Bringing the Power of Advanced Modeling to Acquisition

April 22, 2016

Jeffery P. Holland, PhD
David R. Richards,
Owen J. Eslinger, PhD
US Army Engineer Research and Development Center (ERDC)
Vicksburg, MS

DoD Goal – Resilient Materiel Systems

A Resilient System…

- ***is reliable 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

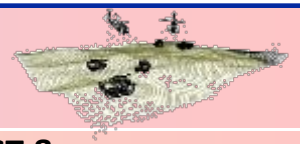
EC-130E
Airborne battlefield command and control & electronic warfare

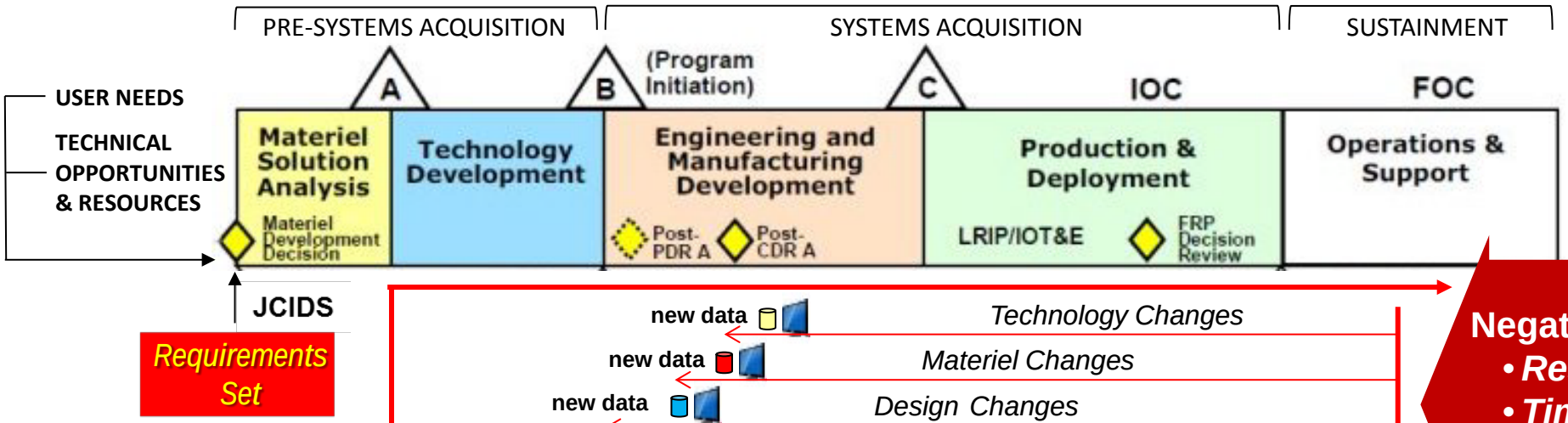
HC-130H
Maritime and Ice Patrol

JC-130
Mid-air Retrieval

Problem – the last 50 years:

Design Engineering - a Linear, Process-heavy Environment

Operational		***EVOLVING THREAT***	***MISSION CHANGE***		
Engineering & Cost	**FIXED 75% Lifecycle Costs Material Solution**	**TECHNOLOGY DISRUPTION**	**UNSTABLE PERFORMANCE**	**COST & SCHEDULE OVERRUN**	**LIMITED EFFECTIVENESS**



5000.1

Negatively impacts:
- ***Response time***
- ***Time & delivery***
- ***Budget***
- ***…etc.***

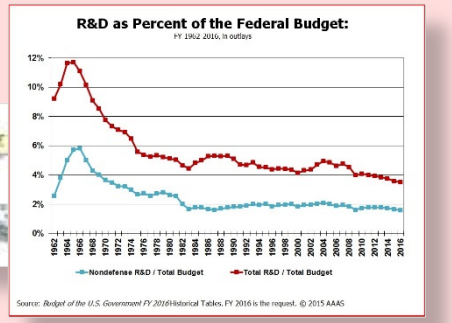
- ***Linear acquisition process***
- ***Lacks adaptability to changes***
- ***Stove-piped workforce and data sources***
- ***Information shared via static documents***
- ***Limited Reuse***

Objective: Utilize Advanced Computational Power to Buy Down Acquisition Risk

Problems

- *Increasing Costs*
- *Rate of change and uncertainty*

GROWING COMPLEXITY



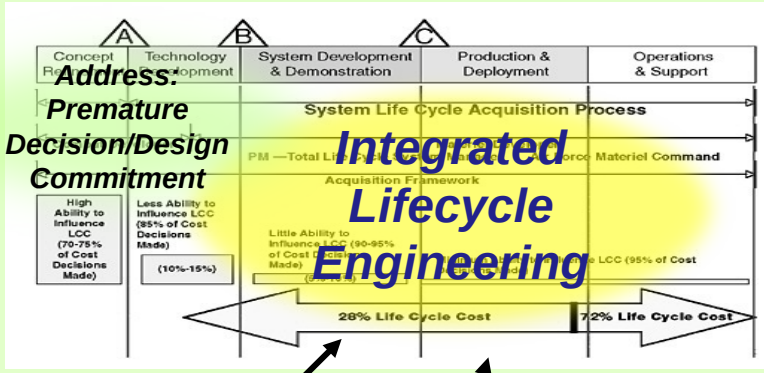
BUDGET CONSTRAINTS

- *Rapid, emergent threat*
- *Requirements creep*
- *Adaptability deficiency*
- *Life extension demand*
- *Technology disruptors*
- *Workforce decline/expertise*

New Technology Approach

Empower rigorous risk analysis

- *Requirements Generation*
- *Analysis of Alternatives*
- *Lifecycle Intelligence*
- *Virtual Prototyping*



