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Design Modification of the Combi-Type Body Considering the Impact on Vehicle Aerodynamics - Case Study

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Car manufacturers are constantly looking for new options to make the vehicle more attractive to the customer. In terms of design, this is usually done in the middle of a model's life cycle, when a so-called facelift of a production model is carried out. This involves small changes to the shape of the bodywork to improve the design of the vehicle until it is time for a new model range. This paper discusses a case study that focuses on the modification of the rear body components of a ŠKODA Superb III in Combi version. The aim of the study is to assess how the proposed modifications will affect the aerodynamics of the vehicle. The most significant changes concern the rear spoiler and finlets. The aerodynamic properties are assessed based on CFD simulations that are performed for a series production and a modified variant of the vehicle, and the results of which are compared and discussed.

Keywords: vehicle aerodynamics, CFD simulation, air drag coefficient, combi-type body, design modification, spoiler, finlet

1 Introduction

The aesthetics of the body design still have a decisive influence on the sales success of the models of individual car companies. In the 1960s and 1970s, trends were set by Italian manufacturers and Italian design studios such as Ferarri, Pininfarina and Ital Design. Among the designers, it was especially Nuccio Bertone [1] and Giorgetto Giugiaro [2] who designed the bodies for European car manufacturers. The most famous example is the VW Golf of 1974, designed by Giorgetto Giugiaro. The design of the VW Golf influenced the lower-middle class segment for nearly five decades and established the term "hatchback" in the lexicon of automotive terms. Although the designers worked with pencil and paper they later created clay models. The whole subsequent process of designing, testing and manufacturing the tooling is carried out using CAx systems. The introduction of CAx systems has reduced car design time and facilitated the implementation of change procedures in all phases of car design. These systems are also interfaced with the manufacturing processes of individual components or the production of component tooling, such as injection moulds or moulds for forming sheet metal components. Computer models are also used in calculations and simulations. The most well-known are finite element strength analyses of components or complex analyses, which include 'crash tests'. Nowadays, it is also common for computer models to be used to assess the aerodynamics of a vehicle in so-called CFD simulations.

Since the design process is completed by creating a life-size clay model of a car, this model needs to be "transferred" into the virtual environment of the computer. Based on these models, data for production (programs for controlling CNC machines, robots) or models for simulation and analysis are prepared in advance. The individual designed shapes are digitised by reverse engineering and further processed in the CAx systems environment. The use of CAD systems in the process of product design and development is presented by Hirz et al. [3]. He discusses advanced methods for the creation of integrated virtual product development processes by implementation of knowledge-based design strategies, product-specific simulation procedures and automated routines into a comprehensive virtual product model within the CAD environment. Stadler et al. [4] deal with the challenges of full-vehicle conceptual development, where a method for support of geometrical full-vehicle development processes (e.g. geometrical integration, vehicle packaging) during early product generation phases is key. The production of freeform surfaces used in the design of automotive shapes using CAM is described in [5]. Aerodynamic calculations receive a great deal of attention, both in engineering practice and in research, especially in the case of vehicle aerodynamics [6, 7]. Researchers are mainly focusing on shape optimisation in order to reduce aerodynamic air resistance and thus fuel consumption or unwanted aerodynamic noise. Kumar et al. [8] analyse the possibilities of reducing aerodynamic drag. He performed a complex flow analysis using ANSYS Fluent, identified areas of high pressure drag, determined design parameters, and proposed appropriate geometric modifications to the vehicle. Fabian et al. [9] describe effect of the aerodynamic elements of the hatchback tailgate on the aerodynamic drag of the passenger car.

The digitisation itself is carried out using a "reverse engineering" approach. This involves scanning the shape of the vehicle's surface using a 3D scanner. The output of the scan is a so-called point cloud, which is imported into 3D CAD systems where it is further processed. A triangulation mesh model is created, from which we can obtain the cross-sectional curves of the surface regions. The so-called A-class surfaces fitted over these curves to create the final surface model of the car body. Várady et al. [10] already in 1997 describe the digitization of free form surfaces, where they give an example of creating a surface model of a car fender. Vinesh and Kiran in [11] describe the use of reverse engineering approaches in automotive, aerospace and medical engineering. Sansoni and Docchio [12] deal with the issue of three-dimensional optical measurements and reverse engineering for automotive applications. Pralay and Ballav [13] deal with the reconstruction of the shape of the scanned object through the interpolation of the NURBS surface. Fabian et al. [14] deal with the principles of digitization based on 2D drawing documentation. In [15] Fabian et al. deal with the use of the intuitive tool Imagine & Shape CATIA V5 in the process of digitization of shapes and in [16] describe the use of reverse engineering and rapid prototyping in the process of developing prototypes of automotive parts. Daneshjo et al. [17] deal with the issue of utilization of modern software systems for design and realization of prototype of three-dimensional model.

