NDIA Conference on Physics-Based Modeling for US Defense
Nov. 6-8, 2012, Denver, CO

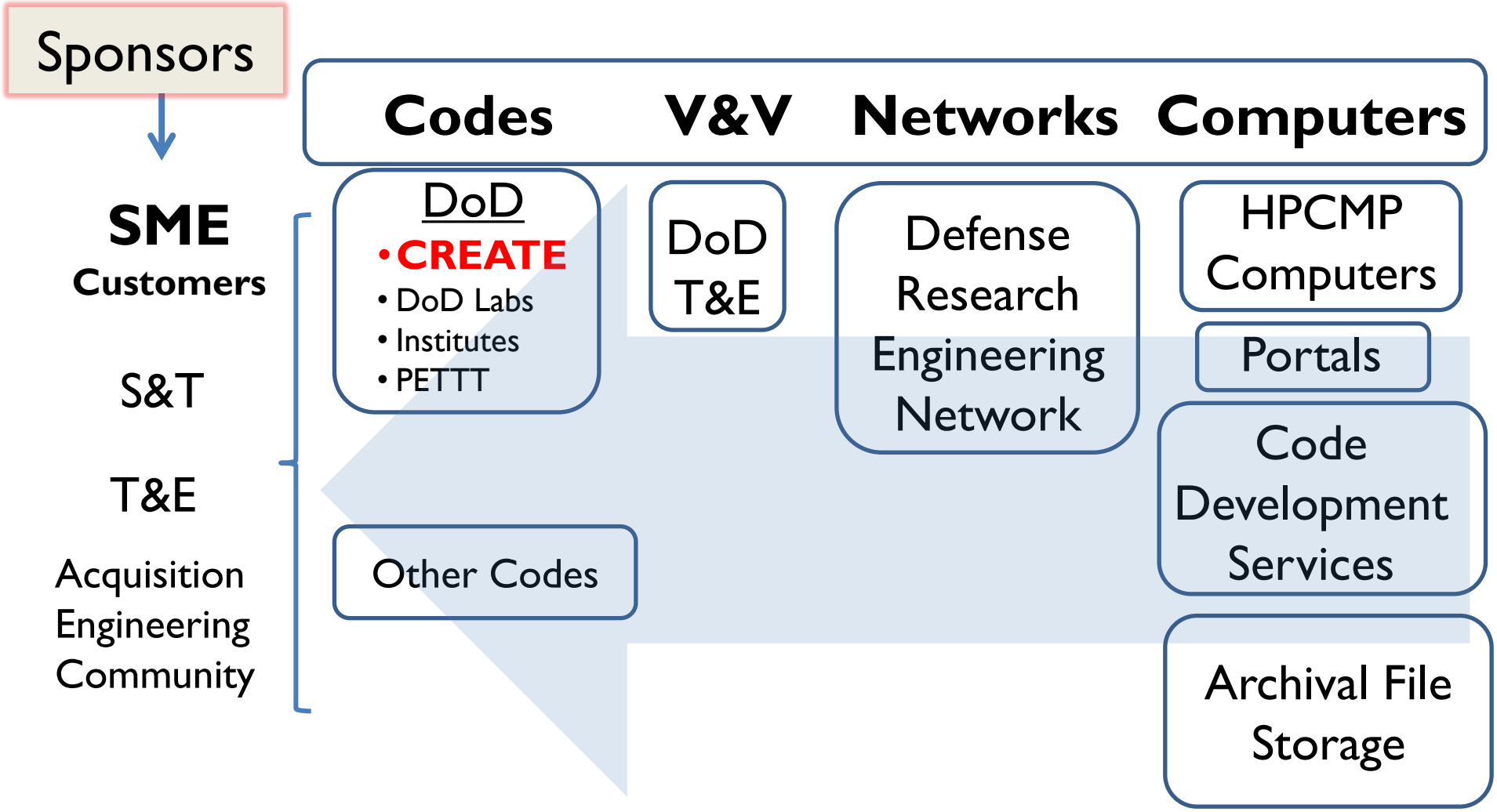
DOD HPC MODERNIZATION PROGRAM

Dr. Douglass Post
HPCMP Chief Scientist & Associate Director CREATE

DoD Computational Research and Engineering Acquisition Tools and Environments (CREATE) Program is Focused on the DoD Technical Community

- Goals and Perspective
- Technical Progress
- Programmatic Progress
- Path Forward

DoD High Performance Computing Modernization Program (HPCMP) Provides an HPC Problem-Solving Service Ecosystem for the DoD

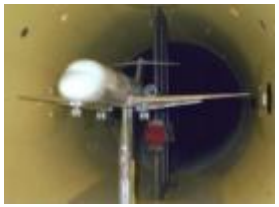


Computational Research Engineering Acquisition Tools and Environments (CREATE) Objectives and Goals

- **Develop and deploy multi-physics-based computational engineering software that, when used in conjunction with increasingly capable high performance computing systems, accurately predicts the performance of weapons systems**
  - To enable trade space optimization of new and retrofit designs
  - To avoid costly (time and money) design flaws and rework
- **CREATE ultimate goal: Catalyze a revolution in weapons system design and development methodology**
  - From reliance on building and testing physical prototypes
  - To virtual prototype design and evaluation
  - Followed by physical prototype validation
  - For the research, engineering, and acquisition communities

Present Product Development Process-based on Trial-and-Error Iterated Design → Build → Test Cycles



