Engineered Resilient Systems (ERS) S&T Priority Description, Status and Roadmap

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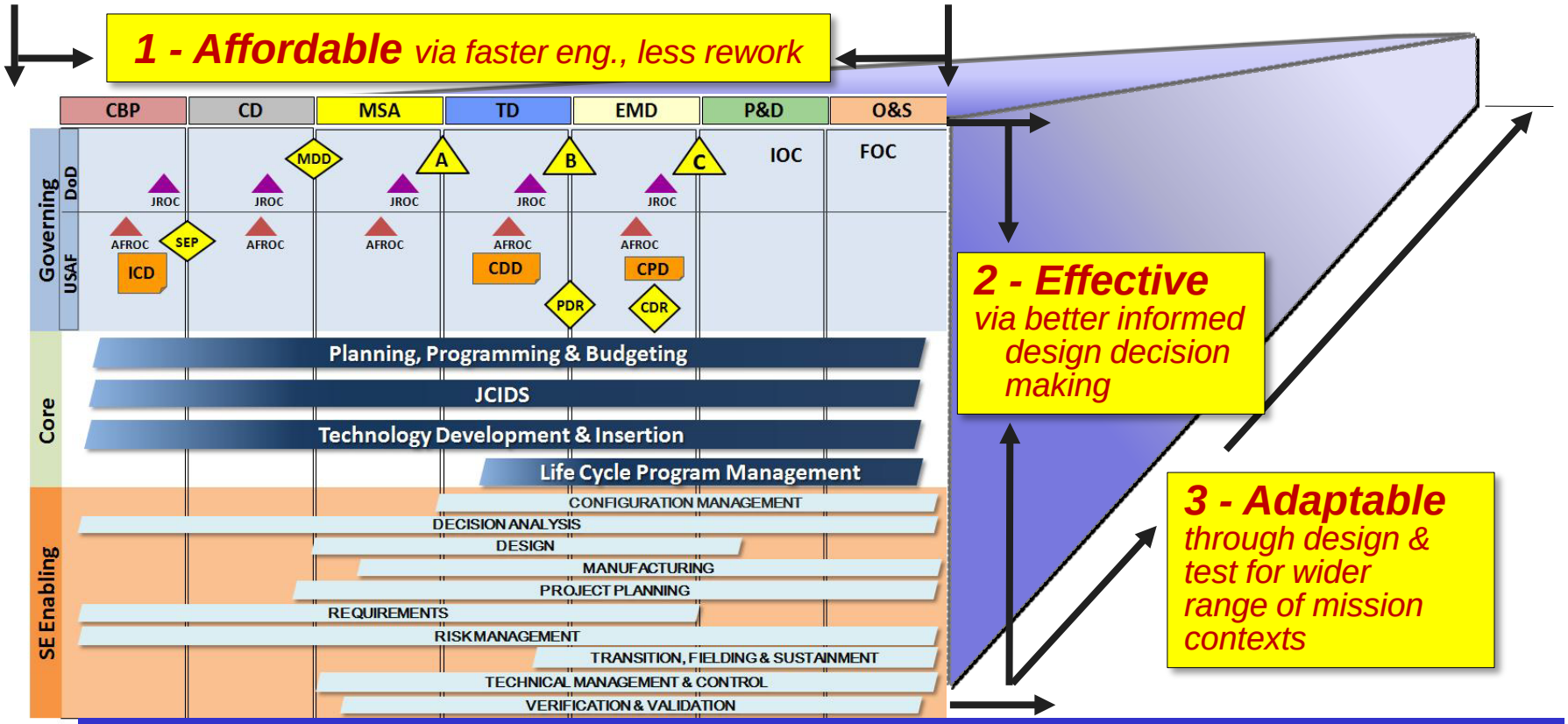
Engineered Resilient Systems Spans the Systems Life cycle

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



Uncertain futures, and resultant mission volatility, require affordably adaptable and effective systems – done quickly

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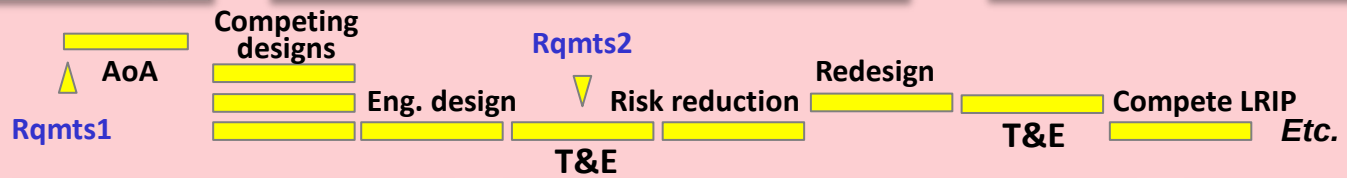
The Problem Goes Beyond Process:
Need New Technologies, Broader Community

Today

Prematurely culls 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 help Engineers & Users understand interactions, identify implications, manage consequences

