Brunel university formula student car

Project Introduction

The aim of the project is to utilise and optimise the flow over the front of the 2010 Brunel University Formula Student Car, the BMMIV; for competitions in England and Italy. The application is to obtain sufficient negative lift to increase the overall car performance without significantly increasing drag. To accomplish this aim a front wing will be designed for the BMMIV.

Aerofoil Background

The principal of airfoils are based upon Bernoulli's equation which relates static pressure against velocity. Airfoils generating downforce require high-pressure air above and low pressure air below them; such that the high pressure air above 'pushes' down whilst the low pressure air 'sucks' the wing down.

Consequently both sides of the wing will generate downforce. This favourable pressure difference is caused by increasing the flow velocity beneath and reducing the velocity above the wing; this effect is obtained by increasing the tip-to-tail length under the wing whilst decreasing the length above the wing. Therefore the air has further to travel under the wing, which induces an increase in the speed at which it travels and therefore reduces static pressure. The shape of this pressure distribution is shown in a contour plot of static pressure in Figure 2 of the appendix; where it can be observed that the magnitude of the 'suction' low pressure is much larger than the magnitude of the 'pushing' pressure; demonstrating that downforce inducing wings are generally pulled down by the air, rather than pushed upwards. Additionally, in the same figure it can be observed that the leading area of the wing generates more downforce than the trailing area. (McBeath 2008. pp. 81-84. Katz 2006, pp. 109-112)

An unavoidable consequence of generating downforce is drag. Drag can be defined as the force that resists the movement of any solid object through a fluid. It can exist in many forms; one of which is lift-induced drag. The effect is caused by the resultant force generated by the air flowing across an aerofoil not being at a perfect 90° to the road. Instead, it trails the wing by around 20° dependant on the wings' angle of attack. This force can be broken down into its X and Y components, the Y component being downforce and the X component being drag.

An additional significant type of drag is flow separation where the streams of air flowing across the wing's lower surface can become detached. This results is a turbulent wake to form downstream of the wing, causing a substantial increase in drag. Unlike lift-induced drag, flow separation can be reduced or avoided completely depending on the wing's design. Furthermore, other drag forces - for example vortices and skin friction - can be reduced by optimising the esign of the aerofoil.

The downforce generate by a race cars' wings can have a substantial effect on the cars' overall performance. Downforce has the effect of increasing the cars' mass relative to its speed; this increase in mass results in an increase in grip from the tyres as friction is dependant on mass. When cornering at high speed downforce is of accumulative benefit as the speed results in more downforce and thus more grip; this extra grip means the driver can corner at even higher speeds; the higher speeds result in even more downforce and more grip; thus the driver can corner even faster and so the cumulative effect continues. Inevitably there comes a point where the increased grip induced by the downforce is unable to overcome the increase in the car's lateral g-forces.

The drag generated by the car's wings is also of importance as it has the effect of absorbing power from the engine; this absorbed power being relative to the force required to drive the wing through the air. The reduction in useable power from the engine results in a decrease in the cars' straight line speed. (Kieffer, W. Moujaes, S. and Armbya, N. 2005)

In the British and European formula student events the cars compete on tight, twisty, low-speed circuits; meaning the average velocity of air slowing across the wings is very low - in the region of 40 mph. This low velocity results in the wings having a negligible effect on the car performance as they will not beable to induce enough pressure difference to generate downforce.

Background Research

Output Variables For Aerofoil

Drag coefficient CD, is a dimensionless quantity that relates to how much force is required to move that object through a fluid. Lift coefficient CL, is very similar in that it is a dimensionless quantity that is related to how much lift force an aerofoil generates. The relationship between the coefficients and their relative forces are given by the drag and lift equations:

Determining the Lift/Drag ratio (L/D) is a swift and universal way of gauging the efficiency of an airfoil's design. However, it does not give a completely accurate measurement of efficiency as downstream turbulence, weight manufacturing cost and regulatory restrictions are not taken into account. (McBeath 2008, pp. 34. Katz 2006, pp. 49-51)

Motorsport Wings, Identification Of Variables

In the interest of consistency all experimental data in the following sections was sourced from Advantage CFD, who were bought by the BAR Honda formula 1 team on the 31st March 2007, the data can now be found within, McBeath 2008.

