Abstract

Study of Cooling Airflow: Comparison of PIV and CFD Results

Sven Lange, Johannes Haff, Sigfried Loose, Claus Wagner
The German Aerospace Centre (DLR), Institute of Aerodynamics and Flow Technology
Bunsenstraße 10, 37073 Göttingen, E-Mail: Sven.Lange@dlr.de

Tarik Barth, Uwe Görn, Waldemar Maister, Alexander Wittmaier
Volkswagen AG (VW AG), Windkanal und Aerodynamik - Entwicklung
Brieffach 1787, 38436 Wolfsburg

Luis G. Garduno
Exa GmbH
Curiestr. 4, 70563 Stuttgart

In order to develop vehicles with a strong focus on comfort and drive experience, but without disregarding the environmental protection laws, it is fundamental to invest research efforts on vehicle aerodynamics. The main focus lays on the reduction of drag force, which is characterized by the drag coefficient (c_D). Together with the basic shape of the car - being the most relevant design element influencing this force - the airflow responsible of the cooldown of the engine plays a major role in the total drag forces. The contribution of the cooling airflow in modern car models represents around $10\ \%$ of the total c_D [2]. The Golf 7 used in the present study, for example, has a total drag coefficient of $0,316$. The share of this value coming from cooling drag is equal to $\Delta c_{DC} = 0,031$ as seen on experiment, which represents $10\ \%$ of the total drag. This coefficient is known as cooling drag coefficient (Δc_{DC}). Given that the total drag coefficient of any realistic basic automotive body cannot be reduced below c_D =0.14, the relevance of cooling drag in the reduction of total drag becomes evident [4].
To be able to reduce the total drag by reducing the cooling drag, it is required to study how the air is distributed around and through the vehicle, as well as which elements contribute to the total drag of the car. To understand these phenomena, it is required to investigate the flow fields and the flow rates of the vehicle. Because of the geometrical complexity in the motor compartment of the car, the observation of flow fields on the region involves major efforts. Furthermore, the flow fields can also be influenced through the presence of measuring probes in the area. It is in this point, where nonreactive measurement systems, together with the integration of Computational Fluid Dynamics (CFD) can be used to obtain a full picture of the flow fields. A suitable nonreactive measurement procedure for this type of study is the Particle Image Velocimetry (PIV). On one hand, because PIV technology can only be used in optically accessible areas, it is required to complement the information obtained with CFD results. On the other hand, the common question upon usage of CFD rises: Does CFD represent the real flow structures. In order to clear any doubt, experimental measurements need to be compared to numerical results. At this point, the usage of the integral c_D value is not enough. It is therefore relevant, to analyze the local flow topology, as well as the mass flow rates in comparison with the numerical results [3]. With help of the PIV it is possible to study structures in the visible regions, and compare them with the CFD results in order to determine a level of correlation among them.

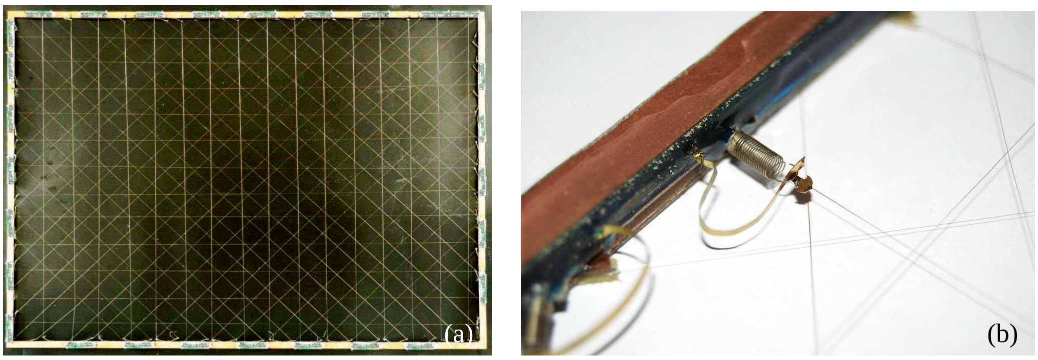

Figure 1: Multi Constant Current Anemometer (MCCA) for evaluation of velocity behind the cooling package (a) Frame with $0,08\ \mathrm{mm}$ thick hotwires; (b) detailed view of the MCCA [1]

