National Aeronautics and Space Administration

Fundamental Aeronautics Program

Subsonic Rotary Wing Project Overview

Susan A. Gorton
Project Manager

Isaac López
Deputy Project Manager

Dr. Colin R. Theodore
Project Scientist

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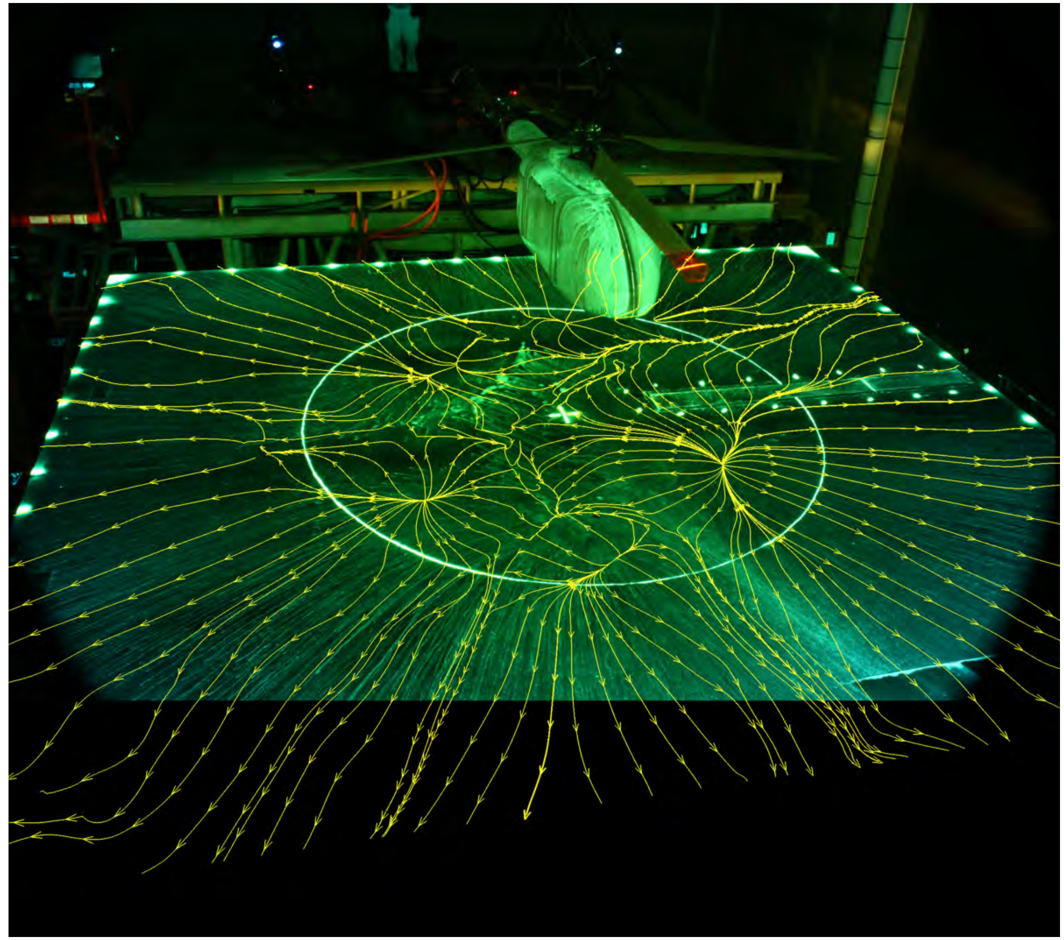
Outline

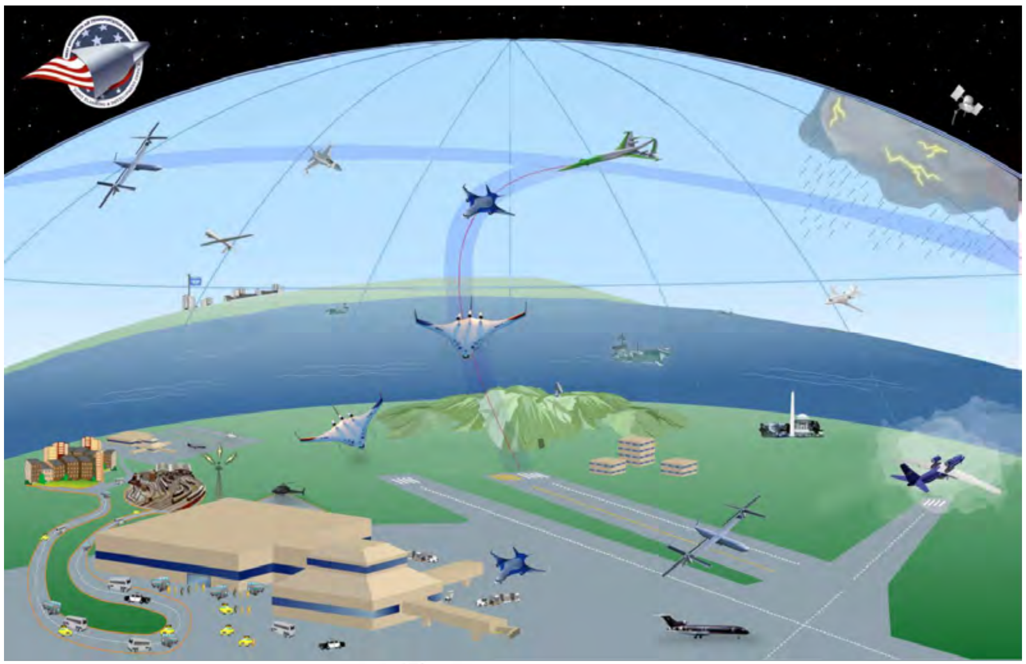
- Goal
- Objective
- Technical Challenges
- Approach
- Summary

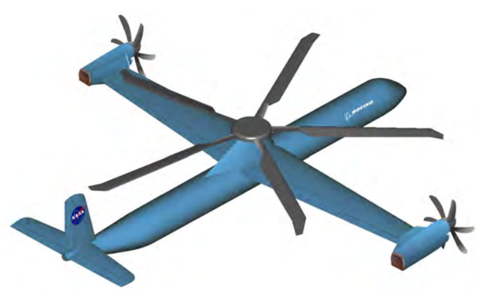


Rotor in hover ground effect. CFD streamlines superimposed on oil flow visualization

Subsonic Rotary Wing (SRW) Project

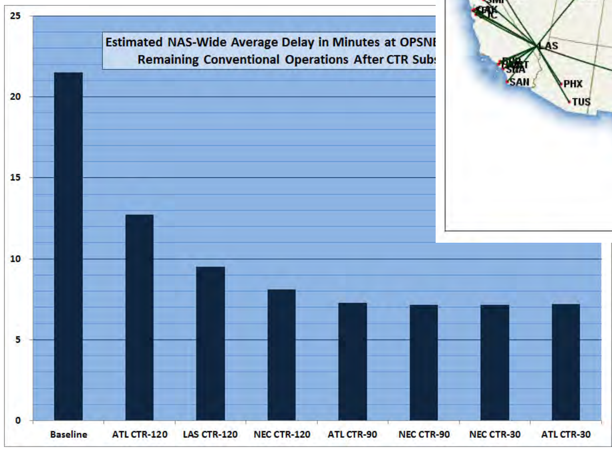
Goal: Enable radical changes in the transportation system through advanced concept rotary wing vehicles

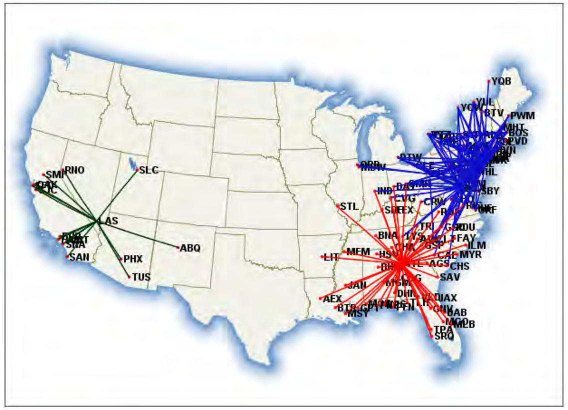




Strategic Direction

- **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

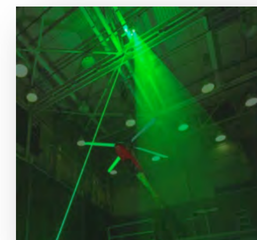
- **Status/Results**
  - Vertical capability at one or both ends of a 300-600nm mission increases airport capacity.
  - Large, advanced technology tiltrotors consistently outpace other configurations in the ability to meet the transportation mission
  - Advanced technologies (SFC, weight reduction, drag 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

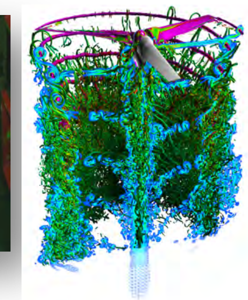
Subsonic Rotary Wing (SRW) Project

Objective: Identify enabling technologies and research areas for advanced concepts

