Advanced Problem 2

Jacob Mills and Isaac Smith

October 12, 2020

1 Setup and Grid Generation

For this case the $k - \varepsilon$ and $k - \omega$SST turbulent solvers were compared at Reynolds numbers of $10,000$ and $600,000$. Using the Reynolds numbers, the constants used were calculated as seen in Table 1. The grid (see Figure 1) was generated using $10,000$ cells. The generated grid used 4 blocks and were arrayed in quarters of a annulus with the inner ring being the cylinder wall. The inner ring was $10cm$ in diameter and outer ring was $4.1m$ in diameter. The mesh was heavily graded to the cylinder wall in order to achieve convergence on the boundary layer which is very thin for turbulent cases. The outlet was so close to the cylinder, special boundary conditions were used. For U, k, ε, and ω the inletOutlet boundary condition was implemented, with the outletInlet boundary condition used for p.

Table 1: Constants calculated from the Reynolds number using a velocity of $1m/s$

Reynolds Number	nu	nuT	k	ε	ω
$10,000$	$1.00e-05$	$5.00e-05$	0.00375	0.0253	6.75
$600,000$	$1.67e-07$	$8.33e-07$	0.00375	1.52	405

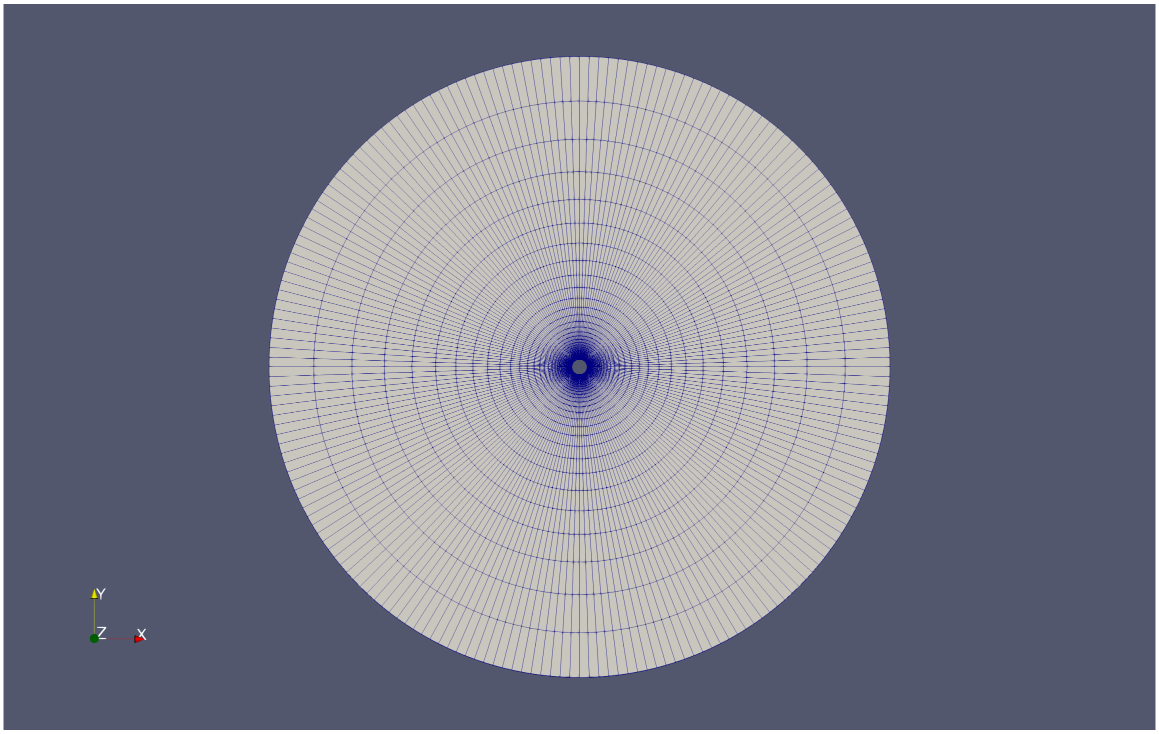


Figure 1: New Grid constructed using 10,000 cells among 4 blocks

2 Laminar

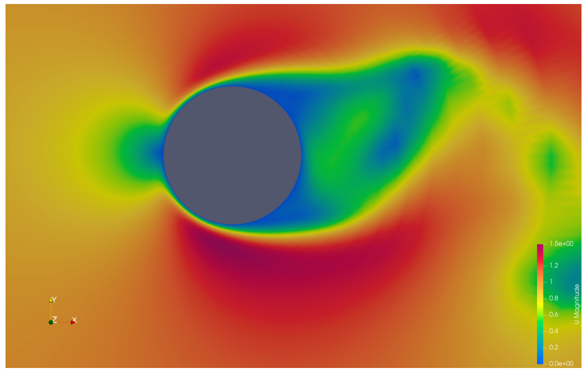


Figure 2: Velocity flood plot for laminar flow around the cylinder

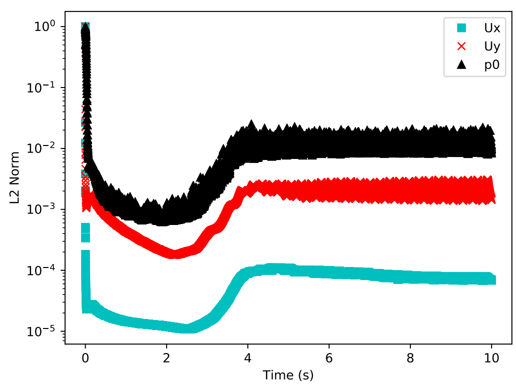


Figure 3: Convergence plot for laminar case

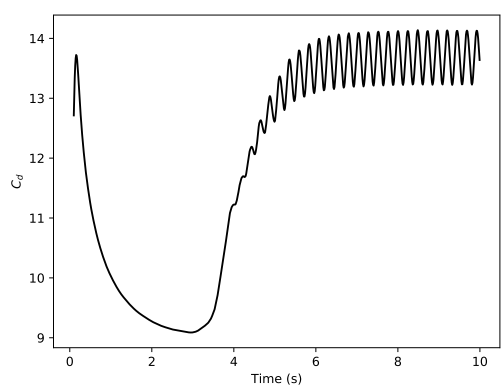
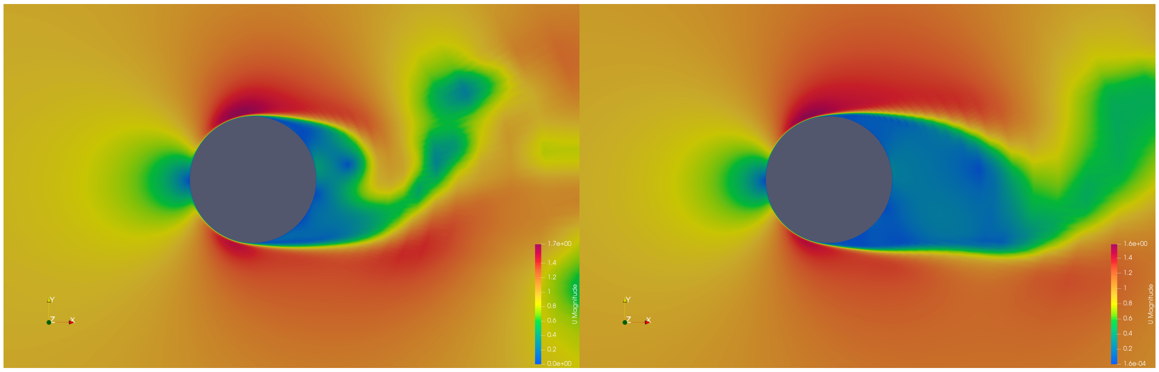


