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RDECOM

AHS Technical Meeting on Aeromechanics Design for Vertical Lift
San Francisco, CA, January 22, 2016

SAN FRANCISCO BAY AREA CHAPTER

HPCMP CREATE™-AV Helios Prediction of BVI Loading and Rotor Wakes of HART II Rotor

AMRDEC

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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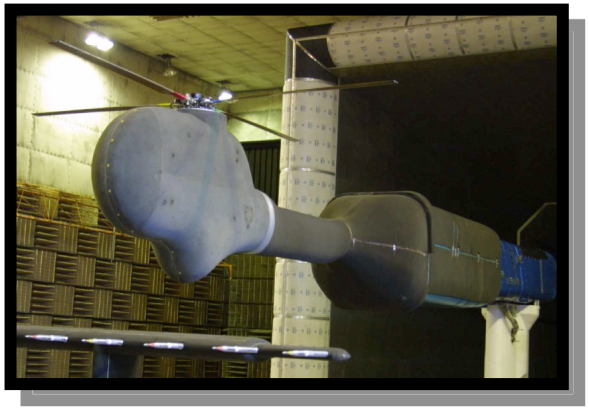
Presentation Outline

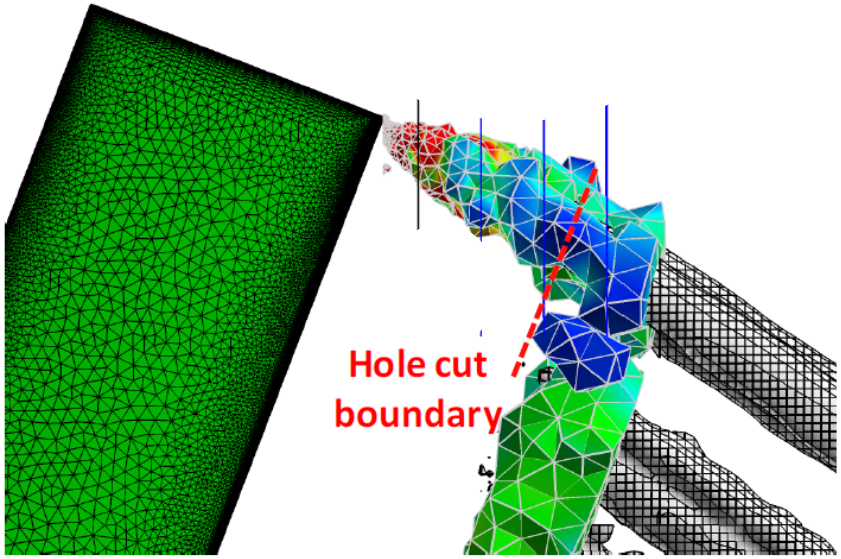
- **Summary of previous research**
- **Objectives**
- **Implicit DES off-body solver**
- **Validation using HART II rotor**
  - Airload prediction for baseline, minimum noise, and minimum vibration cases
  - Wake prediction for the baseline case
- **Summary**

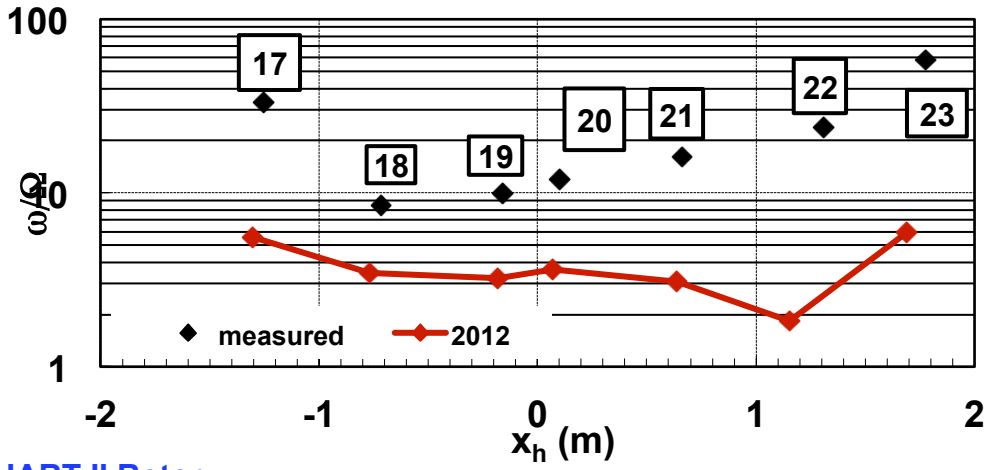


HART II Work using Helios

HART II Baseline case

- **2012: Helios V3 (Lim et al., AHS 2012)**
  - NSU3D unstructured near-body solver
  - Wake prediction using Adaptive mesh refinement (AMR) in off-body
  - Airload predictions were in good agreement with measured data
  - Poor wake predictions due to coarse near-body blade grid

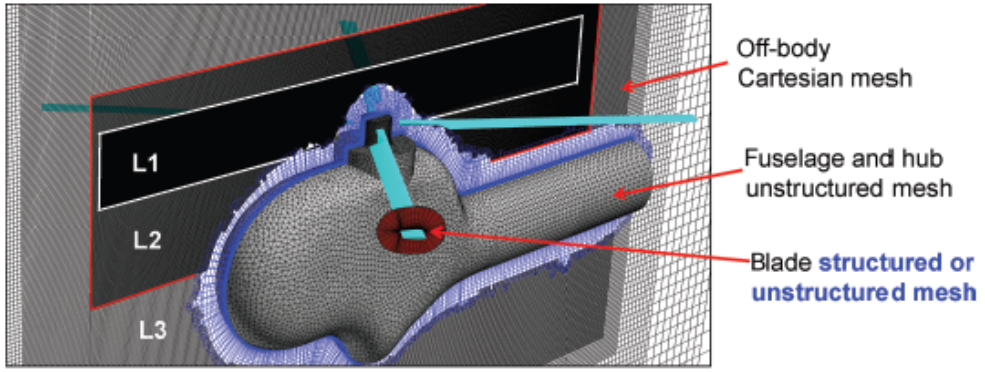




Lim et al. "Helios Adaptive Mesh Refinement for HART II Rotor Wake Simulation", 68th AHS Forum, Fort Worth, TX, May 2012.

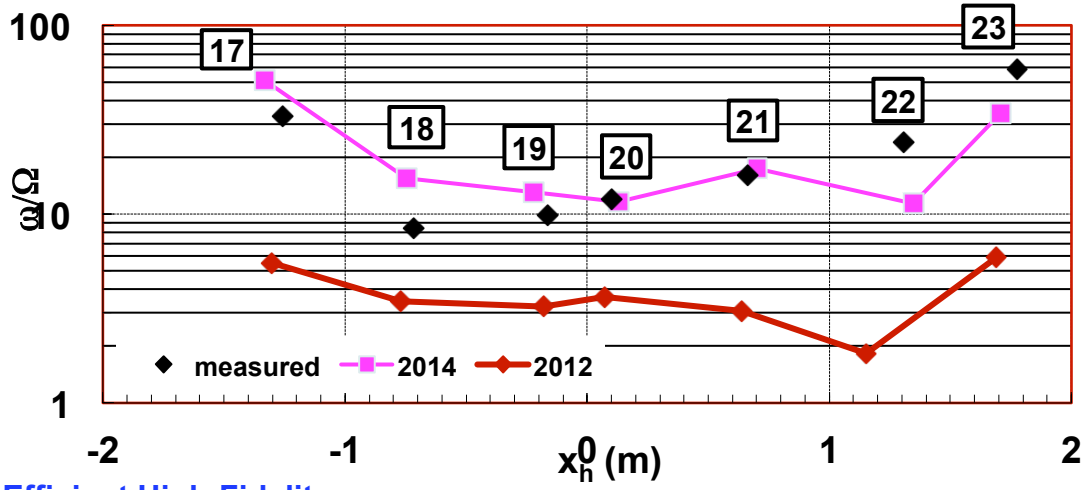
HART II Work using Helios

- **2014: Helios V4 (Jain et al., J. AHS 2015)**
  - Very fine structured blade grid (20M nodes) using OVERFLOW
  - Fixed off-body grid with 2% chord spacing in the finest level
  - Vortex strength predictions in excellent agreement with measured data



Rotor wake: ~800 million points, static adaption (no AMR)

Fuselage and hub: 0.8 million points

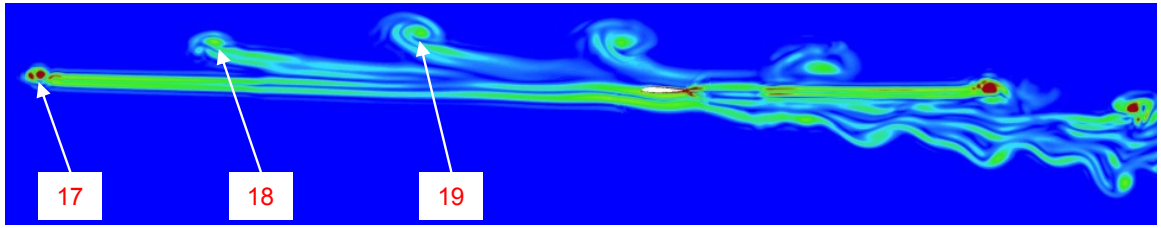


Jain et al. "Modular Multisolver Approach for Efficient High-Fidelity Simulation of the HART II rotor", J. of AHS, Vol 60, 2015, pp.1-11

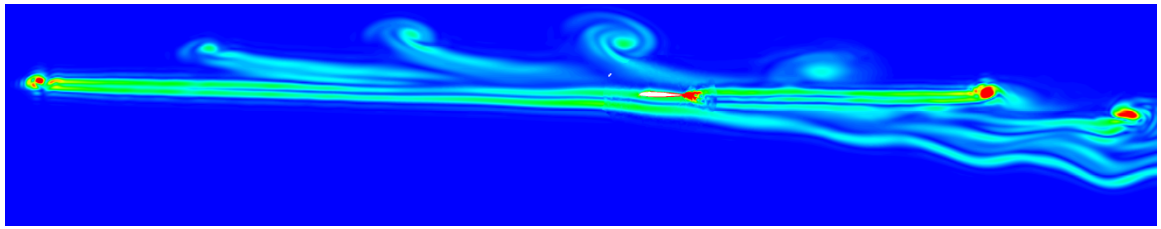
HART II Work using Helios

HART II Baseline case - Continued

- **2016: Helios V5 (Jain et al., AIAA 2016)**
  - Integration of NASA's FUN3D in Helios
  - Same unstructured grid as 2014
  - Airload prediction comparable to OVERFLOW and wake prediction similar to NSU3D



