Multi-Disciplinary, Physics-Based Simulation Software Products of the CREATE-AV Project

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Air vehicles are indispensable systems of reconnaissance, transport (manpower and material), and projection (force and humanitarian aid)
TRADITIONAL “DESIGN-BUILD-TEST-FIX” ACQUISITION

- Requires many lengthy and expensive design/build/test/fix iterations
- Process converges slowly, if at all
- Design flaws discovered late in process (Long time to market)

This is not a sustainable paradigm in today’s global economic and political environment
In 2007, DoD HPCMPO proposed an initiative to develop and deploy Computationally Based Engineering (CBE) tools that exploit next generation HPC computer resources to improve DoD acquisition processes for aircraft, ships, and RF antennas.

CREATE is a sustained development program to produce production quality design and analysis software that is both adaptable & maintainable.

CREATE-AV is the part of CREATE focused on aeronautical defense systems.
PROJECT MISSION

Develop and deploy a set of CBE Software Products that enable...

• **Increased capacity** of the acquisition engineering workforce of the services,

• Reduced workload through **streamlined** and more efficient acquisition **workflows**, and

• **Minimized need for rework** due to early detection of design faults or performance anomalies,

through exploitation of the capacity of next generation computer resources.
Ownership of Processes & Potential for Decision Impacts

Decision Impact on Lifetime System Cost vs Phase of Acquisition in Which Decision is Made
1 of Targeted Set of Government Owned Engineering Processes

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<thead>
<tr>
<th>ID</th>
<th>Process Name</th>
<th>Use Case</th>
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| AV-026 | **Navy Conceptual Design Process** | Rapidly produce physics-based, optimized conceptual designs in days to weeks. Quantification of design concept performance and sensitivity to new technology.  
(Benefits: Better decision data at the earliest phases of acquisition have potential to positively impact all subsequent acquisition costs.) |
1 of Targeted Set of Government Owned Engineering Processes

Government Owned Processes

Industry Owned Processes

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<td>AV-006</td>
<td>Store Compatibility Cert Recommend for Store Separation Air Force</td>
<td>Evaluate separation characteristics of all store combinations for a given aircraft. The number of configurations necessary to analyze is growing exponentially. (Benefits: Expansion of flight envelope / improve effectiveness &amp; reduce cost of test programs)</td>
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AN OBSERVATION...

A commonality of governing physics make it possible for a relatively small set of CBE software products to impact a large number of important acquisition processes.
CREATE-AV Products

DaVinci

Conceptual Design tool

High-Fidelity design verification tool for FIXED-WING aircraft

Kestrel

Helios

High-Fidelity design verification tool for ROTARY-WING aircraft
**Helios** is a multi-disciplinary, physics-based software product developed to enable full-vehicle (rotary-wing) design analysis and testing via high-fidelity simulation. The key use cases envisioned for the product include the following ...

- Design verification – verify vehicle performance
- Evaluate planned or potential operational use scenarios
- Perform flight certifications and qualifications
- Rehearse ground-based and full-scale flight tests
- Calibration of Lo-Fi analysis tools associated with conceptual design

all prior to fabrication of test articles, full-scale prototypes, or implementation of aircraft modifications.
• v1.0 “Whitney” is in General Release
• v2.0 “Shasta” General Release in early Spring
• v3.0 “Rainier” General Release in early Spring 2012
v1.0 “Whitney” Capability Summary

- Helicopter fuselage aerodynamics
- Helicopter fuselage + engineering model of rotor
- Isolated rotor in hover
- Isolated rotor in forward flight

v1.0 Key Technologies

- Dual-mesh paradigm
- High-order off-body solver
- Aero-structural coupling for rotor dynamics
v1.0 Examples

- **Shadow-Ops application for Harrier AV-8**
  - Helios off-body high-order Cartesian grids provide much better resolution of shed vortices from wing

