

Optimizing the External Shape of Vehicles at the Concept Stage: Integration of Aerodynamics and Ergonomics

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ABSTRACT

The automotive field is facing increasing pressure towards the reduction of design times and costs and towards the improvement of car performance, especially with respect to fuel consumption and CO₂ emissions. Aerodynamics is one of the fields where this performance improvement can be achieved, but any improvement in this area must not affect negatively other performances, like cooling or ergonomics and space for occupants.

This paper presents current methods in CRF (Centro Ricerche FIAT) and FGA (Fiat Group Automobiles) for multi-objective optimisation of the external shape of new models, with respect to aerodynamic and ergonomic performances, and how the conflicting requirements coming from the different disciplines can be managed in a systematic way.

An application of these method is presented, showing the work performed in preparation of the design of a new model: since the style of the new model was not yet defined, the shape of an older model of the same segment was optimized, in order to understand how to reach the new targets in terms of drag coefficient and frontal area. The most significant ergonomic performances were verified for all the

configurations analysed for aerodynamics, highlighting potential conflicts and possible compromises. The methodology is then ready to show its full potential during the development of the new model, where aerodynamic and ergonomic optimization can be performed simultaneously from the beginning of the project.

INTRODUCTION

The use of numerical optimisation has emerged in the latest years as a powerful tool to drive the design of new models in a systematic way, and its range of application has constantly increased [1,2,3]. The reason for this success is not only the ability of these tools to optimize one particular performance at a time, task for which the traditional approach based on engineering experience and extensive testing is still effective, but on the ability of these methods to optimize distant or conflicting performances at the same time. This is a major breakthrough with respect to the traditional approach, where many iterations were needed before freezing a design that was respectful of all the constraints and performance requirements for a new model.

In order to reduce the overall design time and design cost it is important to limit the number of such design iterations, and, mostly important, to avoid the situation where the design

must be modified at a late stage (in order to reach the requirements for some performance).

Numerical simulation is a fundamental tool in order to reach these objectives, since potential problems can be highlighted months before the first prototype exists. However, simulation tools alone can not guarantee that all performances will be reached if there is not a tool for identifying and managing performance conflicts. In the present paper it will be shown an application regarding the management of conflicting performances related to aerodynamics and ergonomics, performances that are often in contrast and that are assessed at the very early stages of vehicle design, when the style has not been frozen yet.

Over the latest years CRF has developed a tool, based on morphing and CFD, for the automatic optimization of the shape of the car versus aerodynamic performances [4,5].

This tool has been recently extended in order to perform an approximate ergonomic analysis on some of the characteristic measures of the passenger compartment, like visibility, accessibility and room available for passenger: the aim of this tool is not to replicate existing tools for ergonomic analyses, but to give first indications of possible ergonomic issues during the analyses for aerodynamic purposes, on the same model used for CFD.

These indications are used as constraints during the optimization: as a result the final shape resulting from the aerodynamic optimisation will have a small probability of breaking ergonomic limits. Since the method used during the optimization is still approximate, a proper assessment of the actual ergonomic properties of the modified passenger compartment will be anyway performed with dedicated ergonomic software for a final validation.

The details of the tool and an example of application will be described in the following paragraphs.

AERODYNAMIC OPTIMIZATION

With aerodynamic optimization we intend the automated search of the optimal shape of a car, relatively to one or several aerodynamic performances, evaluated with the use of CFD techniques. In current approach, optimization is performed with the use of an optimization software (in our case modeFrontier™) that can drive a loop in which, at each step, a new geometry is generated and analysed from the aerodynamic point of view.

The shape parameters that can be optimized simultaneously with this approach are of different kind:

- Shape parameters: continuous variables describing the shape of the car, relatively to a parametric description of the external surface

- On/off parameters: boolean variable, indicating the presence or absence of thin surfaces like screens, seals or flow guides.

- Catalogue parameters: integer variable allowing to choose a component (like a rear view mirror) from an indexed catalogue

In order to make this possible, all the steps that need to be performed in order to run a CFD simulation, with the use of commercial software available in CRF and FGA, have been automated via scripting and a software has been developed internally that coordinates all the work. The steps that have been automated are listed below:

SHAPE MODIFICATION

Mesh morphing has been chosen as the standard technique for the creation of parametric geometries, since starting models are always style models that are not parametric at the beginning; with this technique all the parameterization can be prepared efficiently inside the aerodynamic department.

SHAPE MEASUREMENT

Measurements must be taken on each model after morphing, since parameters affecting aerodynamic coefficients, like frontal area or wheel-base, may have changed. This is achieved in a specific step of the analysis, in which measurements like point positions, distances, angles or frontal area, are extracted and recorded. The use of this step for the extraction of measurements related to ergonomics will be described in the next section.

