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

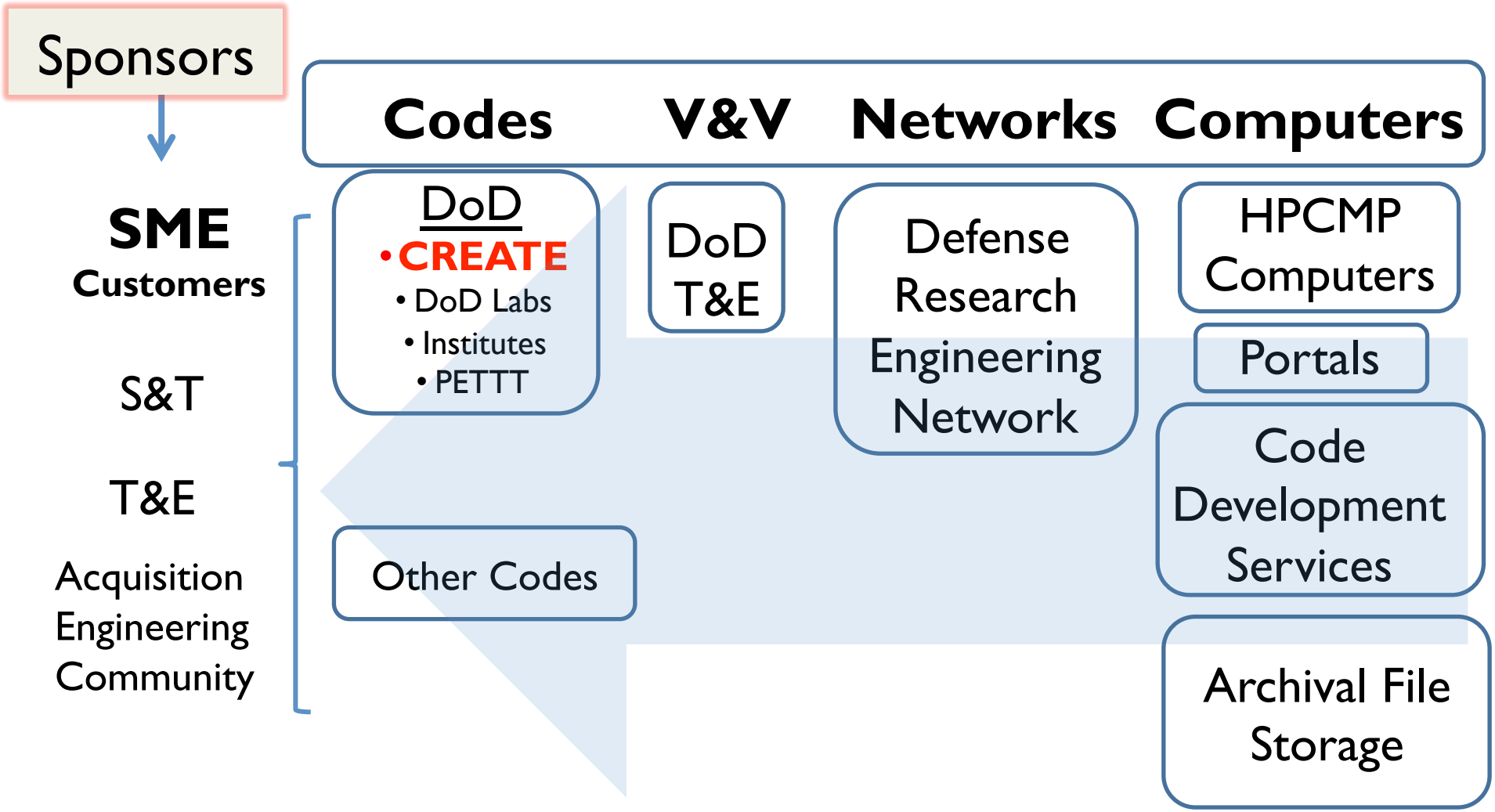
DOD HPC MODERNIZATION PROGRAM

Dr. Douglass Post (Presented by Dr. Saikat Dey)
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



