Engineered Resilient Systems (ERS) Overview

December 2013

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Director, US Army Engineer Research and Development Center (ERDC)
Director, Research and Development, US Army Corps of Engineers
Engineered Resilient Systems

Integrated Lifecycle Engineering
What is a “Resilient” System?

A Resilient System…

• is trusted and effective in a wide range of contexts,
• is easily adapted to many others through reconfiguration or replacement, and
• has predictable degradation of function.

C-130 Hercules

AC-130A
Drone Control

EC-130E
Airborne battlefield command and control & electronic warfare

HC-130H
Maritime and Ice Patrol

JC-130
Mid-air Retrieval
ERS: Part of DoD S&T Portfolio

Defense Strategy

1. **Mitigate** new and emerging capabilities
   - Electronic Warfare  - Counter Space
   - Cyber  - Counter-WMD

2. **Affordably** enable new or extended capabilities in existing military systems
   - Systems Engineering  - Engineered Resilient Systems
   - Data Reuse  - Developmental Test & Evaluation

3. Develop technology **surprise** through science and engineering
   - Autonomy  - Data-to-Decisions
   - Basic Research  - Human Systems

Technology Needs

- Middle East Instability
- North Korean Nuclear Ambitions
- Anti-Access/Area Denial
- Cyber Attacks
- Electronic Warfare

Mr. Al Shaffer, Principal Deputy, ASD Research and Engineering

October 29, 2013
ERS Addressing the Acquisition Challenge

ERS will empower Pre-materiel analysis with significant impact on

- Requirements Generation
- Analysis of Alternatives
- Lifecycle Intelligence

“We need to continually move forward with designing an acquisition system that responds more efficiently, effectively and quickly to the needs of troops and commanders in the field.”

Secretary of Defense Chuck Hagel, April 3, 2013
Today: Process-driven

- Stove-piped workforce and data sources
- Redundant processes
- Little data reuse
- Inefficient: both time and cost
- Lacks adaptability to new requirements/missions
ERS: Data-driven

Roles:
- Acquisition
- Training
- Engineering
- Cost Analyst
- Users

Collaboration Capabilities:

**Portal**

- **Enter data once**
- **Leverage throughout lifecycle**

**Framework Interface**

- **Lifecyle Cost Analysis**
- **Tradespace Analysis**
- **Mission Context Analysis**

**Common Core Platforms**

- Rapid, Reconfigurable Systems

**Needs (illities)**
- Manufacturability
- Affordability
- Reliability
- Sustainability
- Usability
- Testability
- Etc.

**Previous Design Successes, Lessons-learned**

**Data, Information, Knowledge**

- High & Low Fidelity Codes

**HPCMP Resources**

**S&T Resources, Research**

**ERS: Data-driven**
Data-driven Decisions

1. REQUIREMENTS
   - Capture Needs & Requirements
   - Create a project
   - List of potential project team Members from Knowledge Hub

2. CONCEPTUAL MODELING
   - Develop conceptual model of the system
   - Complete conceptual model - SysML
   - Build team

3. SYSTEM CONFIGURATION
   - Assemble all model packages
   - Configure Orchestrator

4. ALTERNATIVE ANALYSIS
   - Execute Decision Analyzer
   - Identify Design Alternatives

5. COST ASSESSMENT
   - Assess lifecycle cost of alternatives

6. IMPACT ANALYSIS
   - Mission Context Analysis
   - Tradespace Exploration

- Cont.

A set of designs with a known and acceptable satisfaction and risk

Millions of Possible Designs

Capture Needs & Requirements

Team evolves system ontology

- Cont.
ERS Framework Concept

Pre-Milestone A
Systems Engineering

Open Architecture
Common Environment
Shared Capabilities
Enables Collaboration

Acquisition teams leverage ERS capabilities throughout the systems lifecycle

Needs/Requirements

Army
Tools, Information & Infrastructure

Air Force
Tools, Information & Infrastructure

Navy
Tools, Information & Infrastructure

ERS Framework

Knowledge Environment
Social Computing
Knowledge Portal

Decision Support
Tradespace Analysis & Dashboards

Tools & Services
Common Tools & Services

Information
Ontologies ERS Web

Infrastructure
ERS Wiki

Framework Standards

Acquisition

Acquisition Program

Framework Interface
Major ERS Components
ERS Technology Anchors

ERS Framework and Open Architecture
- Connects existing tools, information, and data in a common framework
- Acquisition teams leverage ERS capabilities throughout the system lifecycle

Tradespace Analysis
- Enables informed decisions
- Empowers AoA and Requirements Generation
- “Visualizes” trades of many more designs in far less time

Throughout Product Lifecycle
Design → Disposal
FY13 Tasks and Results

Architecture

Technology Development

Demonstrations and Results
Architecture Development Goals

Build a cohesive framework to share, leverage and reuse capabilities.

