*Presented to:*

**18th Annual NDIA Systems Engineering Conference**

# *Impact of Modeling and Simulation on Rotorcraft Acquisition*



AMRDEC

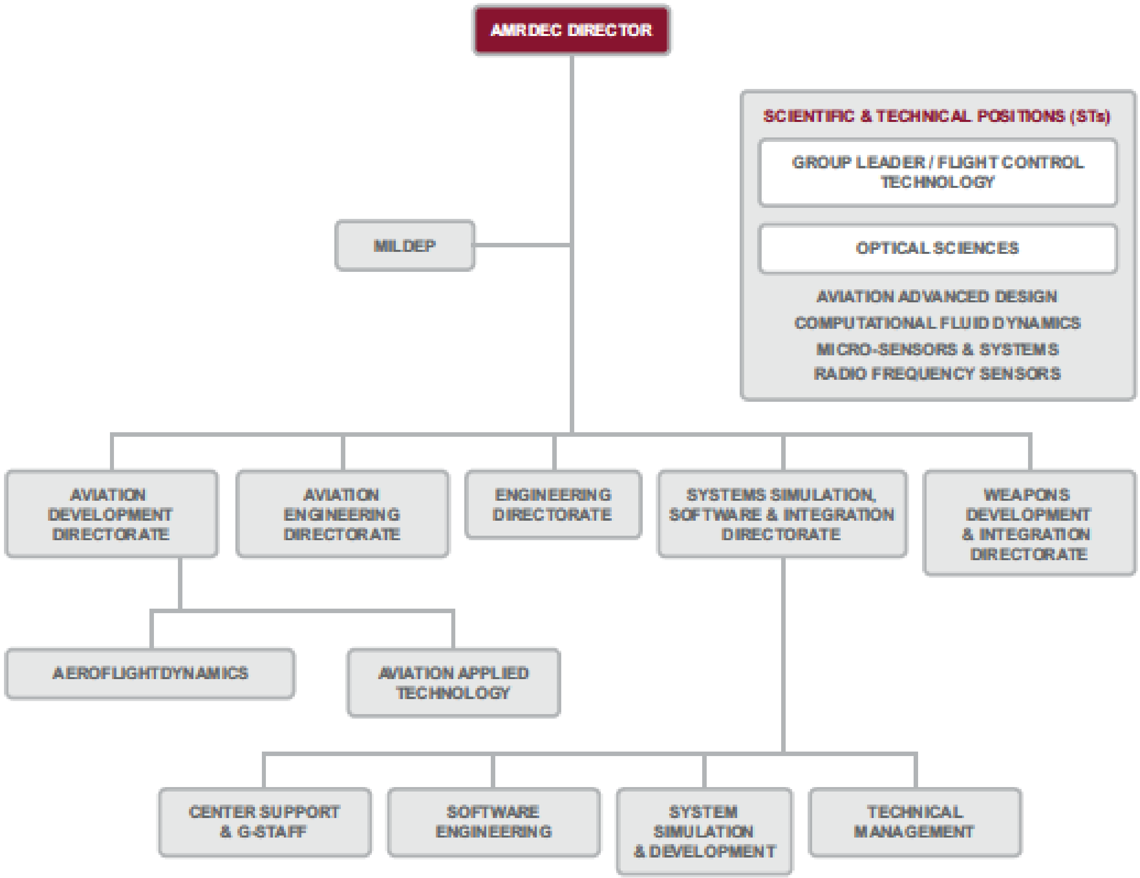
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

*Presented by:*

**Dr. Marty Moulton**
**Chief, Simulation and Aerodynamics Branch**
**U.S. Army Aviation and Missile Research, Development, and Engineering Center**

**Date: 28 October 2015**

# AMRDEC Org Chart




## CHAIN OF COMMAND


## 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

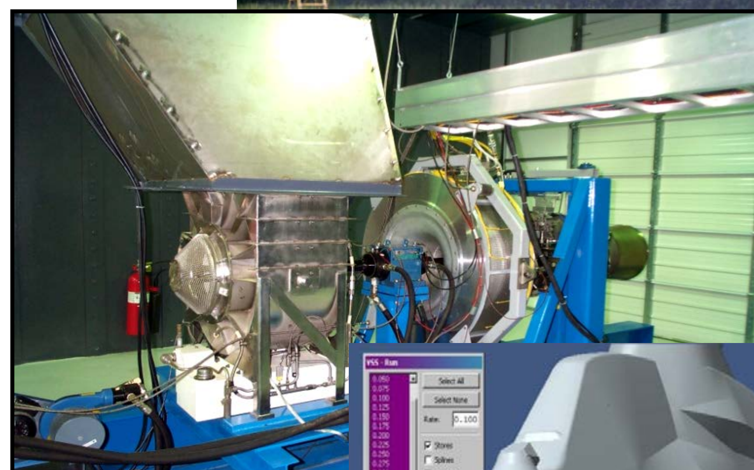
- Required by law (49 USC 106)
  - Under 14 CFR, FAA does for civil aviation
- Governed by Army Regulation 70-62
- Airworthiness Authority = CG AMCOM

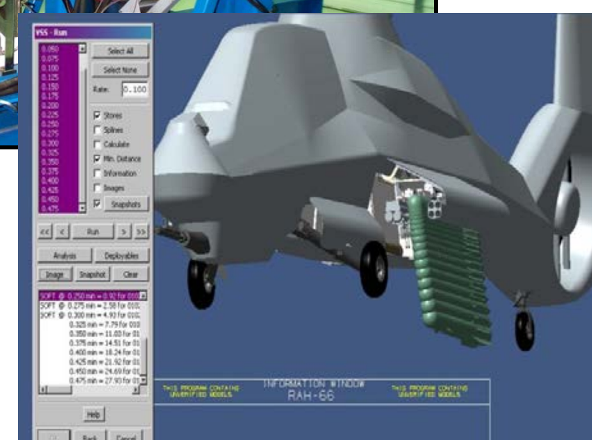
## Principal Products: Airworthiness Releases, Statements Of Airworthiness Qualification, Airworthiness Impact Statements, Safety of Flight Messages

**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"



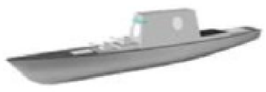


- Engineering analysis, modeling, and simulation
- Formal inspection, design review, and safety assessment
- Contractor development test
- Component qualification test of performance under specified conditions and duration
- Formal contractor demonstrations
- Government testing

