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

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CREATE Program Concept
A Vision for Improving Acquisition

- **CREATE Goal: Enable the US to maintain a competitive advantage in weapons systems**
- **Enable innovation and reduce system development time**
  - Produce optimized designs early in the acquisition process with fewer defects and design flaws
  - Reduce testing requirements and rework thereby enabling faster system development and deployment
- **How?**
  - Supplement physical testing with multiphysics-based predictions from the beginning of the conceptual design and analysis process through deployment and sustainment
  - Develop and deploy production quality design and analysis software that is adaptable and maintainable
  - Develop and deploy multi-physics based Computational Engineering tools that exploit the 10^{15} growth in computer power since 1945
- **CREATE is a long term program**
  - Funding started in FY2008, $45M for first 3 years
  - Sponsored by OSD HCPMP

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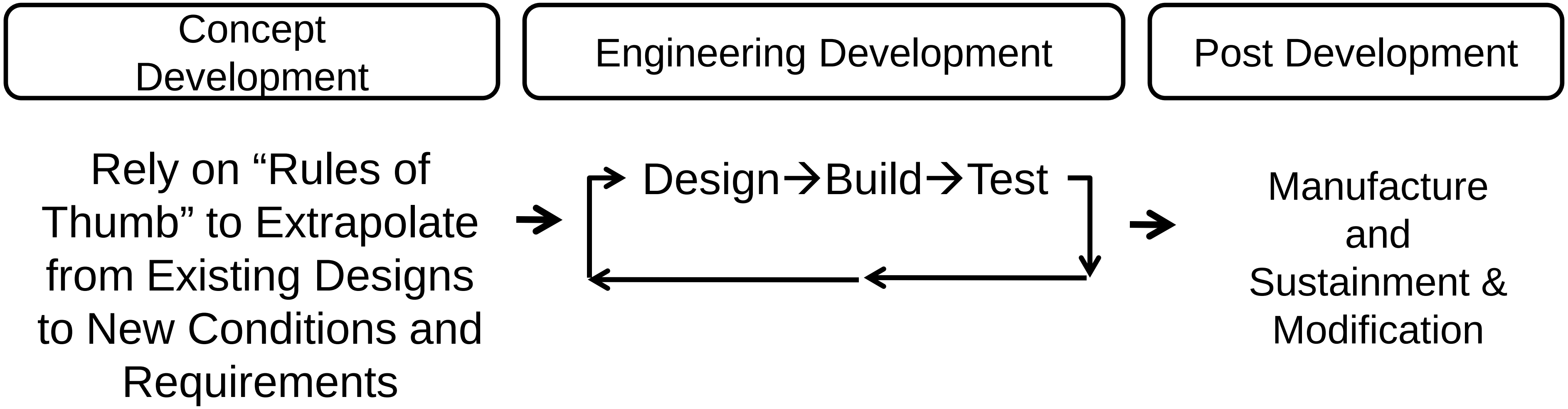
The Classic Product Development Process (what the DoD uses now)

- Productivity gains for Concept and Engineering Development have lagged gains in manufacturing



Concept Development

Engineering Development

Post Development

Rely on “Rules of Thumb” to Extrapolate from Existing Designs to New Conditions and Requirements →

Design→Build→Test

→ Manufacture and Sustainment & Modification

Since 1700s

Some Productivity Gains	Some Productivity Gains	Enormous Productivity gains

Present Product Development Process: Iterated Design → Build → Test Cycles

Requirements → Design → Build Physical Product → Test Physical Product → Manufacture and Sustainment

(Many) Design iterations

F-22 Flight Test

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

A Paradigm Shift in Industrial Product Development Is Happening

- **Past :**
  - Repeated Design→Build→Test Cycles
- **Present:**
  - Occasionally Augment Design→Build→Test with Limited Single-Physics Analysis by Use of Research or Commercial Codes
- **Future:**
  - Design Through Analysis, Multi-Physics Design and Analysis with Supercomputer Power
  - Repeated CAD→Mesh→Analyze Cycles Followed by a Few Design→Build→Test Cycles

Multiphysics-Based Software Can Enable Rapid Product Innovation

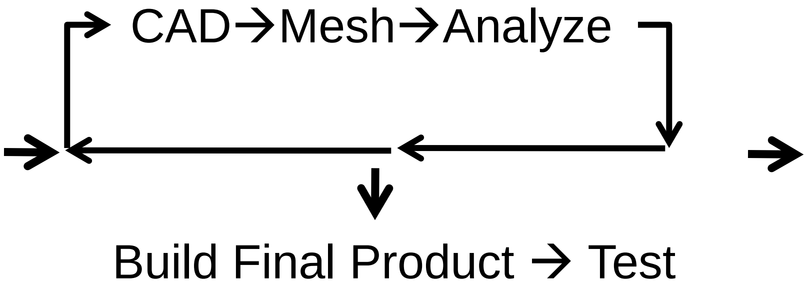
Use virtual prototypes at every stage of the acquisition process

Concept Development

Engineering Development

Post Development

Multi-physics based software tools allows use of the laws of nature to extrapolate to new conditions and needs



CAD→Mesh→Analyze

Build Final Product → Test

Manufacture And Sustainment & Modification

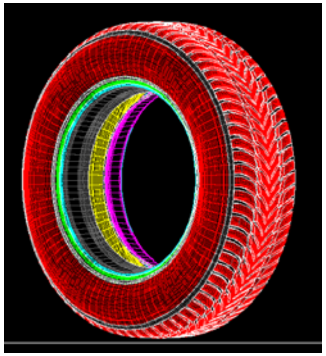
21st Century Result

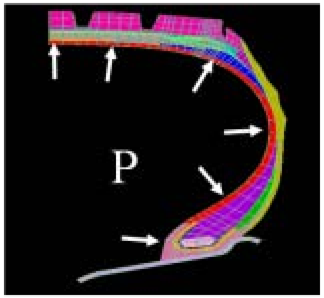
Large Productivity Gains

Large Productivity Gains

Additional Productivity gains

Industry is Beginning to Adopt this Paradigm.





Inflation and Seating

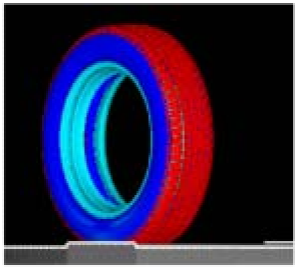
Hydroplaning Tests

Flight Radial

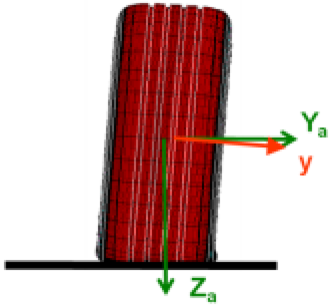
Requirements → Design and Mesh Virtual Product → Analyze and Test Virtual Product → Build and Test Physical Product → Market

Design iterations

- Reduced time to market from 3 years to less than 1 year
- Increased new products delivery from 1 every 3 years to 5 per year



Running Over Obstacles



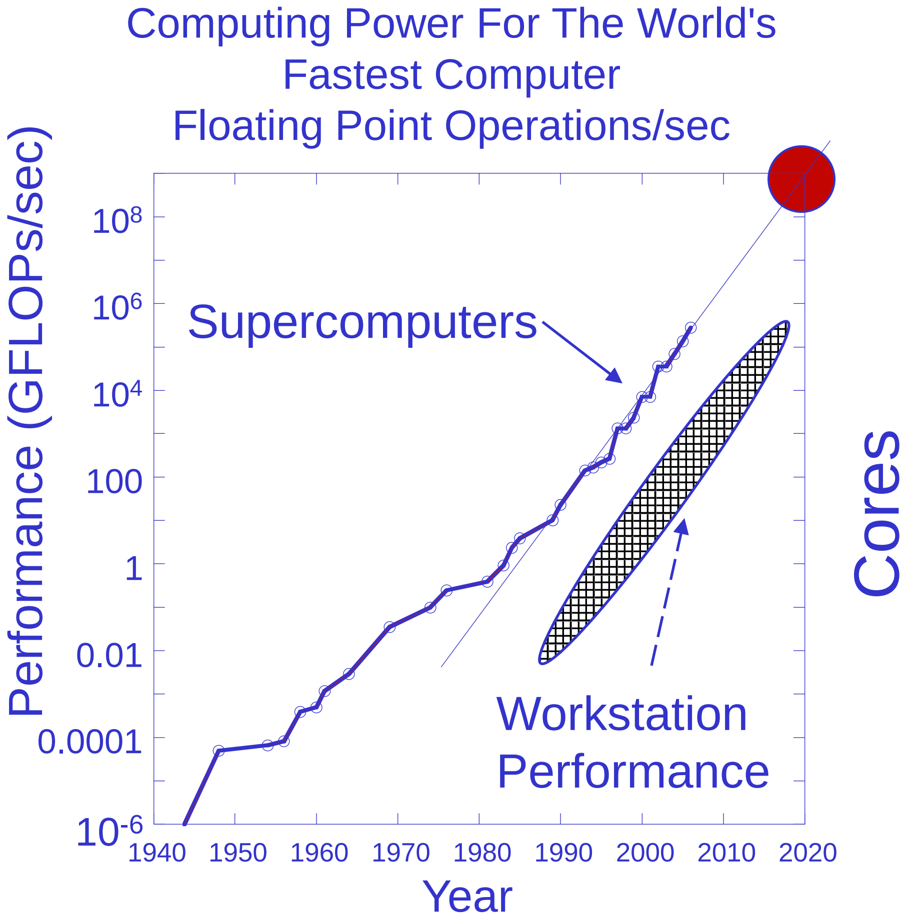
Camber

Fortera TripleTred

L. K. Miller, *Simulation-Based Engineering for Industrial Competitive Advantage*, *2010, Computing in Science and Engineering*, ***12*****, *14-21***

