

Open Grille DrivAer Model - First Results

Felix Wittmeier and Timo Kuthada
FKFS

ABSTRACT

Cooling air flow is an important factor when it comes to vehicle performance and operating safety. In addition, it is closely linked to vehicle aerodynamics. In recent years more and more effort is being spent to optimize the losses generated by the flow through the vehicle. Grille shutters, better sealing and ducting are only some examples for innovations in this field of work, resulting in a lower contribution of the cooling air flow to overall drag.

When investigating those effects, both experiments and numerical simulations are commonly used in the automotive environment. Still, when comparing the results from both methods, differences in the effect of cooling air flow can often be observed.

To better understand the effects of cooling air flow, the ECARA Subgroup CFD decided to establish a common design for a generic open source vehicle model with a detailed underhood compartment to lay the foundation for a common investigation model. The DrivAer-model, developed at the TU Munich, was chosen as the baseline vehicle, due to its high level of detail and the good acceptance in the community in recent years.

Based on the input of the members of the group, FKFS designed a baseline version of the underhood compartment including a radiator package with fan and a representation of the engine in close cooperation with TU Munich. Since the majority of DrivAer models built are for scale model testing, the engine features a simplified design to be used as a starting point for CFD validation. This simplified design fits well to the level of detail of the original model. The underhood flow can both exit through defined openings in the front wheel houses and into the underfloor region, which allows different cooling air concepts to be investigated. The cooling air package is based on component data of a mid-size passenger car.

This paper gives some insight into the model and presents first results from both CFD and wind tunnel measurements in quarter scale including rotating wheels and state-of-the-art ground simulation.

CITATION: Wittmeier, F. and Kuthada, T., "Open Grille DrivAer Model - First Results," *SAE Int. J. Passeng. Cars - Mech. Syst.* 8(1):2015, doi:10.4271/2015-01-1553.

INTRODUCTION

To guarantee the function of today's passenger cars, it is necessary to ensure that all components with thermal loads are sufficiently cooled. This is usually realized by extracting air from the flow around the vehicle, guiding it through heat exchangers mounted within the vehicle and returning it back into the external flow. This leads to a change in the aerodynamic properties of the vehicle.

The purpose of this work is to present a first analysis of the cooling air drag based on detailed generic model. Due to the design of the hardware model, a number of uncertainties which occur in full scale testing like deformations of sealing lines, leakage flows and geometric uncertainties can be excluded.

STATE OF THE ART

The following section gives a short introduction to cooling air flow and corresponding research work on reference models.

Cooling Air Flow Systems

A cooling air flow system is the sum of all components which contribute to the task of delivering cooling air to the place where it is needed, including cooling air inlets, ducting, heat exchangers and fans. There are a large number of parameters, which can influence the performance of such a system e.g. the size and location of the cooling air inlets, the performance curve of the heat exchangers including pressure loss, the package of the underhood compartment and the location of the cooling air exits. A study of the effect of such parameters on the aerodynamic performance can be found in [1].

The majority of today's passenger cars have the engine mounted in front of the passenger compartment. A standard cooling air flow system for such a car is also positioned in the front with its air inlets positioned in the vicinity of the stagnation point and cooling air exits to the underfloor region and front wheel houses. This type of cooling air flow system is also used for the investigations presented in this paper. The flow through such a system is pressure driven, with a high pressure at the inlets due to the stagnation at the front of the vehicle and exits in a low pressure region. After entering through the air intake grilles, the flow loses energy due to turbulence, friction and the pressure loss of the heat exchangers. Energy is added to the air flow in case the fan is in operation.

AERODYNAMIC COEFFICIENTS OF A COOLING AIR FLOW SYSTEM

The losses mentioned above, together with momentum losses at the inlets and outlets in combination with interference effects of exiting air and the surrounding flow are measured by a differential method. The cooling drag coefficient c_{DC} is derived from the difference between the measured drag of a vehicle with cooling airflow minus the drag of the same model with closed air inlets, the so called mock-up:

$$c_{DC} = c_{D \text{ with cooling air}} - c_{D \text{ mock-up}} \quad (Eq. 1)$$

Results of the mock up setups presented are deduced with open exit regions. The values for lift are derived by the same method. Different analytical methods have been presented to assess the influence of the cooling air flow on drag and lift values [2, 3]. These approaches work well for checking the overall influence but cannot take interference effects into account and therefore they tend to fail in predicting the absolute value.

