National Aeronautics and Space Administration

Fundamental Aeronautics Program

Subsonic Rotary Wing Project Overview

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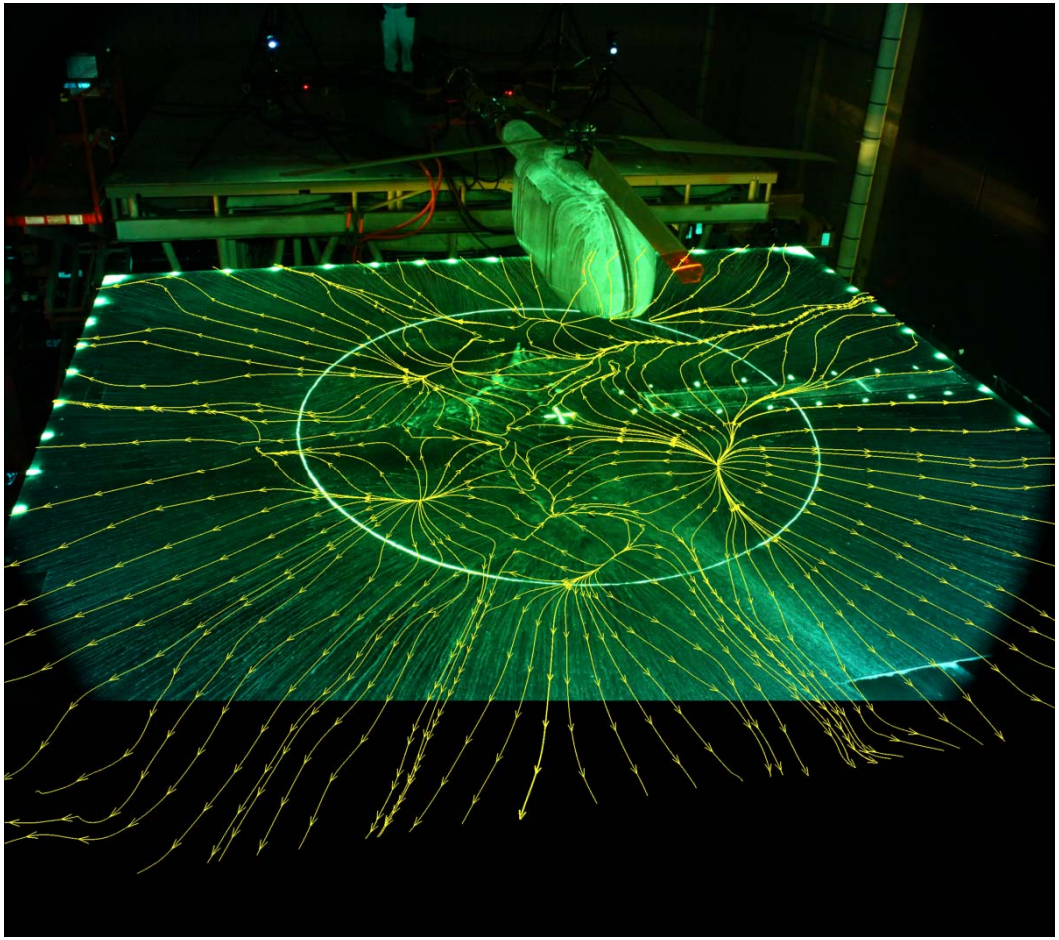
2012 Technical Conference
March 13-15, 2012

Outline

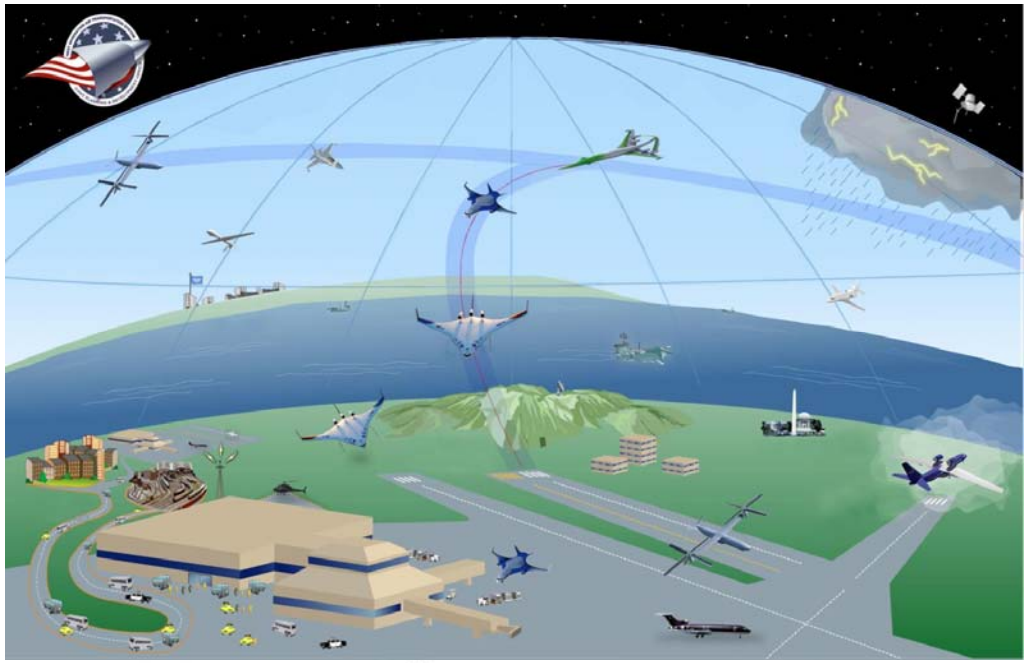
- Goals
- Objectives
- Technical Challenges
- Approach
- Project snapshot
- Recent success
- Meeting agenda
- Upcoming activities

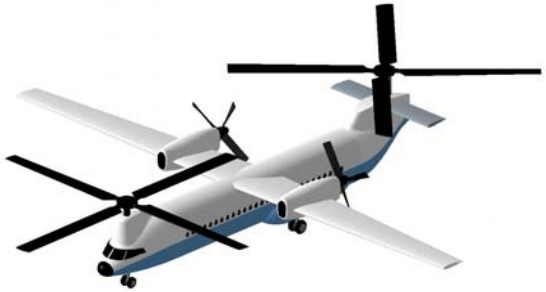


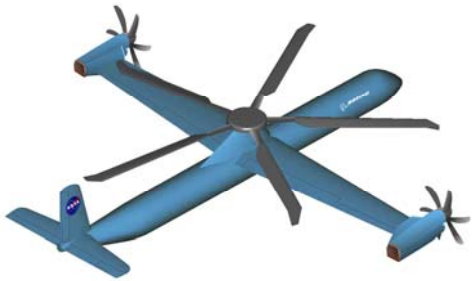
Rotor in hover ground effect. CFD streamlines superimposed on oil flow visualization

Subsonic Rotary Wing (SRW) Project

Goal: Enable radical changes in the transportation system through advanced concept rotary wing vehicles



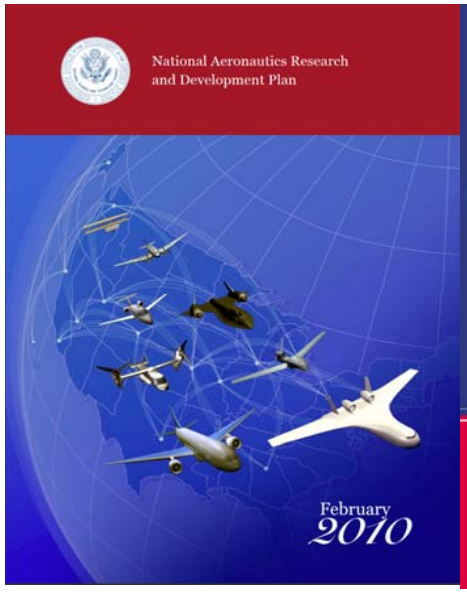


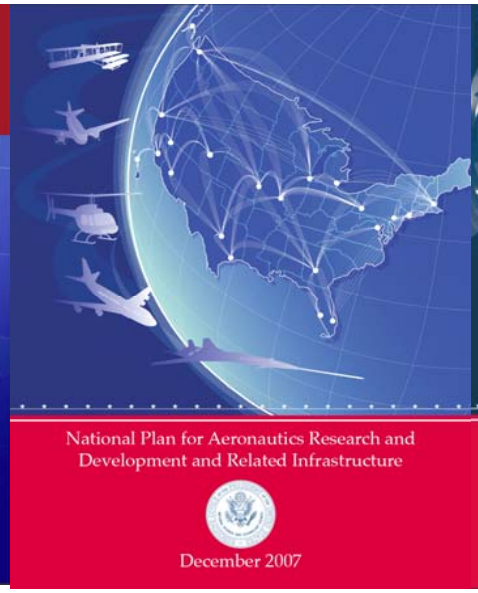


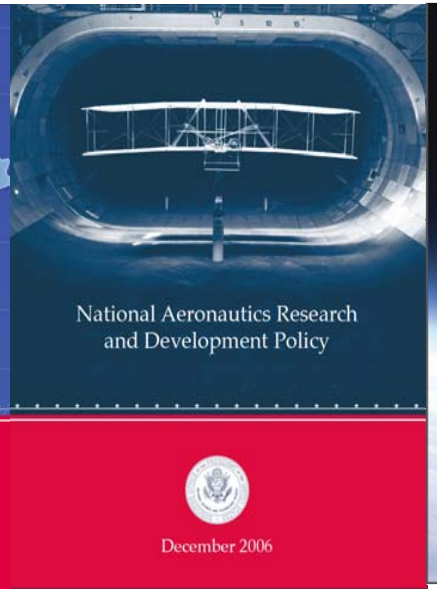
Subsonic Rotary Wing Project

Directed to focus on:

- NextGen Rotorcraft Developments
- Mobility / Capacity
- Efficiency
- Energy and Environment



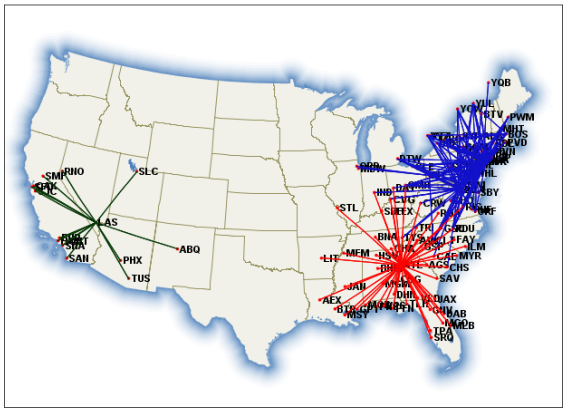




System Study Results

Recent System Studies:

- NASA Heavy Lift/ Large Civil Tiltrotor (LCTR2)
- Future Concepts in the NextGen
- Technology Benefit Assessment for Compound and Tiltrotor Systems
- Tiltrotor Fleet Operations in the NextGen



Status/Results

- Vertical capability at one or both ends of a 300-600nm mission increases airport capacity.
- Large, advanced technology tiltrotors consistently outpace other configurations in the ability to meet transportation mission
- Advanced technologies give tiltrotors cost and operational parity with configurations already in use
- **In latest 3 studies (2009, 2010, 2011) Civil tiltrotors show capability to improve airspace system performance significantly.**

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 350 fps

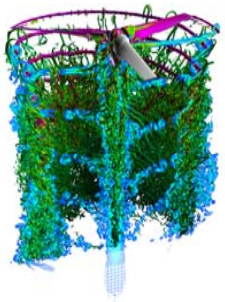
Reference: Acree, C. W., Hyeonsoo, Y., and Sinsay, J. D., "Performance Optimization of the NASA Large Civil Tiltrotor," NASA TM-2008-215359.

Subsonic Rotary Wing (SRW) Project

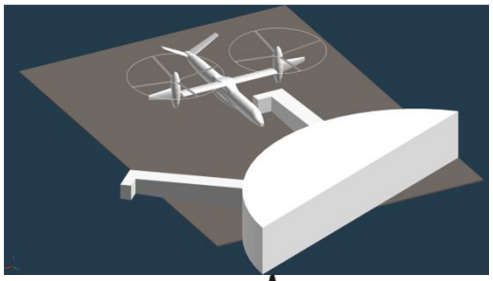
Objective: Identify enabling technologies and research areas applicable to many different advanced concepts and missions

Active Rotor Systems

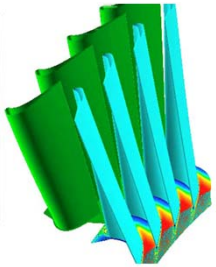
Modeling and Validation

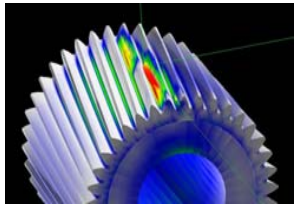


NextGen Integration

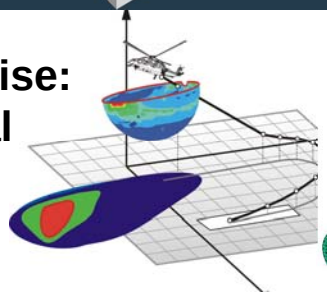


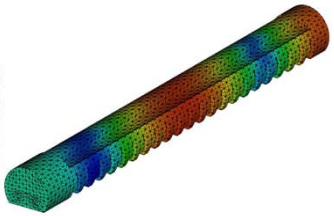
Propulsion System

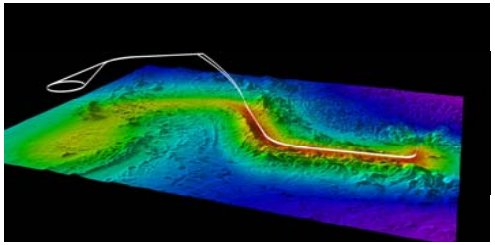




Low Noise: External and Internal







Subsonic Rotary Wing (SRW) Project

Technical Challenges: Areas to focus NASA research

SRW Technical Challenge Criteria

- Attacks a barrier issue for rotorcraft
- Challenges the State of the Art
- Reaches for the boundaries of the problem
- Provides long-term challenge but produces relevant technology to transition in the interim steps
- Benefits multiple configurations and multiple missions
- NASA has critical mass to accomplish major pieces
- Provides partnership opportunity for gaps

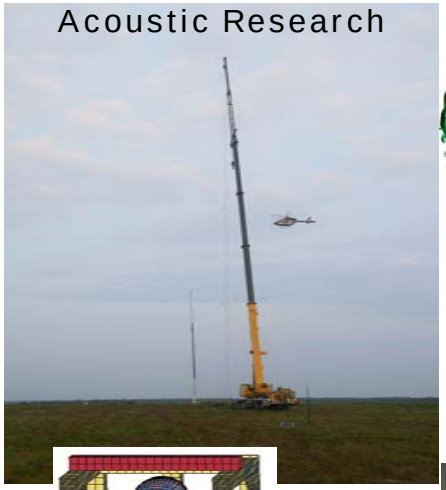
Industry	DOD 6.1/6.2/6.3/6.4	NASA (TRL 1-6)	University	
0-5 years	5-15 years	10-20 years	15-25 years	Time to Entry in Service

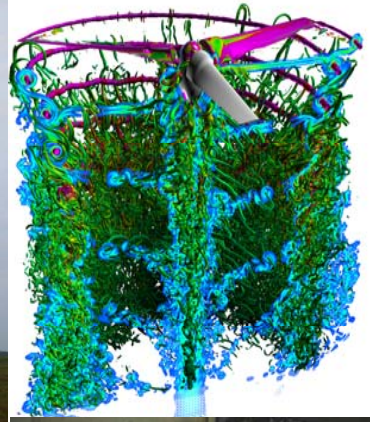
2012 SRW Technical Challenges

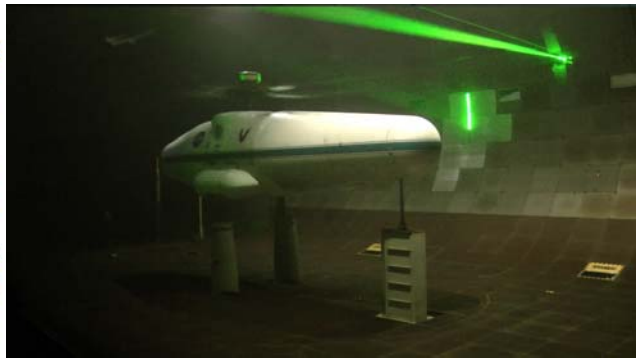
- Integrated Aeromechanics/Propulsion System (IAPS): Develop and demonstrate technologies enabling variable-speed rotor concepts
  - Goal: 50% main rotor speed reduction while retaining propulsion efficiency
- Actively-Controlled, Efficient Rotorcraft (ACER): Simultaneously increase aerodynamic efficiency, control dynamic stall, reduce vibration, reduce noise
  - Goal: 100 kt speed improvement over SOA; noise contained within landing area; 90 pax /10 ton payload
- Quiet Cabin (QC): Reduce interior noise and vibration
  - Goal: Internal cabin noise at level of regional jet with minimal weight penalty
- NextGen Rotorcraft: Foster, develop and demonstrate technologies that contribute to the commercial viability of large rotary wing transport systems in NextGen.
  - Goal: mature technologies (icing, crashworthiness, condition based maintenance, low noise flight operations, damage mitigation, etc) needed for civil, commercial operations
- High Fidelity Validated Design Tools: Develop the next generation comprehensive rotorcraft analysis and design tools using high-fidelity models.
  - Goal: first-principles modeling in all disciplines; tools scalable to many processors

Subsonic Rotary Wing (SRW) Project

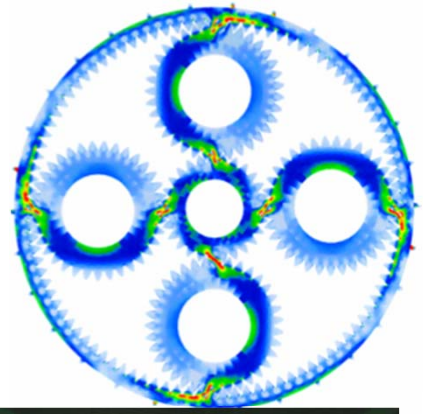
Approach: Analytical, computational, and experimental research that is multi-platform, multi-discipline, rigorous, innovative, relevant, forward-thinking, and pushes the State-of-the-Art