Growth in Computers Since 1945 Provides Unparalleled Problem Solving Power

- **The 10^{15} increase in computer power since 1945 can enable us to develop and deploy codes during the next decade that are much more powerful than past tools:**
  - **Utilize accurate solution methods**
  - **Include all the effects we know to be important**
  - **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 supercomputers**
- **Greatest opportunities for 2020 (and 2010) include large-scale codes that integrate many multi-scale effects to model a complete system**



Moore's "Law"

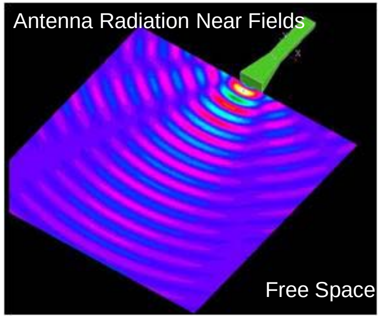
CREATE – Four Projects, Ten Products
Conceptual Design → Sustainment

- **Air Vehicles**
  - **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**
  - **RDI -** Rapid Design and Synthesis Capability—Partnership with ONR and NAVSEA
  - **NESM -** Ship Shock & Damage-prediction of shock and damage effects
  - **NAVYFOAM -** Ship Hydrodynamics-predict hydrodynamic performance
  - **IHDE -** Environment to facilitate access to Naval design tools
- **RF Antenna**
  - **SENTRI -** Electromagnetics antenna design and integration with platforms
- **Meshing and Geometry**
  - **Capstone -** Components for generating geometries and meshes

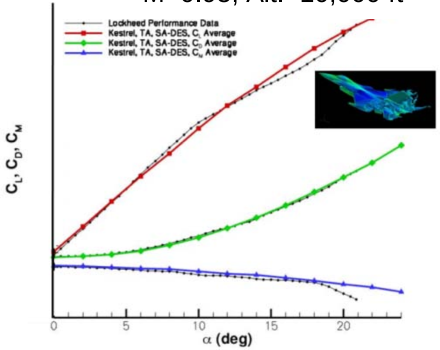
Two Years After Program Start (FY08), CREATE Began Delivering Usable Software.

- 5 beta releases in CY09 with good V&V and ~ 150 beta testers:
  - Helios 1.0—accurate calculation of rotorcraft vortex shedding
  - Kestrel 1.0—Rigid body CFD fixed wing AV with preliminary aeroelastics
  - SENTRI 1.0 and 1.5—initial RF antenna design and analysis
  - NESM 0.1—initial ship shock vulnerability analysis for underwater explosions
  - IHDE 1.0—initial user interface for ship hydrodynamics
- 10 releases planned for CY10 and each succeeding year
- Helios 2.0, Kestrel 2.0, SENTRI 2.0, NESM 1.0 and IHDE 2.0 plus:
  - Rapid design: RDI 1.0 for Ships, DaVinci 1.0 for Aircraft plus SENTRI 2.0
  - Components: Capstone 1.0 for geometry and mesh, Firebolt 1.0 for gas turbines
  - Detailed ship hydrodynamics NavyFoam 2.0 (seakeeping, drag, resistance,…)
- Continuing to build product teams, and develop and improve software engineering and project management processes and practices
- Developing approaches to improve scalability

More accurate vortex shedding



Kestrel vs. F-16 Flight Data
M=0.95, Alt.=10,000 ft



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Critical Factors for Success

- **HPCMP analyzed what worked and what didn't**
  - A new, complex software application is an invention
  - Invention requires experienced teams with domain science & engineering, and computational skills
  - Success requires stable support from the sponsor
  - Development approach must achieve the right balance between flexibility & agility and project structure and management, between risk taking and risk avoidance,…
  - Requires sound software engineering practices tailored for computational engineering
- **Success also requires:**
  - Stable sponsor support,
  - Strong customer focus,
  - An inventive development team with excellent domain science and computational skills,
  - V&V, and
  - High performance computers
- **HPCMP applied these principles to CREATE**

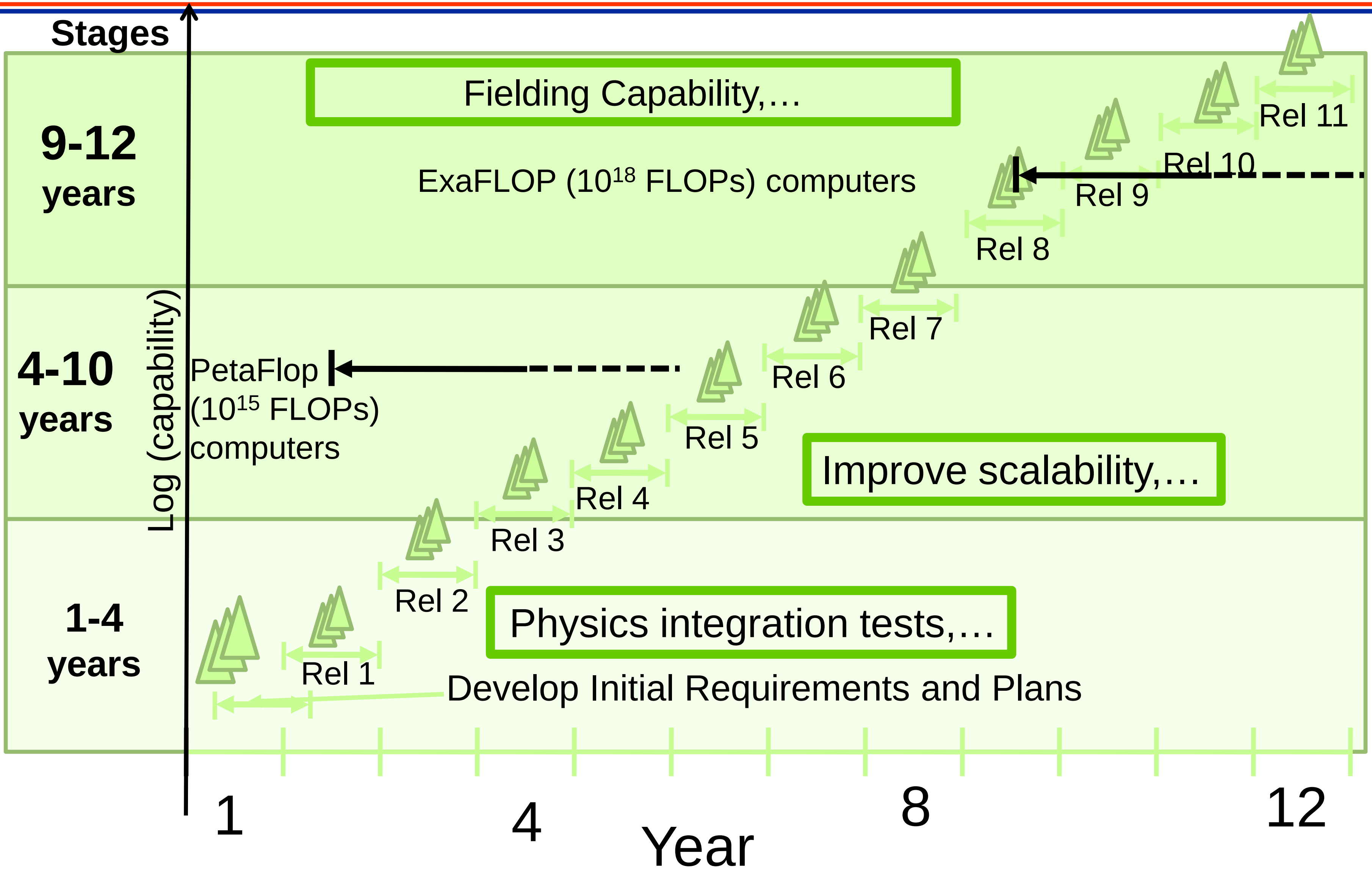
CREATE Emphasizes Software Engineering for a 30 Year Product Life

Software Engineering Practices and Processes

- **Goal is maintainable, extensible, portable and reliable software products developed with the right balance of agility and flexibility and short and long term planning**

  1. Requirements Management and Stakeholder Engagement
  2. Software Quality Attributes
  3. Design and Implementation
  4. Software Configuration Management
  5. Verification and Validation of CREATE Products
  6. Software Release
  7. Customer Support
- **Documents: Initial Capabilities Document +….**
  - Three Manuals: Technical, Developer, User
  - Plans: Test (V&V), Risk, Project and Product Development (EVMS),…
- **Agile development methods such as SCRUM**
- **Annual releases to engage users early and get their feedback**

Incremental Development and Deployment in Annual Releases



Stages

9-12 years

4-10 years

1-4 years

Log (capability)

