Comparison between NEK5000 and Xcompact3D

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1 Case for Comparison

Flow over cylinder at $Re = 40$ was simulated using NEK5000 and Xcompact3D to compare the codes in terms of accuracy and performance. The flow properties have been studied by **Kawaguti (1953)** and **Taneda (1955)**. The data from the steady flow analysis by Kawaguti and experiments by Taneda are used for comparison.

Six simulations where performed by varying the number of elements as well as the domain height.

Table 1: Labels for different simulations.

Label	**Description**
X3D-LR	Low resolution simulation using Xcompact3d with a domain height of $16D$
X3D-HR	High resolution simulation using Xcompact3d with a domain height of $16D$
X3D-H20	Low resolution simulation using Xcompact3d with a domain height of $20D$
NEK-P6	Simulation using NEK5000 with a domain height of $16D$ and 5th Order Polynomial
NEK-P8	Simulation using NEK5000 with a domain height of $16D$ and 7th Order Polynomial
NEK-H20	Simulation using NEK5000 with a domain height of $16D$ and 5th Order Polynomial

2 Results

2.1 Performance

All the simulations were run on an HPC using 36 cores. We compare the time taken by each code to compute 1 second of flow i.e.

$$\tau = \frac{\text{Compute Time}}{\text{Simulation Time}}$$

Table 2: Performance comparison of the different simulations

Label	**No. of Elements**	**dt**	**Simulation Time (s)**	**Compute Time (Hr)**	τ **(hr/s)**
X3D-LR	526336	0.00025	40	0.7967	0.019917
X3D-HR	657920	0.000125	60	5.063	0.084383
X3D-H20	657920	0.00025	30	0.8544	0.02848
NEK-P6	7000	0.005	60	1.0046	0.01674
NEK-P8	7000	0.005	60	5.35	0.089166
NEK-H20	9300	0.005	60	1.2163	0.02027

NEK-P6 has the smallest value of τ i.e. it has the best performance among all the simulations.

2.2 Accuracy

The accuracy of the simulations are tested by comparing four parameters

- Drag Coefficient
- Velocity Distribution along the x-axis
- Length of Twin-vortices
- Angular position of flow seperation

The values of the following parameters are compared with the results of steady-state numerical computation of the flow by **Kawaguti (1953)** which are in good agreement with the experimental results as shown by **Taneda (1955)**.

Drag Coefficient

The drag coefficient for a flow over a cylinder at Re=40 is 1.6177. The closest value of drag coefficient among all the simulation were obtained by all the NEK5000 simulations i.e. 1.921 (18% Error). The time evolution of drag coefficient for all the simulations is presented in **Figure 1**.

