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- LIGO -
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2D wind fence modeling

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Abstract

Strong winds in the vicinity of the LIGO Hanford detector limit the operation time of the interferometer. The wind pressure on the observatory buildings introduces ground tilt that causes significant low-frequency noise. Reducing the influence of the wind is therefore crucial. Building a wind fence to shield the affected buildings, namely the two end stations, is planned. In this report the results from finite element simulations of different methods to mitigate the influence of the wind on the detector are discussed.

1 A wind fence for Hanford

The wind-induced ground tilt causes significant low-frequency noise at LHO. In wind speeds higher than approximately $13\,\mathrm{ms}^{-1}$ the interferometer is not even operational. Such high winds occur in more than 5 % of the time at the site [1, 2]. In particular, the two end stations are exposed to the wind. In addition, their box-shaped geometry is aerodynamically unfavorable.

In order to mitigate the effect of the wind on the interferometer, it is foreseen to set up a wind fence upwind of the two end stations [3]. It should consist of a semipermeable mesh attached to rigid posts. The length of the fences is set to 91.4 m (300 ft).

Accumulating tumbleweed at the fence is a potential fire hazard and removing it from a fence might be problematic, since it might tangle in the fence material. It furthermore might be hard to remove it from in between the posts and potential stabilization wires. Currently the tumbleweed is collected at the building. It was therefore planned to leave a 1.2 m gap between the fence and the ground, in order to allow the tumbleweed to pass through. In particular, the influence of this gap on the wind speed profile behind the fence and the load on the building were investigated in finite element simulations. A significant deterioration due to the gap compared to the full-height fence led to the simulation of other possible designs that potentially would mitigate the influence of the wind on the detector. The results of these simulations are summarized in this report. A more detailed description of these investigations can be found in the SWG logbook [4].

2 A 2D FEM model

The described simulations were mainly done with 2-dimensional models of the structure. Such a model describes the behavior of a typically one-meter-wide (in the third dimension) slice of an infinitely wide structure. This naturally neglects the dynamics in the direction of the third dimension and therefore results have to be analyzed accordingly. However, the computational time of a 2D simulation compared to a 3D simulation is vastly lower. This is in particular significant for more complex models with a high finite element grid (mesh) resolution (compare to figure 2). In the case of the wind fence model, the wind-induced force on the building is of interest. An accurate prediction of this force requires to resolve the fluid dynamics in the vicinity of the regarded surfaces which in turn requires a relatively low finite element height and thereby a low y+ value [5]. Testing different geometries and scenarios in such a high-resolution 3D model is hardly feasible. A 2D model, on the other hand, can be modified in a relatively time-efficient manner.. It provides a good basis for comparisons with selected 3D simulations and experiments.

2.1 Basic setup of the 2D model of the end station X

Figure 1 shows the basic setup of the 2D model of the end station X building. The building is located approximately 4 m below the ground level behind a slope. In order to simplify the model, the building is not included in the geometry, but designed as a boundary of the fluid domain. This reduces the number of mesh cells. The fence is modeled with a 50 % permeability. This is realized in ANSYS Fluent by assigning a porous-jump property to the front line of the green rectangular shape (see figure 1). It is located approximately 26 m in front of the building. The inlet of the flow channel is 120 m high. Lower flow channels have shown to influence the simulation results strongly. Higher fluid domains would increase computing time while changing the results insignificantly. The inlet wind velocity profile is chosen to be logarithmic in height as described in [6]. At 10 m height the wind speed is set to 10 ms^{-1}. A more detailed description of how the ANSYS Fluent model is set up and how an efficient mesh was assigned to the geometry can be found in the SWG logbook [4].

