National Aeronautics and Space Administration

Status of NASA/Army Hover Test

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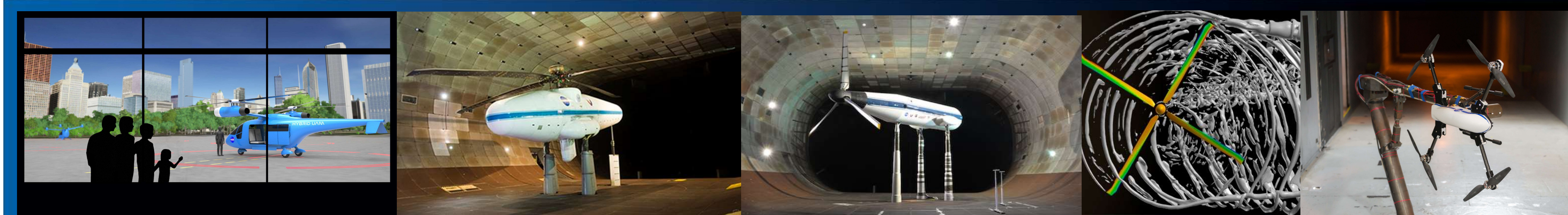


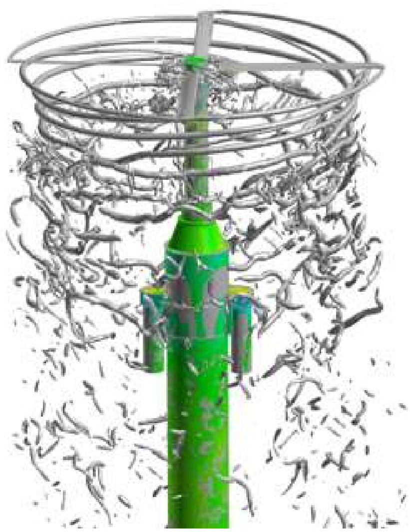
Outline

- Hover Test Objective and Planning Considerations
- Testing Approach
- Recent Progress/Status including schedule
- Summary

- Backup Slides
  - Test Description and Key Measurements
  - Data Products for CFD Validation

Hover Test Objective

Acquire key experimental data for a hovering rotor of sufficient quality and quantity to allow validation of SOA hover analysis codes. Once validated, these codes should be able to predict hover performance in free air.

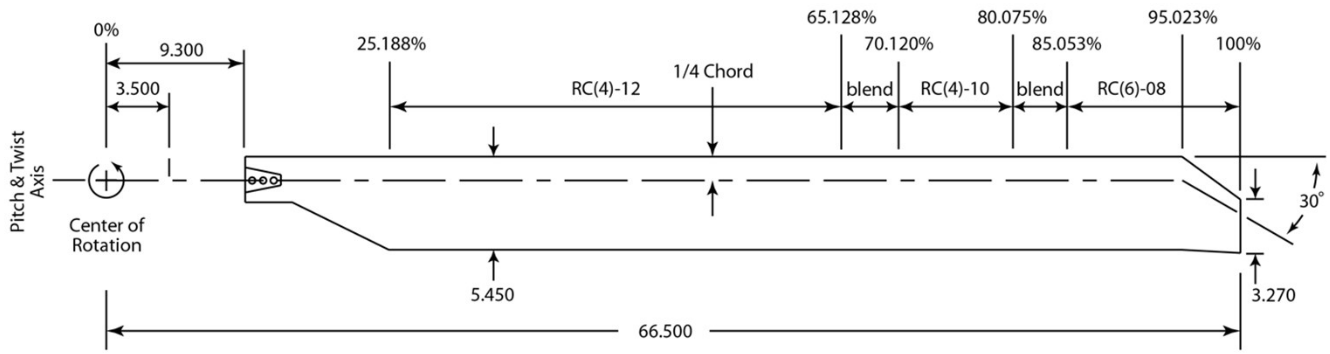


Hover Test Planning Considerations

- Rotor should be representative of “modern” multi-bladed helicopter with consistent and documented properties (publicly available)
- Test measurements should be sufficiently accurate for CFD validation (e.g. FM = +- .005) and comprehensive enough to ensure correct physics are represented (airloads, wake geometry, etc)
- Experimental uncertainties due to effects that aren’t easily measurable (facility walls and Reynolds number) should be minimized
- Existing NASA/Army hardware and facilities should be utilized as much as possible (for cost and accessibility reasons)

