Race car mirror cover production focused on reducing air drag

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Abstract: The paper presents a mirror cover manufacturing process, focused on geometry optimization by reducing air drag for Silesian Greenpower electric car. Silesian Greenpower is a student’s interfaculty project, of which aim is to design, build, and race an electric vehicle. Each car is equipped with the same motor and batteries. Target is to finish as many laps as possible during a set amount of time. Major development takes place in aerodynamics to decrease movement resistance. In the presented development process, computer-aided design software was used to create part concepts and then aerodynamics simulation was carried out to determine quality of each design. The influence of chosen geometric parameters was analysed and discussed in the article. The final concept was manufactured using 3D-printing technology with ABS - acrylonitrile butadiene styrene, because of good mechanical properties but also availability and relatively low cost. 3D-printed elements were verified experimentally using smoke stream generator.

1. Introduction
Aerodynamic properties of a product is a major factor in many technical fields such as aviation, energetics, automotive and more. The most obvious method that can be used during development process is experiment. Unfortunately it requires aerodynamic tunnel or at least a room isolated from external conditions, proper source of gas velocity and indicator, for example a smoke stream. Alternatively a numerical method can be used, which require only a computing machine and a proper software. Because of high accessibility of computers, numerical method is very popular, especially in low budget and small series production.

The problem of aerodynamic quality of various elements is widely described in literature. Most of the technical solutions are designed to satisfy multiple criteria and it is not possible to adapt them to different problems. Development process presented in the paper was carried out independently because of the specific geometric constraints not present in other publications.

The aim of the process shown in this paper was to design and manufacture a mirror cover for Silesian Greenpower electric race car shown on figure 1. Silesian Greenpower is a student’s interfaculty project, of which aim is to design, build, and race an electric vehicle. Each car is equipped with the same 240 W motor and two 36 Ah batteries and the target is to finish as many laps as possible during a set amount of time. Major development takes place in aerodynamic and lightweight construction field to decrease movement resistance [1, 2].
The mirror cover design process was carried out in Siemens NX computer aided design module. Various concepts of external surfaces were created and properly prepared for the simulation. Later on the final concept chosen based on the simulation results was used to design ready to manufacture part.

The main criterion in the mirror cover designing process was minimal air drag [4, 5]. Each concept was analysed using ANSYS Fluent software. Numerical method was chosen because of high accessibility, short time of experiment and low cost. All cases were simulated with exactly the same boundary conditions.

Final part was manufactured using 3D-printing technology using ABS - acrylonitrile butadiene styrene. Element was also verified experimentally using smoke stream generator towards compliance to the aerodynamic simulation results.

2. Mirror cover concepts
The function of the mirror cover is to attach mirror to the body of the car, allow the driver to adjust the mirror angle for good vision behind the car and to minimalize air drag. Major development took place in optimizing aerodynamics for minimizing air drag. Geometry optimization was limited by the required volume for mirror fitment and a maximum length of 110 mm of the cover. Dimensions of the mirror assembled with the angle adjusting element are shown on figure 2.
Development process shown below was carried out using Siemens NX computer-aided design module, mostly with advanced surface modelling tools. At this stage of research only external surfaces, that have an impact on aerodynamics were created to simplify the geometry for later simulation. Particular attention was paid to the surface quality and type of transition between surfaces. In the direction of air velocity during normal conditions car movement continuity of the surface is G2. On plane normal to air velocity continuity is at least G1, depending on the concept.

Previous unoptimized model of the mirror cover was presented on figure 3. Mirror dimensions are shown using a blue line. First concept of improved mirror cover was a similar rotary element but with optimized smooth surface and smallest possible maximum diameter that satisfy the mirror fitment limitation (figure 4). Because of relatively wide and short shape of the mirror, next designs are non-rotary. One of them is based on an ellipse to compromise smooth surface and low frontal area of the element (figure 5). Last concept was based on a rectangle with rounded vertices to create minimum possible frontal surface at the cost of surface smoothness (figure 6).

Each of the external surface concept was converted to a volumetric element. Final simulation model was a 2500x500x500 cuboid with subtracted volume of the mirror cover. Ready for simulation model was converted to neutral *.stp format.

Figure 3. Old mirror cover design.  
Figure 4. Round based concept.  
Figure 5. Oval based concept.  
Figure 6. Rectangle based concept.

Quality of the surface was checked using curve analysis and reflection analysis available in Siemens NX environment. For curve check, curves that are intersections of part surfaces and main planes were found and then graph with local extremes was created. Reflection tool allows to project set amount of lines on the analysed surface that change position depending on view movement. Because of that, any surface flaws are more visible on a computer screen.
Used surface quality check methods were presented on figures 7 and 8, on an example of the most complex and problematic geometry analysed in this paper. On figure 8 there are some minor flaws observed in surface quality. Keeping in mind that volume of production is very small and that the planned production method using 3D-printing has limited accuracy, these flaws are acceptable. Further improvement of the model is possible but not necessary for purpose described in the paper.

