Application of CAD/CAE class systems to aerodynamic analysis of electric race cars

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Abstract. Aerodynamics is one of the most important factors which influence on every aspect of a design of a car and car driving parameters. The biggest influence aerodynamics has on design of a shape of a race car body, especially when the main objective of the race is the longest distance driven in period of time, which can not be achieved without low energy consumption and low drag of a car. Designing shape of the vehicle body that must generate the lowest possible drag force, without compromising the other parameters of the drive. In the article entitled „Application of CAD/CAE class systems to aerodynamic analysis of electric race cars” are being presented problems solved by computer analysis of cars aerodynamics and free form modelling. Analysis have been subjected to existing race car of a Silesian Greenpower Race Team. On a basis of results of analysis of existence of Kammback aerodynamic effect innovative car body were modeled. Afterwards aerodynamic analysis were performed to verify existence of aerodynamic effect for innovative shape and to recognize aerodynamics parameters of the shape. Analysis results in the values of coefficients and aerodynamic drag forces. The resulting drag forces \( F_x \), drag coefficients \( C_d \) and aerodynamic factors \( C_x A \) allowed to compare all of the shapes to each other. Pressure distribution, air velocities and streams courses were useful in determining aerodynamic features of analyzed shape. For aerodynamic tests was used Ansys Fluent CFD software. In a paper the ways of surface modeling with usage of Realize Shape module and classic surface modeling were presented. For shapes modeling Siemens NX 9.0 software was used. Obtained results were used to estimation of existing shapes and to make appropriate conclusions.

1. Introduction

In the design process of electric race cars, which main objective of the races is car economy, one of the most important factor affecting achieved result is aerodynamic quality of the car’s body shape. The aspiration to create the perfect shape of the vehicle’s body, which is characterized by low values of the aerodynamic drag forces, exact the expansion of exploration for innovative and efficient aerodynamic solutions that potentially could influence reduction of aerodynamic drag of vehicles of Silesian Greenpower race team. The aim of research was application of Kammback effect in a race car body, which could directly influence on aerodynamic quality of a shape and thus achieved results of a Greenpower race team. This effect allows to shorten the body in relation to the original shape without worsen aerodynamic properties of shape. Air flows around Kammback shape and creates so-called virtual tail, which is the outline of the shape which has been subtracted from the primary body. It allow to improve model of front part of a car so as to minimize aerodynamic drag. For design of a
body Siemens NX 9.0 software were used. Realize Shape, innovative free form modeling tool, were applied. For study of aerodynamics, Ansys Fluent CFD software were used, using the license of Department of Theoretical and Applied Mechanics, located at the Faculty of Mechanical Engineering in Silesian University of Technology. Obtained result of analysis were used to compare with results of previous models of Greenpower Race Team cars [1, 2, 3, 4, 6, 7, 8, 9].

2. Modeling of a SG2014 Shape

Based on the results obtained during analysis of occurrence of the aerodynamic Kammback effect conditions that should be fulfilled for shape for occurrence of this effect were specified. On this basis, the shape of the vehicle of Silesian Greenpower Race Team, SG2014 Bullet was modeled. The dimensions of the vehicle, length limit, were specified in the rules of races organized by Greenpower Education Trust. Length limit is 2800 mm. Compared to the shape of the car’s body from previous years, the back part of the body was removed, then the front of the vehicle has been lengthened by this distance, creating more streamline shape, which should improve the aerodynamic quality of the shape [5, 6].

The shape was modelled using surface modelling tool, Realize Shape, from Siemens NX program and traditional free form modelling techniques. Modelling using Realize Shape tool is based on modifications of basic shape (pulling / stretching) of the faces of basic body. The modelling process of the SG2014 Bullet car body was started by insertion of the base body, in this case it was a sphere, which was then subjected to modifications. Pre-shape was modelled based on the overall dimensions of the vehicle, and then the vehicle chassis with wheels and model of driver were added. Shape of a body has been adapted to added elements to perfectly describe in the frame and wheels and simultaneously not to increase the frontal area (A), which directly affects the aerodynamic drag.

