Hybrid "Quick-Deploy" Fabric Fairing to Reduce Drag in Trucks

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Abstract: Design of a flexible fairing that covers the gap between a truck and its trailer while still allowing free rotation about the trailer's pivot axis. The fairing also allows for quick installation by implementing a combination of rigid structural rods linked to elastic fabric.

1. Introduction

The mass trucking industry is extremely important for sustenance of daily needs and transportation of goods across the county. At the same time, this industry has adverse effects on the climate due to the trucks' large diesel engines. Although electric trucks exist, their shortcomings (long charging times, heavy batteries, lack of charging infrastructure) make them far less appealing for trucking companies compared to their diesel counterparts. Until these shortcomings are addressed, electric trucks will not hit extensive commercial use. In the meantime, the best we can do is improve existing truck design to make it more energy efficient, thus contributing fewer emissions to the environment. This paper considers one such improvement that can increase energy efficiency by taking advantage of light elastic fabrics.

2. Application

When a truck links to a trailer, there is a gap which forms between the two. This 'trailer gap' is necessary for the truck to turn because the trailer comes closer to the side of the truck that turns. This gap does not pose any problems at lower, city/town speeds; however, a large part of a freight truck's journey is on high-speed roads, where the gap plays a more significant role. This gap creates a turbulent region of air which forces air going overhead to 'roll' into the gap, forming vortices that increase drag and reduce efficiency. Furthermore, trailers vary in size, potentially making this turbulent effect more significant.

To attempt to solve this issue, trucks are often fitted with rigid fairings to reduce the trailer gap as much as possible and account for the height difference between the truck and trailer. However, due to their rigid structure, these fairings can only cover a small portion of the gap without creating turning issues.

As an alternate solution, elastic materials come to mind. Using their elastic properties, the entire gap can be covered without creating any turning issues because one side would contract and the other would stretch during a turn. However, even this method has its shortcomings. Firstly, the unstructured fabric material will flutter and vibrate at high speeds due to turbulent side winds; this negates, at least in part, its purpose to reduce drag. Additionally, the fabric fairing will take long installation times whenever a trailer is attached.

To create a suitable fairing that fulfills all the criteria, a hybrid approach must be taken: rigid structures to reduce flutter and make installation simpler, and elastic fabric to cover the entire trailer gap.

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3. Method

<u>*3.1 Control Model and Hybrid Fairing Design*</u>

I started by designing a simple truck and trailer model on Fusion 360 CAD. I ensured that the trailer was able to rotate about its pivot axis. This model was meant solely to test trailer gap drag and the hybrid fairing, so other potential areas of drag (under the trailer, wheels, behind the trailer) were excluded to make simulations simpler and reduce other variables. The height difference between the truck and trailer is on purpose: this design should work with any sized trailer.

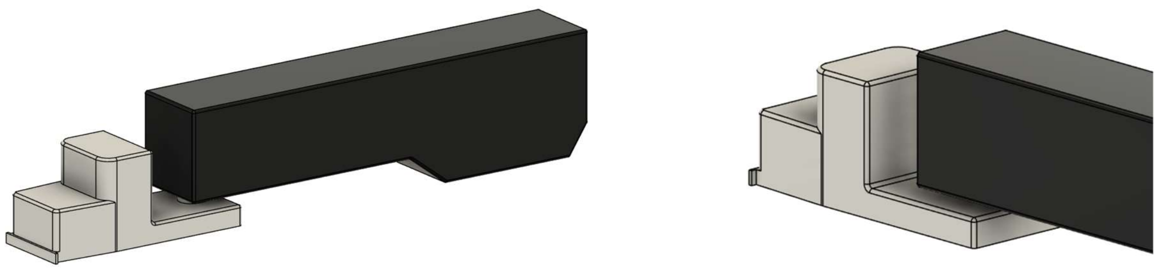

Figure 1: Truck & Trailer Model

Now, I can design the rigid structural braces that connect the truck to the trailer. These braces will be used to support the elastic fabric. By taking advantage of telescoping joints, the brace will not interfere with turning because it can expand and contract based on the direction of the turn.

Figure 1: Telescoping Rod - Contracted and Expanded

I then added spheres on each end to serve as the balls on ball-socket joints, since simple pivot joints would not work due to the movement on multiple axes because of the elevated trailer height.

On a copy of the original truck model, I added anchor points with sockets to retain the spheres to each of the top corner on truck and trailer. After programming the joint appropriately, the telescoping rods were able to expand and contract as I rotated the trailer about its axis.

