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CAD MODEL OF REAR-VIEW MIRROR AND SIMULATION OF ITS AERODYNAMICS AND NOISE

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Abstract

Very important aspect of the designer's work, which requires going through the process from the initial idea, through the design of the concept, to the desired final state of the selected product, is to understand, what will be impact of designed part on physical properties of product. The paper focuses on the analysis of aerodynamics resistance and noise of proposed design of a selected car component. The car's exterior mirror was chosen as the component for the analysis. In the paper, it is proposed our own design of rear-view mirror. The 3D model was created in the CATIA system and it was then transferred to the environment of SolidWorks system, where were performed Computation Fluid Dynamics (CFD) simulations and analyses. There are described the results of aerodynamics resistance and noise analyses in different speeds. As a default speeds were chosen typical allowed speeds: urban (50 km/h), rural (90 km/h) and motorways (130 km/h). The values obtained by the simulations indicate a further direction of the rear-view mirror design in order to achieve better parameters in terms of aerodynamics and noise.

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Key Words: Rear-View Mirror, CAD Modelling, Airflow, Simulation, Noise, Aerodynamics

1. INTRODUCTION

Design and aerodynamics are two different parameters, but they play very important role in the automotive industry. When the designer proposes rear-view mirrors, it is very important to pay attention to the lines and shapes of the final design. The goal of the development teams is to create an ergonomically, visually and dimensionally perfect product that will harmonize with the final design of the car. Safety is also important parameter in the design. The protruding rear-view mirror should also provide the necessary safety features to prevent collision between pedestrians and the car.

Every designer should also have an attention to detail. The design development process can take very long time (months to years). Manual or software sketches are gradually prepared from the initial idea and inspiration. From the prepared sketches is selected one, which is used in further development process.

The process of continuous research and development forms a substantial part of the whole work. Subsequently, a three-dimensional object is created using 3D software programs, where the shape as well as dimensional predispositions of the design are evaluated. Thorough analysis will solve all the necessary elements and details. This fine-specified 3D model, which has gone through all software simulations and analyses, can be produced as a prototype in a 1 : 1 scale.

In today´s competitive environment there are high demands on car development and, given the number of parts and components that must be designed, produced, tested and ensured their consistency, this is a very challenging task. It is a large-scale project with many inputs, stages and phases [1], where are a large amount of information and a high degree of risk and it is an effort to reduce [2]. At present, it is almost impossible to imagine car development without computer support at all stages of car design [3, 4] starting with initial sketch design, through development and modelling of individual components, simulation and testing, continuing to assembly [5], its tests and subsequent optimization. Furthermore, it is production planning and preparation of individual parts, including design of tools and moulds [6] such as production preparation of the whole car and its assembly [7], design of production facilities and workplaces [8, 9], their management and control, planning and verification of logistics [10], etc. Software applications are constantly being developed as well as the theoretical foundations on which software are built. Some are focused on solving specific tasks, e.g. [11, 12], others have a more universal usage [13]. At the same time, it is necessary to solve the problems associated with managing the huge amount of data generated by such a project [14], as well as with the data exchange between different systems [15].

At present, the priority in the automotive industry is given to low emissions in the case of cars with internal combustion engines and car range in the case of electric cars. This leads to a prioritization of car weight reduction and improvement of car aerodynamics [16]. Weight reduction is achieved by application of new lighter materials as well as by optimization of the components design using computer technology. Several publications deal with the issue of car aerodynamics, e.g. [17]. Improvement of aerodynamics is achieved by testing and simulating both the whole car [18] as well as the individual parts [19, 20] that have big impact on aerodynamics. In this area, Computation Fluid Dynamics (CFD) systems working on the principle of the finite element method (FEM) are used. These methods are developed at a very good level, but this does not mean that their development does not continue. Car producers are still looking for ways to improve and enhance these methods [21]. One of the ca components that receives a lot of attention in terms of aerodynamics is the exterior rear-view mirror.

