Notes on Full Scale Computational Fluid Dynamics Simulation for LHO End X Wind Fence

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8/1/18

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Background.

Ansys Fluent Computational Fluid Dynamics (CFD) modeling can be used to simulate the effect of the proposed porous fence on wind flow around End Station X at LHO. The computational fluid domain is shown below.

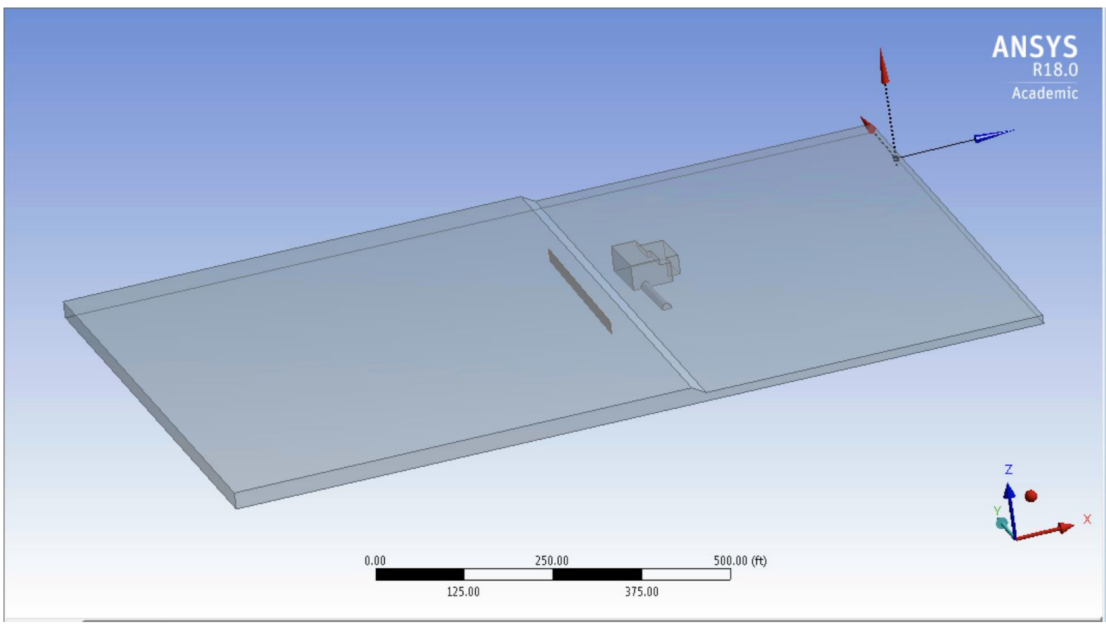

Figure 1. Computational fluid domain. The ground and the building were drawn in Solidworks and then imported into Ansys Fluent.

The building is to scale and is located 25 feet from the 12 foot high cut in the ground. The fence is 300 ft long and is located 85 feet from the building. The fence is modeled as a continuous porous jump that begins at 4 feet from the ground and ends at 24 feet from the ground. The enclosed fluid domain is not shown, but it is 300 feet high, based on recommendations to make the fluid domain as large as feasibly possible. I attempted to make it larger, but I encountered issues with the amount of time it took to mesh the fluid domain.

Note that the axes defined by Fluent are not the same as the axes defined at LHO. In Fluent, the wind blows from the x axis, whereas at LHO this would be the y axis. To avoid confusion, I will use the conventions employed at LHO. Thus, when I refer to force on the building, I am referring to wind blowing from the y axis. This analysis assumes that the wind direction is orthogonal to the building, which may not be physically accurate.

At the atmospheric boundary layer, it is more accurate to specify a logarithmic wind velocity input that depends on height rather than a constant velocity input. This logarithmic velocity input is defined in fluid dynamics literature as $v = \frac{u^*}{K} ln \frac{z+z_0}{z}$, where u^* and K are constants and z_0 is the roughness height of the bottom wall. For our model, we specified the roughness height to be 0.03 to correspond to the vegetation at LHO. We used a RNG k epsilon model to characterize the turbulent flow associated with the atmospheric boundary layer and the turbulent flow associated around bluff bodies such as End Station X. k epsilon models are the most widely used and validated turbulence models. They include two extra transport equations to represent the turbulence of the flow. The first transported variable is turbulent kinetic energy, k. The second transported variable in this case is the turbulent dissipation, ε. ε determines the scale of the turbulence, whereas the first variable, k, determines the energy in the turbulence.

For our model, we specified a constant k input and a logarithmic epsilon input that also depends on height. I defined the bottom of the flow domain to be the higher part of the ground around End X. At the top of the flow domain, I calculated the proper velocity and epsilon conditions given the height of 300 ft. I ran each simulation for 5,000 trials. I did have some issues with mesh size and convergence. I'm not sure if the RNG model is the best model for this scenario, and I would like to explore other options such as the standard k epsilon model if necessary. However, I'm not sure if this is extremely useful for our purposes.

The porous fence is modeled as a pressure jump with a finite thickness over which the pressure change follows the equation:

$$\Delta p = -\left(\frac{\mu}{\alpha}v + C_2\frac{1}{2}\rho v^2\right)\Delta m$$

For turbulent flow, the first term (viscous loss) in this equation can be ignored. We set our boundary conditions to be face permeability (α) = 1e+20 m, porous medium thickness (Δm) = 0.01 m, and C_2 = 400 1/m for a 50% porous fence.

Results.

