Available online at www.prace-ri.eu

Partnership for Advanced Computing in Europe

WB-Sails: Modelling Sail Boat Performance in HPC

Mikko Brummer[a*], Ruddy Brionnaud[b], Jorge Ginés[b], Jussi Heikonen[c], Jyrki Hokkanen[c], Esko Järvinen[c] and Jarmo Pirhonen[c]

[a] *WB-Sails Ltd Oy (WBS)*
[b] *Next Limit Dynamics (NLD)*
[c] *CSC - IT Center for Science Ltd. (CSC)*

Abstract

In this PRACE SHAPE project WB-Sails wished to implement a HPC based CFD analysis of sails and sailboats, using the XFlow dynamic simulation code. The code allows 6 degrees of freedom (DOF) for motion of the objects, for a realistic simulation of forces and moments around a boat moving in seaway.

Coupled with a FEA solver, full fluid-structure analysis including optimization is possible.

1. Overview

WB-Sails designs and manufactures sails, specialising in top-end racing products. From the beginning WB-Sails has relied on technology, research and development to become one of the very few sailmakers in the world present at the Olympic level. In London 2012 their sails, designed and manufactured in Finland, won a gold and a bronze medal in two different disciplines (boat classes). In Rio 2016, a silver medal was won.

WB-Sails has a long tradition in CAD and CAM, with computer based design since 1979 and manufacturing (automated laser cutter) since 1988.

In this project WB-Sails wished to utilize HPC resources to perform simulations of sailboats using XFlow software. In addition to simulating airflow around sails, two phase studies with free surfaces and realistic motion of the hull in seaway were planned. Ultimately, the goal was to combine CFD with structural analysis of sails (FSI).

Unfortunately, due to a number of reasons, not all the goals could be achieved and the obtained results were mostly qualitative. However, important experience in using HPC resources was gained which may prove valuable in future work.

2. XFlow Lattice-Bolzmann particle based CFD software

The preferred CFD code used in the project is XFlow (1). XFlow represents the next generation of CFD, beyond the industry standard Reynolds Averaged Navier-Stokes often abbreviated as RANS. While a RANS code solves the Navier-Stokes equations based on time averaged turbulence modeling, XFlow solves the Boltzmann equation, utilizing large eddy simulation (LES) for turbulence modeling. RANS represents a time averaged snapshot of the flow, while XFlow's Boltzmann method is inherently transient in nature.

XFlow features a Lattice-Bolzmann particle based environment, with no meshing, and allows 6 DOF motion with no limit on complexity of geometry. The distributed (DMP) solver makes use of MPI supporting both HPC clusters

* Corresponding author. *E-mail address:* mikko@wb-sails.fi

with a shared file system, or a group of workstations without a shared file system. One of XFlow's partners is Teide HPC (2), where the software is successfully deployed.

XFlow's data storage requirements are large, typically 0.5-1 Terabytes per run. However, since all the post-processing is done remotely on the HPC platform, very little data transfer is needed for running an analysis.

During the project, Next Limit Dynamics, the company developing Xflow, was acquired by the simulation giant Dassault Systémes.

