National Aeronautics and Space Administration

Fundamental Aeronautics Program

Subsonic Rotary Wing Project

Aeromechanics Overview

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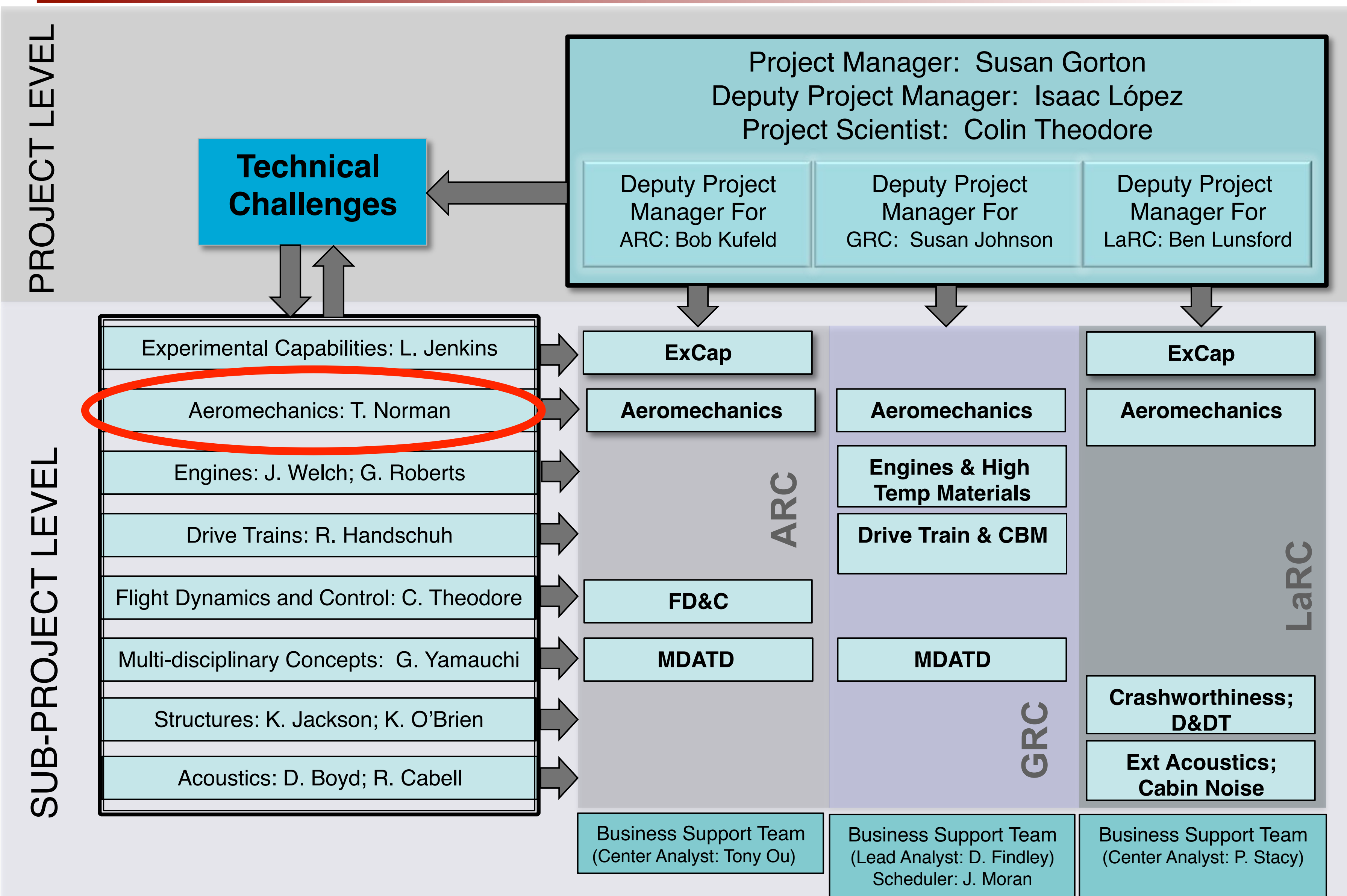
Outline

- Organization
- Aeromechanics Task Areas
- Aeromechanics Highlights
- Near-Term Plans

- Questions?

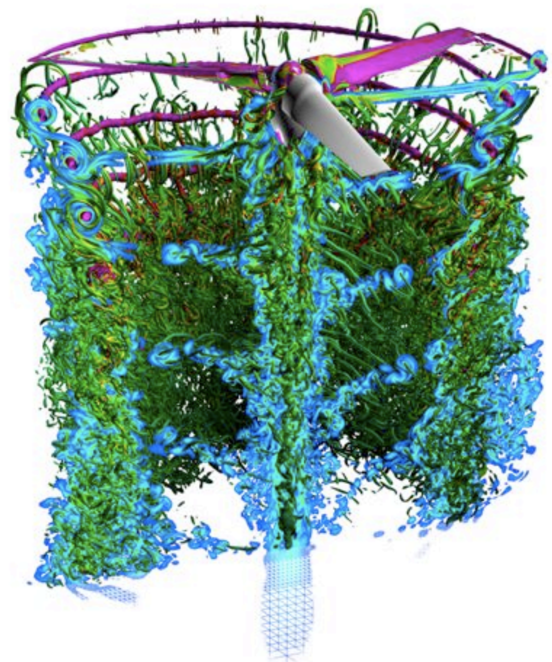
SRW Project Organization



SRW Aeromechanics

Objectives

- Advance the understanding of phenomena in aerodynamics, dynamics, and active control of rotorcraft in support of SRW Technical Challenges
    - Develop and validate first-principles tools
    - Acquire data for tool validation from small- and large-scale testing of existing and novel rotorcraft configurations

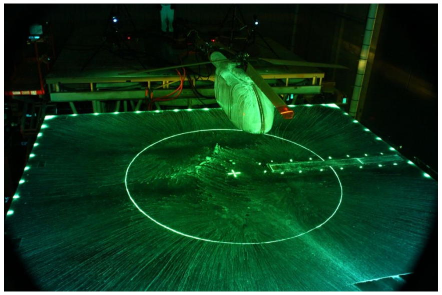


Isolated tiltrotor in hover (OVERFLOW)

UH-60A Airloads Test

Aeromechanics Facilities

- Primary Facilities
  - ARC
    - Supercomputing Complex (NAS)
    - USAF National Full-Scale Aerodynamics Complex (NFAC) – 40x80
    - Army 7x10 Wind Tunnel
  - GRC
    - Icing Research Tunnel (IRT)
  - LaRC
    - 14- by 22-Ft Wind Tunnel (14x22) and hover test cell
    - Transonic Dynamics Tunnel (TDT)
    - 2x3 Tunnel