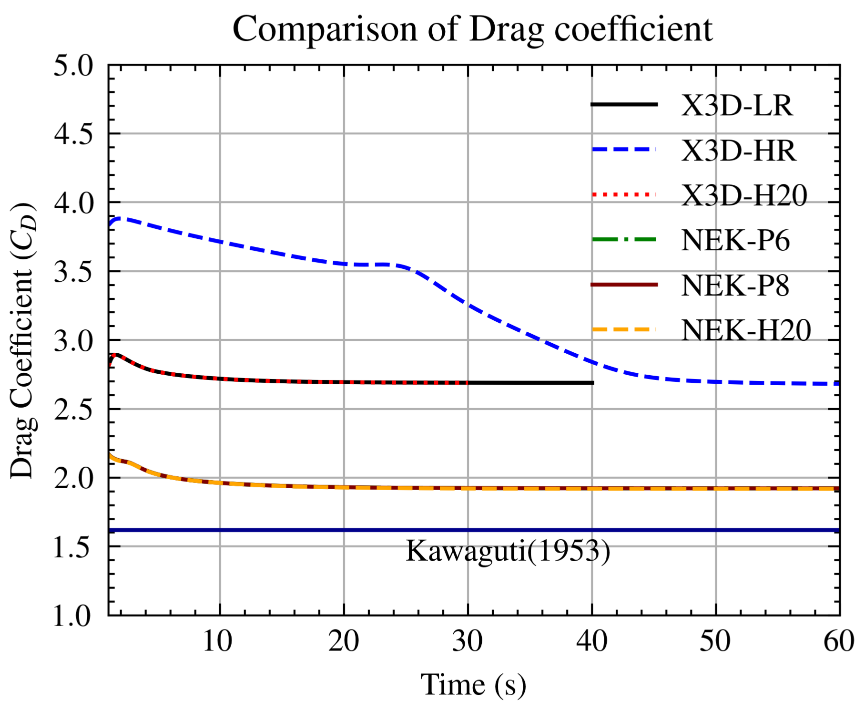

Figure 1: Time evolution of C_D for the different simulations.

We observe that increasing the domain height from $16D$ to $20D$ didn't affect the drag values as the plot for NEK-P6 and NEK-H20 coincide with each other. The same is also observed with X3D-LR and X3D-H20 cases.

Velocity Distribution along the X-axis

The time evolution of the velocity at two points is plotted to find the instant when flow reaches steady-state. The velocity along X-axis after flow has reached steady state is compared with the results of **Kawaguti (1953)**.

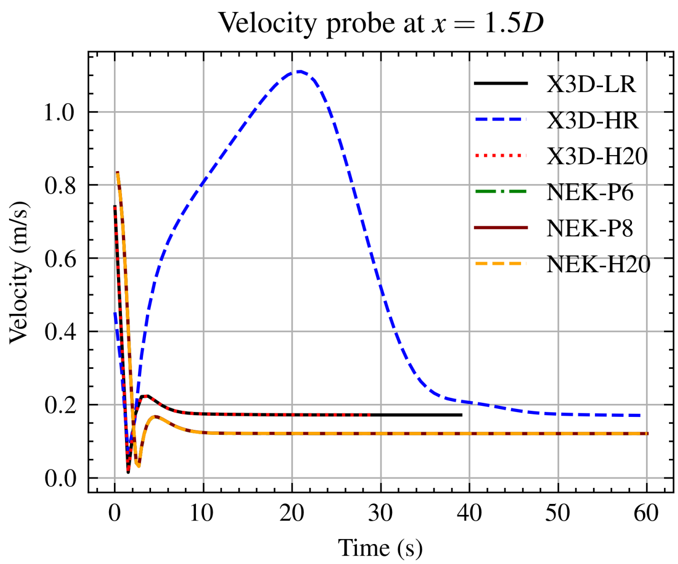

Figure 2: Time evolution of velocity magnitude at $x = 1.5D$ for the different simulations.

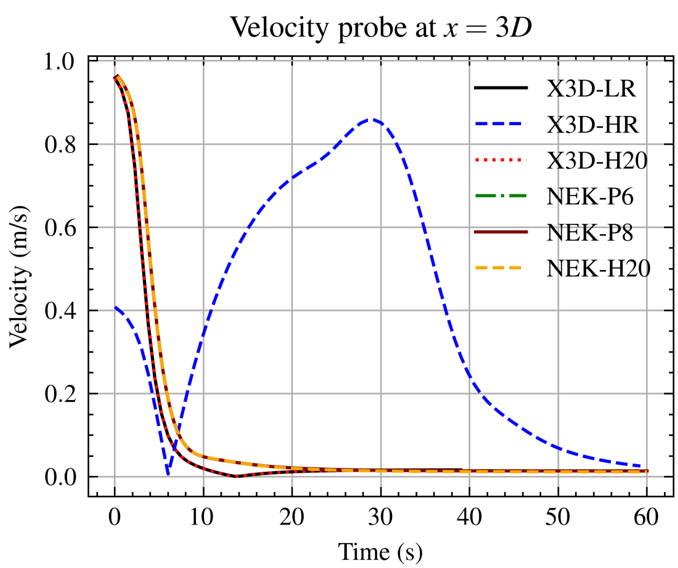

Figure 3: Time evolution of velocity magnitude at $x = 3D$ for the different simulations.