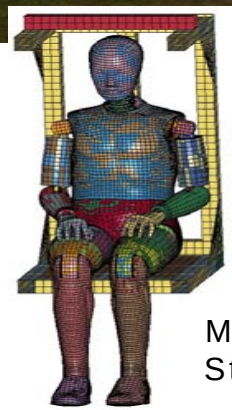




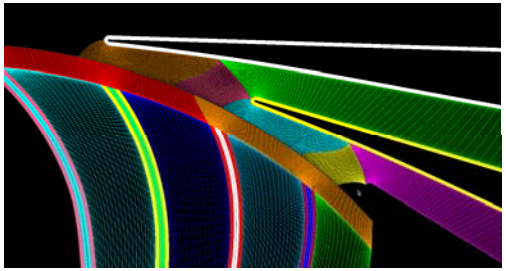


Mechanical Components





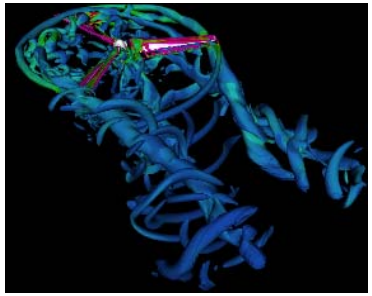
Materials & Structures



Engine Research

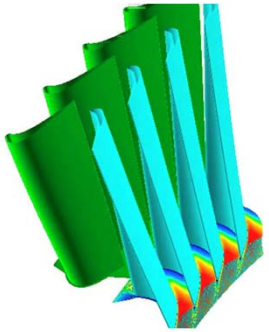
New instruments and techniques

Subsonic Rotary Wing Project Team



FY12 SRW Project Summary

~133 work/years (108 CS / 25 Contractor)
~ $28M per year (includes salary)
Work across 3 NASA Centers



Ames Research Center
~40 work/years

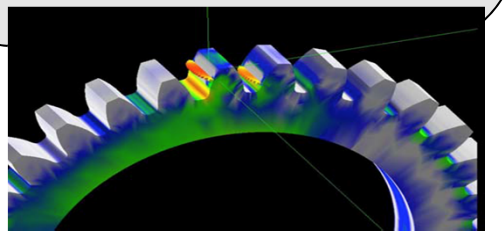
- **Aeromechanics**
- **CFD**
- **Flt Dyn & Ctrl**
- **Acoustics**
- **Exp Capability**
- **System Analysis**

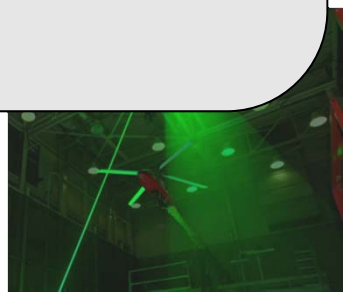
Glenn Research Center
~45 work/years

- **Drive Train**
- **Turbomachinery**
- **Icing**
- **System Analysis**
- **CBM**
- **High Temp Materials**
- **Mechanical Components**

Langley Research Center
~48 work/years

- **Acoustics**
- **Aeromechanics**
- **Exp Capability**
- **CFD**
- **Crashworthiness**
- **Materials**
- **Durability**





SRW Major Facilities

FY12 SRW Project Summary

~133 work/years (108 CS / 25 Contractor)
~ $28M per year (includes salary)
Work across 3 NASA Centers

Ames Research Center

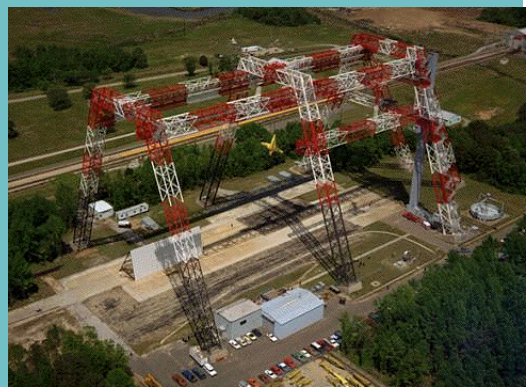
- National Full-Scale Aerodynamics Complex (NFAC)
- Supercomputing Complex (NAS)
- Vertical Motion Simulator

Glenn Research Center

- Engine Component Research Lab
- Compressor Test Facility (CE-18)
- Transmission Test Facilities (ERB)
- Icing Research Tunnel

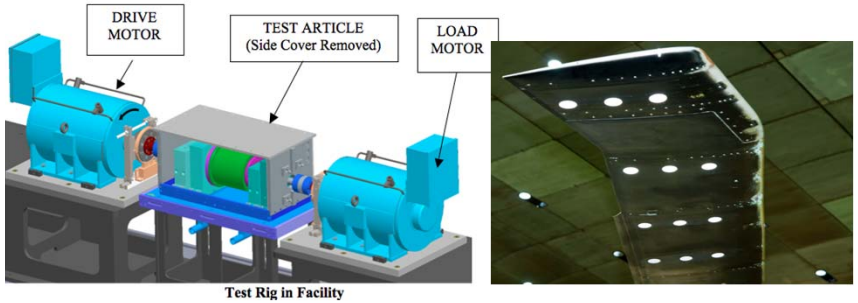
Langley Research Center

- 14- by 22-Foot Subsonic Tunnel
- Transonic Dynamics Tunnel
- Landing and Impact Research
- Structural Mechanics Lab

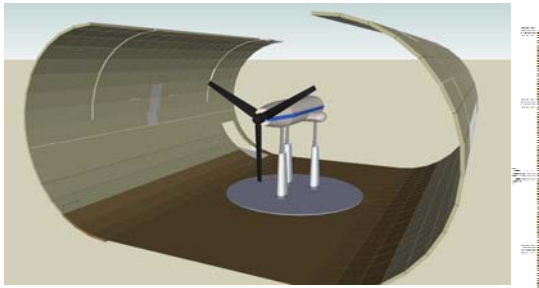


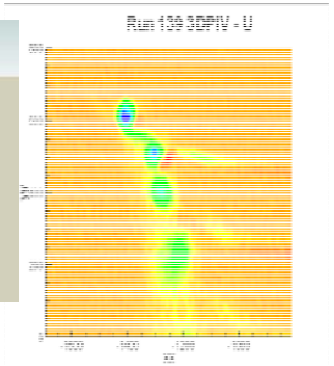
SRW Investment in NASA Facilities, 2009-2012

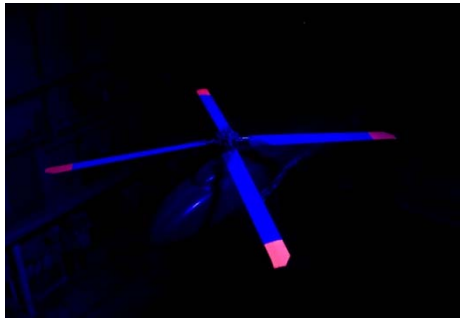
- National Full Scale Aerodynamics Complex, NFAC
  - Large Field of View Particle Image Velocimetry
  - Tiltrotor Test Rig**
- 14- by 22-Foot Subsonic Tunnel
  - Unsteady Pressure Sensitive Paint capability*
  - Large Field of View Particle Image Velocimetry***
- Transonic Dynamics Tunnel
  - Blade deformation measurement system*
- Drive Train Facilities
  - New windage research rig*
  - New variable/multi-speed transmission test rig*
  - New spur gear fatigue test rig*
- Turbomachinery Test Facilities
  - CE-18 (small compressor test facility) upgraded capability*
- Flight acoustic measurement capability*

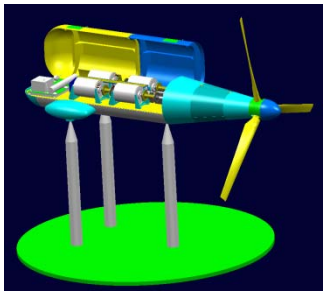


Test Rig in Facility









**partnership with Army*
***partnership with Army, Air Force, Bell Helicopter*
****partnership with Army and ATP*

TiltRotor Test Rig (TTR)

PROBLEM

NASA, DOD, and industry lack ability to test large-scale tiltrotor concepts

OBJECTIVE

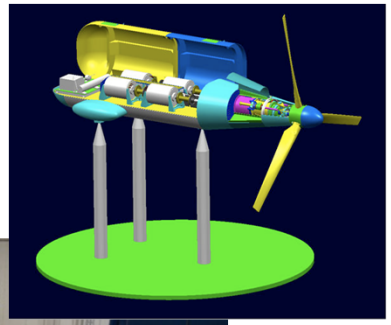
Fabricate new tiltrotor test rig to test proprotors ≤ 26-ft diameter in the National Full-Scale Aerodynamics Complex (NFAC) in axial mode, transition, and edgewise flight

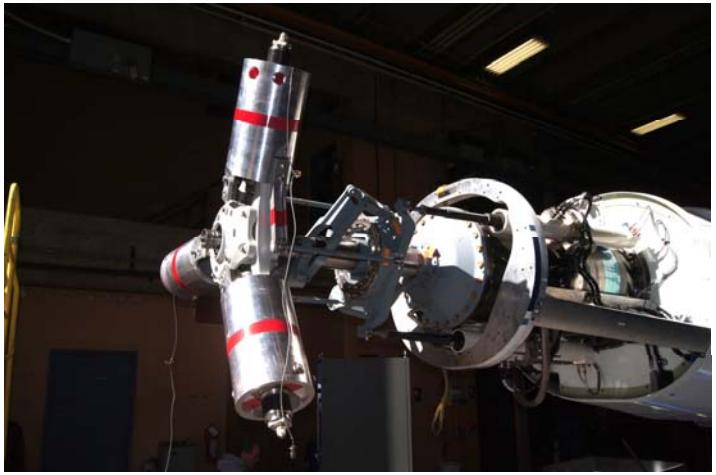
ACCOMPLISHMENTS

SRW assembled multiple funding sources (SRW base, Recovery Act, Army, Air Force) and using multiple contracts to support TTR development. Bell Helicopter under contract to deliver TTR in CY2012.

