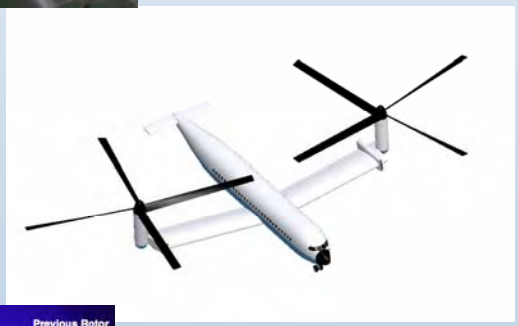
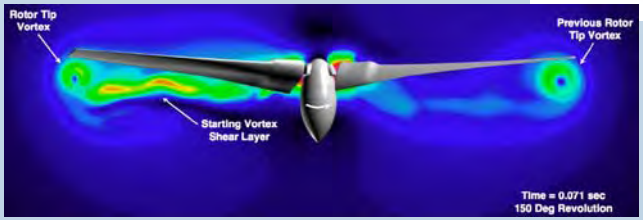
Subsonic Rotary Wing

Susan A. Gorton, Principal Investigator
Barbara M. Esker, Project Manager
Dr. Gloria K. Yamauchi, Project Scientist

Outline

- Rotary Wing Project charter, goals, structure
- Research areas
  - Propulsion
  - Flight Dynamics
  - Aeromechanics
  - Acoustics
  - Materials and Structures
  - Experimental Capabilities
- Partnerships

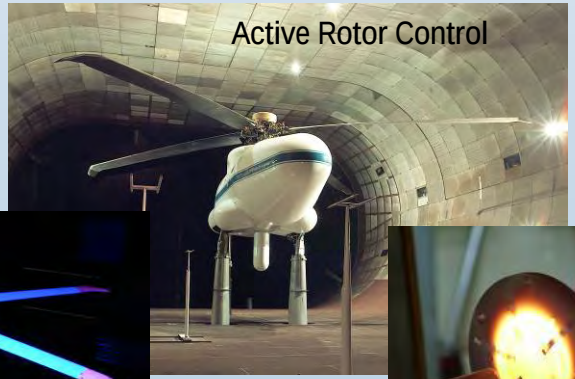


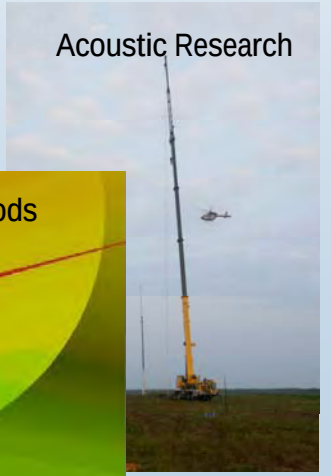


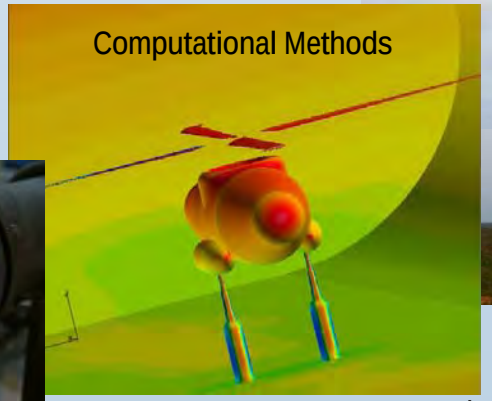
Subsonic Rotary Wing (SRW) Project Mission

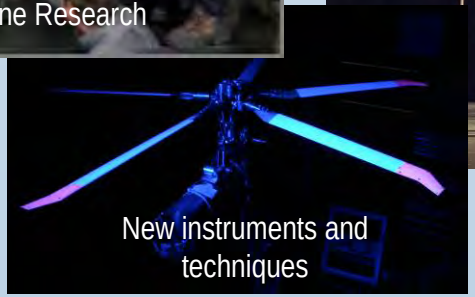
Goal: Improve civilian potential (ease of access, reduce congestion at airports, emergency and rescue services) of rotary wing vehicles

Research Areas		Civil Requirements
Noise propagation and reduction	→	Community acceptance
Increase speed and range	→	Reduce airport congestion
Increase propulsion efficiency	→	Reduce emissions
Increase payload	→	Decrease cost, increase utility
Improve control systems	→	Safe operations for advanced concepts









SRW Approach

Approach has three main components

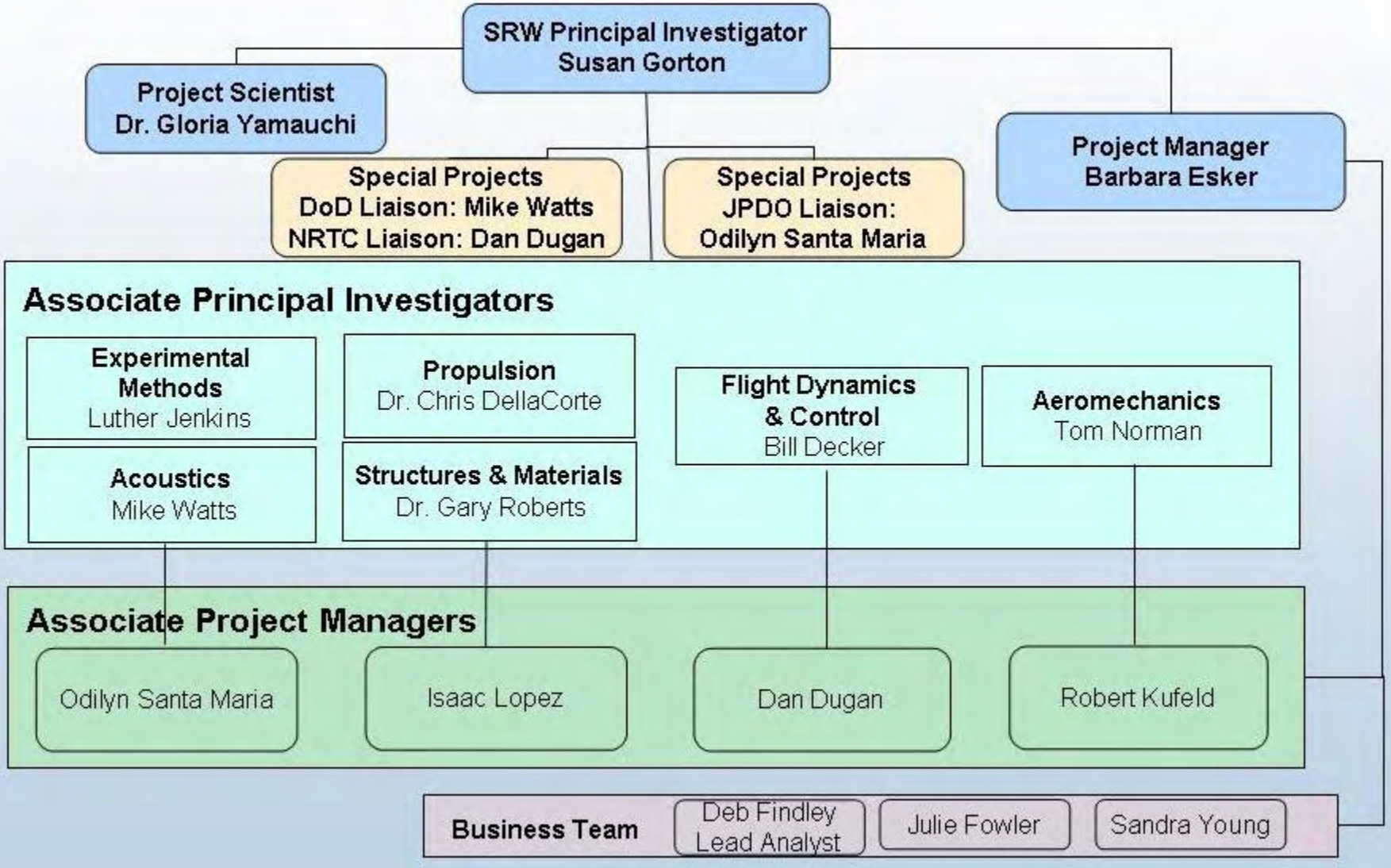
- NASA in-house research
- Research with partners (Other Government Agencies, Industry, University)
- Sponsored foundational research through NASA Research Announcement (NRA)

