National Aeronautics and Space Administration

Fundamental Aeronautics Program

Subsonic Rotary Wing Project

SRW Aeromechanics Overview/UH-60 Airloads Wind Tunnel Test Summary

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Aeromechanics Discipline

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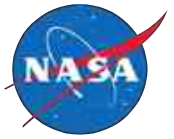
www.nasa.gov

Agenda



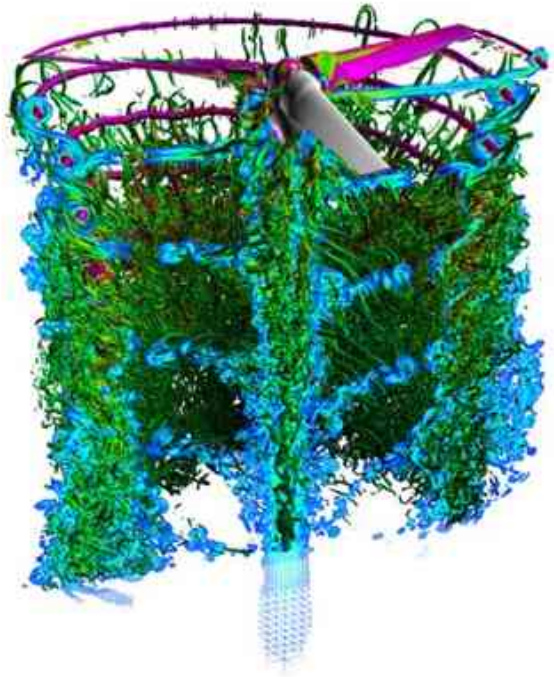
- Aeromechanics Overview
  - Aeromechanics Objectives and Task Areas
  - Recent Accomplishments
  - Aeromechanics Near-Term Plans

- UH-60 Airloads Wind Tunnel Test Summary

SRW Aeromechanics

Objectives

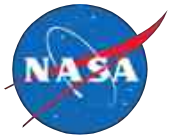
- Advance the understanding of phenomena in aerodynamics, dynamics, and active control of rotorcraft
- Develop and validate first-principles tools
- Acquire data for tool validation from small- and large-scale testing of existing and novel rotorcraft configurations



Isolated tiltrotor in hover (OVERFLOW)

UH-60A Airloads Test

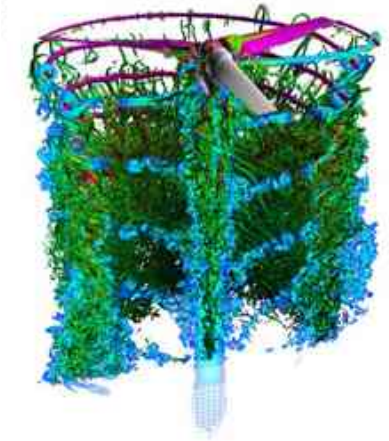
Aeromechanics Task Areas



- Aeromechanics Discipline organized into 6 interrelated task areas
  - CFD/CSD Tool Development and Applications
    - Structured
    - Unstructured
  - Icing
  - Active Rotors
  - Advanced Configurations
  - Rotor Aerodynamics and Interactions
  - Rotor Dynamics and Control

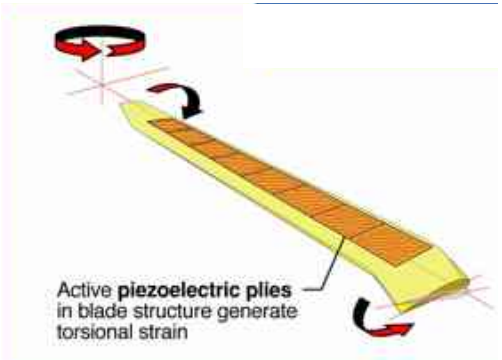
Recent Accomplishments

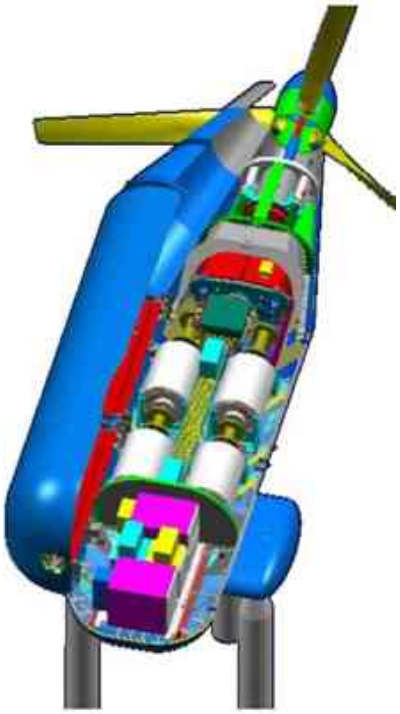
- CFD
  - Made significant improvements in structured and unstructured rotorcraft CFD methods (OVERFLOW and FUN3D)
- Icing
  - Continued development of high-fidelity icing analysis tools
  - Completed test of oscillating airfoil in Icing Research Tunnel (IRT)
  - Developed plans and began detailed preparations for subscale rotor test in IRT