Address:
Premature Decision/Design Commitment

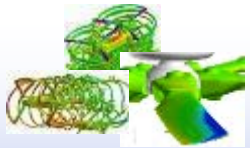
Integrated Lifecycle Engineering

Mitigate Issue:
28% Life Cycle Cost vs. 72% Life Cycle Cost

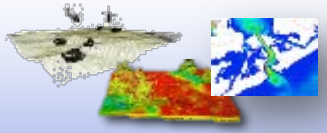
National Academies Press (NAP) 2008

Engineered Resilient Systems - ERS

ERS LEVERAGES YEARS OF MAJOR DOD S&T INVESTMENTS



ADVANCED MODELING



CONTEXT SIMULATION

HIGH PERFORMANCE COMPUTING

MATHEMATICAL OPTIMIZATION

OPEN & TRUSTED SYSTEMS

2012

ERS INTEGRATED CAPABILITY

OPEN ARCHITECTURE IMPLEMENTATION

MODELS

MULTI-DIMENSIONAL TRADESPACE ANALYTICS

LIFECYCLE INTELLIGENCE & MODELING

Linked to Acquisition Processes

HIGH PERFORMANCE COMPUTING

DATA ACCESS & RETENTION

BIG DATA ANALYTICS & VISUALIZATION

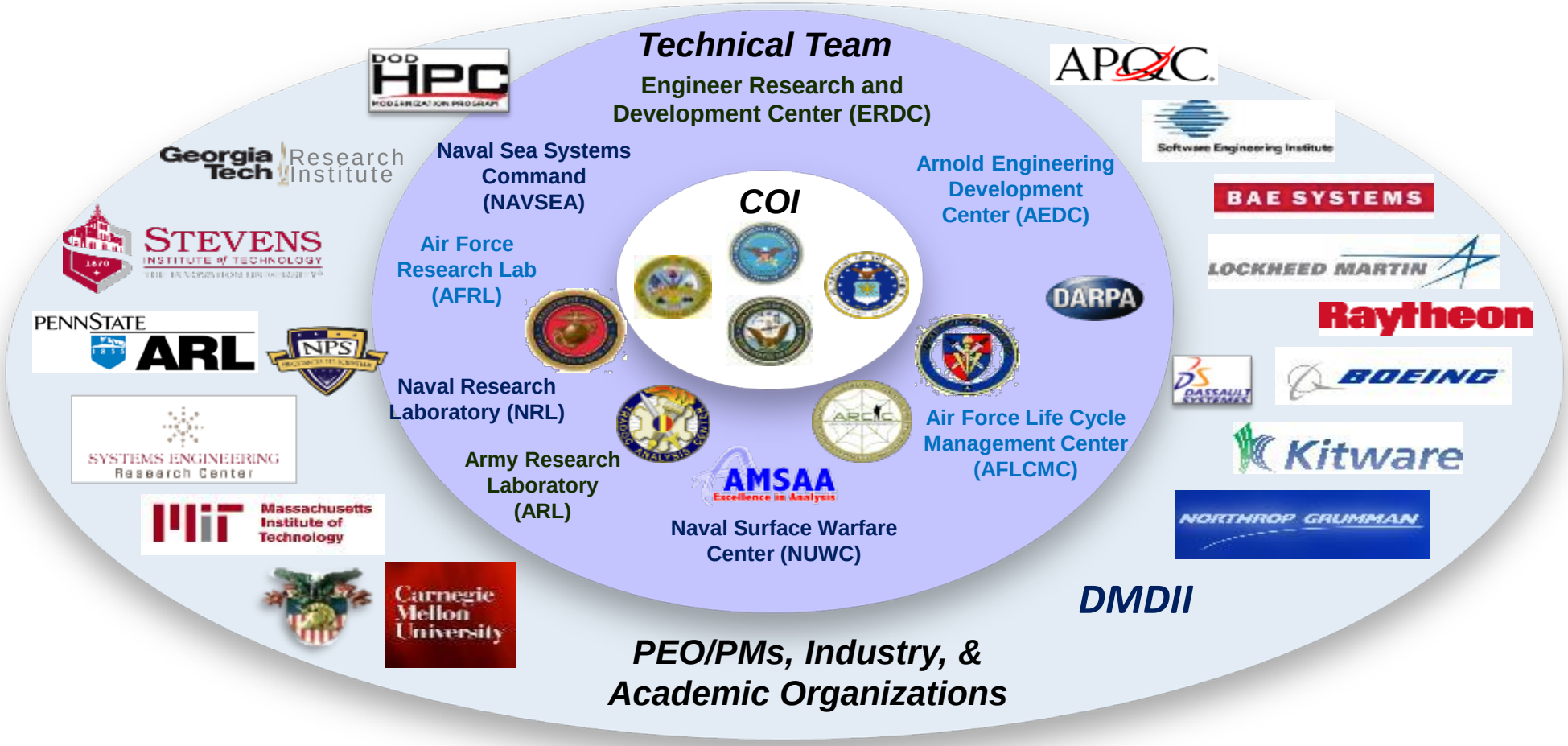
KNOWLEDGE MANAGEMENT

IP PROTECTION

SECURITY

ERS is the first integration of modern computational engineering tools and technologies that directly impact DoD Acquisition environments.

ERS Development Team



Include Established ERS Partnership Team

Components of the ERS Design Environment

Tradespace Tools & Analytics

Policy / Regulation

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

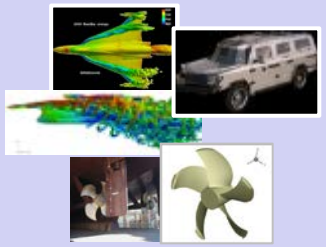
ERS Cloud

10,000X Productivity Improvement In AoA

HPCMP & S&T Resources

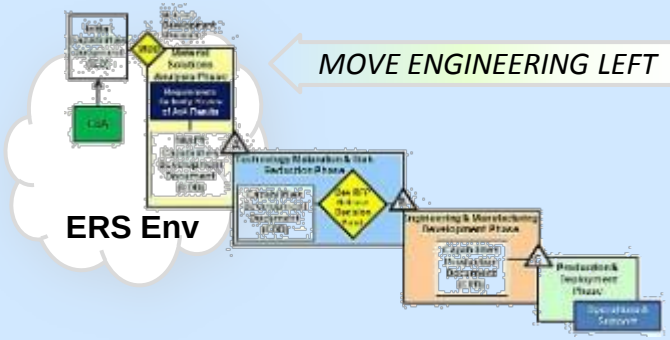
Integrated Capability and Workflow

CREATE



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

Requirements Generation



Fully Explore & Identify KPPs

Analysis of Alternatives

Reduces alternatives from thousands to tens or less

Design Req | *Analytic Tools*

Feedback | *Adv M&S*

Rapidly Distill Many More Alternatives

Virtual Prototyping & Evaluation

RAPID PROTOTYPING & RESPONSE

Virtual Warfighting, Reduce Prototyping Time & Costs

HPCMP High-Level Operational Concept

Users

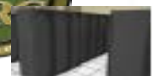
DOD HPC
DEPARTMENT OF DEFENSE
HIGH PERFORMANCE COMPUTING
MODERNIZATION PROGRAM

A technology-led, innovation-focused program committed to extending HPC to address the DoD's most significant challenges

DoD Supercomputing Resource Centers (DSRCs)

US Air Force Research Laboratory DSRC

US Army Research Laboratory DSRC



US Army Engineer Research and Development Center DSRC

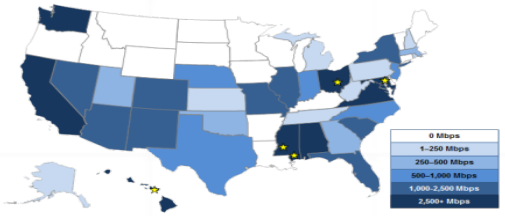
Maui High Performance Computing Center DSRC

US Navy DSRC

Networking and Security

Defense Research & Engineering Network (DREN)

Connects DoD HPC Centers and Users



High-bandwidth, Low-latency Full-service Network

Software Application

Core Software

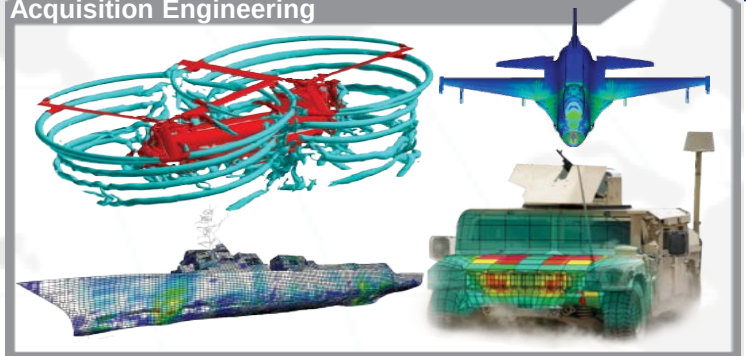
Computational Environments

Education and Training

Support

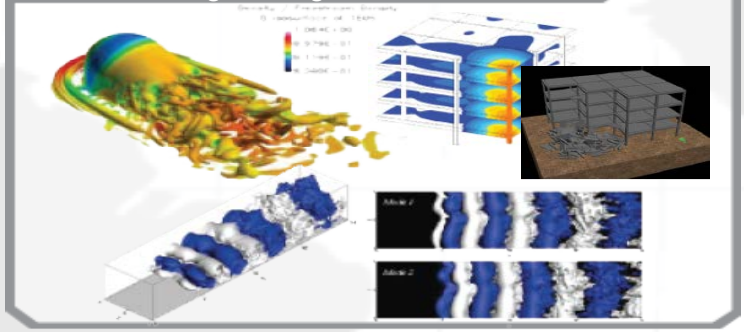
Results

Acquisition Engineering



Decision Support

Science and Engineering Research

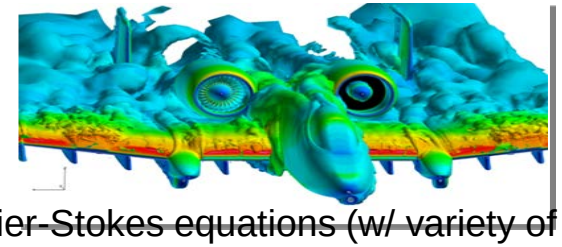


ERS Layered Architecture

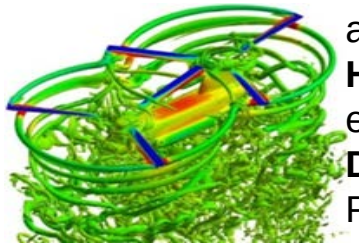
- Reduction to manageable pieces
- Isolates complexity
- Organizes development
- Abstracts details
- Promotes reusability
- Clear frame of reference

Computational Research and Engineering Acquisition Tools and Environments

Accurate Multi-physics Predictions of DoD Weapon System Performance

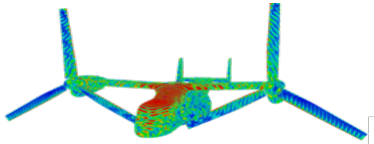


CREATE Aircraft (AV): Fixed-wing aircraft, rotorcraft, conceptual design, and operational testing and transition

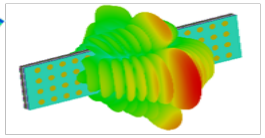


Kestrel: Multi-disciplinary, physics-based simulation tool for fixed-wing aircraft. Solves the Navier-Stokes equations (w/ variety of turbulence models) for aerodynamics and modal models (or finite element analysis) for structural dynamics. Capabilities for assessing airframe/propulsion integration and flight control systems of maneuvering aircraft are also included.
Helios: The rotary-wing equivalent of Kestrel. Enables high-fidelity simulation of full vehicles with arbitrary rotor configurations, e.g., main/tail-rotor, tandem rotor, coaxial rotors, tilt-rotor, etc.
Davinci: Model-centric conceptual design tool that enables trade-space evaluation, concept refinement, and design analysis. Parametric geometry, enabling hi-fi analyses using variable, but consistent fidelity tools.

CREATE RF-Radio Frequency (RF):): Design tool for high frequency electromagnetics. Models complex materials, complex shapes, antenna geometries, phased arrays, frequency selective surfaces, platform integration, co-site interference, and near and far-field computations



CV-22 Aircraft



Ka-Band Phased Array Antenna

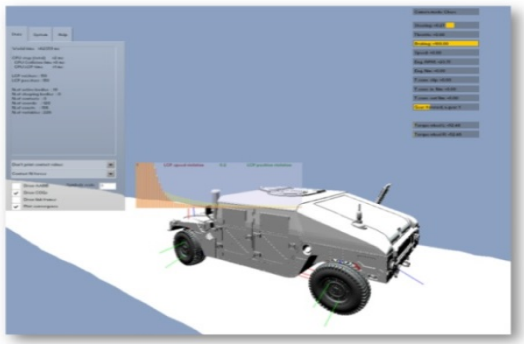
SENTRi: Advanced computational electromagnetics code utilizing a hybrid finite element and boundary element technique on HPC resources for solving Maxwell's equations. Highly accurate, matches range data measurements. Detailed modeling, e.g. models entire antenna systems up to the electronics.