Technical Challenges require integration of disciplines to succeed

- Integrated Variable Speed Rotorcraft Concept
- Super-Integrated Control Design
- Advanced Structural and Propulsion Concepts for Interior Noise and Vibration Reduction
- Interactional Aeroacoustics Investigation
- Unified Experimental Techniques

Chinook at New Orleans Levee

Rotary Wing Project Management Structure



Investment Strategy

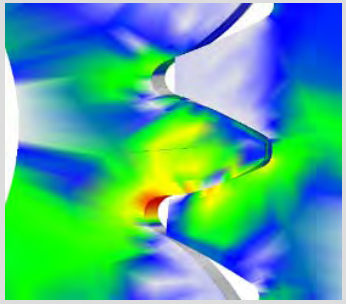
SRW prioritizes research areas based on the following set of criteria:

- Does the technology apply specifically to rotorcraft?
- Is the technical challenge likely to be addressed in any other NASA project?
- Is the technical challenge a barrier to the increased use of rotary wing vehicles in the national airspace?
- Is there a wide community of users interested in the solution of the technical challenge?
- Does SRW have enough critical mass to make significant progress in the area?

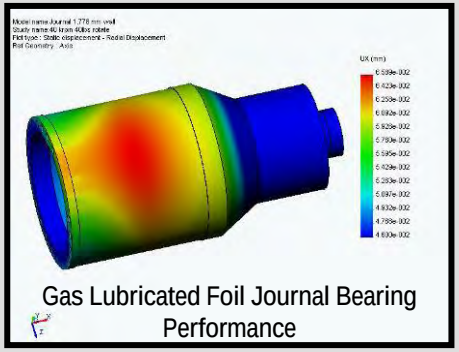
SRW Discipline: Propulsion

Advanced modeling tools/concepts essential to allow an engine/drive system to achieve a significantly larger speed range without sacrificing power and efficiency

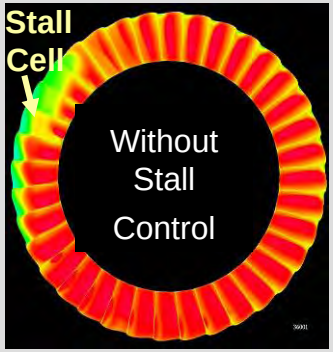
Physics-Based Modeling & Analysis



3-D Analysis of Spur / Helical Gears



Gas Lubricated Foil Journal Bearing Performance

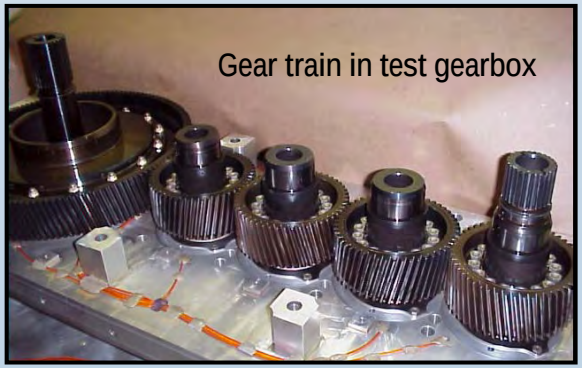


- High efficiency,multi/variable-speed drive systems
- Oil free engine/optimized gearbox systems
- Wide operability engine systems for rotary wing applications

