

The CREATE Program  
Software Applications for the Design and Analysis of Air Vehicles, Naval Vessels, Radio  
Frequency Antennas, and Ground Vehicles

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## Abstract

Today, rapid product innovation is essential to remain competitive. To help spur innovation in the acquisition of major defense systems and reduce their cost, time and risks, the Department of Defense launched the Computational Research and Engineering Acquisition Tools and Environments (CREATE) Program in 2006. The CREATE goal is to develop and deploy physics-based high performance computing software applications for the design and analysis of military air craft, ships, and radio frequency antenna systems (and more recently ground vehicles) through the construction and analysis of virtual prototypes for those systems. Code development began in 2008, and eight years later, CREATE is already beginning to accomplish these goals.

## Introduction

Since the end of World War II, the calculating power of computers has grown exponentially from ~1 Floating Point Operation / second (FLOP/s) to over  $10^{16}$  FLOP/s (<http://www.top500.org/>). This means that—for the first time in history—we have the potential to make accurate predictions of the behavior of complex physical systems (e.g. the weather, the behavior of chemical systems, airplanes, ships, automobiles, etc.). We can now (2015) develop and deploy science-based software applications for high performance computers that:

1. Include the major physical effects that determine the performance of the system,
2. Utilize highly accurate mathematical and numerical solution algorithms,
3. Are experimentally validated,
4. Can predict the performance of a full-scale system (e.g. an entire ship or air plane),
5. Enable multidimensional design of experiments to generate large trade-spaces for a full scale system, and
6. Can complete a high-fidelity, time-dependent, three-dimensional multi-physics calculation for a maneuvering system in a few days in 2015 that took weeks in 2005, and months (if even possible at the same level of fidelity) in 1995.

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This capability enables design engineers to construct realistic virtual prototypes of physical systems (ships, microprocessors, earth moving equipment, etc.) and make accurate predictions of their performance by solving the physics equations that govern their behavior.

In the past, it was necessary to construct real prototypes and use live tests to assess their performance and find the design flaws. With simple systems, and incremental changes, there was time to follow the traditional product development paradigm of “design, build, test, fail, re-design,…” iterated cycles. For the standard system engineering product development process[1] (Figure 1), the design of new products is based on “rule of thumb” extrapolations of existing products. Sub-system physical prototypes are tested during the engineering design phase, and full system physical prototypes are tested just before full scale production. With today’s more complex systems, these live tests occur too late to provide timely data on design defects and performance shortfalls. Expensive and time-consuming rework is required to fix the problems uncovered by live testing.

In 2006, recognizing the need to help spur innovation for major defense systems, the Department of Defense launched the Computational Research and Engineering Acquisition Tools and Environments (CREATE) Program. CREATE was chartered to reduce the cost, time and risks of DoD acquisition programs by developing and deploying multiphysics-based high performance computing software applications for the design and analysis of military air craft, ships, and radio frequency antenna systems.

Using the CREATE tools, engineers can construct virtual prototypes and analyze product performance at any stage of the development process, supplementing data from live tests. For conceptual design of new systems, “rule-of-thumb” extrapolations of existing designs can be replaced with physics-based generation of design options allowing rapid trade-space exploration, and assessment of the feasibility of design options with physics-based analysis tools. They can consider thousands of design options instead of a few. For detailed design development, high-fidelity analysis of virtual prototypes can replace “failure data from live tests” with “physics-based accurate predictions of virtual prototype performance.” This provides timely decision data that enables engineers to identify design flaws and performance shortfalls early, allowing problems to be fixed before metal is cut, minimizing rework that cause schedule delays and cost growth. The tools can be applied at all stages of the product development process, from early concept design through operation, support, sustainment and modernization.

Code development began in 2008, and eight years later, CREATE is beginning to accomplish those goals. The CREATE tools are being used by more than 70 DoD organizations for the assessment of more than 80 DoD weapon systems and platforms. There are over 600 active CREATE user software licenses.

The CREATE tools can help make the testing process more productive, more effective, and more efficient. The tools can be used to identify the most sensitive and uncertain operating conditions so that testing programs can concentrate on those areas, so that the total test data requirements can be reduced a factor of 5 or more with a concomitant reduction in the required testing time[2]. In addition it frees the testing community to address the basic issues that determine weapon system performance.