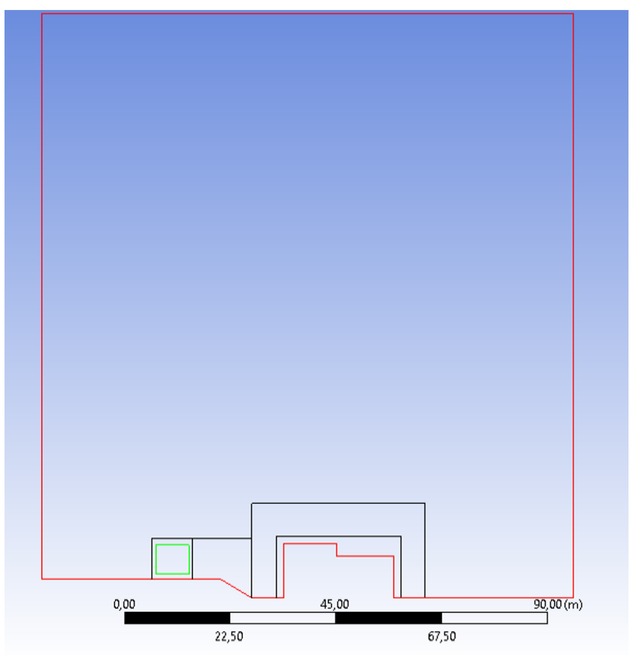

Figure 1: Setup of the flow domain. The red lines are the outline of the fluid domain. A logarithmic wind profile is assigned to the inlet (left). The front face of the green rectangular shape is the fence. The black lines are subdividing different mesh domains. In order to resolve the dynamics at and behind the fence a relatively fine mesh is assigned to the green rectangular shape (compare to figure 2).

2.2 Model geometries

In the following a selection of different 2D geometries are compared and discussed:

- No fence
- A 7.3 m high fence with a 1.2 m gap at the bottom
- A 7.3 m high fence without a gap
- A 7.3 m high fence with a 1.2 m gap and a barrier in front of the fence
- No fence but a modified building geometry

The height of 7.3 m was chosen based on previous 3D simulations [6]. The variation of the fence height in the 2D model here discussed confirmed that higher fences do not improve the load on the building significantly. Lower fences increased mainly the vertical force on the building due to a higher wind velocity close to the roof.

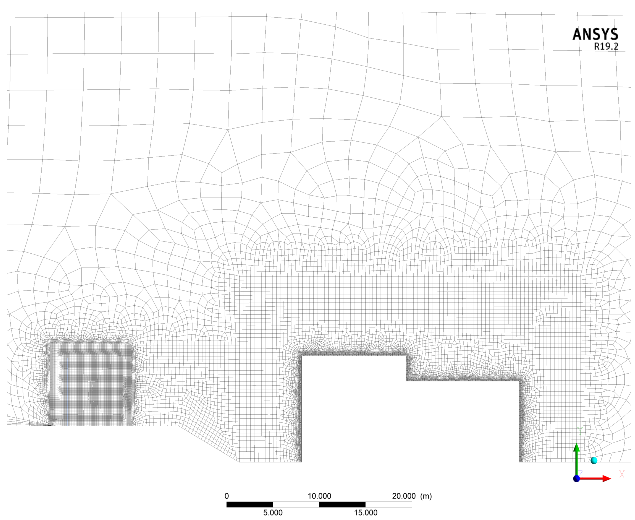

Figure 2: Finite element mesh. The mesh is strongly refined in the areas of interest. In particular on the boundary layers the cell density is relatively high. This way the fluid dynamics in this areas are well resolved. The mesh in a higher altitude is relatively coarse in order to reduce the computing time.

3 Modeling results

As described above, the 1.2 m gap was initially intended for enabling the tumbleweed to pass under the fence. The velocity profile behind the fence, however, shows a strong wind speed enhancement close to the ground with respect to the wind speed without a fence (see figure 3). [1]

[1] Naturally also the wind velocity above the fence is higher compared to the velocity at the same position without an obstacle in the way.