• Current State in DoD:
  • Investments in ERS-like projects are currently made across the DoD (estimated $120M+)
  • Yet, no overarching framework exists to share and reuse capabilities (tools, models, algorithms, data, etc.)

• Goals of ERS Architecture:
  • Leverage technical standards that support a modular, loosely coupled and highly cohesive system structure
  • Enable an “Open” computing framework that allows software to plug-and-play
  • Openness drives opportunities to enhance innovation across government, academia and industry
FY13/14 Accomplishments

Architecture Development

• FY13 Accomplishments
  – Assessment of existing, ERS-relevant software products (Gov’t & commercial)
  – Established ERS Enclave - segregated network to host ERS products – ers.hpc.mil
  – Developed Ontological Modeling (DOM) - set of concepts defining a system
    o shared vocabulary to denote the types,
    o properties, and
    o interrelationships among components of a system.

• FY14 Currently in Progress
  – Knowledge Environment (KE) - installed a suite of knowledge products as the initial knowledge management environment for ERS
  – Model Packages – software standards to encapsulate models that support system analysis
  – Connectors – software standards for communicating with ERS Model Packages
  – SysMLGen – software that translates ontologies into SysML block and parametric diagrams
  – Architecture COI – Online community of interest to connect those interested in ERS architecture
Architecture Roadmap

ERS Capability Analysis
• LEAPS (USN)
• FACT (USMC)
• DaVinci
• Kestrel
• WSTAT
• Erc.

Conceptual Modeling
- Ontologies describe system and trades
- Computation for tradespace calculation in SysML

Orchestrator
Execution manager oversees processing of user inputs into results

Decision Visualization
Visualizes models (graphs, charts, 3-D objects)

Knowledge Manager
Interface decision support tools.

Teaming
Methods to adapt teams to design process

Advance Visualization (HPCMO)
ParaView provides insights into myriad data generated in analyses

Analysis of Alternatives
Display, discuss, select among alternative systems

Manufacturability (solicitation)
Analytics to assess manufacturability

Risk and Uncertainty
Measure and display risk associated with designs

Lifecycle Cost Analysis
Cost analytics integrated in tradespace

Mission Context Analysis
System performance within a simulated mission

HPC Interoperability (HPCMO)
Non-HPC machines interoperable with HPC resources

M&S (DoD)
Suite of DoD modeling and simulation capabilities

HPC Interface
Machine-to-machine connectivity (HPC and non-HPC resources)

CREATE (HPCMO)
Deploy advanced computational design tools:
- CREATE – Air Vehicles, - Ships, -Antennas, - Meshing and Geometry

CRES-GV (HPCMO)
High-fidelity design/analysis tools for ground vehicles

Environmental Simulator (EnvSim) (ERDC)
Physics-based codes to create a digital representation of an environment

Lifecycle Cost Analysis
Cost analytics integrated in tradespace

Model Integration
Method to integrate models: 1) simplification to meta-models, 2) meta-models packaged, hosted on ERS environment

Establish hosting environment for Navy

Needs Analysis
Conducted with the Navy, Air Force and Marine Corp

FACT selected as baseline for future ERS development

Establish ERS computing enclave

Establishing ERS computing enclave

Implement Timeline

Apply
Leverage
Build

Future Releases FY16+

Release 1 FY14

Release 2 FY15

Receive Statement A – Approved for public release by OSR on 12/09/2013; SR Case #14-S-0514 applies. Distribution is unlimited.
ERS Architecture Attributes

“Open System Architecture is a key contributor to Resilient Design.”
Mr. Stephen P. Welby, Deputy Assistant Secretary of Defense for Systems Engineering

- Non-proprietary, open framework
- Interactive with outside entities (API)
- Platform agnostic
- System—not Service—centric
- Multi-fidelity analysis
- Legacy system compatibility
- Shares benefit of R&D among users
Tradespace Analysis Goals

Develop a prototype tool linking Mission Context and Tradespace tools into a combined system

Demonstrate collection and validation of capabilities requirements in virtual and synthetic environments

Map the current lifecycle cost mythologies to more fully understand the process, and

Draft a strategy and lifecycle cost model(s) based on stakeholder values
FY13/14 Accomplishments
Tradespace Analysis