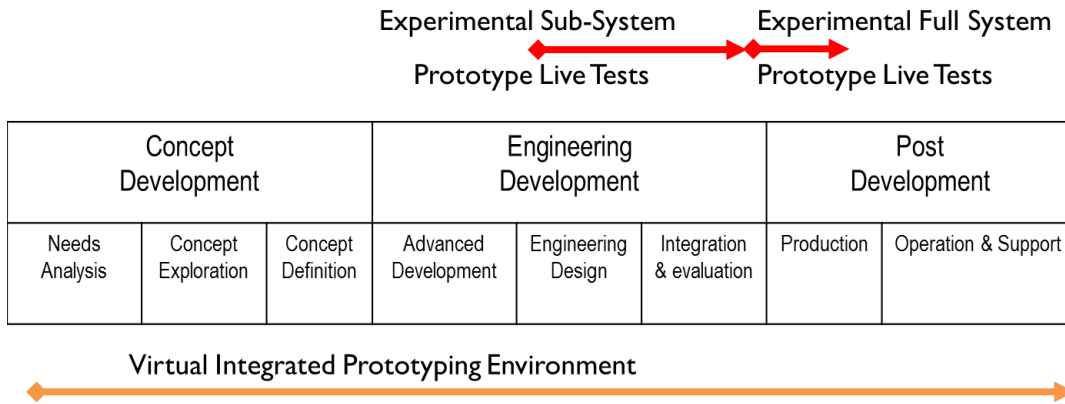


Figure 1. System Engineering Product Development Life Cycle Model (adapted from [1])

Many industries and Federal Agencies have successfully adopted the virtual prototype paradigm[3-5]. Until recently, however, there has been little public information on the value of the paradigm, chiefly because it gives organizations that use it a significant competitive advantage, and their use of the paradigm is considered a trade secret. A few examples are publically available. The Partnership for Advanced Computing in Europe (PRACE) established an Automotive Simulation Center (ASC) in Stuttgart, with projects in vehicle drive, vehicle structure, vehicle physics, etc. ASC director, Alexander Walser, noted in 2014 that “numerical simulation made its way in the design phase of automotive development and productions (as) a useful tool for faster problem analysis and reduction of cost and product design time.[6]” Specific benefits, however, were not detailed. In an aerospace industry example, however, Doug Ball, then Boeing’s chief engineer for enabling technology and research, stated “When we were designing the 767 back in the 1980s, we built and tested about 77 wings. By using supercomputers to simulate the properties of the wings on recent models such as the 787 and the 747-8, we only had to design seven wings, a tremendous savings in time and cost...”[7]

Starting in 1992, Goodyear developed a physics-based design tool for tires that became the core of their “innovation engine.”[4] Goodyear CEO Richard Kramer noted in the Q4 2010 Earnings Call: “*Our innovation engine* again delivered in 2010. The percentage of new products in our overall lineup is the highest ever... Our innovative new products continue to accumulate an impressive list of test wins and third-party endorsements.”[8] In the 2009 Annual Report, then Goodyear CEO Robert Keagan stated that: “Our new product engine is poised to take advantage of the demand for high-value-added tires and to do so with unmatched speed to market.”[9] With this approach, Goodyear reduced its product development time from three years to as little as eight months and reduced its new product prototyping and testing costs from 40% to 15% of the R&D budget, an annual savings of \$100 million. [10]

### The CREATE Program

CREATE began in 2006 as a set of four projects (Air Vehicles, Naval Ships, Radio Frequency Antennas, and Meshing and Geometry) with nine individual software products (Table 1). The choice of the projects was dictated by consideration of the relative size and importance of major defense acquisition programs and the potential of physics-based high performance computing applications to predict the performance of those systems.

Each of the CREATE projects has two types of software products: 1) a concept development tool to generate conceptual designs and analyze their feasibility and performance using fast, but lower-fidelity tools (DaVinci, RSDE/IHDE, and a module of SENTRi); and 2) high-fidelity tools to provide accurate predictions of the system performance (Kestrel, Helios, NESM, NavyFOAM, and SENTRi). A fourth project, Meshing and Geometry, provides capability for concept design tools to generate numerical representations of the platform and then to generate the meshes needed for computational analysis (Capstone). The Meshing and Geometry tool can also produce meshes from geometry representations generated by the most commonly used commercial CAD tools. Overview papers describing these products will appear in this and future issues of this journal.

Table 1: HPCMP CREATE™ Projects and Products

- 
- 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
  - Naval Ships—CREATE Ships
    - Rapid Ship Design Environment (RSDE) - Rapid Design and Synthesis Capability
    - Navy Enhanced Sierra Mechanics (NESM) - Ship Shock & Shock Damage Assessment
    - NavyFOAM - Hydrodynamic-predict hydrodynamic performance
    - Integrated Hydro Design Environment (IHDE) - Facilitates hydrodynamic performance evaluations in early stage ship design
  - 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

The CREATE tools have been developed, deployed and supported by the DoD (DoD employees and contractors), are validated with DoD experimental data for DoD use cases, and are “owned” by the DoD. In general the DoD has unlimited distribution rights to the CREATE software. The CREATE tools give DoD acquisition program engineers the ability to make independent assessments of proposed designs and contractor deliverables. The tools are directly helping the DoD acquisition engineering community grow its organic engineering capability, a DoD priority.