2 Fundamentals of vehicle aerodynamics

The total resistance of a moving vehicle is the sum of rolling resistance, acceleration resistance, gravity, and air resistance. These resistances must be overcome in order for the vehicle to move in the forward direction of travel. The value of the air drag coefficient c_D is used to calculate the air drag. Air drag depends not only on the shape of the body but also on other factors, such as its size, surface roughness, air density, velocity, and the flow, whether it is laminar or turbulent. Individual body shapes have different coefficients of air drag. [6]. The individual shapes and their coefficients of air drag are shown in Fig. 1.

The aerodynamic properties of vehicles are a consequence of their aesthetic, economic, and functional properties. Low air drag is a prerequisite for lower fuel consumption. But the other aerodynamic properties of vehicles are not negligible and depend on the air flow around the vehicle. These features include, e.g., crosswind stability, wind noise, body, headlight or glass contamination, engine, transmission, and brake cooling, and finally interior heating and ventilation.

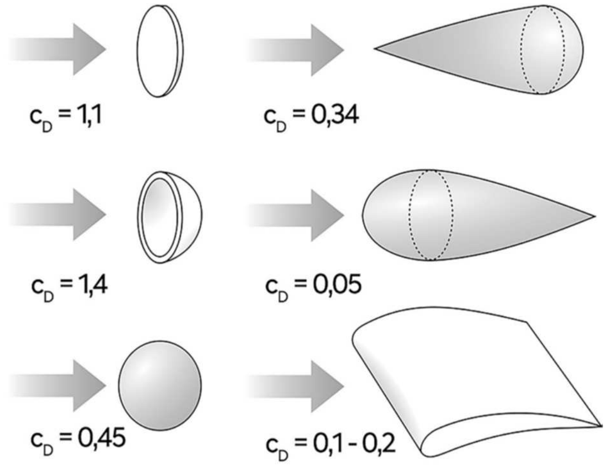

Fig. 1 *Air drag coefficients of basic shapes*

Aerodynamics deals not only with external flow but also with problems with internal flow systems. Indeed, the external and internal flow fields are interconnected, and both must be considered simultaneously. According to the laws of fluid mechanics, motor vehicles are considered to be surface objects in close proximity to the road.

The external airflow acts on the vehicle, generating forces and moments that affect the vehicle's dynamics and stability. The air drag coefficient c_D is a number used to describe all the complex dependencies of shape, slope, and flow conditions on drag. The crucial parameter is the size of the frontal area (Fig. 2). For currently produced cars, air drag coefficient values range from 0.2 to 0.35 [6, 9].

The air drag of a European mid-size vehicle is almost 75 to 80% of the total resistance of the vehicle at a speed of 100 km/h. This creates scope to improve fuel consumption by improving the aerodynamics of the vehicle. [9].

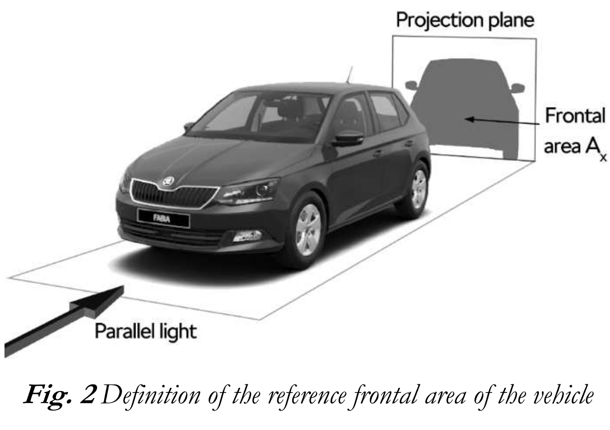

Fig. 2 *Definition of the reference frontal area of the vehicle*

2.1 Forces and moments in vehicle aerodynamics

In the development of vehicle aerodynamics, all the forces and moments acting on the car during driving are studied. It must also be taken into account that drag is not only imposed on the car against the direction of travel but can also act in other directions. The forces and moments generated also cause the car body to tilt and roll. This affects the driving characteristics of the car, the overall stability, and therefore the driving safety. The forces and moments involved in relation to a coordinate system with an origin at the vehicle's center of gravity are shown in Fig. 3. The direction of the crosswind with flow velocity V_∞ is defined by the angle β.

