Impact of Modeling and Simulation on Rotorcraft Acquisition

Presented by:
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U.S. Army Aviation and Missile Research, Development, and Engineering Center

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AMRDEC ORGANIZATION CHART

AMRDEC is part of the U.S. Army Research, Development and Engineering Command (RDECOM), which has the mission to develop technology and engineering solutions for America’s Soldiers. RDECOM is a major subordinate command of the U.S. Army Materiel Command (AMC). AMC is the Army’s premier provider of materiel readiness — technology, acquisition support, materiel development, logistics power projection, and sustainment — to the total force, across the spectrum of joint military operations. If a Soldier shoots it, drives it, flies it, wears it, eats it or communicates with it, AMC provides it.
Airworthiness: A **Demonstrated Capability** of an Aircraft, Subsystem or Component to **Function** Satisfactorily when used and maintained within **Prescribed Limits**

- Required by law (49 USC 106)
  - Under 14 CFR, FAA does for civil aviation
- Governed by Army Regulation 70-62
- Airworthiness Authority = CG AMCOM

**Principal Products:** Airworthiness Releases, Statements Of Airworthiness Qualification, Airworthiness Impact Statements, Safety of Flight Messages

**What this means to the Aviation Units…**
- It is Safe to Operate and will Perform the Mission when Delivered
- It will Continue to Safely Perform the Mission if Operated Maintained per the Manuals
- Parts and Overhaul work must be per approved sources and standards to Maintain Airworthiness
“Demonstrated Capability”

• Engineering analysis, modeling, and simulation
• Formal inspection, design review, and safety assessment
• Contractor development test
• Component qualification test of performance under specified conditions and duration
• Formal contractor demonstrations
• Government testing
CREATE* Program

- CREATE is a DoD program to develop and deploy multiphysics-based software for engineering design and analysis of:
  - **Air Vehicles (AV)**
    - Aerodynamics, structures, propulsion, control, concept design…
  - **Ships**
    - Shock vulnerability, hydrodynamics, concept design
  - **Radio Frequency (RF) Antennas**
    - RF Antenna electromagnetics and integration with platforms
  - **Mesh and Geometry (MG) Generation**
    - Rapid generation of mesh and geometry representations

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

* Computational Research and Engineering Acquisition Tools and Environments
CREATE Software 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
  - **Firebolt** - Module for propulsion systems in fixed and rotary-wing air vehicles

• **Ships—CREATE Ships**
  - **RDI** - Rapid Design and Synthesis Capability
  - **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—CREATE RF**
  - **SENTRI** - Electromagnetics antenna design integrated with platforms

• **Meshing and Geometry—CREATE MG**
  - **Capstone** - Components for generating geometries and meshes
High Fidelity Multi-Disciplinary Analysis Tool for Fixed-Wing Aircraft

- Verify design prior to key decision points (and prior to fabrication of test articles or full-scale prototypes)
- Plan/rehearse wind-tunnel and full-scale flight tests (more bang per test dollar)
- Evaluate planned (or potential) operational use scenarios
- Perform flight certifications (e.g., airworthiness, flight envelope expansion, mishap investigation, etc.)
- Generate response surfaces usable in DaVinci, flight-simulators, and other environments that require real-time access to performance data.

Introducing

HPC CREATE™-AV

Full Aircraft Design Analysis and Testing via High Fidelity Physics-Based Simulation

Key Disciplines
- Aerodynamics NS solvers w/ full suite of BC’s & turbulence models
- Structural Dynamics Modal models or FEA for aero-structure interaction
- Flight Control Systems: Control surface movement via deforming geometry or overset
- Operational Conditions: High-g turn maneuvers, store separation events, take-off/land conditions, refueling events, formation flight, etc.
- Propulsion: Options for 0-D engine deck for unsteady propulsion effects, or direct engine simulation including inlet & rotating machinery, nozzle, and moving walls

Key Technologies
- User interface and web access to Kestrel at HPCMP Defense Supercomputing Centers
- Common Scalable Infrastructure (CSI) to enable integration of new components, collaborations, and long-term software maintenance
- Dual Mesh Paradigm & Adaptive Mesh Refinement
- Sys ID model construction & application tools

Want to request access to Kestrel? go to http://create.hpc.mil
Rotorcraft – multi-disciplinary, physics-based software product developed to enable full-vehicle design analysis and testing via high-fidelity simulation

✓ Fuselage and rotors
✓ Multiple rotors (arbitrary configurations, for example conventional main rotor & tail-fan; tandem rotors; tiltrotor; tiltwing; quad tiltrotor; etc.)

Kestrel and Helios use a Common Scalable Infrastructure (CSI), enabling
- Shared components
- Reduced development cost
- Software maintenance over time
- Collaboration with US Industry, Other Federal Agencies, and Academia

Introducing HPC CREATE™-AV

A multi-disciplinary, physics-based software product developed to enable rotorcraft design analysis and testing via high-fidelity simulation.

