ROOF RACKS AERODYNAMIC OPTIMIZATION FOR A UTILITY VEHICLE

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ABSTRACT –The factors that impact the aerodynamic design of a vehicle have been and continue to be the subject of extensive research in the design of ground vehicles. Stricter environmental regulations force the automotive industry to invest a large amount of resources to improve fuel efficiency and emissions requirements. It is expected that automakers will improve fuel consumption by 20% to 60% by the year 2025 which represents a very difficult engineering challenge. However, there is a growing number of after-market accessories that can be attached to a vehicle resulting in a change of the original vehicle performance that many times is not rigorously studied, carrying consequences that are not clearly explained to consumers. The most common accessory are roof racks which are used to transport oversized items. According to Yuche et al. [1] roof racks are responsible for 0.8‰ of light duty vehicle fuel consumption in the United States in the year 2015 corresponding to 100 million gallons of gasoline per year. It is then important that the design of roof racks is improved to reduce the individual vehicle fuel consumption. In this work, the aerodynamic design of roof racks for a utility vehicle will be improved using Computational Fluid Dynamics (CFD). The solver used in this work is the LS-DYNA module ICFD which resolves the incompressible Navier-Stokes equations for turbulent flows. To study the influence of the different geometric design parameters LS-DYNA is coupled to the LS-OPT tool which is used for optimization. Finally LS-OPT is coupled to ANSA to handle mesh morphing in a fully automatic optimization loop. The results show that a simple modification in the slant angle for the roof rack model considered in this work may produce a favorable result in the reduction of the drag force when compared to the original design provided by the manufacturer.

TECHNICAL PAPER -

1. INTRODUCTION

The use of CFD simulations in the area of ground vehicle aerodynamics is primarily used during the initial design phase of a vehicle. At this point engineers and designers interact to find a compromise between aesthetics and aerodynamic efficiency. When a vehicle is delivered to the market place all the original components and optional components like spoilers, wheels, etc. have been tested in wind tunnels experimentally and numerically and their impact in the performance of the vehicle is very well understood by engineers. On the other hand consumers have access to a large amount of aftermarket products that can be attached to the vehicles with the purpose of performance improvement, aesthetics or for adaptation for specific practical functionalities. Most of these adaptations have little to none testing and many times with counter-intuitive or unpredictable aerodynamic effect for some vehicle models.
One of the most widely used accessories in cars with growing popularity are roof racks. Although they are a practical and useful addition consumers do not realize that they may be paying a penalty of up to 25% increase in fuel consumption due to the increase aerodynamic drag.
The study presented by Chen et al. [1] provides excellent insight into the aerodynamics effects of roof racks and their economic impact.

Figure 1 –Basic configuration for the utility vehicle and the roof rack used in the analysis

In the current paper the focus is on roof racks adapted to a utility vehicle (see Fig. 1). The main objective of this study is to attempt an aerodynamic improvement that reduces drag by optimizing the geometric shape of the rack. This is achieved by solving iteratively a computational fluid dynamics (CFD) model of the vehicle with the roof rack for different geometric configurations until an optimal shape that minimizes the drag force is found. The CFD solver used in this work is part of the LS-DYNA [2] suite of solvers called ICFD. The iterative optimization process is done using the optimization tool LS-OPT [3] which is also part of LS-DYNA.

2. METHODOLOGY

The goal of this project is to find a geometry configuration for the roof racks that reduces the total drag of the racks and vehicle as a whole. Thus the objective function during the optimization loop will be total drag and the goal will be to minimize it. The first thing is to identify the critical regions in the geometry that will have the largest impact in the result and parameterize those regions. The idea is that by iteratively modifying the parameters the optimization algorithm will converge to values that minimizes the objective function. The least number of parameters the better since the optimization loop will require less iterations. In this work two parameters have been used (see Fig. 2). They produce a vertical displacement in the front and back of the rack modifying the angle.

