
LABORATORY

3rd EAWE PhD SEMINAR
CENER - IRUÑA

A CFD Method for Detailed Aerodynamic Analysis of HAWT

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Sponsored by cener centro nacional de energías renovables FUNDACIÓN CENER CIEMAT

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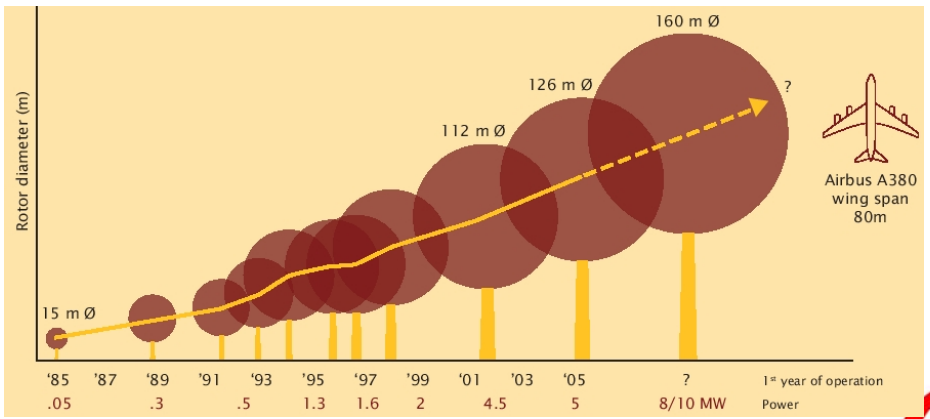
Background

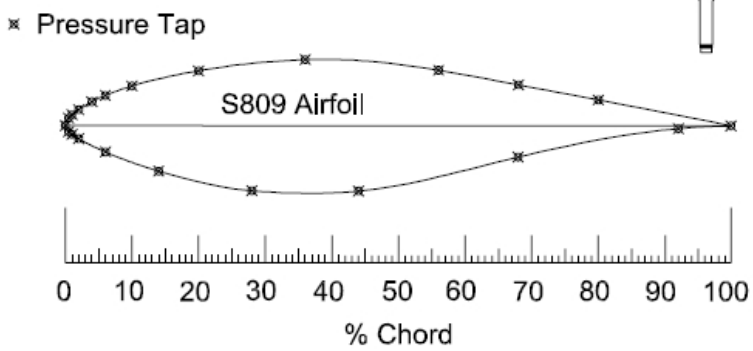
- The design of large-diameter wind turbines is outside the knowledge envelope of wind turbine manufacturers (Larger diameters wind turbines)
  - Flow compressibility
  - Stalled flow
  - Aerodynamic Noise
- CFD base WT design
- The objectives are to take into account compressibility effects, aeroelastic influence and to analyze the computation of full HAWT

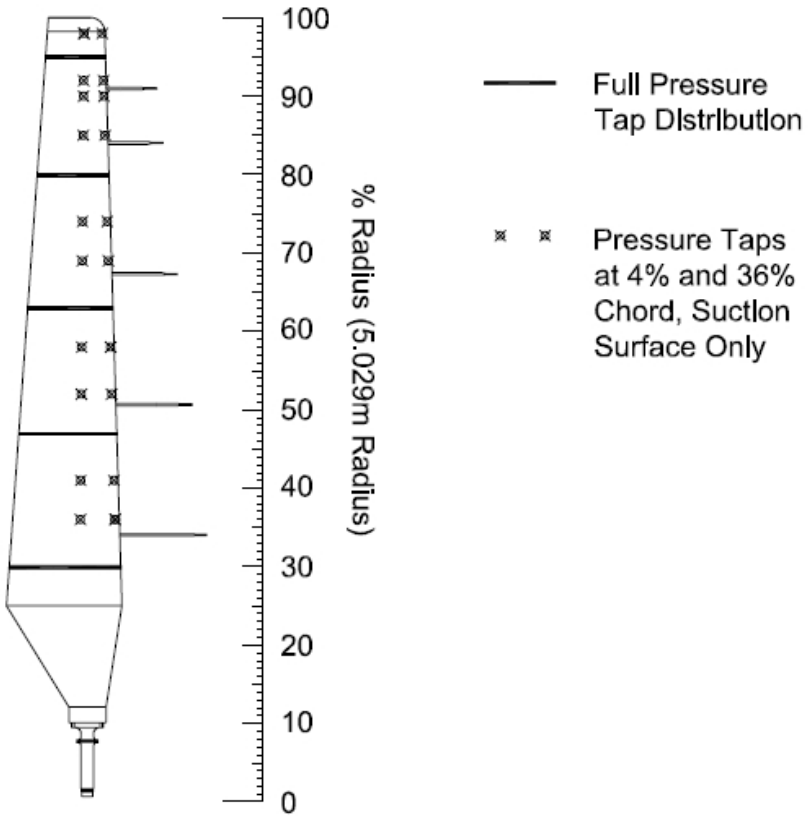


Picture from EWEA:
http://ec.europa.eu/research/energy/nn/nn_pu/renews/005/article_4133_en.htm

Data for CFD Validation

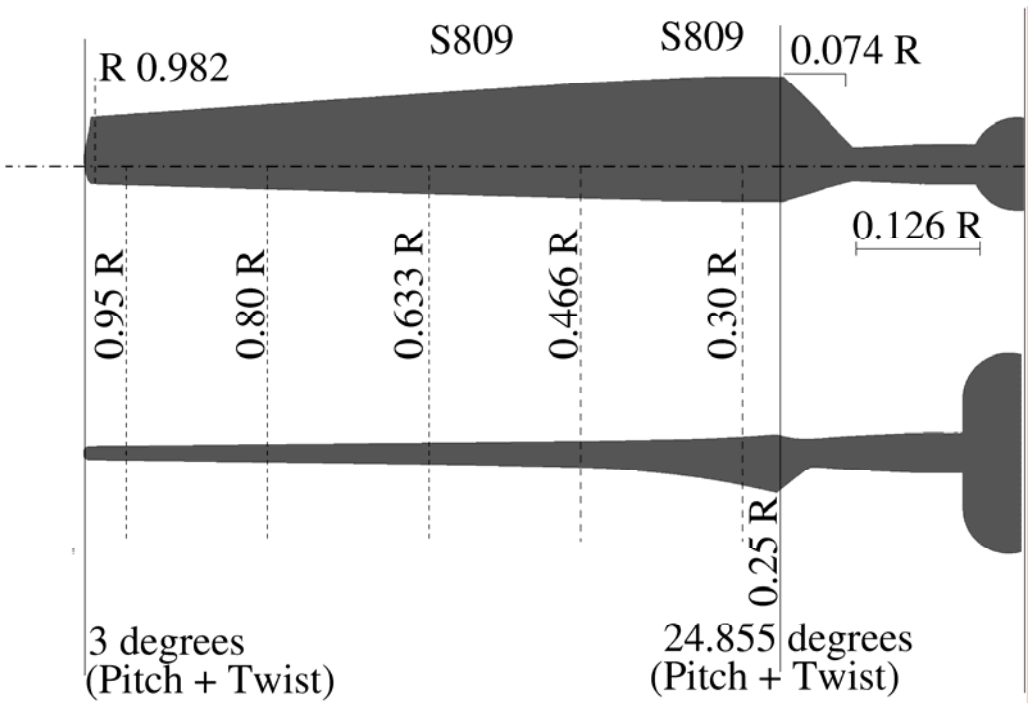
- NASA Ames wind tunnel 24.4 m x 36.6 m test section
- Two bladed upwind wind turbine, with S809 aerofoil after the 25% of the span
- Test instrumentation (INPUT)
  - 22 Pressure taps each at 5 span-wise sections
  - Wind tunnel's dynamic, static and total pressures, density, temperature, velocity,...



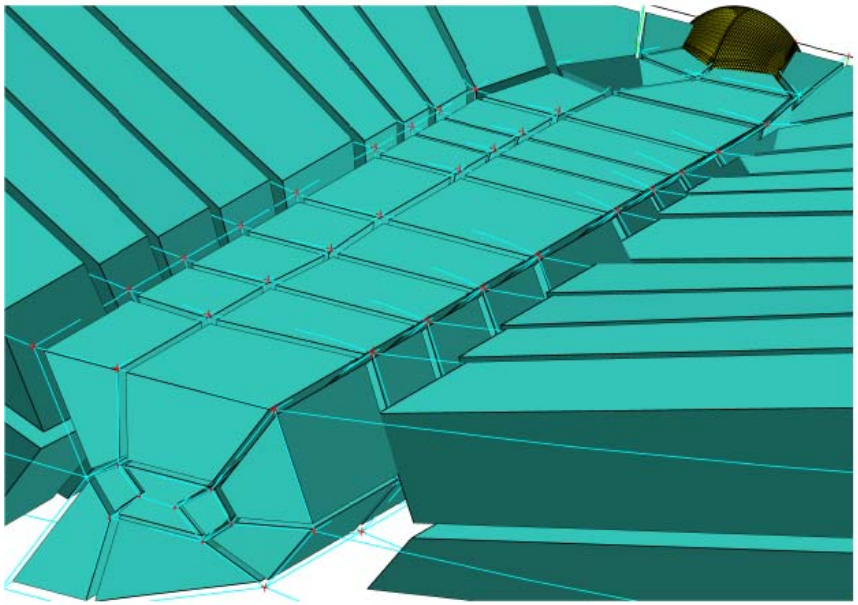


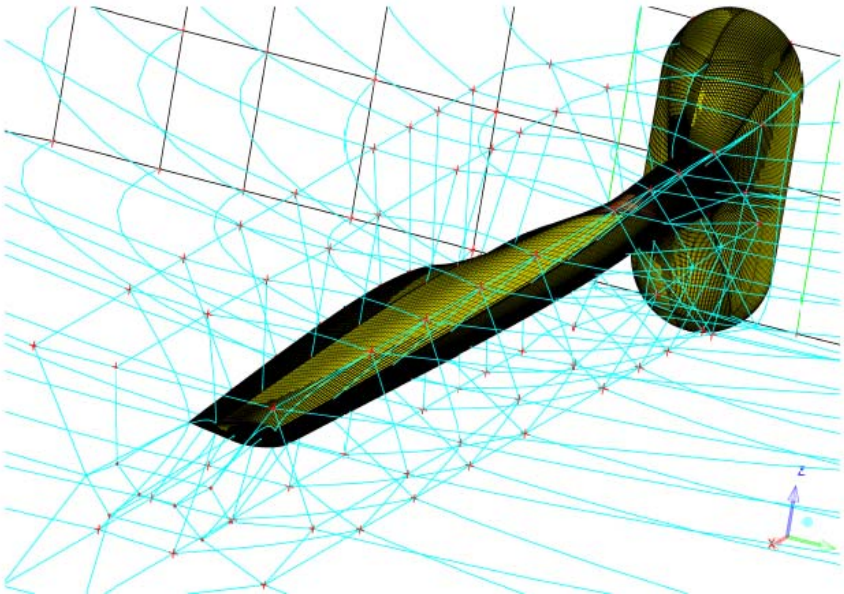
Images taken from M.M. Hand et al. Unsteady Aerodynamics Experiment Phase VI: Wind Tunnel Test Configurations and Available Data Campaigns, T.R. NREL/TP-500-29955, NREL, December 2001.

