Engineered Resilient Systems

Power of Advanced Modeling and Analytics in Support of Acquisition

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Director, US Army Engineer Research and Development Center (ERDC)
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ERS Community of Interest (COI)

- Significantly advance the state of engineering practice and productivity
- Replace sequential, fixed requirement approach to design
- Explore new concepts to integrate advanced engineering models...inherently more adaptable across mission sets and environments

Introduced in 2010

Dr. Jeffery P. Holland
Steering Group Lead (Army)

Dr. Martin Irvine, DASN RDT&E
US Navy Lead

Robert A. Gold, DASD/SE
OSD Lead

Col. K. Colin Tucker, SAF/AQ
USAF Lead
## ERS Partners on Current Key Projects

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ERS Leverages Years of Major DoD Investments

**ENGINEERING ANALYSIS**
- **CAPABILITIES ASSESSMENTS**
- **EMERGING RESEARCH**
  - X-ARPAs
  - Research Algorithms
- **MODELS**
  - CREATE
  - Envir Sims
  - Lifecycle Intel
- **TRADES ANALYSIS**
- **ANALYSIS OF ALTERNATIVES**
- **DECISION SUPPORT & ANALYSES**
  - TradeStudio
  - Analytic Tools
- **OPERATIONS**
  - UTL
  - Mission
  - Doctrine
- **KNOWLEDGE MGMT**
  - Notebooks
  - Knowledge Hub
  - Wiki
- **PROTOTYPING**
- **DEVTEST & EVALUATION**
- **HPC**
- **General Computing**
- **Amazon Web Cloud**
- **Enterprise Computing**
- **Embedded Computing**

**HIGH-PERFORMANCE COMPUTING**

**MATHEMATICAL OPTIMIZATION**

**OPEN & TRUSTED SYSTEMS**

**CONTEXT SIMULATION**

**ADVANCED MODELING**

**TRADES ANALYSIS**

**ANALYSIS OF ALTERNATIVES**

**DECISION SUPPORT & ANALYSES**

**OPERATIONS**

**KNOWLEDGE MGMT**

**PROTOTYPING**

**DEVTEST & EVALUATION**

**HPC**

**General Computing**

**Amazon Web Cloud**

**Enterprise Computing**

**Embedded Computing**
ERS Spans the DoD Acquisition Lifecycle
ERS: A 10-Year Challenge

Conceptual Design

Adaptable Design

Computational Prototyping

Virtual Proving Ground


INTEGRATED CAPABILITY \(\rightarrow\) HPC-EMPOWERED OPEN ARCHITECTURE AND SECURE SYSTEM

TRADESPACE ANALYTICS \(\rightarrow\) MILLIONS OF OPTIONS RAPIDLY CONSIDERED

RAPID ACQUISITION ANALYSES – YEARS TO MONTHS, MONTHS TO WEEKS, WEEKS TO DAYS DEMONSTRATED

PHYSICAL REPRESENTATIONS \(\rightarrow\) IN CONCEPTS, TRADES, PROTOTYPING, TESTING

BIG DATA SOLUTIONS \(\rightarrow\) ADVANCED VISUALIZATIONS, BILLIONS OF DATA POINTS CAPTURED

COLLABORATION \(\rightarrow\) KNOWLEDGE SHARING, DATA ACCESS, RETENTION, REUSE

PHYSICS-BASED PROTOTYPING \(\rightarrow\) COMPUTATIONAL PROTOTYPING ENVIRONMENT

RIGOROUS VIRTUAL DT&E \(\rightarrow\) RAPID OPS TEST ENVIRONMENT
Components of the ERS Design Environment

**Tradespace Tools & Analytics**
- Decision Support
- Data Retention
- Knowledge Mgmt
- Open Architecture
- Big Data Analytics & Visualization
- Virtual Prototyping & Evaluation

**Integrated Capability and Workflow**
- Policy / Regulation
- HPCMP & S&T Resources
- Tradespace Tools & Analytics
- ERS Environment
- ERS Cloud
- ARCHITECTURE TRADE ANALYSIS
- ADVANCED MODELING
- ENVIRONMENT REPRESENTATION
- MISSION CONTEXT

