CFD Simulation of Vertical Axis Wind Turbines

An UberCloud Experiment

With Support From

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UberCloud Case Study 189:

CFD Simulation of Vertical Axis Wind Turbines

http://www.TheUberCloud.com

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Welcome!

The UberCloud* Experiment started in July 2012, with a discussion about cloud adoption in technical computing and a list of technical and cloud computing challenges and potential solutions. We decided to explore these challenges further, hands-on, and the idea of the UberCloud Experiment was born, also due to the excellent support from INTEL generously sponsoring these experiments!

We found that especially small and medium enterprises in digital manufacturing would strongly benefit from technical computing in HPC centers and in the cloud. By gaining access on demand from their desktop workstations to additional compute resources, their major benefits are: the agility gained by shortening product design cycles through shorter simulation times; the superior quality achieved by simulating more sophisticated geometries and physics and by running many more iterations to look for the best product design; and the cost benefit by only paying for what is really used. These are benefits that increase a company's innovation and competitiveness.

Tangible benefits like these make technical computing - and more specifically technical computing as a service in the cloud - very attractive. But how far away are we from an ideal cloud model for engineers and scientists? In the beginning, we didn't know. We were just facing challenges like security, privacy, and trust; conservative software licensing models; slow data transfer; uncertain cost & ROI; availability of best suited resources; and lack of standardization, transparency, and cloud expertise. However, in the course of this experiment, as we followed each of the 175 teams closely and monitored their challenges and progress, we've got an excellent insight into these roadblocks, how our teams have tackled them, and how we are now able to reduce or even fully resolve them.

This case study is about computing and optimizing the performance of vertical axis wind turbines (VAWT) through CFD simulations. Apart from the computational effort involved, the task is complicated by the fact that turbulence models are not very good at predicting the (dynamic) stall of the blades at high angles of attack. In order to get around this problem, a small VAWT for validation studies was developed and manufactured at the HSR. The first part of the project consisted of performing detailed simulations and measurements of this turbine to verify the meshing and turbulence models. Once acceptable agreement has been found, the simulations will be applied to new and much larger wind turbine designs.

We want to thank the team members for their continuous commitment and voluntary contribution to this experiment, and especially **CD-adapco** for generously providing free STAR-CCM+ licenses for this cloud experiment. And we want to thank our main Compendium sponsors for **Hewlett Packard Enterprise and Intel** generously supporting the UberCloud experiments.

Now, enjoy reading!

Henrik Nordborg, HSR, Wolfgang Gentzsch and Burak Yenier
The UberCloud, June 2016

**) UberCloud is the online community and marketplace where engineers and scientists discover, try, and buy Computing Power as a Service, on demand. Engineers and scientists can explore and discuss how to use this computing power to solve their demanding problems, and to identify the roadblocks and solutions, with a crowd-sourcing approach, jointly with our engineering and scientific community. Learn more about the UberCloud at: http://www.TheUberCloud.com.*

Team 189:
CFD Simulation of Vertical Axis Wind Turbines

"Cloud based computing extends our potential to design/develop better products. By utilizing this potential the products can be optimized with a much faster pace and higher quality."

MEET THE TEAM

End user and Team Expert – Henrik Nordborg, Adrian Rohner, Hochschule für Technik in Rapperswil (HSR), Switzerland
Software Provider – CD-Adapco providing STAR-CCM+
Resource Provider – Microsoft Azure with UberCloud STAR-CCM+ software container
Technology Experts – Fethican Coskuner, Hilal Zitouni, and Baris Inaloz, UberCloud Inc.

USE CASE

Vertical Axis Wind Turbines (VAWT) represent an interesting alternative to the more conventional horizontal axis design, promising a simpler and more robust design with lower costs. Furthermore, the fact that the turbine does not have to be turned to face the wind makes it ideally suited for difficult locations with constantly changing wind direction.