Computational Research and Engineering Acquisition Tools and Environments

CREATE Ships: Ship design tools for shock/damage, hydrodynamics and early-stage design, and operational testing and transition

Rapid Ship Design Environment (RSDE) codes are used in early stage design acceptability analysis and tradespace studies. RSDE leverages legacy Navy tools for quick turnaround studies at low fidelity physics.
Integrated Hydrodynamics Design Environment (IHDE) is used in conjunction with RSDE to support early stage concept development but the range and fidelity of capabilities also support engineering design of ship hydrodynamic surfaces, features, and propulsors.
Navy Enhanced Sierra Mechanics (NESM): Shock hydro code to assess fluid-structure interactions for implicit and explicit effects. Euler equations for shock in water and full element methods from Sandia SM and SD codes for structures. Used to assess ship shock vulnerability and damage and to support Live Fire Test & Evaluation requirements.
NavyFoam: Reynolds Averaged Navier-Stokes (RANS) CFD code with several turbulence models for high fidelity hydrodynamics studies for assessing propulsors, seakeeping, and maneuvering. Acoustics and free surface packages available.

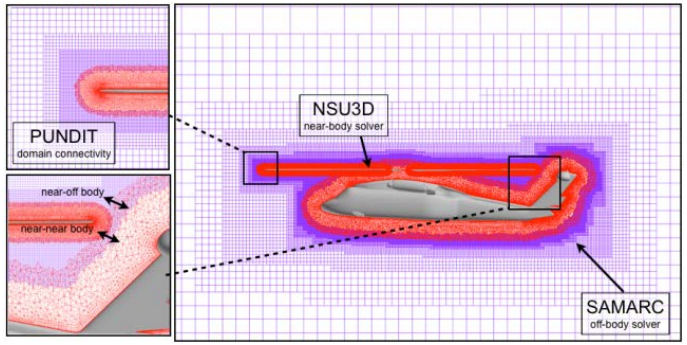
CREATE Ground Vehicles (GV): Tools to predict the tactical mobility of ground vehicles in various environments, terrains, and soils



Mercury: Mobility simulator with integrated multi-body dynamics (MBD), powertrain, and soil mechanics. The MBD code (Chrono) uses a full-space solver with a semi-implicit first-order scheme with fixed-step integration. The powertrain code (PACE) is a behavior-based component level performance simulation. The soil mechanics model is the Ground Contact Element (GCE), which uses slip-driven equations to calculate traction and resistance and each tire node. This integrated code allows for complex, dynamic mobility problems, such as sandy slope climbing, to be realistically simulated.

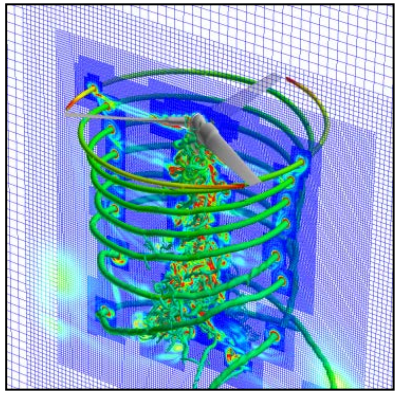
Helios Solver for Rotorcraft Aeromechanics

Dual Mesh Paradigm



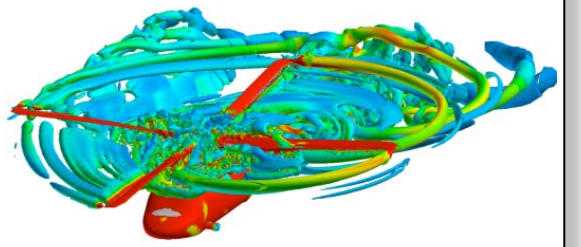
Unstructured grids for near-body complex geomety
Cartesian adaptive grids for off-body rotor wakes

Adaptive Mesh Refinement



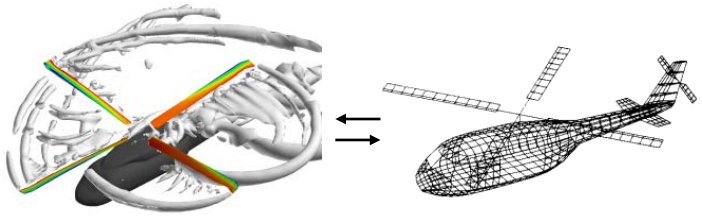
To resolve unsteady rotor wakes

Moving Body Overset



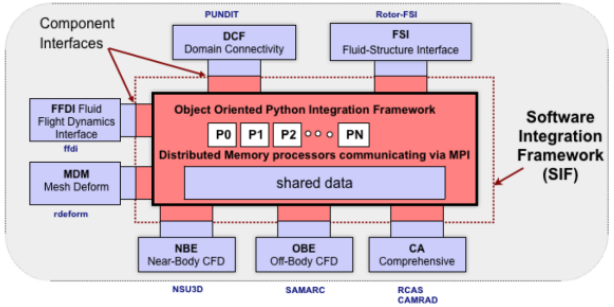
Interactional aerodynamics between multiple rotors and fuselage

Aero and Structural Dynamics Coupling



RCAS and CAMRAD structural dynamics models for rotors including full vehicle trim

Advanced Software Infrastructure



Python-based infrastructure readily supports addition of new software

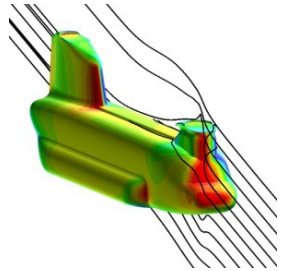
High Performance Computing

Runs on HPC hardware with focus on parallel scalability

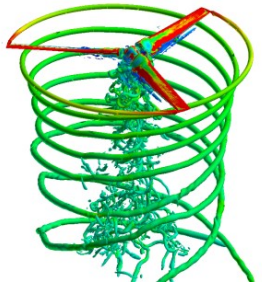
Helios v6 Capabilities

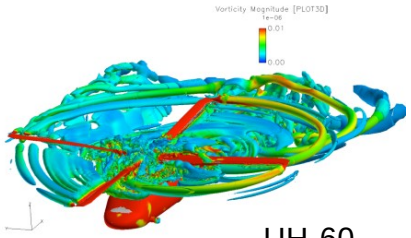
- SAMCart off-body solver for Detached Eddy Simulation (DES)
- Melodi method for mesh motion
- mStrand solver to improve near-body meshing
- FUN3D and kCFD solvers for improved near-body solutions
- Improved analysis using unsteady particle tracing and moving slice planes

TRAM

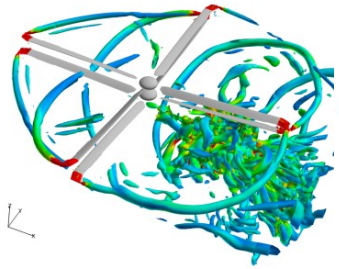


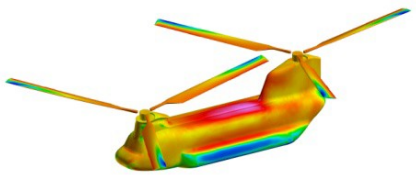
CH-47





UH-60





CH-47

ERS Powerful Tradespace Approach

ERS Tradespace Concept

- Architecture
- Tradespace Analytics
- Advanced Modeling
- Environmental Rep.
- Mission Context

Cost models
-ilities
….other

ERS CLOUD COMPUTING ENVIRONMENT (CCE)

10,000X *Improvement in productivity in Analysis of Alternatives*

Efficiently discover key performance parameters (KPPs)