In **Figure 2** and **Figure 3**, we observe that all the simulations except X3D-HR reach steady state after $20s$ approximately.

The flow velocity along the X-axis for all the simulations at the last time-step is plotted in **Figure 5**. Here also we can observe that plots for all the NEK5000 simulation coincide.

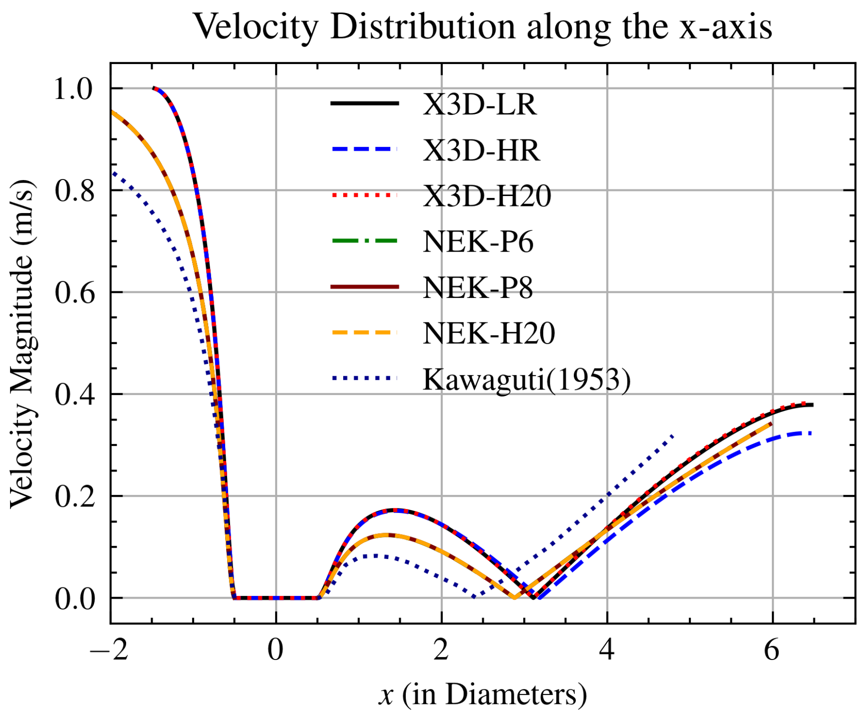

Figure 4: Varition of velocity along the X-axis after reaching steady-state.

Twin Vortices

The twin vortices is a flow characteristic of low Re flows around a cylinder such as Re=40. The length of the twin vortices (L) and angle of flow seperation from the cylinder surface (θ) are few of the many flow properties used for validation. Here, the values of L and θ obtained by **Kawaguti** and **Taneda** are presented in the following table.

Table 3: Twin Vortices length L and the seperation angle θ used for reference.

Source	**L**	θ
Kawaguti (1953)	1.9 D	52.2°
Taneda (1955)	2.1 D	53°

Table 4: Twin Vortices length L and the seperation angle θ for different simulations.

Source	**L**	θ
X3D-LR	2.6 D	50.32°
X3D-HR	2.65 D	54.81°
X3D-H20	2.6 D	50.8°
NEK-P6	2.37 D	54.17°
NEK-P8	2.37 D	54.03°
NEK-H20	2.37 D	53.77°