Based on the success of the original CREATE projects, in 2013 CREATE began initial development of a fifth project for the design and analysis of Ground Vehicles. It is too new to have yet delivered an initial release, and will be discussed in a subsequent paper.

**The Nine HPCMP CREATE™ Products:**

### **DaVinci—Concept design tool for air vehicles:**

**DaVinci** will allow engineers to populate design option spaces of fixed and rotary wing aircraft and provide an initial assessment of the performance of the design. Choosing from previously engineered components, the tool will allow engineers to select and modify wings, fuselage, and propulsion components. Aircraft designers then can select, adjust, and rearrange internal components in aircraft designs. It is “Model Centric”. It will support highly efficient construction and maintenance of Air Vehicle models, including geometry that is parametric and includes water-tight external geometry, internal structure, subsystem layout, volumes, and mass properties. It will provide a multi-disciplinary, physics-based analysis capability that is variable fidelity, but is consistent across disciplines. It provides the ability to persist design data and intent throughout acquisition and program life. The virtual model can be tested virtually through its flight envelope to assess basic performance characters, including mission performance, and decision support with uncertainty quantification and sensitivity analysis.

The current version (3.1) has the capability to build parametric designs for fighter, transport, and surveillance aircraft that include the Outer Mold Line (OML) and structural envelope. It supports geometric analysis including areas, volumes, centroids and moments and high fidelity aerodynamic analysis using the high-fidelity tool Kestrel. It can design and build a geometric model of a platform, and build a mesh that captures this geometry with Capstone for high fidelity analysis with Kestrel. Surrogate geometry models have been built for the support of the KC-46, the new Air Force Tanker based on the Boeing 767, and JSTARS, the new Air Force AWACS airplane based, for instance, on a Gulfstream 650, 550 or a Boeing 737.

### **Kestrel—High-Fidelity Tool for Fixed Wing Air Vehicle Performance Prediction**

**Kestrel** has the capability to provide accurate predictions of the performance of DoD air vehicles, with a specific focus on the fixed-wing community. It integrates computational fluid dynamics, structural dynamics, propulsion, and control for sub-sonic through supersonic aircraft operation. In detail, the capabilities available in Kestrel v5.0 include: 1) Aerodynamics (Navier-Stokes solvers and a full suite of boundary conditions and turbulence models), 2) Structural Dynamics (Modal models or Finite Element Analysis for aero-structure interactions), 3) Flight Control Systems (Control surface movement – deforming geometry or overset), and 4) Propulsion (Engine “cycle-decks” for propulsion effects, or direct engine simulation including inlet and rotating machinery, nozzle, and moving walls). This set of capabilities is unique in the international aerospace community. It provides the capability to develop major innovations in the design of next generation aeronautical weapon systems. With Kestrel, engineers can verify designs prior to key decision points (and prior to fabrication of test articles or full-scale prototypes), plan and rehearse wind-tunnel and full-scale flight tests, evaluate planned (or potential) operational use scenarios, perform flight certifications (e.g., airworthiness, flight envelope expansion, mishap investigation, etc.), and generate response surfaces usable in DaVinci, flight-simulators, and other environments that require real-time access to performance data. Kestrel has been applied to the analysis of over 30 fixed-wing DoD Aviation systems including store separation, A-10, F-18E, F-15, B-52, E-2D, P-3, and many others.

### **Helios—High-Fidelity Tool for Rotary Wing Air Vehicle Performance Prediction**

**Helios** is a high-fidelity, full-vehicle, multi-physics analysis tool for rotary-wing aircraft. Helios v5.0 can calculate the performance of a full sized rotorcraft, including the fuselage and rotors. It can handle arbitrary rotor configurations (e.g., conventional main rotor/tail-fan; co-axial

main rotor/pusher propeller; tandem main rotors; tiltrotors; quad-tiltrotors; etc). It has the capability to analyze and predict prescribed maneuvers with tight coupling of rotor aerodynamic structural dynamics. A highly accurate treatment of the vortex shedding from the rotor blade tips using adaptive mesh refinement gives Helios unique capability to assess the interaction of these vortices with the fuselage and nearby rotor blades. Helios can provide all the benefits for rotary-winged aircraft that Kestrel can for fixed-wing aircraft.