Of the components shown in Fig. 3, the force *D* (drag) acting directly against the movement of the vehicle, has the greatest effect. The aerodynamic drag calculated according to eq. (1) increases with the square of the velocity of the moving car. The force D has the greatest effect on reducing the energy consumption of the vehicle and therefore increasing the efficiency of its propulsion; therefore, it will be the most discussed. The other forces and moments (see Tab. 1) have an effect on the driving characteristics of the car, but their effect on the energy efficiency in the forward direction of travel is minimal.

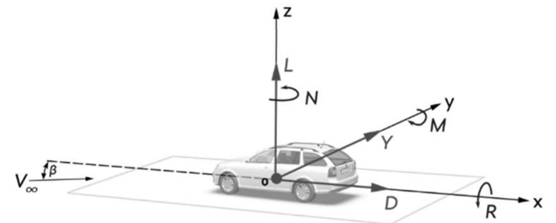

Fig. 3 *Aerodynamic forces and moments on the car*

Tab. 4 *Aerodynamic forces and moments acting on vehicle during driving [1]*

Force / Moment	Equation	
Aerodynamic drag	$D = \frac{1}{2} c_D \, \rho \, v^2 A_x \, \mathrm{F_D} = \frac{1}{2} \mathrm{c_D \rho v^2 A_x F_D} = \frac{1}{2} \cdot \mathrm{C_D} \cdot \rho \cdot \mathrm{V}^2 \cdot \mathrm{A}$	(1)
Aerodynamic lift	$L = \frac{1}{2} c_L \, \rho \, v^2 A_x$	(2)
Aerodynamic lateral force	$Y = \frac{1}{2} c_Y \, \rho \, v^2 A_x$	(3)
Pitching moment	$M = \frac{1}{2} c_M \, \rho \, v^2 A_x \, l$	(4)
Rolling moment	$R = \frac{1}{2} c_R \, \rho \, \mathrm{v}^2 A_x \, l$	(5)
Yawing moment	$N = \frac{1}{2} c_N \, \rho \, v^2 A_x \, l$	(6)
Where: ρ is air density, v - vehicle velocity, A_x - car frontal area (Fig. 2), c_D - dimensionless air drag coefficient, c_L - dimensionless lift coefficient, c_Y - dimensionless lateral force coefficient, l - the distance between the front and rear axles of the vehicle, c_M - dimensionless pitching coefficient, c_R - dimensionless rolling coefficient, and c_N - dimensionless yawing coefficient.		

Nowadays, CFD calculation programs are often used in vehicle design along with experimental wind tunnel measurements. CFD computational programs make it possible to analyze multiple models and thus achieve the optimum vehicle body shape relatively quickly and at a low cost. [6, 21, 22].

2.2 Aerodynamics of the rear body of a combi-type vehicle

The rear of the vehicle is specific in that each body variant (sedan, combi, hatchback) requires an individual shape geometry solution to achieve the desired flow. For the Combi body type, it is important to tune the trailing edge of the rear of the vehicle to eliminate turbulence behind the vehicle. (Fig. 4)

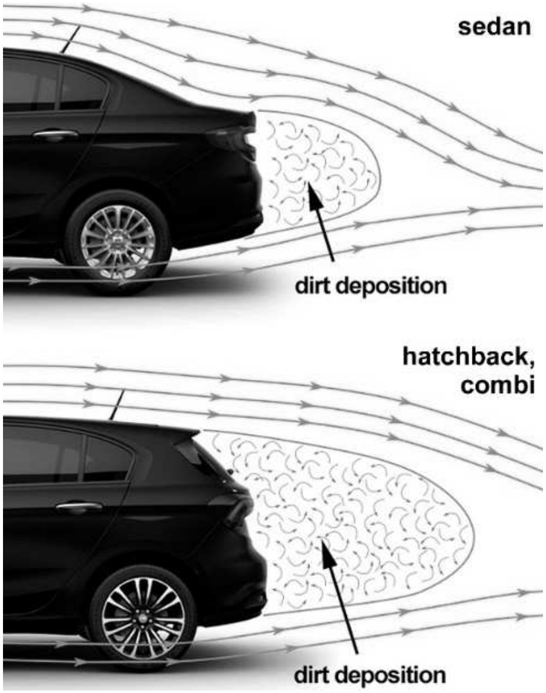

Fig. 4 *Wake region behind the vehicle and deposition of dirt*

3 Modifying the bodywork of a combi-type vehicle

The case study deals with the body modification of a third-generation ŠKODA Superb Combi. The changes were focused on the rear part of the car's bodywork in order to make the car interesting for younger and sporty customers and at the same time to add honour to the car. The changes were also intended to bring the benefit of better aerodynamics and thus reduced fuel consumption. The body modifications were carried out in the 3D CAD system ICEM Surf and the aerodynamic analysis was assessed on the basis of a virtual model using CFD analysis.

