CFD calculations on the NREL Phase VI rotor in operating and standstill conditions within the IEA task 29 Mexnext: Phase 2, task 4.1 and 4.2

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Mexnext I

- The Mexnext project lies within the framework of the EU FP5 project.
- A aerodynamic experiment on a three bladed rotor model of 4.5 m diameter was designed. The rotor was designed and manufactured within the framework and speed controller and pitch actuator were included in the model built.
- The rotor was successively tested in the 9.5m x 9.5 m open test section of German Dutch Wind tunnel Organisation (DNW) in December of 2006.





Mexnext II

Use of old and recent measurements. This phase was divided in 9 tasks:

Task 4.1 (Standstill)

Task 4.2 (Sensitivity of results on Reynolds number)

Task 4.3 (Angle of attack)

Task 4.4 (Near wake aerodynamics)

Task 4.5 (Non uniformity of the flow between the blades)

Task 4.6 (3D effects)

Task 4.7 (Yawed flow and unsteady airfoil aerodynamics)

Task 4.8 (Dynamic Inflow)

Task 4.9: (Boundary layer transition)

New measurements (e.g. the New Mexico data). Carried out in june/july 2014



Task 4.1 Parked-Standstill case

- Dimensioning case for the industry
- High loads in extreme conditions
- Complex case for CFD solvers due to
 - Separation
 - Flow instability
- Results from the NASA-AMES test on the NREL phase VI turbine
- Participants (CENER, DTU, IFE)

Task 4.2 Sensitivity of results on Reynolds number

- Complex case for CFD solvers due to
 - Compressibility effect
 - Scaling
- Results from the NASA-AMES test on the NREL phase VI turbine at 4degrees pitch
- Participants (Kiel, IFE)



TAU - DLR

- URANS code
- Finite volume
- Compressible
- Developed at DLR
- Hybrid meshes
- Highly parallelizable (Open MPI)
- Multigrid
- Low Mach preconditioning (MAPS+)
- Different schemes (Runge Kutta, etc.)
- Different turbulence models
 - 1 equation (SAO, SAM, etc.)
 - 2 equations (k-ω, k-ε, etc.)
 - Transition models GammaReTheta
 - RSM

Workflow

Operational

3D – Steady state Fullscale 4° pitch angle

- 72rpm
- 3D Steady state Scaled model 4 ° pitch angle
 - 1:8 576rpm
 - 1:8 800rpm

Stand Still

- 2D Steady state
- 2D URANS
- 3D Steady state
- 2D-3D DES SA



Geometry

- Two blades.
- The rotor diameter is 10.058 m and the hub height is set to 12.192 m. Aerodynamical and structural properties are well documented in the literature.
- The blade is built so that, except for the root, the same airfoil (s809) with different twist angles and chords has been used at all span locations





Mesh and grid dependency



Mesh:

3million points, ca. 200000points on surface, y+ ca.5 Refinement on leading and tralining edge. Grid Adaptation technique

Adaptation



Adaptation



IF₂

K-g Turbulence model

• Reimplementation of the Menter model in terms of the time-scale variable

 $g = 1/\sqrt{\beta * \omega}$

- ω specific dissipation rate
- The advantage of this length-scale providing variable is that it is well defined at solid walls, where g_{wall}=0. The exact model formulation can be found in

Lakshmipathy, S. and V. Togiti, *Assessment if alternative formulations for the specificdissipation rate in rans and variable-resolution turbulence models.*, in *AIAA Fluid Dynamics Conference June h*, . 2011: Honolulu, Hawaii.

Results Operational conditions

Rotating speed 72rpm

Wind spee	d	Tip Speed Ratio λ						
5m/s	\longrightarrow	7.6						
10m/s	\longrightarrow	3.8						
15m/s	\longrightarrow	2.5						
20m/s	\longrightarrow	1.9						
25m/s	\longrightarrow	1.5						



Operational Conditions



IF2

Pressure at 80%

IF2

Friction lines suction side

Results Standstill

Angle of attack (geom angle) Pitch Angle

Standstill conditions 30m/s

Detached Eddy Simulations

3D extrusion process

Mesh size ca. 4 million cells

Vortex breaking

IF2

Vorticity for DDES (left) and URANS (right)

Spanwise velocity for DDES (left) and URANS (right)

Results for Re=620000

Conclusions

- Operational and standtill conditions were correctly predicted within the limit of validity of the models used.
- Adaptation technique was proved to be convenient.
- Steady state RANS and URANS calculations showed good agreement with the experiments at low angles of attack for both 2D and 3D calculations but they perform poorly in separated flow conditions.
- DDES provided good results for separated flow conditions and will be used for standstill cases

Aknowledgments

NOWITECH MEXNEXT group Sugoi Gomez Iradi (CENER) Peter Schaffalczyk (Kiel) Scott Schreck (NREL)

2D Steady State and Turbulence model choice

[8] Somers, D.M., Design and Experimental Results for the S809 Airfoil. 1997, NREL
[9].Pellegrino, A. and C. Meskell, Vortex shedding from a wind turbine blade section at high angles of attack. Journal of wind energy and industrial aerodynamics, 2013. **121**: p. 131-137.