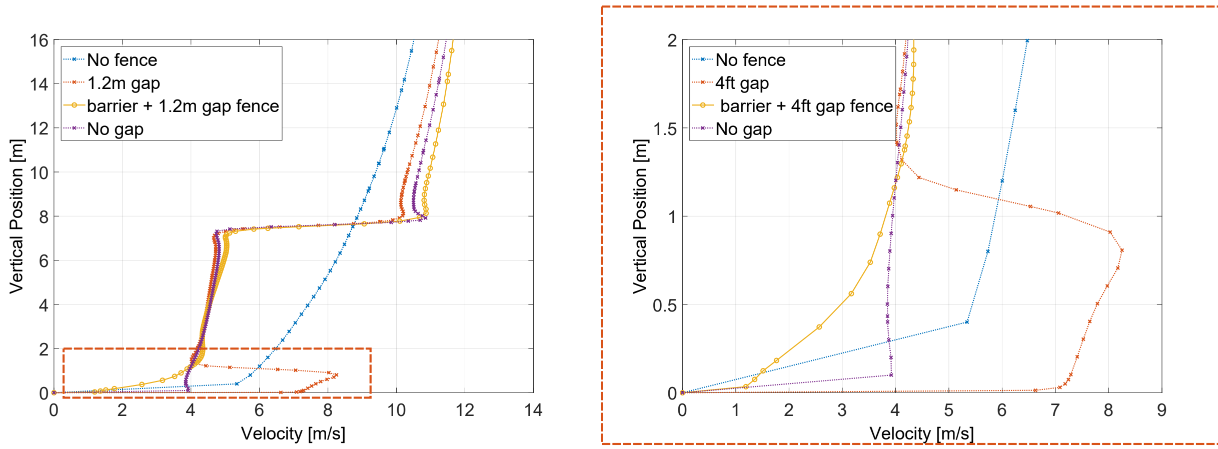

Figure 3: Wind velocity profile 0.5 m behind the fence. The right plot zooms in the wind profile behind the gap. It shows the strong velocity enhancement due to the 1.2 m gap (red line).

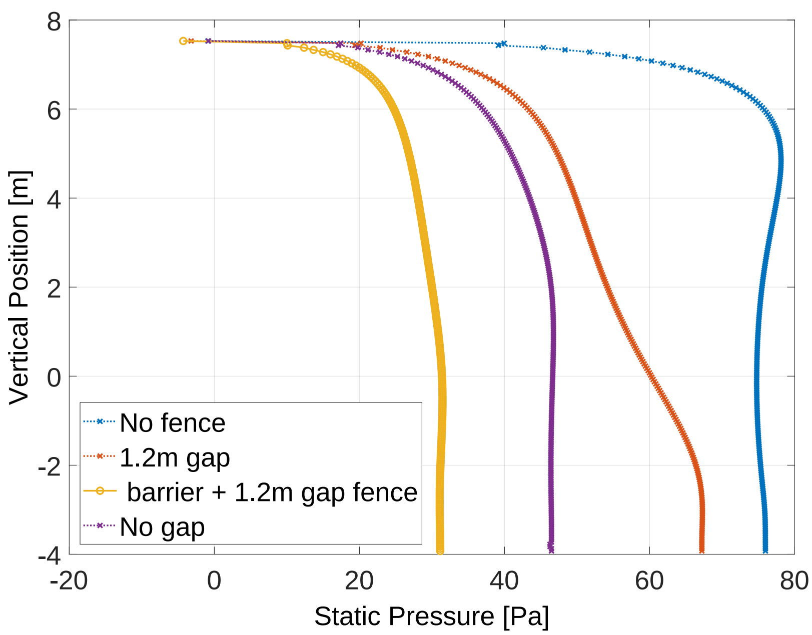

Figure 4: Pressure profile on the building front.

The fence reduces the pressure on the building as shown in figure 4, however, close to the ground, the pressure on the building front is reduced only by a factor of about 0.88 compared to the scenario without a fence. At the top of the building, the pressure reduction is higher. This has a greater influence on the torque on the building and thereby on the wind-induced ground tilt. Tables 1 and 2 show that the total wind induced force on the building front and on the entire building is reduced by a factor of 0.73. Figures 5 and 6 show an illustration of the wind velocity vectors. The wind velocity is significantly reduced in front of the building by the fence. The illustration furthermore visualizes that the air is channeled through the gap down to the bottom of the building.

Fence structure	Force on front face only [N] x	y	Total	reduction factor
No fence	852	0.14	852	
Fence with 1.2 m gap	622	0.79	622	0.73
Fence without gap	493	0.26	493	0.58
Barrier + 1.2 m gap fence	326	0.23	326	0.38

Table 1: Total force on the building front for the 4 simulated scenarios

Fence structure	Force on entire building [N] x	y	Total	reduction factor
No fence	884	157	897	
Fence with 1.2 m gap	646	129	658	0.73
Fence without gap	495	63	499	0.56
Barrier + 1.2 m gap fence	341	115	360	0.40

Table 2: Total force on the entire building for the 4 simulated scenarios

The disadvantages of the gap under the fence can be avoided by simply closing it. The velocity profile, the pressure on the building as well as the total force on the building suggest that a full fence provides significantly better shielding from the wind (see figures 3, 4 and 7 and tables 1 and 2). These results were confirmed by preliminary 3D simulations of the building and the three different fence configurations (for more information see the SWG logbook page 11603).

The closed fence has the disadvantage that a new method for tumbleweed removal would need to be employed. Due to the fence structure and possible stabilization wires, the tumbleweed removal might be difficult. A different approach to improve the wind shielding while keeping the tumbleweed away from the fence would be to build a relatively short barrier in front of the fence. The tumbleweed could pile up and be removed in front of that barrier. Such a barrier could, for instance, be constructed from compressed tumbleweed blocks which are available at the site due to the current tumbleweed removal method. Figure 8 visualizes the wind velocity for a structure with a 2 m high and 1 m wide barrier. The front face of the barrier is located 3 m in front of the fence. The 1.2 m gap is maintained in this geometry such that tumbleweed that passes over the barrier does not pile up.