Geometry and Blocking



Case 4: Geometry used for validation





Multi-block topology

Sensitivity of the CFD Results: Grid and Geometry

- Different grid sizes were analyzed (from 1.3 mill. to 4.6 mill.)
  - The majority of the results were obtained for 3.4 million grid
- Effect of far-field location was analyzed
  - From 2 blade radii inflow, 4 R outflow and 4 R far-field
  - From 4 blade radii inflow, 8 R outflow and 8 R far-field
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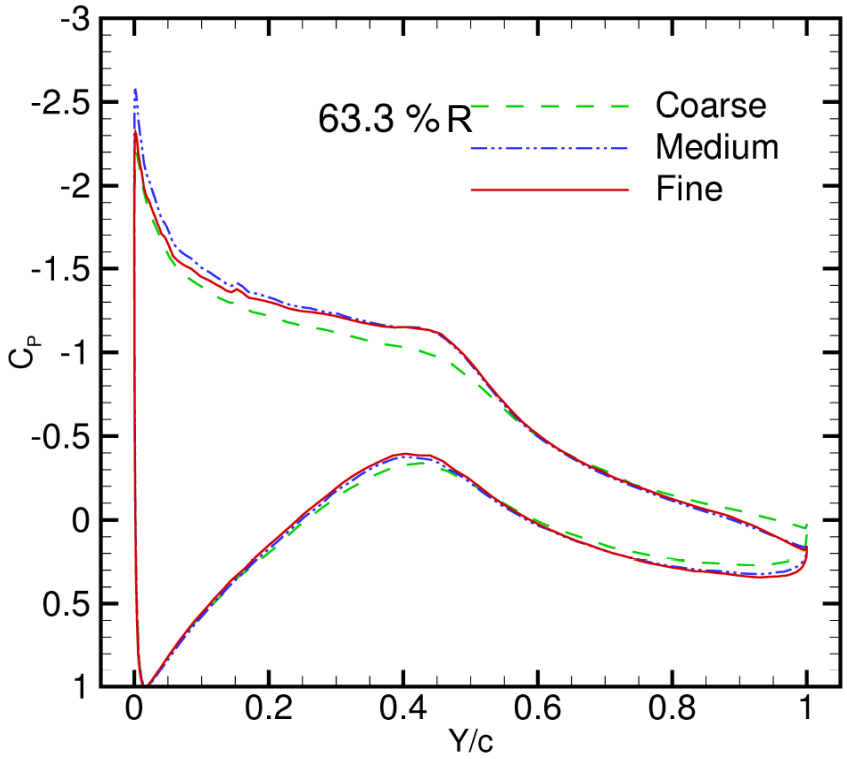
Grid Convergence

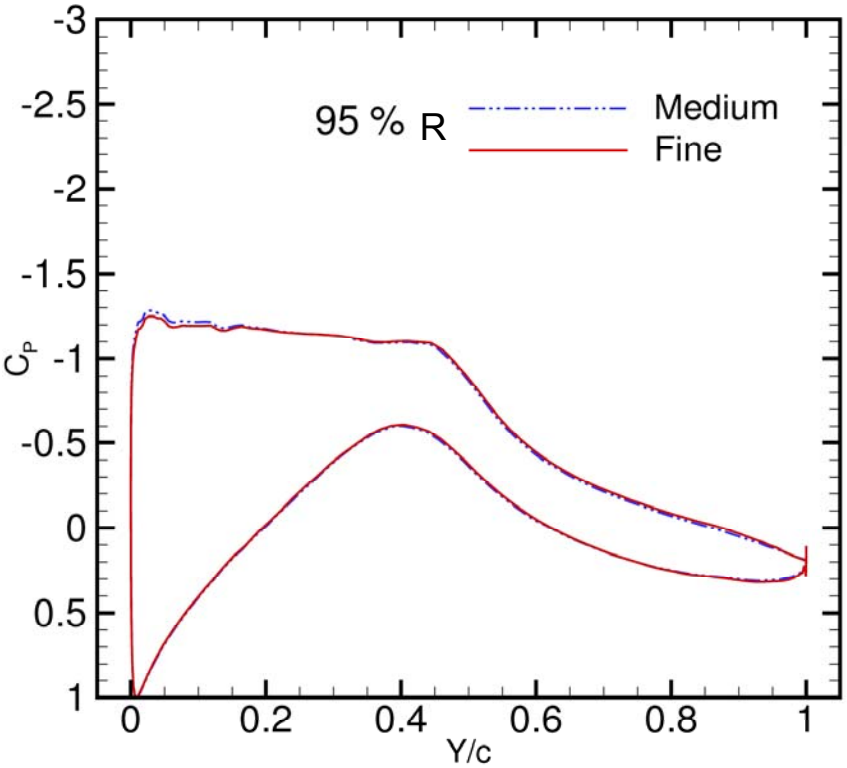
GRID SIZE

Coarse:
1.3 mill.

Medium:
3.4 mill.

Fine:
4.6 mill.





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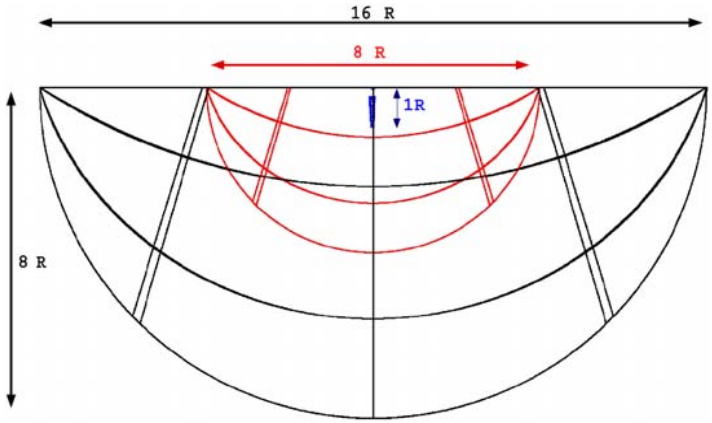
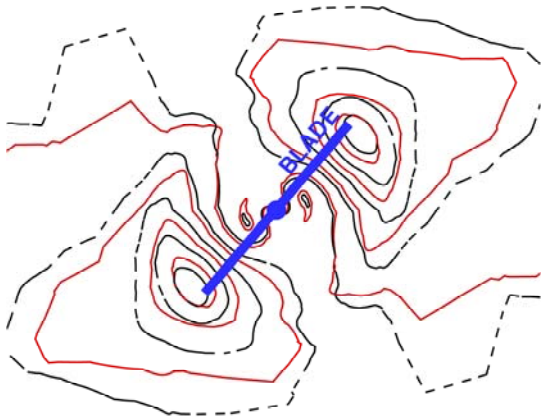
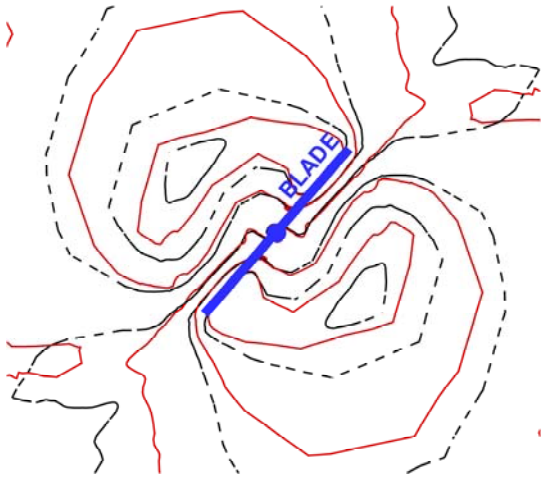
Effect of Domain: Far-field