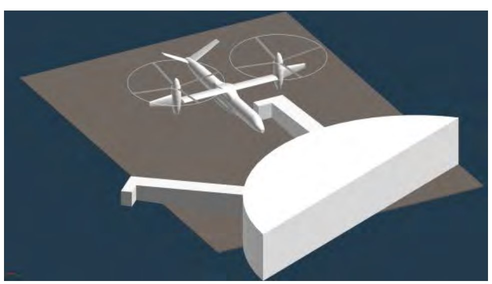
Active Rotor Systems

Modeling and Validation

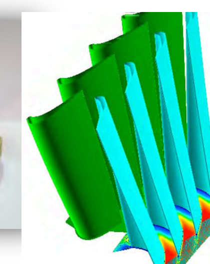


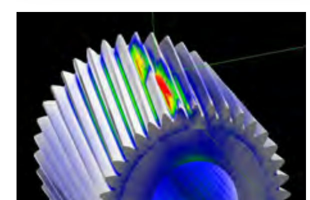


NextGen Integration

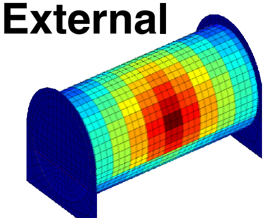


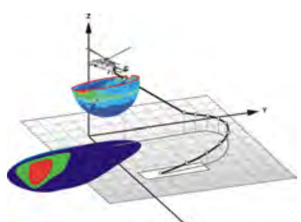
Propulsion System

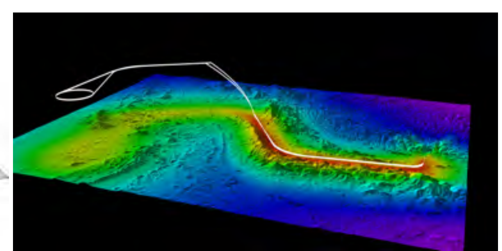




Low Noise: External and Internal







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

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

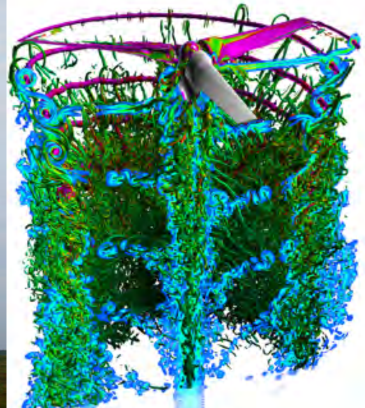
SRW Technical Challenges

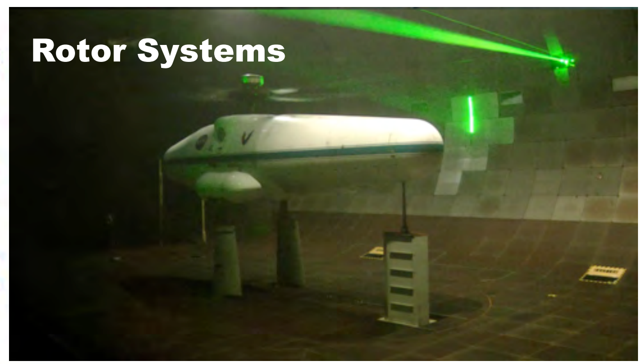
- **Integrated Aeromechanics/Propulsion System (IAPS):** Develop and demonstrate technologies enabling variable-speed rotor concepts
  - **Goal**: 50% main rotor speed reduction while retaining propulsion efficiency
  - **Benefits:** very high-speed, efficient cruise; efficient hover; reduced noise, increased range
- **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
  - **Benefits**: very high-speed, efficient cruise; efficient hover; reduced noise; improve ride quality
- **Quiet Cabin (QC):** Reduce interior noise and vibration
  - **Goal**: Internal cabin noise at level of regional jet with minimal weight penalty
  - **Benefit**: passenger acceptability; increased efficiency through weight reduction
- **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
  - **Benefit**: enables vehicle acceptability for passengers and operators
- **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
  - **Benefit:** Reduce design cycle time and cost of NextGen rotorcraft; increase confidence in new concept design

Subsonic Rotary Wing (SRW) Project

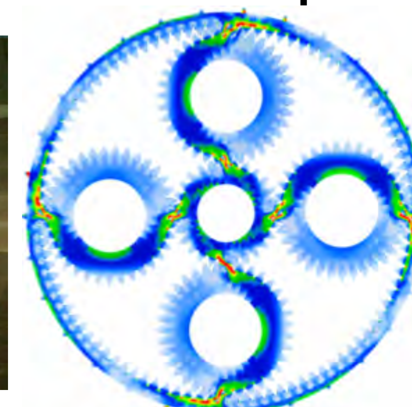
Approach: Analytical, computational, and experimental research that is multi-platform, multi-discipline, rigorous, innovative, relevant, forward-thinking, and pushes the State-of-the-Art

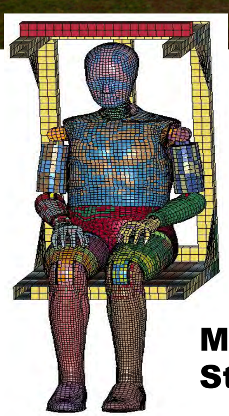
CFD Methods



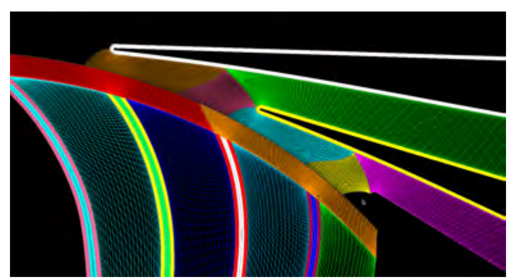


Mechanical Components

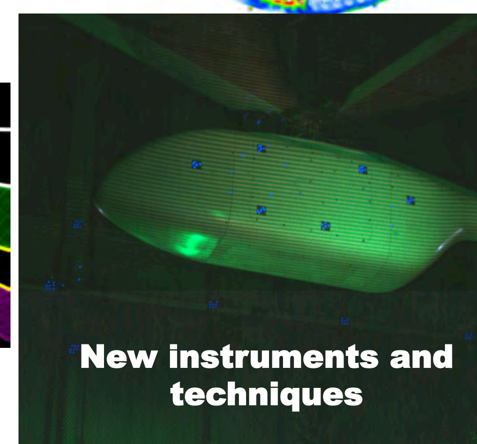




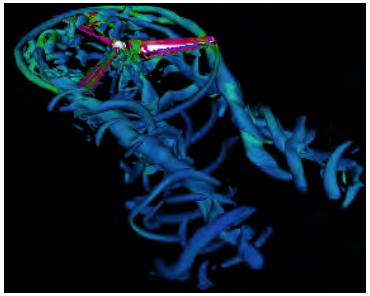
Materials & Structures



Engine Research

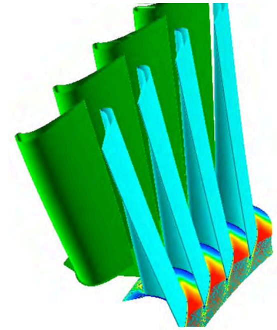


Subsonic Rotary Wing Project Team



2012 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

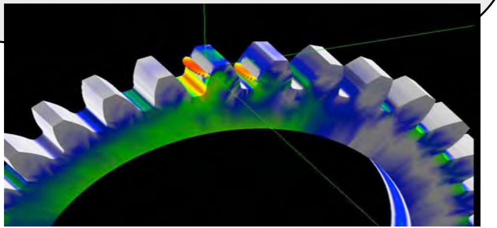
- Aeromechanics
- CFD
- Flt Dyn & Ctrl
- Acoustics
- Exp Capability
- System Analysis

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 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

GT

PENNSTATE 1855

University of Maryland 1856

SRW Major Facilities

2012 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

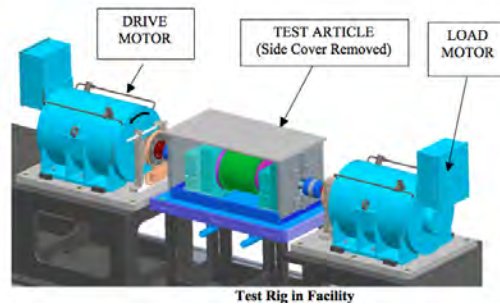
- Engine Component Research Lab
- Compressor Test Facility (CE-18)
- Transmission Test Facilities (ERB)
- Icing Research Tunnel

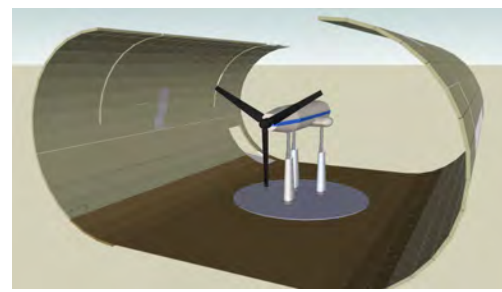
Langley Research Center

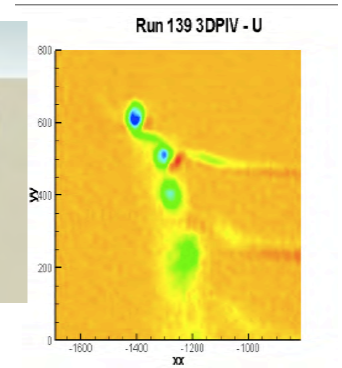
- 14- by 22-Foot Subsonic Tunnel
- Transonic Dynamics Tunnel
- Landing and Impact Research
- Structural Mechanics Lab

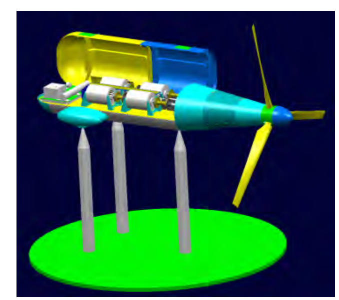
SRW Investment in NASA Facilities, 2006-2012

- 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*









*partnership with Army

**partnership with Army and Air Force

TiltRotor Test Rig (TTR)