Recent Accomplishments

- Active Rotors
  - Actuators developed, blade fabrication initiated, and test prep continuing for Active Twist Rotor (ATR) in Transonic Dynamics Tunnel (TDT)
- Advanced Configurations
  - Completed design and began fabrication of Tiltrotor Test Rig (TTR) and supporting equipment (balance calibration stand, model prep facility) for future testing in 40x80

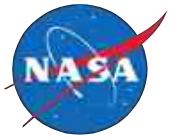




Recent Accomplishments

- Rotor Aerodynamics and Interactions
  - Completed UH-60 Airloads rotor testing in NFAC 40x80 tunnel
  - Completed 1st phase of downwash/ outwash hover testing
  - Completed testing and analysis of small-scale active flow control for fuselage drag reduction
  - Completed actuator development, fuselage fabrication, and test preparations for 14x22 test of active flow control fuselage with rotor

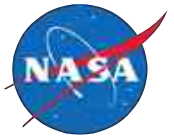
Aeromechanics Near-Term Plans



- Continue development and validation of structured and unstructured rotorcraft CFD methods
- Conduct icing test of sub-scale rotor in IRT
- Conduct Active Twist Rotor test in TDT
- Complete fabrication and development of TTR and conduct checkout test in 40x80
- Continue data evaluation/reduction and analysis validation with data from UH-60 Airloads wind tunnel test
- Downwash/outwash hover testing
- Conduct active flow control evaluation for fuselage in presence of rotor in 14x22

UH-60A Airloads Wind Tunnel Test Summary

Outline



- Test Objectives
- Test Description
- Test Phases and Conditions
- Sample Results
- Summary
- Near-Term Plans

Test Objectives

- Objectives
  - Acquire comprehensive set of validation-quality data (including airloads) to challenge SOA modeling and simulation tools
  - Acquire data to evaluate similarities/differences between small-scale wind tunnel, full-scale wind tunnel, and full-scale flight tests

- UH-60A Airloads Test successfully completed (May 2010) in USAF 40- by 80-Foot Wind Tunnel

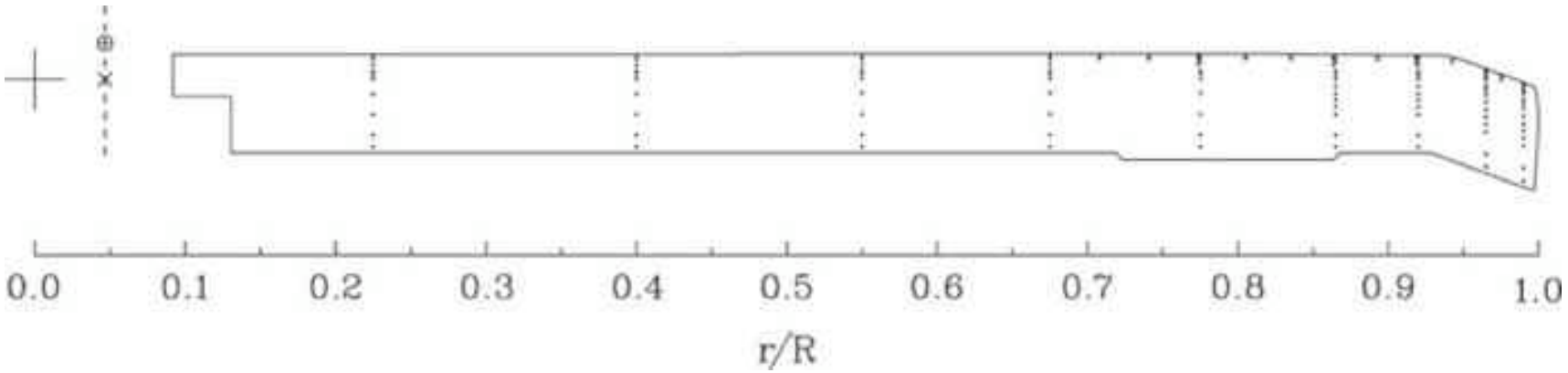
Hardware

- Testing conducted in USAF National Full-Scale Aerodynamic Complex (NFAC) 40- by 80-Foot Wind Tunnel