Aeromechanics Task Areas

- Aeromechanics sub-project organized into 6 interrelated task areas
  - CFD/CSD Tool Development and Applications
  - Icing
  - Active Rotors
  - Advanced Configurations
  - Rotor Aerodynamics and Interactions
  - Rotor Dynamics and Control

Aeromechanics Task Areas

- CFD/CSD Tool Development and Applications
  - Structured (OVERFLOW)
    - Code enhancements, improved gridding, coupling methods, optimization, validation
  - Unstructured (FUN3D)
    - Code enhancements, improved gridding, coupling methods, optimization, validation
- Icing
  - LEWICE/ CFD developments
  - Experimental Research
- Active Rotors
  - Root pitch and on-blade flap (IBC, SMART)
  - Active Twist (ATR, STAR)
  - Flow control in rotating system

Aeromechanics Task Areas

- Advanced Configurations
  - Tiltrotor research, use of Tiltrotor Test Rig (TTR)
  - Slowed rotor compound research
- Rotor Aerodynamics and Interactions
  - Airloads
  - Drag reduction
  - Rotor/fuselage/tail interactions
  - Dynamic stall
  - Flow control in fixed system
  - Downwash/outwash
- Rotor Dynamics and Control
  - Oscillatory hub loads
  - Stability
  - Active Controller development

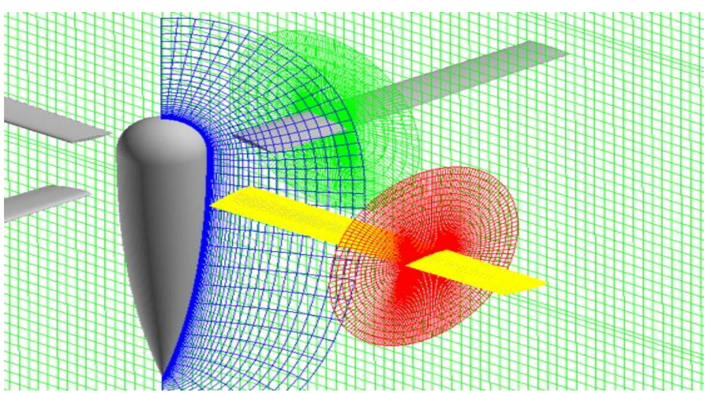
Research Areas to be Highlighted

- Structured CFD Development and Applications*
- Unstructured CFD Development and Applications*
- **Rotorcraft Icing**
- **Apache Active Twist Rotor (ATR-A)**
- **Tiltrotor Test Rig Development**
- UH-60 Airloads Wind Tunnel Test Highlights*
- Fuselage Drag Reduction via Active Flow Control*
- **Rotor in Ground Effect (Downwash/Outwash)**

*Separate Presentation

Rotorcraft Icing

- Objective
  - Acquire key experimental data and develop computational methods to accurately predict the effects of ice accretion on rotor performance
- Approach
  - Develop high-fidelity coupled analysis capability (CFD/CSD and ice accretion codes)
  - Evaluate analysis capabilities using existing and new experimental data
  - Work closely with industry and university partners to best leverage NASA investment (NRA's, VLC/NRTC partnerships, VLRCOE collaboration)
- Recent Accomplishments
  - Completed 3 highly successful NASA-sponsored NRA's to develop and apply coupled CFD/ice accretion codes to rotor performance predictions



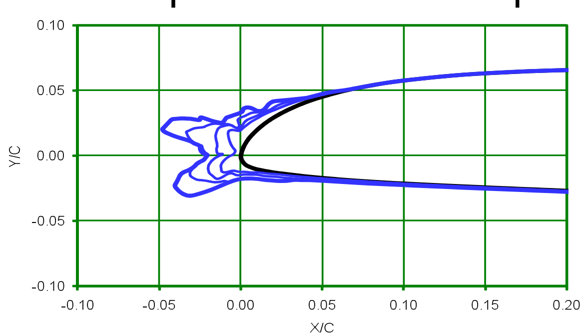
CFD Modeling

Oscillating Airfoil Icing Test

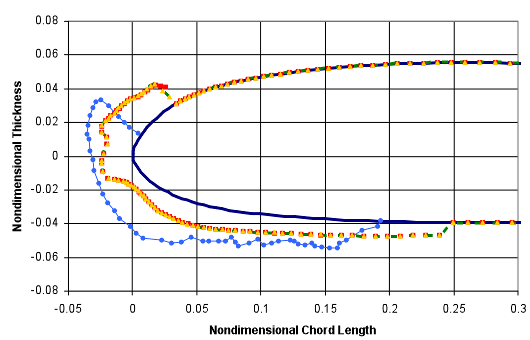
Icing NRA's

- Boeing
  - Loose-coupling of OVERFLOW-RCAS for rotor performance prediction with Lewice3D for thermal analysis and ice accretion (2D)
  - Performance and ice shapes compared with experimental hover/forward flight data
- Georgia Tech/Sikorsky
  - Integrated tool set (Python-based script) with CFD/CSD, grid generation, and ice accretion modeling. Stand-alone module for runback-refreeze characteristics.
  - Key computational parameters explored, preliminary results encouraging
- Penn State/Bell
  - Generalized unstructured CFD approach for simulating ice accretion on aircraft
  - Calculates air flow, droplet trajectories, surface-liquid flow, solidification, and computes deformed ice shape. Initial validation cases promising.

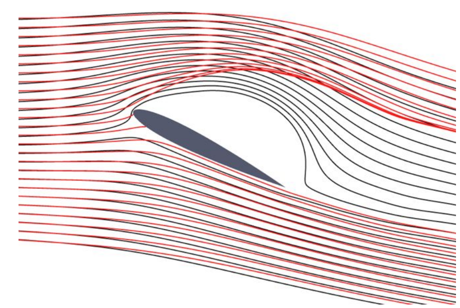
Boeing
Sequential Ice Build-up



GT/Sikorsky
Ice Shape Validation



Penn State/Bell
Droplet Trajectories

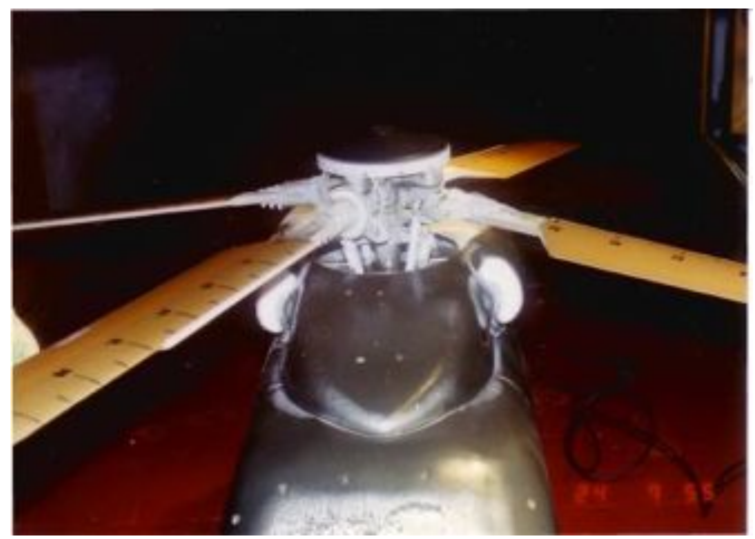


Icing Plans

- Evaluate new computational approach(es) for non-iced and iced rotor performance and ice accumulation predictions
  - Identify limitations in approaches and address needs for improved models and/or key experimental data (shedding, surface heat transfer prediction, collection efficiency)
  - Internal NASA evaluation and collaboratively with VLC/NRTC/VLRCOE