The lines of the production vehicle form an aesthetically harmonious whole and the individual components ensure smooth airflow around the body. The most important components of the rear bodywork in terms of aerodynamics are the roof, the C and D pillars, the spoiler and the finlet. The spoiler is installed on the rear lid in the area of the rear window. The reason for this is to improve airflow in the rear of the vehicle and to divert it away from the body. The rear spoiler also includes a brake light. The finlet is an additional device installed directly on the rear window of the car. It delays the tear-off edges on the sides of the glass so that turbulent streams are not created directly on the glass.

In terms of design, a number of body parts at the rear of the car have been slightly changed, including the C-pillar, D-pillar and tailgate. The chassis groups and rear bumper are unaffected by the changes, as there is no change to the wheelbase dimensions. A side view of the production car is shown in Figure 5.

Fig. 5 *Side view of a real production vehicle*

The condition of the changes was to make modifications to the bodywork while maintaining the wheelbase, in order to improve aesthetics and aerodynamics while maintaining the technical parameters. The basic principle is to keep the original roof length with a slight reduction in the slope. The main role here is played by the spoiler itself, which should be considerably lengthened so that the trailing edge is as far away as possible. The finlet needs to be adapted accordingly, and must also be larger to be able to cover the open area under the spoiler. The intention was also to slightly modify the C and D pillars, with them pointing more inwards to create a slightly better aero-dynamic shape and thus improve airflow around the bodywork. From the side view, the pillars were angled more forward and from the rear view, they were angled more towards the median plane of the vehicle at the top, resulting in a slightly narrower rear end. These modifications also affected the slope of the rear hatch window and the overall shape of the lid. The modifications directly affected the sidewall, the roof and the tailgate. The tailgate spoiler was given a completely new shape, with finlets added to the sides (*Fig. 6*). By combining the spoiler and the finlets, a complete assembly is obtained that creates an aerodynamic body modification to improve the aerodynamic performance of the vehicle. The result of the overall modifications as well as their comparison with the production vehicle is shown in Fig. 7-9.

Fig. 6 *The assembly consists of a spoiler and finlets*

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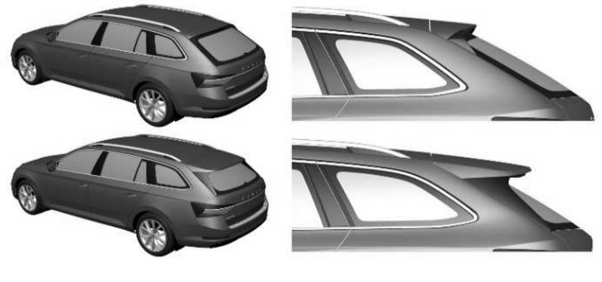

Fig. 7 *Comparison of production (top) and modified (bottom) body shape design*

Fig. 8 *Top view comparison of production (top) and modified (bottom) body shape*

Fig. 9 *Rear view comparison of production (left) and modified (right) body shape*

From the comparison of production and modified model, it is clear that there have been changes in the inclination of the already mentioned C and D pillars. The third side window has changed its shape, which was forced by the greater slope of the roof and a higher rear hatch inclination. The D-pillar was slightly narrowed, making the side glass slightly longer. The modified body shape is followed by a modified rear lid with a "massive" spoiler with finlets on its sides.

An increase in the size of the hatch window and an extended spoiler visually lengthen the body. The rear view gives the impression of a Combi Coupé. Overall, the body looks balanced and puts the car into the luxury Combi category, also called Shooting Brake, which increases the honour of the car [18, 20].

4 CFD analysis of the vehicle

CFD (Computational Fluid Dynamics), belongs to the field of CAE (Computer Aided Engineering). It is the computational analysis of fluid or air flow as well as heat transfer in various industrial fields. It has been part of the development of automotive aerodynamics for several decades. At the vehicle development stage, it provides a high-resolution representation of the complete flow field around the vehicle, from which changes can be made for better aerodynamic results. The computational methods contained in the CFD solvers are based on the laws of conservation of mass, conservation of momentum and conservation of energy.