Fielding Capability,…

ExaFLOP (10^{18} FLOPs) computers

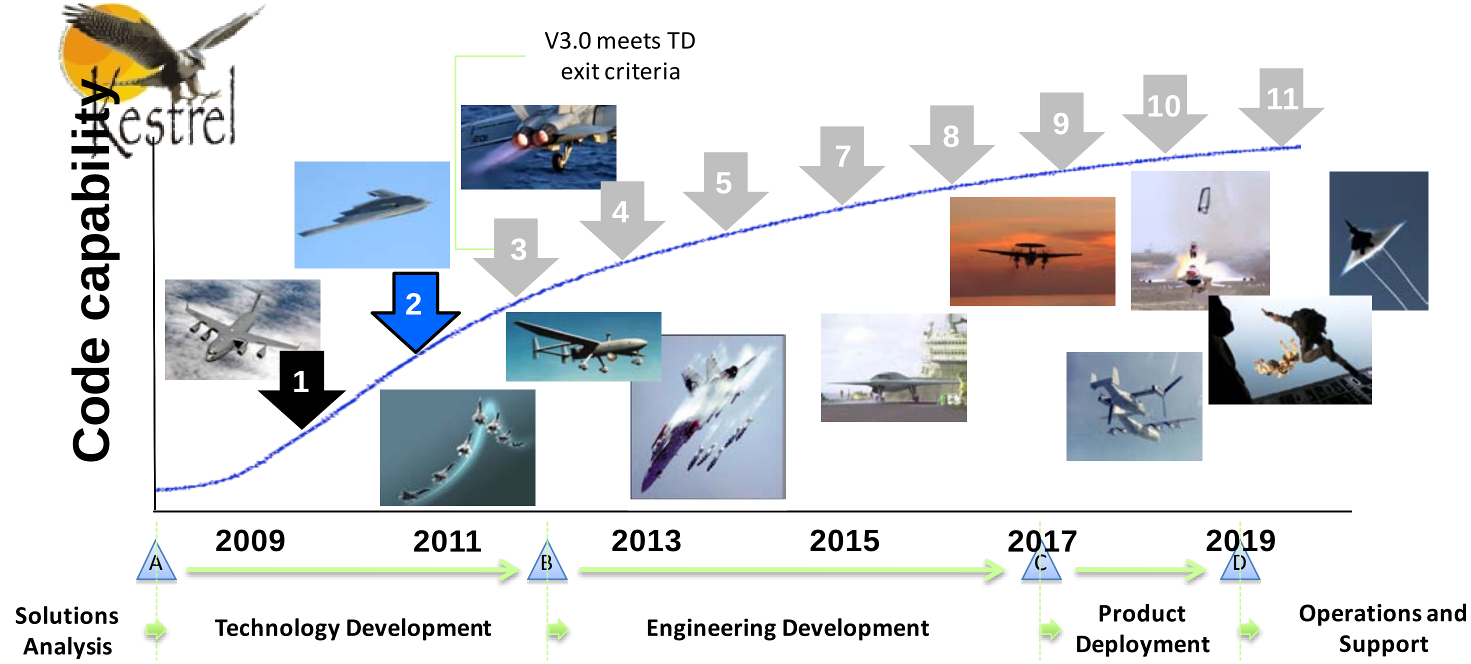
PetaFlop (10^{15} FLOPs) computers

Improve scalability,…

Physics integration tests,…

Develop Initial Requirements and Plans

Each Product Team Delivers New Capability Annually Following a Roadmap!



1) Arbitrary complete aircraft (rigid) for low-subsonic through high supersonic flight and steady or unsteady regimes.
2) Add capability to accommodate movable control surfaces, aero-structure interaction (flexible aircraft), and prescribed maneuvers.
3) Add capability to simulate arbitrary multi-body relative motion (e.g., simulation of store separation events subject to applied aerodynamic loads), dynamic propulsion effects, and to accommodate flight control systems (FCS) .
4) Add capability to accommodate autopilot, dynamic engineering models of fans, rotors, propellers, and significant physical accuracy upgrades.

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11) Sustained Kestrel Product Capability. Full-vehicle, multi-physics design analysis and mission planning tool – enables scalable practices and is highly parallel, modular, maintainable, extendable, and introspective.

CREATE – Radio Frequency (RF) Product Component

- **SENTRI enables antenna design integrated with platforms**
  - Able to calculate multiple antenna arrays for small- and large-scale systems (small UAVs → ships)
- **Staged capability**
  - Rapid design – coarse resolution with fast, first-order codes for small antenna systems
  - Detailed design, high-resolution complex antenna systems integrated with large platforms
  - Enabled by improved computational algorithms (n^3 → n log n scaling improvement)



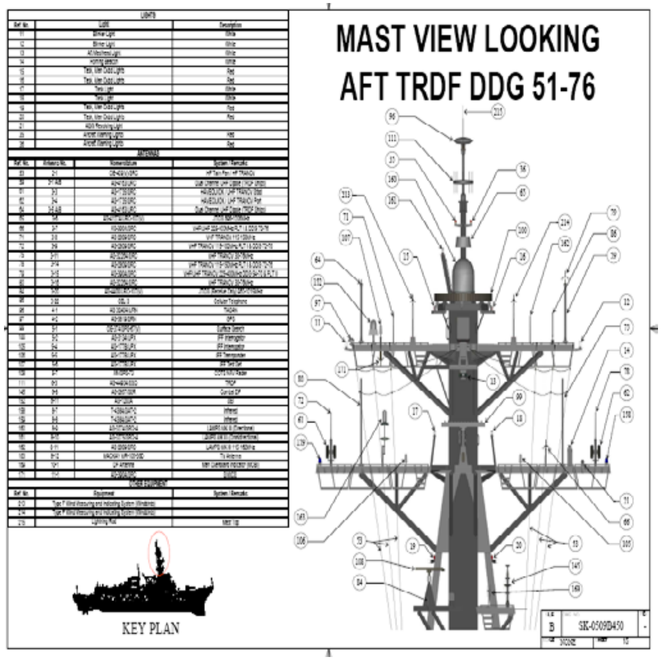
Small
Less Complex

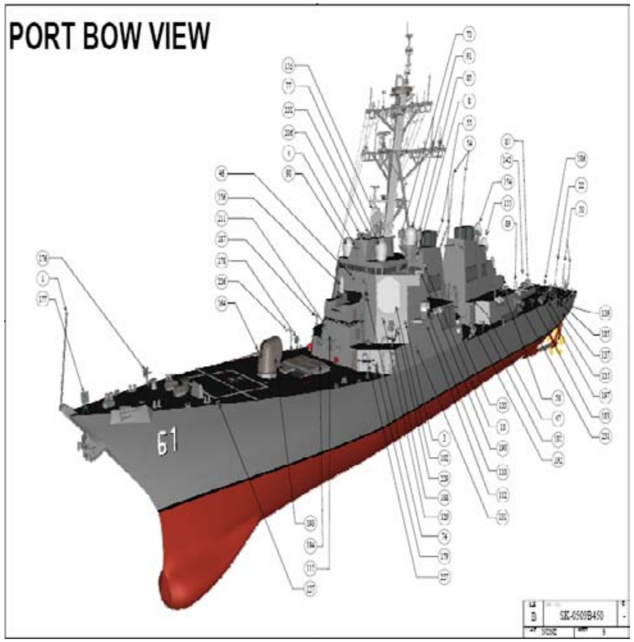
→

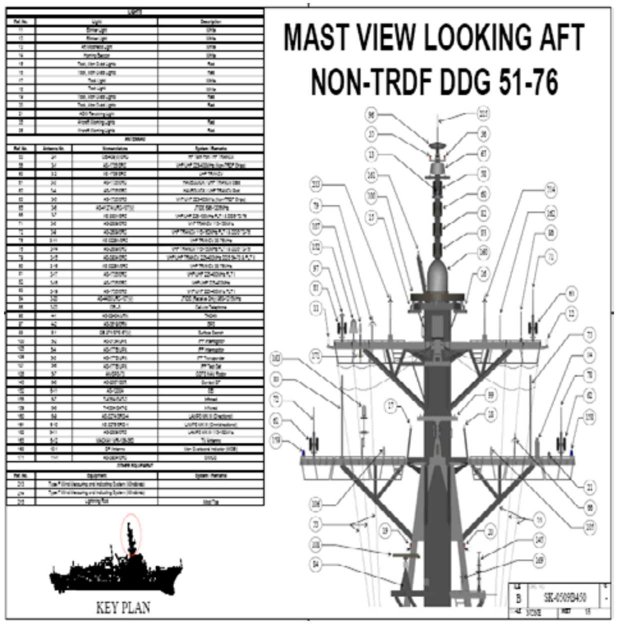
Larger
Highly Complex

Ships, airplanes, and land vehicles have complex antenna requirements

Co-site interference is a major issue.







Numerous antennas competing for limited space and coverage result in a complex electromagnetic environment (EME), presenting a challenge for effective topside integration and maintaining the topside baseline.

SENTRI 1.0 – RF Antenna Design

Development Approach

Product Roadmap

CREATE RF

SENTRI v1.0 and v1.5

First Iteration → Multiple Functions for Wide Applicability

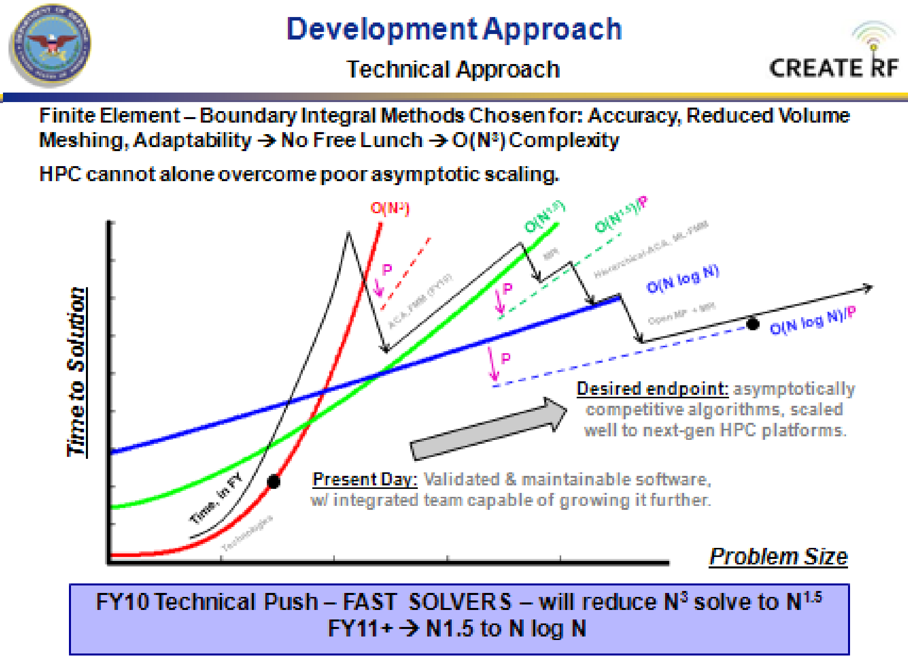
SENTRi

Antenna Modeling
- Patch, Notch, Horn, Spirals (Applications: Radar, Communication, GPS)
- Phased Array Antennas
- Cavity Backed Antenna (Approximate In-Situ Analysis)

Periodic Structures
- Frequency Selective Surfaces
- Circuit Analog Absorbers
- Metamaterials
- Infrared Filters / Absorbers

Microwave Circuits
- Power Splitting
- Material Measurement
- Filters
- Circulators

Radar Cross-Section Prediction



Development Approach

Technical Approach

CREATE RF

Finite Element – Boundary Integral Methods Chosen for: Accuracy, Reduced Volume Meshing, Adaptability → No Free Lunch → O(N³) Complexity

HPC cannot alone overcome poor asymptotic scaling.

