Rotorcraft Aeromechanics Research Activities at Konkuk University

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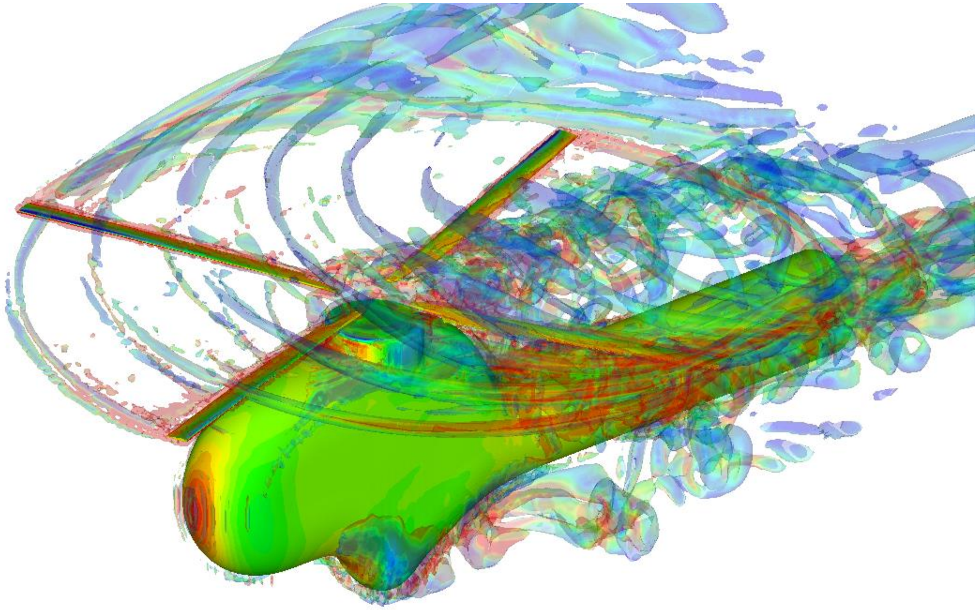
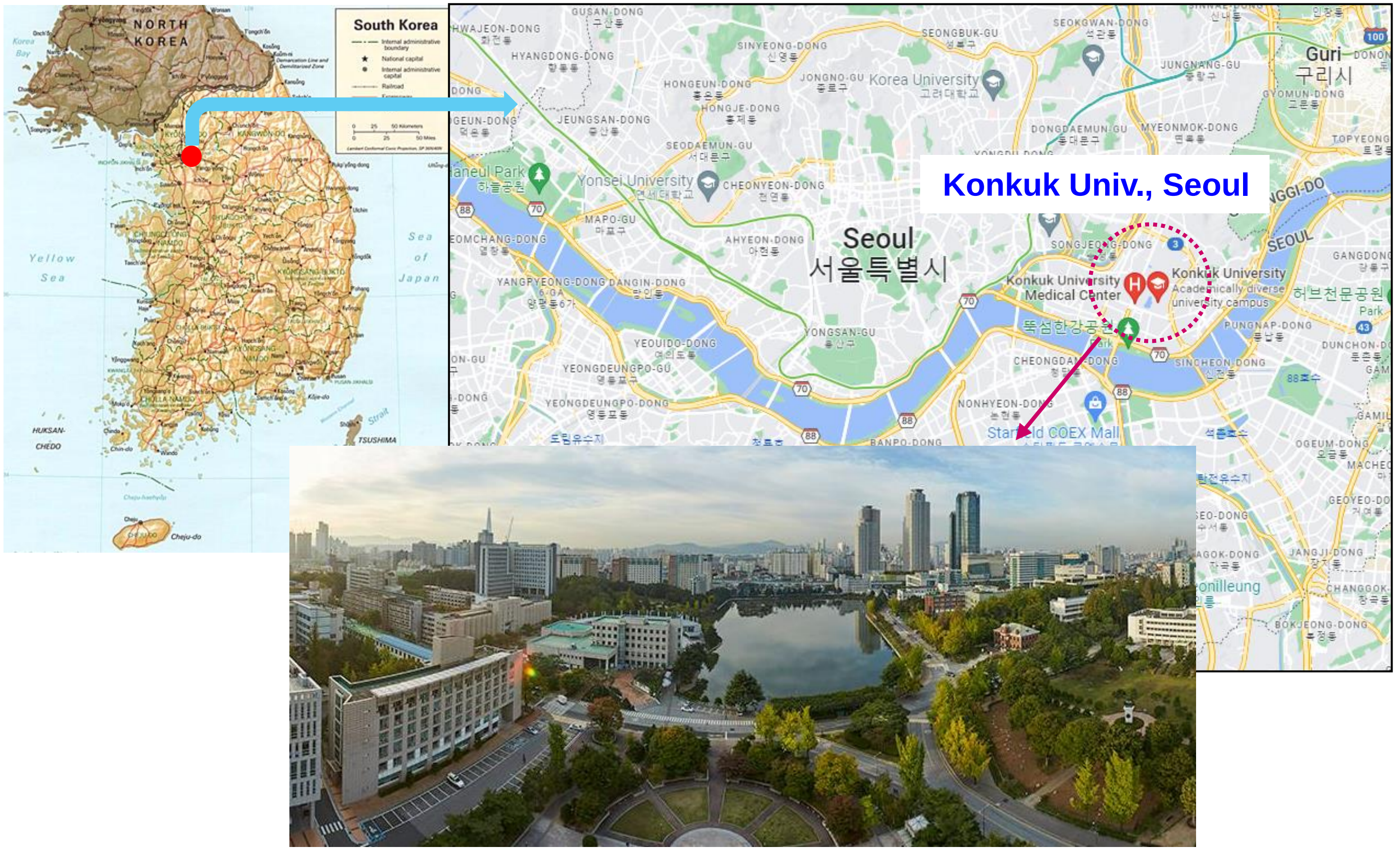
Part I

Introduction to Konkuk IRT Group



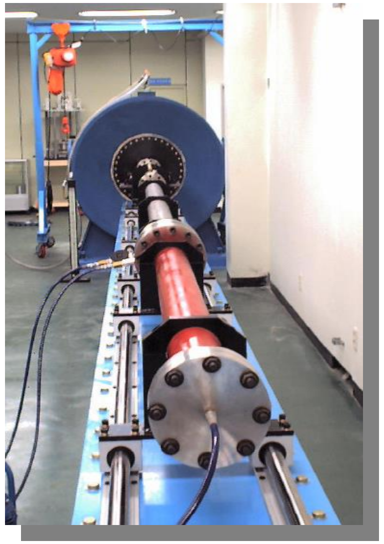
Konkuk University (KU)



❖ Dept. of Aerospace Eng.

- Established in Mar. 1990
- Currently 12 faculty members
- About 160 undergraduate students & 70 graduate students enrolled
- Home of BK21 ST-IT fusion program sponsored by MOE (2006 – 2013)

Subsonic wind tunnel



High speed shock tube (M = 2.5)

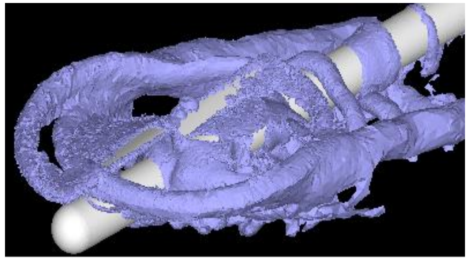
- **Konkuk University (KU):**

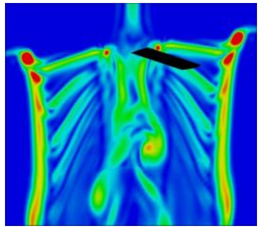
- Founded in 1946; One of the leading private universities in Korea
- Located in the northeastern region of Seoul
- About 25k students enrolled, including 3k graduate students
- Over 700 faculty members

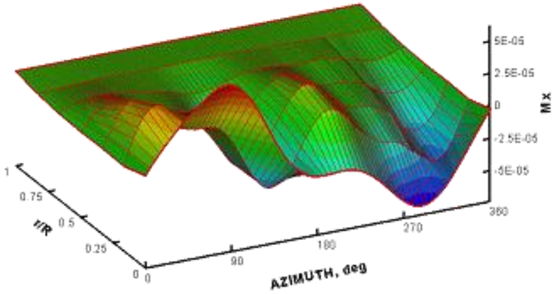
KU KONKUK UNIVERSITY

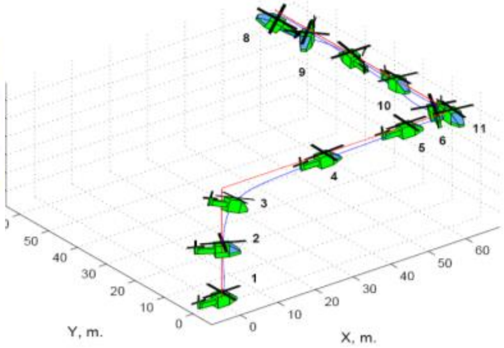
KU Int. Rotorcraft Technology (IRT) Group

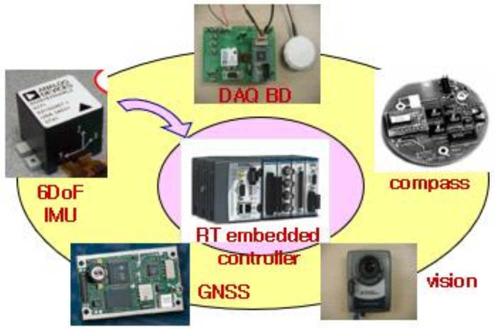
❖ **IRT group members of Int. R&D Hub program sponsored by KRF (2006 – 2013)**

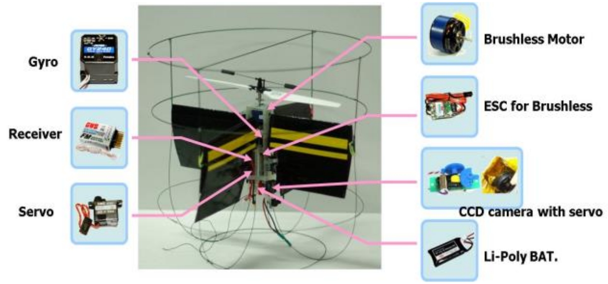












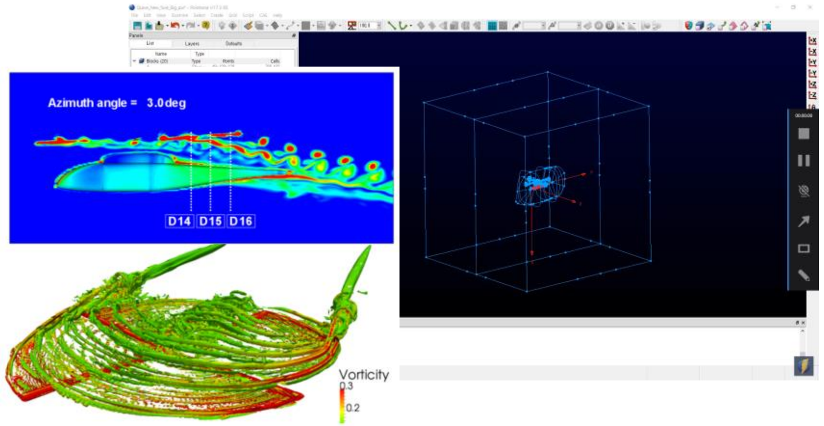
- **All IRT members joined on or after BK-21**