Figure 1: Large scale vertical axis wind turbine (VAWT) (courtesy of Agile Wind Power, Switzerland)

Aerodynamically, the VAWT is more difficult to model than the horizontal axis design. The problem is that the blades see very different wind velocities and flow patterns at the upwind and downwind positions. A semi-analytical approach to estimate the performance of a VAWT, the Double Multiple Stream Tube method (DMST), is therefore not very accurate can only be used for rough estimates. A more promising approach is to use CFD simulations, which fully resolve the flow pattern inside and around the turbine. Obviously the best results are obtained from a fully transient simulation of the entire structure, including the all the struts in additions to the blades. As this is very time consuming, it makes sense to optimize the blades using two-dimensional simulations of a cut through the turbine.

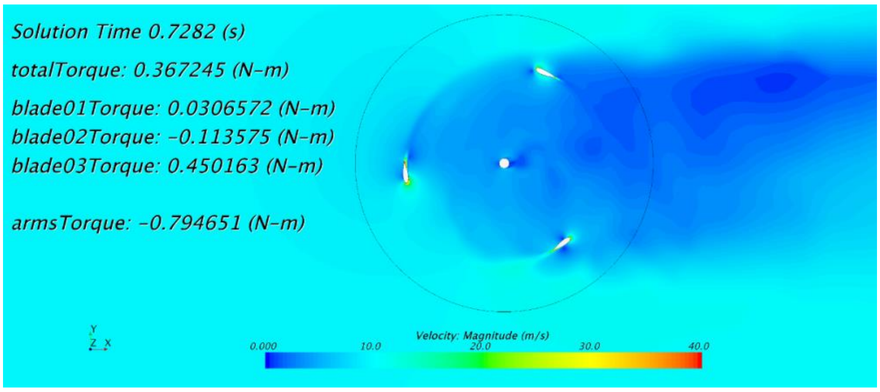

Figure 2: Two-dimensional cut through the simulation of a VAWT

A more difficult problem is the proper handling of stall. It is not very difficult to compute lift and drag of an airfoil for small angles of attack. For larger angles, however, the flow will detach from the blade, leading to stall and a significant reduction of the lifting force. It is well known that standard turbulence models have problems capturing this transition. On the other hand, the effect on the total torque might not be dramatic, as the main torque is produced from blades with a fairly small angle of attack.

In order to validate the simulations, a small VAWT and a simple wind tunnel have been developed at the HSR. The blades can be manufactured using 3D printing, making it easy to test new designs. The goal is to compare measurements with accurate transient 3D simulations in order to determine the accuracy which can be obtained from numerical simulations.

Figure 3: The small VAWT used for the validation studies

The power generated by a wind turbine can be written

$$P = c_p(Re, \lambda)\frac{1}{2}\,\rho v^3 A$$

where ρ is the density of air, v is the wind speed, and A is the swept area. The efficiency is given by the dimensionless power coefficient, $c_p(Re, \lambda)$ which depends on the design of the wind turbine, the Reynolds number, and the tip speed ratio (TSR)

$$\lambda = \frac{\omega R}{v}$$

In the case of a VAWT, the power generated by the turbine is not a constant but depends on the momentary position of the blades. This makes it necessary to simulate a number of complete revolutions of the turbine in order to obtain the average power. Furthermore, in order to determine the dependence on the Reynolds number and the TSR, we need to run the simulations at different wind speeds and different angular velocities. This means that a large number of simulations have to be computed during a short period, making the application ideal for Cloud computing.

TECHNOLOGY: Running STAR-CCM+ in the Cloud

This STAR-CCM+ wind turbine simulation with about 20 million cells first ran on the in-house 3-year old 96-core computing cluster of HSR, the Hochschule für Technik in Rapperswil, Switzerland, and we decided to repeat the same simulation as an UberCloud Experiment on 96 cores of Microsoft Azure A8/A9 compute instances interconnected with Infiniband with UberCloud's STAR-CCM+ software container. This case study presents a quite common situation: in-house hardware ages quickly, while on Azure you always get the latest and greatest hardware. In fact, the simulation of the wind turbine on the Azure A8/A9 cluster ran 22% faster.