Desired endpoint: asymptotically competitive algorithms, scaled well to next-gen HPC platforms.

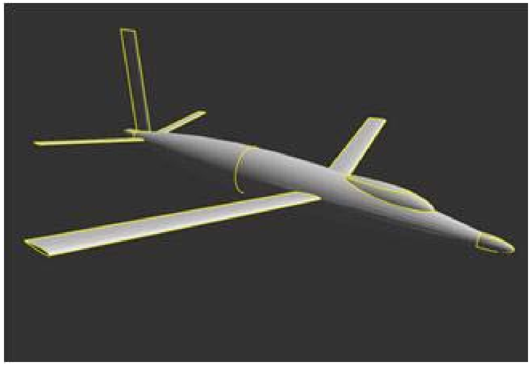
Present Day: Validated & maintainable software, w/ integrated team capable of growing it further.

FY10 Technical Push – FAST SOLVERS – will reduce N^3 solve to $N^{1.5}$
FY11+ → N1.5 to N log N

- **SENTRI 1.0 → deliver initial capability, now in beta testing**
- **SENTRI 1.5 → refactored SENTRI 1.0 to enhance software quality**
- **Strong V&V program (SENTRI 1.0 benchmarked against current CEM design codes & extensive verification and validation tests)**
- **SENTRI 2.0→Begin improving scaling**

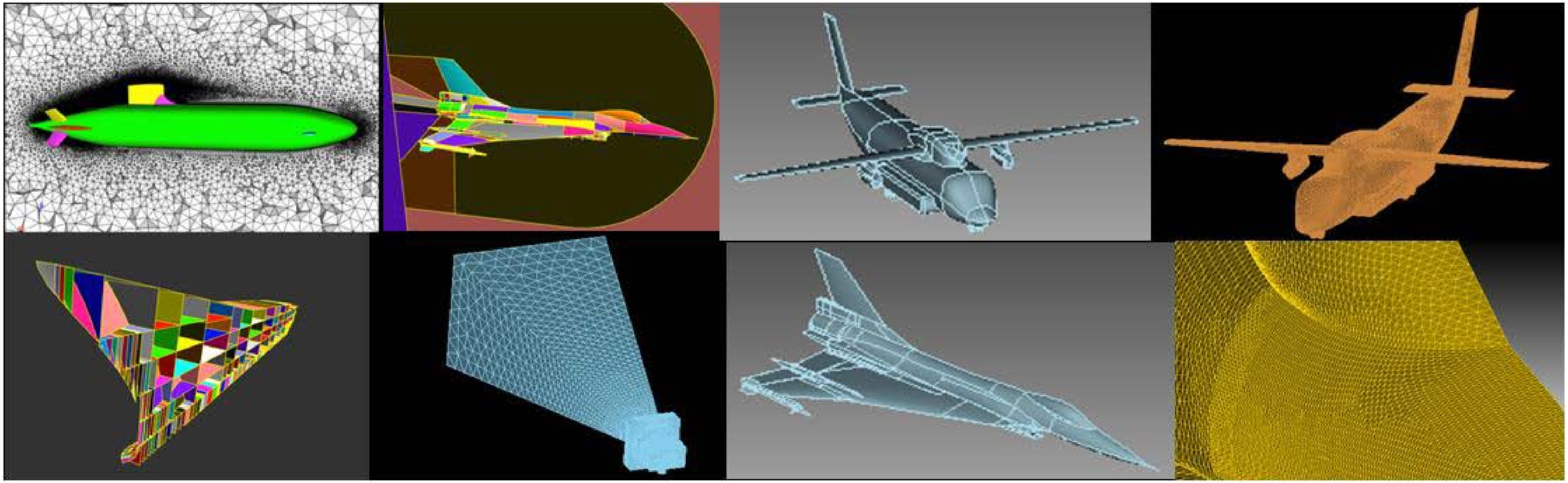
CREATE – Meshing and Geometry (MG) Components: CAPSTONE

- **CAPSTONE**
  - Collection of components that enable rapid generation of the geometry and mesh representations needed for all phases of acquisition engineering (conceptual, preliminary, detailed design, and operational support)
  - Emphasis is on geometry as key representation of product



Enable parametric, associative geometry and meshes in AV: DaVinci, Ships: RDI

Produce analyzable representations for complex and detailed analysis



CREATE Designed to Support the Government and Contractor Engineering Workforce

- **CREATE tools will enable government engineers to develop and explore design concepts, and oversee engineering development, manufacturing and sustainment**
- **CREATE tools will enable industry to participate in concept development, and improve engineering development, manufacturing and sustainment**
- **CREATE beginning to engage with industry through NDIA to identify how industry can use the CREATE tools to improve DoD acquisition**
  - Please share your perspectives and thoughts with us
- **Improve product innovation and reduce product development time**
- **Issues:**
  - Provide equal access to all potential contractors
  - Retain US competitive advantage in weapon system development

Two Examples Out of Four Projects

- **Air Vehicles—Dr. Robert Meakin**
  - **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—Mr. Myles Hurwitz**
  - **RDI -** Rapid Design and Synthesis Capability—Partnership with ONR and NAVSEA
  - **NESM -** Ship Shock & Damage-prediction of shock and damage effects
  - **NAVYFOAM -** Ship Hydrodynamics-predict hydrodynamic performance
  - **IHDE -** Environment to facilitate access to Naval design tools

Backup slides

Meshing and Geometry Project → Tools for AV, Ships and RF

Product: CAPSTONE

Core

API and library components for core framework, geometry and mesh representations and algorithms, attribution modeling

Provides:

- APIs for writing external meshing and add new higher-level functionality plugin(s)
- Access to Mesh Modification capability (refinement, coarsening, local-remeshing)
- Runtime access to geometry

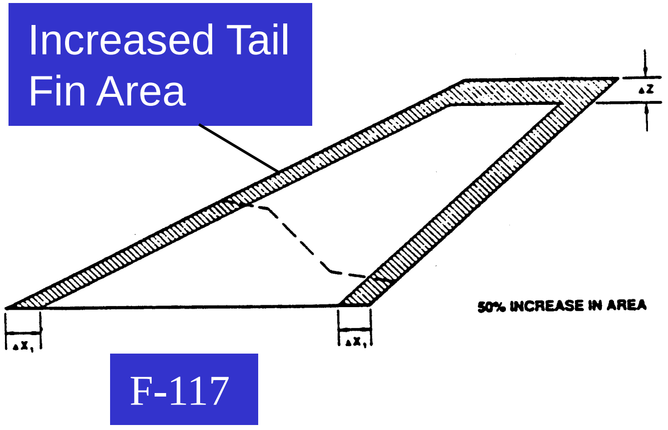
Front-end

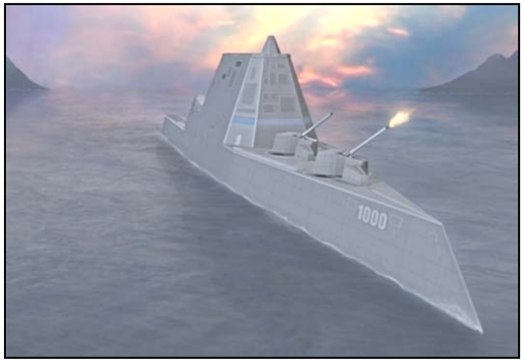
Provides geometry preparation and mesh generation

- Support graphical user interface (GUI), command-line, and scripting interfaces for end-user
- Provides traditional pre-processor capabilities for end-users
- Specialized application plugins (e.g. mesh implant for Ships)