OVERFLOW

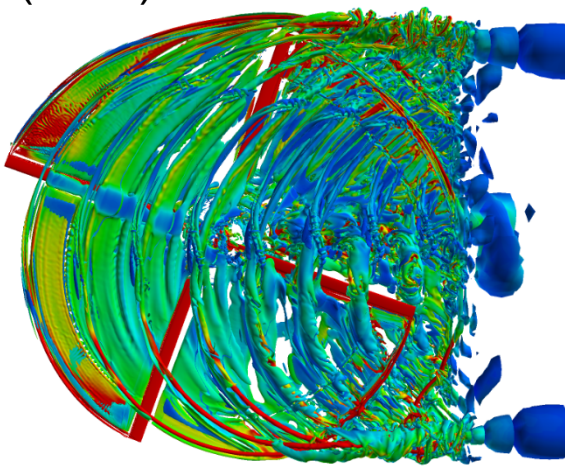


FUN3D

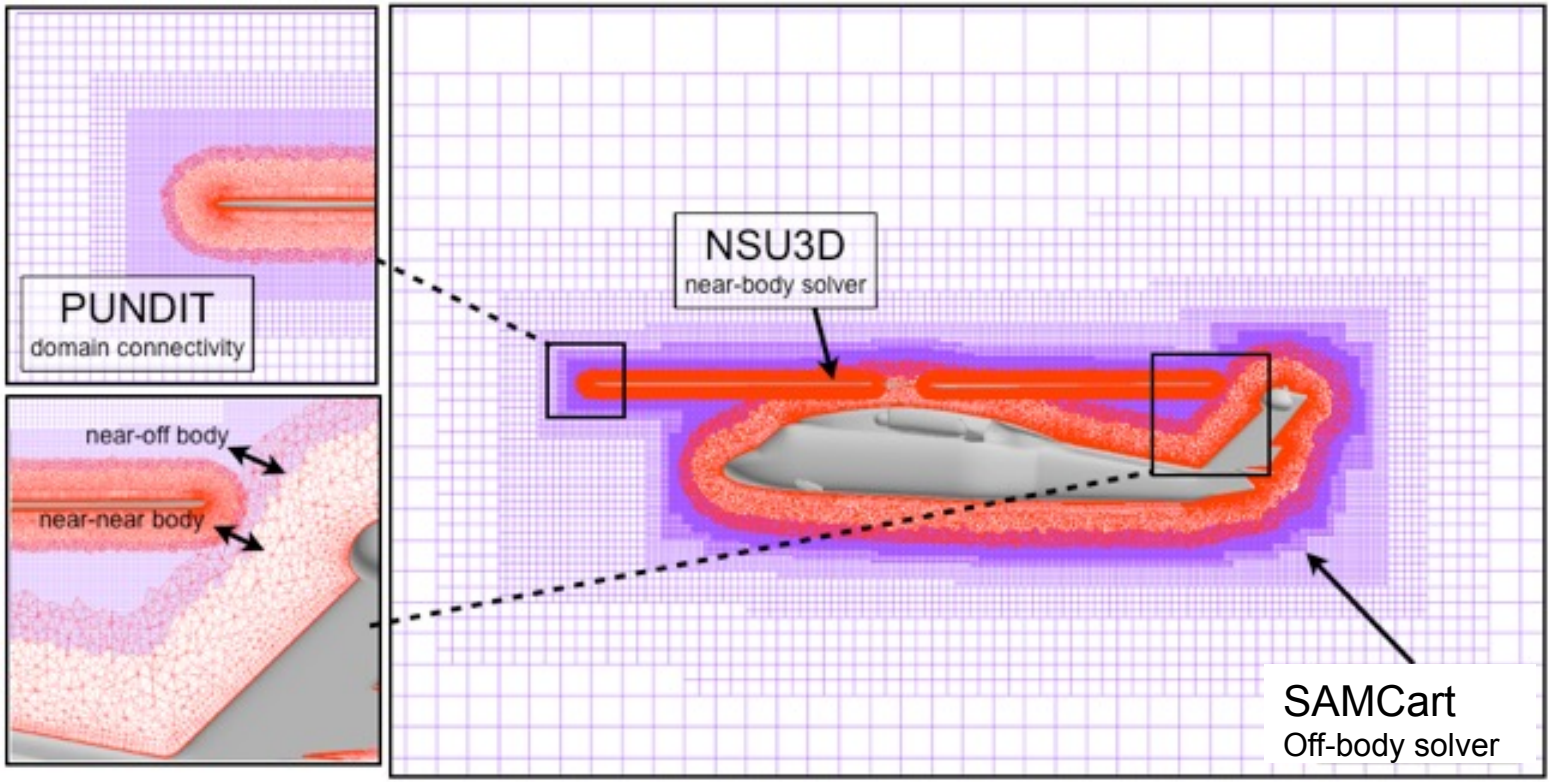
Jain et al. "Modularization and Validation of FUN3D as a CREATE-AV Helios Near-body Solver", 54th AIAA SciTech Forum, San Diego, CA, January 2016

Objectives

- **Validate Helios version 6**
  - FUN3D integrated in Helios as a near-body solver
  - Compare the three-near body solvers: NSU3D, FUN3D, and OVERFLOW
  - Evaluate SAMCart: Implicit off-body solver with DES
- **Understand the difference between the structured and unstructured grids**
- **Aerodynamic loads comparison for three conditions**
  - Baseline (BL): Very strong blade-vortex-interaction (BVI)
  - Minimum noise (MN): Includes higher-harmonic control (HHC) to reduce noise
  - Minimum vibration (MV): Includes HHC to reduce vibration
- **Comparison of wake prediction for BL case**



Helios Multi-mesh Paradigm



Multi-Mesh CFD Paradigm

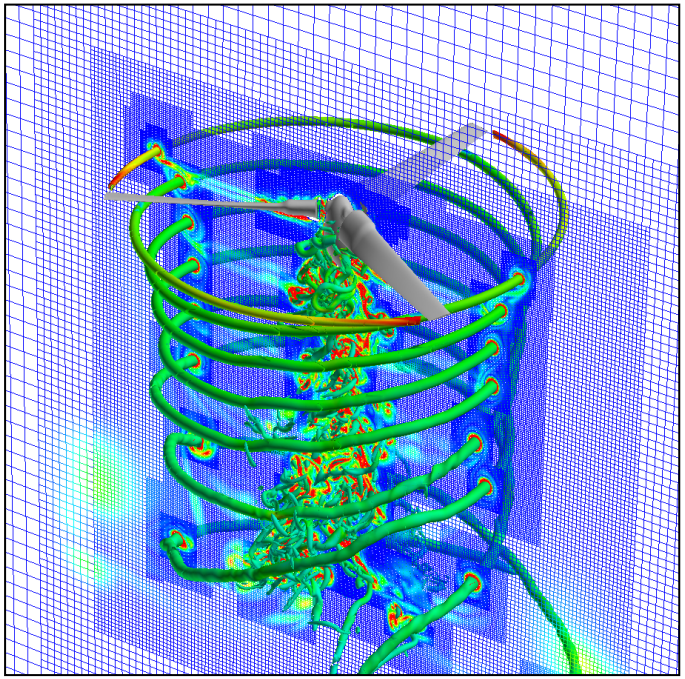
- Unstructured/Structured Near-Body
- Adaptive Cartesian Off-Body
- Overset Connectivity

Near-body Solvers

- **Reynolds-averaged Navier-Stokes (RANS)**
- **2nd order implicit BDF time integration**
- **Unstructured solver**
  - **Spatially 2nd order accurate**
  - **NSU3D**
    - Central difference with artificial dissipation
  - **FUN3D**
    - Approximate Riemann solver based spatial discretization
    - 2nd order implicit BDF2OPT time integration
- **Structured solver**
  - **OVERFLOW**
    - Central difference up to 5th order spatial discretization

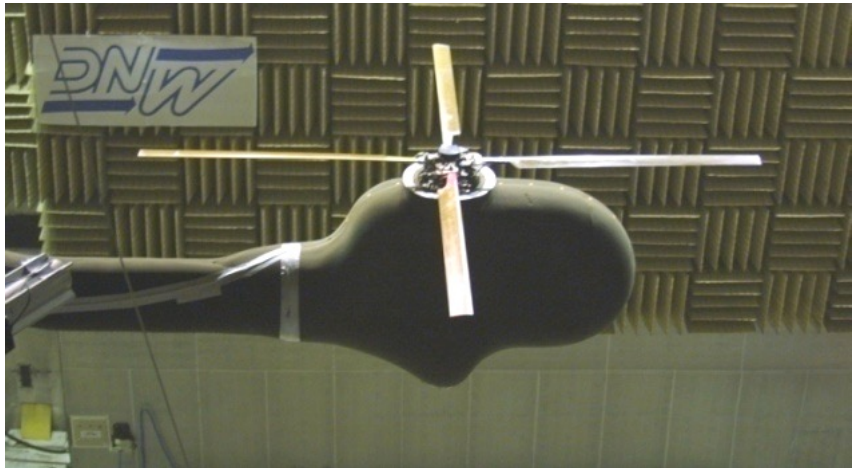
SAMCart off-body Solver

- **Replaced ARC3D (used in SAMARC) with new "Cart" solver**
- **Implicit solver added**
  - Explicit is fast and efficient but suffers from time step restrictions
  - Implicit – local & global
    - LU-SGS
    - ADI – diagonally dominant variation
    - Gauss Seidel Line relaxation
  - Viscous 4^{th}-Order terms
  - SA & DES turbulence modeling
- **Global implicit scheme intended for running on large number of processors**