Intelligent Rotorcraft Structures Lab

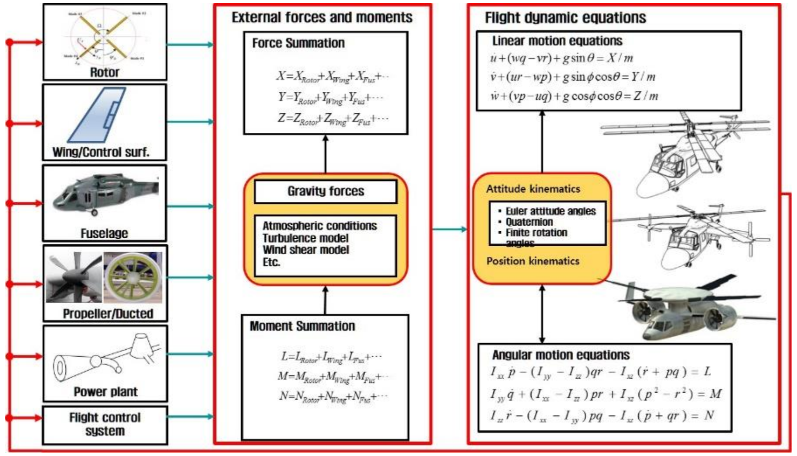
KU Int. Rotorcraft Technology (IRT) Group Activities

❖ Major research activites of KU IRT group

- Home of national BK21 & IRH programs sponsored by NRF Korea (2006- 2013)
- German DLR - Konkuk MoU research (2008 - 2013)
- Active participants of Int. HART II Workshop (2008 - 2012)
- One of STAR (Smart Twisting Active Rotor) int. consortium project members (since 2008)
- Founding member of international meetings such as Rotor Korea (2007, 2008) and ARF
- Development of various rotorcraft software tools: KFLOW, HETLAS, Ksec2D, etc.
- Establishment of high precision numerical schemes such as CFD/CSD coupling for HART I/II validation



3D compressible RANS flow solver KFLOW



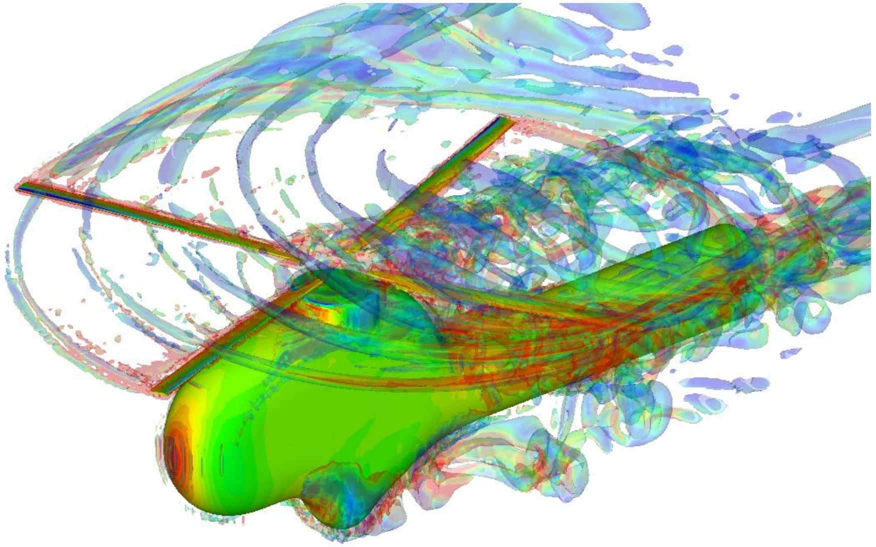
Rotorcraft flight dynamics simulation S/W HETLAS

2D FE cross-sectional analysis S/W Ksec2D

Intelligent Rotorcraft Structures Lab

Part II

Summary of Rotorcraft Aeromechanics Research Outcomes at KU



HART I Blade Property Test

Motivation:

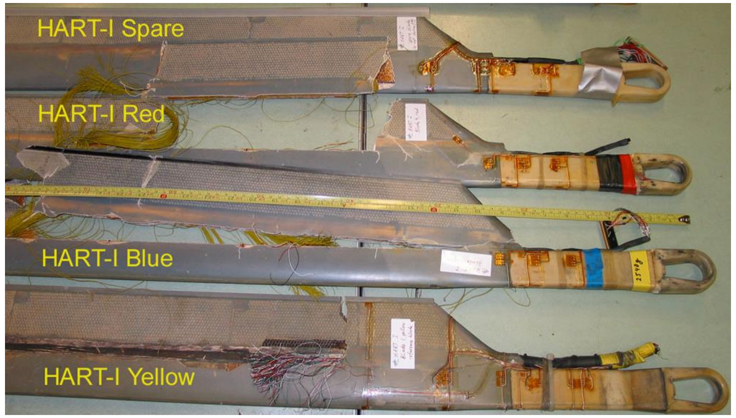
- HART I rotor test conducted in 1994
- No systematic measured blade property data available so far
- All blades damaged at a follow-on test

Approaches:

- In collaboration with NASA, DLR, KU
- Use the original blade set tested in DNW (1994)
- Well-established test techniques employed
- Destructive-type of test techniques adopted

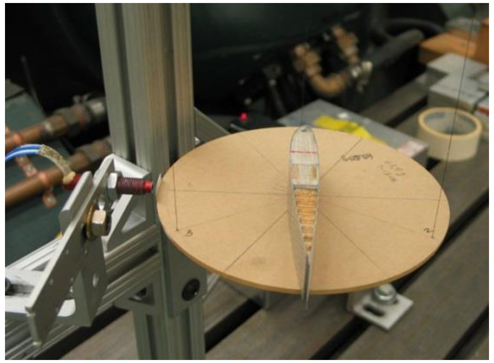
Outcomes:

- Property table completed for HART I blades and documented as NASA tech report (NASA/CR-2012-216039)
- Property data released in JAHS 2013

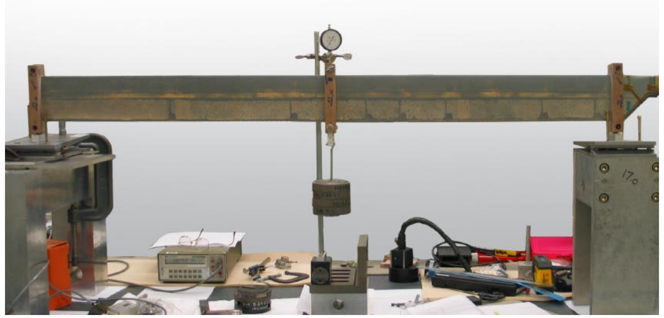


HART I blades used for structural test

Mirror method for flap bending



Trifillar pendulum for section MOI



3 point bending for chord stiffness

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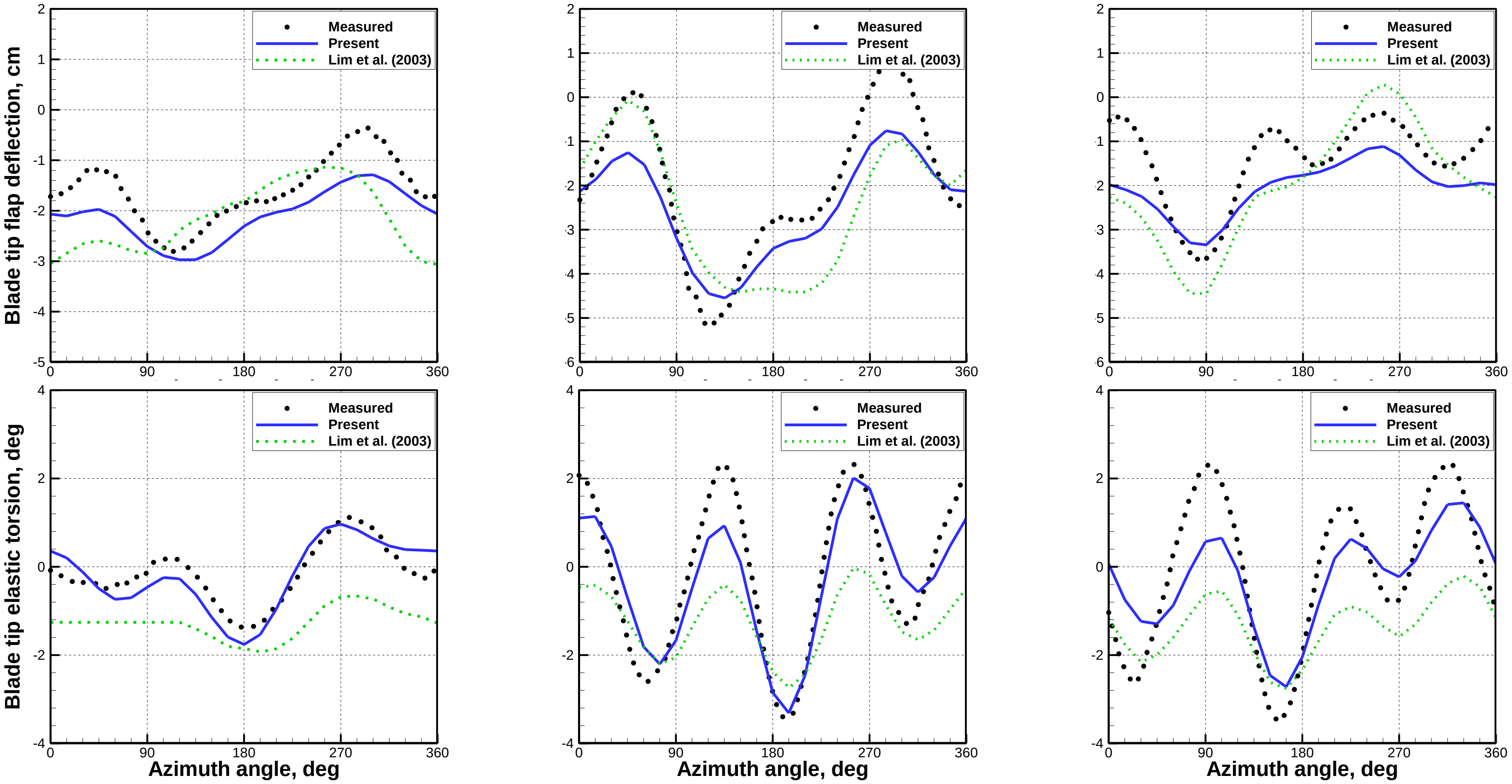
Result: HART I Blade Property Test

Elastic flap motion:

Elastic torsion motion:



(a) BL (b) MN (c) MV

- Jung, S. N., You, Y. H., Lau, B., Johnson, W., and Lim, J. W., "Evaluation of Rotor Structural and Aerodynamic Loads Using Measured Blade Properties," Journal of the American Helicopter Society, Vol. 58, No. 4, Oct. 2013
- Jung, S. N., and Lau, B., “Determination of HART I Rotor Blade Structural Properties by Laboratory Testing,” NASA CR-2012-216039, Aug. 2012.