For the purpose of analyzing the effects of cooling airflow, as well as to understand the boundary conditions required for the CFD model, diverse tests were conducted on a VW-Golf 7 in the Volkswagen Wind Tunnel in Wolfsburg. Together

with the evident usage of the wind tunnel balance, other measurement systems had been used in parallel; for example, the usage of the Multi Constant Current Anemometer (MCCA) illustrated in Figure 1, developed by the University of Prag for evaluation of the mass flow through the cooling package. This device allowed the measurement of mass flows with an increase of the blockage of less than $0,1\ \%$.
It is relevant to mention that the acquisition of this information is associated with the study of the flow structures, as well as the changes of pressure around and through the vehicle. It is not productive to force the reduction of drag through the net reduction of mass flow, as this amount of air is required to maintain the operative temperatures of the motor, as well as to ensure the reliability of other components in the motor compartment which can be affected by high temperatures, e.g. sensors, cables and board control components. With the goal of studying the flow field, PIV measurements have been performed on a Golf 7 in the VW-Wind tunnel. Object of the study was the mid-plane in three windows: upstream, underbody (Figure 2), and in the motor compartment. For this last measurement, only the region between motor and bonnet has been studied.

Figure 2: Detecting the flow field on a Golf 7 with Particle Image Velocimetry in the Volkswagen Wind Tunnel in Wolfsburg

These three representative areas were selected, in order to compare the results of the CFD Simulation, as well as to thoroughly evaluate the interaction of cooling airflow as well as the flow field around the vehicle. Previous to the analysis of the three above mentioned windows, the accuracy on the incoming flow field was evaluated through a PIV measurement without a vehicle on the test section of the wind tunnel. This allowed an efficient parameter study that provided information for the proper establishment of boundary conditions in the CFD Model.
In the first measurement window in the upstream mid-plane, the main objective was to understand how accurate is the incoming flow represented through the fluid dynamics computational solver; on the other hand, this analysis of results provided information how the flow field around the front of the vehicle changed by means of different modifications in the car. On second place, the measurement window in the underbody of the vehicle, endorsed the comprehensive study of the unsteady interaction among the flow below the car and the flow coming from the engine bay. Finally, the third window of interest lay on the engine bay. This area was chosen in order to determine if the simulation tool (EXA PowerFLOW®) provided correct flow structures in places with high level of detail and complex geometries. To achieve this analysis, a region was chosen were the optic measurement could be executed with the least blockage possible. Therefore, the most adequate region for such a measurement is the area between motor and bonnet.
The three areas were observed with 7 cameras, each obtaining double pictures with a $10\ \mathrm{Hz}$ frequency. To illuminate the regions, two light sheets from Nd:YAG Laser (Spit Light 600, Innolas) were used. The data of 4 cameras in the underbody region, as well as 2 more cameras upstream provided a full picture of the measurement areas. Furthermore, the flow in the engine bay was captured in a separate measurement session with similar characteristics.
After evaluating the PIV acquired data, it was possible to observe the corresponding velocity fields (Figure 3(b) and (a)). In order to determine the deviation of PIV field to CFD results, an evaluation line was established for each window (Figure 3). In an initial CFD run, up to $20\ \%$ discrepancy could be found in the averaged velocities in comperison with PIV-data. In the engine compartment the deviation reached up to $60\ \%$. Through a correct adjustment of the geometry position in the frontal area of the car, together with the parametrical analysis of the boundary conditions upstream, the deviation was reduced to $5\ \%$ in the underbody flow, less than $1\ \%$ in the upstream and $10\ \%$ in the engine bay, respectively; thus, PowerFLOW provides accurate results when the geometry modelled in the CFD analysis corresponds to that in the experiment. Oppositely, this does not mean that a PIV measurement is required for the evaluation of every vehicle, because the setup can be transferred to different vehicles studied in the Volkswagen Wind Tunnel.
Together with the PIV results and the prepared CFD Model, it is possible to determine the distribution of airflow through and around the vehicle and how they interact with each other (as simplified in Figure 4). In this way it was possible to

