This case study was created as part of the free and voluntary
UberCloud Experiment

Aerodynamic Simulation of an Airfoil using UberCloud Containers on Microsoft Azure

Key Findings

- Complex OpenFOAM simulations require big hardware. Microsoft Azure proved equal to the task.
- The cloud enables advanced computations that could never be attempted on a normal workstation.
- The combination of Microsoft Azure, UberCloud Containers, and OpenFOAM required minimal setup and produced outstanding results.

An UberCloud Technical Case Study

This document one of the more than 200 technical case studies that have been generated by engineering teams participating in the UberCloud Experiment. You will benefit from the candid descriptions of the problems they encountered, innovative solutions, and lessons learned.

Coping with Complexity

Accurately predicting flow behavior around an airfoil can be a technically complex challenge.

It involves defining appropriate eyelet and element sizes for the mesh model – the finer the mesh, the higher the simulation runtime. An additional challenge was to perform the simulation within a stipulated timeline for the project.

Evaluating Microsoft Azure

The other major challenge for the team was defining the process to use the cloud. This included registering on the Azure cloud platform and learning to use its many features.

The team performed the aerodynamic study with an incompressible airflow around a 2D airfoil. The model setup included preparing the geometry for a surrounding air volume with the airfoil profile at the center. The airfoil profile needed to be accurately modeled to capture the variation in the airflow pattern around the airfoil.

The model was setup in OpenFOAM, an open source software application and the CFD simulations were performed on Microsoft Azure. The main objective of this study was to evaluate the HPC performance of Azure.

THE TEAM

- Praveen Bhat, Technology Consultant and the project's end user and CFD (Computational Fluid Dynamics) expert
- ESI Group, provider of OpenFOAM software
- Microsoft Azure with UberCloud OpenFOAM Container was the resource provider.

> *The combination of Microsoft Azure with UberCloud's OpenFOAM container, showcased the possibilities and ease of performing highly complex simulations in the cloud*
>
> — Praveen Bhat
> Technology Consultant and CFD expert

SETTING UP THE SIMULATION USING OPENFOAM

The mesh density was very fine around the airfoil and along the path of the trailing edge. The grid was modeled more coarsely as it moved away from the airfoil (air inlet and outlet). Using Open FOAM, the team performed the following steps to set up the simulation:

- We created a Finite Element volume mesh model and defined the fluid properties. The volume surrounding the airfoil was treated as incompressible air.

- The fluid properties were defined to be Newtonian, which posits a linear relationship between the shear stress (due to internal friction forces) and the rate of strain of the fluid.

- The atmospheric air was with a phase transition from turbulent to laminar in the region near the airfoil. Because of this transition, we needed to refine the mesh model accurately near the airfoil region and define the turbulent behavior of the air. Defining turbulence models typically captures this behavior – in this case we used a Spalart – Allmaras turbulence model.

- Next we defined model boundary conditions and assigned the initial values for pressure and velocity. Boundary conditions were assigned where the airfoil edges were considered as walls. Three sides were inlets; the edge following the trailing edge of airfoil was considered as air outlet.

- We then set up the solution algorithm. The problem was solved as steady state using the SimpleFOAM OpenFOAM solver. The solution parameters were: Start time: 0 sec; end time=500 sec; time step= 1sec. SimpleFOAM used the Gauss-Seidel method. The pressure field was provided with a relaxation factor of 0.3 and the velocity field was assigned a relaxation factor of 0.7. Along with the relaxation factor, the residual parameter was set at $1x10^{-5}$. The above parameters defined the convergence criteria of the model