MESH GENERATION

Surface mesh is smoothed after morphing in order to correct eventual distorted elements. Volume mesh is regenerated each time: this is less computationally efficient, but it is more robust and minimizes manual work during the generation of the parametric morphing model.

CFD RUN

All input files needed for a CFD simulation are automatically generated for each case. The procedure is integrated with the available queue managers and cases are submitted automatically. Automated convergence controls are used in order to run a case for the iterations that are strictly needed to reach convergence.

REPORTING AND POST PROCESSING

For each case, relevant aerodynamic parameters are extracted by CFD results and stored in .xml files. A set of standard images of convergence histories and aerodynamic flow field is generated for each case and all the images are then collected into a single html file for visualization. Different types of aerodynamic data can be extracted from the raw

CFD data, that can be used as object functions for the optimizer:

- drag,
- lift,
- flow rate through radiators,
- velocity homogeneity (for radiators or passenger compartment flows)

ERGONOMIC OPTIMIZATION

In order to take into account the ergonomic issues during the optimization, the same shapes generated for CFD analyses are used to take measurements on the body of the car and assess ergonomic performances. The method makes use of the same software modules used for shape measurement during aerodynamic optimization.

Since the CFD model includes only the external shape of the car, it is not detailed enough for taking all the measures that are significant for ergonomic evaluations: it does not include body thickness, soundproofing and aesthetic panels, internal structure and pillars, etc. For this step then a model containing all these details is morphed with the same morphing parameters of the CFD model, and used for taking ergonomic measurements.

The measurements that need to be considered for ergonomics evaluations include visibility, accessibility and passenger comfort measurements.

The measurements that have actually been considered for this study are the following:

- Front and rear visibility angles, in the vertical plane
- Pillars visual obstruction, in the horizontal plane
- Pillars - A lateral position and obstruction in the horizontal plane
- Roominess available for the heads of front and rear passengers

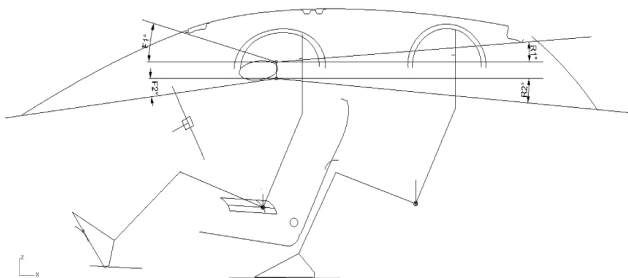


Figure 1. Longitudinal visibility angles (lateral view)

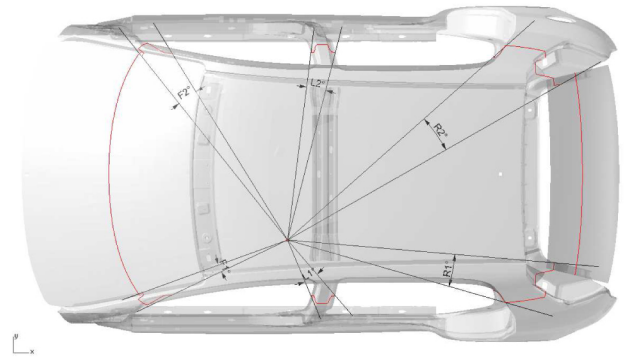


Figure 2. Pillars visual obstruction angles (top view)

The measurements that have actually been considered for this study are the following:

- Front and rear visibility angles, in the horizontal plane
- Front and rear visibility angles, in the vertical plane
- Room available for the heads of front and rear passengers

These are the parameters that are most affected by the shape modifications introduced for the aerodynamic optimization. For example the pedals or steering wheel position are not moved during the aerodynamic optimization, and so all the measures related to them are not affected at all. Also, the accessibility is moderately affected by the aerodynamic modifications and was not included into this first analysis.

The visibility angles are transformed into ranks, according to an internal scale; a minimum rank for acceptability is defined for each of the angles. The roominess available for passenger instead defines not a rank, but a percentile of the population that will fit into the seats, but again a minimum percentile must be guaranteed.

An implicit assumption is that the position of the seats and the passengers will not be changed during the optimization.

APPLICATION AND RESULTS

The application that will be discussed is a concept study that has been performed in preparation of the development of a new model for the B-segment. A parametric study has been performed on one of the current FIAT B-segment models, in order to get design information for the new model, and an optimal solution has searched with the optimization tool.

The target that was given for the aerodynamic optimisation was to decrease the drag coefficient of the current model by 15 counts, while keeping the frontal area in a given range.

The geometric parameters that were chosen are listed in the table below.