Validation with Experimental Data

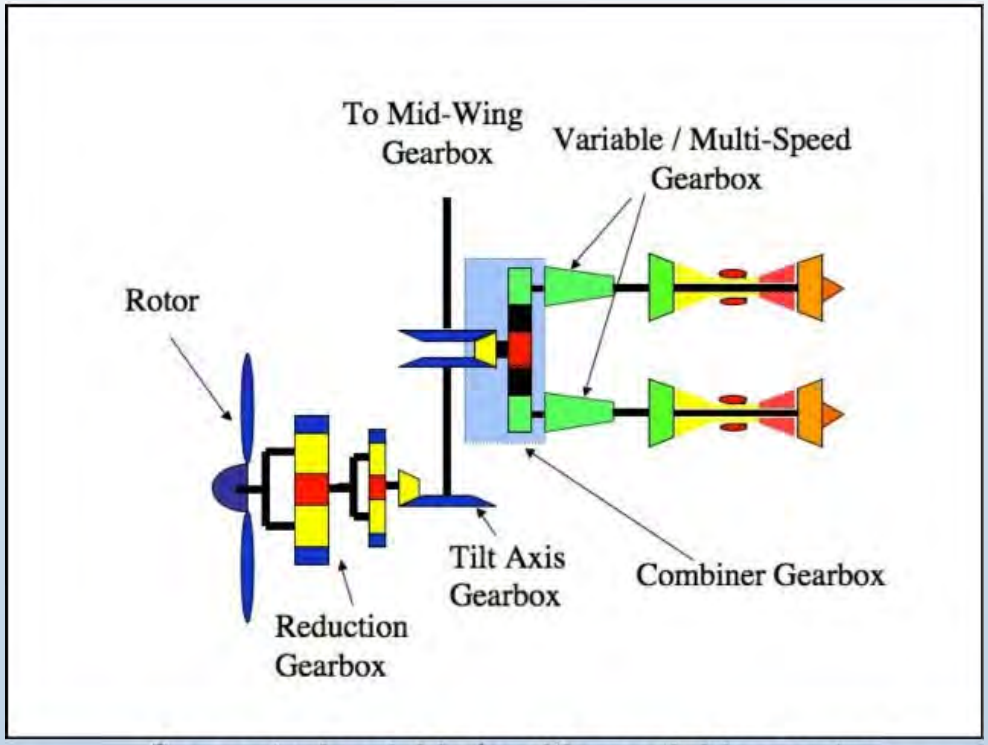
Highly-loaded compressor test facility

Gas Lubricated Foil Journal Bearing Performance

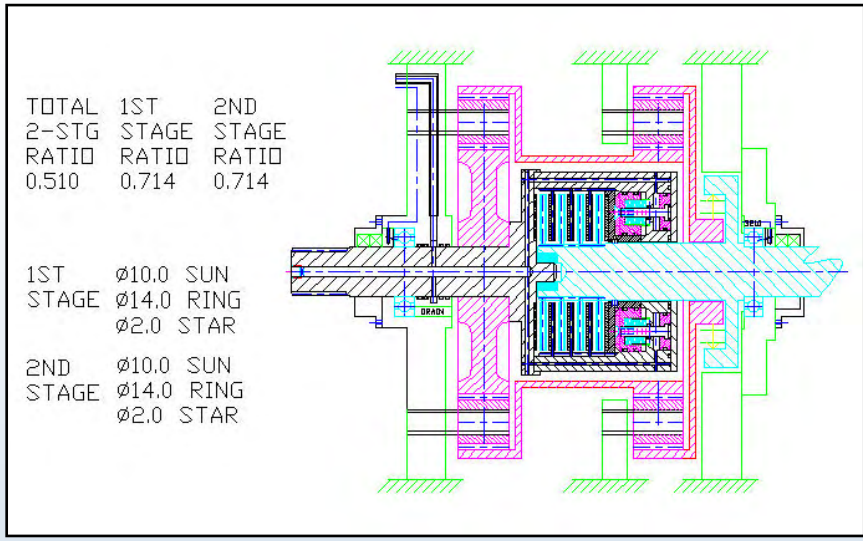


Propulsion: Multi/Variable-Speed Drives

Multi/variable-speed drives are necessary for future large, high-speed rotorcraft (e.g. large tiltrotor or slowed-rotor compound)



Conceptual variable / multi-speed drive system for a tiltrotor aircraft

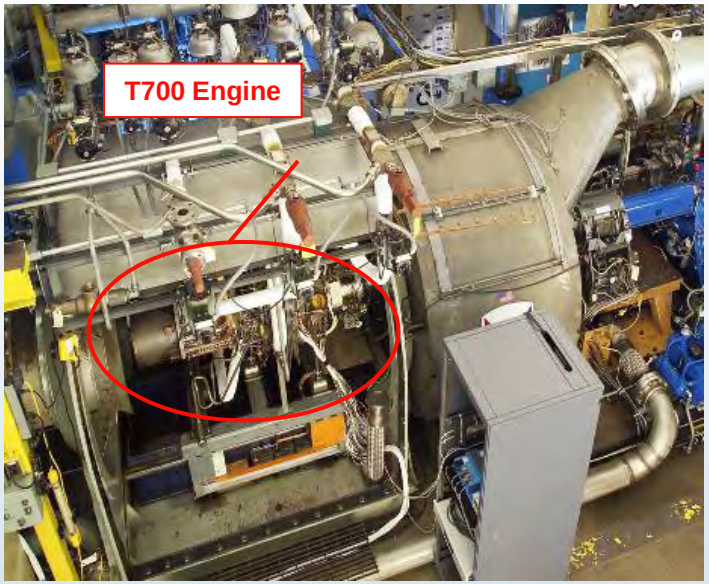


2-stage counter-rotating planetary drive concepts

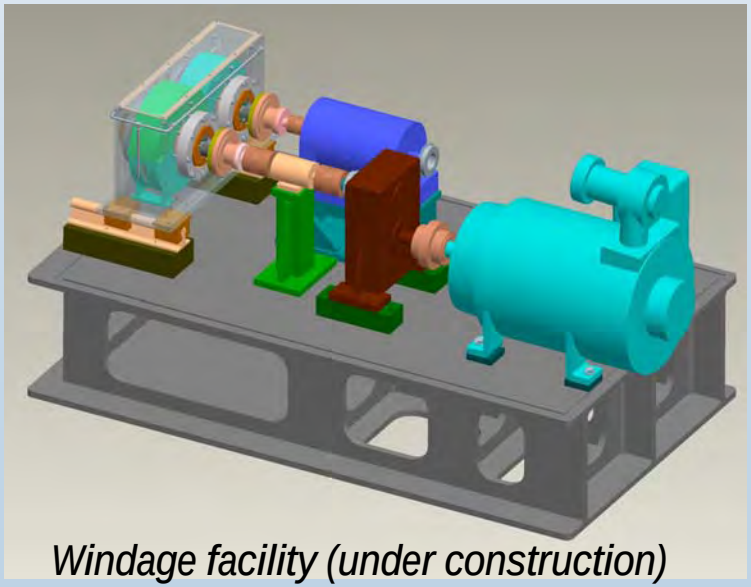
- Multiple concepts investigated with consideration of
  - Clutching mechanisms
  - Gear types
  - Offset vs inline drives
  - Reversers
  - Variable vs 2-speed

Propulsion: New/Upgraded Facilities

Upgraded CE-18 high speed compressor test cell



ECRL w/T700 engine rebuild



Windage facility (under construction)

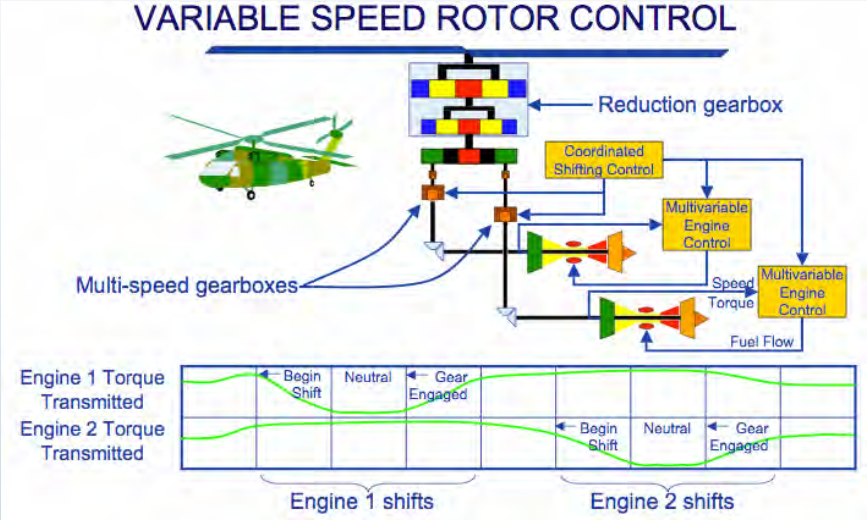
Additional upgrades:

- Spur gear facility
- Multi/variable-speed transmission test stand
- High-speed foil bearing test rig

SRW Discipline: Flight Dynamics and Control

Flight dynamics and control research focuses on modeling, testing, and validating real-time control of integrated, advanced rotorcraft technologies with emphasis on variable-speed rotor control

First-Principles Modeling

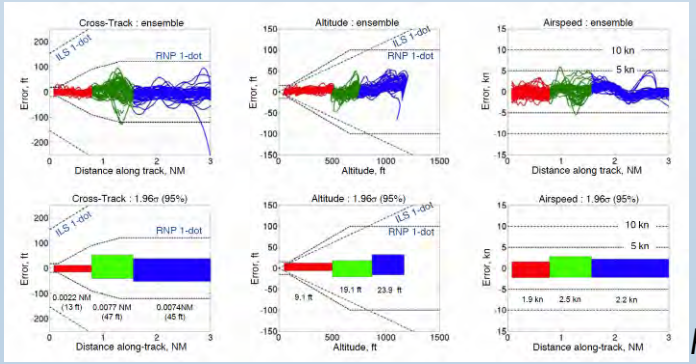


Testing (simulation and flight)