HART II Blade Property Test

Motivation:

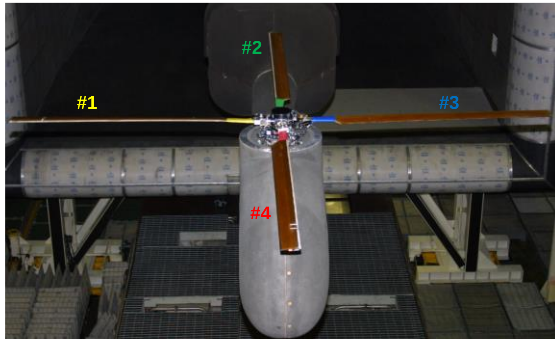
- No measured properties available for HART II blades
- Reliable measured properties needed for accurate predictions

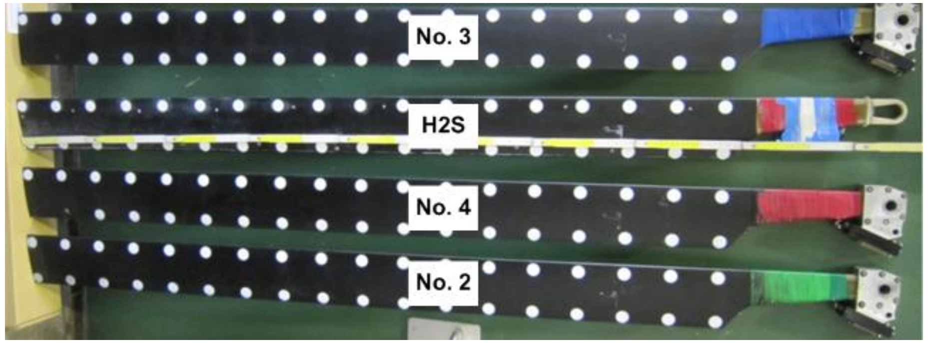
Approaches:

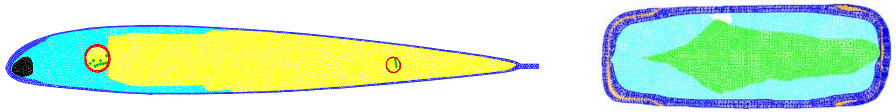
- In collaboration with NASA, DLR, KU
- Use the original set of HART II blades tested in DNW (2001)
- Non-destructive test techniques (x-ray CT-scan plus 2D FE section analysis system Ksec2D) adopted
- Assess measurement quality

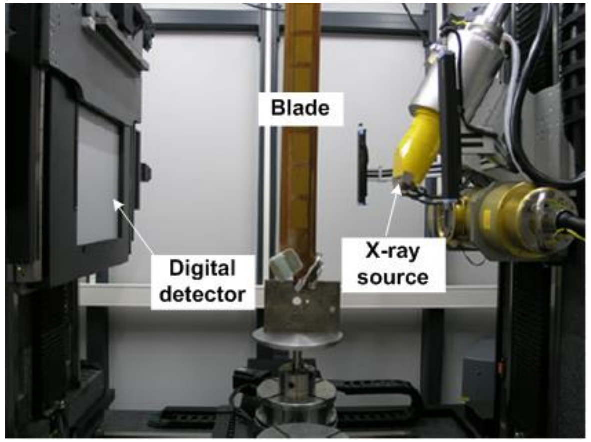
Outcomes:

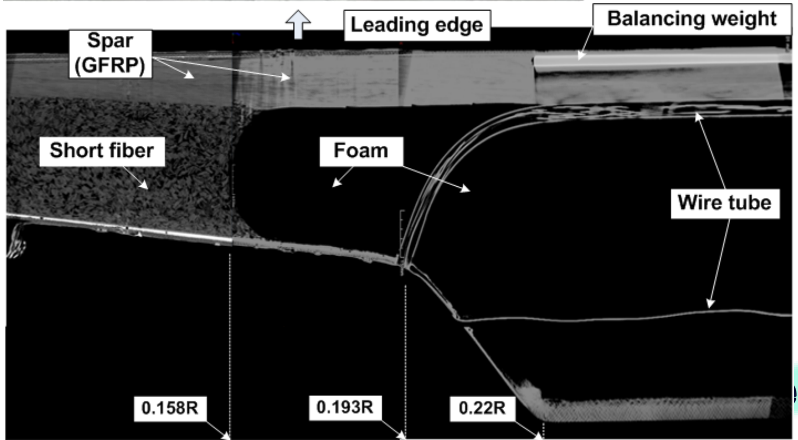
- Updated structural property data of HART II blades released
- Documented in journal papers: AIAA J & Comp Str (2015)





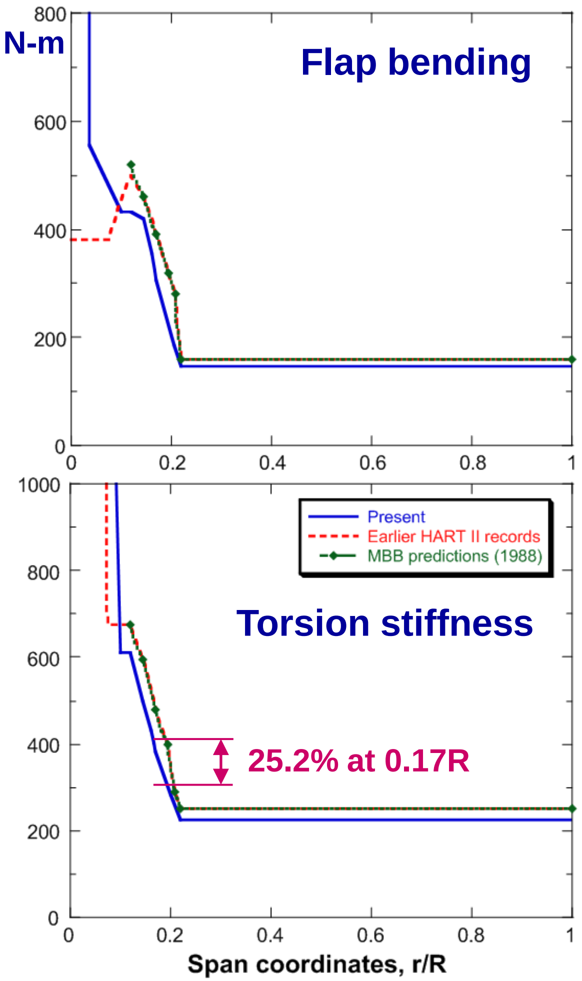


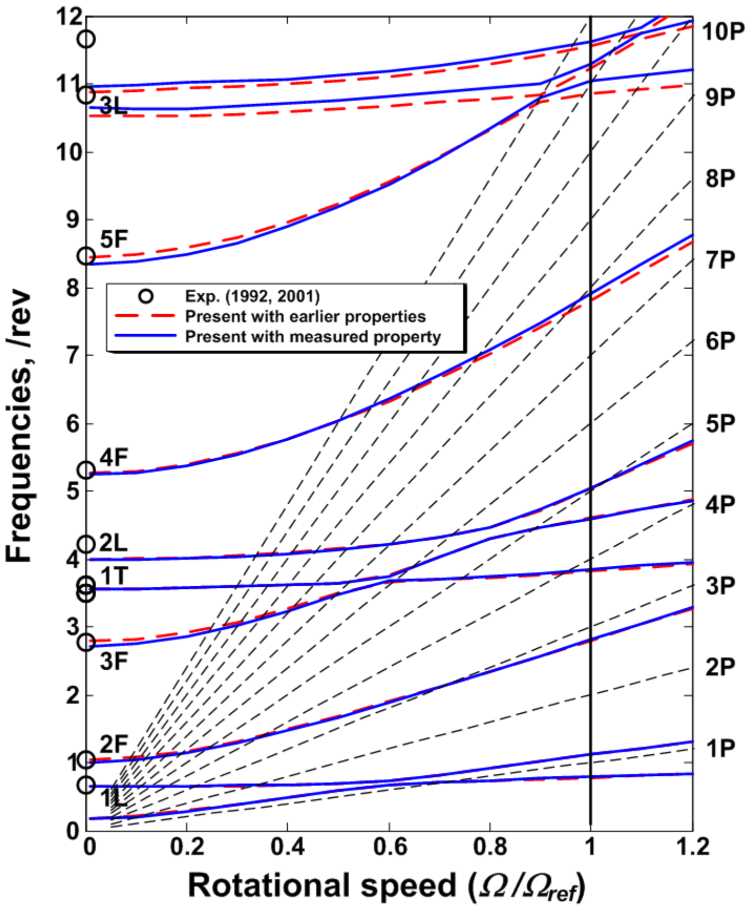


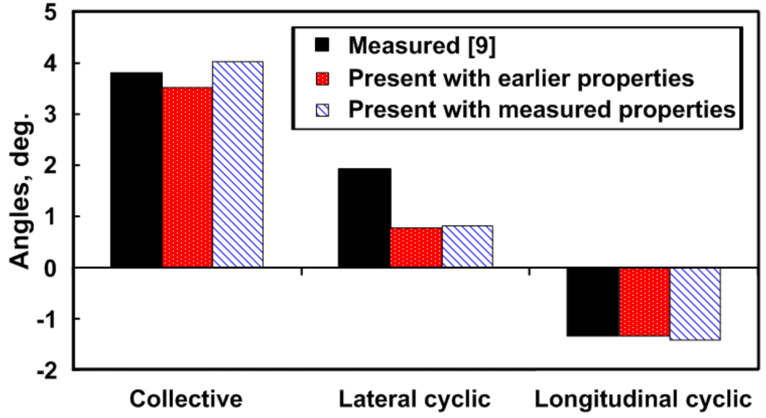


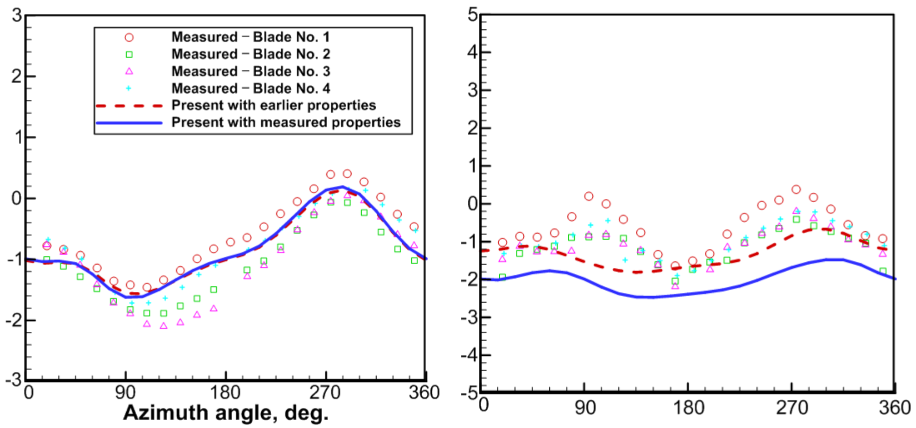
Flap bending

Result: HART II Blade Property Test









- Jung, S. N., You, Y. H., Dhadwal, M., Riemenschneider, J., and Hagerty, B., "Study on Blade Property Measurement and Its Influence on Air/Structural Loads," AIAA Journal, Vol. 53, No. 11, 2015
- Jung, S. N., M. Dhadwal, Kim, Y. W., Kim, J. H., and Riemenschneider, J., "Cross-section Constants of Composite Blades Using Computed Tomography Technique and Finite Element Analysis," Composite Structures, Vol. 129, Oct. 2015