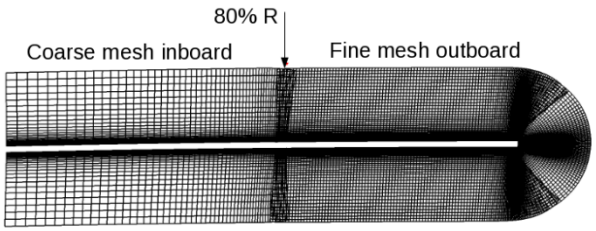
Simulation Setup

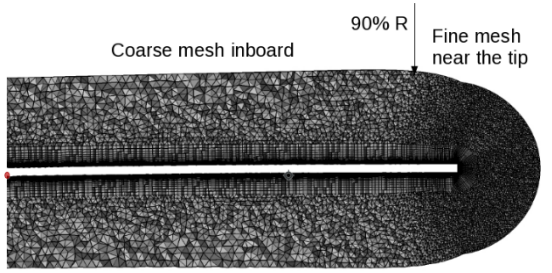
- 40% Mach-scaled model of Bo105 rotor with 2m radius and 0.121m chord
- Tests conducted at DNW wind tunnel
- A descending flight at μ = 0.15 and corrected shaft angle 4.3°
- MN and MV cases have HHC with 3/rev and blade root pitch control and a corrected shaft angle of 4.12°
- Prescribed blade motions from a previously coupled simulation

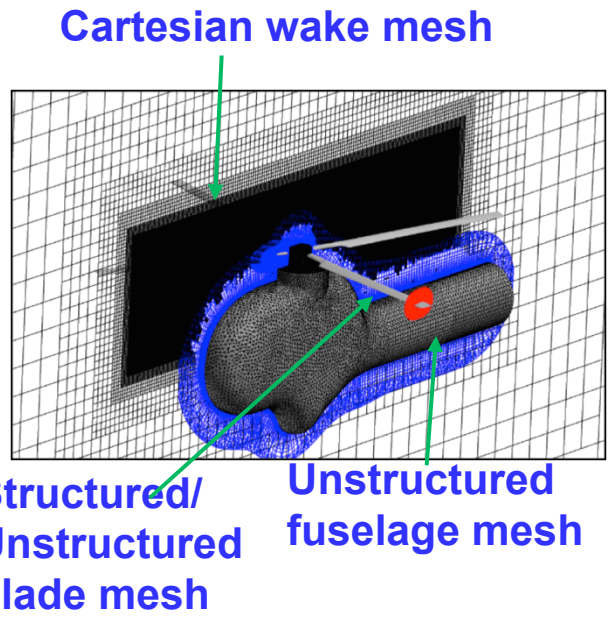


Computational Grid

- **Rotor grid**
  - **Extends to one chord from surface**
  - **Structured blade grid**
    - 5M nodes per blade
    - Fine mesh with 2% chord spacing from 80% to tip
  - **Unstructured blade grid**
    - 3.5M nodes mixed element grid
    - Refinement in the tip region
- **Fuselage grid**
  - Unstructured fuselage grid with 0.8M nodes
  - Same fuselage grid for all cases
- **Off-body Cartesian grid**
  - 2.5% c in fine level with 500M nodes for BL case
  - 5% c in fine level with 113M nodes for MN and MV cases







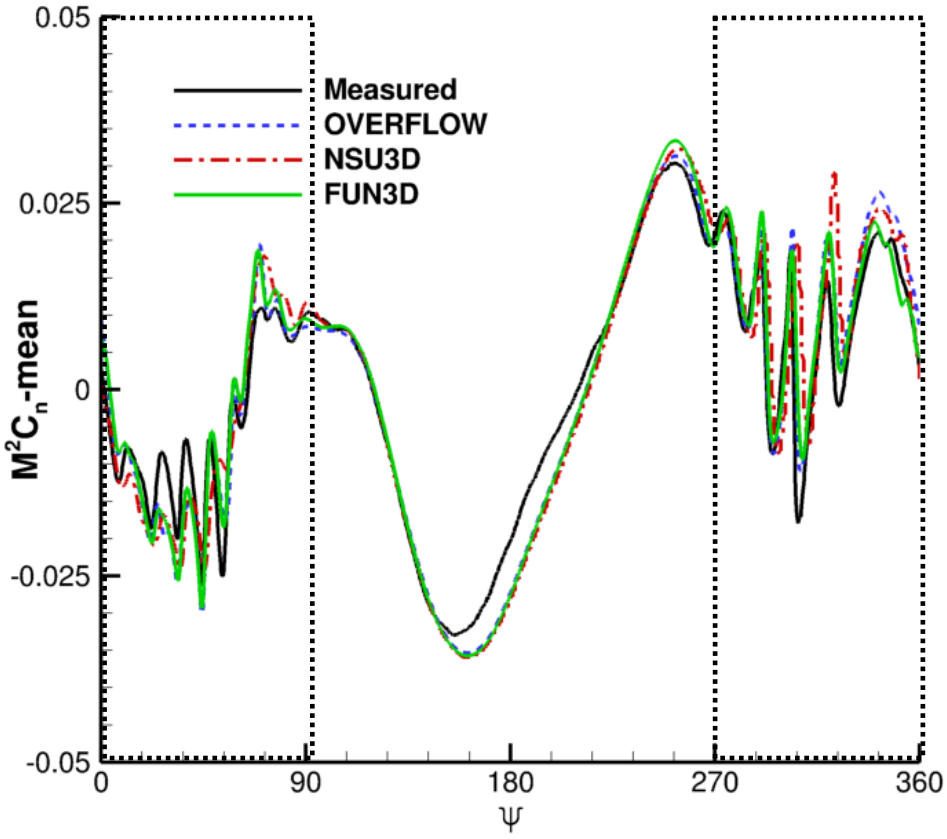
Run Conditions

- Time step 0.1 deg azimuth (3600 time steps/rev)
- 30 sub-iterations per time step for near-body
- 12 sub-iterations per time step for off-body
- Spalart-Allmaras turbulence model with rotation correction
- 4 full rotor revolutions for convergence
- Computation time in seconds using 1024 processors

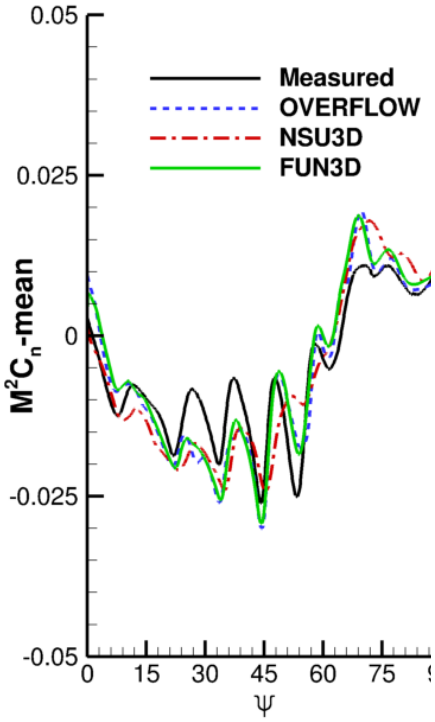
	Near-body (sec)	Order of convergence	Off-body (sec)	Total/step (sec)	Number of nodes/blade
OVERFLOW	2.8	3.5	31	38.4	5M
NSU3D	7.3	0.5	31	46	3.5M
FUN3D	20.5	4	31	68.2	3.5M

Normal Force – Baseline Case

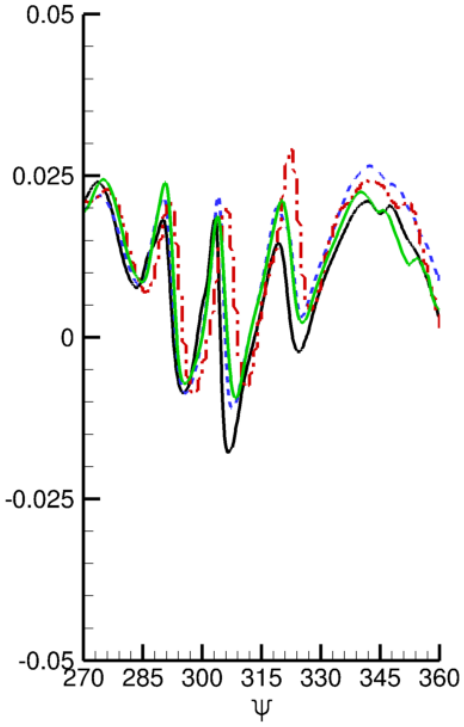
Radial station r/R = 0.87



Advancing side



Retreating side



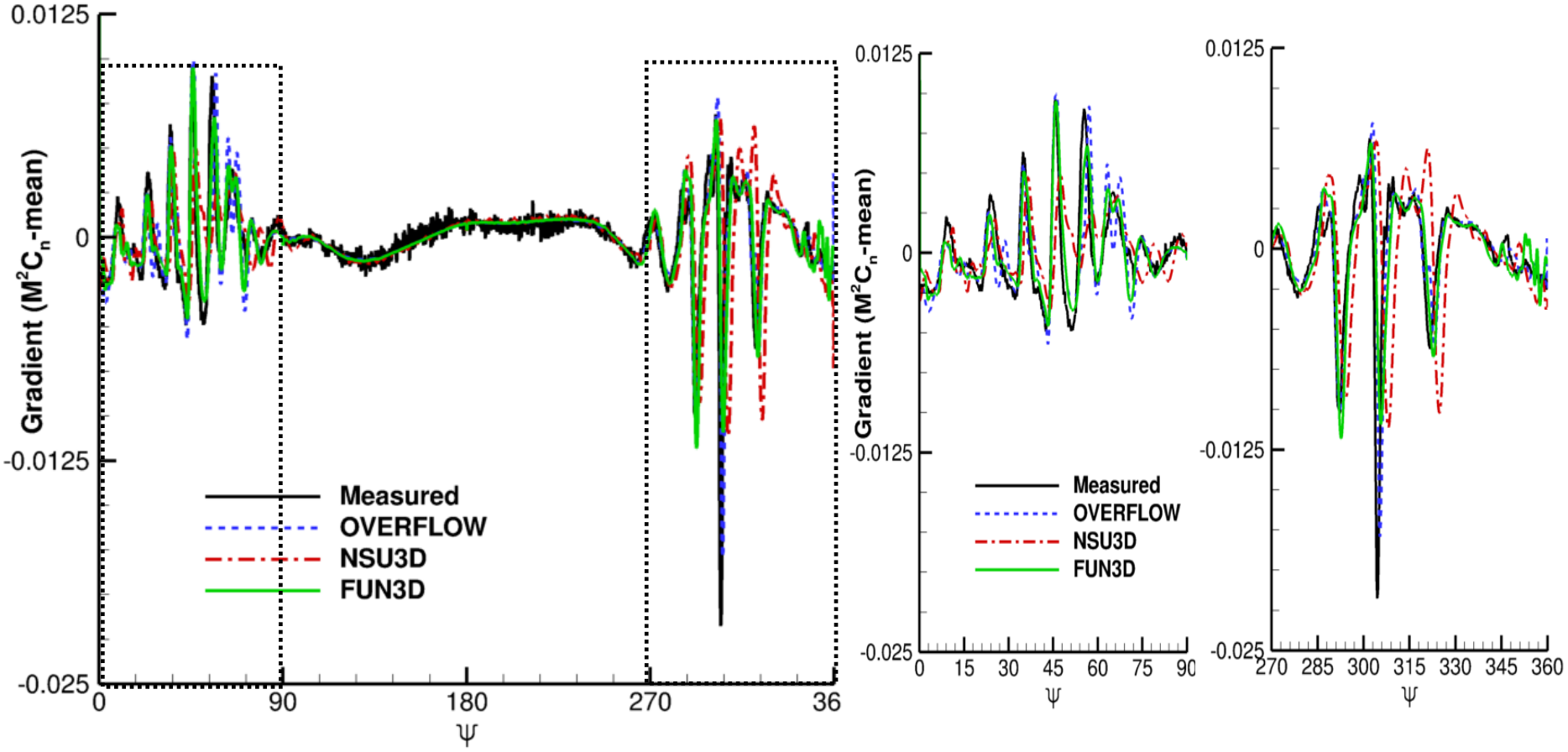
- **All codes agree well with the data**
- **BVI events captured well**
- **Small phase shift in NSU3D**

