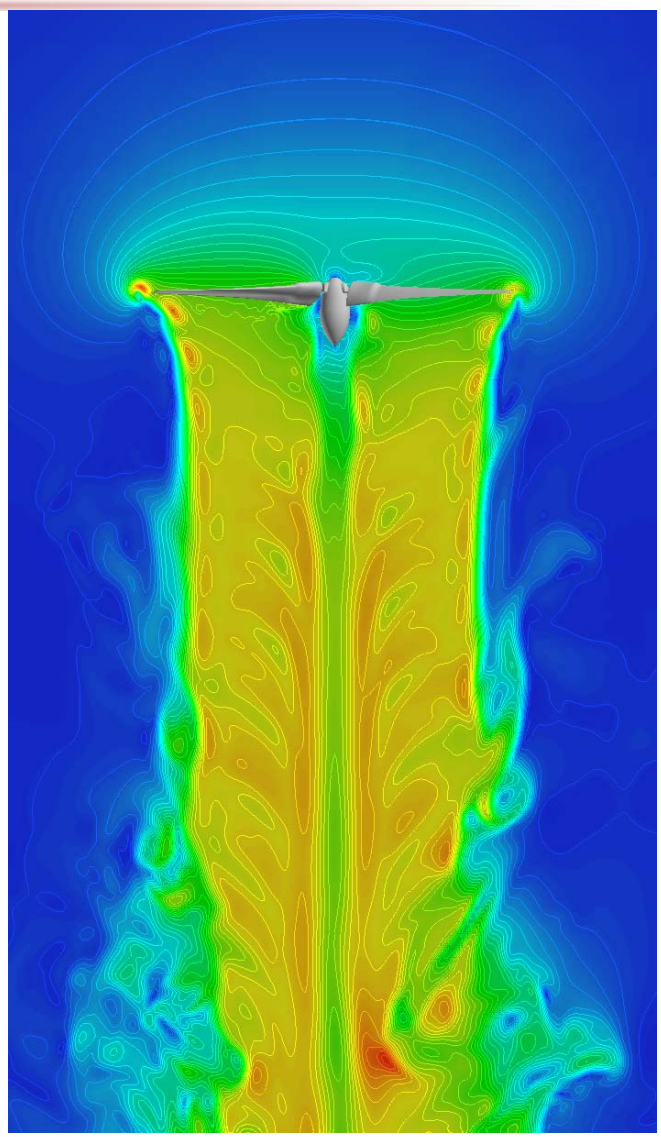
NASA
Subsonic Rotary Wing Project

Susan A. Gorton
PI, Subsonic Rotary Wing Project
Fundamental Aeronautics Program

2009 Fundamental Aeronautics Program Annual Meeting
September 29-October 1, 2009

Outline

- Guidance/Strategy/ Direction
- NEW Technical Challenges
- FY09 Highlights
- FY10 Upcoming Activities
- Summary



Subsonic Rotary Wing Project

Project Leadership Team
Principal Investigator: Susan Gorton
Project Manager: Temporarily Vacant
Project Scientist: Isaac López

Special Projects
DoD Liaison: Mike Watts
NRTC Liaison: Dan Dugan
JPDO Liaison: Odilyn Santamaria Luck

NRA Manager
Karen Crandall

Business Support Team
Lead Resource Analyst: Debra Findley
Center Resources Analysts:
Shanen Pady
Christian Aguilar
Lead Scheduler: Joyce Moran

Research Disciplines

Acoustics
API: Dr. Doug Boyd
APM: Odilyn Luck

Experimental Methods
API: Luther Jenkins
APM: Odilyn Luck

Multi-Disciplinary Analysis & Technology
API: Dr. Gloria Yamauchi
APM: Bob Kufeld

Structures & Materials
API: Michael Halbig
APM: Susan Johnson

Aeromechanics
API: Tom Norman
APM: Bob Kufeld

Flight Dynamics & Control
API: Bill Decker
APM: Dan Dugan

Propulsion
API: Dr. Paula Dempsey
APM: Susan Johnson

Strategy/Guidance/Direction

- **Directed to focus on:**
  - NextGen Developments
  - Mobility / Capacity
  - Efficiency

- **System Studies to date:**
  - NASA Heavy Lift/ Large Civil Tiltrotor (LCTR2)
  - Future Concepts in the NextGen
  - Technology Benefit Assessment for Compound and Tiltrotor Systems
  - Large Tiltrotor Operations in the Airspace System
  - Propulsion-Airframe Integration

- **Status/Results**
  - Vertical capability at one or both ends of a 300-600nm mission increases airport capacity
  - Simultaneous, Non-Interfering (SNI) operations appear viable in the NextGen
  - Large, advanced technology tiltrotors consistently outpace other configurations in the ability to meet the mission
  - Advanced technologies (SFC, weight reduction, drag reduction, rotor L/D) give tiltrotors cost and operational parity with configurations already in use

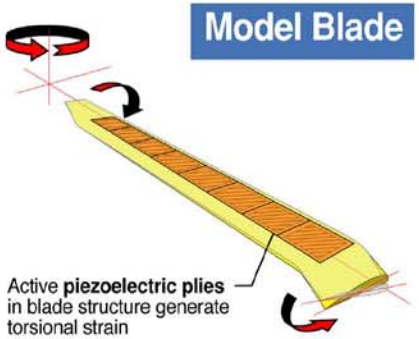
Large Civil Tiltrotor 2nd Gen (LCTR2)

- NASA's notional high-speed configuration
  - Use to model configuration capabilities in the Airspace
  - 90 passengers, 300 knots cruise speed, 1000 nm range (nominal)
  - Hover tip speed 650 fps / cruise tip speed 400 fps

Circa October 2007

Reference: Acree, C. W., Hyeonsoo, Y., and Sinsay, J. D., "Performance Optimization of the NASA Large Civil Tiltrotor" International Powered Lift Conference, London, UK, July 22-24, 2008

Challenges for Next Generation of Rotary Wing Aircraft

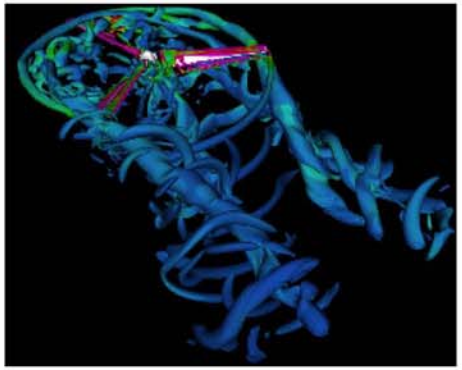


Active rotor systems

High-speed configurations for efficient transport systems require advanced arodynamic performance: high-lift, low drag, low vibration, low noise rotors.

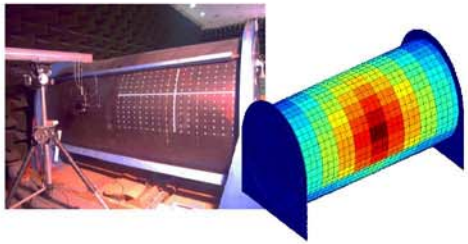
Modeling and Validation

Physics-based Multi-disciplinary design and analysis tools required to design new configurations. New computational and measurement systems required to understand rotor wake system.



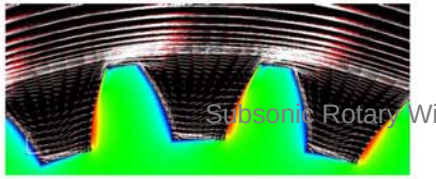
Low Noise: External and Internal

Address barrier technologies in external source noise, low noise operations, internal cabin noise.



Propulsion System

Engine improvements needed in technology and efficiency.
Drive Train and transmission advanced design required for variable speed, low noise, high efficiency



L3 Milestones have Evolved to Technical Challenges

2006 SRW Project Formulation
- 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

NRC Decadal Study

HQ Direction

National Aeronautics R&D Policy

SRW Execution, 2006-2009

Research Results

System Studies

OGA Industry Review Panels

SRW Team Offsite, Dec 08

2009 SRW REVISED L3 Technical Challenges ★
- **Integrated Aeromechanics/Propulsion System (IAPS)**
- **Actively-Controlled, Efficient Rotorcraft (ACER)**
- **Quiet Cabin (QC)**
- **NextGen Rotorcraft**

★ more focused
reflects current research direction
more realistic timeline for major efforts

Primary Focus on Four Technical Challenges

- Integrated Aeromechanics/Propulsion System (IAPS) (FY21): Develop and demonstrate technologies enabling variable-speed rotor concepts
  - Goal: 50% main rotor speed reduction while retaining propulsion efficiency
  - Benefits: very high-speed, efficient cruise; efficient hover; reduced noise

- Actively-Controlled, Efficient Rotorcraft (ACER) (FY19): Simultaneously increase aerodynamic efficiency, control dynamic stall, reduce vibration, reduce noise
  - Goal: 100 kt speed improvement over SOA; noise contained within landing area; 90 pax /10 ton payload
  - Benefits: very high-speed, efficient cruise; efficient hover; reduced noise; improve ride quality