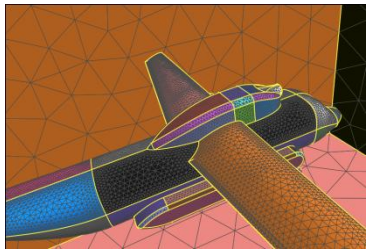
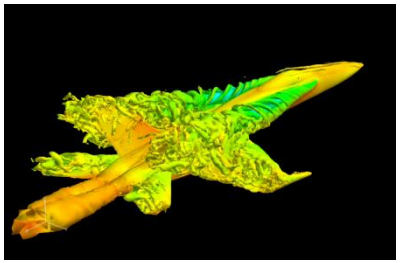

Requirements → Design → Build Physical Product → Test Physical Product → Manufacture, Sustain, and Modify

(Many) Design iterations

- **Long time to market**
  - Requires many lengthy and expensive design/build/test iteration loops
- **Process converges slowly**
  - Process is rigid, not responsive to new requirements
  - Design flaws discovered late in process leading to rework
  - Systems Integration happens late in process

New Concept for DoD: Use Multi-Physics-Based Computational Tools to Improve Product Development of Complex Systems



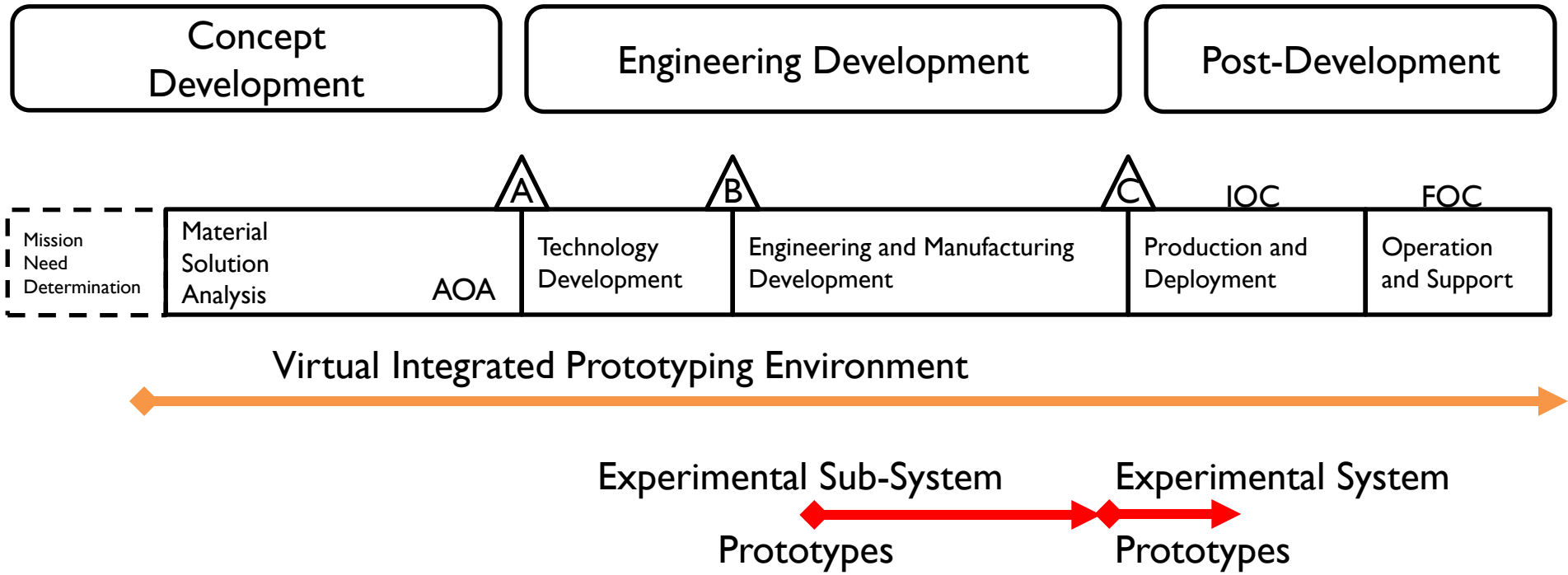

Requirements → Design on Computer → Build Mesh → Analyze Performance → Ground-based and Flight Tests

(Many) Design iterations

Manufacture, Sustain, and Modify

- **Reduced design and development time**
  - Highly-scalable computational performance analysis of virtual prototypes reduces the need to test real prototypes
- **Process converges much faster**
  - Process is flexible, very responsive to new requirements
  - Identify and correct design flaws early in process reducing rework
  - Systems Integration happens at every step of the process

Performance Analysis of Virtual Prototypes is the Key

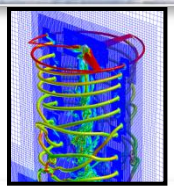


- **Replace "rule-of-thumb" extrapolations of existing designs with physics-based designs**
- **Inject physics into design early and all through the process!**

CREATE Program Focuses on Four Project Areas

- **Air Vehicles (AV)—Air Force, Army & Navy**
  - Aerodynamics, structural mechanics, propulsion, control, …
- **Ships—Navy**
  - Shock vulnerability, hydrodynamics, concept design
- **Radio Frequency (RF) Antennas—Air Force, Army & Navy**
  - RF Antenna electromagnetics and integration with platforms
- **Mesh and Geometry (MG) Generation**
  - Rapid generation of mesh and geometry representations needed by