Problem: DoD Weapon Systems Design Process Is Not Effective

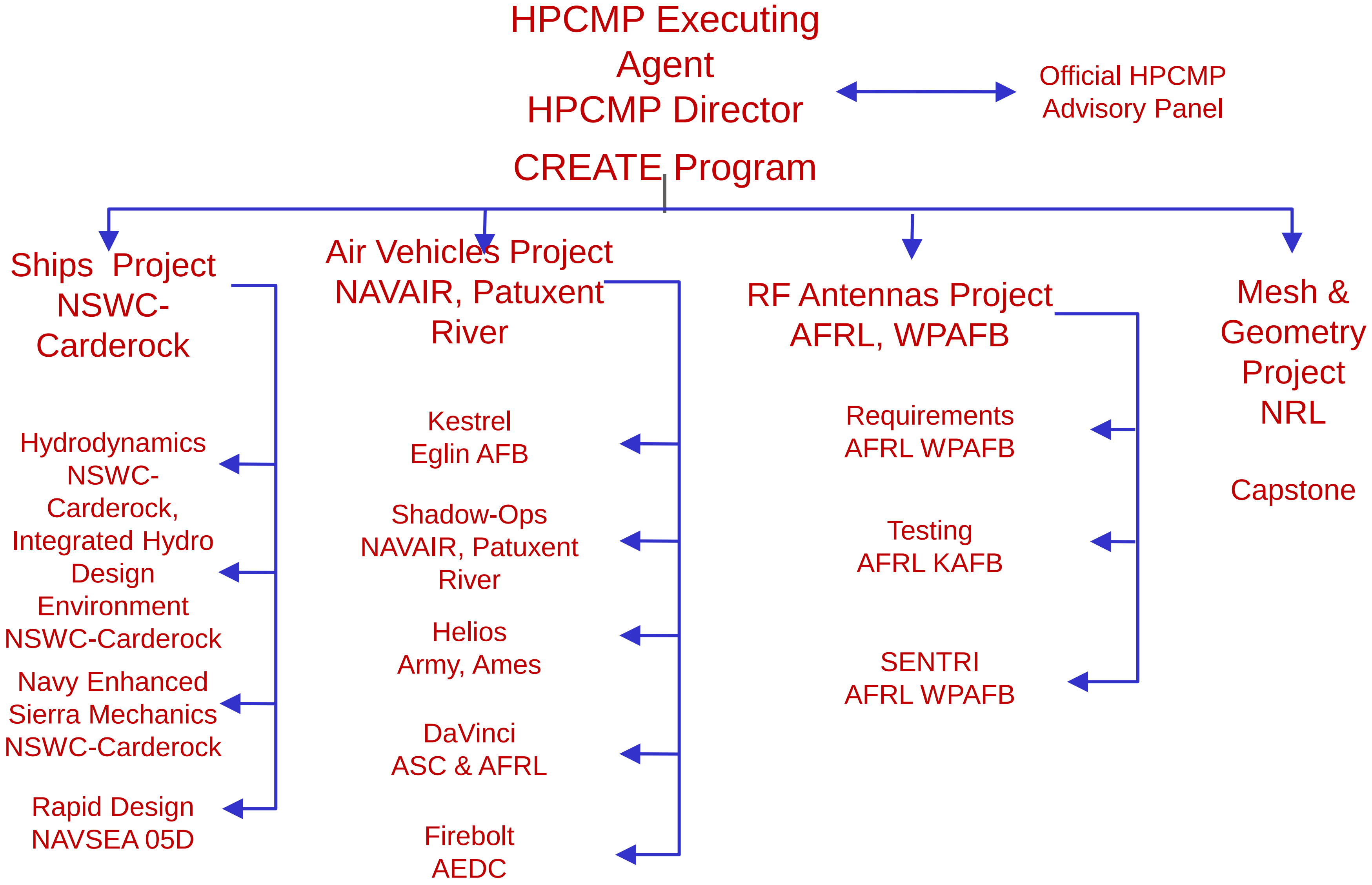
- **Tailfin design problems for:**
  - F-100, F-102, F-105, F-7U, F-11F, F-16, F-117
  - All needed to increase tail fin size between 25% to 50% after initial design
- **For stealth, DDG-1000 was built with a new hullform that sloped *in* rather than *out* as do all prior hullforms, but “Is New U.S. Destroyer Unstable?” Defense News Headline-04/02/07**
- **Lessons Learned:**
  - Can’t base radically new designs on “rules of thumb” empirically based scaling of historical experience
  - Physics-based design tools required for new concepts





DDG-1000

CREATE is a Tri-Service Program



HPCMP Executing Agent
HPCMP Director

Official HPCMP Advisory Panel

CREATE Program

Ships Project
NSWC-Carderock

Hydrodynamics
NSWC-Carderock,

Integrated Hydro Design Environment
NSWC-Carderock

Navy Enhanced Sierra Mechanics
NSWC-Carderock

Rapid Design
NAVSEA 05D

Air Vehicles Project
NAVAIR, Patuxent River

Kestrel
Eglin AFB

Shadow-Ops
NAVAIR, Patuxent River

Helios
Army, Ames

DaVinci
ASC & AFRL

Firebolt
AEDC

RF Antennas Project
AFRL, WPAFB

Requirements
AFRL WPAFB

Testing
AFRL KAFB

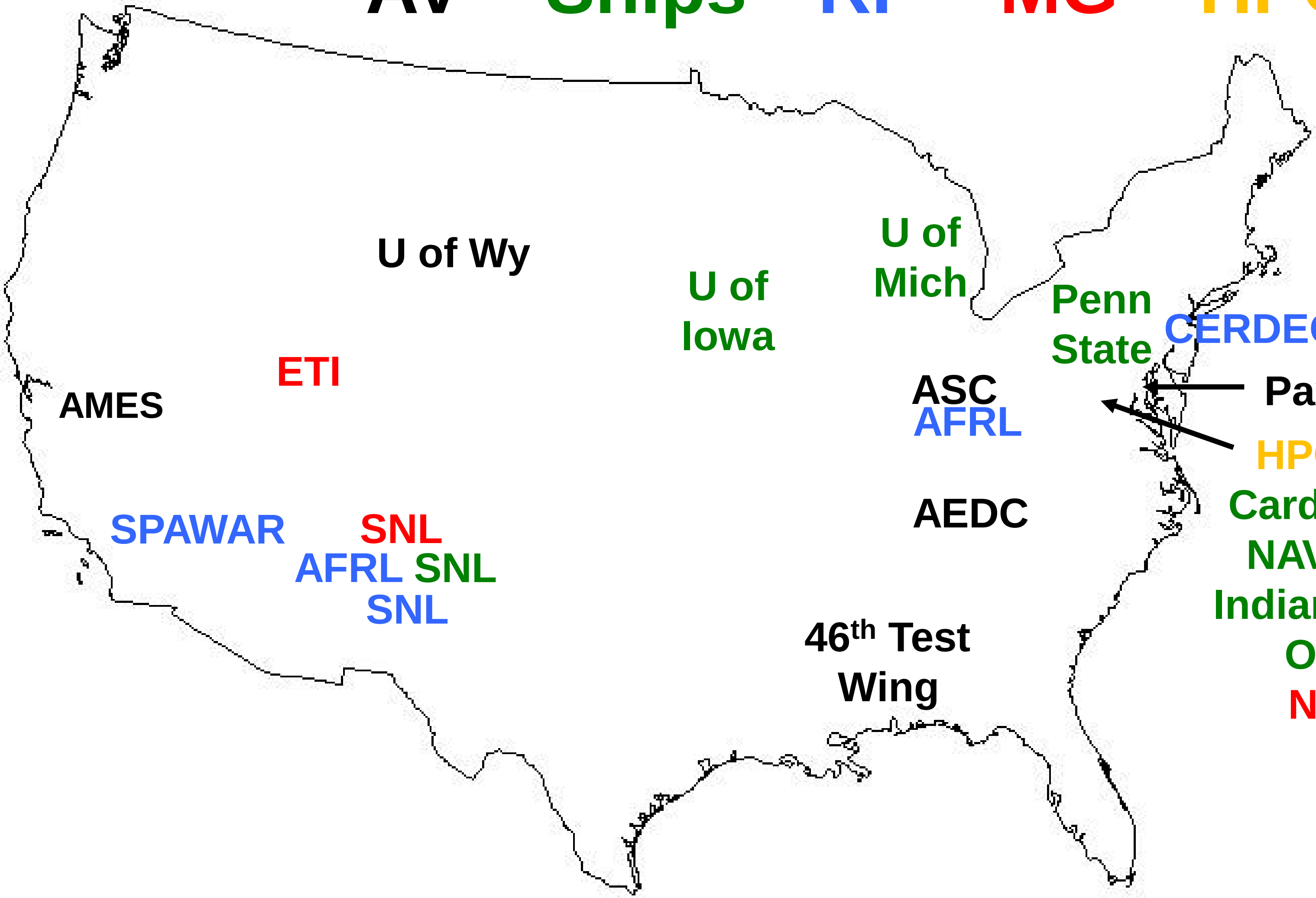
SENTRI
AFRL WPAFB

Mesh & Geometry Project
NRL

Capstone

CREATE is a Multi-Institutional and Multi-Service Program

AV **Ships** **RF** **MG** **HPCMP**



CREATE – Air Vehicles (AV) Product Components

- **DaVinci**
  - Targets early-phase acquisition engineering (conceptual design)

- **Kestrel**
  - High-fidelity, full-vehicle, multi-physics analysis tool for arbitrary fixed-wing aircraft

