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An investigation of Aerodynamic Improvement on Truck's Forebody

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Abstract: An overview of aerodynamics of heavy-duty vehicles is the main focus of this paper. To be more specific, drag reduction systems, implementation of which can noticeably decrease fuel consumption of a truck, thus improving its efficiency. To do that, several different deflector designs were created. To evaluate them, multiple simulations of the flow field acting on a truck were made with Computational Fluid Dynamics (CFD) techniques. The simulations are based on steady-state formula, and their purpose is to evaluate aerodynamic properties of trucks. All the important characteristics and aerodynamic variables were determined by using TRIZ method. The resulting data clearly showed that curtain deflector designs can decrease drag coefficient and fuel consumption by as much as 0.02 and 0.83 liters respectively. It was proven that the solid basis can be established for future aerodynamic enhancements and their numerical and experimental evaluations.

Keywords: Aerodynamic, laminar flow, truck, forebody, TRIZ

Introduction

Starting from construction and mining, many industries rely on heavy trucks for their operations (Drollinger 1987). Harsh working conditions, heavy loads and bad roads take a grate tall on them and thus there has always been a demand for making them stronger and more reliable. On the other hand, the characteristics such as aerodynamics of these machines have mostly been neglected (Bayındırlı et al., 2016; Cooper 2003). However, with all the capabilities that engineers gained in the recent years and a new demand for fuel economy, many advancements in this area started appearing (Englar et al., 2001). Thus, the relevance of studying different techniques of improving drag resistance for the industry is as high as it has ever been (Ma'arof et al., 2018; Ali et al., 2013; Nor et al., 2019).

As mentioned before, drag reduction systems, implementation of which can noticeably decrease fuel consumption of a truck, thus improving its efficiency. Another important parameter mentioned in various sources, is the drag value. Furthermore, some real-world examples, like Dongfeng in this instance, indicate that digital modelling is playing a crucial role in the design of heavy trucks, as it allows to understand their aerodynamic properties better and have a great impact on some crucial design decisions (Holloway et al., 2009; Tang, 2015). This statement also finds validation in the article by McCallen et al., (2004), where the author claims that the reduced fuel consumption for large heavy trucks will be accomplished by adjusting the pattern of the truck to reduce the aerodynamic resistance or dragging.

Going deeper into the discussion of how trucks with better aerodynamics are far more superior than their older counterparts which were designed without flow resistance in mind. That was the particular case where a truck is driven down a highway cannot be neglected (Mosaddeghi et al., 2015). Drag resistance is a major parasitic loss in this case. Practical methods for minimizing aerodynamic drag provide cost-effective solutions that improve fuel economy (Mason et al.,1978). Most of these methods are evaluated when a small-scale test truck is placed into an air stream tube where the conditions are as close to a real-world case as they need to be for the particular test.

In order to evaluate the effect of air flow on different deflector designs, multiple simulations were made with Computational Fluid Dynamics (CFD) techniques. Those simulations are based on steady-state formula, and their purpose is to evaluate aerodynamic properties of trucks. The resulting data clearly shows that curtain deflector designs can decrease drag coefficient and fuel consumption by as much as 0.0176 and 0.83 liters respectively.

About the TRIZ methodlogy, TRIZ consists of the initials of the original named “Theoria Resheneyva Isobretatelskehuh Zadach” in Russian which is translated into English as “Theory of inventive Problem Solving and used acronym” (Ekmekci, 2019). In general, the TRIZ process starts with stripping away the side issues and preconceptions in order to define the core problem. This involves breaking the problem down into its most elementary components, understanding each component, expressing the components in the most elementary or fundamental way, and then finally freeing oneself from the constraints of the language in which the problem is expressed (Webb, 2002)

Methodology

Figure 1 shows process flow chart. Characteristics of aerodynamic variables that determine the behavior of the air flow around the deflector can be determined by using TRIZ methodology. These are the steps of TRIZ methodology that will apply to this project. Basically, the problem of the truck is related to the environment injure by air (wind) and water (rain) and also cannot drive in a high speed with low fuel consumption. The cause-and-effect Chain Analysis will identify the cause of the problem after this.