- Quiet Cabin (QC) (FY17): Reduce interior noise and vibration
  - Goal: Internal cabin noise at level of regional jet with no weight penalty
  - Benefit: passenger acceptability; increased efficiency through weight reduction

- NextGen Rotorcraft (FY21): Foster, develop and demonstrate technologies that contribute to the commercial viability of large rotary wing transport systems in NextGen.
  - Goal: mature technologies needed for civil, commercial operations
  - Benefit: enables vehicle acceptability for passengers and operators

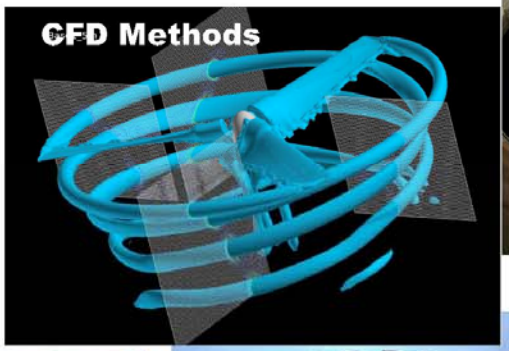
Subsonic Rotary Wing (SRW) Project

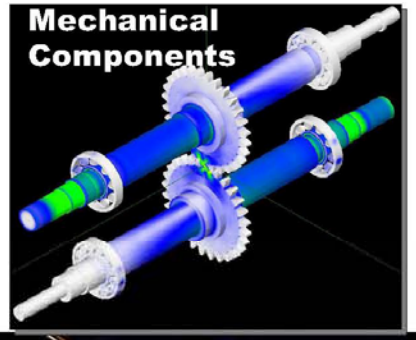
Goal: Radically improve the capabilities and civil benefits of rotary wing vehicles

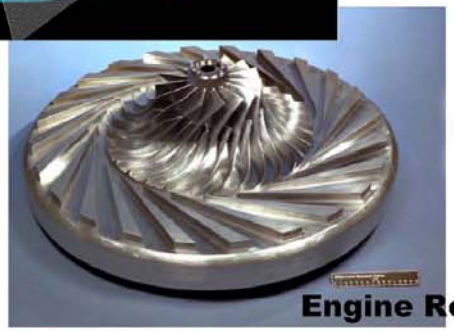
Civil Requirements (supporting NextGen)
- Mobility: reduce airport congestion
- Low noise
- Reduce emissions
- Decrease cost, increase utility
- Safe operations for advanced concepts

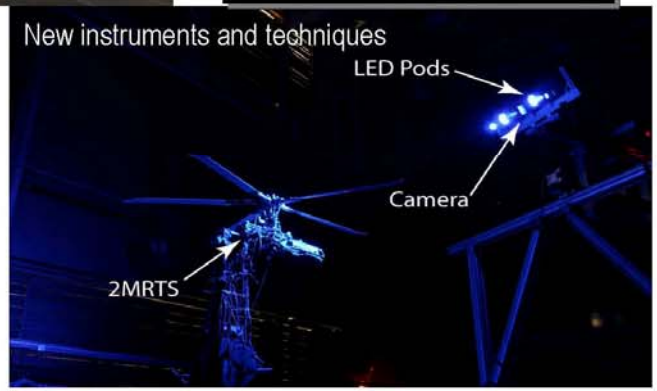
Technical Challenges
- Integrated Aero/Propulsion System
- Actively-Controlled, Efficient Rotorcraft
- Quiet Cabin
- NextGen Rotorcraft

Project Goals
- 50% main rotor speed reduction
- 100 kt speed increase
- Noise contained in landing area
- Cabin Noise < 77dB; no weight penalty
- Advanced vehicle capabilities and operations









Partnerships

Completed last 12 months

- AATD, composite crashworthiness modeling and drop testing (SARAP)
- Army, Vertical Motion Simulator Heavy Lift Simulation
- Army/Boeing, Small Scale Active Rotor

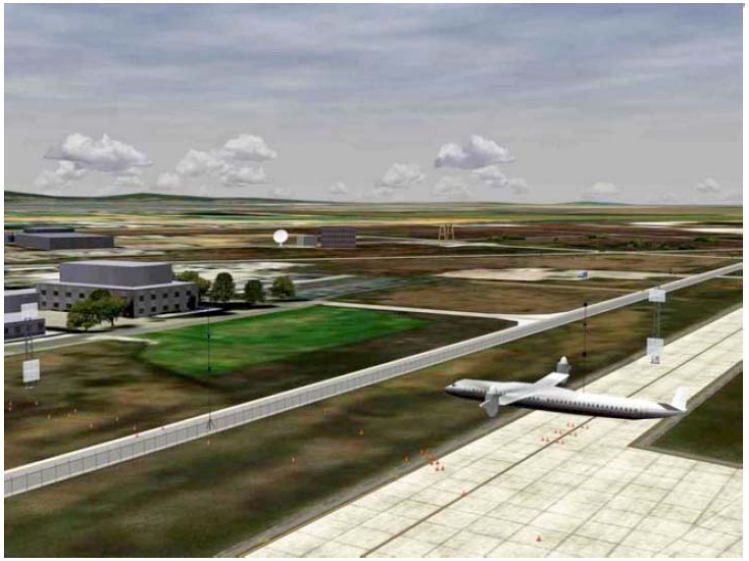
On-Going

- ZFL, Army, Sikorsky Individual Blade Control
- FAA, drive system health monitoring
- Army slowed rotor research
- Army, Sikorsky UH-60 Airloads research
- JAXA active rotor prediction and test
- Army, Joint Heavy Lift
- Army, AFRL, acoustic flight research@ White Sands
- Sikorsky, internal acoustics, sidewall transmission study
- Army, Active Twist Rotor
- Army, PSP, PIV and PMI
- KIST, oil-free engine technology
- UTRC, advanced compressor research
- CRI, rotorcraft icing
- OSD, Survivability
- ONERA, Active Flow Control on fuselage

Under Negotiation

--HART III active twist rotor

--Sikorsky, impact resistance, icing



SMART Rotor Demonstration 2008

Partnership with DARPA, Boeing, Army, Air Force, UMD, MIT

Objective

Assess use of active flap to improve performance and reduce vibration and noise.

Approach

Complementary approach to IBC rotor for active rotor control. Full-scale MD 900 rotor tested in the NFAC.

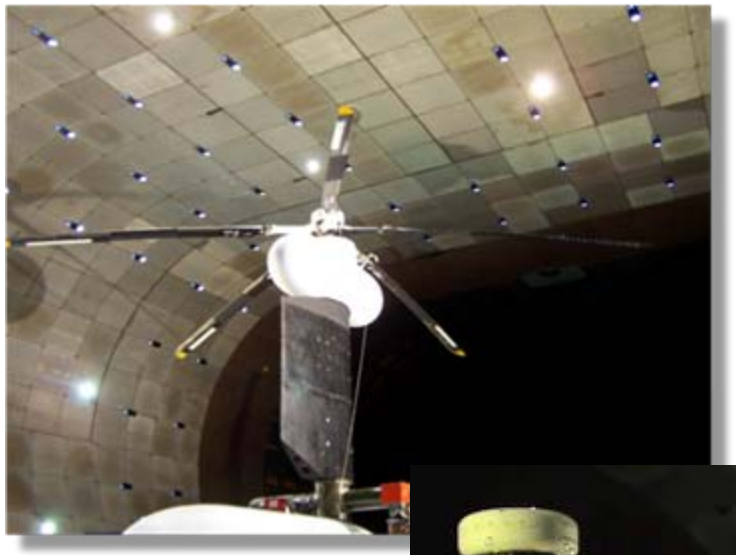
- Open and closed-loop flap control
- "SMART" piezo-electric material actuators move the flap
- 3 deg flap displacement

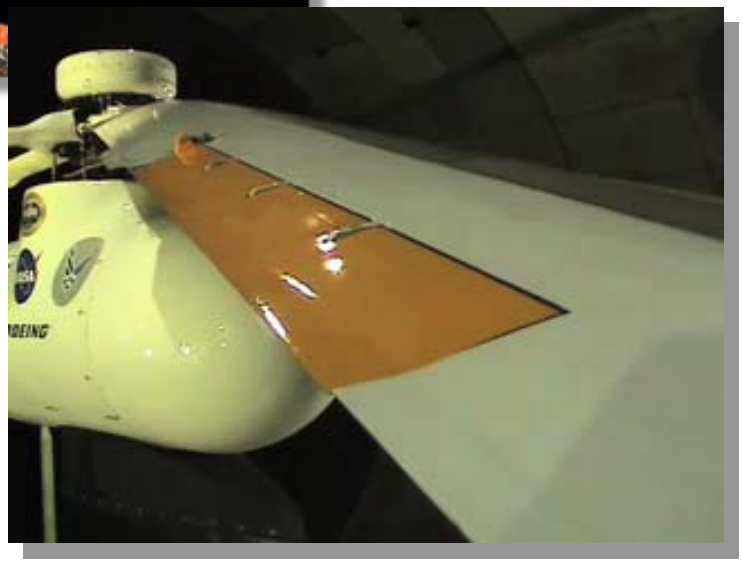
Impact

Measurements show some types of noise reduced by 50%

Hub vibration reduced

Proof-of-concept of blade deformation measurement for full-scale blades





Winner American Helicopter Society 2009 Howard Hughes Award for fundamental research

IBC Rotor Demonstration 2009

Partnership with Army, Sikorsky, ZFL

Objective

Assess Individual Blade Control (IBC) approach to improve performance and reduce vibration and noise.