- **Sikorsky X-2 hub drag studies**
  - Helios produced similar drag results to Fluent solutions
  - “The software could be used by an average CFD practitioner with a basic level of training”
- **Boeing CH-47 fuselage drag studies**
  - “Helios converged well in terms of density, residual, forces and moments”
  - “Helios solutions are similar to BCFD results”

- **Boeing MELB fuselage drag studies**
  - Helios solutions are similar to BCFD
  - Helios solutions converge much faster than BCFD
Bell 409 hub drag studies
  Helios results match experimental data and also match results from UNCLE CFD code
v2.0 “Shasta” Capability Summary

- Full vehicle (rotor and fuselage)
- Prescribed maneuver w/ tight coupling (aero-structural)
- Active rotors w/ flaps/slats
- Store separation w/ prescribed store motion
- Arbitrary shaft angles
- Multi-bladed rotors

v2.0 Key Technologies

- Automated AMR (Adaptive Mesh Refinement)
- Parallel FSI (Fluid Structure Interface)
v2.0 Examples

- **Tilt Rotor Aeroacoustic Model (TRAM)**
  - Quarter-scale model V-22 rotor/nacelle
  - DNW-LLF
  - $M_{\text{tip}} = 0.58, 0.625$

- **Computational conditions**
  - Rigid blade
  - Specified collective pitch
  - Rotor with center-body
  - $M_{\text{tip}} = 0.625, \text{Re}_{\text{Tip}} = 2.1M$
  - Spalart-Allmaras turbulence model

**Effects studied:**
1. Dual-mesh paradigm
2. Grid resolution
3. Adaptive grids
4. Inertial (moving mesh) vs. non-inertial (fixed mesh)
Fully-Unstructured vs. Dual Mesh

Q-criterion - iso-surface colored by vorticity

14° collective, $M_{\text{tip}} = 0.625$

Fully Unstructured

(b) Subset 2.8M

5M nodes
Near-body refinement

Off-body refinement

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TRAM Adaptive Wake Solution

- Solution in a day-and-a-half
- 50K total steps
- Adapt every 100 steps
- 128 core linux cluster

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<th># points</th>
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<td>Unstructured solver</td>
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<td>Cartesian solver</td>
<td>23.46 (55%)</td>
<td>110.2M</td>
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<td>Adaptive overhead</td>
<td>1.02 (2%)</td>
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<tr>
<td>Total</td>
<td>42.71 hours</td>
<td>119.6M</td>
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UH60 Rotor in Forward Flight

- Adaptive Mesh Refinement
  - Low Speed Case - 8513

Theory

```
\begin{figure}
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\includegraphics[width=\textwidth]{figures/adaptive_mesh_refinement.png}
\caption{Adaptive Mesh Refinement for UH60 Rotor in Forward Flight}
\end{figure}
```
Upcoming v2.0 Gov/Industry Beta Testing

- **HART-II rotor wake simulations**
- **UH-60 rotor and fuselage simulations**
- **Boeing Mesa MELB applications**
  - Main rotor hover performance predictions for isolated and installed cases
  - Predictions of rotor download on fuselage
- **Boeing Philadelphia CH-47 applications**
  - Main rotor hover performance predictions for isolated and installed cases
  - Predictions of rotor download on fuselage
- **Sikorsky X-2 rotor and fuselage**
  - Main rotor performance prediction
  - Rotor and fuselage interactions
- **Bell isolated rotor systems**
  - M427 forward flight performance predictions
v3.0 “Rainier” Capability Summary

STATUS: FDR Complete (Aug 2010)

Capability Enhancements

- Full Rotorcraft configurations
  - Fuselage + multiple rotors, tail rotor, etc.