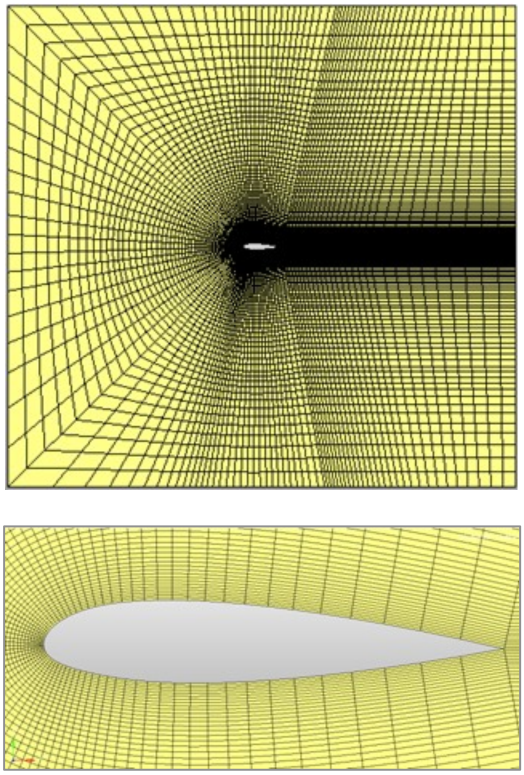

Figure 1:

- The OpenFOAM model was then modified for parallel processing with the existing model decomposed according to the number of the available compute nodes. We created independent processes for the decomposed model with each process on one processor.

- The model was solved in parallel and once the solution converged, the decomposed solved model was reconstructed to get the final results.

REVIEWING THE RESULTS

We viewed the output of the airfoil simulation in ParaView - the post-processing software tool. The flow of air and laminar behavior observed in the airfoil region is shown in the plots below.

Figure 2 shows the pressure variation around the airfoil with the low-pressure region at the upper section of the leading edge of the airfoil, and a higher-pressure region in the lower section of the leading edge.

Figure 3 shows the low pressure and high-pressure variation section in the air volume. The high-pressure section near the airfoil creates the lift forces. This lift on the airplane wing conforms to Newton's third law with a downward reaction force on the airfoil. This lift should be consistent since it is based on the conservation of energy in the fluid.

Angle of attack is the orientation of the airfoil cord with respect to the travel direction. The state of stall can be analyzed by determining the pressure co- efficient distribution over the airfoil for various angles of attack. It allows us to evaluate how the pressure co- efficient varies with the increase or decrease in the angle of attack.

They achieved this goal by defining the appropriate eyelet size for the mesh model. This included a highly accurate prediction of flow behavior, achieved by defining the appropriate element size to the mesh model – the finer the mesh, the higher the simulation runtime. An additional challenge was to perform the simulation within a stipulated timeline for the project.

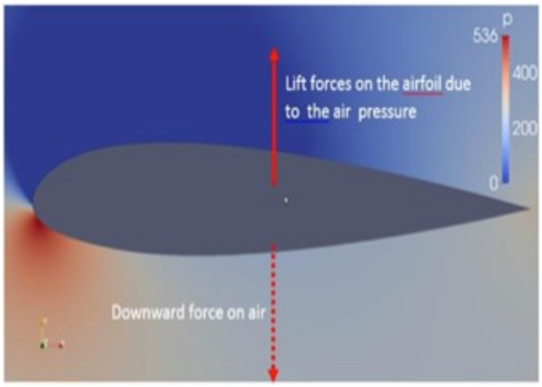

Figure 2: Pressure distribution around airfoil with high & low pressure zone.

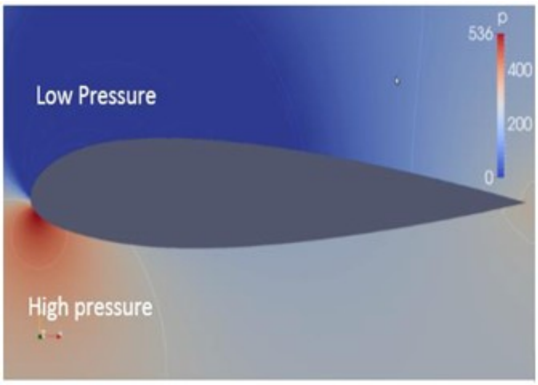

Figure 3: Lift forces represented in the airfoil.