There have already been important examples of the use and value of Helios. The Army Rotorcraft Program (AMRDEC/AED) used Helios with Boeing to generate early design stage predictions of helicopter performance for a proposed rotor blade upgrade for the CH-47F helicopter (Chinook) to achieve up to an estimated 2,000 pounds improved hover thrust for 400+ Chinooks with limited degradation of forward flight performance. The Army Joint-Multi-Role Technology Demonstrator (JMR-TD) Program used Helios to provide decision data on the proposals from four vendors for the JMR-TD program. Helios enabled government engineers to provide the government the ability to conduct an independent analysis of the contractor proposals. The Army Rotorcraft Program (AMRDEC/AED) is using Helios to assess the H-60 tail rotor effectiveness for providing directional control of aircraft in combination with increased engine power and main rotor performance.

### **Rapid Ship Design Environment (RSDE) —Rapid Concept Design for Ships:**

RSDE is a concept design tool that allows engineers and naval architects to assess the trade-offs inherent in designing ships to meet a spectrum of competing key performance parameters. Employing the concept of design space exploration, engineers and naval architects can provide data for decision makers on the impact of tradeoffs in range, speed, armament, aviation support, etc. on the size and, in large measure, the cost of a proposed ship concept. RSDE can generate tens of thousands of candidate ship designs with varying hullforms, subdivision, and machinery arrangements. An initial assessment of the intact and damaged stability, resistance, and an initial structural design and analysis is done for each candidate ship design. RSDE has been used to enable set-based design[11] on Navy acquisition programs. This design method allows down-selection of a ship design to occur later in the process when the trade-offs are more fully understood. It has been applied to numerous ship design studies including the Amphibious Landing Craft LX(R) Analysis of Alternatives, and the Small Surface Combatant Trade Study. The team leader for the RSDE tool was awarded the 2014 American Society of Naval Engineers (ASNE) Gold Medal for his work developing and applying the RSDE tool.

### **NavyFOAM - High fidelity predictions of ship hydrodynamic performance**

NavyFOAM is based on the OpenFOAM ([www.openfoam.org](http://www.openfoam.org)) libraries and code architecture. To that base, we have added a number of features and capabilities that enable simulation of the air-sea interface (e.g., surface waves) and other effects important for naval vessels. NavyFOAM is a fully parallelized, multi-physics computational fluid dynamics (CFD) framework developed using modern object-oriented programming (OOP). The code enables high-fidelity hydrodynamic analysis and prediction of ship performance such as resistance, propulsion, maneuvering, seakeeping and seaway loads. It has demonstrated accuracy against experimental data for a number of target applications such as resistance, propeller characteristics, hull/propulsor interaction, and 6-degree-of-freedom ship motion of underwater vehicles and surface ships. Offering a suite of Navier-Stokes-based flow solvers tailored to specific

applications including single- and multi-phase solvers, NavyFOAM allows assessment of alternative hull and propulsor designs. With NavyFOAM users can evaluate a ship's performance in a wide array of operating conditions including both subsea and surface operations. Its modularity expedites coupling with third-party software and collaborative multi-disciplinary software development (e.g. fluid-structure interaction, hydroacoustics). It has been applied to many naval systems including assessment of the safe operating envelope of the DDG-1000, propeller designs, the USMC Amphibious Combat Vehicle, the Ohio Replacement Program (a \$100B procurement of the next generation ballistic missile launch submarine) and many other systems of interest to the US Navy.

### **Navy Enhanced Sierra Mechanics (NESM)- Ship Shock & Shock Damage Assessment**

NESM builds on the Department of Energy's shock analysis tool Sierra Mechanics to provide a means to assess ship and component response to external shock and blast using accurate high performance computational tools. NESM can reduce the time and expense required for physical shock testing of ship classes and also improves the initial ship design process by assessing planned component installations for shock performance prior to final arrangement and installations decisions. The tightly coupled multi-physics capabilities include: 1) Structural Dynamics (Implicit linear-elastic solver: static, modal, transient, acoustics, and more), 2) Solid Mechanics (Explicit plasticity solver: failure, high-strain, multi-grid, and more), 3) Fluid Dynamics (Euler solver: shock propagation, load environments, and threat modeling), and 4) Fluid-Structure Interaction. The solution algorithms in NESM can exploit massively parallel computers, and can scale to thousands of cores, enabling efficient computer use and the ability to address full-sized naval vessels up and including next generation aircraft carriers and submarines.