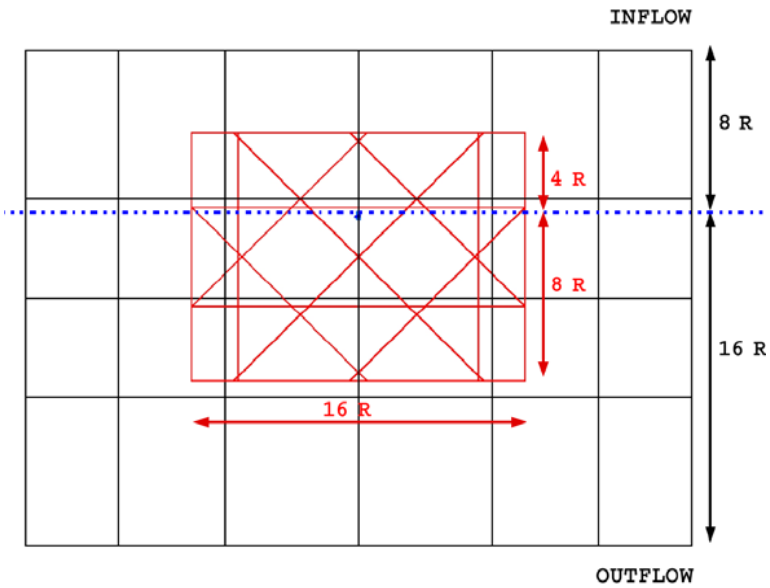


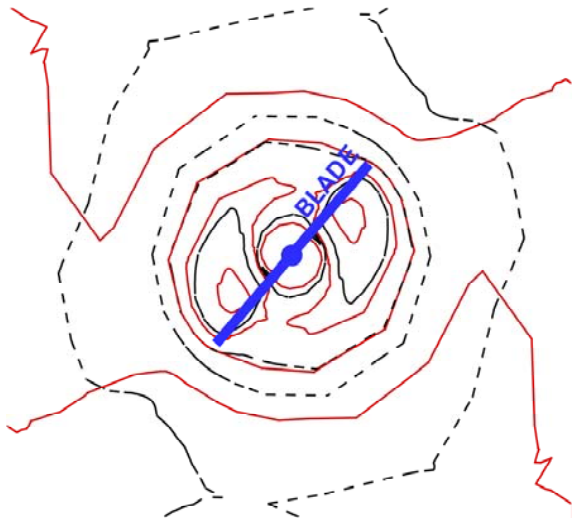


U velocity component

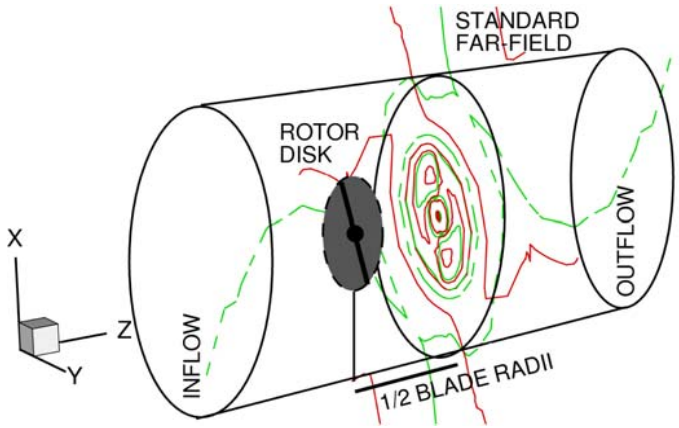


V velocity component





W velocity component



The contours are taken half radii downwind wind turbine

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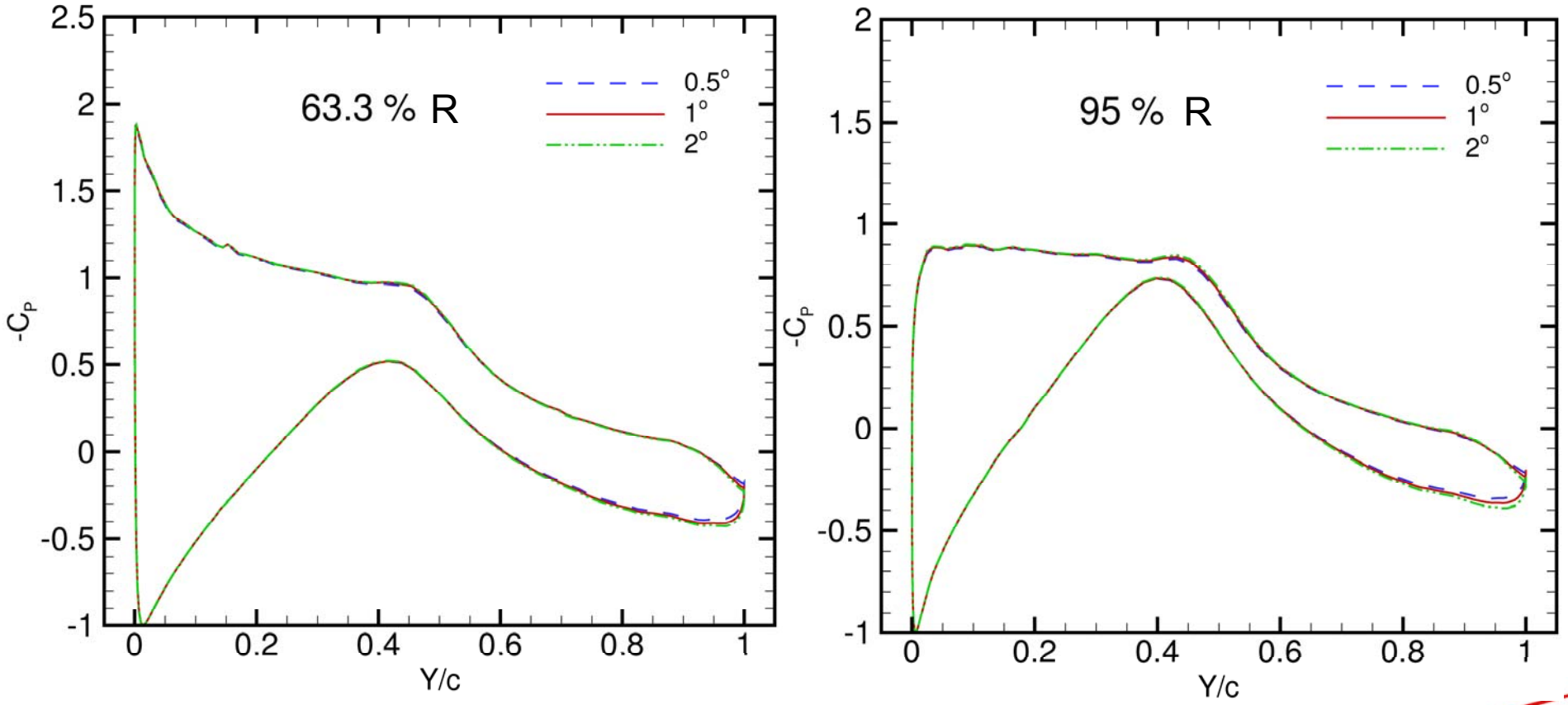
Effect of Time Step Convergence

Variation in azimuth per time step.



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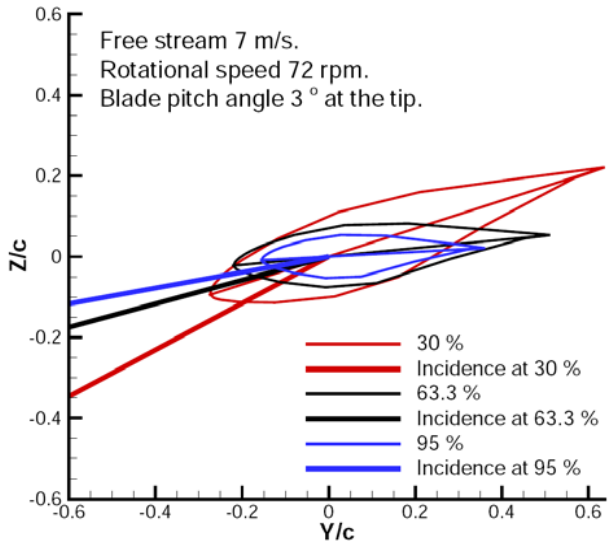
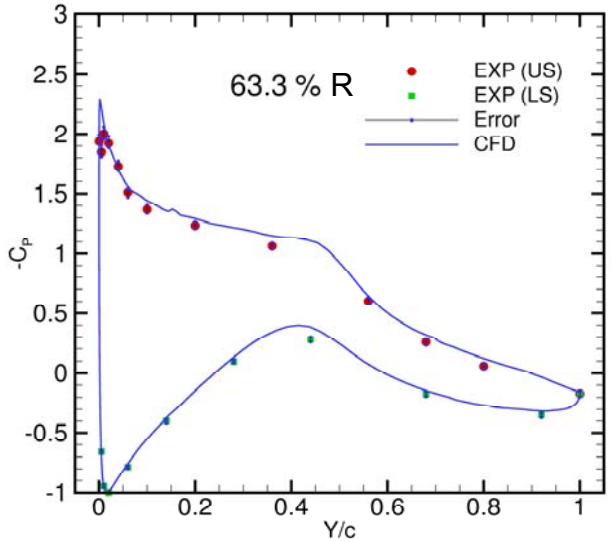
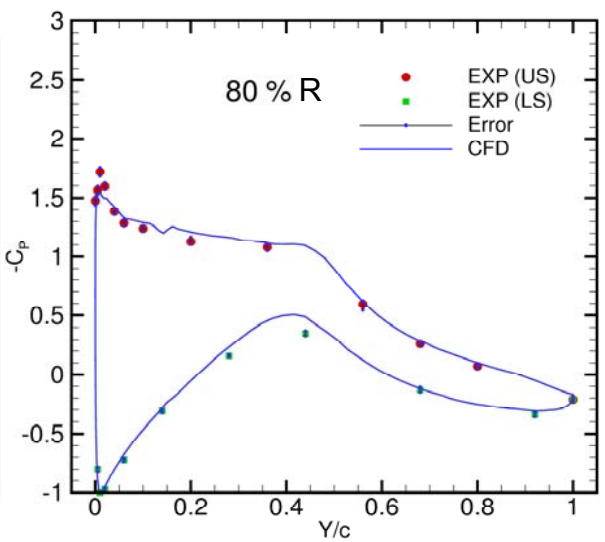
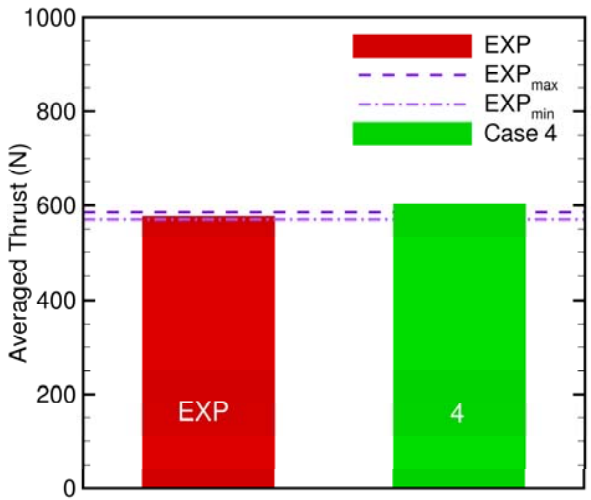
7 m/s Wind: Working Conditions

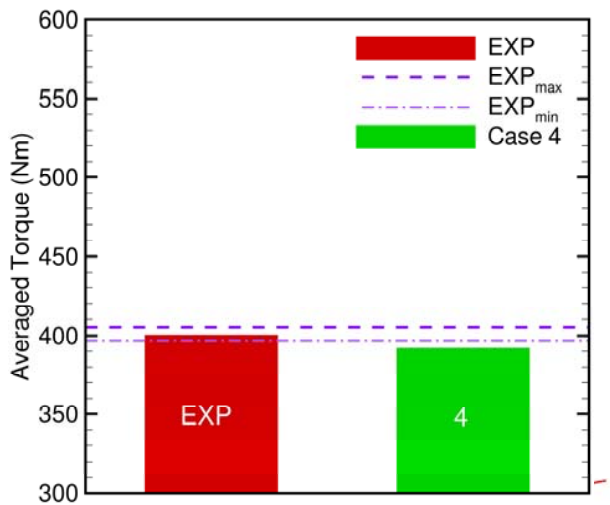
- Assumptions:
  - No tower.
  - Steady and attached flow.
  - 3 full rotations.
- Grid and CFD computation:
  - 3.4 mill. cells.
  - κ-ω turbulence model