Validation of HART I Rotor

Summary:

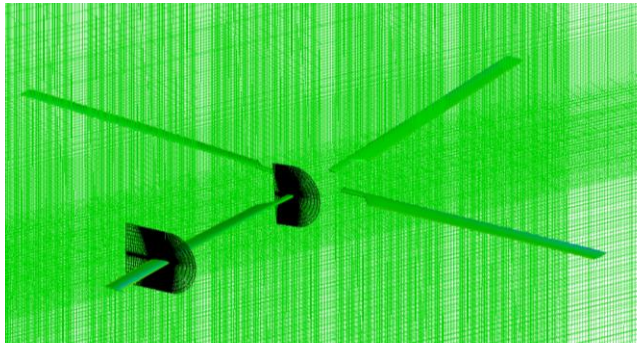
- HART I test performed at DNW in 1994
- First international joint effort to apply HHC technology to reduce rotor noise/vibration
- Measured blade properties available due to the recent measurement campaign

Approaches:

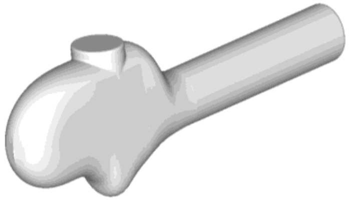
- Modern CFD/CSD coupling used
- Both isolated rotor & rotor-fuselage models used
- In CFD, up-to-date space/time marching schemes adopted for high precision results

Findings:

- CFD/CSD coupled airloads results showed excellent correlation with the test data
- BVI characteristic of HART I data captured precisely
- Structural loads correlation showed slight improvements

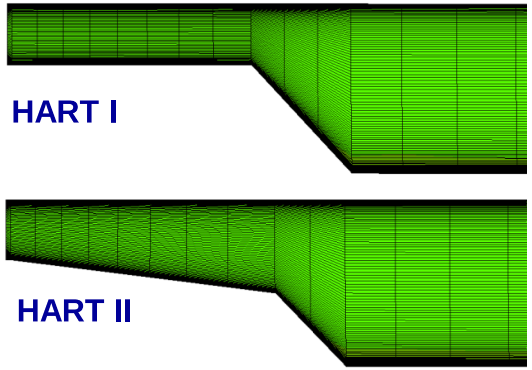


	HART I	HART II
No. of air stations	3 (0.75, 0.87, 0.97R)	1 (0.87R)
No. of strain gages	34 → 32!	6

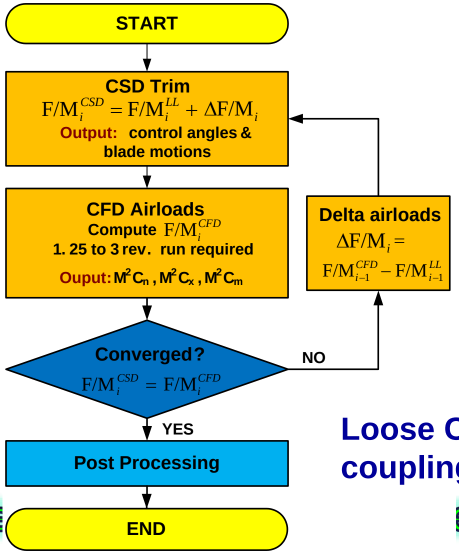


Isolated rotor: 20.9M cells

Rotor-fuselage: 37.5M cells



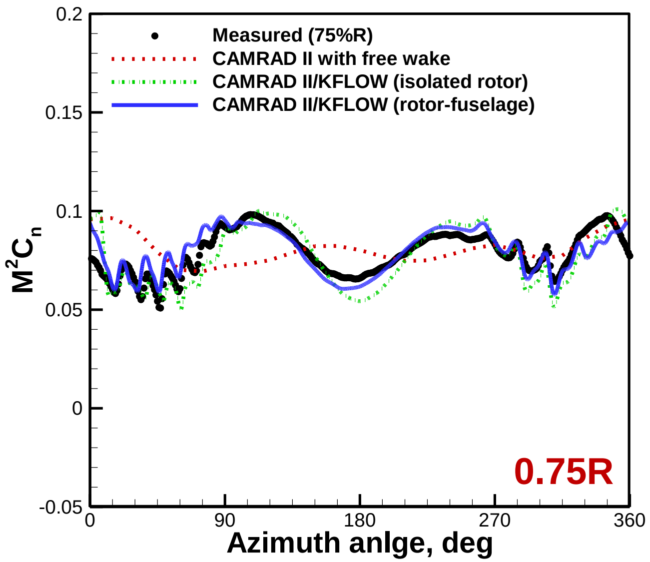
Shank models

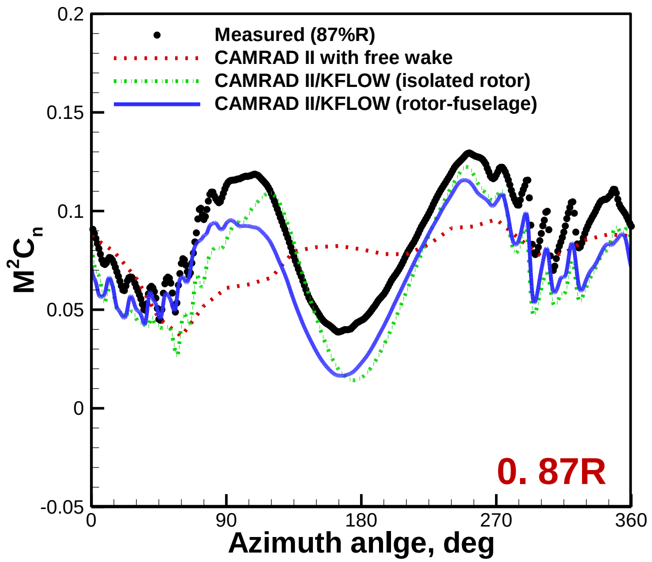


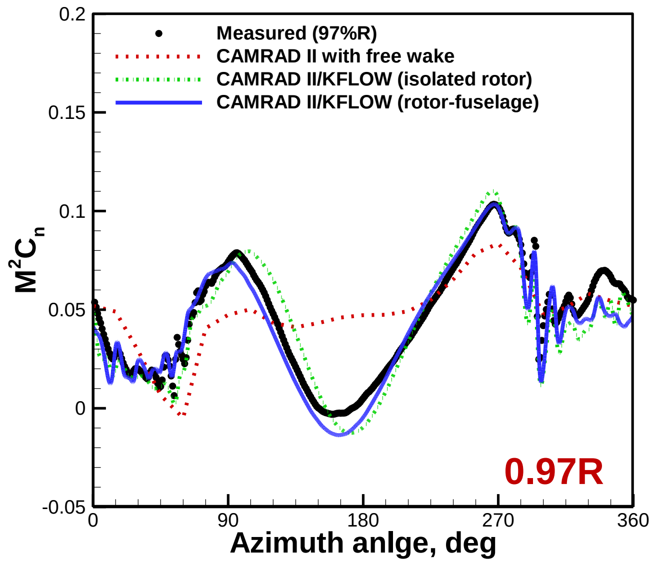
Loose CFD/CSD coupling algorithm

Validation of HART I Test Data

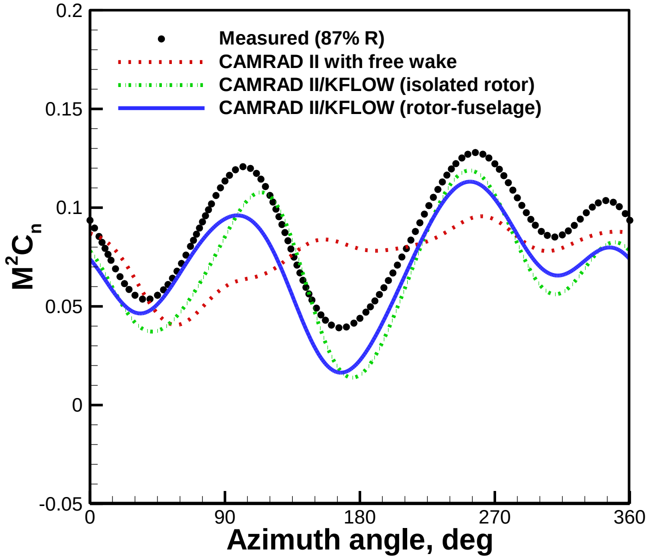
Section airloads:



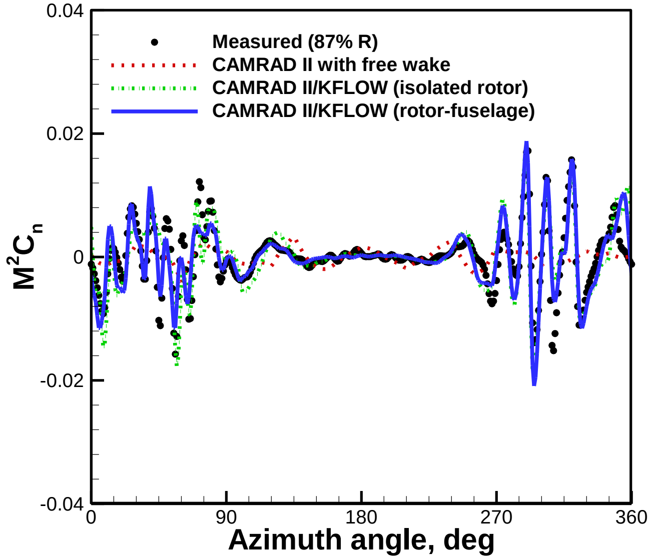




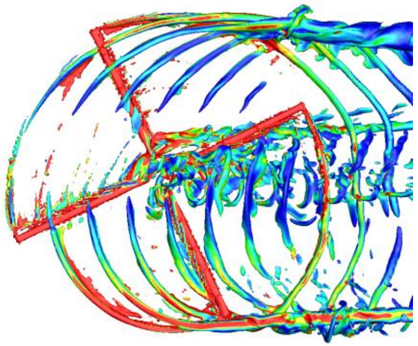
Harmonic analysis on M^2C_n (at 0.87R):