**Requirements Generation**
- Fully Explore & Identify KPPs

**Analysis of Alternatives**
- Reduce alternatives from thousands to tens or less
- Rapidly Analyze Many More Alternatives

**Virtual Prototyping & Evaluation**
- RAPID PROTOTYPING & RESPONSE
- Virtual Warfighting, Reduce Prototyping Time & Costs

**ERS Env**
- Tradespace Tools & Analytics
- Integrated Capability and Workflow
ERS Tradespace Approach

Architecture

TradeSpace Analytics

Advanced Modeling

Environmental Rep.

Mission Context

ERS CLOUD COMPUTING ENVIRONMENT

10,000X improvement in productivity in AoA

Analytical Toolset

Efficiently discover key performance parameters (KPPs)

Environmental Rep.

Advanced Modeling

Mission Context

Architecture

- Cost models
- Architectures
- other

ERS CLOUD COMPUTING ENVIRONMENT

Cost models

Build & Analyze Very Large Tradespaces

Highly computational

Sifts through millions of designs

Refined set of specifications for viable design solutions

TradeStudio

A software suite used for assembling, conceptualizing, and analyzing tradespaces

Early concept tool

Functional / component breakdown

Explore tradespace edges
Product Organization

DEFINE
Define the system and its requirements in SysML

BUILD
Construct accurate and complete tradespaces

ANALYZE
Visualize and explore the tradespace

SysML Authoring Tool

TradeStudio

Tradespace Exploration

Environment al Simulation

CREATE

Large Data Analysis
Select and Compare
Analysis of Alternatives
Mission Context Analysis
Statistical & Predictive Analysis

ERS NDIA SYS ENGINEERING CONF – OCTOBER 2016
An overarching software suite that encompasses ERS tradespace tools **TradeBuilder** and **TradeAnalyzer**

Construction, Visualization, and Exploration of Accurate and Complete Tradespaces.

**TradeBuilder**
- A generalized and reusable workflow engine
- Accelerates common tradespace assembly tasks

**TradeAnalyzer**
- An enterprise-level web portal
- Assists user in visualizing and analyzing a tradespace
The BIG Data Challenge

**ERS is moving analytics to supercomputers**

- **Centralize data** to minimize the need to move it from machine-to-machine
- **Organize software** tools around data
- **Define an approach to connect simulations with analytical tools**
- **Exploit data** in a timely and cost-effective fashion
- **Architect overall data ecosystem** for HPCMP
Computational Research & Engineering Acquisition Tools and Environments (CREATE) Program

Aircraft (AV) Tools:
Fixed-wing aircraft, rotorcraft, conceptual design, and operational testing and transition

Ground Vehicle (GV)
Autonomous navigation and operational testing

Meshing and Geometry (MG) Support:
Improves the ease, speed, flexibility, and quality of geometry and mesh generation

CREATE-AV
Aircraft (AV) Design Tools

CREATE-SHIPS
Ship Design Tools

CREATE-RF
Radio Frequency (RF) Antenna Design and Integration Tools

CREATE-MG
Meshing and Geometry (MG) Support

CREATE-GV
Ground Vehicle (GV) Design Tools

Fully Validated on Real Problems

Ship Design Tools:
Shock/damage, hydrodynamics, early-stage design, and operational testing and transition

Radio Frequency (RF) Antenna:
Conceptual design and detailed analysis tools for a myriad of DoD platforms
Key Features of the CPE

- Complement and reduce reliance on physical experimentation
- Fast, accurate – compute before bending metal
- Consider vast array of factors
- Understand and mitigate systems risk
- Inverse modeling to understand how to defeat concepts
Basis of Computational Prototyping Environment

Engineered Resilient Systems
- Architectural Integration
- Tradespace Analysis
- Environmental Simulation
- High Fidelity Physics Supporting Tradespace Analysis
- Big Data Analytics
- Knowledge Management

CREATE
- High-Performance Computing
- High-Fidelity Computational Physics
- AV, Ships, GV, RF, MG
- Future Possibilities in Space and Electronic Warfare

