Computational Research Engineering Acquisition Tools and Environments

A DoD Program to Aid Acquisition Engineering

DOD HPC MODERNIZATION PROGRAM

Dr. Douglass Post

CREATE Associate Director and Scientific Advisor to the Director

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HPCMP High-Level Operational Concept

DOD HPC MODERNIZATION PROGRAM

Users

DOD HPC 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)

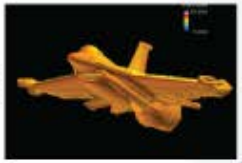
Computer Network Defense, Security R&D, and Security Integration

Software Applications Support

Core Software

Education and Training

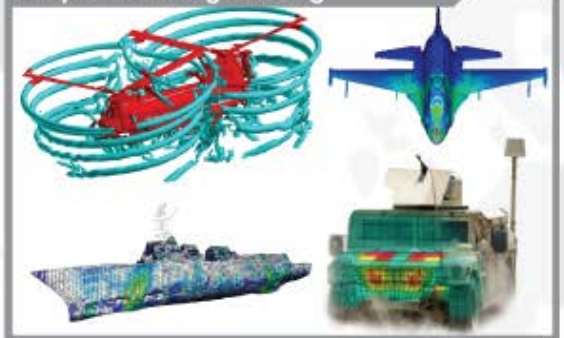
Support



Computational Environments

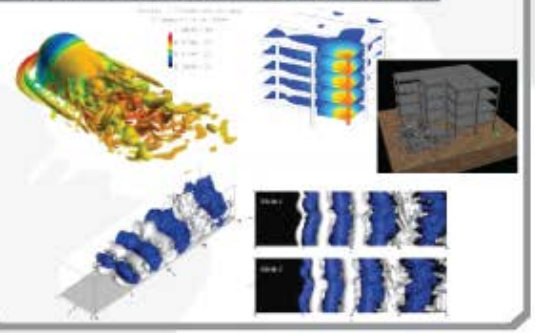
Results

Acquisition Engineering



Decision Support

Science and Engineering Research



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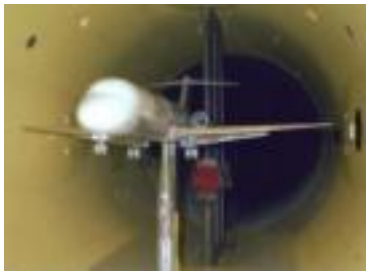
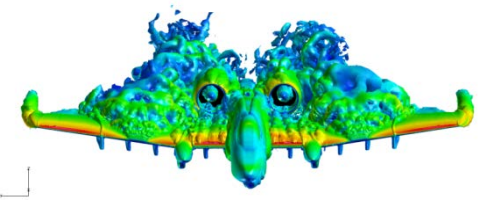
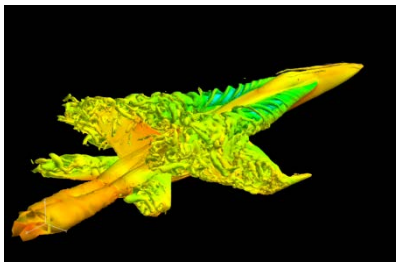
CREATE Vision: Physics-Based Virtual Prototyping

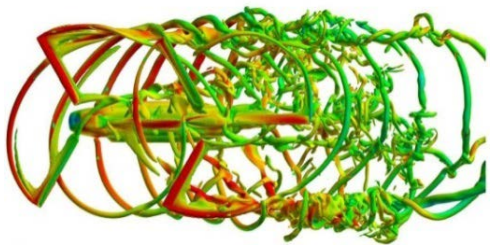
- Supplement Experimental testing of physical prototypes

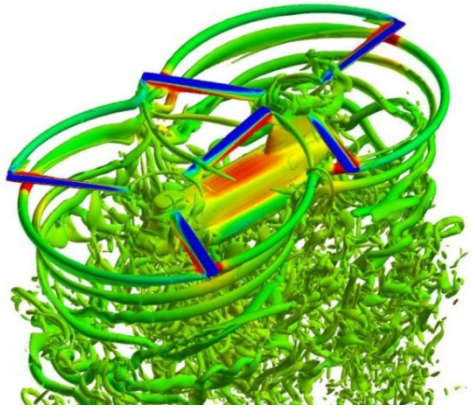


- With Physics-based computational performance predictions of digital product models


A-10


F-18


Forward Flight


Hover

- Faster and cheaper evaluation of far more design options [LX(R) 6→22,000]
- Provides performance data very early, but codes must be very accurate

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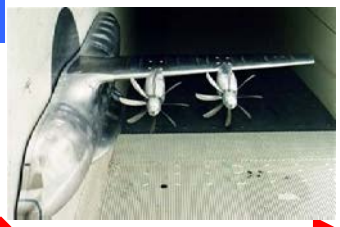
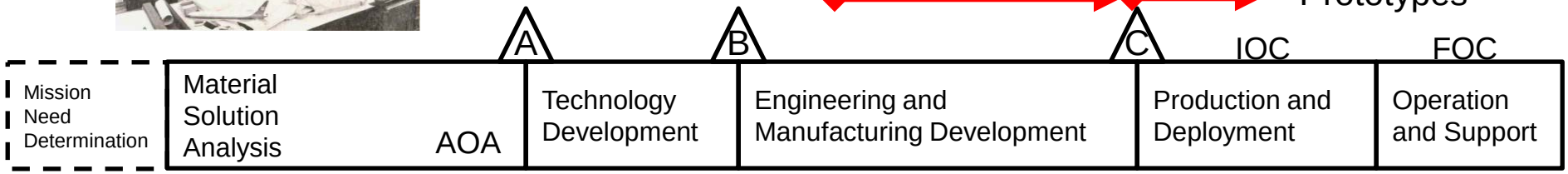
CREATE Supports ERS Vision