- Resolution of time-step mismatch problem between main rotor and tail rotor
  - high tail rotor-RPM results in very small global time steps for main rotor simulation

- Free-flight trim with CFD-based fuselage loads

- General control surfaces
  - Support for integral/conformal control surfaces (single grid with re-meshing or mesh motion)

Capability Enhancements (con’t)

- Engine module integration for propulsion effects
  - 0-D engine model from CREATE-A/V Firebolt program

- Store separation with 6-DOF motions
  - Most of this software will be adapted from existing Kestrel modules using published interface definitions
    - Prescribed mesh motion
    - Rigid mesh motion
    - Mesh deformation
    - 6-degree of freedom body motion
v3.0 “Rainier” Key Technologies

- Strand solver prototype to enable
  - High automation for problem setup
  - High scalability for solver and domain connectivity
  - AMR and High-Order near vehicle surfaces
  - Small memory footprint, which maps well to hierarchical memory machine architectures

This is a new meshing paradigm introduced in 2007 by current members of the CREATE-AV technical staff. The technology is being matured in the Helios product and will be deployed through both Helios and Kestrel.
• **3-D Structural Dynamics and Trim**
  – 3D FEM prototype for rotor blades
  – *Internal evaluations and Shadow-Ops testing only*

• **Improvements to automated dynamic off-body adaption procedure**
  – Fixed-resource specification for mesh adaption
  – New options for error estimation
1) Arbitrary complete fuselage (rigid)
   - Engineering model of rotor
   - Isolated rotors (hover and forward flight)
   - Aero-elastic blades w/trim
2) Full rotorcraft configurations (fuselage, rotor, fan)
   - Elastic rotor and fan blades
   - Automated mesh adaptation for accurate wake capturing
3) Arbitrary full rotorcraft configurations
   - Multiple rotors/fans
   - Propulsion effects
   - Improved fidelity of aerodynamics
   - Introduction of fuselage structural dynamics

11) Arbitrary full rotorcraft configurations
   - High fidelity aerodynamics (hover, fwd-flight, sep flow, etc)
   - High fidelity structural dynamics (fuselage and blades)
   - Multiple vehicles w/ land and ship takeoff/land sim capability
   - Adaptive mesh refinement for evolving near-body dynamics and vortex wake capturing
   - Full complement of operational conditions and environments (e.g., hot, heavy, high altitude, dynamic ship deck/sea-states, brownout, icing, etc)
**Product Status: v2.0 General Release in early Spring (2011)**

**Kestrel** is the FIXED-WING counterpart of Helios. It is a multi-disciplinary, physics-based software product developed to enable full-vehicle (fixed-wing) design analysis and testing via high-fidelity simulation. The key use cases envisioned for the product include the following …

- Design verification – verify vehicle performance
- Evaluate planned or potential operational use scenarios
- Perform flight certifications and qualifications
- Rehearse ground-based and full-scale flight tests
- Calibration of Lo-Fi analysis tools associated with conceptual design

all prior to fabrication of test articles, full-scale prototypes, or implementation of aircraft modifications.
**Note:** both Kestrel and Helios will deliver airframe propulsion system integration capability starting in v3.0 release year. Gas Turbine Engine (GTE) simulation capability is provided through CREATE-AV Module “Fireblot”.
Kestrel (Firebolt enabled) C-17 Exhaust Simulation

Jump Door

C-17/F117-100
M=0.23 AOA=0° Alt.=6000’ PLA =80.5°
Total Temperature Isosurface Colored by Cp
A Key CREATE-AV MODULE

v1.0 of the Firebolt module
Enables airframe/propulsion integration analysis via “engineering models” of Gas Turbine Engines (GTEs). Appropriate for…

• use in DaVinci for propulsion system analysis in conceptual design studies
• use in Kestrel and Helios to include propulsion effects in high-fidelity multi-physics simulations.

v2.0 through vN.0 (updates released annually) of the Firebolt module
Delivers increasingly higher and more complete physical fidelity for GTEs in engine alone and complete aircraft simulation to the Kestrel and Helios communities.
Product Status: v1.0 General Release in Summer of 2011

Conceptual design tool, enabling multi-disciplinary, physics-based (multi-fidelity) generation of actionable decision data at the earliest stages of defense acquisition.

Enables designers to rapidly produce high quality parametric associative mesh-able geometry & system models for design space exploration in support decision making.