HPCMP and S&T Resources

Currently Applied ERS Advanced Tradespace Analytics

Expand Tradespace Fully

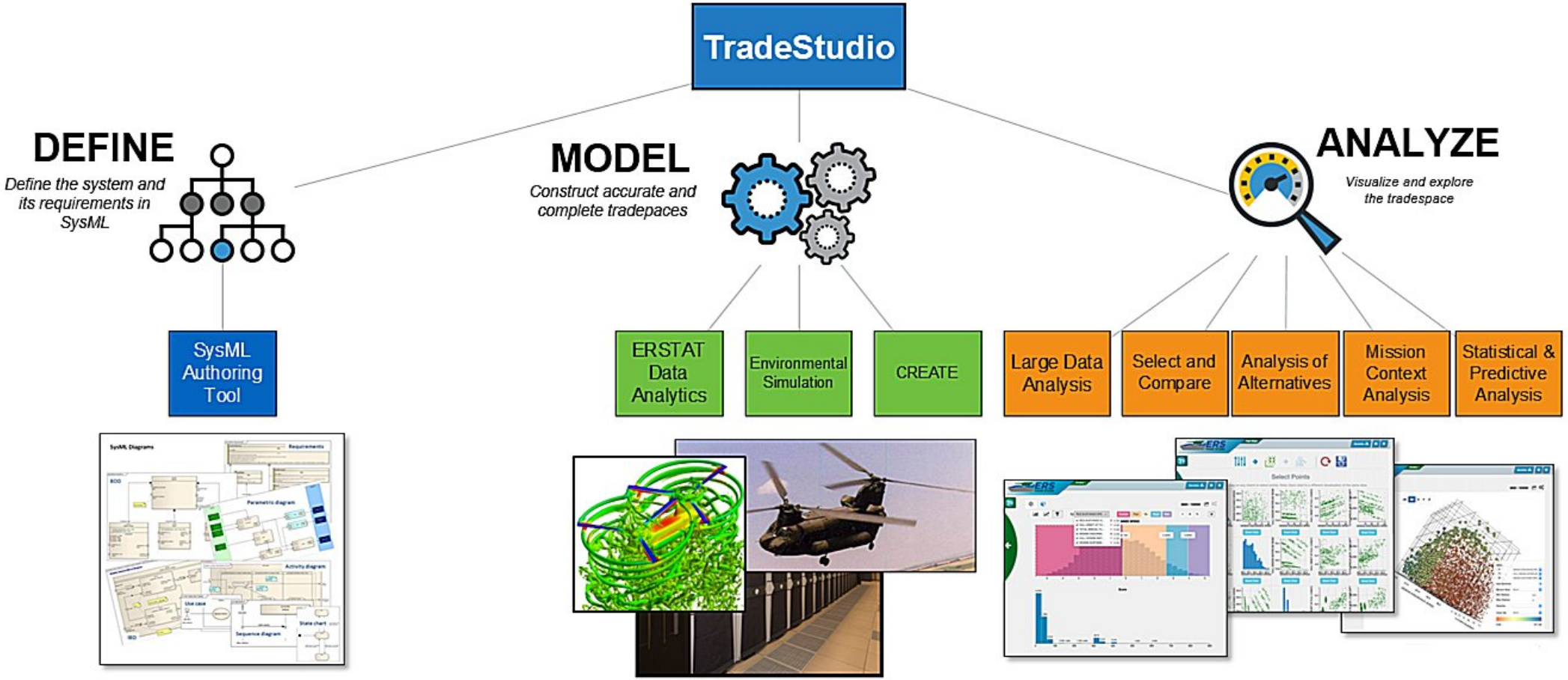
- **Early concept tool**
- **Functional / component breakdown**
- **Explore tradespace edges**

Performance Assessments
Performance Metrics

High-fidelity Models
Parameter Sweeps:
Design Variations

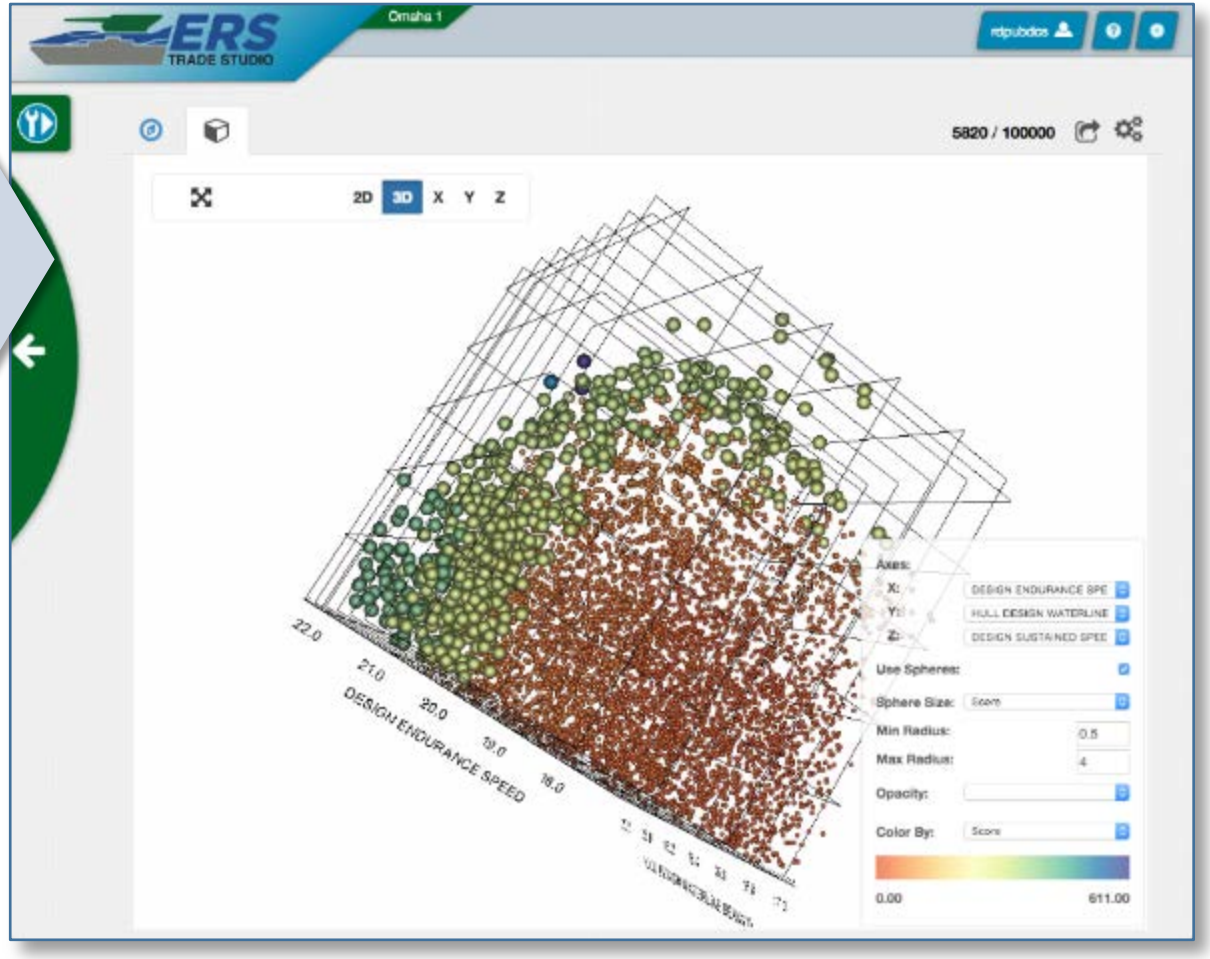
- **Highly computational**
- **Sifts through millions of designs**
- **Refined set of specifications for viable design solutions**