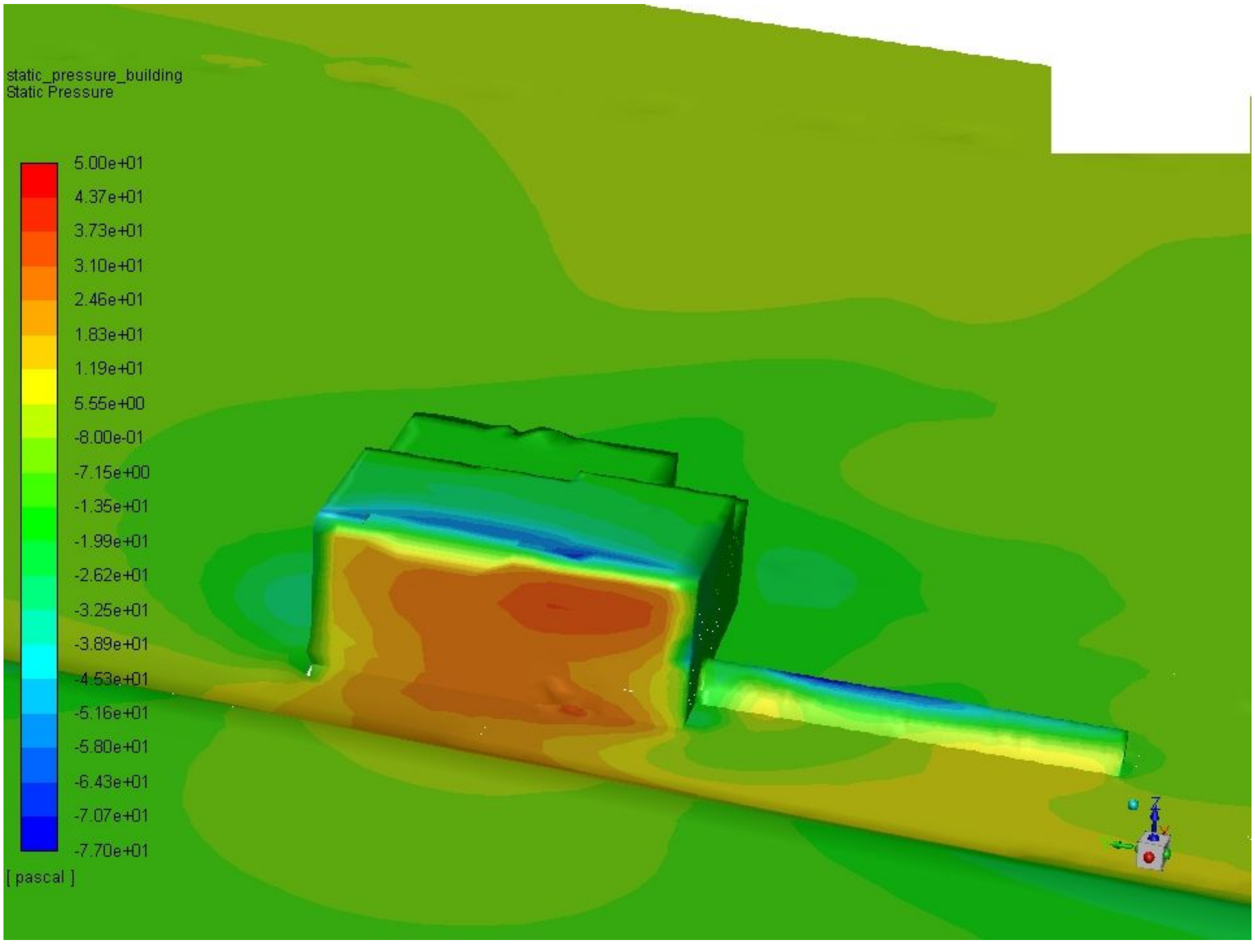

Figure 2. Pressure on End X without the fence.

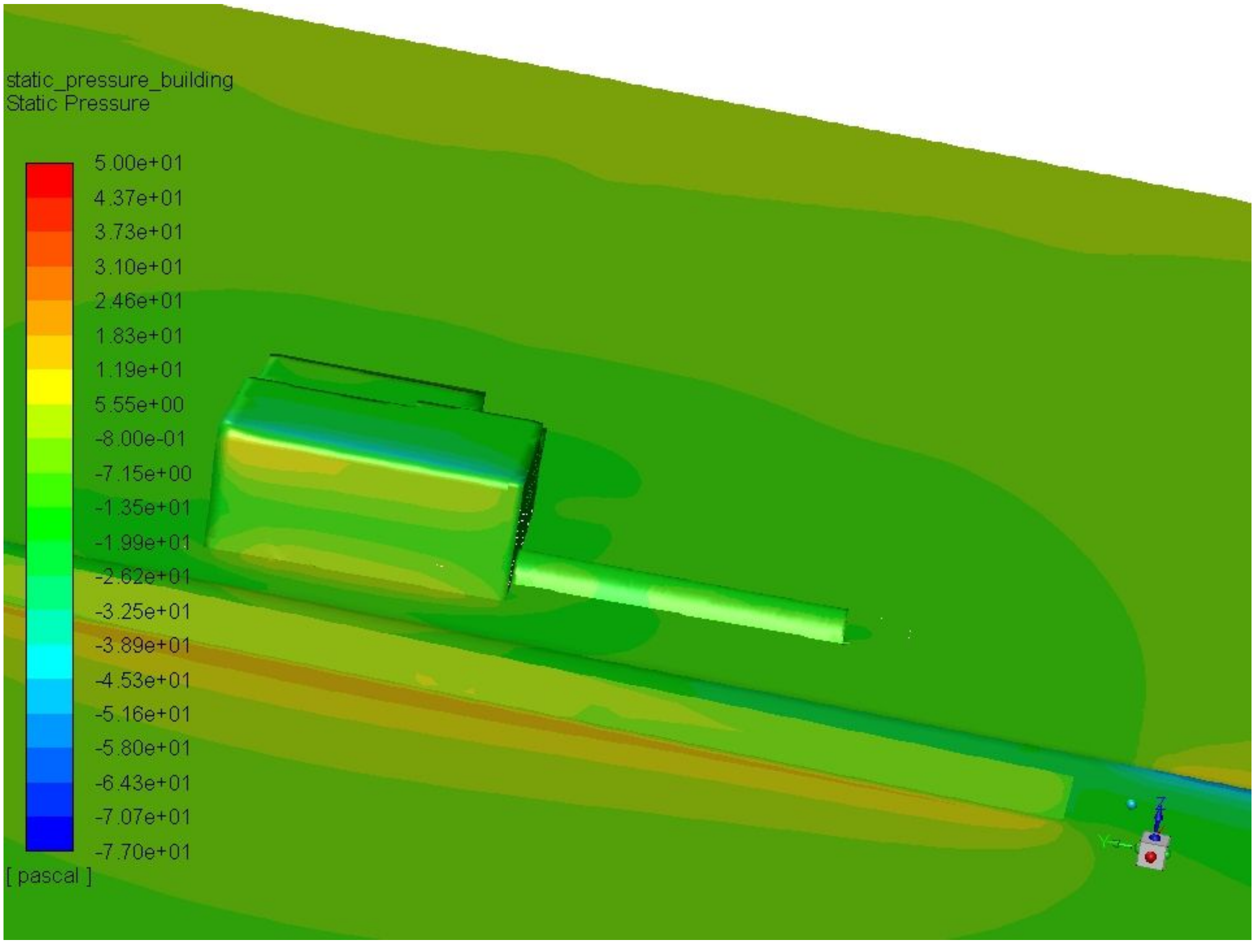

Figure 3. Pressure on End X with the fence.

There is evidently much less pressure on the building in the case with the fence. The fence particularly lessens the high pressure on the front of the building. It also mitigates the low pressure zones on the top of the building. The force on the building without the fence was calculated to be 11897.705 N, while the force on the building with the fence was 3146.8936 N. This marks a 73.5% decrease in force on the building.

The moment about the y axis was also calculated. The "pivot point" of the building has been found to be about 2 meters below the center of End X. Without the fence, it was 67728.859 Nm, while it was 35822.721 Nm with the fence. The moment about the y axis decreases by about 47.1% with the addition of the fence.