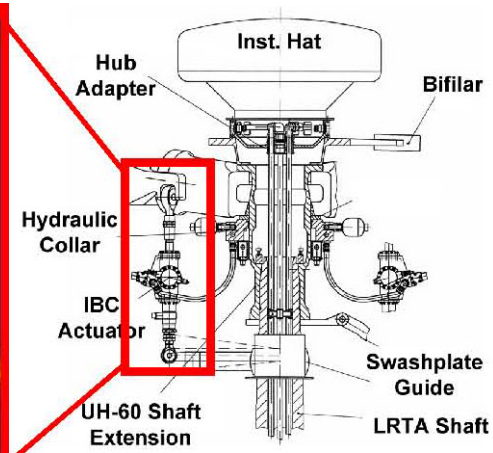
Approach

IBC dynamic actuators allow $\pm 3^{\circ}$ blade pitch to be input to each blade at up to 7/rev frequency on full-scale UH-60A rotor in NFAC

- Closed-loop rotor trim control system
- Open and closed-loop IBC controllers (adaptive and non-adaptive algorithms searched for optimum IBC input control)

Impact

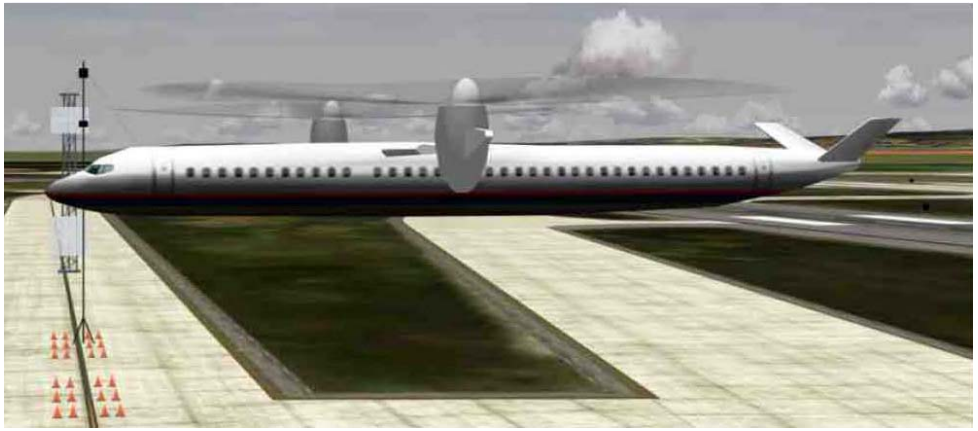
Preliminary data show power reductions of 5%, increased L/De of 8%, reduced in-plane noise, & multi-parameter hub load reductions. In-flight tuning capability validated. These data are the first time IBC concept has been evaluated for constant trim conditions.



Rotating Hardware Schematic

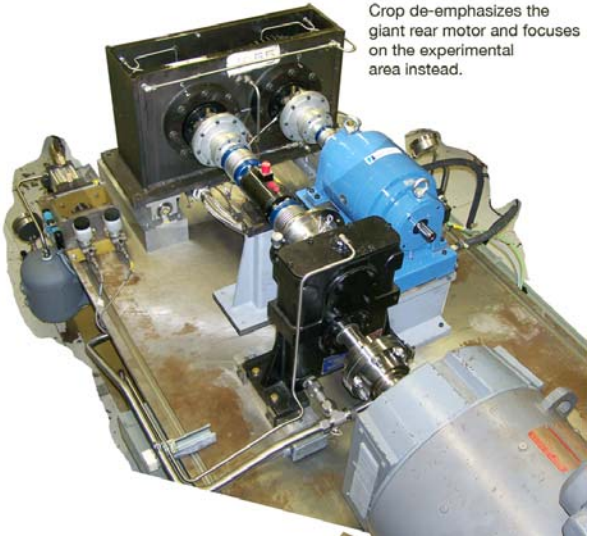
Control of Large Civil Rotary Wing Transports

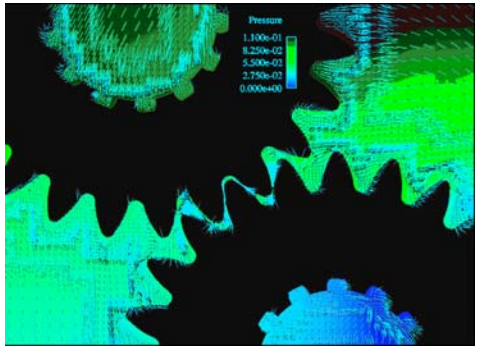
- July 2009 at Ames Research Center
- Partnership with US Army
- Examine lateral handling qualities for large rotary wing transports
- Determine pilot response to large vehicle dynamics
- Assess aspects of operation of large rotary wing vehicles in terminal areas
- Second simulation entry for LCTR2

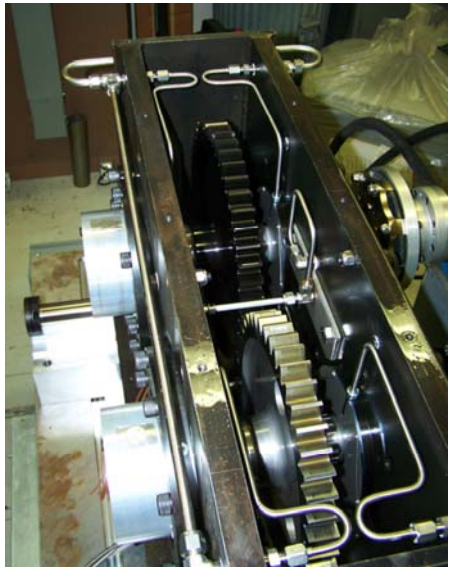


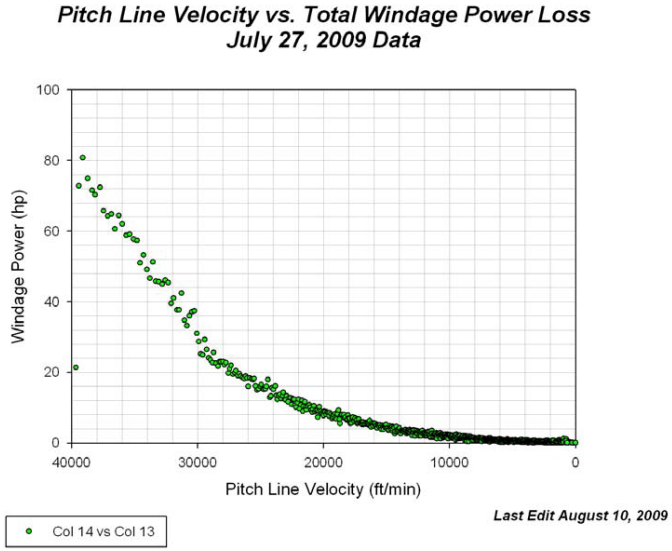
Gear Windage Research

- Windage exclusive facility designed, fabricated and on-line
- 50,000 ft/min pitch line velocities
- New and unique ability to isolate gear windage loss
- Experimental work closely coordinated with computational work under NRA sponsorship at Applied Research Lab (ARL)/Penn State
- Additional hardware under fabrication