PROBLEM

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

OBJECTIVE

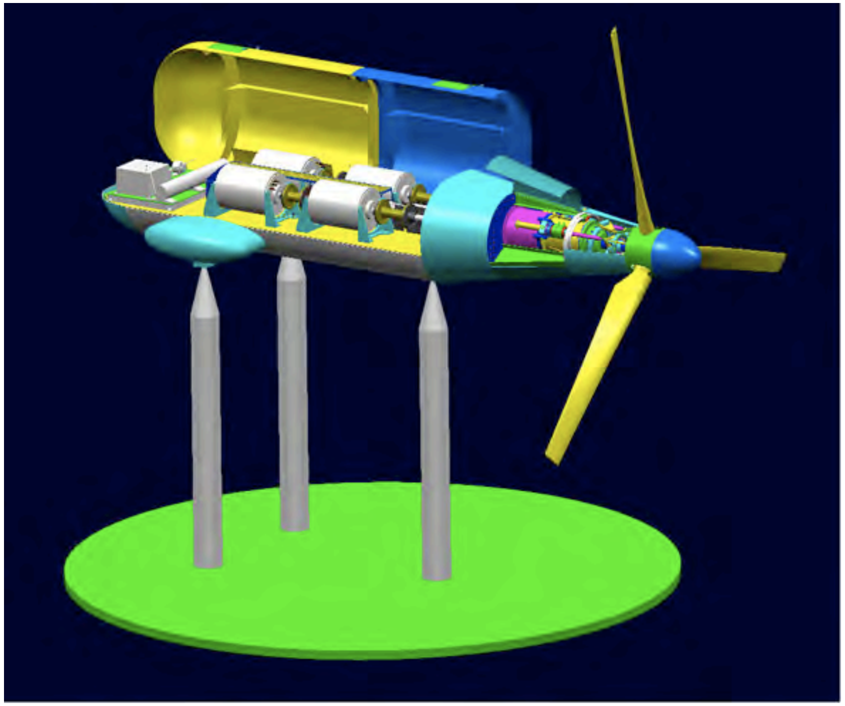
Fabricate new tiltrotor test rig to test proprotors ≤ 26-ft diameter in the National Full-Scale Aerodynamics Complex (NFAC) in axial mode, transition, and edgewise flight

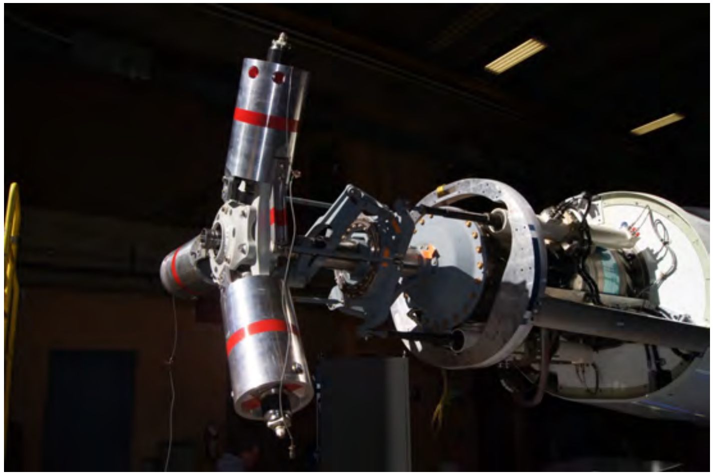
ACCOMPLISHMENTS

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

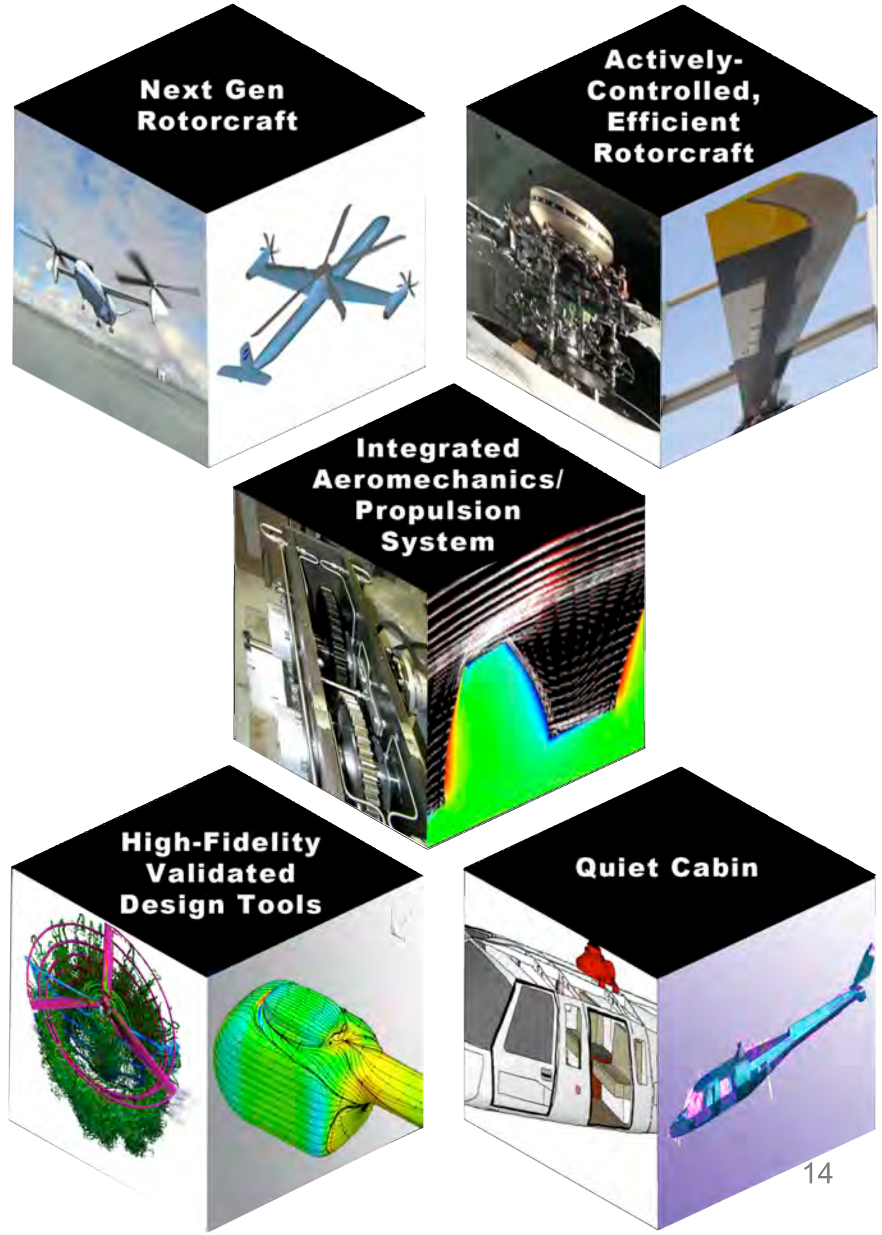
TTR is a national facility that will enable advanced, large-scale tiltrotor technology testing for speeds up to 300 knots. Will provide unique testbed for NASA, DOD, and industry research.





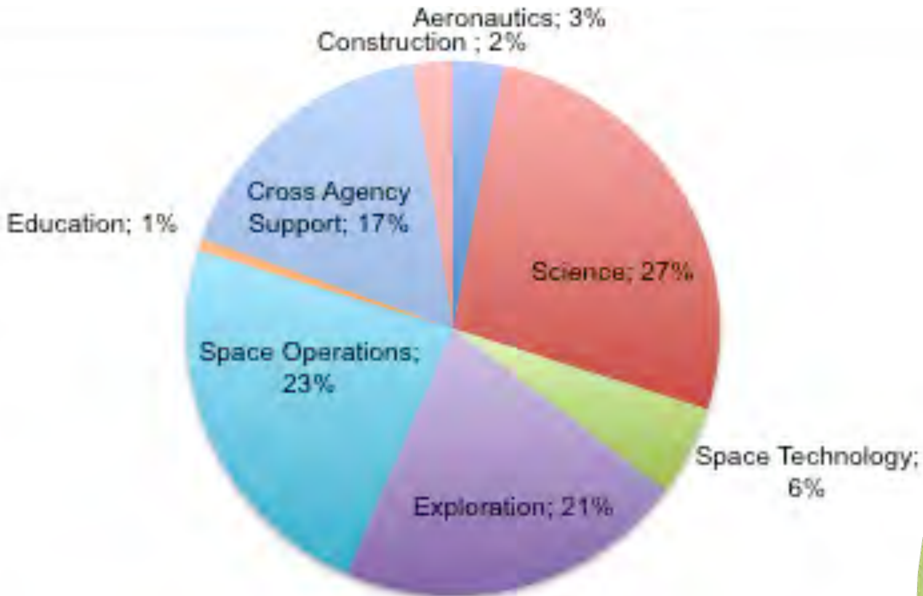
Concluding Remarks

- NASA 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

FY2012 President's Budget



NASA FY2012 President's Budget

Fundamental Aeronautics Program

FY2012 President's Budget - $186.33M (full cost)

Integrated Aero/Propulsion System (IAPS) (FY25)

What what are we trying to do?

- Demonstrate (ground test) a variable speed (50% reduction from hover to cruise) rotor

Why?

- Ability to use variable speed as a design parameter is crucial for enabling high-speed civil rotorcraft for NextGen
- Variable speed expands design space
- Variable speed enables efficiency in hover and high-speed cruise

How is it done today, and what are the limits of current practice?

- Always single speed transmission; limited variable rotor speed via changes in engine speed
- No demo of engine & transmission for variable speed operations
- No integrated platform
- No aeromechanics/propulsion test
- Only 10-15% variation in rotor speed for existing rotorcraft

What is new in our approach?

- Integrated components in a wind tunnel test
- Control system design that integrates propulsion, rotor, flight controls
- Engine gearbox speed reduction
- Efficient turbomachinery operation at variable speeds (power turbine and compressor)
- Validate transmission/engine shifting capability for cruise/hover rotor speed changes

What are the payoffs if successful?

- Variable speed rotorcraft (e.g. LCTR2) can have significant positive impact on NextGen
- New capability enabled to improve rotorcraft speed 50-70%
- New national capability for testing integrated engine/drive system

Actively-Controlled, Efficient Rotorcraft (ACER) (FY17)

What what are we trying to do?

- Evaluate active rotor technologies and develop methodologies to predict their effects

Why?

- Extend flight envelope and capabilities of current rotorcraft and maximize the capabilities of rotorcraft for future civil and military missions

How is it done today, and what are the limits of current practice?

- Passive devices; currently limited to things like swept tips, etc.
- Cannot predict performance and loads; current prediction methods are starting now to get reasonable predictions of conventional designs

What is new in our approach?

- Examination of active control technologies in an integrated way (aeromechanics + acoustics + FD&C)
- A systematic evaluation of several active rotor technologies with corresponding computational method development and evaluation

What are the payoffs if successful?

- Active devices that could be used in a practical manner
- Higher-performance, quieter rotor systems
- Extensive databases with aero performance, acoustic, structural, and flowfield data for validating analysis tools

Quiet Cabin (QC) (FY20)

What what are we trying to do?