Acquisition Today: Process-Driven

Sub-System Prototypes

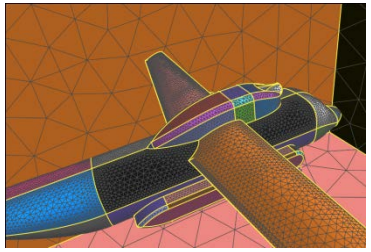


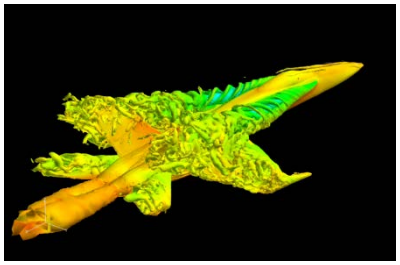
Full System Prototypes



Acquisition Tomorrow: Data-Driven and platform-based

CREATE Virtual Prototyping Integrated Environment Provides Physics-Based Data





- Replace extrapolations of existing designs based on past experience WITH new designs guided by past experience and based on the laws of physics
- Identify and fix design flaws before metal has been cut → Reduced rework, cycle time and risk

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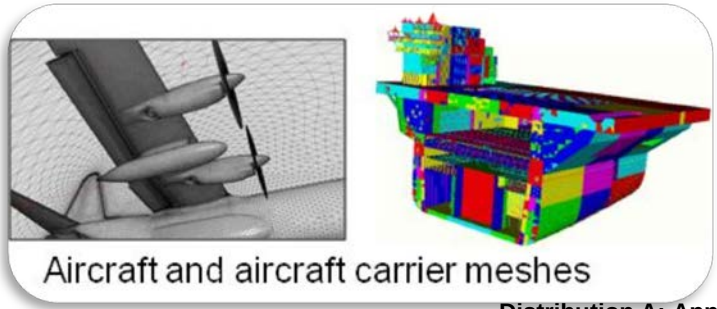
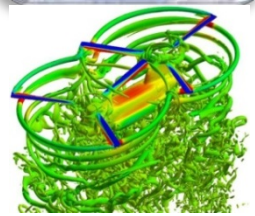
CREATE: Suite of Physics-based HPC Tools for the Design and Analysis of DoD platforms:

- **Air Vehicles (AV)—Air Force, Army & Navy**
  - Concept design, High Fidelity Fixed-Wing and Rotary-Wing
- **Ships—Navy**
  - Concept design, Shock and Life Fire Vulnerability, Hydrodynamics
- **Radio Frequency (RF) Antennas—Air Force, Army & Navy**
  - RF Antenna electromagnetics & integration with platforms
- **Mesh and Geometry (MG) Generation**
  - Rapid generation of geometry representations and meshes
- **Ground Vehicles (GV) —Army & Navy**
  - Concept Design and Performance Prediction

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


Aircraft and aircraft carrier meshes


Military platforms with antennas


CH-47


HMMWV

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Multi-Physics Integration is a Key Differentiator

10 CREATE tools integrate the major physics performance drivers:

- **AV**— Kestrel and Helios —fixed & rotary wing: air frame (aerodynamics & structural mechanics), control, propulsion,…, DaVinci—Aircraft concept design
- **Ships**— NESM —LFT&E: shock in water/air coupled to ship; NavyFOAM —hydrodynamics, acoustics, surface waves,…; RSDE — Ship design synthesis: Hydro, structures, compartments, propulsion; IHDE — Simplified Hydro analysis tool…
- **RF**— SENTRI — Full wave and lower fidelity treatments of multiple antenna arrays at multiple frequencies embedded integrated with full-size, realistic platforms
- **MG**— Capstone — CAD-neutral, robust digital product models (geometries with attributes) for full size, complex platforms (ships, air vehicles, tanks, etc.) that enable analysis with CREATE tools
- **GV**— Ground Vehicle concept design and analysis.

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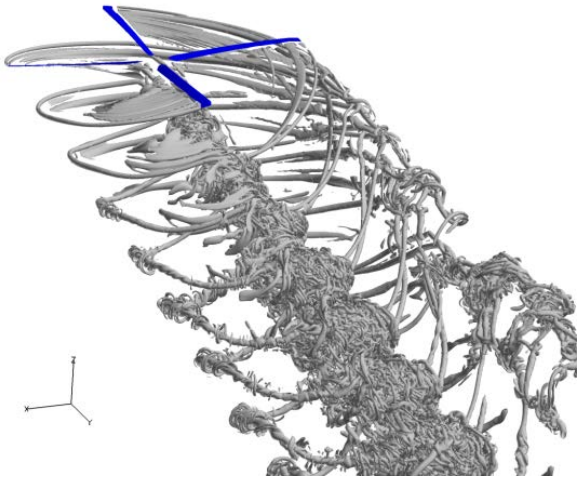
A Paradigm Change for Acquisition of Air Vehicles

- **Multi-disciplinary, physics-based software** and next-generation HPC systems **enable full-vehicle "virtual test" capacity** – the key to a paradigm shift in aircraft acquisition.