AFSIM, SIMAF, EAAGLES, JSE, Digital Thread, Digital Twin

Computational Prototyping Environment
- Virtual Proving Ground for T&E
- Generic Workflow Automation for Army Platforms
- High-Fidelity Physics Supporting Tradespace Analysis
- 3D Physics-Informed, Gaming-Based Visualization
ERS Transition to Acquisition Community

**US Navy NAVAIR / NAVSEA**

**NGAD AoA Tools Enhancements**
- AoA support
- HPC CREATE tool
- Tradespace tool enhancements

**Submarine Virginia-class replacement**
- Early-stage submarine design
- ERS trades analysis

Currently Developing ERS-supported Advanced Design Space Exploration (DSE)

**US Army AMRDEC/TARDEC**

**ERS Rotorcraft Design Adaptation**
- CH-47 rotor blade improvement; Concept to LRIP in 1.5 years

**Gray Eagle flight performance predictions**
- Full-scale aircraft with articulating control surfaces
- Trade & evaluate aircraft modification impact

**LRV Tradespace Expanded Design**
- Expanded tradespace resulted in new design concept

**US Air Force AFLCMC/AFRL**

**Low Cost Attritable Aircraft Technology**
- Developing integrated toolset for rapid design creation
- Ability to trade many new designs rapidly
- Understanding conceptual design via advanced tradespace analytics and physics-based computations.

ERS Rotorcraft Design Adaptation

Kestral CFD Model Built [CREATE-AV] from scanned model
ERS Exemplar: CH-47-F Chinook Rotor: Adaptable Design / Rapid Decision-making

CH-47-F Improved design element
Rapid, robust computational analysis
High-Fidelity Performance Predictions
PM made rapid, confident decision
Low-rate Initial Production (LRIP)

Planned Work
Full use of TradeStudio Toolset
Integrate mission planning with computational prototyping: Virtual Proving Ground

New Rotor Blade Design Proposed
HPC CREATE Tools inform Helop mission sims
AMRDEC

Comprehensive and complete analysis available up-front.
Time-consuming “go-back” tasks eliminated.

Planned: CH-47 test – Q1-FY17 Mesa, CA Boeing Test Site

Now: < 1.5 years from new design concept to LRIP
Future: < 2 years from concept design to Operational Testing
Light Reconnaissance Vehicle (LRV) Project

Apply CREATE-GV and ERS tools to the Light Reconnaissance Vehicle (LRV) concept and perform tradespace exploration

- Capability demonstration of LRV tradespace exploration with ERS Tools
- Assessment of how new tools complement and enhance current ground vehicle M&S and trade studies
- Delivery of new modeling capabilities for the LRV
- Establishment of more collaborative processes for tradespace exploration

Original LRV concept  
LRV model for tradespace analysis

CREATE-GV

Ground Vehicle (GV) Design Tools

HPC CREATE tools  
Collaboration  
Advanced Tradespace Tools
Reviewed initial LRV concept and tradespace
TARDEC + ERDC

Learned and applied CREATE-GV & ERS tools
TARDEC + ERDC

Expanded tradespace
analytics + concepts + ECP
(warfighter customer)

Used CREATE-GV & ERS tools for tradespace exploration

Generated new design set, new LRV concept

LRV Tradespace Exploration
Low Cost Attritable Aircraft Technology (LCAAT)

Deliver a prototype of an inexpensive, Attritable aircraft that can be readily reconfigured to various, unanticipated missions

- Integrated tool set for rapid creation of design concepts and tradespace analysis of designs
- Understanding of tradespace around conceptual designs
- Studies at conceptual/preliminary level design concepts and data
Gray Eagle Flight Performance Model

The development of a validated computational model and processes to predict flight performance.

Future: investigate the effects of cross winds on takeoff and landing performance.