# CREATE* Program

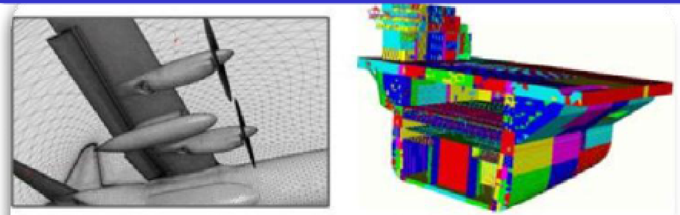
- **CREATE is a DoD program to develop and deploy multiphysics-based software for engineering design and analysis of:**
- **Air Vehicles (AV)**
  - Aerodynamics, structures, propulsion, control, concept design…
- **Ships**
  - Shock vulnerability, hydrodynamics, concept design
- **Radio Frequency (RF) 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***



Design concept


Seakeeping and resistance


Shock vulnerability


Aircraft and aircraft carrier meshes

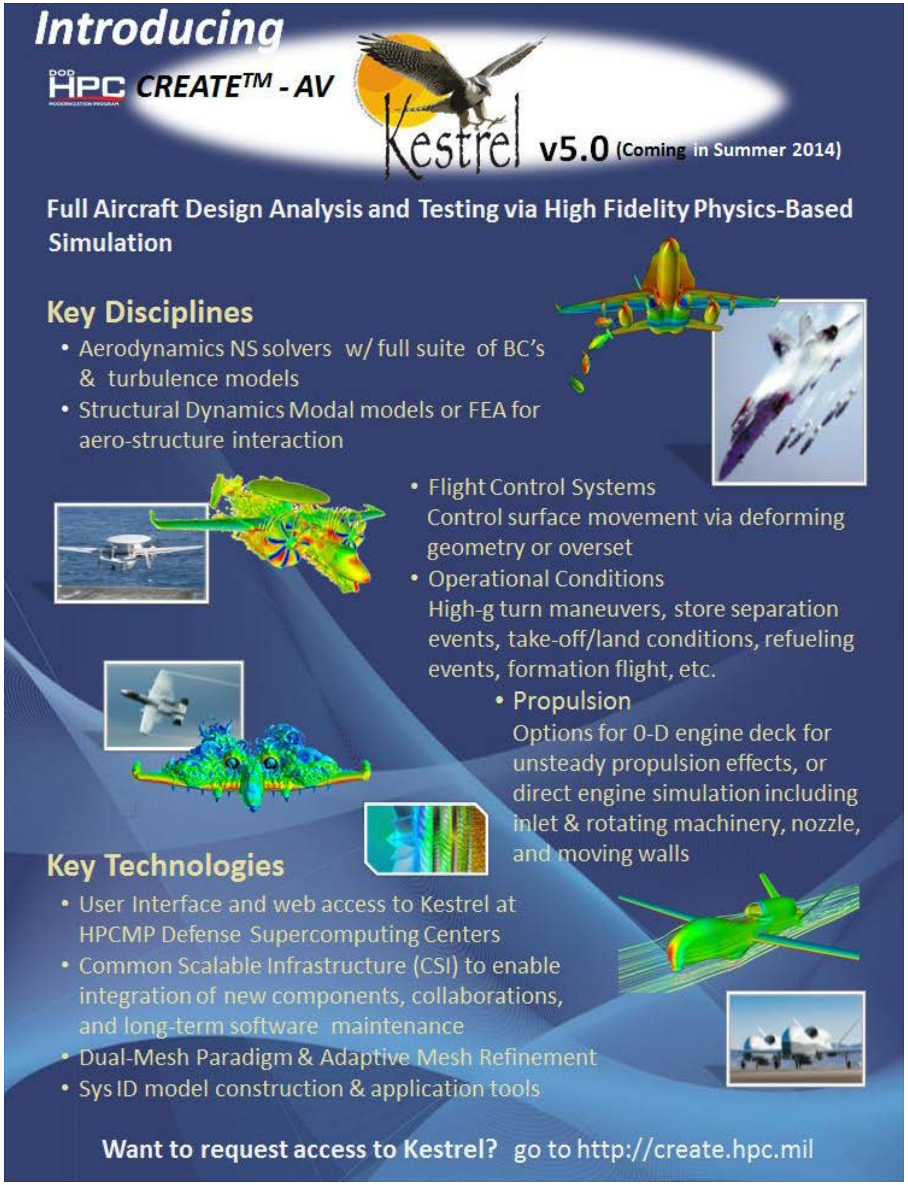

Military platforms with antennas

*** Computational Research and Engineering Acquisition Tools and Environments**

- **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.**



# CREATE-AV Helios

**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**

# Projects

- CH-47 Advanced Rotor Blade Design (2009)
- MH-60M Flight Simulation Database (2010)
- Performance Validation of CH-47 Rotor Blade (2011)
- OH-58D Rotor Power Effects (2012)
- OH-58 Tail Loading (2013)
- CH-47 Installed Rotor Performance (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)

# AED Org Chart

- **Director**
  - *Executive Officer*
  - *Program Support Assistant*
  - **Deputy Director**
    - **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

# Aeromechanics Division

- Associate Director of Technology
  - *Aeromechanics*
  - *Structures*
  - *Propulsion*
  - *Mission Equipment*

**Aeromechanics Division Chief**

**Chief Engineer**

**Flight Performance & Mass Properties Branch**
- Flight Performance AH/OH/Utility Team
- Flight Performance CH/FW/UAS Team
- Mass Properties Team