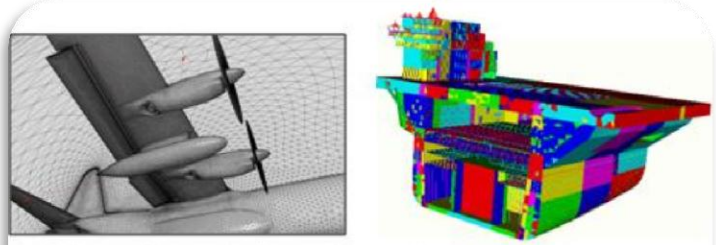
CREATE tools will support all stages of acquisition from rapid early-stage design to full life-cycle sustainment



Design concept

Seakeeping and resistance

Shock vulnerability



Aircraft and aircraft carrier meshes

Military platforms with antennas

CREATE –

Four Projects → Ten Software Applications

- **Air Vehicles—CREATE AV**
  - **DaVinci -** Rapid conceptual design
  - **Kestrel -** High-fidelity, full-vehicle, multi-physics analysis tool for fixed-wing aircraft
  - **Helios -** High-fidelity, full-vehicle, multi-physics analysis tool for rotary-wing aircraft
  - **Firebolt -** Module for propulsion systems in fixed- and rotary-wing air vehicles
- **Ships—CREATE Ships**
  - **Rapid Design & Integration (RDI) -** Rapid Design and Synthesis Capability
  - **Navy Enhanced Sierra Mechanics (NESM) -** Ship Shock & Shock Damage Assessment
  - **NAVYFOAM -** Ship Hydrodynamics-predict hydrodynamic performance
  - **Integrated Hydro Design Environment (IHDE) -** Facilitates access to Naval design tools
- **RF Antenna—CREATE RF**
  - **SENTRI -** Electromagnetics antenna design integrated with platforms
- **Meshing and Geometry—CREATE MG**
  - **Capstone -** Components for generating geometries and meshes needed for analysis

Annual Product Release Cadence Established

Fiscal Year	FY2010				FY2011				FY2012				FY2013-planned			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
AV-DaVinci									1					2		3
AV-Helios		1						2					3	4		
AV-Kestrel				1		2							3		4	
MG-Capstone					1				2				3			
RF-SENTRI	1	1.5						2					3			
Ships-IHDE	1				2				3				4			
Ships-NavyFoam					1				2				3			
Ships-NESM	0.1				1				1.1				2.1			
Ships-RSDE									0.5				1.1			

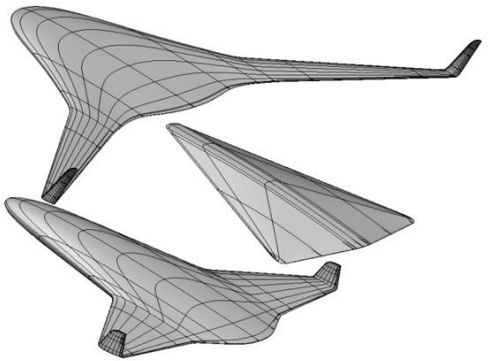
- **Approximately every year, a fully-tested upgraded code with the new features identified in the roadmap is released**

DaVinci: Conceptual Air Vehicle Design

- **Delivered capabilities in Version 2.0**
  - Enable creation of parametric, associative engineering models of fixed- and rotary-wing aircraft from pre-engineered components (e.g., airfoils, 3-D wing surface, rotor, fuselage, engines) resulting in mesh-able, NURBS-based surface geometry
  - An agile infrastructure that allows building of conceptual design capabilities and tools:
    - Rapid model development and seamless transition from conceptual design to preliminary-/detailed-level analysis (e.g., Kestrel/ Firebolt and Helios/ Firebolt products)
    - Being used for assessments of next-generation AF Cargo Plane

Kestrel use by DaVinci

1. Create water tight OML geometry in *DaVinci*
2. Pass OML geometry to *Capstone* for grid generation
3. Pass grid to *Kestrel* for static & dynamic analyses
   - Static rigid aircraft
   - Rigid single body prescribed motion
4. Pass *Kestrel* analyses in coefficient, force, moment form to *DaVinci*
5. Integrate *Kestrel* results for use in *DaVinci*

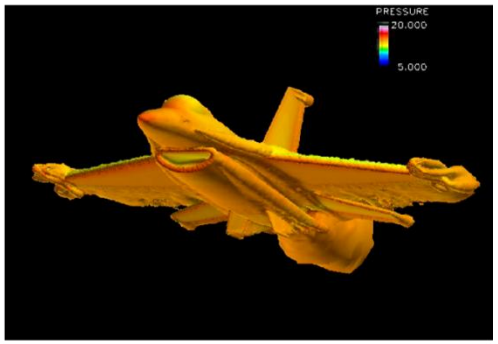


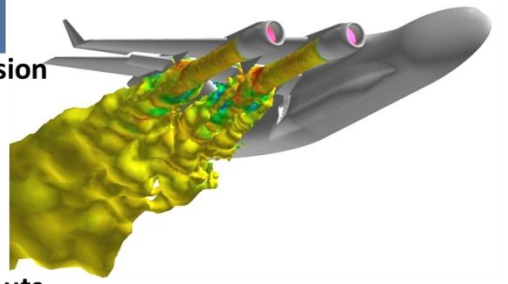
Kestrel

- **Delivered capabilities—2012**
  - Simulations with two or more bodies in relative motion with control surfaces
    - User-prescribed time histories of position and orientation data
    - 6DoF predictive motion
    - Systems Identification Models
    - Airframe Propulsion Integration
  - Meeting accuracy (~5%) and scalability goals (90% parallel efficiency for ~1,000 core problems)