The main steps of CAE computational methods are pre-processing, processing and post-processing. In the context of passenger vehicle aerodynamics research, the CFD method according to [19] can be more specifically described as follows. Pre-processing involves processing the imported data, discretizing the computational domain, and defining boundary conditions and material models. In the simulation software, the flow medium is divided into a finite number of elements in a three-dimensional space. These form the so-called numerical mesh, which represents the region to be analysed. It is necessary to adjust the size of the mesh elements appropriately, especially in relation to the actual vehicle dimensions, in order to obtain results with sufficient accuracy in the areas of interest. In automotive development, methods of densifying the mesh in regions of high significance, such as front A-pillar, brake disc area, etc., are well established to more accurately analyse the flow in these regions. The refinement strategies are varied, one of which is shown in Fig. 10. The mesh created discretizes the problem to be solved. This converts the system of partial differential equations into a system of linear algebraic equations, from which the pressure fields, velocity vectors and other quantities characterizing the flow are subsequently calculated. This system of equations is solved by a numerical iterative method.

Post-processing involves detailed analysis and visualization of the results of individual variables. Various visualisation tools are available to graphically represent individual aerodynamic parameters and their distribution on the vehicle surface geometry in the form of coloured field, as well as streamlines that can be used to assess the air flow in the vicinity of the bodywork. In this analysis, the following aspects were investigated:

- change in drag coefficient c_D,
- change in the shape of the airflow behind the vehicle,

- normalised air flow velocity field around the vehicle body,
- the direction and velocity of particle flow on the vehicle surface.

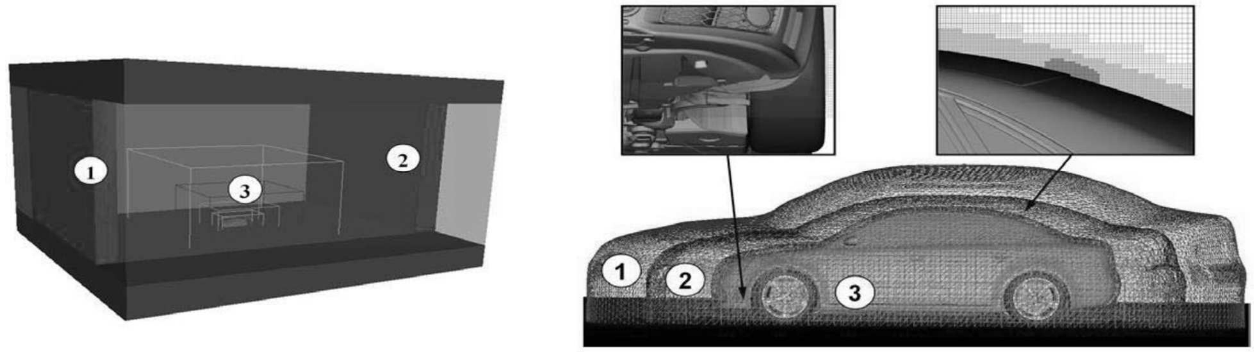

Fig. 10 *Varied discretization of flow regions from the coarsest (1) to the finest (3) mesh in the boundary layer closest to the vehicle body*

4.1 Change in drag coefficient c_D

The results of the flow simulation at 140 km/h show an improvement in the aerodynamic properties of the modified body. The overall coefficient of air resistance is reduced by $\Delta c_D = -0.021$ compared to the series production model.

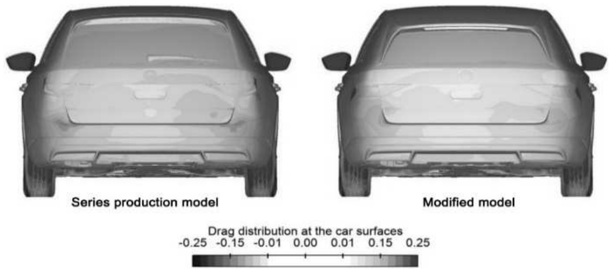

Fig. 11 *Distribution of air resistance on the surface of the rear part of the vehicle*

Fig. 11 shows a graphic representation of the distribution of air resistance on the surface of the rear part of the vehicle. As can be seen, in the case of the modified design, the distribution of air drag on the rear window and the tailgate has been improved [19].

4.2 Change in the shape of the airflow behind the vehicle

Fig. 12 and Fig. 13 show a comparison of the change in airflow behind the production and modified vehicles. During flooding, laminar flow changes to undesirable turbulent flow. It is evident that the flow on the modified model descends at a greater angle compared to production vehicle and also narrows more. This means that the unwanted turbulent flow is milder and therefore this is a positive change that improves the aerodynamic behaviour of the vehicle. There is a significant change in the area where the air breaks off at the trailing edge of the spoiler and starts to cause unwanted swirling. The trailing edge is shorter on the production vehicle than on the modified variant. The modified design has a positive effect on the flow by reducing the length of unwanted swirling.