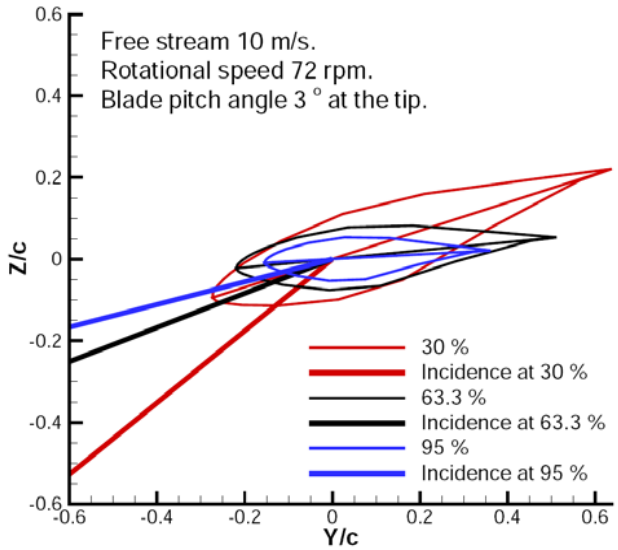


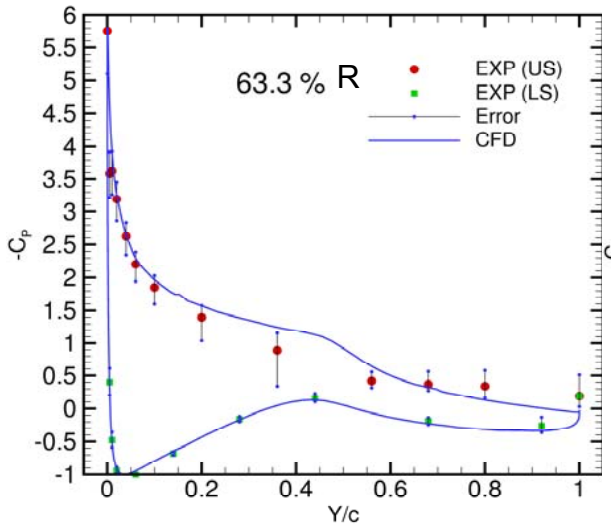


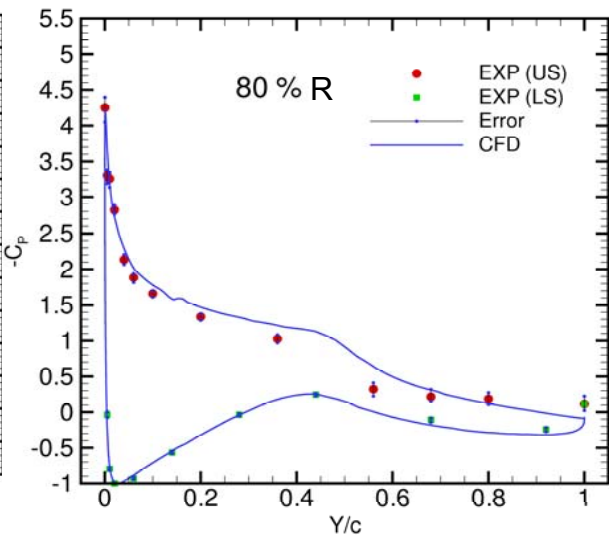
Run number: S0700000

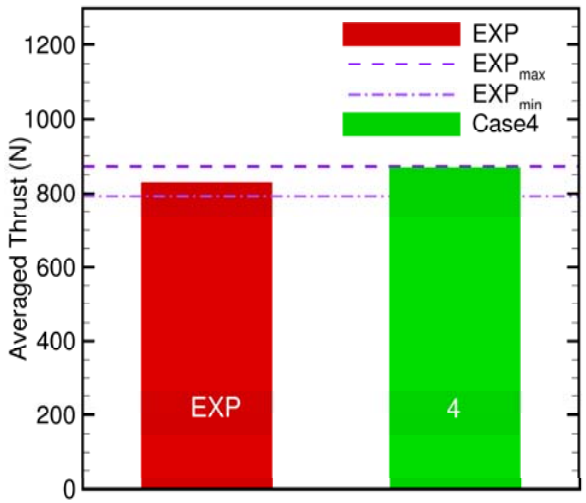
10 m/s Wind: Stalled Flow

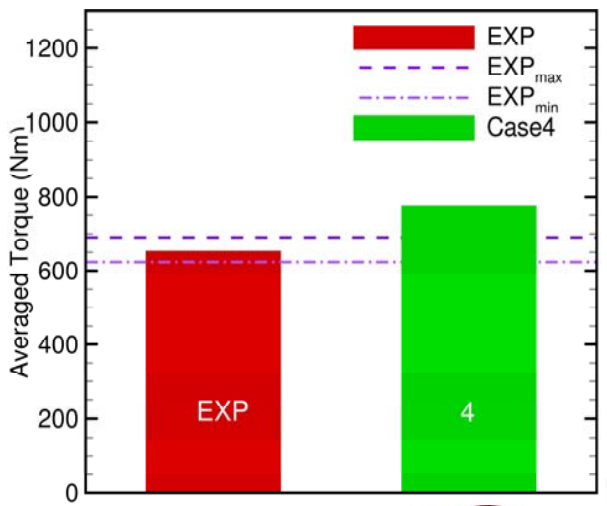
- Assumptions:
  - No tower.
  - Attached and de-attached flow.
  - 3 full rotations.
- Grid and CFD computation:
  - 3.4 mill. cells.
  - κ-ω turbulence model







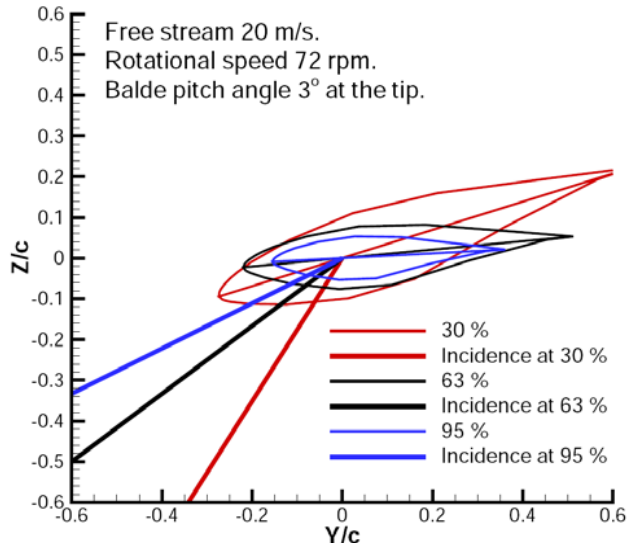


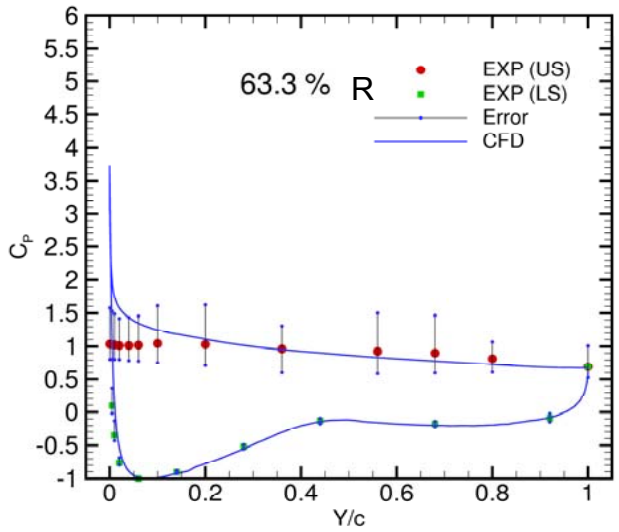


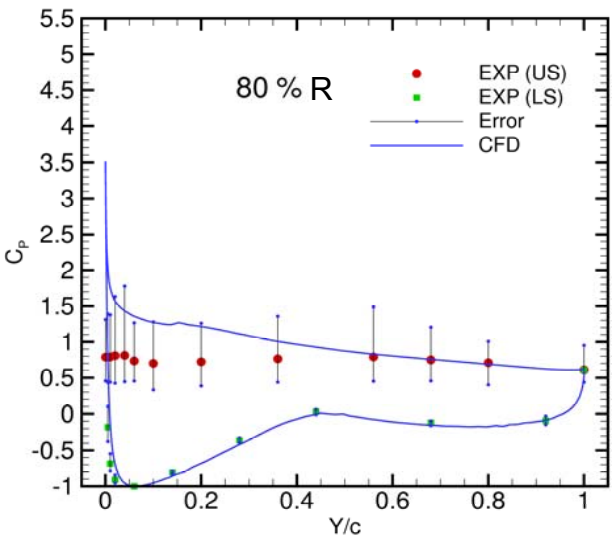
Run number: S1000000

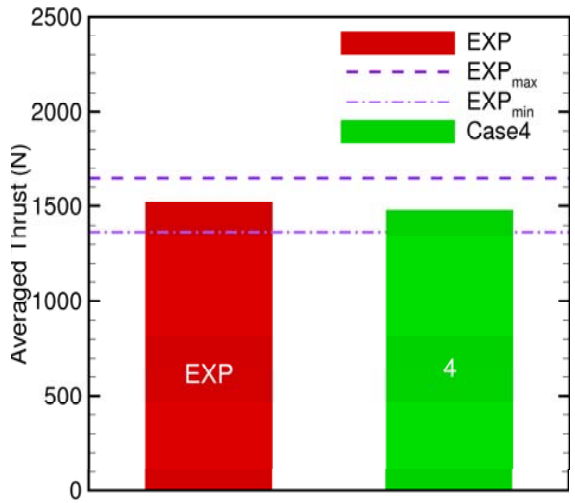
20 m/s Wind: Deep Stalled Flow

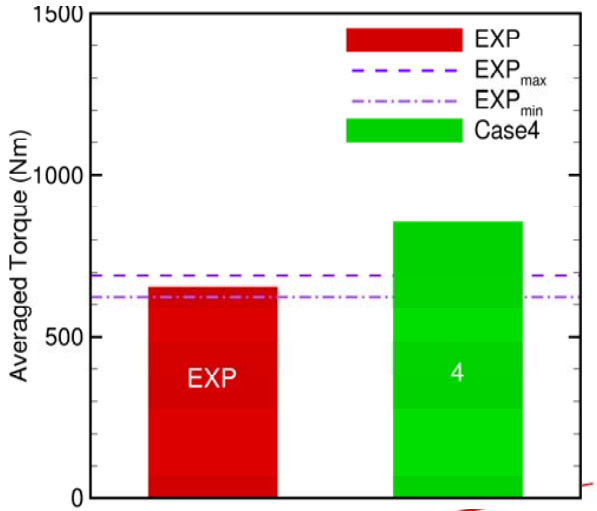
- Assumptions:
  - No tower.
  - De-attached flow.
  - 3 full rotations.
- Grid and CFD computation:
  - 6.4 mill. cells.
  - κ-ω turbulence model











