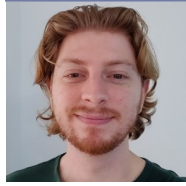


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Joseph is a final year PhD student within the department of Mechanical Engineering. His research focusses on simulating blood flow in artificial hearts to predict their compatibility with the human body.



Improving Heart Failure Outcomes: Using Nimbus for the Simulation of Blood Flow in a Total Artificial Heart

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Figure 1: The Realheart TAH, by Scandinavian Real Heart AB.

"Joseph's research on simulating blood flow in artificial hearts using Nimbus HPC resources unlocks insights into total artificial heart performance, advancing biocompatibility and patient outcomes"

Heart failure affects millions worldwide, with numbers only expected to increase in the coming years [1]. For those with end-stage heart failure, a heart transplant is the gold standard treatment. However, the number of available donor hearts is limited, with the number of patients on the heart transplant waiting list growing over the last decade [2]. To alleviate this shortfall, doctors can turn to mechanical circulatory support, such as total artificial hearts (TAHs), to bridge the gap to transplant. Assessing these devices to ensure they are compatible with the cardiovascular system is a key concern and can be investigated using *in silico* tools such as computational fluid dynamics (CFD).

Joseph's research investigates the haemodynamics of a novel total artificial heart, the Realheart TAH (Scandinavian Real Heart AB, Sweden), a positive-displacement pump that mimics the mechanics of the native heart to produce pulsatile blood flow (Figure 1). Utilising ANSYS Fluent (V2023R2), he combines CFD and fluid-structure interactions (FSI) for the flow driven motion of valves to accurately simulate the fluid flow response and potential negative side effects of the Realheart TAH under a wide range of operating conditions. The instability of the heart valves is accentuated by their in-series combination and necessitated the implementation of a novel, in-house FSI method [3]. Such a complex model requires extensive computational power, something not readily offered by local compute options.

This application therefore was an ideal use case of the HPC resources offered by Nimbus. By varying the heart rate and

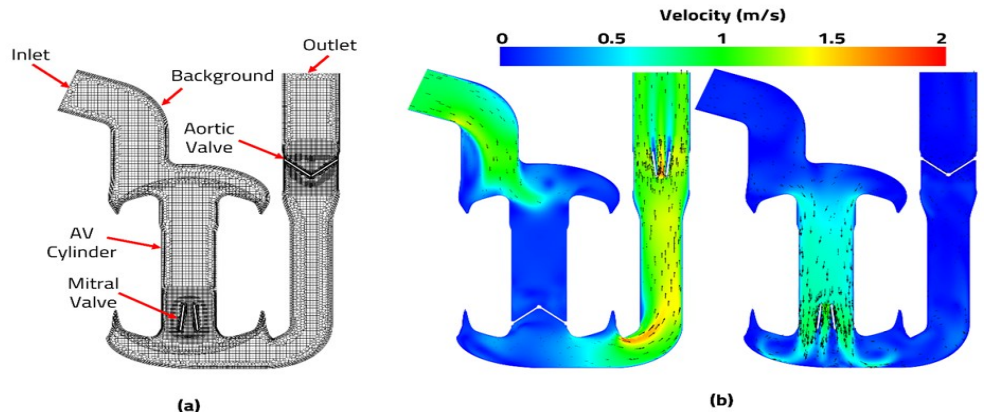


Figure 2: (a) CFD mesh and boundary conditions of the Realheart TAH (b) Velocity contour plots during systole and diastole.

stroke length of the device, he produced 16 different operating conditions to be simulated. With 32 cores per simulation, he used the HC-44 nodes with Intel Xeon Platinum CPUs to simulate the different conditions in parallel, noting that this node offered the best price to performance of all the compute options for a simulation of this kind. Each simulation was solved for a total of 5 heartbeat cycles, taking approximately 45 hours to solve, generating up to 200GB per operating condition. To manage data storage efficiently, Joseph implemented strategies such as periodic transfers to local storage and automated email alerts for simulation status updates. In total, almost 25k CPU hours were utilised, speeding up the time taken to obtain results by at least 32x compared to sequentially solving all 16 conditions on a local machine. The results (figure 2) were validated against experimental data generated by a hybrid cardiovascular simulator, showing that the model was accurate and robust across all the operating conditions.

By utilising Nimbus resources, the comprehensive assessment of the performance of a total artificial heart was achieved, paving the way for future analyses that could unlock improvements to biocompatibility and ultimately patient outcomes. Joseph's work was published in Scientific Reports in 2023 [3].