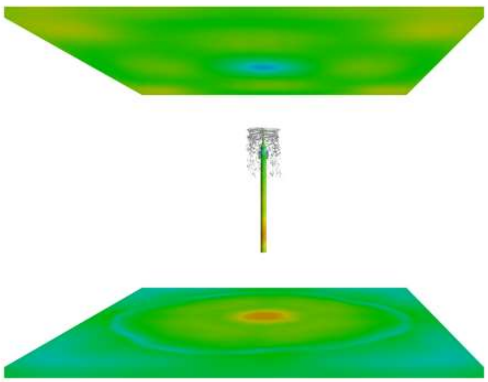
Testing Approach

- Develop new 4-bladed Hover Validation and Acoustic Baseline (HVAB) blade set based on Army's PSP rotor design
  - 11.08 ft diameter
  - 2 pressure instrumented blades, 1 strain gaged blade
  - Matched structural properties
  - Capable of higher tip Mach numbers (.675)



Testing Approach

- Test in NFAC 80- by 120-Foot test section to minimize facility effects on performance
  - Use refurbished Army ARTS test stand
  - Mount rotor at 32 to 40 ft above floor (TBD) in wake down configuration
- Acquire key measurements for CFD validation
  - Performance, airloads, transition location, wake info, blade deflection, etc
- Acquire data sets for both natural and tripped boundary layer

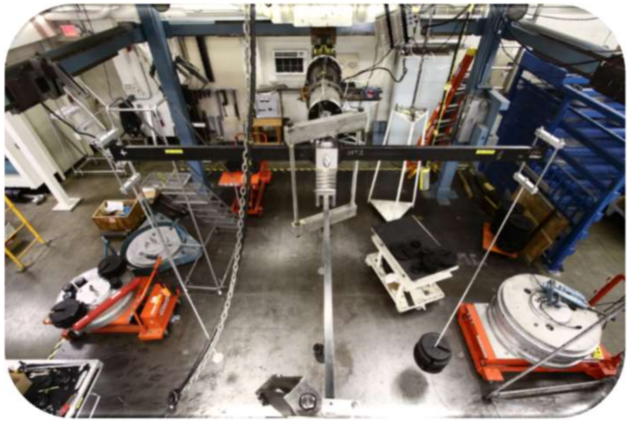


Recent Progress/Status

- Test preparations are continuing
  - **Army Rotorcraft Test Stand (ARTS) refurbishment and checkout**
  - **HVAB blade set design and fabrication**
  - Test stand integration into NFAC
  - Implementation of non-intrusive measurements in NFAC