One of the novelties in this experiment was to use UberCloud's new STAR-CCM+ software containers, https://www.TheUberCloud.com/containers/, which are ready-to-execute packages of HPC software. These packages are designed to deliver the tools that an engineer needs to complete his task in hand. The ISV or Open Source tools are pre-installed, configured, and tested, and run on bare metal without loss of performance. They are ready to execute, literally in an instant, with no need to install software, deal with complex OS commands, or configure. This UberCloud Container technology allows wide variety and selection for engineers because the containers are portable from server to server, Cloud to Cloud. The Cloud operators or IT departments no longer need to limit the variety, since they no longer have to install, tune and maintain the underlying software. They can rely on the UberCloud Containers to cut through this complexity. This technology also provides hardware abstraction, where the container is not tightly coupled with the server (the container and the software inside isn't installed on the server in the traditional sense). Abstraction between the hardware and software stacks provides ease of use and agility that bare metal environments lack.

CHALLENGES

The main challenge in this application is running a large number of very time-consuming simulations in order to perform parameter studies. For each set of parameters, we ran 10 full revolutions of the turbine, requiring 3600 time steps per simulation. The geometry was meshed using the built-in polyhedral mesher of STAR-CCM+, resulting in meshes with 4.7 million elements. The boundary layer around the blades was resolved using inflation layers, and the SST k-ω model with wall functions was used to model turbulence.

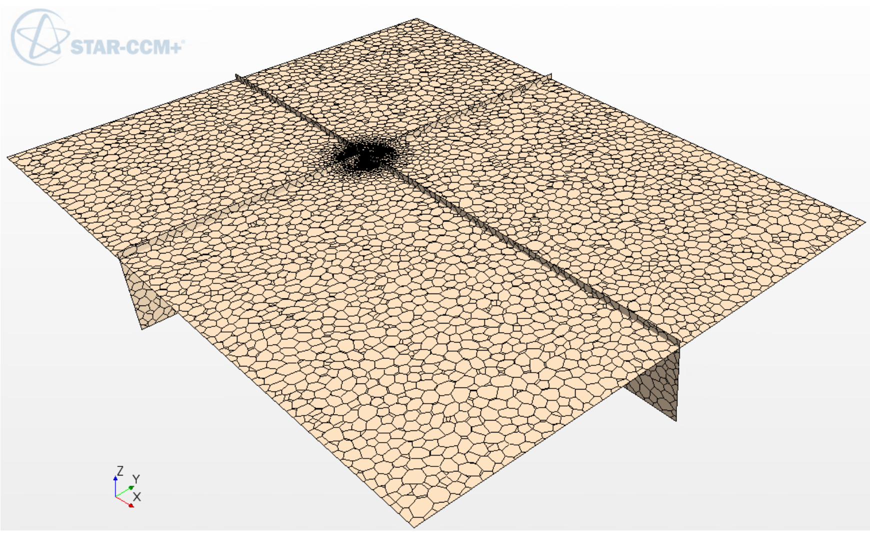

Figure 4: A polyhedral mesh used in the simulation

PROCESS AND BENCHMARK RESULTS

The computations were performed on the in-house Windows Cluster at the HSR and the in the Cloud using Microsoft Azure. In both cases, 96 cores and 40 Gbit/s Infiniband networking were used. The compute nodes at the HSR are equipped with dual Intel Xeon X5645 processors running at 2.40 GHz and using Windows Server 2012 with the Microsoft HPC Pack 2012 R4. The hardware in the Cloud is provided by Microsoft Azure and used A8/A9 nodes. Given the large number of the elements and the highly efficient CFD software, the scaling up to 96 cores was very good in both cases. However, it turned out that the Cloud was significantly faster, requiring only 25 hours per simulation (10 revolutions) as compared to 32 hours with the in-house cluster. This represents a speedup of 22%.