Aris/Bell 206 Helicopter, Hollister, CA

Validation

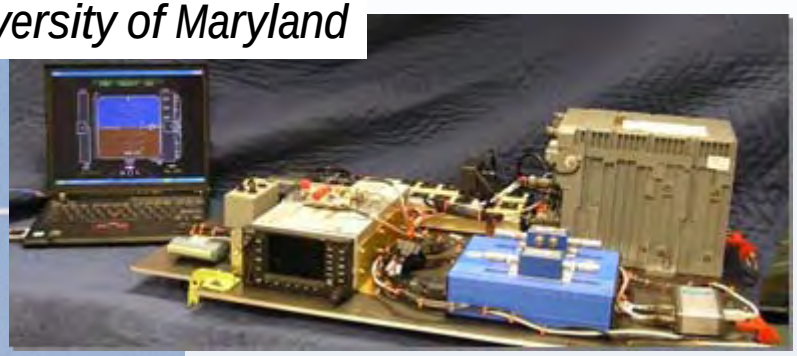
Assessment of Flight Procedures in Vertical Motion Simulator



Precision guidance flight path

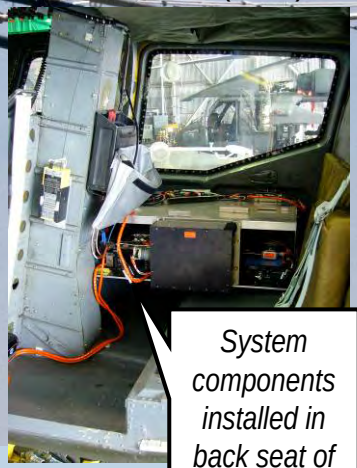
In-Flight Precision Guidance System

Joint with Center for Rotorcraft Innovation, Army, University of Maryland

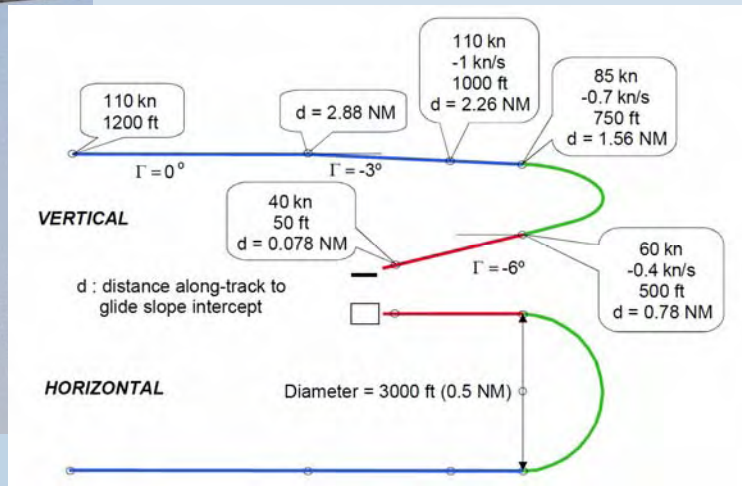


Portable Flight Guidance System includes inertial and GPS sensors, collective stick position sensor, cockpit and operator displays

Terminal area guidance concepts demonstrated to achieve precise flight path control in tight Required Navigational Performance (RNP) boundaries with minimal to moderate pilot workload.



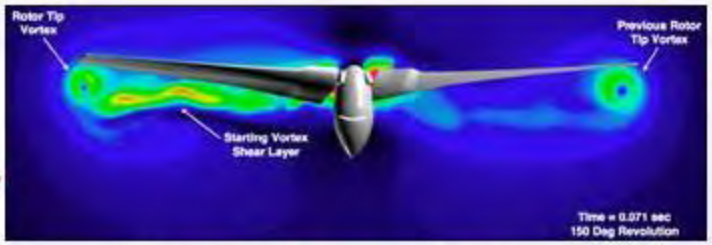
System components installed in back seat of OH-58

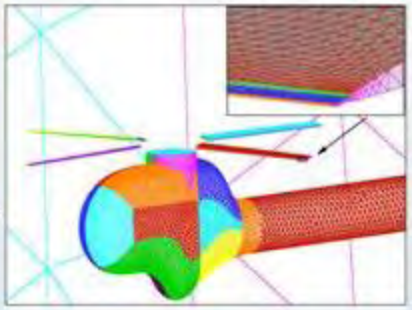


SRW Discipline: Aeromechanics

Rotorcraft aeromechanics research extends from first-principles modeling through testing and validation for isolated and multi-disciplinary phenomena

First-Principles Modeling

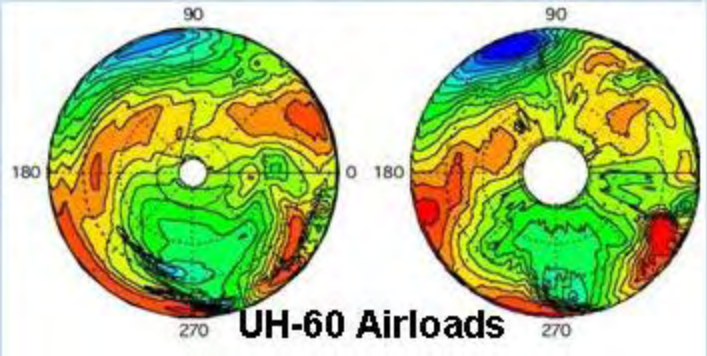




Testing (small, large and full-scale)

Validation

Coupled Solution



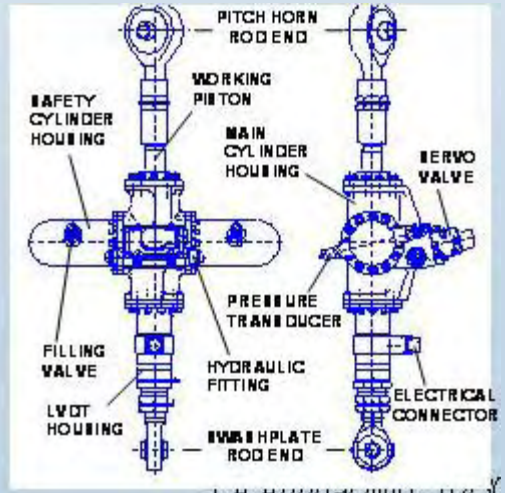
Flight Test

Aeromechanics: Individual Blade Control (IBC)

- Full-Scale 40x80 Test to evaluate:
  - Performance improvement at high speed
  - Potential for simultaneous vibration/noise control
  - Effectiveness of closed-loop control to find optimum solutions
  - Interactions between IBC and flight control systems
  - Capability to predict effects of IBC
- Partners:
  - Army AFDD
  - Sikorsky
  - ZF Luftfahrtechnik
- Schedule
  - Currently scheduled for ~March 2008