Driving parameters of the vehicle, including the vehicle turn radius should not be affected. The next step was modelling using traditional techniques of surface modelling, creation of the outline frame using curves of the fairing and then using extrusions modelling of fairing shape were performed. Afterwards,
the shape of the fairing was combined with modelled shape of the vehicle body.

The next step was to correct the length of the vehicle to fulfill dimensions described in the Rules of Race. Rear part of body were subtracted by the length of 600[mm] to create characteristic Kammback effect shape. Afterwards cut-outs in the rear section of the body, necessary to obtain the effect, and hatch for the driver were created. Created shape was modeled as full solid block in order to excision of the vehicle body from the air volume, which is necessary for aerodynamic analysis.

Necessary simplification were made, in order to achieve adequate quality finite element mesh, such as the omission of the holes in wheel neighborhood and the driver's hatch geometry simplification. Modeled shape has been analyzed to determine aerodynamic parameters of the aerodynamic vehicle [1, 2, 3, 4, 5, 6, 7, 9].

3. Aerodynamic analysis of SG2014 Bullet

After modeling of the body of SG2014 Bullet vehicle, analysis to determine the aerodynamic properties of the shape were performed. During analysis, aerodynamic characteristics of Kammback effect of the created shape has also been proven.

The shape of the vehicle was designed in such a way that the air pressure area influencing front part of the body was as small as possible. The shape of a front creates small angle between two surfaces, upper and lower, forming the front part of the body. This should also affect the growth of aerodynamic efficiency of a car. On figure 8 the streamlined shape of the vehicle were showed. Application of innovative rear part of the vehicle which was modeled to use Kammback effect allows to create optimum shape configuration of the front part of a body. It should also have a beneficial influence on the aerodynamic drag values.

For analysis CFD method using Finite Element Method was used. The size of FEM elements, quality and their type are selected with due to the aerodynamic analysis standards for the automotive industry. The dimensions of the virtual wind tunnel were 18000x8000x8000[mm]. Tetrahedral Finite Element shape were used for FEM mesh. The maximum size of the initial Finite Element, placed on a wall of a tunnel, was set as 250[mm], the minimum size of element was set as 1[mm], the decrease of the dimension of the Finite Element with decreasing distance from the walls of the tunnel to the analyzed shape was set as 120%.

In order to increase the accuracy of the aerodynamic analyzes influence zones were applied, in which the density of the finite elements is significantly greater and the Finite Element length has a
uniform size. For this type of analysis the size of edge of Finite Element was set as $10[\text{mm}]$. The block of influence, built around the analyzed shape, had size $6000\times1000\times1000[\text{mm}]$. The next step was the creation of the inflation layers on the surface of the model and on a road. Five layers of elements describing inflation layer were set, growth ratio of 120% of the original size of the size of element [3, 5, 6].

![Figure 9. Fragment of Finite Element Method Mesh.](image)

![Figure 10. Inflation layer.](image)

Analysis were performed for the following boundary conditions. For virtual aerodynamic tunnel proper properties of air were initialized. Initial air speed was set as $40\text{[m/s]}$. For analysis, k-omega (k-ω) air turbulent model was used, with Non-Equilibrium Wall Function parameter (responsible for air behavior around the walls). It was chosen on the basis of previous analysis and literature information [3, 4, 5, 6].

Numerical analysis results were obtained, the force of air drag was equal to $F_x=9.558211952[\text{N}]$. Drag coefficient was equal to $C_x=0.19632$. Aerodynamic factor (drag area) was equal $C_x\cdot A=0.05399738$. Frontal area was equal to $A=0.2750478[\text{m}^2]$. Drag Force component, which was caused by air pressure, was equal to $6.15[\text{N}]$, and it is 65% of the total drag force. The force resulting from viscous friction of air is $3.42[\text{N}]$, it is approximately 35% of the total aerodynamic drag forces. Calculated results obtained in aerodynamic analysis for the SG2014 Bullet vehicle concept are the best results among all vehicles of Silesian Greenpower Race Team [3, 4, 5].