- Continue preparations for subscale rotor testing in Icing Research Tunnel (IRT) in 2013 (joint with VLC/NRTC)
  - Test will provide key data on rotor performance decrement, runback-refreeze phenomena, and ice shedding
  - In preparation for test, will develop improved methods to measure/document three-dimensional ice accretion shapes

Powered Force Model With Simulated Ice Shapes (1994)

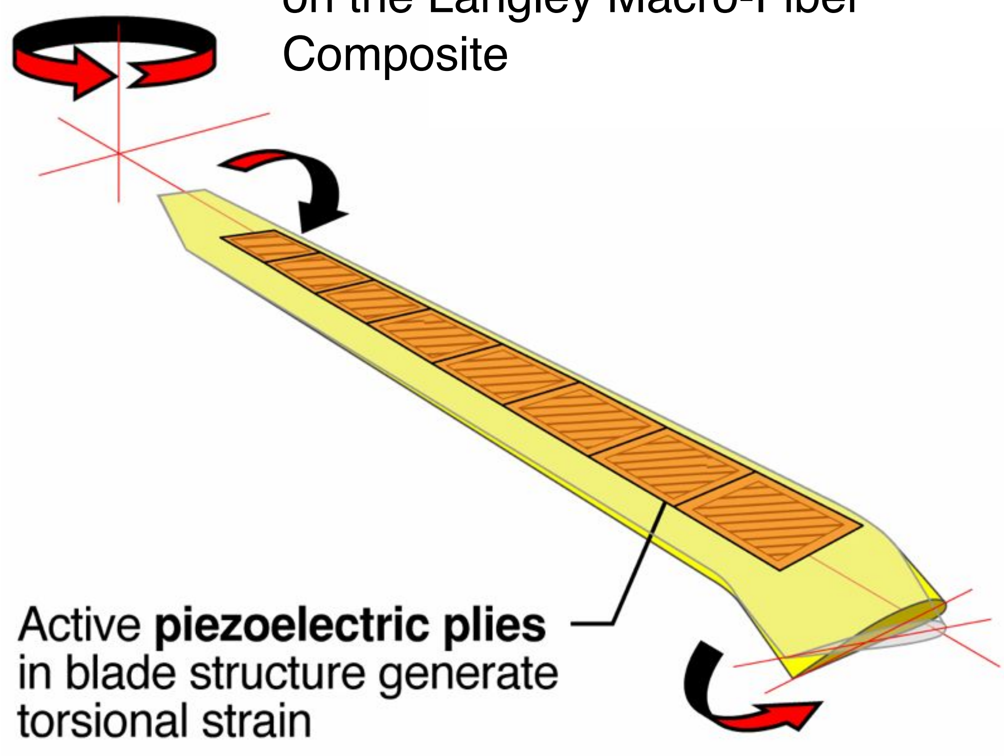


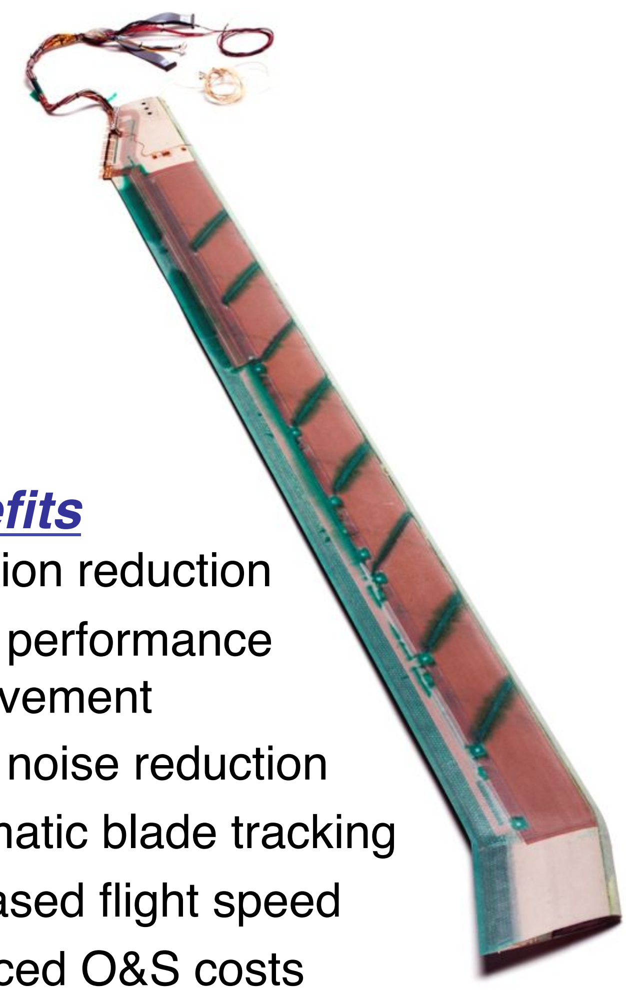
Apache Active Twist Rotor (ATR-A)

Joint Army/NASA Test Program

Objective

- Demonstrate active-twist control of a model-scale rotor system in NASA TDT
  - AH-64A Apache
  - Advanced, custom actuators based on the Langley Macro-Fiber Composite





Benefits

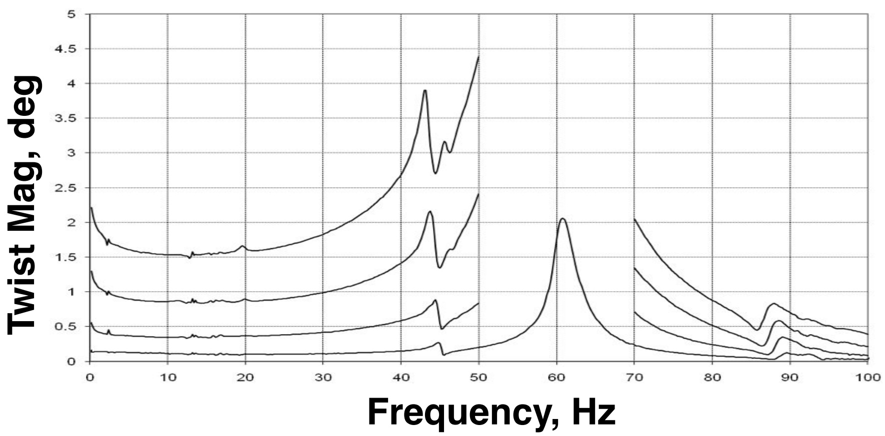
- Vibration reduction
- Rotor performance improvement
- Rotor noise reduction
- Automatic blade tracking
- Increased flight speed
- Reduced O&S costs