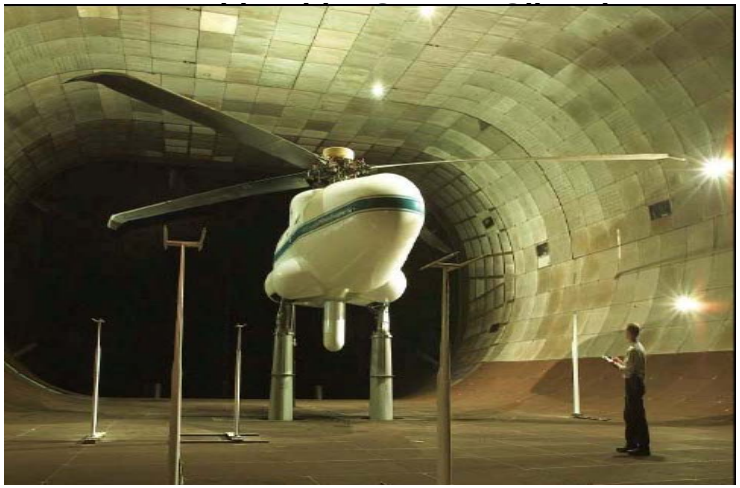




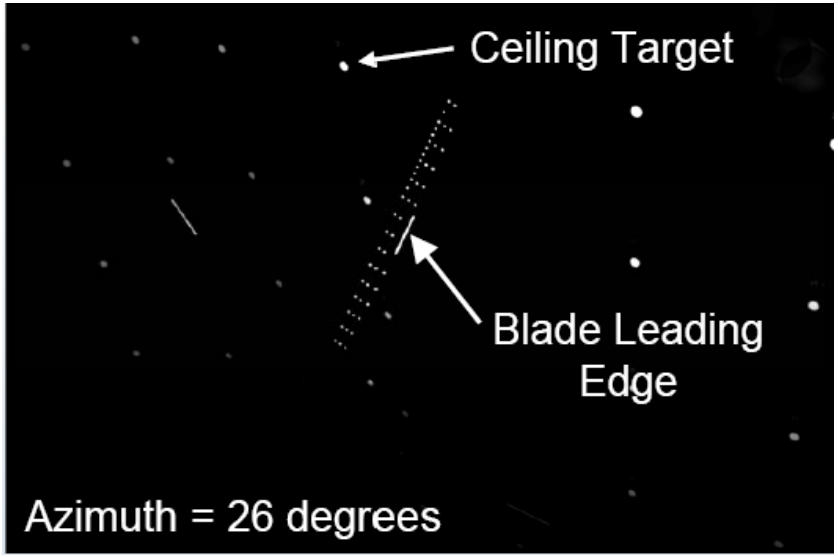


Upcoming Activities in Rotary Wing Research

- UH-60 Airloads in NFAC
  - FY10 NFAC test to create a full database of airloads, blade deflections, and wake properties for a full-scale UH-60 rotor.
  - One-of-a-kind experimental data set for validation of physics-based predictive capabilities for rotorcraft aeromechanics
  - Photogrammetric measurements of blade deflections
  - Large field-of-view PIV measurements of wake
  - Time-accurate blade pressures using surface measurements
  - Full forces, moments, torque using Large Rotor Test Apparatus (LRTA)



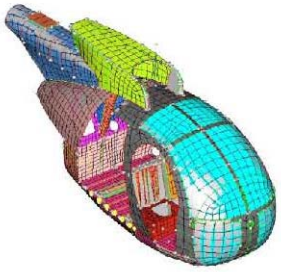
LRTA in NFAC with UH-60 rotor

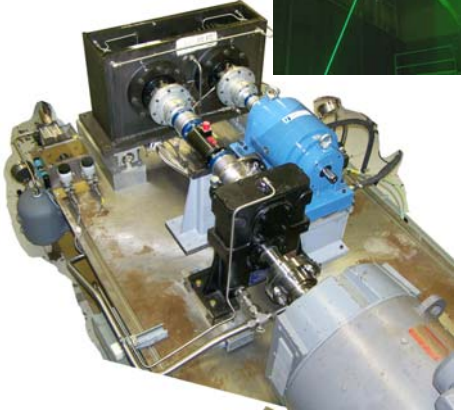


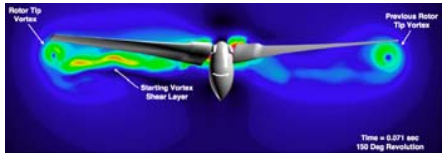
Photogrammetry targets and rotor blade in NFAC

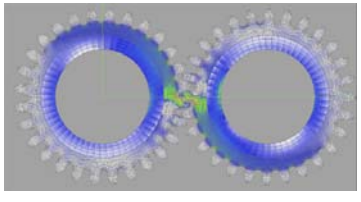
Upcoming Activities (2)

- Acoustics flight test for low noise approach database
- First release of new civil rotorcraft design sizing tool, NDARC
- Icing investigation in Icing Research Tunnel
- Advanced compressor design and fab under NRA
- Gear windage studies completed
- Full Scale Crash testing with torso model
- Hover testing for Outwash/Downwash









Publications Summary

- 94 papers
  - 9 Journal
  - 52 Conference
  - 9 NASA Reports
  - 12 Non-NASA contractor / NRA
  - 12 others
    - Invited
    - Workshops
    - Overviews
    - …
- 1 Patent
  - US Patent # 7,518,234, entitled, "MEMS Direct Chip Attach Packaging Methodologies and Apparatuses for Harsh Environments," was awarded April 14, 2009.
- Journal papers
  - Journal of Engineering for Gas Turbines and Power
  - 3 – AIAA Journal of Aircraft
  - 2 – Journal of Aerospace Engineering
  - 2 – Journal of the American Helicopter Society
  - Ceramics International
- Conference papers
  - 37 – 65th AHS Forum, Grapevine, TX, May 27-29, 2009
  - 7 – AHS Specialist meetings
    - Condition Based Maintenance, Feb 2009, Huntsville, AL
    - Next Generation Vertical Lift Technologies, Oct. 15-17, 2008, Dallas, TX

Publication Titles and Venue in Backup Charts

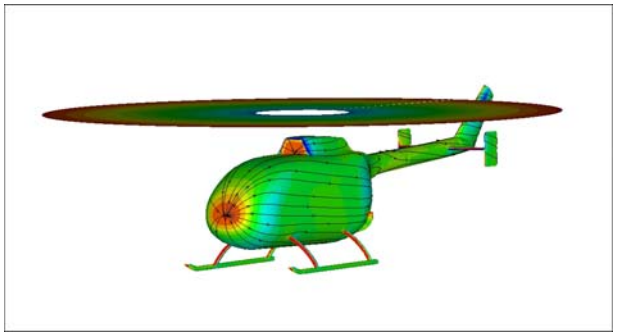
Upcoming Sessions

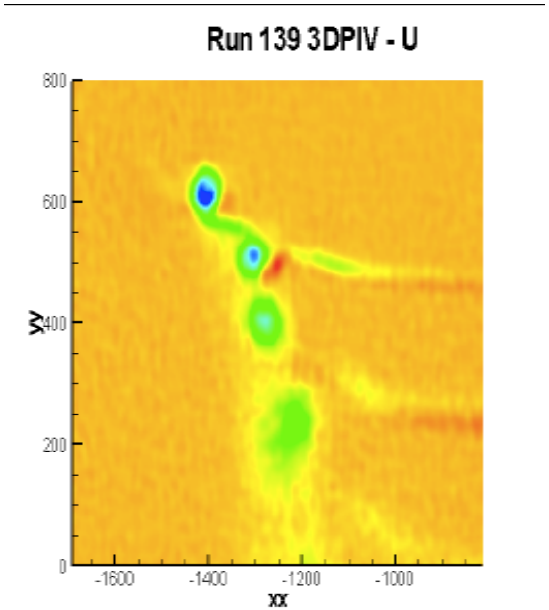
Tuesday Afternoon:	**Propulsion**
Wednesday Morning:	**Acoustics** **Structures and Materials**
Wednesday Afternoon:	**Flt Dynamics and Control** **Multi-Disciplinary Analysis**
Thursday Morning:	**Experimental Capabilities** **Aeromechanics (1)**
Thursday Afternoon:	**Aeromechanics (2)** **Feedback session 3:30-4pm**

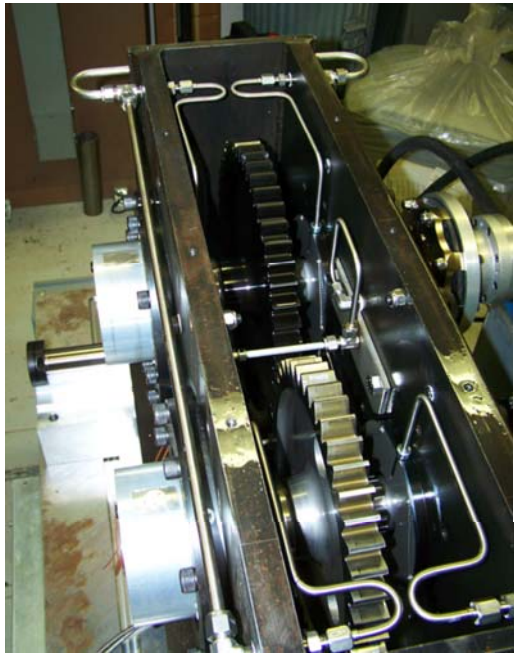
Summary

- Subsonic Rotary Wing is focused on the civil benefits of rotary wing concepts in the NextGen Airspace, particularly high-speed rotorcraft transport concepts

- Significant progress being made towards Technical Challenges through in-house research, partnerships, and sponsored research







