Engineered Resilient Systems

Power of Advanced Modeling and Analytics in Support of Acquisition

19th Annual NDIA Systems Engineering Conference
October 26, 2016

Jeffery P. Holland, PhD, PE (SES)
ERS Community of Interest (COI) Lead
Director, US Army Engineer Research and Development Center (ERDC)
Director, Research and Development, US Army Corps of Engineers

ERS Community of Interest (COI)

ERS ENGINEERED RESILIENT SYSTEMS

Introduced in 2010

- ***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***

Advanced Electronics	Air Platforms	Autonomy	Biomedical (ASBREM)
C4I Command & Control	Counter IED	Counter-WMD	Cyber
Energy & Power Technologies	ERS ENGINEERED RESILIENT SYSTEMS	EW	Ground & Sea Platforms
Human Systems (Training)	Materials & Manufacturing Processes	Sensors & Processing	Space
	Weapons Technologies		

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

Robert A. Gold, DASD/SE
OSD Lead

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

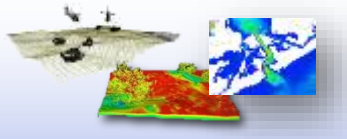
Col. K. Colin Tucker, SAF/AQ
USAF Lead

ERS Partners on Current Key Projects

Decision Analysis & Armaments Tradespace Ground Vehicle Tradespace Gray Eagle Flight Performance Database	ARDEC TARDEC/TACOM AMRDEC
Next Gen Air Dominance Tradespace Robust Early-Stage Submarine Design Data Repository Services	NAVAIR NSWC NSWC
Low Cost Attritable Aircraft Tech (LCAAT) ISR Futures	AFRL AFLCMC
Satellite and Projectile Analysis and Design Efficient Supersonic Air Vehicle Exploration Architecture Considerations for Industry LCAAT Cost and Reliability Modeling	Raytheon Lockheed Martin BAE Boeing
Small Arms Ammunition Config Study Architecture and Software Engineering Resiliency and Decision Analysis ERS Tool Dev. & Resiliency Research	USMA/ARDEC CMU/SEI Univ of Arkansas GTRI

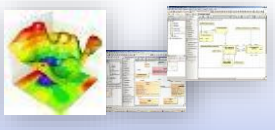
ERS Leverages Years of Major DoD Investments

ADVANCED MODELING



CONTEXT SIMULATION

HIGH-PERFORMANCE COMPUTING



MATHEMATICAL OPTIMIZATION

OPEN & TRUSTED SYSTEMS

TRADES ANALYSIS

ANALYSIS OF ALTERNATIVES

ENGINEERING ANALYSIS

PROTOTYPING

DECISION SUPPORT & ANALYSES
TradeStudio
Analytic Tools

MODELS
CREATE
Envir Sims
Lifecycle Intel

OPERATIONS
UTL
Mission
Doctrine

CAPABILITIES ASSESSMENTS

DEVT TEST & EVALUATION

EMERGING RESEARCH
X-ARPAs
Research
Algorithms

KNOWLEDGE MGMT
Notebooks
Knowledge Hub
Wiki

HPC ***General Computing*** ***Amazon Web Cloud*** ***Enterprise Computing*** ***Embedded Computing***

ERS Spans the DoD Acquisition Lifecycle

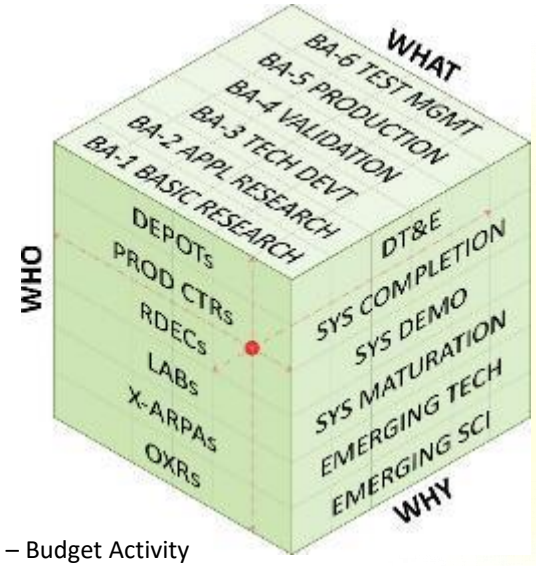
ERS PROCESSES

CAPABILITIES ASSESSMENTS	ENGINEERING ANALYSIS	TRADES ANALYSIS
AoA	DT&E	PROTOTYPING

RESEARCH/DEVELOPMENT

EMERGING S&T

PROOF OF CONCEPT



BA – Budget Activity
UTL – Universal Task List

ERS CAPABILITIES

NUMERICAL SIMS

MODELS
CREATE
Envir Sims
Lifecycle Intel

DECISION SUPPORT & ANALYSES
TradeStudio
Analytic Tools

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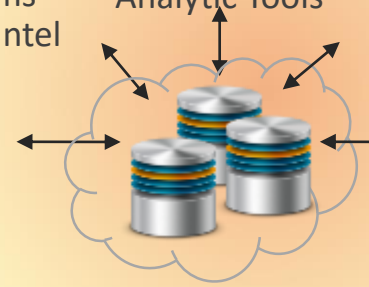
UTL
Mission
Doctrine

ANALYTICAL INSIGHTS

EMERGING RESEARCH
X-ARPAs
Research
Algorithms

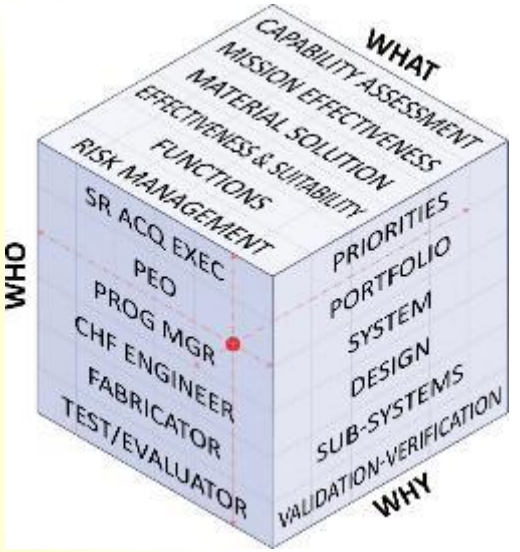


KNOWLEDGE MGMT
Notebooks
Knowledge Hub
Wiki

ACQUISITION

CAPABILITIES

EFFECTIVENESS



ERS SECURE COMPUTING

HPC | *General Computing* | *Amazon Web Cloud* | *Enterprise Computing* | *Embedded Computing*

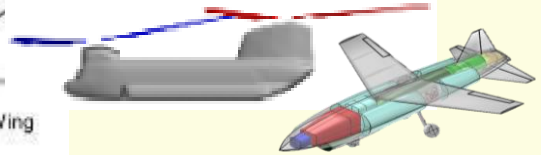
RESEARCHERS SMEs ENGINEERS DECISION-MAKERS WARFIGHTERS

GOVERNMENT INDUSTRY ACADEMIA

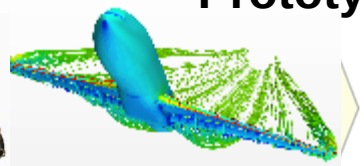
ERS: A 10-Year Challenge

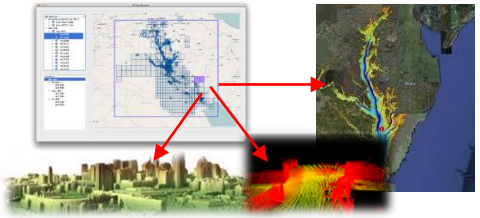
Conceptual Design

Adaptable Design



Computational Prototyping





Virtual Proving Ground

2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022

INTEGRATED CAPABILITY → *HPC-EMPOWERED OPEN ARCHITECTURE AND SECURE SYSTEM*

TRADESPACE ANALYTICS → *MILLIONS OF OPTIONS RAPIDLY CONSIDERED*

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

PHYSICAL REPRESENTATIONS → *IN CONCEPTS, TRADES, PROTOTYPING, TESTING*

BIG DATA SOLUTIONS → *ADVANCED VISUALIZATIONS, BILLIONS OF DATA POINTS CAPTURED*

COLLABORATION → *KNOWLEDGE SHARING, DATA ACCESS, RETENTION, REUSE*

PHYSICS-BASED PROTOTYPING → *COMPUTATIONAL PROTOTYPING ENVIRONMENT*

RIGOROUS VIRTUAL DT&E → *RAPID OPS TEST ENVIRONMENT*

Components of the ERS Design Environment

Tradespace Tools & Analytics

Policy / Regulation

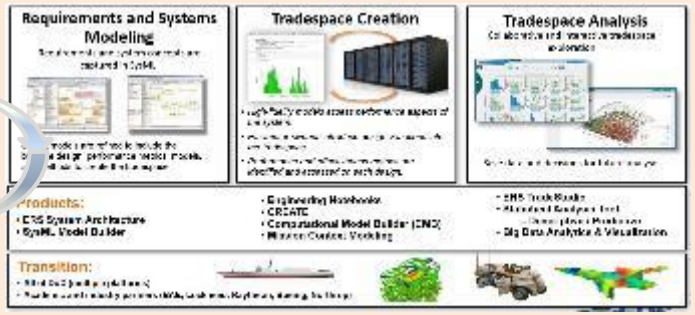
ARCHITECTURE
TRADE ANALYSIS
ADVANCED MODELING
ENV REPRESENTATION
MISSION CONTEXT
...ilities
other