NESM will materially contribute to the design of next generation naval weapon systems and platforms, support planning and rehearsal of ship tests prior to Life Fire Testing (more "bang" per test dollar), and the evaluation of planned (or potential) operational use scenarios. NESM has been officially adopted by the Navy for these uses. "The NAVSEA Technical Warrant (for Shock/Ships) concurs that NESM is the appropriate and technically acceptable modeling and simulation (M&S) tool which meets the M&S requirements to support current and future surface ship shock applications." It was previously approved for "Full Ship Shock Trials (FSST) Alternative R&D Programs (PEO Ships & PEO Carriers)," which led to the release of OPNAVINST 9072.2A providing future ship classes w/ an alternative to Full Scale Shock Trials. NESM has been used to support Littoral Combat Ship (LCS) Live-Fire Test & Evaluation (LFT&E) and the USS Cole Validation Study, and to provide support for Live Fire Test and Evaluation for the Navy's next generation Nuclear Aircraft Carrier (CVN-78 and 79).

### **Integrated Hydrodynamic Design Environment (IHDE) —Facilitates hydrodynamic performance evaluations for early stage ship design.**

IHDE is a desktop application that integrates a suite of Navy hullform design and analysis tools allowing a user to perform evaluations of performance, including visualization, in a simplified and timely manner from a single interface. Prior to the development of IHDE, naval architects and marine engineers often had to learn how to use a dozen or more individual design tools, each with a different user interface and input format. IHDE provides a single interface for access to all of the tools. In a few days to weeks, a single user with IHDE can finish projects that took several highly experienced users many months to complete. Current capabilities are geared

toward surface ships, both monohulls and multihulls—including catamarans and trimarans. Typical uses include predicting: 1) resistance in calm water, 2) seakeeping behavior in waves, 3) hydrodynamic loads due to wave slamming, and 4) operability (percentage of time a ship can carry out its particular mission in various parts of the world based on historic sea state data.

The US Navy’s Center for Innovation in Ship Design (CISD) has used IHDE to assess the performance of many ship designs, including: 1) T-AGOS-19 Ocean Surveillance ship; 2) Hospital ship (Mercy) replacement design; 3) Salvage Tow & Rescue (T-STAR); 4) Green Arctic Patrol Vessel (GPAV); 5) Medium Affordable Surface Combatant (MASC); and 6) an optimized MASC. IHDE is also an important adjunct capability for medium fidelity analysis of ship designs developed with RSDE. It was used with RSDE as part of the Amphibious Landing Craft LX(R) Analysis of Alternatives and the Small Surface Combatant Trade study.

### **SENTRI—Electromagnetic Tools for DoD Systems**

**SENTRI** is a robust and high-fidelity Full Wave electromagnetic prediction code for RF modeling of antennas, microwave circuits, and radar cross-section prediction. **SENTRI** is designed for the modeling of complex structures—including highly, heterogeneous material structures with multi-scaled features. A key goal is the calculation of the simultaneous performance of multiple-antenna systems embedded on a platform. The key features for electromagnetics are based on solutions of Maxwell’s equations with advanced hybrid finite-element boundary-integral techniques. This provides high accuracy with the ability to solve large, complex problems. **SENTRI** is continuously validated with DoD measurements. **SENTRI** is being used for antenna design, antenna in-situ analysis, RF signature prediction, Electromagnetic Interference (EMI), Electromagnetic Compatibility (EMC), material modeling, microwave device analysis (i.e. waveguides, filters, circulators, power dividers), phased array antenna systems, and apertures (i.e. radomes, windows, frequency selective surfaces). **SENTRI** is being used by approximately 30 DoD organizations (government and industry).

### **Capstone—Rapid Geometry and Mesh generation**

**Capstone** is a CAD-neutral application that provides two distinct capabilities. The first is the capability to develop numerical representations of a DoD weapon system (i.e. a Nonuniform Rational B-Splines (NURBS)-based digital product model consisting of the platform geometry with the associated attributes). The second is the capability to generate a mesh from the geometry. Valid and easily produced meshes with the required accuracy are the essential starting point for the other CREATE (solver) tools for detailed analysis. In addition, a number of non-CREATE groups use Capstone for its geometry and mesh generation capability for their applications.

A digital product model has many advantages for acquisition. It enables automated design optimization. It facilitates the transfer of design information between the government and contractors, eliminating much of the reliance on paper documents, and improving the accuracy and speed of information flow. It provides a permanent, analyzable description of the platform through all stages of the acquisition process. Copies of the product model can be generated and assigned to individual airplanes allowing the DoD to track the history, performance and maintenance of entire life cycle of each airplane. Together with DaVinci, which builds on top of the Capstone platform, it enables the recent Air Force initiatives of the Digital Thread and the Digital Twin[12].