Publications

Publication	Presented/Published
Summary of Research to Implement CBM for a Grease Lubricated Bearing from the Army's AH-64 Helicopter	American Helicopter Society's Condition Based Maintenance Specialist's Meeting hosted by the Huntsville Redstone Chapter, Feb 2009
High Pressure Performance of Foil Bearings in Various Gases	Proceedings of IJTC 2008: International Joint Tribology Conference. Miami, FL, October 20-22
Design, Fabrication, and Performance of Foil Gas Thrust Bearings for Microturbomachinery Applications	1 October 2008, in Journal of Engineering for Gas Turbines and Power (Vol.131, Iss.1): URL: http://link.aip.org/link/?GTP/131/012301
Data Fusion Applied to Health Monitoring of Dynamic Mechanical Components	2009 Wind Turbine Reliability Workshop, June 17-18, 2009, Albuquerque, NM
Assessment of composite delamination self-healing"	23rd American Society for Composites Technical Conference in Memphis, TN, September 9-10,
Overset Solution Adaptive Grid Approach Applied to Hovering Rotorcraft Flows	27th AIAA Applied Aerodynamics Conference, San Antonio, TX, June 22-25, 2009, AIAA Paper No. 2009-3519, June 2009
Discrete Adjoint-Based Design Optimization of Unsteady Turbulent Flows on Dynamic Unstructured Grids	27th AIAA Applied Aerodynamics Conference, San Antonio, TX, June 22-25, 2009, AIAA Paper No. 2009-3802 June 2009
Joining and Integration of Silicon Nitride Ceramics for Aerospace and Energy Systems	33rd International Conference & Exposition on Advanced Ceramics & Composites (ICACC), Daytona Beach, FL during January 17-23, 2009
Modeling of Thermal Residual Stresses in Environmental Barrier Coated Silicon Nitride	33rd International Conference & Exposition on Advanced Ceramics & Composites (ICACC), Daytona Beach, FL during January 17-23, 2009
Modeling the Human Pilot Controlling a Rotorcraft With Time-Varying Dynamics	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Developing Soil Models for Dynamic Impact Simulations	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Evaluation of Material Models within LS-DYNA™ for Kevlar-129 Fabric/Epoxy	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Characterization of Triaxial Braided Composite Material Properties for Impact Simulation	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Blade-Vortex Interaction Noise Characteristics of a Full-Scale Active Flap Rotor	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Reduced In-Plane Low Frequency Helicopter Noise Using an Active Flap Rotor	65th AHS Forum, Grapevine, TX, May 27-29, 2009

Publications

Publication	Presented/Published
VTOL Aircraft Thrust Control	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Correlation of SMART Active Flap Rotor Loads	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Dynamics and Active Flap Control of the SMART Rotor	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Signal Detection Theory Applied to Helicopter Transmission Diagnostic Thresholds	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Experimental Determination of AH-64 Apache Tailshaft Hangar Bearing Vibration Characgteristics with Seeded Faults	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Gear Fault Detection Effectiveness As Applied to Tooth Surface Pitting Fatigue Damage	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Preliminary Axial Flow Turbine Design and Off-Design Performance Analysis Methods for Rotary Wing Aircraft Engines;I Validation	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Preliminary Axial Flow Turbine Design and Off-Design Performance Analysis Methods for Rotary Wing Aircraft Engines; II Applications	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Compressor Study to Meet Large Civil Tilt Rotor Engine Requirements	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Gas Turbine Characteristics for a Large Civil Tilt-Rotor	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Rotary-Wing Relevant Compressor Aero research and Technology Development Activities at Glenn Research Center	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Wind Tunnel Test of the SMART Active Flap Rotor	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Evaluation of Scaling Methods for Rotorcraft Icing	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Development of a Large Field of View PIV System for Rotorcraft Testing in the 14x22 Subsonic Wind Tunnel	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Full Scale Wing Tunnel Test of a UH-60 Individual Blade Control System for Performance Improvement and Vibration, Loads, and Noise Control	65th AHS Forum, Grapevine, TX, May 27-29, 2009
HART-II Acoustic Predictions using a Coupled CFD/CSD Method	65th AHS Forum, Grapevine, TX, May 27-29, 2009

Publications

Publication	Presented/Published
Three-Dimensional Finite Element Formulation and Scalable Domain Decomposition for High Fidelity Rotor Dynamics Analysis	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Double Helical Gear Performance in High Speed Helical Gear Trains	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Face Gear Development Under the Rotorcraft Drive System for the 21st Century Program	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Development of Life Prediction of Erosion Resistant Turbine Low Conductivity Thermal Barrier Coatings	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Simulation of an Isolated Tiltrotor in Hover with an Unstructured Overset-Grid RANS Solver	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Adjoint Based Design of Rotors Using the Navier-Stokes Equations in a Noninertial Reference Frame	65th AHS Forum, Grapevine, TX, May 27-29, 2009
An Investigation of Rotorcraft Stability-Phase Margin Requirements in Hover	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Foil Bearing Starting Considerations and Requirements for Rotorcraft Engine Applications	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Advancements Toward Oil-Free Rotorcraft Propulsion	65th AHS Forum, Grapevine, TX, May 27-29, 2009
A Navier-Stokes Simulation of a Heavy Lift Slowed-Rotor Compound Helicopter Configuration	65th AHS Forum, Grapevine, TX, May 27-29, 2009
A Physics-Based Investigation of Gurney Flaps for Rotor Noise and Vibration Reduction	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Measurements and XFD-Based Acoustic Computations of Experimentally Simulated Blade Vortex Interaction (BVI) Noise	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Thermohydrodynamics Model Predictions and Performance Measurements of Bump-type Foil Bearing for Oil-Free Truboshaft Engines in Rotorcraft Propulsion Systems	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Integration Technologies for Silicon Nitride Based Ceramic Systems for Advanced Rotorcraft Applications	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Modeling the Human Pilot Controlling a Vehicle with Time-Varying Dynamics	65th AHS Forum, Grapevine, TX, May 27-29, 2009
Overview of NASA FAP	AHS Specialist meeting, Dallas, TX, Oct 15-17, 2008
VTOL Aircraft Thrust Control	AHS Specialist meeting, Dallas, TX, Oct 15-17, 2008

Publications

Publication	Presented/Published
Blade Loading Criteria for Heavy Lift Tiltrotor Design	AHS Specialist meeting, Dallas, TX, Oct 15-17, 2008
Aeroelastic Stability of the LCTR2 Civil Tiltrotor	AHS Specialist meeting, Dallas, TX, Oct 15-17, 2008
A Candidate Structure for Modeling Pilot Control Behavior with Sudden Changes in Vehicle Dynamics	AIAA Atmospheric Flight Mechanics Conference and Exhibit, Aug. 10-13, 2009, Chicago, Illinois
Evaluation of Two High-Order Weighted Essentially Nonoscillatory Schemes	AIAA J, Vol. 46, No. 12, Dec. 2008, pp. 3090-3102
Coupled CFD and Particle Vortex Transport Method: Wing Performance and Wake Validations	AIAA Journal of Aircraft submission
A Candidate Structure for Modeling Pilot Control Behavior with Sudden Changes in Vehicle Dynamics	AIAA Journal of Aircraft
"Flow Characteristics of Tip-Injection on Compressor Rotating Spike via Time-Accurate Simulation	AIAA Journal of Aircraft submission
Suggar++: An Improved General Overset Grid Assembly Capability	AIAA-2009-3992 ,19th AIAA Computational Fluid Dynamics, San Antonio, Texas, June 22-25, 2009
CFD/CSD Based Aeroelasticity Of Rotor Blades Using a Modular Approach	AIAA-2009-4119, AIAA 39th Fluid Dynamics Conf. June 2009
Unsteady Full Annulus Simulations of a Transonic Axial Compressor Stage	AIAA/ASM conference
"Evaluation of Pd-Based Brazes to Join Silicon Nitride to Copper-clad-Molybdenum	Ceramics International, published by Elsevier
"Development and Validation of a Finite Element Simulation of a Vertical Drop Test of an ATR 42 Regional Transport Airplane	DOT/FAA/AR-08/19, June 2008
Progress Towards Modeling the Effects of Ice Accretion on Rotorcraft Performance.	European Rotorcraft Forum in Hamburg, Germany, 22-25 September, 2009
Analytical Assessment of Performance, Handling Qualities, and Added Dynamics in Rotorcraft Flight Control	IEEE:SMC-A in January 2009
Analytical Assessment of Performance, Handling Qualities, and Added Dynamics in Rotorcraft Flight Control	IEEE:SMC-A in January 2009
Pilot-Centered Handling Qualities. Assessment for Flight Control Design	invited session at the AIAA Atmospheric Flight Mechanics Conference Chicago, August, 2009

