# Fundamental Aeronautics Program

## *Subsonic Rotary Wing Project Overview*

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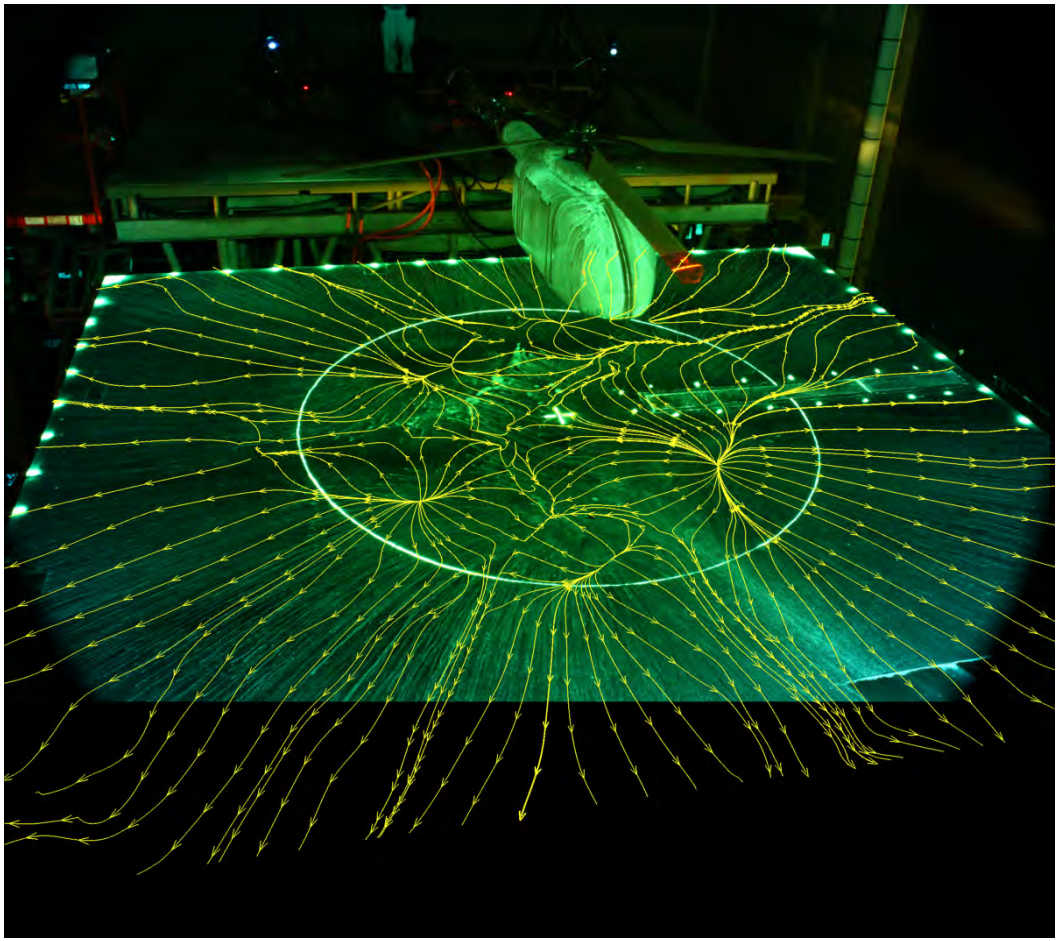
2012 Technical Conference
March 13-15, 2012