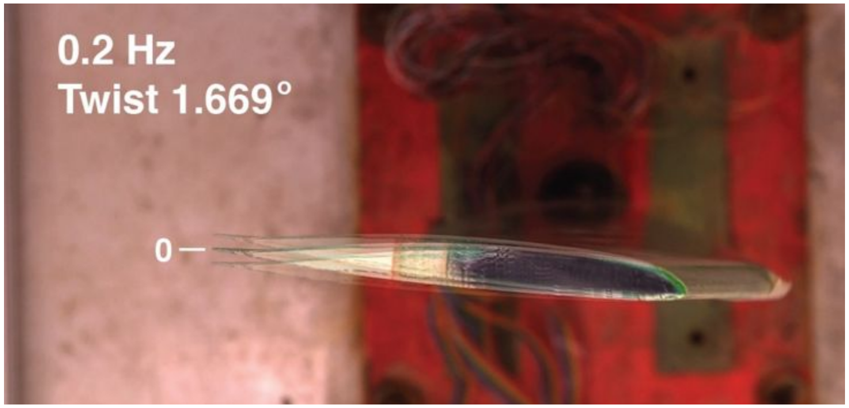
Active Twist Rotor (ATR)

Accomplishments and Future Plans

Joint Army/NASA Test Program

- One sample and 4 (of 6) test-quality ATR blades delivered
    - Complete blade set delivery expected in April 2012
- Blade response characterized through benchtop testing



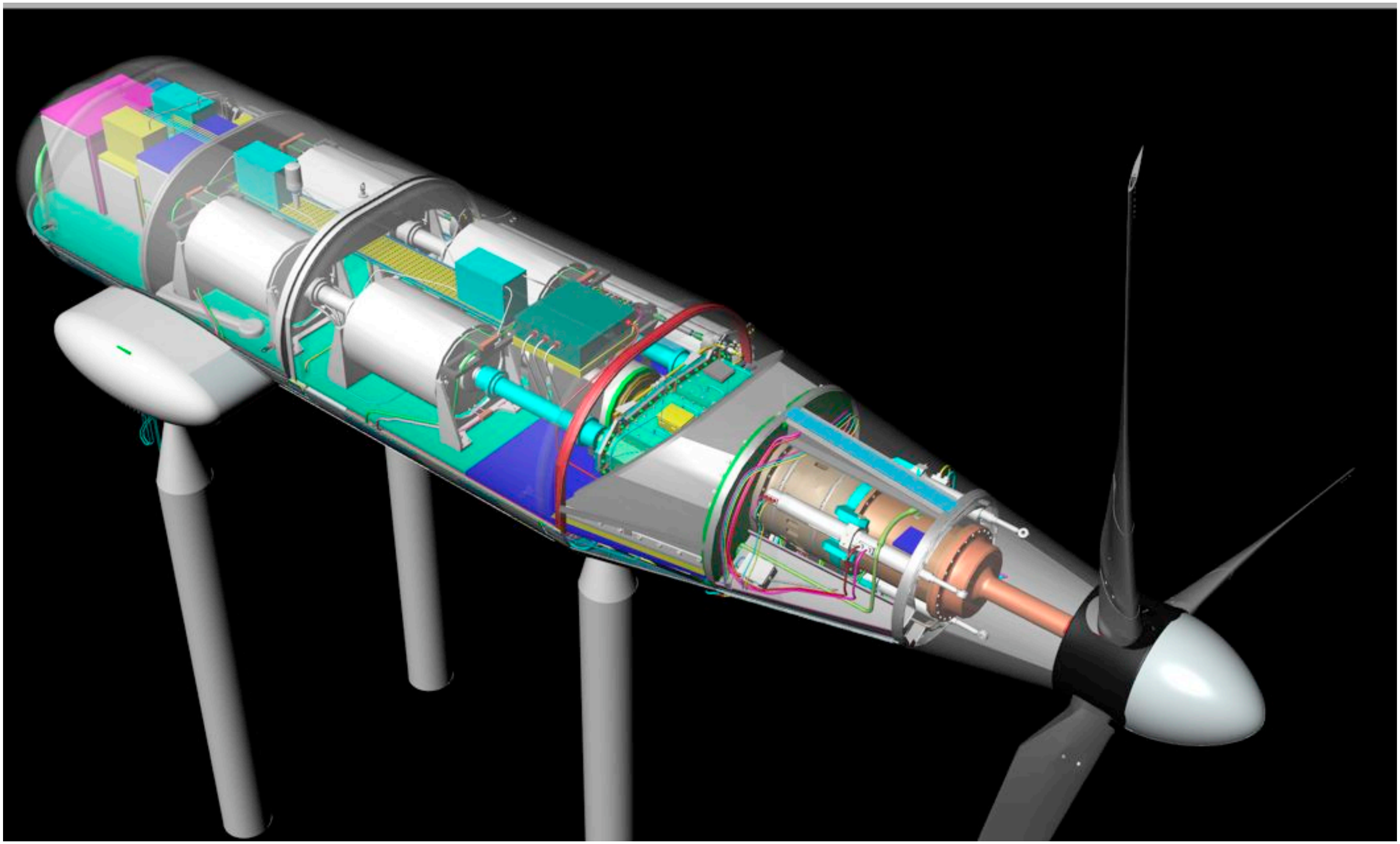


- Testbed and data system checkout currently underway
- Projection Moiré Interferometry (PMI) acquisition techniques and analysis software specific to 4-quadrant application currently under development
- Hover testing planned for summer 2012
- Wind tunnel entry planned for October-November 2012