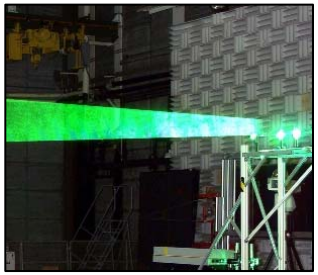
Publications

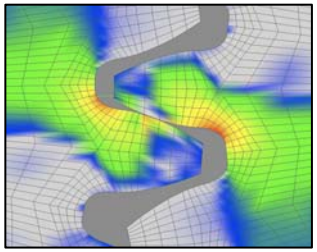
Publication	Presented/Published
Recent Enhancements To The FUN3D Solver For Moving Mesh Applications	Jan 2009 Aerospace Sciences Meeting AIAA 2009-1360
Joining of Silicon Carbide: Diffusion Bond Optimization and Characterization	Joining of Advanced and Specialty Materials X (JASM) Symposium of the Materials Science and Technology 2008 Conference and Exhibition, Pittsburg, PA, Oct. 5-9, 2008
Overview of the NASA Subsonic Rotary Wing Aeronautics Research Program in Rotorcraft Crashworthiness	Journal of Aerospace Engineering, Special Issue on Ballistic Impact and Crashworthiness of Aerospace Structures, July 2009, Volume 22, No 3, pp229-239.
Overview of the NASA Subsonic Rotary Wing Aeronautics Research Program in Rotorcraft Crashworthiness	Journal of Aerospace Engineering, Special Issue on Ballistic Impact and Crashworthiness of Aerospace Structures, September 26, 2008
Performance Analysis of the Slowed -Rotor Compound Helicopter Configuration.	Journal of the American Helicopter Society, Vol 54, No 2, April 2009, pp 022002-1-022002-12
Variable/Multi-Speed Rotorcraft Drive System Concepts	March 2009 under NASA/TM-2009-215456 / ARL-TR-4758
Compressor Study to Meet Large Civil Tilt Rotor Engine Requirements	NASA, TM-2009-215641, August 2009
Framework for Multidisciplinary Analysis, Design and Optimization with High-Fidelity Analysis Tools	NASA CR-2009-215563, February 2009.
Tiltrotor visualization techniques	NASA Supercomputing 2008 Conference, Austin TX
NASA PS400: A New High Temperature Solid Lubricant Coating for High Temperature Wear Applications	NASA TM-2009-215678, August 2009
Design of Quiet Rotorcraft Approach Trajectories	NASA TM-2009-215771, July 2009
FUN3D Code Developement Activities	NASA/Boeing, Unstructured Grid Technology Interchange on Sept. 22-24, 2008 Seattle, WA
FUN3D Time-Accurate and Rotary Wing Activities	NASA/Boeing, Unstructured Grid Technology Interchange on Sept. 22-24, 2008 Seattle, WA
Preliminary Axial Flow Turbine Design and Off-Design Performance Analysis Methods for Rotary Wing Aircraft Engines; I-Validation	NASA/TM—2009-215651/PART1
Preliminary Axial Flow Turbine Design and Off-Design Performance Analysis Methods for Rotary Wing Aircraft Engines; IIApplications	NASA/TM—2009-215651/PART2

Publications

Publication	Presented/Published
Report on the Joint Eglin Acoustic Week III	Presented at the American Helicopter Society Next Generation Vertical Lift Technologies Specialist Meeting, Oct. 15-17, 2008, Dallas, TX
Aeroelastic Stability of the LCTR2 Civil Tiltrotor	Presented at the American Helicopter Society Next Generation Vertical Lift Technologies Specialist Meeting, Oct. 15-17, 2008, Dallas, TX
Non-Proprietary Foil Gas Thrust Bearings for High Speed Turbomachinery	Publication in Tech Brief Magazine as LEW-18397-1
Vertical Drop Testing and Analysis of the WASP Helicopter Skid Gear	Submitted Journal of the American Helicopter Society, October 2008
Current Results of Testing PVD Coatings for Wave Bearings for Use in Aerospace-Transmissions	The Coatings Meeting, Oct 1-3, 2008, Kassándra, Greece
Tests of Bearings and Gears With PVD Coatings for Aerospace Transmissions; Results and Problems", A Keynote to 2008 "The Coatings" Meeting	The Coatings Meeting, Oct 1-3, 2008, Kassándra, Greece
JVX Proprotor Performance Calculations and Comparisons with Hover and Airplane-Mode Test Data	NASA TM-2009-215380
Aircraft System Analysis of Technology Benefits to Civil Transport Rotorcraft	NASA CR 2009-214594, June 2009
A Status of NASA Rotorcraft Research	NASA TP-2009-215369, September 2009
Intermetallic Nickel-Titanium Alloys for Oil Lubricated Bearing Applications	NASA TM-2009-215646

NASA Investment in Rotary Wing through American Recovery and Reinvestment Act + FY09 Augmentation Funding



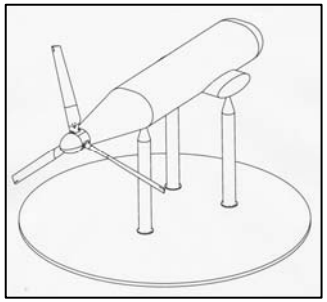


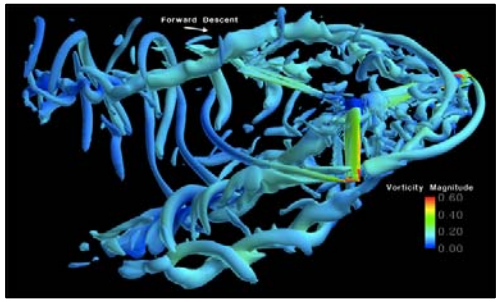
$2M Augmentation directed to Rotary Wing Technology

- Advanced rotary wing concepts in the NextGen
- Airframe/propulsion system integration trade studies
- High-Speed, full-scale aeromechanics research
- Advanced measurement and sensor investment
- Gear windage research

$11M ARRA directed to Rotary Wing Technology

- Investment in restoring large-scale tiltrotor testing capability for NFAC
  - Previous propeller test rig damaged in 1991
  - New Tiltrotor Test Rig (TTR) detailed design and fabrication started. Delivery expected 2011.
  - Joint investment with DOD/Army, Air Force
- Additional investment in large-scale test hardware and measurement capability

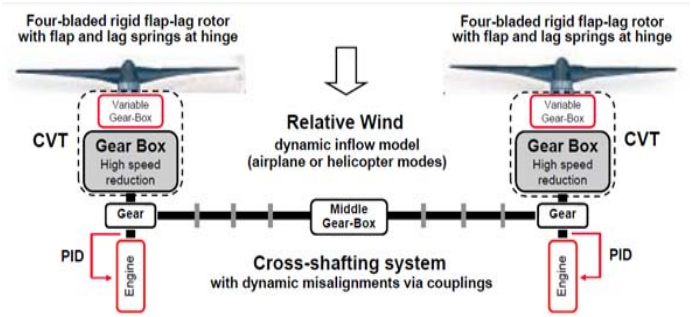


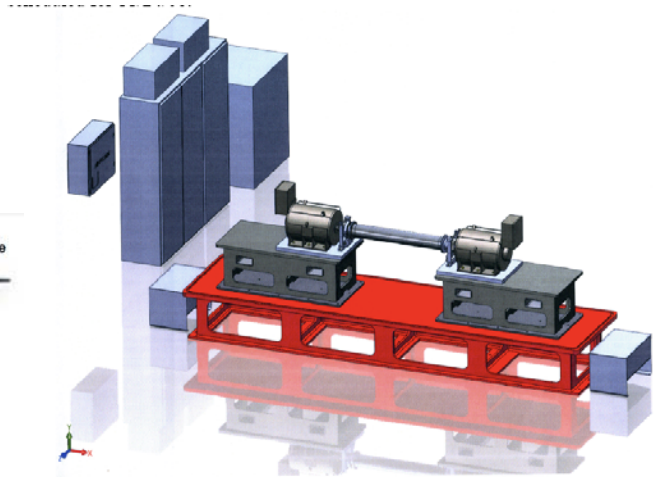


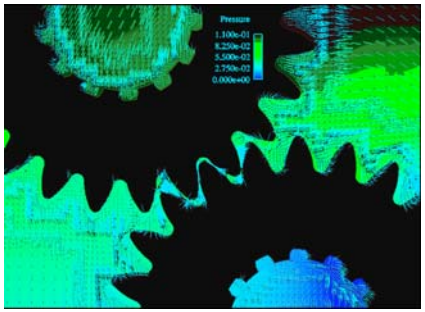
SRW Discipline: Propulsion

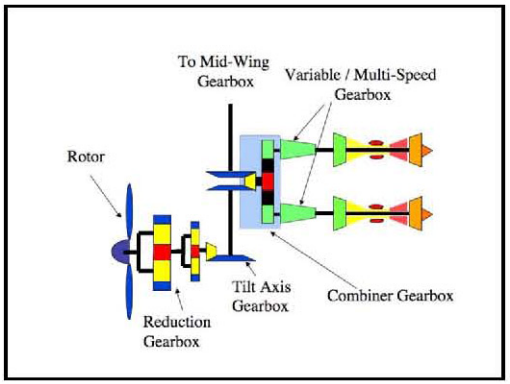
Advanced modeling tools/concepts essential to allow an engine/drive system to achieve a significantly larger speed range without sacrificing power and efficiency

- High efficiency, multi/variable-speed drive systems
- Efficient, variable-speed turbomachinery

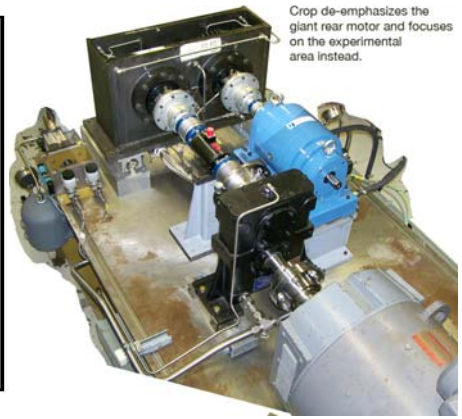








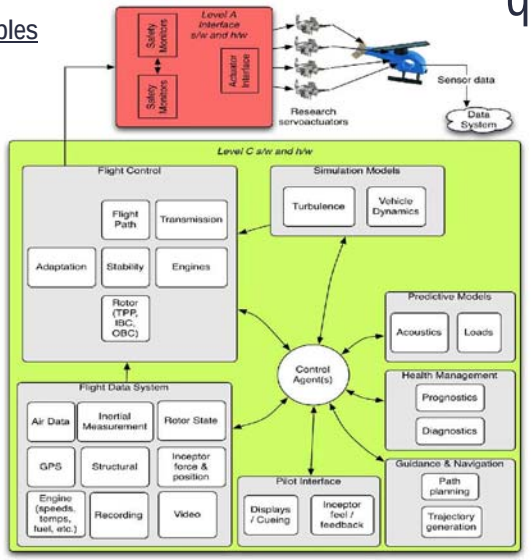
Conceptual variable / multi-speed drive system for a tiltrotor aircraft



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 handling qualities for large rotorcraft.