LRTA in 40 x 80 Wind Tunnel

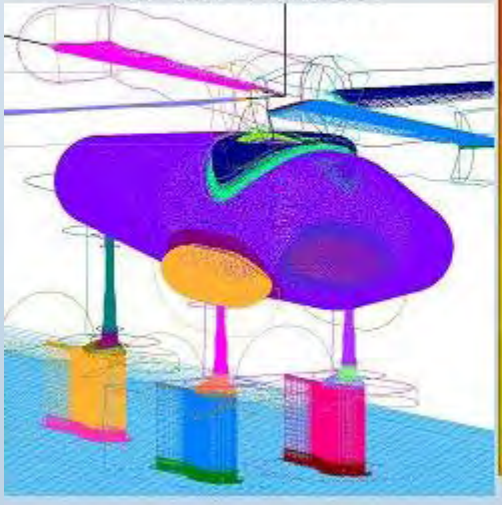
IBC Actuators Made for LRTA Test Stand



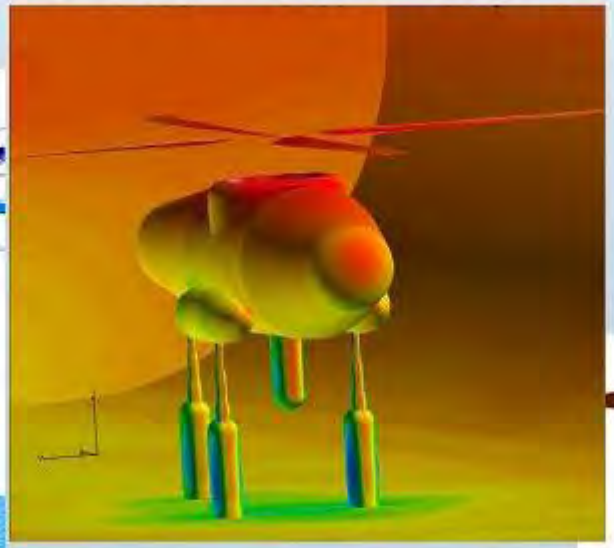
CFD Research for Aeromechanics

- Develop OVERFLOW2 for relevant rotorcraft problems and assess capabilities (turbulence models, high-order numerical schemes, static and dynamic stall, modal structure software integration, etc.)
- Develop FUN3D for relevant rotorcraft problems and assess capabilities (overset unstructured grids, overset connectivity, hole-cutting, dynamic slicing and extraction, automated topology extraction, etc)
- Model active control systems and their effects

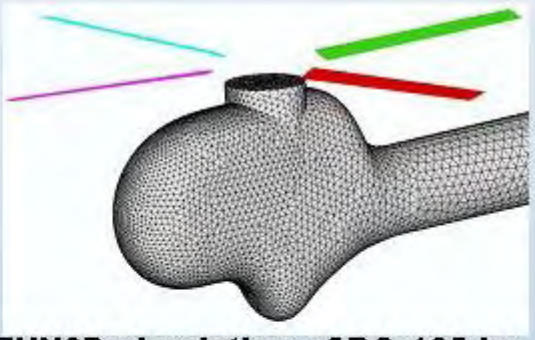
OVERGRID Grid System for IBC on LRTA



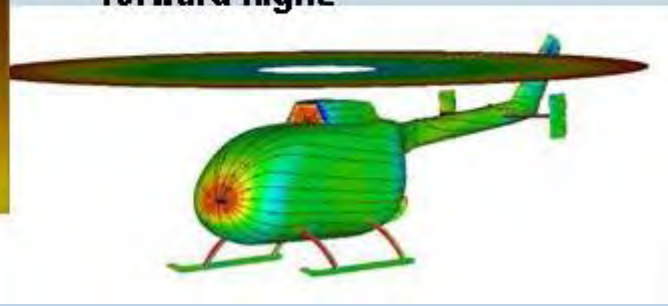
Pressure Contours from OVERFLOW



Triangular surface representation for the HART-II fairing

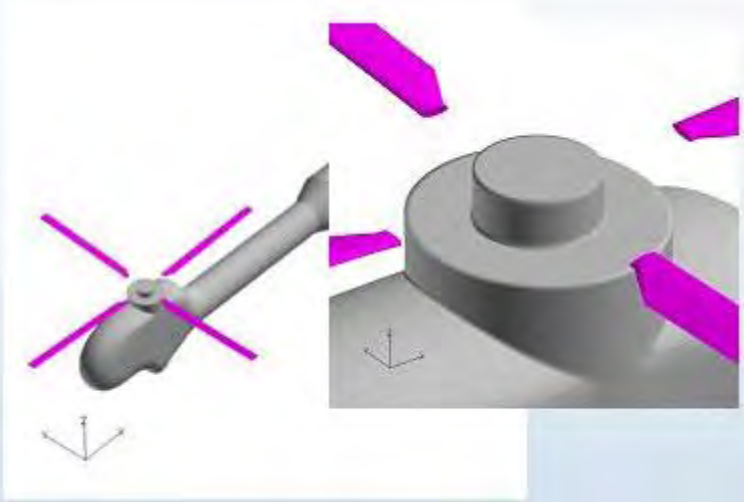


FUN3D simulation of BO-105 in forward flight



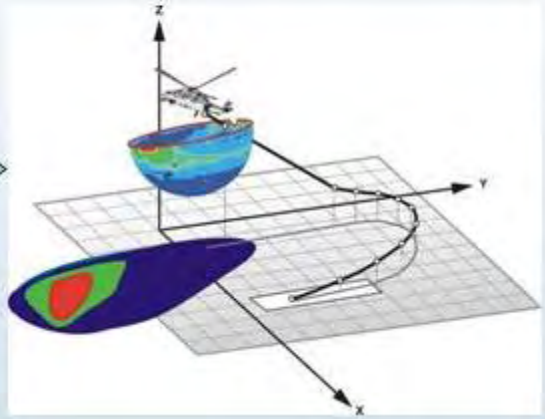
SRW Discipline: Acoustics

Rotorcraft acoustics research focus includes the study and control of source noise, interior noise, gear noise, propagation, and concepts for low-noise operations



Noise Analyses

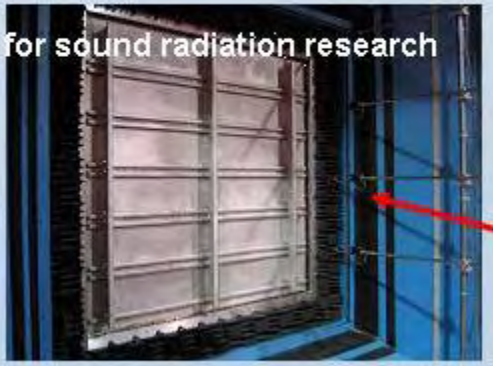
Harmonic
Impulsive
Broadband
Scattering



Digital Field Measurements

Laboratory and Wind Tunnel Measurements

Panel for sound radiation research

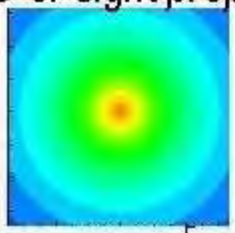


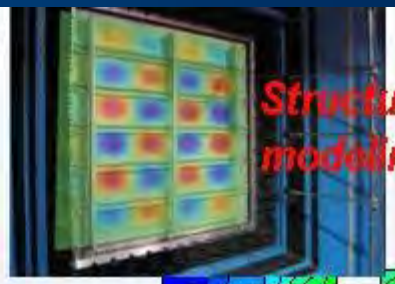
Acoustics: Propagation and Noise Modeling

Progress in Analysis

- Propagation modeling
- OVERFLOW and FUN3D acoustic coupling
- Gear Train Noise Model
- Inlet distortion and engine noise modeling
- Vehicle Aeroacoustics
- Rotorcraft Acoustic Characterization
- Energy Finite Element Method (EFEM)