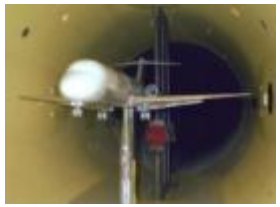
Computational Research Engineering Acquisition Tools and Environments (CREATE) Objectives and Goals

- **Develop and deploy multi-physics computational engineering software that, when used in conjunction with increasingly capable high performance computing systems, accurately predicts the performance of weapon 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 weapon 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



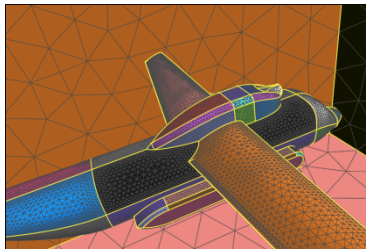
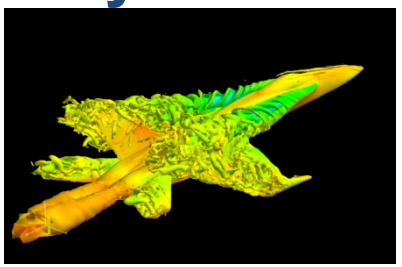

Requirements → Design → Build Physical Product → Test Physical Product → Manufacture, Sustain, and Modify

(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 MultiPhysics-Based Computational Tools to Improve Product Development of Complex Systems



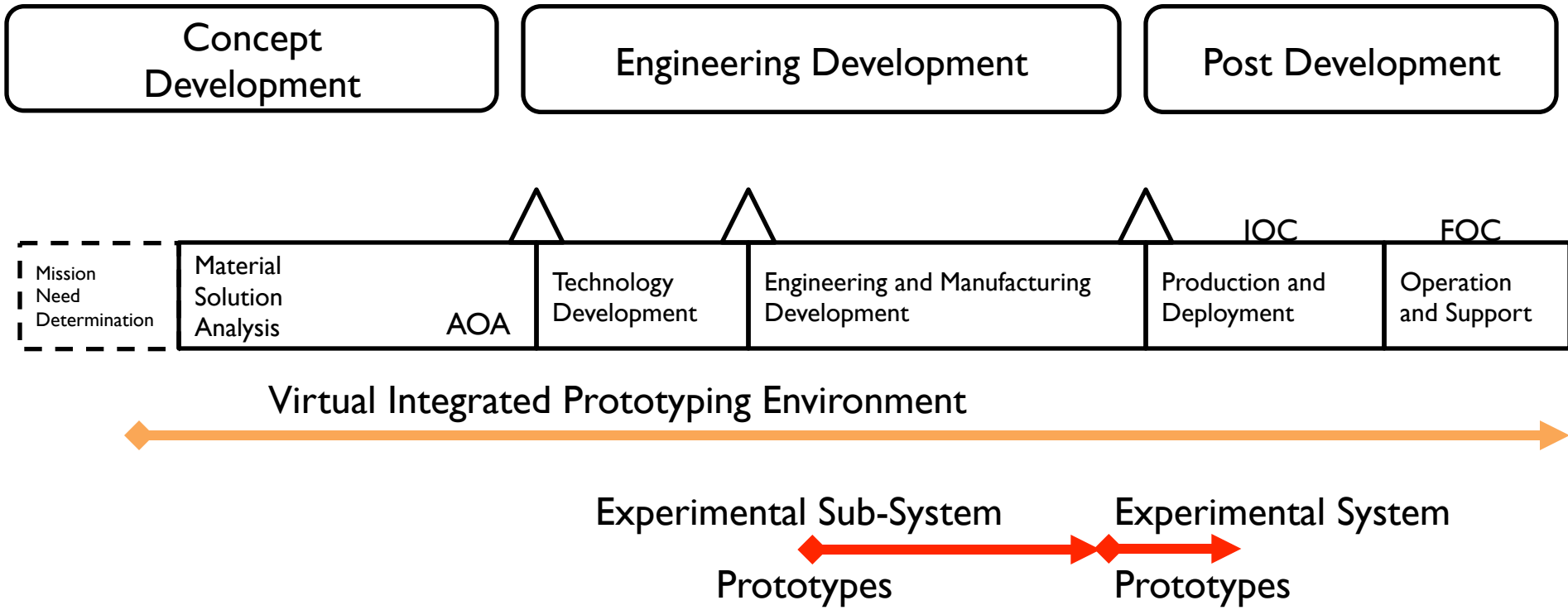

Requirements → Design on Computer → Build Mesh → Analyze Performance → Ground-based and Flight Tests