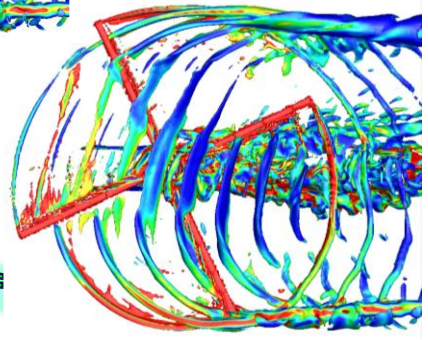
Low harmonic (0 to 10P)



High harmonic (11P and higher)



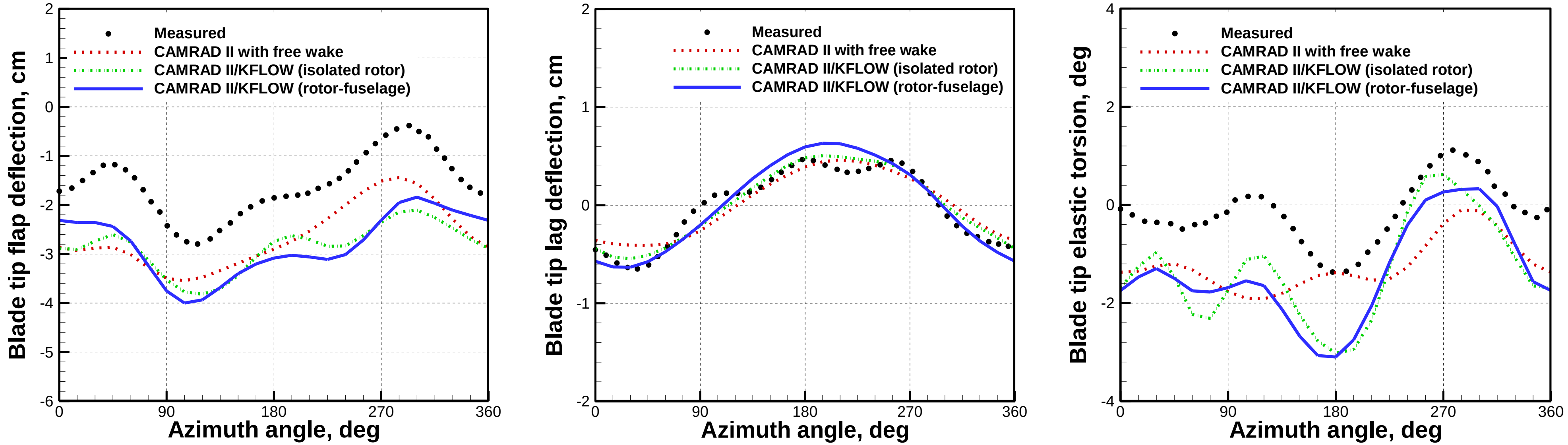
Isolated rotor model



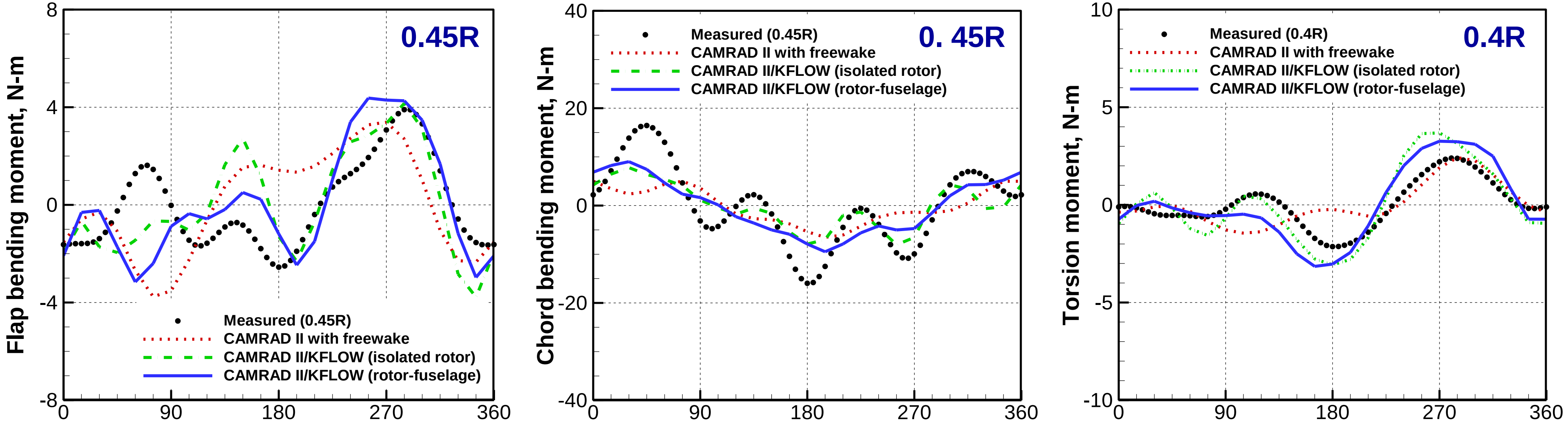
R-F model

Validation of HART I Test Data

Blade tip motions:



Blade structural loads:



- "Improved Rotor Aeromechanics Predictions using a Fluid-Structure Interaction Approach," Aerospace Science and Technology, Vol. 73, No. 2, Feb. 2018
- "Data Transfer Schemes in Rotorcraft Fluid-Structure Interaction Predictions," International Journal of Aerospace Engineering, Vol. 2018, Mar. 2018
- "Comprehensive Aeromechanics Predictions on Air and Structural Loads of HART I Rotor," Int. J. of Aeronautical and Space Sciences, Vol. 18, No. 1, 2017

Validation of HART II Rotor

Motivation:

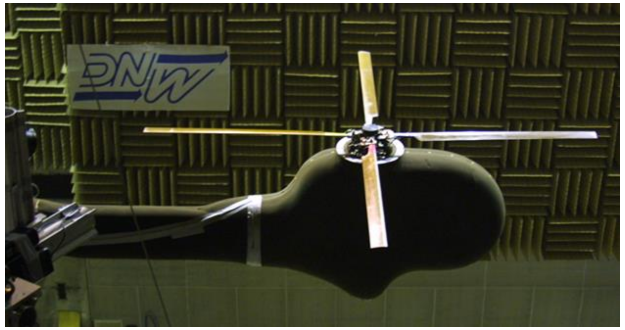
- HART II test performed at DNW in 2001
- Wind tunnel test data open to public in 2006
- High resolution test data used to demonstrate the prediction capability

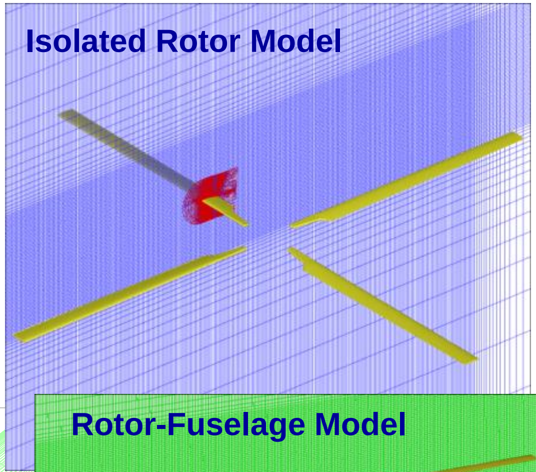
Approaches:

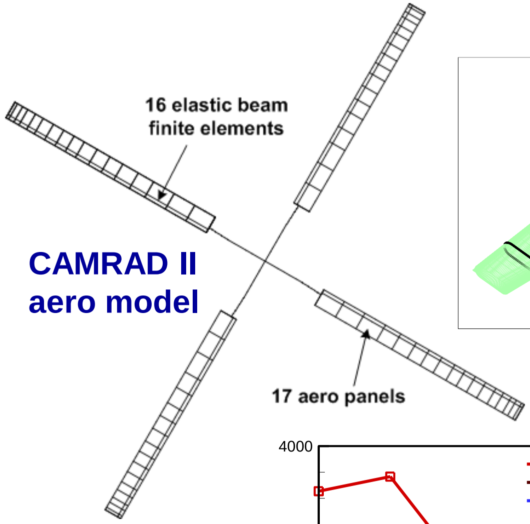
- Step-by-step approaches taken for the validation of measured data
  1) CSD approach: CAMRAD II alone or with prescribed (CFD or measured) airloads
  2) CFD approach: KFLOW with measured blade motions
  3) Loose CFD/CSD coupled approach

Outcomes:

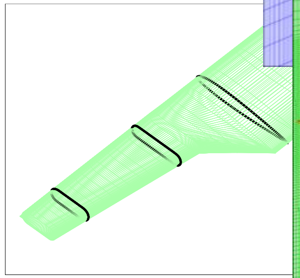
- Code-to-code validation proved efficient for improved correlation of HART II data
- Mechanism of BVI noise reduction via HHC inputs explained
- Loose CFD/CSD coupling algorithm shown to be highly reliable for aeromechanics predictions