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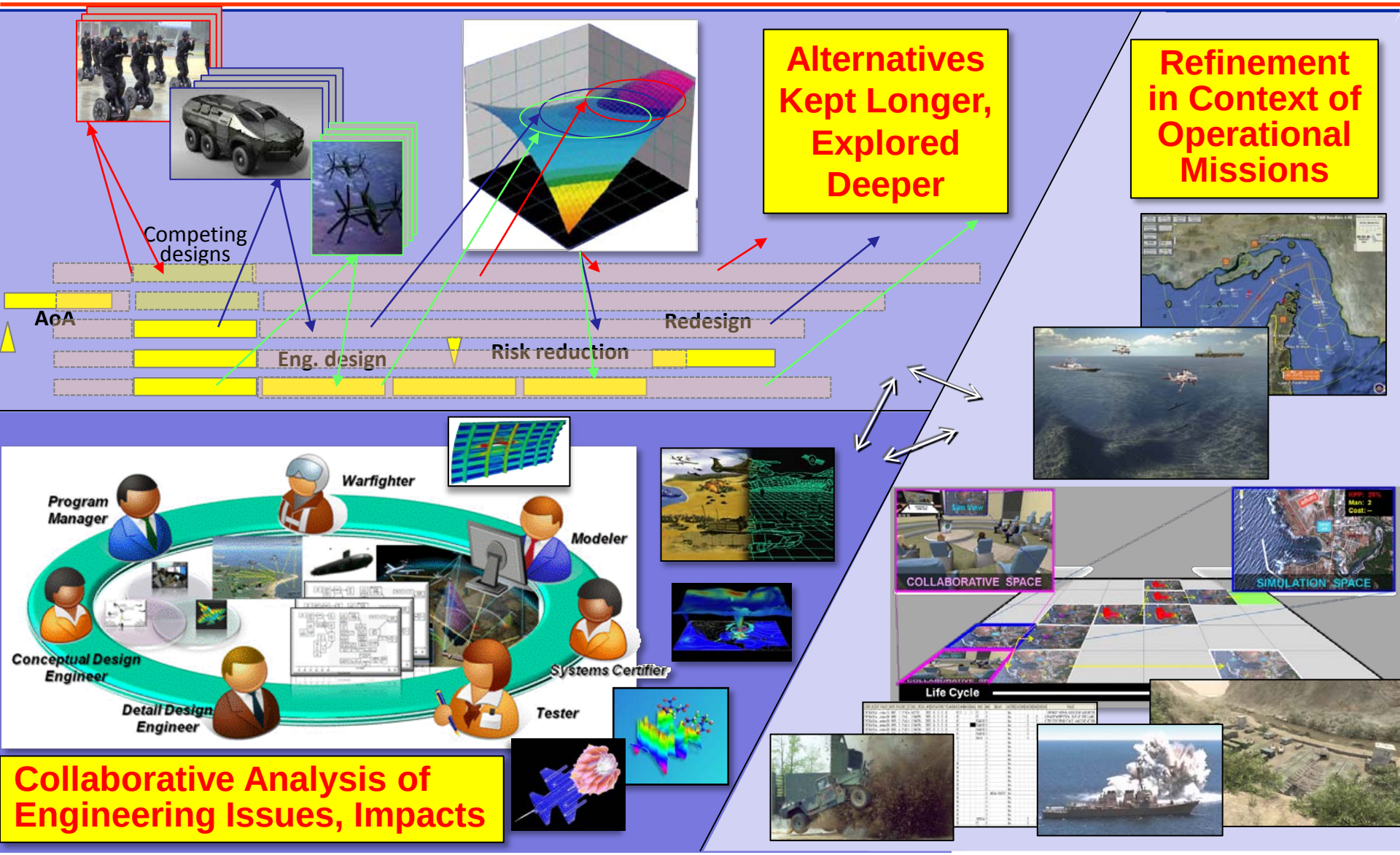
Engineering Interactions



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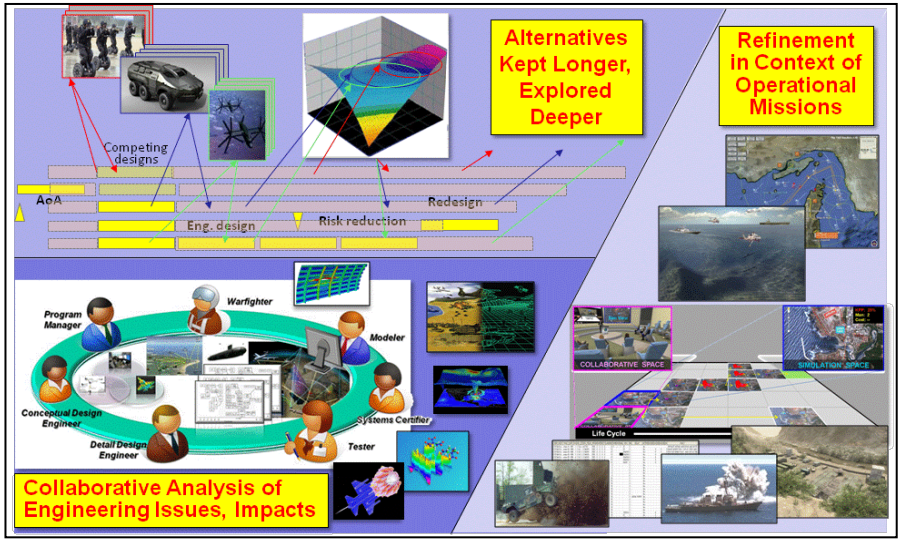
Key Technical Implications