- Develop a tool-set to analyze engine/transmission noise propagated through the structure into a representative cabin

Why?

- Need a capability for predicting noise transmission through advanced structures and provide guidance during aircraft design on interior noise impact of transmission and supporting structure design

How is it done today, and what are the limits of current practice?

- Integrated analysis does not exist
- There is no capability today to correlate changes in transmission/gearbox noise levels with expected changes in cabin noise levels. State of the art is to fly and fix hardware.

What is new in our approach?

- Develop a test rig (transmission + representative cabin) capable of varying transmission noise using interchangeable gears with interchangeable structural panels
- Integrate separate analyses into a comprehensive toolset

What are the payoffs if successful?

- Quieter cabins w/o weight penalty
- Capability to model vibroacoustic implications of variable-speed rotor
- Passenger acceptance and comfort
- New capability to trade noise reduction technologies

NextGen Rotorcraft (FY21)

What what are we trying to do?

- Foster, develop and demonstrate technologies that contribute to the commercial viability of large rotary wing transport systems in NextGen

Why?

- NASA Aeronautics and SRW goals are tied to the National R&D Plan and the national goals to support NextGen as a national priority. Advanced rotorcraft capabilities are necessary for rotorcraft to play a significant role in the future air transportation system

How is it done today, and what are the limits of current practice?

- New capability.
- There are no large (>20) passenger transport rotorcraft in service today
- Transport rotary wing limited by noise, speed, cost, payload, efficiency, safety and passenger acceptance issues.
- Operations in the airspace system need to be developed

What is new in our approach?

- Address significant commercial requirements for a large, transport rotorcraft

What are the payoffs if successful?

- Enhanced air transportation system capacity.
- Time-sensitive and fuel efficient use of rotorcraft.
- Alternative air transportation mechanism for designated service access to major hub airports (connection to long-haul system)

High-Fidelity Integrated Design Tools (FY25)

What what are we trying to do?

- Develop the next generation comprehensive rotorcraft analysis and design tools using high-fidelity models

Why?

- New rotorcraft developmental risk is too high and design cycle is too long
- Designer needs higher fidelity tools earlier in the design cycle
- High performance computing will require new design tool paradigms
- Need modular suite of tools, consistent in fidelity, to analyze rotorcraft for all operating conditions for all disciplines

How is it done today, and what are the limits of current practice?

- Mostly uncoupled discipline analyses (aero, structures, propulsion, flight dynamics and control, acoustics); limited optimization
- Analyses vary widely in accuracy
- Restricted to certain configurations, flight conditions
- Current low-fidelity/low- resolution tools are not efficient on new parallel computers—with rapidly evolving compute hardware, this is a dramatically worsening trend

What is new in our approach?

- Aiming toward first-principles modeling in all disciplines
- Insuring design tools are hardware flexible and scalable to a large numbers of processors
- Working interfaces between codes from Aero and Propulsion; Structures and Acoustics; Acoustics and Propulsion
- Facilitating closer collaboration between analysts and experimenters, resulting in better designed experiments and validation efforts

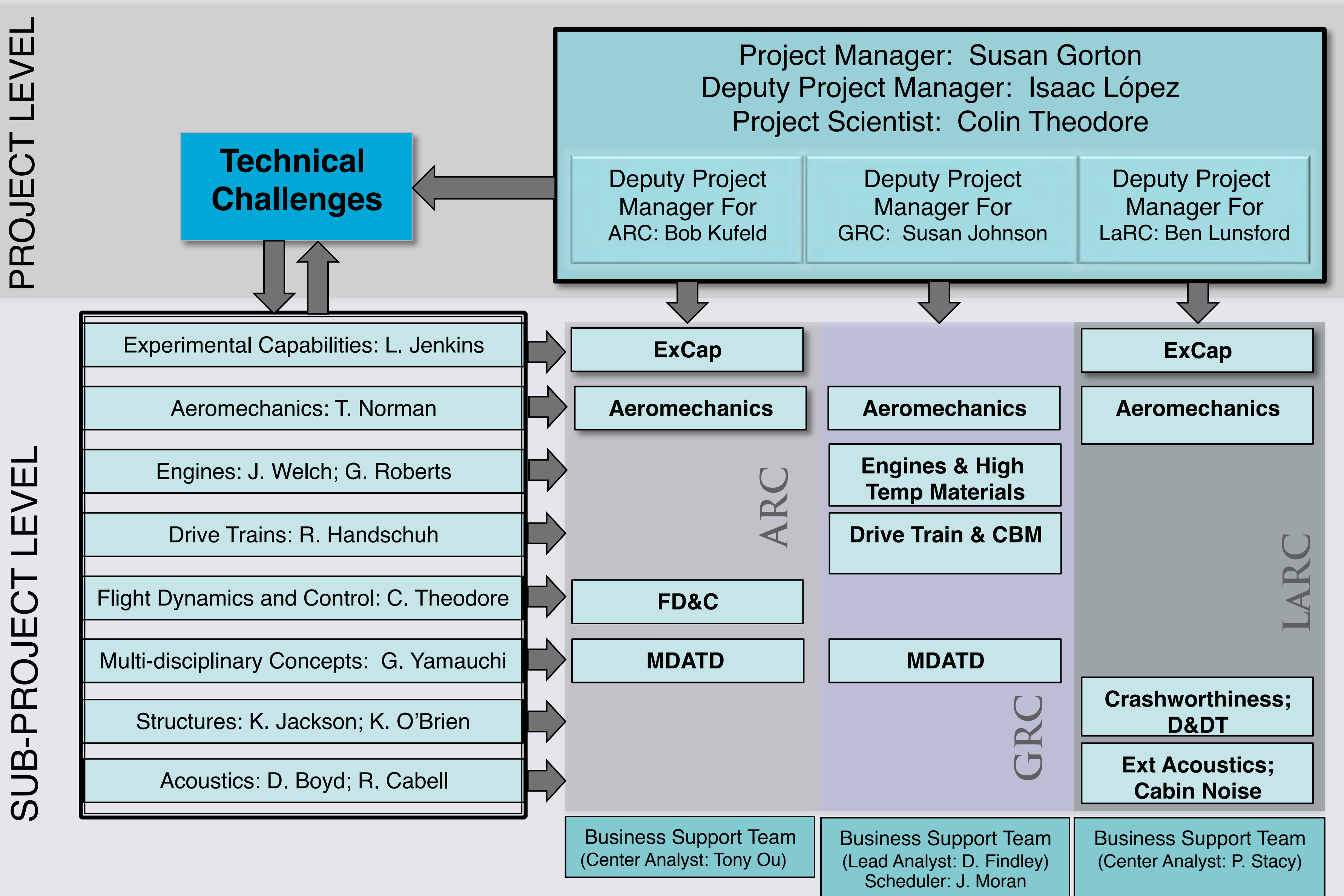
What are the payoffs if successful?

- Reduce design cycle time and cost of NextGen rotorcraft
- Enable rotorcraft to fly as designed – safely and efficiently

Specific NASA Technology Investment

- **Aeromechanics:** active rotors (flapped, active twisting, active flow control); ice accretion and shedding models; drag reduction (fuselage, hub, rotor); computational fluid dynamics (structured, unstructured); conceptual design methods; mid-fidelity design methods
- **Flight Dynamics and Control:** handling qualities for large rotary wing concepts
- **Acoustics:** external noise generation; source noise physics and prediction; low noise flight profiles; cabin noise reduction (active and passive through materials); human response
- **Drive Train/Transmission:** variable-speed drive systems; lightweight gears; low noise gears; loss of lubrication; condition based maintenance; computational models of transmissions and windage; new gear materials; new quiet teeth design
- **Turbomachinery:** variable-speed power turbines; incidence-tolerant turbine blading; ceramic matrix composite joining technology for engine blades; thermal barrier coatings for high performance engine blades; high efficiency centrifugal compressors; computational methods for compressors and turbines
- **Structures:** crashworthiness design and modeling; durability and damage tolerance for composite flexbeams and stringers; flexible composite shaft design and inspection; acoustically absorbing, lightweight materials
- **System studies:** civil tiltrotor fleet in the airspace; drive train-engine integration; compound helicopter configuration assessment; disaster relief operations for large rotary wing vehicles
- **Experimental techniques and methods:** wind tunnel test methods and pressure measurements; optical measurements of the rotor wake; rotor blade deformation measurements under flight loads; unsteady pressure measurements on the rotor blade