![Figure 11. Air pressure distribution on SG2014 Bullet body.](image)

Another part of the test was results analysis of pressure distribution on the vehicle body. Range of a high pressure is marked in red on figure 11. The highest pressure value occur on the driver's helmet, which is result of impact of overlapping air stream along body. In front of the vehicle was a small zone of high pressure, revealing that the shape of the front part of a body causes slight losses caused by high air pressure. At the top of the driver's helmet is a low pressure zone, marked in blue, it leads to the conclusion of occurrence of overlapping streams of air and high air velocity. The area around wheels reveals occurrence of high and low pressure in close proximity, which can cause turbulent flow of air streams around the wheels. Graphical analysis of the results of air pressure distribution on the vehicle body and around shape of a race car reveal similar results.
Analysis of the pressure distribution of air around the body indicates a large area of high pressure on the driver's helmet. This is the main area of the losses resulting from the pressure. At the front of the vehicle high pressure zone occurs on slight area, in comparison to the area on shape of driver’s helmet.

Analysis of the results of air velocity showed zone of low air velocity at the rear of the vehicle. In this location turbulences of air could occur. Zone of low pressure behind car creates so-called virtual tail, which is lapped by the air at higher velocities without increasing air drag. This phenomenon is characteristic for Kammmback effect shapes. The zone of low velocity also occurs in the driver's cockpit, the air which is reflected from the helmet circulates until outlet from cockpit opening. High-velocity zone is located in the upper part of the driver's helmet; this phenomenon could be caused by overlapping streams of air on helmet’s body.

Another element of the study was to analyze the air streams flowing around concept SG2014 Bullet vehicle bodywork. On figure 14 and 15 are shown undisturbed, not turbulent, the course of the streams of air around the body of the vehicle. Streams are not subject to change direction of flow rapidly. Stream of air separated by the front of the vehicle does not stop or not causing turbulences of air. In the side of vehicle stream flows regularly, in a laminar manner.

Behind rear part of a car, to air streams follow so-called virtual tail (virtual removed part) and connect with other streams flowing around vehicle body, which indicates the presence of Kammmback effect. Streams are not premature separation from the body, adhere on the entire length of the body. Small air turbulences are visible, around the driver’s cockpit; streams are circulating and leaving the cockpit on the side of the driver's helmet (figure 15).

Air stream create virtual tail of the vehicle, according to the assumptions of Kammmback effect theory. Air flowing near the top of the vehicle tends to connect with the streams flowing near the bottom part of a car. In the vicinity of the vehicle body, with exception of the helmet and the wheels vicinity, areas of rapid change of values of velocity of air streams do not occur, which proves the high aerodynamic quality of the shape. Courses of air streams have been analysed in both directions of
flow, consistent with the inflow of air and in the opposite direction (figure 16). The purpose of this study was to examine the behaviour of the air within the notch at the rear of the vehicle. Visible are symmetrical, regular air circulation around the notch. This kind of air behaviour is characteristic for shapes applying correctly applying Kammback effect. This is another element proving the existence of the Kammback effect in the concept vehicle SG2014 Bullet.

![Figure 16. Air stream courses around SG2014 Bullet body.](image)

The analysis results of shape of SG2014 Bullet showed low aerodynamic drag of the vehicle and confirmed the occurrence of Kammback effect around the body.

Table 1 shows a comparison of results of performed aerodynamic analysis on Silesian Greenpower team vehicles. Obtained results of analysis of air flow around the shapes of the bodies of all vehicles revealed the lowest values of air drag of SG2014 Bullet of all the existing Silesian Greenpower race cars. Results allow to claim that the use of the Kammback effect in the shapes of vehicle reduces aerodynamic drag. Usage of Kammback aerodynamic effect in construction of a car could minimalize drag force values resulting in lower energy consumption and creation of more eco-friendly vehicles.

![Table 1. Comparison of aerodynamic drag values of Silesian Greenpower race cars.](table)

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