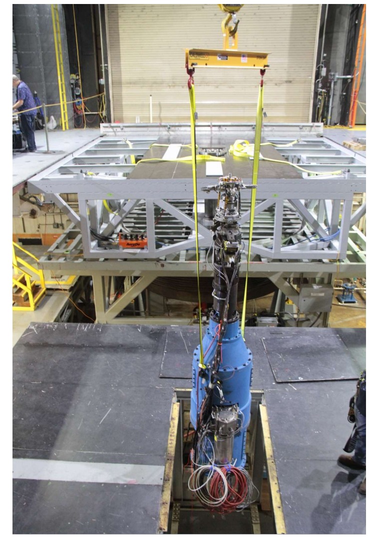
ARTS Refurbishment and Checkout

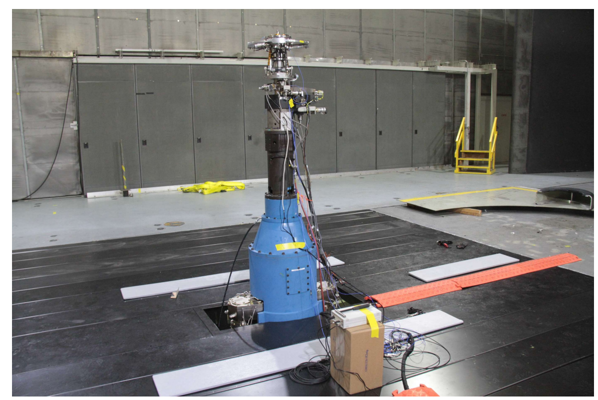
- Key ARTS checkout activities
  - Rotor balance calibration demonstrated desired accuracy
    - **Thrust = 0.03% = 0.54 lbs (1800 lb FS Range)**
    - **Torque = 0.07% = 6.3 in-lbs (9020 in-lbs FS Range)**
    - **FM Accuracy estimated to be < 0.002-0.005**
  - Completed rap test and preliminary stability analysis
    - Suggests no stability issues of concern
  - Torque bat tests successfully completed up to 1/3 power



ARTS Refurbishment and Checkout

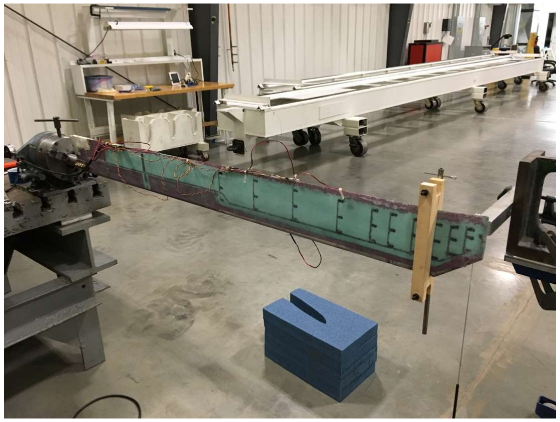
- Key ARTS checkout activities
  - Initiated blades-on testing in 14x22 Wind Tunnel to provide final checkout prior to HVAB blade delivery
    - ARTS successfully run up to 1150 RPM and various thrust levels
    - Identified and repaired ARTS control system anomalies
    - Developed test procedures for higher quality performance measurements
    - This test entry significantly reduced risk for planned hover test
  - Generated plans for hover checkout at LaRC using HVAB rotor

