technology
			• Laser Effects, Modeling and Simulation
				• Adaptable Low Cost Sensors	

Data / Knowledge Management/ Training	• C4ISR & Network Modernization
	• Defeat of Emerging Adaptive Threats
	• Safe Operations of Unmanned Systems for Reconnaissance in Complex Environments
	• Materials Modeling for Force Protection
		• Advanced Sea Platform Science
		• Advanced Sea Platform Technology
		• Manufacturing Science and Technology
		• Materials Chemistry
		• Manufacturing Science
		• Modular Photonics Mast Housing
		• Power Electronics (6.1, 6.2)
		• Platform Survivability Science
			• Accelerated Insertion of Reliable Materials into Electronics
			• Multidisciplinary Design and Analysis
			• Munition System Effects Science Modeling &Simulation
			• Integrated Computational Methods for Composite Materials
			• Manufacturing of C4ISR Hardware
			  • Communications
			  • Mid-Wave Infrared Optics
			  • Solar Space Cells
			• Manufacturing Research
			• Residual Stress Engineering of Nickel Superalloy Structures
				• Open Manufacturing
				• Living Foundries
				• Microphysiological Systems
				• Manufacturable Gradient Index Systems (M-GRIN)
				• Multifunctional Materials and Structures
				• Low Cost Thermal Imager -- Manufacturing
				• Gratings of Regular Arrays and Trim Exposures (GRATE)
				• Maskless Nanowriter
					• Automated and Rapid Boot Installation
					• Additive Manufacturing

Virtual Collaborative Environment				• Fast, Adaptable Next Generation Ground Vehicle	

Observations and Questions

"Components we do right away, *systems* take a little longer"*

*** With apologies to the Marine Corps**

- **Key issue: the real challenges lie at the *systems* level**
  - Interdisciplinary interactions across components / subsystems
  - Interactions caused by physics among components, possibly without any functional or architectural connections
  - Emergent behavior
  - Dynamics
  - ***Example: interdisciplinary dynamics among actuators increased total RDTE costs by 30X over initial budget in a major aircraft program***

- **A lot of work in certain ERS thrust areas, but ...**
  - Are we doing enough toward addressing systems-level problems?
  - Will investments in creating new technologies, devices or manufacturing methods improve or compound the systems problem?
  - How can Government and industry move to address the open areas?

Engineered Resilient Systems: A New Community of Interest

- **Critical issues of National importance**
- **Substantial investments**
- **Significant questions and work remaining**
- **Tremendous grass roots support**
  - Over thirty government experts contributing time
  - Over 400 government, industry and academic names on the interest list
- **Highly distributed and decentralized**
- **Many participants just learning about each other**
- **Many disciplines involved**

Communication and Information Exchange are Essential