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AERODYNAMIC DESIGN OF A FORMULA SAE RACE CAR

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Abstract *The objective of the research in this paper was to maximise the amount of performance enhancing aerodynamic down-force generated by the 2005/2006 University of Auckland Formula SAE race car. This was done through a combination of physical modelling using a rolling road wind tunnel research facility and by using computational fluid dynamics.*

Computational fluids analysis was used for the design of the body and under-tray of the vehicle. Optimal design gave a lift coefficient of -0.9 from the under-tray. Simulations showed that when the exhaust was vented into two diffuser tunnels under the car, the down-force was increased by 35%. Half-scale modelling using the wind tunnel rolling road facility gave a lift coefficient of -2.4. In its optimal configuration, the aerodynamic load on the front and rear wheels respectively was able to be adjusted between 43% on the front and 57% on the rear to 33% on the front and 67 % on the rear by changing the angle of the foils. The drag coefficient also varied from 0.9 to 1.1.

Full-scale on-track measurements showed that only 6% less down-force was being generated than was predicted from the wind tunnel test programme, and validated the experimental approach that was taken. Data collected from the car during the endurance event at the 2006 Formula Student Germany competition showed that the aerodynamic package was responsible for a significant increase in the performance of the vehicle under braking and during cornering, while the increase in the drag force had only a minimal effect on the top speed which was achieved during the event.

1 INTRODUCTION

The Formula SAE competition was established in 1981 by the Society of Automotive Engineers (SAE) in the United States of America as an educational tool to develop the knowledge and skill base of the automotive industry at the University level. The competition requires that each team from their respective universities design, build, and test a small, open-wheeled, single-seater race-car with the premise that a manufacturing firm has employed the team to design the vehicle for a one-make racing series, for which the cost to reproduce each of the vehicles must not exceed US$25,000. The competition comprises both static and dynamic events. The static events consist of a business and design presentation each of which are marked by a panel of experts. A tilt test of the vehicle is also performed to simulate cornering and the determination of the height of the centre of gravity of the vehicle. The dynamic events aim to test the vehicle in all aspects of competition car performance with acceleration, skid pan cornering, autocross and a final twenty-two kilometre endurance test. Marks are awarded for the performance of the vehicle in each of these tests as well as on the fuel economy of the vehicle during the endurance event. The total marks received from both the static and the dynamic events determine the overall winner of the competition.

Aerodynamic downforce is hugely exploited in the design of the modern race car (Refs. [1][2]). The performance benefits which can be gained through the resulting increase in traction has made the search for increased downforce and reduced drag a highly sought after performance edge in motorsport. The benefits of downforce and effective aerodynamic design in the Formula SAE car, however, were not entirely clear. It was the goal of the present research to determine areas where the aerodynamic forces are most performance enhancing by utilising CFD as well as model testing in a wind tunnel equipped with a moving belt ground plane, and then to validate the predictions using on-road measurements. Further details are available in Ref. [3].

2 NUMERICAL MODELLING

The purpose of the CFD analysis was primarily to design the body (including side pods) and the under-tray of the vehicle prior to carrying out wind tunnel testing. The CAD models of the car body and under-tray were constructed using ProEngineer Wildfire 2.0, the

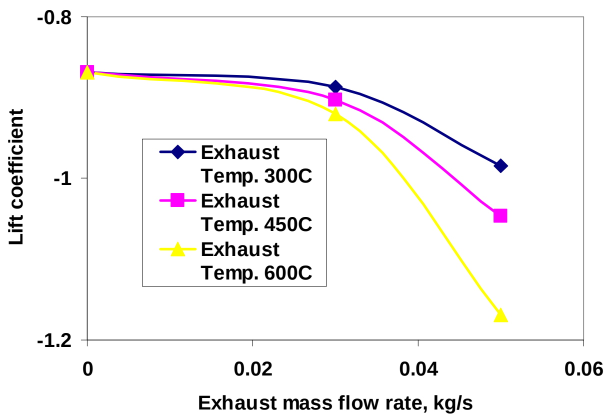

Figure 1: Effect of rear diffuser tunnel exhaust mass flow rate and gas temperature on the lift coefficient

Figure 1 Photograph of half-scale model mounted in wind tunnel above moving belt ground plane

computational domain was meshed using ICEM CFD mesh builder, and the CFD analysis was carried out using the CFX 5.6 Pre, Solver and Post programs. To get the maximum performance from the available software and hardware, a computational half-model was used (cut along the longitudinal centreline) 13m long, 3m wide, and 2.5m high, giving a blockage of 3.7%, or in terms of the model maximum dimensions: l, w, h: 4.56 x l, 4.69 x w and 3.56 x h. A mesh refinement study was conducted and it was determined, given the computational power available, that the optimal mesh for the study of the body and under-tray consisted of approximately 1.5 million cells. The surface of the model was given an inflated mesh consisting of five layers of inflation with an expansion rate of 1.2 between each layer. The remainder of the mesh was generated using tetrahedral cells with a minimum edge length of 1.4mm and a maximum of 106mm. The software solved the Reynolds Averaged Navier Stokes (RANS) equations, using the Shear-Stress-Transport (SST) turbulence model.

As an example of a typical result obtained, the effect of directing the exhaust gases into the rear diffuser tunnels under the car on the lift coefficient for a number of exhaust gas temperatures was investigated, and the results are shown in Fig. (1) for a vehicle speed of 15 m/s. It is clearly evident that the downforce is increased as the mass flow rate and gas temperature increase.