The development of rear-view mirrors has been moving forward rapidly recently, and many design changes have come with it. Over time, we can monitor various integrated advanced features such as built-in cameras, dynamic turn signals, blind spot detection lights, heating, tilting and dimming mirrors. However, the basic essence of the rear-view mirror remained unchanged. Its task is to give the driver an overview of the situation around the vehicle. Although the rear-view mirror is only a small element from the point of view of the car as a whole, from the point of view of vehicle design it is a very important component, which significantly affect the overall appearance of the vehicle. The design of the rear-view mirror affects the aesthetic appearance of the vehicle, but it also affects aerodynamics and noise. A number of works can document the importance of the rear-view mirror in terms of aerodynamics and noise, such as [22-28].

The paper deals with the analysis of proposed rear-view mirror modelled in a CAD system [29]. The created CAD model of rear-view mirror is analysed in terms of aerodynamic properties as well as in terms of noise. The importance of aerodynamics lies in the fact that poor aerodynamic properties generally have an adverse effect on driving a car in several respects. These are mainly fuel consumption and thus emissions, as well as crew comfort, which can be affected by the increased noise concentration around the rear-view mirror due to changes in airflow.

Today's conventional cars achieve an overall drag coefficient in the range of 0.25 to 0.30. The share of rear-view mirrors in this total resistance ranges from 2 to 7 %. It seems that is not so much, but it is necessary to pay attention to this factor and try to reduce the overall air resistance of the car by focusing on the individual components of the car that affect the air resistance. By integration of the partial improvements of individual components, it is possible to achieve a significant benefit in terms of air resistance and thus the range of electric cars, respectively emissions from cars with internal combustion engines.

2. COMPONENT CAD MODEL

We chose Catia V5 software for component modelling. The reason for our choice is the wide use of this software in the automotive industry. This software is used by designers, constructors and engineers around the world and is applicable across various industries in the market. The program has long been used in well-known carmakers such as BMW or in the Volkswagen Group, including the Škoda carmaker. The software itself was created in France by Dassault Systems, which is constantly developing and innovating it in the field of 3D modelling with a purpose to achieve perfect CAD products. In addition the Dassault Systems, has brought a number of other software for modelling and simulation, of which we also draw attention to Solidworks software.

The model of the outer cover was the very basis, according to which we later modelled the remaining parts, such as a dynamic camera, a temperature sensor, a camera, a holder with an electric tilting motor and the glass itself. The main task was to create space for the placement of all these components already in the sketch. Curves of the cover in the environment generative shape design are in Fig. 1 and model surface created using surface modelling is in Fig. 2.

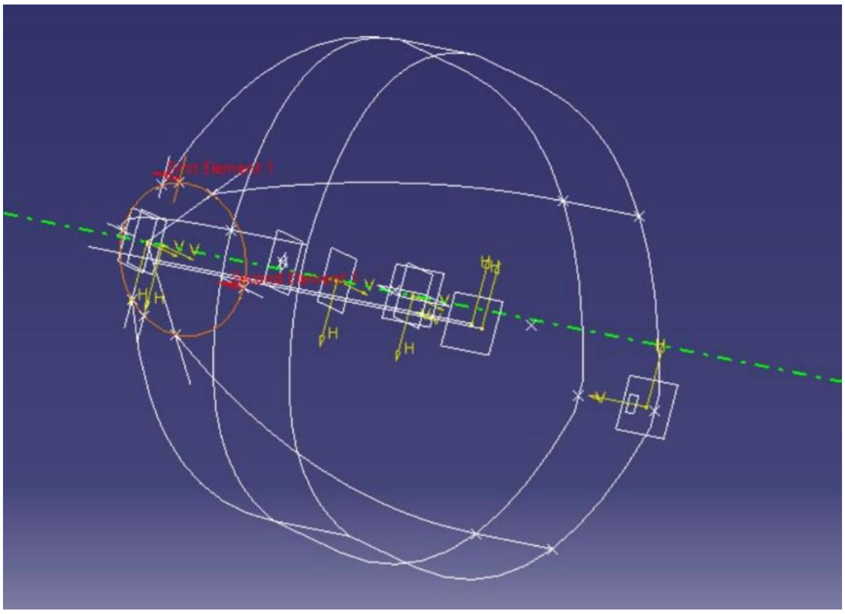


Figure 1: Curves of the cover in the environment generative shape design [29].