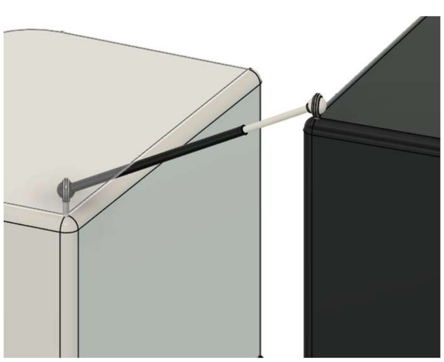

Figure 2: Anchored Ball Joint Brace

Figure 4: Right-Turn Brace Motion

Figure 5: Left-Turn Brace Motion

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Repeating this process another time, I completed the top braces. Unlike the top two braces, the bottom two braces only need standard pivot joints because their motion is about one axis. The entire bracing system is complete with two pairs of telescoping rods on each side.

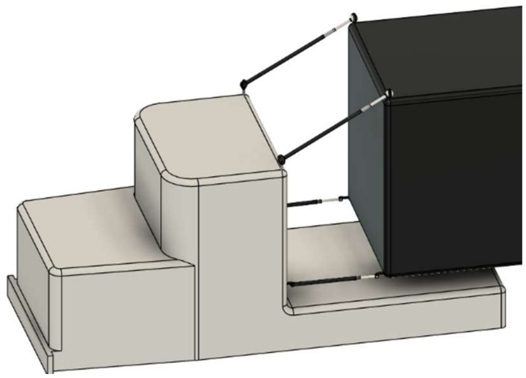

Figure 6: Full Brace System

Next, I assess the maximum turn angle this setup can reach. The bracing system allowed for 80° of motion on each side without interfering with other parts or creating joint restrictions. This limit is fine because it is far higher than the safe limit; anything over 80° may lead to a Jackknife turn, which is extremely dangerous.

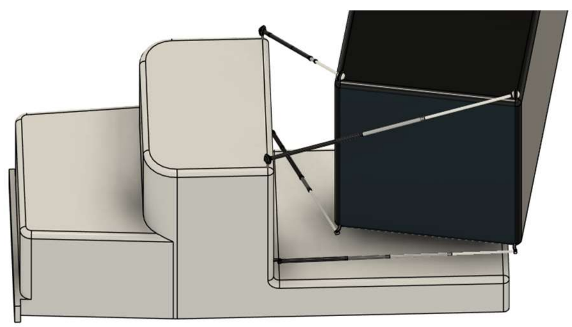

Figure 7: 80-Degree Right Turn with Braces

In this design, one edge of the elastic fabric is permanently attached to the truck and four points on the other side of the fabric are attached to the opposing ends of the telescoping rods. The four anchors for the joints are permanently connected to the trailer, allowing for quick installation and removal of the fairing. With this approach, only four connections must be detached to collapse the entire system. By implementing this hybrid approach, fabric flutter and installation time are both minimized.

Unfortunately, because it is not possible for CAD software to properly simulate the intricacies of fabric, I opted to create a solid body which would follow the same design of the fabric when in tension. For simulations purposes, the straight solid body is perfect because at high speeds, roads are straight anyways, so the trailer angle does not change.

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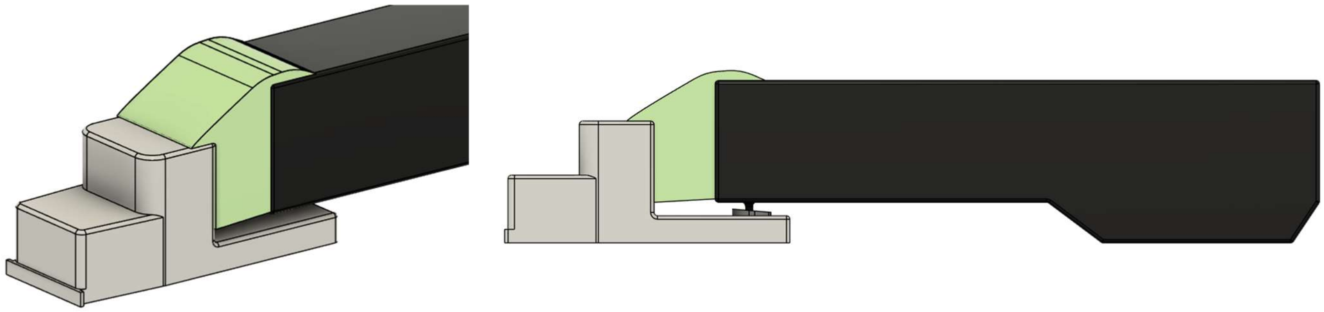

Figure 8: Straight Fairing Model

Finally, these CAD models are ready to simulate airflow and quantify the improvement in the drag coefficient.