- UH60A rotor system mounted on Large Rotor Test Apparatus (LRTA)
  - Rotor system uses same blades as used during 1993 flight testing, including pressure blade
  - Production UH-60 rotor system (hub, spindles, shaft extender, swashplate, pitch links)
  - LRTA provides rotor mount and calibrated rotor balance

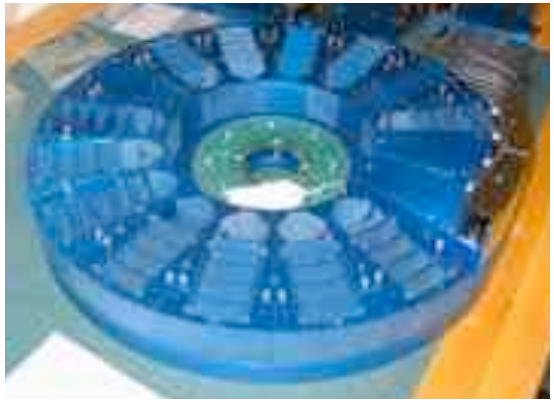
Instrumentation

- 456 unique measurements acquired at each data point
- Key Instrumentation
  - Blade Pressures
    - 235 pressure transducers, mostly in chord-wise arrays at 9 radial stations
  - Rotor Performance
    - 28 LRTA balance gages to determine rotor forces and moments
  - Blade Structural Loads
    - 28 blade bending gages at 9 radial stations
  - Blade Root Motion Measurements
    - Two sets of 12 measurements each to measure blade root motion



Data Acquisition

- Two Primary Data Acquisition Systems
  - NFAC Data Acquisition System for most data
    - Standard wind tunnel system, 16-bit
    - Data acquired at 256 samples/rev
  - Rotor Mounted Data Acquisition and Transmission System (RMDATS) for blade pressures
    - New rotating data system designed for this test, 16-bit
    - Data acquired at 2048 samples/rev



RMDATS Rotating Subsystem

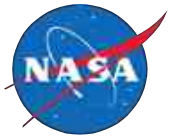
Independent Measurement Systems

- Three new systems developed specifically for this test
  - Blade Displacement System
    - Blade displacement and deformation
  - Retro-reflective Backward Oriented Schlieren (RBOS)
    - Tip vortex trajectory and orientation
  - Particle Image Velocimetry (PIV)
    - Flow velocities and vortex properties

Laser for Particle Image Velocimetry

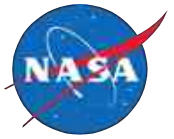
Retro-reflective Blade Displacement Targets

Test Phases and Conditions



- 1-G Level Flight Sweeps
- Parametric Sweeps
- Airloads Flight Test Simulation
- DNW Wind Tunnel Test Simulation
- Slowed Rotor Testing
- PIV Testing

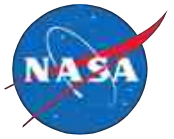
Test Phases and Conditions



- 1-G Level Flight Sweeps
  - Simulated 1-g level-flight speed sweeps (matching lift and propulsive force)
  - Advance ratio sweeps up to 0.4 for 3 lift levels

- Parametric Sweeps
  - Controlled variations of thrust, advance ratio, hover tip Mach number, and shaft angle across and beyond flight operating conditions
  - Thrust sweeps at 6 advance ratios, 3 tip Mach numbers, and 5 shaft angles

Test Phases and Conditions



- Airloads Flight Test Simulation
  - Matched conditions from Airloads Flight Test, including derivative points around the baseline to determine sensitivities
  - 3 flight conditions matched (c8425, c8525, c9020)

- DNW Wind Tunnel Test Simulation
  - Matched conditions from DNW small-scale test, including derivative points around baseline
  - 3 DNW conditions matched (11.24, 13.12, 13.20)