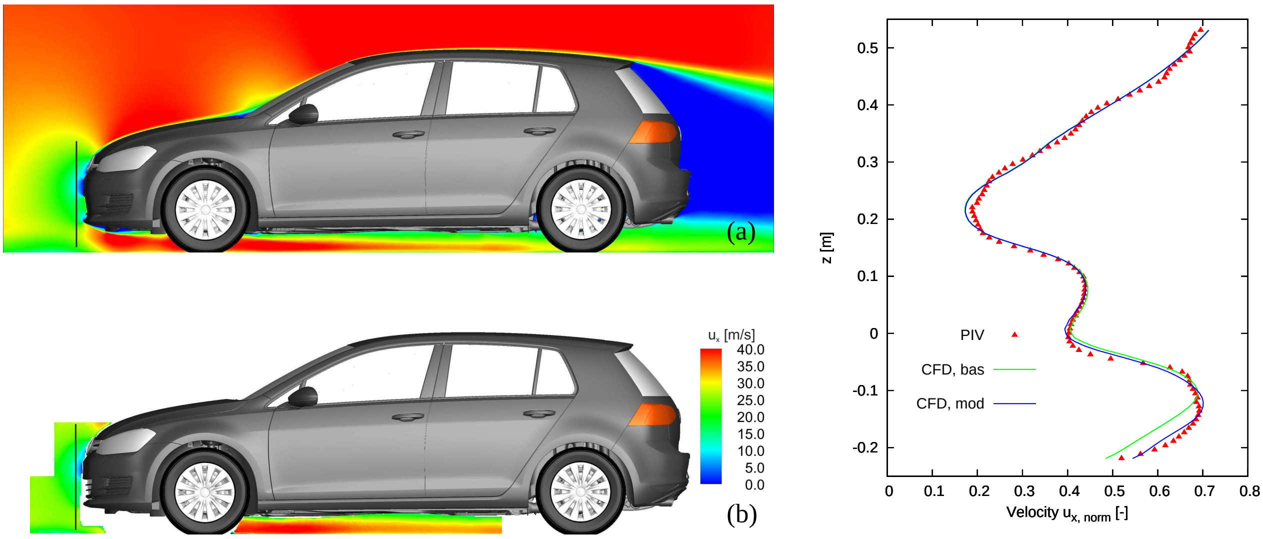

Figure 3: Representation of the velocity field in the y_0-plane (a) calculated with PowerFLOW® and (b) measured with PIV. Comparison of the velocity field along the evaluation line: before (bas) and after (mod) correct adjustment of the geometry for motor compartment in the calculation model.

determine that almost $60\ \%$ of the mass flow coming into the engine compartment is caused through the wheel houses to the exterior. Other $25\ \%$ is ejected through the exhaust tunnel. The remaining $15\ \%$ is generated through the diverse gaps and seals around the underbody, body in white, and the car body. Furthermore, it was possible to study the strong interaction of the flow from the underbody together with the flow ejected from the engine bay.

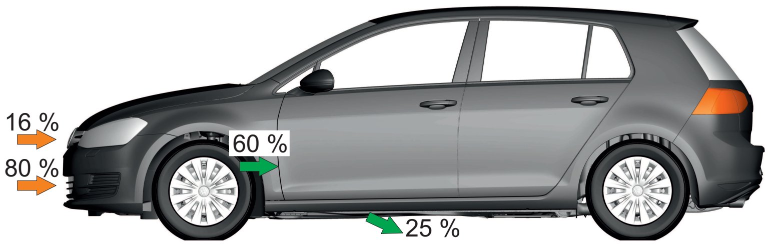

Figure 4: Simplified distribution of the cooling massflow.

These results represent the basis for understanding where and how cooling airflow degrades the total drag value. Based on this results, it is possible to develop components that positively affect the drag coefficient through influencing the cooling airflow.

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