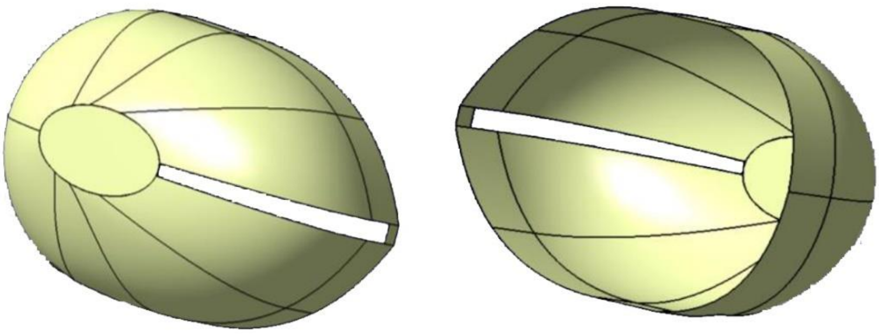


Figure 2: Model surface created using surface modelling [29].

The glass was modelled in reduced dimensions according to the shape of the mirror cover so that it provided space for the necessary rotation. It consists of several layers, which we divided into separate groups during modelling. In Fig. 3, the image of proposed rear-view mirror is shown.

Figure 3: Proposed rear-view mirror [29].

3. SIMULATIONS OF AERODYNAMICS AND NOISE OF DESIGNED MIRRORS

After modelling the rear-view mirror models in Catia V5, we began analysing these mirrors using Solidworks. The primary goal was to determine the behaviour of this rear-view mirror during car operation, especially in terms of airflow and aerodynamics as such, but we also examined the pressure on the front surface of the mirror and noise at three different air velocities.

The advantage of the above-mentioned computer software is a certain connection between them. They also play an important role in the automotive industry in terms of computer support in model design, research and subsequent analysis of various simulations. Programs from one software producer can usually exchange data between them without problems. We appreciated it in our work in situations where we needed to transfer the designed rear-view mirror model created in the Catia as a Product file type (assembly) to the Solidworks interface as a Solidworks assembly document file type. Programs can perform these tasks completely without errors.

The reason for performing the analyses in Solidworks was the fact that the available Catia configuration do not contain the appropriate modules to perform the above-mentioned analyses and simulations.

By entering the input parameters of simulation (Fig. 4) we created a model for simulation.

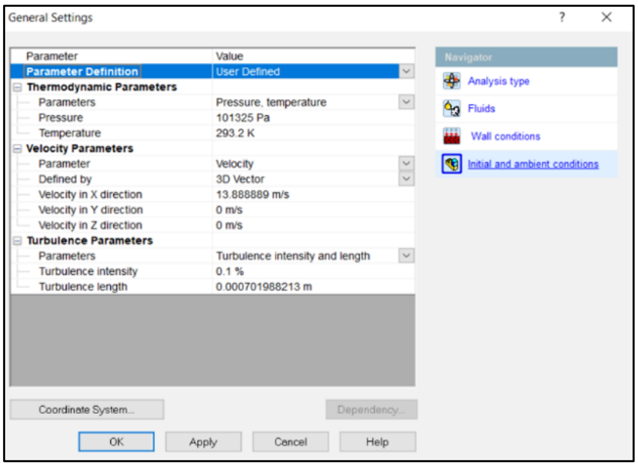


Figure 4: Defining input parameters for the simulation model.

4. CALCULATION OF THE DRAG COEFFICIENT

Before the calculation of the drag coefficient, it was necessary to define a formula for its calculation. “The aerodynamic drag coefficient is a measure of the effectiveness of a streamline aerodynamic body shape in reducing the air resistance to the forward motion of a vehicle" [30]. The lower this drag coefficient, the less resistance is placed on the body, or more aerodynamic. In the case of conventional automobiles, this resistance is in the range of 0.2 to 0.4. In practice, this factor determines the quality of the body in terms of aerodynamics.

To calculate the drag force in the program, we followed Eq. (1).

$$F_d = c_d \cdot \frac{1}{2} p \cdot v^2 \cdot A \tag{1}$$

where:

- F_d – drag force,
- c_d – drag coefficient,
- p – fluid density (1.2 kg/m^3 for air),
- v – flow rate (m/s),
- A – characteristic front surface of the body (m^2).