• Aerodynamic Database based on a Kestrel CFD Model of full-scale aircraft with articulating control surfaces
• Flight Performance Model
  • Climb – Decent – Cruise
  • Specific Range
  • Time on Station vs. Mission Radius
• Provide PM UAS with an independent tool for evaluating flight performance for proposed modifications
  • OML changes (e.g., antenna, control surfaces)
  • Addition of store (e.g., pods, weapons)
• Independent evaluation of operator manuals
Next Generation Air Dominance (NGAD)

Explored needs to recapitalize capabilities currently provided by Navy F/A-18E/F and EA-18G platforms

ERS-enhanced MAOIE
- Modernized to current DoD .NET standards
- Parallelized on all platforms
- Scaled from (typical) 9,000 aircraft in a week to 320,000 aircraft in 70 minutes
- Includes enhanced parametric modeling through NASA OS software OpenVSP allowing larger, more accurate runs

- Faster examination of new ideas
- Rapid construction of parametric aircraft with thousands of “morphable” properties
- Avoid manual redrawing of aircraft
- Crosscutting capability (currently extending capability to AFRL)
Connecting with Industry Partners

INDUSTRY IS KEY TO ERS
Industry connection to ERS tools and technologies is critical to success and acquisition reform.

IP PROTECTION IS CRITICAL
Protection of Intellectual Property is provided via privately controlled Amazon Web Services.

SECURITY ASSURANCE
Data in motion and at rest is protected via the ERS Security measures.

CURRENT EXPERIMENTATION

- Use 3rd party web service (such as AWS, Microsoft Azure, Google, etc.)
- Contractor info hosted / secured on 3rd Party system
- Government pulls from web service as needed
ERS – BAE Systems

Develop ERS Cloud Computing Architecture prototype that provides

- Secure provisioning of defense contractor proprietary models and simulation tools
- Insures alignment with ERS Architecture standards

Enables

- Access contractor component data / simulations
- Methods to assemble tradespace analyses using collections of heterogeneous model simulations
ERS – Lockheed Martin

- **Experimentation with LM tools and CREATE/AV HPC tools and resources**
- **Assessing ERS Architecture via Architecture Working Group participation**

- Multi-discipline, multi-domain computational aeroelasticity analysis leveraging Lockheed ESAVE methodology with CREATE/AV tools (Kestrel)
- Feasibility investigation of integrating current LM tools into Kestrel’s multidisciplinary framework
- Explore integration of ERS HPC resources for expanded or higher fidelity exploration of product design space
ERS – Boeing

**OPTIMIZED INTEGRATED MULTIDISCIPLINARY SYSTEMS (OPTIMUS)**

Develop & verify collaborative multi-disciplinary optimization (MDO) methods that consider aero, structure, sub systems, cost and reliability

**Key Optimization Areas:**
1. Cost
2. Reliability Based Design
3. Attritable Design

- Expand the MDO-based design process to include cost, reliability-based design and attritable design.
- Perform effectiveness-based design using the OPTIMUS MDO process developed to an LCAAT SEAD mission.

Optimized LCAAT configuration early in conceptual design process

LCAAT MDO demonstration
ERS – Raytheon

Expand and enhance Engineered Resilient Systems (ERS) model-based requirements and design by analysis for missile/projectile design studies

- ERS Architecture definition including
  - ERS Architecture baseline
  - Big Data and Visualization software evaluation
  - evaluation of data link between contractor-provided computing facilities and computing facilities at US Army ERDC-ITL
  - protection of IP during pre-Milestone A acquisition activities
  - using a software architectural interface (e.g., REST (Representational State Transfer)) to demonstrate the linkage between model-based design information and modeling and/or simulation toolsets

- Use of CREATE AV tools in early-stage vehicle & sensor design to develop simulations
S&T Work Remains

**Advanced Infrastructure**
Computing infrastructure tailored to ERS-based decision making for all data classification levels

**Workflow Automation**
Automated workflows over multiple critical domains, in multiple security levels

**Critical S&T Focus Areas**

**Reduced Order Modeling**
Current tools often require force functioning of ERS high-fidelity physics, not utilizing computational burdens. Requires users to be SMEs to properly train and execute high-fidelity models

**Environmental Simulation**
Rigorous capability to provide environmental conditions to the warfighter anywhere in the world

**Cost Modeling**
ERS does not have a formal approach to cost modeling
Closing Comments

- Engineered Resilient Systems has completed the architecture and is implementing an open and secure ERS system
- Tradespace Toolset is operating and being used in cross-community real and experimental projects
- Computational prototyping is necessary to achieve acquisition reform
- S&T challenges remain

Industry has contributed greatly to the development of ERS. Future partnerships on real, acquisition tasks are critical.
Questions
Back-up
Multiple Partners are formally engaged in ERS development.