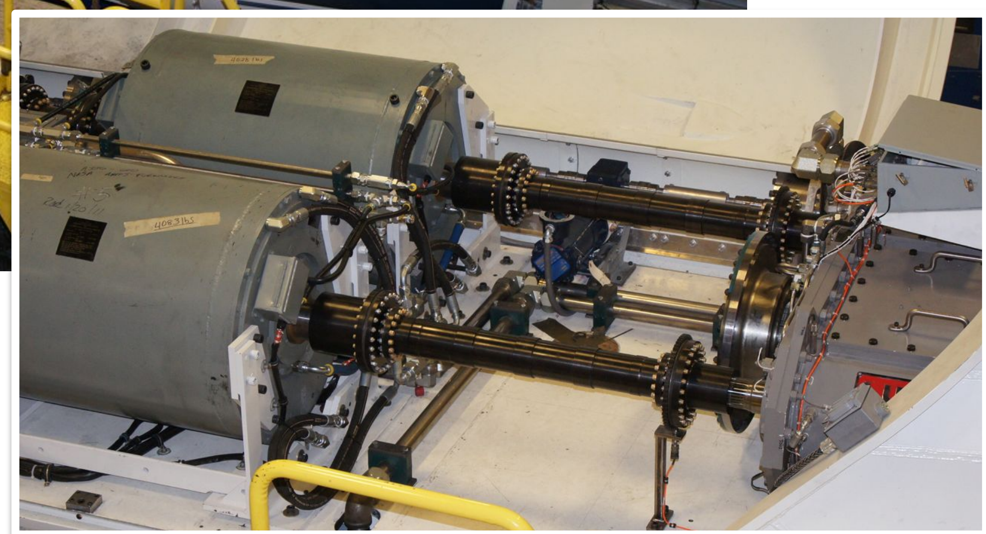
Tiltrotor Test Rig (TTR)

- Objective
  - Fabricate new Tiltrotor Test Rig (TTR) to test large-scale proprotors in axial, transition, and edgewise flight
    - Fills NASA, DOD, and industry gap for testing large-scale tiltrotor concepts (LCTR, JMR)
- Capabilities
  - Rotor Configurations: Proprotor and Edgewise Rotors
  - Maximum Wind Speed: 300 kt axial, 180 kt edgewise
  - Maximum Rotor Diameter: 26 ft (NFAC 40'x80' Tunnel)
  - Maximum Rotor Thrust: 30,000 lb
  - Maximum Power: 6000 HP
- Contracts
  - SRW assembled multiple funding sources (SRW base, Recovery Act, Army, Air Force) to support development
  - Bell Helicopter contracted to deliver TTR plus 609 hub/blades