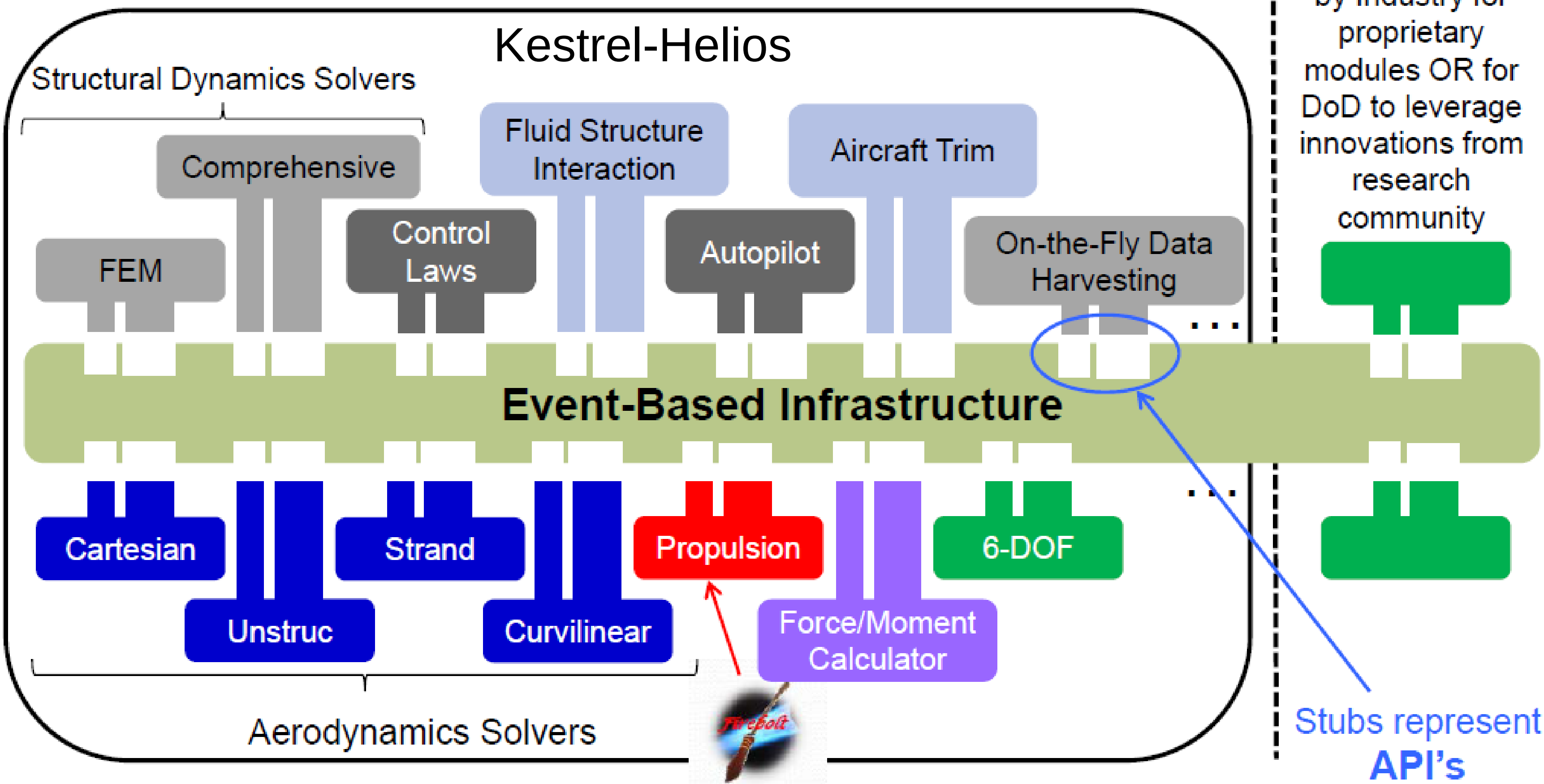
- **Helios**
  - High-fidelity, full-vehicle, multi-physics analysis tool for arbitrary rotary-wing aircraft

- **Firebolt**
  - Module for propulsion systems in fixed and rotary-wing air vehicles

Use of Lightweight Infrastructures Facilitates Rapid Integration of Physics Capability

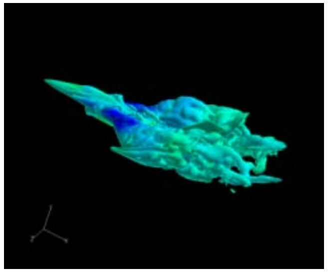
"Light-Weight" Infrastructure – Highly Scalable and Modular
(available as executable)

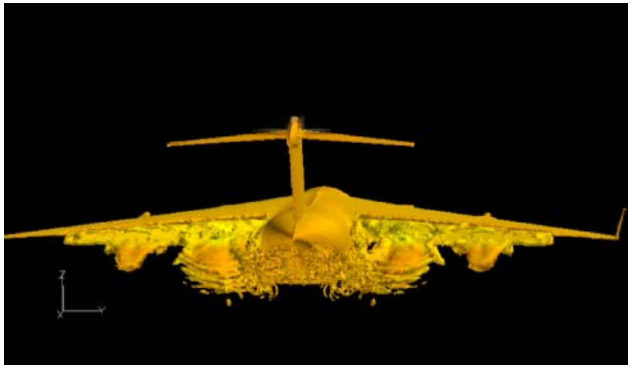
Well Defined APIs available for use by Industry for proprietary modules OR for DoD to leverage innovations from research community



Stubs represent **API's**

AV: Kestrel 1.0—Fixed Wing Aircraft





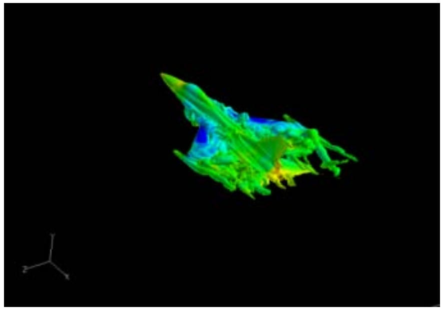
Spiral One Phase One Capability

1 - Static Rigid Body Aircraft

- Single Mesh
- Steady, Unsteady
- Inviscid, Viscous, Laminar, Turbulent

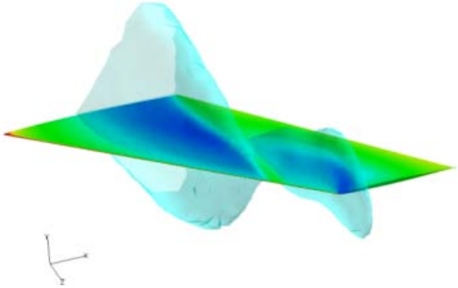
2 - Dynamic Rigid Body Aircraft

- Single Mesh
- Rigid Body Motion
- Arbitrary Motion file built externally
- Pitch, Yaw, Roll, Sinusoid or constant rate and hold in KUI
  - body axis and stability axis



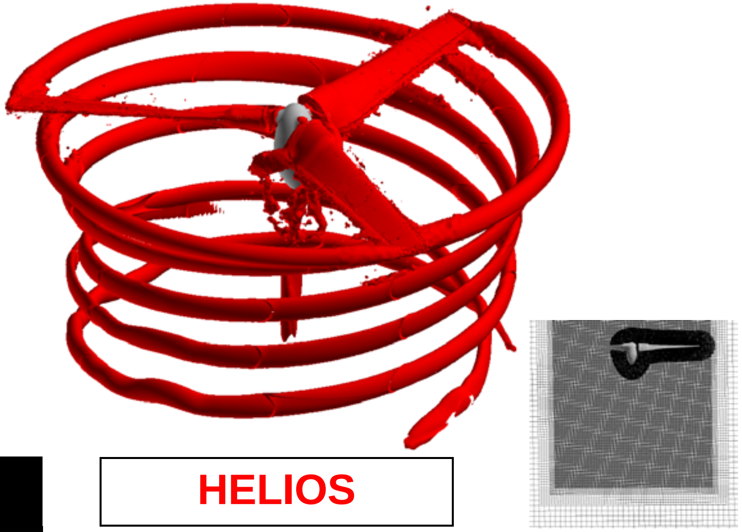
3 - Flexible Wing

- Static Position Single Mesh Aeroelastic
- 2^{nd} Order Temporal Coupling
- Structural Solver
  - Modal solver and mode shape forced motion
- Algebraic Mesh Deform with 3-4 method choices (Surface Influence, Delaunay, Hybrid)



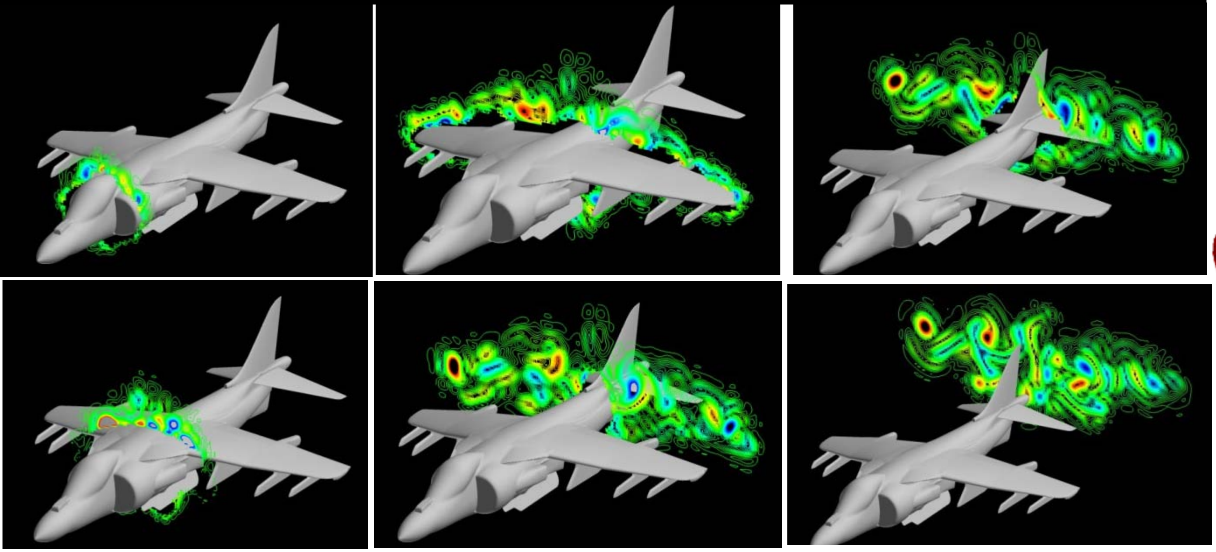
AV: Helios 1.0 (Whitney)--Rotorcraft

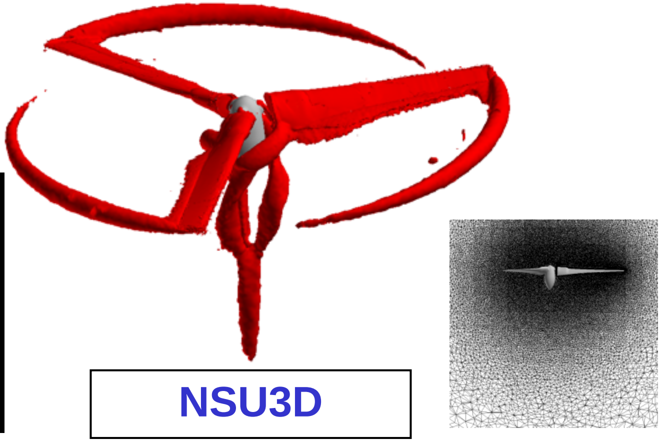
- **Helios v.1.0 (Whitney) Release Capabilities**
  1. Fuselage aerodynamics
  2. Fuselage with actuator disk model for rotor
  3. Isolated rotor in ideal hover
  4. Isolated rotor in forward flight with structural dynamics and trim
  - Stand-alone-NSU3D & Helios models also supported