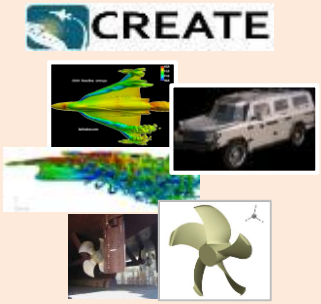
ERS Cloud

10,000X Productivity Improvement In AoA

HPCMP & S&T Resources

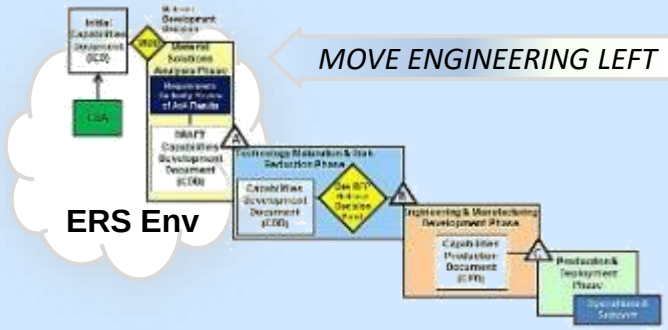
Integrated Capability and Workflow





Decision Support | *Big Data Analytics & Visualization* | *Open Architecture* | *Knowledge Mgmt* | *Data Retention*

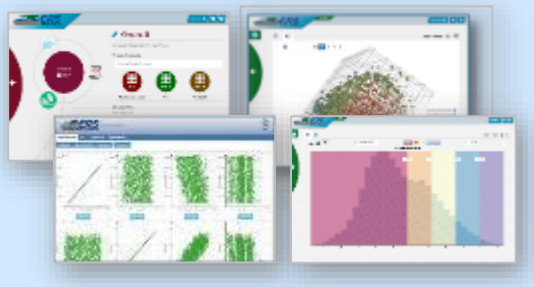
Requirements Generation



Fully Explore & Identify KPPs

Analysis of Alternatives

Reduces alternatives from thousands to tens or less



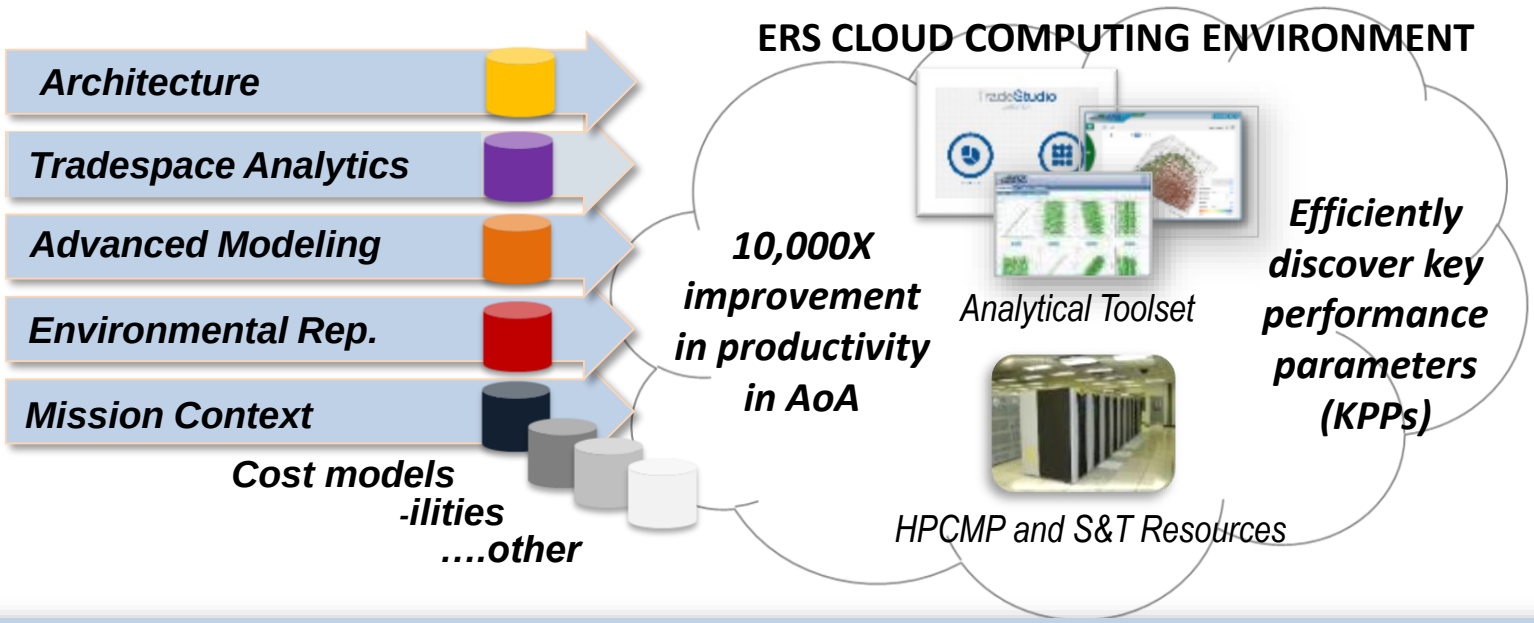
Rapidly Analyze Many More Alternatives

Virtual Prototyping & Evaluation

RAPID PROTOTYPING & RESPONSE

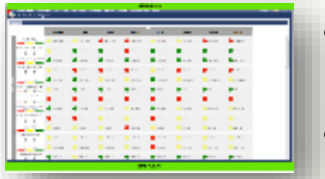
Virtual Warfighting, Reduce Prototyping Time & Costs

ERS Tradespace Approach

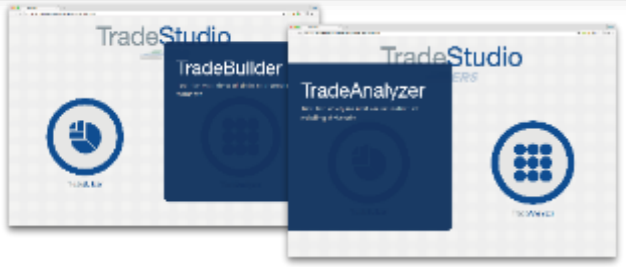


TradeStudio

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



- Early concept tool
- Functional / component breakdown
- Explore tradespace edges



Build & Analyze Very Large Tradespaces

- Highly computational
- Sifts through millions of designs
- Refined set of specifications for viable design solutions

