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Simulation of ground vehicle aerodynamics applied to a generic Le Mans prototype

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Abstract

Optimisation of the aerodynamic design of a vehicle is paramount in achieving peak performance. In the case of racing cars, it is required that extensive research be conducted into the aerodynamic response to different vehicle attitudes such that performance and safety envelopes can be established. Chiefly amongst the numerical techniques typically employed is Computational Fluid Dynamics (CFD). The objectives of the current research are to simulate the flows around a high performance ground vehicle, and estimate the performance characteristics and aerodynamic safety envelope; perform a suitable numerical validation study to ascertain the accuracy and efficacy of the numerical methods; and to engage design and setup parameters which affect the track-wise performance of the racing car. In this dissertation, steady-state three-dimensional Reynolds Averaged Navier Stokes (RANS) equations are employed, where closure is provided by the two-equation $\kappa - \omega$ SST turbulence model. Numerical simulation is accomplished with ANSYS ICEM and CFX softwares. Both low Reynolds number ($Re \approx 0.58 \times 10^6$) and high Reynolds number ($Re \approx 25 \times 10^6$) simulations are conducted. Vehicle ride-heights are modified to establish the relationship and sensitivity of performance characteristics to physical geometry changes. Downforce generated by the vehicle is shown to be strongly dependent on the front ride-height h_{g_f}, where $-0.73 < c_l < -1.84$ based on the frontal area of the car. Over the full range of geometries studied, the downforce remains positive, however the ratio of front / total downforce production is shown to be highly variable. Vehicle drag is found to vary as $0.36 < c_d < 0.45$. A strong correlation is found between the production of drag and the rear ride-height h_{g_r}. The overall aerodynamic efficiency ϵ is found to vary as $2.2 < \epsilon < 4.2$. A strong correlation is found between ϵ and h_{g_f}. The numerical prediction methods are first validated through a numerical study of the generic Ahmed body, and secondly through an experimental investigation of a 1/6th scale model of the LMP vehicle in the University's low speed wind tunnel. Boundary layer reduction on the ground plane is accomplished through the use of distributed suction on a perforated raised plane. It is found that insufficient reduction of the boundary layer thickness δ and displacement thickness δ^* occur before the leading edge of the vehicle. However, through direct comparison of underbody surface static pressures to numerical predictions, it is found that the suction system does greatly improve the level of correlation between the experimental and numerical results. As well as through direct comparison of surface static pressure coefficients, experimental verification is accomplished using pictorial comparisons of the flow-fields and wall shear stress distributions. Optimisation of the vehicle's lap-time is undertaken using quasi-static vehicle dynamics simulations, which employ numerically-derived aerodynamics data. The resulting optimisation process produces a Le Mans lap-time of 3' 41" seconds. This prediction is within the performance range of current production racing cars. Further numerical research is required into the nature of forces which act during vehicle yaw and extreme pitch scenarios. To facilitate further experimental investigations, a more powerful suction system is required to remove the boundary layer on the ground plane.