ERF 2011, Paper 148, Potsdam, et al.

- **Enabling Use Cases such as…**
  - ✓ Design verification prior to key decision points (and prior to fabrication of test articles or full-scale prototypes)
  - ✓ Evaluation of planned or potential operational use scenarios
  - ✓ Planning/rehearsel of wind-tunnel and full-scale flight tests
  - ✓ Performance of flight certifications (e.g., airworthiness, flight envelope expansion, …)
  - ✓ Calibration of low-fidelity analysis tools associated with conceptual design

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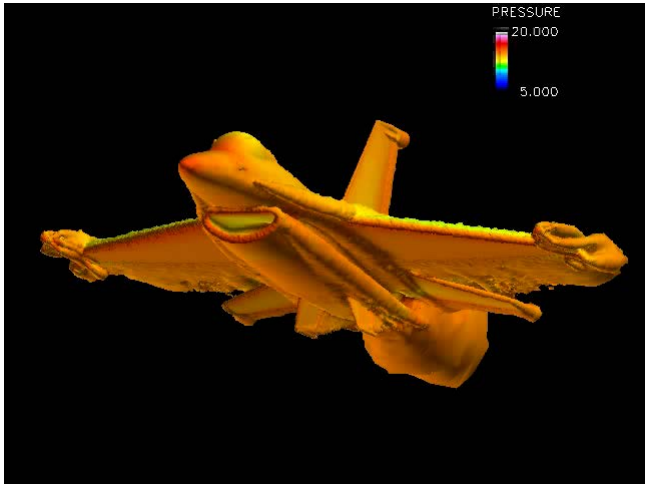
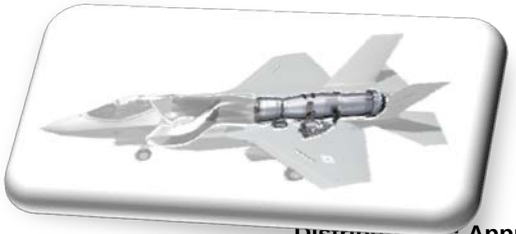
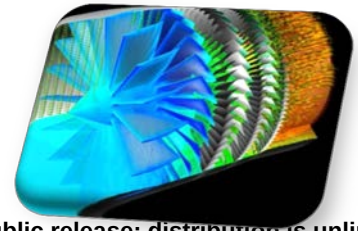
A Paradigm Change…

- **Design Verification (example)**
  Airframe/Propulsion System Integration Process



Virtual airframe/propulsion system integration assessment is a high payoff activity. Currently, component mating does not occur until late in the development cycle (i.e. flight tests) which may not occur for 15-20 years after concept development.





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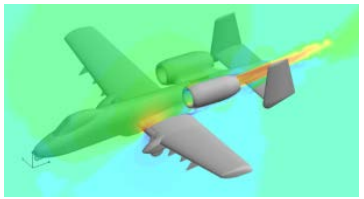
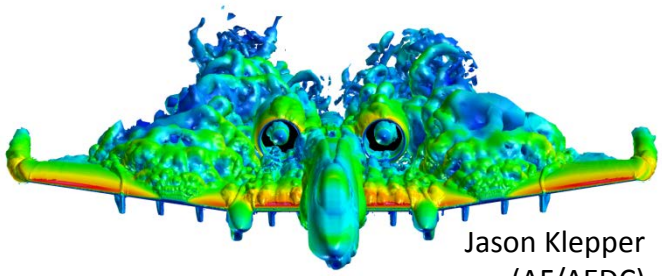
A-10 Engine Inlet Flow Distortion

Context The A-10 System Program Office (SPO) is exploring enhancements to the aircraft's current inboard leading edge slat system. The A-10 mission requires operation at high angles-of-attack and high sideslip, which increases the likelihood of engine inlet flow distortion.

Objective Apply HPCMP CREATE-AV™ Kestrel to simulate the A-10 with baseline and alternative wing leading-edge configurations to assess potential for improvements realizable from the planned enhancement. Explore wind-tunnel scale and full-scale conditions with both flow-through nacelles and the integrated TF34-GE-100 0-D engine model.





Jason Klepper
(AF/AEDC)

AEDC provided the A-10 SPO with engine inlet distortion data associated with various wing leading-edge designs. Analysis of the simulation results have identified the contributing sources of engine inlet distortion that could not be determined from wind tunnel data alone. The A-10 enhancement program is still in progress. AEDC engineers have demonstrated that HPCMP CREATE™-AV Kestrel is a valuable tool in design validation testing.

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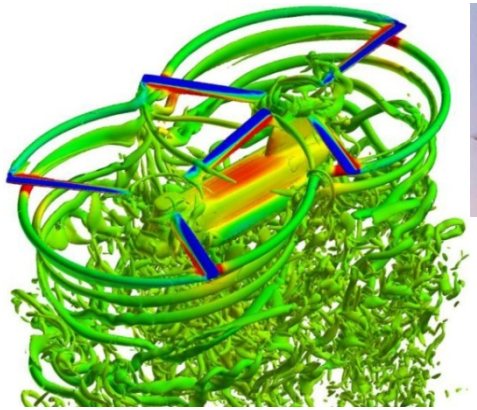
CH-47F Performance Improvement

Problem: Increase hover thrust for CH-47F without degrading forward flight performance.