Airframe Propulsion Integration

Multidisciplinary Physics-
A/C Propulsion Interaction:
- F-22 Thrust Vectoring
- B-2 Aft Deck Thermal Effects
- C-17 Blown Flap Ops





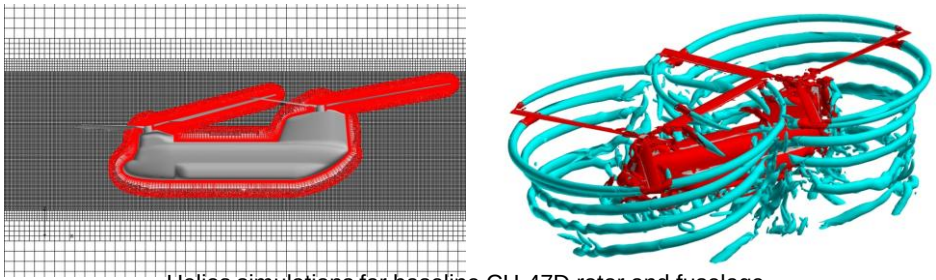
- **Requires hi-fi aero coupled with propulsion cycle analysis or full annulus modeling**
- ***Kestrel* is the only production quality S/W capable of coupling engine with aircraft (a/c) for throttle changes**
- **Warfighter Payoff –Safety of flight checkouts, less conservative flight envelopes, NO ground test facility in the world can model this**

Helios

- **Helios v3.0 2013 Capability**
  - General multi-rotor and fuselage modeling
  - Co-visualization ParaView module
  - AMR with generalized vorticity threshold
  - Parallel unstructured mesh partitioning
  - DES turbulence modeling

Army / Boeing CH-47 Modeling

- **Boeing claims that its new CH-47F rotor blade will have 2,000 lbs. of increased thrust in hover with no degradation in forward flight performance**
  - New dihedral-anhedral blade tip shape similar to Comanche rotor
  - Wind-tunnel tests completed in 2010
  - Flight tests scheduled for 2014 with plans to retrofit new blades into CH-47F models
- **Army AFDD and AED are working with Boeing to run Helios simulations for new CH-47F rotor and fuselage combinations**
- **CREATE-A/V Helios simulations will reduce risk in the deployment of this new CH-47F rotor blade by:**
  - Confirming Boeing's performance predictions for the isolated rotor prior to flight tests
  - Confirming that the rotor/rotor interference and/or rotor/fuselage aerodynamic interactions don't adversely affect the performance of the installed rotors … Boeing cannot predict these interactional aerodynamics effects without using Helios



Helios simulations for baseline CH-47D rotor and fuselage

CH-47 Rotorblade Upgrade

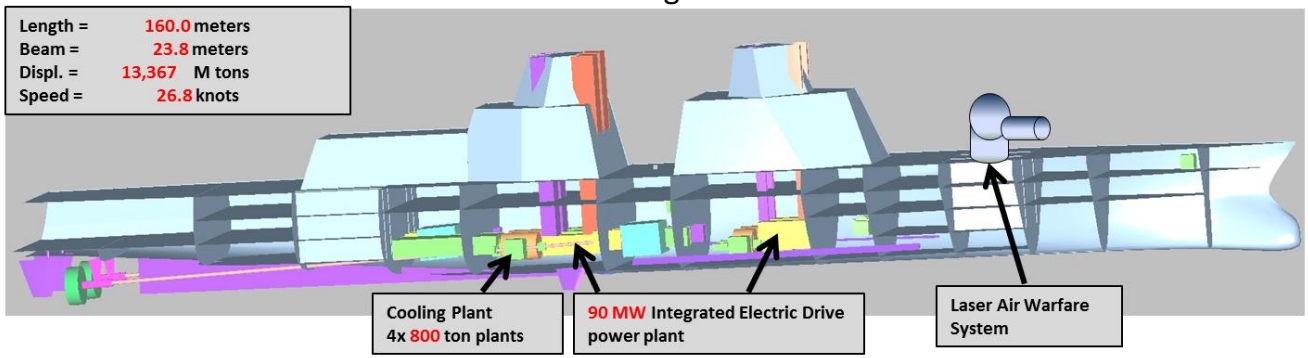
Rapid Design Integration (RDI)

- **RSDE 1.0 (Dec 2012)**
  - Capability to perform design space exploration using the Advanced Ship and Submarine Evaluation Tool (ASSET ver 6.3)
  - Release of LEAPS 4.4 with Multi-disciplinary Design Optimization Toolkit and ship structure definition in LEAPS focus model