HELIOS

Helios predicts AV-8B tail fatigue due to vortex shedding

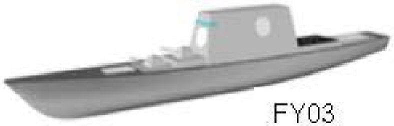




NSU3D

CREATE – Ships Product Components

- **Rapid Design Capability and Design Synthesis**
  - Rapid development, assessment, and integration of candidate ship designs to avoid cost versus capability mismatches
  - Partnership with ONR & NAVSEA



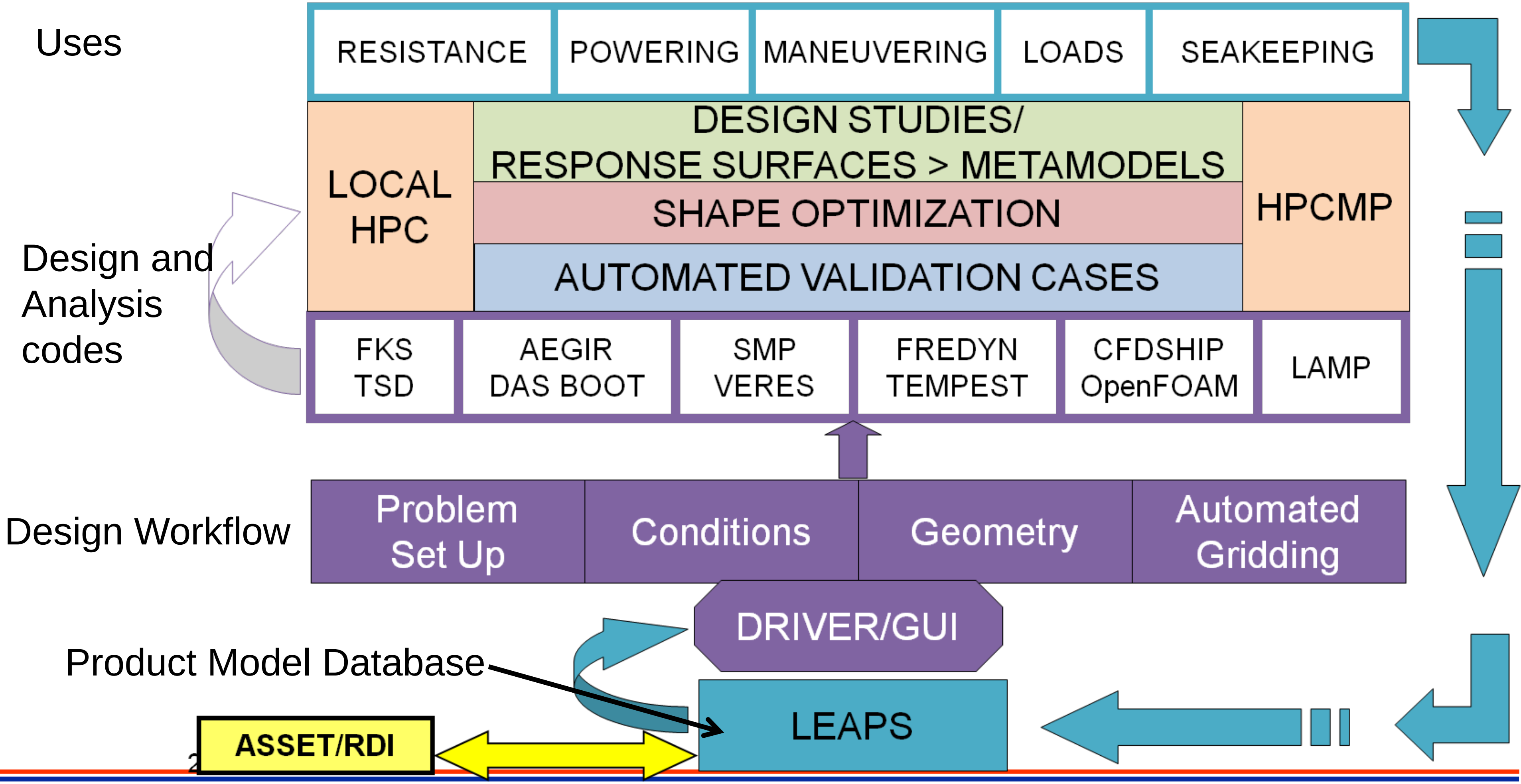
FY03
OPNAV
Sponsored
Cruiser
Concept

- **Ship Shock & Damage**
  - Provide analysis of shock and damage effects and reduce need for tests to assess ship shock and damage effects

- **Ship Hydrodynamics**
  - Accelerate and improve all stages of ship hydrodynamic design (seaway loads, sea keeping, resistance…)

IHDE 1.0 – Ships: Integrated Hydro Design Environment

- Four Use Cases: 1. Resistance, 2. Powering, 3. Maneuvering, 4. Seakeeping



Uses

RESISTANCE | POWERING | MANEUVERING | LOADS | SEAKEEPING

LOCAL HPC

DESIGN STUDIES/ RESPONSE SURFACES > METAMODELS

SHAPE OPTIMIZATION

AUTOMATED VALIDATION CASES

HPCMP

Design and Analysis codes

FKS TSD | AEGIR DAS BOOT | SMP VERES | FREDYN TEMPEST | CFDSHIP OpenFOAM | LAMP

Design Workflow

Problem Set Up | Conditions | Geometry | Automated Gridding

DRIVER/GUI

Product Model Database

LEAPS

ASSET/RDI

Use Cases Are Good for Capturing Requirements and Guiding Development

- **Ship Shock software (Navy Enhanced Sierra Mechanics, NESM) analyzes ship vulnerability**
- **NESM 12-year Product Development Plan & Requirements Based On Six (6) Use Cases**
  - UC I → Ship Response To Standoff UNDEX Where Structure Remains Predominantly Elastic (minimal damage) (FSST)
  - UC II → Ship Response to UNDEX & SURFEX Causing Moderate Structural Damage
  - UC III → Ship Response To UNDEX & SURFEX Causing Severe Structural Damage (including SURFEX)
  - UC IV → Ship Response To AIREX Causing Moderate Structural Damage
  - UC V → Ship Response To AIREX Causing Severe Structural Damage
  - UC VI → Ship Response To Unconventional Weapon Attacks
- **Sandia National Laboratory participation provides structural mechanics software (Sierra Mechanics Suite) to achieve good scalability**

Meshing and Geometry Project → Tools for AV, Ships and RF

Product: CAPSTONE

Core

API and library components for core framework, geometry and mesh representations and algorithms, attribution modeling

Provides:

- APIs for writing external meshing and add new higher-level functionality plugin(s)
- Access to Mesh Modification capability (refinement, coarsening, local-remeshing)
- Runtime access to geometry

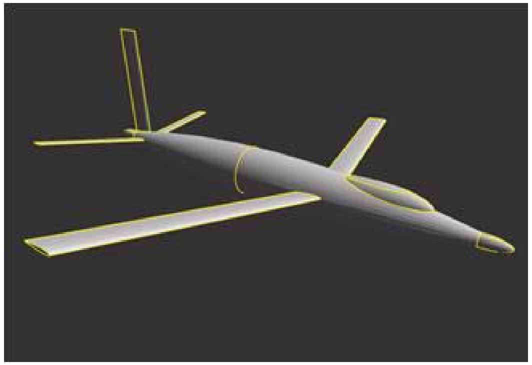
Front-end

Provides geometry preparation and mesh generation

- Support graphical user interface (GUI), command-line, and scripting interfaces for end-user
- Provides traditional pre-processor capabilities for end-users
- Specialized application plugins (e.g. mesh implant for Ships)

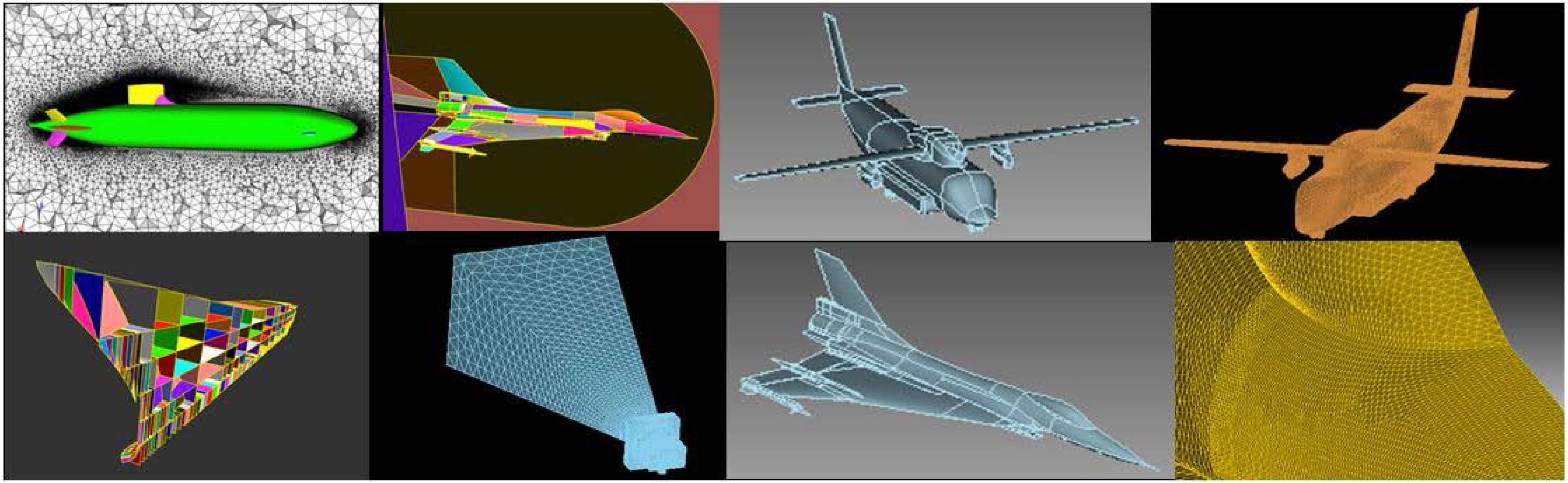
CREATE – Meshing and Geometry (MG) Components: CAPSTONE