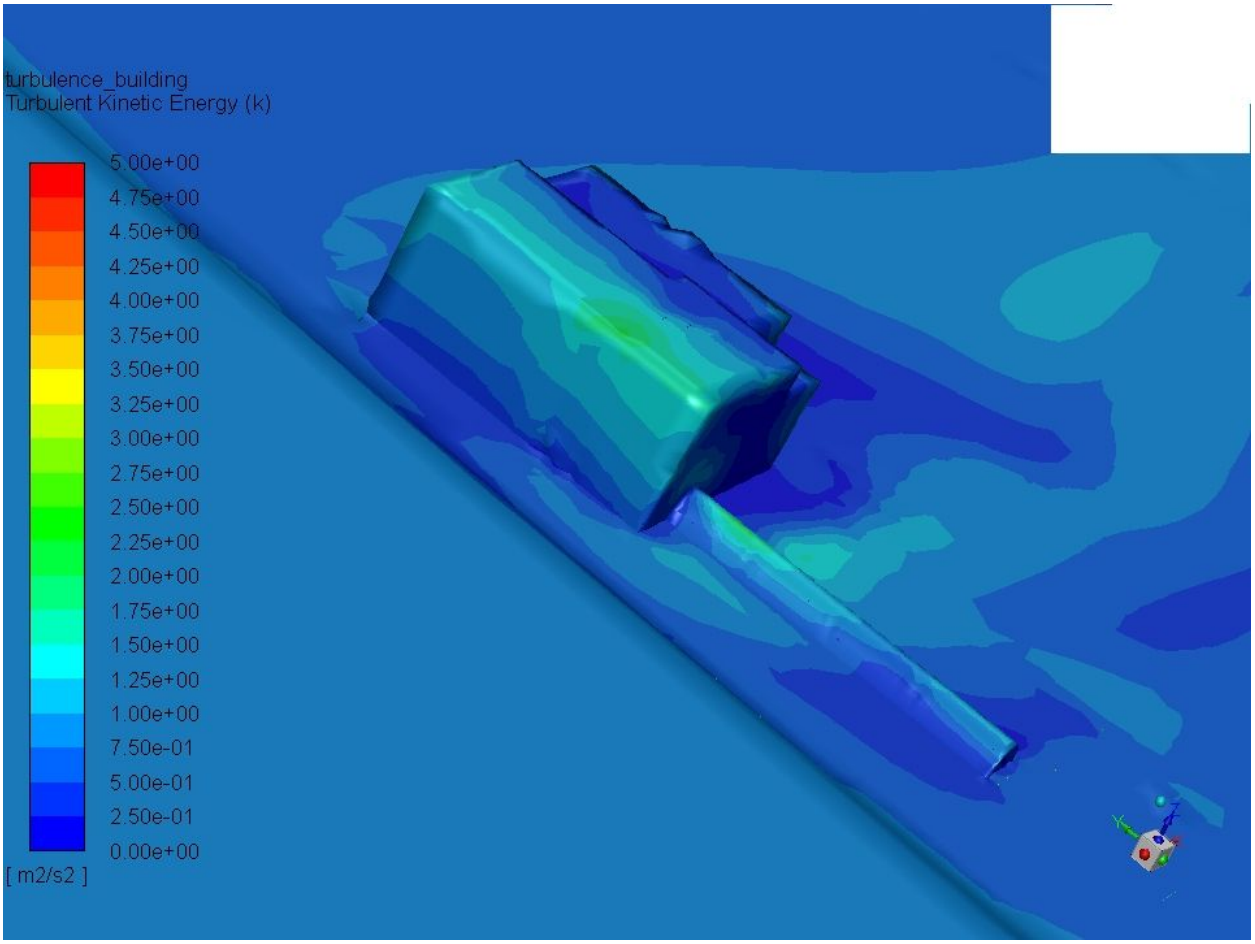

Figure 4. Turbulent kinetic energy on the building without the fence.

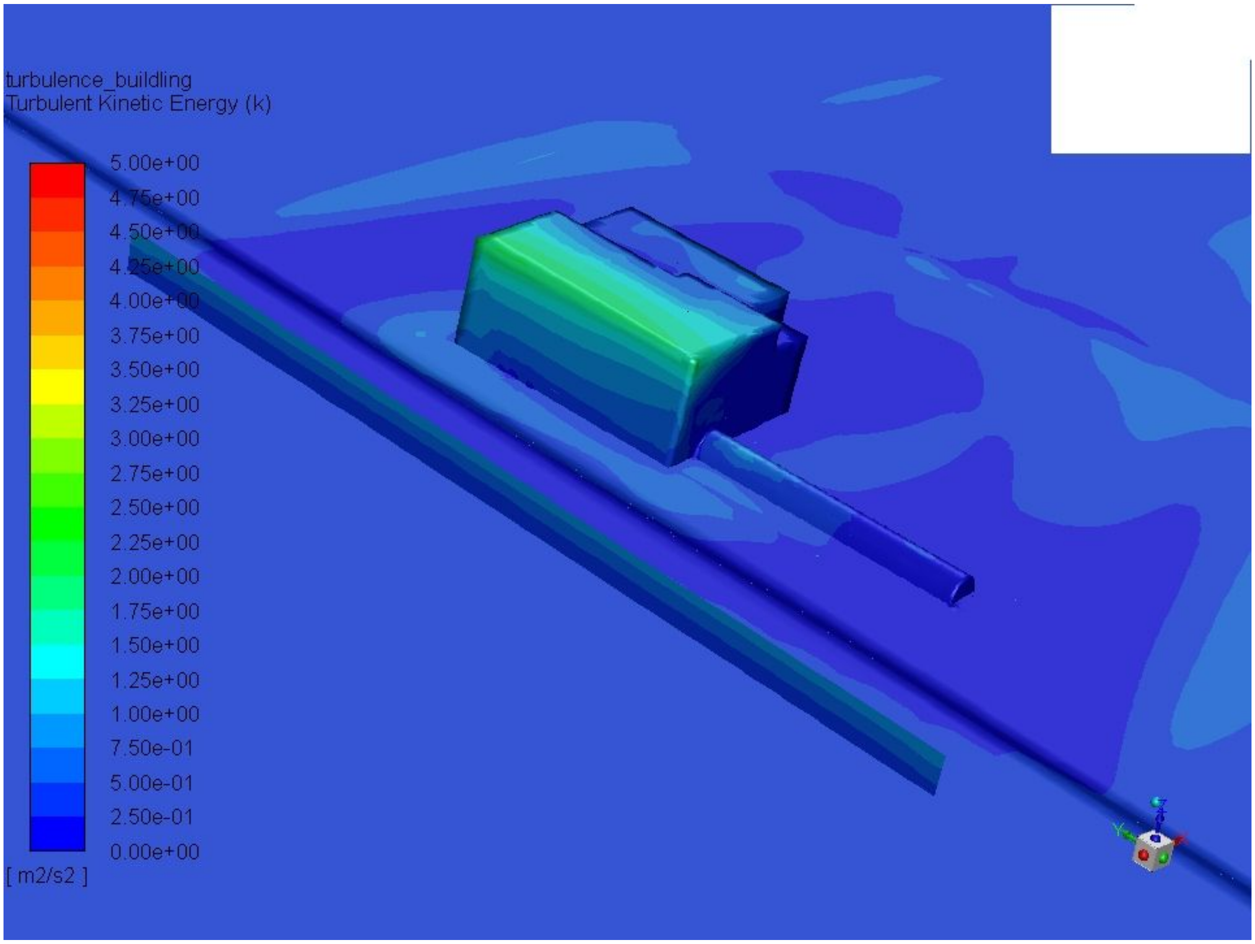

Figure 5. Turbulence kinetic energy on the building with the fence.