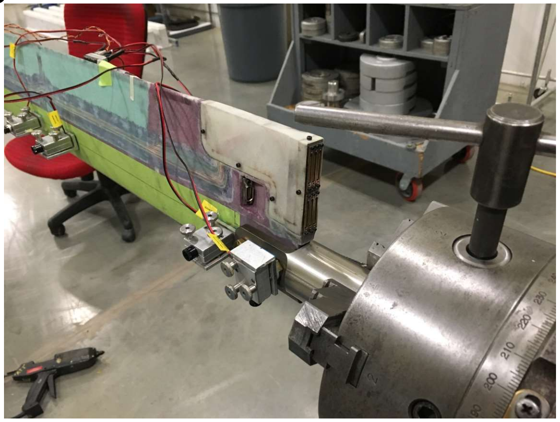




HVAB Blade Set Design and Fab

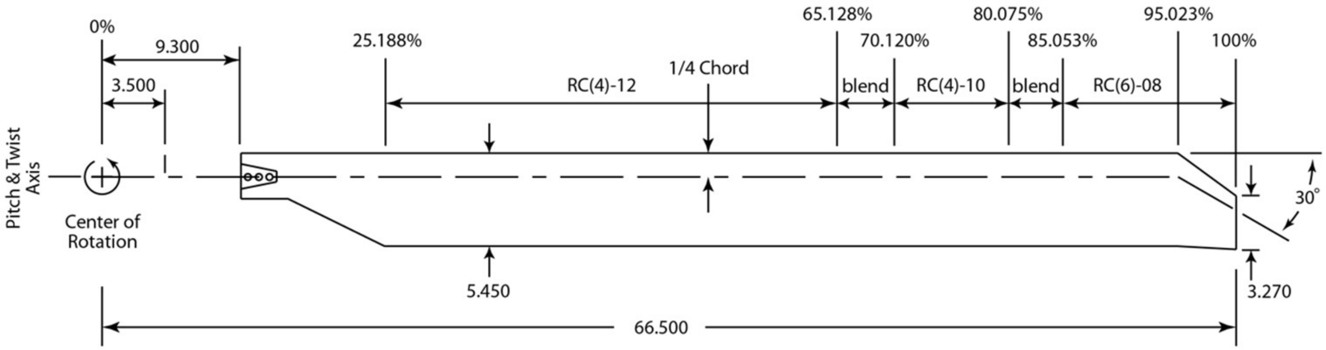
- Completion of pressure blade design and fab has been the key schedule driver
  - Delays caused by significant revisions to the pressure transducer installation
  - Preliminary and Critical Design Reviews with modified design successfully held in 2019
- Fabrication of the “Process Blade” completed in October 2019
  - Used to verify fabrication/assembly process for pressure blade
  - Also used for stiffness and frequency testing





HVAB Blade Set Design and Fab

- Next step is to begin fabrication using approved blade design
  - Some potential issues with blade-skin material availability but workarounds have been identified
- Scheduled HVAB delivery date is June 2020



Test Schedule

- Current plan shows testing beginning September 2020

	CY2018	CY2019				CY2020			
Task	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
HVAB Blade Design/Fab									
ARTS Stand Refurb and C/O									
Rotating C/O w/ HVAB Blades									
NFAC Integration									
Hover Testing in NFAC									

Summary

- NASA/Army Hover Test planning and preparations made significant progress in 2019
  - Successful ARTS test stand refurbishment and checkout
  - HVAB blade design completed and “process blade” fabricated

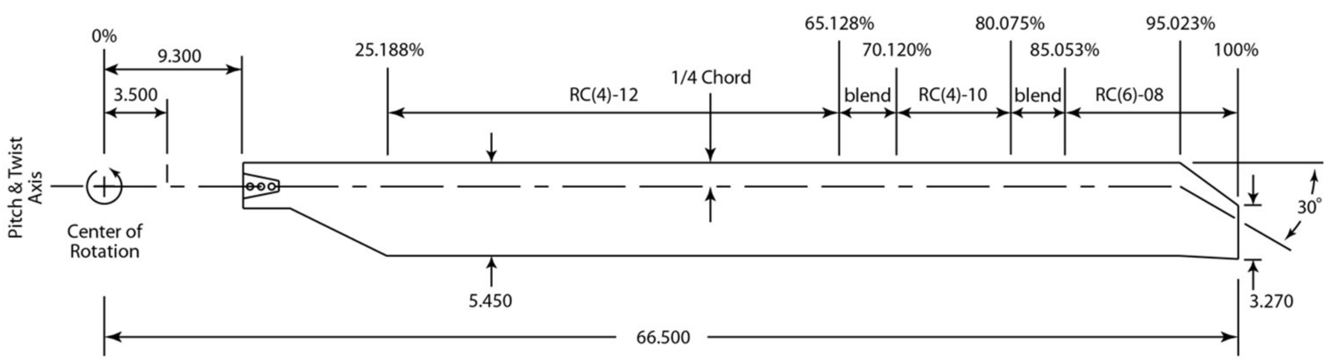
- Hover test in NFAC 80- by 120- Test Section currently scheduled to begin in September 2020

Backup Slides

- Test Description
  - Rotor System, Test Stand, Facility
  - Key Measurements
- Data Products for CFD Validation