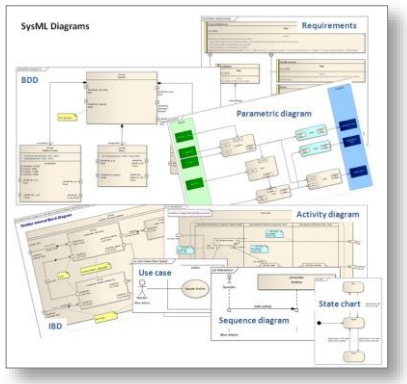
Product Organization

TradeStudio

DEFINE

Define the system and its requirements in SysML

SysML Authoring Tool



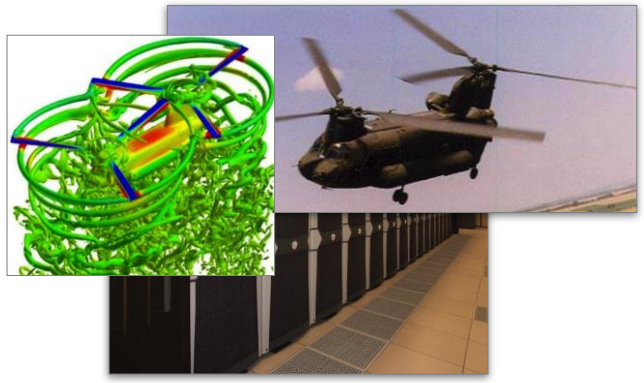
BUILD

Construct accurate and complete tradepaces

Tradespace Exploration

Environmental Simulation

CREATE



ANALYZE

Visualize and explore the tradespace

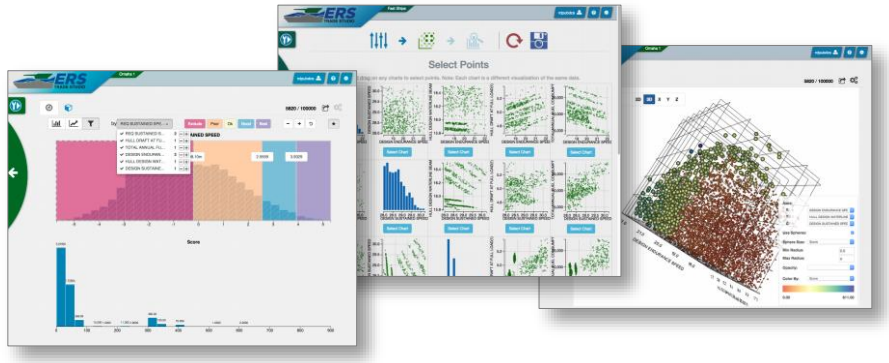
Large Data Analysis

Select and Compare

Analysis of Alternatives

Mission Context Analysis

Statistical & Predictive Analysis



TradeStudio

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

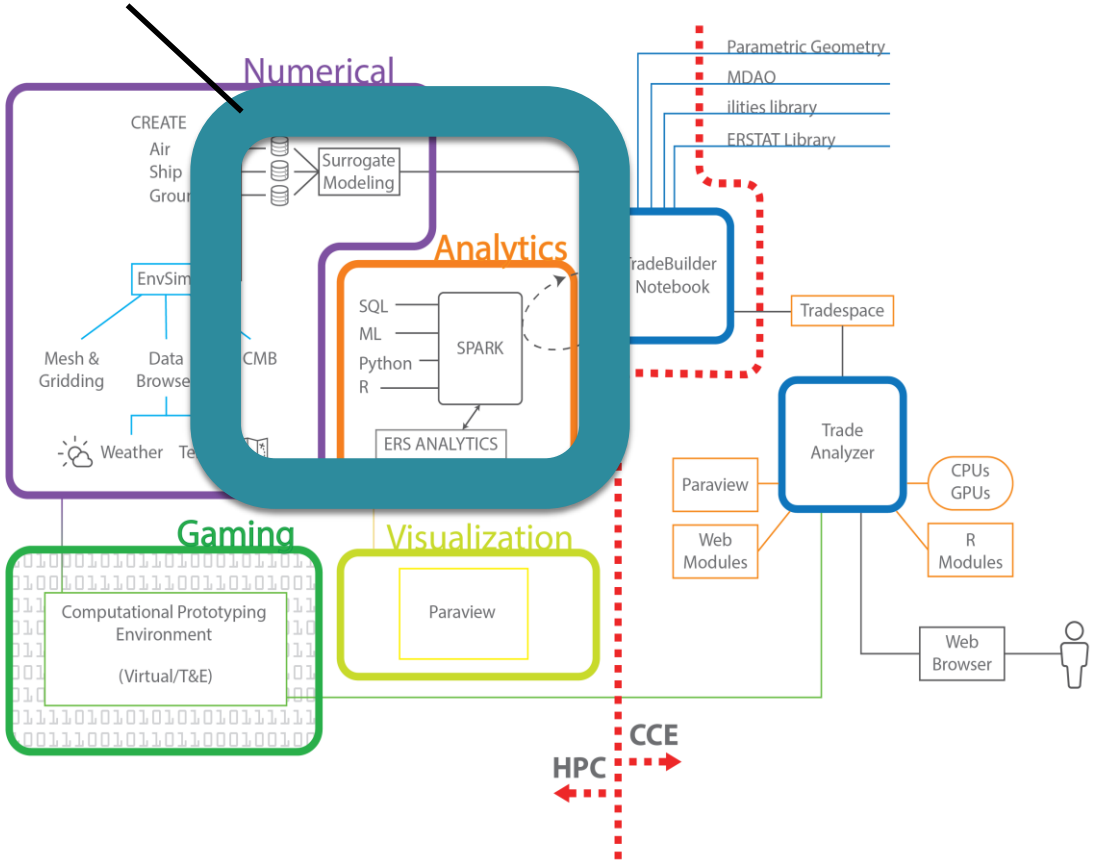
TradeAnalyzer

- An enterprise-level web portal
- Assists user in visualizing and analyzing a tradespace

The BIG Data Challenge

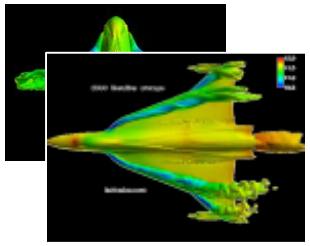
- **Centralize data** to minimize the need to move it from machine-to-machine
- **Organize software** tools around data
- Define an approach to **connect simulations with analytical tools**
- **Exploit data** in a timely and cost-effective fashion
- Architect overall **data ecosystem** for HPCMP

ERS is moving analytics to supercomputers

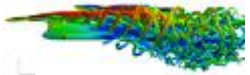


Computational Research & Engineering Acquisition Tools and Environments (CREATE) Program

Aircraft (AV) Tools:



Fixed-wing aircraft, rotorcraft, conceptual design, and operational testing and transition

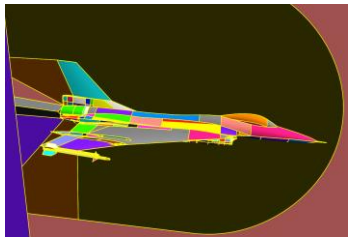


Ground Vehicle (GV)

Autonomous navigation and operational testing

Meshing and Geometry (MG) Support:

Improves the ease, speed, flexibility, and quality of geometry and mesh generation



CREATE

Fully Validated on Real Problems

CREATE-AV
Aircraft (AV) Design Tools

CREATE-SHIPS
Ship Design Tools

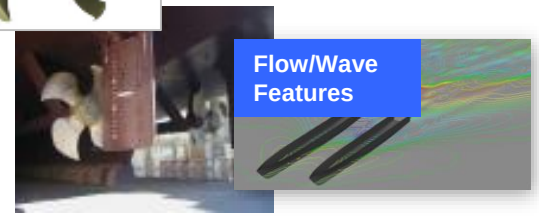
CREATE-RF
Radio Frequency (RF) Antenna Design and Integration Tools

CREATE-MG
Meshing and Geometry (MG) Support

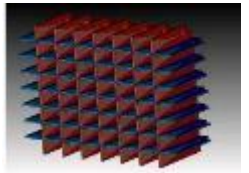
CREATE-GV
Ground Vehicle (GV) Design Tools

Ship Design Tools:

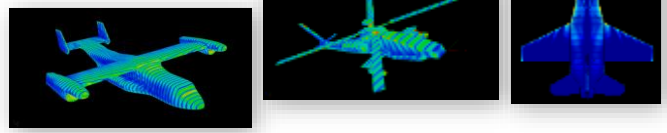
Shock/damage, hydrodynamics, early-stage design, and operational testing and transition



Radio Frequency (RF) Antenna:



Conceptual design and detailed analysis tools for a myriad of DoD platforms

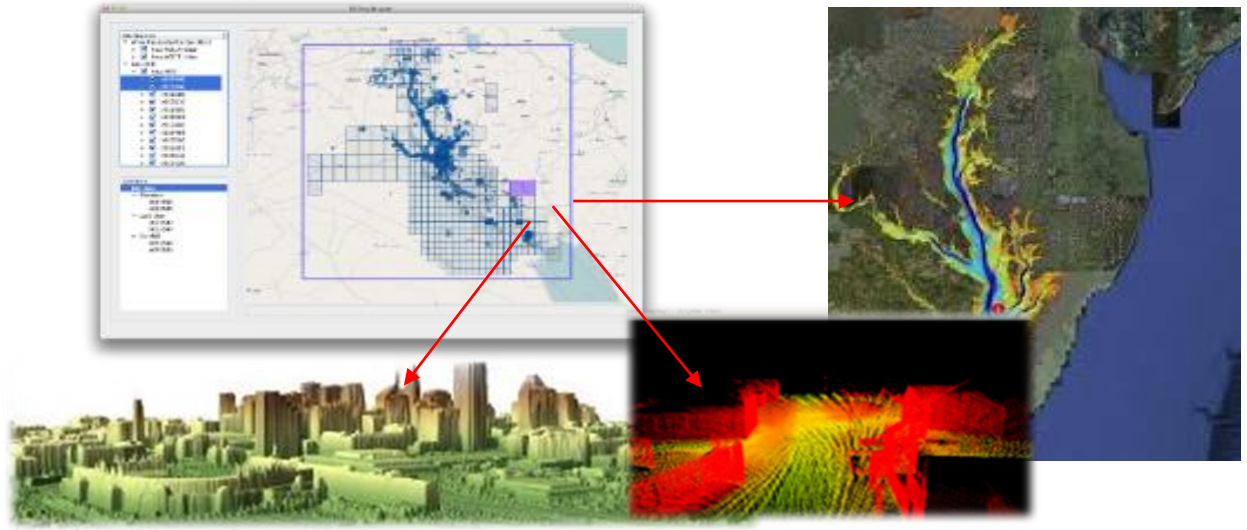


DoD Computational Prototyping

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

Physics-based Models & Simulations



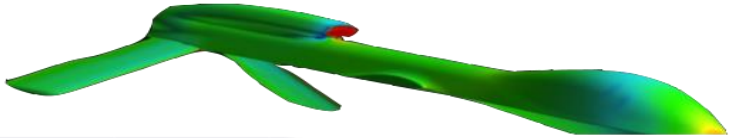
Mission Location

Physical Environment

Basis of Computational Prototyping Environment

Engineered Resilient Systems

- Architectural Integration
- Tradespace Analysis
- Environmental Simulation
- Big Data Analytics
- Knowledge Management