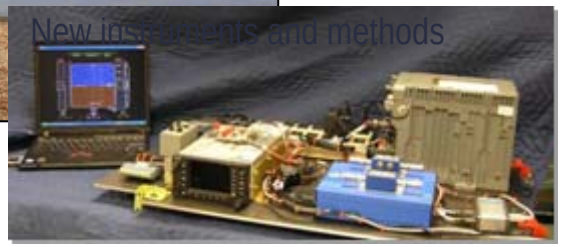
First-Principles Modeling



Testing (simulation and flight)

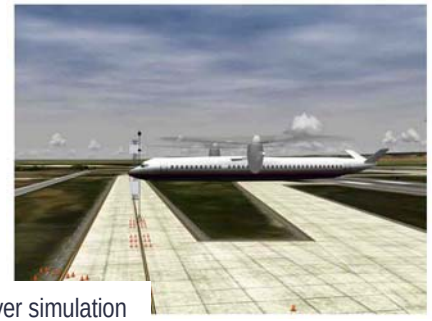
Aris/Bell 206 Helicopter, Hollister, CA

New instruments and methods



Validation

Assessment of Flight Procedures in Vertical Motion Simulator

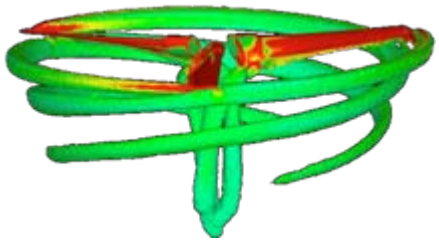


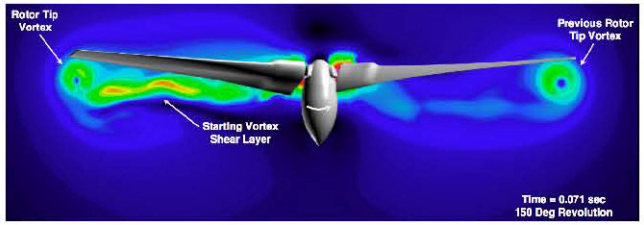
LCTR2 precision hover simulation

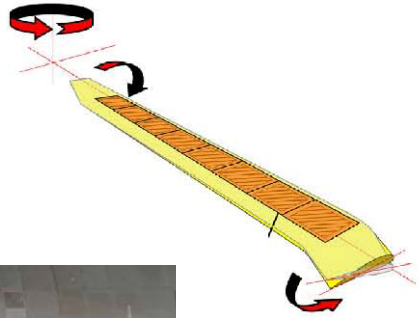
SRW Discipline: Aeromechanics

Rotorcraft aeromechanics research extends from first-principles modeling through testing and validation for isolated and multi-disciplinary phenomena. Particular emphasis on: active rotors (active flaps, active twist, IBC), active flow control, CFD modeling and coupling (structured and unstructured), icing

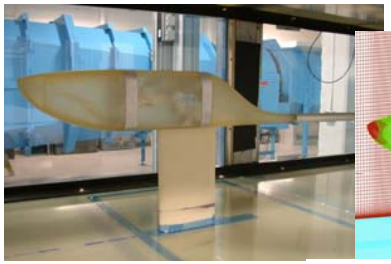
First-Principles Modeling

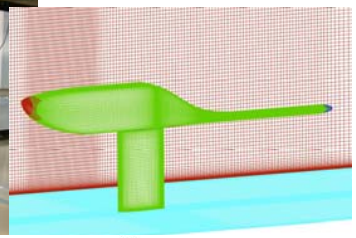






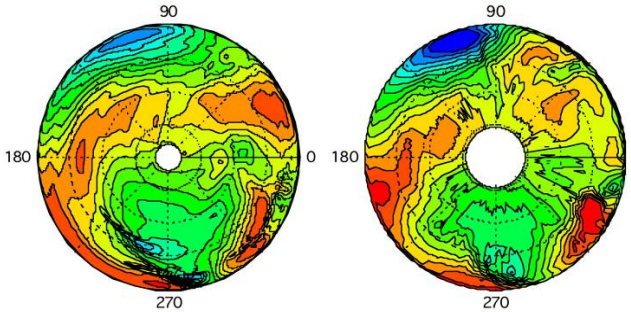
Testing (small, large and full-scale)





Validation

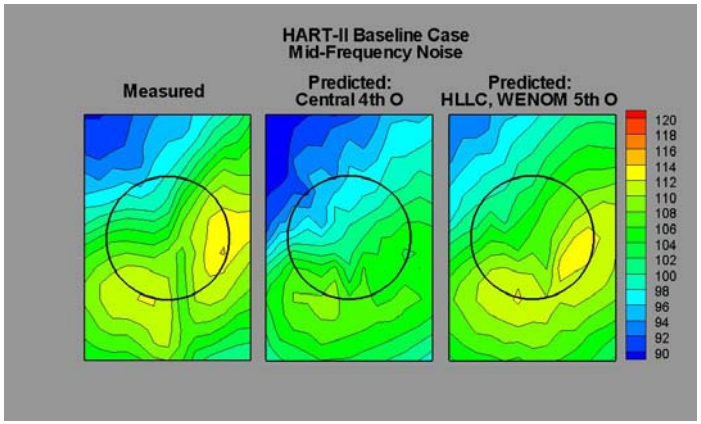
Coupled Solution

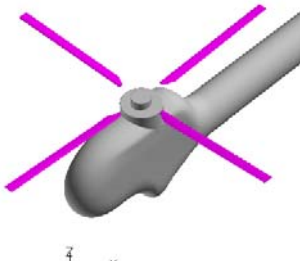


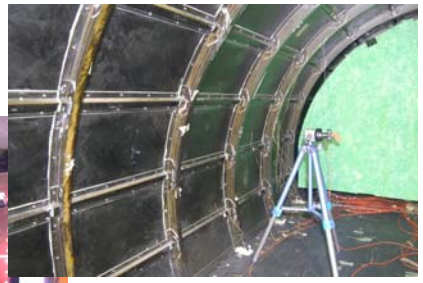
Flight Test

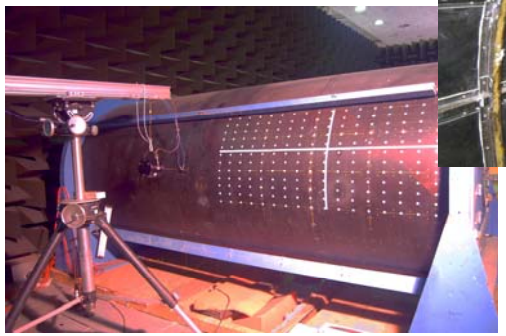
SRW Discipline: Acoustics

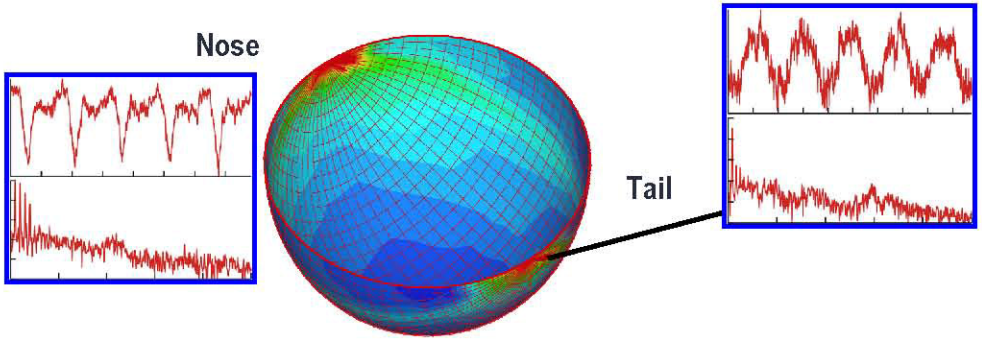
Rotorcraft acoustics research focus includes the study and control of source noise, interior noise, gear noise, community acceptance, low frequency effects, and concepts for low-noise operations