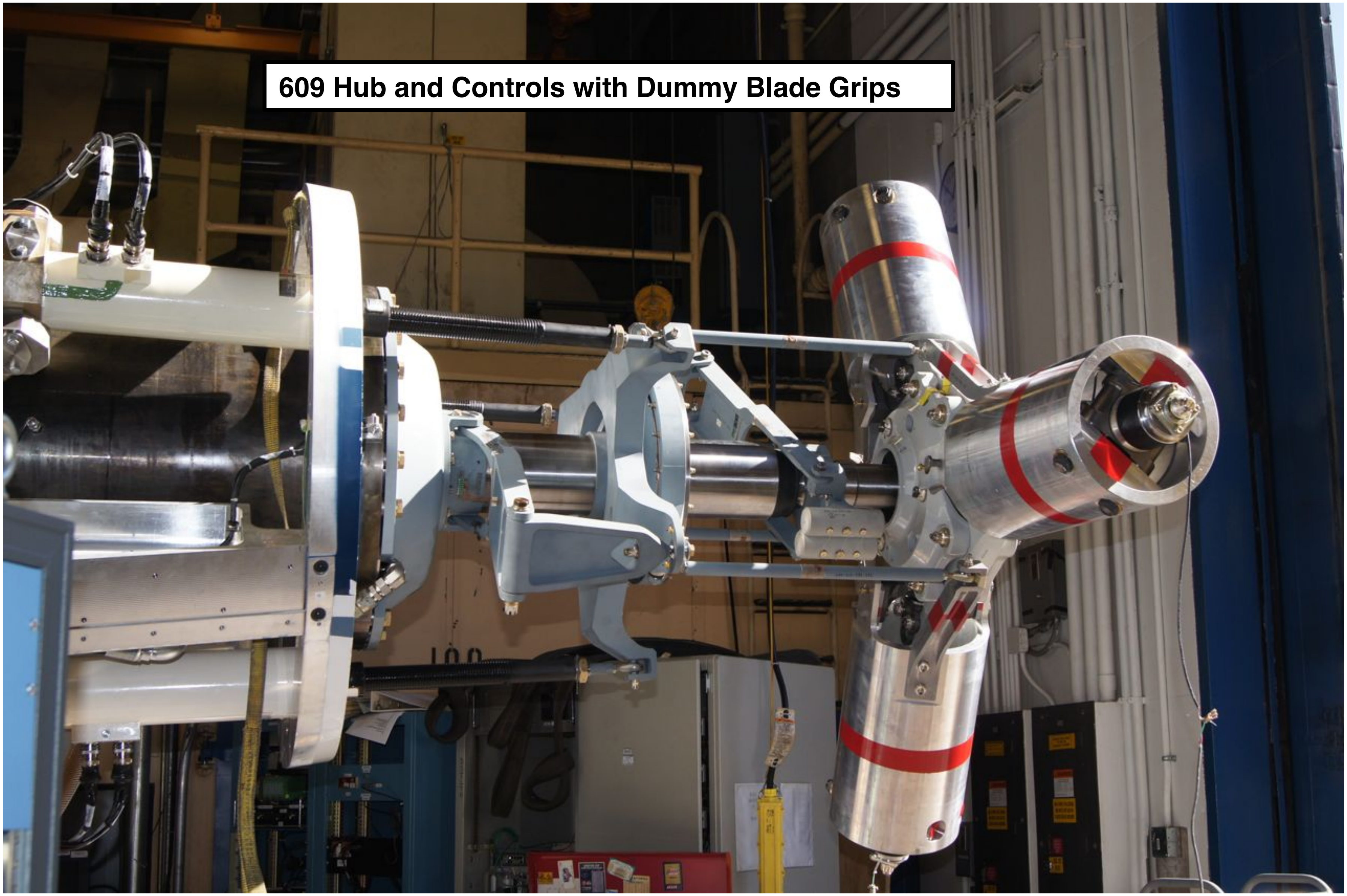
TTR model with 609 rotor



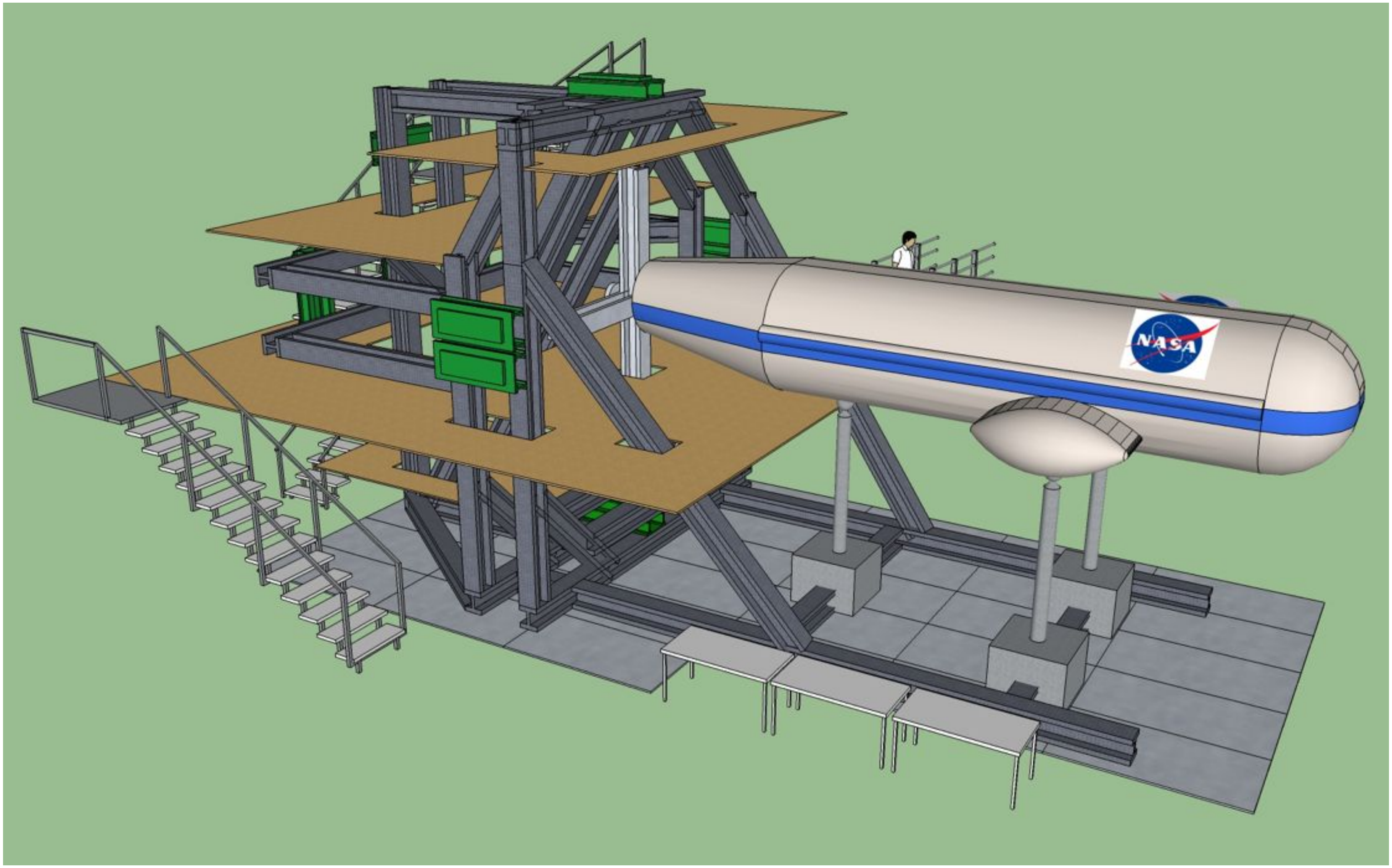
TTR Frame and Fairing



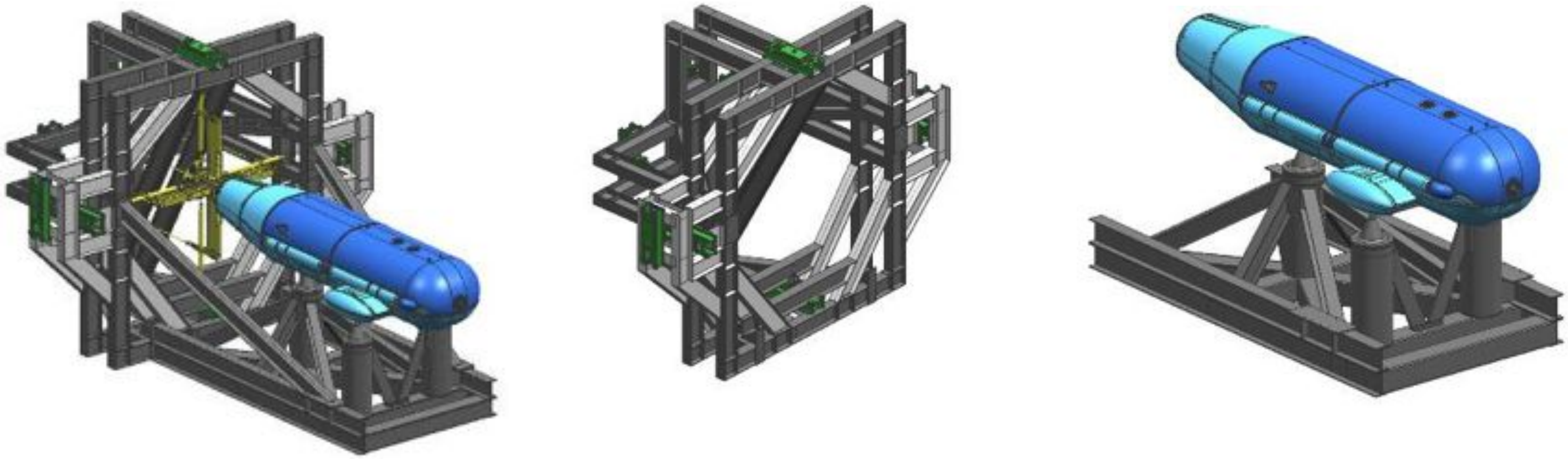
TTR Control System

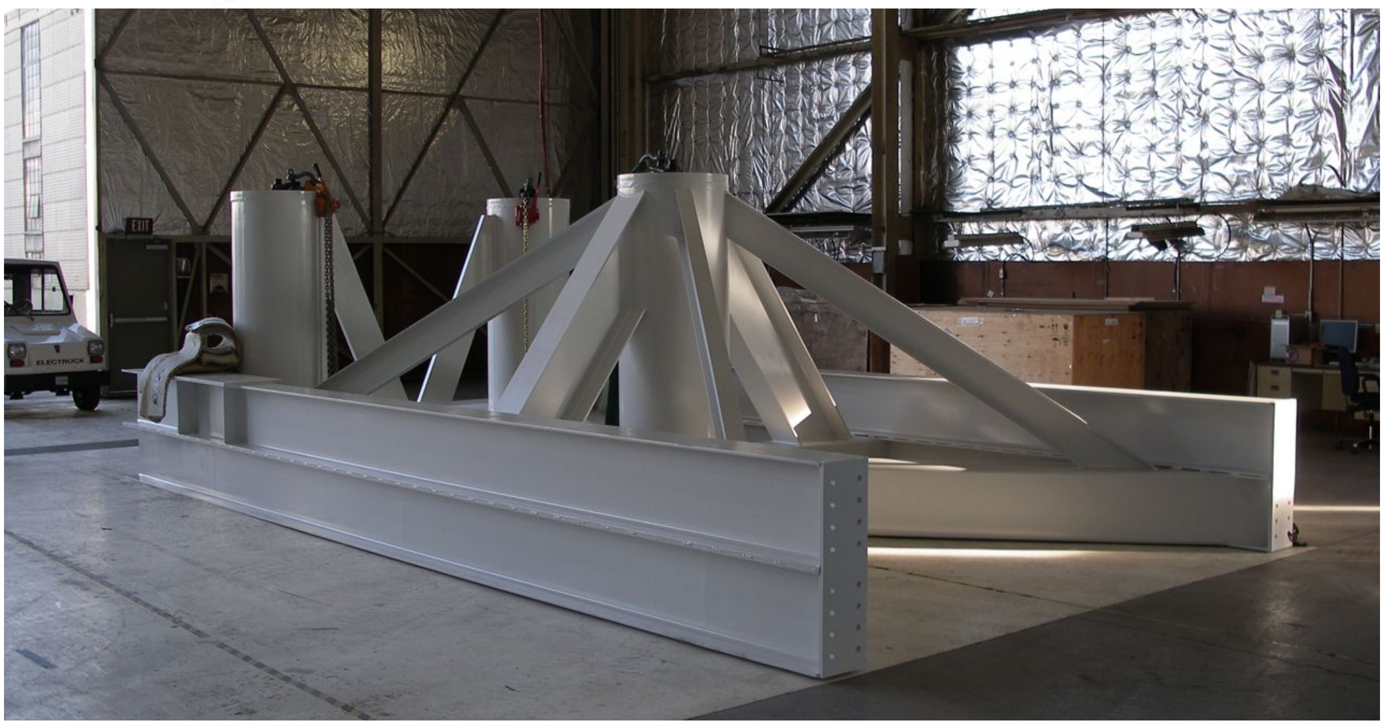


TTR in the Calibration Rig



Calibration Rig Modular Components





TTR Status

- Accomplishments and Plans
  - TTR fabrication complete and assembly/checkout underway
    - Primary mechanical assembly at Bell complete
    - Hub and actuators installed
    - Functional checkout/control console checkout underway
  - NASA model prep building facility mods complete
  - TTR calibration rig designed, base frame fabricated and delivered

3/12	Functional and control console checkouts at Bell