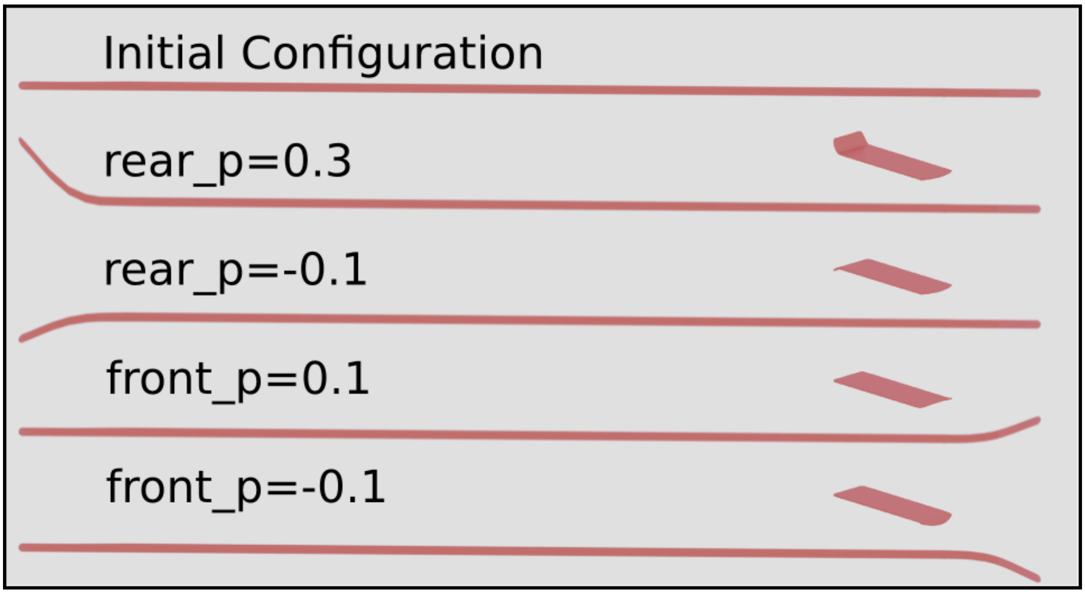

Figure 2 –Parameters used in the optimization loop and the extreme roof racks configurations.

The parameters will be named *rear_p* and *front_p* and the values will change so that -0.1<*rear_p*<0.3 and -0.1<*front_p*<0.1. Once the parameters are identified the next challenge is to modify the geometry during the optimization loop. In this work the mesher ANSA by BETA_CAE will be used. ANSA allows user to create morphing boxes that control the shape of the underlying geometry (see Fig. 3). The workflow is simple: LS-OPT will compute the value of the optimization parameters and request ANSA to modify the mesh. With the new mesh LS-DYNA will compute a new value for the objective function (drag) and with this LS-OPT will evaluate a new set of parameters. The loop continues until LS-OPT converges to parameters that minimize the functional *drag.*

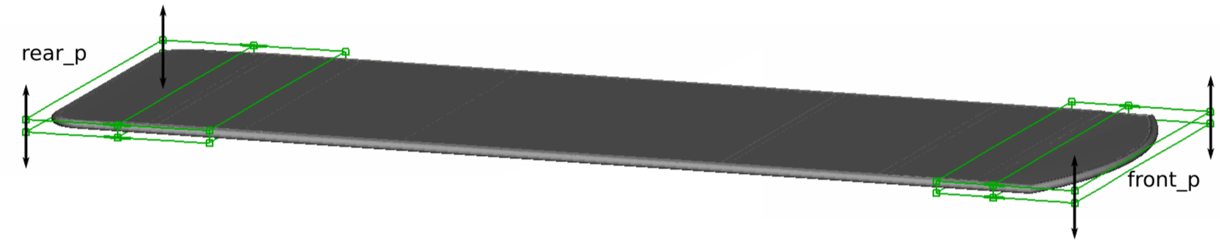

Figure 3 – Rear and front morphing boxes defined in ANSA to modify the geometry using parameters rear_p and front_p.