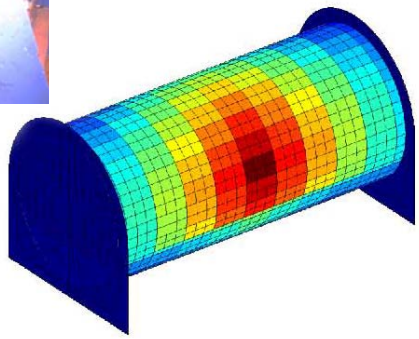






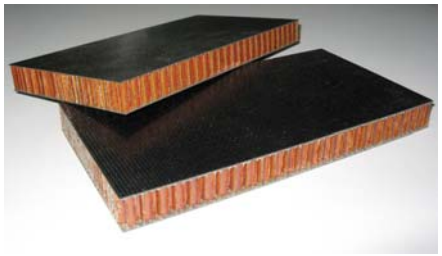


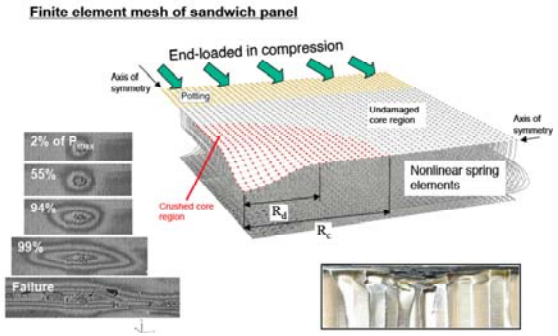


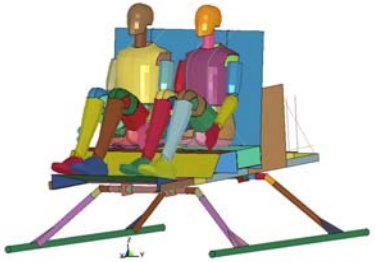


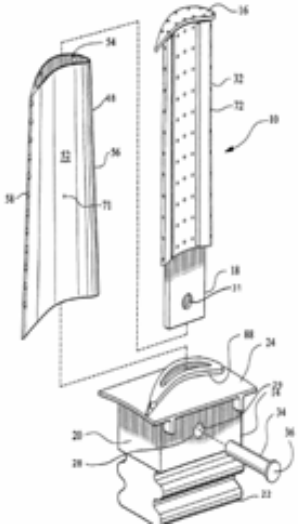
SRW Discipline: Material and Structures

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

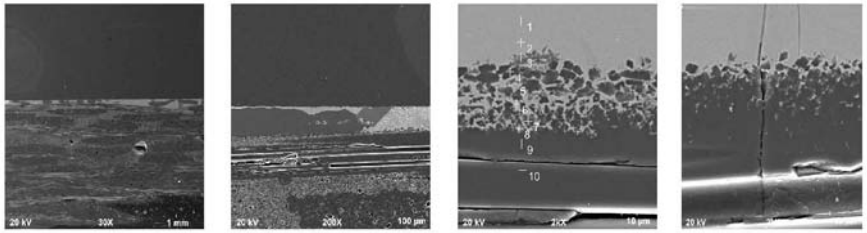








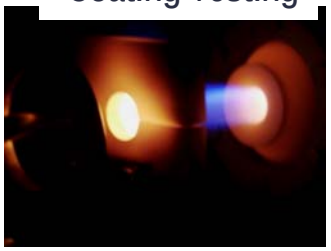
Hybrid turbine blade
Spar and Shell Concept



Electron images of Silicon Nitride joined to itself

Solid modeling of Little Bird MD500

Thermal Barrier
Coating Testing



Crash Analysis Validation

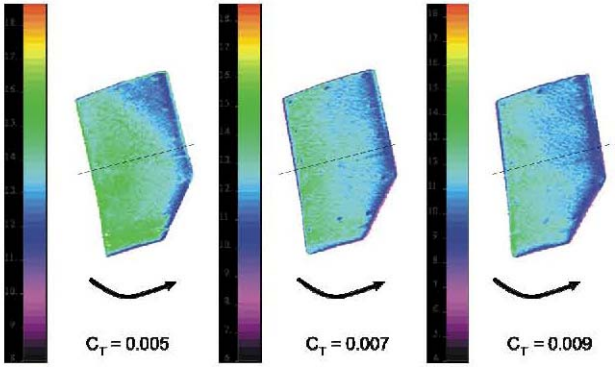
SRW Discipline: Experimental Capabilities

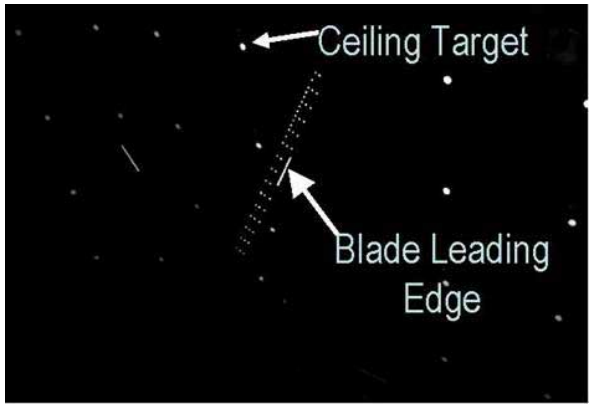
Experimental Capabilities development is essential for validation of aeromechanics, acoustics, structural response, and propulsion fundamental methods

Deformed blade geometry

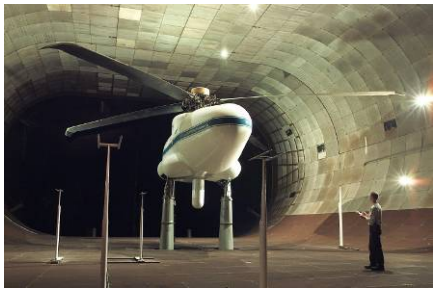
Large field rotor wake assessments

Blade/fuselage unsteady pressures



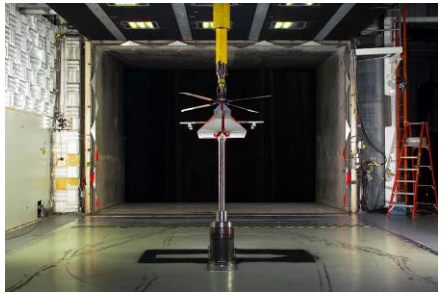


Targeted Primary NASA Rotorcraft Test Facilities



National Full-Scale Aerodynamics Complex

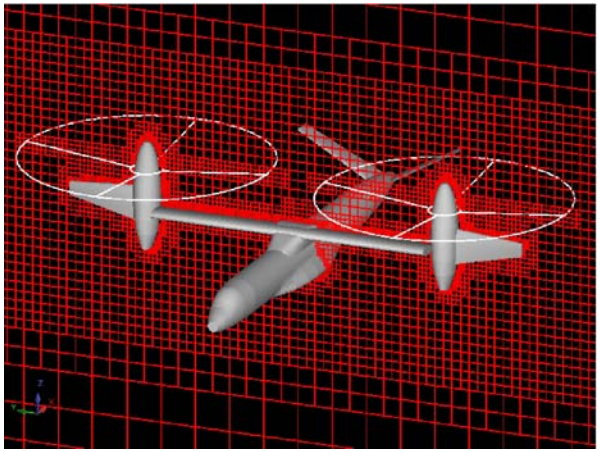
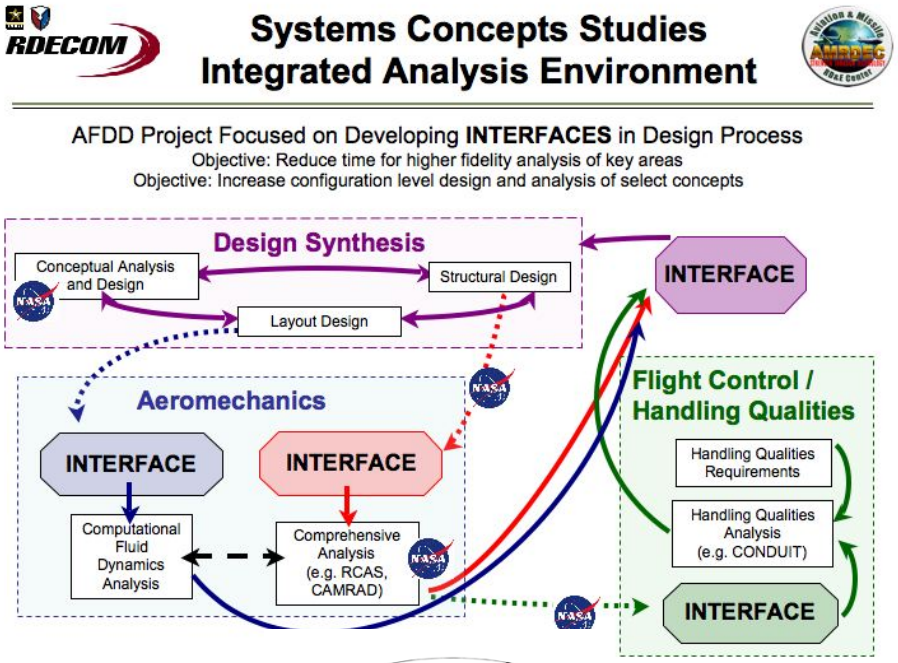
Transonic Dynamics Tunnel



14- by 22-Foot Subsonic Tunnel

SRW Discipline: Multi-Disciplinary Analysis and Technology Development

Provides a focal point for the integration of discipline technologies to guide fundamental research priorities. Analyses development at the system level and demonstrations of integrated components to enable advanced rotorcraft.

Elements

- Integrated Systems Technology Challenges
- Design and Analysis
  - Tools
  - Technology Assessments