Turbulent kinetic energy is the mean energy per unit mass associated with eddies in turbulent flow. If a velocity field is denoted by U, the deviations of the velocity field from the mean or the turbulent part of the signal can be denoted as $U' = U - \overline{U}$. Turbulent kinetic energy is calculated in the same way as mean kinetic energy (ie $\frac{1}{2}mv^2$), simply using the turbulent part of the signal as opposed to the mean. As higher turbulence is associated with eddies, we would ideally want to fence to reduce or keep the turbulence constant. It appears that the fence causes the turbulence to be more uniform on the front of the building and that it reduces it along the arm.

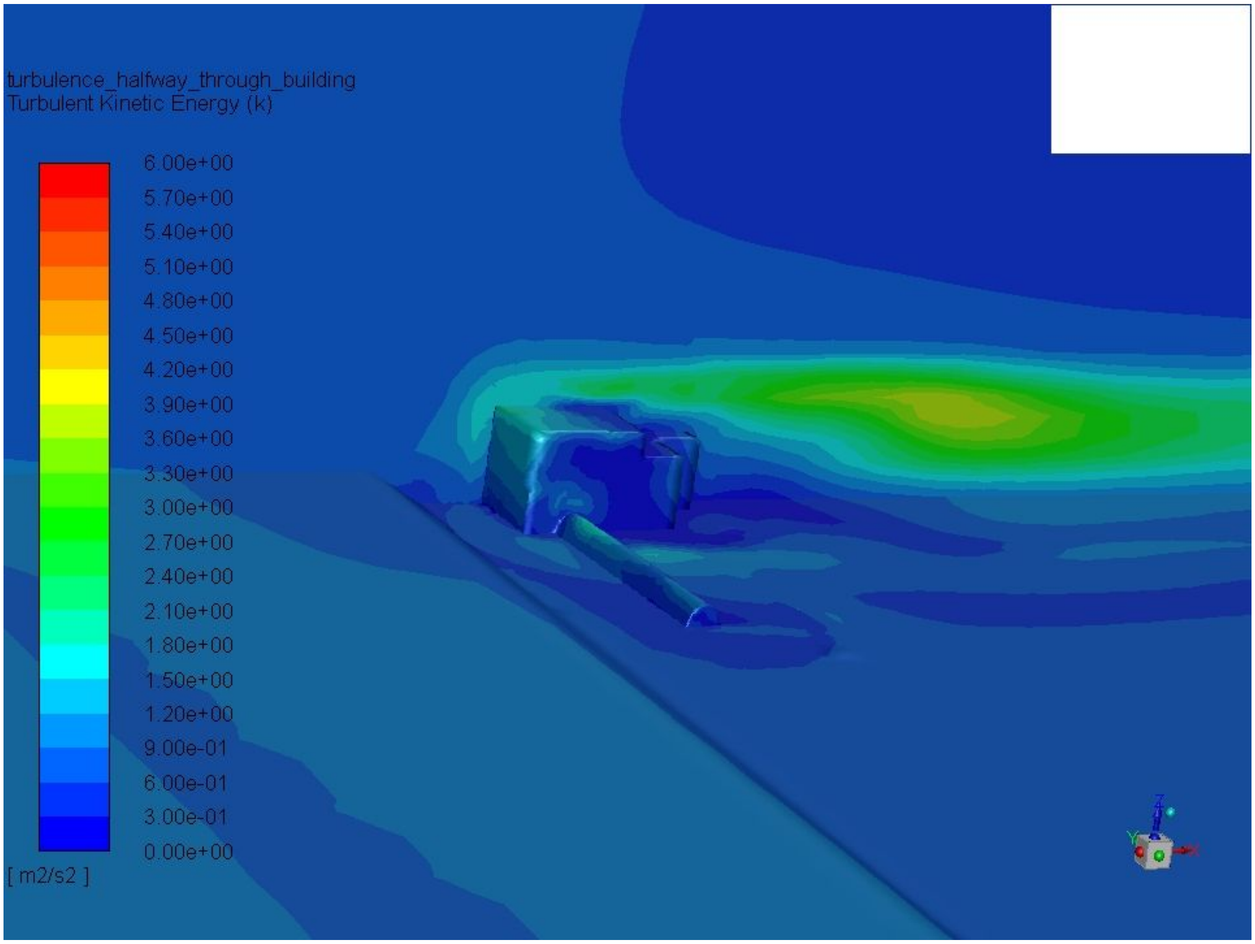

Figure 6. Turbulence at a plane halfway through the building without the fence.