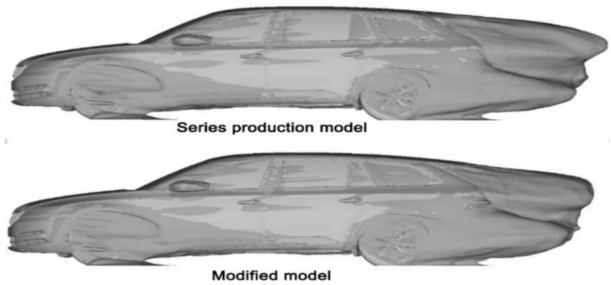

Fig. 12 *Comparison of flooding behind the vehicle from the side view*

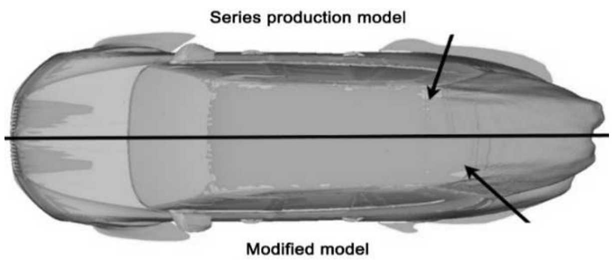

Fig. 13 *Comparison of the air flow over the vehicle from the top view*

4.3 Normalized air flow velocity field around the vehicle body

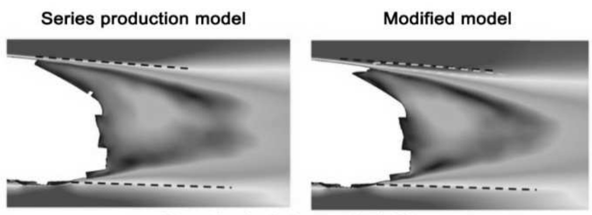

Fig. 14 *Comparison of normalized velocity fields in the Y=0 cross-section*

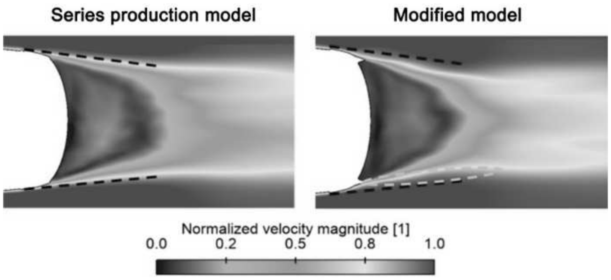

Fig. 15 *Comparison of normalized velocity fields in the Z=900 cross-section*

The flow analysis was carried out at 140 km/h because at this speed a significant flood is generated behind the vehicle. In this case, we evaluate a field of normalized airflow velocity. As can be seen in *Fig. 14*, the flow field in the longitudinal direction in the Y=0 plane is smoother and less turbulent for the modified vehicle, and due to the optimised shape of the roof, it is directed at a greater angle of inclination. This means that the undesirable swirling is milder. Fig. 15 shows the flow in the horizontal plane Z=900 mm. From the comparison, it is evident that unlike the production vehicle, the flow is narrowed and less turbulent, which results in improved aerodynamic performance. This improvement was achieved by optimizing the finlets and tilting the C and D pillars to the centre of the vehicle [19].

4.4 The direction and velocity of particle flow on the vehicle surface

Fig. 16 shows streamlines indicating the velocity and direction of air particles on the surface of the vehicle. They flow in the direction of the airflow, i.e. from the front of the car to the rear. Behind the vehicle, in the flood area, vorticity is already occurring and therefore the streamlines do not have a regular direction and the particles' velocity decreases (shown in blue). The highest velocities are reached at the line boundaries and at the trailing edges (shown in red). As the new optimised spoiler is longer than the original, the streamlines run longer along it, so that there is a gentler swirl behind the car and the flow is more regular. The modified spoiler and finlets thus have a positive effect on the vehicle's aerodynamic properties and improve them. This is mainly visible on the rear window, which results in a reduction of its fouling in the rain [19].