Figure 4: Drag coefficient plot for laminar case

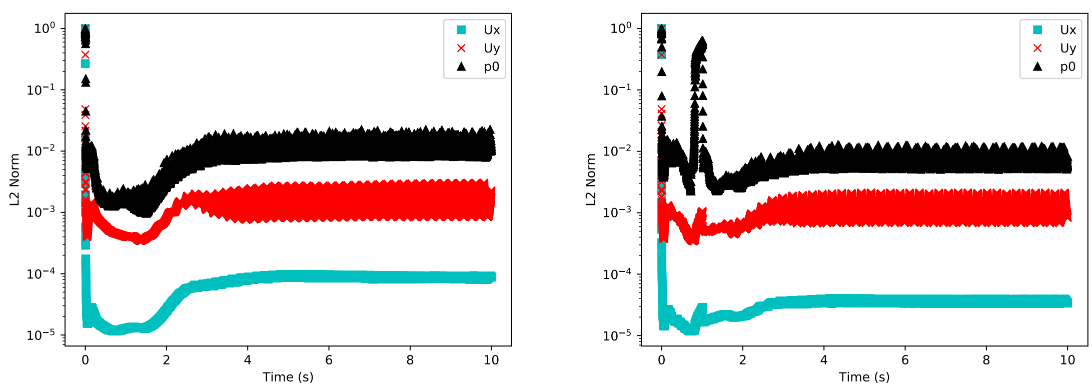
3 Re = 10,000

For the cases where the Reynolds number was $10,000$ both the $k-\varepsilon$ and $k-\omega$SST turbulent solvers were unable to achieve the correct coefficients of drag (see Table 2). Both turbulent solvers produced a drag coefficient below the 1.2 actual (see Figure 7) but only the $k-\omega$SST solver produced a stable coefficient of drag around 0.905. The $k-\varepsilon$ solver fluctuated rapidly between a drag coefficient of around 0.96 and 1.09. Flow separation occurred at around $100°$ for the $k-\varepsilon$ solver and around $90°$ for the $k-\omega$SST solver (see Figure 5). A turbulent solution should show a separation of $120°$ or more. This is indicative that both cases were not fully turbulent in the solution.



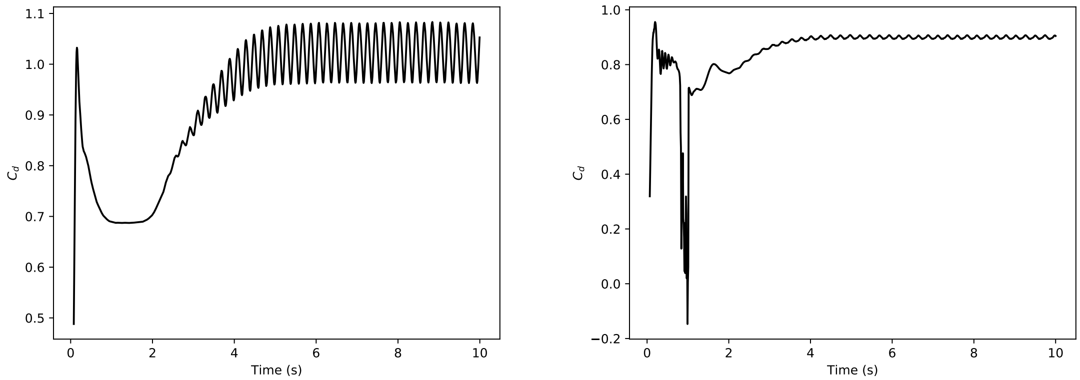
(a) Velocity Flood plot for $k - \varepsilon$ solver (b) Velocity Flood plot for $k - \omega$SST solver

Figure 5: Velocity flood plots for the $Re = 10,000$ case



(a) Convergence plot for $k - \varepsilon$ solver (b) Convergence plot for $k - \omega$SST solver

Figure 6: Convergence plots for the $Re = 10,000$ case



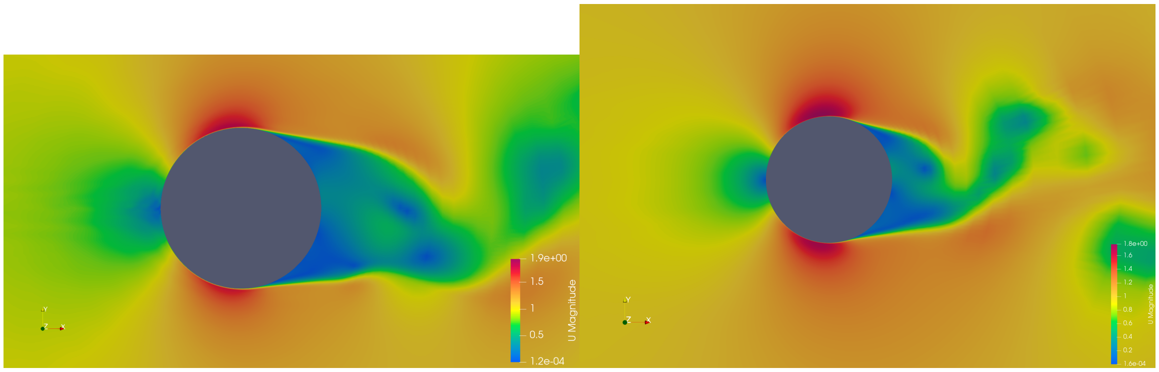
(a) Drag coefficient plot for $k-\varepsilon$ solver