The simulation shows the formation of an eddy behind the barrier which partly dissipates its energy to half-permeable fence (see figure 8). As a result the pressure on the building front is significantly reduced over the whole height, even with respect to the no-gap-scenario (see figure 4). The total force on the building is by a factor of 0.72 lower than for the no-gap-scenario. It is reduced by a factor of 0.40 with respect to the case without a fence. Such a barrier can be realized relatively simply and it can be added and removed after the fence is constructed. This way the simulations could be verified experimentally.

3.1 Altering the building profile

A different way to mitigate the influence of the wind on the building would be to change its outline to one with less aerodynamic resistance. In preliminary 2D simulations it was tested to round the edges of the roof. This way the airflow over the roof can be shaped less turbulently, which significantly decreases the wind-induced force on the building front. The vertical force on the building, however, increases. Figure 9 shows a simple version of such a modified building. Here a 1 m wide structure is added to the building front. The top of it is rounded. The total horizontal force on this building is only around 300 N. The vertical force is 439 N. This results in a total force of 532 N. The illustration shows that the large eddy on top of the building from the previous is not present in this case. The highest pressure acts in the area of the rounded corner. A solution might be to connect a spoiler-like structure to the roof, which could generate a counter force. Preliminary simulations with such a structure have shown some improvement.

4 Conclusion

The presented simulations show that the influence of the wind on the buildings can be mitigated significantly by the construction of a wind fence. The best performing shielding structure is a 7.3 m high fence with a 2 m high barrier in front. Apart from its good shielding abilities also the tumbleweed removal should be relatively simple since it should accumulates in front of the barrier it. Preliminary studies of an altered building profile which reduces its aerodynamic resistance suggest a further reduction of the influence of the wind.

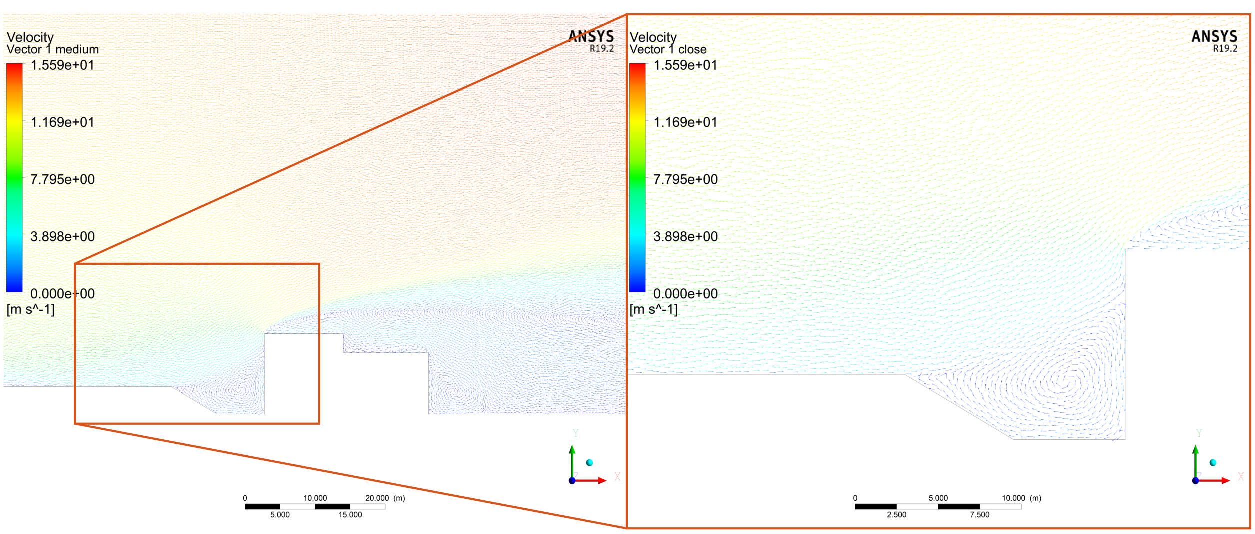

Figure 5: Illustration of the wind velocity in the vicinity of the building. This simulation uses a model without a fence