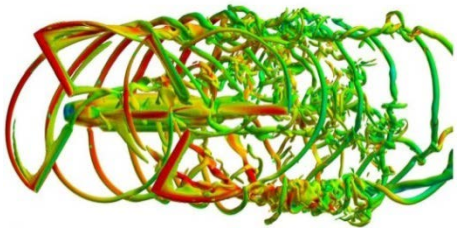
Potential Impact: 2000 pounds improved hover thrust for 400+ Chinooks.

Response: Army AMRDEC/AED and Boeing used HPCMP CREATE-AV Helios software and three million CPU-hours on DSRC supercomputing hardware to confirm Boeing predictions of isolated rotor performance and then, for the first time, verified computationally that rotor/rotor and rotor/fuselage interactional dynamics do not adversely affect the installed performance of the new rotors.



Hover

Forward flight



HPCMP CREATE-AV Helios™ full-configuration, full physics simulation of CH-47F in hover and forward flight

Risk Mitigation Benefits:

- **Virtual testing of the integrated CH-47F with new rotor via high fidelity analysis early in the design process, including aft pylon height and blade indexing.**
- **Enabled flight test planning, previews, and rehearsals.**

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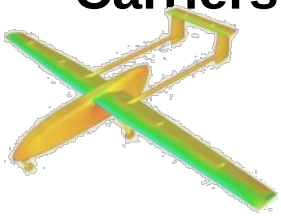
CREATE Tools Being Tested & Used by ~ 70 Programs

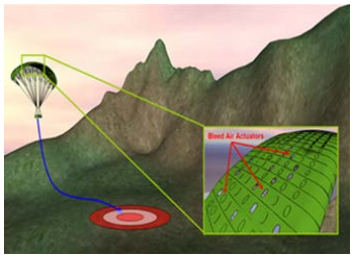
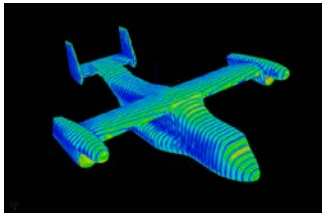



- **NAVSEA: DDG-1000 Surface Combatant, the CVN 78 and 79 Aircraft Carriers, LX(R) and the Ohio Replacement Submarine program**

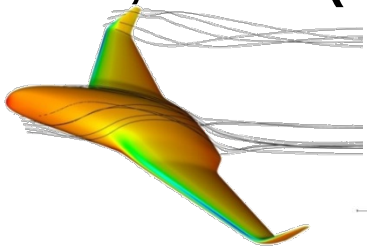
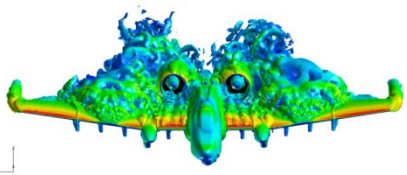


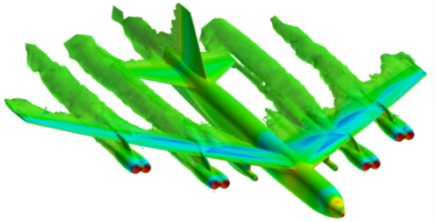

- **NAVAIR: Aerostar & Raven UAVs, F/A-18E, JSF**



- **Army: UH-60, CH-47 (ACRB), Guided Airdrop (RDECOM), V-22**



- **AF LCMC: F-15 SA/DB-110, Strategic Airlift CP&A, A-10, JSF, B-52**

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Key FY14 CREATE Accomplishments

- **Coupled turbulent effects between airframe and turbofan engine compressor for fixed-wing aircraft model—CREATE Kestrel** *
  - Used to evaluate wing design modification to reduce engine intake turbulence for A-10 Warthog and to certify store-separation for military aircraft (e.g. A-10, F-15, F-16, F-22)
- **Coupled aerodynamic and structural effects to model multiple rotors plus fuselage for rotorcraft model—CREATE Helios** *
  - Used to determine if new blade proposed by Boeing for the CH-47F Chinook increased payload allowance while still allowing the same maximum forward velocity
- **Ability to assess large platforms at L-band (i.e. 1GHz – 2GHz) and radar signature of propulsion systems — CREATE SENTRi** *
  - Being used to analyze performance of antenna systems for military platforms (e.g. C-130, V-22 Osprey helicopter) and to determine EM scattering for jet engines (classified work)
- **Added ability to capture full ship response to external stimuli and to maneuver vessels in various sea states for ship models—CREATE NESM and NavyFOAM** *
  - NESM being used to support the Live Fire Test and Evaluation (LFT&E) requirements for CVN 78/79, the new class of supercarriers
  - NavyFOAM being used to determine surface/underwater maneuverability for follow-on to Ohio-class ballistic missile submarines