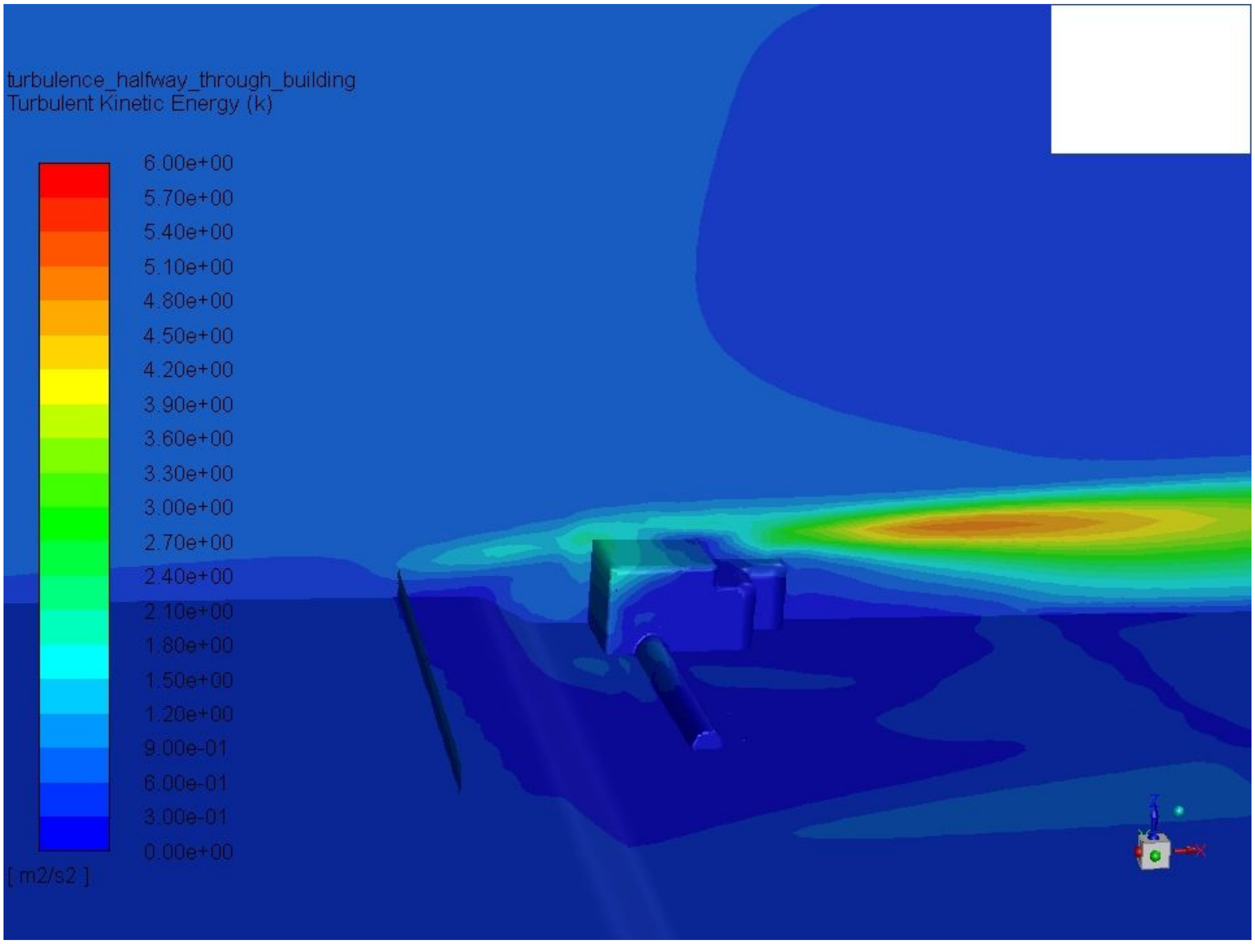

Figure 7. Turbulence at a plane halfway through the building with the fence.

Turbulence appears to be slightly reduced in front of the building with the fence. However, the fence causes a larger turbulent wake behind the building. However, this will most likely not matter to a large extent as we are more concerned with the protection of the building and the arm. We feared that the fence would cause eddies and regions of increased turbulence in front of the building, but this fear appears to be unfounded.

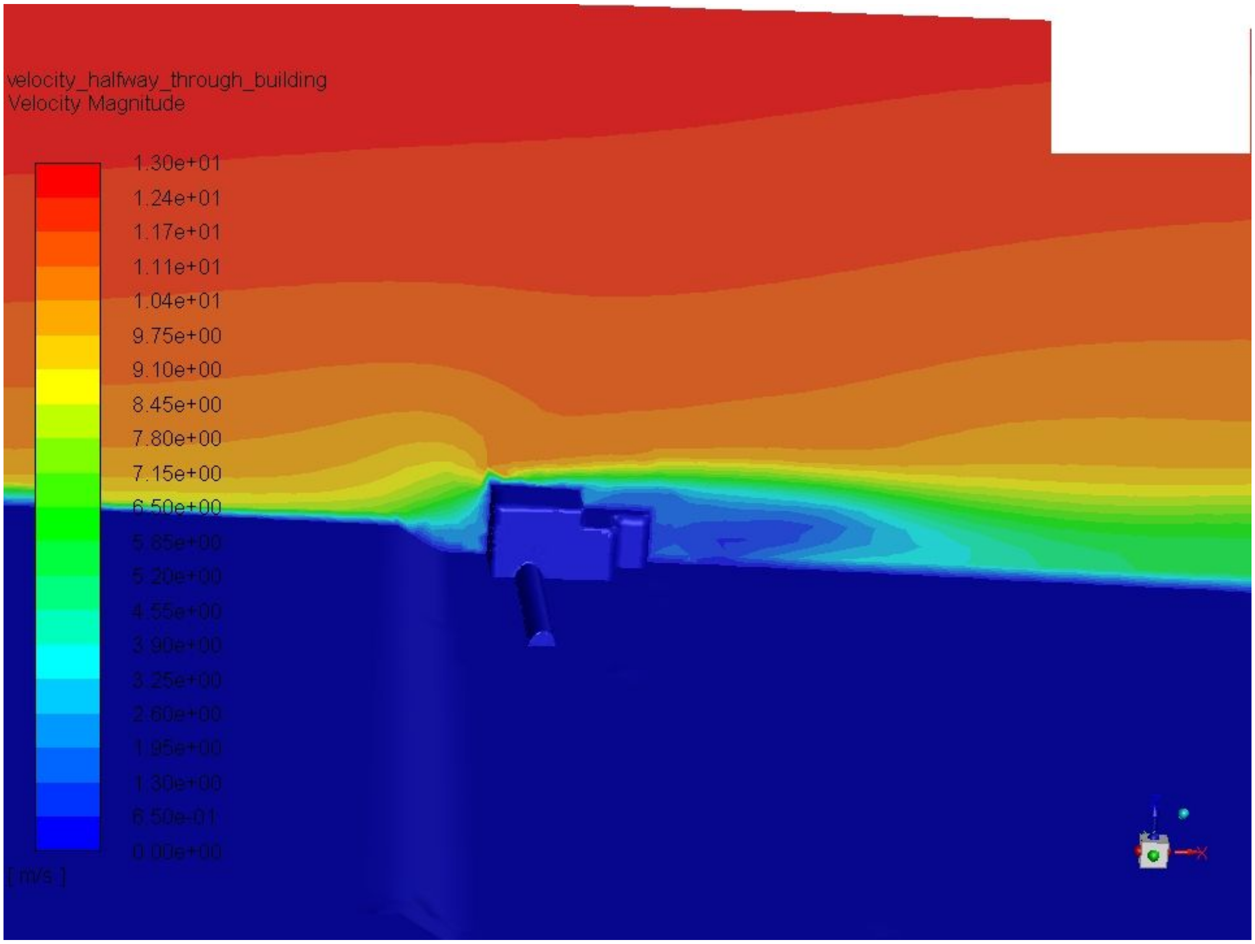

Figure 8. Velocity at a plane halfway through the building without the fence.