Run number: S2000000

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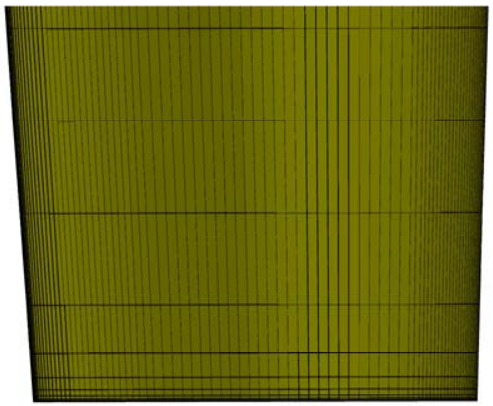
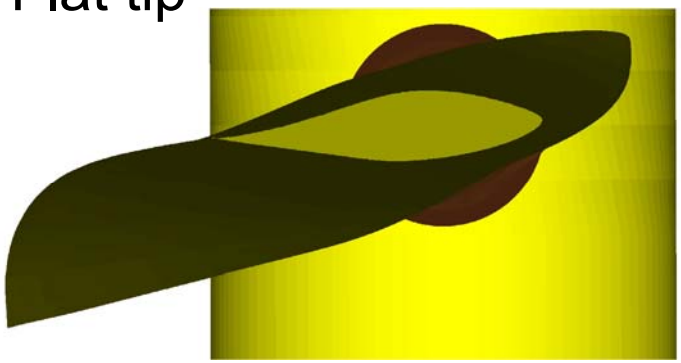
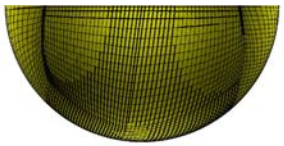
Sensitivity of CFD Results