By obtaining data from a consistant source, it can be assumedthe CFD set up and testing was identical for the analysis of each variable, therefore making the data more serviceable. All experiments were carried out using a NACA 632-615 profile in the same two-dimensional virtual wind tunnel with an air flow rate of 50m/s (112mph), all initial and boundary conditions were kept constant. (McBeath 2008, pp. 85. www. symscape. com/node/246 10/11/2008)

Angle Of Attack

The angle of attack, AOA, is the angle between the chord line (tip-to-tail) of the wing and the horizontal, generally it is considered to be the simplest and most important variable effecting aerofoil design. Increasing the angle of attack will, to a point, increase downforce. In this test case, setting the angle of attack to 12° will generate 954 Newton's of downforce per metre span of wing (N/m), relative to just 321 N/m at 0°; clearly a substantial increase. However, increasing the angle to 16° reduces downforce to 871 N/m. This is due to major flow separation andthe wing stalling, resulting in less downforce and substantially more drag. This can be observed in figure 2. (McBeath

2008, pp. 85-88. Katz 2006, pp. 111-113. www. flightsimbooks. com/ flightsimhandbook/42-2. jpg 13/12/08)

Camber

Interestingly, downforce can be generated by a wing at an angle of attack of 0° or even as low as -5°, this is because most wings are not symmetrical in profile but cambered. Camber is the radius of the curve of an aerofoil and is usually defined as a percentage of the airfoils chord length.

The test results show that at an angle of attack of 8° with 4% camber the wing in question generates 810 N/m of downforce, but with 6% camber 924 N/m of downforce is generated, and at 12% camber 1021 N/m is generated. Flow remained fully attached at 6% suggesting very little drag, however, at 12% major flow separation had occurred and at 16% the wing stalled; subsequently significant increases in downforce can be generated at high cambers, a large increase in drag is also resulant.

(McBeath 2008, pp. 88-92, Katz 2006, pp. 112-116)

Wing Thickness

Both the location and magnitude of the wing thickness are usually quoted as either percentages or fractions of the chord lengths, eg 12% chord or 0. 12c. Increasing the maximum thickness increases downforce; however, there comes a point at which maximum downforce is achieved is dependant on angle of attack. Perhaps more usefully, for angles of 4° to 12° the L/D of the wings is at a maximum when thickness is 16% (figure 4). When the angle of attack is 16° maximum efficiency is with a thickness of 20%, therefore if the wings angle of attack is adjustable it would most likely prudent to manufacture the wing element to 18% maximum thickness allowing it to be used at a wide range of angles.

(McBeath 2008, pp. 92-94)

Leading Edge Radius

Traditional aerofoil profiles feature a somewhat flat front with the stagnation point towards the upper wing surface due to the angle of attack. This can result in flow rapidly changing direction around the stagnation point causing high pressure in front of the wing thus increasing drag. It would be desirable to change this to a peaked leading edge design with the stagnation point being closer to the leading edge. This means a sharper leading edge can be used and the wings L/D ratio will increase. However, the leading edge radius is restricted by formula student regulations to

12. 7mm thus prohibiting the sharp leading edge design. (McBeath 2008, pp. 94. Katz 2006, pp. 123-125)

Gurneys

A gurney is a small sharp flap attached to the trailing edge of a wing at90° to the flow across the upper surface. It acts to reduce the boundary layerthickness at the trailing edge of the suction side of the wing. For wingsrunning at high lift coefficients this reduces trailing edge separation andincreases downforce. Gurneys can also work when applied to side plates, wherethey act to effectively add camber to the side plate reducing pressure on thesuction side of the main wing. (Katz 2006, pp. 143-144. Gerontakos and Leeundated, pp. 110) (insideracingtechnology. com/tech304gurney. htm accessed 14/12/08)