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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A Possible Development Path

Black = in progress, or likely to happen *Red = needs to happen*

Thoughts about Foci over Time

Integrated Capability Demo 1

Integrated Capability Demo 2

Integrated Capability Demo 3

Final Demo & Tool Suite

Support for Collaborative Analyses (Design and Decision Support)

Data-driven engineering concept development and evaluation

Accelerated exploitation of user operational information

Tradespace Generation and Analysis Tools Incorporating Risk and Cost

Risk and Cost Tools that Learn

Analysis of Tradespaces in Joint Contexts

Models Aiding Design and Analysis
Physical/environmental models
Behaviorial/contextual models

Cooperating Heterogeneous Models & Services
Physical/environmental models
Behaviorial/contextual models

User-Friendly Control of Distributed Systems

Massive Scale Engineering Computations

Ubiquitously Available Massive Scale Engineering from Libraries

Today | 3 Years | 5 Years | 7 Years | 10 Years

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BACK-UPS

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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.

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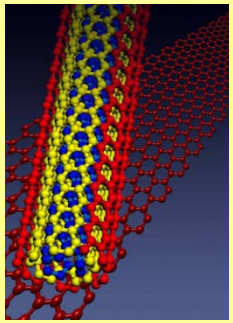
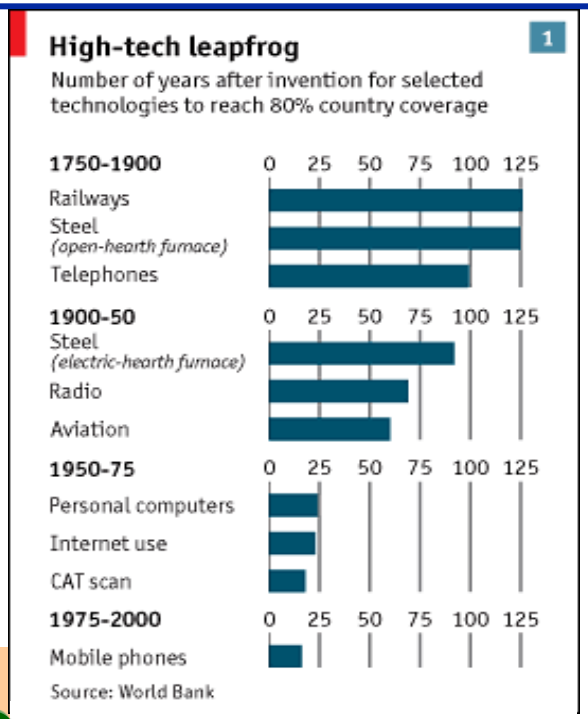
Pace of Technology is Increasing in An Increasingly Globalized Environment

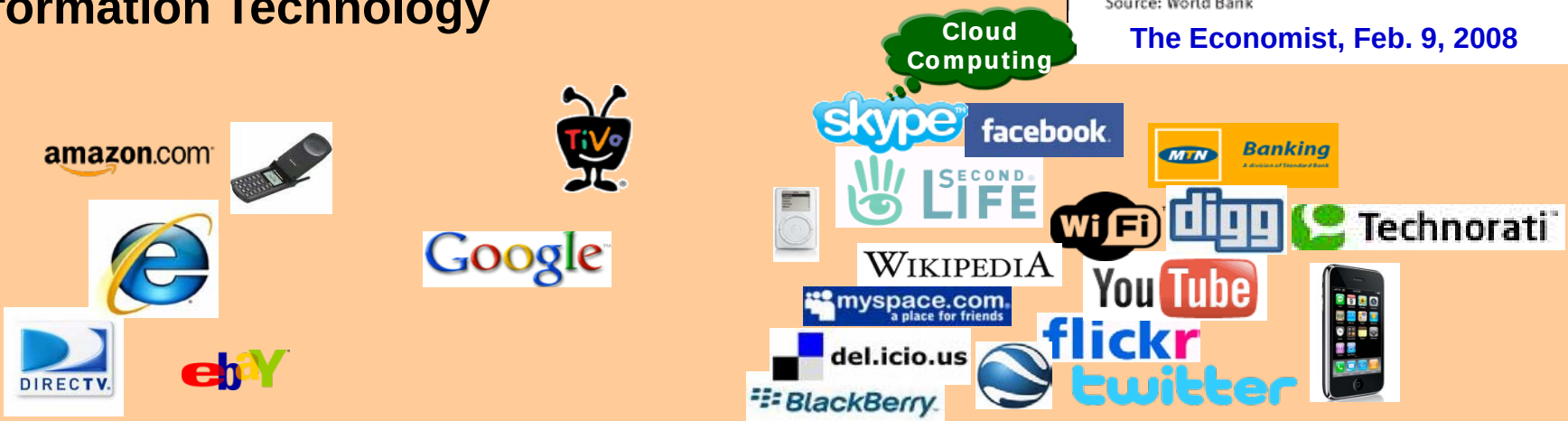
- **Time between modeling of semiconducting properties of germanium in 1931 and first commercial product (transistor radio) was 23 years**
- **Carbon nanotube**
  - **Discovered by Japan (1991)**
  - **Researchers recognized carbon nanotubes were excellent sources of field-emitted electrons (1995)**
  - **"Jumbotron lamp" - nanotube-based light source available as commercial product (2000)**