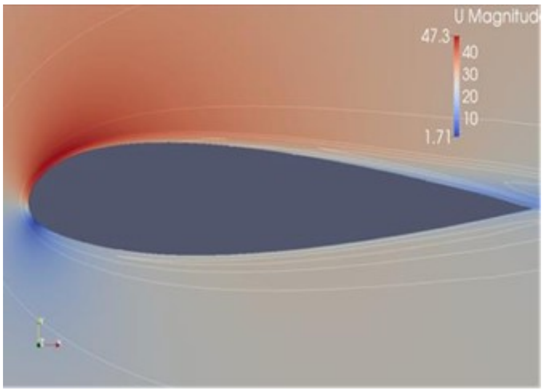

Figure 4: Velocity contour of streamlines.

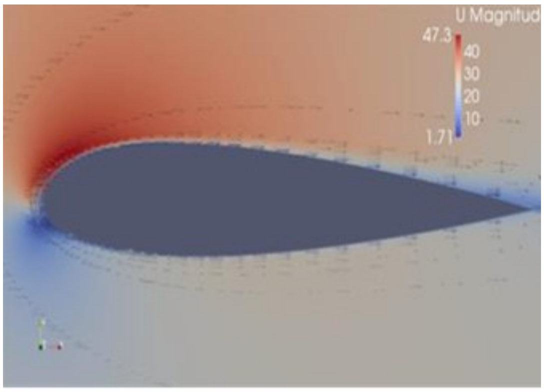

Figure 5: Velocity contour with airflow vectors.

HPC PERFORMANCE BENCHMARKING

The HPC system was a 32 core system with a 32GB RAM CentOS v6 operating system. The software application was OpenFOAM version 2.3 with pre-installed MPI and ParaView software in the UberCloud container. The container was integrated with the Microsoft Azure cloud platform.

We evaluated the model to determine the accuracy of the predicted air flow behavior around the airfoil. We developed different finite volume models for fine and coarse meshes and captured the time required to solve the model with different mesh densities. The boundary conditions, solution algorithm, solver setup and convergence criteria remained the same for all the models. The simulations were performed on Azure G5 virtual machine instances featuring latest Intel Xeon processor E5 v3 family.

