

COMPUTATIONAL SIMULATION OF THE TURBULENT FLOW AROUND AN AIRFOIL USING SPECTRAL/HP METHOD

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1 Abstract

The precise calculation of loads in turbulent flow is still problematic for most Computational fluid dynamics (CFD) approaches. The spectral/hp approach allows to solve the incompressible Navier-Stokes equation with spectral accuracy on unstructured grids by means of Direct Numerical simulation (DNS) or Large Eddy Simulation (LES). Here we present first results we obtained from DNS compared to LES and measurements at a low Reynolds number.

2 Introduction

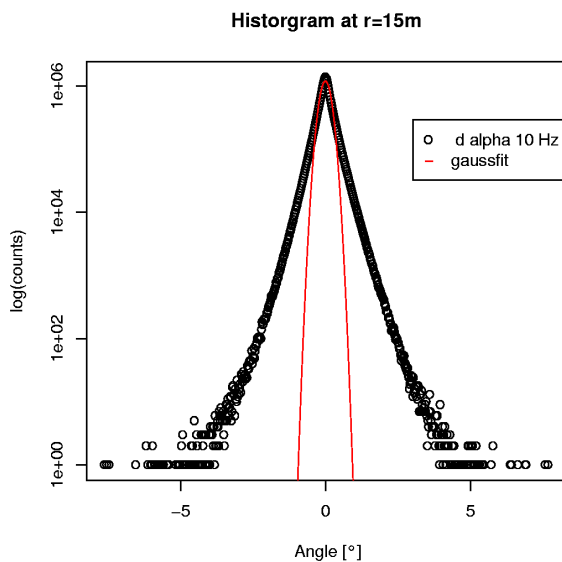


Figure 1: *Probability density function (PDF) of change of angle of attack within 0.1 seconds due to wind speed changes during a measurement of 7 days calculated for a turbine turning at 20 rpm at r=15m*

Unlike in most wind tunnel experiments the wind on the blade of the wind turbine is highly turbulent, causing rapid changes of angle of attack on the airfoil[1](see fig. 1). Such changes lead to the effect of dynamic stall. This type of stall effect causes sudden changes in all the loads on the blade.

Nevertheless the correct calculation of such loads is a tedious task. There exist some semi-empirical models for the calculation of the effect[2]. For the precise calculation a computational flow model would be convenient. But so far CFD-Programs do have some problems resolving turbulence precisely. For the calculation of temporal, local turbulence effects occurring in the dynamic stall, the solvers based on the Reynolds averaged Navier-Stokes Equation (RANS) reach their limit, as they are based on a time averaging method[3]. Even newer LES-Codes reach at this task their limits of precision as seen in the results of the LESFOIL project[4].

A newer approach for CFD is the use of high order polynomials in the so called spectral element method established mainly by G. Karniadakis and S. Sherwin. As the accuracy increases exponentially with the increase of the order, a higher accuracy can be easily implemented[5].

3 The approach using the spectral/hp method

The spectral/hp element method combines the accuracy of classical spectral codes with the flexibility of finite element methods (FEM) using spectral methods on grid elements in a C^0 continuous space.

In a first approach presented here we used the $\mathcal{N}\varepsilon\kappa\mathcal{T}ar$ code [7][8]. The code is parallelised using MPI and was run at the CLUH cluster at Hannover University on 16 processors. For the simulation a 2D mesh with 1490 elements and a Fourier expansion us-

ing 64 Fourier planes in span wise (third) direction has been chosen. The grid was a hybrid grid using quadrilateral and triangular elements at a polynomial order of 9.

The calculation was done using the incompressible Navier-Stokes equation. In this case the flow of the air can be considered as an incompressible Newtonian fluid flow, which can for DNS be described by the dimensionless Navier-Stokes equations:

$$\nabla \cdot \mathbf{u} = 0, \quad \frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla) \mathbf{u} = -\nabla p + \nu \Delta \mathbf{u} + \mathbf{F} \quad (1)$$

For LES the equations can be modified using the Smagorinsky model:

$$\begin{aligned} \nabla \cdot \tilde{\mathbf{u}} &= 0, \\ \frac{\partial \tilde{\mathbf{u}}}{\partial t} + (\tilde{\mathbf{u}} \cdot \nabla) \tilde{\mathbf{u}} &= \\ -\nabla \tilde{p} + \nabla \cdot [(\nu + \nu_s)(\nabla \tilde{\mathbf{u}} + \nabla \tilde{\mathbf{u}}^T)] + \tilde{\mathbf{F}} \end{aligned} \quad (2)$$

where $\tilde{\mathbf{F}}$, $\tilde{\mathbf{u}}$ and \tilde{p} denote the filtered force, velocity and pressure fields, respectively. The Smagorinsky eddy-viscosity model is presented by the term $\nu_s = l_s^2 |\tilde{S}|$, where l_s is the Smagorinsky length scale which is dependent on the filter width Δ as $l_s = c_s \Delta$. Δ is chosen to be dependent on the polynomial order and grid spacing. $|\tilde{S}|$ is the magnitude of the strain rate tensor.

The simulation was done for the flow around a fx79-w151a airfoil section at an angle of attack of 12° . The domain was homogeneous in the span wise direction with a depth of the chord length. The Reynolds number was 5000 at a laminar inflow.

4 First Results

At a Reynolds number of 5000 the flow around the airfoil leads to the typical Karman street like flow separation at the tail of the airfoil. As a results lift and drag fluctuate over the time.