SIGNIFICANCE

TTR is a national facility that will enable advanced, large-scale tiltrotor technology testing for speeds up to 300 knots. Will provide unique testbed for NASA, DOD, and industry research.





SRW Research Approach

Three main paths to accomplish research:

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

Glenn Research Center

NASA AMES Platinum Jubilee 70

NASA Langley 90th Anniversary

U.S.ARMY

DARPA

DEPARTMENT OF THE NAVY · UNITED STATES OF AMERICA

Liberty Works **Sikorsky** **DLR**

Boeing **VLC** **Bell** **UTRC** **JAXA**

ONERA **Bombardier** **Williams**

PENNSTATE 1855

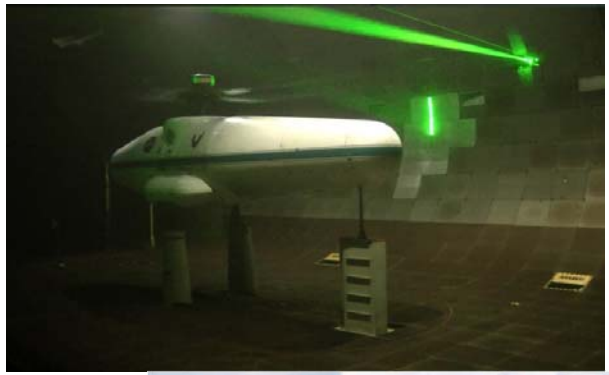
UNIVERSITY OF MARYLAND 1856

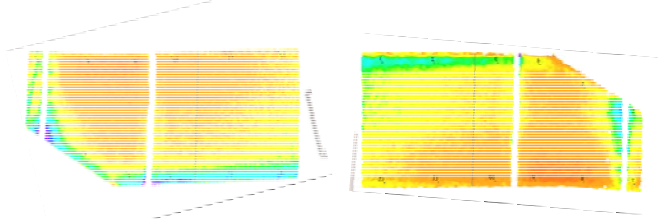
Formal Partnerships

- Army, slowed rotor research
- Army, Joint Multi-Role
- Army, acoustic flight research
- Army, Active Twist Rotor
- Army, PSP, PIV and PMI
- Army, UTRC, advanced compressor research
- Army, Navy, Vertical Lift Research COEs
- Bell, manuever acoustics
- Bombardier/Learjet, interior noise
- DLR, Active Stick Controller
- DLR, Rotor wake measurement techniques
- FAA, drive system health monitoring
- NLR, psychoacoustics
- ONERA, Active Flow Control on fuselage
- ONERA, cabin noise
- Sikorsky, crashworthiness
- STAR International Team, Active Twist Rotor
- University of North Dakota, high incidence tolerant blading
- University of Padua, Italy, trajectory optimization for low noise
- Vertical Lift Consortium, fatigue life methods

Highlights of Recent Research Activities

- **UH-60A Airloads Wind Tunnel** test team completes initial data release to government-sponsored working group
- **Variable Speed Transmission Test Facility** operational
- **High incidence-tolerant blading** tests on-going in modified linear cascade test facility
- **Advanced compressor** delivered and installation continues in CE-18
- **FUN3D team** demonstrates implementation of unsteady adjoint for overset meshes and improved accuracy of calculations
- **OVERFLOW team** demonstrates adaptive mesh refinement and accuracy improvements within experimental error
- **Unsteady Pressure Sensitive Paint** technique demonstrated on rotor blades in forward flight test conditions
- **Active Flow Control** on fuselage demonstrates up to 16% simultaneous drag and download reduction
- **Acoustic maneuver flight test** with Army and Bell completed





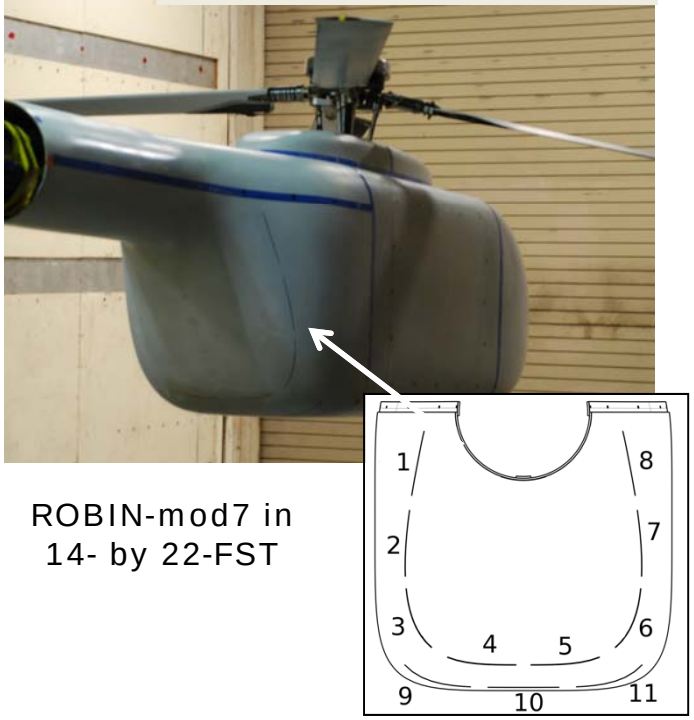
Upcoming Sessions

Session	Topics
Tuesday PM	• Propulsion – Engine – Drive System – Advanced Materials • Conceptual Design Overview
Wednesday AM	• Aeromechanics Overview • Experimental Capabilities Overview • CFD Overview • OVERFLOW (structured) • FUND3D (unstructured) • UH-60A Airloads Wind Tunnel Data Presentations • Fuselage Drag Reduction
Wednesday PM	• Structures • Flight Dynamics Overview • Acoustics

Upcoming Research Activities

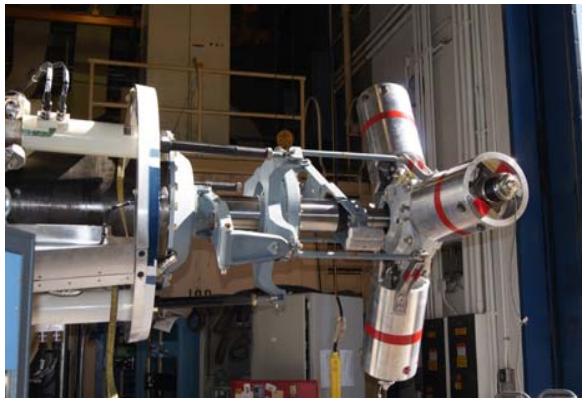
- Initiate evaluation of new Variable Speed Transmission designs
- Complete advanced compressor research with UTRC under NRA in CE-18
- Initiate acceptance testing of Tiltrotor Test Rig
- Conduct joint wind tunnel test using Kiowa configuration with Army to demonstrate measurement technology
- Conduct Active Twist Rotor wind tunnel investigation with Army in TDT
- Conduct Active Twist Rotor wind tunnel investigation with STAR team in DNW
- Follow-on wind tunnel test to further investigate fuselage Active Flow Control and unsteady Pressure Sensitive Paint
- Evaluate CFD improvements in aeromechanics, wake prediction, acoustic predictions, turbomachinery, and crash predictions