The metamodel used in the LS-OPT optimization is called Sequential with Domain Reduction and the flowchart image is depicted in Fig. 4. For a detailed tutorial on how to set up the optimization loop refer to [4].

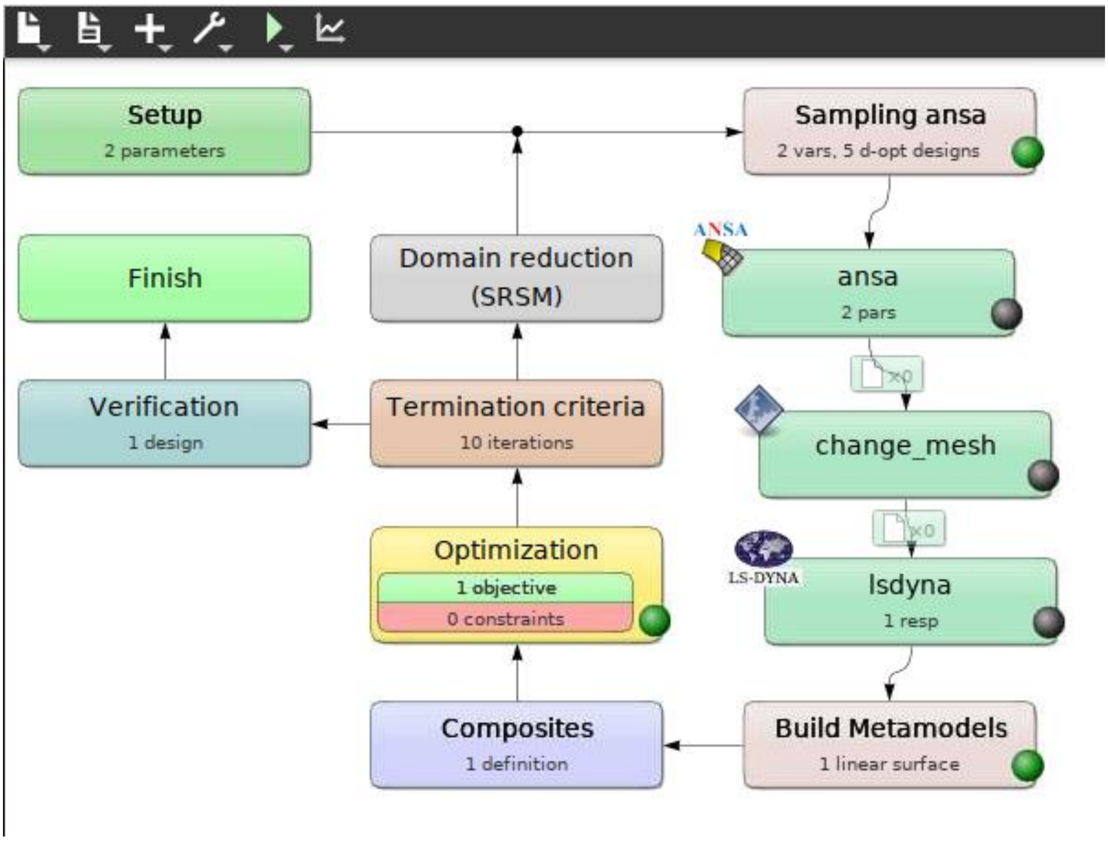

Figure 4 –LS-OPT flow chart for the optimization metamodel “Sequential with Domain Reduction”.

The mesh used during the CFD analysis is shown in Fig. 5 i.e a section cut right at the center of the vehicle for one of the optimization iterations. Observe the highly refined areas where the optimization parameters deform the mesh. The total mesh size is about 20 million elements.