Based on the Eq. (1), we can calculate drag coefficient c_d, see Eq. (2):

$$c_d = \frac{F_d}{\frac{1}{2} p \cdot v^2 \cdot A} \tag{2}$$

After converting the units and then substituting the numbers, we performed a simulation. The front surface can be easily determined using the measurement function in the program. The drag force is also determined. Based on the input values, the software calculated the approximate value of the drag coefficient c_d at the selected air flow speed of 50 km/h. These are the initial values that can be used to determine the approximate parameters of individual product models. More accurate analyses are performed by car manufacturers through testing laboratories, where they specifically test the air resistance and all aerodynamic capabilities of cars in a wind tunnel.

Fig. 5 shows the calculation of the drag coefficient c_d at a speed of 50 km/h. We can also notice the drag force acting on the rear-view mirror. The drag coefficient for this rear-view mirror model is 0.0281365.

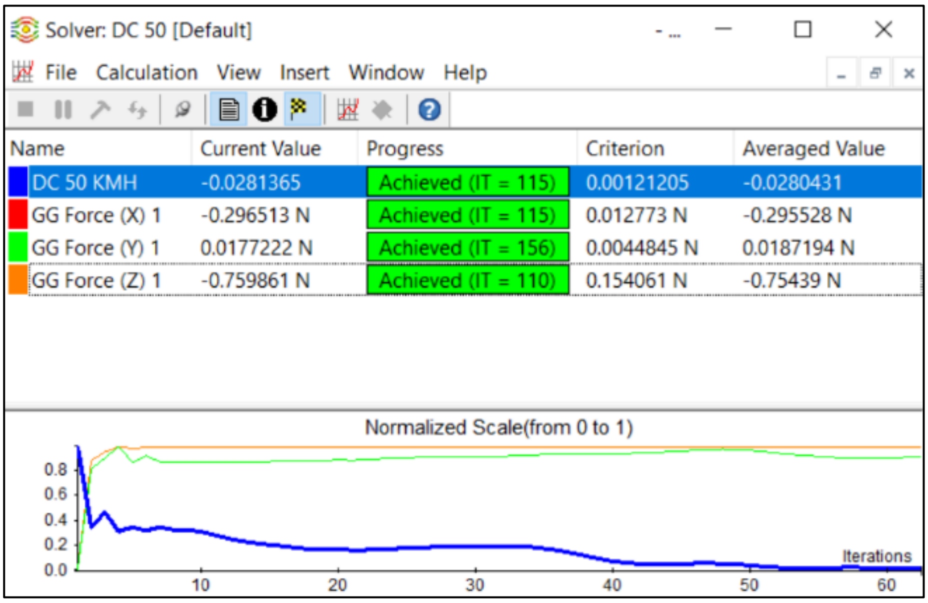


Figure 5: Calculation of the drag coefficient c_d at a speed of 50 km/h.

Similar to the urban speed of 50 km/h, we proceeded in defining new parameters for the rural speed of 90 km/h (Fig. 6) and the motorway speed of 130 km/h (Fig. 7).