3.2 Computational Fluid Dynamics Simulation

To simulate the models, I used the Computational Fluid Dynamics (CFD) simulation environment in SimScale, an open-source simulation platform. I ran two simulations to compare the results: a control model without the fairing, and the hybrid fairing model. Because these are external simulations, I needed to set up a fluid path: the volume of space around the model the fluid can flow. I was able to do this by simply creating an External Flow Volume around each model and subtracting the truck surface from the volume.

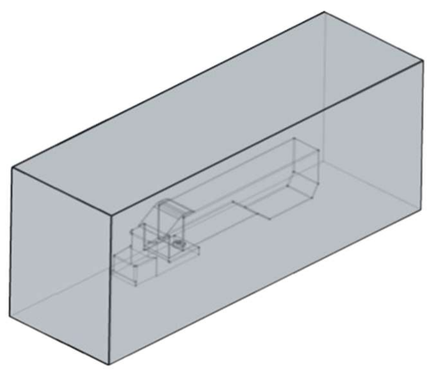

Figure 9: Fluid Path Volume

Next, to create the simulation, I used incompressible air as the fluid type. I then made the front face a velocity inlet and the back face a pressure outlet. For consistency, the inlet velocity in all simulations was set to 70mph. After completing the set up, I ran the simulations.

4. Results and Discussion

4.0 Representation

To represent the results, I used two methods: pressure analysis and particle flow analysis. The pressure analysis shows the pressure gradient of the air that forms on the truck surface, while the particle flow analysis depicts the path that individual particles take around the surface of the model.

4.1 Control Model

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As seen in Figure 10, the air collides with the top of the trailer, indicated by the red high-pressure zone. Another high-pressure zone is visible on the truck bed, which indicates that air curls into the gap after hitting the trailer, forming vortices.

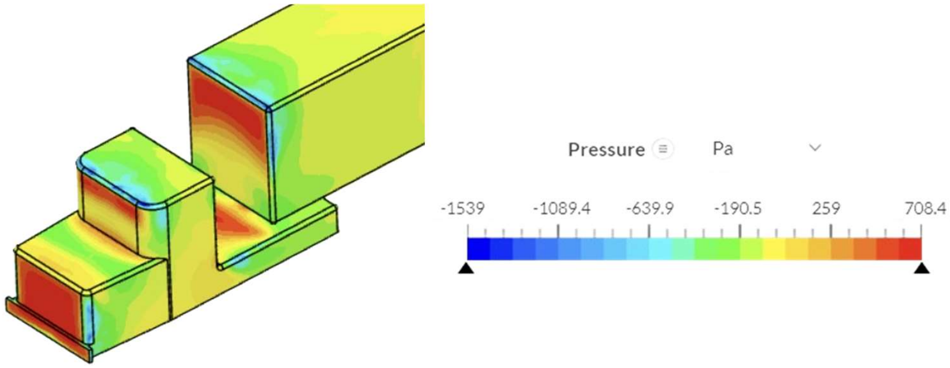

Figure 10: Pressure Gradient on Control Model Surface

These vortices become especially clear when looking at the particle flow analysis.

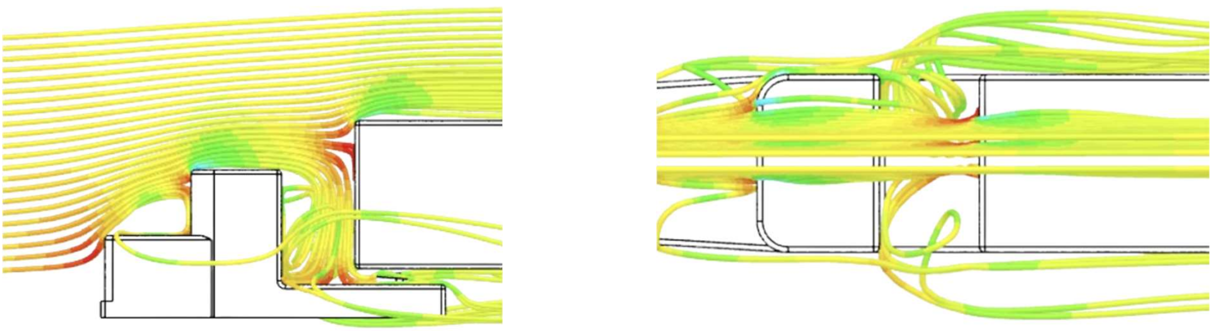

Figure 11: Particle Flow over Control Model

Figure 11 shows the air getting trapped within the trailer gap. This reduces energy efficiency because it adds a resistive force opposing the direction of motion.