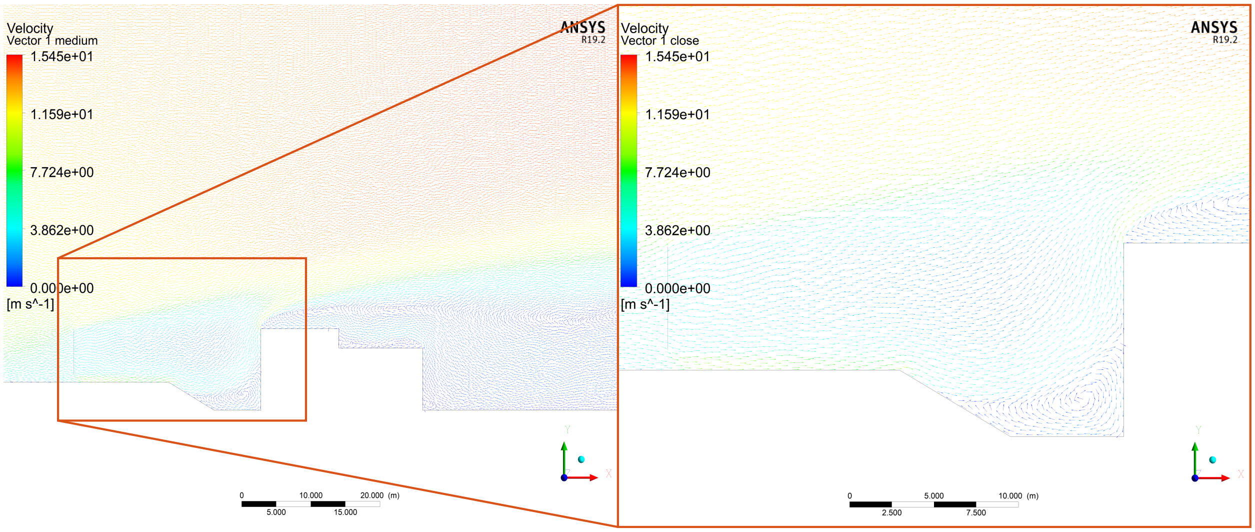

Figure 6: Illustration of the wind velocity in the vicinity of the building. This simulation uses a model with a fence and a 1.2 m gap.

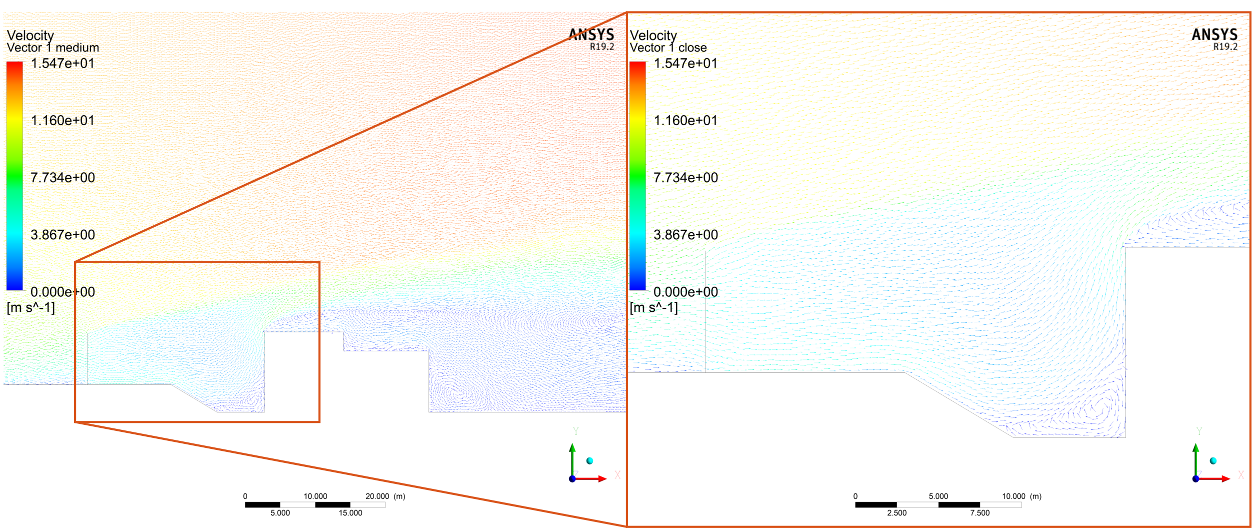

Figure 7: Illustration of the wind velocity in the vicinity of the building. This simulation uses a model with a fence and no gap.