## **CREATE Program Organization and Management**

To develop and deploy the CREATE software applications, we worked with the DoD organizations responsible for overseeing the design and analysis of air vehicles, naval vessels and RF antennas (Figure 2) to empower them to develop and deploy the tools. The CREATE Program first formed four projects with a total of nine multi-disciplinary teams of subject matter experts. Then they identified a team leader within a DoD customer organization for each software product who possessed the right mix of subject matter and high performance computing expertise; and leadership, program, and project management skills. They helped the leader build a multidisciplinary software development team with approximately 10 members. Each core development group is located at a customer organization (e.g. the Navy's ship design groups are located at the Naval Surface Warfare Center, Carderock Division, Bethesda, MD). Additional developers are drawn from other organizations as needed to provide expertise not available in the customer organization. For instance, the structural dynamics modules for NESM and Kestrel are being supplied by the Sierra Mechanics group at the US Department of Energy's Sandia National Laboratory. Generally about 1/3 of each team resides at the core organization, and the remaining two-thirds are located at other organizations. The CREATE staffing mix is about 45 DoD employees and about 75 DoD support contractors. The team members are distributed across ~25 collaborating institutions.

The CREATE Program leaders then sponsored each team by providing funding and active management and oversight of the development process. They developed a set of software project management and software engineering practices for the CREATE Program and promulgated them to the teams as guidance. They sought a balance between a very agile development process to allow the teams the flexibility to accomplish technically difficult tasks and ensuring adequate accountability together with an organized code development process. The HPCMP and CREATE Program Office actively manages the nine teams cooperatively with the hosting Service organizations. While clear lines of authority and obligation have been formally established between the HPCMP CREATE program and each executing and hosting organization, both groups have developed a high degree of trust and work together to resolve conflicts. There is a strong degree of alignment on the technical aspects of the CREATE Program between both groups.

Each project has a Board of Directors consisting of senior members of the relevant customer organization (Navy, Air Force and Army acquisition engineering communities). Each Board meets at least once a year. The Boards review the progress during the prior year, advise the project about new requirements, and serve as liaisons between the CREATE projects and their DoD customer community. The Board members are members of the Senior Executive Service, or other senior staff of the Navy, Air Force or Army.

The annual CREATE budget is about \$25M/year. The total investment in CREATE by the DoD HPCMP from 2008 through 2015 is ~ \$160M. The Services provide "in-kind" contributions of another ~\$11M/year, a testament to the value of CREATE to them. The Service contributions include office space and supplies; admin support; network and other host services; additional professional staff for the code development teams; and access to validation experiments and data.