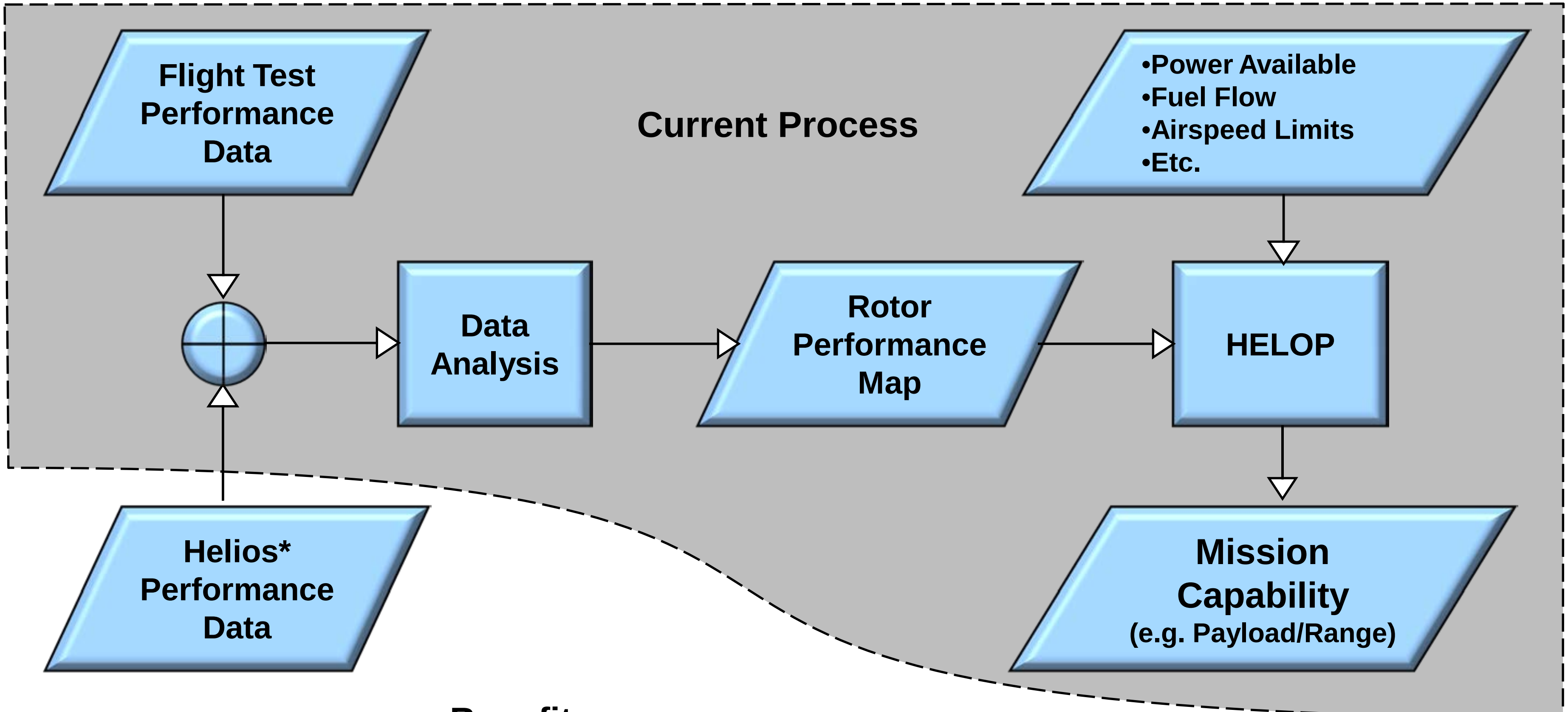
**Flight Controls & Handling Qualities Branch**
- Handling Qualities AH/FW/OH/UAS Team
- Handling Qualities Cargo/Utility Team
- Flight Controls Technology Team

