Universitatea *Transilvania* din Braşov

HABILITATION THESIS

SUMMARY

Title: **ROAD VEHICLE AERODYNAMIC DESIGN**

Domain: **Mechanical Engineering**

Author:Angel HUMINC, PhD

Transilvania University of Brasov

BRASOV, 2016

Summary

ROAD VEHICLE AERODYNAMIC DESIGN

Until recently, the exterior shape of the vehicles was the main concern of the engineers, the underbody geometry playing a secondary role, or being neglected for some type of vehicles, as for off-road ones. In the last decade, in order to reduce the values of the drag coefficient of cars, the underbody flow management becomes a major problem of the designers, too. In this sense, the thesis presents some theoretical, CFD and experimental results concerning the influence of the underbody geometry on main aerodynamic characteristics of a car.

The first part of the thesis presents an overview of the main concepts of road vehicle aerodynamics, which are used in the next chapters.

A theoretical study of the aerodynamic interaction between vehicles and road is performed in chapter 1.2. Thus, because the decomposition of the aerodynamic forces into measurable components would facilitate the optimization of the design process, it was presented a theoretical method for computation of the drag of an underbody shaped as a Venturi tube/nozzle. In this way, there was proposed the decomposition of the total drag (D) into two following components

$$D = D_{ext} + D_{ub}$$

where D_{ext} is the drag due to the airflow on external upper surfaces of the vehicle, having the flow rate Q_{ext}, and

D_{ub} is the drag due to the flow under the body of vehicle, in the space between the lower surface of the vehicle and road, treated as a convergent-divergent nozzle, having the aria $b \times h$ and flow rate Q_{ub}.

Assuming that the resultant fluid is homogeneous in the entire cross section of the nozzle (b × h), for the second component of the drag of vehicles was established analytically the following Equation

$$D_{ub} = \zeta_{ub}\; b\; h \frac{\rho}{2} \frac{\mathrm{v}^3}{\mathrm{v}_\infty},$$

where ζ_{ub} is the coefficient of the equivalent aerodynamic resistance of the nozzle (underbody geometry),

v is the average velocity of the air through the constant section of the nozzle.

Also, the following dimensionless indicators were proposed in order to characterize the underbody airflow

- K_D is the coefficient what represent the ratio between underbody drag and total drag defined as product of three dimensionless factors,

- K_Q is the coefficient which shows the contribution of the underbody flow rate on total flow rate

$$K_D = \frac{D_{ub}}{D} = \frac{\zeta_{ub}}{c_D}\frac{b\,h}{A}\left(\frac{\mathrm{v}}{\mathrm{v}_\infty}\right)^3,$$

$$K_Q = \frac{Q_{ub}}{Q},$$

where (ζ_{ub}/c_D) is the relative drag,
$(b\,h/A)$ is the relative area,
$(\mathrm{v}/\mathrm{v}_\infty)$ is the relative velocity.

In this way, the underbody drag coefficient $c_{D_{ub}}$ can be expressed as

$$c_{D_{ub}} = K_D c_D = \zeta_{ub}\frac{b\,h}{A}\left(\frac{\mathrm{v}}{\mathrm{v}_\infty}\right)^3.$$

The results, using as example the experimental model ARO 26 of ARO SA former Automotive Company, show that the increasing of the flow rate under the vehicle has a negative impact on underbody drag of vehicle, also for total drag. Thus, there is necessary to minimise the value of Q_{ub} using auxiliary structural elements, as a special profiled aerodynamic radiator shell, or using a solution with lateral apertures to exhaust the air from engine compartment. Obviously, the decreasing of Q_{ub} can be obtained through the diminution of the ground clearance of the vehicle, as for the recent automobiles which have variable ground clearance with speed.