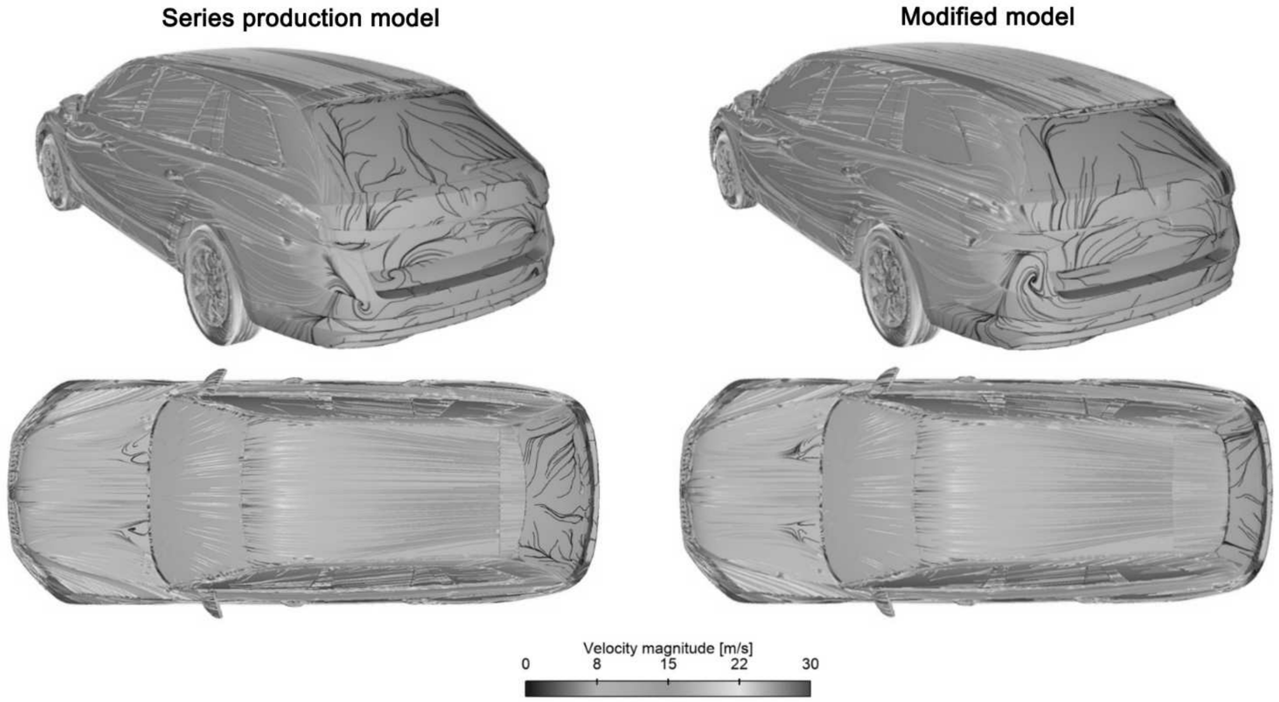

Fig. 16 *Comparison of velocity streamlines on the surface of the vehicle*

5 Results

The case study focused on design modifications to the rear bodywork of a ŠKODA Superb III passenger car in Combi version. The redesign was carried out with an emphasis on the aerodynamic properties of the vehicle. For this purpose, CFD simulations were carried out, the results of which showed that the proposed design modifications have a positive effect on the aerodynamic properties. The changes concerned the rear spoiler, the rear window finlets and the C and D pillars. Based on a comparison of the aerodynamic performance of the production model and the modified model, it can be concluded that the overall air drag coefficient has been reduced by 0.021. At the same time, there has also been a slight improvement in the flow behind the vehicle. The reduction in aerodynamic drag results in a reduction in emissions and therefore a reduction in fuel consumption. Such modifications improve the economy and ecology of vehicle operation. At a time when car manufacturers are paying for every extra gram of CO_2 emitted above the permitted limit, and these penalties are reflected in the price of the vehicle, such modifications make a lot of sense.

Acknowledgement

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References

[1] Automotive Hall of FAME, Nuccio Bertone, [cit. 07.09.2023], Available online <http://www.automotivehalloffame.org/inductee/nuccio-bertone/725/>

[2] Automotive Hall of FAME, Giorgetto Giugiaro, [cit. 07.09.2023], Available online <https://www.automotivehalloffame.org/honoree/giorgetto-giugiaro/>

[3] HIRZ, M., HARRICH, A., ROSSBACHER, P.: Advanced computer aided design methods for integrated virtual product development processes, In: *Computer- Aided Design & Applications*, 8, 2011, 901–913, ISSN: 1686-4360

[4] STADLER, S., HIRZ, M., THUM, K., ROSSBACHER, P.: Conceptual full-vehicle devel. supported by integrated comp. aided design meth., In: *Computer-Aided Design & Applications*, 10, 2013, 159–172, ISSN: 1686-4360