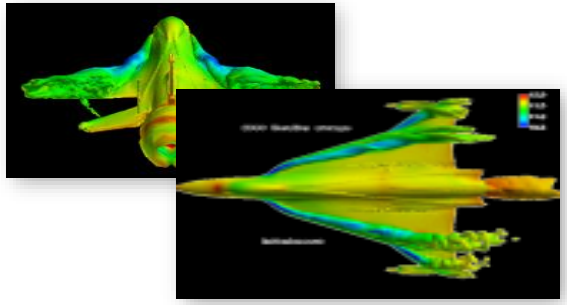
CREATE

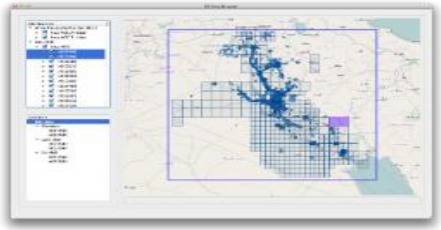
- High-Performance Computing
- High-Fidelity Computational Physics
- AV, Ships, GV, RF, MG
- Future Possibilities in Space and Electronic Warfare

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



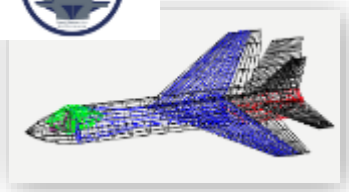


ERS Transition to Acquisition Community

US Navy
NAVAIR / NAVSEA

NGAD AoA Tools Enhancements

- AoA support
- HPC CREATE tools
- Tradespace tool enhancements



Submarine Virginia-class replacement

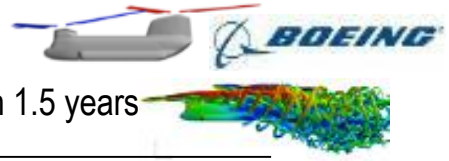
- Early-stage submarine design
- ERS trades analysis

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

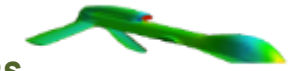
US Army
AMRDEC/TARDEC

ERS Rotorcraft Design Adaptation

CH-47 rotor blade improvement;
Concept to LRIP in 1.5 years



Gray Eagle flight performance predictions

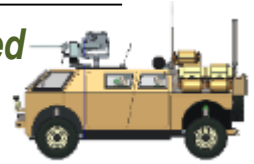


- Full-scale aircraft with articulating control surfaces
- Trade & evaluate aircraft modification impact

Kestral CFD Model Built [CREATE-AV] from scanned model

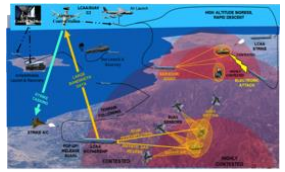
LRV Tradespace Expanded Design

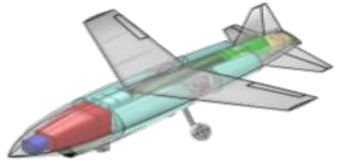
Expanded tradepace resulted in new design concept

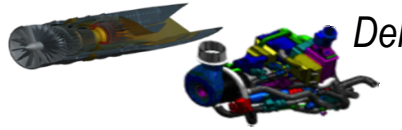


US Air Force
AFLCMC/AFRL

Low Cost Attritable Aircraft Technology







Delivering LCAAT Prototype

- 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 Exemplar: CH-47-F Chinook Rotor: Adaptable Design / Rapid Decision-making

CH-47-F Improved design element

BOEING

New Rotor Blade Design Proposed

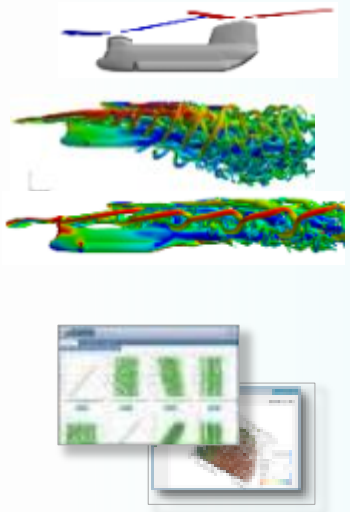
Rapid, robust computational analysis

Helios

HPC CREATE Tools inform Helop mission sims

AMRDEC

High-Fidelity Performance Predictions



PM made rapid, confident decision

Comprehensive and complete analysis available up-front.

Time-consuming "go-back" tasks eliminated.

Low-rate Initial Production (LRIP)

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

Planned Work

Full use of TradeStudio Toolset

TradeStudio

ERS ENGINEERED RESILIENT SYSTEMS

Integrate mission planning with computational prototyping:
Virtual Proving Ground

***Now:* < 1.5 years from new design concept to LRIP**

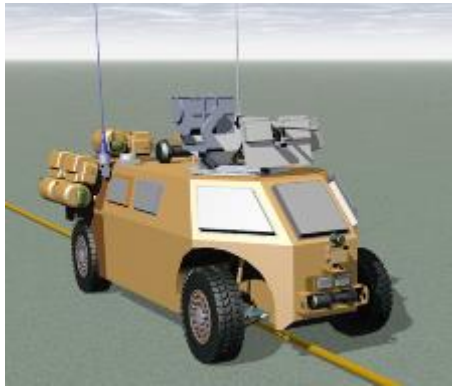
***Future:* < 2 years from concept design to Operational Testing**

Light Reconnaissance Vehicle (LRV) Project

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

Original LRV concept

LRV model for tradespace analysis



- 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

HPC CREATE tools *Collaboration* *Advanced Tradespace Tools*

LRV Tradespace Exploration

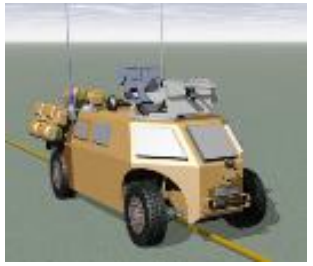
Reviewed initial LRV concept and tradespace
TARDEC + ERDC

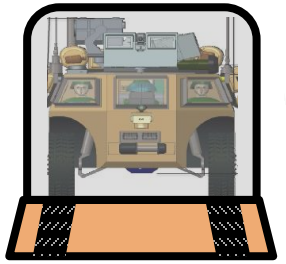
Learned and applied CREATE-GV & ERS tools
TARDEC + ERDC

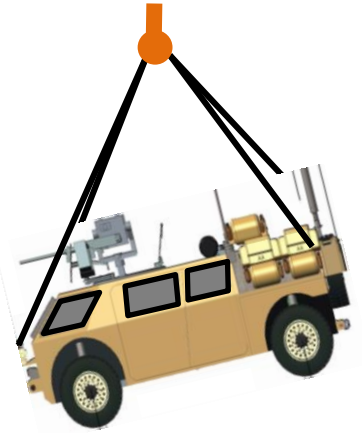
Expanded tradespace
analytics + concepts + ECP (warfighter customer)

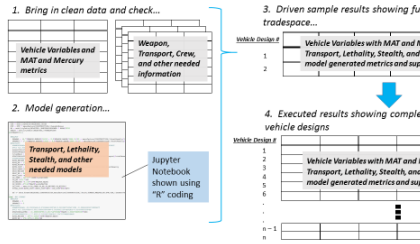
Used CREATE-GV & ERS tools for tradespace exploration

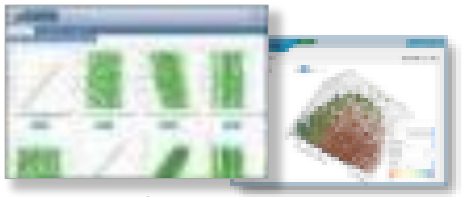
Generated new design set, new LRV concept