The Economist, Feb. 9, 2008

- **Information Technology**

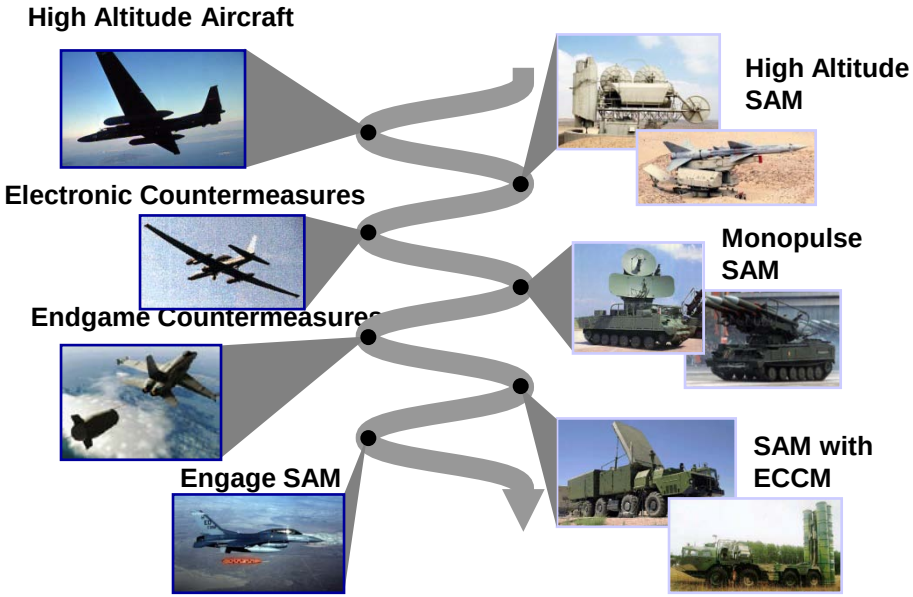


1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008

The Timeline has Collapsed (For Military Systems)!

Conventional Warfare

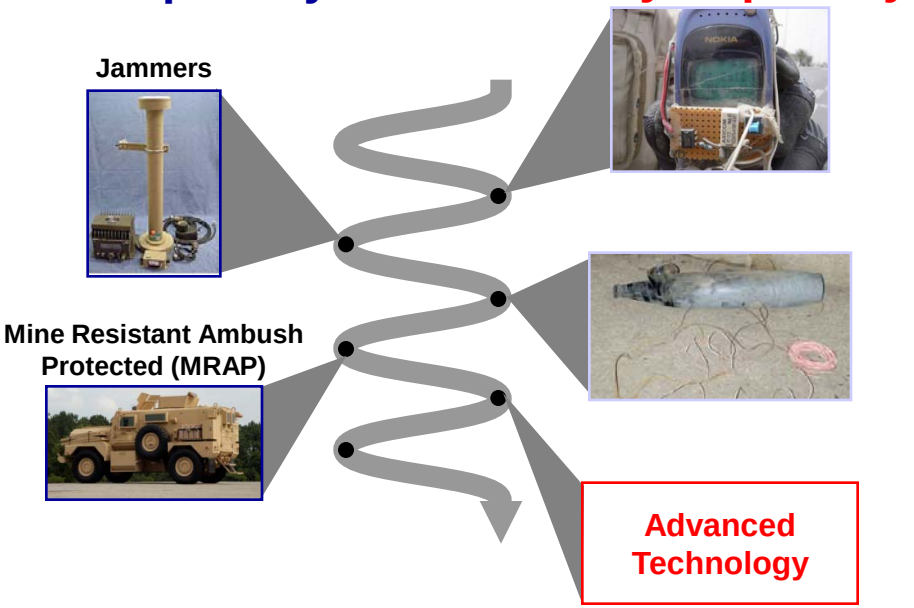
US Capability | **Adversary Capability**