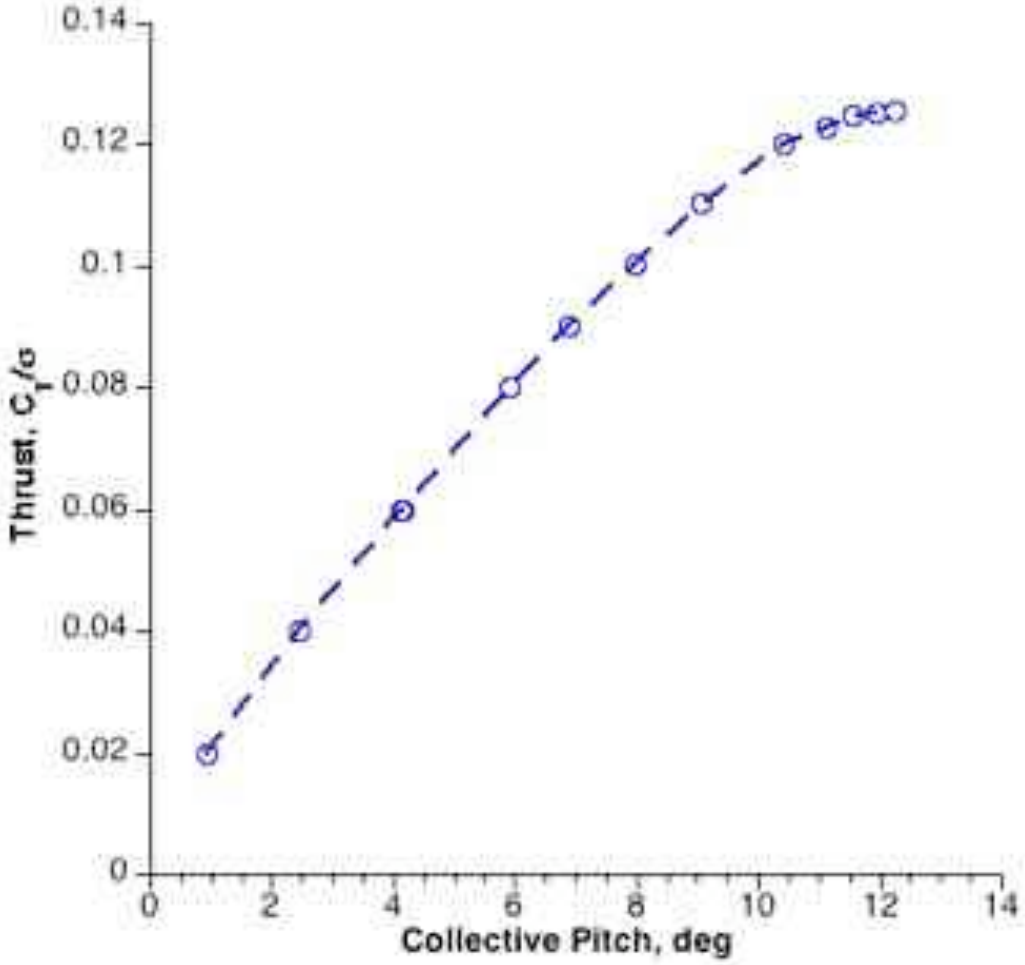
Test Phases and Conditions

- Slowed Rotor Testing
  - Parametric sweeps to evaluate non-conventional operating envelopes made possible by large reductions in rotor RPM
  - Collective sweeps at 3 hover tip Mach numbers and 3 shaft angles up to advance ratios as high as 1.0

- PIV Testing
  - Acquired detailed velocity data at selected test points to better understand flow physics
  - 11 different flight conditions

Sample Data – Stall Sweep

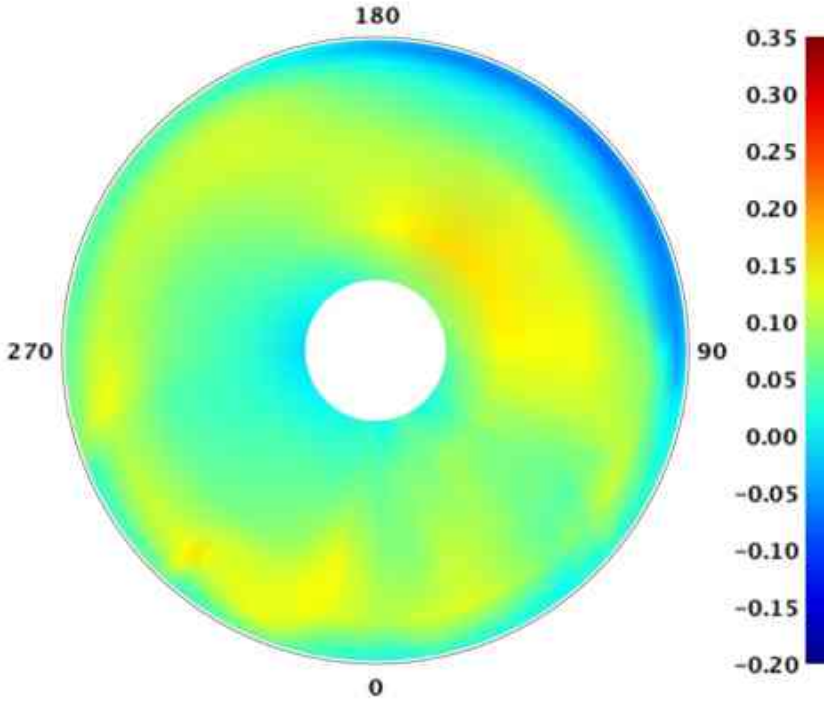
- Thrust vs. collective for collective pitch sweep (Mtip=0.625, mu=.30, alpha=0)
- Roll-off of thrust at high collectives indicative of stall