Normal Force Gradient – Baseline

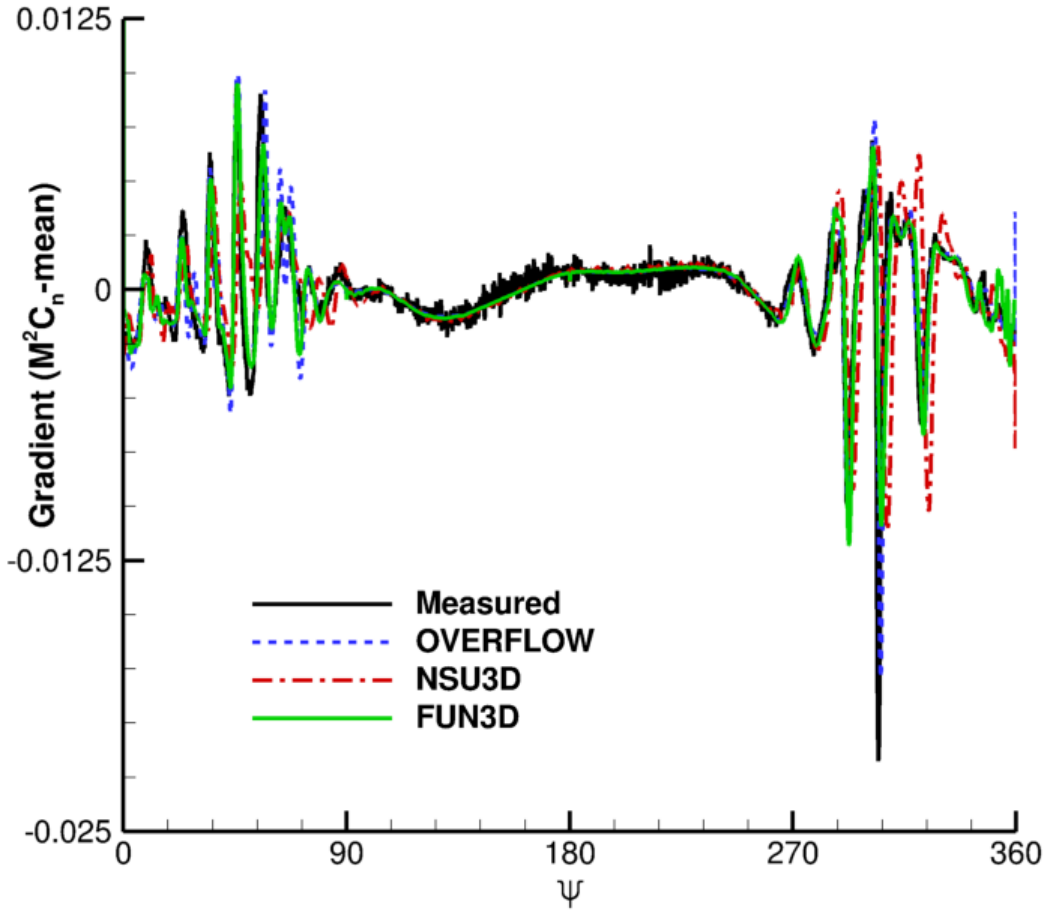
Radial station r/R = 0.87

Advancing side

Retreating side



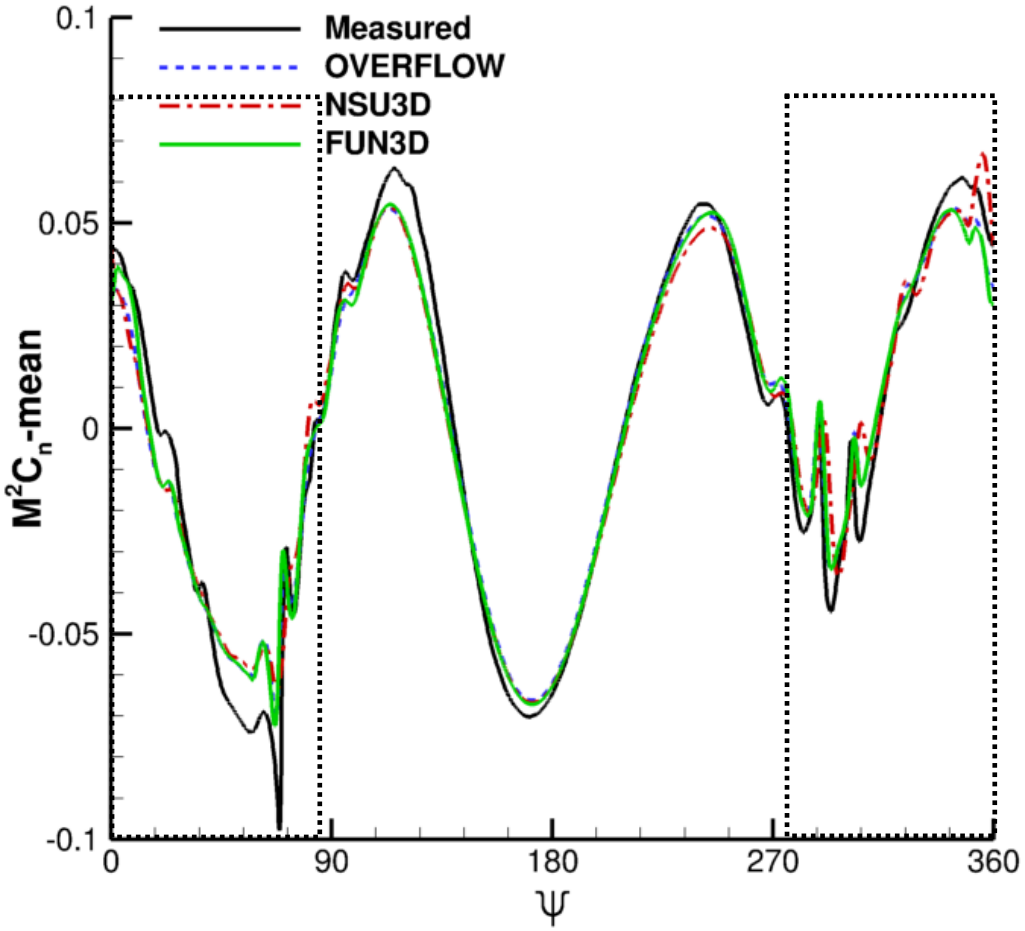
Normal Force Gradient – Baseline



- Gradient computed as derivative of airload with rotor azimuth
- Important for acoustic calculations
- Magnitude of BVI spikes show the intensity of noise
- OVERFLOW predictions compare closely with data

