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Unsteady Hybrid Navier-Stokes/Vortex Model Applied to Wind Turbine Aerodynamics under Yaw Conditions

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Abstract: A new analysis tool, an unsteady Hybrid Navier-Stokes/Vortex Model, for the horizontal axis wind turbine (HAWT) in yawed flow is presented, and its convergence and low cost computational performance are demonstrated. The unsteady hybrid model is applied to the NREL Unsteady Aerodynamic Experiment (UAE) Phase VI rotor at 10 and 20 degrees of yaw and the global and local results are compared with the Vortex Line Method (VLM) and experiments. The unsteady motion of the blade tip vortices in yawed flow is visualized. A 10% backward swept rotor is also analyzed in yawed flow as an example of the new tool. A new acceleration technique for prescribed wake model is introduced, and its successfull result is presented.

Keywords: Unsteady flow, Hybrid model, Wind turbine aerodynamics, Dual time steps, Acceleration technique.

1 Introduction

The Hybrid Navier-Stokes/Vortex Model was developed by Schmitz and Chattot and applied to the UAE Phase VI experiment for steady flow at zero yaw [1]. The results showed that the model improved the global force predictions over wind speeds from fully attached flow to separated flows, as well as the agreement of the local pressure distributions with the experiments, compared to the results from participants of the NASA Ames blind comparison workshop [2]. In earlier work, the steady hybrid model was applied to an optimum wind turbine blade [3], and a 10% backward swept blade [4], to investigate these designs for HAWT. An unsteady VLM code has been developed for yawed flow, blade tower interaction, earth boundary layer effects and wind gusts, and has been validated with the UAE experiment and other reference data [5, 6]. The unsteady VLM was used by GE, coupled with ADAMS/AeroDyn, to study aeroelastic effects due to blade sweep and winglets [7]. In this work, the unsteady helicoidal vortex model is coupled with the unsteady Navier-Stokes solver, CFX V12.0 and the convergence and computational performance are tested.

2 Problem Statement

Analysis of the two-bladed NREL rotor under yawed flow requires the solution for each blade subdomain and each vortex sheet, as they experience different conditions. This is in contrast with steady flow when only one blade, its vortex sheet and the influence of the other blade vortex sheet need to be calculated. The computational domain and vortex sheet modeling are illustrated in figures 1 and 2. Note that the vortex method can easily carry the wake 20 blade radii, about 200 chords, downstream of the rotor to give accurate induced velocities at the Navier-Stokes domain outer boundary, which is confined to a few chords in the vicinity of the blades. This makes the computational cost quite low. A dual time step is introduced to couple the unsteady Navier-Stokes solver with the unsteady vortex model. The results show that the coupling takes 3-4 sub-iterations to converge. The computational performance is estimated using a multiple CPU system benchmark summary, updated Dec. 4, 2011. The data is partially included in the estimation table, courtesy of Pass Mark Software Pty Ltd. The estimated cost of the present hybrid method is 28.4 hours (1 day and 4 hours and 24 minutes) for 10 cycles of a yawed case using the latest high speed system, as summarized in Table 1. Cross-flow solution contours are presented in Figure 3.

3 Conclusion and Future Work

An unsteady hybrid method has been presented for unsteady wind turbine analysis under yawed conditions, at low computational cost. In future work, the blade tower interaction, which has been tested with the VLM [6], could be implemented for high fidelity simulations.

	System	Bench Mark score	Speed factor	Cost [sec]	Cost [day]	The system Price [USD]
The fastest	[3-Way] Intel Xeon E7- 8837 @ 2.67GHz	33504	6.69	1.03e+05	1.19	NA
The second	[Quad CPU] AMD Opteron 6174	29628	5.91	1.16e+05	1.34	5119.96
The third	[Quad CPU] AMD Opteron 6168	23735	4.74	1.45e+05	1.68	3079.96
Used	[Dual CPU] Quad-Core AMD Opteron 2354	5010	1	6.87e+05	7.95	NA (578.28, June 2011)

Table 1: Computational cost estimations for 10 cycles. The bench mark and price data are by courtesy of Pass Mark Software Ltd.

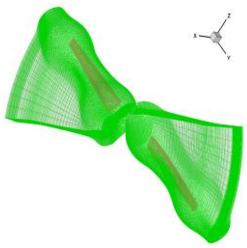

Figure 1: NS zone.

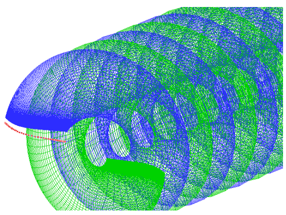

Figure 2: Vortex sheets.

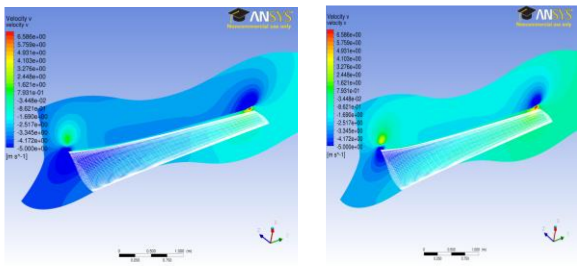

Figure 3: Velocity v contour, azimuth angle 0 degree (left) and 90 degree (right).

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