4/12	**Delivery of TTR test stand and control console**
7/12	Delivery of rotor balance and mast module
8/12	TTR drive system checkout at NASA
8/12	**Delivery of 609 rotor**
11/12	Delivery of final TTR Cal Rig components
CY13	TTR rotor balance calibration
CY14	**40x80 Wind Tunnel installation**

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Rotor in Ground Effect (IGE)

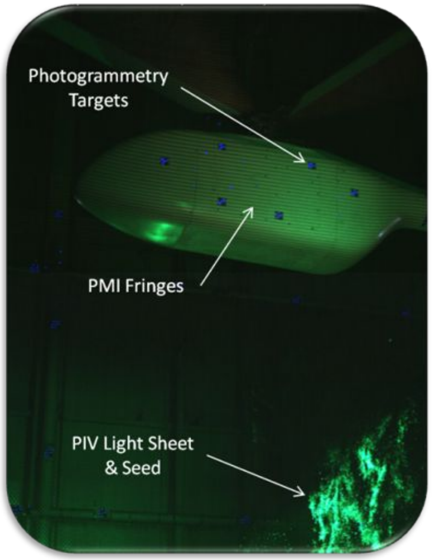
Joint Army/NASA Test Program

Objective

- Characterization of rotor IGE flow field to study phenomenological features and enable improved hover, downwash/outwash and Degraded Visual Environment (DVE) predictions
  - Heavily instrumented with conventional, non-intrusive and developing measurement techniques