Line-of-sight propagation

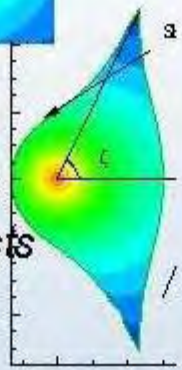




Structural acoustic modeling

HART II Calculations

Wind and Temp Refraction Effects



Experimental data for system noise validation

Eglin Flight Testing*

- VH-71 (source noise data for flyovers, approaches, departures)
- MD-903 (source noise data for flyovers, approaches, departures, hover, and steady state circular flight; sound jury data)
- Mi-8 (source noise data for flyovers, approaches, departures, hover and steady state circular flight; sound jury data)

*Joint research with DARPA, Army AFDD

Hollister Flight Testing**

- Precision guidance for turns
- Source noise research

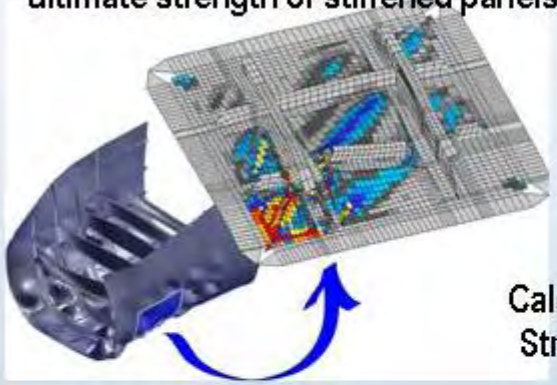
**Joint research with Bell, UMD, Army AFDD

SRW Discipline: Structures and Materials

Structures and Materials research focused on rotorcraft-specific issues in durability, damage tolerance, crashworthiness, and advanced materials for airframes and engines

First-Principles Modeling

Post-buckling response and ultimate strength of stiffened panels



Probabilistic Fatigue Life Prediction for Advanced Turbine Disk Alloys

Testing

Fatigue life for flexbeams

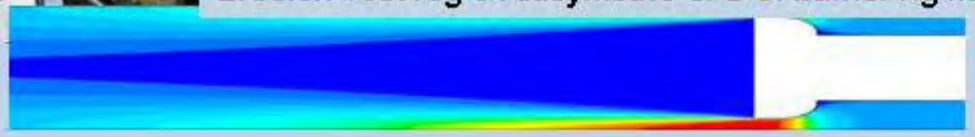
Thermal Barrier Coating Testing

Calculation of Max Principal Stress for a Turboshaft HP Turbine Disk

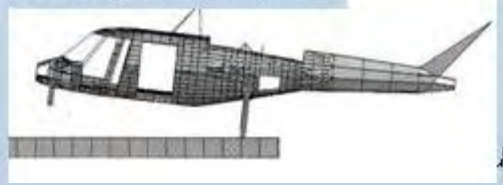
New Hybrid Foam

Validation

Erosion Test Rig & Axisymetric CFD of burner rig flame



Crash Analysis Validation

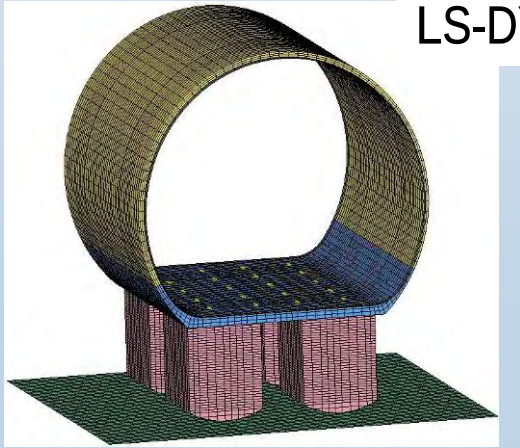


Multi-Terrain Impact Testing and Simulation of an Externally Deployable Composite Energy Absorber

Pre-test photo

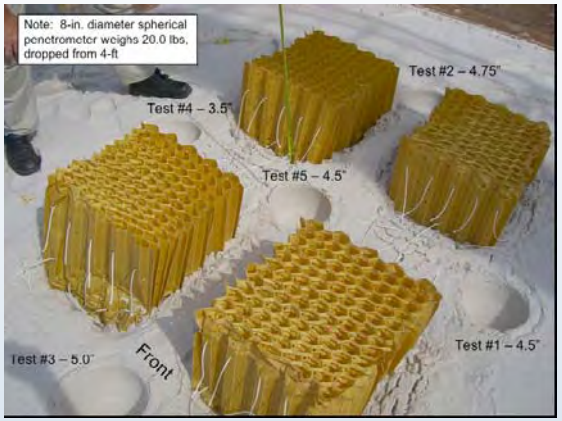
Post-test photo

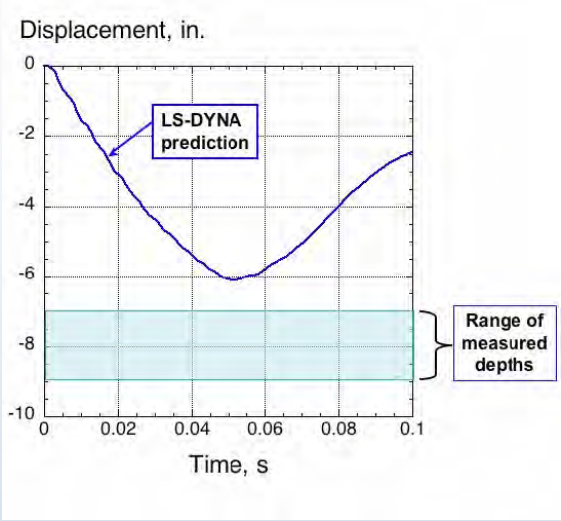
LS-DYNA Model



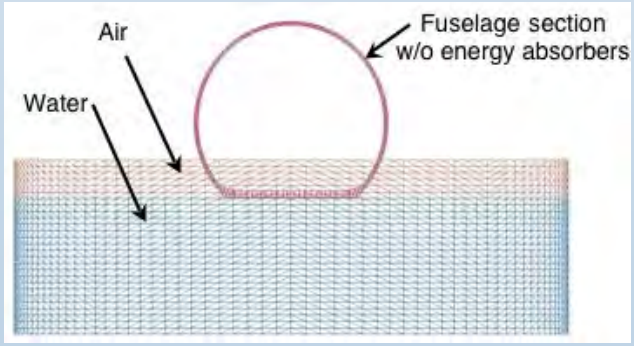
Multi-Terrain Impact Testing and Simulation of an Externally Deployable Composite Energy Absorber

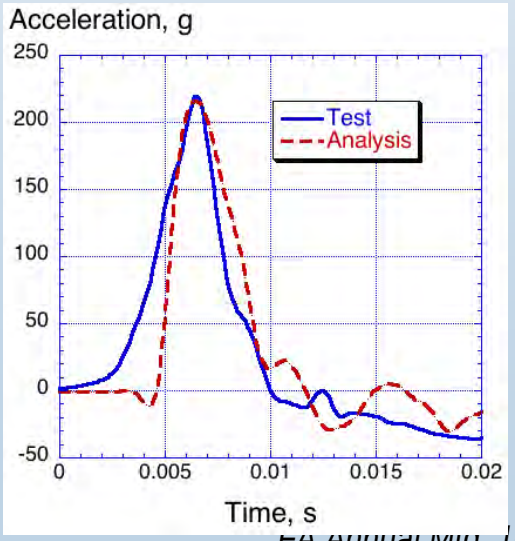
Drop test onto sand, measurement and prediction of sand displacement