(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

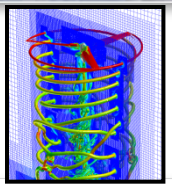
Performance Analysis of Virtual Prototypes Is the Key



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

Computational Research and Engineering Tools and Environments (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 for analysis

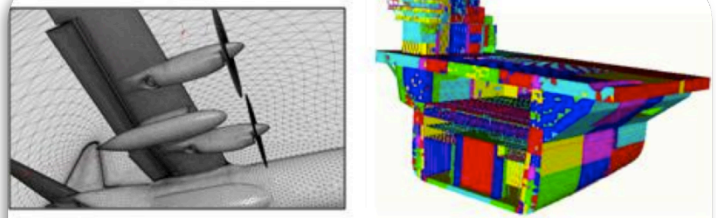


Design concept

Seakeeping and resistance

Shock vulnerability

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



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**

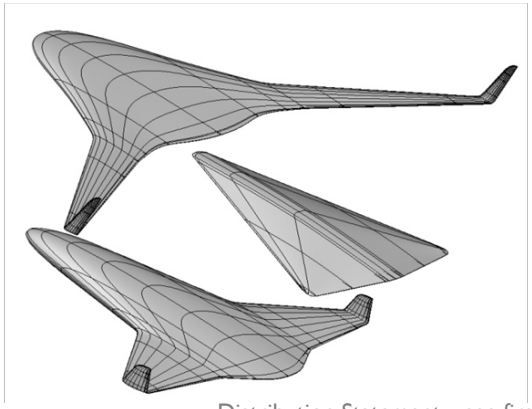
DaVinci: Conceptual Air Vehicle Design

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*

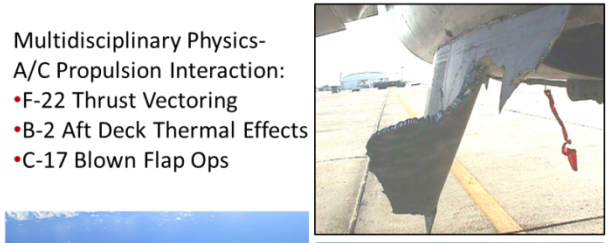


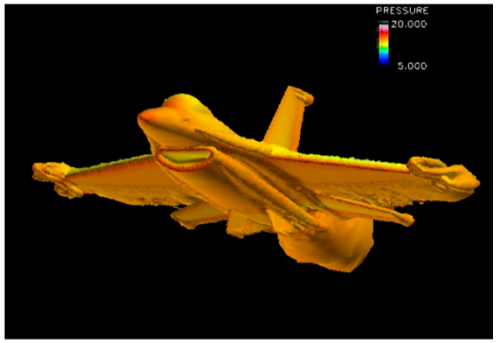
Kestrel

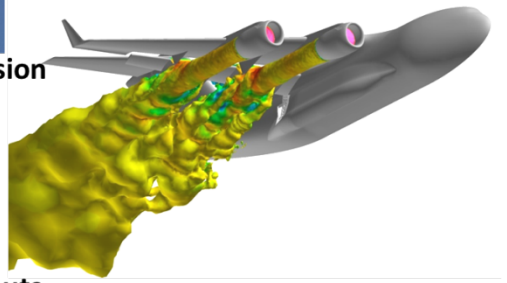
- **Delivered Capabilities--2012**
  - Simulations with two or more bodies in relative motion with control surfaces
    - User prescribed time histories of position and orientation data
    - 6DoF predictive motion
    - Systems Identification Models
    - Airframe Propulsion Integration
  - Meeting Accuracy (~5%) and scalability goals (90% parallel efficiency for ~1000 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