SRW Project Organization

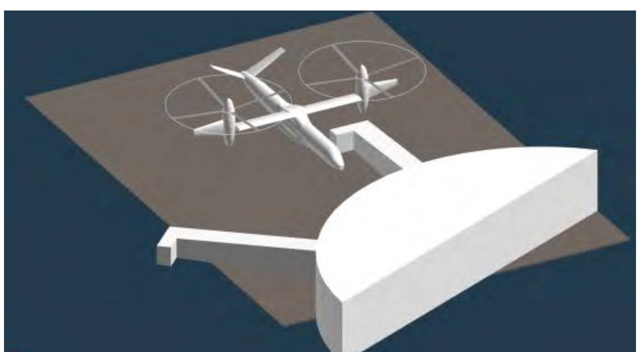


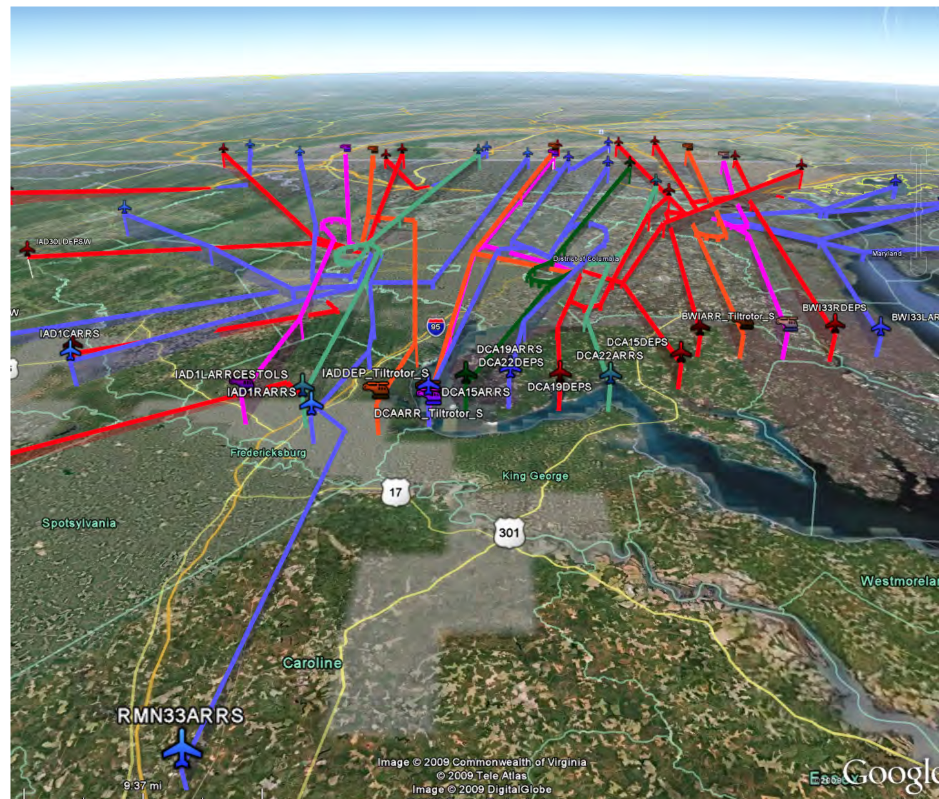
Advanced Vehicles in the NextGen

Study (~$6M) by NASA Airspace Program (2007-2009)

- "Advanced Vehicle Concepts and Implications for NextGen"
- Assessed Hybrid-Wing-Body, Supersonic Transport, Very Light Jets, Short Take Off and Landing and Large Civil Tiltrotor for variety of airspace considerations
- Showed sequencing and Simultaneous, Non-Interfering Operations possible
- Pointed out additional areas for study

NASA Contractor Report:
CR—2010–216397, October 2010
http://hdl.handle.net/2060/20110011147





Modeling High-Speed Civil Tiltrotor Transports in the Next Generation Airspace

Three-year study objectives:

… to conduct a systems study that addresses the issues associated with deploying a fleet of CTRs by exploring the trades among procedures, CTR capabilities, and overall NextGen performance

Year 2 report: "Modeling High-Speed Civil Tiltrotor Transports in the
Next Generation Airspace"
http://rotorcraft.arc.nasa.gov/CR-2011-215960_10_26_11_Hi_Res.pdf

NASA/CR–2011-215960

Modeling High-Speed Civil Tiltrotor Transports in the Next Generation Airspace

William W. Chung, Dennis Linse, Al Paris, and Dan Salvano
Science Applications International Corporation (SAIC)
McLean, Virginia

Ted Trept and Tom Wood
Bell Helicopter Textron, Inc.
Hurst, Texas

Huina Gao, Dave Miller, Ken Wright, and Ray Young
Sensis Corporation
Reston, Virginia

Victor Cheng
Optimal Synthesis, Inc.
Los Altos, California

Civil Tiltrotor in NextGen Study

Problem

Assessment of impact of civil tiltrotor (CTR) fleet is needed to validate assumptions that CTR configuration improves NextGen

Objective

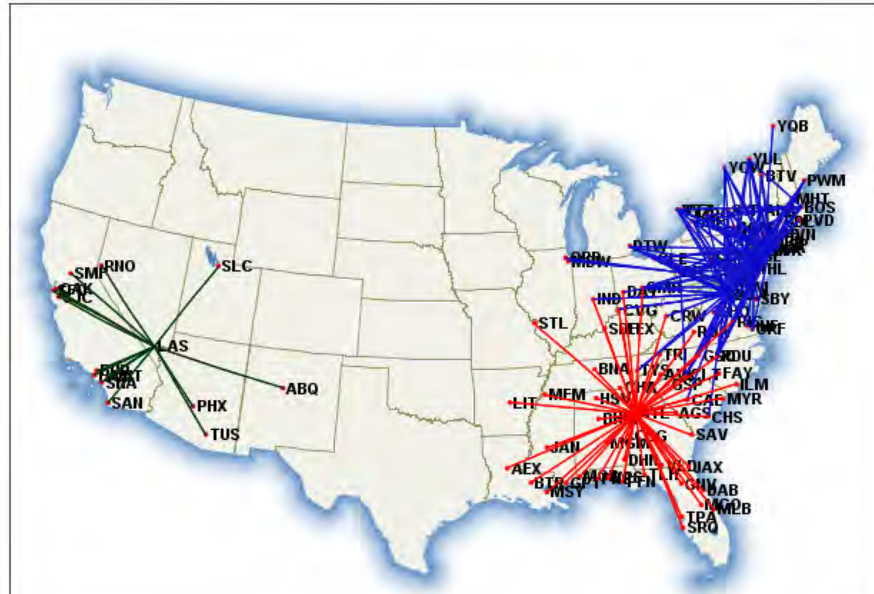
Develop a fleet of various size CTRs and assess operational affect on airspace system.

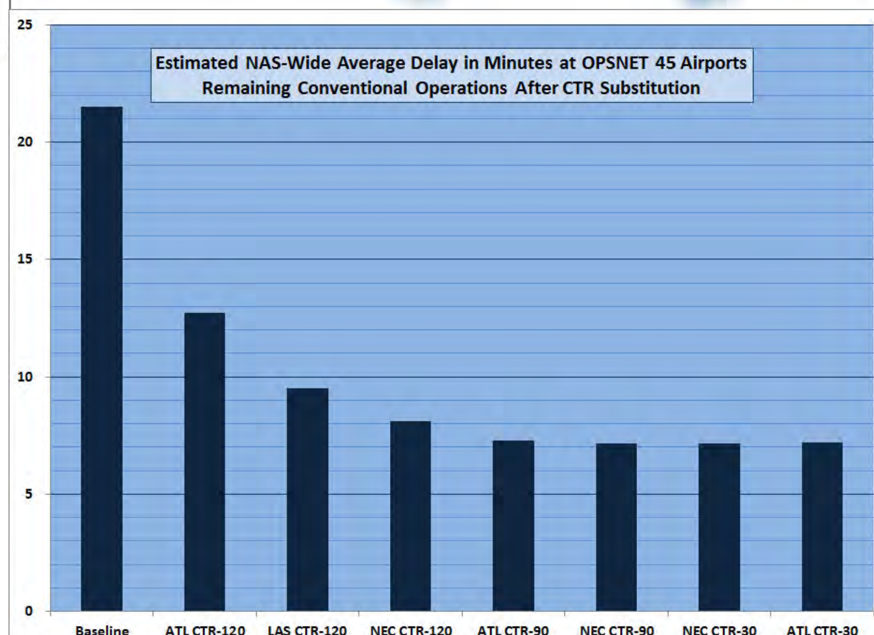
Accomplishment

Design of 30, 90, and 120 passenger CTRs were modeled in airspace system. Assessed most likely routes and operational effect.

Significance

Insertion of CTR at key locations improves the total airspace unconstrained delay time by 66%.
Year 2 report: “Modeling High-Speed Civil Tiltrotor Transports in the Next Generation Airspace”
http://rotorcraft.arc.nasa.gov/CR-2011-215960_10_26_11_Hi_Res.pdf





Technology Benefit Assessment Study

Study Objective: assess technologies that have significant benefit for Single Main Rotor Compound (SMRC) and Civil Tiltrotor (CTR) configurations

- Conducted by Boeing under NASA contract
- Results published: NASA Contractor Report 2009-214594
- Metric: Direct Operating Cost per Available Seat Mile (DOC/ASM)

Technology Benefit Study Results

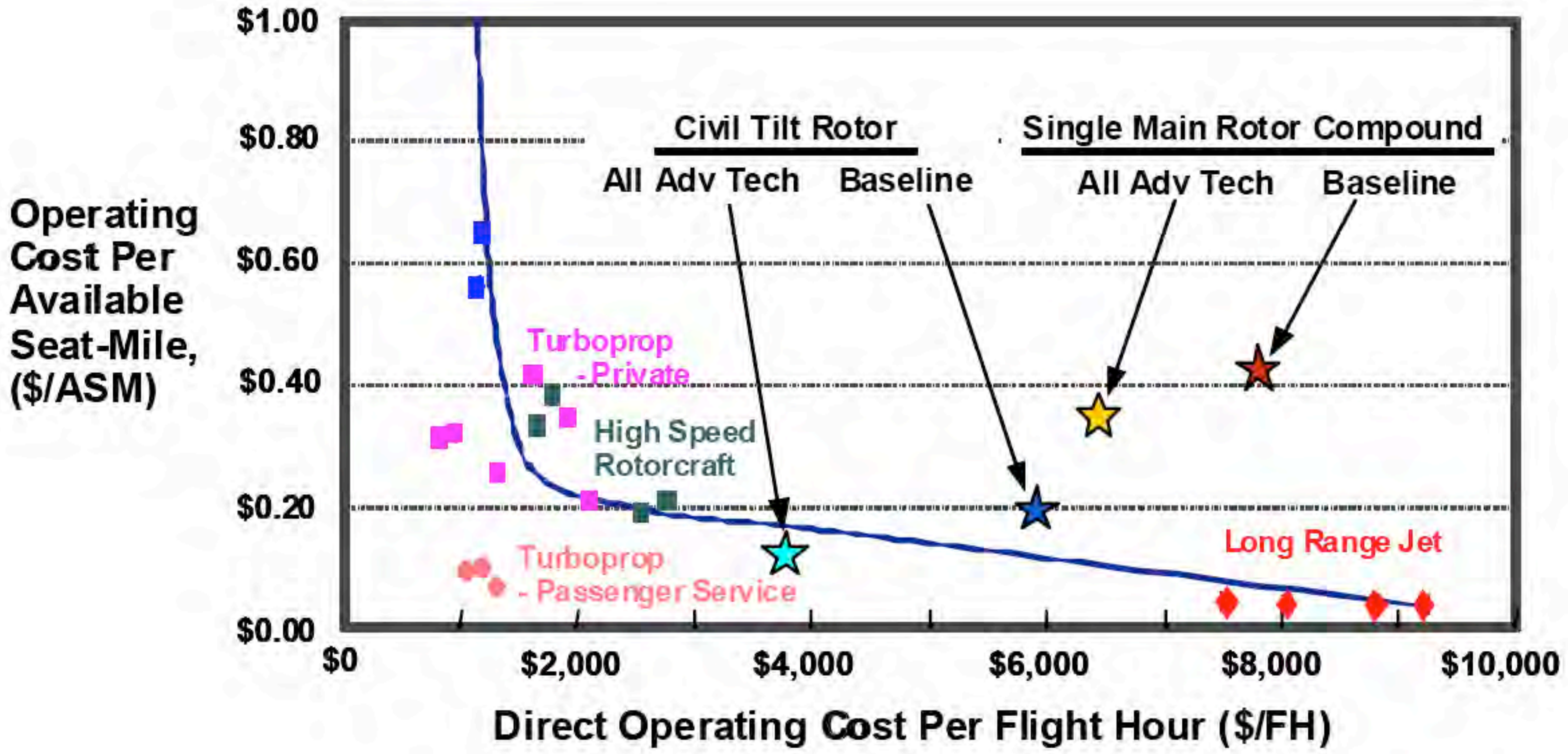
Most beneficial categories (benefit amount depends on the configuration)