The cooling air volume flow coefficient

$$c_{VR} = \frac{\dot{V}}{v_{\infty} \cdot A_R} \quad (Eq. 2)$$

is the quotient of the cooling air volume flow and the product of radiator area A_R and free stream velocity v_{∞} , which is equivalent to the maximum possible volume flow through a given radiator [1]. c_{VR} is also equivalent to the non-dimensional mean velocity through the radiator v_R .

INTERFERENCE EFFECTS WITH SURROUNDING FLOWS

The flow through the underhood compartment results in interferences with the surrounding flow at inlets and outlets. Garrone and Masoero determined the contributions of vehicle upper- and underbody as well as of the air flow system using a vehicle model with integrated balances for vehicle surface and air ducts [4]. They could show that the cooling air drag coefficient c_{DC} was smaller than the drag on the air flow system determined by the balance. This indicates, that the interference effects at in- and outlet cause a reduction of the total drag compared to the measurement without cooling air flow.

Examples for these interference effects are e.g. a changed approach flow angle towards the front wheels due to the cooling air flow, as reported by Wiedemann and Settgaest [5]. This results in an increased drag of the front wheels. The influence of engine compartment undershields and different outlet openings was investigated by Herbig [6]. He could achieve an improvement of cooling air drag of 60% by minimizing the momentum losses and disturbances, especially at the outlet.

A full scale passenger car was investigated in detail in [7]. It was shown that most of the changes in drag due to cooling air are located in the region of the underhood. Leakage flows around the radiator are strong contributors to the cooling air drag. Results for a sedan and an estate demonstrated that the cooling air drag can change due to rotating wheels.

Generic Models for Aerodynamic Investigations

Generic models have a long history in aerodynamic research. They can basically be subdivided in two classes: simple bodies like the Ahmed model and basic car shapes like the SAE Reference Body or the MIRA Reference Model. The benefit of generic models is the free availability of their geometries, which makes it easy for research institutions to work on those models and to compare their results with published work. An overview over the different available models was presented by Le Good and Garry [8].

The majority of these models have been defined in the last century, before ground simulation techniques became available in automotive wind tunnels and are therefore either placed on struts or equipped with fixed wheel stubs only. In addition, even the basic car shapes like models do only feature a limited extent of details and cooling air flow is neither considered.

Barnard [9, 10] investigated cooling drag using a modified Ahmed model with internal ducting. Due to the design of the model, which was somewhat closer to an aircraft engine nacelle than a vehicle, the results are better suited for comparison with the analytical approaches but the relevance for automotive aerodynamics is limited due to the absence of wheels and detailed underhood geometries.

In 1995 Cogotti [11] presented a study of the SAE reference model with ground simulation, which extended the standard SAE reference model [12] with different sets of wheels and wheel arches. The dimensions of this full scale model were later picked up by Kuthada et al. [13] for a quarter scale model. A generic cooling air duct was added to this design represented by either a radiator simulator according to Wiedemann [14] or a simplified engine block and a heat exchanger [1]. This geometric setup was also adopted by Baeder et al. [15] for the validation of underhood CFD simulations. In a later work, this model was furthermore extended to be used for validation work on heat transfer in the underfloor region [16].

The freely available models were missing a level of detail which is comparable to today's vehicles. This shortcoming was attributed in the work of Heft et al. [17], who presented a realistic generic car geometry derived from two midsize passenger cars (Sedan and Estate).

The model features three different car and geometries (sedan, estate

and fastback) as well as two different underfloor configurations (smooth and detailed). It is freely available for download [18] and has been adopted quickly in the aerodynamic community (e.g. [19, 20]). However, this model is still missing the representation of the underhood compartment and can therefore not simulate its aerodynamic influences.

Implementation of Underhood Flow to the DrivAer Model

To overcome this shortcoming of the DrivAer model, it was decided within the ECARA subgroup CFD [21] to retrofit a simplified underhood compartment into the DrivAer body. The design of this model was done in a cooperation of the Institute of Aerodynamics and Fluid Mechanics of TU Munich and FKFS with the input of the ECARA subgroup members. Like the mock-up DrivAer model, the model will be available to all interested parties via the DrivAer website [18].

The purpose of the open grille DrivAer model is to broaden the range of applications for this generic model and to give the aerodynamicists a standardized model, on which the influence of cooling air flow can be investigated. Therefore the baseline of the open grille DrivAer is equipped with a simplified engine compartment and cooling air package.