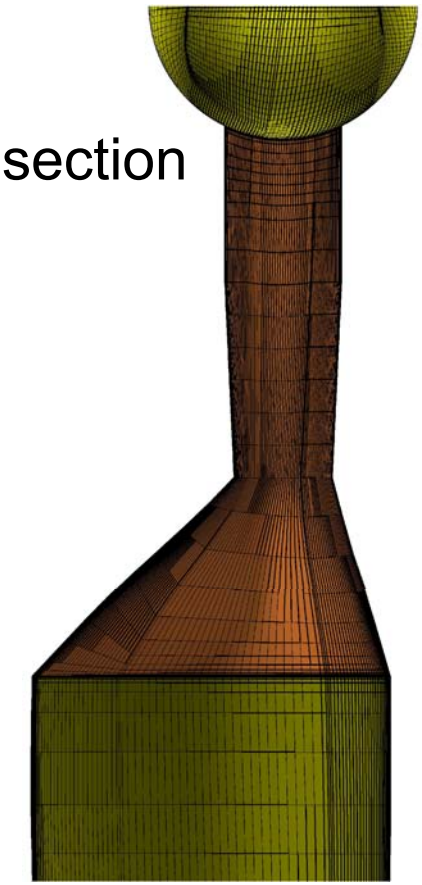
Flat tip

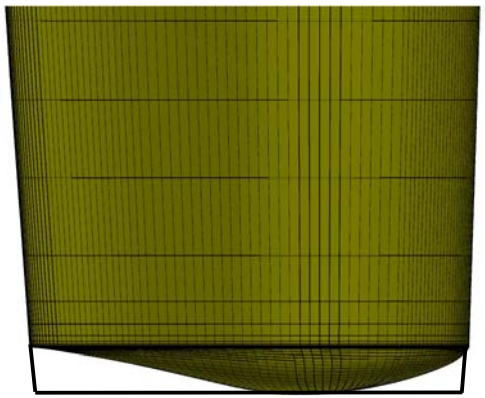


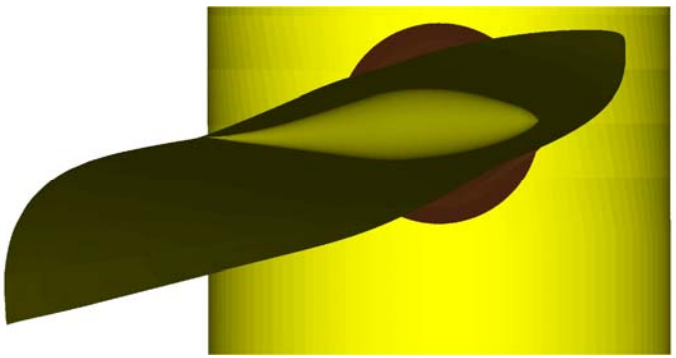


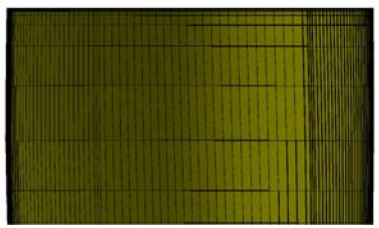


Root section

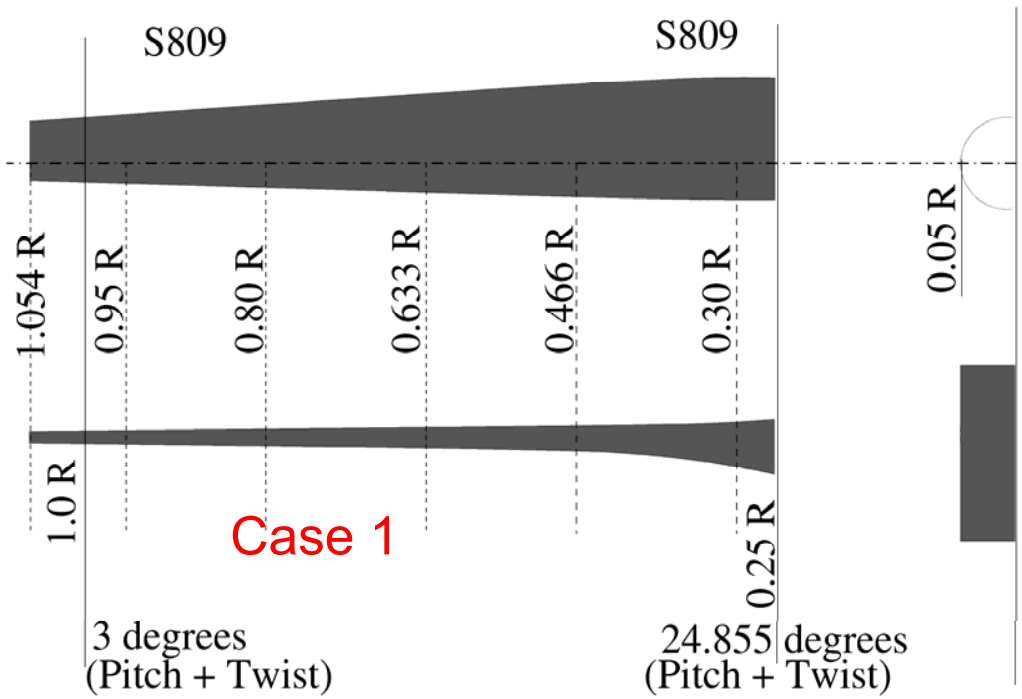


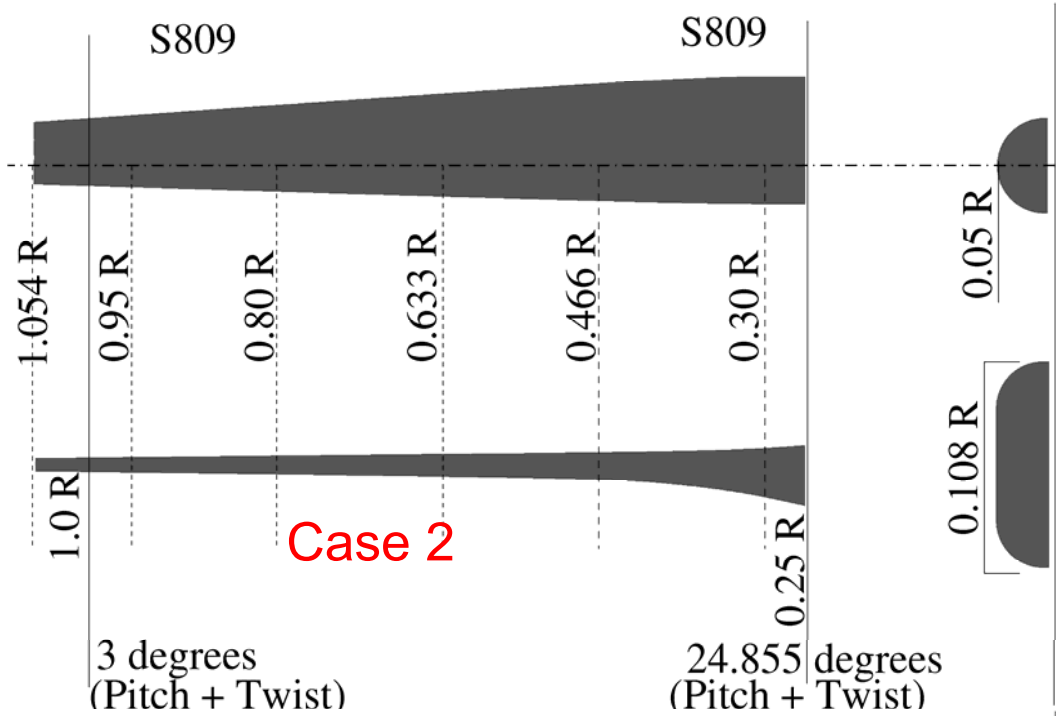


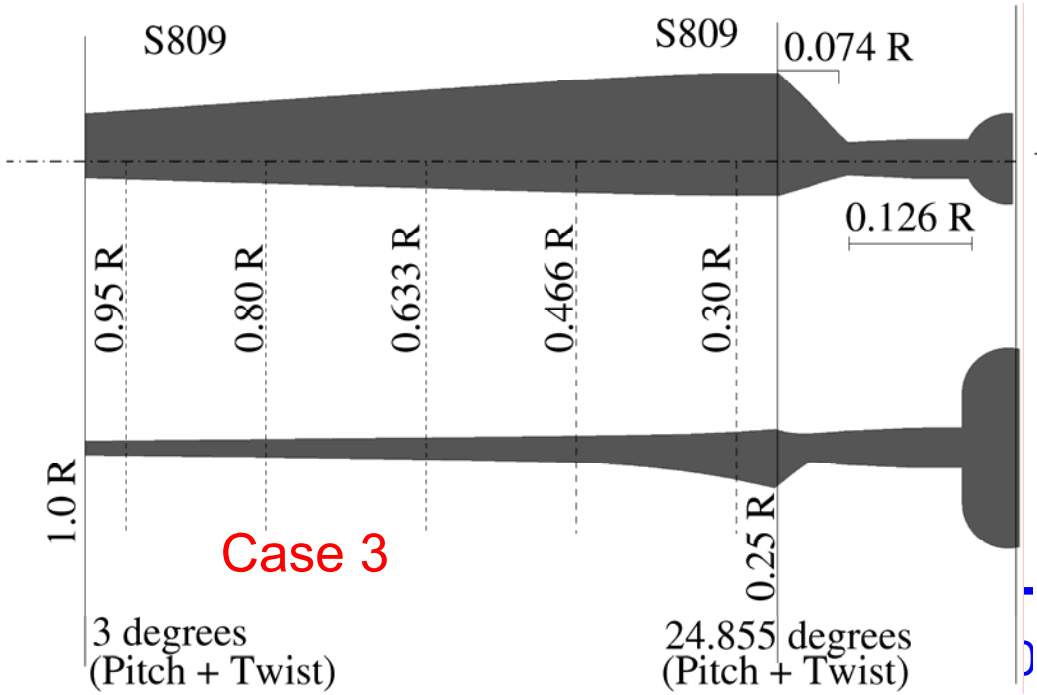


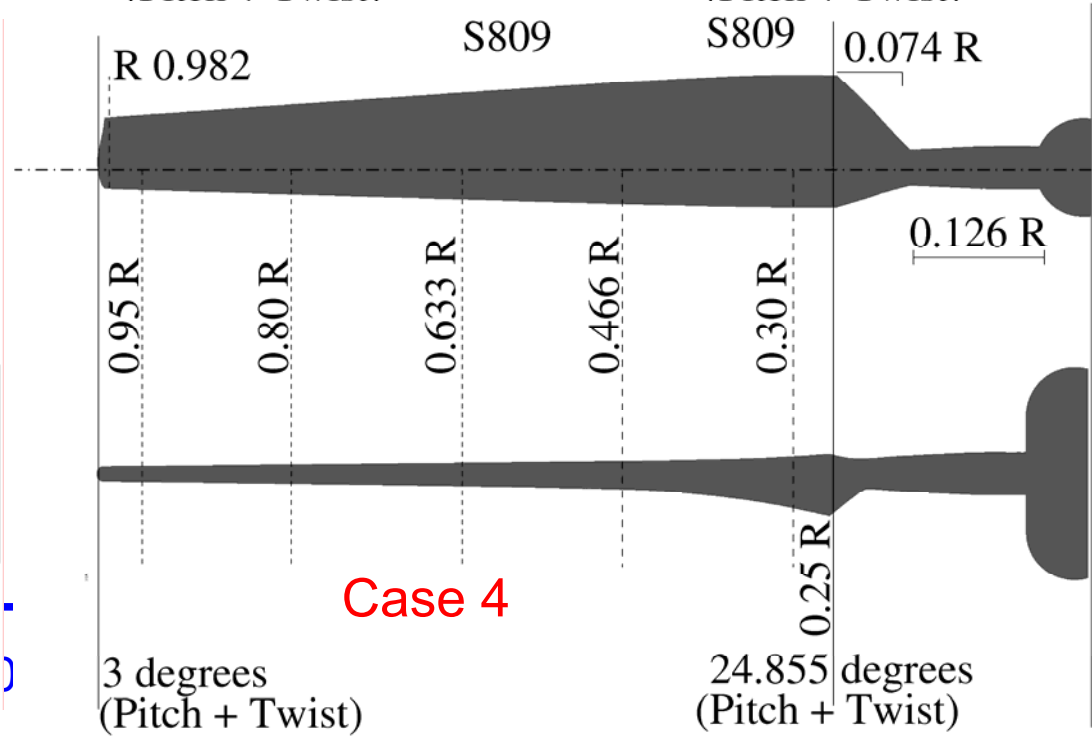


Rounded tip


S809
S809
1.054 R
0.95 R
0.80 R
0.633 R
0.466 R
0.30 R
0.05 R
1.0 R
0.25 R
Case 1
3 degrees
(Pitch + Twist)
24.855 degrees
(Pitch + Twist)

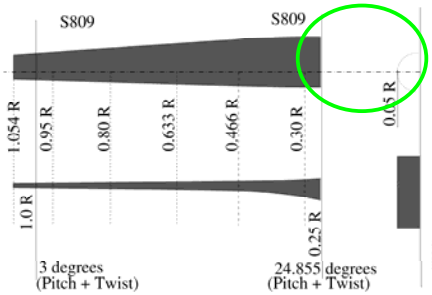

S809
S809
1.054 R
0.95 R
0.80 R
0.633 R
0.466 R
0.30 R
0.05 R
0.108 R
1.0 R
0.25 R
Case 2
3 degrees
(Pitch + Twist)
24.855 degrees
(Pitch + Twist)


S809
S809
0.074 R
0.126 R
0.95 R
0.80 R
0.633 R
0.466 R
0.30 R
1.0 R
0.25 R
Case 3
3 degrees
(Pitch + Twist)
24.855 degrees
(Pitch + Twist)


R 0.982
S809
S809
0.074 R
0.126 R
0.95 R
0.80 R
0.633 R
0.466 R
0.30 R
0.25 R
Case 4
3 degrees
(Pitch + Twist)
24.855 degrees
(Pitch + Twist)

CFD Results

1



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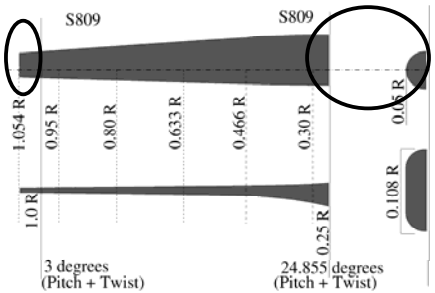

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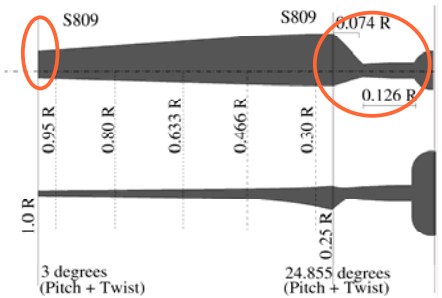

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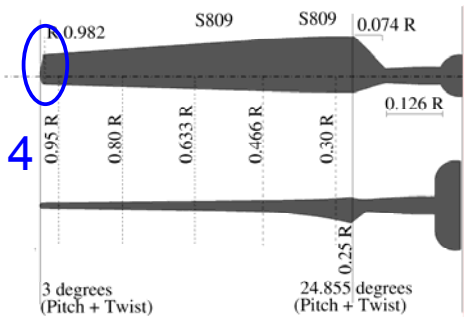
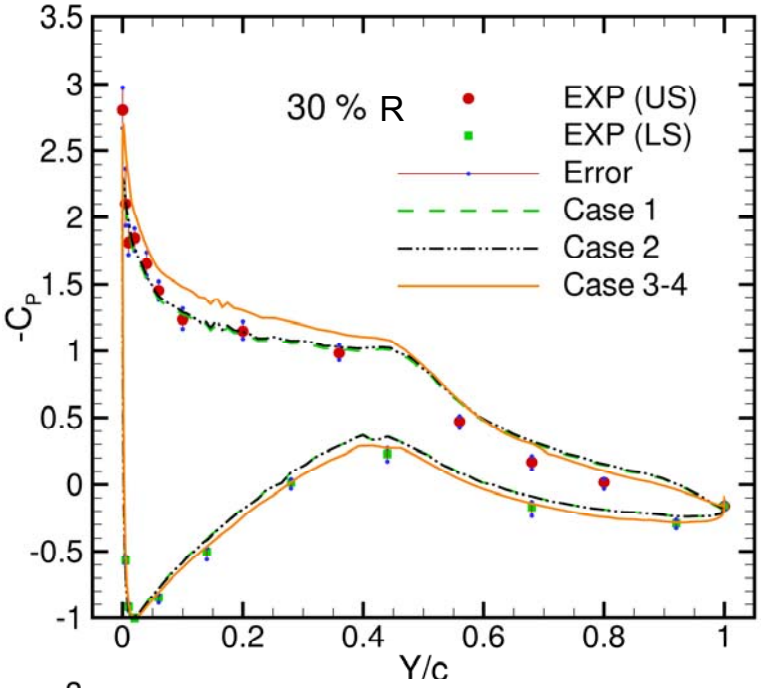
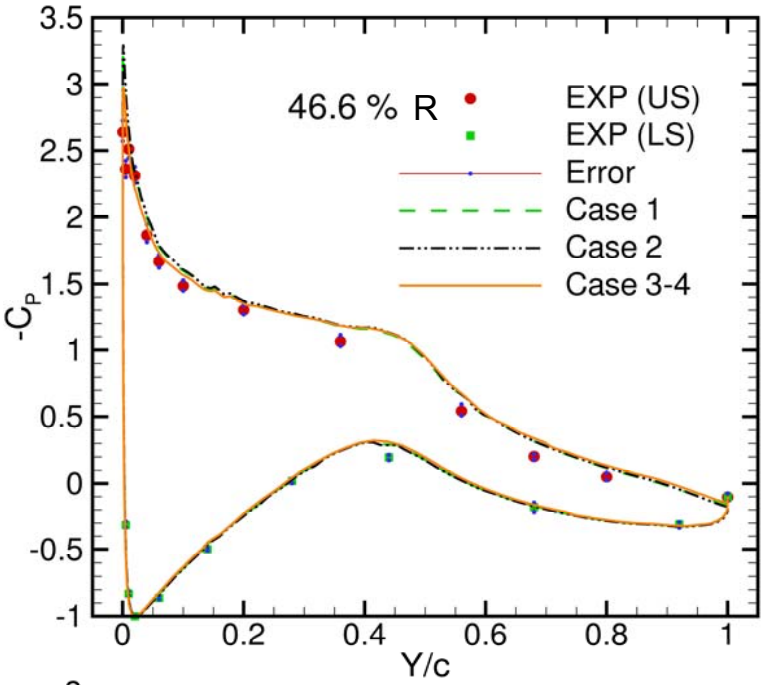
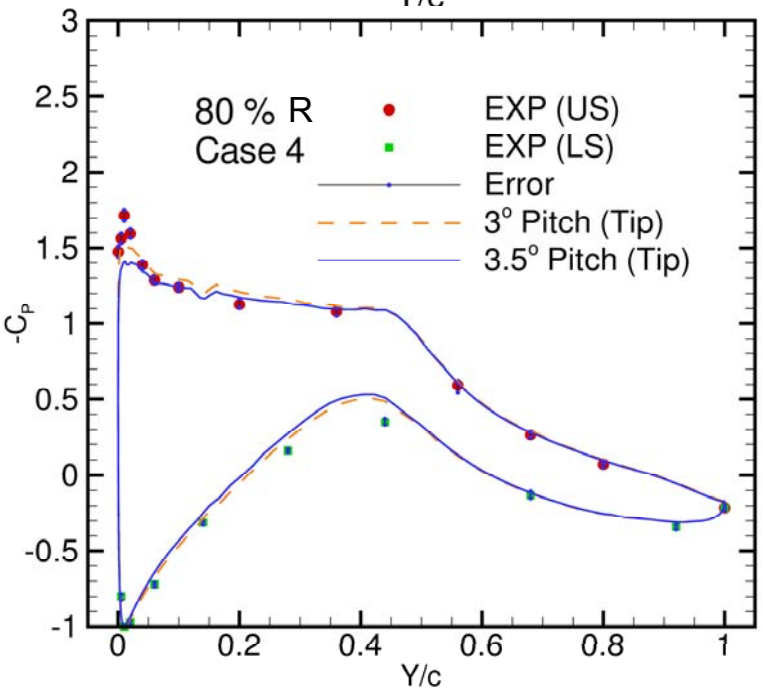
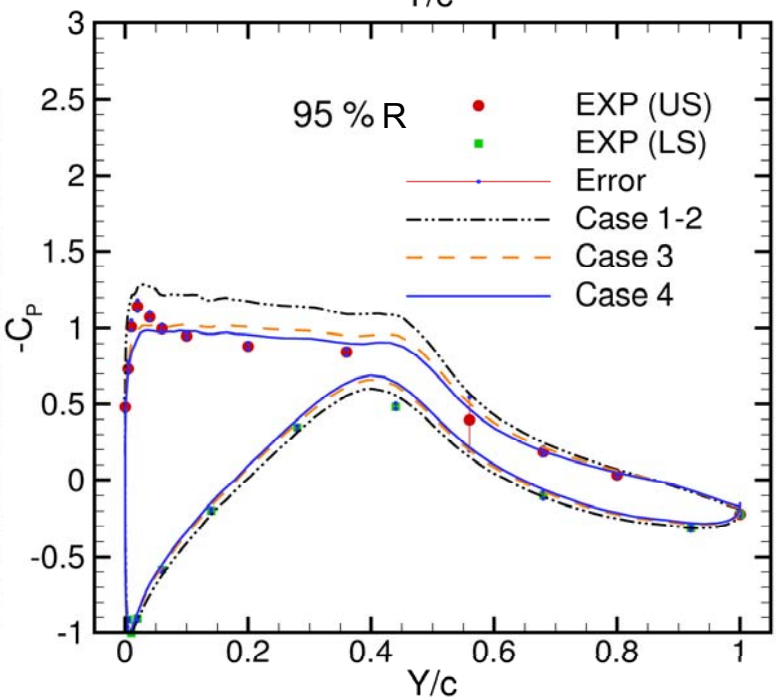