**Simulation & Aerodynamics Branch**
- Simulation Team
- Aerodynamics Team

**Dynamics Branch**
- AH/OH/UAS/MS Team
- Cargo/Utility/FW Team
- CBM Vibration Technology Team
- CBM Data Analysis Team

# Mission Capability Process





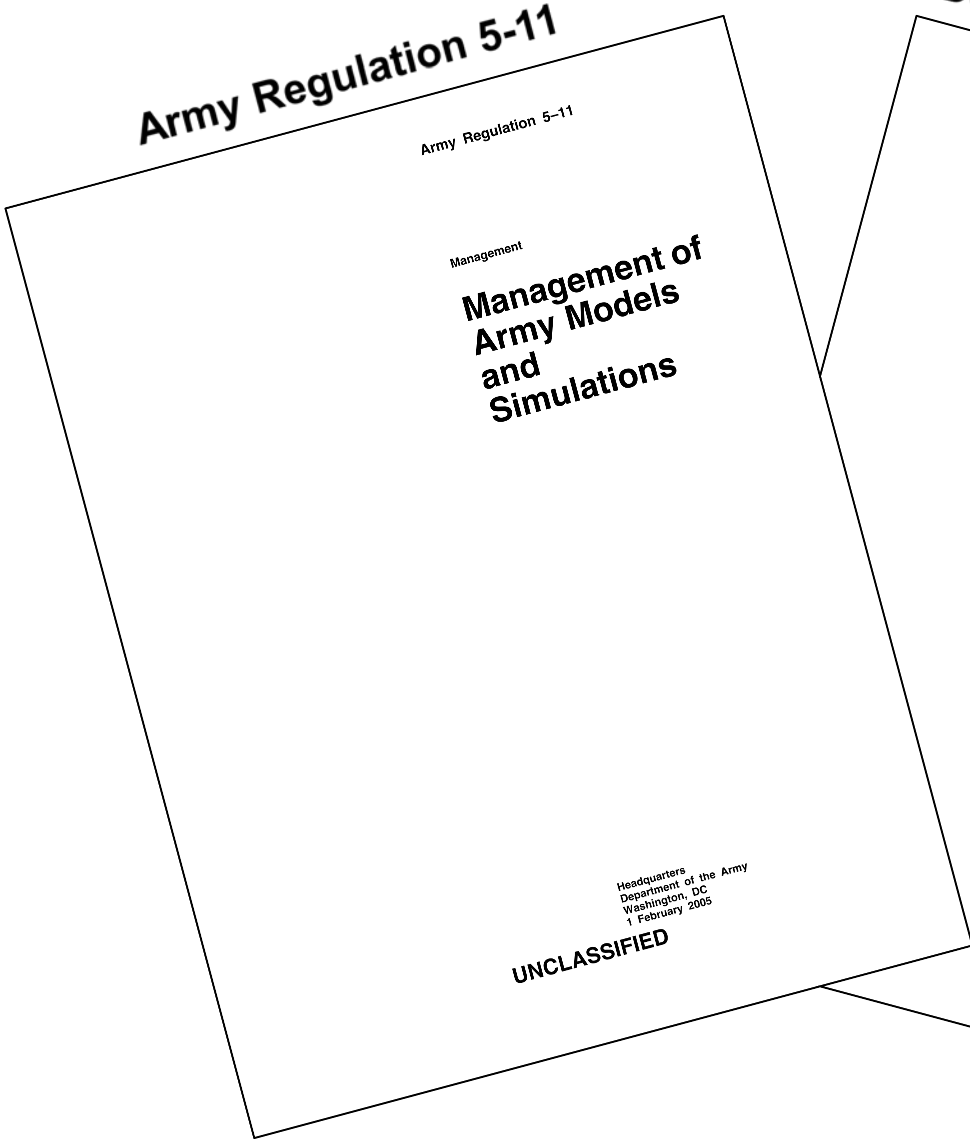

**Benefits**

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

*** High fidelity CFD codes accurately predict complex rotor blade performance**

# Verification, Validation, and Accreditation (VV&A)

Army Regulation 5-11



Army Regulation 5–11

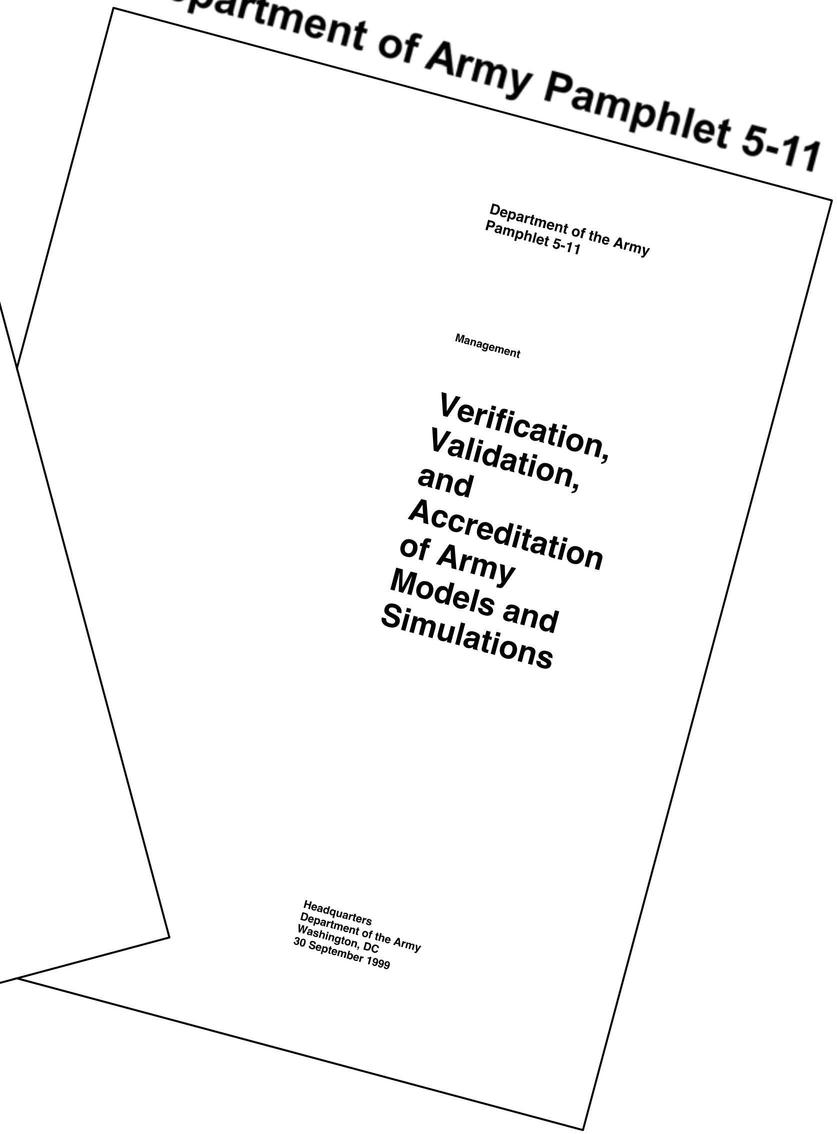
Management

Management of Army Models and Simulations

Headquarters
Department of the Army
Washington, DC
1 February 2005

UNCLASSIFIED

Department of Army Pamphlet 5-11



Department of the Army
Pamphlet 5-11

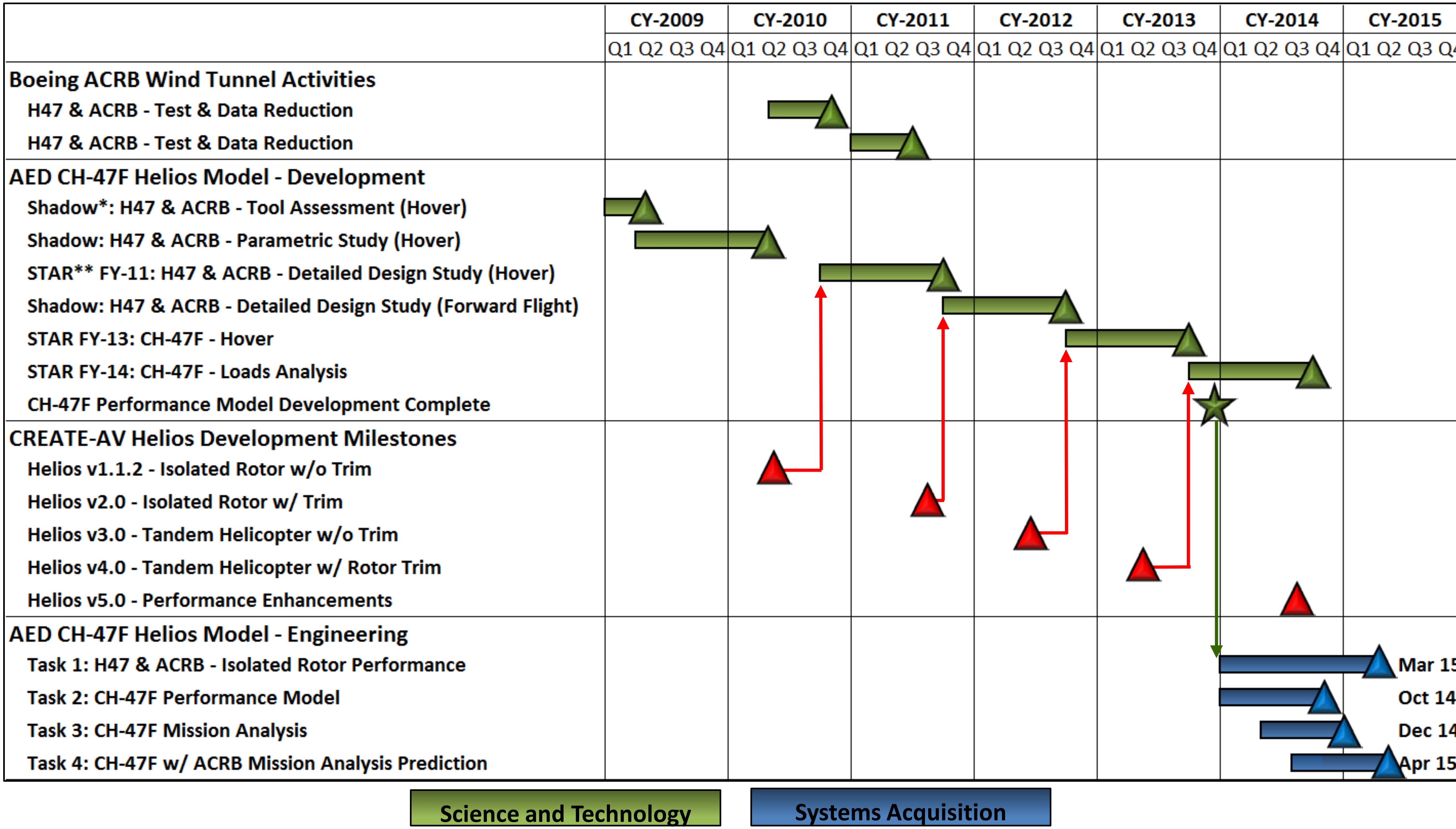
Management

Verification, Validation, and Accreditation of Army Models and Simulations

Headquarters
Department of the Army
Washington, DC
30 September 1999

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