Organization of Tradespace Capability



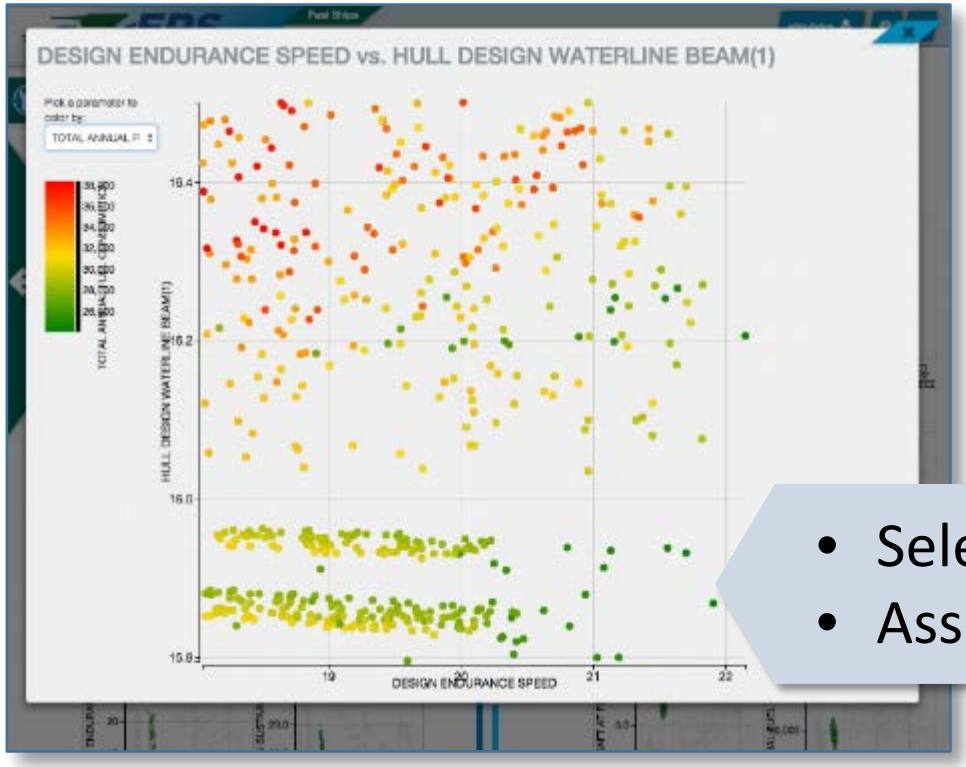
Data Visualization

- 2D/3D visualizer
- Use color, size and opacity or a fourth attribute



Data Analysis

- Select attributes to show plot matrix with histograms



- Select any graph for close-up
- Assign parameter colors

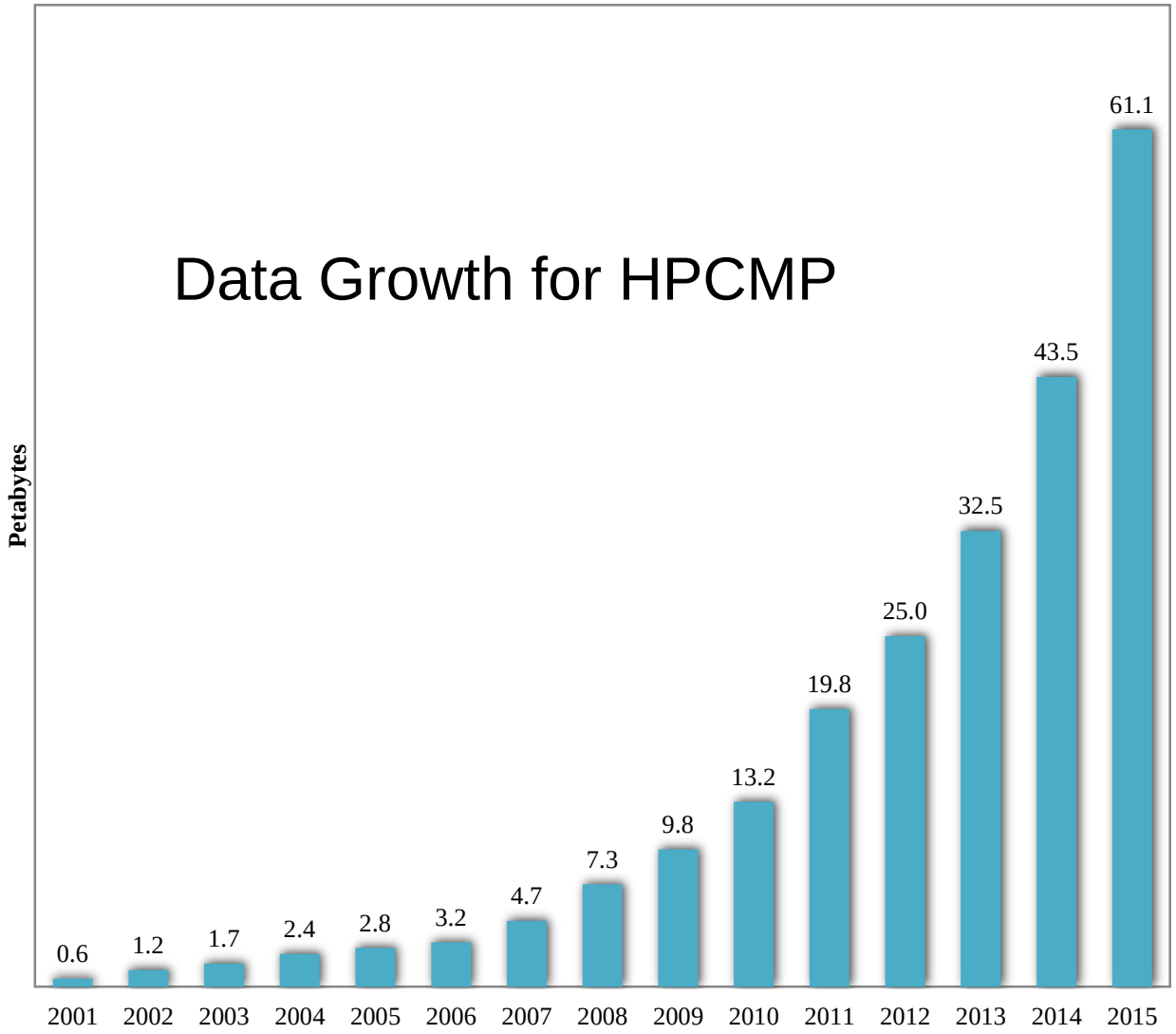
Data Analysis

- Select “Analyze Points” to run analysis tool
- Select objective attributes
- Change objective values
- Tool calculates score for each design

Big Data

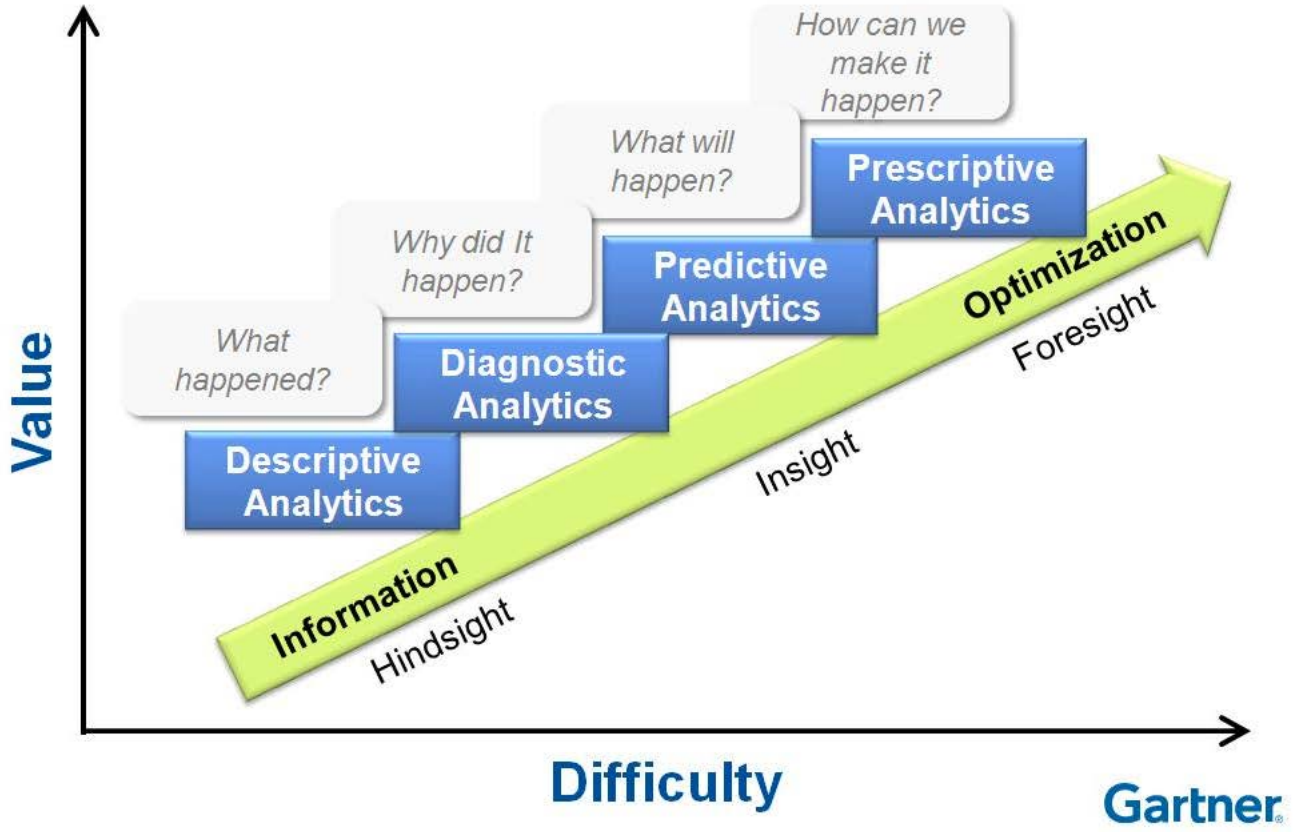
Primary Growth Factors

- Data Analysis
- Data Locality and Movement
- Data Duplication
- Data Recovery
- Network Loading
- Storage Technologies



Big Analytics

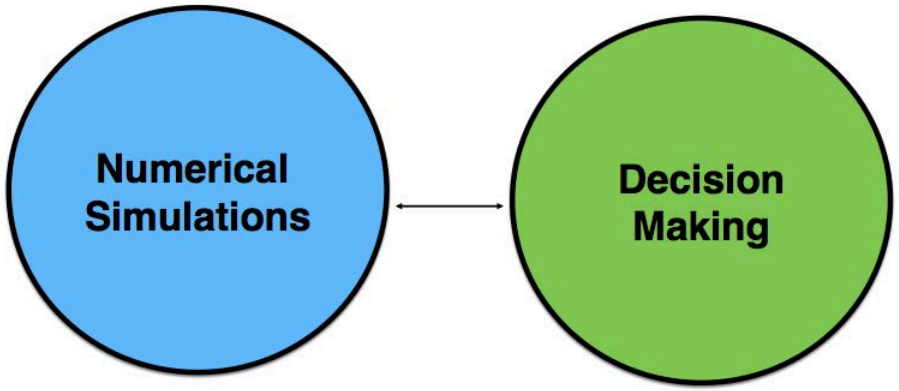
Analytics Are No Longer a Nice to Have



Computing Convergence

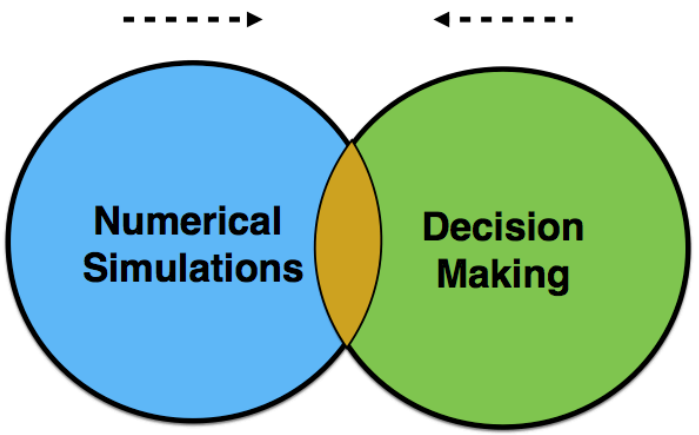
Today

- *Moving data back-and-forth is complicated due to communications, security, data incompatibilities, etc.*
- *Simulation results require post-processing for decision tools*



Interchange between HPC and decisioning capabilities is difficult.