# Outline

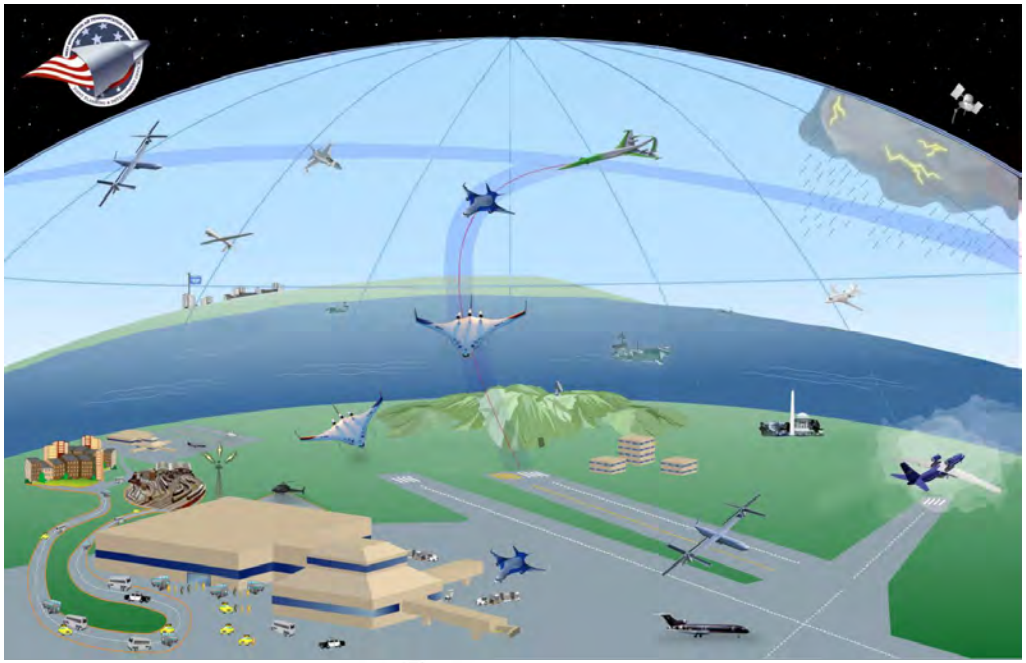
- Goals
- Objectives
- Technical Challenge
- Approach
- Project snapshot
- Recent Success
- Meeting agenda
- Upcoming activities

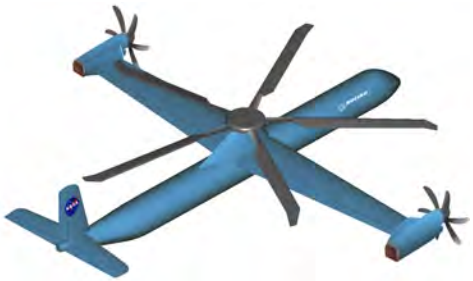


Rotor in hover ground effect. CFD streamlines superimposed on oil flow visualization

# Subsonic Rotary Wing (SRW) Project

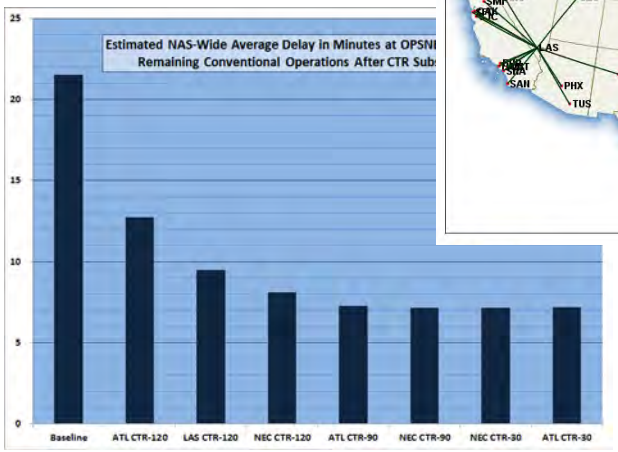
**Goal: Enable radical changes in the transportation system through advanced concept rotary wing vehicles**

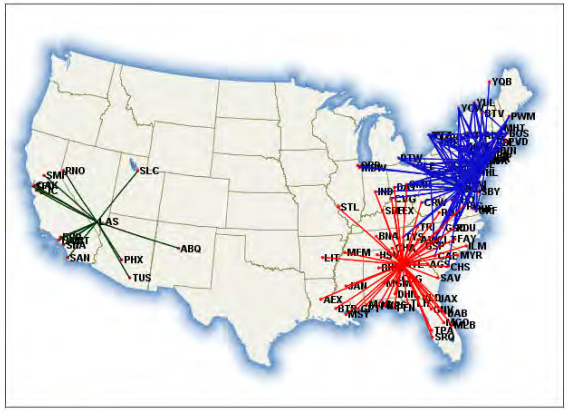




# Strategic Direction

- **Directed to focus on:**
  - NextGen Rotorcraft Developments
  - Mobility / Capacity
  - Efficiency / Energy and Environment


- **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
  - Propulsion-Airframe Integration

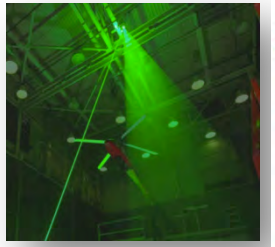
- **Status/Results**
  - Vertical capability at one or both ends of a 300-600nm mission increases airport capacity.
  - Large, advanced technology tiltrotors consistently outpace other configurations in the ability to meet the transportation mission
  - Advanced technologies (SFC, weight reduction, drag reduction, rotor L/D) give tiltrotors cost and operational parity with configurations already in use
  - Civil tiltrotors estimated to reduce airspace delay significantly, equating to billions/year in savings