# CH-47 Performance Model Development Timeline




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

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

# Task 1: Isolated Rotor Performance



## Objective

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

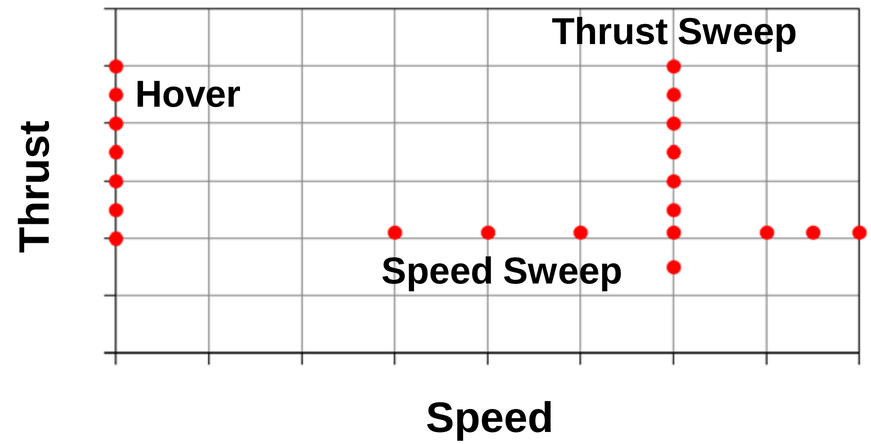
## Software Basis

Helios v4.0

## Evaluation Data

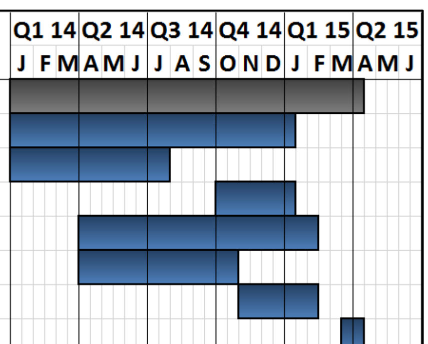
Boeing Wind Tunnel (WT) Report: D724-10458-1

## Run Matrix



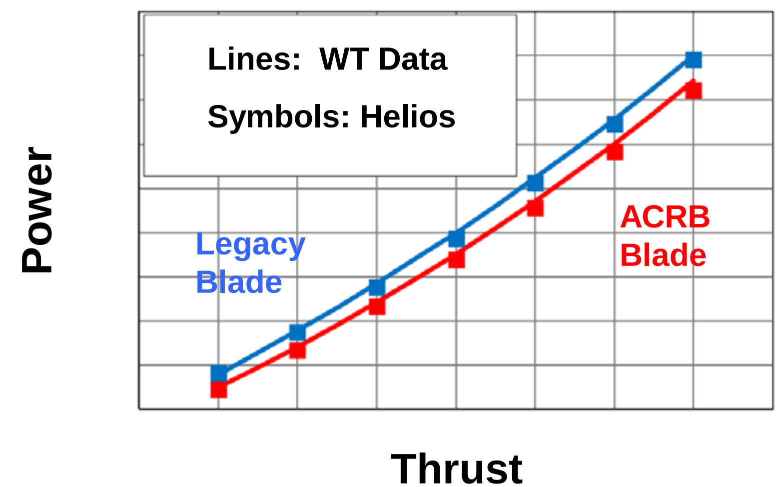

## Schedule

| Task ID | Task Name |
|---|---|
| 1 | Isolated Rotor Performance |
| 1.1 | Legacy Blade |
| 1.1.1 | Initial Model Parameters |
| 1.1.2 | Updated Model Parameters* |
| 1.2 | ACRB Blade |
| 1.2.1 | Initial Model Parameters |
| 1.2.2 | Updated Model Parameters* |
| 1.3 | Report |




* Updated based on lessons learned from tasks 2, 3, & 4.

## Results



# Task 2: CH-47 Performance Model



## Objective

Demonstrate capability to predict full-scale, tandem helicopter performance with the Helios Engineering Model.