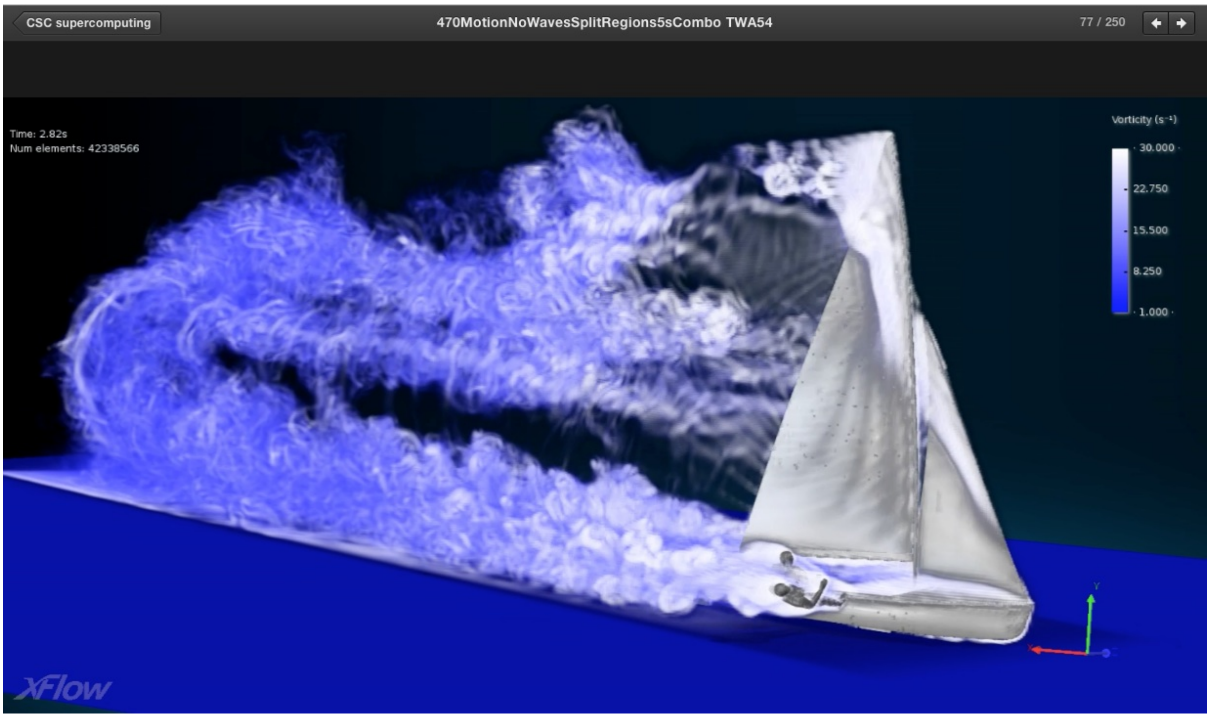

Figure 1: *A 470 class boat simulated pitching in waves. Runtime 13.7 hours on 192 cores/12 nodes with 42 million elements. The same simulation on desktop would take about 19 days.*

3. CFD modelling with Xflow in the CSC Taito supercluster

The Xflow CFD code was deployed on the CSC Taito supercluster (3). Taito is a 16 cabinet HP cluster based on commodity off-the-shelf building blocks. The theoretical peak performance of the cluster, calculated on the aggregate performance of the computing nodes, is about 600 TFlop/s.

Taito has a total of 983 compute nodes that use either Intel *Haswell* or *Sandy Bridge* processors which are well suited for high performance computing. There are 407 Apollo 6000 XL230a Gen.9 server blades, installed in November 2014, and 496 (Sep 10th 2015) older HP Proliant SL 230s Gen8 half-tray servers. The 407 most recent servers host two twelve core Intel Haswell E5-2690v3 processors, running at 2.6GHz. The older blades host two eight-core Intel Sandy Bridge 2.6 GHz processors (Intel E5-2670, 64bits). This means that there are in total 18984 computing cores available in the cluster. For this project, Haswell nodes were used.

On Taito, Xflow was run with MPI through a launcher script tailored for CSC by Ruddy Brionnaud, XFlow Lead Application Engineer. The script generates the simulation domain and binary files needed for the parallel MPI run. The project, with all the geometries, would need to be created off-line in a local copy of XFlow, and uploaded to Taito before the execution of the launcher-script. Alternatively, CSC offered an experimental VNC-connection to Taito-GPU, where one could prepare the whole project and generate the domain and binaries in a single GPU node, running the full, graphical GUI of XFlow. This was very helpful and practical, as the GPU node also allowed follow-up and post-processing of the batch run, as if the project was run locally.