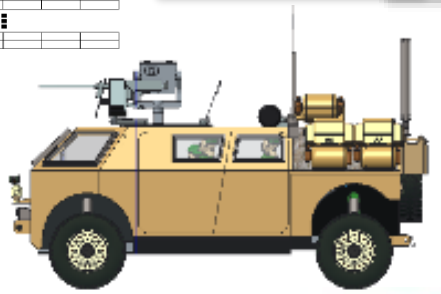






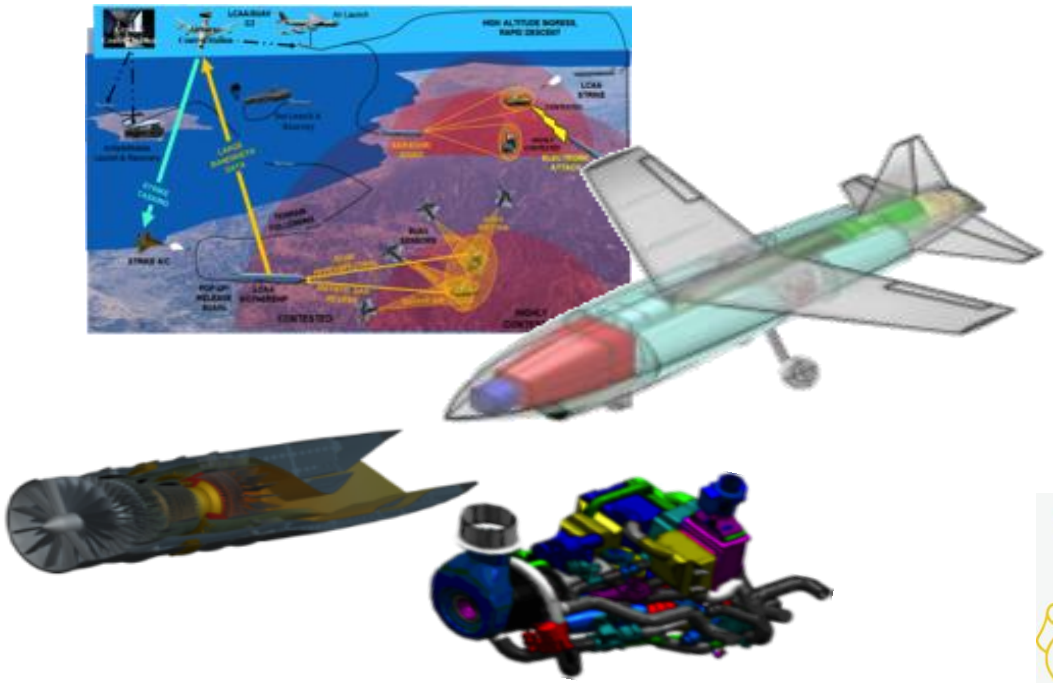






Low Cost Attritable Aircraft Technology (LCAAT)

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

AIR FORCE LCMC

AIR FORCE RESEARCH LABORATORY

BOEING

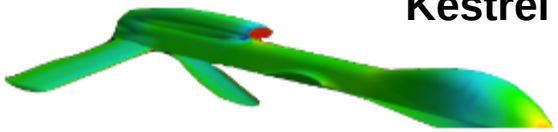
Gray Eagle Flight Performance Model

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.

Scanned Model

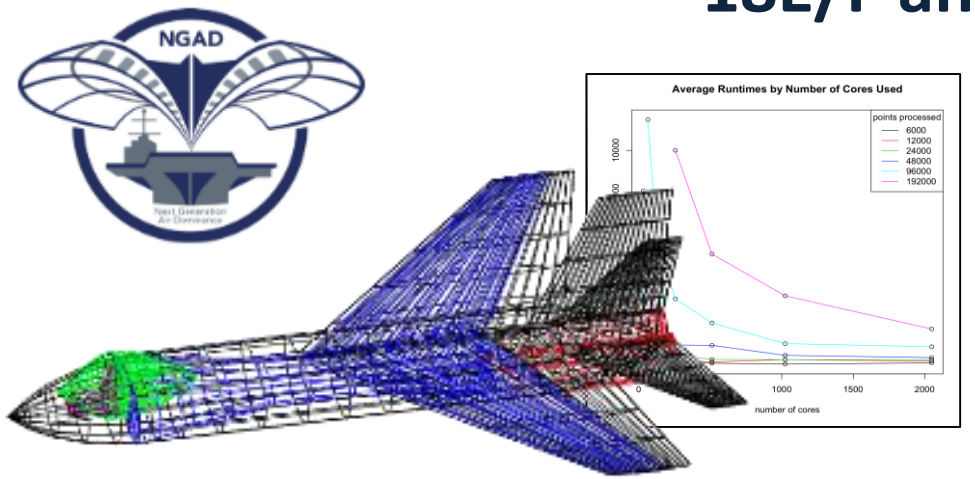
Kestrel Solution



- 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



- 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)

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

NAVAL AIR SYSTEMS COMMAND

ERDC
INNOVATIVE SOLUTIONS for a safer, better world

Connecting with Industry Partners

INDUSTRY IS KEY TO ERS

Industry connection to ERS tools and technologies is critical to success and acquisition reform