RESPONSE LOOP MEASURED IN YEARS OR DECADES

Hybrid, Dynamic Warfare

US Capability | **Adversary Capability**



Response loop measured in *months or weeks*

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What's New

- **Focus on re-design: retrofit/upgrade/adapt more quickly and for less $$**
- **Rapidly vector in on feasible reconfigurations and extensions**
  - Without loss of confidence in security
- **Focus on design and testing in context**
- **Model more of the operating environment**
- **Explore and evaluate current and future scenarios, jointly with associated CONOPS**

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Engineered Resilient Systems: Needs and Technology Issues

Creating & fielding affordable, effective systems entails:

- **Deep trade-off analyses across joint mission contexts**
  - **Adaptability, effectiveness and affordability in the trade-space**
  - **Maintained for life**
- **More informative requirements**
- **Well-founded requirements refinement**
- **More alternatives, maintained longer**

Doing so quickly and adaptably requires new technology:

- **Models with representational richness**
- **Learning about operational context**
- **Uncertainty- and Risk- based tools**

Starting point: Model- and Platform- based engineering

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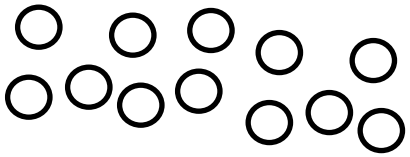
Engineered Resilient Systems
Key Technical Thrust Areas

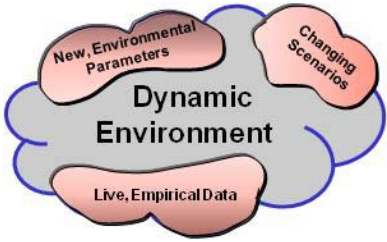
Systems Representation and Modeling

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



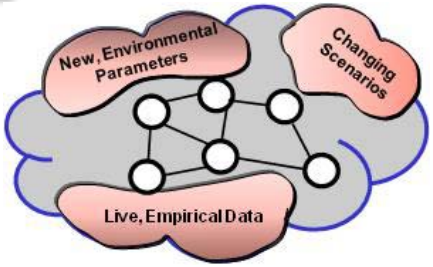
Characterizing Changing Operational Contexts

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



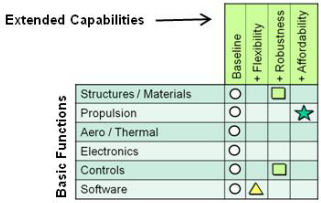
Cross-Domain Coupling

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



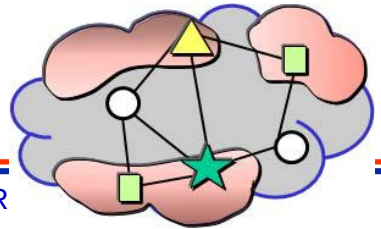
Data-driven Tradespace Exploration and Analysis

- 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 decisionmakers



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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

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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."

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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)

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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

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Collaborative Design & Decision Support: Technical Gaps and Challenges

Technology	10-Yr Goal	Gaps
Well-informed, low-overhead collaborative decision making, spanning lifecycle concerns	**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

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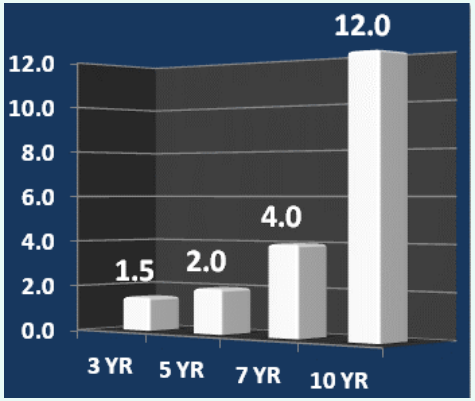
What Constitutes Success?

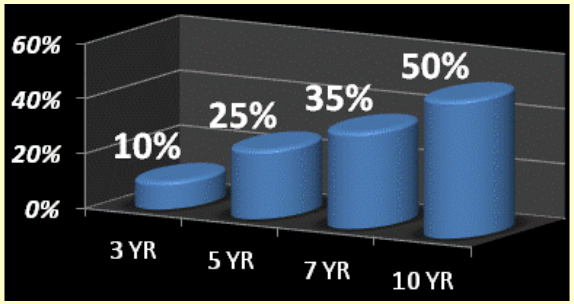


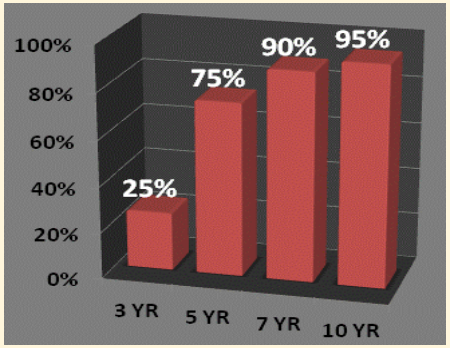
Faster, more efficient engineering iterations

- 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***

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
- ***Target: 50% of system is modifiable to new mission***