- Engine fuel flow
- Structural weight
- Drive system weight
- Parasite drag
- Rotor hover and cruise performance

Investment in these technologies provides benefit to both compound and tiltrotor configurations

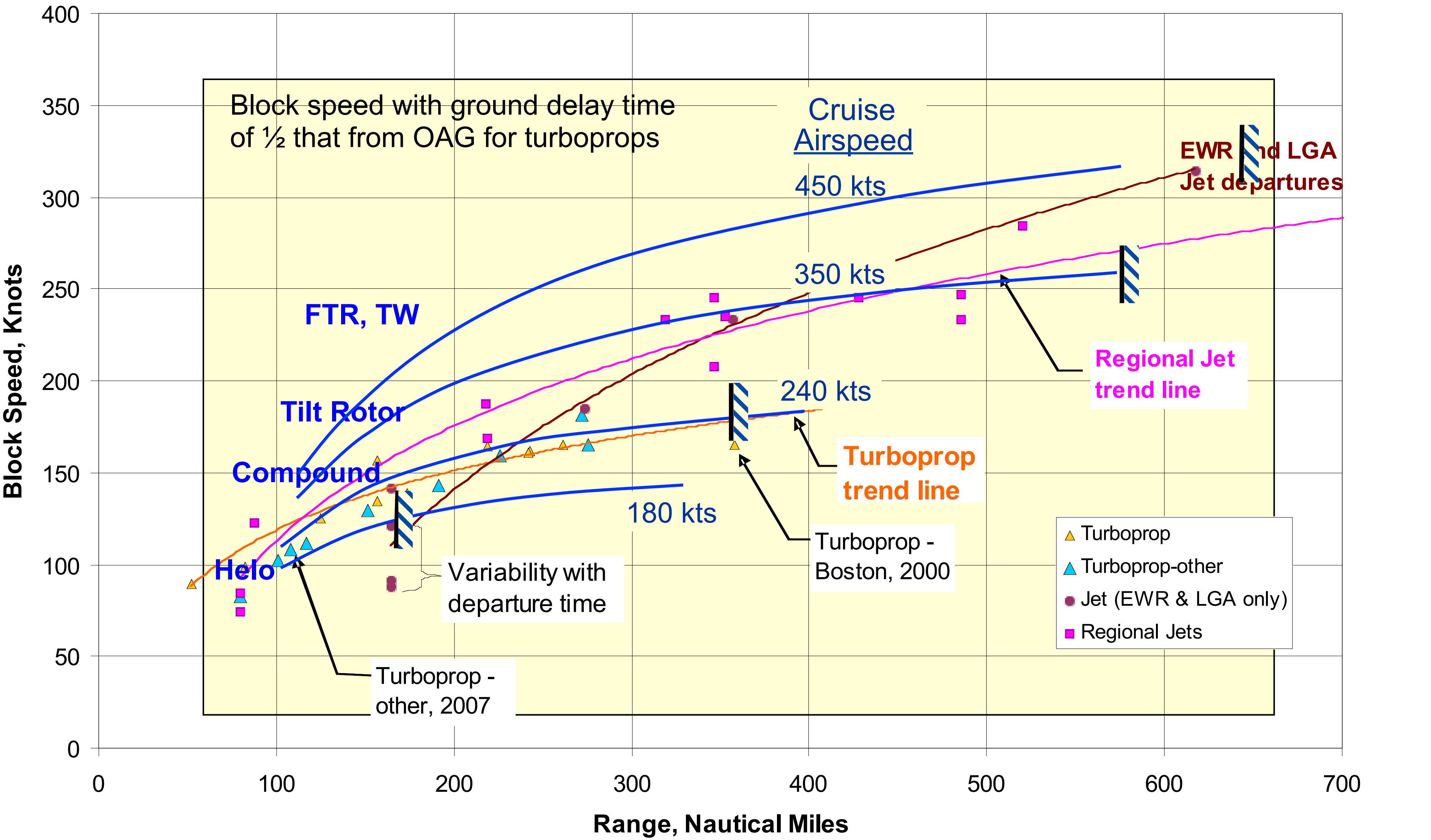
- Cost: DOC/ASM for advanced tiltrotor about the same as commercial turboprop service
- Block speed: **<u>IF</u>** cruise speed is ~300-350kts, over 300-600nm, block speed comparable to regional jet

Looking at Operating Cost



Ref: NASA CR-214594, June 2009

The Rationale for Range



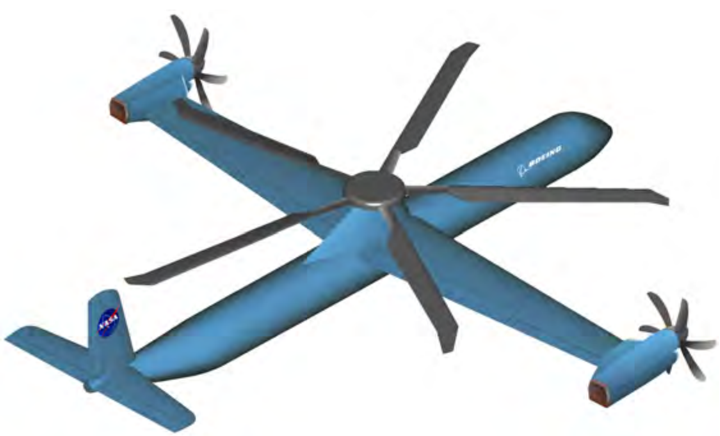
Ref: NASA CR-214594, June 2009

Common Needs with DOD

Performance, speed, payload, efficiency

JMR…

UAS…



FVL…

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.

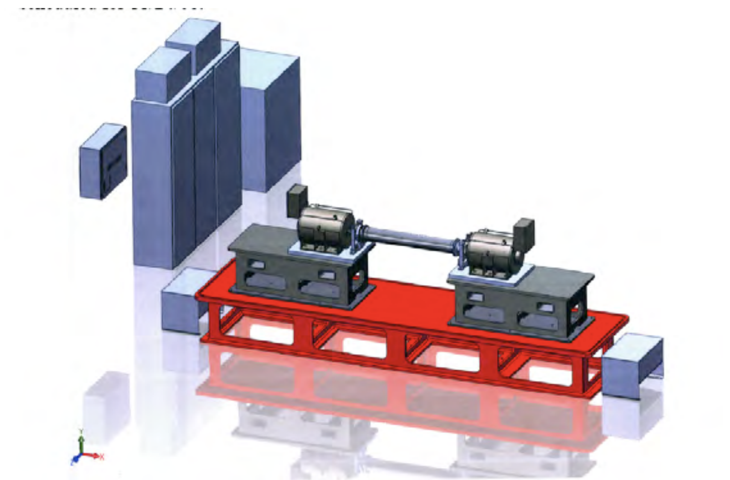
Formal Partnerships

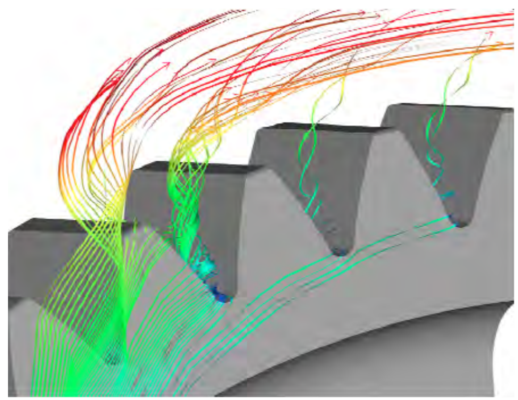
- FAA, drive system health monitoring
- Army slowed rotor research
- JAXA active rotor prediction and test
- Army, JMR
- Army, acoustic flight research
- Army, Active Twist Rotor
- Army, PSP, PIV and PMI
- Army, UTRC, advanced compressor research
- VLC/CRI, fatigue life methods
- ONERA, Active Flow Control on fuselage
- ONERA, Cabin Noise
- DLR, Active Stick Controller
- DLR, Rotor wake measurement techniques
- STAR (formerly HART III) ATR
- Bombardier/Learjet, interior noise
- University of Padua, Italy, trajectory optimization for low noise
- University of North Dakota
- Sikorsky, impact dynamics
- Bell, maneuver flight acoustics