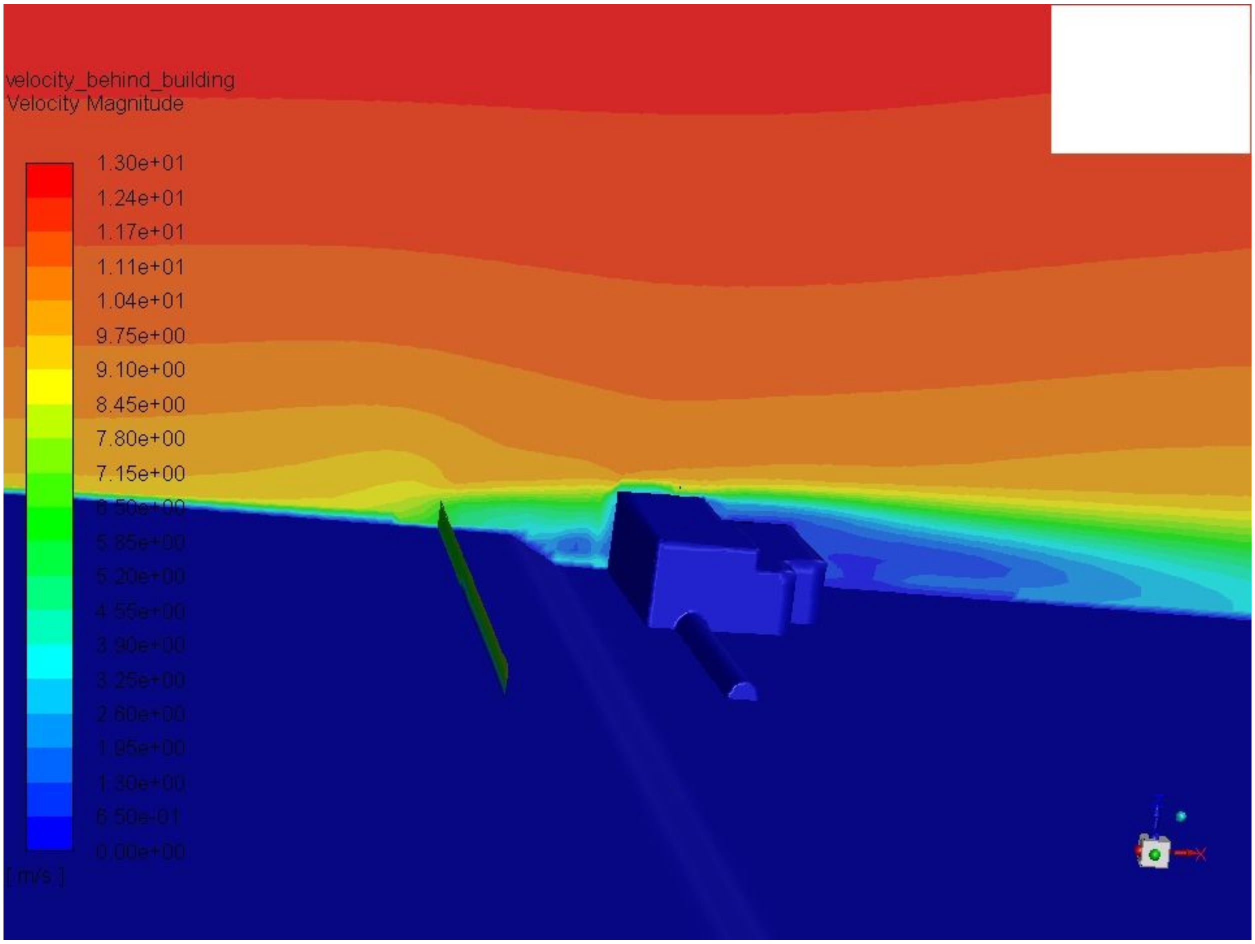

Figure 9. Velocity at a plane halfway through the building with the fence.

The fence reduces the velocity on the other side of the building for a longer distance. It also has the effect of smoothing the flow over the top of the building, perhaps because the wind already must travel over the fence. The average velocity on the front face of the building without the fence was 2.08 m/s, while the average velocity with the fence was 1.41 m/s, showing a decrease of about 33%.

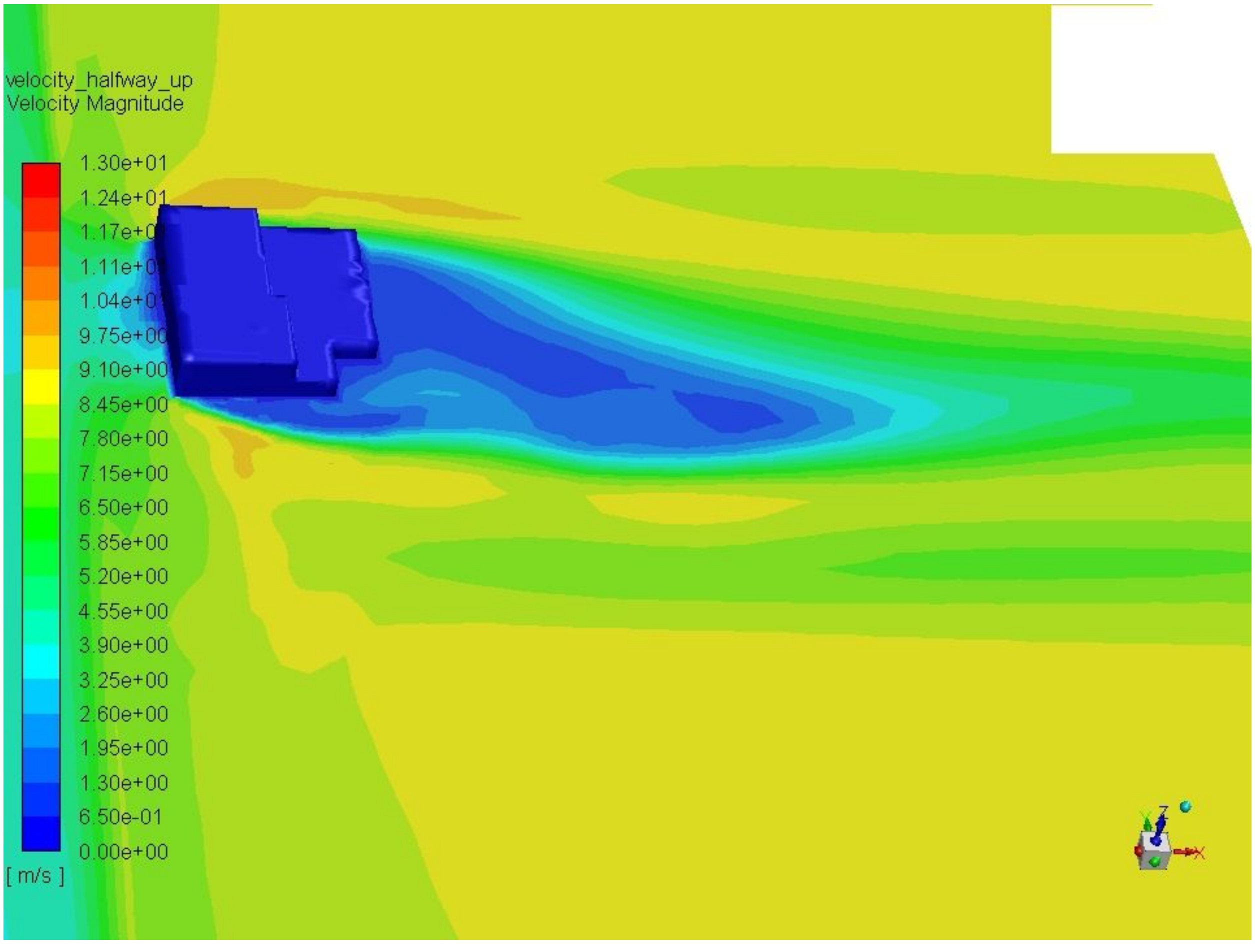

Figure 10. Velocity at a horizontal plane halfway up the building without the fence.