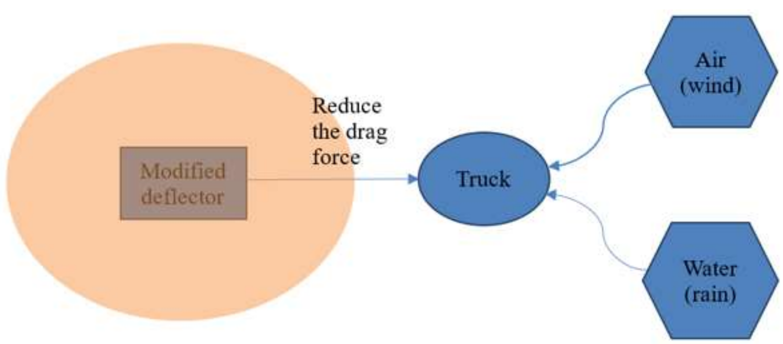


Figure 1. Process Flow Chart

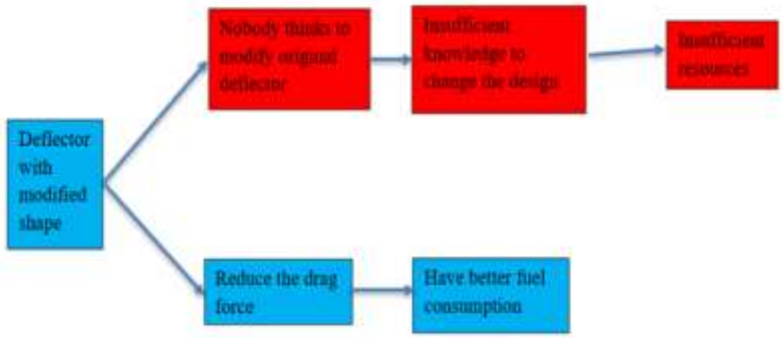


Figure 2. Cause and Effect Chain Analysis

Table 1. Design Parameter

Constant Variable	Manipulated Variables	Responding Variable
Material (aluminum)	Top edge fillet radius	Pressure contour
Truck dimension	Both side edge fillet radius	Velocity streamline
Length of deflector	Height of deflector	-
Width of deflector	-	-

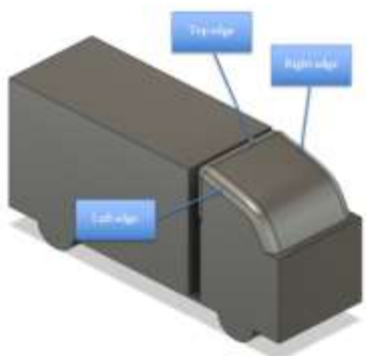


Figure 3. Design 1

The CAD drawing of the truck with deflector created by using fusion360 as shown in Figure 3. The following is indeed a step-by-step guide to creating a truck with deflector CAD model in Fusion360.

ANSYS simulation analysis to determine the benchmark compare a design modification to meet a new condition and optimize a five (5) new deflector type by following design parameter depending on the manipulate variable requirement, common truck properties of material are constant. For the deflector are redesigned to apply new fillet radius on both side of the edge and top edge, the height and length of the truck and the deflector will be remaining the same. ANSYS Workbench fluid flow of fluent are used in this project journey.

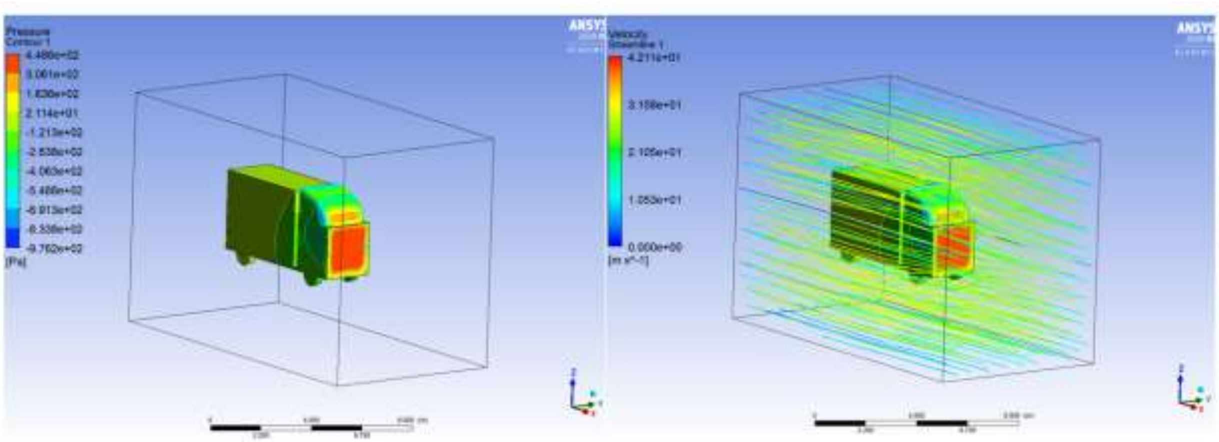
Altshuller, the founder of the TRIZ method analyzed thousands of worldwide patents from leading engineering fields, by categorizing these patents in a novel way through removing the subject matter to identify the problem-solving process rather than by classifying the patents by industry. He found that the same problems were often solved repetitively by using one of only 40 fundamental inventive principles as shown in Figure 4 (Ekmechi, 2019). On the other hand, Mann

(2002) indicated that TRIZ researchers have encapsulated the principles of good inventive practice, and then set them into a general problem solving structure. Meanwhile Loebmann (2002) explained the general process by which the TRIZ method overcomes the psychological inertia barrier, and this is through the generalization of the specific problem to an analogous TRIZ generic problem. Throughout the comparison of this generic TRIZ problem with the analogous generic TRIZ solution in the knowledge database obtained from scientific effects and patents research, one can generate the solutions for the specific problem