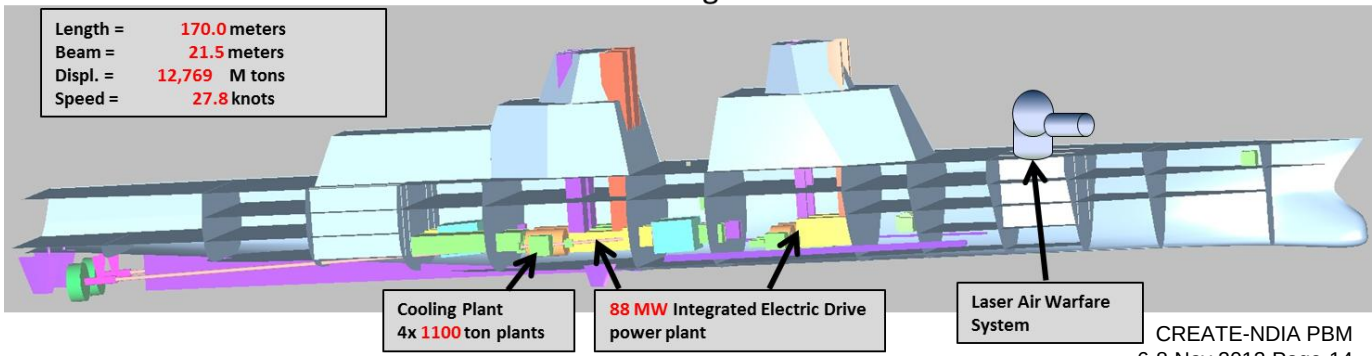
- **Being used for Engineered Resilient Systems Pilot Design Optimization**
- **Comparing traditional point-based and better set-based design methodology**

RSDE Design Optimization – Point based vs. set-based design (less weight and higher speed)

Point-Based Design Result



Set-Based Design Result



Navy Enhanced Sierra Mechanics (NESM)

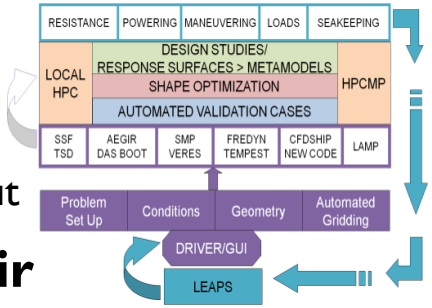
- **NESM Capability 2012**
  - Production capabilities for UC I: Underwater explosions with minor hull damage
    - Extensive verification & validation for test platforms/ship components
    - Full ship validation initiated with good preliminary results at release
  - Beta Capabilities for UC II/III
    - Required elements and material models supported
    - Preliminary multi-scale modeling supported
    - All features fully-verified and preliminary validation promising

- **NESM Selected as the main candidate for CVN-78 Full Ship Shock Trail Alternative**
- **Undergoing validation and accreditation**

CVN-78 is the new Gerald R. Ford class of carriers being launched starting in 2015

Integrated Hydrodynamics Design Environment (IHDE)

- **Current State (Available Capability IHDE V4.0)**
  - UCR1: Bare hull resistance using thin ship theory
    - Total Ship Drag (TSD) applicable to monohulls and multihulls
  - UCR2: Bare hull resistance using a Boundary Element Method (BEM)
    - Das Boot: Current capability for monohulls
  - UCS1: Frequency domain seakeeping analysis
    - Standard Ship Motions Program (SMP) applicable to monohulls
  - UCS2: Time domain inviscid seakeeping prediction
    - Large-Amplitude Motions Program (LAMP): currently applicable to monohulls
  - UCS5: Seaway Loads
    - Obtainable via LAMP for monohulls
  - UCS6: Environmental conditions
    - Seakeeping Evaluation Program (SEP): provides operability with SMP input



- **Being used by US Navy Naval Architects to improve their productivity for hydro assessments of ship designs**
- **Allows Naval Architects to complete design studies in weeks instead of months**
- **Being used by MIT naval architecture students in their classes**

NavyFOAM

- **Current State (Available Capability NavyFOAM V3.0)**
  - UCR1: Hull resistance with fixed-sinkage and trim
  - UCR2: Hull resistance with computed-sinkage and trim
  - UCP1: Body force model for the propulsor
  - UCM1: Maneuvering capability for rotating arm (e.g., steady turns)
  - UCM2: Maneuvering capability for Planar Motion Mechanism (PMM)
  - UCM3: Maneuvering capability for moving appendages

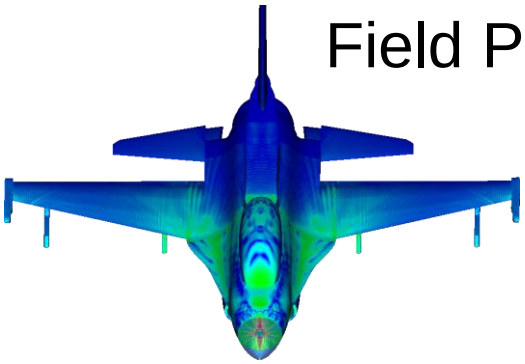
- **Being used for hydrodynamic design of the Ohio Replacement, the Navy's new Ballistic Missile Launch Submarine**

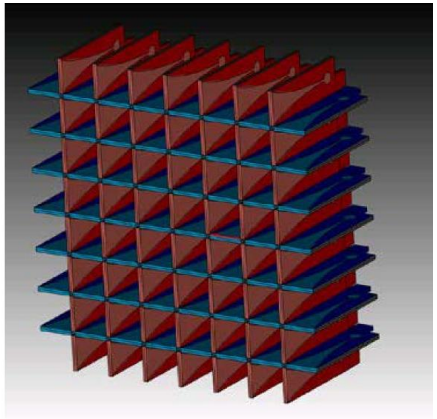
Ohio Replacement Submarine

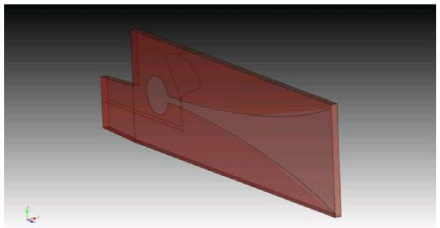
SENTRI (RF Antenna Design)