Joint with Army AFDD



ROBIN-mod7 in 14- by 22-FST

Slot locations

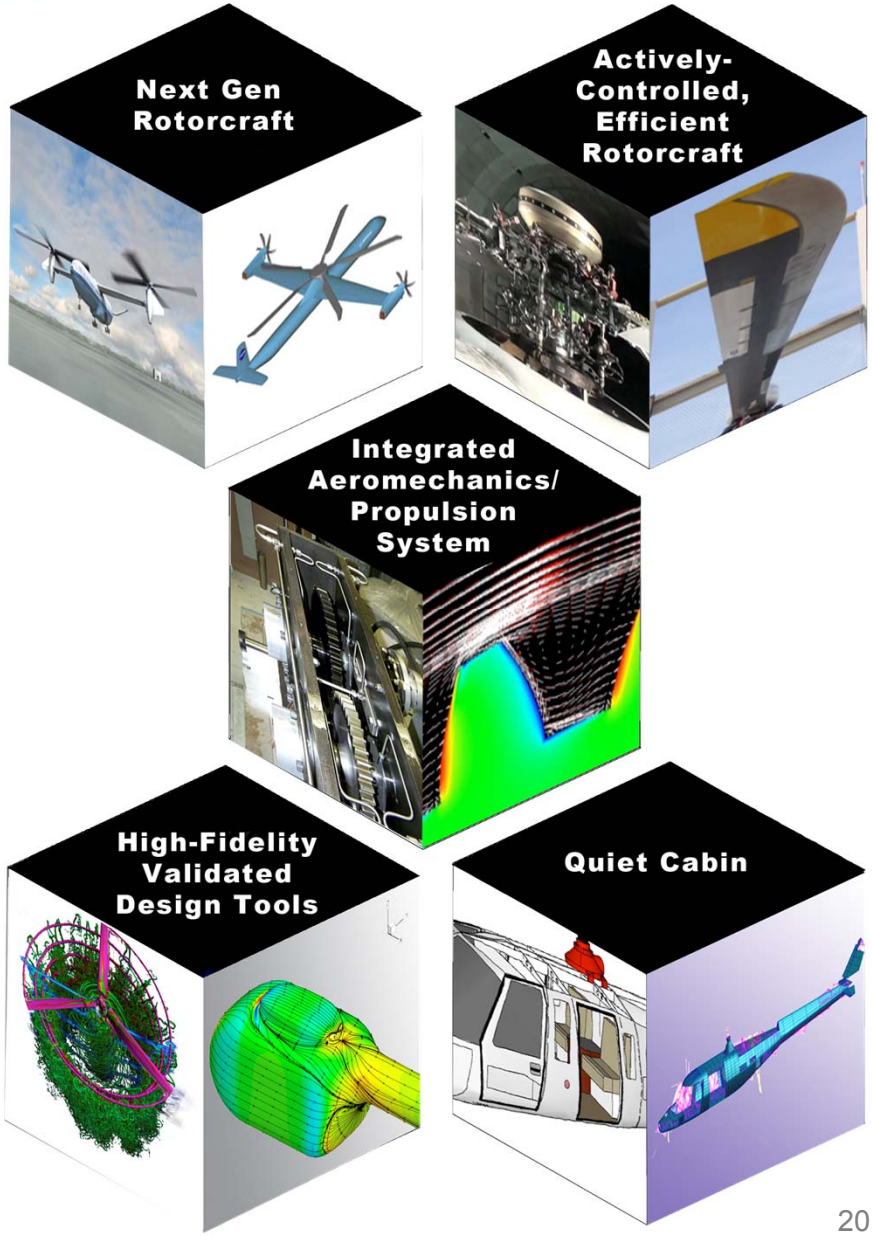


Concluding Remarks

- NASA Subsonic Rotary Wing research focused on 5 Technical Challenges that enable use of rotary wing vehicles as large, commercial transportation

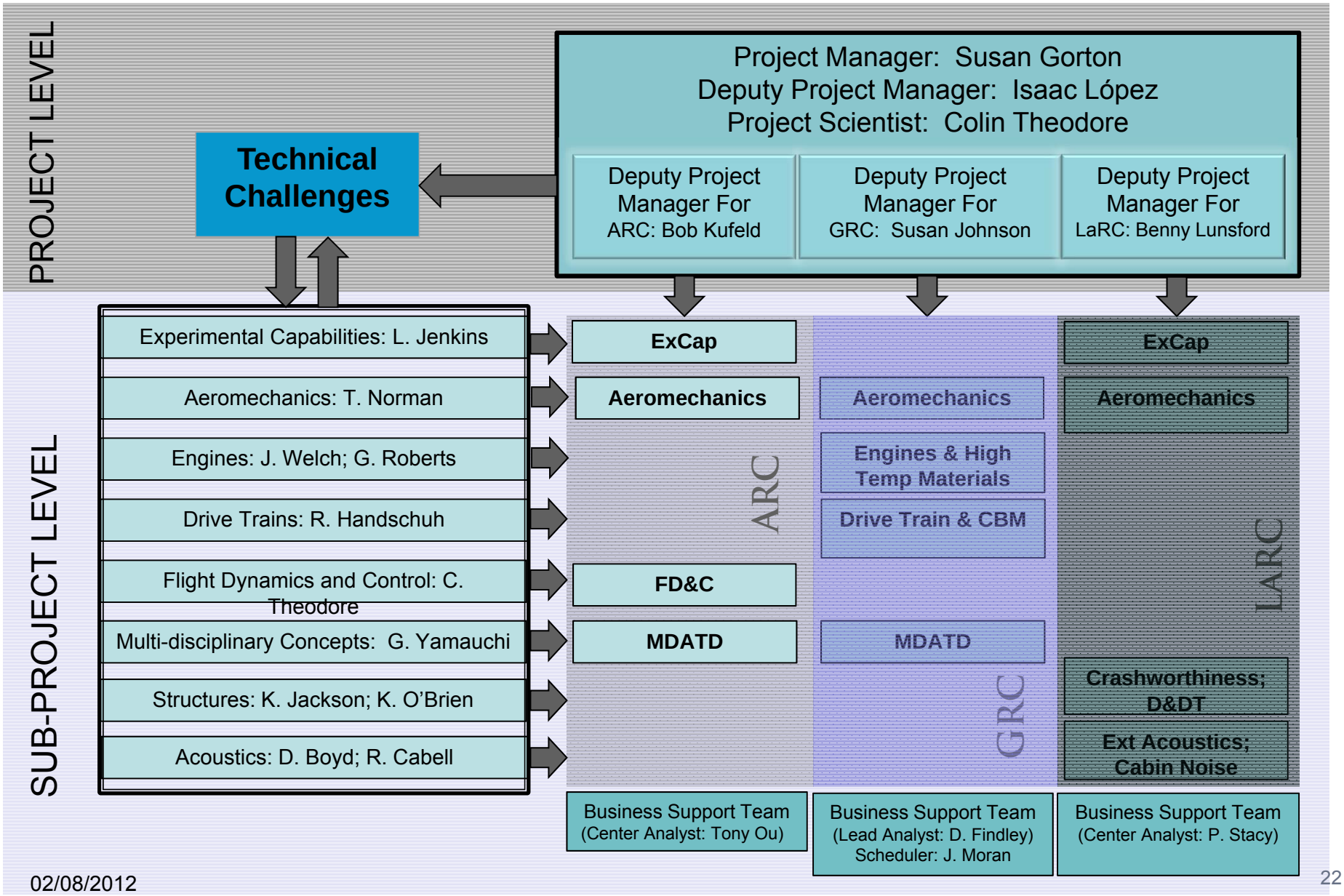
- Technical Challenges designed to promote effective use of NASA resources in support of many future configurations and the barriers they will face

- Partnerships, people and facilities are key to SRW success



NASA

SRW Project Organization



FY11 Publications

Publication	Author(s)	Presented/Published
Code-to-Code Comparison of CFD/CSD Simulation for a Helicopter Rotor in Forward Flight	Ahmad, J. and Biedron, R.T.,	29th AIAA Applied Aerodynamics Conference, Honolulu, HI, June 27-30, 2011
High-Order Accurate CFD/CSD Simulation of the UH60 Rotor in Forward Flight	Ahmad, J. and Chaderjian, N. M.	29th AIAA Applied Aerodynamics Conference in Honolulu, HI, June 27-30, 2011
Numerical Investigation of Rotorcraft Fuselage Drag Using Active Flow Control	Allan, B. and Schaeffler, N.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Comparison of Test and Finite Element Analysi	Annett, M.S.,	Proceedings of the 52nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Denver, CO, April 4-7, 2011
Active Metal Brazing of Silicon Nitride to Metals using Refractory Metal Interlayers	Asthana, R., Singh, M., and Martínez-Fernández, J.	invited talk in 3rd International Congress on Ceramics (ICC-3), Osaka, Japan, November 2010
Adaptive Control of Linear Modal Systems using Residual Mode Filters with Application to Flexible Structures	Balas, M. and Frost, S.	2011 American Control Conference - ACC 2011, San Francisco, CA, June 29 - July 1, 2011
Augmented adaptive control of flexible structures using residual mode filters	Balas, M. J. and Frost, S. A	ASME 2010 Conference on Smart Materials, Adaptive Structures and Intelligent Systems, 2010, SMASIS2010-3624, 28 September – 1 October 2010, Philadelphia, PA
Adaptive control of non-minimum phase modal systems using residual mode filters: Part I & Part II	Balas, M. J. and Frost, S. A	submitted Council of European Aerospace Societies 1st European Aerospace Guidance, Navigation and Control Conference, 13-15 April 2011, Munich, Germany.
Adaptive control of flexible structures using residual mode filters	Balas, M. J. and Frost, S. A.,	49th IEEE Conference on Decision and Control, 2010, 15-17 December 2010, Atlanta, GA
Blade Displacement Measurements of the Full-Scale UH-60A Airloads Rotor	Barrows, D. A., Burner, A. W., Abrego, A. I., and Olson, L. E.	29th AIAA Applied Aerodynamics Conference, Honolulu, HI, June 27-30, 2011
Gear Health Threshold Setting Based On a Probability of False Alarm	Bechhoefer, E., He, D., and Dempsey, P.	2011 Annual Conference of the Prognostics and Health Management Society
Computation of UH-60A Airloads using CFD/CSD Coupling on Unstructured Meshes	Biedron, R. and Lee-Rausch, E.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Cartesian Off-Body Grid Adaption for Viscous Time-Accurate Flow Simulation	Buning, P.G. and Pulliam, T.H.	29th AIAA Applied Aerodynamics Conference, Honolulu, HI, June 27-30, 2011
High Resolution Navier-Stokes Simulation of Rotor Wakes	Chaderjian, N, and Buning, P.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Capability Extension to the Turbine Off-Design Computer Program AXOD With Applications to the Highly Loaded Fan-Drive Turbines	Chen, S. S.	NASA/TM—2011-217129, July 2011