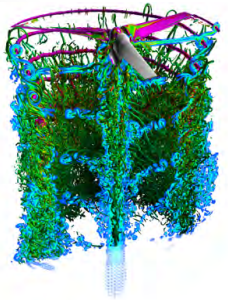
# Subsonic Rotary Wing (SRW) Project

**Objective: Identify enabling technologies and research areas for advanced concepts**

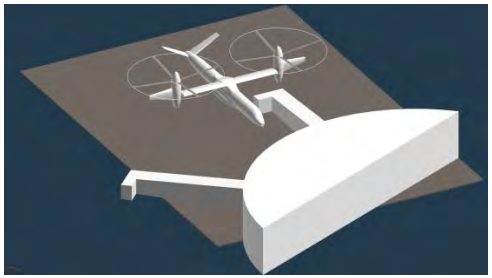
Active Rotor Systems

Modeling and Validation

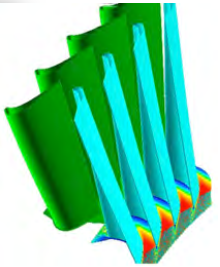


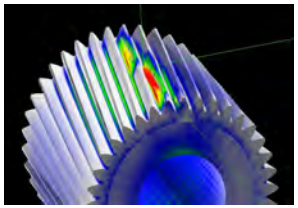


NextGen Integration

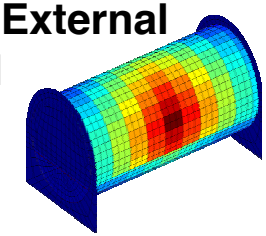


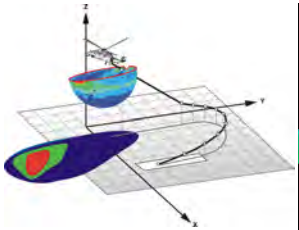
Propulsion System

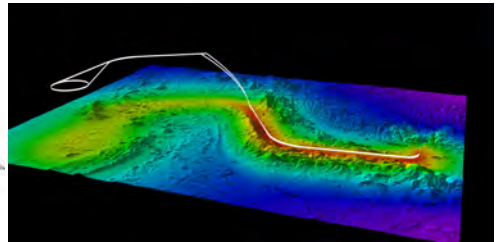




Low Noise: External and Internal







# 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

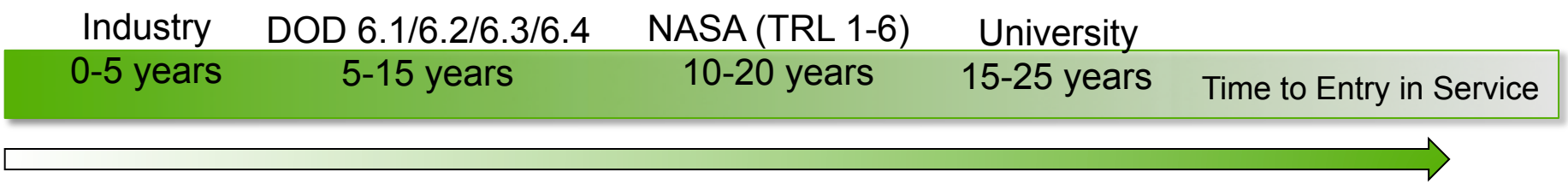
Reference: Acree, C. W., Hyeonsoo, Y., and Sinsay, J. D., "Performance Optimization of the NASA Large Civil Tiltrotor," NASA TM-2008-215359.

# Subsonic Rotary Wing (SRW) Project

## 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
- NASA has critical mass to accomplish major pieces
- Provides partnership opportunity for gaps



# SRW Technical Challenges

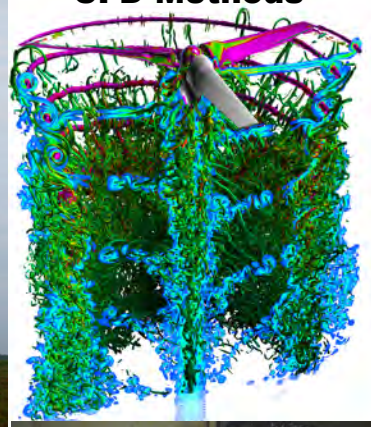
- **Integrated Aeromechanics/Propulsion System (IAPS):** Develop and demonstrate technologies enabling variable-speed rotor concepts
  - **Goal**: 50% main rotor speed reduction while retaining propulsion efficiency
- **Actively-Controlled, Efficient Rotorcraft (ACER):** Simultaneously increase aerodynamic 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; ensure design tools are hardware flexible and scalable to a large numbers of processors