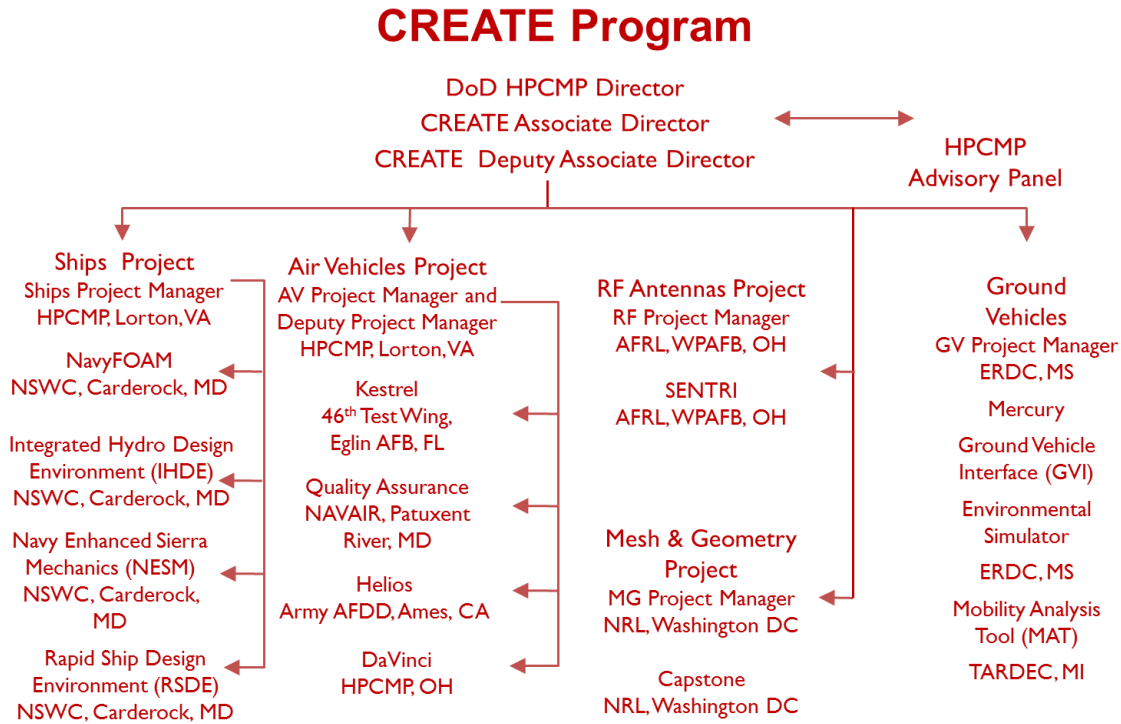


Figure 2 CREATE Program Organization Chart

## CREATE Builds the Right Software and Builds It Right

The CREATE Program developed a vision for how DoD could implement virtual prototypes with physics-based high performance computing engineering software within its own processes to “revolutionize” its lethargic acquisition process. It then fleshed out that vision through joint assessments with each service of their detailed acquisition processes to identify the specific tools needed to reduce the time, cost, and risk and improve the system performance for the Service’s acquisition programs. This vision is described in an “Initial Capability Document” (ICD) for each project. The ICDs were reviewed and approved by the Board of Directors for each project and are reviewed periodically.

Although CREATE was proposed to be a 12 year program, the CREATE tools are designed for a 30 to 40 year life since that is the expected life span of successful engineering codes. Each CREATE code development team follows a highly disciplined software development process. There is a strong emphasis on software quality. To facilitate development by non-located teams, the CREATE Program provides a supportive code development environment with virtual clusters, central servers with code and document repositories, issue trackers, user and developer forums, configuration management services, and access to high performance computers for testing and performance enhancement, and high quality video conferencing. Guided by the ICD, a 12-year product roadmap and feedback from the BODs and customers, each product team issues a new release each year with the upgraded capability and new features needed by the customer communities. This places the upgraded tool into the hands of the user community, and gives the code development team rapid feedback on the quality and

usefulness of the upgraded code. The annual release cadence (Figure 3) adds discipline to the development process.

The CREATE teams generally use a SCRUM “agile” development process tailored for their environment and code. The releases are designed and tested for all the standard Linux and Unix operating systems. Each release is extensively tested both during the development process, and during the release process.

Each software release is documented with a: 1) Product Technical Description that describes the physics and engineering capabilities (including the equations) in the code, the computer science approaches, and the solution algorithms; 2) Developers Manual that describes the source code in detail, provides an index/table of contents, and other information essential for understanding the source code; 3) Users’ Manual to help the users set up their problems, run the code, and analyze the results; and 4) test plan with an archive of test problems with the input and test results. In addition there are tutorials and a user forum on the CREATE server, all backed-up by a user support group.

Fiscal Year	FY2011				FY2012				FY2013				FY2014				FY2015				FY2016											
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4								
AV-DaVinci					1							2								3*												4*
AV-Helios					2				3			4					5			6*												7*
AV-Kestrel			2						3			4					5			6								7*				
MG-Capstone	1				2				3				4				5				6*											
RF-SENTRI				2					3				4				5				6*											
Ships-IHDE	2				3				4				5				6				7*											
Ships-NavyFoam	1				2				3					4			5				6*											
Ships-NESM	1				1.1					2					2.1					3								4*				
Ships-RSDE					0.5				1.0				1.1				1.2				2*											

Figure 3. CREATE Annual Releases with version numbers. The FY2015 4th quarter and FY2016 releases are planned. Some CREATE products had releases prior to 2011.

## **Information Assurance for the CREATE products**

Information assurance for computational engineering applications can be understood from its role in the high performance computing (HPC) ecosystem. The CREATE tools are part of an ecosystem consisting of 1) Subject Matter Experts (SMEs) who use the tools on high performance computers over high speed networks to generate virtual prototypes and analyze their performance; 2) software applications like the CREATE tools that can be used to generate virtual prototypes and predict their performance; 3) Experimental testing organizations to generate validation data to establish the validity of the models that are the basis of the software applications; 4) high speed computer networks that provide the SMEs access to supercomputers; 5) supercomputers; and 6) sponsors who need the results of the calculations and provide the funds to generate the results.

CREATE is designed to provide the DoD a military competitive advantage. Thus the DoD must control the distribution and use of the codes. The CREATE codes are unclassified, but are subject to the International Traffic in Arms Regulations (ITAR). To be effective, DoD users must be able to run the CREATE codes securely and access their proprietary data on a high performance computer. The codes and data are encrypted at rest and accessed and transferred over a secure encrypted network with two-factor authentication. To ensure integrity of the codes and the users' data, the codes and the user's data are archived on the HPCMP supercomputers and backed up frequently to a remote data repository.

However many, if not most, DoD engineers have access only to a Windows Personal Computer with Microsoft Office and a Browser. Usually no other software is allowed so those engineers cannot access the HPCMP supercomputers and the CREATE tools. To remove this barrier to access, the DoD HPCMP CREATE program has developed a "portal" that allows DoD users to access the DoD HPCMP supercomputers through their browser. The "portal" features two-factor authentication and encrypted data transfer. It allows users to set up their job; run it; and store, analyze, and visualize the results through their browser.