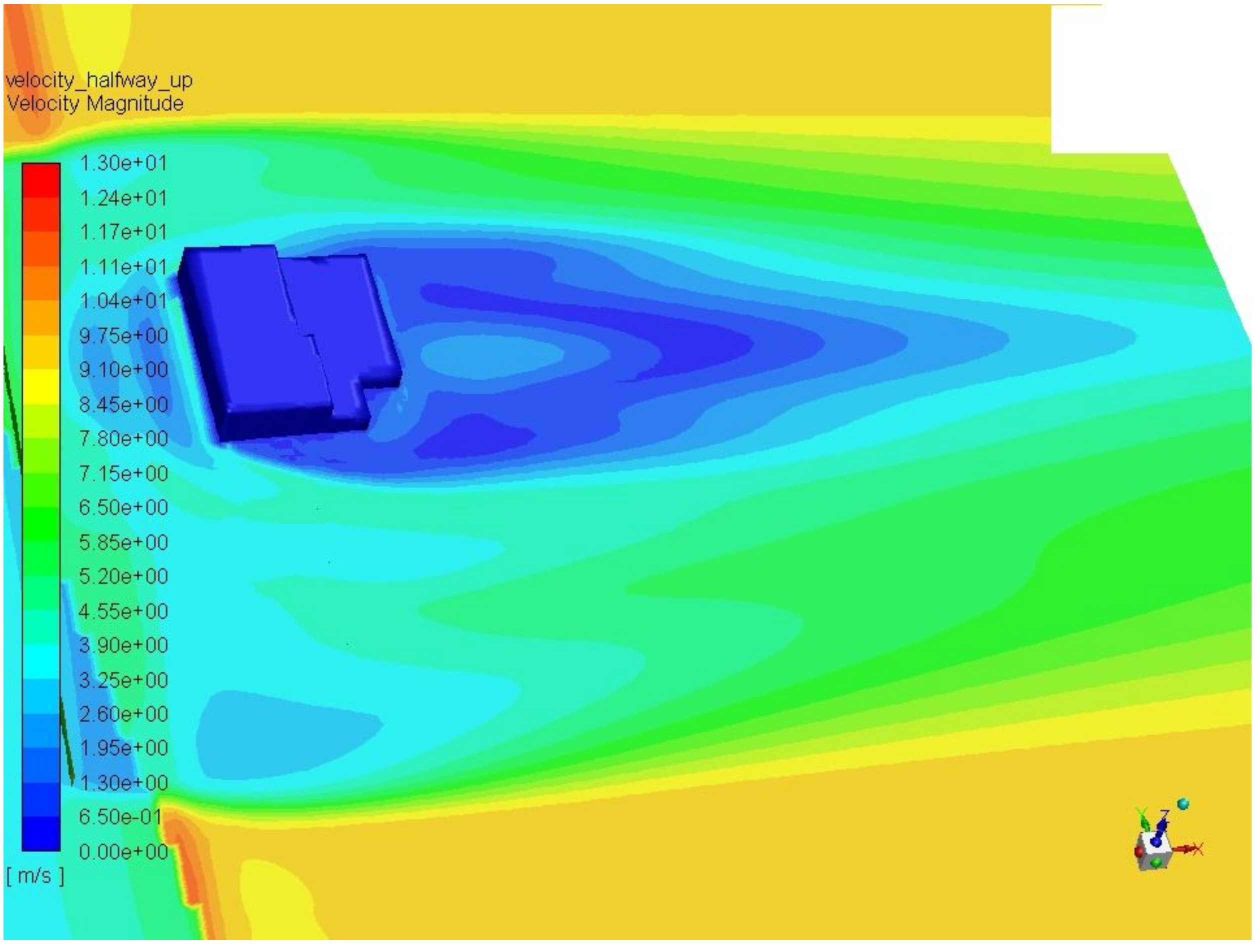

Figure 11. Velocity at a vertical plane halfway up the building with the fence.

From this viewpoint, the fence evidently reduces the velocity in front of the building. It is interesting to note that it also reduces the velocity on the sides of the building and that it appears to make the velocity contours behind the building more symmetric.