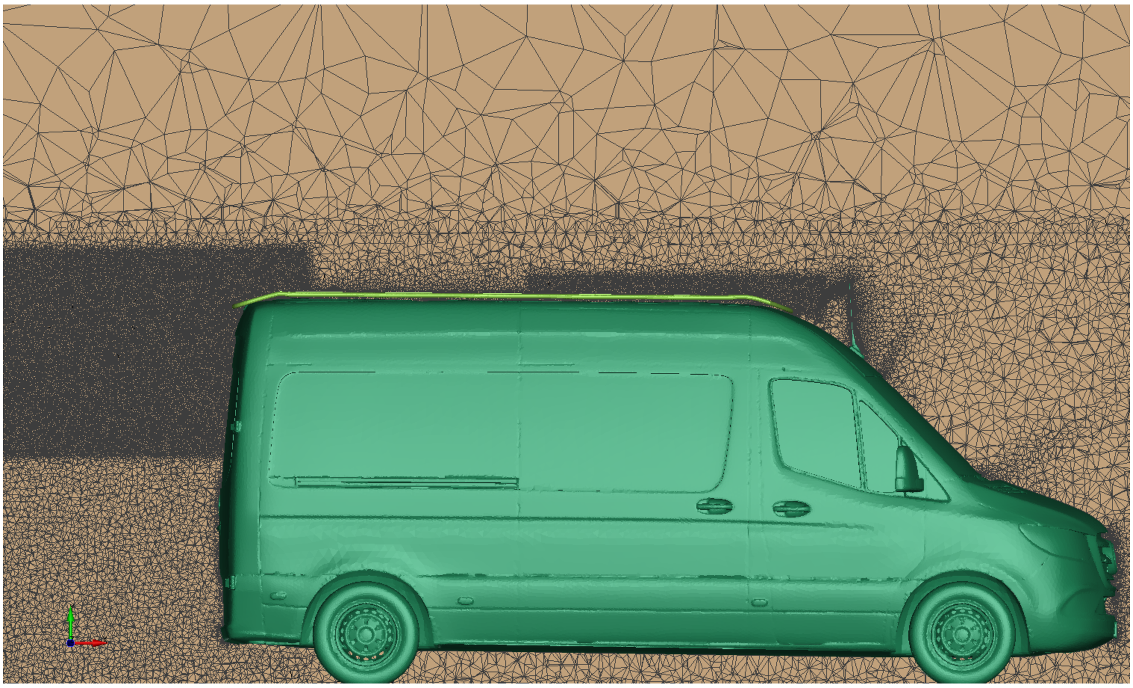

Figure 5 –Section cut of the volume mesh showing the refinement regions at the leading and trailing edges of the roof racks.

3. RESULTS

Once the optimization stages are set up in LS-OPT and a baseline run is proven to work as expected then the normal run will initiate the optimization task. As seen in Fig. 4 there are 5 runs per iteration. The jobs were run on a cluster and each job was allowed to use 24 cores. The loop terminated after 10 iterations for a total of 50 jobs. In Fig. 6 the scatter plot for all the iterations is shown. The highlighted value in blue corresponds to the minimum while the initial configuration is shown in green.