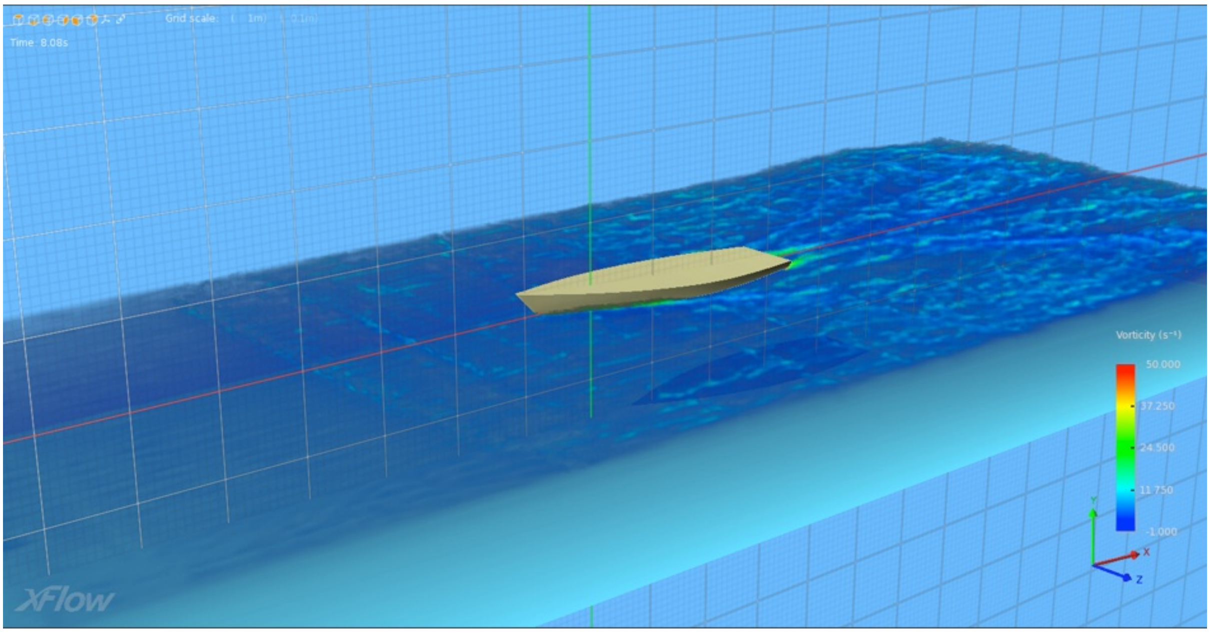

Figure 2: *The free surface engine tested with MPI with a Laser class model. Results correlate fairly well with tank tests performed at Chalmers.*

4. Challenges and results

One of the challenges in the project was that XFlow currently only supports adaptive refinement in serial and not in parallel mode. In parallel mode, the domain has to be split into regions, with higher resolution in areas where refinement is desired. While XFlow's adaptive refinement is a very powerful way of saving computational resources, without it lots of resources are wasted in areas of less interest, where a smaller resolution would be sufficient. Hence, the power of parallelization is not fully realized in the HPC version.

In scaling tests, XFlow would scale well as soon as the element count was 15-20 million or more, with an efficiency around 0.88. For smaller element counts, typical of desktop work with adaptive refinement, scaling efficiency was worse. A low resolution, 5.2 million element job on 256 cores/16 nodes would run in 3 hours. On 192 cores/12 nodes, up to 56 million elements was tested. More cores could not be used, due to a bus/memory error. The reason for this was unresolved, but was possibly associated with the memory reservation scheme in the XFlow launcher script.

Another challenge was that during the project it turned out that due to its ownership policy CSC could not provide core hours for free for the project. As an alternative, DECI access was considered and successfully applied for. However, due to challenges associated with simulation environment setup and support, this choice was discarded and instead a number of schemes with CSC and Next Limit Dynamics were suggested. Unfortunately, no mutually agreeable solution was found despite all the effort.

Also, no mutually satisfying way to provide for the license fees associated with Next Limit Dynamics could be agreed upon. Therefore, the original plan of running FSI simulations coupled with Nastran had to be abandoned. The actual runs consisted of testing with several models, both in air alone and two-phase with a free surface, with different resolutions and computational resources. Even if limited, these test were most valuable in learning how HPC could be used to enhance simulation compared to working on the desktop.