Ground Effect

Ground effect is where the air flowing under the wing is trapped between the wing and the ground causing it to accelerate and thus reducing pressure under the wing, inducing a greater pressure difference. The magnitude of this effect can be substantial: the lift coefficient of a wing running at a ride height of 50mm could be as much as 50-60% greater than that of a wing running at 150mm without a significant increase in drag. The formula student rules limit ride high to no less than 25. 4mm meaning that ground effect can be exploited. Therefore the front wing will run at minimum ride height to maximise efficiency. (McBeath 2008, pp. 111-114. Formula SAE Rules 2008, pp. 54. Ahmed and Sharma, 2004]

Further improvements in efficiency and increased maximum downforces can be achieved by using larger multi-element wings, such as 3 or 4 elements. However, the manufacturing cost for these wings rule them out as a viable design.

(McBeath 2008, pp. 96-104. Katz 2006, pp. 137-141)

End Plates

End plates act to reduce pressure drop off at the ends of wings, and reduce drag. This is where high pressure air on the upper surface of a wing can roll off the edge into the lower pressure area underneath. This causes an equalisation of the pressure difference at the edges of the wing, reducing downforce. As well as inducing a large vortex to form off the edges of the wing where the flow spirals from the upper to the lower surface, increasing drag; both of these problems can be reduced by using end plates to keep the airflow separated. They are also very simple to manufacture and can act as structural supports holding the various wing elements together. On the front wing, foot plates can be used, which act almost exactly like end plates in that they reduce the pressure drop off at the edges of the wing. The end plates however, cannot be lower than 25. 4mm from the ground; as stated in the formula student rules. Foot plates however, are parallel with the ground and so can work around this ruling to effectively extend the end plates. The impact of different sized end plates and how they influence the wings downforce and drag can be seen below in figure 7.

End Plate Size	Downforce, N	Drag, N
None	769. 2	194. 8
Small	786. 7	188. 3
Medium	873. 4	183. 8
Large	900. 1	178. 1

(McBeath 2008, pp. 104-110. Formula SAE Rules 2008, pp. 54. Fig. 7 McBeath 2008, pp. 105)

Wing Mountings

The suction side of the wing is more sensitive to flow separation due to its low pressure, therefore, wing mountings are better placed on the high pressure side. The mounts themselves should also be as streamlined as possible to minimise drag, while also being structurally sound to support the wing and as cheap as possible to manufacture. (McBeath 2008, pp. 120. Katz 2006, pp. 154)

Size, Aspect Ratio

The size and aspect ratio of the wing are important, with a bigger wing generating more downforce than a smaller wing. However, with skin friction being fairly insignificant there is no reason to use a wing that is smaller than permitted. The size of the wing is limited by the formula student rules, the leading edge can be no further forward than 450mm from the front of the front tires, and the wing can not be wider than 1300mm. (McBeath 2008, pp. 121-122. Formula SAE Rules 2008, pp. 54)

Vortex Generators

Vortex generators should be a little taller than the local boundary layer and should be placed near the expected point of flow separation. They work by adding momentum into the boundary layer which can help delay flow separation. However, in order to do this they have to be small and have very sharp edges. The formula student rules state that every edge must have a radius of at least 3mm, thus, vortex generators are not a viable aerodynamic aid. (Katz 2006, pp. 141-142. Formula SAE Rules 2008, pp. 54)

CFD

Computational Fluid Dynamics (CFD) provides unrivalled clarity in visualising how aerodynamic forces occur and how design modifications effect airflow around an object. This is achieved through mathematically simulating the fluid flow and displaying the results using both visual/graphical and quantitive methods through the use of algorithms and numerical methods of fluid mechanics to