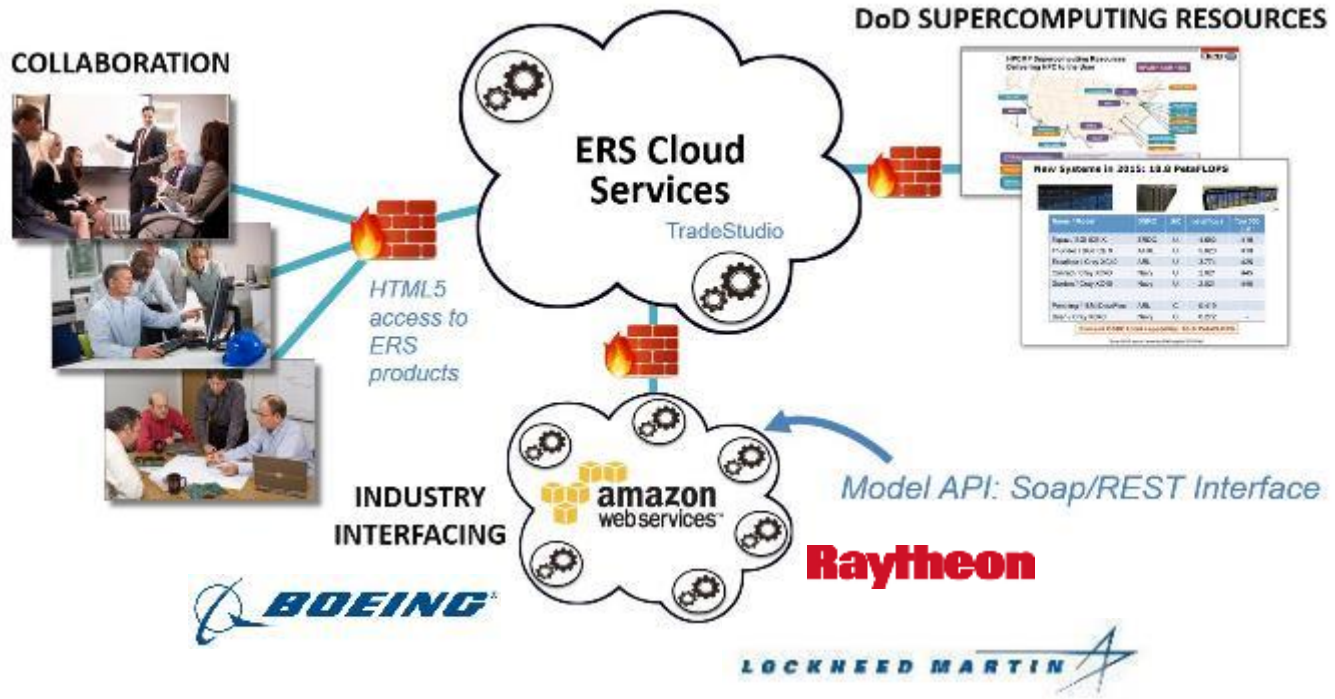
IP PROTECTION IS CRITICAL

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

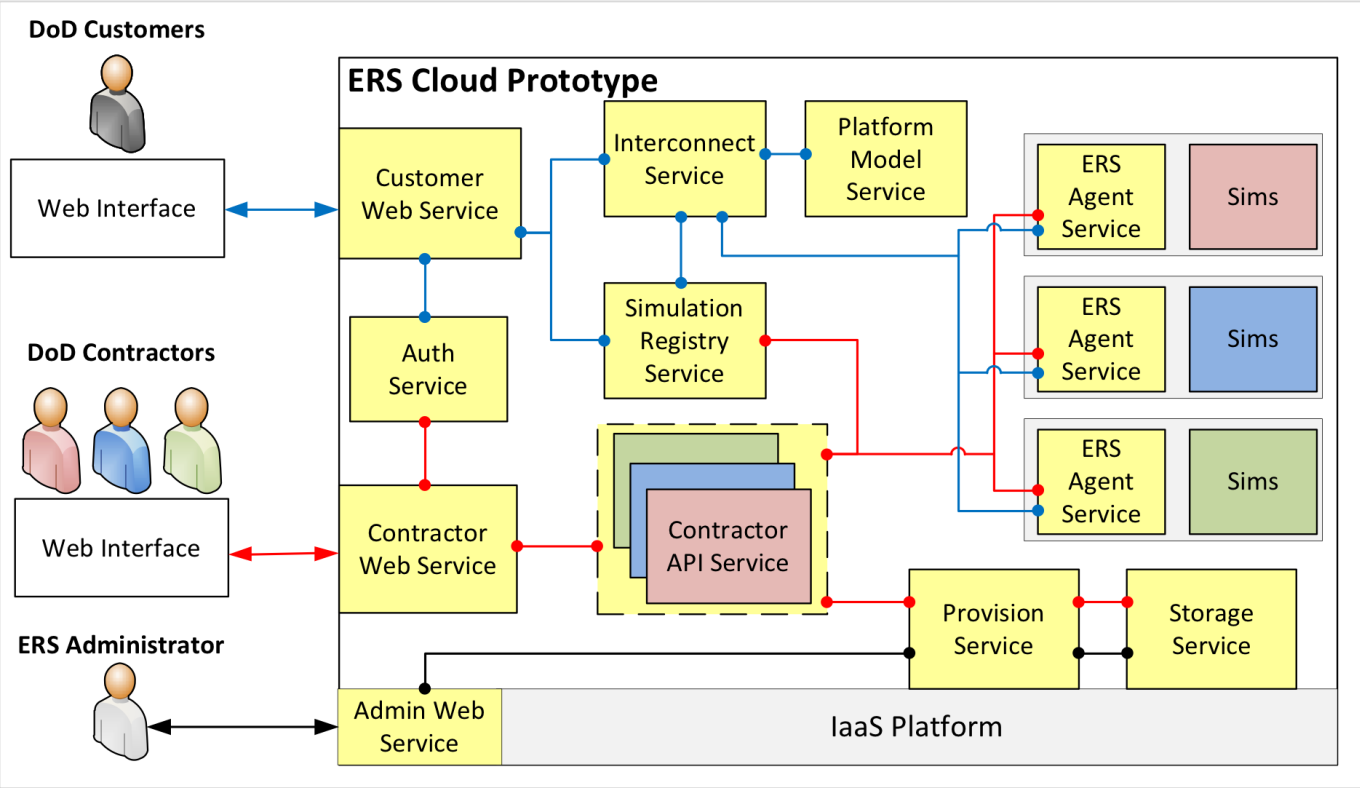


- Use 3rd party web service (such as AWS, Microsoft Azure, Google, etc.)
- Contractor info hosted / secured on 3rd Party system
- Government pulls from web service as needed

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

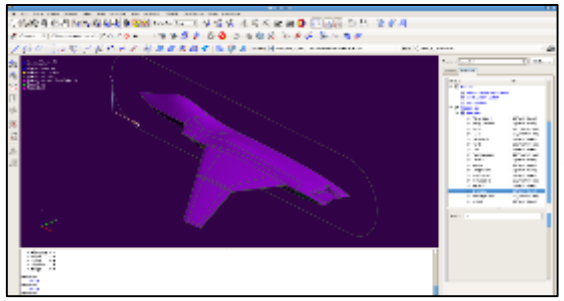
- Access contractor component data / simulations
- Methods to assemble tradespace analyses using collections of heterogeneous model simulations

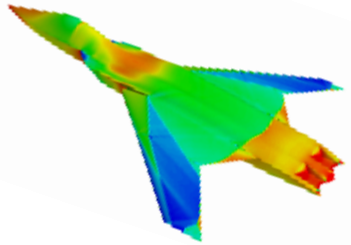
BAE SYSTEMS

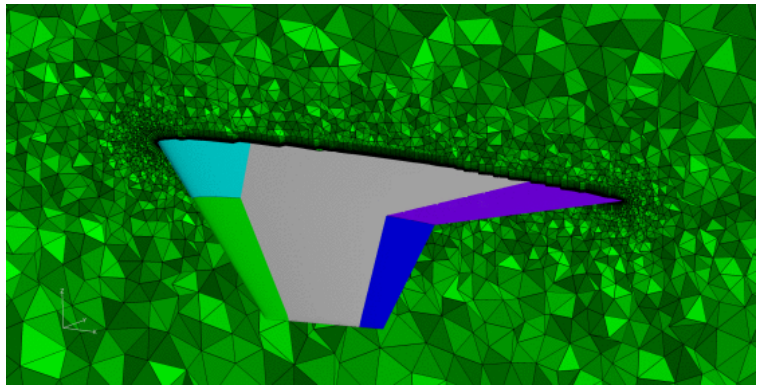
ERS – Lockheed Martin

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

Capstone MedFi01 CAD and Mesh







- 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

LOCKHEED MARTIN

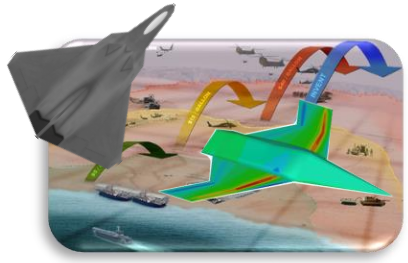
ERS – Boeing

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*



Optimized LCAAT configuration early in conceptual design process

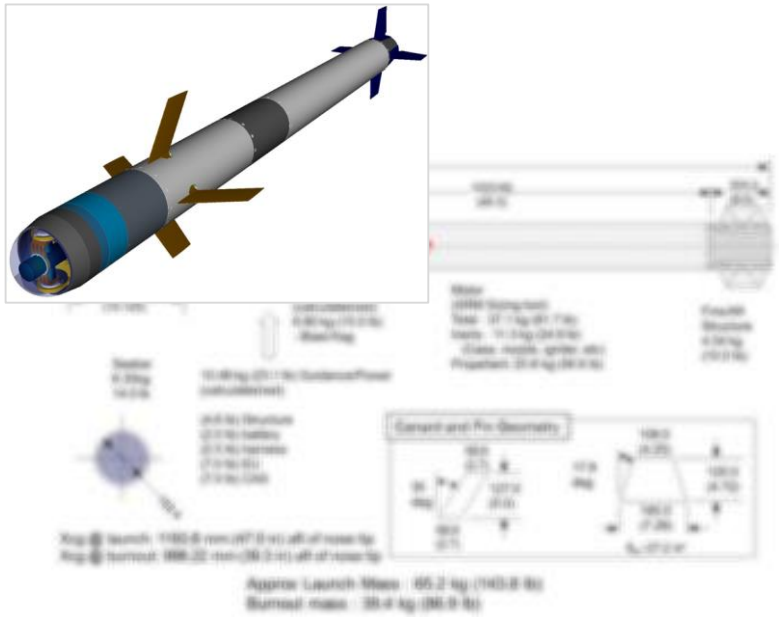
LCAAT MDO demonstration

- 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.