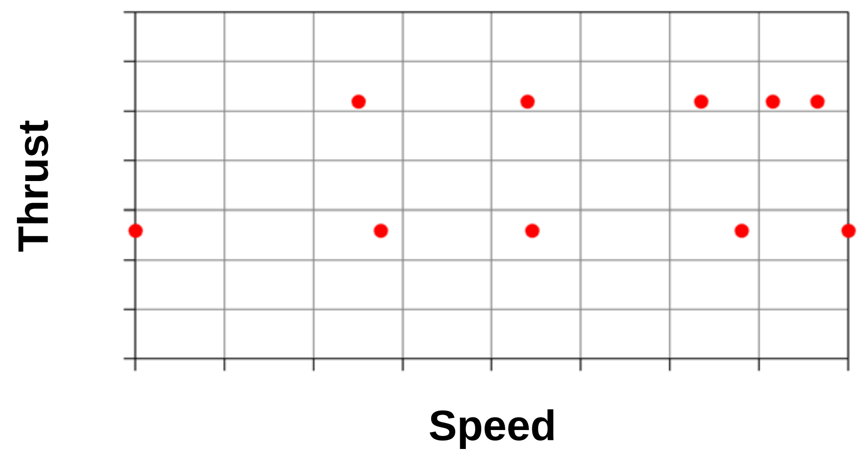
## Software Basis

Helios v4.0

## Evaluation Data

Legacy CH-47 Flight Performance Model (FPM)

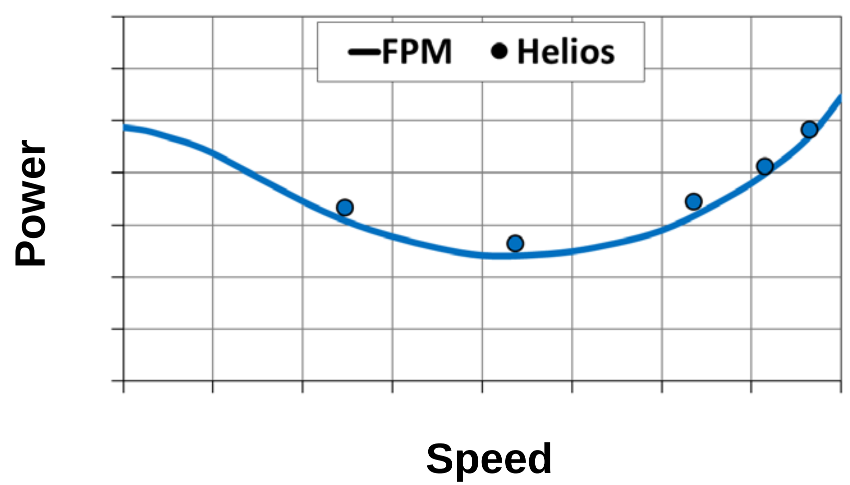
## Run Matrix




## Schedule

| Task ID | Task Name | Q1 14 | Q2 14 | Q3 14 | Q4 14 | Q1 15 | Q2 15 |
|---|---|---|---|---|---|---|---|
| | | J F M | A M J | J A S | O N D | J F M | A M J |
| 2 | CH-47F Performance Model | | | | | | |
| 2.1 | Model Preparation | | | | | | |
| 2.2 | Speed Sweep - Mid Gross Weight | | | | | | |
| 2.3 | Speed Sweep - High Gross Weight | | | | | | |
| 2.4 | Report | | | | | | |

## Results



# Task 3: CH-47 Mission Analysis

## Objective

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

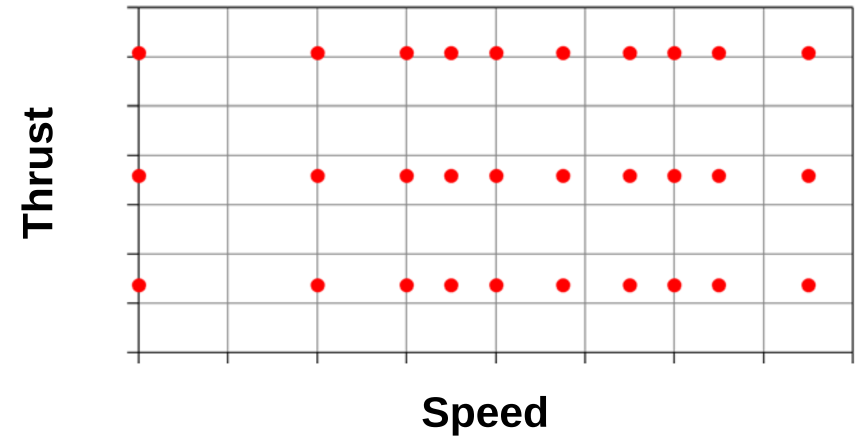
## Software Basis

Helios v4.0

## Evaluation Data

Legacy CH-47 Flight Performance Model (FPM)