Normal Force – Minimum Noise

Radial station r/R = 0.87

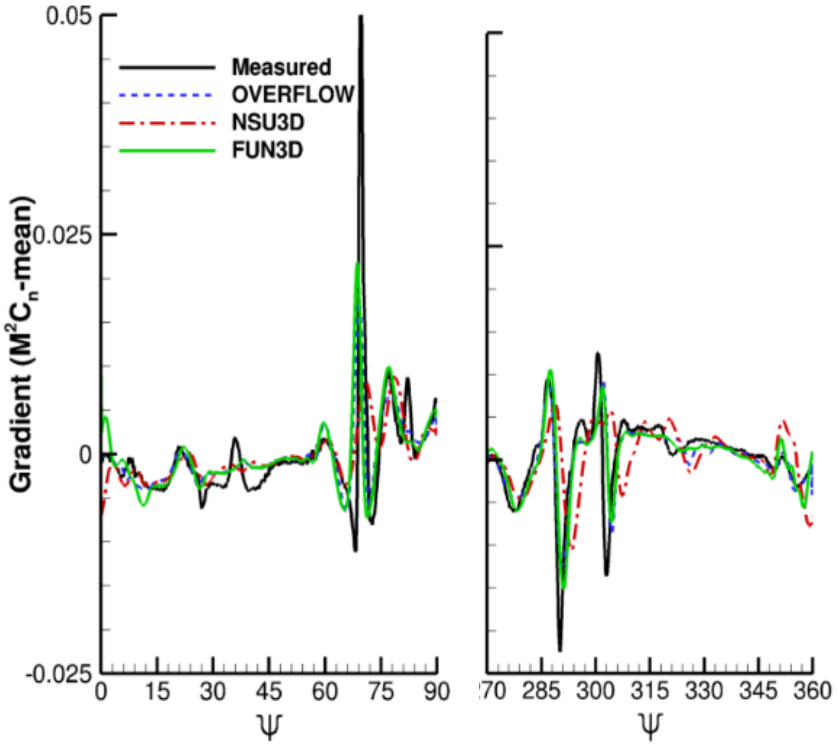


3/rev HHC pitch control input

$\Theta_{HHC} = 0.8*\cos(3\Psi+300°)$

Gradient of normal force

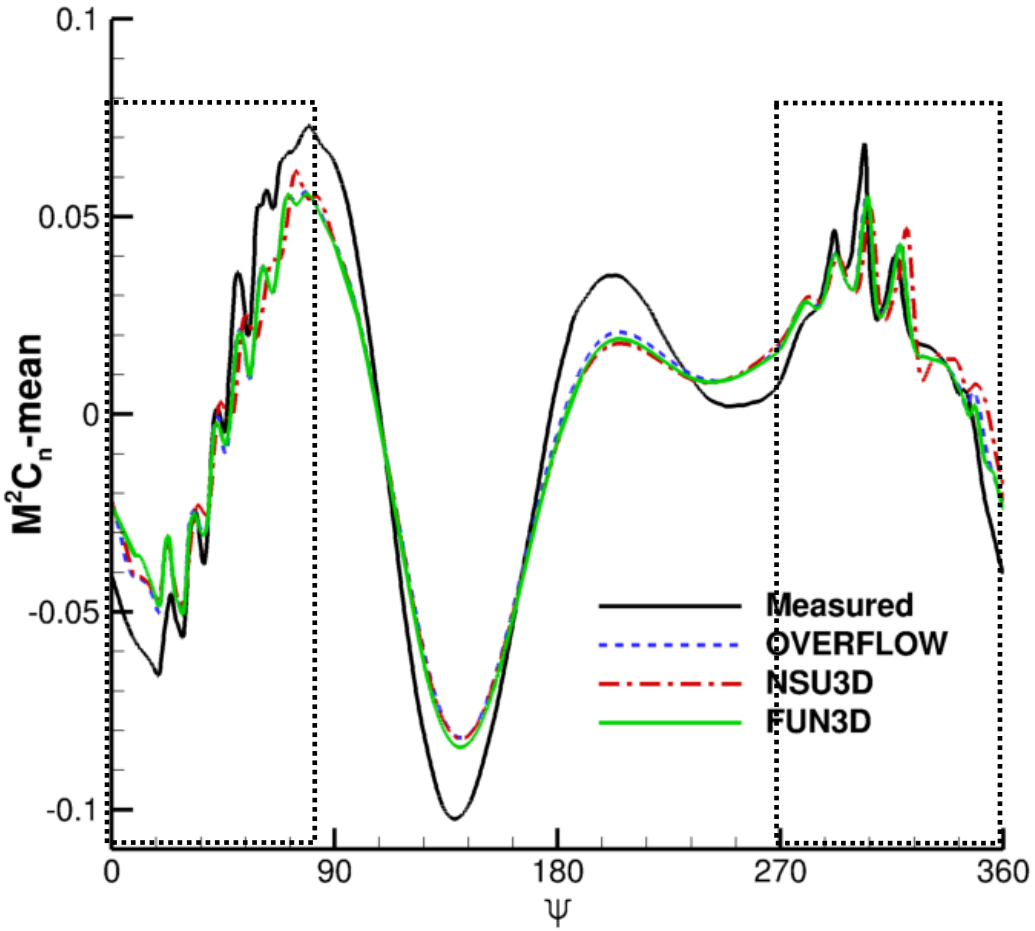
Advancing side Retreating side



- All codes agree well with the data
- BVI events captured well
- Small phase shift in NSU3D

Normal Force – Minimum Vibration

Radial station r/R = 0.87

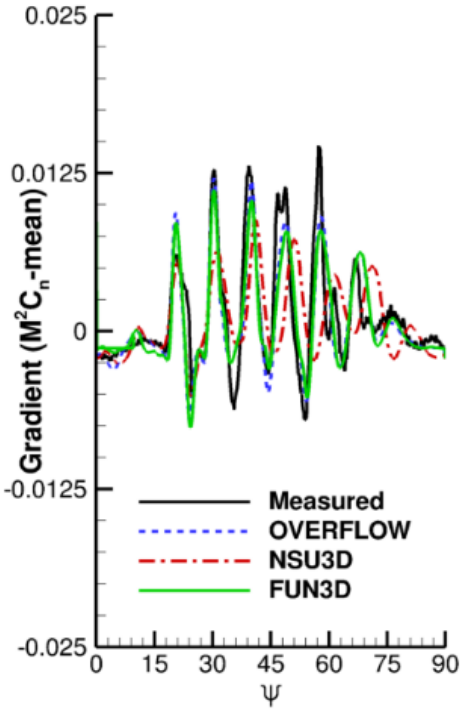


3/rev HHC pitch control input

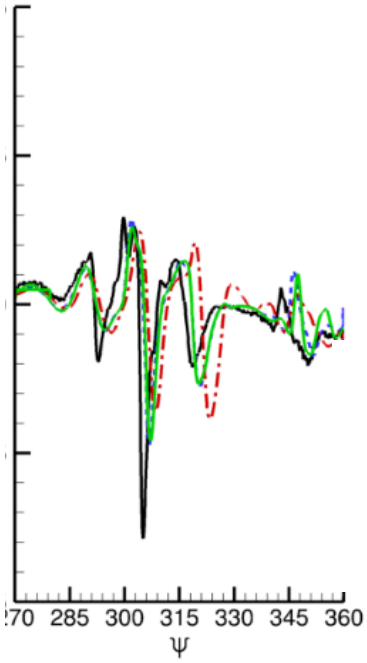
$\Theta_{HHC} = 0.8*\cos(3\Psi+180°)$

Gradient of normal force

Advancing side

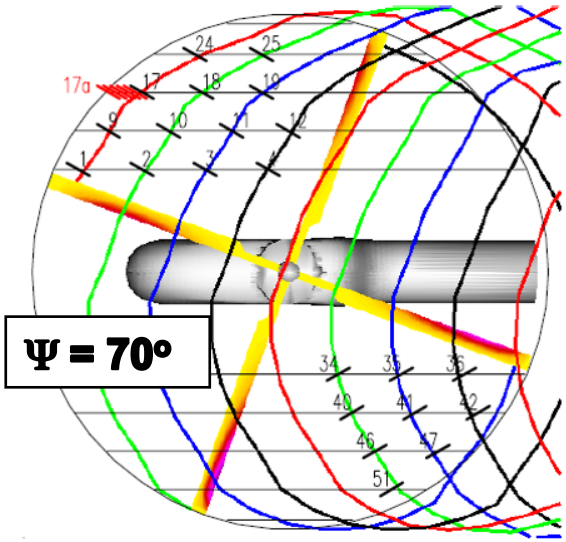


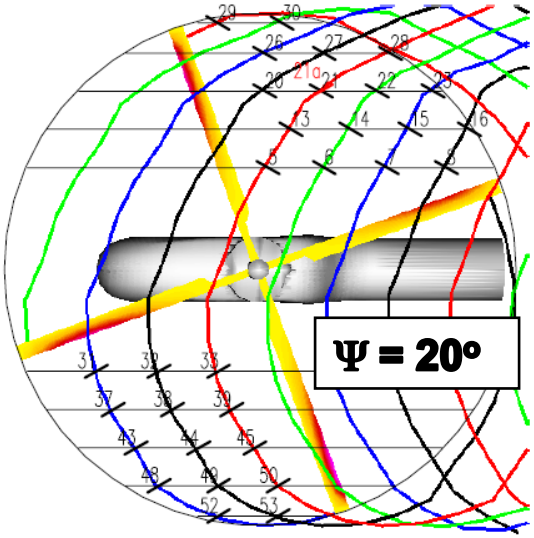
Retreating side



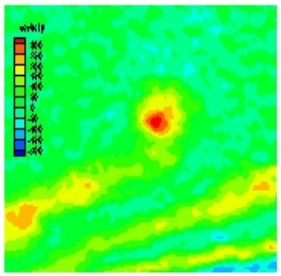
- All codes agree well with the data
- Small phase shift in NSU3D