• Tradespace Tool Survey
  – Review of tradespace methodologies, techniques and tools
  – Provided input for initial requirements document (CDD) for the ERS Tradespace Analysis Tool

• Expanded Capability of FACT (Framework for Assessing Cost and Technology) for ERS:
  – Used by USMC in AVM program for tradespace visualization (2013)
  – Enhanced capabilities for tradespace visualization of multiple parameters with FY13 ERS Ships Demo (FACT-Ship)
  – Requirements for tool modification for generic use (land, air and sea systems)
  – Initial linking of tradespace tool with combat simulation(s) for inclusion of mission context (FACT-EASE)
Richly Informed Decisions

Tradespace Analysis

Mission data
Mission context
Lifecycle data
Physics-based models
Other data sources…

100X
# of parameters and scenarios considered in setting requirements

Space spanned by completely enumerated design variables

HPCMP & S&T Resources

75% reduction in time to complete systems by reducing rework

Much faster computation; Ample data storage

Data and lessons-learned retained for rework

Mission data
Mission context
Lifecycle data
Physics-based models
Other data sources…
Multi-dimensional Data Analysis

“If only we had this last year.” Center for Army Analysis, Sep 2013

Automatic Analysis of Alternatives

- Sensitive to small perturbations
- Inclusive of lifecycle data (costs over time, disposal, corrosion, etc.)

System parameters, attributes, and characteristics required to satisfy performance standards

Completely enumerated design variables

Auto-analysis of design elements
Ship Design Experiment

- **Point-based vs. Set-based design teams**
  - 3 requirements changes introduced during design phase:

<table>
<thead>
<tr>
<th>Task</th>
<th>Point-based Design</th>
<th>Set-based Design</th>
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</thead>
<tbody>
<tr>
<td><strong>Measure of Effectiveness</strong></td>
<td>Complete design iteration with requirements changes.</td>
<td>Required no design re-work for requirements changes.</td>
</tr>
<tr>
<td><strong>Cost vs. Time</strong></td>
<td>Necessary to <em>guess</em> in cost analysis</td>
<td>Analysis from data-driven knowledge</td>
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<tr>
<td><strong>Risk</strong></td>
<td>Gravitated to <em>higher-risk design</em> over time</td>
<td>Developed <em>lower-risk design</em></td>
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</table>

- **Physics-based analysis tools** provide information for early ID of sub-optimal requirements
- **Tradespace information** enables identification of risk-reducing technologies
- **Systems of Systems (SoS)** insights are more deeply understood and utilized
Aircraft Design Experiment

**Mission context metrics can feed into the design loop and enable physics-based analysis: visual, quantifiable assessments**

- CREATE-AV tools (DaVinci): efficient, rapid, comprehensive evaluation of design space
- Surrogate design: Enables interface with operational (mission) models – assess requirements against cost & risk
- Probability-based analysis: Visualizes quantified assessment of feasibility/affordability for decision-makers
# ERS Roadmap (FY14 - FY18)

<table>
<thead>
<tr>
<th>ERS</th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
<th>V4</th>
<th>V5</th>
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<tbody>
<tr>
<td><strong>PLAN</strong></td>
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<tr>
<td><strong>Architecture</strong></td>
<td>Prototype CCE - Navy</td>
<td>ERS CCE on Demand</td>
<td>Tech Area Integration</td>
<td>Tool Pipeline</td>
<td>Re-Configurable</td>
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<tr>
<td><strong>TRADE</strong></td>
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<tr>
<td><strong>Tradespace</strong></td>
<td>Use USMC-FACT</td>
<td>ERS-FACT</td>
<td>Improved Visualization</td>
<td>Industry Integration</td>
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<td>Proprietary Data Broker</td>
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<td><strong>KNOW</strong></td>
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<tr>
<td><strong>Knowledge Management</strong></td>
<td>Ships</td>
<td>AV</td>
<td>Helo</td>
<td>GV</td>
<td>Industry – Government Usage</td>
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<td><strong>DEMO</strong></td>
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<tr>
<td><strong>Pilot Projects</strong></td>
<td>Ships – AoA</td>
<td>Early AoA</td>
<td>Cost-Risk Tool</td>
<td>AV Lifecycle Model</td>
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<td><strong>ENHANCE</strong></td>
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<tr>
<td><strong>Technology Focus Areas</strong></td>
<td>Environmental Simulators</td>
<td>Lifecycle tool</td>
<td>Cost Tool</td>
<td>Mission Context</td>
<td>Manufacturability</td>
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**FY14** | **FY15** | **FY16** | **FY17** | **FY18**