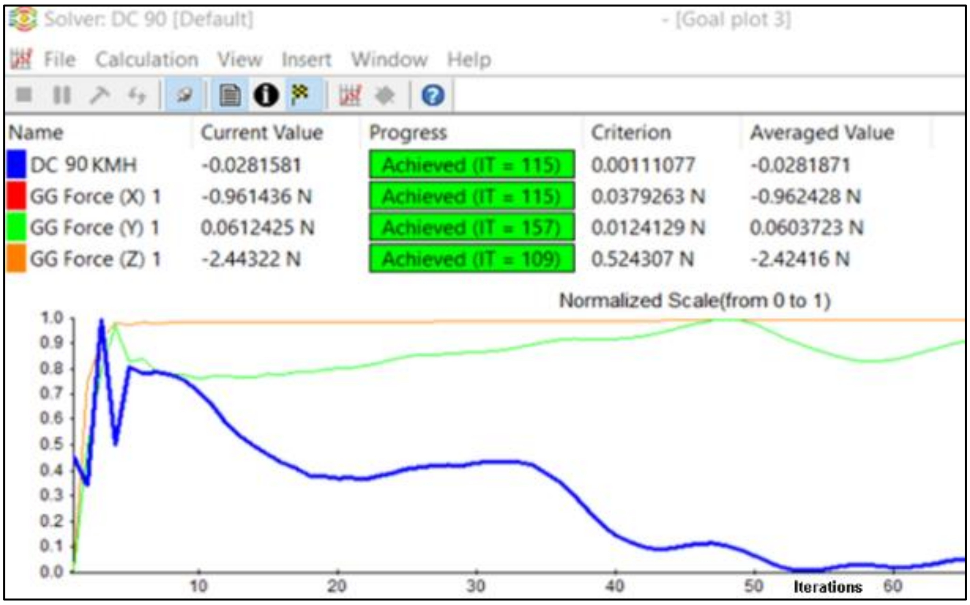


Figure 6: Calculation values at a speed of 90 km/h.

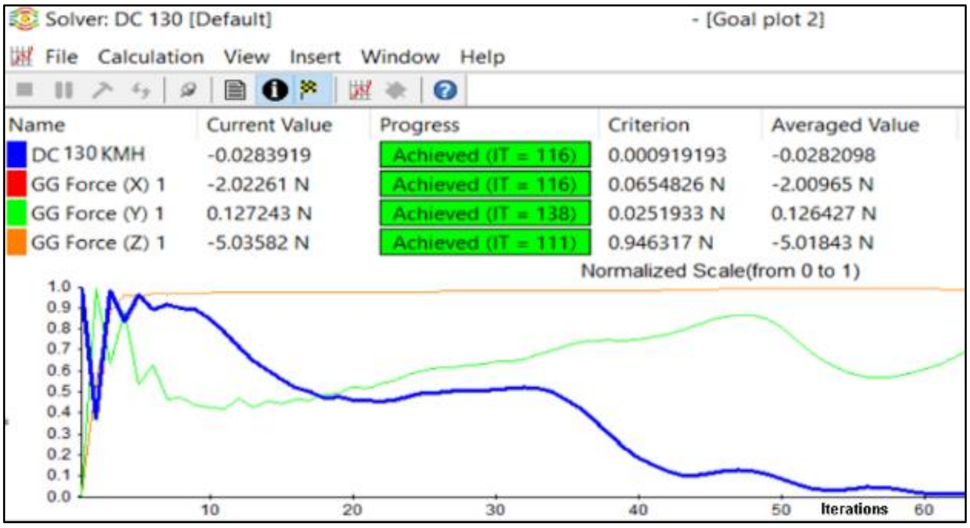


Figure 7: Calculation values at a speed of 130 km/h.

Fig. 8 presents the graph of the drag coefficient.

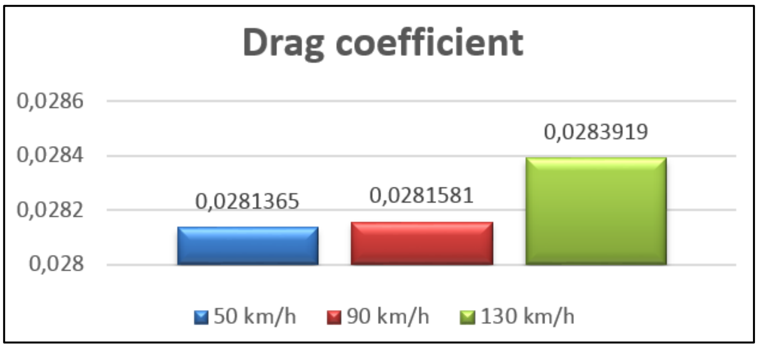


Figure 8: Graph of the drag coefficient.

In Fig. 9, we can see an almost linear increase in drag force with the increasing speed.

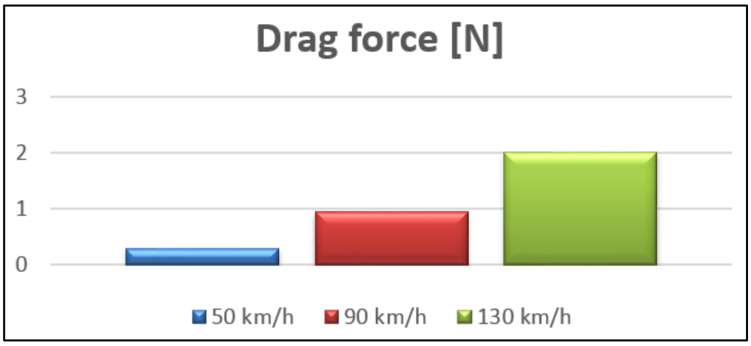


Figure 9: Graph of drag force.