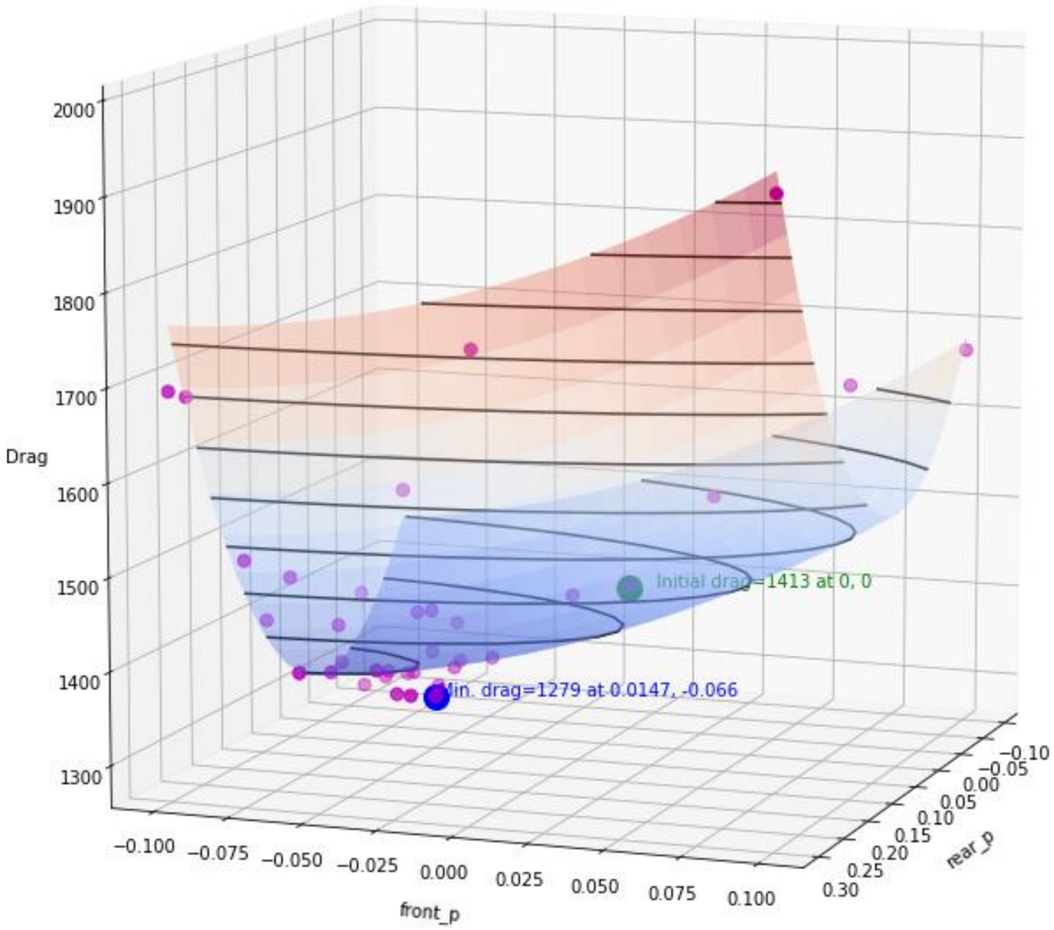

Figure 6 –Optimization results after 10 iterations of LS-OPT. Blue colour shows the minimum value while green shows the initial configuration.

The difference between the initial and the minimum optimal value is around 9% of total drag reduction which is a significant amount. For this minimum rear_p=0.0147 and front_p=-0.066. The CFD results showing the fluid features near the roof racks and behind the vehicle is shown in Fig. 7. For a better graphical comparison the difference between the initial and optimal configurations is shown in Fig. 8.

4. CONCLUSIONS

In this work the optimization of roof racks for a utility vehicle was performed using LS-DYNA for CFD analysis coupled to LS-OPT for optimization and ANSA for the mesh morphing. Roof racks impose a penalty on fuel efficiency due to the added drag force. The optimization functional is the drag force and the objective is to minimize the drag. After ten optimization iterations a new configuration was found that reduces the drag by 9% with respect to the initial geometry.