Enables model propagation from conceptual to preliminary/detailed design

Example Use Cases
• Explore, optimize, and understand the system trade-space and tradeoffs
• Effectively execute conceptual studies, including uncertainty quantification, & sensitivity analysis
**CADENCE OF DEVELOPMENT**

**ANNUAL** release cycle – increasing functionality, physical accuracy, computational efficiency, usability

- **Technology Demonstration**
  - Initial Conceptual Design & Roadmap
  - Annual Product Prototyping Loop

- **Engineering Development**
  - Final Product Design
  - "Next Gen" Annual Product Development Loop

- **Product Deployment**
  - Final Product Implementation Loop

- **Operations and Support**

2008

- **Kestrel** v3.0
- **Helios** v3.0

2012

- **DaVinci** v3.0

2017

- **Kestrel** v8.0
- **Helios** v8.0

2019

- **DaVinci** v8.0

Deploy to targeted government workforce for **DoD owned** acquisition engineering processes. Engage industry via technical advisory boards and professional societies.

Expand industry involvement via Beta-test events

Full deploy to government and industry for **DoD acquisition engineering**
For Context, consider an example schedule of CREATE-AV Project

**ANNUAL Product Development Milestones**

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<th>Month</th>
<th>Milestone</th>
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<td>Feb</td>
<td>Complete General Release – Version N-1</td>
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<td>Complete PDR – Version N</td>
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<td>Complete Product Branch – Version N</td>
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<td>May</td>
<td>Complete Integration – Version N</td>
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<td>Jun</td>
<td>Reconcile Requirements – Version N+1</td>
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<td>Sep</td>
<td>Freeze Release – Version N</td>
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<tr>
<td>Oct</td>
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<td>Nov</td>
<td>Complete Product Acceptance Test (PAT) Release – Version N</td>
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<td>Dec</td>
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<td>Jan</td>
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<td>Feb</td>
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<td>Feb</td>
<td>Declare End of Life for Release – Version N-2</td>
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<tr>
<td>Feb</td>
<td>Complete PDR – Version N+1</td>
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</table>
Annually between 4 and 6 acquisition programs are “shadowed” in terms of engineering workflows…

– **Build bridges** between product developers and targeted acquisition engineering orgs

– **Learn workflows** and actual requirements of targeted org

– Key roles in product VV&QA (Verification, Validation, & Quality Control)
  
  ➢ **Build computational baselines**
  
  ➢ **Build archive of validation cases** (VERY big deal)
Examples of Shadow-Ops Projects

**SO2010-1:** STUAS Flight Certification

**SO2009-4:** CH-47 Advanced Rotor Assessment

**SO2009-5:** AV-8B Tail Aero-Structure Interaction

**SO2010-4:** E-2D Power effects
Welcome to CREATE

The Computational Research and Engineering Acquisition Tools and Environments (CREATE) program is designed to improve the DoD acquisition process by developing and deploying three sets of advanced computational engineering design tools for acquisition programs: (1) military aircraft design, (2) military ship design, and (3) RF antenna design and integration with platforms.

The military aircraft design project will develop a design optimization tool that can simulate unsteady, separated flow, initially for individual aircraft components and ultimately for an entire aircraft. The military ship design project will develop and deploy accurate physics-based models for Navy vessels that address three key capabilities: ship shock response, hydrodynamics, and design space exploration for concept design. The RF antenna design project will build an efficient electromagnetic design code that incorporates modern physics and computational algorithms for high performance computers. This new generation of computational design tools will enable acquisition system engineers to rapidly produce optimized designs for complete systems and make better design decisions than has been possible with prior design tools.

Present acquisition programs largely follow a "build, test and break, fix, build..." methodology. This results in late discovery of design flaws, immature technologies issues, and system integration problems, resulting in costly rework and redesign that contribute substantially to cost overruns and schedule delays. Optimized engineering designs developed early in the acquisition process using the CREATE tools will substantially reduce costs, shorten schedules, increase design and program flexibility and agility, and, among all, improve acquisition program performance by reducing design flaws, developing sound engineering designs quickly and flexibly, and beginning the systems integration engineering process much earlier in the acquisition process. CREATE will be a joint program of the Air Force, Army, Navy, and the Office of the Secretary of Defense.