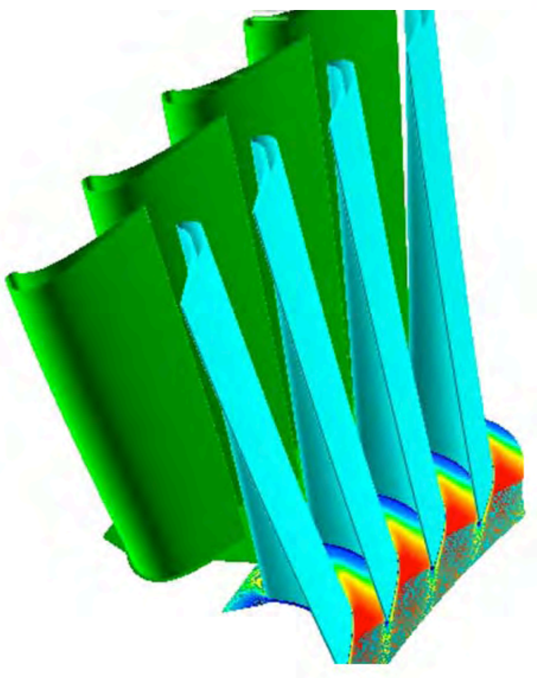
SRW Discipline: Propulsion

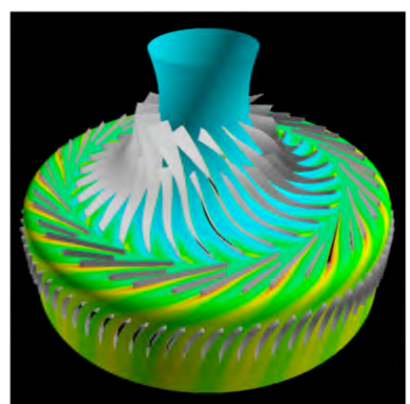
Advanced modeling tools/concepts essential to allow an engine/drive system to achieve a significantly larger speed range without sacrificing power and efficiency

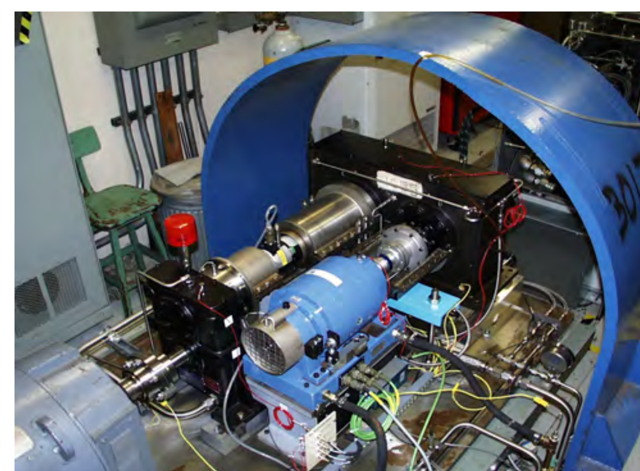
- High efficiency, multi/variable-speed drive systems
- Efficient, variable-speed turbomachinery







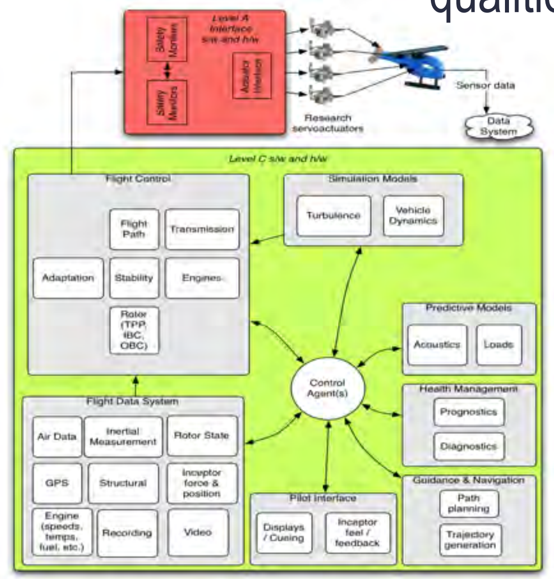




SRW Discipline: Flight Dynamics and Control

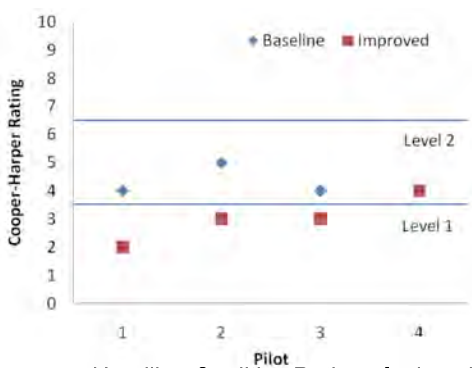
Flight dynamics and control research focuses on modeling, testing, and validating real-time control of integrated, advanced rotorcraft technologies with emphasis on handling qualities for large rotorcraft.