4.2 Hybrid Fairing Model

As seen in Figure 12, the streamlined transition between the truck and trailer made by the hybrid fairing reduces the pressure by facilitating a gentle slope. This slope allows for smoother airflow, as seen by the relatively low-pressure region on the slope. Additionally, since the trailer gap is fully covered, no air can come inside the trailer gap, meaning vortices cannot form.

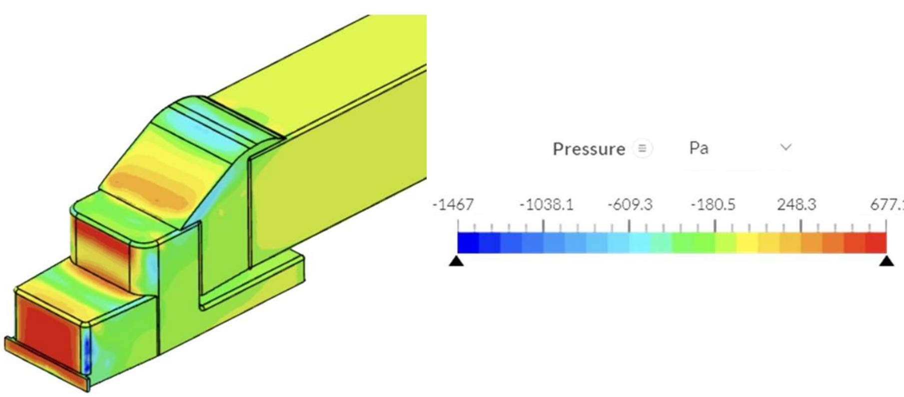

Figure 12: Pressure Gradient on Fairing Model Surface

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Just as predicted, the particle flow analysis in Figure 13 shows that air cannot enter the gap and simply goes around it, increasing energy efficiency.

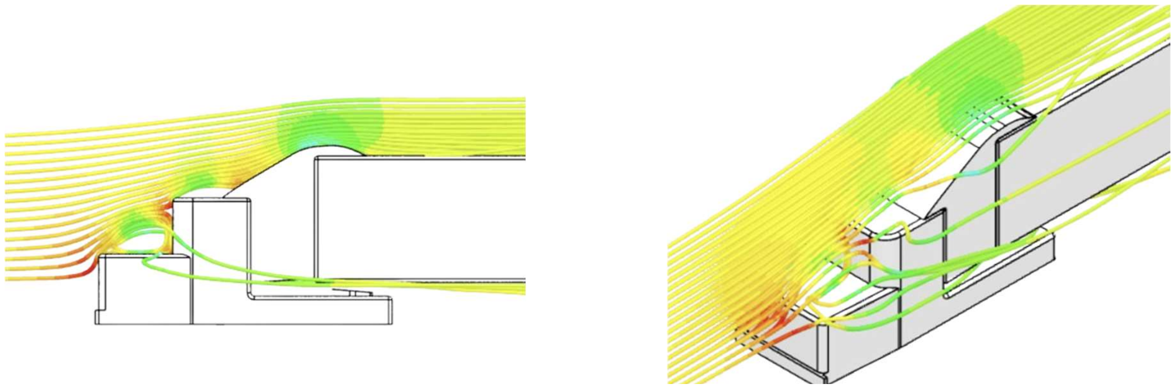

Figure 13: Particle Flow over Fairing Model

4.3 Drag Coefficients

To quantify the change in airflow, the drag coefficient must be calculated. To do this, I created another simulation in which I added force and moment coefficient parameters so that SimScale can plot graphs as the simulation runs to calculate the drag coefficient.

Drag Coefficients:

- Control model: 0.01591
- Fairing model: 0.01168

(Note that these values are relatively small because the models are scaled down)

The pressure and particle flow analysis shows a noticeable difference in turbulent air formations inside the gap between the two models. Looking at the calculations, the drag coefficient of the hybrid fairing model is over 36% smaller than that of the control model, indicating that by blocking the air from entering the trailer gap, there is a significant impact on a truck's airflow profile.

5. Conclusion

This project presents a detailed analysis of a hybrid truck fairing design promising improvements over rigid fairings. CFD analysis performed using an open-source simulation platform, SimScale, shows the hybrid fairing reduces the drag coefficient by over 36%. Extrapolating the results of this project into real life will take more experimentation regarding the actual impact it will have on energy efficiency. As explained earlier, the purpose of these simulations was to solely focus on the impact of airflow within the trailer gap. It ignores other turbulent areas around the truck. Still, from these preliminary simulations, the hybrid fairing design can be expected to increase fuel efficiency, but to quantify this impact and the effect on overall truck dynamics, more research, simulations, and analysis is required.