Tomorrow



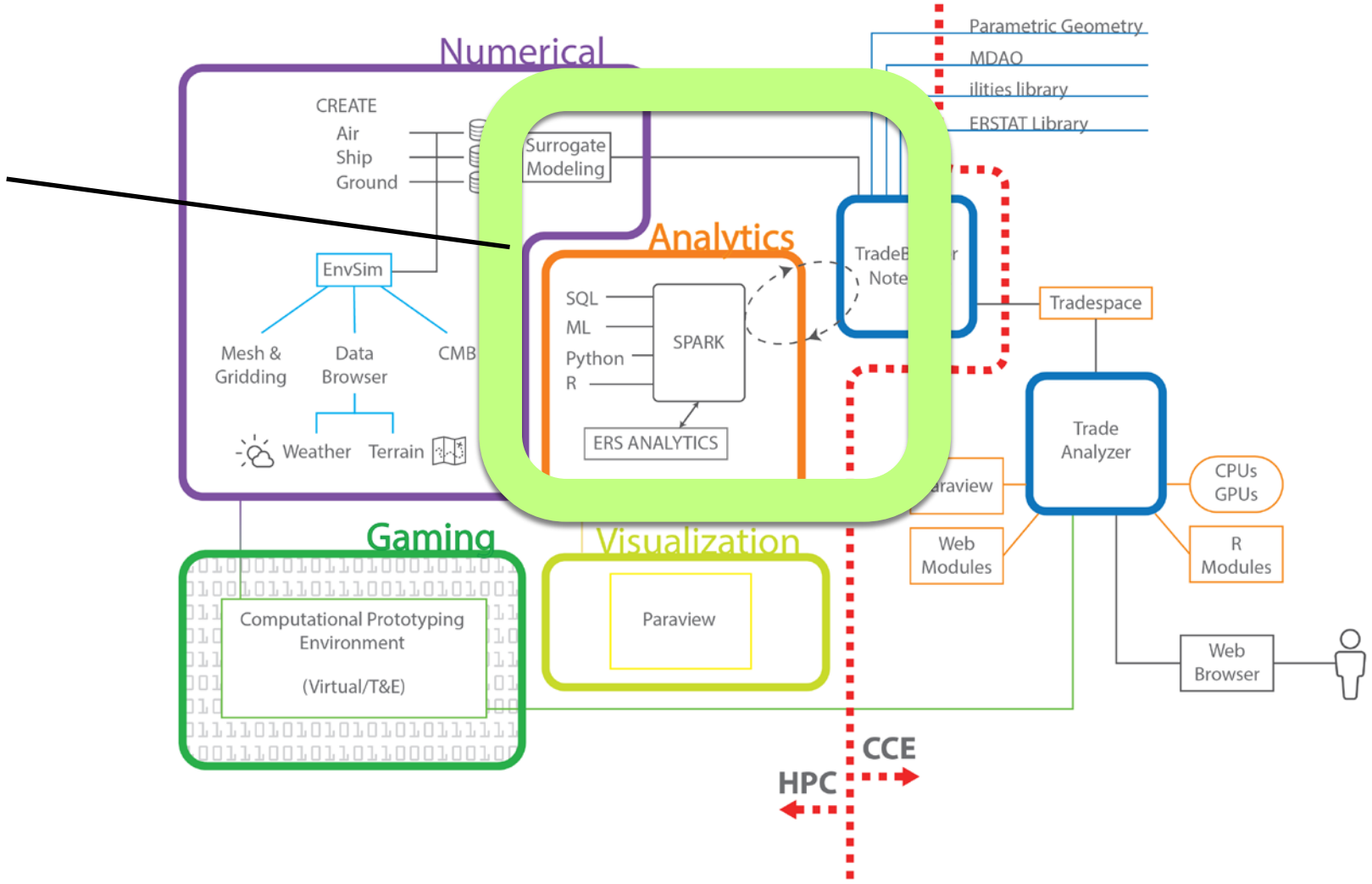
Integration between HPC and decisioning capabilities opens the door to streamline deep analytics into decisioning tools for users.

The BIG Data Challenge

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

ERS Approach to Analytics

ERS is moving its analytics onto supercomputers

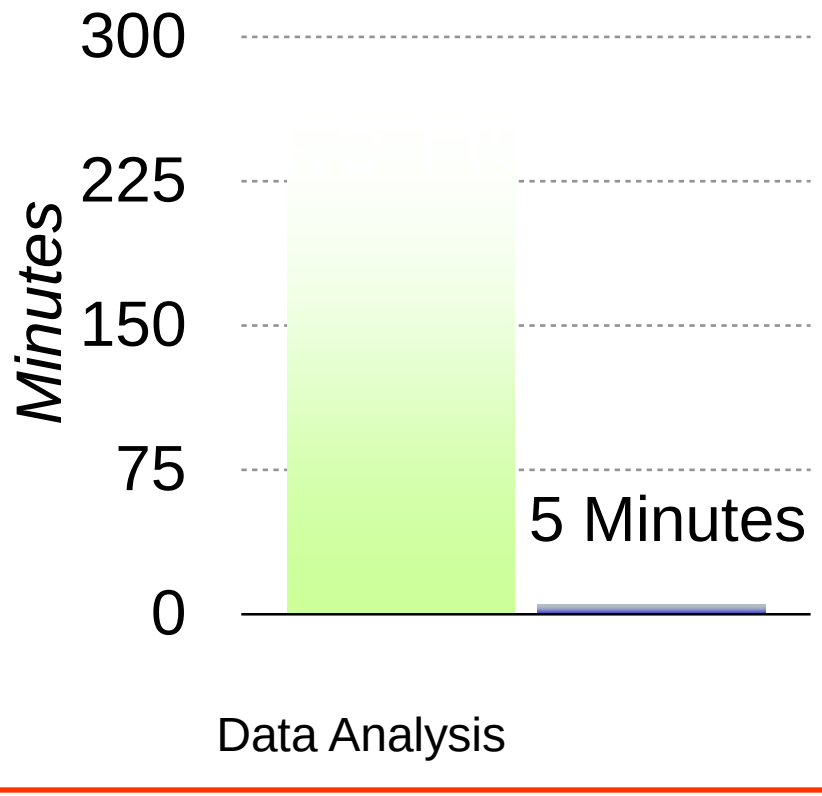


Big Data Strategy

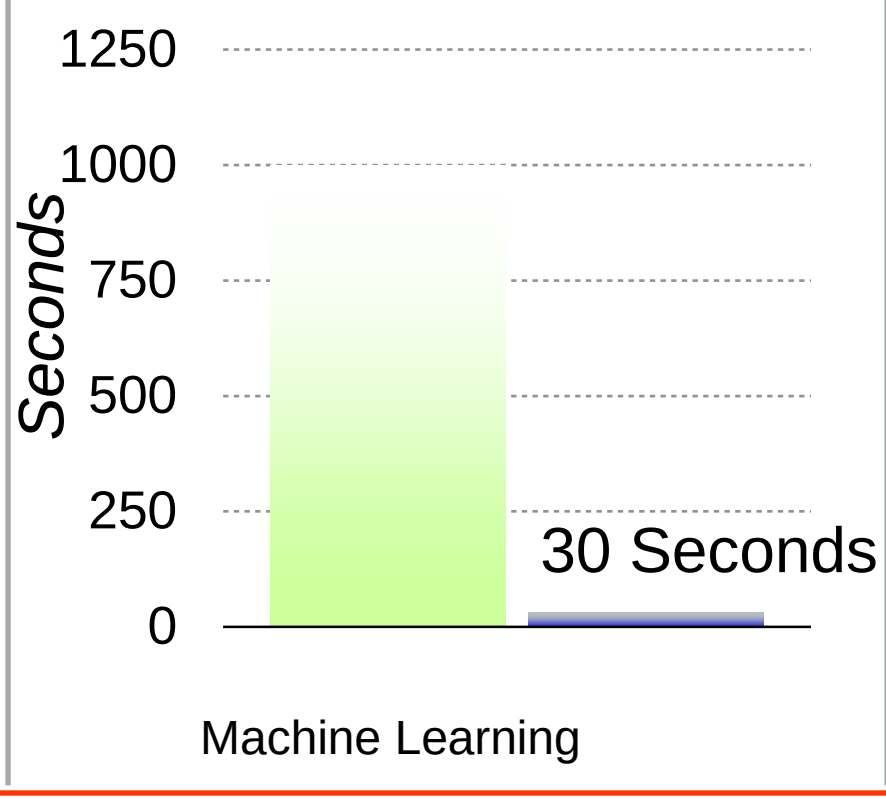
- Expand the use of supercomputers from their primary focus (numerical simulations) to large-scale data analytics
- Leverage existing investments in supercomputing, networks, and storage to serve as the underlying infrastructure for Big Data
- Allow decision tools to reside in close proximity to environment hosting decision tools
- Integrate decision and computational resources that host various types of models
- Integrate hardware, software, communications, storage, etc., into an overall Data Ecosystem