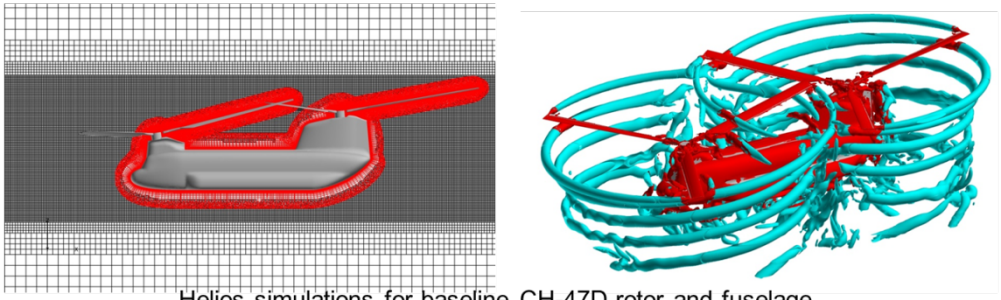
- **Requires hi-fi aero coupled with propulsion cycle analysis or full annulus modeling**
- ***Kestrel* is the only production quality S/W capable of coupling engine with aircraft (a/c) for throttle changes**
- **Warfighter Payoff –Safety of flight checkouts, less conservative flight envelopes, NO ground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

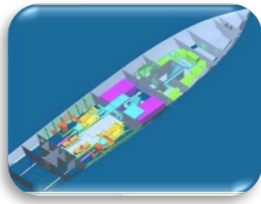


Helios simulations for baseline CH-47D rotor and fuselage

CH-47 Rotorblade Upgrade

Rapid Design Integration (RDI)

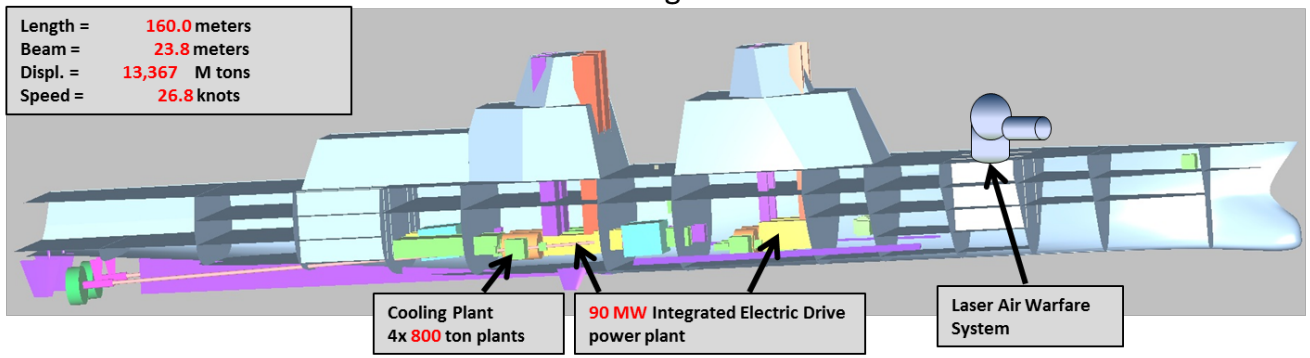
- **RSDE 1.0 (Dec 2012)**
  - Capability to perform design space exploration using the Advanced Ship and Submarine Evaluation Tool (ASSET ver 6.3)
  - Release of LEAPS 4.4 with Multi-disciplinary Design Optimization Toolkit and ship structure definition in LEAPS focus model