Test Description – HVAB Blades

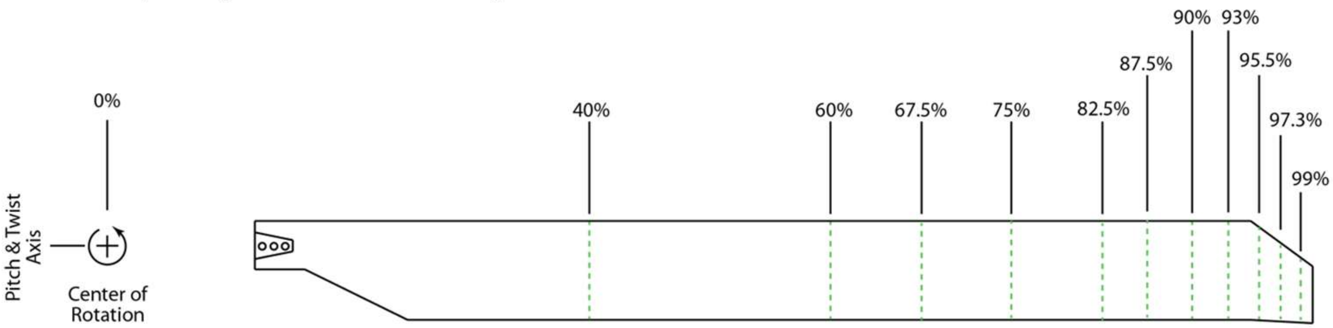
- Identical to Army PSP rotor except for root attachment location



Radius	**66.5 inches**
Reference chord	**5.45 inches**
Tip taper ratio	**60%**
Tip sweep (quarter chord)	**30 deg. at 95% R**
Airfoils	**RC series**
Number of blades	**4**

Test Description – HVAB Blades

- Strain-gaged and pressure-instrumented blades
- Pressure taps (for airloads) located at 11 radial stations

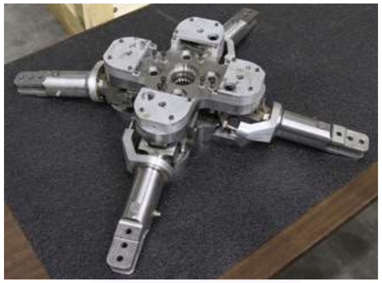


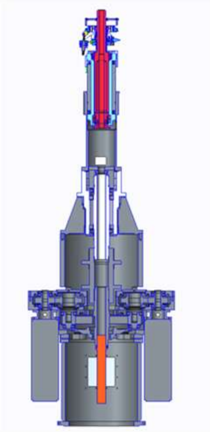
Blade Number	Blade Type	Blade Instrumentation									
		Strain Gages				Pressure Transducers					
		Beam	Chord	Torsion	Radial Stations	Total	Radial Stations	None	Tip LED	Active Heater	RTDs
SN000	Process							X		X	
SN001	Production	X	X	X	1			X	X	X	X
SN002	Production	X	X	X	1			X	X	X	X
SN003	Production	X	X	X	1			X	X	X	X
SN004	Production	X	X	X	1	187	11		X		X
SN005	Production	X	X	X	1	51	14		X		X
SN006	Optional	X	X	X	4			X	X	X	X

Test Description – Test Stand/Facility

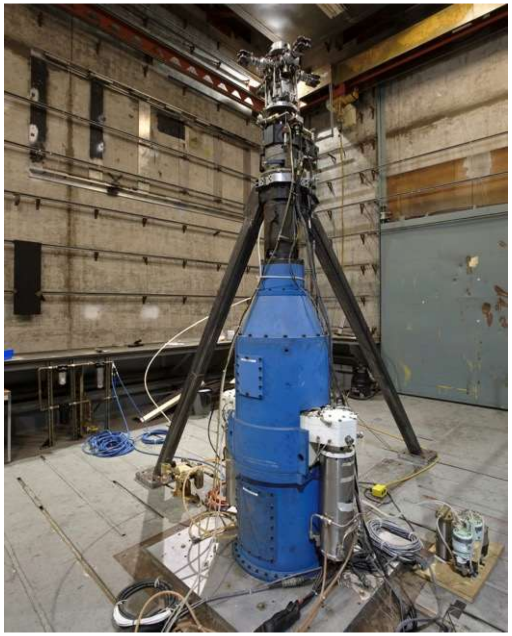
- Army ARTS test stand in NFAC 80- by 120-Foot test