To prevent unauthorized access to the CREATE codes and to the intellectual property of the users, we limit access to codes to DoD employees or DoD contractors who have a valid reason for access to the CREATE software. They must sign a software distribution agreement that describes the limitations of their use (not to redistribute the code, reverse engineer it, etc.) and their intended use. They also agree to abide by the ITAR procedures which have civil and criminal penalties if violated. The CREATE source code is only accessible to the development team. The ideal is a "Software as a Service" model where the user can only execute the code, but not get a copy, even an executable. However, that's not practical for some users.

## **Intellectual Property Rights**

The DoD HPCMP must have "government purpose rights" to be able to distribute the CREATE software to users. Even a single line of code for which the DoD doesn't have these rights would leave the DoD vulnerable to lawsuits and large financial settlements for copyright or patent infringement and theft of intellectual property. Legal reviews of the ~ 40 CREATE contracts have determined that the DoD does have "government purpose rights." Remedial action was necessary for some of the contracts.

It is DoD policy to share DoD RDT&E results with the US Defense Industry if it is in the interests of the DoD because a strong US defense industry is essential for national security[13]. Several defense industries have expressed a strong interest in adopting the CREATE tools for use in their commercial as well as military design work. This requires that the DoD have

“unrestricted rights” for the relevant CREATE software. As the result of further extensive legal reviews of the CREATE contracts over the last three years together with additional remedial action, the DoD now has “unrestricted rights” to the CREATE tools. We expect that by early 2016, several large Defense Companies will be using CREATE tools for both military and commercial systems.

### **Transition and Adoption**

Transition of research results to applications and products has been a historic challenge for much of the Science and Technology research done by the DoD research community. The approach adopted by the CREATE Program of embedding the CREATE development teams in the DoD customer organizations responsible for the design and development of the relevant weapon system has been very successful in overcoming that challenge. The CREATE teams are trusted agents of their DoD organization. For example, to assess various options for a follow-on to the Littoral Combat Ship, or develop a concept for the Ohio Replacement Submarine, the Navy turned to the trusted organizations responsible for those tasks, the Naval Architecture and Engineering Department at the Naval Surface Warfare Center at Carderock. These were the same groups developing the ship design tool, RSDE and the hydrodynamics tool NavyFOAM. The transition was almost automatic.

In general, computational design tools are very effective methods for capturing the corporate knowledge and new research results in a field, and giving design engineers access to that knowledge in a tool that the engineer can use to design a new system. This greatly facilitates the development of innovative designs. It also gives the engineer an opportunity to compare the impact of new research results in the context of present practice, and allows the engineer to answer many “What if?” questions. This has caught the attention of a number of groups in the DoD Science and Technology research community. Those groups are beginning to work with the CREATE team to incorporate their research results into the CREATE codes as a means to transition their research results to acquisition programs.

### **Summary and Future**

The CREATE program is a set of physics-based high performance computing software tools that enable the DoD to develop innovative systems. The tools enable DoD engineers to generate and analyze virtual prototypes of DoD Air Vehicles, Ships, and RF antennas, and in the future, Ground Vehicles, and accurately predict their performance. The CREATE tools are: 1) Government-developed, government-owned, and government-supported to enable the DoD to independently evaluate contractor designs and other deliverables; 2) Designed for a ~30 year+ life cycle; 3) Being adopted by DoD acquisition engineering communities (government and industry); and 4) Are beginning to have significant impact on acquisition programs.

While CREATE was proposed as a 12 year program, it is proving to be highly successful and very promising after only 8 years.. In addition, there are many more opportunities for tools like CREATE in other areas. CREATE Ground Vehicles was started in 2013. Recently two Army and Air Force hypersonics groups have requested that CREATE upgrade the fixed-wing aircraft tool, Kestrel, to handle hypersonic flight. Other potential topic areas include rocket and missile design; satellite operations; structural design for ships and air vehicles; application to improving the DoD Test and Evaluation Process; lifetime prediction for ships, air vehicles and ground vehicles; incorporating life cycle costs in the design concept tools RSDE and DaVinci; continuing support for the DoD Engineered Resilient Systems Program

([http://www.defenseinnovationmarketplace.mil/resources/ERS\\_COI\\_March\\_2015.pdf](http://www.defenseinnovationmarketplace.mil/resources/ERS_COI_March_2015.pdf)), the Air Force Digital Thread and Digital Twin Programs[12]; and similar programs by the Navy for ships and the Army for ground vehicles.

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