- **CAPSTONE**
  - Collection of components that enable rapid generation of the geometry and mesh representations needed for all phases of acquisition engineering (conceptual, preliminary, detailed design, and operational support)
  - Emphasis is on geometry as key representation of product



Enable parametric, associative geometry and meshes in AV: DaVinci, Ships: RDI

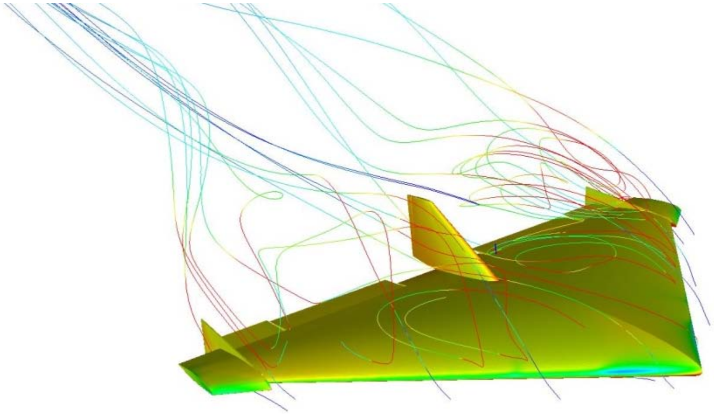
Produce analyzable representations for complex and detailed analysis



Another Early Success → Improved Flight Certification Process for Marine Corps UAV

- **Problem: Expensive and lengthy UAV flight certification for small-vendor designs due to physical testing required for flight data.**
- **Solution: Joint Navy and CREATE Air Vehicles Shadow-Ops STUAS project used computational engineering tools to rapidly and cheaply develop the flight certification database.**
- **Benefits to DoD Aircraft Programs**
  - **Reduced time and cost by eliminating the need for physical model testing**
  - **Enabled industry competitiveness through quick Services assessment of many vendor designs**
  - **Provided unbiased performance data to STUAS Program Office for assessment of contractor vehicles**
- **Six new vendors are now able to compete for UAV contracts**

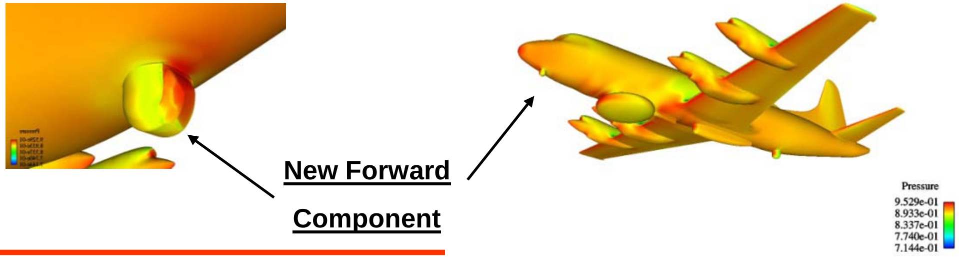
8 foot wingspan

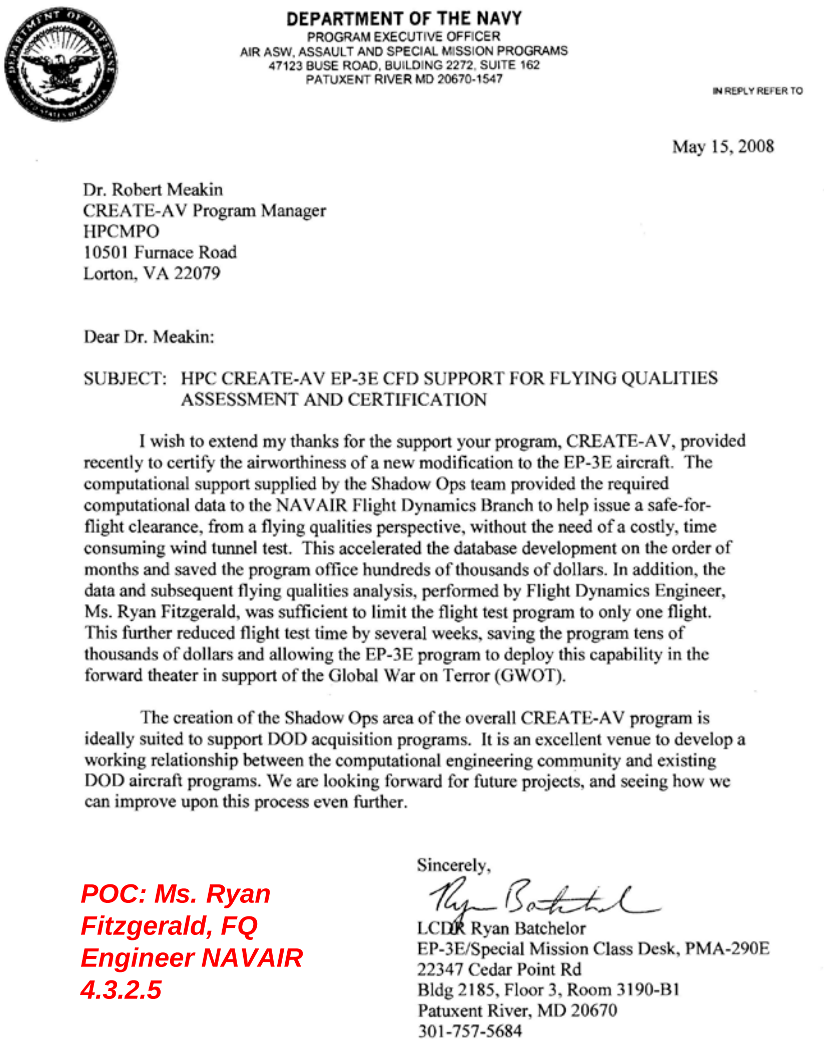


Engineers: Drs. Theresa Shafer / Gary N. McQuay - PMA-263 STUAS/Tier II UAS

Early Success: Rapid Deployment of EP-3E

- **Shadow-Ops: CREATE staff use computational tools to support acquisition programs → provide experience and establish connections and value**
- **Performed CFD analysis of impact of electronic countermeasure pod for EP-3E flight clearance--Not sufficient time for conventional process (flight tests)**
  - **Eliminated construction cost of wind tunnel model and tests and need for contractor flying quality report.**
  - **Provided aircraft flying qualities characteristics within required time frame.**
  - **Provided data required to issue flight clearance in time for direct deployment.**
- **Reduced overall program cost and time.**
- ***Only* 1 flying qualities flight test required – Saving between 3-4 flight tests.**
- **System was deployed in the forward theatre in less than four months instead of twelve**





DEPARTMENT OF THE NAVY
PROGRAM EXECUTIVE OFFICER
AIR ASW, ASSAULT AND SPECIAL MISSION PROGRAMS
47123 BUSE ROAD, BUILDING 2272, SUITE 162
PATUXENT RIVER MD 20670-1547

IN REPLY REFER TO

May 15, 2008

Dr. Robert Meakin
CREATE-AV Program Manager
HPCMPO
10501 Furnace Road
Lorton, VA 22079

Dear Dr. Meakin:

SUBJECT: HPC CREATE-AV EP-3E CFD SUPPORT FOR FLYING QUALITIES ASSESSMENT AND CERTIFICATION

I wish to extend my thanks for the support your program, CREATE-AV, provided recently to certify the airworthiness of a new modification to the EP-3E aircraft. The computational support supplied by the Shadow Ops team provided the required computational data to the NAVAIR Flight Dynamics Branch to help issue a safe-for-flight clearance, from a flying qualities perspective, without the need of a costly, time consuming wind tunnel test. This accelerated the database development on the order of months and saved the program office hundreds of thousands of dollars. In addition, the data and subsequent flying qualities analysis, performed by Flight Dynamics Engineer, Ms. Ryan Fitzgerald, was sufficient to limit the flight test program to only one flight. This further reduced flight test time by several weeks, saving the program tens of thousands of dollars and allowing the EP-3E program to deploy this capability in the forward theater in support of the Global War on Terror (GWOT).

The creation of the Shadow Ops area of the overall CREATE-AV program is ideally suited to support DOD acquisition programs. It is an excellent venue to develop a working relationship between the computational engineering community and existing DOD aircraft programs. We are looking forward for future projects, and seeing how we can improve upon this process even further.

Sincerely,

Ryan Batchelor

LCDR Ryan Batchelor
EP-3E/Special Mission Class Desk, PMA-290E
22347 Cedar Point Rd
Bldg 2185, Floor 3, Room 3190-B1
Patuxent River, MD 20670
301-757-5684

POC: Ms. Ryan Fitzgerald, FQ Engineer NAVAIR 4.3.2.5