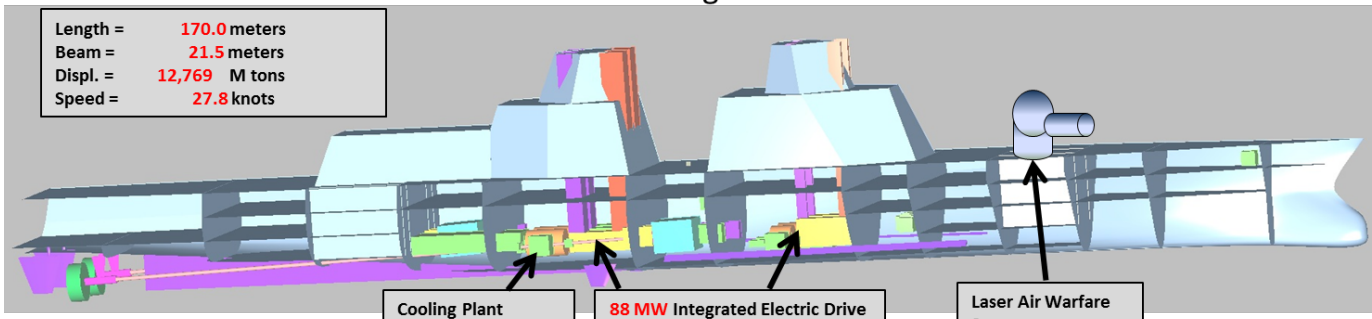
- Being used for Engineered Resilient Systems Pilot Design Optimization
- Comparing traditional point-based and better set-based design methodology

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)

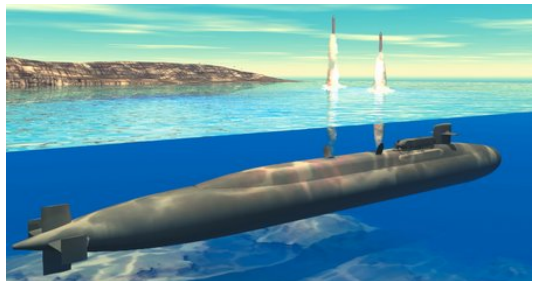
- **NESM Capability 2012**
  - Production Capabilities For UC I: Underwater explosions with minor hull damage
    - Extensive Verification & Validation For Test Platforms/Ship Components
    - Full Ship Validation Initiated with Good Preliminary Results At Release
  - Beta Capabilities For UC II/III
    - 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 Trial Alternative
- Undergoing validation and accreditation

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

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 Submarine, the Navy's new Ballistic Missile Launch Submarine**

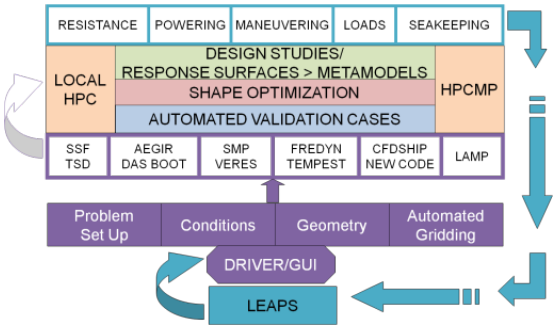


Ohio Replacement Submarine

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

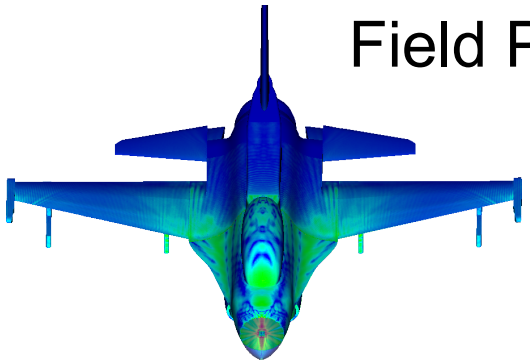
- Being used by US Navy Naval Architects to improve their productivity for hydro assessments of ship designs
- Allows Naval Architects to complete design studies in weeks instead of months
- Being used by MIT naval architecture students in their classes



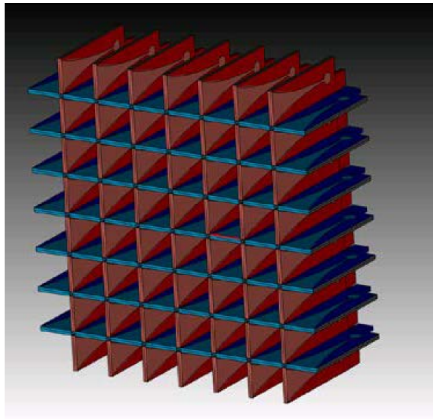
SENTRI (RF Antenna Design)