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Publication	Author(s)	Presented/Published
Vertical Takeoff Rescue Amphibious Firefighting Tiltrotor Design Report	Creaven, M. P., Tenney, J., Smith, J., Steinert, A., Paetzell, R., Hom, M., Diner, J., Berg, R., Carra, A., and Tomlin, B.	AIAA 2011-6998, AIAA Centennial of Naval Aviation Forum "100 Years of Achievement and Progress" 21 - 22 September 2011, Virginia Beach, VA
Experimental Investigation and Fundamental Understanding of a Slow UH-60A Rotor at High Advance Ratios	Datta, A., Yeo, H., and Norman T.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Resilient and Corrosion-Proof Rolling Element Bearings Made From Superelastic Ni-Ti Alloys for Aerospace Mechanisms	DellaCorte, C., Noebe, R. D., Stanford, M. K., and Padula, S. A.	Journal of the ASTM and presented at the ASTM Rolling Element Bearing Symposium in Anaheim, CA, April 13-15th, 2011
Bearing Fatigue Damage Life Prediction Using Oil Debris Monitoring	Dempsey, P. J.	NASA Technical Memorandum 2011-217117
NASA Glenn SRW Propulsion System Health	Dempsey, P. J.	AHS HUMS / CBM Integrated Technology Team Meeting at the AHS 67 Forum.
Investigation of Data Fusion Applied to Health Monitoring of Wind Turbine Drive Train Components	Dempsey, P. J.	American Wind Energy Association (AWEA) Wind Power Conference, Anaheim, CA, May 22-25, 2011
Bearing Fatigue Damage Life Prediction Using Oil Debris Monitoring	Dempsey, P. J.	NASA Technical Memorandum 2011-217117
Variable-Speed Simulation of a Dual-Clutch Gearbox Tiltrotor Driveline	DeSmidt, H., Smith, E.C., Wang, K.W., and Lewicki, D.G.,	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
An Investigation of the Wave Bearing Attenuation Effects on Vibration and Noise Generated by a Gearbox Compared ot the Rolling Element Bearings	Dimofte, F., Ene, N. and Oswald, F.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Grease Degradation in Critical Helicopter Drivetrain Bearings	Dykas, B., Krantz, T., Berger, G., Street, K., and Morales, W.,	Proceedings of the STLE/ASME International Joint Tribology Conference, 17-21 Oct. 2010, San Francisco, CA. #IJTC2010-41200. Society of Tribologists and Lubrication Engineers and the American Society of Mechanical Engineers
Acoustic Performance of an Installed Real-Time Three-Dimensional Audio System – Part II	Faller II, K. J., Rizzi, S. A., and Aumann, A. R.	161st Meeting of the Acoustical Society of America, Seattle, WA, May 23-27, 2011

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Publication	Author(s)	Presented/Published
Real-time acoustic performance of the EER	Faller, J.	2nd Pan-American/Iberian Meeting on Acoustics, in Cancun, Mexico, on November 15-19, 2010
Broadband Noise Prediction When Turbulence Simulation is Avaliable – Derivation of Formulation 2B and its Statistical Analysis	Farrassat, F. and Casper, J.	Accepted for publication as a Rapid Communication in the Journal of Sound and Vibration (JSV)
The Effect of Non-Harmonic Active Twist Actuation on BVI Noise	Fogarty, D., Wilbur, M., and Sekula, M.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
A Tribute to Professor Rene H. Miller--A Pioneer in Aeromechanics and Rotary Wing Flight Transportation	Friedmann P., Johnson, W., and Scully, M.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Adaptive control using residual mode filters applied to wind turbines	Frost, S. A. and Balas, M. J.,	AIAA Infotech@Aerospace Conference 2011, 29-31 March 2011, St. Louis, MO
Generator Speed Regulation in the Presence of Structural Modes through Adaptive Control using Residual Mode Filters	Frost, S. A.,, Balas, M. J., and Wright, A. D.	Mechatronics, Volume 21, Issue 4, June 2011, Pages 660-667
Vertical Drop Testing and Analysis of the WASP Helicopter Skid Gear	Fuchs, Y. T., and Jackson, K. E.	Journal of the American Helicopter Society, Vol. 56, No. 1, January 2011, pp. 012005-1 through 012005-10
The Effects of Ambient Conditions on Helicopter Rotor Source Noise Modeling	Greenwood, E. and Schmitz F.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Preliminary Assessment of the Interior Noise Environment in the Large Civil Tiltrotor (LCTR2)	Grosveld, F.	Aircraft Interior Noise session at Noise-Con 2011 in Portland, Oregon.
Statistical Energy Analysis (SEA) and Energy Finite Element Analysis (EFEA) Predictions for a Floor-Equipped Composite Cylinder	Grosveld, F., Schiller, N., and Cabell, R.	NASA/TM-2011-217171, June 2011
High Speed Gear Windage Research	Handschuh, R.	International Conference on Gearing, Munich, Germany Oct 4-6, 2010
Gear Mesh Loss-of-Lubrication Experiments and Analytical Simulation	Handschuh, R., Polly, J. and Morales, W.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Helical Face Gear Development under the Enhanced Rotorcraft Drive System Program	Heath, G.F., Slaughter, S.C., Fisher, D.J., Lewicki, D.G., and Fetty, J.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Measuring Time-Varying Human Pilot Behavior	Hess, R.	AIAA 2011 Atmospheric Flight Mechanics Conference, Portland, OR, August 8-11, 2011

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Publication	Author(s)	Presented/Published
A Framework for Robust Rotorcraft Flight Control Design	Hess, R.	Journal of the American Helicopter Society, 56, 022004 (2011); doi:10.4050/JAHS.56.022004 (11 pages)
A Preliminary Study of Human Pilot Dynamics in the Control of Time-Varying Systems	Hess, R.	AIAA Modeling and Simulation Technologies Conference, Portland, OR, Aug 8-11, 2011
CFD Analysis of Gear Windage Losses: Validation and Parametric Aerodynamic Studies	Hill, M. J., Kunz, R. F., Medvitz, R. B., Handschuh, R. F., Long L. N., Noack, R. W., and Morris, P. J.	Journal of Fluids Engineering, 133, 031103 (2011)
Multi-Dimensional Correlation of Impact Dynamic Models	Horta, L. G., Reaves, M. C., Annett, M. S., and Jackson, K. E.	IMAC-XXIX Conference & Exposition on Structural Dynamics, Jacksonville, Florida, January 31 - February 3, 2011
Multi-Dimensional Calibration of Impact Models	Horta, L., Reaves, M., Annett, M., and Jackson, K .	Chapter of book: Aeronautics and Astronautics, by INTECH. Prof. Max Mulder is the book editor. No publication date, yet
Integration Methodology for Oil-Free Shaft Support Systems: Four steps to Success	Howard, S. A., DellaCorte, C. and Bruckner, R. J.	The 8th IFToMM International Confernece on Rotordynamics, September 12-15, 2010, Seoul, Korea
A New Analysis Tool Assessment for Rotordynamic Modeling of Gas Foil Bearings	Howard, S.A.	Journal of Engineering for Gas Turbines and Power, 133, 022505 (2011)
Mesh Independent Matrix Cracking and Delamination Modeling in Laminated Composites	Iarve, E., Gurvich, M., Mollenhauer, D., Rose, C. A., and Davila, C. G.	International Journal of Numerical Methods in Engineering, 14 APR 2011, DOI: 10.1002/nme.3195
Finite Element Simulation of the MD-500 Helicopter Full-Scale Crash Test	Jackson, K.	Composite Materials Handbook (CMH-17) Crashworthiness Working Group , Feb 28, 2011
Assessment of an Externally Deployable Energy Absorbing Concept for Improved Helicopter Crash Protection	Jackson, K. E.	Aircraft Survivability Symposium 2010, Naval Postgraduate School in Monterey, California on November 2-5, 2010
A Comparative Evaluation of Two Helicopter Crash Tests	Jackson, K., Kellas, S., Annett, M., Littell,J., and Polanco, M.	Sixth Triennial International Aircraft Fire and Cabin Safety Research Conference, Atlantic City, NJ, October 25-28, 2010
Milestones in Aeromechanics	Johnson, W.	HeliJapan 2010 conference, Nov. 1-3, 2010 in Omiya, Japan
Automated Vortex Core Analysis for Multi-Zone Numerical Flow Simulations	Kao, D.	29th AIAA Applied Aerodynamics Conference, Honolulu, HI, June 27-30, 2011
Skin Friction Predictions Over a Hovering Tilt-Rotor Blade Using OVERFLOW2	Kaul, U. K. and Ahmad, J.	29th AIAA Applied Aerodynamics Conference, Honolulu, HI, June 27-30, 2011
Multi-Terrain Vertical Drop Tests of a Composite Fuselage Section	Kellas, S. and Jackson, K. E.	Journal of the American Helicopter Society, Vol. 55, No. 4, October 2010, pp. 042002-1 through 042002-7

