A Brief History of Road Vehicle Aerodynamics (RVAD)

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1. Introduction

Today and in the coming decades a number of heavy legislations will be forced on the automotive industry in terms of lower fuel consumption and reduced emissions. The fact that the time of cheap oil basically is over has also focused the interest of most car manufacturers on a significant reduction of the fuel consumption in the coming years. All this constitutes real challenges for the automotive community; however, by utilizing modern technology it is possible to meet the demands on three fronts; through the development of advanced power trains and a reduction of roll as well as drag resistances. The latter is especially important since it is here that the introduction of new technology is expected to yield the greatest returns in terms of reduced fuel consumption. Figure 1 shows a graph of the rolling and drag resistance as a function of the driving speed for a typical sedan model, from Barnard [1]. Three important observations may be made in his figure; the rolling and drag resistance are of approximately the same magnitude already at about 50 km/h, at higher velocities the drag resistance increases significantly with the velocity and (by looking at similar curves for other types of vehicles) the slope of these curves is basically the same for all road going vehicles. Figure 1 emphasizes clearly the central role of drag reduction in lower fuel consumption, and that this occurs at a surprisingly low speed.

From the perspective of road vehicle aerodynamics (RVAD) it is drag reduction, lift forces, flow induced sound and vibrations, and dirt deposition which are of primary interest to understand and control. Looking at the drag coefficient, it is the exterior form, i.e. the styling of the body, air intakes, under body and wheel houses which are the key parameters. During the nineties much work has been devoted to the shape of the upper body, and currently the drag coefficient for a passenger car has been reduced to the typical range of 0.30-0.32. However, further reductions are possible through detailed consideration of the flow along the under body, in the wheel houses and the flow around the rotating wheels where complex, drag generating and three-dimensional flow fields are formed.

Another area of RVAD which recently has achieved increasing interest is linked to the general trend in the automotive industry to fabricate small and light cars. Very few car manufacturers produce slower vehicles and with the performance of these modern, light cars safety issues like stability against transient side-winds or air pressure loads created through the interaction between vehicles of different size have come into focus. In this context, the lift forces of the vehicle or rather the down force distribution has turned out to be a key parameter as the cruising speed on modern highways in general has increased significantly during the latest years. In connection to down force generation it is worth mentioning the excellent demonstrators of RVAD that Formula-One and other high performance racing series constitute, since here the control of generated down force is the key to a winning concept. Several chief designers of Formula-One teams claim that today the outcome of the winning team is more than 80% determined by the aerodynamic devices used, and hence, during the last decades an economically important industry has been created in the racing world.

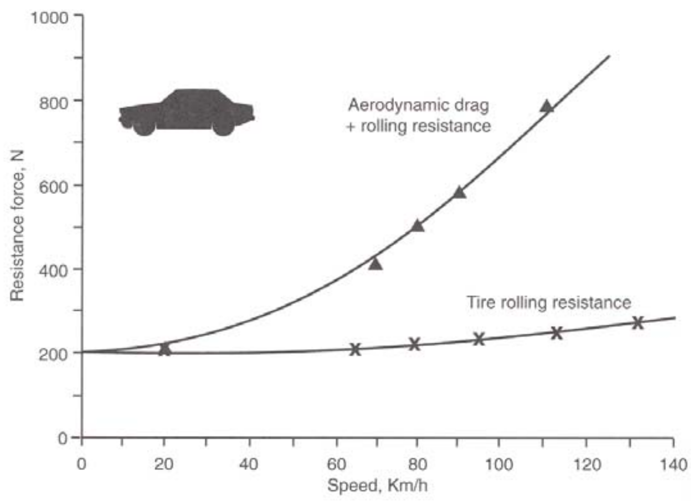

Figure 1. Aerodynamic drag + rolling resistance as function of driving speed for a typical sedan, from Barnard [1].

At an increasing speed the aerodynamic noise gains more and more importance in comparison to the drive-train and the tyre-road noise, and currently there is a large on-going activity in the automotive industry to reduce and control sound generation. From the RVAD perspective, the introduction of fast computers advanced computational fluid dynamics (CFD) and new experimental techniques, including measurements in specially equipped wind tunnels, have opened up new possibilities for a significant reduction of flow induced noise. Dirt distribution and deposition has also become of primary interest in modern car design and also here RVAD constitutes a cornerstone for further improvements. However, in both aero acoustics and dirt contamination the common denominator is that the governing equations of fluid dynamics have to be re-written or complemented with the basic equations of acoustics or mass transfer and an integration of these equations create a real challenge for future optimizations.

This lecture starts with a brief survey on historical sport and racing cars that are of aerodynamic interest; the presentation is divided into one part dealing with down force generation and a second part on a few attempts to design low drag vehicles. A few model experiments are discussed shortly in order to elucidate these possibilities in the development of RVAD, and the lecture is closed with an outlook and identification of future challenges.

2. Brief historical survey of RVAD

It is out of the scope of the current paper to cover all interesting aerodynamic vehicles that have been produced throughout the years. The vast amount of examples is enormous, and therefore only some illustrative examples, preferably from the world of high performance cars, have been selected and will be discussed. The literature in this field is also large, and today almost all car manufacturers have own surveys on their history and interesting cars manufactured. There exists also a vast amount of books on RVAD, and here only a few samples will be given on hand- and textbooks. First to mention is the comprehensive book by Hucho [2] which should be considered as a classic in the field; it covers numerous experiments conducted in almost all branches of RVAD. The book has been published in several editions; a new edition is planned to be released this year. The book by Barnard [1] gives a broad view of RVAD; it is a good introduction to the field and with complementing