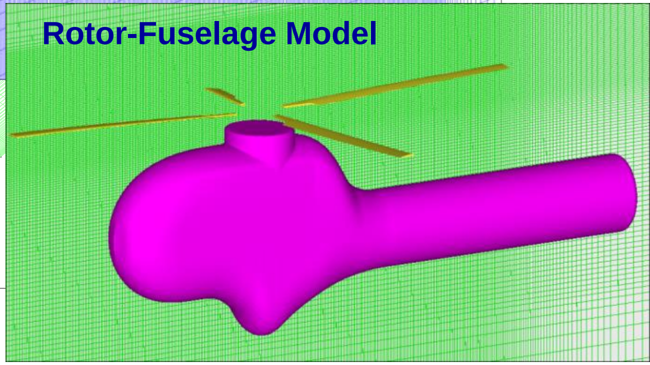




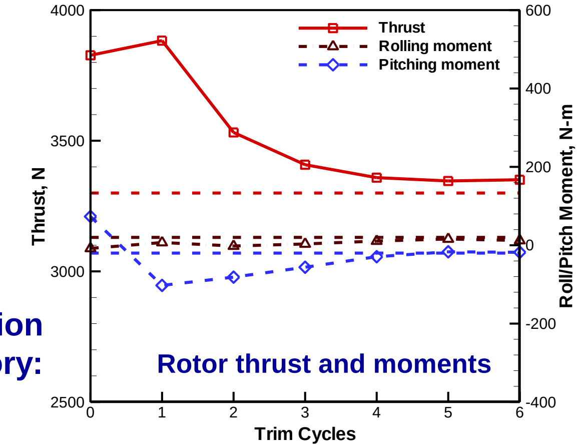


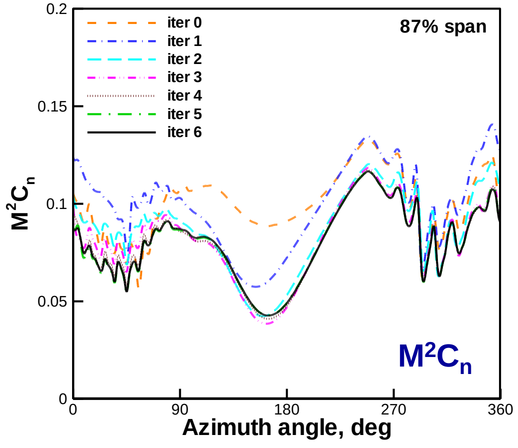
CAMRAD II aero model





Trim iteration history:





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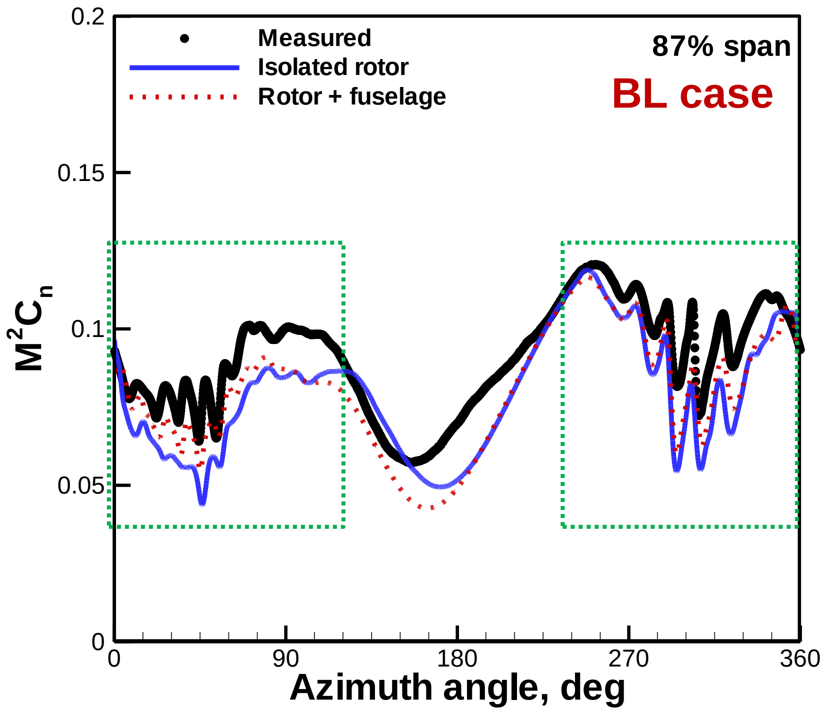
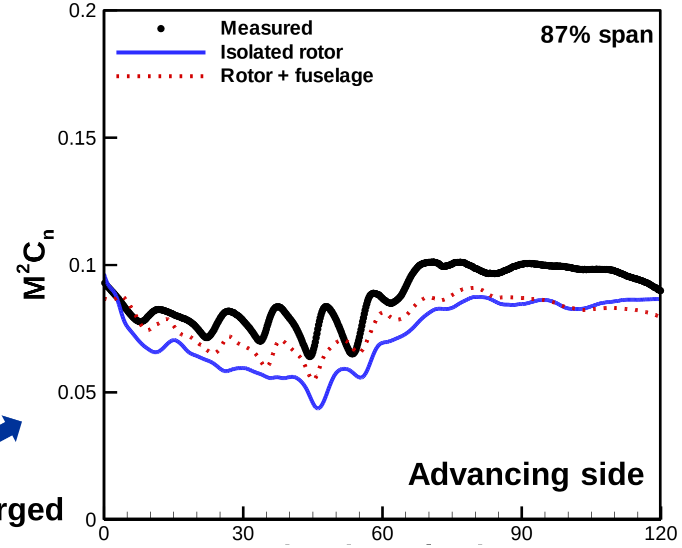
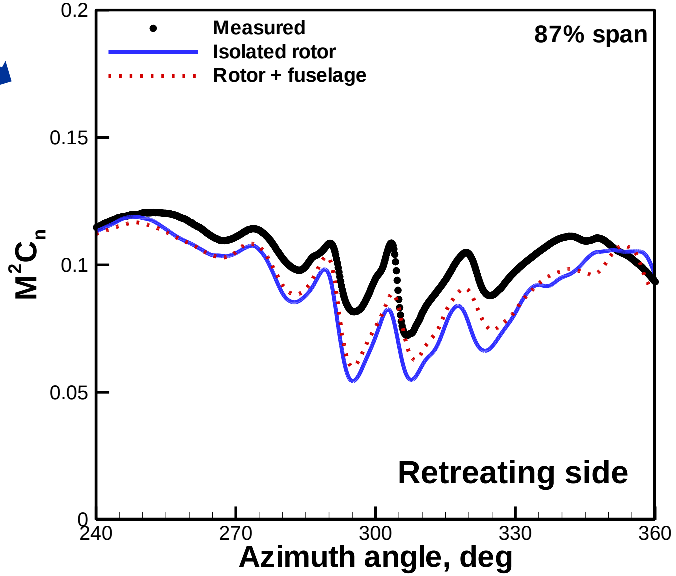
Validation of Section Airloads

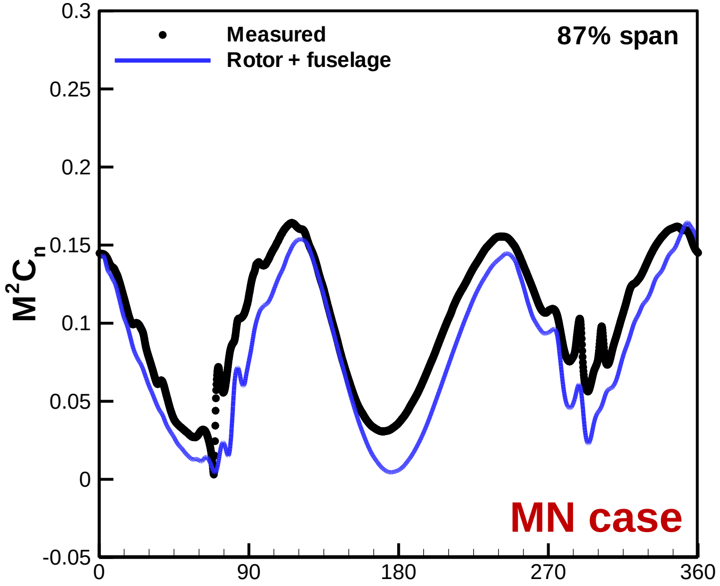
❖ Validation of section normal forces M^2C_n

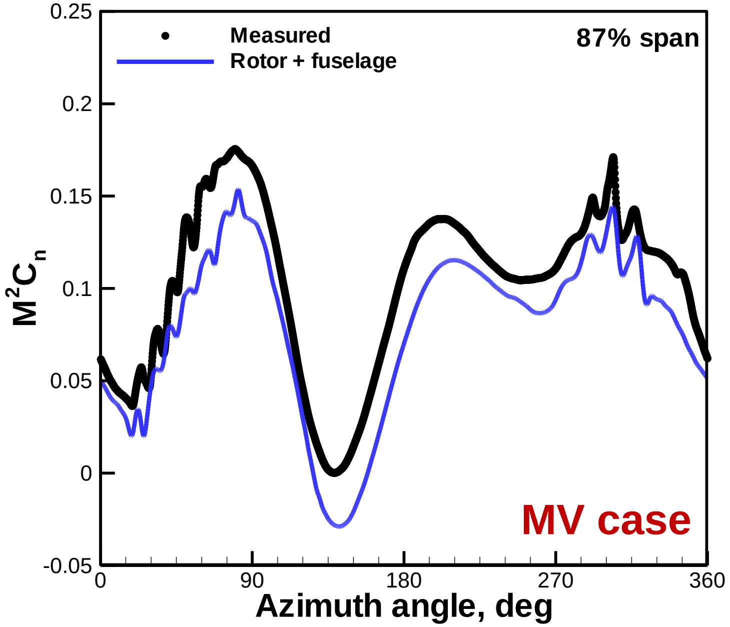


Enlarged view





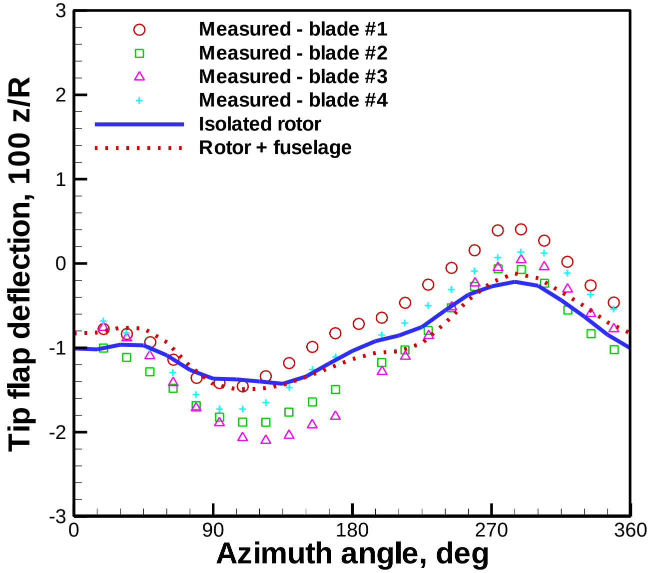


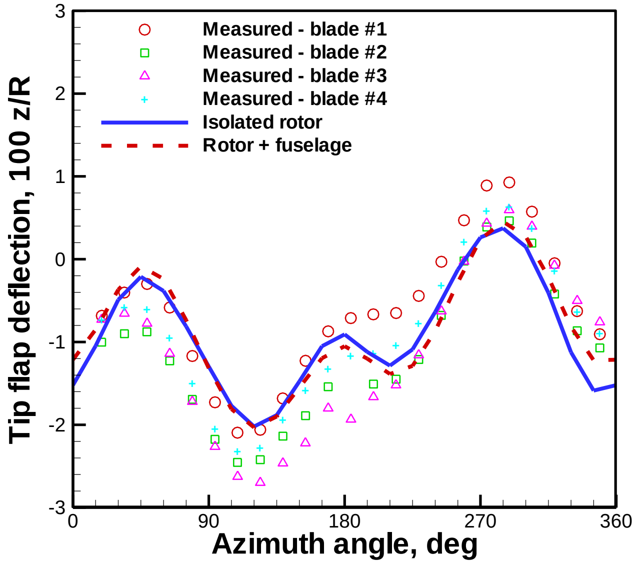


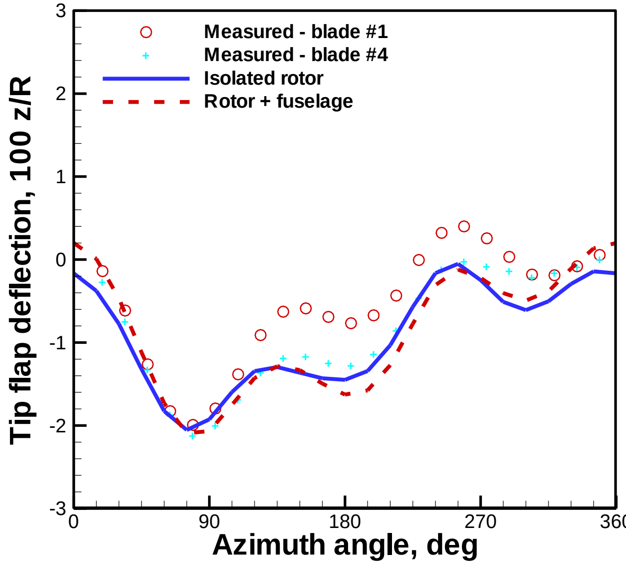
➢ **Good correlation (BVI peaks, phase) obtained, particularly with R-F model**