Measured Vorticity Field
Baseline, r/R = 0.87

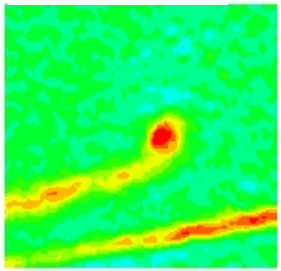




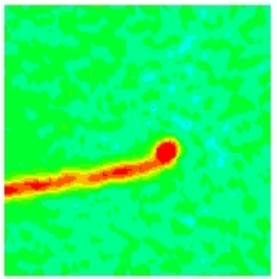
Pos 19



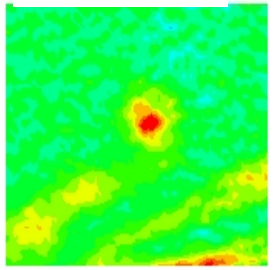
Pos 18



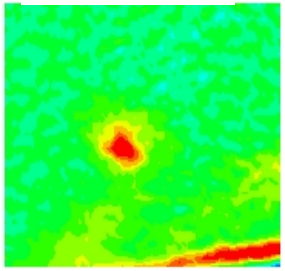
Pos 17



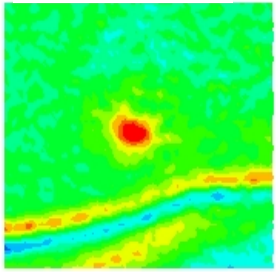
Pos 20



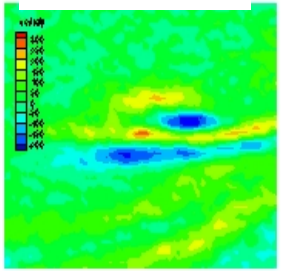
Pos 21



Pos 22

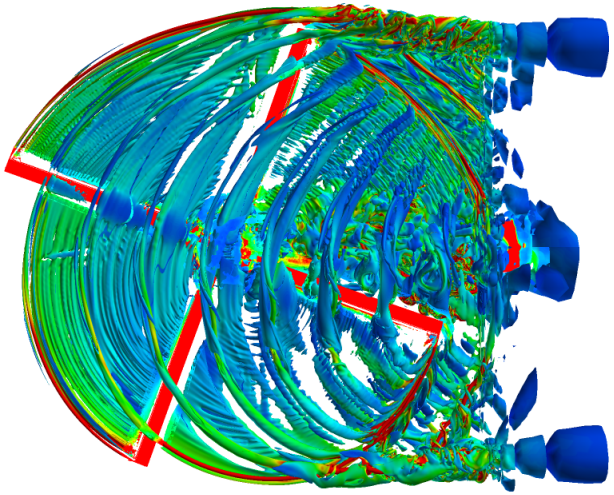


Pos 23

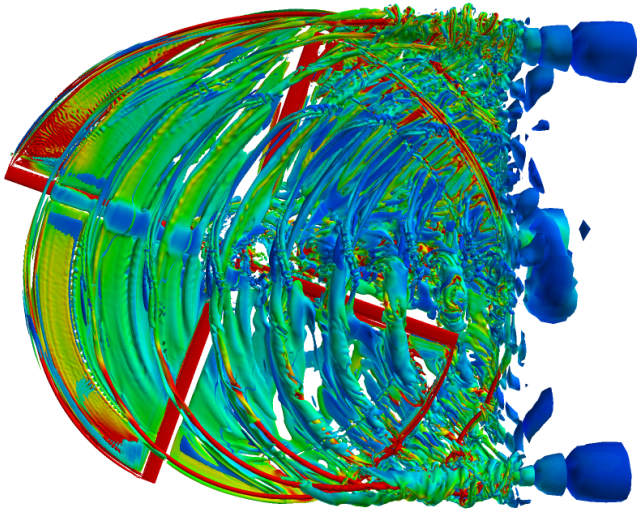


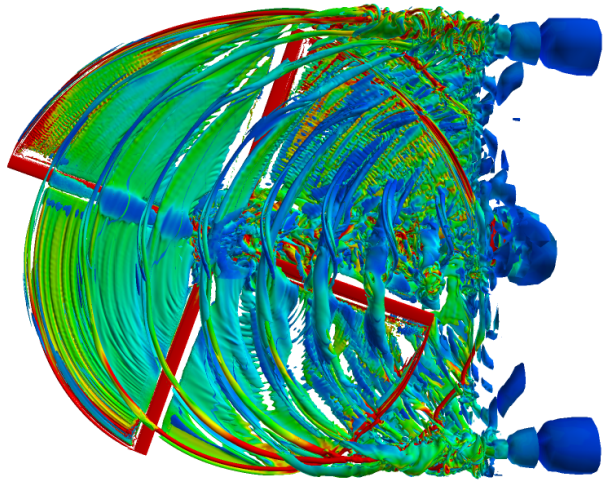
(* Unscaled PIV images)

Computed Wake Iso-surface



NSU3D





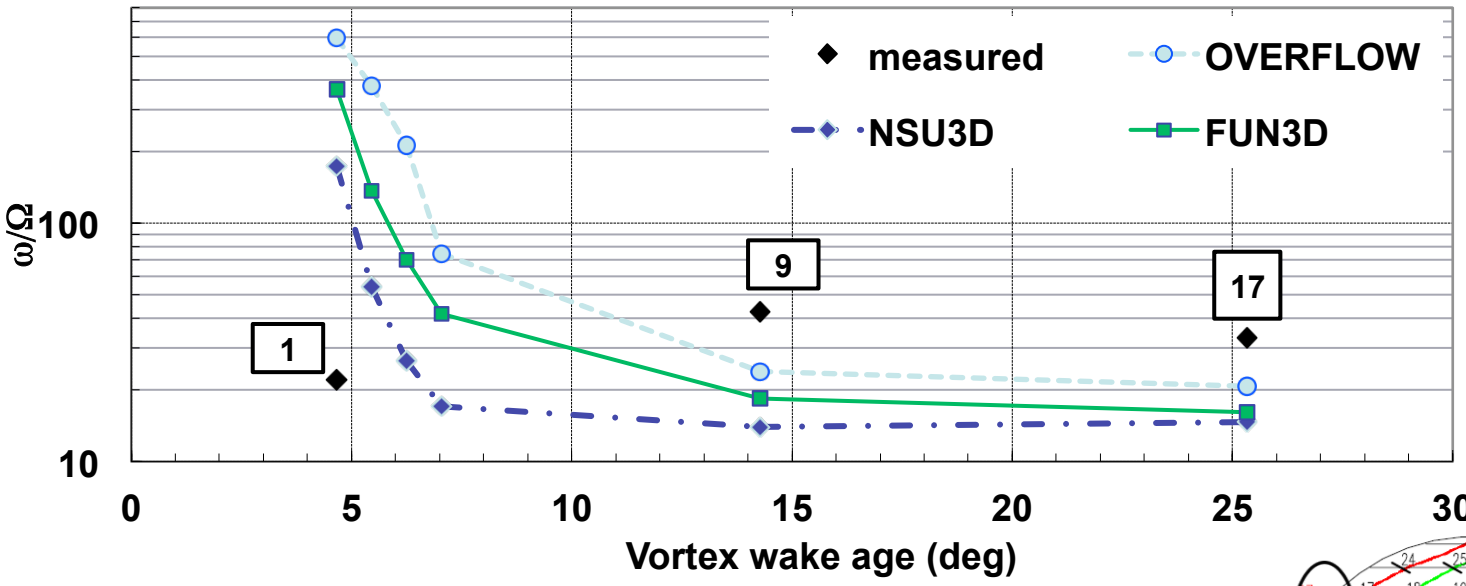
FUN3D

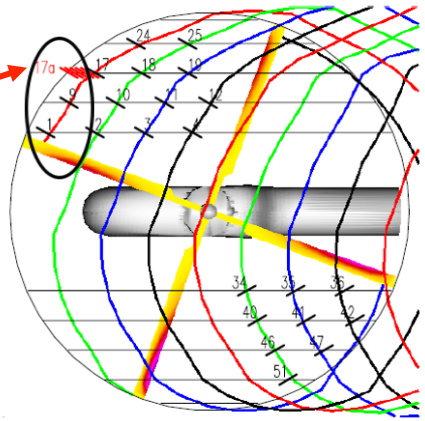
OVERFLOW

- Iso-surfaces of Q criterion colored with vorticity magnitude (Q = 1e-4)

Wake Prediction Positions 1,9,17

Near-body blade mesh | Off-body wake mesh

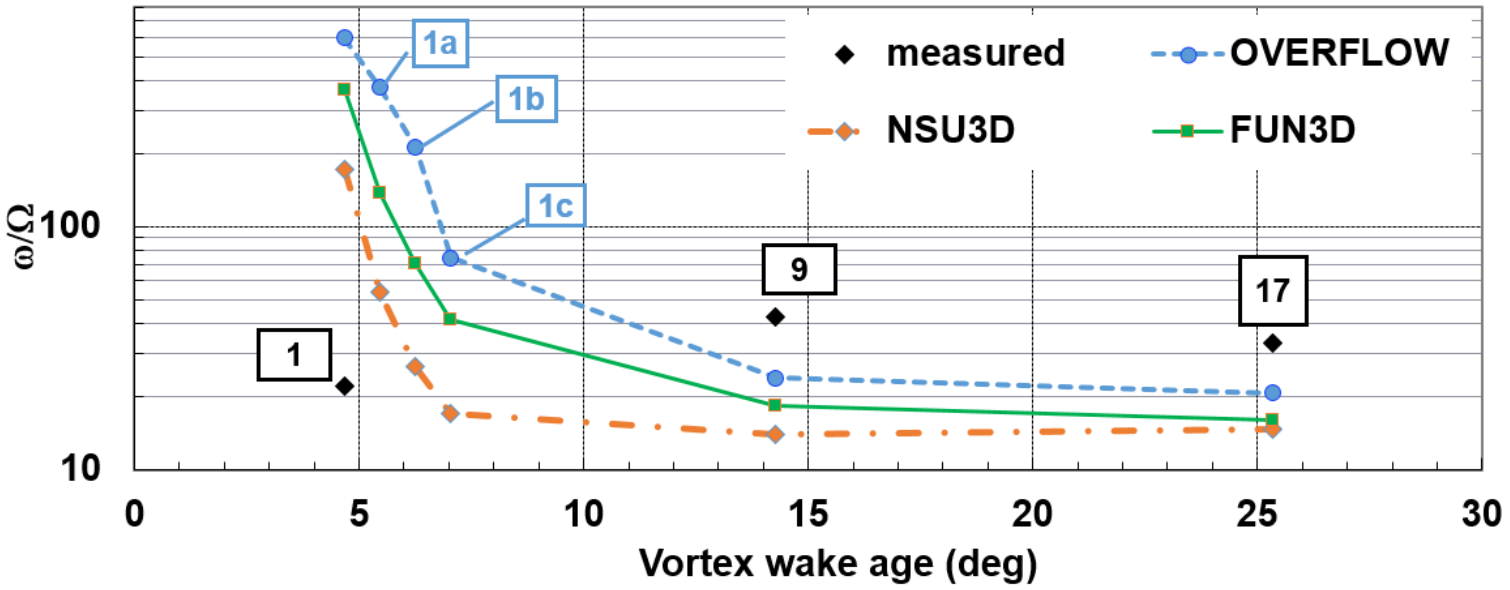




- Vortices at positions 1,9, and 17 are young vortices of high strength
- Measured peak vorticity ranges from 21 to 52
- CFD predictions show significant loss of strength from position 1 to position 9