Preliminary Results

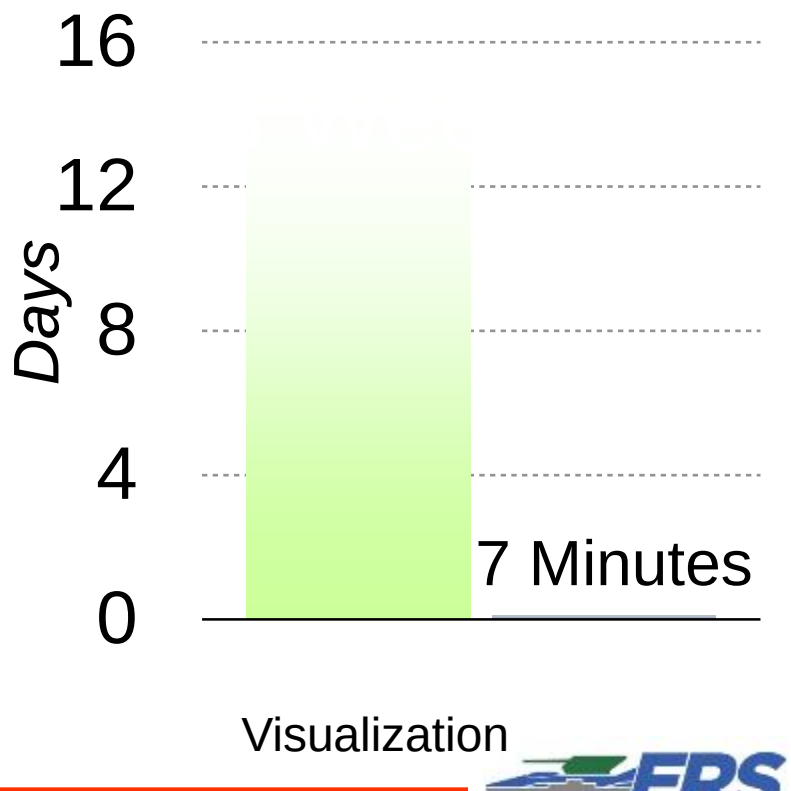
Calculate correlation matrix - 3M rows x 500 columns



Train a machine-learning technique (GLM) (10 years of airline data)



Processing of numerical simulation for visualizations



Application of ERS

US Navy NSWCCD

ERS Ship Design Projects

LX(R) AoA

22,000 alternatives analyzed in 6 weeks

~$16 Billion Decision

Small Surface Combatant (SSC)

19M designs analyzed in 3 months resulting in 270K feasible alternatives

~$12 Billion Decision

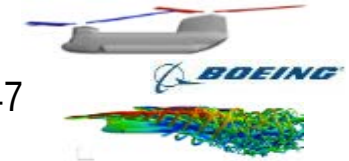
Submarine Class

Virginia-class replacement - Currently preparing analysis tools

US Army AMRDEC

ERS Rotorcraft Projects

Evaluated Boeing's IRAD-produced, CH-47 rotor blades



Full, accurate assessments achieved with ERS tools & CREATE Helios models.

ERS and CREATE tools ready for transition to Future Vertical Lift program

US Air Force

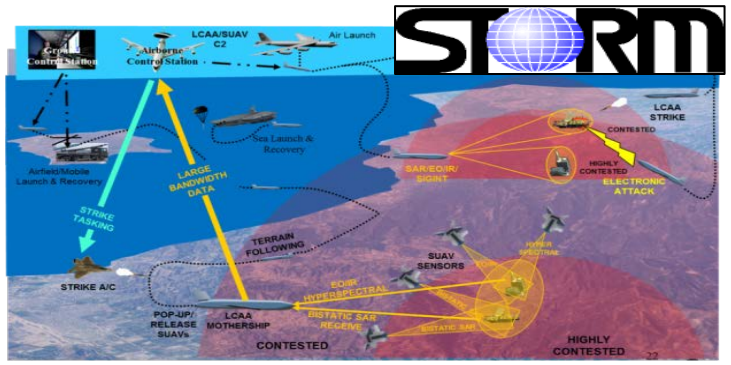
Future Application of Trades Analysis & Virtual Prototyping

Low Cost Attritable Aircraft Technology (LCAAT)

Trades Analysis (Air Force)
Design Trades, Mission Trades

Virtual Prototyping (OSD ECP)
Virtually Test & Warfight Designs

Future Application of ERS
Low Cost Attritable Aircraft Technology (LCAAT)



Purpose:

To deliver prototype of an inexpensive, attritable aircraft that can be configured for various A2AD missions including ISR, strike, SEAD, electronic attack, and C2

Products:

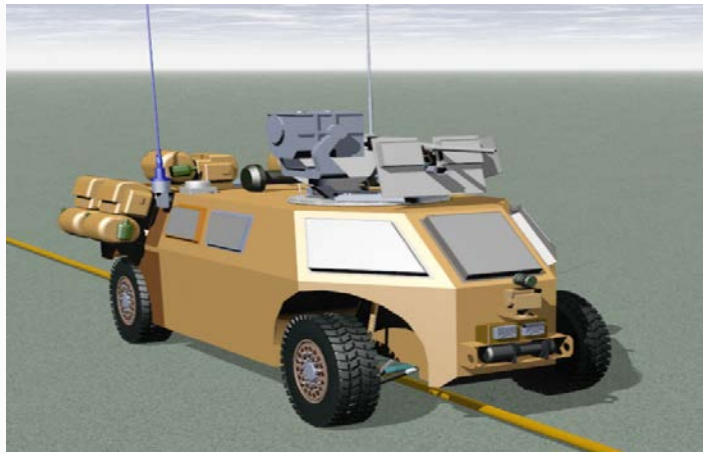
- Integrated tool set for rapid creation of design concepts and tradespace analysis of designs;
- Understanding of tradespace around conceptual designs;
- Studies at conceptual/preliminary level design concepts and data

Payoff:

- **Benefit to Soldier –** Unmanned technologies decrease manpower required to complete mission objectives, promoting Soldier safety
- **Technology Details –** Unmanned aircraft designed for short service life at low cost, allowing for loss of system without major consequences and eliminating maintenance costs (developed by AFRL)
- **Attritable –** Falls between single-use expendable system and fully-developed exquisite system
- **Desired Requirements –** 3000 nm range, 12g capable, 500 lbs. international payload, transonic, multi-use capable

LRV Tradespace Exploration

Light Reconnaissance Vehicle
(LRV Concept ACT3180)



New Chrono model of the LRV

Purpose:

- Learn CREATE-GV and ERS tools and apply them to the Light Reconnaissance Vehicle (LRV) concept to perform M&S and explore the tradespace and deliver new modeling capabilities

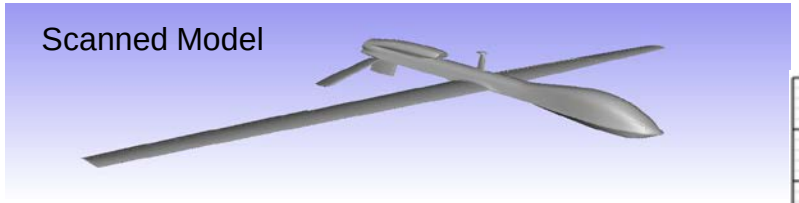
Products:

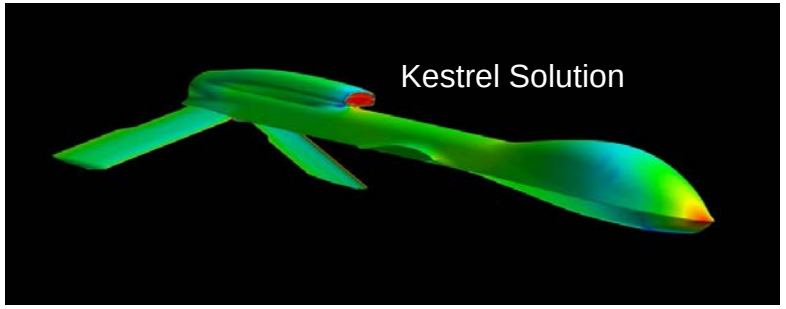
- CREATE-GV/ERS training for ground vehicle SMEs
- User feedback for CREATE-GV and ERS tools
- New LRV mobility and vehicle dynamics models
- Initial tradespace exploration results for LRV concept ACT3180