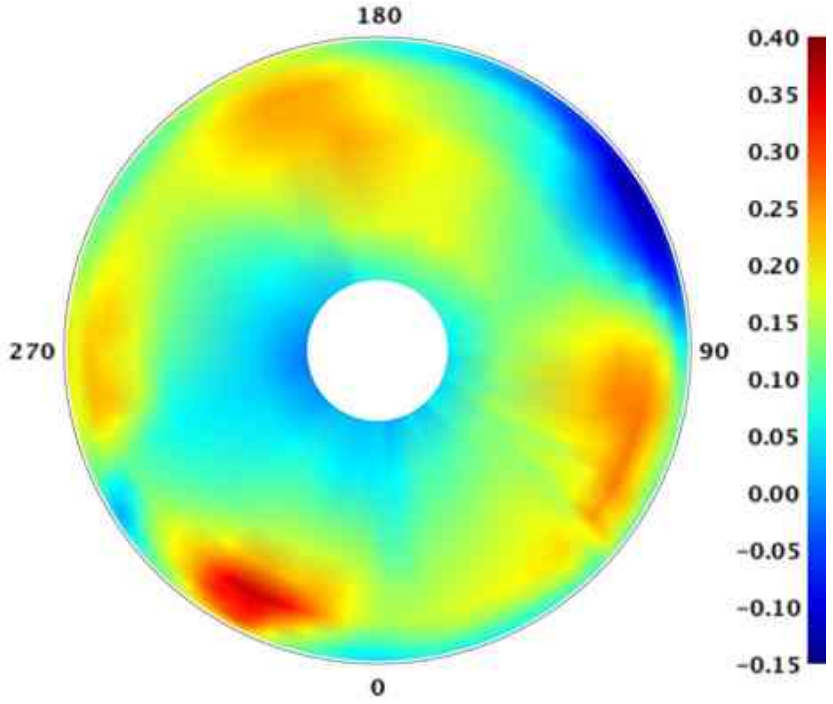
Sample Data – Stall Sweep

- Radial plots of section normal force (M2CN) at nominal and deep stall conditions (Mtip=0.625, mu=.30, alpha=0)
- Significant changes in lift distribution at stall