- **SENTRI 3.0 Capabilities**
  - General Release scheduled for 30 Nov 2012
  - Faster solvers
  - Phase 1 of distributed memory version
  - Prescribed functional material characterization
  - Directed acyclic graph solver for parallel scalability
- **Code being tested and validated**
- **Example problem**
  - 8x8 dual polarized phased-array antenna
  - Antennas: strip-line Vivaldi notch-printed circuit

Surface Electric Field Pattern





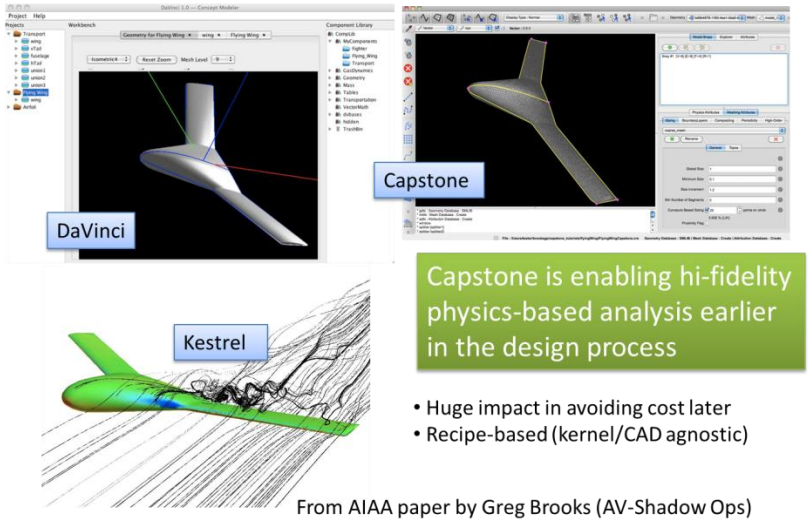


Capstone (Meshing and Geometry)

- **Automated near-body volume meshing with boundary-layers**
- **Unstructured surface meshing improvement**
  - Anisotropic (general and boundary-layer-like) meshes on surfaces
  - Exact representation of key model features like trailing-edges, tips, etc.
- **Boundary-layer volume meshing for bodies with external attachments**
- **Composite topology support**
  - Ability to merge several faces and edges when meshing
- **Expanded and easier to use SDK**
  - Expose both basic APIs as well as more complex functions
- **Volume mesh visualization**
  - Slices, crinkle-cut rendering of volume meshes

Capstone Impact: Design it better, faster and cheaper!

AF LCMC Pilot Project

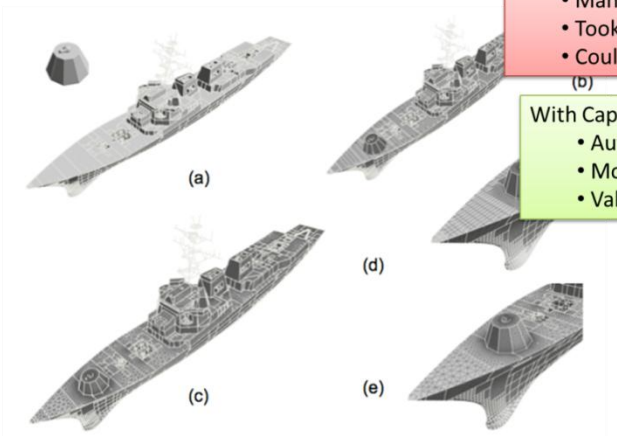


Capstone is enabling hi-fidelity physics-based analysis earlier in the design process

- Huge impact in avoiding cost later
- Recipe-based (kernel/CAD agnostic)

From AIAA paper by Greg Brooks (AV-Shadow Ops)