Validation of Blade Elastic Motions

Flap motion:

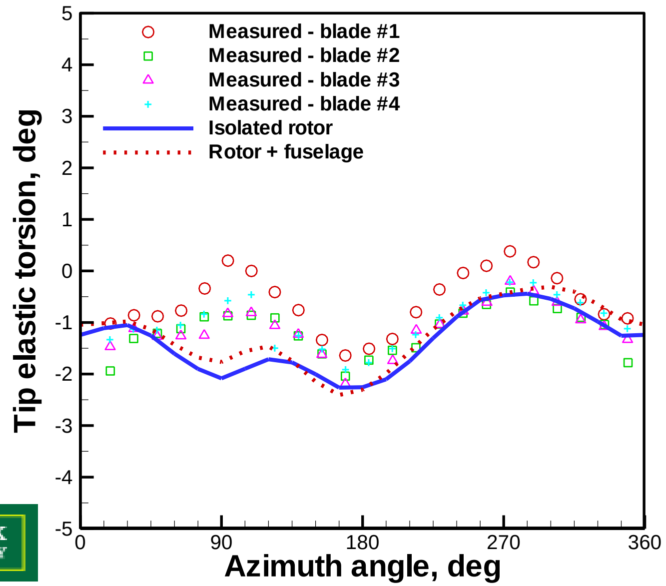


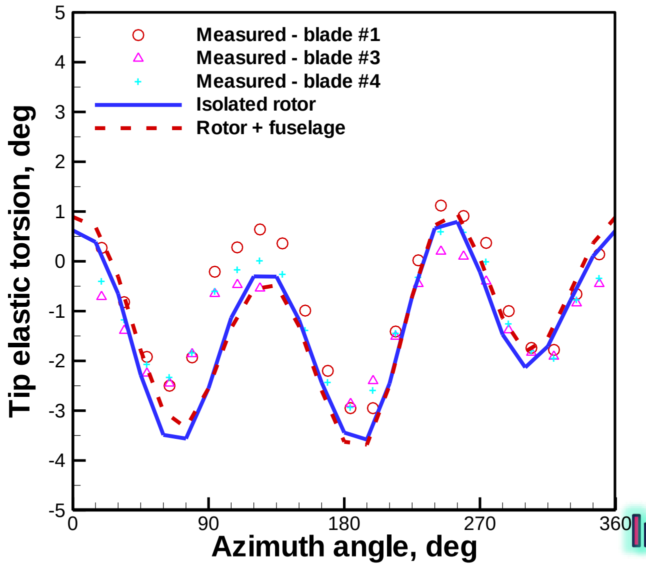


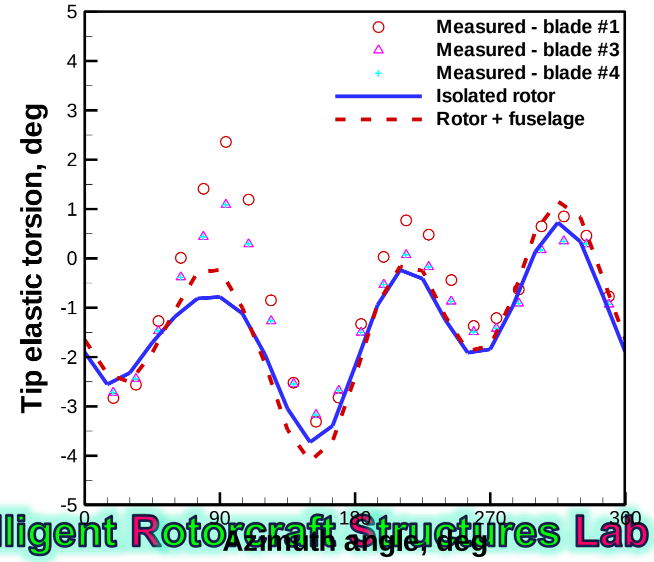


(a) BL　　(b) MN　　(c) MV

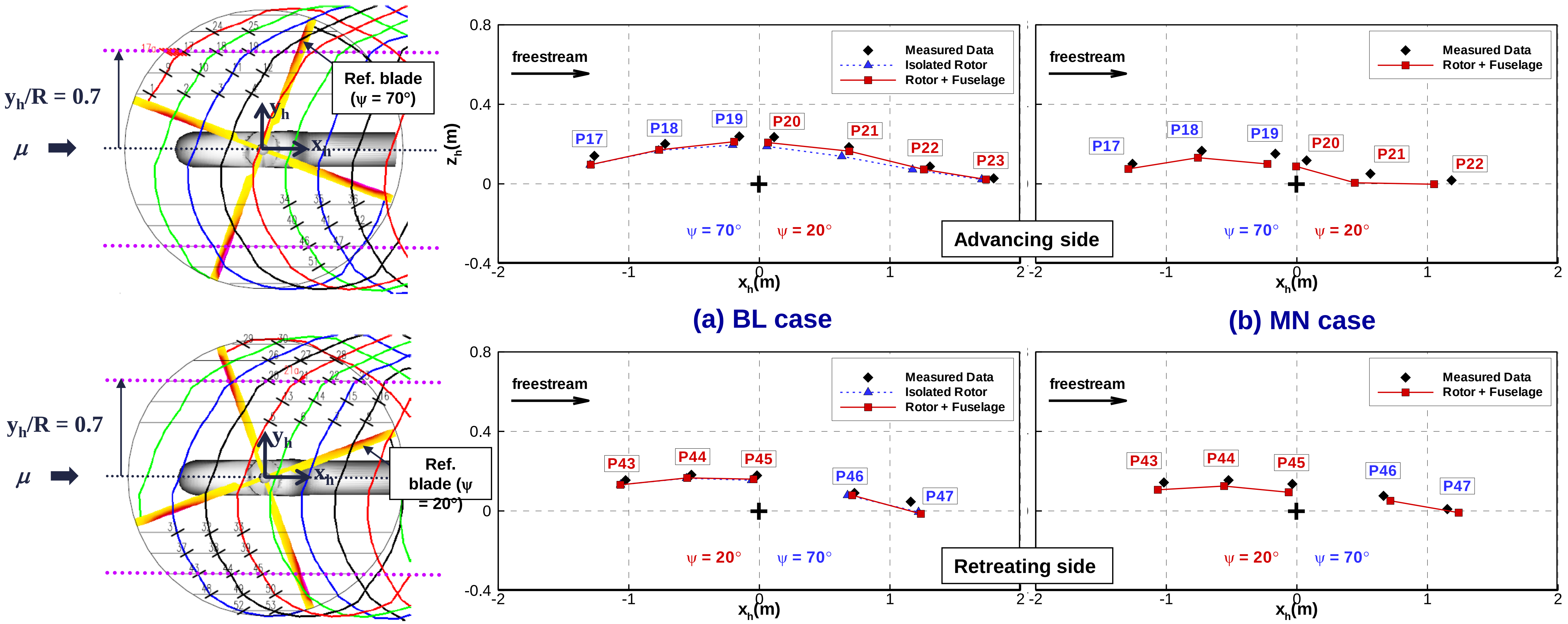
Torsion motion:







Validation of Tip Vortex Trajectories

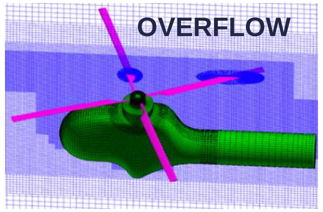


- "Modern Computational Fluid Dynamics/Structural Dynamics Simulation for a Helicopter in Descent," Journal of Aircraft, Vol. 50, No. 5, 2013
- "Loose Fluid-Structure Coupled Approach for a Rotor in Descent Incorporating Fuselage Effects," Journal of Aircraft, Vol. 50, No. 4, 2013
- "Correlation of Aeroelastic Responses and Structural Loads for a Rotor in Descending Flight," Journal of Aircraft, Vol. 49, No. 2, 2012
- "Comprehensive Code Validation on Airloads and Aeroelastic Responses of the HART II Rotor," Int. J. of Aeronautical and Space Sciences, Vol. 11, No. 2, 2010

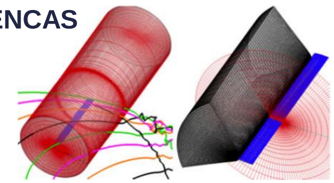
International HART II Workshop

- 1st Int. HART II Workshop started: Sept. 2005
- HART II test data opened to public: 3 test points in descending flight
  - Test data points: BL, MN, MV (at μ = 0.15)
  - Data released: Blade motions, Airloads, Rotor trim, Acoustics, PIV wake, Flow visualization for descending flight
- Workshop held biannually at AHS & ERF until 2012

Participating organizations for joint workshop:



GENCAS



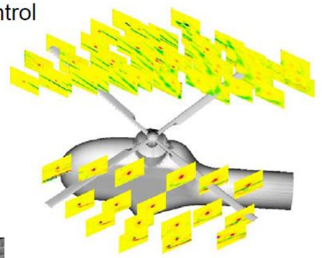
Partner	Partner label	CFD code	CSD code
US Army Aero-flightdynamics Dir.	AFDD-1	OVERFLOW	CAMRADII
US Army Aero-flightdynamics Dir.	AFDD-2	HELIOS	RCAS
NASA-Langley	NL-1	OVERFLOW	CAMRADII
NASA-Langley	NL-2	FUN3D	CAMRADII
Georgia Institute of Technology	GIT-1	FUN3D	DYMORE4
Georgia Institute of Technology	GIT-2	GENCAS	DYMORE2
Konkuk University	KU	KFLOW	CAMRADII
University of Maryland	UMD	TURNS	UMARC
German Aerospace Center	DLR	N/A	S4