# Subsonic Rotary Wing (SRW) Project

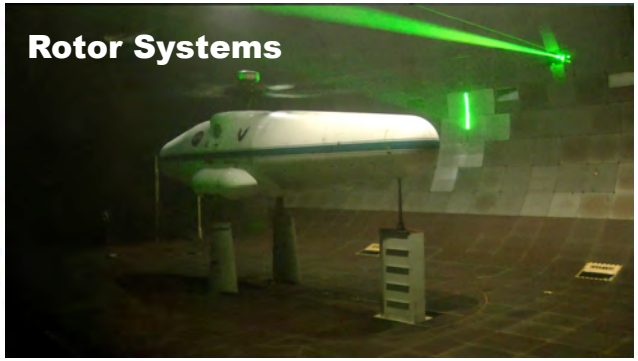
**Approach: Analytical, computational, and experimental research that is multi-platform, multi-discipline, rigorous, innovative, relevant, forward-thinking, and pushes the State-of-the-Art**

Acoustic Research

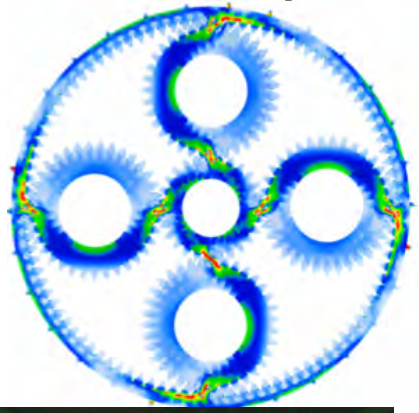
CFD Methods



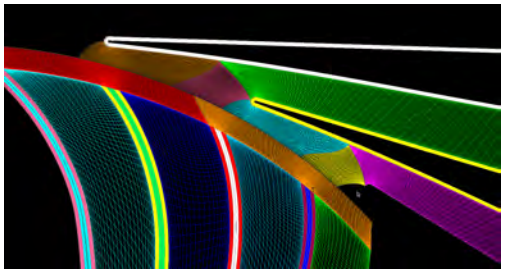
Rotor Systems



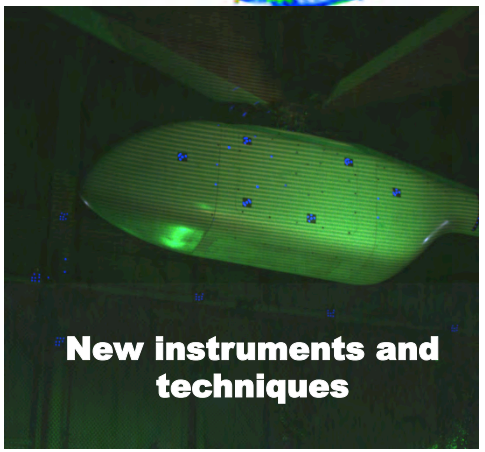
Mechanical Components



Materials & Structures

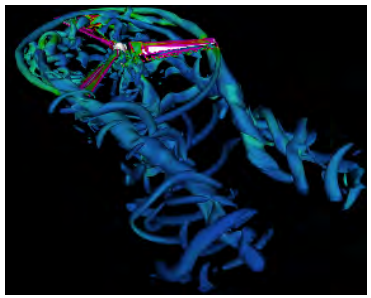


Engine Research



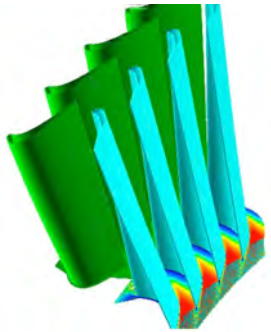
New instruments and techniques

# 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

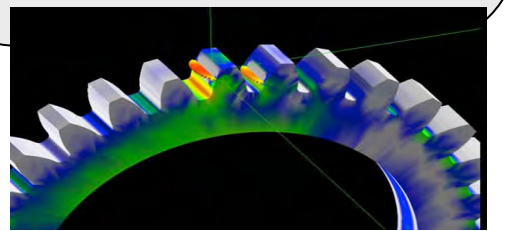
- Aeromechanics
- CFD
- Flt Dyn & Ctrl
- Acoustics
- Exp Capability
- System Analysis