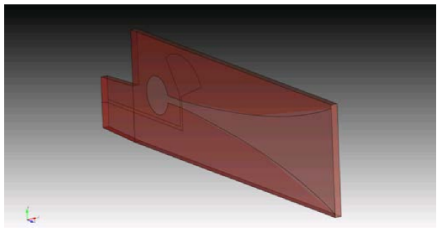
- **SENTRI 3.0 Capabilities**
  - General Release scheduled for 30 Nov 2012
  - Faster Solvers
  - Phase I of Distributed Memory Version
  - Prescribed Functional Material Characterization
  - Directed acyclic graph solver for parallel scalability

Surface Electric Field Pattern



- Code Being tested and validated
- Example Problem:
  - 8x8 dual polarized phased array antenna
  - Antennas: strip-line Vivaldi notch printed circuit



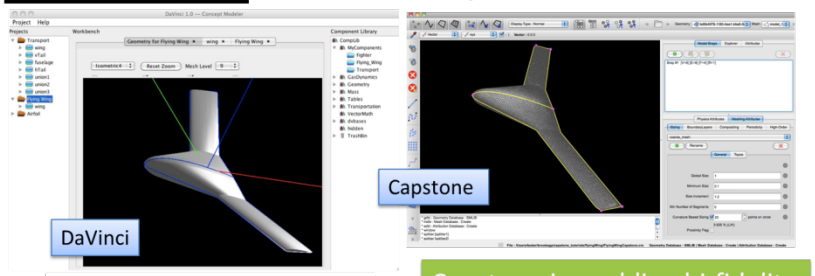


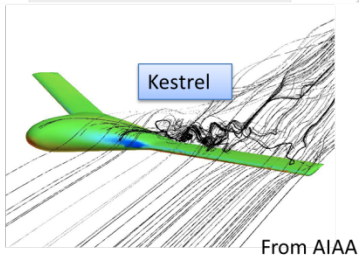
Capstone (Meshing and Geometry)

- **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



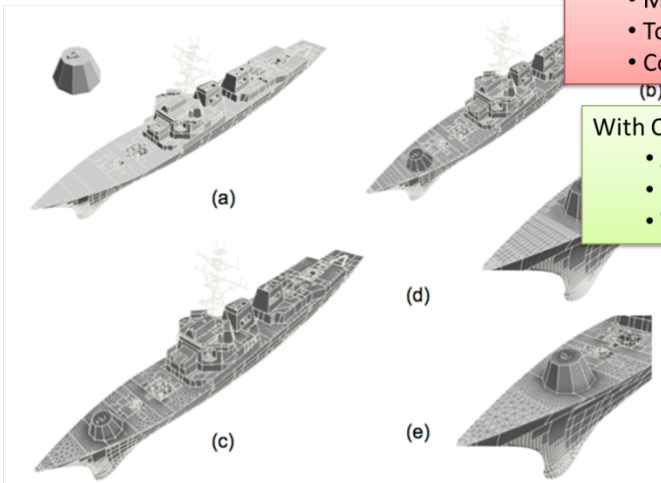


Capstone is enabling hi-fidelity physics-based analysis earlier in the design process