For the reasons above, the results of the project were more qualitative than quantitative in nature. Typical results are illustrated in Figure 1, Figure 2 and Figure 3, showing some of the simulations that were performed using XFlow at CSC. In Figure 1, XFlow's ability to handle motion is demonstrated by a boat pitching in waves. In Figure 2, we study the free surface engine, with a model of the Olympic Laser boat. Finally, Figure 3 shows vorticity around a Finn class boat sailing upwind, at a relatively high resolution of 43 million elements.

As a whole, taking on parallel computing in HPC proved to be a more complicated process than WB-Sails had anticipated. A lot of time was spent in understanding and learning the basics. During the whole process, support from both Next Limit Dynamics and CSC was more than outstanding, far beyond what could be expected as ”normal support”. Both seemed endlessly patient in helping out and solving obstacles met in the project.

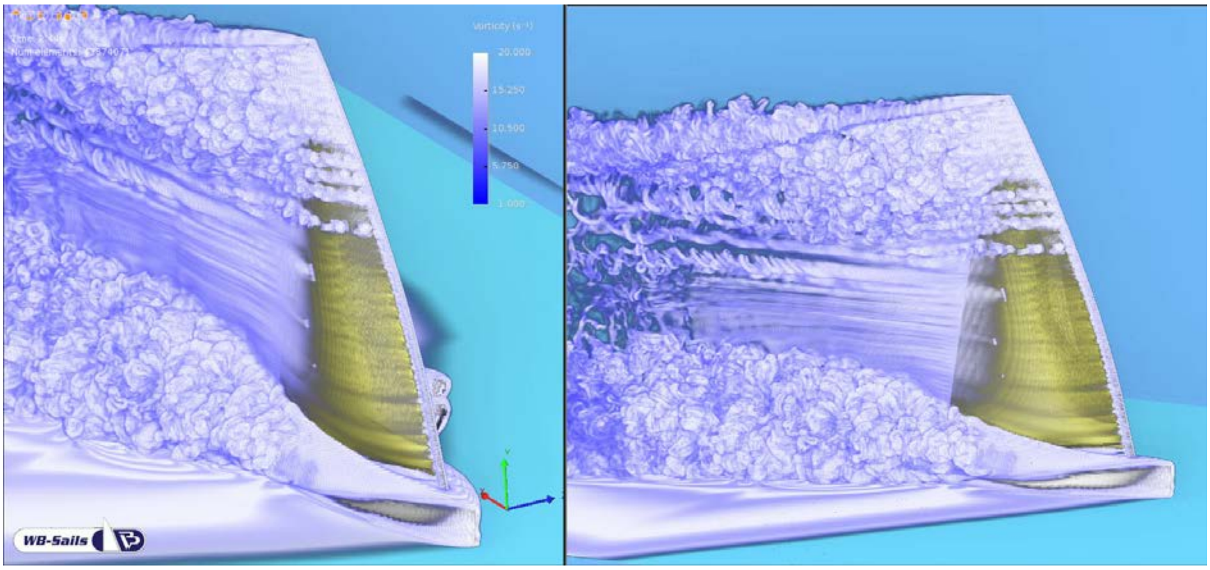

Figure 3: *Turbulence around a Finn-class sailing boat.*

5. Summary

The CFD code XFlow was successfully deployed at CSC. WB-Sails was well educated into the use of HPC. Despite not meeting the original simulation targets, the project proved a success and extremely useful for WB-Sails as an introduction to HPC. Hopefully what was learnt can be put fully into use in a future project.

6. References

1. **http://www.xflowcfd.com/. [Online]**
2. http://teidehpc.iter.es/en. [Online]
3. https://research.csc.fi/csc-s-servers#taito. [Online]

Acknowledgements

This work was financially supported by the PRACE project funded in part by the EU’s Horizon 2020 research and innovation programme (2014-2020) under grant agreement 653838.