5. SIMULATION OF AIRFLOW AND PRESSURE OF THE REAR-VIEW MIRROR MODEL

After calculating the drag coefficient at three different speeds, we continued in the working environment by simulating the air flow through the rear-view mirror. By entering the input values, we achieve result shown in Fig. 10.

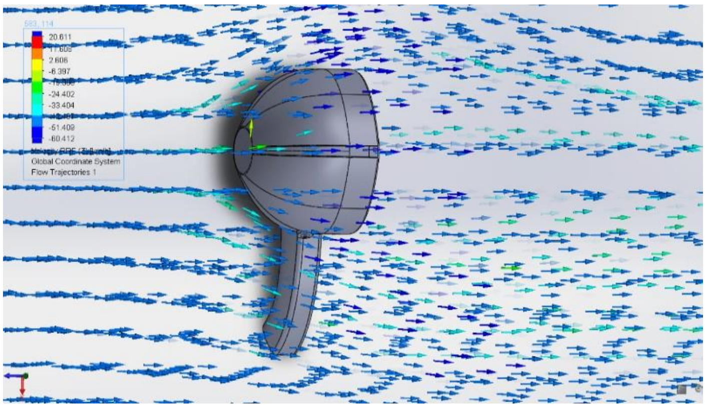
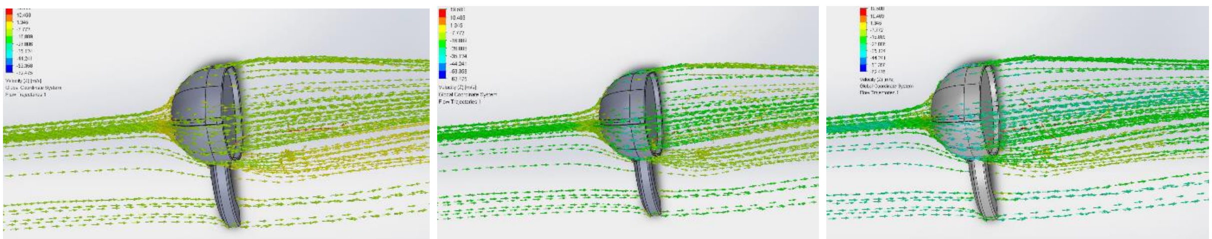


Figure 10: Simulation of air flow through a rear-view mirror [29].

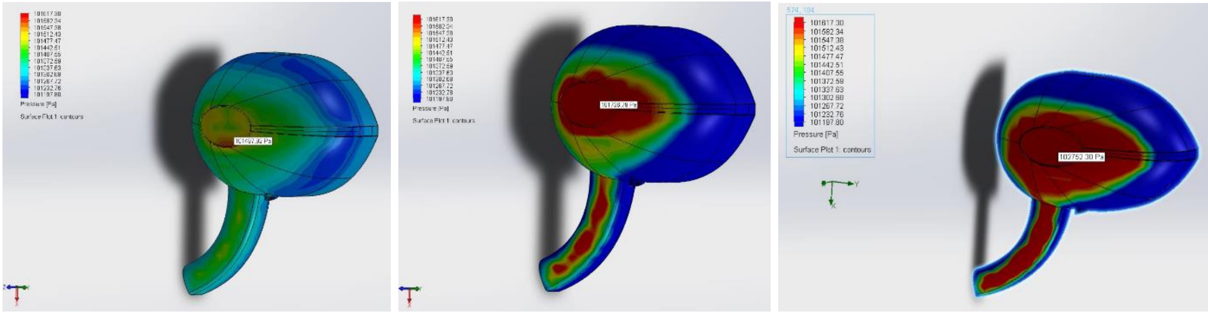
In Figs. 11 a-c we can see flow of air calculated in the program during simulation for the given speeds of 50, 90 and 130 km/h. It is possible to see relationship between increasing speed and a turbulent air flow. With increasing speed the flow around of the rear-view mirror is more turbulent, which is undesirable in comparison with a smooth flow.



a) b) c)

Figure 11: Air flow around rear-view mirror at: a) 50 km/h, b) 90 km/h, and c) 130 km/h.