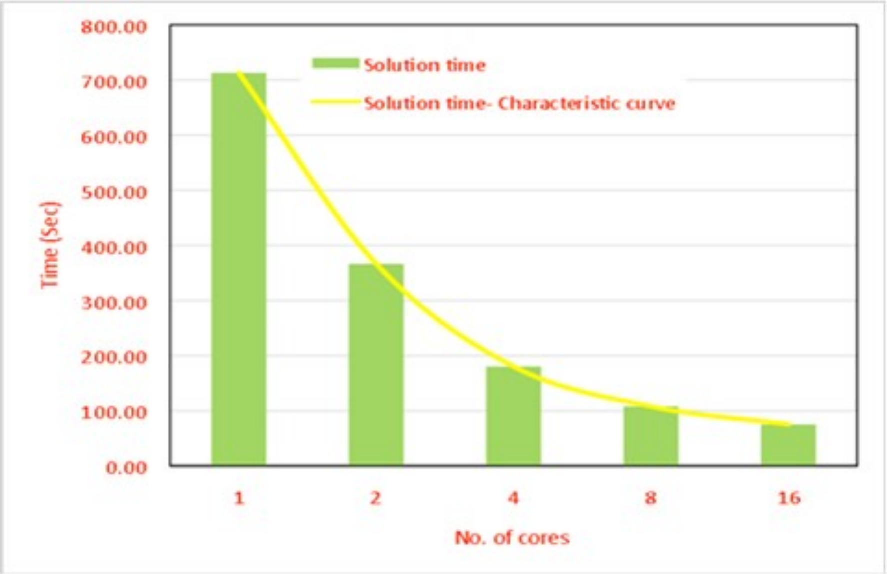

Figure 6: Faster Solution Time with More Cores on Cloud HPC

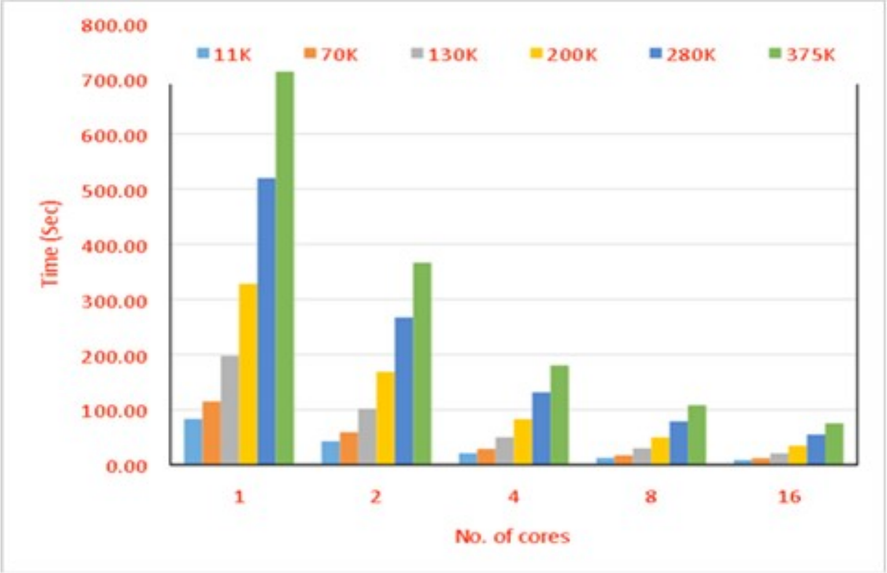

Figure 7: Higher Quality Results With More Cores

LESSONS LEARNED

Easy Model Generation Dramatically Faster Processing

The UberCloud container environment with OpenFOAM and ParaView made the process of model generation extremely easy. This approach dramatically reduced processing times, including results viewing and post-processing.

In addition, we were able to generate mesh models for different cell numbers and perform the experiments using coarse-to-fine to highly fine mesh models. The OpenFOAM container helped us achieve smooth completion of the simulation runs without re-trials or resubmission.

The computation requirement for a highly fine mesh (2 million cells) is substantial and almost impossible to achieve on a normal workstation. However the HPC Cloud capabilities provided by the UberCloud made it feasible to solve highly fine mesh models with the simulation time drastically reduced. This allowed us to obtain the simulation results within an acceptable run time (~30 min).

The experiments performed in the HPC Cloud environment gave us the confidence to setup and run the simulations remotely in the cloud. The different simulation setup tools required were installed in the UberCloud OpenFOAM container, which enables the user to access and use the tools without any prior installations.

With UberCloud's VNC Controls in the Web browser, the HPC cloud access was very easy, requiring minimal or no installation of any pre-requisite software. The user experience was similar to accessing a website via a browser.

The UberCloud containers provided smooth execution of the project with easy access to and use of the server resources. The regular UberCloud email auto-update module allowed us to continually monitor the job in progress without having to log-in to the server and check the status.

The integration to the Microsoft Azure platform also proved to be powerful – it facilitated running parallel UberCloud containers and the Azure let us view system performance and usage.

Recommendations

We found that UberCloud's containerized OpenFOAM on Microsoft Azure was a great fit for performing complex simulations that involved huge hardware resource utilization and large numbers of simulation experiments.

We could perform advanced computational experiments that involved complex technical challenges that could not be solved using a normal workstation.

There are a variety of high-end commercial software applications that can be used to perform virtual simulations. OpenFOAM -- an open source tool designed for HPC environments -- helped us solve this problem with minimal effort in setting up the model and performing the simulation trials.

The combination of Microsoft Azure, UberCloud Containers, and OpenFOAM helped in speeding up the simulation trials and also allowed us to complete the project within the stipulated time frame.

ABOUT UBERCLOUD

UberCloud makes it easy to run your simulations on powerful cloud infrastructure.

No more compromises on mesh quality or model fidelity because of hardware limitations. With UberCloud's flexible software platform and network of cloud partners, you get on-demand access to major providers such as Microsoft Azure, HPE and others. Choose from a variety of secure data centers, and hardware options such as InfiniBand, GPUs etc.

Unleash the full power of your analysis software and boost confidence in your results.

With over 200 technical-computing-as-a-service case studies, UberCloud has the experience, software platform and partnerships required for your success.

Engineers and scientists rely on UberCloud to manage the complexity of cloud and software operations, so they can focus on their analysis.

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