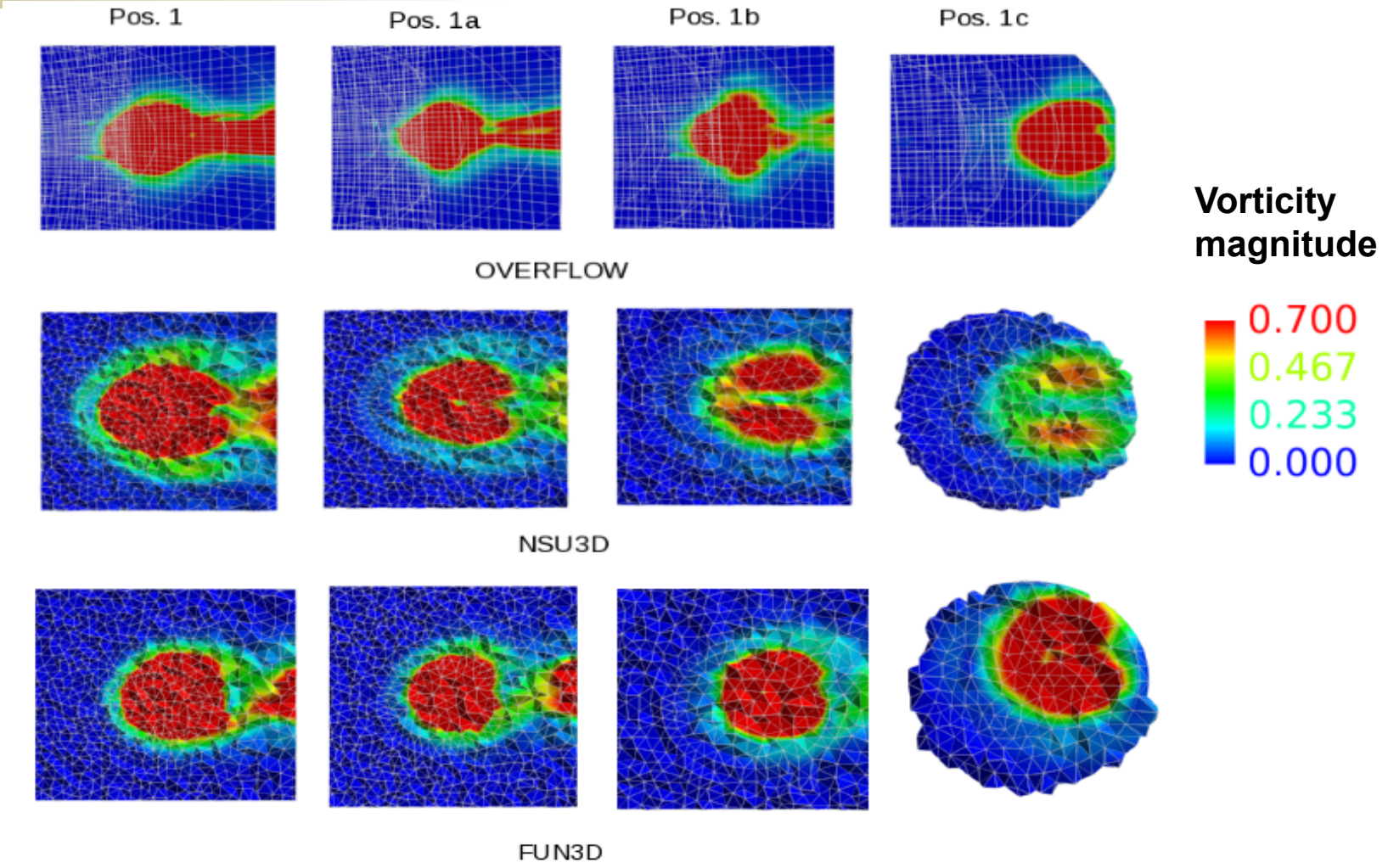
Wake Prediction Positions 1,1a,b,c

Near-body blade mesh | Off-body wake mesh



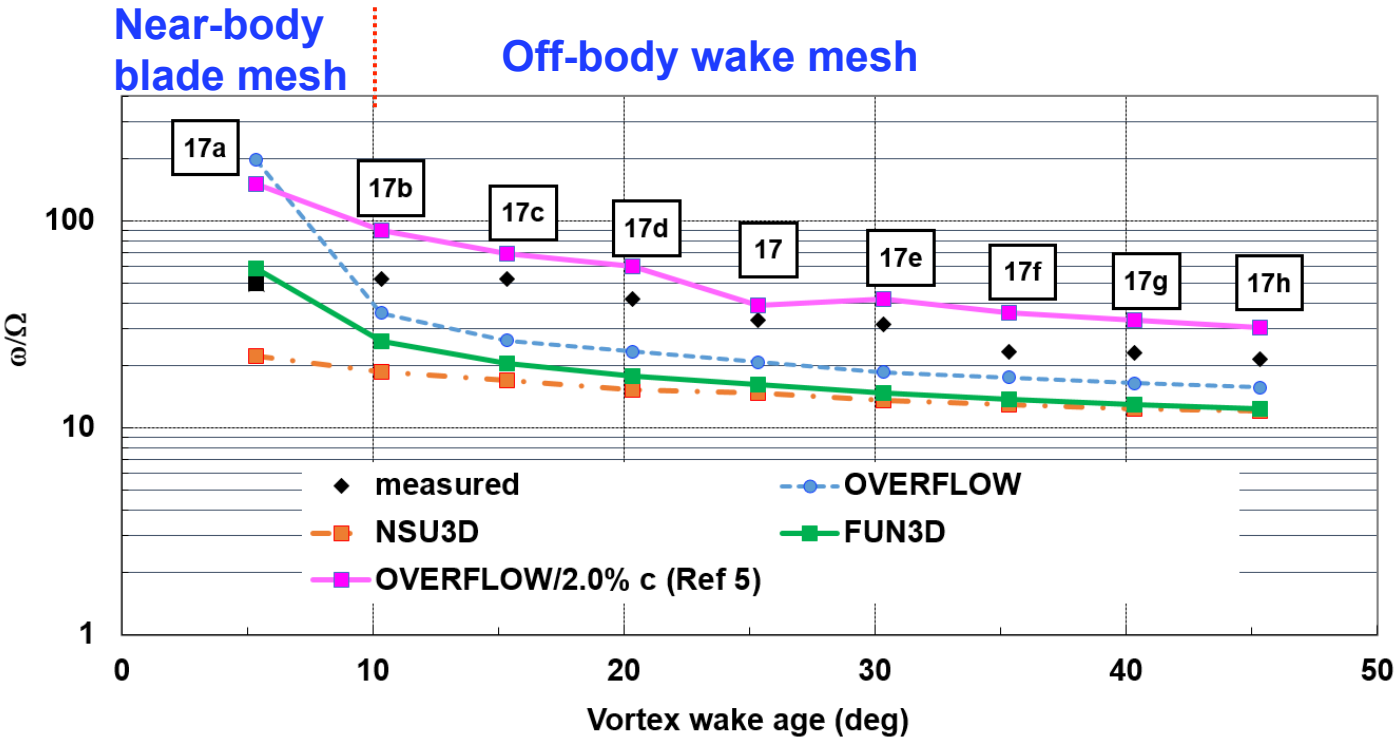
- Additional positions (1a, 1b, 1c) near position 1 considered to compare the different solvers
- OVERFLOW predicts a stronger vortex at 1c
- NSU3D prediction of vortex strength at 1c is weaker compared to FUN3D

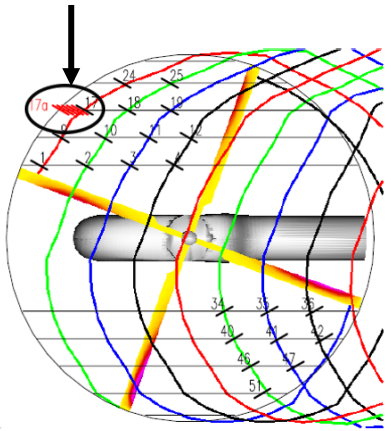
Comparison of Mesh Resolution
Positions 1a-c



- Loss of unstructured grid resolution from position 1 to 1c
- Same scale is used for all plots

Wake Prediction Positions 17a-h

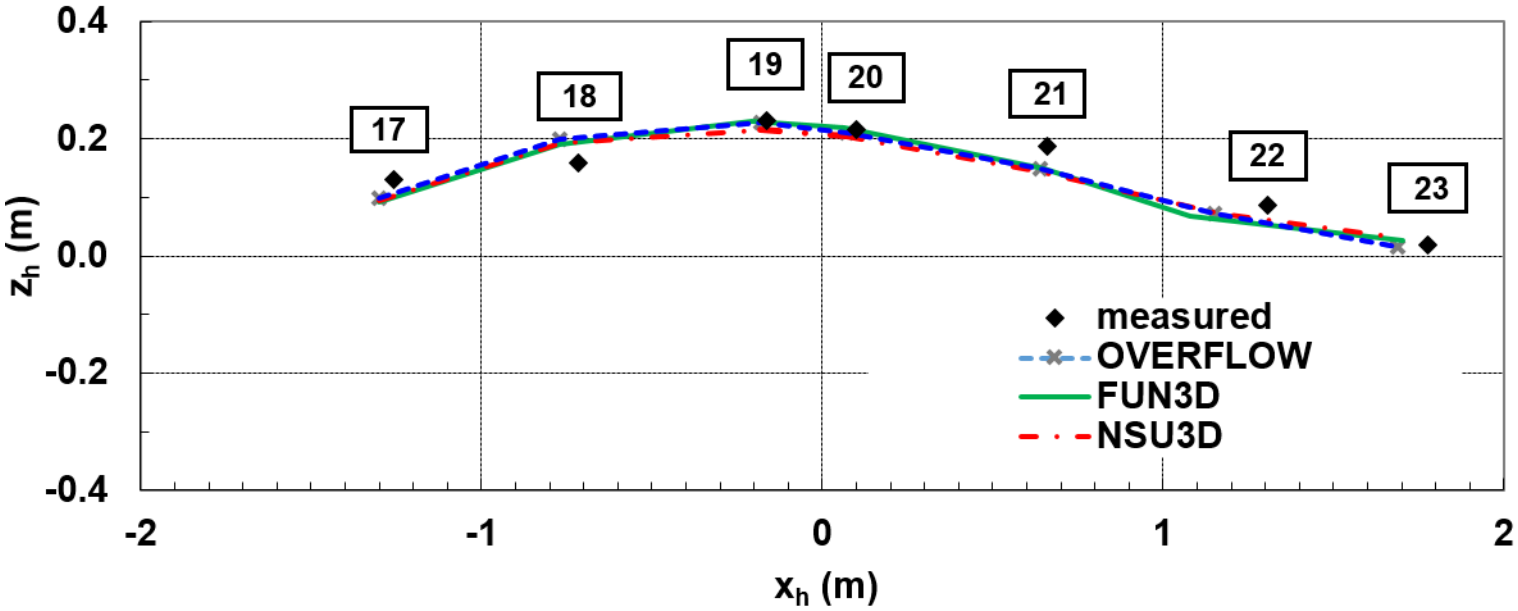




- PIV measurements taken at intervals of 5° wake age starting from 5.3°
- OVERFLOW predicts the strongest vortex at 17a
- NSU3D predicts a weaker vortex at 17a compared to FUN3D
- Finer near-body (20M) and off-body mesh (2% c) with OVERFLOW from Jain et al. significantly improves the predictions