One important prerequisite for the design of the underhood compartment of the DrivAer model was to keep the changes of the existing geometry to a little extend. This should ensure that the aerodynamic characteristics of the vehicle remain the same if the cooling air inlets on the models are closed. By this, already existing hardware models can be upgraded without changing the whole vehicle.

The cooling air inlets in the vehicle's front end are already indicated in the baseline model. For the open grille configuration, these areas are replaced by an upper and lower grille with horizontal lamella (see Figure 1). The opening area is distributed to 59% at the upper grille and 41% at the lower grille.

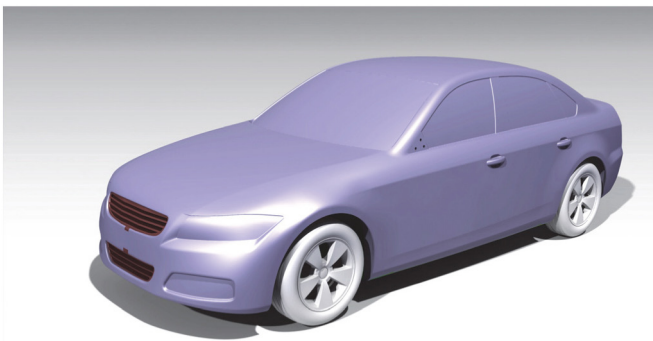


Figure 1. CAD model of the DrivAer with new open grille design

Behind the grilles lies a closed ducting guiding all the air entering the grilles through the simplified radiator package. The model is equipped with a simplified 4 cylinder engine. There are both openings to the wheel arches and to the underfloor for the cooling air to exit the

underhood area. The remaining engine compartment is completely sealed to again guarantee defined exit surfaces and prevent any leakage flow.

The available space for the radiator package is sufficient to implement different kinds of grille shutters, fan shroud designs or to have a defined leakage flow around the radiator. This allows not only investigations with the baseline model, but gives the aerodynamicists also plenty of room for modifications, allowing the model to be used for various kinds of investigations.

It was decided within ECARA that the pressure loss of the radiator package will be taken from the 2001 Ford Mondeo with 2.2 l diesel engine. This gives the possibility to implement not only the generic radiator package, but also to use it for full scale models a production sample. The chosen pressure loss curve is displayed in Figure 2 and represents the combined pressure loss of both the full scale radiator and the AC condenser.

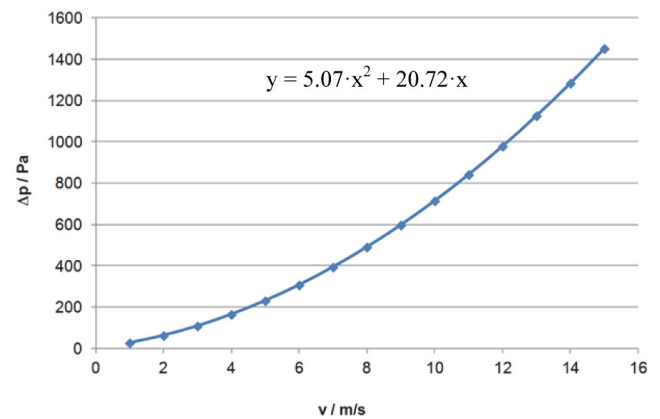


Figure 2. Pressure loss curve for the DrivAer radiator package

EXPERIMENTAL AND NUMERICAL SETUP

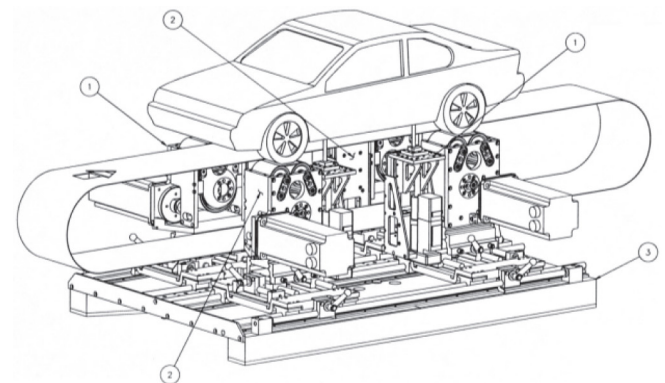


Figure 3. 5-belt system in the model scale wind tunnel of University of Stuttgart [22]

For the experimental investigations, the IVK model scale wind tunnel of University of Stuttgart (MWK) was used. This closed circuit wind tunnel with an open test section is suitable to measure models in 20% and 25% scale. It is equipped with a state-of-the-art ground