**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

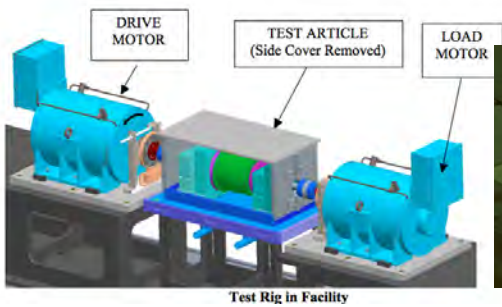
- Engine Component Research Lab
- Compressor Test Facility (CE-18)
- Transmission Test Facilities (ERB)
- Icing Research Tunnel

## Langley Research Center

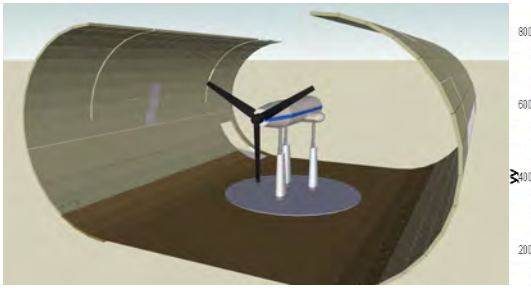
- 14- by 22-Foot Subsonic Tunnel
- Transonic Dynamics Tunnel
- Landing and Impact Research
- Structural Mechanics Lab

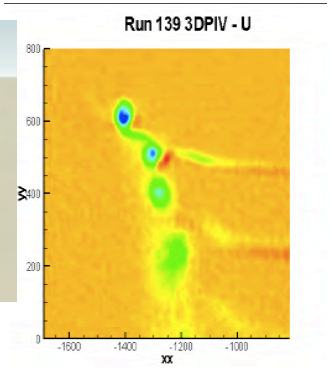
# SRW Investment in NASA Facilities, 2006-2012

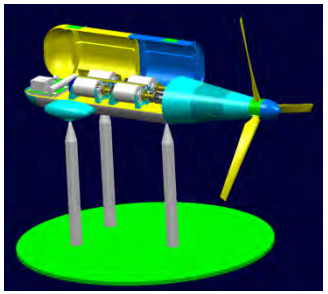
- National Full Scale Aerodynamics Complex, NFAC
  - Large Field of View Particle Image Velocimetry
  - Blade deformation measurement capability
  - Retroreflective Background Oriented Schlieren (RBOS)
  - Tiltrotor Test Rig**
- 14- by 22-Foot Subsonic Tunnel
  - New acoustic foam and traverse system
  - New instrumentation interface racks and A/D systems*
  - Upgrade and refurbish Laser Velocimeter system
  - 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
  - Refurbished T700 engine*
  - CE-18 (small compressor test facility) upgraded capability*
- Upgraded flight acoustic measurement capability*



Test Rig in Facility





*partnership with Army
**partnership with Army and Air Force
***partnership with Army and ATP

# TiltRotor Test Rig (TTR)

**PROBLEM**

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

**OBJECTIVE**

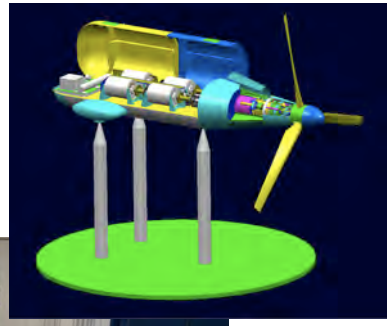
Fabricate new tiltrotor test rig to test proprotors ≤ 26-ft diameter in the National Full-Scale Aerodynamics Complex (NFAC) in axial mode, transition, and edgewise flight

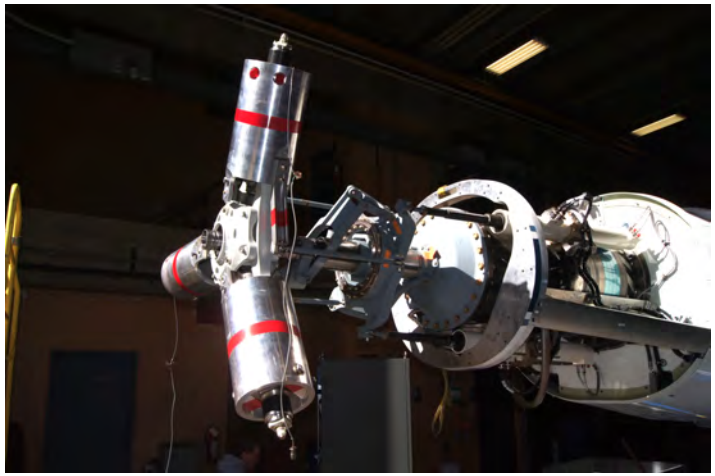
**ACCOMPLISHMENTS**

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. Other contracts complete. In-house preparations complete.