** First of its kind simulation*

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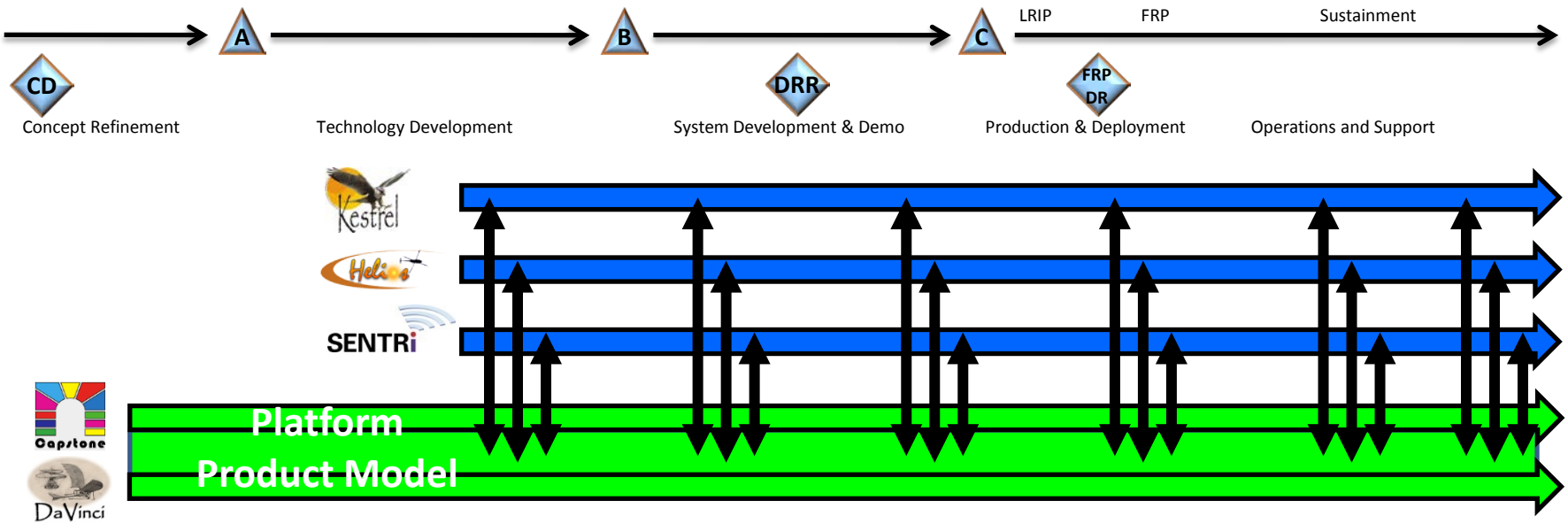
With HPC and multi-disciplinary, physics-based simulation tools We have the capability to:

- ✓ Validate and assess requirements
- ✓ Materially contribute to the design of next generation aeronautical weapon systems
- ✓ Verify design prior to key decision points (and prior to fabrication of test articles or full-scale prototypes)
- ✓ Plan/rehears wind-tunnel and full-scale flight tests (more bang per test dollar)
- ✓ Evaluate planned (or potential) operational use scenarios
- ✓ Perform flight certifications (e.g., airworthiness, flight envelope expansion, mishap investigation, etc.)
- ✓ Generate response surfaces usable in DaVinci, flight-simulators, and other environments that require real-time access to performance data.
- ✓ Persist design intent and key engineering data throughout the subsequent acquisition lifecycle…



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CREATE Summary

- Developing and deploying software with the new features needed by the DoD Air Vehicle, Ship, and RF engineering communities
- Acquisition community interest and customer use growing exponentially (AF, Navy & Army Engineers, Boeing, LMC, NG, Raytheon, Sikorsky, Bell, Pratt & Whitney, AFLCMC, AMRDEC, NAVAIR, NAVSEA, C-130/C-17 Cargo Release, F/A-18E, ARL, SPAWAR, Ball Aerospace,…)
- Already contributing to the analysis and design of dozens of important DoD systems (CH-47 rotor-blade retrofit, Ohio replacement submarine, CVN-78 shock test, NAVAIR UAV flight certification, AF next-generation cargo plane, …)
- Major progress in major challenges: user support, intellectual property, deployment capability, software engineering,…
  - ⇨ Achieving initial goals → potential to revolutionize the way the DoD procures major weapon platforms
- Actively participating in and supporting the ERS Program

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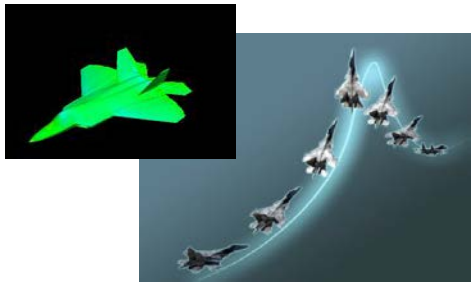
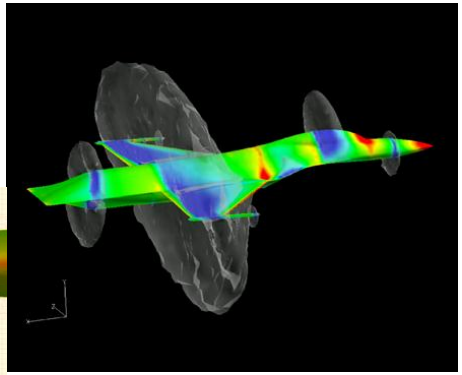
Questions?