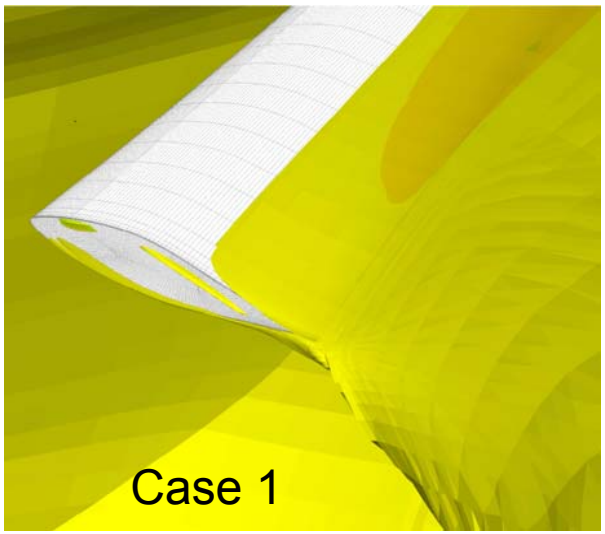


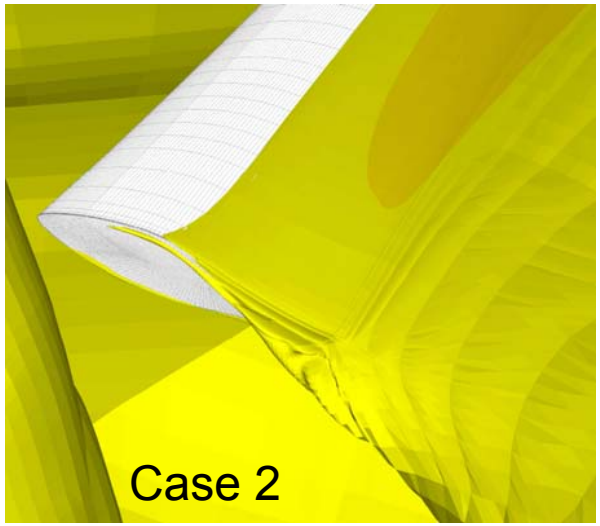


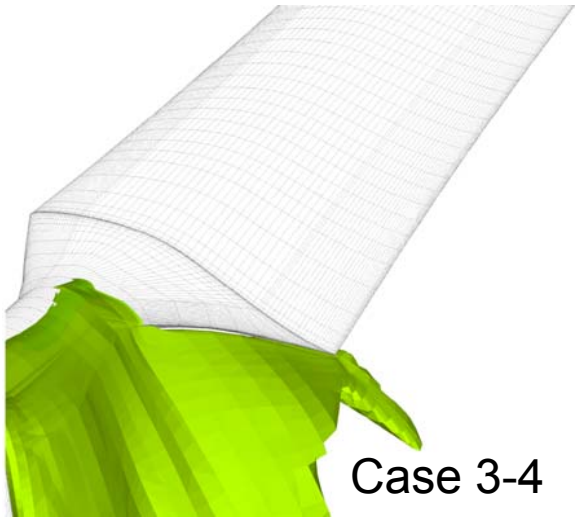


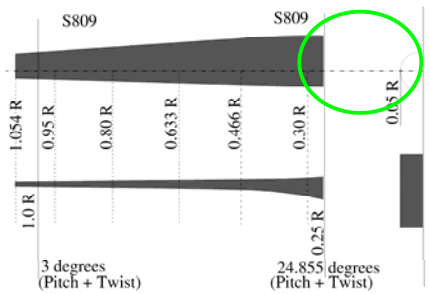
CFD Results: Flow Visualization

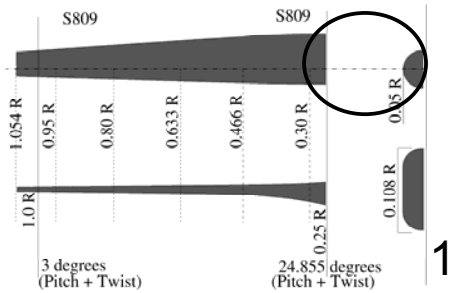
ROOT











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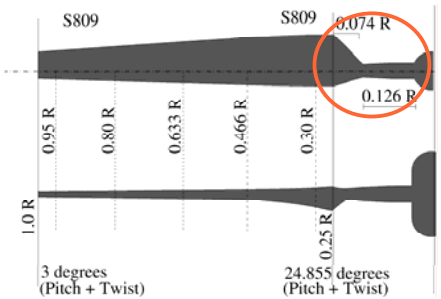
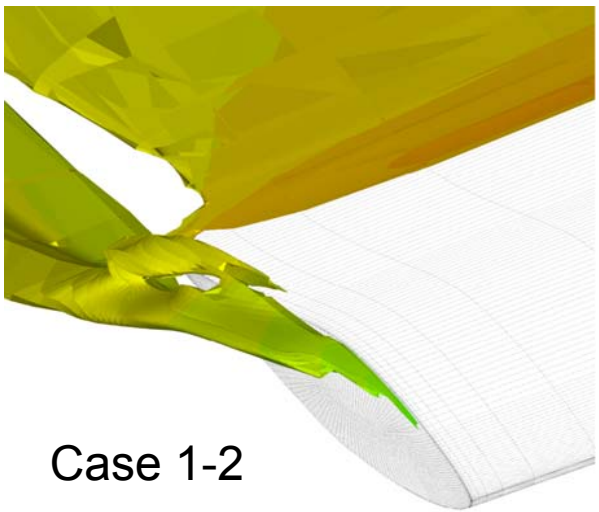


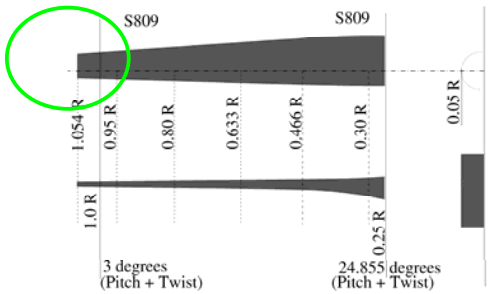
Turbulent Reynolds number isosurface colored with pressure levels