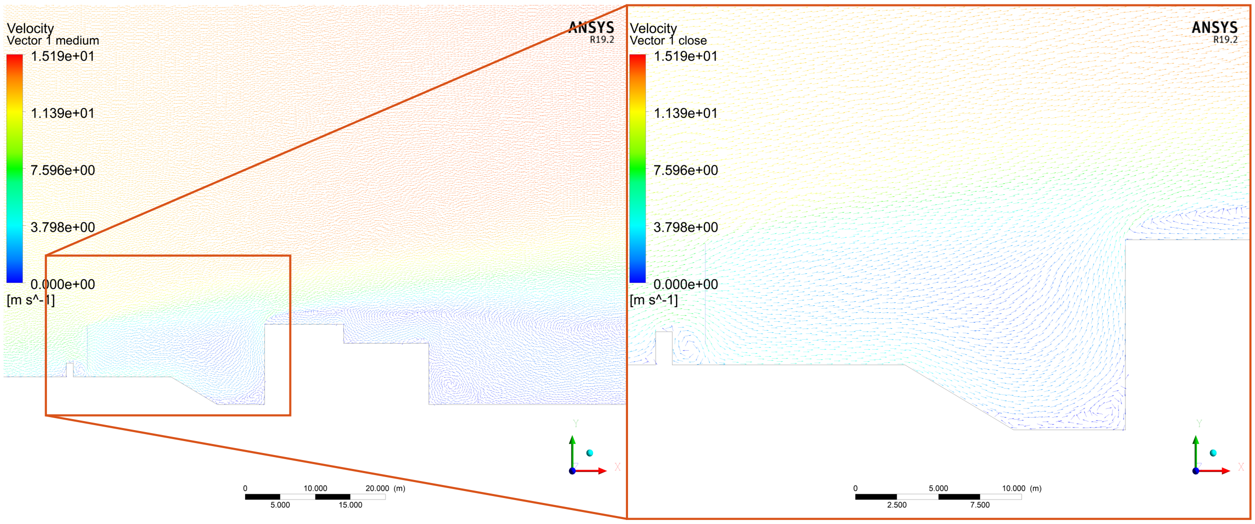

Figure 8: Illustration of the wind velocity in the vicinity of the building. This simulation uses a model with a fence and a 1.2 m gap and a 2 m high barrier.

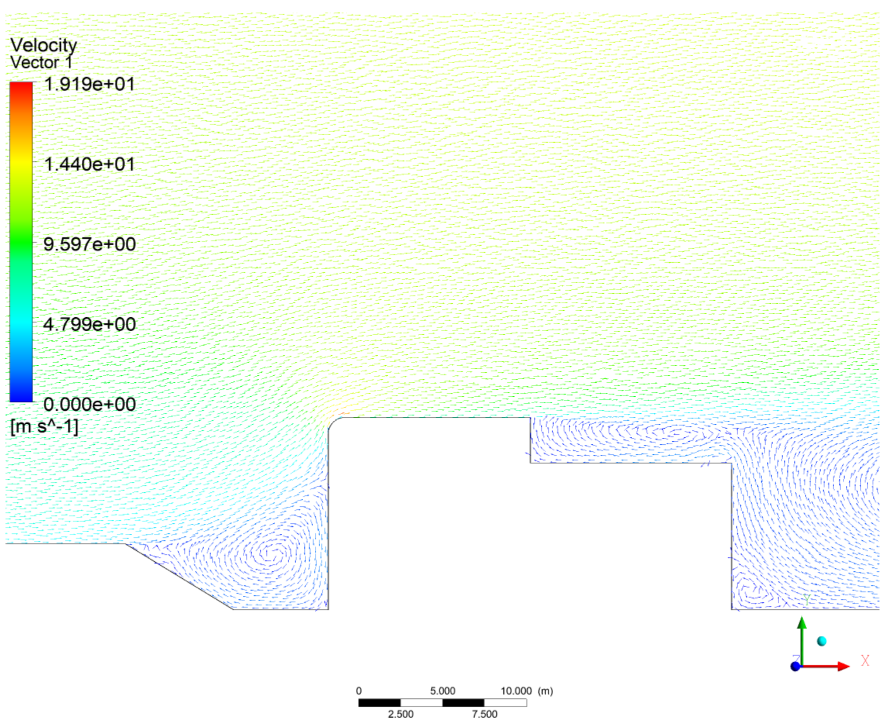

Figure 9: Rounded top edge. The wind flow over the building is much smoother. This results in a lower horizontal but a higher vertical force.

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