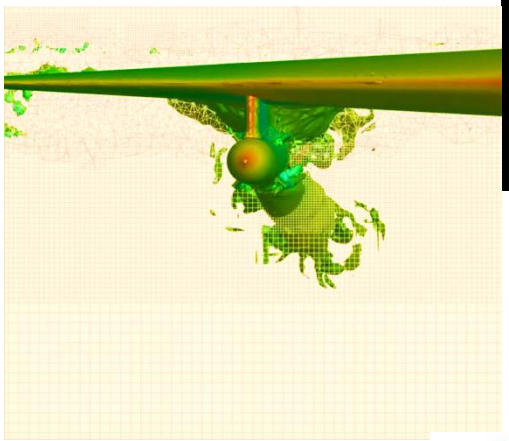
Additional Information

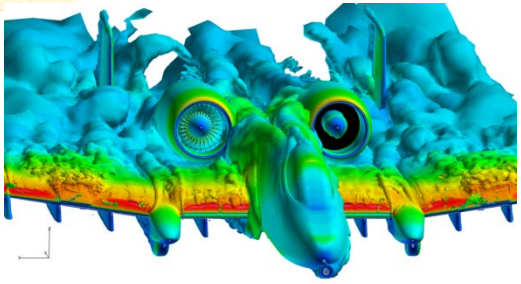
Kestrel V5 Capabilities

- ***Multi-body static/dynamic motion w/moving control surfaces & aero-elastic aircraft***
  - ***Maneuvering aircraft; predictive or prescribed***
  - ***Flight control systems (under development)***
- ***Overset / automated near-body / off-body solutions***
  - ***Adaptive mesh refinement, implicit hole cutting, high order algorithms***
  - ***Store separation simulation***
- ***Aero-elastic Capability***
  - ***Modal model & Finite Element Method (FEM)***
- ***Aero-propulsion: Firebolt module***
  - ***Simple 0-D method***
  - ***Complete internal rotating machinery capability***
- ***GUI (KUI) for input file generation, grid manipulation and post-processing***



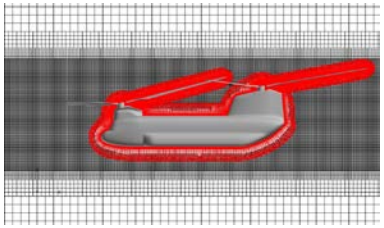
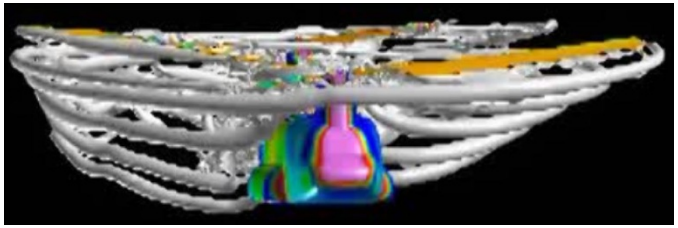






A Paradigm Change…

- **Engineering Analysis (example)**
  Modified/New Configuration Certification process

CH-47F to be retrofitted with new rotors

- ✓ New dihedral-anhedral blade tip shape similar to Comanche rotor.
- ✓ Boeing completed WT tests (isolated rotor – no fuselage) in 2010.
- ✓ Boeing has scheduled full-scale flight tests for 2014.

Army AED and Boeing using CREATE-AV Helios to virtually test full-vehicle configuration. This minimizes risk associated w/ planned 2014 flight tests.

- ✓ Confirms Boeing's performance predictions of the isolated rotor.
- ✓ Can confirm that rotor/rotor interference and/or rotor/fuselage aerodynamic interactions don't adversely affect the performance of the installed rotors…

Boeing cannot predict these interactional aerodynamic effects without using Helios.

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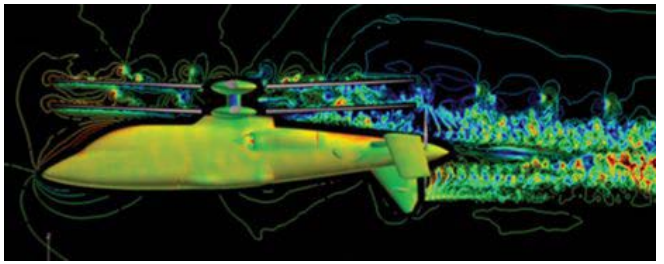
AIAA Aerospace America: 2013 in Review

CREATE Recognition

New Tools for Applied Aerodynamics

by Nathan Hariharan

- **HPCMP CREATE was recognized for deploying scalable, multi-disciplinary, physics-based computational engineering products for the design and analysis of ships, air vehicles, and RF antennas.**
- **Sikorsky Aircraft is evaluating HPCMP CREATE-AV Helios software by using it on the Sikorsky coaxial X2TD aircraft.**

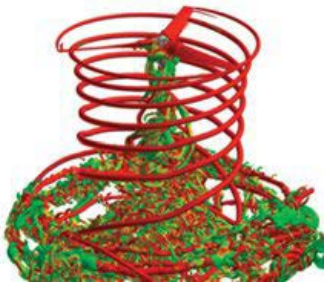


Sikorsky conducted a full-configuration rotor/ fuselage/propeller simulation of its coaxial X2TD aircraft.

Visualizing Success

by Vincent Charles Betro

- **Automation of mesh adaptation is on the horizon, as discussed by researchers from the Army Aeroflightdynamics Directorate in "An Automated Adaptive Mesh Refinement Scheme for Unsteady Aerodynamic Wakes" (AIAA-2012-0160). The paper was this year's recipient of the AIAA MVCE Technical Committee's Shahyar Pizradeh Best Paper Award.**



A tiltrotor aeroacoustic model wake features different levels of Richardson extrapolation error control.