- 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

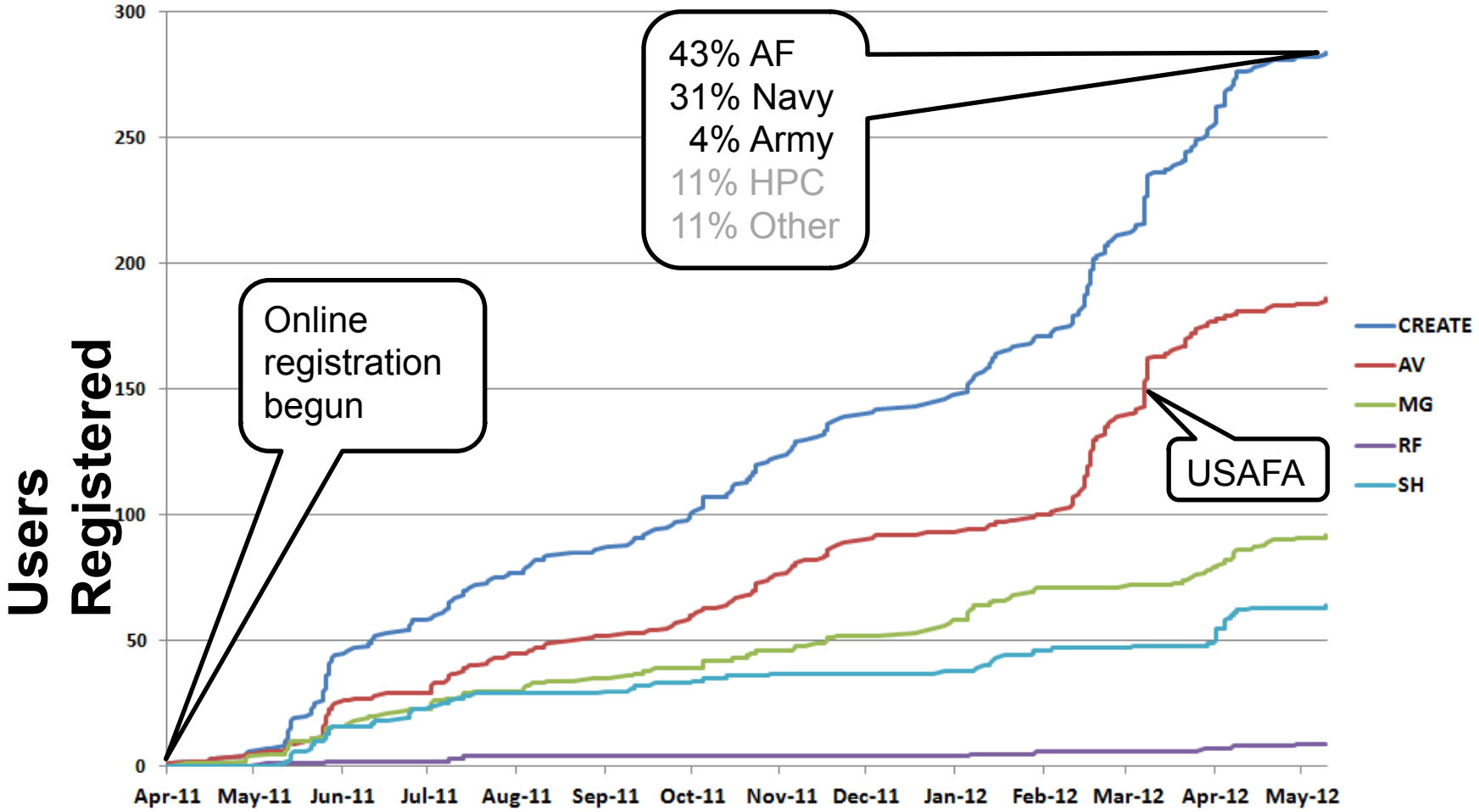
With Capstone:
- Automated
- Month or less
- Valid

Critical for enabling Computational Full Ship Shock Tests

Huge improvement in turnaround time!

Acquisition Engineering Customer Base Growing

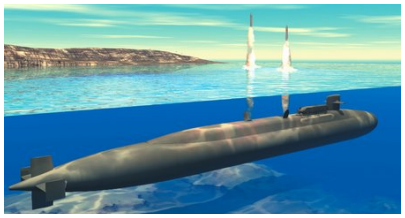
- CREATE AV licenses up to ~275 (not all active)



- 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)