Capability Summary
- Full vehicle (fuselage and rotors)
- Multiple rotors
- Arbitrary shaft angles
- Prescribed maneuver w/ tight coupling of rotor aero-structural dynamics
- Store carriage and release

Key Technologies
- User Interface and web access to Helios at HPCMP Defense Supercomputing Centers
- Common Scalable Infrastructure (CSI) to enable development of multi-disciplinary components, collaborations, and long-term software maintenance
- Automatic Adaptive Mesh Refinement (AMR)
- Dual-mesh paradigm
- Significant flow solver innovations (automation, accuracy, and efficiency)
- Aero-structural coupling for rotor dynamics
- 3-D FEM Structural Dynamics

Want to request access to Helios? go to http://create.hpc.mil
Projects

- MH-60M Flight Simulation Database (2010)
- Performance Validation of CH-47 Rotor Blade (2011)
- OH-58 Tail Loading (2013)
- UH-60 In-Ground Effects (2013)
- Dynamic Hub and Pitch Link Loads on the CH-47 (2014)
- Tail Rotor Effectiveness During High/Hot Low Speed Turns (2014)
- Modeling and Simulation Effort to Support the CH-47 Block II Program – ACRB Flight Performance (2014-15)
Director

Executive Officer

Deputy Director

Program Support Assistant

Associate Director of Programs

Aviation Systems

Cargo

Apache

Non Standard Rotary Wing

Special Ops

Utility

UAS

Acquisition Business Mgr (AE-Z)

Maintenance /Sustainment Engineering (AE-M)

Associate Director of Technology

Aeromechanics

Structures and Materials

Propulsion

Mission Equipment

SED Aviation Division (RDMR-BAV)

Aviation Engineering Directorate
Bldg 4488, Redstone Arsenal
Huntsville, AL 35898-5000
RDMR-AE
Phone: 256-313-8400
Mission Capability Process

**Current Process**

- **Flight Test Performance Data**
- **Data Analysis**
- **Rotor Performance Map**
- **HELOP**
- **Mission Capability** (e.g. Payload/Range)

**Benefits**

- Basis for predicting impact of future modifications
- Supports Data Analysis
- Optimized flight test matrix

*High fidelity CFD codes accurately predict complex rotor blade performance*
### CH-47 Performance Model Development Timeline

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<td>Shadow*: H47 &amp; ACRB - Tool Assessment (Hover)</td>
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* Shadow – Collaborative with Boeing,  ** STAR – Strategic TARgeting Project

** Science and Technology ** Systems Acquisition

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* Shadow – Collaborative with Boeing,  ** STAR – Strategic TARgeting Project

** Science and Technology ** Systems Acquisition
**Task 1: Isolated Rotor Performance**

**Objective**
Demonstrate accuracy in predicting isolated rotor performance for the Legacy and ACRB blades with the Helios Engineering Model.

**Software Basis**
Helios v4.0

**Evaluation Data**
Boeing Wind Tunnel (WT) Report: D724-10458-1

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**Run Matrix**

<table>
<thead>
<tr>
<th>Speed Sweep</th>
<th>Hover</th>
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<tbody>
<tr>
<td>Thrust</td>
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**Results**

<table>
<thead>
<tr>
<th>Lines: WT Data</th>
<th>Symbols: Helios</th>
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<tr>
<td>Legacy Blade</td>
<td>ACRB Blade</td>
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**Schedule**

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<tr>
<th>Task ID</th>
<th>Task Name</th>
<th>Q1 14</th>
<th>Q2 14</th>
<th>Q3 14</th>
<th>Q4 14</th>
<th>Q1 15</th>
<th>Q2 15</th>
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* Updated based on lessons learned from tasks 2, 3, & 4.
Objective
Demonstrate capability to predict full-scale, tandem helicopter performance with the Helios Engineering Model.

Software Basis
Helios v4.0

Evaluation Data
Legacy CH-47 Flight Performance Model (FPM)

Schedule

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<th>Task ID</th>
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Results

Run Matrix

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<th>Thrust</th>
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Power

Speed

- FPM
- Helios
Objective
Demonstrate accuracy in predicting mission capability for the Legacy CH-47 helicopter using Helios Engineering Model based rotor map.

Software Basis
Helios v4.0

Evaluation Data
Legacy CH-47 Flight Performance Model (FPM)

Schedule

Results

Run Matrix

Thrust

Speed

Power

Speed
CH-47 Mission Analysis
Mission Capability Process

Flight Test Performance Data

Data Analysis

Rotor Performance Map

• Power Available
• Fuel Flow
• Airspeed Limits
• Etc.

HELOP

Mission Capability
(e.g. Payload/Range)

Modified Process

Helios Performance Data
CH-47 Mission Analysis
Sample Missions

SPEC MISSION II

SPEC MISSION III

SPEC MISSION VII

SPEC MISSION IX
Task 4: CH-47 w/ACRB Blades
Mission Analysis Prediction

Objective
Predict mission performance for the CH-47 helicopter w/ACRB blades using Helios Engineering Model based rotor map.

Software Basis
Helios v4.0

Evaluation Data
Will compare with flight test data when available.