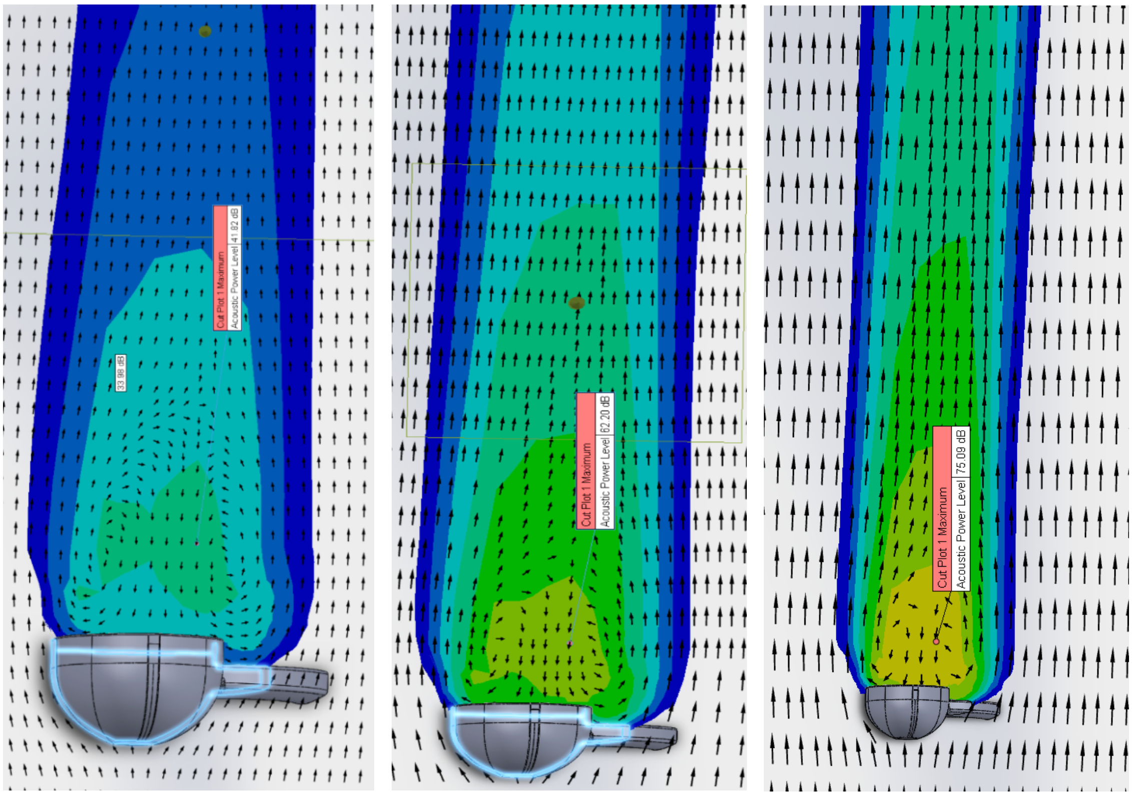
Fig. 12 (a, b, c) shows the body surface pressures, which arise in the individual areas of the rear-view mirror due to the pressure of air on the body surface. The areas are colour different, depending on the magnitude of the applied pressure. The amount of pressure on the front surface changes significantly with increasing wind intensity, which flows around the rear-view mirror. In figures below, the highest pressure on the surface acting at a given speed is shown in red.



a) b) c)

Figure 12: Body surface pressures at: a) 50 km/h, b) 90 km/h, and c) 130 km/h.

There is also some noise when the wind blows and swirls. In the simulations below, we can see how the acoustic noise increases significantly with increasing wind speed. This noise in case of insufficient sound insulation of car, can pass into the interior of the car even at low speeds. It makes comfort and safety unpleasant. Therefore, it is important to pay attention to such details during proposing component. Different shapes of the mirror surface create different airflow and swirl, which can result in worse or better acoustic noise level. In Fig. 13 (a, b, c) we have shown a simulation of the airflow around the mirror, where we can see the direction of the flow and the subsequent swirling of the air. At a speed of 50 km/h, the highest measured noise was 41.82 dB, at a speed of 90 km/h it was 62.20 dB, and at a motorway speed of 130 km/h the highest measured noise was 75.09 dB.



a) b) c)

Figure 13: Noise at speed: a) 50 km/h, b) 90 km/h, and c) 130 km/h.