**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)



NASA Langley 90th Anniversary




Liberty Works Sikorsky DLR

Boeing VLC Bell UTRC JAXA

ONERA Bombardier Williams

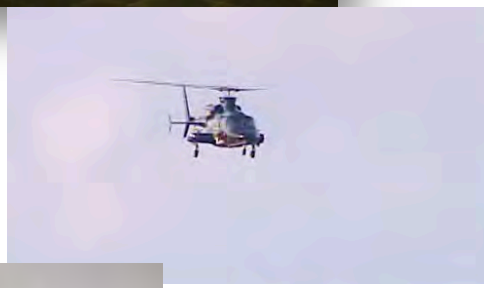
PENNSTATE 1855

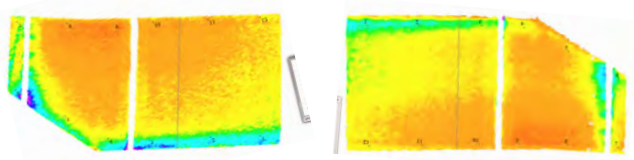
# Formal Partnerships

- Army slowed rotor research
- Army, JMR
- Army, acoustic flight research
- Army, Active Twist Rotor
- Army, PSP, PIV and PMI
- Army, UTRC, advanced compressor research
- Army, Navy, VLRCOE
- Bell, manuever acoustics
- Bombardier/Learjet, interior noise
- DARPA, MAR
- 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 (formerly HART III) ATR
- University of North Dakota, high incidence tolerant blading
- University of Padua, Italy, trajectory optimization for low noise
- VLC/CRI, fatigue life methods
- VLC/CRI, rotorcraft icing

# Highlights of Recent Research Activities

- UH-60A Airloads Wind Tunnel Data sets continue analysis and preparation for release
- 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% drag and download reduction
- Acoustic maneuver flight test with Army and Bell completed





Retreating side

Advancing side

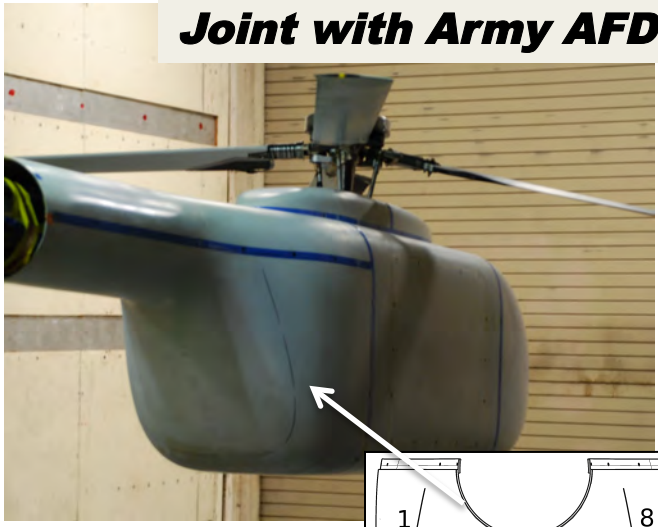
# Upcoming Sessions

| Session | Topics |
|---|---|
| Tuesday afternoon | • Propulsion<br>– Engine<br>– Drive System<br>– Advanced Materials<br>• Conceptual Design Overview |
| Wednesday morning | • Aeromechanics Overview<br>• Experimental Capabilities Overview<br>• CFD Overview<br>• OVERFLOW (structured)<br>• FUND3D (unstructured)<br>• UH-60A Airloads Wind Tunnel Data<br>• Overview<br>• PIV data<br>• Blade Displacement<br>• Fuselage Drag Reduction |
| Wednesday afternoon | • Structures<br>• Flight Dynamics Overview<br>• Acoustics |