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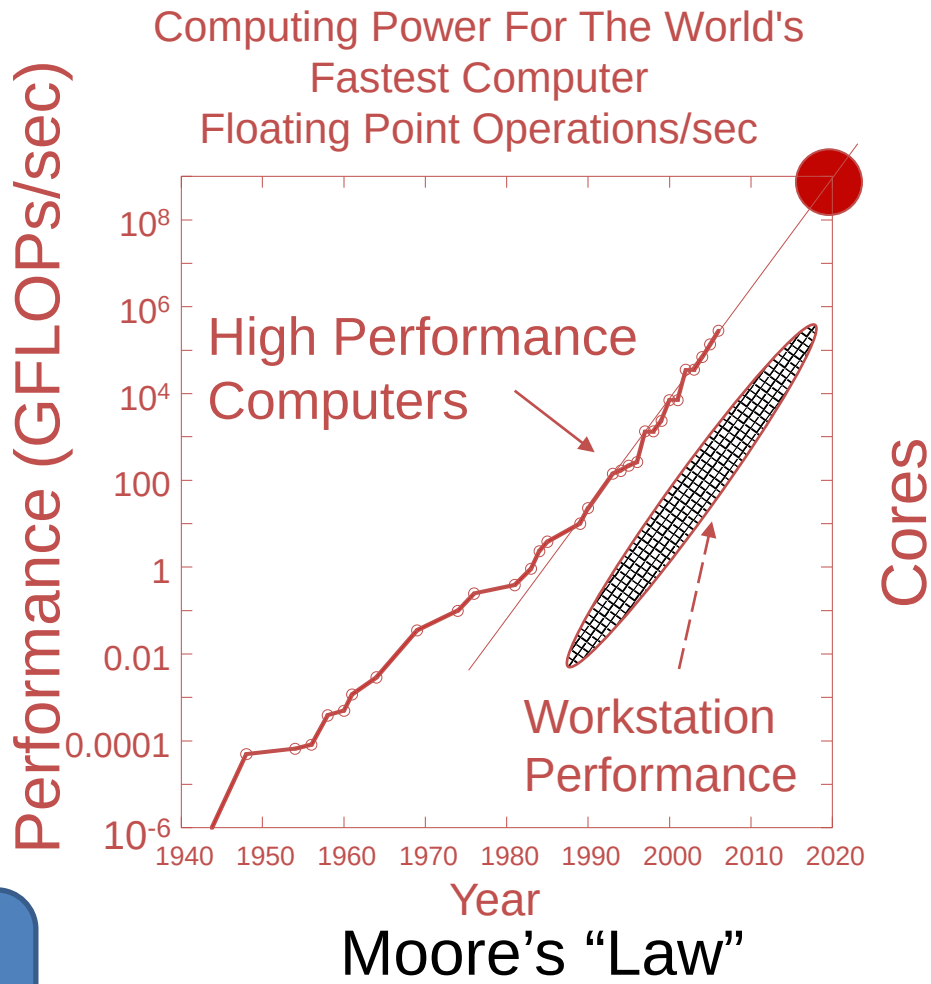
Enabling Technology: High Performance Computers

- **The 10^{15-18} increase in computer power over the last seven decades enables codes to:**
  - **Include all the effects we know to be important—multi-physics**
  - **Utilize accurate solution methods with extensive VV&UQ**
  - **Model a complete system**
  - **Complete parameter surveys in hours rather than days to weeks to months**
- **In ~ 10 years, workstations will be as powerful as today's high performance computers**
- **Software applications capable of exploiting this computer power are the missing link!**



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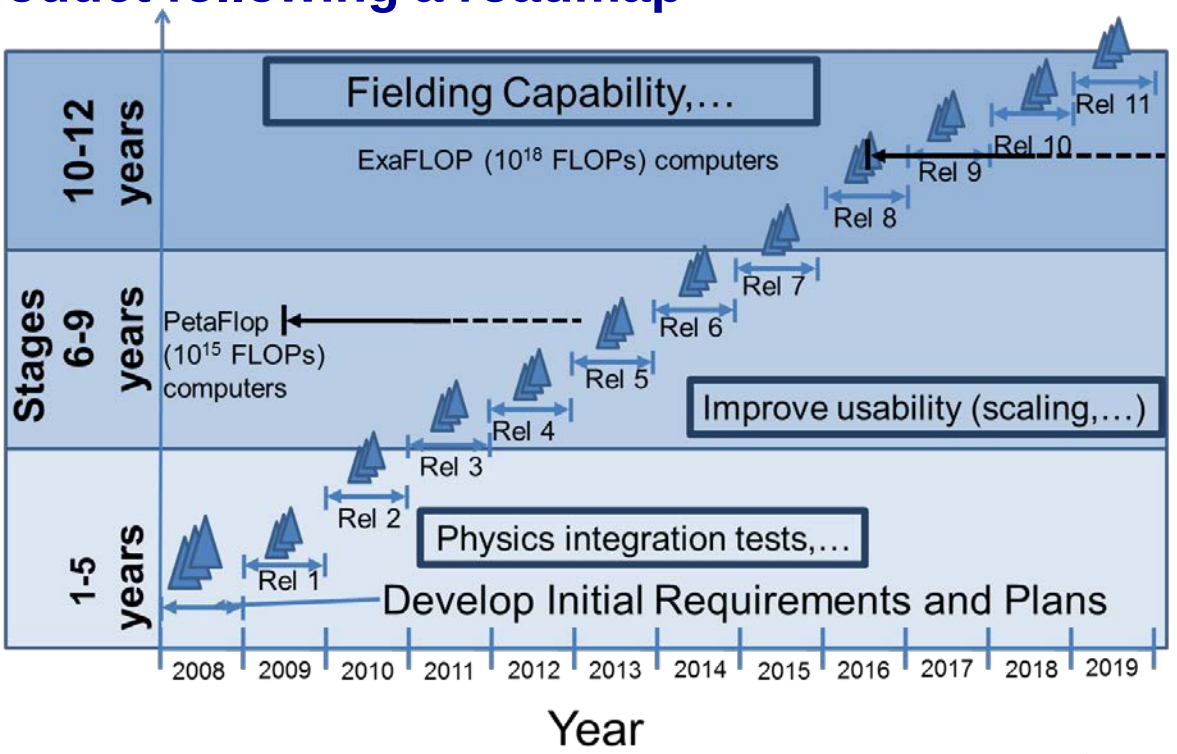
Build the Right Software, and Build it Right!

