TRANSIENT AUTOMOBILE AERODYNAMICS PROBLEMS, SIMULATIONS & ANALYSES

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1. Introduction

An automobile vehicle is a short-length body incorporating a series of cavities and a solid base, which moves close to ground in a turbulent airflow at a high Reynolds number. When moving on straight line in a confined space without any external disturbance, the design of the vehicle - by virtue of its operational and packaging constraints - prompts a significant amount of airflow separation, which in turn contributes to a significant increase in aerodynamic drag and noise. Such separations originate at various locations of the vehicle such as the air inlets and outlets, the side parts, bumper, wheel arches, windscreen pillars, under body and on the rear window and base.

In an outdoor setting, as the vehicle moves along the road, these separations continuously increase and decrease in an asymmetrical manner. This is because the moving vehicle is subjected to variations in the relative direction of the wind, to the unsteady nature of the outdoor wind and to the transient effects of successive overtaking and crossing phases. These variations influence the values of the aerodynamic forces and moments and cause rapid variations the dynamic stability of the vehicle, factors which are liable to have a significant impact on the comfort and safety of the passengers.

These variations are particularly notable when the vehicle is subjected to a gust of crosswind, when it crosses or overtakes another vehicle or when it exits a tunnel in the presence of a crosswind. Under such conditions, the distribution of the static parietal pressures evolves rapidly, the aerodynamic moments vary according to time and the vehicle is then subjected to movements around the axes of roll, pitch and yaw. In practice, the movements around the yaw axis are the most significant. As a counter measure, the driver makes rapid trajectory corrections, which may have a negative effect on the dynamic stability of the vehicle or even cause an accident. These transient phenomena are associated with variations in aerodynamic drag and prompt an increase in fuel consumption.

The models and methods used for analyzing the transient processes that occur when the vehicle is subjected to a gust of crosswind and when two vehicles overtake or cross each other are described chronologically in this paper. The analytical models associated with the experiments conducted in a wind tunnel are exposed in detail and the main findings are presented with a view to obtaining a better understanding of the prevailing physical phenomena and to developing effective dynamic airflow control strategies accordingly. The presentation is based on the findings of research projects developed by the "Fluid Mechanics & Aerodynamics" group at the Renault Research Department.

2. References Works

The process during which a vehicle is subjected to a gust of crosswind is analyzed according to experimental and numerical methods, which are often difficult to implement. Gilliéron *et al [*1] provide a detailed overview of the simulation, computation and analysis techniques used. For physical experiments, tests can be conducted on full size models or small size models. In full size tests, the vehicle moves at a stable velocity and is subjected locally to a constant crosswind applied by a battery of fans. In this configuration, it is difficult to estimate the extent to which the aerodynamic characteristics evolve. Experiments conducted in a wind tunnel on small size models are more numerous. Some authors propose catapulting the models in a direction perpendicular to the direction of the incident windflow. The body is catapulted along a rectilinear ramp and the sideslip angle is simulated by varying the velocity of the incident airflow. Macklin et al [2] have compared the unsteady and steady lateral and lift forces and the moments of yaw and roll. These coefficients are measured using an aerodynamic balance which moves in tandem with the model. Chadwick et al [3] determine the lateral forces and the moments of yaw by integrating the static pressures noted on the surface of the models at different velocities of motion. In all these experiments, no indication is given of the variation of the aerodynamic drag coefficients.

Garry et al [4] suggest oscillating the models around their vertical axes. An aerodynamic balance is used to measure the aerodynamic torsor and the variations between the steady and unsteady responses. The results show that the steady and unsteady aerodynamic drag responses exhibit a phase-shift, which is a function of the geometry of the model. Chometon *et al* [5] have investigated how unsteady wakes evolve on small size models. The analysis is conducted by obtaining the dynamic total pressure loss readings measured in the wake downstream from the base. Data acquisition and post-processing methods are used to view the variation of the unsteady pressure field and then develop a film. The findings highlight the influence of the sideslip angle on the topological evolution of the wake vortices along with the phenomena of phase-shifting [5] and hysterisis, Gilliéron *et al* [6]. No drag measurement is proposed. Another solution consists in subjecting a fixed model to an airflow generated by oscillating profiles, Bearman et al [7]. The findings show that the unsteady forces may be evaluated according to steady drag measurements. All of these experiments are conducted in open section and semi-guided wind tunnels. In this type of installation, the geometry of the test section located downstream from the models modifies the structure of the wake and the parietal pressure distribution is no longer representative of real life conditions. Dominy et al [8] propose a new approach. The model is immobilized in an open-ended tunnel without an open return circuit. The incident airflow is then simulated by a jet directed along the longitudinal axis and a lateral jet is used to simulate a cross flow. This system eliminates problems of inertia, measures the unsteady response of the aerodynamic torsor and conducts velocity and pressure measurements in parallel. Even though certain similarities may appear, the structure of the unsteady airflow appears fundamentally different from the structure noted in a stationary setting.

From a numerical point of view, to our knowledge, no findings have been published on the unsteady responses of models subjected to incidental airflow in a variable direction as a function of time. Experiments have however been carried out by the Renault Research Department in order to test the capacity of industrial computation codes, to develop computation methods that can be used in an operational context and to qualify and quantify the unsteady effects of a gust of crosswind. In practice, the objective is to obtain information conducive to estimating the values of unsteady aerodynamic coefficients measured in a wind