**Context**
- Improved Visualization
- Support Mission Context
- Industry – Government Usage
- Cost Tool
- Mission Context
- Manufacturability
FY14-15 Technical Milestones
Building Components & Integrating

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Description of Milestone</th>
<th>Status</th>
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<tbody>
<tr>
<td>3QFY13</td>
<td>Pilot Projects: ERS Ships and AV, Phase 1</td>
<td>Completed</td>
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<tr>
<td>1QFY14</td>
<td>ERS Ships and Air Vehicle, Phase 2</td>
<td>In Progress</td>
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<tr>
<td>1QFY14</td>
<td>Initial Release: ERS Integrating Architecture (corresponds to ERS V0.1)</td>
<td>Planned</td>
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<tr>
<td>4QFY14</td>
<td>ERS V1.0 Release (Major Milestone)</td>
<td>Planned</td>
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<tr>
<td>4QFY15</td>
<td>ERS V2.0 Release (Major Milestone)</td>
<td>Planned</td>
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**Technical Goals:**

- Capture and simulate essential components of the DoD acquisition and operational analysis processes;
- Integrate M&S, collaborative tools, tradespace analysis, engineering design processes into single architecture;
- Express lessons learned and create communities of interest through DoD social media exploitation;
- Demonstrate ERS for various platforms, such as Ships, Fixed-Wing Air Vehicles, and Helicopters; and
- Provide the technical basis for improvements to DoD policy.
## FY14-15 Program Milestones

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Description of Milestone</th>
<th>Status</th>
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<tbody>
<tr>
<td>1QFY13</td>
<td>PSC Transition of Leadership – R. Neches to J. Holland</td>
<td>Completed</td>
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<tr>
<td>2QFY14</td>
<td>Outreach/engagement of Academia and Industry (e.g., GTRI, SERC, Lockheed Martin ATL, BAE Systems, etc.)</td>
<td>Complete/Task Ongoing</td>
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<tr>
<td>4QFY13</td>
<td>Annual General PSC Meeting to discuss FY14 Activities</td>
<td>Complete</td>
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<tr>
<td>1QFY14</td>
<td>Continue Industrial Outreach (Boeing, Northrop, Raytheon, etc.)</td>
<td>Planned</td>
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<tr>
<td>2QFY14</td>
<td>Deliver priority research topics to the SERC</td>
<td>Planned</td>
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<tr>
<td>2QFY14</td>
<td>Virtual ERS-wide Technical Workshop (VTW)</td>
<td>Planned</td>
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<tr>
<td>3QFY14</td>
<td>Hold Senior Advisory Meeting to discuss FY15 Activities</td>
<td>Planned</td>
</tr>
<tr>
<td>4QFY14</td>
<td>Annual Technical/Program Review</td>
<td>Planned</td>
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- The ERS Program Management team is actively engaging the Services, the DoD’s industrial base, commercial tool-makers, academia and research institutes. Technical exchange between Government and industry is built into the ERS management goals.

- Engineered Resilient Systems (ERS) has developed three levels of Government engagement and support:
  - OSD serves as a surrogate for the Services and DoD in general.
  - A joint-services, Senior Advisory body will provide technical direction, guide service engagements, provides insights and opportunities related to the Services, and assist with enlistment of relevant projects.
  - ERS Working Groups will identify technical needs and gaps related to policy, standards, data and training (and issues that arise), and draft working plans to address issues.
ERS Knowledge Hub

- Critical outreach tool for multiple communities of interest (COI)
- Prototype framework for decision-making
- Cloud-based collaboration system
- Connect, leverage and share data

Capture/engage COIs
- Government, Non-government, stakeholders, academia, etc.

Host behind-the-firewall search
- Smart search of millions of documents
- Avoid recreation, redundancy, etc.

Locator of experts
- Cross-divisions, communities
- Leverage remote communities of practice (COPs)
- Individual management of information
- Foster interaction and sharing

“Google” search
Wiki Pages
Experts
ERS Technical Team & Partners

Technical Team

Engineer Research and Development Center (ERDC)

Arnold Engineering Development Center (AEDC)

Naval Undersea Warfare Center (NUWC)

Air Force Life Cycle Management Center (AFLCMC)

Marine Corps Systems Command (MARCORSYSCOM)

Air Force Research Laboratory (AFRL)

Naval Research Laboratory (NRL)

Army Research Laboratory (ARL)

PSC

Programs, Industry, & Academic Organizations

Partnering with and Leveraging Key Program Executive Offices (PEOs), Program Managers (PMs), Industry and Academia