Decisions informed both ways (engineering by mission needs, missions by engineering opportunities/risks)

- 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.***

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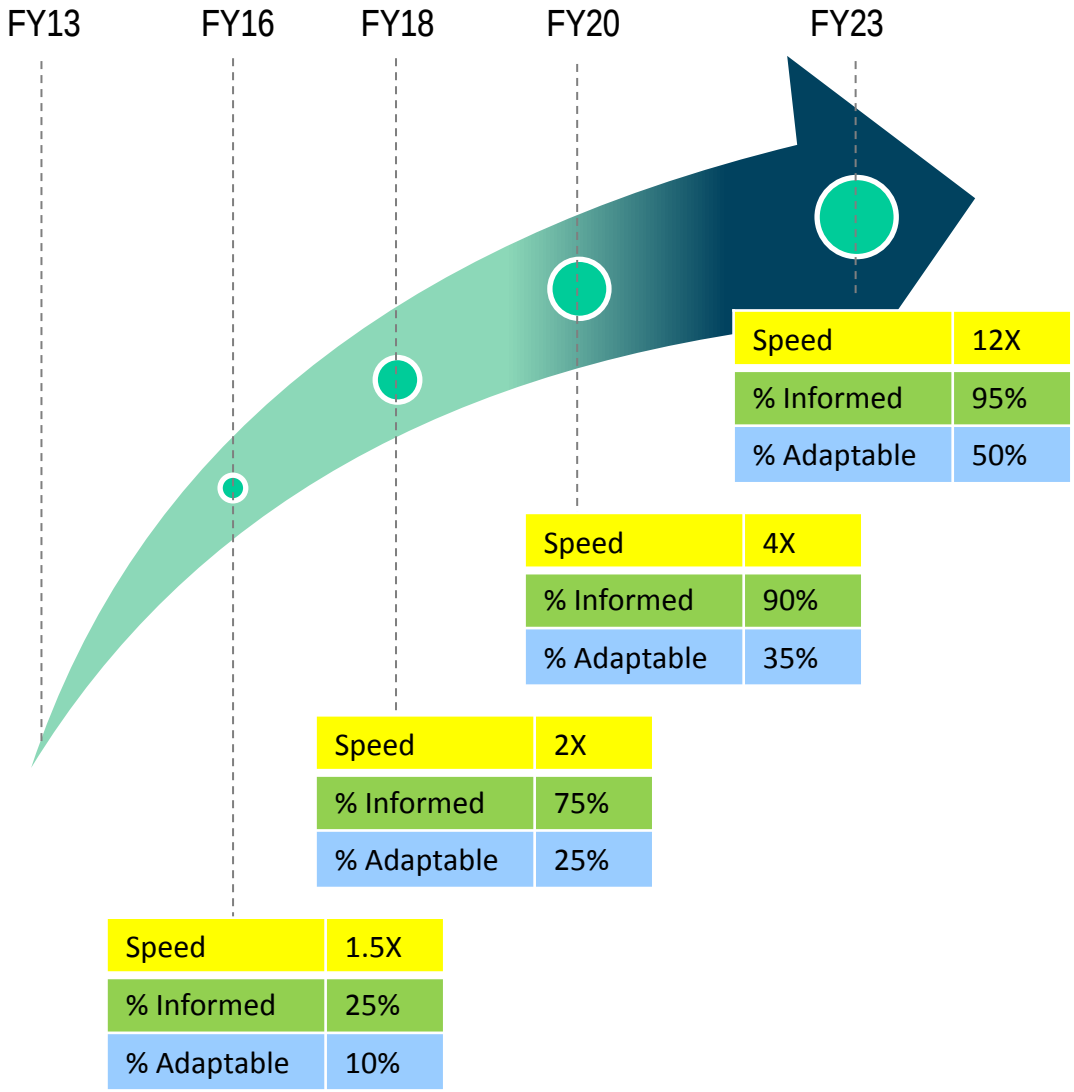
Potential High-level Goals and Metrics over 10 Years



- **How Fast?**
  - Developmental response time improvement (relative to baseline)
- **How Informed?**
  - Percent of system informed by models and trades within operational environment
- **How Adaptable?**
  - Percent reduction in cost and effort required to adapt system to support new mission

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Potential Detailed Goals and Metrics