Articulated Hub





NFAC 80- by 120-Ft Test Section

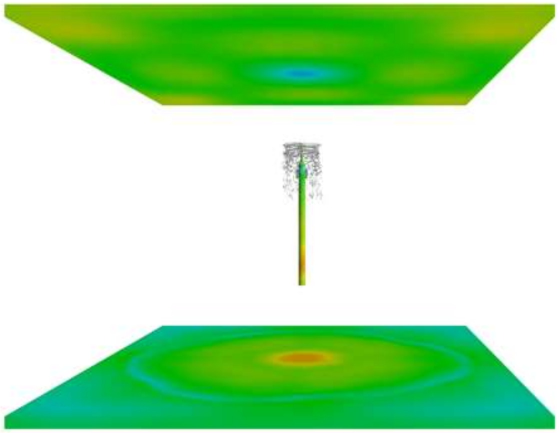


ARTS Test Stand in Hover Chamber

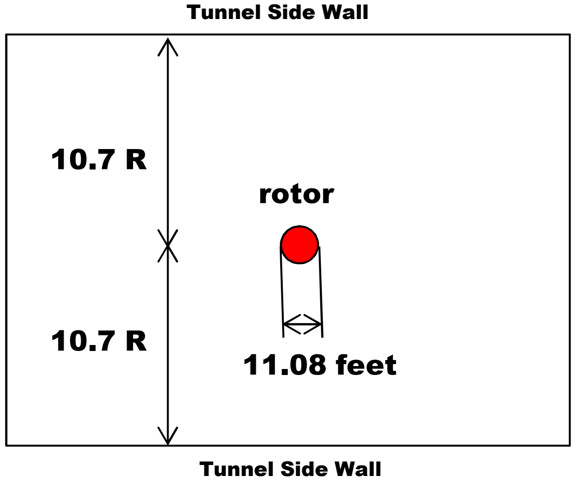
Test Description – Test Stand/Facility

- Test stand and rotor – relative scale

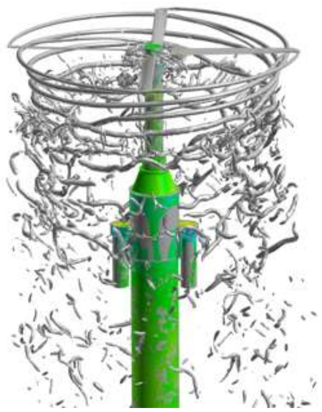
Rotor/Stand relative to floor/ceiling



Rotor relative to side walls– top view



Rotor relative to test stand



Test Description – Key Measurements

- Rotor Thrust and Torque (rotor balance and flex coupling)
- Blade Root Motion (root collective, flap, lag) and Blade Deflections (Hall effect transducers, photogrammetry)
- Blade Pressures (Kulites)
- Boundary Layer Transition Measurements (IR Thermography)
- Rotor Wake Geometry (shadowgraphy)
- Rotor Vortex Properties (particle image velocimetry)

Data Products for CFD Validation

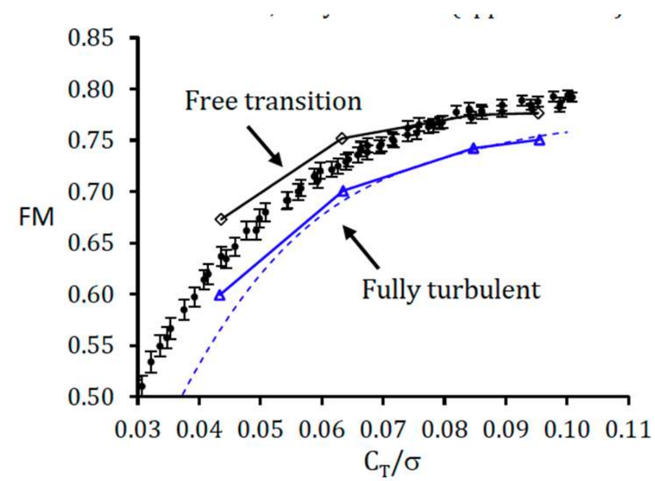
- Initial list of data products for CFD validation has been prepared
- Includes data needed to support CFD inputs as well as for validation