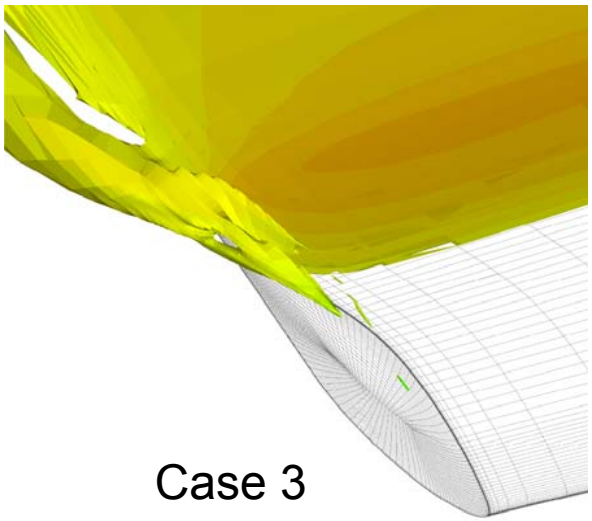
CFD Results: Flow Visualization

TIP

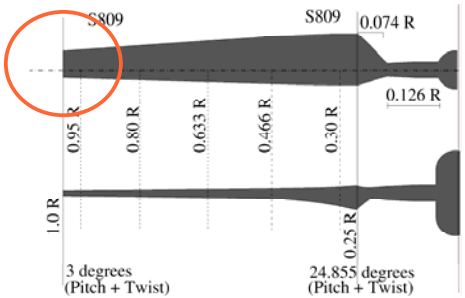


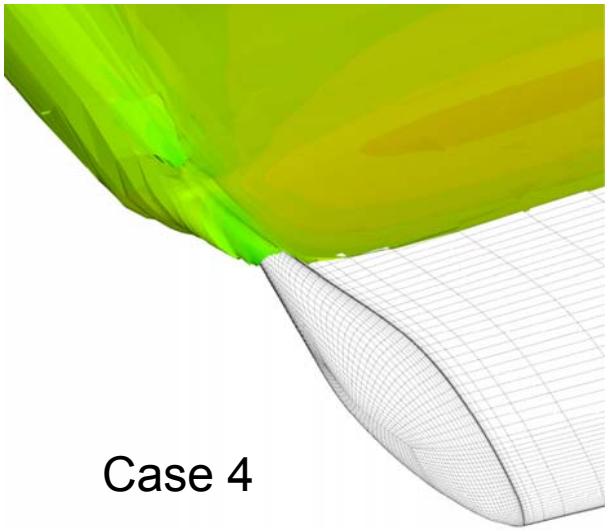
Case 1-2



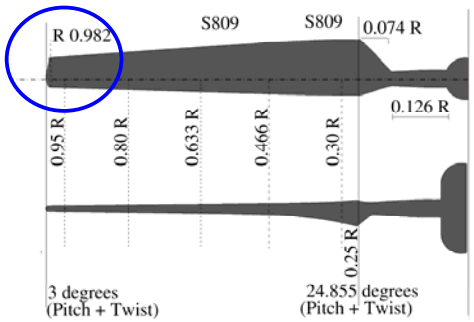


Case 3



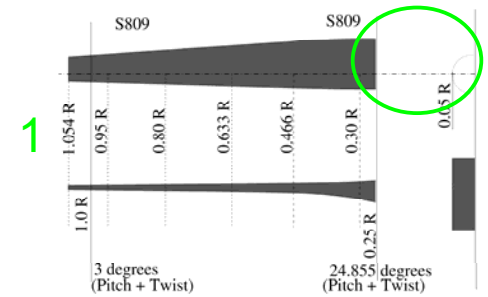


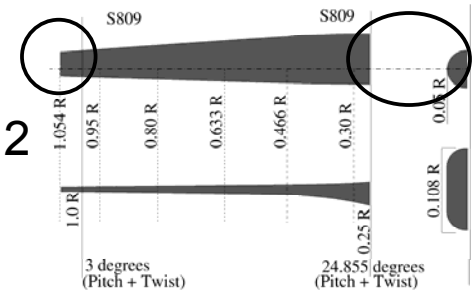
Case 4

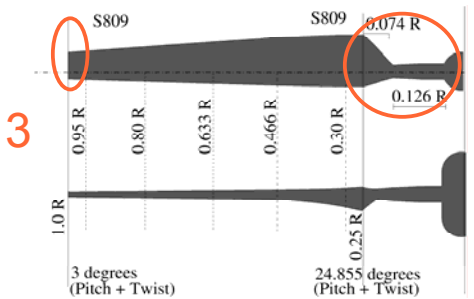


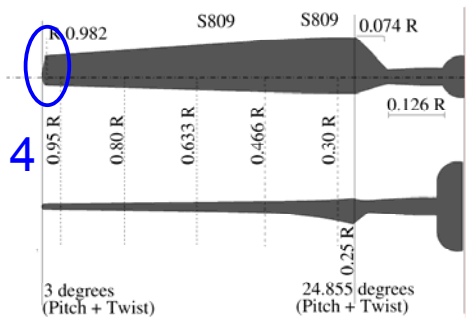
Turbulent Reynolds number isosurface colored with pressure levels

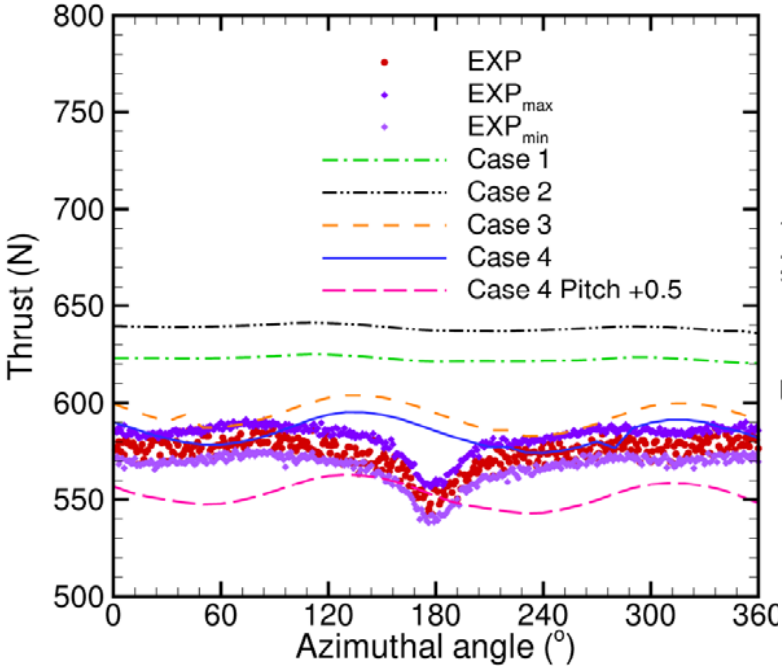
Thrust & Torque

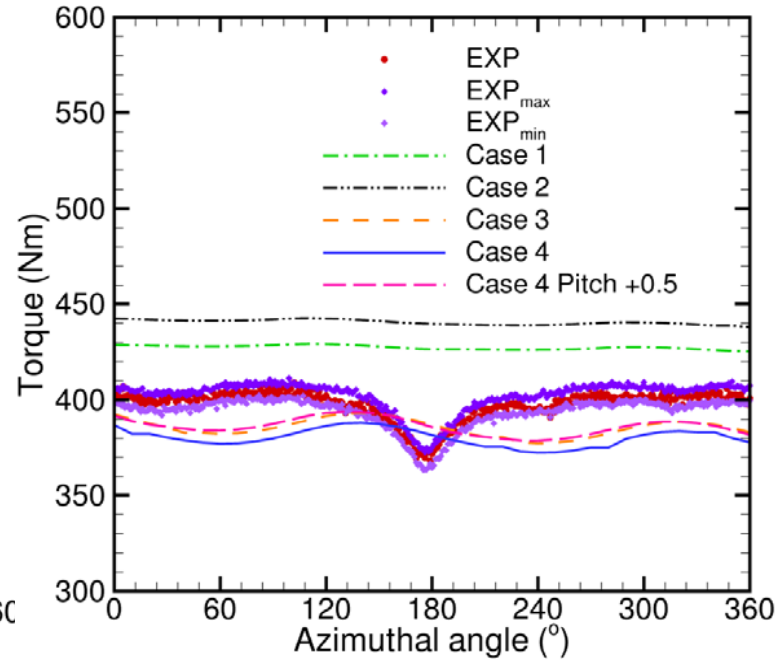


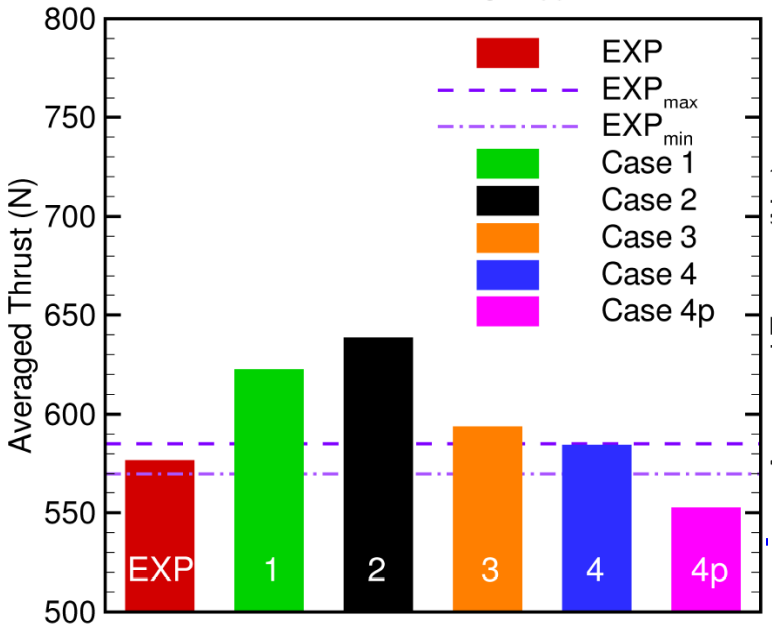


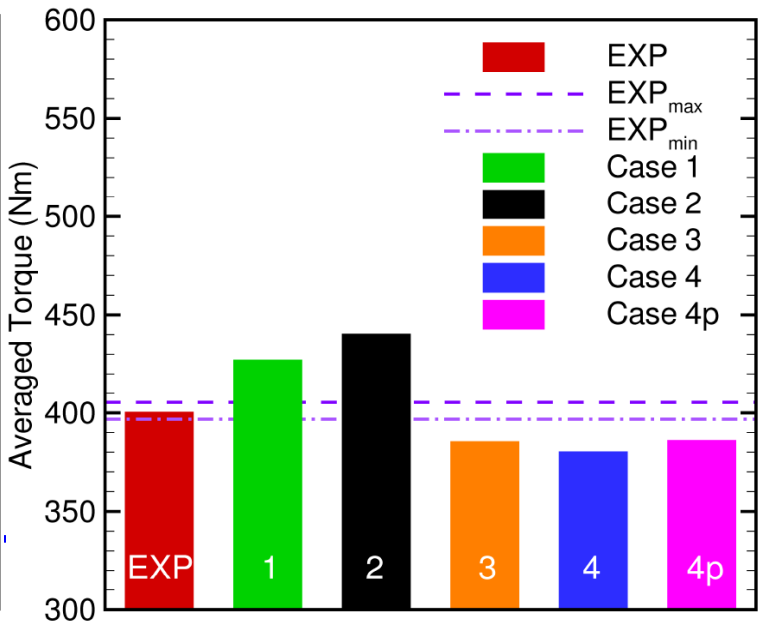












Summary and Next Steps

- CFD solver was validated for working conditions.
  - Stalled flow needs further investigation
- Blade geometry variations were studied and their sensitivity analyzed.
  - Aspect ratio and adequate pitch are essential outputs as expected.
  - Tip and root sections have smaller role and can be neglected for first calculations.
- Next step will be the implementation of sliding grid technique in order to analyze the effects of the tower, nacelle and the ground in the wind turbine aerodynamics.


LABORATORY