First-Principles Modeling

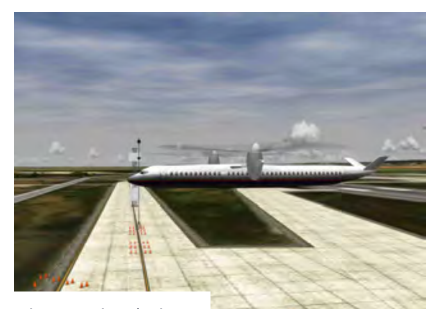


Vertical Motion Simulator
T-Cab with baseline inceptors

Validation



Handling Qualities Ratings for baseline and improved configurations

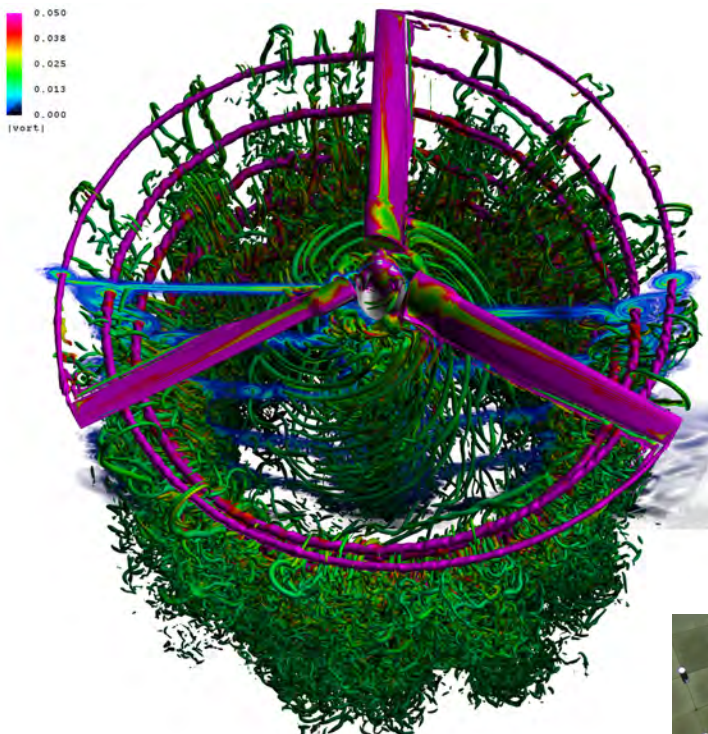


LCTR2 precision hover simulation

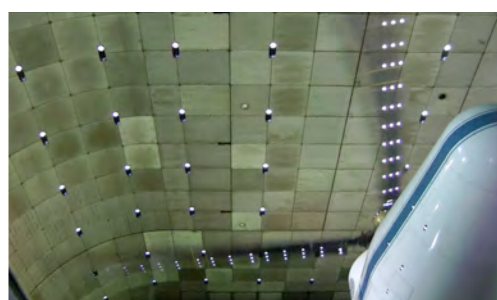
SRW Discipline: Aeromechanics

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

First-Principles Modeling

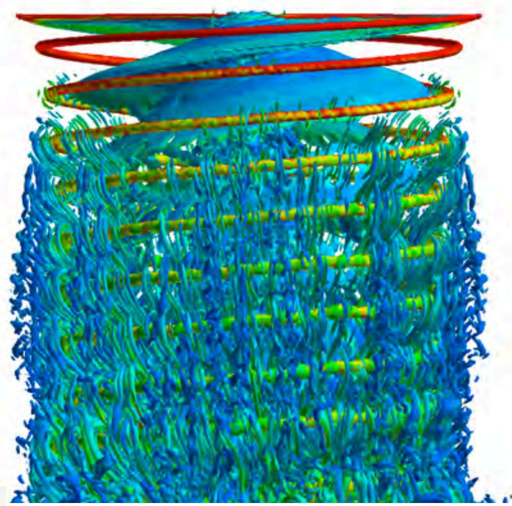


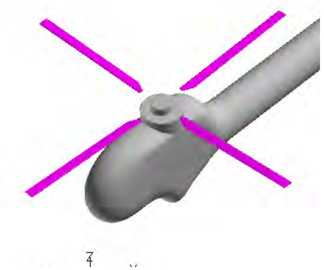
Testing

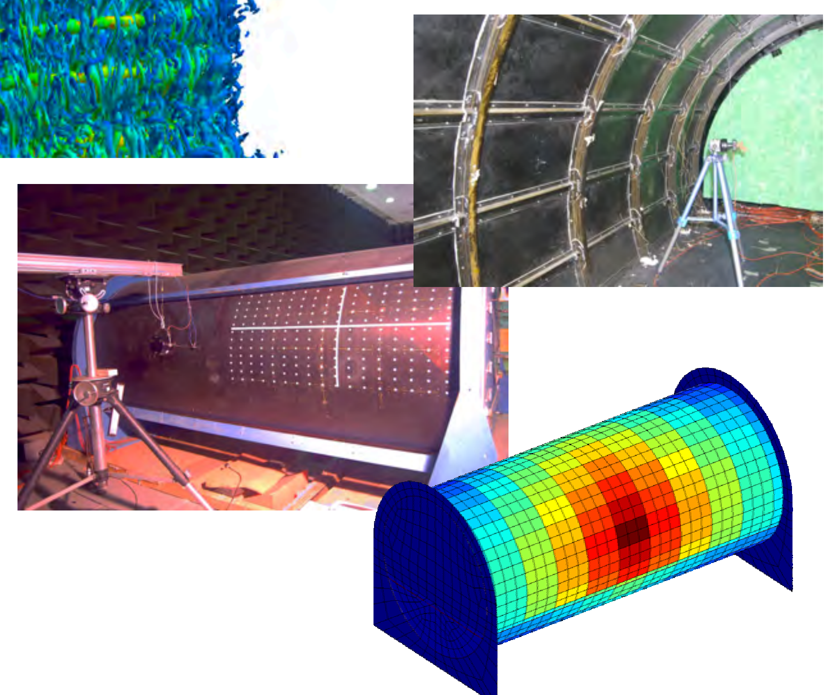


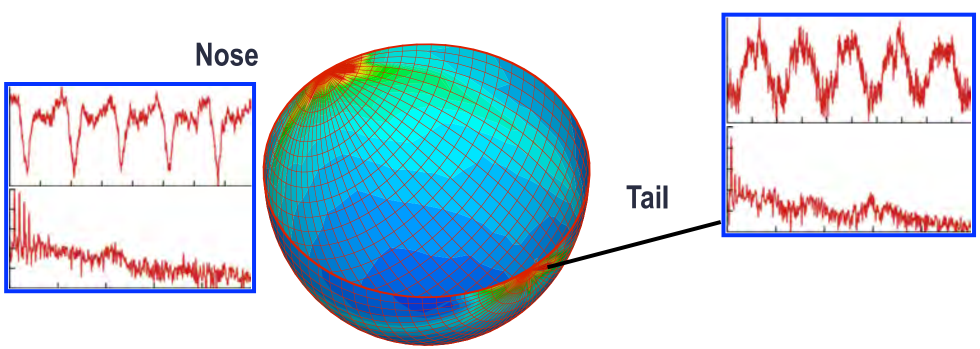
SRW Discipline: Acoustics

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



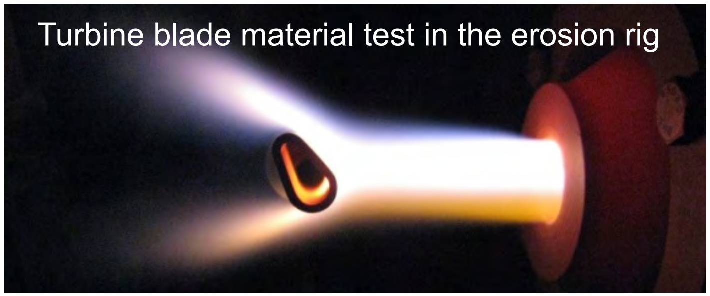






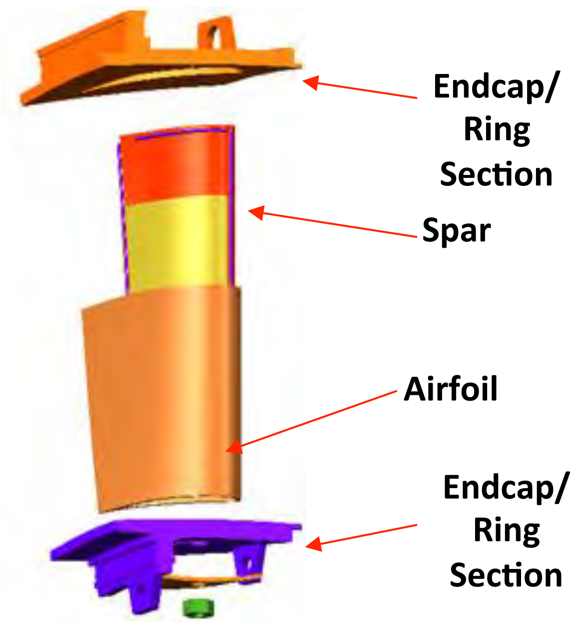
SRW Discipline: Material and Structures

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

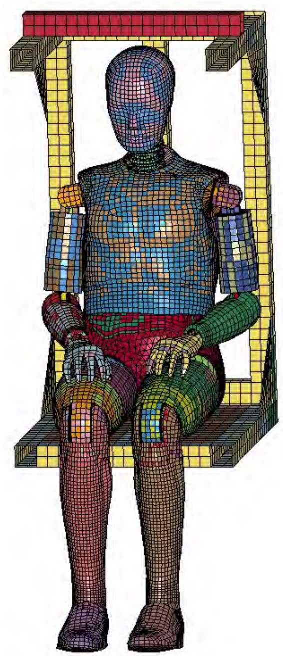


Turbine blade material test in the erosion rig

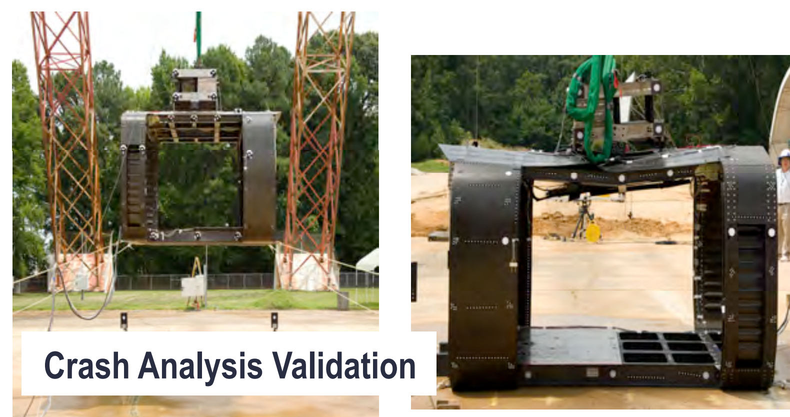
Post-failure pictures of imperfect specimen. Grey/blue zone under flange represents manufacturing defect.



Hybrid Vane for HPT



FTSS finite element model



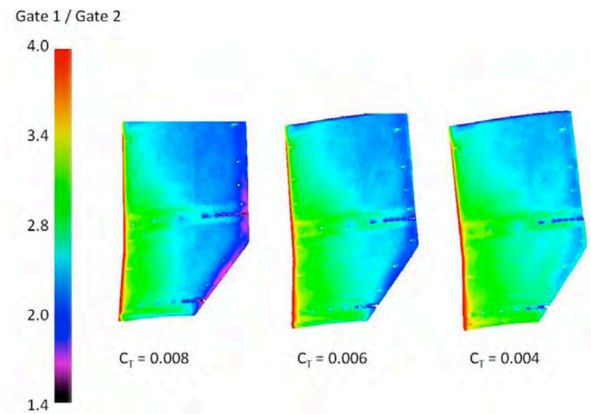
Crash Analysis Validation

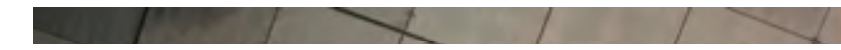
SRW Discipline: Experimental Capabilities

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

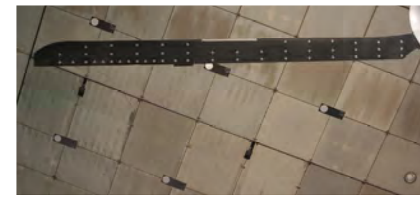
Large field rotor wake assessments

Representative porous polymer PSP data from a rotorcraft blade in hover





Deformed blade geometry



Blade Displacement

Targeted Primary NASA Rotorcraft Test Facilities

National Full-Scale Aerodynamics Complex

Transonic Dynamics Tunnel

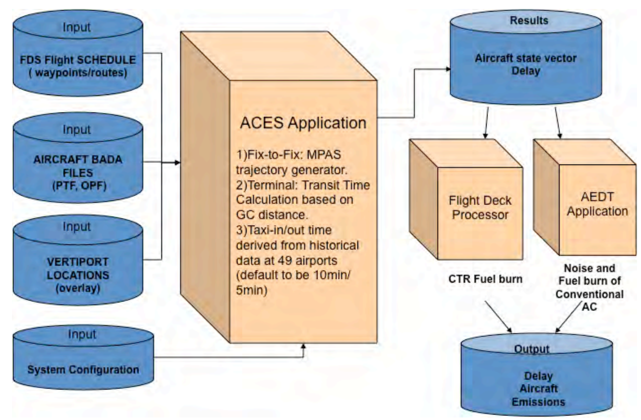
14- by 22-Foot Subsonic Tunnel

SRW Discipline: Multi-Disciplinary Analysis and Technology Development

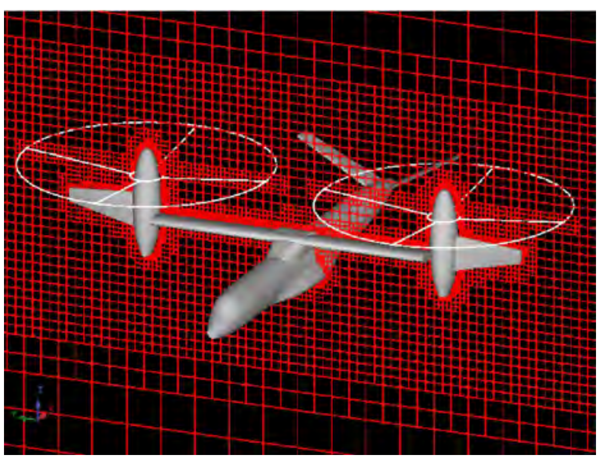
Provides a focal point for the integration of discipline technologies to guide fundamental research priorities. Analyses development at the system level and demonstrations of integrated components to enable advanced rotorcraft.

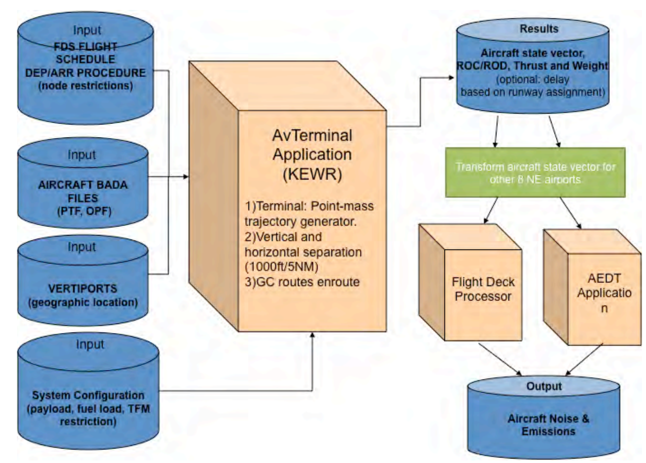
Elements

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



"CTR in Next Gen Airspace" Simulation Framework





NASA