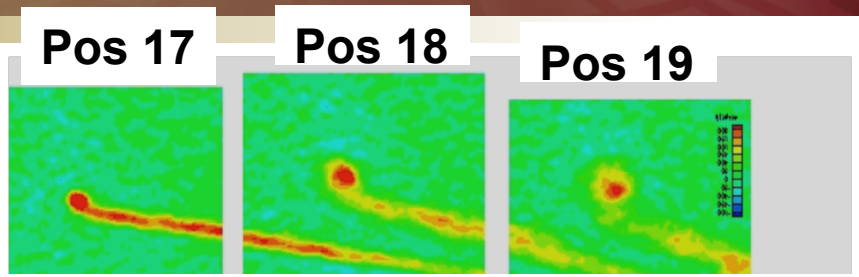
Ref: Jain et al. "Modular Multisolver Approach for Efficient High-Fidelity Simulation of the HART II rotor", J. of AHS, Vol 60, 2015, pp.1-11

Vortex Position

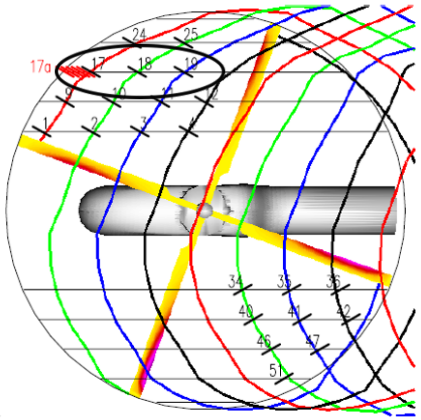


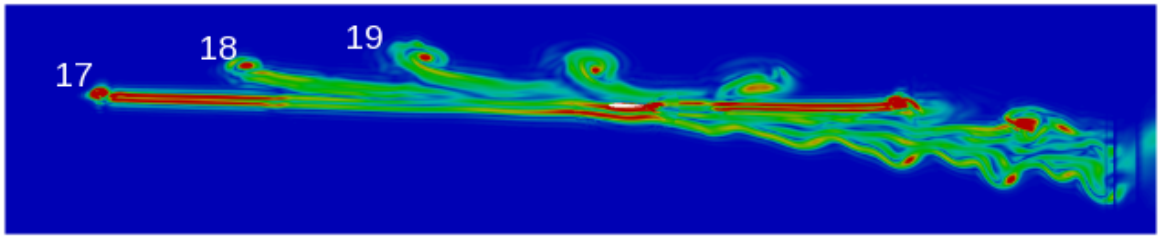
- **Vortex position is predicted well by all three solvers**

Advancing Side Predictions



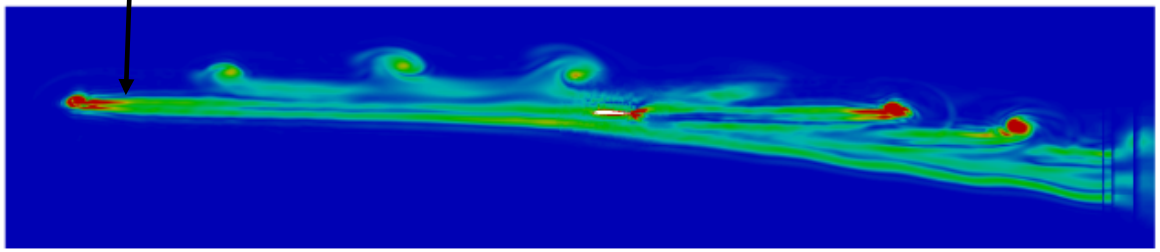
Measured data



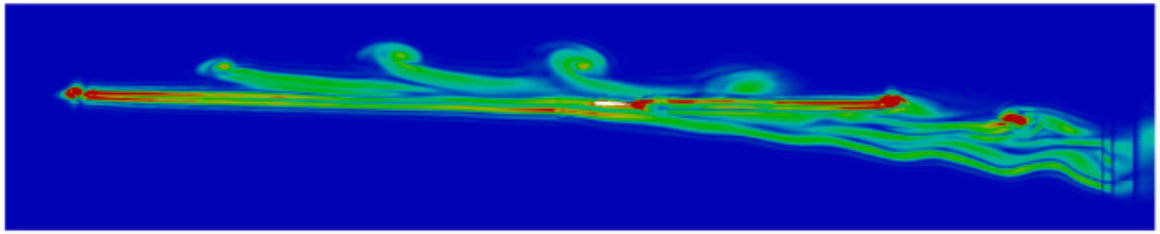


(a) **OVERFLOW**

Missing shear layer



(b) **NSU3D**

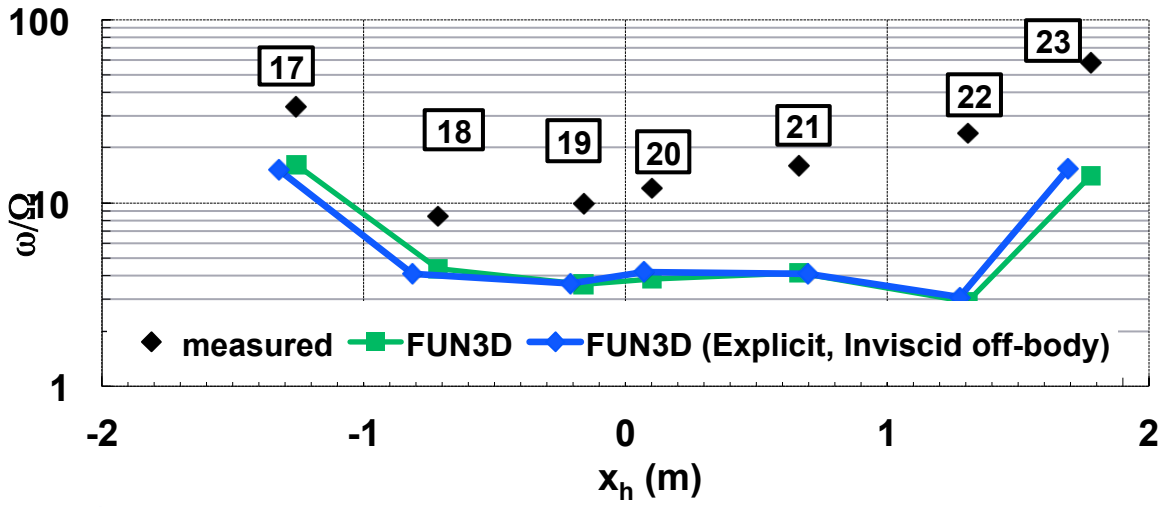


(c) **FUN3D**

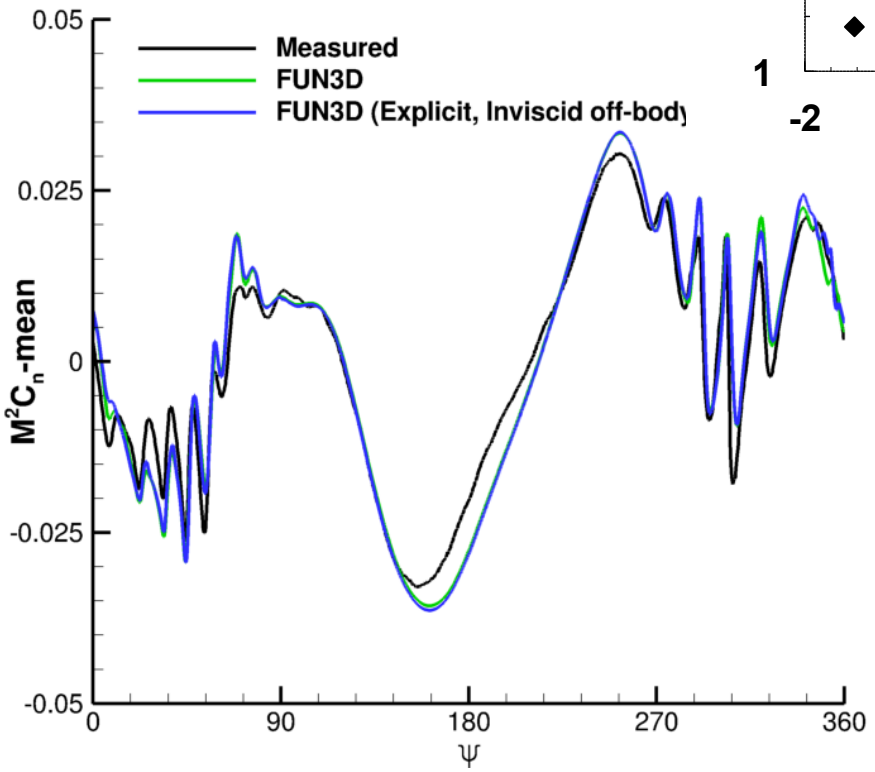
- OVERFLOW predicts the strongest vortex at 17
- NSU3D and FUN3D have diffused vortices at 18 and 19
- NSU3D missed the shear layer prediction at position 17

Implicit DES vs Explicit Inviscid Solver

Advancing side vortex strength predictions



Normal force at r/R = 0.87



- Implicit DES off-body solver is comparable to explicit Euler

Ref: Jain et al. "Modularization and Validation of FUN3D as a CREATE-AV Helios Near-body Solver", 54th AIAA SciTech Forum, San Diego, CA, January 2016

Summary

- **Presented a comparison of the three near-body solvers in Helios using HART II rotor dataset**
- **Airload Predictions**
  - Airloads for baseline, minimum noise, and minimum vibration cases are predicted well by all three solvers
  - Sharper BVI peaks are better resolved by OVERFLOW
  - FUN3D predictions are closer to OVERFLOW for all three cases
  - NSU3D shows a slight phase shift in BVI predictions
- **Wake Predictions**
  - OVERFLOW predictions of peak vorticity are in closest agreement with measured data
  - FUN3D predicts stronger peak vortex in the near-body region compared to NSU3D
  - Implicit off-body with DES comparable to explicit Euler off-body
- **Future work will use Strand solver for near-body**

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CREATE
Computational Research & Engineering Acquisition Tools & Environments

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