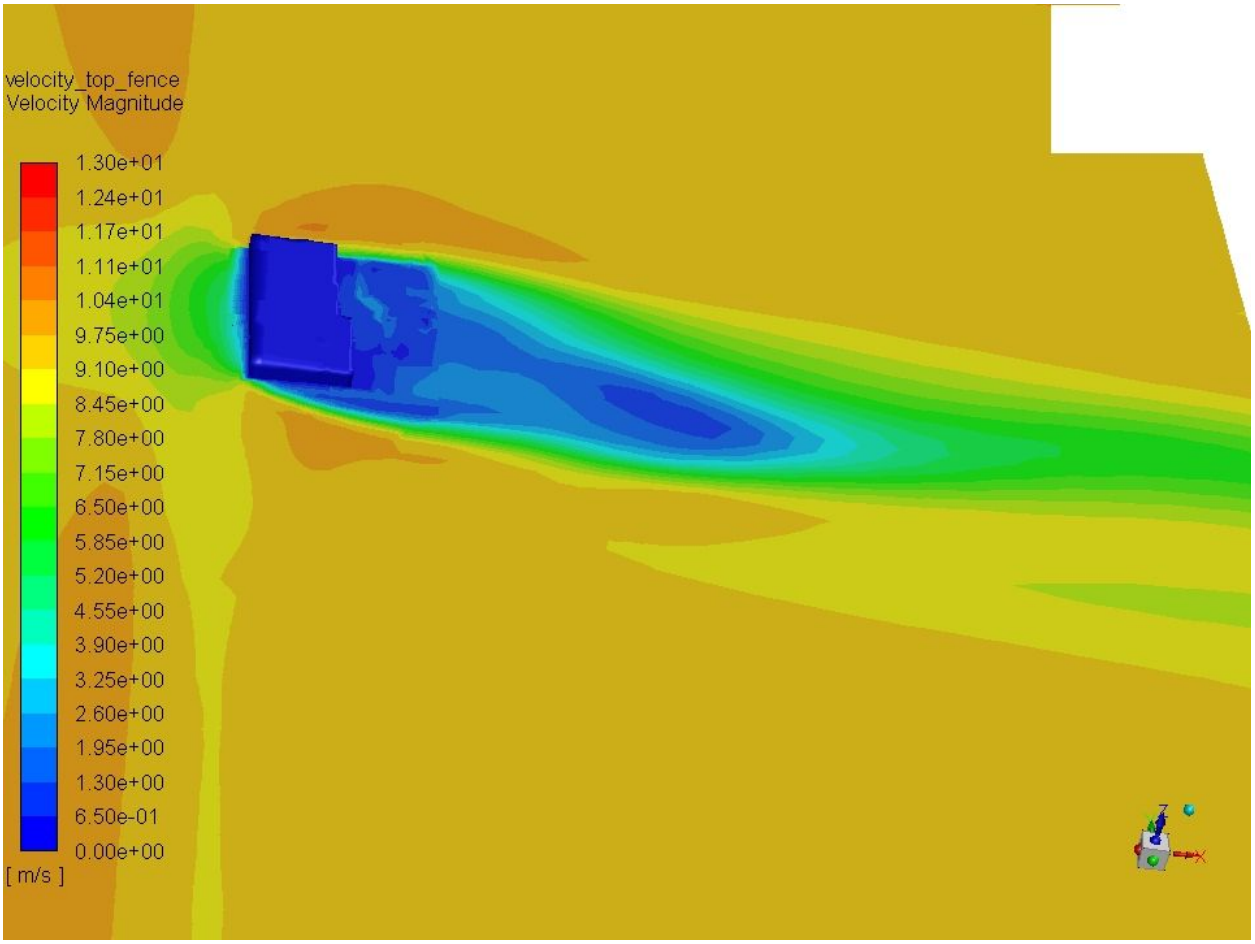

Figure 12. Velocity at a horizontal plane at the height of the fence without the fence.

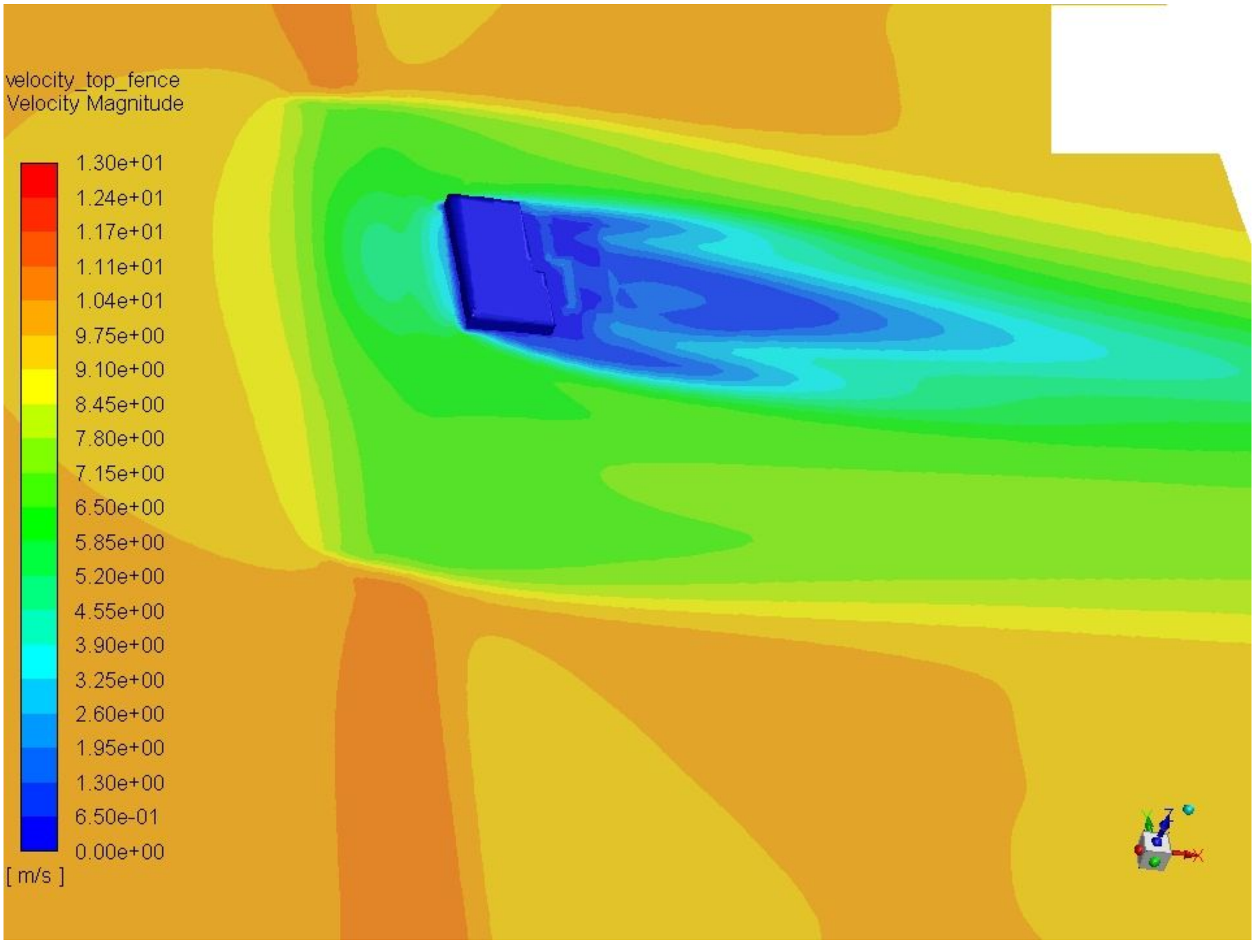

Figure 13. Velocity at the height of the fence with the fence.

The velocity contours around the building with the fence appear to be much more uniform, leading to less turbulence and eddies.

Conclusions.

These simulations demonstrate that a porous fence may be quite effective in reducing the force on End X by 73.5%, the tilt of the building about the y axis by 47.1%, and the average velocity on the front face of the building by 33%. A 50% porous fence clearly has quite a large effect on protecting End X from wind. Although the fence does introduce higher turbulence behind the building, it does not seem to create additional turbulence on the front face of End X. The model does not take the effect of fence posts and gaps in the fence into account, so this could be the next step. This model also does not take the direction of the wind into account. It may be interesting to run this model again with a higher inlet velocity. In this model, due to the specified logarithmic velocity input, the wind hitting the building does not exceed about 10 m/s or 22 mph.

At Hanford, problematic wind speeds against the building can be much higher than this, so this may be worthwhile to explore.