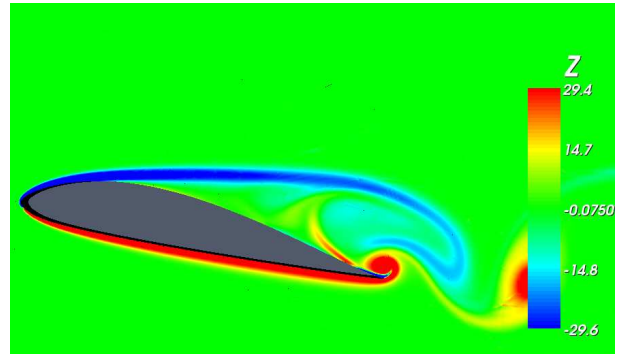
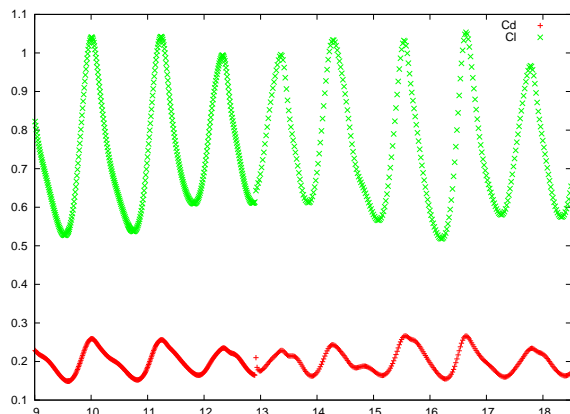


Figure 2: Forces on the airfoil over time simulated with DNS (top). The $(u-v)$ -plane vorticity at the airfoil giving the flow structure at about $t=18.9$ with DNS (bottom).

Comparing the fluctuations at the airfoil the DNS and the LES simulation show some general agreement of the flow structure with another. Yet the magnitudes of the fluctuations do still differ. Also the shapes of the wake do not quite agree. The main reason for this lies so far in the insufficient calculation time of the LES simulation, which are indicated by the weak fluctuations in the further wake of the LES simulation.

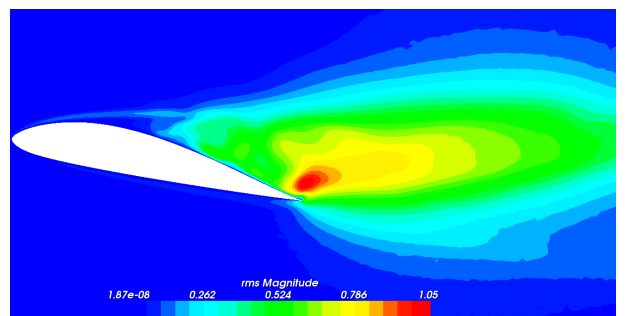
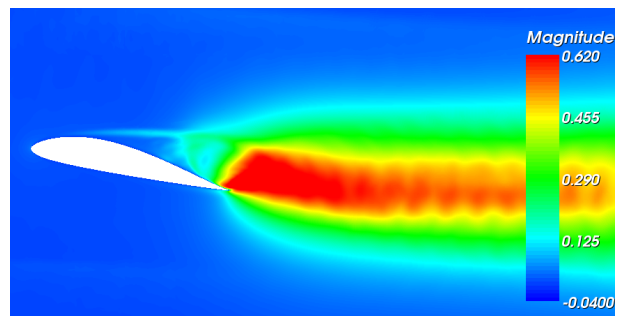


Figure 3: RMS of velocity magnitude for DNS (top) and LES (bottom) (LES pictures by Andrei Shishkin).

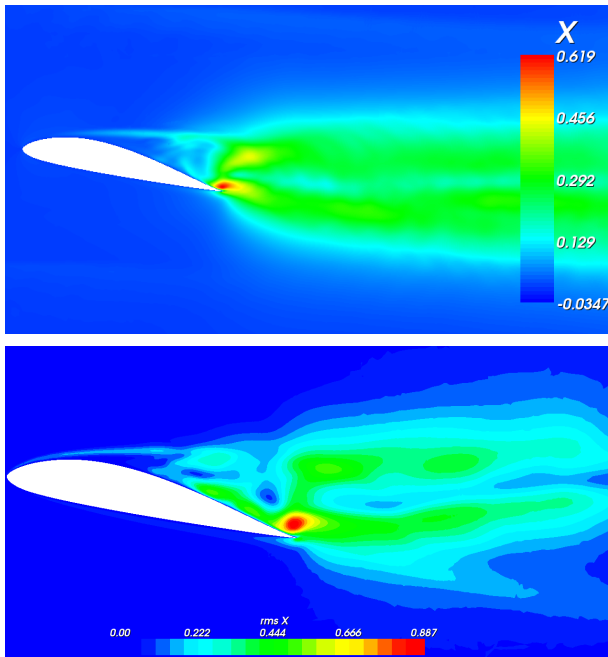


Figure 4: RMS of u -velocity for DNS (top) and LES (bottom) (LES pictures by Anrdrei Shishkin).

5 Conclusion

Simulating turbulence on blades is still a difficult task if time resolved accurate results are needed. The main problem for LES codes have so far been the high resolution needed on wall functions. The high polynomial orders of spectral element methods are a promising approach to overcome the problems.

The first tests of the DNS and LES solvers show similar flow patterns. Nevertheless the quantitative results deviate so far from another. Since the large eddy simulation has not been running over a comparable time period as the direct numerical simulation, some of the deviances might be explained by this fact.

After all the method is so far in a scientific state. Calculation times of many weeks for one simulation on computational clusters are so far too much for industrial use.

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