		FY13	3 Yrs / FY16	5 Yrs / FY18	7 Yrs / FY20	10 Yrs / FY23
System Representation & Modeling, plus Cross-Domain Coupling	*Breadth*		25% of whole sys/subsys	75% of whole sys/subsys	90% of whole sys/subsys	95% of whole sys/subsys
	*Fidelity**		±20% error limit	±10% error limit	±5% error limit	±2% error limit
	Degree of Integration		Electronics and CAD (swap circuit board)	Cross-scaling (swap micro-processors)	Software and micro elec (change oper system)	Ability to swap major subsys, remodel without redesign
	* = Predict behaviors accurately					
Characterizing the Changing Operational Context	*Breadth*		25%** of whole sys/subsys	75% of whole sys/subsys	90% of whole sys/subsys	95% of whole sys/subsys
	*Fidelity**		±20% error limit	±10% error limit	±5% error limit	±2% error limit
	Degree of Integration		Single model sys embedded in simple realistic env	Single model sys embedded in complex realistic env	Mult modeled systems integrated in a simple, realistic env	Mult modeled systems interacting in a complex realistic system
	* = % of sys in realistic, simulated environment					
Data-driven Tradespace Exploration &Analysis			100 Trades SOA Basic algorithms Add 2 dimensions (such as affordability and reliability)	1000 Trades Cloud data Application prototype Add 1 dimension	10,000 Trades Implementation Heuristics Add 1 dimension	100,000 Trades Full service Tradespace algorithms that "think" Add 2 dimensions
Collaborative Design/ Decision Support			2 domains of expertise collaborate on a design w/o speed degradation	4 domains of expertise collaborate on a design w/o speed degradation	8 domains of expertise collaborate on a design w/o speed degradation	16 domains of expertise collaborate on a design w/o speed degradation
ERS Capability Exercise (OSD)			Speed 1.5X % Informed 25% % Adaptable 10%	Speed 2X % Informed 75% % Adaptable 25%	Speed 4X % Informed 90% % Adaptable 35%	Speed 12X % Informed 95% % Adaptable 50%

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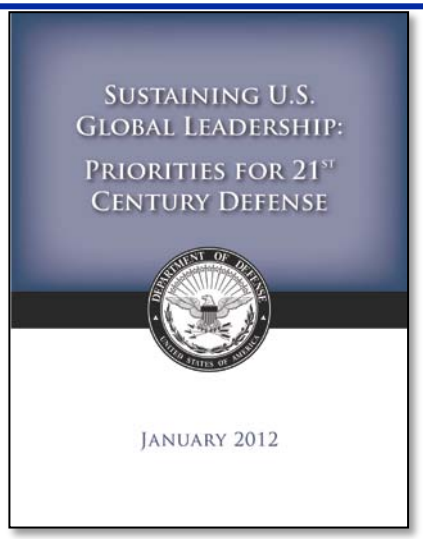
ERS: *Foundational* for Defense Systems across All Mission Areas