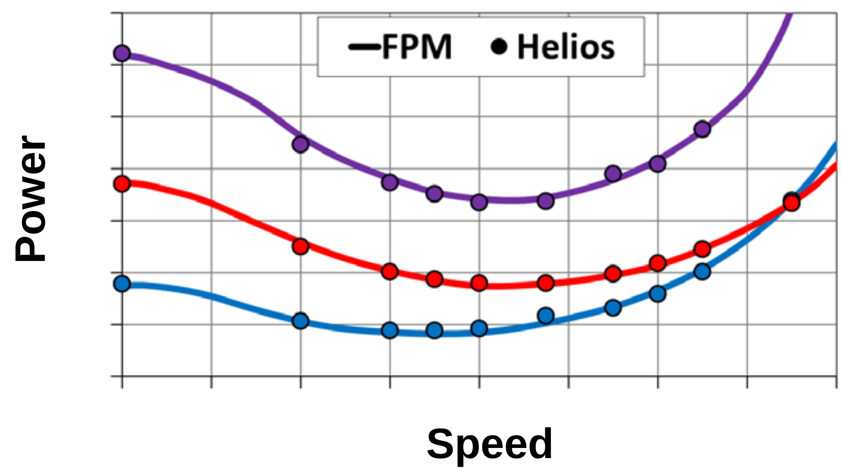
## Run Matrix




## Schedule

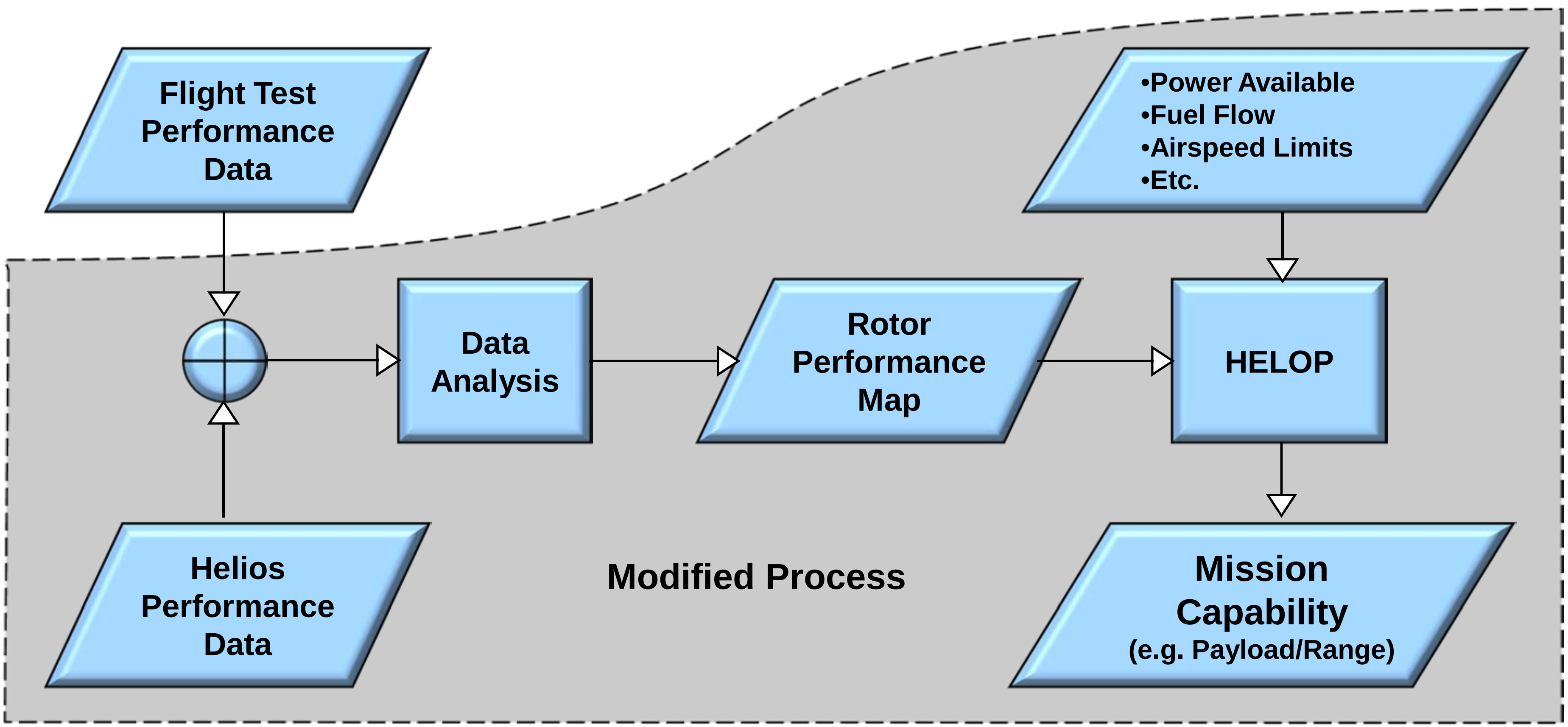
| Task ID | Task Name | Q1 14 | Q2 14 | Q3 14 | Q4 14 | Q1 15 | Q2 15 |
|---|---|---|---|---|---|---|---|
| | | J F M | A M J | J A S | O N D | J F M | A M J |
| 3 | CH-47F Mission Analysis | | | | | | |
| 3.1 | Thrust Sweep - Hover | | | | | | |
| 3.2 | ~~Thrust Sweep - 200 ft/min VROC~~ | | | | | | |
| 3.3 | Speed Sweep - High Gross Weight | | | | | | |
| 3.4 | Speed Sweep - Mid Gross Weight | | | | | | |
| 3.5 | Speed Sweep - Low Gross Weight | | | | | | |
| 3.6 | Perform Mission Analysis | | | | | | |
| 3.7 | Report | | | | | | |