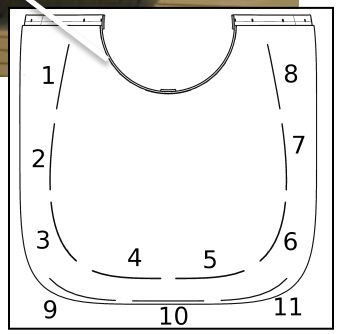
# Upcoming Research Activities

- 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, and crash predictions

***Joint with Army AFDD***



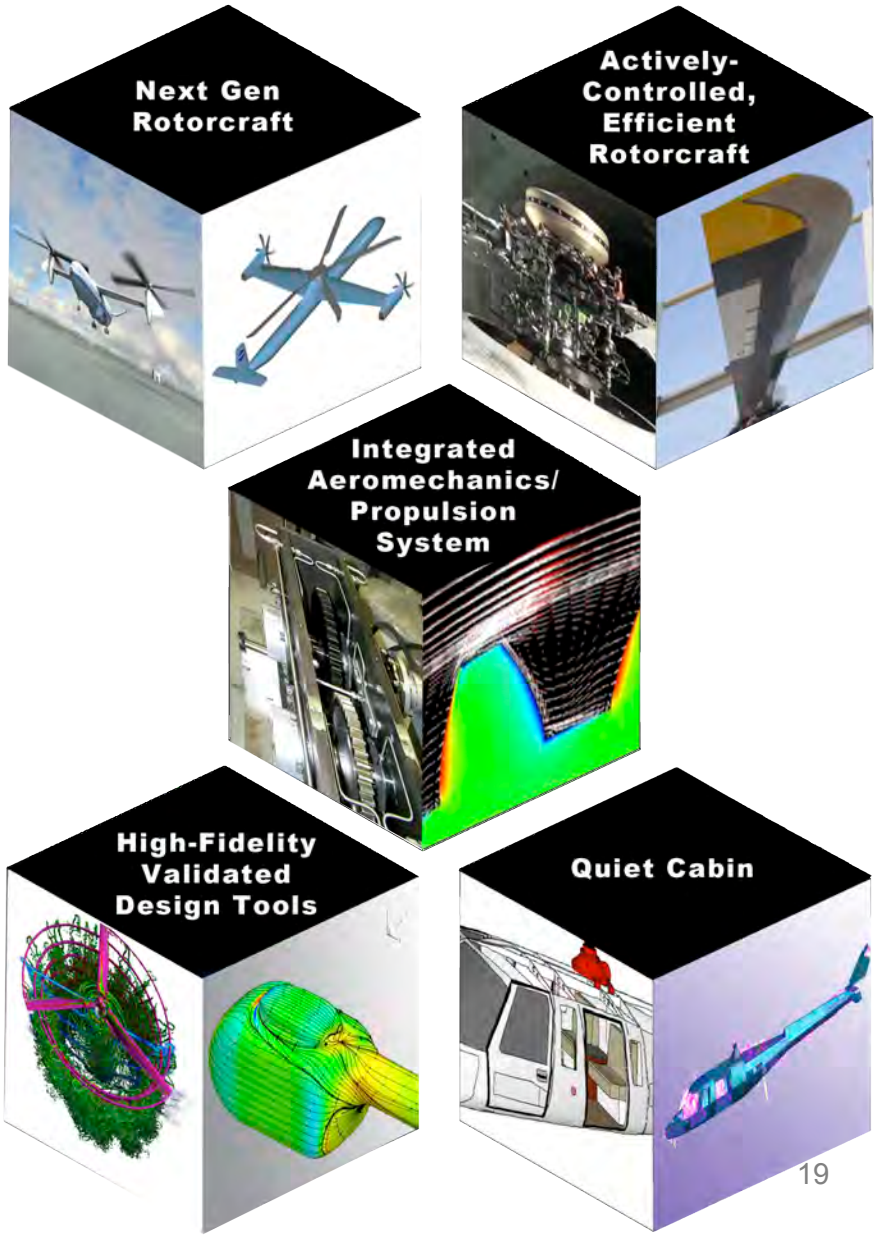
**ROBIN-mod7 in 14- by 22-FST**

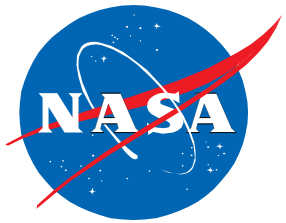



**Slot locations**

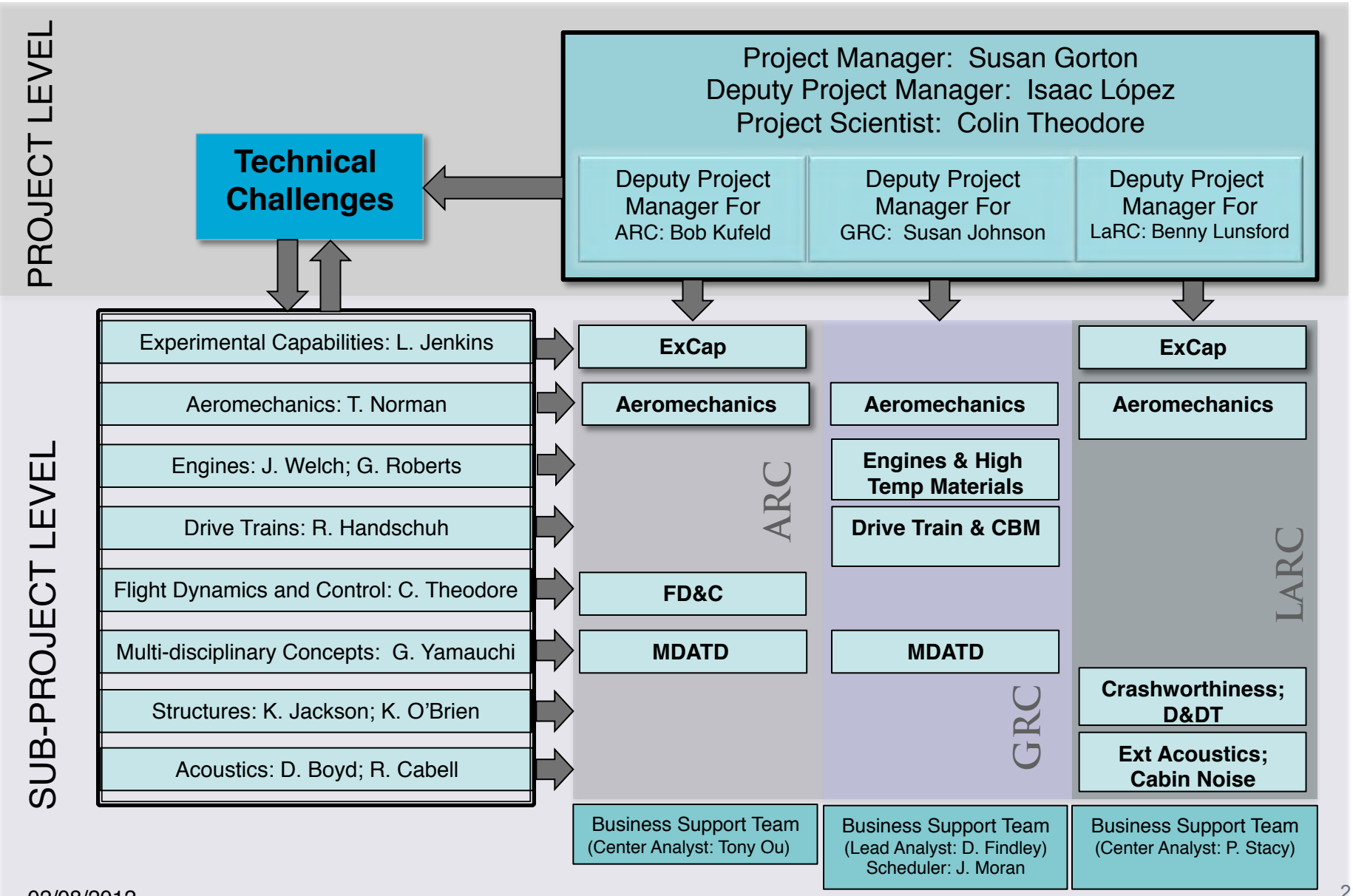
# Concluding Remarks

- 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 |

# FY11 Publications

| 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 |

# FY11 Publications

| 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 |
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| 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,I 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 |

# FY11 Publications

| 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 |

# SBIR Support for SRW

| 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 |

# SBIR Support for SRW

| 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 |
| A Surface-Mounted Rotor State Sensing System, Continuum Dynamics, Inc., A2.09-8759 | 2008 Phase 1 |
| 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 |
| Fully Integral, Flexible Composite Driveshaft, Lawrie Technology, Inc., A2.10-8919 GRC | 2007 Phase 2 |
| Computational Wind Tunnel: A Design Tool for Rotorcraft, Sukra Helitek, Inc., - A2.10-8873 ARC | 2007 Phase 2 |
| Elastomeric Dampers derived from First-Principles-Based Analytical Simulation, Materials Technologies Corporation, A2.10-8476 ARC | 2007 Phase 2 |