Capstone Impact: Automated Ship Modeling



Before Capstone:
- Manual
- Took 1 year
- Could produce invalid meshes

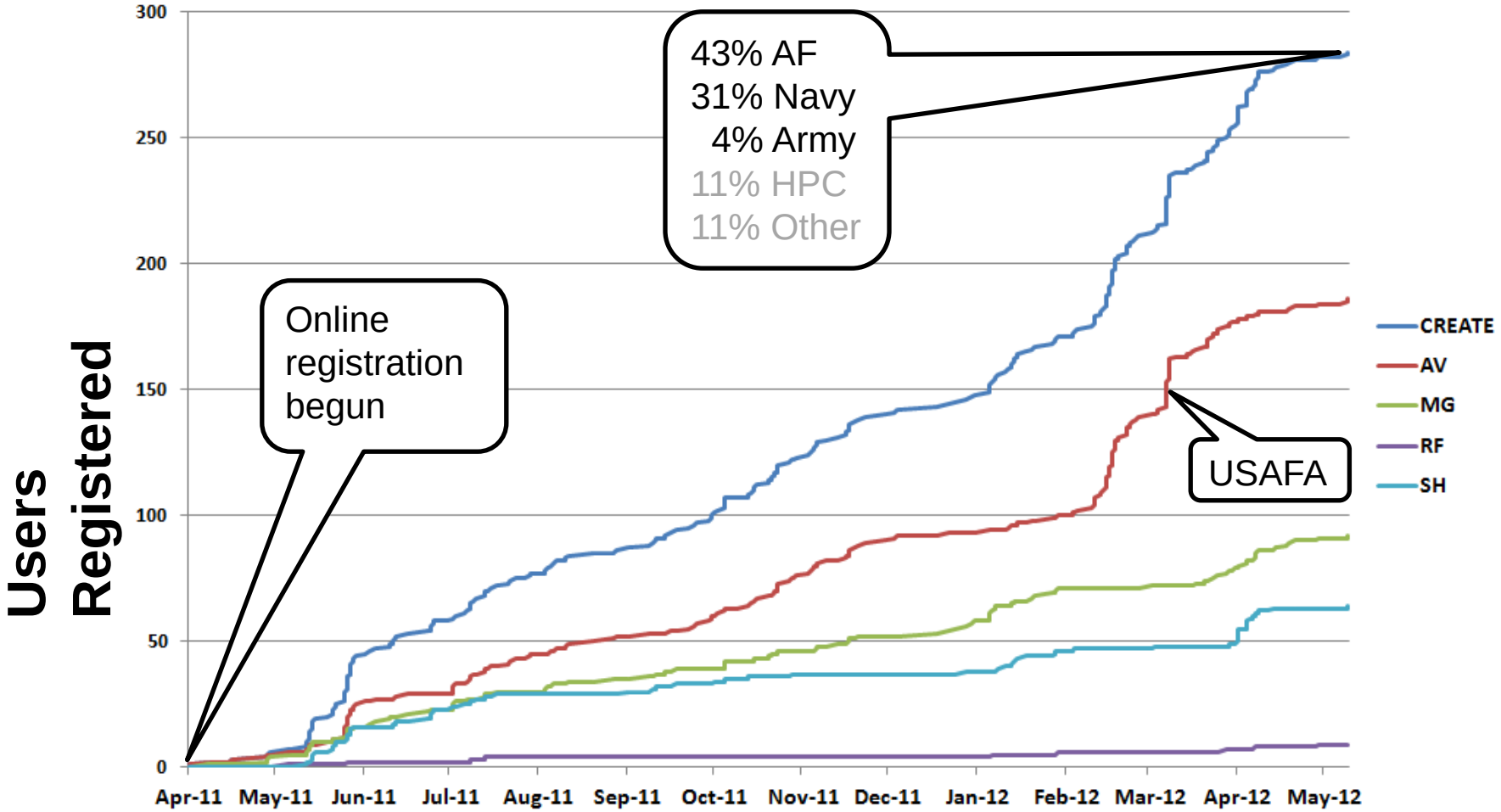
With Capstone:
- Automated
- Month or less
- Valid

Critical for enabling Computational Full Ship Shock Tests

Huge improvement in turnaround time!

Acquisition Engineering Customer Base Growing

- **CREATE AV licenses up to ~275 (not all active)**



- **User base growth is a good thing, but represents a growing demand on flat development team resources**
- **CREATE setting up an AV Support organization to be owned and supported by the Services (Army, Navy, and Air Force Aviation communities)**

Notes:

- Developers omitted from above
- 196 users not registered online and omitted
- Service usage based on sponsor email

CREATE Tools Being Tested & Used by ~ 50 Programs



- **NAVSEA: DDG-1000 Surface Combatant, the CVN 78 and 79 Aircraft Carriers, and the Ohio Replacement Submarine program;**