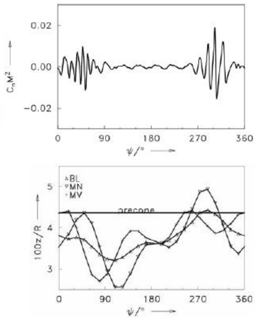
Invitation to the 1st International HART II Workshop

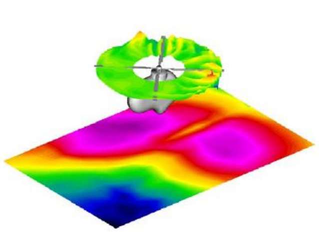
at the 31st European Rotorcraft Forum, Florence, Italy, Sept.12, 2005, 8-12am

Organized by DLR, ONERA, NASA, AFDD, DNW

- Higher Harmonic Control
- Wind tunnel data
- Rotor data
- Blade deformation
- Blade pressure
- Rotor acoustics
- Flow visualization
- 3C-PIV wake data





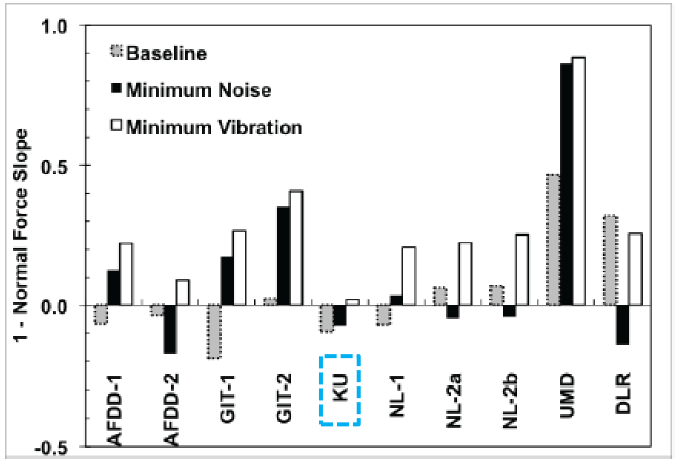


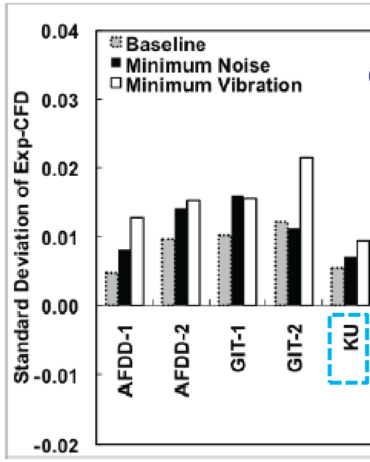
Point of contact:

DLR:
Berend G. van der Wall
berend.vanderwall@dlr.de

NASA Langley:
Casey L. Burley
casey.l.burley@nasa.gov

HART II Workshop Database
ftp://HART-II@ftp.dlr.de
Password: HART-II





Correlation results:

Joint workshop held in AHS Forum, Fort Worth, TX, May 1-3, 2012

KU KONKUK UNIVERSITY

DLR-KU MoU Research

Goals:

- To establish an int. collaboration
- To broaden the technology base by increasing fundamental knowledge on helicopter aeromechanics area

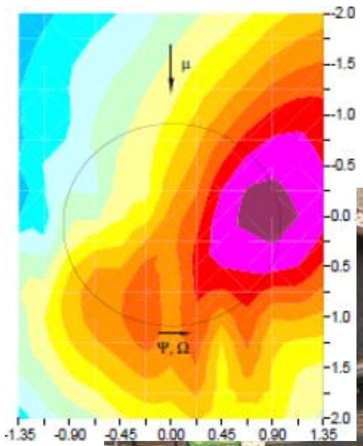
Summary:

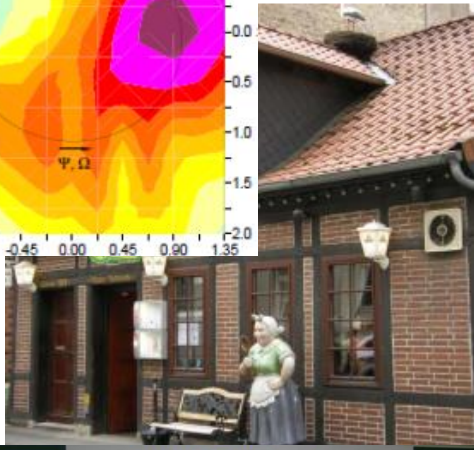
- MoU began in Apr. 2008 for 6 years
- Consisted of 2+ tasks: rotor aeromechanics, dynamic stall, and information exchange (rotary UAV)
- Meetings held twice per year at the other organization
- Points of contact: Sung N. Jung (KU), Berend G. van der Wall (DLR)

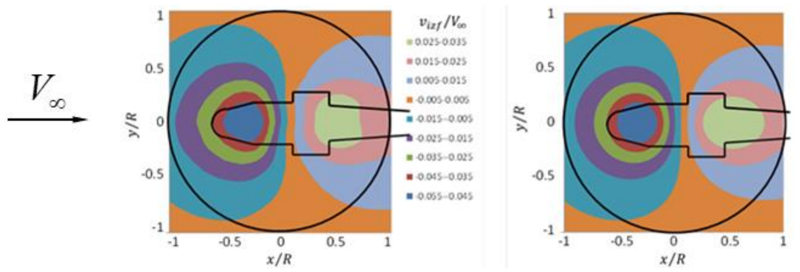
Outcomes:

- S4-KFLOW coupling attempted
- Bound meeting minutes (11 meeting volumes)
- 1 journal papers and 7 conference papers

Task	Area
Task I - 1	Aeromechanics on: Various Rotorcraft Activities
Task I - 2	Aeromechanics on: STAR/HART Blades
Task II	Dynamic Stall: CFD prediction and validation
Potential Task	UAV Activities or other areas (e.g., FBW)
	KARI Rotorcraft Activities







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STAR (Smart Twisting Active Rotor) Int. Consortium Project

Goals

- Reduce noise/vibration with improved performance via ATR concept (post-decessor of HART II)
- Realize active rotor technology

Members

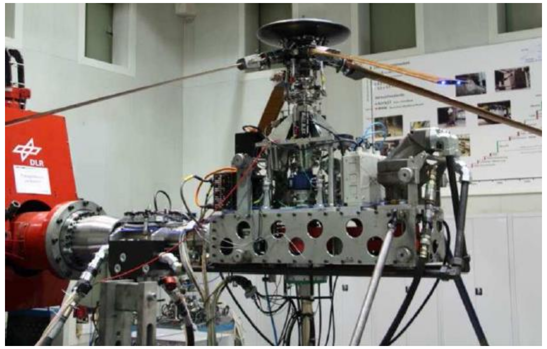
- German DLR / French ONERA
- US Army AFDD & NASA Ames
- Korea Konkuk Univ. & KARI
- Japan JAXA
- UK DSTL & Univ. of Glasgow

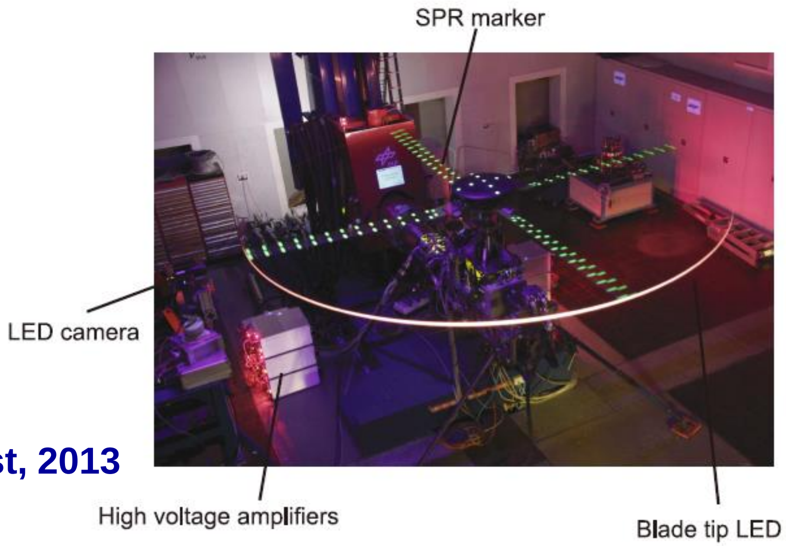
Flight Conditions

- Hover, Low speed descent
- Cruise/high speed
- High load, High μ (at 50% RPM)
- Speed/thrust/phase sweep

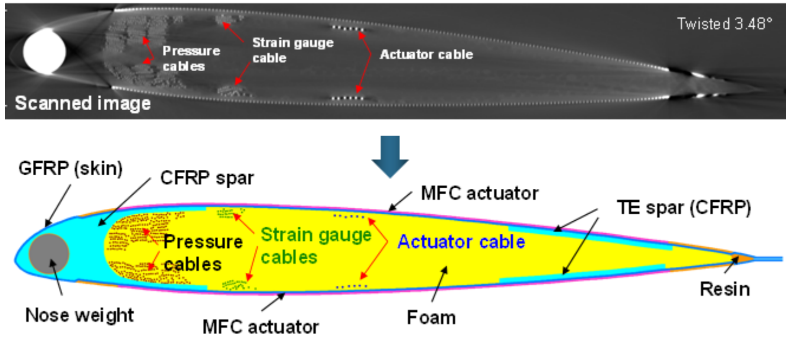
Schedule

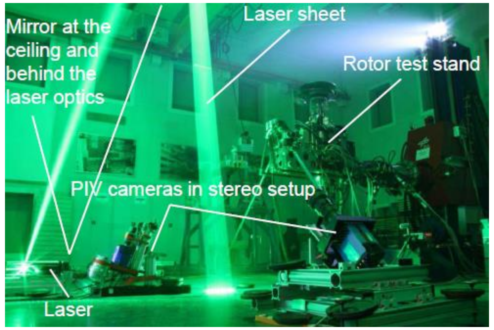
- Phase I: Launched at May 2009
- Phase II: Resumed in 2018
- Wind tunnel test planned: Sept. 2024 at DNW, Netherlands





STAR hover test, 2013





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- Ahn, J. H., Hwang, H. J., Jang, S., Jung, S. N., Kalow, S., and Keimer, R., "X-ray Computed Tomography Method for Macroscopic Structural Property Evaluation of Active Twist Composite Blades," Aerospace, Vol. 8, Nov. 2021

Q & A

Thank you!

Contact: snjung@konkuk.ac.kr