3 WIND TUNNEL TESTING

The wind tunnel testing was carried out in the University of Auckland's Twisted Flow Wind Tunnel, with the twisting vanes removed, and the walls contoured into a contraction to form an open jet of size 3.5 x 3.5 m^2. In addition, a moving belt 1.6m wide and 3m long driven by an electric motor was used to provide the correct boundary condition at the ground by being driven at the same speed as the onset air flow. A half-scale model made of carbon fibre was used for the testing. It was attached to the under-floor wind tunnel balance. The car wheels were not attached to the car model, but were positioned accurately and spun by the belt action. A photograph of the model mounted above the belt is given in Fig. (2). The flow quality above the belt was examined by performing many velocity profiles. There is not space in this abstract to include those profiles.

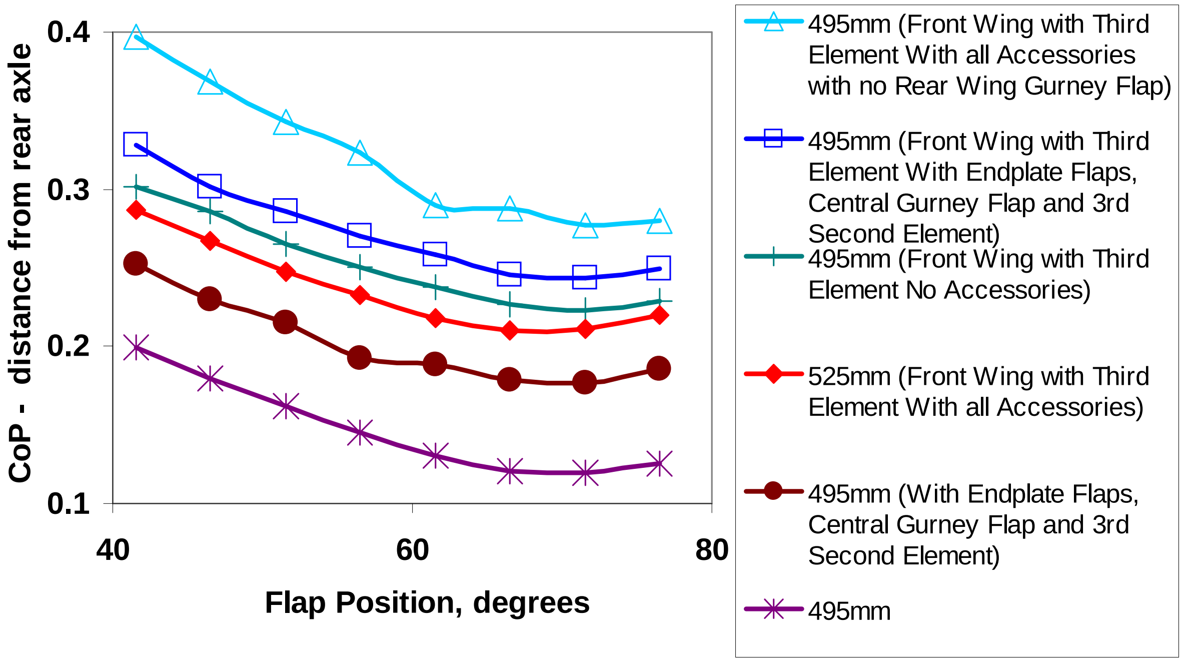

Figure 3: Rear wing height Effect on centre of pressure

A large amount of wind tunnel testing was carried out including: independent front and rear wing testing, evaluation of Reynolds number effects on the half-scale model, on-model front and rear wing testing at various angles with a Gurney flap of various sizes, pitch and yaw tests, and estimation of the centre of pressure. As an example, the effect of the rear wing height and front wing accessories on the location of the centre of pressure are presented herewith in Fig. (3). The aerodynamic appendages enable the centre of pressure to be moved substantially, and give the designer considerable freedom to optimise the design.

4 ON-TRACK EVALUATION OF THE AERODYNAMIC FEATURES

Data were recorded from the 2006 University of Auckland Formula SAE race car utilising a MOTEC ADL2 advanced data logger. The data received by the ADL2 which is most useful for the analysis of the performance of the aerodynamic appendages are those of the movement of the shock absorbers, longitudinal and lateral accelerations recorded by the vehicle, as well as engine parameters such as throttle position, RPM and coolant temperature. Two of the three available axes from the accelerometer were utilised to determine the braking, acceleration and cornering performance of the vehicle. Data were collected from the four acceleration runs undertaken at the 2006 Formula Student Germany competition. As the track was particularly bumpy in places only data recorded from a smooth section in the middle of the run was utilised to establish the relationship between the position of the shock absorber and the speed with which the vehicle was travelling. Full details of the effect of adding the aerodynamic features, and a comparison with the CFD and wind tunnel test predictions will be given in the full paper.

5 CONCLUSIONS

From the CFD analysis of the vehicle it was established that a lift coefficient of -0.87 could be obtained from an under-tray design consisting of three rear diffuser tunnels, and one either side in front of the rear wheels. Exiting the exhaust flow into to each of the outside rear diffuser tunnels through a 20mm diameter pipe produced a 34.5% increase in the amount of downforce produced by the model.

The wind tunnel testing of a half-scale model determined that a lift coefficient of -2.36 was able to be obtained with the inclusion of a front and rear wing to the under-tray and body designed using the CFD programs. It was found that the centre of aerodynamic load for three-element front and rear wing configurations was able to be adjusted so that a weight split ranging from 43% on the front wheels and 57% on the rear to 33% on the front and 67% on the rear, could be obtained with a rear wing height of 495mm above the belt.

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