Government-Industry-Academia Architecture Working Group

Nov. 18-19, 2015
Software Engineering Institute

Amazon Web Services Workshop

August 24-25, 2016
ERDC ITL

August 5-6, 2016
ERDC ITL
Parametric Airplane with High-Fidelity Physics

Generate a tradespace while utilizing high-fidelity physics tightly in the loop

- Greater tradespace fidelity
- Demonstrate the robustness of this approach

Varied Main Wing Aspect Ratio and Leading Edge Sweep Angle
Varied Vertical Rear Wing Aspect Ratio
Varied Horizontal Rear Wing Aspect Ratio

Stall at high alpha

Lift / Drag vs. Angle Of Attack

Greater tradespace fidelity
Demonstrate the robustness of this approach
TradeBuilder

A generalized and reusable workflow engine used for accelerating common tradespace assembly tasks

- Develops more comprehensive and complete tradespaces
- Facilitates move of DoD conceptual design pipelines to HPC
- Solves cross-cutting issues in design process.

MBSE Builder:
- Create SysML-like diagrams for systems description

Tradespace Execution:
- Create new datasets using executable models

Visualization Tool:
- Explore the tradespace and examine alternatives
TradeAnalyzer

An enterprise-level web portal designed to assist the user in visualizing and analyzing a tradespace.

- TradeAnalyzer tools select, visualize, and analyze tradespaces.
- Tools operate on many data types and sizes, from (desktop spreadsheets to HPC-generated big-data sets.

**Large Data Visualization:**
- Data reduction, histograms, and 2D scatterplots

**Tradespace Analysis:**
- Interactive 2D scatterplot matrix, system requirements, and alternative comparisons

**R-Analytics:**
- R scripts for custom data analyses and visualizations

**3D Scatterplot:**
- Large data 3D scatterplot
Architecture Framework

Designed to span the lifecycle of a system from concept formulation through sustainment

- Provide a cohesive, integrating capability for ERS tools, technologies and products
- Develop reference architecture
- Promote reuse and common infrastructure
- Develop guidance and standards
- Work closely with application and development teams

- ERS System Architecture document in final stages of review, release Q2 FY17
- Online availability [DTIC] in FY17
ERS Workflow

Requirements and Systems Modeling
Requirements and system concepts are captured in SysML.

SysML models are refined to include the baseline design, performance metrics, models, and methods to create the tradespace.

 Tradespace Creation
• High-fidelity models assess performance aspects of the system.
• Parameter sweeps introduce design variations into the tradespace.
• Performance and effectiveness metrics are identified and assessed on each design.

 Tradespace Analysis
Collaborative and interactive tradespace exploration

Products:
• ERS System Architecture
• SysML Model Builder
• Engineering Notebooks
• CREATE
• Computational Model Builder (CMB)
• Mission Context Modeling

Transition:
• All of DoD (multiple platforms)
• Academic and industry partners (BAE, Lockheed, Raytheon, Boeing, Northrop)

• ERS TradeStudio
• Statistical Analysis Tool
  - Descriptive / Predictive
• Big Data Analytics & Visualization

Save data and decisions for future analyses
Computational Notebooks

TEXT, DIAGRAMS, EQUATIONS, EXPLANATIONS

HIGH-LEVEL CODE DIRECTLY EXECUTABLE ON ERS HPC

RESULTS, TABLES, GRAPHS, STATISTICS

COMPUTATIONAL NOTEBOOK: PIPELINE OF ACTIVITIES
EASE OF USE
EASILY SHARED

NOTEBOOKS ARE DESIGNED TO BE SHARED

ERS Computing Environment

NOTEBOOKS CAN RUN ON ANY ERS PLATFORM