BOEING

ERS – Raytheon

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



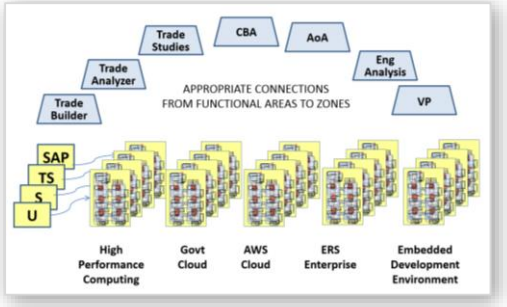
- ERS Architecture definition including
  - ERS Architecture baseline
  - Big Data and Visualization software evaluation
  - evaluation of data link between contractor-provided computing facilities and computing facilities at US Army ERDC-ITL
  - protection of IP during pre-Milestone A acquisition activities
  - 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

Raytheon

S&T Work Remains

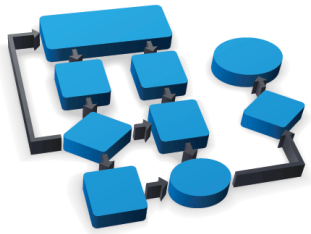
Critical S&T Focus Areas

Advanced Infrastructure



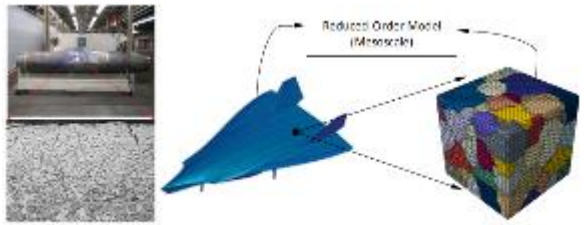
Computing infrastructure tailored to ERS-based decision making for all data classification levels

Workflow Automation



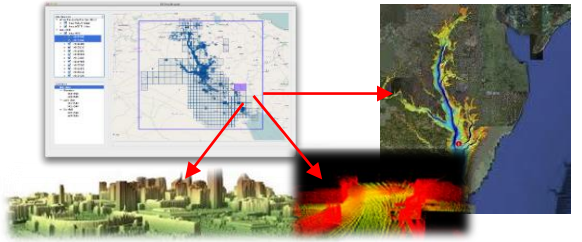
Automated workflows over multiple critical domains, in multiple security levels

Reduced Order Modeling



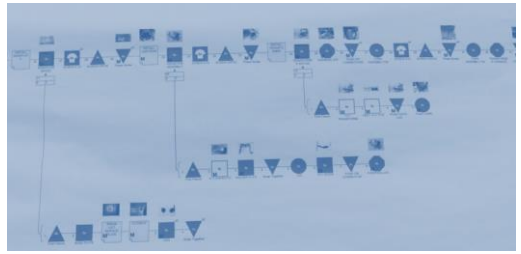
Current tools often require force functioning of ERS high-fidelity physics, not utilizing computational burdens. Requires users to be SMEs to properly train and execute high-fidelity models

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 hallenges remain**

NDIA Systems Engineering Conference 2012, 2014, 2015, 2016

Industry has contributed greatly to the development of ERS. Future partnerships on real, acquisition tasks are critical.

Questions

Back-up

ERS Architecture Working Group
Government, Industry & Academia – Active Engagement

Multiple Partners are formally engaged in ERS development.

Government-Industry-Academia Architecture Working Group

Nov. 18-19, 2015
Software Engineering Institute

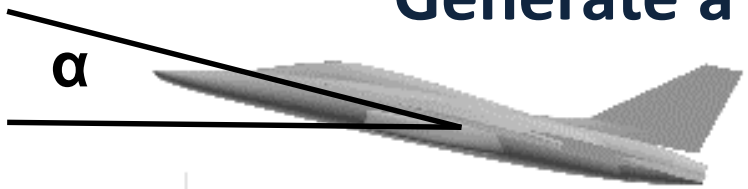
August 24-25, 2016
ERDC ITL

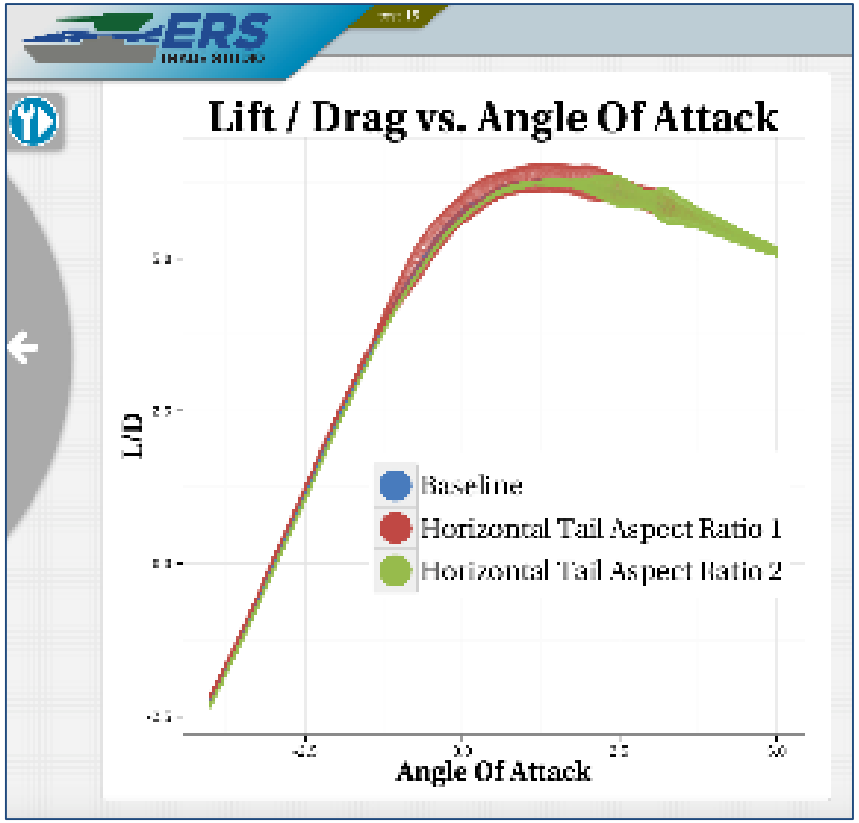
Amazon Web Services Workshop

August 5-6, 2016
ERDC ITL

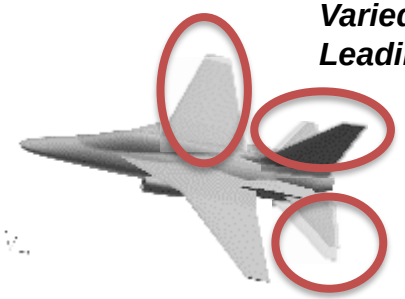
Parametric Airplane with High-Fidelity Physics

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





- Greater tradespace fidelity
- Demonstrate the robustness of this approach

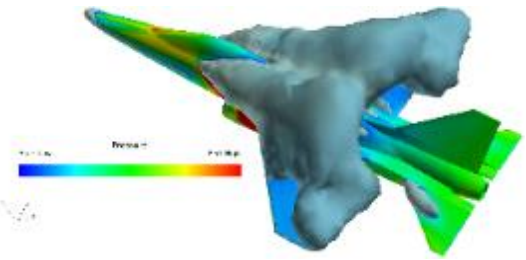


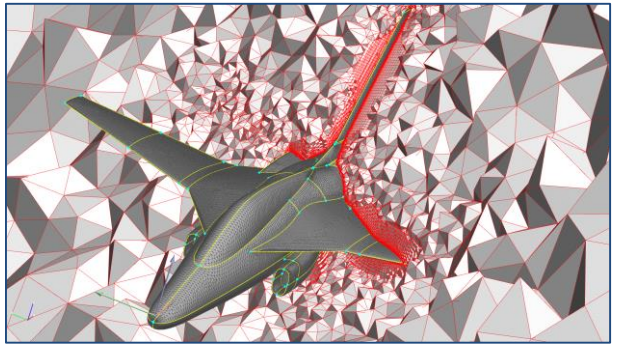
Varied Main Wing Aspect Ratio and Leading Edge Sweep Angle

Varied Vertical Rear Wing Aspect Ratio

Varied Horizontal Rear Wing Aspect Ratio

Stall at high alpha





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.**

DEFINE

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

EXECUTE

Tradespace Execution:
- Create new datasets using executable models

EXPLORE

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.**

REDUCE

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

INTERACT

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

CUSTOMIZE

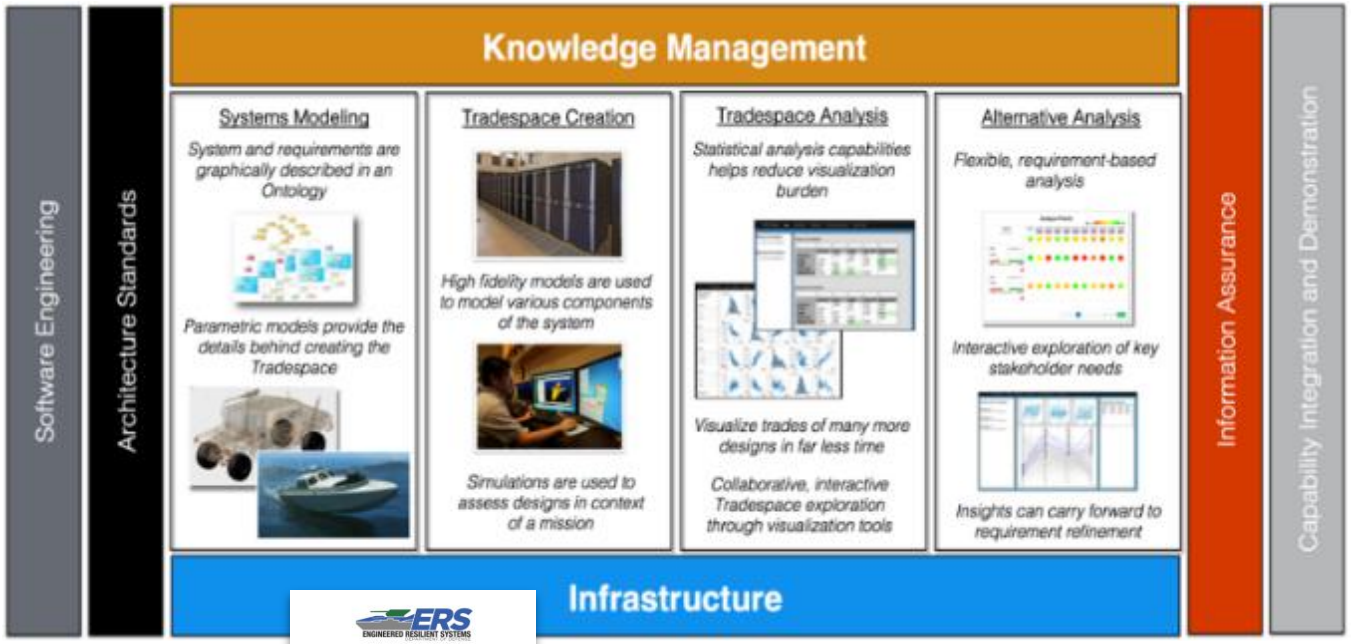
R-Analytics:
- R scripts for custom data analyses and **visualizations**

