A REVIEW OF SOME PROBLEMS IN ROAD VEHICLE AERODYNAMICS

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Introduction

Current research into road vehicle aerodynamics can be separated into three broad areas: the development of reliable wind tunnel test techniques, the physical understanding of the flow around three-dimensional bluff bodies near to a ground plane and the evolution of numerical simulation methods to predict vehicle flow fields. One feature that all road vehicles have in common is that their flow fields are extremely complicated and they are the combined result of a number of interacting flow modules. Separations on the forebody, from such features as bonnet edges and A-posts, generate vortices which trail back to influence the remainder of the flow. Flow separation at the base of the vehicle maybe predominately of the recirculating type, as with an estate car, or it may generate strong longitudinal vortices as in the case of a fast-back [1]. The underbody flow plays an important part in generating lift and drag forces as well as influencing the flow when the vehicle is yawed. Add to this the flow around the wheels, through the engine compartment and the ventilation flows and you have an extremely complex problem. Advances in understanding can only be achieved by studying flow modules separately or in simple combinations.

The present interest in vehicle aerodynamics can be attributed to the requirements to decrease the lap times of racing cars and to reduce the impact of increasing fuel prices on passenger vehicle running costs. The use of lighter construction techniques for passenger cars has brought into focus the important problem of passenger car handling in side winds.

Test Techniques

A wind tunnel cannot reproduce precisely the flow environment encountered on the road. The flow around a vehicle travelling in zero wind conditions can be simulated by using a moving ground. The moving ground can be used to drive wheels which are in contact with it. Low ground clearance racing cars are strongly influenced by the ground condition but with typical passenger cars the effects are not so clearly defined. A moving ground induces more flow under a vehicle and its use always generates a decrease in lift or an increase in downforce. Its effect on the flow field depends on the geometry of the underbody. Recently it has been shown that a moving ground changes the base flow behind a bus and alters the dust deposition patterns [2].

All the research using a moving floor that has been reported in the literature has been at model scale, full scale testing presents formidable problems. Many car manufacturers have built, or are building, fixed floor wind tunnels to test full-size cars. Scale effects on cars are largely unknown and little has been done to try and correlate the results of testing at different scales. One of the advantages of working at full scale is that the fine details of the body geometry can be reproduced precisely. Full-scale testing is not without its problems, however, and one of the most serious difficulties is coping with the effects of wind tunnel blockage. Cost is a strong factor in limiting the size of a wind tunnel and the final design is often dictated by the value of the highest blockage that can be tolerated. Considerable research has gone into devising reliable correction methods for typical car shapes. An alternative approach has been to develop wind tunnels with slotted-wall test

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sections to minimize the effects of blockage. It is claimed that geometric blockage can be increased to up to around 15 percent without the need for any correction to measured coefficients [3]. The use of this type of facility in other application areas should be studied.

Little is available on the influence of the natural wind on the aerodynamics of road vehicles. In a tunnel the effect of the wind is usually simulated by placing the vehicle at a fixed yaw angle to the uniform tunnel flow. On the road the approaching wind is sheared and turbulent and the relative conditions experienced by the vehicle are dependent on its own speed. The influence of the wind on vehicle flows is an area requiring much greater attention.

Flow Field Studies

Three-dimensional bluff body flows depend very strongly on the details of the geometry. In two-dimensions a few simple bluff body shapes have been extensively researched by a large number of authors. There are no corresponding standard shapes that have been used widely for 3D bluff bodies near the ground. In order to introduce a relatively simple family of shapes Davis [4] devised a form with a smooth forebody and a flat under surface that generated no separations at zero yaw. To this could be added different base geometries ranging from a flat base to a continuously sloping fast back. He investigated the time-mean wake structure at various downstream positions using a multi-tube, self-aligning pressure probe. The pressure data can be processed to give mean velocity and vorticity profiles. Typical cross flow velocity plots together with longitudinal vorticity contours are shown in figure 1. Using a method due to Maskell [5], the wake data can be suitably integrated to determine drag and side force. The calculated values agree well with balance measurements [6]. Further information is being gathered on the turbulence characteristics of vehicle wakes. An outstanding question is what proportion of the unsteadiness in the wake is associated with turbulence and how much is due to the movement of coherent vortex structures?

Numerical Simulation

From the previous discussion it will be realized that it is extremely difficult to predict vehicle flows accurately. The first techniques employed used panel methods and assumed attached flow. More recently, attempts have been made to incorporate boundary layer development and to use a simple wake model. At best success has been very limited. Current developments with panel methods include the representation of the wake using a time development of discrete line vortex elements. This approach is promising but it still leaves the difficult problem of predicting flow separation position.

Most effort at present is being directed towards using Navier-Stokes codes with a time-averaged Reynolds formulation and a simple turbulence model. Some of the shapes examined experimentally by Davis [4] are being used as computational test cases. In some recent impressive calculations by Coeffe and Darras [7] the flat back model of Davis was calculated using a finite element code and the k-e turbulence model. The general features of the flow were reproduced but the drag coefficient was in error by 20 percent. It should be borne in mind that manufacturers are often interested in drag coefficients to better than 1 percent. Although numerical methods require considerably more development they may one day be able to reduce expensive tunnel testing time.

References

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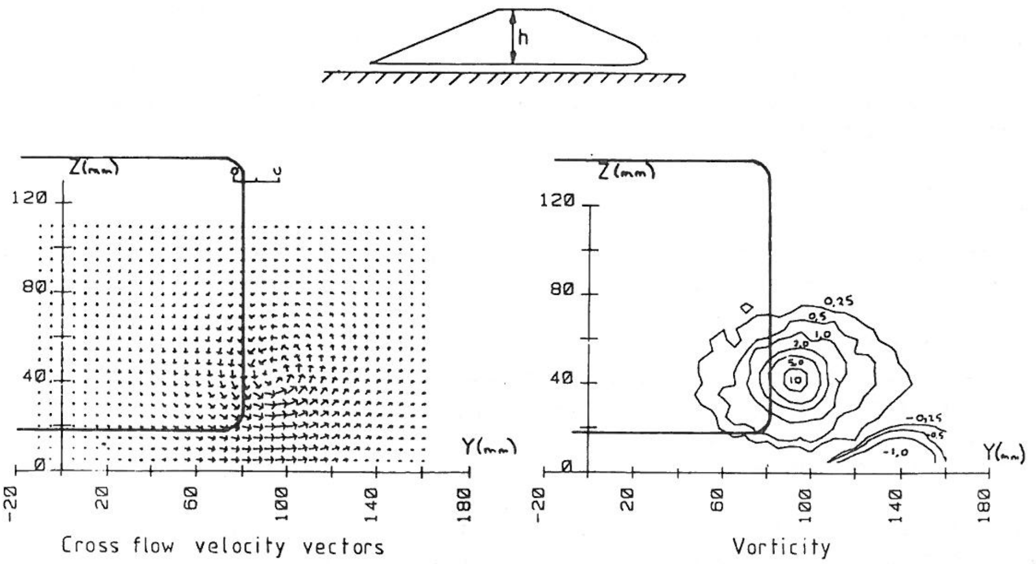

Cross flow velocity vectors

Vorticity

Figure 1. Wake survey behind 25 deg slanting base at x/h = 6.5, ground clearance = 0.15h.