Point of Contact: Dr. Douglass Post, DoD High Performance Computing Modernization Program (HPCMP), 703 612 2206, dougpost@email.hpcmp.mil.
Welcome to the CREATE-AV Software Support Page

CREATE-AV technical support, documentation, tutorials, and discussion forums can be found here. Please choose from the software products below.

Products

Looking for Kestrel or Helios information? Search, discuss, and ask here.
Kestrel Support

Kestrel is the software product produced by the fixed-wing team of the CREATE Air Vehicles project. Its primary purpose is to reduce the cost of acquiring new fixed-wing aircraft by making accurate, timely, and easy-to-use simulations available to every participant in the acquisition process, including early design and contractor partners.

Kestrel is composed of three major pieces:

1. The Kestrel User Interface (KUI) which serves as the main “face” to the user
2. The Kestrel Infrastructure Executive (KIE)
3. The set of components that operate together in a simulation to produce the desired vehicle behavior.

Resources

- **Discuss** - Share your ideas and search for answers on the Kestrel forum.
- **FAQ** - Click to download.
- **Documentation** - Download the Kestrel Users’ Guide.
- **Tutorials** - Click to download.
- **Request Help** - If you are unable to find the answer to your issue using the resources above, send a message to one of our issue coordinators.
Contact Kestrel

Kestrel Issue Form

A Kestrel issue coordinator should respond to you within 5 working days.

Your input here will better help us understand that issue that you are experiencing. Please provide us with your email address, which version of Kestrel you are using, the operating system on which Kestrel is running, and the hardware on which the issue occurs. Additionally, please be as detailed as possible when explaining your issue.

Your Email*

Kestrel Version*

Operating System

Hardware

Statement Of Issue*

Sund
Measures of success for the software products should be **Specific**, **Measurable**, **Actionable**, **Realistic**, and **Time-bound**, or “SMART”.

- CREATE-AV Project has set of validated tech gaps & supporting requirements
- Traceable to targeted defense programs and associated acquisition engineering workforces

Direct measures of impacts to acquisition engineering are valuable, but very difficult to obtain except in an historical sense. This is not useful in terms of “in-progress” software development.

**A “SMART” approach is to track USER ADOPTION, which indirectly measure impacts to acquisition engineering.**
• Transition AV products to targeted DoD acquisition engineering workforce

• Threshold measure
  – Achieve 10% BASELINE two years after product release
  – 35% BASELINE four years after product release
  – 75% BASELINE six years after product release

Specific? Yes

Measurable? Yes (and traceable by product to project strategic goals, targeted acquisition process workflows and organizations)

Actionable? Yes (if numbers don’t hit targets, we can …)

Realistic? Yes

Time-bound? Yes
SUCCESS MEASURES

- Adoption of CREATE-AV Products by service organizations that own responsibility for targeted acquisition processes (see charts below).

### CY2010

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Industry adoption is a highly desirable “stretch goal”, but is not a success threshold (gross estimate of current industry and NASA baseline – right).
SUMMARY

- Identified capabilities that can be delivered by CBE and next generation computer resources to positively impact the acquisition engineering processes and workflows
  - Based on review of DoD acquisition engineering workforce processes and workflows
- Have developed and are implementing plans to deliver highest impact capabilities through ANNUAL product releases
- Early-phase workflows have the greatest potential for long-term positive impact on defense acquisition
  - Ability to generate physics-based decision data in a timely way during conceptual design is paradigm changing
- Sustainment-phase workflows have greatest potential for immediate impact on Warfighters (i.e., during aircraft service-life)
  - Flight clearance, modified/new configuration/loading certification, launch and recovery envelope generation, envelope expansion, mishap investigation, …