- **NAVAIR: E-2D, F/A-18E, JSF, F/A-18 MALD, Fire Scout, and Small UAV PMA**



- **Army Rotorcraft: UH-60, CH-47 (ACRB), OH-58**

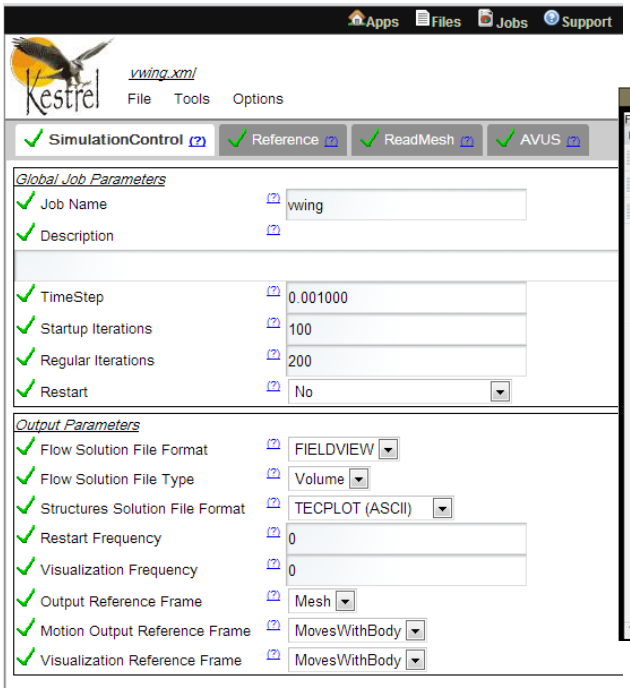

- **AF LCMC: F-15 SA/DB-110, B-1B/ELLA, Strategic Airlift CP&A, JSF**

CREATE Making Deployment Progress

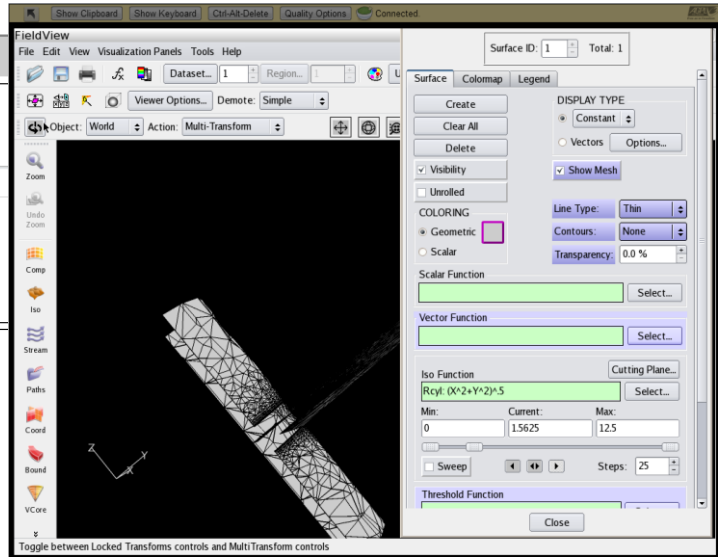
- **DoD needs to maintain government use rights and control of distribution**
  - Export control designation vetted by DTSA
  - Enables FOIA exemption as military Tech Data
- **Successfully deployed applications to government engineers**
- **Successfully deployed applications to US Defense Industry under contract to the DoD**
- **Exploring CRADAs for deployment to US Defense Industry not under contract to the DoD**
- **CREATE tools being used by AF Academy aeronautical engineering students and MIT naval architecture students**

Kestrel Delivery Using HPC-Portal

- **DoD security restrictions will limit users to MS Office and Browser**
- **HPCMP developing a Portal to allow users to access codes on HPC platforms through a browser**

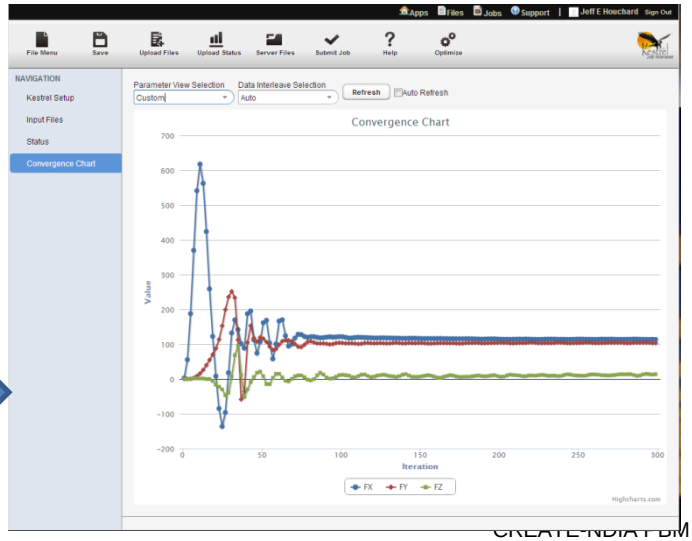


Field-view Integrated into workflow



Smart Parameter Entry

Convergence Plot (User-Selected Parameters)



CREATE Next Steps

- **Improve scaling**
  - Next-generation computer architecture will rely on massive parallelism and mixtures of special purpose processors
  - Re-architecting and refactoring basic solvers
  - CREATE exploring use of new computational mathematics libraries and algorithms
- **Increasing emphasis on V&V and Uncertainty Quantification (UQ)**
  - Following guidelines listed in recent NAS study on VV&UQ
  - Already following most "best practices," but greater emphasis on obtaining validation data would be highly useful
  - Assessing UQ and methods and options

Summary

- **CREATE Program is continuing to develop and deploy software with the new features needed by the DoD aircraft, Naval, and RF engineering community**
- **Customer growth is strong, both in terms of users and programs**
- **Already contributing to the analysis and design of important DoD systems (CH-47 rotor-blade retrofit, Ohio replacement submarine, CVN-78 shock test, NAVAIR UAV flight certification, and AF next-generation cargo plane)**
- **Progress in user support, IP and deployment issues, and Software Engineering**

Fourteen CREATE Papers in Parallel Sessions

- 15039 - Verification, Validation and Uncertainty Quantification in CREATE—A Case Study; Dr. Larry Votta,
- 14961 - 2012 Highlights of the CREATE Program; Dr. Douglass Post
- 15102 - CREATE-AV DaVinci: Informed Systems Engineering Decision-Making for DoD Acquisition; Mr. Gregory Roth
- 15048 - Prediction of Ship Shock Response & Damage with the Navy Enhanced Sierra Mechanics Code; Dr. E. Thomas Moyer
- 15082 - Modeling Antennas with CREATE-RF's SENTRi Application Dr. John D'Angelo
- 14965 - Using CREATE's Rapid Ship Design Environment to Perform Design Space Exploration for a Ship Design; Mr. Adrian Mackenna
- 15010 - First-Principles Hover Prediction for Multiple Rotor Blades using CREATE-AV Helios; Dr. Nathan Hariharan
- 15088 - Capstone: A Platform for Geometry, Meshing and Attribution Modeling for Physics-Based Analysis and Design; Dr. Saikat Dey
- 14769 - Portal Development for HPC at Maui High Performance Computing Center DoD Supercomputing Resource Center; Mr. David Morton
- 15028 - Using Kestrel in the Cloud; Mr. Joshua Calahan
- 15012 - Prediction of Unsteady Flow in UCAV Weapon's Bay Using CREATE-AV's Kestrel; Mr. Benjamin Hallissy
- 15040 - Software Engineering in CREATE—Lessons Deployed; Dr. Richard Kendall
- IHDE; Adrian Mackenna; late addition to the agenda
- NavyFoam; Sung-eon Kim; late addition to the agenda