In chapter 1.3, with the aid of the CFD techniques, there were studied the influence of the wheels motion and underbody geometry on drag. The vehicle body (ARO 26 as in theoretical study) was drawn as a CAD data. It was carefully reproduced, with the exception of the air-cooling vent, which was closed for this study. For the underbody geometry were considered medium and large assembly, as chassis with reinforcing frames and bracing rib, front and rear main suspensions, elements of rear transmission and driving axle, guard screen of the front axle and also some components of the exhaust of burnt gasses, respectively the rear silencer. Also, the exterior surfaces of the wheels and wheelhouses were carefully reproduced in order to achieve realistic results, much as possible.

Concerning the wheels, there are two possibilities to put them in motion during experiments in wind tunnels: using a rolling stand, and with the aid of a moving belt device. In this sense, were performed four kinds of CFD analyses, without and with wheels in motion. Analysis with wheels in motion showed variations of the aerodynamic characteristics, more significant in the case of the lift coefficient, revealed also by the experiments performed with rotating wheels: $\Delta C_D = (3-5)\%$, $\Delta C_L = (15-20)\%$. For both methods used, ΔC_D has a parabolic variation with a minimum value for $Re \cong 10^7$, what is corresponding for economical sped of the car from fuel consumption point of view. Concerning ΔC_L, its variation depends on method for driving of wheels. For the moving belt method, ΔC_L has a variation similarly as ΔC_D. Using the method of the rolling stand, the ΔC_L variation changes, and it is continuously increasing.

The obtained results suggest that is important, from quantitative point of view, to simulate the rotation of the wheels for small and higher velocity. Also lift coefficient is more sensitive by the underbody flow, comparatively with the drag coefficient. From qualitative point of view, taking into consideration of the wheels' rotation is important for a better evaluation of the aerodynamic characteristics of the vehicle. In this way the vortex structures generated by wheels can be visualised, their contribution at the wake of vehicle being important.

Concerning the underbody geometry, the results show that it influences the drag more than 40% for vehicle with a large ground clearance and many unprotected components (from aerodynamics point of view). This percentage is a larger for lower to medium velocity and is decreasing for higher velocity. A major percent of underbody drag is due to the wheels, and their influence on drag decreases with velocity. An opposite behaviour has the elements of structure exposed to the airstream. The drag due to these elements is rising with the velocity.

In chapter 1.4 there are presented the equipments used in experimental research and the tests performed in order to evaluate their performances according with SAE requirements J2084 JAN93.

A gauge balance was designed for the evaluation of the aerodynamic loads. It was connected to an automatic data system acquisition, which is controlled by a PC. In order to reproduce the relative motion between road and vehicle, a moving belt device was designed and built.

In chapter 1.5 there are presented the results of the experimental studies, which were focused on

- the influence of the ground clearance on the main aerodynamic characteristics (drag and lift) of the car (ARO 26) having the underbody as a Venturi tunnel;
- the influence of the underbody geometry of a car on aerodynamic characteristics;
- the influence of the method to simulate the ground (flat wall and moving belt device).

The obtained results show an improvement of the aerodynamic characteristics of the car using a Venturi tunnel configuration for the underbody geometry, emphasised mainly by the lift coefficient.

Also, it was revealed an increasing of the aerodynamic coefficients for the underbody geometry having structural elements exposed to the air stream, including the wheels, which represent areas of impact.

In the third chapter of the thesis there are presented several results concerning the aerodynamic characteristics of the automobiles with ailerons and the effect of the later ones on the lift and drag.

There are also studied the ailerons assisted by Coandă effect, ussing as reference ClarkY (11.7 %) and Eppler E423 (12.5 %) airfoils. This type of active control of flows represents a new approach in the field of the auxiliary devices of the cars, used to generate download. In this sense, such of automotive ailerons takes advantages of both types of usually used fixed ailerons of cars, without mechanical parts in motion, and respectively, the adjustable ailerons, mechanically controlled, used to generate variable download.

The influence of several parameters was inverstigated, as the initial velocity of jet and the characteristic dimension of nozzle (width of slot). The results show that Coandă effect can be used to reduce trailing edge separation, in order to improve the aerodynamic characteristics of the ailerons, and latter to increase the aerodynamic behavior of the vehicle concerning the aerodynamic loads, drag and lift, consequently, stability and handling.