Drop test onto water, measurement and prediction of acceleration





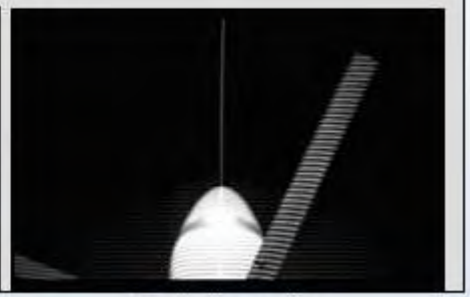
SRW Discipline: Experimental Capabilities

Experimental Capabilities development is essential for validation of aeromechanics, acoustics, structural response, and propulsion fundamental methods

Primary Measurement Technologies

Wake Assessment

Surface Pressures



Blade Geometry

- Large field rotor wake assessments
- Blade/fuselage unsteady pressures
- Blade geometry as deformed under load

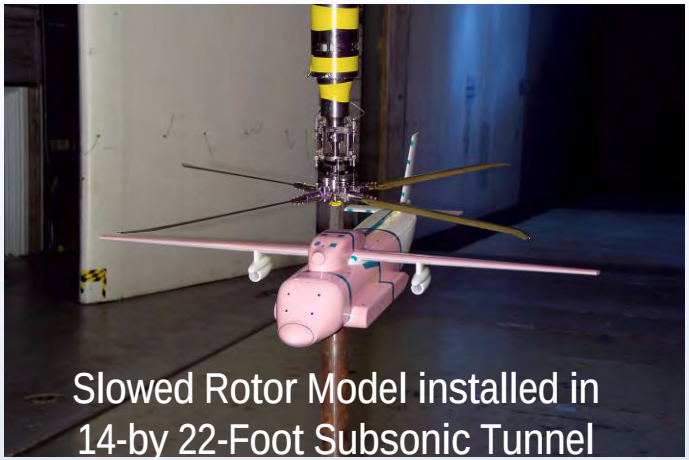
Targeted Primary NASA Rotorcraft Test Facilities

National Full-Scale Aerodynamics Complex

Transonic Dynamics Tunnel

14- by 22-Foot Subsonic Tunnel

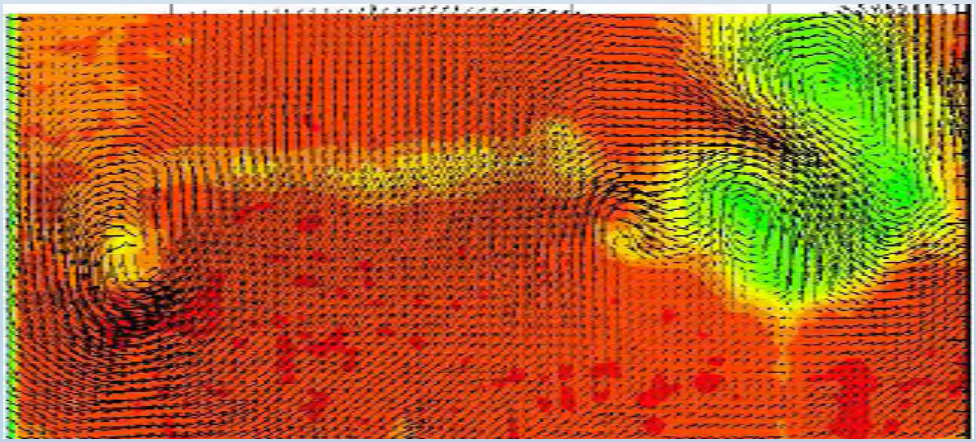
Experimental Capabilities
Progress in Measurement Techniques



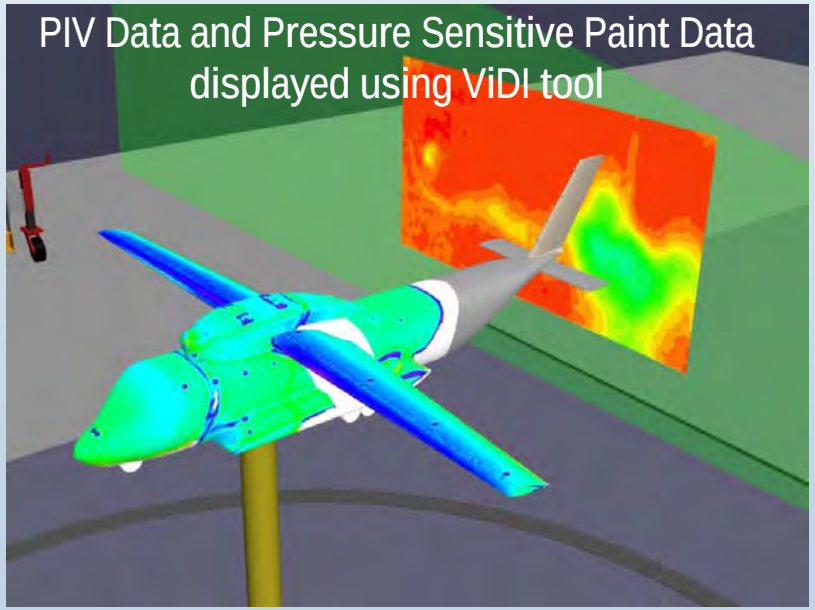
Slowed Rotor Model installed in
14-by 22-Foot Subsonic Tunnel

Large Field-of-View Particle Image Velocimetry

Particle Image Velocimetry data
for 2 x 4.5 Foot Area



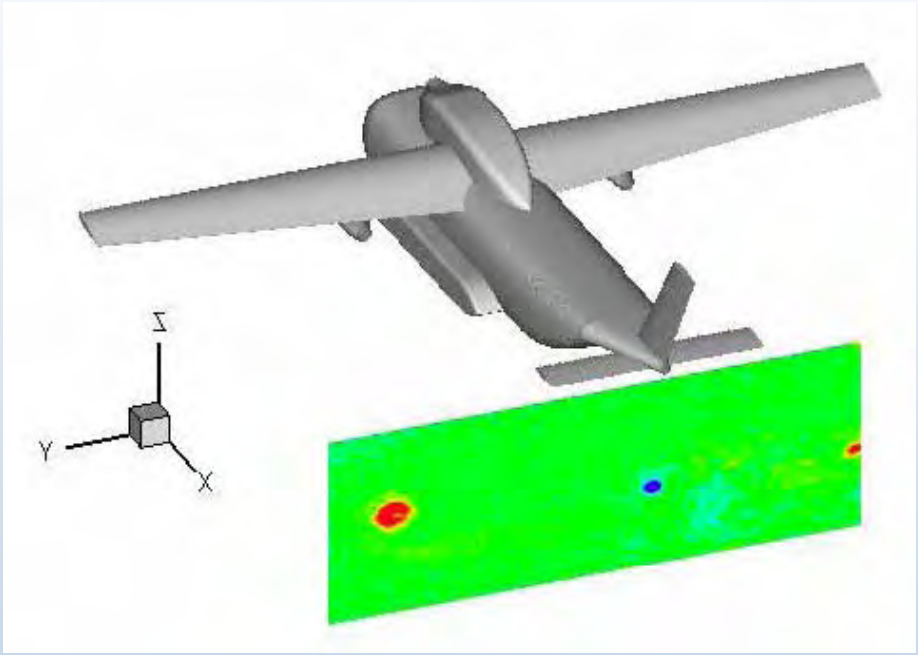
PIV Data and Pressure Sensitive Paint Data
displayed using ViDI tool