Angle of attack (α) Ditch angle (ϕ)	0	5 95	10 80	15 75	20 70	25 65	30 60	35 55	40 50	45 45	50 40	55 25	60 20	65 25	70 20	75 15	80 10	85 E	90 0
Fitch angle (ψ)	50	65	80	75	70	05	00	55	50	40	40	33	50	25	20	15	10	5	U
				1															
30 %	-11.9	-6.9	-1.9	3.1	8.1	13.1	18.1	23.1	28.1	33.1	38.1	43.1	48.1	53.1	58.1	63.1	68.1	73.1	78.1
46 %	-3.4	1.6	6.6	11.6	16.6	21.6	26.6	31.6	36.6	41.6	46.6	51.6	56.6	61.6	66.6	71.6	76.6	81.6	86.6
63 %	-0.5	4.5	9.5	14.5	19.5	24.5	29.5	34.5	39.5	44.5	49.5	54.5	59.5	64.5	69.5	74.5	79.5	84.5	89.5
80 %	0.9	5.9	10.9	15.9	20.9	25.9	30.9	35.9	40.9	45.9	50.9	55.9	60.9	65.9	70.9	75.9	80.9	85.9	90.9
95 %	2.2	7.2	12.2	17.2	22.2	27.2	32.2	37.2	42.2	47.2	52.2	57.2	62.2	67.2	72.2	77.2	82.2	87.2	92.2
Angle of attack ($lpha$)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Pitch angle (ϕ)	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0

30 %	-11.9	-6.9	-1.9	3.1	8.1	13.1	18.1	23.1	28.1	33.1	38.1	43.1	48.1	53.1	58.1	63.1	68.1	73.1	78.1
46 %	-3.4	1.6	6.6	11.6	16.6	21.6	26.6	31.6	36.6	41.6	46.6	51.6	56.6	61.6	66.6	71.6	76.6	81.6	86.6
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Influence of turbulence models on the results for the 30m/s case. The cell colour represent the turbulence model that is better performing giving closer results to the experimental values.

[White] – Same results, all turbulence models perform in a similar way

[Green] – SA gives better predictions

[Grey] – k- w gives better predictions

[Red] k-w Menter SST gives better predictions Its hard to understand this table.

Main Features

- Easy-to-use GUI used to prepare geometry for mesh generation.
- Prismatic Elements
 - (Layers of prisms can be created in boundary layers and viscous regions)
- Hexahedral Elements
 - (Layers of hexahedra can also be formed in boundary layers and viscous regions)
- Complex Geometries
 - (Very complex geometries can be easily meshed)
- Mesh Resolution Control
 - Element sizes are determined automatically or can be user-specified.
- 2D Hybrid Meshes
- 2D geometries can be easily meshed using both triangles and quadrilaterals.

Special Features

- CAD Diagnostics and Cleaning
 - Geometries can be cleaned within CENTAUR.
- Multiple Zones
 - Separate meshes can be generated in multiple regions.
- Structured Quad Layer Regions
 - High aspect ratio structured quadrilaterals can be generated on wall surfaces.
- Hexahedral Blocks
 - Create structured hexahedral mesh regions to resolve wakes and vortices and combustion regions.
- Parallel Mesh Generation
 - Generate meshes using multiple processors.
- Overlapping Meshes
 - Allows for mesh regions to overlap.
- All Tetrahedral Mesh
 - Generate all tetrahedral meshes.
- Moving Hybrid Grids
 - Hybrid mesh follows structural motion.

TAU -DLR

- Software system for the prediction of viscous and inviscid flows about complex geometries from the low subsonic to the hypersonic flow regime employing hybrid unstructured grids.
- The different modules of TAU, briefly described in the following, can both be used as stand-alone tools with corresponding file I/O or within a Python scripting framework which allows also for intermodule communication without file-I/O, i.e. using common memory allocation.
- One of the important features of the TAU-Code is its
 - high efficiency on parallel computers and its optimization for cache processors through specific edge colouring procedures. Parallelization is based on domain decomposition and the message passing concept using MPI. All modules of the system described in the following are capable of running in parallel.
- Mainly used for complex aircraft-type configurations (including coupling to structure and flight mechanics codes) it can be used for a number of other applications
- Grid modification
- Grid adaptation
- Grid deformation
- NO grid generation
- TAU can be used with both (block-) structured and hybrid unstructured grids composed of hexahedrons, prisms, tetrahedrons and pyramids. The first two element types are usually used in semi-structured layers above surfaces allowing for a better resolution of boundary layers. Tetrahedrons are used to fill the computational domain in a flexible way, allowing for local refinement without hanging nodes while the pyramids are needed for the transition between elements with quadrilateral faces and elements with triangular faces.

Parallelization

Almost Linearly parallelizable

NOWITECH WP1+6 Industry reference Group meeting 9th April - Trondheim