References

1. Bragazzi, N. L. et al. Burden of heart failure and underlying causes in 195 countries and territories from 1990 to 2017. *Eur. J. Prev. Cardiol.* 28, 1682-1690.
2. NHS Blood and Transplant. Organ and tissue donation and transplantation-activity report 2022/23 (2023).
3. Bornoff, J., et al. "Overset Meshing in Combination with Novel Blended Weak-Strong Fluid-Structure Interactions for Simulations of a Translating Valve in Series with a Second Valve." *Computer Methods in Biomechanics and Biomedical Engineering*, 2023, pp. 1-15.
4. Bornoff, Joseph, et al. "Fluid-Structure Interaction Modelling of a Positive-Displacement Total Artificial Heart." *Scientific Reports*, vol. 13, no. 1, 2023, p. 5734.

Running Singularity GPU Applications Using Slurm on Nimbus

In the last two articles published in Issue 1 and Issue 2, we demonstrated how CPU applications can be run on Nimbus using Singularity. In today's era of accelerated computing, leveraging the power of GPUs has become essential for executing workloads with GPU-accelerated applications. However, deploying GPU-accelerated applications can be complex, especially when considering the diversity of GPU architectures across different systems. In this article, we explore how to launch GPU-accelerated applications inside containers on Nimbus, ensuring portability and flexibility.

Example Slurm Script to Run GPU Application Singularity Container

Example-1: Executing a GPU burn test from inside the container (**gpu.sif**) using the CUDA module available inside the container only. The output displays the version of CUDA and the burn test code results, neither of which were installed on Nimbus.

```
# The slurm job script to run on 1 GPU card.
[user@nimbus-1-login-1~]$ cat test_gpu.sh
#!/bin/bash
#SBATCH --job-name=test_gpu_container
#SBATCH --output=test_gpu_%A%.out
#SBATCH --error=test_gpu_%A%.err
#SBATCH --account=CA-CS1HGN-001
#SBATCH --qos=spot-ncv3-6
#SBATCH --nodes=1
#SBATCH --ntasks-per-node=2
#SBATCH --partition=spot-ncv3-6
#SBATCH --gres=gpu:1
#SBATCH --time=01:00:00

module load Singularity/4.0.0
output_file="test_gpu.txt"

echo "Running task ${SLURM_JOB_ID} on node:
${SLURM_JOB_NODELIST}" >> $output_file

echo "Check if cuda is available inside the
container" >> $output_file
singularity exec gpu.sif nvcc --version >>
$output_file

singularity exec --nv gpu.sif /opt/gpu-burn/
gpu_burn.sh >>$output_file
```

Modify the scripts according to your nimbus account. The container image is available in Nimbus directory: **/apps/container_images/examples**

```
# Submit the job
$ sbatch test_gpu.sh

# Check the output file
$ cat test_gpu.txt
```

```
Running task 67156376 on node: nimbus-1-spot-ncv3-6-pg0-5
```

```
Check if cuda is available inside the container
```

```
nvcc: NVIDIA (R) Cuda compiler driver
Copyright (c) 2005-2017 NVIDIA Corporation
Built on Fri_Sep_1_21:08:03_CDT_2017
Cuda compilation tools, release 9.0,
V9.0.176
```

```
GPU 0: Tesla V100-PCI-E-16GB (UUID: GPU-7f72d38f-fb46-7f6d-b5fa-26ce7a556e6b)
10.8% proc'd: 8860 (13196 Gflop/s) errors: 0 temps: 37 C
Summary at: Wed Nov 22 15:04:08 GMT 2023
```

```
.
.
98.3% proc'd: 89486 (13192 Gflop/s) errors: 0 temps: 52 C
Summary at: Wed Nov 22 15:05:53 GMT 2023
```

```
100.0% proc'd: 92144 (13194 Gflop/s) errors: 0 temps: 52 C
Tested 1 GPUs:
GPU 0: OK
```

HPC News and Updates

Nimbus Onboarding Training Announcement

Join us for the Nimbus HPC User Onboarding Training on **April 10th, 2024**. This half-day morning session is ideal for new Nimbus users or those curious about its benefits. Register using the link below which also has the agenda to secure your spot:

<https://forms.office.com/e/WcYUjELG2m>

Tip of the Month

The slurm command **"seff"** provides valuable insights into the resource usage of both running and completed jobs on Nimbus. By analyzing CPU and memory efficiency, users can make informed decisions about the suitability of instances for their workloads on Nimbus.

```
[user@login1 ~]$ seff jobid
```

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