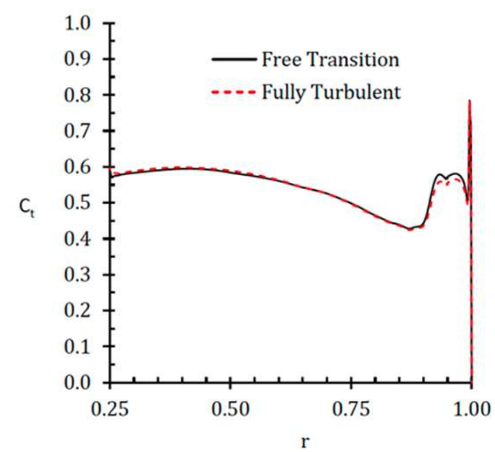
Data Products for CFD Validation

- Data for CFD Inputs
  - Test Hardware Geometry
    - CAD model/grid of rotor blade OML (as-designed and as-measured)
    - CAD model/grid of test stand and attachment hardware
    - Description of rotor hub and blade interface (final form TBD)
    - Description of 80- by 120-Foot Wind Tunnel and model location (final form TBD)
  - Rotor Operating Conditions and Blade Displacements (measured at each condition)
    - Tip Mach number (RPM, atmospheric conditions)
    - Blade root angles (blade root pitch/flap/lag)
    - Blade deflections (flap and twist vs r/R, photogrammetry) for multiple blades

Data Products for CFD Validation

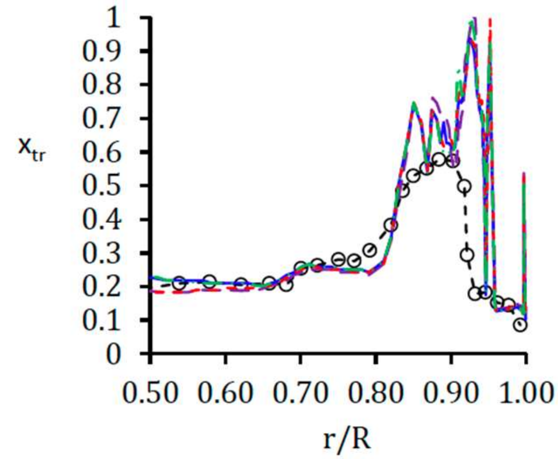
- Data for CFD Validation (at each condition)
  - Rotor Performance
    - Figure of Merit (thrust/torque, rotor balance/flex coupling) vs Ct/s
    - Ct/s vs collective
  - Blade Airloads
    - Kulite pressure transducers at 11 r/R stations, pressures plus integrated airloads

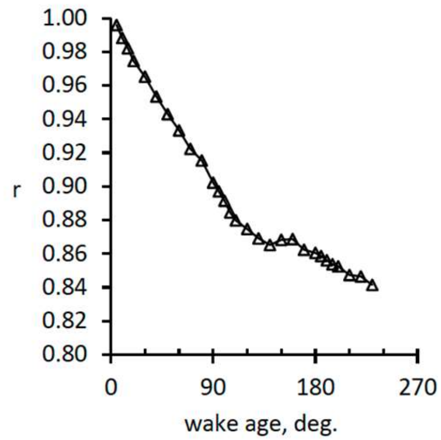


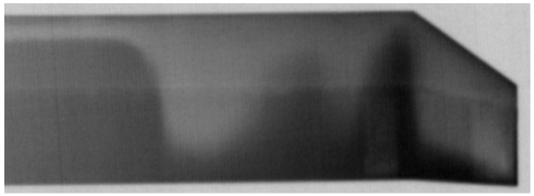


Data Products for CFD Validation

- Data for CFD Validation (at each condition)
  - Transition Location (x/c vs r/R) upper and lower surfaces (multiple blades) (IR Thermography)
  - Tip vortex geometry (z/R and r/R vs wake age) (shadowgraph)







Data Products for CFD Validation

- Data for CFD Validation (at each condition)
  - Tip vortex circulation, vorticity, and core size vs wake age (PIV)
  - Wake velocities and vorticity for different wake ages (PIV)