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**

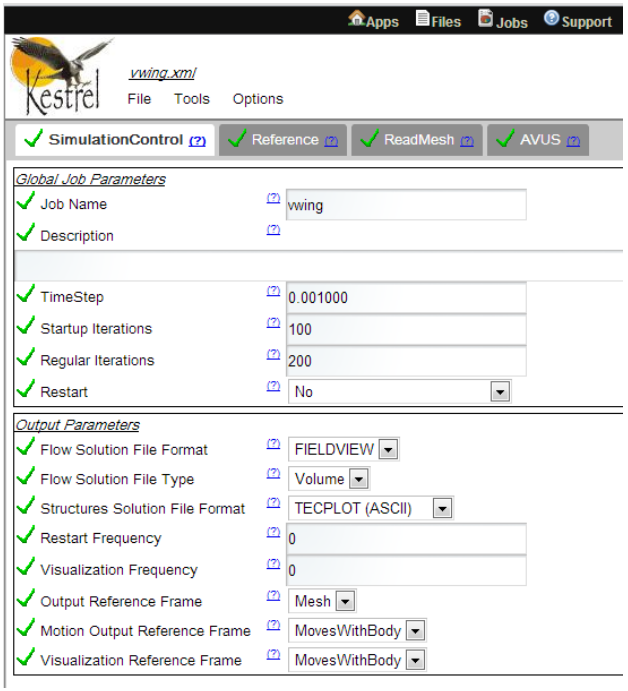

- **AF LCMC: F-15 SA/DB-110, B-1B/ELLA, Strategic Airlift CP&A, JSF**

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**

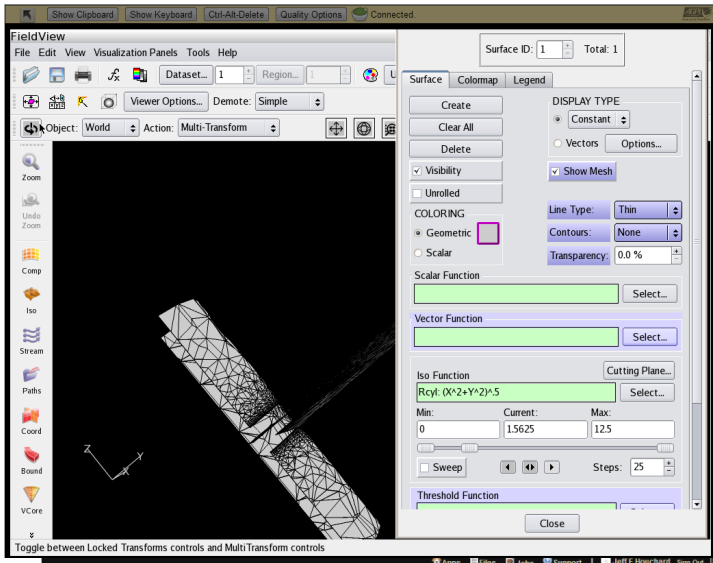
Kestrel Delivery Using HPC-Portal

- 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

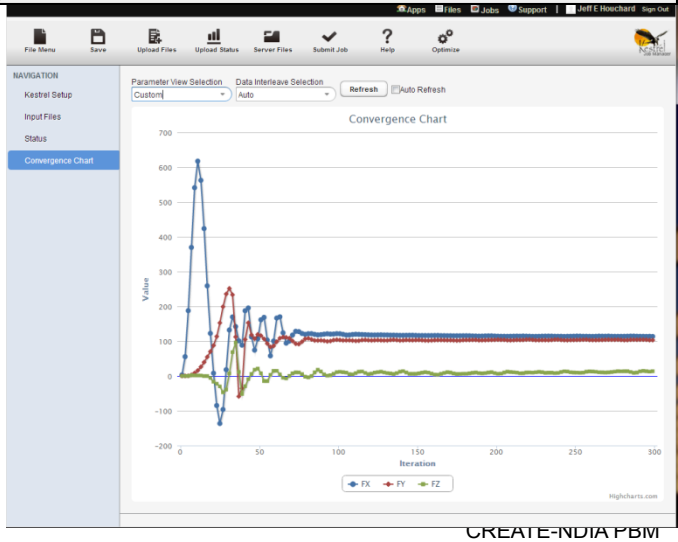


Smart Parameter Entry

Fieldview Integrated into workflow



Convergence Plot (User Selected Parameters)



CREATE Next Steps

- **Continue adding feature enhancements and improving usability**
- **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 acquisition engineering community**
- **Customer grow is strong, both in terms of users and programs**
- **Already contributing to the analysis and design of important DoD systems (CH-47 rotorblade 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, 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 Applicatio;n 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