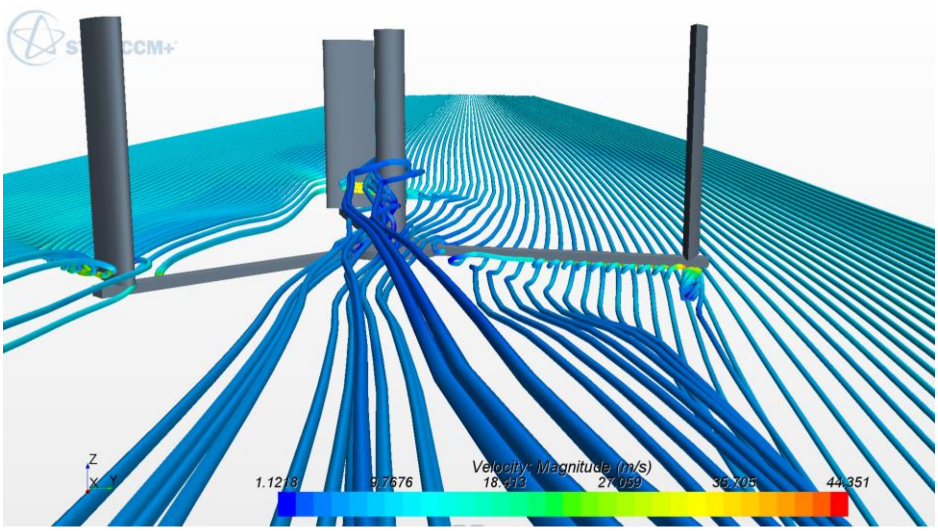

Figure 5 Streamlines illustrating the influence of the blades on the flow

BENEFITS

The Cloud is ideally suited for this kind of computationally demanding parameter studies. Since each simulation with a particular wind speed and tip-speed ratio can be run independently, progress is only limited by the number of available cores and licenses. However, the CD-adapco licensing model using Power on Demand license tokens is very flexible and well suited for on-demand work in the cloud.

CONCLUSIONS

- We showed that the Microsoft Azure based UberCloud cloud solution is a beneficial solution for CD-adapco users who have the need to deliver their simulation results in a much faster time manner.
- To use cloud based cluster computing, there is no investment in in-house HPC equipment or expertise needed, since UberCloud offers customized and handy cloud cluster solutions with all requisite software packages pre-installed.
- With most software vendors catching up to the idea of software as a service, we expect a large part of engineering simulations to run in the Cloud in the near future.

Case Study Author – Henrik Nordborg, Adrian Rohner, HSR

Thank you for your interest in the free and voluntary UberCloud Experiment.

If you, as an end-user, would like to participate in this Experiment to explore hands-on the end-to-end process of on-demand Technical Computing as a Service, in the Cloud, for your business then please register at: http://www.theubercloud.com/hpc-experiment/

If you, as a service provider, are interested in promoting your services on the UberCloud Marketplace then please send us a message at https://www.theubercloud.com/help/

1st Compendium of case studies, 2013: https://www.theubercloud.com/ubercloud-compendium-2013/
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HPCwire Readers Choice Award 2013: http://www.hpcwire.com/off-the-wire/ubercloud-receives-top-honors-2013-hpcwire-readers-choice-awards/
HPCwire Readers Choice Award 2014: https://www.theubercloud.com/ubercloud-receives-top-honors-2014-hpcwire-readers-choice-award/

In any case, if you wish to be informed about the latest developments in technical computing in the cloud, then please register at http://www.theubercloud.com/. It's free.

And finally, a big thanks again to our UberCloud Experiment Sponsors HPE and Intel, and the sponsors of this cloud experiment #189, CD-adapco and Microsoft Azure.