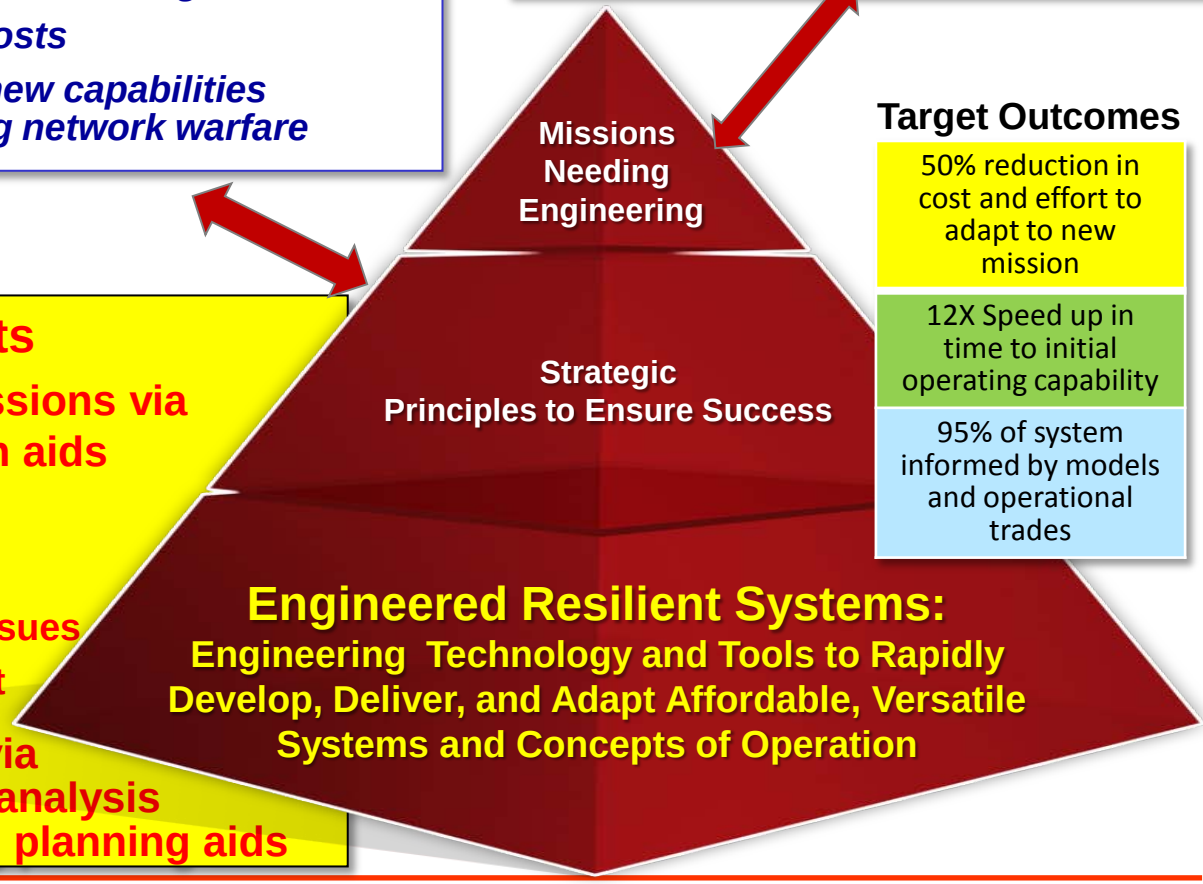


Seven Strategic Principles to Ensure Success, including:

- ***Offer versatility***
- ***Enable course changes***
- ***Reduce costs***
- ***Develop new capabilities leveraging network warfare***

Ten DoD Strategic Missions

Overwhelming majority require affordable, adaptable & effective systems and Concepts of Operation:



Target Outcomes

- 50% reduction in cost and effort to adapt to new mission
- 12X Speed up in time to initial operating capability
- 95% of system informed by models and operational trades

Key ERS Contributing Concepts

- **Co-evolution of systems and missions via information sharing and decision aids**
- **Option-preserving tradespace exploration**
  - **Analyzed/evaluated wrt lifecycle issues**
  - **Informing requirements refinement**
- **Accelerated design and testing via rapidly composable modeling & analysis tools, risk-sensitive engineering planning aids**

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Opportunities to Participate

DoD Needs Innovative Tools and Algorithms from Industry and Academia

Organization	BAA Title	Closing Date	Reference #
ONR	Energetic Materials Program R&D	23-Dec-11	12-SN-0001
Dept of Army	Adaptive Vehicle Management System (AVMS) Phase II	6-Jan-12	W911W6-11-R-0013
NAWC Lakehurst	BAA Reconnaissance and Surveillance payloads, sensors, delivery systems and platforms	14-Feb-12	N68335-11-R-0018
NAVFAC	BAA Expeditionary technologies	2-Mar-12	BAA-09-03-RIKA
US Army USACE	2011 BAA	31-Mar-12	W912HZ-11-BAA-02
NRL	NRL-Wide BAA	16-Jun-12	BAA-N00173-01
US Army RDECOM-ARDEC	Technology Focused Areas of Interest BAA	15-Sep-12	W15QKN-10-R-0513
ARL	Basic and Applied Scientific Research	31-Dec-12	W911NF-07-R-0003-04 & -0001-05
Dept of Army	Army Rapid Innovation Fund BAA	29-Sep-12	W911NF11R0017
ONR	BAA, Navy and Marine Corp S&T	30-Sep-12	ONR 12-002
NASC Training Sys Div	R&D for Modeling and Simulation Coordination Office	4-Dec-12	N61339-08-R-0013
AFRL Kirtland	STRIVE BAA	Draft Posted	FA945311R0285
WHS	DoD Rapid Innovation Fund	n/a	HQ0034-RIF-11-BAA-0001
AFRL WPAFB	Reasoning, Comprehension, Perception and Anticipation in Multi-Domain Environments	n/a	BAA-10-03-RIKA
AFRL Rome	Emerging Computing Technology and Applications	n/a	BAA-09-08-RIKA
AFRL Rome	Cross Domain Innovative Technologies	n/a	BAA-10-09-RIKA
AFRL Rome	Computing Architecture Technologies BAA	n/a	BAA-09-03-RIKA
WHS	Systems 2020	n/a	Subject to Presidential Budget Approval

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Issues in Building an Engineered Resilient Systems S&T Community

- **Complex integration across many technologies:**
  - Interdisciplinary across air, land, sea for electromechanical systems with embedded control computational capabilities
  - Spans the engineering lifecycle: Concept engineering and analysis, Design & Prototyping, Development, Production, Sustainment
  - New tools, methods, paradigms:
    Linking engineers, decisionmakers, other stakeholders
  - Addressing product *robustness*, engineers' *productivity*, and systemic *retention of options*

- **Nascent, emerging ties to basic science, e.g.:**
  - Computational Approximate Representations:
    Can't get all engineering tools talking same language
  - Mathematics and Computational Science of Complexity:
    Can't look at every engineering issue, need aids to determine focus
  - Mathematics and Cognitive Science of Risk, Sensitivity, and Confidence:
    Need decision aids for understanding implications of trades, committing $

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Envisioned End State

Improved Engineering and Design Capabilities

- More environmental and mission context
- More alternatives developed, evaluated and maintained
- Better trades: managing interactions, choices, consequences

Improved Systems

- Highly effective:
  better performance,
  greater mission effectiveness
- Easier to adapt,
  reconfigure or replace
- Confidence in graceful
  degradation of function

Improved Engineering Processes

- Fewer rework cycles
- Faster cycle completion
- Better managed
  requirements shifts

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