1. Segmentation
2. Extraction / Separation / Removal / Segregation
3. Local Quality
4. Asymmetry
5. Combining, Integration, Mergin
6. Universality, Multi-functional
7. Nesting
8. Counter-weight, Levitation, Anti-Weight
9. Preliminary anti-action, Prior counteraction
10. Prior action
11. Cushion in advance, compensate before
12. Equipotentiality, remove stress
13. Inversion, The other way around
14. Spheroidality, Curvilinearity
15. Dynamicity, Optimization
16. Partial or excessive action
17. Another Dimension
18. Mechanical vibration/oscillation
19. Periodic action
20. Continuity of a useful action
21. Rushing through / Skipping
22. Convert harm into benefit, "Blessing in disguise", Make lemonade from lemon
23. Feedback
24. Mediator, intermediary
25. Self-service, self-organization
26. Copying
27. Cheap, disposable/short-living objects
28. Mechanics Substitution
29. Pneumatics or hydraulics / Liquids
30. Flexible membranes or thin film
31. Use of porous materials
32. Changing color or optical properties
33. Homogeneity
34. Rejection and regeneration, Discarding and recovering
35. Parameter changes
36. Phase transformation / transition
37. Thermal expansion
38. Use strong oxidizers, enriched atmospheres, accelerated oxidation
39. Inert environment or atmosphere
40. Composite materials

Figure 4. 40 fundamental inventive principles of TRIZ (Ekmechi, 2019)

Results and Discussion



Forces - Direction Vector (-1 0 0)

	Forces (n)			Coefficients		
Zone	Pressure	Viscous	Total	Pressure	Viscous	Total
truck_surface	2662.2166	42.542656	2704.7592	0.78710405	0.012578052	0.79968211
Net	2662.2166	42.542656	2704.7592	0.78710405	0.012578052	0.79968211

Figure 4. Simulation of Design 1

Table 2. Design Parameter

Design	Drag Coefficient	Drag Force by ANSYS (N)	Drag Force by manual calculation (N)	Fuel Consumption (Liters)
Benchmark Design	0.8173	2831.87	2705.68	21.78
Design 1	0.7997	2704.76	2601.69	20.95

Table 2 shows the contours of static pressure for all designs. Based on the table, we can know that the Design 1 incurred the minimum pressure which is -976.2. However, the pressure for benchmarking is the worst among all the design which is -701.8. As the Design 1 is better than benchmark design, thus the result is validated. Another important parameter that was noticed to be changing is the drag coefficient, which is 0.8173 for the baseline (benchmark) design, and 0.7997 for Design 1. Hence this data also proved that Design 1 has better aerodynamic characteristics. Figure 5 shows the benchmark design on side view of Volvo truck

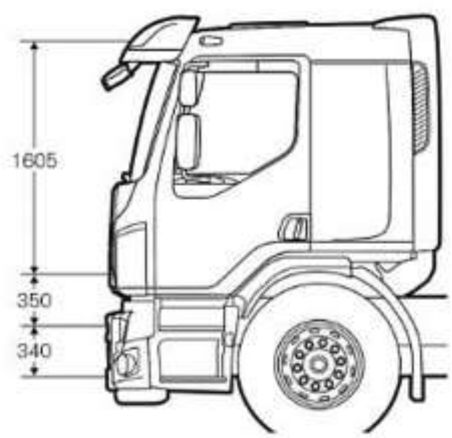


Figure 5. Side view of benchmark design

Also, Table 2 shows design 1 is better because the position of stagnation point for a modified truck-trailer model occurs at a higher distance from the deflector of the truck-trailer when compared with the benchmark design of truck-trailer. This ensures larger surface area of contact on the front end of the modified truck-trailer model for the pressure distribution and thus, the resultant drag force is more uniform when compared with the benchmark design. The pressure distribution across the surface of the modified truck-trailer profile is more uniform in comparison with the basic model. Henceforth, when drag reduction devices (deflector) were used, it helps to provide better control and drag reduction.

As the goal of this study is to calculate the drag force for different designs, the variables that were changed between them are the fillet radii of the top edge, both side edge and the height of the deflector whilst. The variables that were kept constant along the experiment are the material, which in this case is aluminum, and deflector dimensions. The key parameters that were checked to understand the difference are the drag force, pressure contour and velocity streamline. Hence, based on the readings in Table 8, the most optimum drag coefficient and drag force were determined. The visualization of the flow also shows Design 1 is facing a turbulent flow, which, unlike its laminar counterpart doesn't flow smoothly along the surface of the truck model. This mostly happens as a result of high velocities. The same can be said about the benchmark design that was tested in the same manner.

Conclusion

Conclusively, the assessment was a success. It was indeed apparent that based on ANSYS simulation and manual calculation, the most optimal design is Design 1 which able to save the maximum of fuel consumption. Design 1 was the most optimum and suitable fillet radius among all the design including the benchmark design. The values of drag coefficient for the truck become significantly less than the benchmark design. This means as the drag force is reduced thus there is more saving in fuel consumption. Flow visualization can show the flow structure around the truck trailer even though it is turbulent flow for Design 1.

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