## Results



# CH-47 Mission Analysis

## Mission Capability Process

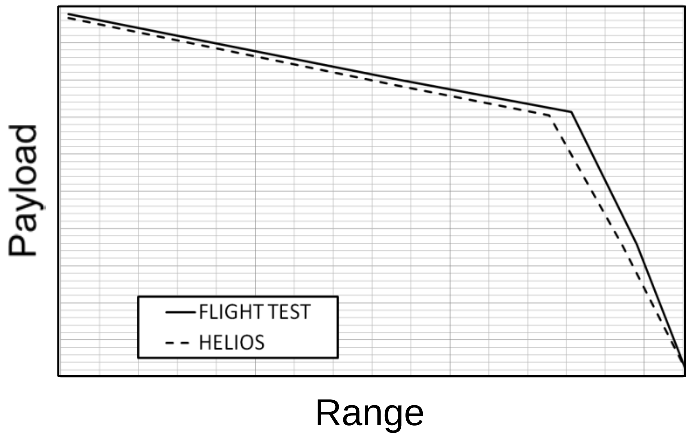


# CH-47 Mission Analysis
## Sample Missions

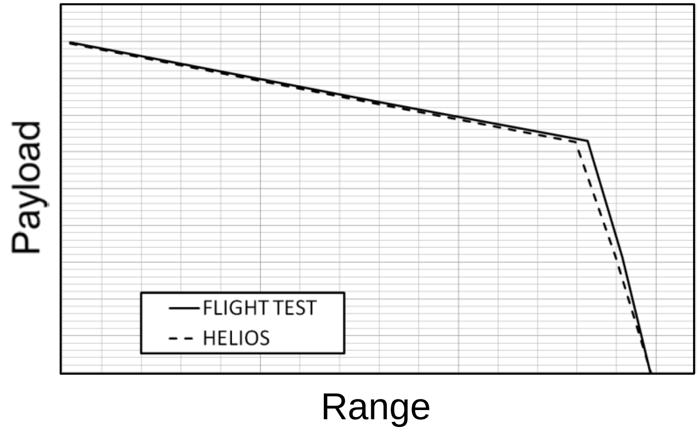


### SPEC MISSION II

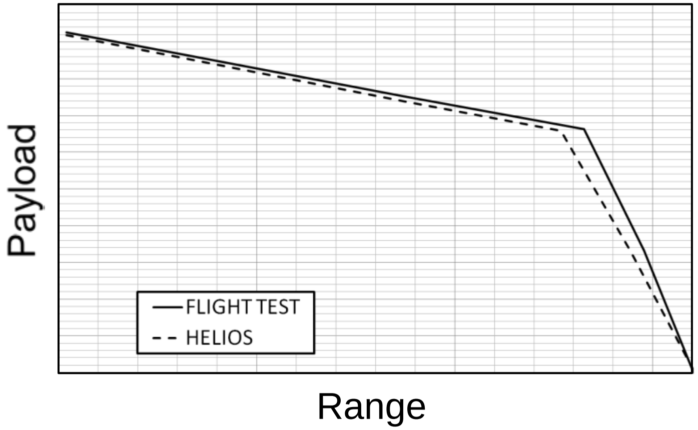

### SPEC MISSION III




### 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.

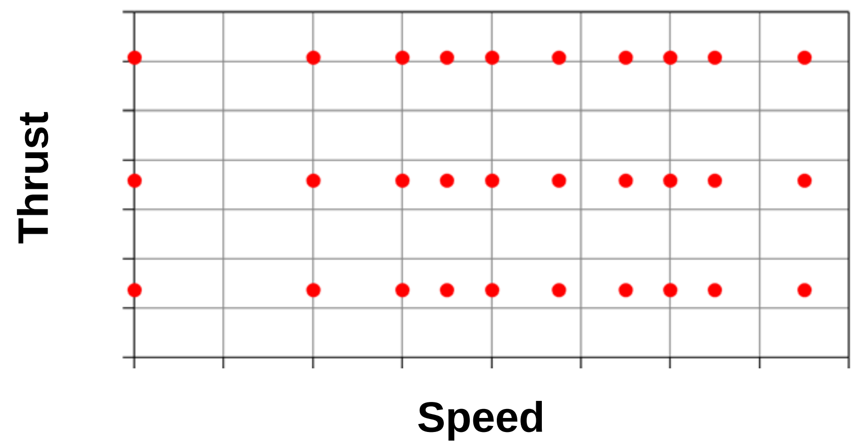
## Software Basis

Helios v4.0

## Evaluation Data

Will compare with flight test data when available.

## Run Matrix




## Schedule

| Task ID | Task Name | Q1 14 | Q2 14 | Q3 14 | Q4 14 | Q1 15 | Q2 15 |
|---|---|---|---|---|---|---|---|
| | | J F M | A M J | J A S | O N D | J F M | A M J |
| 4 | CH-47F w/ ACRB Mission Analysis | | | | | | |
| 4.1 | Thrust Sweep - Hover | | | | | | |
| 4.2 | ~~Thrust Sweep - 200 ft/min VROC~~ | | | | | | |
| 4.3 | Speed Sweep - High Gross Weight | | | | | | |
| 4.4 | Speed Sweep - Mid Gross Weight | | | | | | |
| 4.5 | Speed Sweep - Low Gross Weight | | | | | | |
| 4.6 | Perform Mission Analysis | | | | | | |
| 4.7 | Report | | | | | | |

## 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)
  - Task 2: CH-47 Performance Model Report (completed Jul 2015)
  - Task 3: CH-47 Mission Analysis Report (completed Aug 2015)
  - Task 4: CH-47 w/ACRB Mission Analysis Report (completed Aug 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.
- <u>Demonstrated a repeatable process utilizing Helios to predict Chinook flight performance.</u>

# Future Direction for CH-47 Support



**Today**

**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.

**Additional Model Development Required**

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

**Additional Model and Process Development Required**

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

# Current/Future Projects



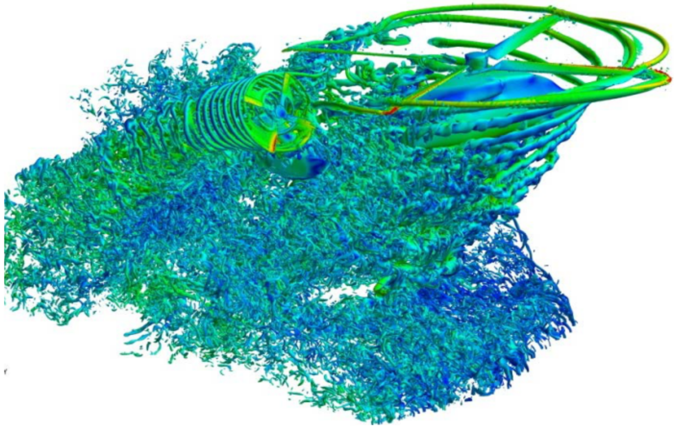
- **Current: Engineering Analysis for Engine/Airframe Integration of ITEP**
  1. Black Hawk Tail Rotor: Recently a Helios tail rotor model (in-plane rotor with blades spaced by 90 degrees) was developed for the Black Hawk helicopter. This model will be leveraged to evaluate a new rigging procedure proposed 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)**

Performed by Army/AMRDEC

# 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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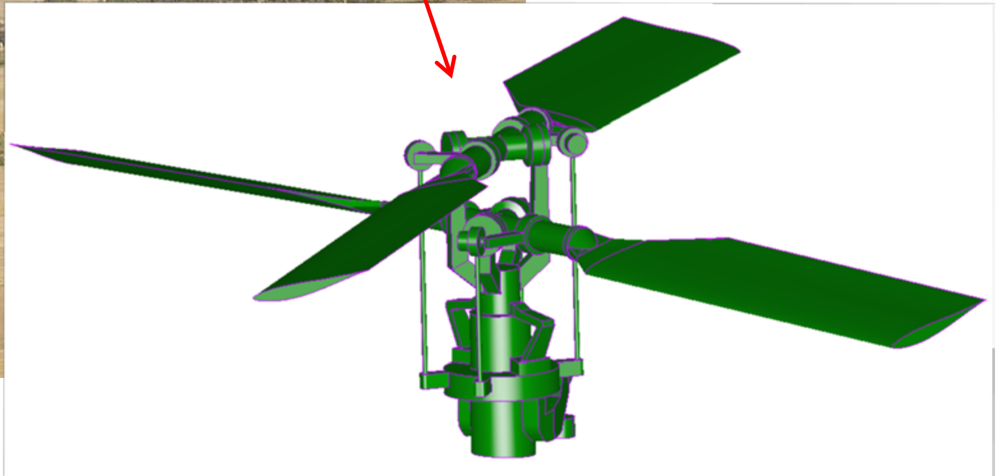
# Apache Tail Rotor



Apache attack helicopter is equipped with a teetering, stacked, scissored tailrotor configuration



**Picture from Wikimedia Commons, the free media repository.**

# Current/Future Projects

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