PLOT

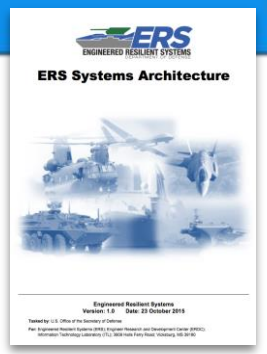
3D Scatterplot:
- Large data 3D scatterplot

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*

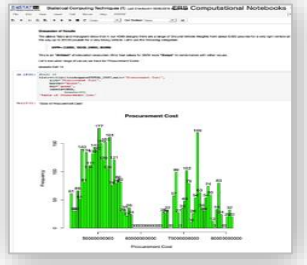
ERS Workflow

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.

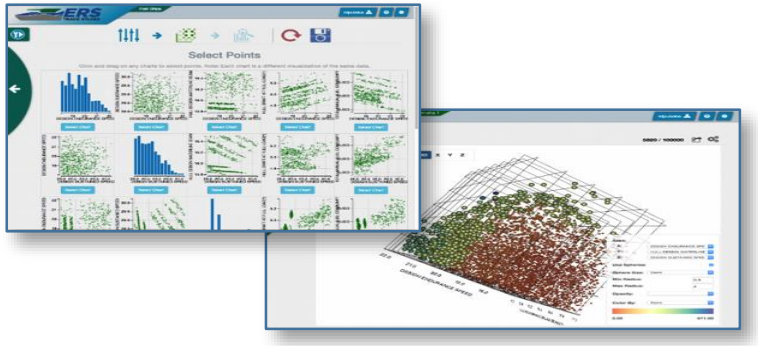
Tradespace Creation



- *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

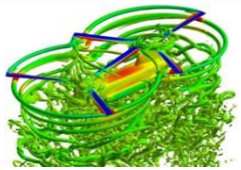


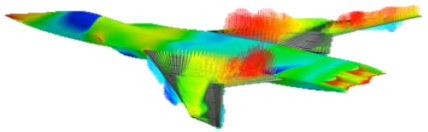
Save data and decisions for future analyses

Products:

- **ERS System Architecture**
- **SysML Model Builder**
- **Engineering Notebooks**
- **CREATE**
- **Computational Model Builder (CMB)**
- **Mission Context Modeling**
- **ERS TradeStudio**
- **Statistical Analysis Tool**
  - **Descriptive / Predictive**
- **Big Data Analytics & Visualization**

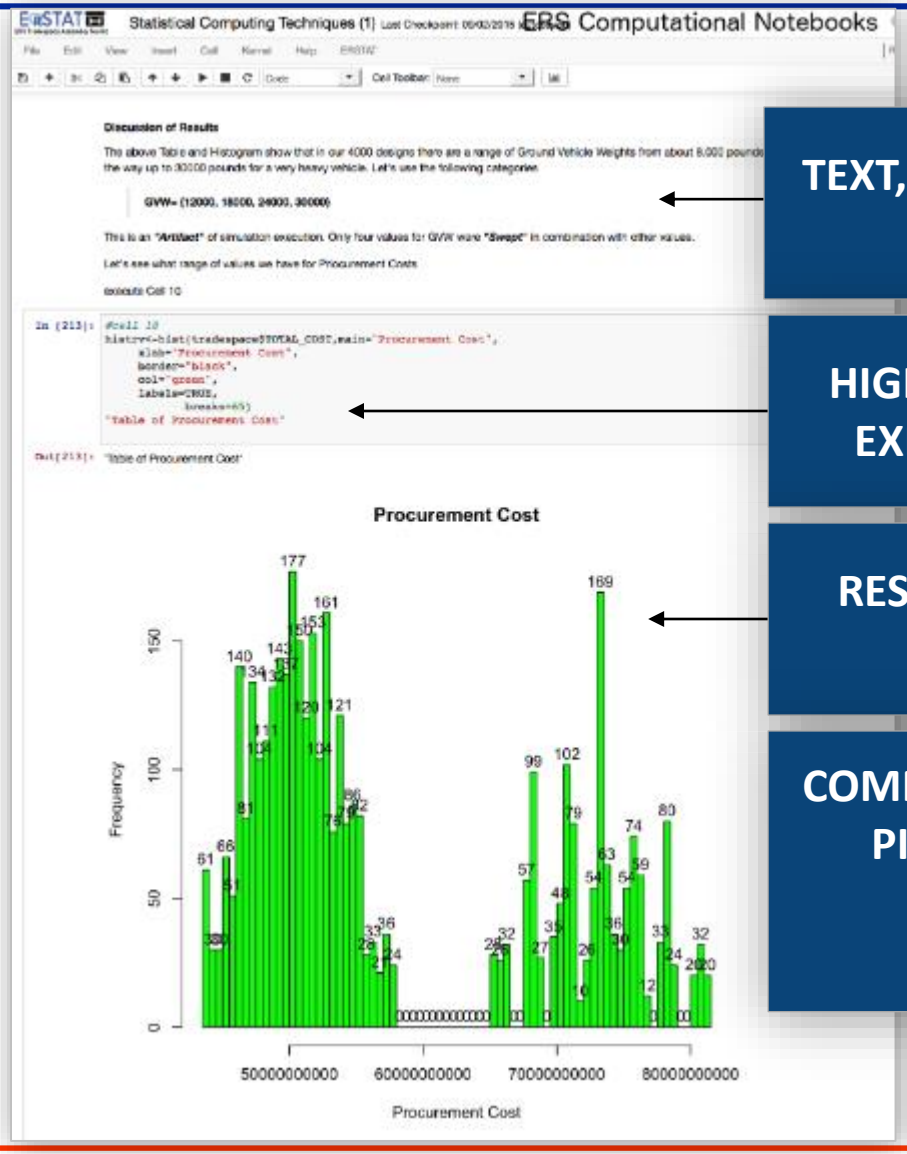
Transition:





- **All of DoD (multiple platforms)**
- **Academic and industry partners (BAE, Lockheed, Raytheon, Boeing, Northrop)**

Computational Notebooks



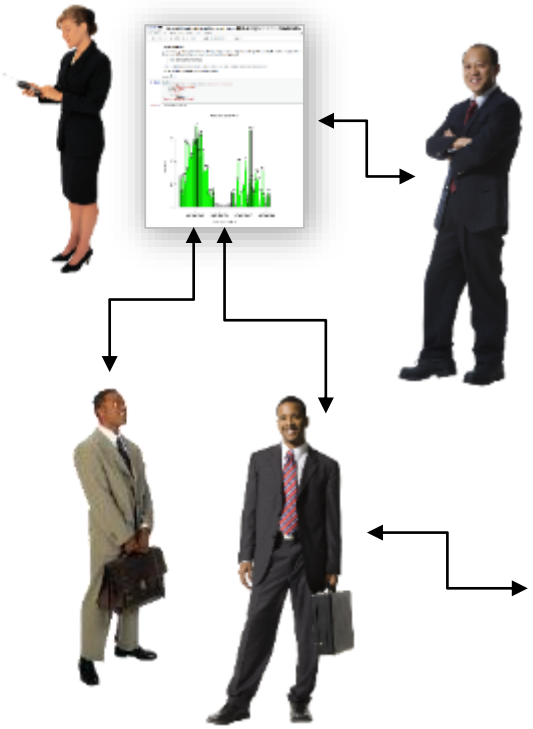
TEXT, DIAGRAMS, EQUATIONS EXPLANATIONS

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