[5] FABIAN, M., IŽOL, P., DRAGANOVSKÁ, D. AND TOMÁŠ, M.: Influence of the CAM Parameters and Selection of End-Mill Cutter when Assessing the Resultant Surface Quality in 3D Milling, In: *Applied Mechanics and Materials*, 2014, ISSN: 1662-7482

[6] HUCHO, W.H.: Aerodynamic of Road Vehicles: From Fluid Mechanics to Vehicle Engineering, Butterworth-Heinemann Ltd, 1987. ISBN 0-408-01422-9

[7] T. SCHUETZ: *Aerodynamics of road vehicles*, 5. edition, 2016, SAE International 400 Commonwealth Drive Warrendale, USA, ISBN-PDF 978-0-7680-8253-1

[8] KUMAR, B.R. et al.: Aerodynamic design optimization of an automobile car using computational fluid dynamics approach, In: *Australian Journal of Mechanical Engineering*, 2019, ISSN: 1448-4846

[9] FABIAN, M. et al.: Effect of the Aerodynamic Elements of the Hatchback Tailgate on the Aerodynamic Drag of the Vehicle, In: *Advances in Science and Technology Research Journal,* 2022, 16(6), 73–87, ISSN 2299–8624

[10] VÁRADY, T. et al.: Reverse engineering of geometric models - An introduction, In: *Computer-Aided Design*, Volume: 29 Issue: 4 Pages: 255-268, 1997, Elsevier SCI LTD, ISSN: 0010-4485

[11] VINESH, R., KIRAN, F.: *Reverse Engineering-An Industriel Perspective*, Springer Series in Advanced Manufacturing, 2008, ISBN 978-1-84628-856-2

[12] SANSONI, G., DOCCHIO, F.: *Three-dimensional optical measurements and reverse engineering for automotive applications*, Robotics and Computer-Integrated Manufacturing 20 (2004) 359–367, Pergamon Elsevier Science LTD, ISSN: 0736-5845

[13] PRALAY, P., BALLAV, R.: Object shape reconstruction through NURBS surface interpolation, In: *International Journal of Production Research*, Vol. 45, No. 2, 15 January 2007, 287–307, ISSN 1366-588X

[14] FABIAN, M. et al.: Principles of car body digitisation based on geometry extracted from views in 2D drawing documentation, In: *International Journal of Vehicle Design*, 2017, Volume74, Issue1, Page62-79, Geneva, Switzerland, ISSN 0143-3369

[15] FABIAN, M. et al.: Design of experimental vehicle specified for competition Shell Eco-marathon 2017 according to principles of car body digitisation based on views in 2D using the intuitive tool Imagine&Shape CATIA V5, In: *Advances in Engineering Software*, 2018, Volume 115, Page 413-428, Elsevier SCI, England, ISSN 0965-9978

[16] FABIAN, M. et al.: Reverse Engineering and Rapid Prototyping in the Process of Developing Prototypes of Automotive Parts, In: *Manufacturing Technology, Engineering Science and Research Journal*, Volume 22, Issue 6, 2022, ISSN 1213–2489

[17] DANESHJO, N et al.: Use of Modern Software Systems for Design and Realization of Prototype of Threedimensional Model, 2019, In: *TEM JOURNAL-Technology Education Management Informatics*, Volume 8, Issue 2, pp.346-353, ISSN 2217-8309

[18] LAGOS, O.: Creating a 3D model of the body part of the Škoda Superb Combi based on design sketches and assessment of its impact on aerodynamics, Diploma thesis, Technical University of Kosice, 2020

[19] SHARMA, A.: *Introduction to Computational Fluid Dynamics*, Mumbai, Maharashtra, India, 2022, ISBN 978-3-030-72883-0

[20] JILEK, P., BERG, J.: The adhesion force change of an experimental road vehicle, In: *Manufacturing Technology*, Engineering Science and Research Journal, Volume 21, Issue 5, 2021, ISSN 1213–2489

[21] MRAZEK, M. et al.: Design of Composite Disc Spring for Automotive Suspension with using Numerical Simulation, In: *Manufacturing Technology*, *Engineering Science and Research Journal*, Volume 21, Issue 6, 2021, ISSN 1213–2489

[22] SCHWEIGHARDT, A. et al.: Modal Analysis of the Tubular Space Frame of a Formula Student Race Car, In: *Manufacturing Technology*, *Engineering Science and Research Journal*, Volume 20, Issue 1, 2020, ISSN 1213–2489