Schedule

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Run Matrix

Summary of Predictions
- Initial 2012 ACRB prediction based on SME experience (not a repeatable process)
- Current 2015 ACRB prediction based on modeling and simulation (repeatable process)
- 2015 ACRB prediction is slightly more conservative at higher thrusts compared to 2012.
ACRB Status Summary

- Technical effort is complete. Reporting is in progress.
  - Task 1: Isolated Rotor Performance Report (completed Apr 2015)
- Interaction with Boeing through bi-weekly telecom has been invaluable.
- Isolated Legacy and ACRB models correlated to wind tunnel test data.
- CH-47 model with legacy blades correlated to flight test based Flight Performance Model (FPM).
- Utilized CH-47 model w/ACRB to predict mission capability.
- Demonstrated a repeatable process utilizing Helios to predict Chinook flight performance.
Future Direction for CH-47 Support

**CH-47 Model**

Model Details:
- Helios v4.0
- Flexible Blades
- Rigid Fuselage
- Ideal Engine
- Ideal Flight Control Laws
- Decoupled Trim Process

Completed Runs:
- Legacy: 3 GW * 10 KTAS
- ACRB: 3 GW * 10 KTAS

**Model Ready For Use**

**Expand ACRB Run Matrix**
- Additional Gross Weights (GW)
- Additional Referred Rotor Speeds (Nr)
- Additional Flight Speeds (KTAS)
- **Payoff:** Improved off-mission capability assessment.

**Additional Block II Modeling**
- Examine other Block II features
  (103% Nr, LCTA Schedule, etc.)
- **Payoff:** Block II mission capability assessment.

**Upgrade to Helios v5.0**
- Coupled Trim Process (faster turnaround)
- Additional Solver Options (improved accuracy)
- **Payoff:** Software performance enhancements and future model supportability.

**Blade Loads**
- Examine Blade Loads (Level Flight Conditions Only)
- May need more accurate solutions
- **Payoff:** Impact flight loads analysis.

**Today**

Additional Model and Process Development Required
Current/Future Projects

- **Current:** Engineering Analysis for Engine/Airframe Integration of ITEP
  1. **Black Hawk Tail Rotor:** Recently a Helios tail rotor model (in-plane rotor with blades spaced by 90 degrees) was developed for the Black Hawk helicopter. This model will be leveraged to evaluate a new rigging procedure proposed by the PM to take advantage of increased engine power available. Current/future flight test data will be available for this effort.
  2. **Apache Tail Rotor:** Boeing’s Apache attack helicopter is equipped with a teetering, stacked, scissored (i.e. the blades are not spaced by 90 degrees) tail rotor configuration. Recently, Boeing has re-designed the tail rotor blade to accommodate an increase in available power. In collaboration with Boeing, this effort will use Helios to validate the re-design and provide a high fidelity tail rotor model for integration into Boeing’s existing full-configuration aircraft model.
  3. **Engine Modeling:** Evaluate ITEP turboshaft engine/airframe integration, to include representative drive system dynamics and a core engine model, to emulate system torsional stability, rotor droop and overshoot for the AH-64 and UH-60 platforms. Existing flight test data will be available for this effort.

- **Future:**
  - Development of a Gray Eagle Model for Airworthiness Assessments (Partially Funded)
  - Engineering Analysis for Dynamic Component Loads-Based Steady State Flight Envelope Determination (Proposal)
Black Hawk Tail Rotor

UH-60 Tail Rotor Effectiveness

Context: The Army is studying the impact of increasing engine power on legacy rotorcraft. An increase in power available will allow the rotorcraft to hover at higher/hotter/heavier conditions. However, a consequence of this increased capability is that the tail rotor may not have sufficient thrust to maintain directional control of the helicopter.

Objective: Apply Engineered Resilient Systems (ERS) resources and HPCMP CREATE™-AV Helios software to simulate the flow about a UH-60 helicopter to assess directional control for conditions of interest to the Army. Investigate various levels of fidelity to ascertain appropriate engineering models.

Impacts
- Developed UH-60 aircraft models with various levels of fidelity to determine tail rotor effectiveness with respect to a potential engine upgrade program.
- Developed a universal process utilizing modeling and simulation (M&S) data to assess directional control margins.
- Demonstrated the ability to utilize M&S, along with other sources of data, to reduce risk associated with future acquisition decisions.
Current/Future Projects

- **Current:** Engineering Analysis for Engine/Airframe Integration of ITEP

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  3. **Engine Modeling:** Evaluate ITEP turboshaft engine/airframe integration, to include representative drive system dynamics and a core engine model, to emulate system torsional stability, rotor droop and overshoot for the AH-64 and UH-60 platforms. Existing flight test data will be available for this effort.

- **Future:**
  - Development of a Gray Eagle Model for Airworthiness Assessments (Partially Funded)
  - Engineering Analysis for Dynamic Component Loads-Based Steady State Flight Envelope Determination (Proposal)
Apache attack helicopter is equipped with a teetering, stacked, scissored tail rotor configuration.

Picture from Wikimedia Commons, the free media repository.
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