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Publication	Author(s)	Presented/Published
Deployable System for Crash-Load Attenuation	Kellas, S. and Jackson, K. E.	Journal of the American Helicopter Society, Vol. 55, No. 4, October 2010, pp. 042001-1 through 042001-14.
Fiber Optic Strain Sensor for Planetary Gear Diagnostics	Kiddy, J.S., Samuel, P.D., Lewicki, D.G., LaBerge, K., Ehinger, R.T., and Fetty, J.,	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Enhanced Correlation of SMART Active Flap Rotor Loads	Kottapalli, S.	52nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference Denver, CO, April 4-7, 2011
Effects of Icing on Rotary Wing Loads and Surface Heat Transfer Rates	Kreeger, R.	49th AIAA Aerosciences Meeting, Orlando, FL, Jan, 2011
A CFD Approach for Predicting 3D Ice Accretion on Aircraft	Kreeger, R.	SAE/AIAA/AHS 2011 International Conference on Aircraft and Engine Icing and Ground-Deicing, June 13-17, 2011 in Chicago Illinois
Further Evaluation of Scaling Methods for Rotorcraft Icing	Kreeger, R.	SAE/AIAA/AHS 2011 International Conference on Aircraft and Engine Icing and Ground-Deicing, June 13-17, 2011 in Chicago Illinois
Development of Benchmark Examples for Static Delamination Propagation and Fatigue Growth Predictions	Krueger, R.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
CFD-Guided Development of Rigs for Studying Erosion and Large Particle Damage of Thermal Barrier Coatings	Kuczmarski, M. A., Miller, R. A., and Zhu, D.	Journal of Modelling and Simulation in Engineering, Volume 2011 (2011), Article ID 837921, 13 pages doi:10.1155/2011/837921
Flight Dynamics Aspects of a Large Civli Tiltrotor Simulation using Translational Rate Command	Lawrence, B., Malpica, C., Theodore, C., Decker, W. and Lindsey, J.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Planetary Gearbox Fault Detection Using Vibration Separation Techniques	Lewicki, D.G., LaBerge, K., Ehinger, R.T., and Fetty, J	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Gear Fault Detection Effectiveness As Applied To Tooth Surface Pitting Fatigue Damage	Lewicki, D. G., Dempsey, P. J., Heath, F. G. and Shanthakumaran, P.	November/December 2010 issue of Gear Technology
A Comparative Analysis of Two Full-Scale MD-500 Helicopter Crash Tests	Littell, J. D.	Proceedings of the SEM 2011 Annual Conference, Uncasville, Connecticut, June 13-16, 2011.
A Comparative Analysis of Two Full-Scale MD-500 Crash Tests	Littell, J. D.	Society of Experimental Mechanics (SEM) Annual Conference in Uncasville, CT June 2011
Full Scale Crash Test of an MD-500 Helicopter	Littell, J. D.,	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Overview of the Subsonic Rotary Wing Project	Lopez, I.	HeliJapan 2010 conference, Nov. 1-3, 2010 in Omiya, Japan

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Publication	Author(s)	Presented/Published
Design of a High-Efficiency Compact Centrifugal Compressor for Rotorcraft Application	Lurie, E., Van Slooten, P., Medic, G., Mulugeta, J., Holley, B., Feng, J., Sharma, O., and Ni, R.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
An Investigation of Large Tiltrotor Hover and Low Speed Handling Qualities	Malpica, C., Decker, W., Theodore, C., Lindsey, J., Lawrence, B., and Blanken, C.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Burner Rig With an Unattached Duct for Evaluating the Erosion Resistance of Thermal Barrier Coatings	Miller, R. A., Kuczmarski, M. A., and Zhu, D.	NASA/TM—2011-217008, June 2011
Designing Noise-Minimal Rotorcraft Trajectories	Morris, R.	Poster presentation, International Workshop on Planning and Scheduling for Space, to be held in Darmstaht, Germany, in June 2011
Application of a High-Fidelity Icing Analysis Method to a Model-Scale Rotor in Forward Flight	Narducci, R., Orr, S., and Kreeger, R.E.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Seeding Cracks Using a Fatigue Tester for Accelerated GearTooth Breaking	Nenadic, N., Wodenscheck, J., Thurston, M., and Lewicki, D.,	IMAC-XXIX Conference & Exposition on Structural Dynamics, Jacksonville, Florida, January 31 - February 3, 2011
Full -Scale Wind Tunnel Test of the UH-60A Airloads Rotor	Norman, T. R.,Peterson R. L., Shinoda, P., and Datta, A.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Low Boom Configuration Analysis with FUN3D Adjoint Simulation Framework	Park, M. A.	29th AIAA Applied Aerodynamics Conference, American Institute of Aeronautics and Astronautics, 2011
Rotorcraft Full Spectrum Crashworthiness and Occupant Injury Requirements,"	Pellettiere, J., Crocco, J., and Jackson, K.E.,	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Vertical Drop Testing and Simulation of Anthropomorphic Test Devices,"	Polanco, M.A., and Little,l J. D.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Processes & Considerations in Extensions to Time Between Overhauls and Paths to On-Condition for US Army Rotorcraft Propulsion Systems	Rickmeyer, T. and Dempsey, P.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Acoustic performance of an installed real-time three-dimensional audio system	Rizzi, S.	160th Meeting of the Acoustical Society of America, Cancun, Mexico, November 15-19, 2010
Acoustic Performance of an Installed Real-Time Three-Dimensional Audio System	Rizzi, S.	Proceedings of Meetings on Acoustics (POMA). POMA is an online open-access journal published by the Acoustical Society of America (ASA).
Simulation of Rotary and Fixed Wing Flyover Noise for Subjective Assessments	Rizzi, S. A., Aumann, A. R., Allen, M. P., Burdisso, R., and Faller II, K. J.	161st Meeting of the Acoustical Society of America, Seattle, WA, May 23-27, 2011

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Publication	Author(s)	Presented/Published
Correlating CFD Simulation with Wind Tunnel Test for the Full-Scale UH-60A Airloads Rotor	Romander, E. , Norman, T., Chang, I-C.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Evaluation of the Rotational Throtte Interface for Converting Aircraft Utilizing the NASA Ames Vertical Motion Simulator	Rozovski, D. and Theodore C.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Overview of the Novel Intelligent JAXA Active Rotor Program	Saito, S., Kobiki, N., Tanabe, Y., Johnson, W., Yamauchi, G., and Young, L.	HeliJapan 2010 conference, Nov. 1-3, 2010 in Omiya, Japan
Active damping using distributed anisotropic actuators	Schiller N., Cabell R., Quinones J., and Wier N.	2010 ASME International Mechanical Engineering Congress, November 12-18, 2010, Vancouver, BC, Canada
Analysis of a Multi-Flap Control System for a Swashplateless Rotor	Sekula, M. and Wilbur, M.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Advanced Gear Alloys for Ultra High Strength Applications	Shen, T., Krantz, T., and Sebastian, J.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Microstructural and mechanical evaluation of a Cu-based active braze alloy to join silicon nitride ceramics	Singh, M., Asthana, R., Varela, F. M., Martínez-Fernández, J.	Journal of the European Ceramic Society, 31, (2011), 1309–1316.
Defining Gas Turbine Engine Performance Requirements for the Large Civil Tiltrotor (LCTR)	Snyder, C.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Summary of the Large Civil TiltRotor (LCTR2) Engine Gearbox Study	Snyder, C., Robuck, M., Wilkerson, J., and Nordstrom, C.	AHS International Powered Lift Conference, Oct. 5-7, 2010, Philadelphia, PA
Ballistic Impact Tolerance of Filament-Wound Composite Tubes with Rigid and Flexible MatrixMaterials	Sollenberger, S. G., Bail, J. L., Kohlman, L., Ruggeri, C. R., Bakis, C. E., Roberts, G. D., and Smith, E. C.	Proc. 25th Tech. Conf., American Society for Composites, DEStech Publications, Lancaseter, PA paper no. 1183.
Continuum Damage Mechanics Models for the Analysis of Progressive Failure in Open-Hole Tension Laminates	Song, K., Li, Y., and Rose, C. A.	52nd AIAA, Structures, Structural Dynamics and Materials Conference, April, 2011
A New High-Speed, High-Cycle, Gear-Tooth Bending Fatigue Test Capability	Stringer, B. LTC., Dykas, B., LaBerge,K., Zakrajsek, A., and Handschuh, R.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Further Evaluation of Scaling Methods for Rotorcraft Icing	Tsao, J. and Kreeger, R.	SAE/AIAA International Conference on Aircraft and Engine Icing and Ground De-Icing, 13-17 June, 2011, Chicago, IL.
PIV Measurements in the Wake of a Full-Scale Rotor in Forward Flight	Wadcock, A. J., Yamauchi, G. K., Solis, E., and Pete, A. E.	29th AIAA Applied Aerodynamics Conference, Honolulu, HI, June 27-30, 2011

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Publication	Author(s)	Presented/Published
Computational Assessment of the Aerodynamic Performance of a Variable-Speed Power Turbine for Large Civil TiltRotor Application	Welch, G.	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Rotorcraft and Enabling Robotic Rescue	Young, L.	HeliJapan 2010 conference, Nov. 1-3, 2010 in Omiya, Japan
Civil Tiltrotor Aircraft Operations	Young, L., Chung, W., Paris, A., Salvano, D., Young, R., Gao, H., Wright, K., and Cheng, V.	AIAA Aviation Technology, Integration, and Operations (ATIO), Virginia Beach, Sept 20-22, 2011.
Identification of Time-Varying Pilot Control Behavior	Zaal, P. and Sweet, B.	AIAA Modeling and Simulation Technologies Conference, Portland, OR, Aug 8-11, 2011
Dual-use transducer for use with a boundary-stiffened panel and method of using the same	Schiller, N. H. and Cabell, R. H.	U.S. Patent 7,893,602, February 2, 2011