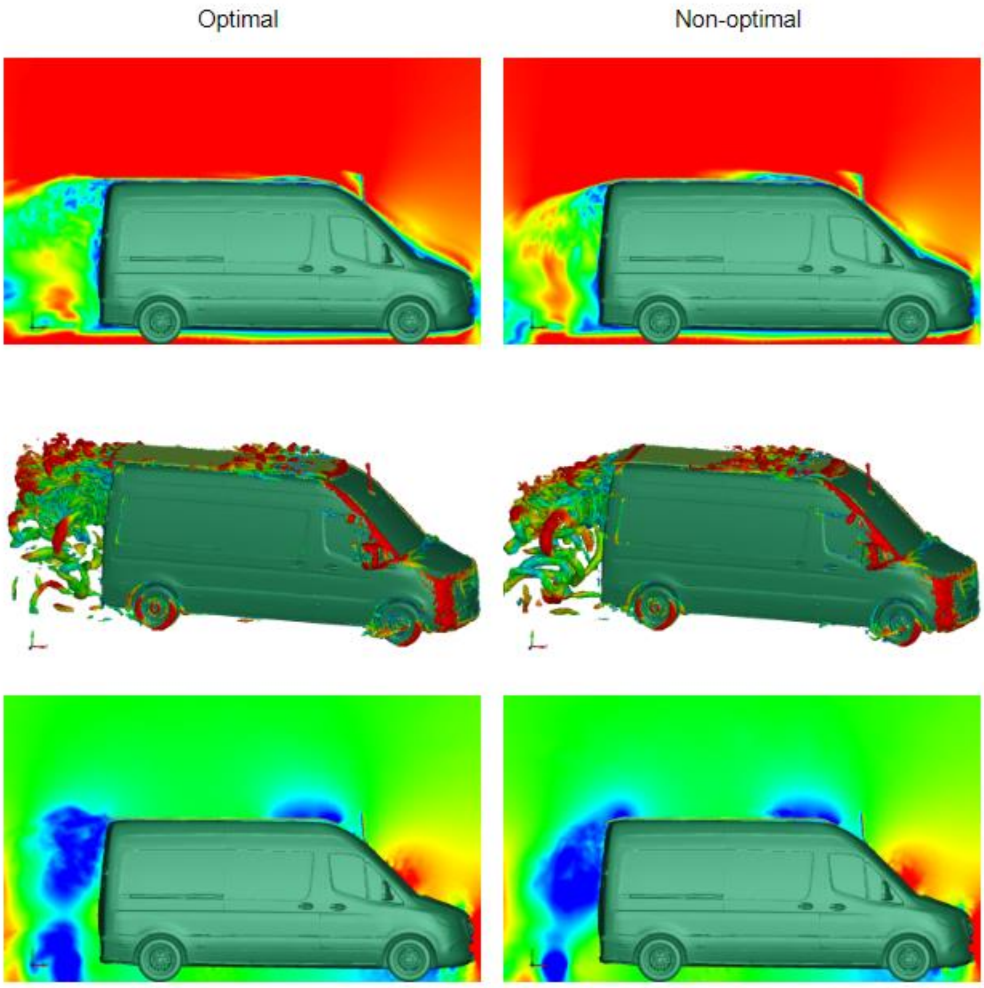

Figure 7 – CFD results comparison between the optimal result and a non-optimal iteration showing the flow features near the roof racks and behind the vehicle. Top: time-averaged velocity on section plane. Middle: Q criterium coloured by the velocity field. Bottom: time-averaged pressure field.

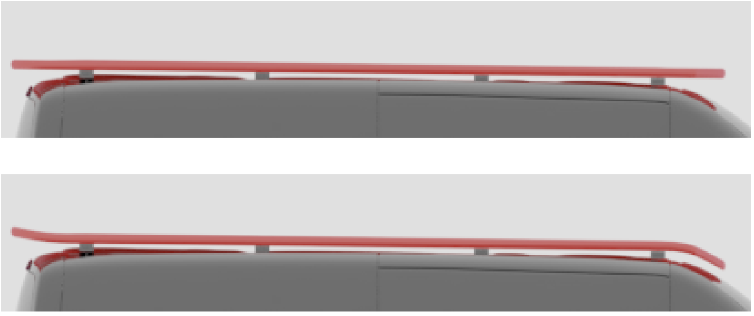

Figure 8 – *Comparison between the initial and the optimal roof racks configuration.*

REFERENCES

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