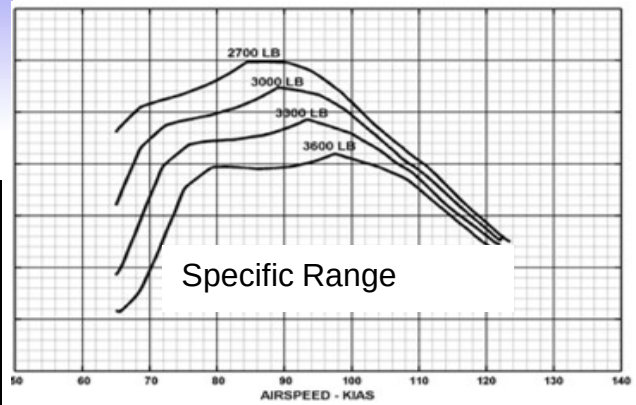
Payoff:

- Ability to model and evaluate LRV performance with CREATE-GV and ERS tools
- Assessment of how CREATE-GV tools complement and enhance current ground vehicle M&S processes
- Delivery of new modeling capabilities for the LRV
- Establishment of ERS framework for tradespace exploration of current and future LRV concepts

Future Application of ERS Gray Eagle Flight Performance Model







Purpose:

- The Gray Eagle is an unmanned air vehicle used by the U.S. Army for a variety of missions. Because maximizing time-on-station for these different missions is of utmost importance, it is of interest to obtain flight performance (climb, cruise, descent) predictions for the Gray Eagle. A key goal for this effort is development of a validated computational model, along with processes for predicting flight performance. This will lead to future efforts that will investigate the effects of cross winds on takeoff and landing performance.

Products:

- 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

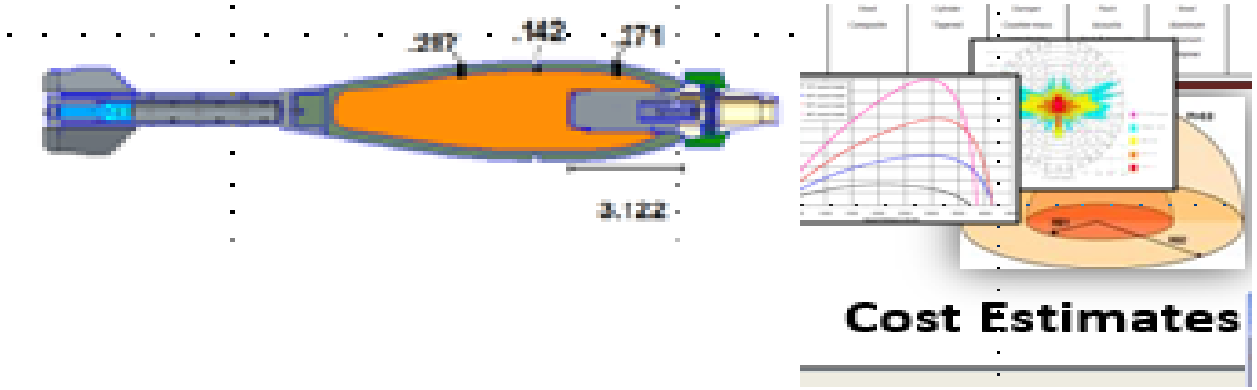
Payoff:

- 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

Schedule

MILESTONES - FY16	Q1	Q2	Q3	Q4
Develop Kestrel 3-Dimensional Model of Gray Eagle				
Develop Flight Performance Aerodynamic Data				
Comparison to Data				
Develop Flight Performance Model of Gray Eagle				
Perform Mission Analysis				
Comparison to Data				

Model-Based SE Tool for Munitions



Purpose:

- Work with ARDEC to develop additional Model-Based System Engineering capabilities in ERS tradespace toolset by incorporating multi-objective decision analysis and integrate methods for executing and visualizing tradespace analysis across multiple dimensions and integrating physics-based analysis to SysML.

Products:

- Use ERS process map/workflow incorporating collaborative analysis and decision making
- Integrated Armament Analytics Multiple Objectives Decision Analysis Tool (AAMODAT) automating decision theory computations, data management, tradespace visualizations, and report generation. Pilot of ERS processes, integration, and tools on ARDEC Munition/Weapon project(s)

Payoff:

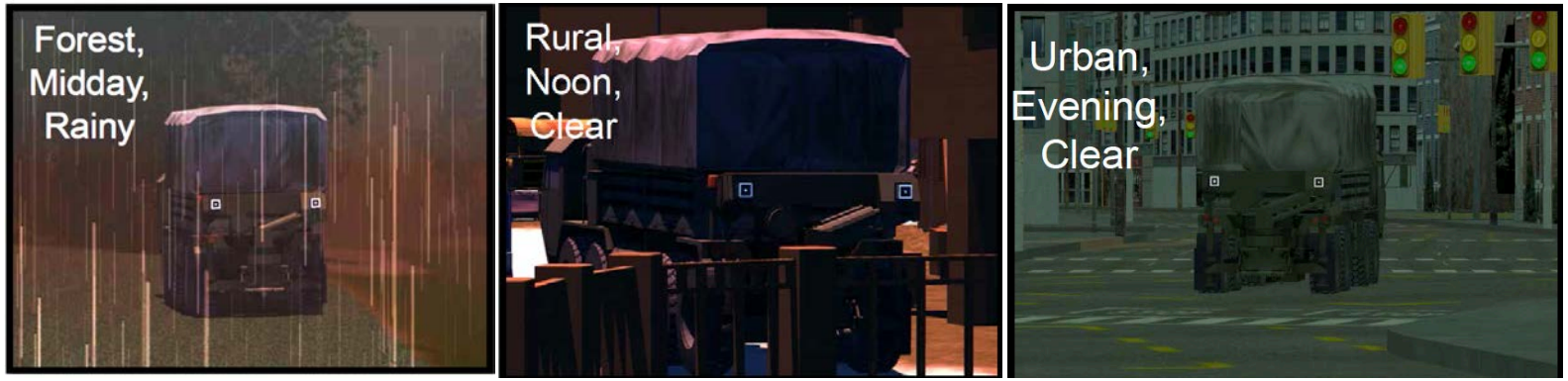
- Ability to conduct tradestudies with MODA theory to help prioritize objectives, visualize data, with rationale/revision control
- Enhance understanding of the applying ERS methodologies on early Army S&T technology development
- Ability to integrate and synchronize conceptual MBSE and Design Engineering analysis consistently with reusable models

Schedule

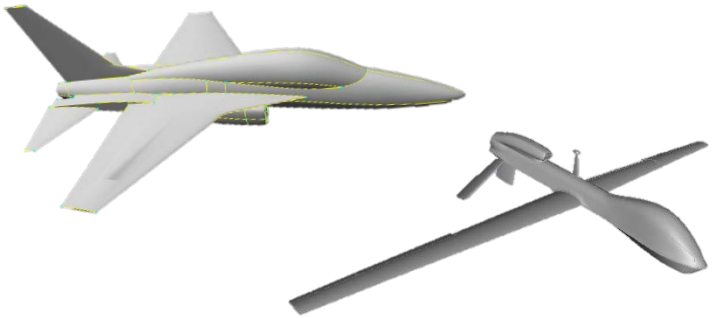
MILESTONES	FY16	FY17	FY18	FY19
Develop ERS (SysML) workflows to integrate with design engineering analysis				
Integrate AAMODAT (MODA) automation tool within ERS tool set				
Conduct ERS proof of concept Armament pilot studies				

Computational Prototyping Environment

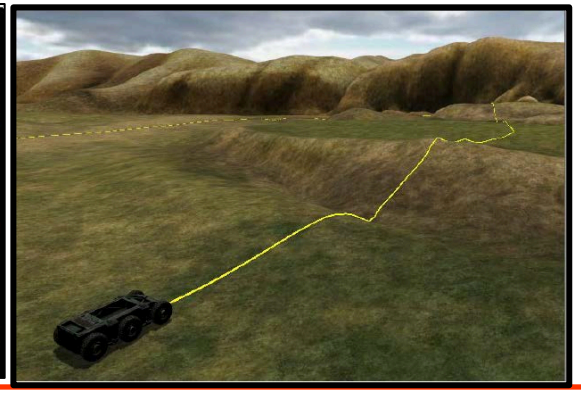
Test every concept before bending metal, in arbitrary conditions, anywhere on the planet

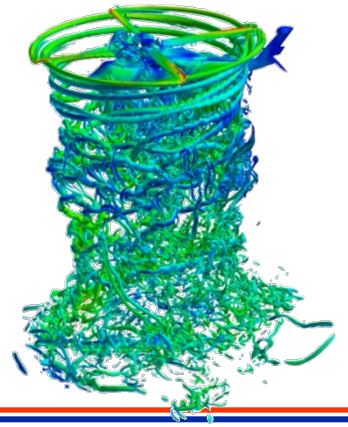


Inverse model proposed designs to understand how to defeat them



Integrate wargaming, physics, tradespace analysis





Summary

- ERS offers a new paradigm in the use of advanced modeling and tradespace analysis in support of Defense acquisition
- Big Data requires an overall data ecosystem (hardware, software, communications, etc.)
- Integrating decision analytics and scientific simulations sets the stage for solving new classes of problems
- ERS has only begun to scratch the surface of the possible contributions validated computational analyses could make to Defense acquisition