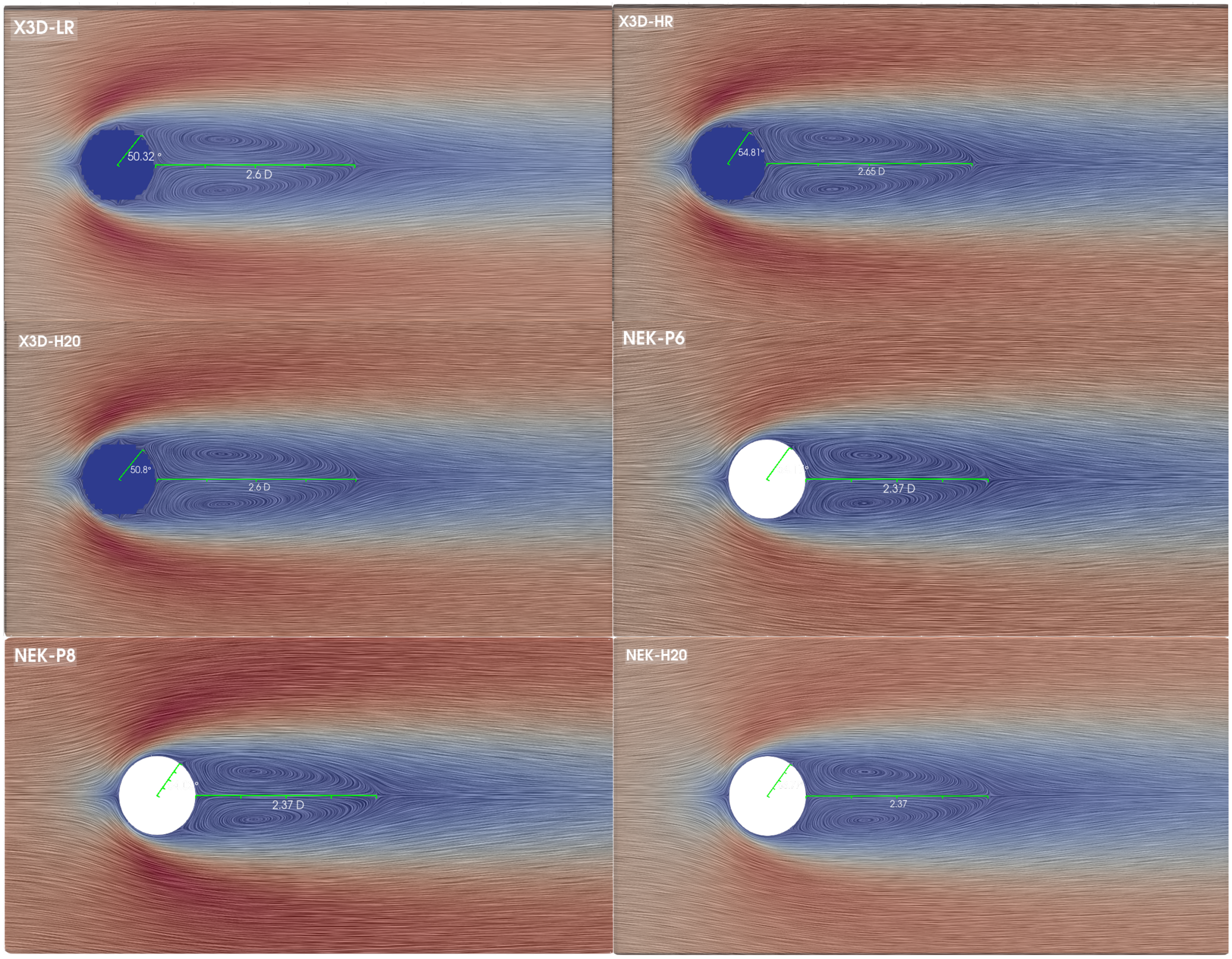

Figure 5: Twin Vorticies formed behind the cylinder for different simulations.

3 Conclusion

From the above comparison, we observe that NEK5000 simulations are more efficient and accurate in comparison to the Xcompact3D simulations. The accuracy of the NEK5000 simulations can be improved further by increasing the number of elements near the cylinder body while keeping the domain big enough such that the far-field boundary condition is achieved. NEK5000 simulations allow mesh refinement in all directions unlike Xcompact3D and hence require less number of elements to achieve much better accuracy.