3. CFD analysis
Aerodynamic simulation was carried out using ANSYS Fluent software. Fluent calculations are based on numerical method called finite volume method. It involves a fluid volume approximation mesh and counts values for every node in the centre of each mesh element, then approximate results to the rest of the volume. Values come from partial differential equations, that are solved by transformation to a system of algebraic equations. Fluent can be used to numerous of issues in the field of fluid mechanics such as turbulence, one or multiphase flow, heat transfer etc. [6].

For the presented case software was used to determine drag force, drag coefficient and air flow distribution. All cases were simulated with exactly the same boundary conditions. Airflow inlet speed was set to 20 m/s which corresponds with maximum speed during an endurance race. Air density is 1.2 kg/m$^3$ at the temperature of 20°C. Mathematical model used was a k-omega standard viscous-laminar. Mesh elements used for discretization were second-order tetrahedrons with low average skewness [7]. The mesh was finer around the shape of mirror cover to obtain more accurate results using fewer elements to save time and computing power. For each case element size around cover was set to 1.5 mm and maximum size at the outer part was 20 mm. Based on cover surface 9 inflation layers were generated with total thickness of 5 mm and 1.1 growth rate. Number of elements for each case varied insignificantly at about 800000. Example of used mesh was presented on figure 9.

Simulation was carried out using double variables precision and until obtaining convergence for high calculation accuracy [8].
4. Results and discussion
For the results visualization in Fluent environment pathlines function was used. Air particles trajectory paths as well as their speed on the plane of symmetry for each case were presented on figures 10-14.

Figure 10. Old model design.
Figure 11. Round model design.
Figure 12. Oval model design.
Figure 13. Rectangular model design.
Figure 14. Rectangular model with wide tip.

The result drag forces for each geometry conception were presented in table 1, as well as calculated frontal surface area and drag coefficient Cx.
Table 1. Simulation results.

| General shape description   | Force [N] | Frontal area [mm²] | Drag coefficient Cx |
|-----------------------------|-----------|--------------------|---------------------|
| Old model design            | 0.605     | 8825               | 0.286               |
| Round model design          | 0.355     | 6362               | 0.233               |
| Oval model design           | 0.328     | 4968               | 0.275               |
| Rectangular model design    | 0.245     | 3665               | 0.279               |
| Rectangular model with wide tip | 0.243 | 3665               | 0.276               |

Based on table 1 the smallest drag force F=0.243N was archived for rectangular shape with a wide tip, which equals to about 40% of the original design force. Chosen concept was converted into a thin-walled volumetric model, filled with necessary mounting points. During this process main criterion was to limit external surface disruption to minimum to keep air drag force low.

Final CAD model was converted into a *.stl format, that is required for the 3D-printing process. This manufacturing technology was chosen because of very complex shape of the part and small planned production volume. Process was performed using FDM technology with material called ABS - acrylonitrile butadiene styrene. The filament used in 3D-printing process was Smart ABS by Spectrum Filament. Temperature of the printing was set to 230°C which is the lowest recommended by the producer value, resulting in the highest impact resistance and toughness. Infill density of the print was 50% to maintain high mechanical properties but also reduce material consumption and time of the printing [9-11]. Figures 15 and 16 shows result of mirror covers 3D-printing process.

![Figure 15. ABS mirror cover.](image1)

![Figure 16. ABS mirror cover upside down.](image2)

3D-printed elements were verified experimentally using smoke stream generator towards compliance to the aerodynamic simulation. Experiment process was shown on figure 17.

![Figure 17. Aerodynamic experiment.](image3)
5. Conclusions
Based on the presented results, the following conclusions were made. Comparing two similar rotary figures, one with a high-quality G2 surface had a significantly lower drag coefficient than the unoptimized model. Non-rotary, irregular objects also had a high Cx number, even with an optimized smooth surface.

On the other hand, the frontal area had such an impact on drag force, that some shape regularity and consequent Cx value can be sacrificed. With the criterion of minimum drag force and given mirror dimensions first priority should be minimalizing frontal area, then surface enhancement. Widening of the cover tip negligibly influenced the drag force. Presented force reduction may be caused by numerical error but also it is possible that wide tip shape with the higher similarity of vertical and horizontal curvature reduces drag force value. In the case of very advanced geometry optimization, it can be a field of further investigation. Aerodynamic experiment confirms that air flows around mirror cover correctly but with available equipment it is not possible to see details like air turbulence. After experiment conditions improvement, more accurate check of the compliance to the simulation could be performed.

6. References
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