NRA Awards – Round 1

	NRA Title	Affiliation	PI	Period of Performance
Round 1 Results	Combustion Powered Actuators (COMPACT) for Aerodynamic Flow Control on Rotorcraft Blades	GaTech	Glezer	2006-2009
	EFEA developments for metallic/composite rotorcraft configurations	Univ of Mich	Vlahopoulos	2006-2010
	Fundamental Acoustic Design Tool Development and Validation for Rotorcraft External Noise	Univ of MD	Schmitz	2006-2009
	A Study of Thermal Barrier Coating Erosion in Rotorcraft Engine	Univ of Cinn	Tabakoff	2006-2009
	High Fidelity CFD Analysis & Validation of Rotorcraft Gear Box Aerodynamics Under Operational & Oil-Out Conditions	Penn State	Kunz	2006-2009
	Comprehensive Modeling & Analysis of Rotorcraft Variable Speed Propulsion System with Coupled Engine/Transmission/Rotor Dynamics	Penn State	Smith, E.	2006-2009
	Detailed Performance, Wakes, Pressures and Loads for High Speed Single and Coaxial Rotors	Univ of MD	Chopra	2006-2010
	Integrated Algorithms for High-Fidelity Rotorcraft Aeromechanics Predictions within CFD/CSD-Coupled Frameworks (PVTM)	NIA	Anusonti-Inthra	2006-2008
	Multidisciplinary Computational Tool for Accurate and Efficient Rotorcraft Noise Prediction (MUTE)	NIA	Liu	2006-2009
	Control of Vibration Transmission and Interior Noise Radiation of Composite Shells with Embedded Passive and Active Periodicity	GaTech	Ruzzene	2006-2009
	Crashworthiness Analysis of Composite Structures	Stanford	Chang	2006-2009
	A Helicopter Tip-Path-Plane Measurement System Using an Optics-Based Method	Univ of MD	Schmitz	2006-2008

NRA Awards – Round 2

	NRA Title	Affiliation	PI	Period of Performance
Round 2 Results	Innovative Overset Grid Connectivity Software for Unstructured Rotorcraft Simulations	Penn State	Noack	2007-2009
	Prediction of Foil Bearing Perfomrance: A computational Model Anchored to Test Data	Texas A&M	San Andres	2007-2009
	Framework for Multidisciplinary Analysis, Design, and Optimization with High-Fidelity Analysis Tools	Boeing	Orr	2007-2008
	Control-Oriented Modeling of Free Vortex Wakes	Univ of MD	Celi	2007-2008
	Aircraft System Analysis of Technology Benefits to Civil Transport Rotorcraft	Boeing	Wilkerson	2007-2008
	Determining Effects of Time-Varying Rotorcraft Dynamics on Pilot Control	Hoh	Mitchell	2007-2009
	Flight Mechanics and Control Oriented Modeling of Next Generation On-Blade Control Concepts	GaTech	Prasad	2007-2009
	Development and Validation of Multi-Axis Pilot Models for Rotorcraft With Time-Varying Dynamics and Biodynamic Interface	UC Davis	Hess	2007-2009
	Innovative Strategies for Rotary-Wing Coupled Aeroelastic Simulations	GTRC	Smith, M.	2007-2010
	Thermal Effects in Gas Lubricated Foil Journal Bearing Performance	Penn State	Carpino	2007 (stop work)
	Unified Computational Platform for CFD and CSD for Rotorcraft Aeromechanics	UC Santa Cruz	Sankaran	2007-2008
	Innovative Parallel Framework for Coupling Advanced Rotorcraft Aeromechanic Simulations	Univ of MD	Baeder	2007-2010

NRA Awards – Round 3

	NRA Title	Affiliation	PI	Period of Performance
Round 3 Results	A Research Plan to Determine the Effects of Low-Frequency Noise on Humans	Wyle Labs	Sharp	2008-2009
	Research Plan for Human Response to Low-Frequency Rotor Noise	Fidell Associates	Fidell	2008-2009
	Vibration Propagation of Gear Dynamics in a Gear-Bearing-Housing System using Mathematical Modeling and Finite Element Analysis	Ohio State	Parker	2008-2010
	Rotorcraft Transmission Noise Path Model, Including Distributed Fluid Film Bearing Impedance Modeling	Penn State	Hambric	2008-2009
	High Efficiency Centrifugal Compressors for Rotorcraft Applications	UTRC	Van Slooten	2008-2010
	Coupled CFD/CSD/Icing Analysis for Rotorcraft in Forward Flight	Boeing	Narducci	2008-2011
	Development of Methodologies for Coupling Ice Accretion Models with Rotary Wing Aeromechanics	GaTech	Sankar	2008-2010
	High Resolution CFD Analysis of Rotorcraft Rotor Icing	Penn State	Noack	2008-2010

NRA Awards – Round 4

	NRA Title	Affiliation	PI	Period of Performance
Round 4 Results	High Fidelity CFD Analysis and Validation of Rotorcraft Gear Box Aerodynamics	ARL/Penn State	Kunz	2010-2012
	Acoustically Tailored Composite Rotorcraft Fuselage Panels	Penn State	Hambric	2010-2013
	Distributed AVC for Interior Noise Reduction using Power Minimization	UTRC	Mendoza	2010-2011
	Self-sealing Composite Sandwich Structures	Univ of IL	White	2010-2012

SBIR Support for SRW

Title/ Performer	Year/Phase
Composite Material for Rotorcraft Drive Systems, A&P Technology, SBIR Contract NNC10CA19C,	Phase 3
Fully Integral Flexible Composite Driveshaft, Lawrie Technology, Inc., Phase 2 SBIR Contract NNX09CA35C, Phase 2E award delayed due to Continuing Resolution	Phase 2E
Hybrid Element Method for Composite Structures Subjected to Boundary Layer Loading, Comet Technology Corporation, 10-1-A2.03-8233 LaRC	2010 Phase 1
RotCFD: A Viscous Design Tool for Advanced Configurations, Sukra Helitek, Inc., 10-1-A2.09-8157 ARC	2010 Phase 1
Innovative Tools for Structural Diagnostics of Rotorcraft Fatigue Critical Composite Parts, Numerical Technology Company, LLC, 10-1-A2.09-9076 LaRC	2010 Phase 1
A Computational Tool for Helicopter Rotor Noise Prediction, D&P, LLC, 10-1-A2.09-9309 LaRC	2010 Phase 1
Real-Time, Maneuvering Flight Noise Prediction for Rotorcraft Flight Simulations, Continuum Dynamics, Inc., 10-1-A2.09-9439 LaRC	2010 Phase 1
Inexpensive Reliable Oil-Debris Optical Sensor for Rotorcraft Health Monitoring, Translume, Inc., 10-1-A2.09-9697 GRC	2010 Phase 1
Implicit Higher Order Temporal Differencing for Aeroacoustic and CFD Applications, CFD Research Corporation, 10-1-A2.03-9097 LaRC	2010 Phase 1
Interior Acoustic Analysis for Early Use in Design, Michigan Engineering Services, LLC, 10-1-A2.03-8991 LaRC	2010 Phase 1

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Title/ Performer	Year/Phase
Design Concepts for Cooled Ceramic Matrix Composite Turbine Vanes, N&R Engineering, A2.10-9062 GRC	2009 Phase 2
Towards More Efficient Comprehensive Rotor Noise Simulation, CASCADE Technologies Inc., A2.09-9045,	2009 Phase 1
Enhanced Prediction of Gear Tooth Surface Fatigue Life, Sentient, A2.09-9343	2009 Phase 1
Rotorcraft Diagnostics, Qualtech Systems, Inc., A2.09-8083	2009 Phase 1
Flight Adaptive Blade For Optimum Rotor Response (FABFORR), Continuum Dynamics, Inc., A2.09-8823,	2009 Phase 1
Alumina Fiber-Reinforced 9310 Steel Metal Matrix Composite for Rotorcraft Drive System Components, Ultramet, A2.09-8630,	2009 Phase 1
Rotorcraft Diagnostics, Ridgetop Group, Inc., A2.09-9940	2009 Phase 1
Fast Responding PSP for Rotorcraft Aerodynamic Investigations, Innovative Scientific Solutions, Inc. (ISSI), A2.09-9022,	2008 Phase 2
Hybrid Finite Element Analysis for Rotorcraft Interior Noise Simulations, Michigan Engineering Services, LLCA2.09-9167	2008 Phase 2
Fast Responding PSP for Rotorcraft Aerodynamic Investigations, Innovative Scientific Solutions, Inc., A2.09-9022,	2008 Phase 1

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Title/ Performer	Year/Phase
ROBUST (Rotorcraft Blade Universal Shape Transformation) System for Controlled Aerodynamic Warping, Materials Technologies Corporation, A2.09-8904	2008 Phase 1
Hybrid Finite Element Developments for Rotorcraft Interior Noise Computations within a Multidisciplinary Design Environment, Michigan Engineering Services, LLC, A2.09-9167	2008 Phase 1
Metal Rubber™ Sensor Appliqués for Rotor Blade Air, Nanosonic, Inc., A2.09-8605	2008 Phase 1
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Physics Based Tool for Rotorcraft Computational Aeroacoustics, Continuum Dynamics, Inc., A2.09-9451	2008 Phase 1
Multifunctional Erosion Resistant Icephobic Appliques for Rotorblades, NanoSonic, Inc., A2.10-9479 LaRC	2007 Phase 2
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Elastomeric Dampers derived from First-Principles-Based Analytical Simulation, Materials Technologies Corporation, A2.10-8476 ARC	2007 Phase 2