(b) Drag coefficient plot for $k-\omega$SST solver

Figure 7: Drag coefficient plots for the $Re = 10,000$ case

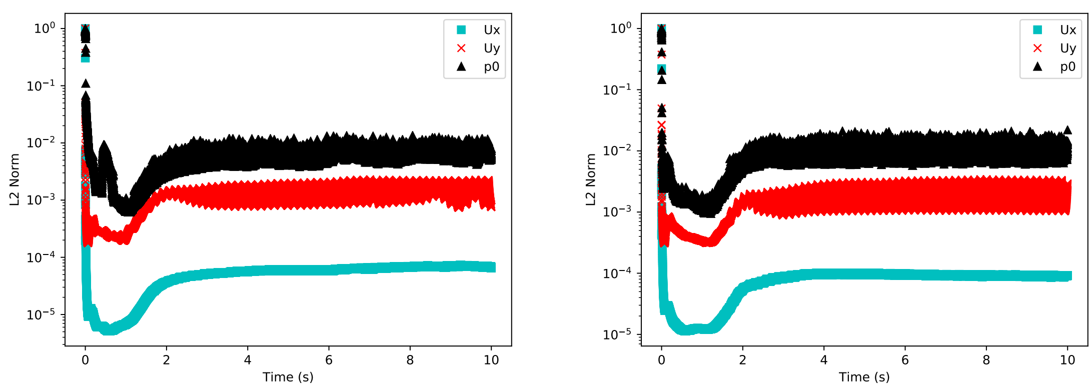
4 Re = 600,000

Both the $k-\varepsilon$ and $k-\omega$SST turbulent solvers produced drag coefficients greater than the actual for a flow with a Reynolds number of $600,000$ (see Figure 10 and Table 2). Flow separation occurred at around $110°$ for the $k-\varepsilon$ solver and around $115°$ for the $k-\omega$SST solver (see Figure 9). Both are below the $120°$ mark which indicates turbulent flow, but were much closer than the $10,000$ Reynolds number cases.



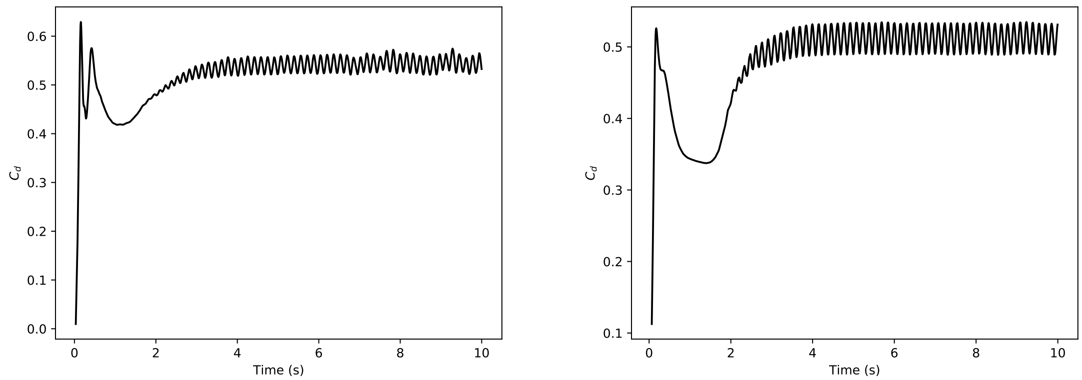
(a) Velocity flood plot for $k - \varepsilon$ solver (b) Velocity flood plot for $k - \omega$SST solver

Figure 8: Velocity flood plots for the $Re = 600,000$ case



(a) Convergence plot for $k - \varepsilon$ solver (b) Convergence plot for $k - \omega$SST solver

Figure 9: Convergence plots for the $Re = 600,000$ case



(a) Drag coefficient plot for $k - \varepsilon$ solver

(b) Drag coefficient plot for $k - \omega$SST solver

Figure 10: Drag coefficient plots for the $Re = 600,000$ case

5 Conclusions

We conclude that for both the turbulent cases, the $k - \omega$SST solvers proved to be more versatile and converging. The drag coefficient plots showcase this by highlighting the smaller oscillations at developed flow than for the $k - \varepsilon$ solvers. The two different types of solvers had vastly different velocity flow fields behind the cylinder. The $k - \varepsilon$ solvers were slightly more pragmatic, yet yielded drag coefficients that were closer to the actual measured values. We conclude that the use of both solvers is beneficial to model turbulent flow.

Table 2: Drag coefficients calculated from each solver

	$k - \varepsilon$	$k - \omega$SST	Actual
Laminar	1.41		1.5
$Re = 10,000$	1.05	0.905	1.2
$Re = 600,000$	0.421	0.489	0.3