- **Software built by government-led teams of 5 to 10 staff**
  - **Embedded in customer institutions**
  - **Oversight by customer institutions**
- **Highly Disciplined Software Development Processes**
  - **Strong emphasis on software quality**
  - **Supportive code development environment—virtual clusters, central servers and code repository, ….**

Annual releases of each product following a roadmap

- Increased capability annually
- Extensive beta-tests of each release
- Rigorous V&V process
- Improved scalability for massively parallel computers
- Improved usability
- Responsive to evolving requirements
- Extensive documentation



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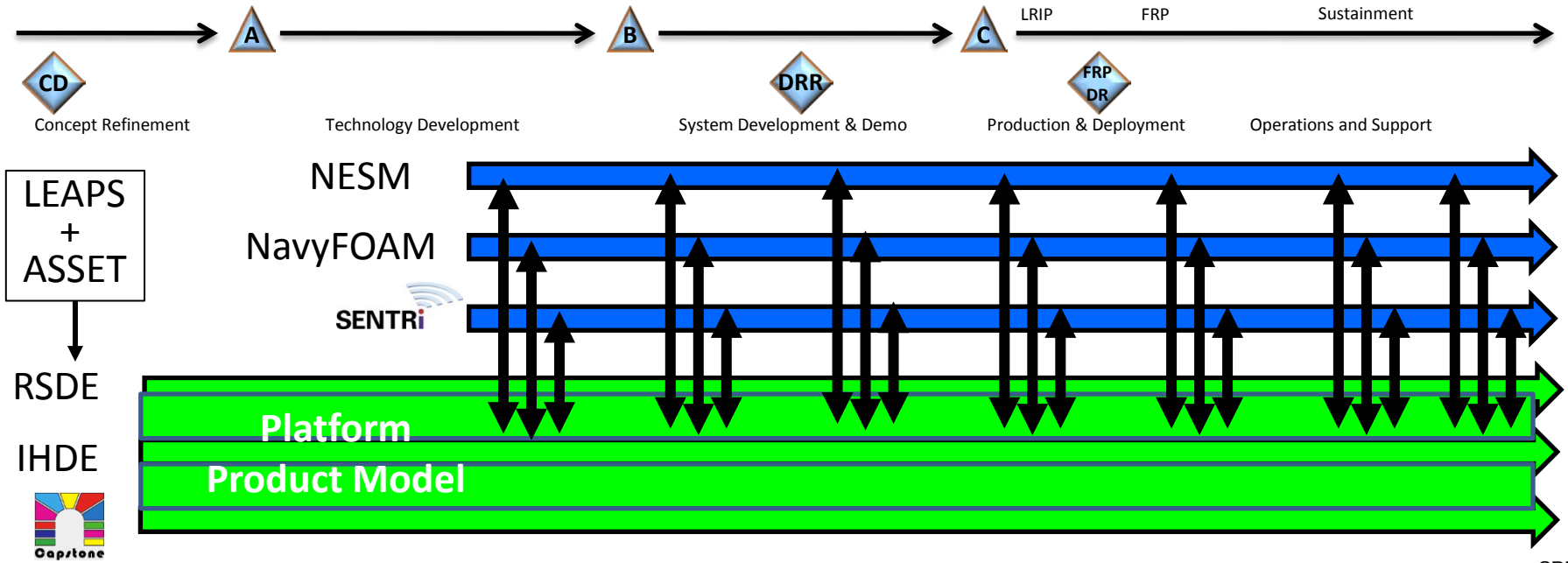
With HPC and multi-disciplinary, physics-based simulation tools We have the capability to:

- ✓ Validate and assess requirements
- ✓ Fully explore design option space
- ✓ Materially contribute to the design of next generation naval vessels
- ✓ Verify design prior to key decision points (and prior to fabrication of test articles or full-size ships)
- ✓ Plan/rehearse wave-tank, shock trials, and full-scale ship tests (more bang per test dollar)
- ✓ Evaluate planned (or potential) operational use scenarios
- ✓ Perform initial naval performance assessments (e.g., vulnerability, seaworthiness, maneuverability, etc.)
- ✓ Persist design intent and key engineering data throughout the whole ship lifecycle…



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