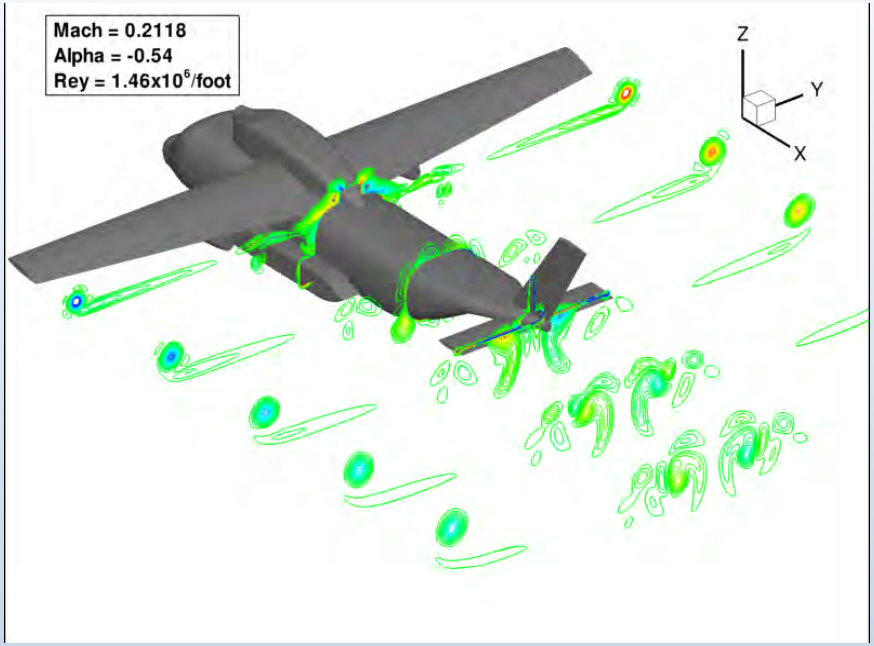
Joint program with Army AFDD

Experimental Capabilities
Progress in Measurement Techniques

Vorticity calculated from PIV data



Vorticity calculated from OVERFLOW



Joint program with Army AFDD

SAA/Partnership Status

Completed FY07

- Helowerks, crashworthiness
- Bell/University of Maryland acoustic flight test
- Polyumac TechnoCore, Bell, Boeing, Gulfstream, and Purdue for polyimide acoustic foam
- DARPA, Eglin acoustic flight test for propagation and system noise prediction

On-Going

- ZFL Individual Blade Control testing
- FAA, drive system health monitoring
- DARPA/SMART Rotor test
- Army JHL/slowed rotor research

Under Negotiation

- Sikorsky Individual Blade Control test (awaiting signature at Sikorsky)
- Boeing, crashworthiness
- Sikorsky, impact resistance of advanced core sandwich construction

• Emerging

- JAXA active rotor prediction and test
- HART 3 active twist rotor (Army, DLR, ONERA, Korea)
- Rotorcraft icing consortium (government, industry, university)

Partnerships

- Army is a major partner at LaRC, ARC, GRC; provides both dollars and workforce in cost sharing efforts
  - Aeromechanics (IBC, slowed rotor, interactional aero)
  - CFD (structured methods, advanced computing, compressor simulations)
  - Active Flow Control (Small Scale Active Rotoro)
  - Acoustics (Eglin acoustic flight test, low noise operations)
  - Flight Dynamics (RIPTIDE, VMS simulations)
  - Experimental Capability (PSP, PIV)
  - Propulsion (windage, drive train, compressor efficiency, engine controls, compressor stall alleviation)
- Army, DARPA: Eglin acoustic flight test
- DARPA: SMART Rotor research
- Sikorsky, ZFL: Individual Blade Control (IBC) testing
- FAA: drive system health monitoring
- SFW: acoustic upgrades to 14x22; instrumentation upgrades to 14x22
- AAD: progressive damage analysis for composite structures
- AvSafety: International Helicopter Safety Initiative (IHST)
- ATP: facility improvements, experimental techniques

NRA Status

NRA - Call 1: 80 proposals received; 12 selected for award (total award: $2.225M)

Propulsion - 2
Aeromechanics (CFD) - 1
Aeromechanics (non CFD) - 2
Acoustics - 4
Structures & Materials - 2
Experimental Capabilities - 1

NRA - Call 2: 36 proposals received; 12 selected for award (total award ~2.9M)

Propulsion - 2
Aeromechanics (CFD) - 4
Flight Dynamics and Control - 4
Multi-Disciplinary Analysis and Optimization & Systems Analysis - 2

SBIR Status

2006 Phase I: 7 proposals awarded

2006 Phase II: 3 proposals awarded

- Patz Materials & Technologies
  Optimized Cellular Core for Rotorcraft

- Continuum Dynamics, Inc.
  Next Generation Modeling Technology for High Speed Rotorcraft

- JMSI, Inc. dba Intelligent Light
  A Post-Processing System for Physics Based Derived Rotorcraft Computational Aero-Acoustics Simulations

2007 Phase I: evaluations underway

Publication Venues (last 6 months only)

- American Helicopter Society (AHS)
  - Annual Forum
  - Specialists' Meeting
  - Local Chapter presentations
- American Institute of Aeronautics and Astronautics (AIAA)
  - Applied Aerodynamics
  - Propulsion
- American Society of Mechanical Engineers (ASME)
- Society of Automotive Engineers (SAE)
- International Congress on Instrumentation in Aerospace Simulation Facilities (ICIASF)
- Tribology Transactions
- International Society for Air Breathing Engines (ISABE)
- Engineering Conference International (AFOSR and ONR sponsored)
- Dept of Energy workshop
- NASA Workshops
- NASA technical reports
- NASA contractor reports

On the Horizon

- Increased research emphasis in some areas supporting technologies enabling large, high-speed rotorcraft
- Increased involvement with the Joint Planning and Development Office (JPDO) for rotary wing concepts in the future airspace environment
- NRA opportunity upcoming within FY08; topics and information will be announced through NSPIRES
- Return to full-scale rotor testing in the NFAC with new measurement capabilities for acquisition of validation data
- Return to engine stall control and compressor component research at the ECRL and CE-18 facilities
- Vertical Motion Simulation to explore the pitch and roll response phase margin requirements for large, heavy-lift rotorcraft
- Increased emphasis on system analysis and trade benefit studies; new NASA rotorcraft system analysis tool under development
- Publication and dissemination of research results from all areas within project, including State-of-the-Art assessment document for all disciplines

Summary

- Goals of Subsonic Rotary Wing are centered around civil applications of rotary wing technologies
- SRW project making measurable and significant progress in many research areas
- Partnerships are providing significant leveraging
- Technical details forthcoming in next several days, upcoming meetings, conferences and publications

Your Future Flight Home?