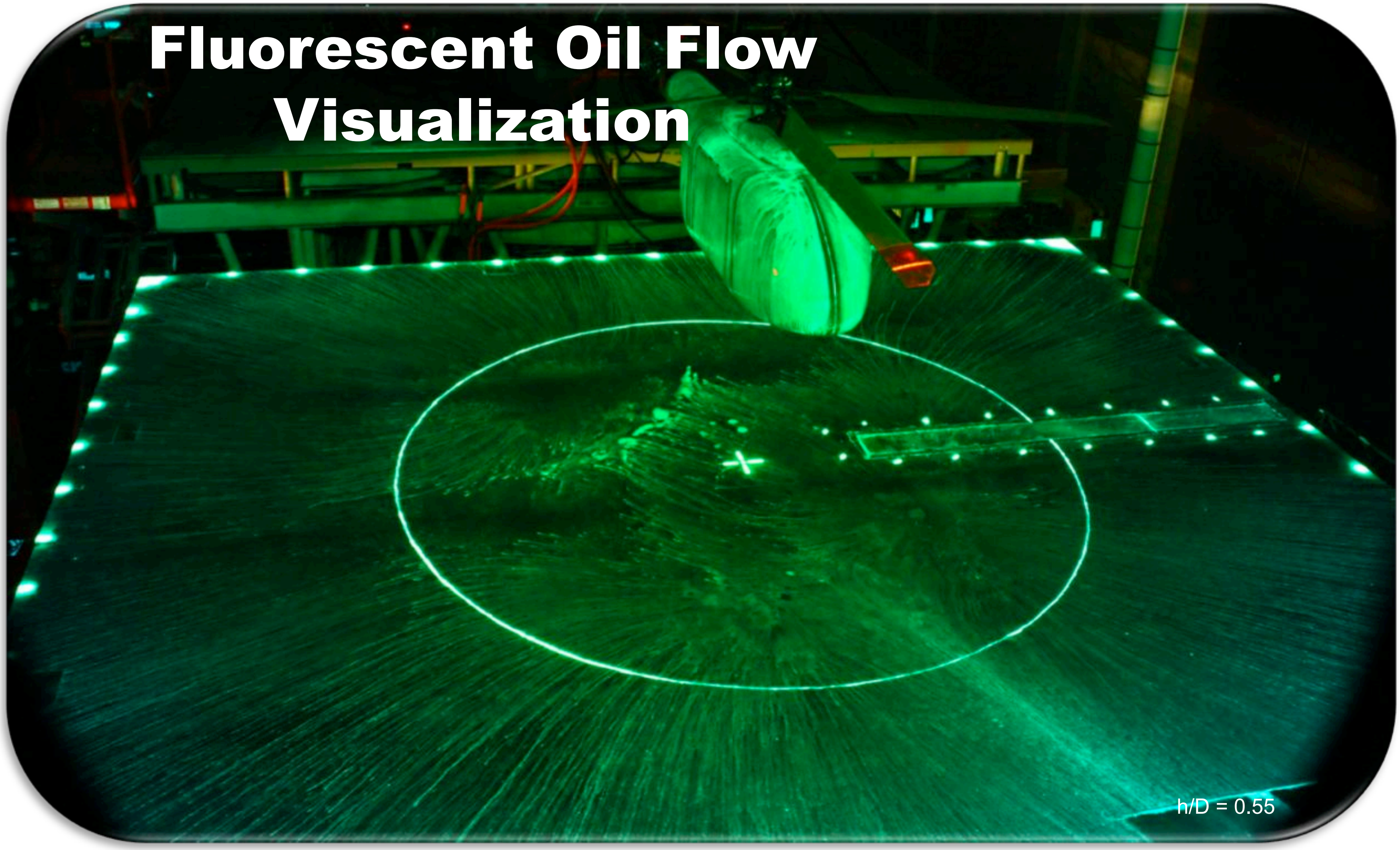
Series of three entries

- Entry 1 – focused understanding of facility, test stand and measurement technique limitations (Winter 2011)
  - Utilized fluorescent oil flow visualization, laser-based **single shot** Pressure Sensitive Paint (PSP), Projection Moiré Interferometry (PMI), Particle Image Velocimetry (PIV), Photogrammetry and surface shear stress measurements (S3F)
  - Simultaneous acquisition of PIV or PSP and PMI and Photogrammetry →



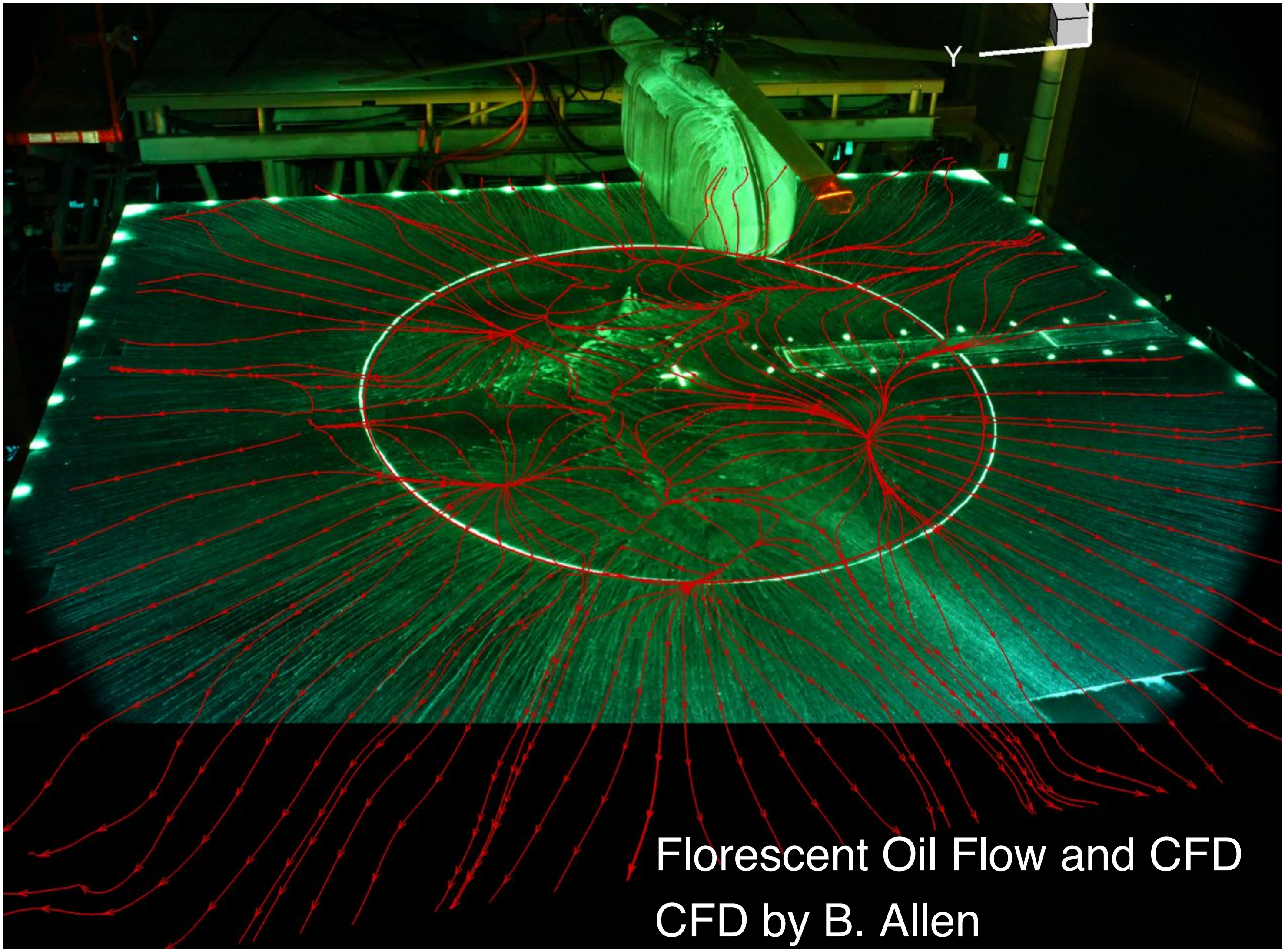
Ground Plane Flow Field

h/D = 0.55, C_T = 0.008



Ground Plane Flow Field w/ CFD

h/D = 0.55, C_T = 0.008



Rotor in Ground Effect (IGE)

Joint Army/NASA Test Program

Series of three entries (cont)

- Entry 2 – Improved ground plane, parametric variations (Fall 2013)
  - Enlarged, dynamic pressure instrumented ground plane, adjustable in pitch and roll
  - Initiate parametric variation studies: disc loading, number of blades, tip shape, root cutout, ground plane inclination, ground plane roughness
- Entry 3 – Complete parametric variations (Fall 2014)

Plans

- Complete detailed review of the data (Fall 2012)
- Initiate design of enlarged ground plane with tilt capabilities for Entry 2
- Parametric testing with improved ground plane (Entry 2, 2013)

Aeromechanics Near-Term Plans

- Continue development and validation of structured and unstructured rotorcraft CFD methods
- Conduct Active Twist Rotor test in TDT
- Conduct icing test of sub-scale rotor in IRT
- Complete fabrication and development of TTR and conduct checkout test in 40x80
- Continue data evaluation/reduction and analysis validation with data from UH-60 Airloads wind tunnel test
- Complete downwash/outwash test analysis and prepare for follow-on testing
- Evaluate fundamental testing options (new start)
  - Hover performance
  - 2-D oscillating active flap
  - Dynamic stall

NASA