Nominal Thrust, C_T/σ=0.08

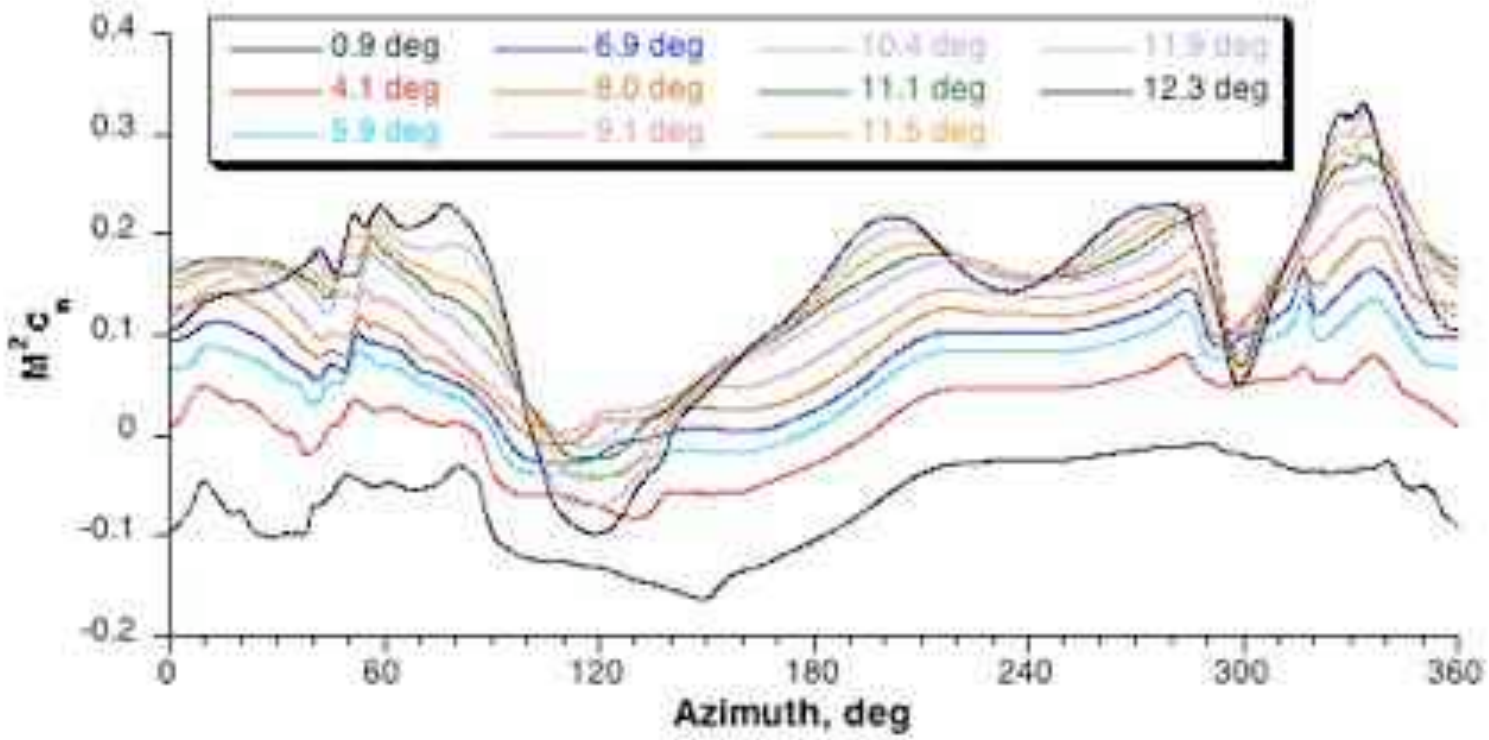


Deep Stall, C_T/σ=0.125



Sample Data – Stall Sweep

- Time history of section normal force (M2CN) at r/R = 0.92 for collective pitch sweep (Mtip=0.625, mu=.30, alpha=0)
- Lift stall evident at ψ= 290 deg and 340 deg at high collective
- Evidence of first stall cycle as low as 4.1 deg collective



Summary

- UH-60A Airloads Test successfully completed (May 2010) in NFAC 40x80 Ft Wind Tunnel
  - Measurements included blade pressures, rotor performance, blade loads, blade displacement, and rotor wake (using large-field Particle Image Velocimetry (PIV) and Retro-reflective Background Oriented Schlieren (RBOS))
  - Data acquired (including airloads) should provide excellent resource for validation of SOA modeling and simulation tools

- Data acquired over wide range of test conditions
  - Speed and thrust sweeps up to 175 kt and 32000 lb
  - Specified conditions from previous full-scale flight test and small-scale DNW wind tunnel test
  - Slowed-rotor simulation data at reduced RPM, achieving advance ratios up to 1.0

Summary

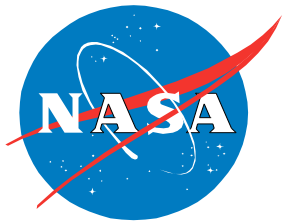
- Unique accomplishments
  - Most highly-instrumented rotor test ever conducted in the NFAC (including 235 rotating pressure transducers)
  - First test of production UH-60 rotor at high advance ratios (up to 1.0)
  - Successful acquisition of PIV data over the largest area ever attempted in NFAC (4 ft by 13 ft)
  - First ever use of an 8-camera, 4-quadrant photogrammetry technique to measure blade displacements

Laser for Particle Image Velocimetry

Retro-reflective Blade Displacement Targets

Near-Term Plans

- Prepare publications documenting test and techniques
  - 3 at May 2011 AHS Forum
    - Test overview
    - Slowed rotor
    - Analysis correlation
  - 2 at June 2011 AIAA meeting
    - PIV system development
    - Blade Displacement system development
- Continue data review, evaluation, and data reduction
- Prepare for external data release (documentation, data formatting)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