Table I shows results of analyses for the rear-view mirror model. If we compare the achieved results with the results published in the studies of other authors, it can be seen that in our case we have achieved average values of noise, which do not significantly exceed and are not below the commonly achieved noise level.

Table I: Results of analyses for different speeds.

CX – coefficient	50 km/h	0.0281365
	90 km/h	0.0281581
	130 km/h	0.0283919
Surface pressure	50 km/h	101497 Pa
	90 km/h	101736 Pa
	130 km/h	102752 Pa
Noise in the area	50 km/h	33.98 dB
	90 km/h	62.20 dB
	130 km/h	75.09 dB

8. CONCLUSIONS

Car producers participate in the development of rear-view mirrors for many years. A few years ago, car producers start to design the concepts of cars, where cameras were used instead of rear-view mirrors. The cameras are built in the place, where the rear-view mirrors were previously located. Cameras transfer the image to screens located inside the car. Since the cameras are significantly smaller than the rear-view mirrors, this considerably reduces the aerodynamic resistance of this component as well as its contribution to the overall aerodynamic resistance of the car. The expected benefit of this solution is the supposed longer range of the car, respectively the lower consumption.

The camera application is a relatively expensive investment compared to conventional mirrors, as it is necessary to use high-quality cameras and high-resolution screens. The advantage of the system is cooperation with active car safety elements, lower aerodynamic drag, smaller dimensions, better acoustic comfort at higher speeds and elimination of blind spot compared to conventional rear-view mirrors. The disadvantage is that this system is more user-intensive and slower screen response. These disadvantages should be gradually eliminated with the development of this technology, but so far, this solution has not created a very good position on the market. The achieved positive effect in terms of consumption and range of the car also did not occur. It is especially in case of electric cars, where the energy that is saved achieved while driving, is used for operation of the camera system itself. Some car producers have opinion that this technology will be inefficient in the future and will not bring the desired results.

However, even if cameras will be used in the future, as long as they will be placed in the places, where they will affect the car design and protrude beyond its contours, it will still be necessary to solve aerodynamics and the noise caused by their construction and location.

Testing the aerodynamic properties of the car´s rear-view mirror is an integral part of development in the automotive industry. The shape of the rear-view mirror also affects the driving stability and subsequently economics of car´s operation.

CAD model of rear-view mirror was created in the CAD program CATIA V5 using commands for surface modelling to create a smoother and rounder surfaces. The surface model was used as a basis for the subsequent creation of solids.

After converting the model to the Solidworks workspace, this model was analysed from the point of view of aerodynamics and noise. Its properties for air flow at speeds of 50 km/h, 90 km/h and 130 km/h were investigated. The achieved result of the drag coefficient is 0.0281365. As was mentioned in introduction, average value of drag coefficient for nowadays cars is in range from 0.25 to 0.30. If we count as average value of drag coefficient 0.275, the reached value 0.0281365 represents 10.23 % of the total air resistance of the car. This is more than obvious, because average ratio of rear-view mirror on total drag coefficient is usually from 2 to 7 %. The achieved value is outside the usual range, although we take the value 0.30 as the default value of the coefficient. In this concrete case, the ratio of rear-view mirror resistance in the total resistance will be 9.38 %.

The goal of further research will be to adjust the shape of the rear-view mirror while maintaining the rounded and smoothed shapes in the dimensions that the ratio of rear-view mirror resistance in the total resistance will be less than 7 %.

In terms of noise, in our case, average values have been achieved that do not differ significantly from the commonly achieved noise levels of the rear-view mirrors. We assume that in an effort to reduce aerodynamic drag, the shape of the rear-view mirror will also change the noise. Subsequently it will be necessary to re-analyse the effect of the change in the shape of the rear-view mirror on the noise. In case of increased noise, we will try to find a compromise that achieves a compliance between low aerodynamic drag as well as low noise.

After taking into account all simulated models at different speeds, it can be argued that it is important to pay attention to the shapes and lines of individual parts of the car's external components, because at current emission limits every detail affects the car's aerodynamics, affecting consumption and resulting emissions.

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