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THE INFLUENCE OF AERODYNAMICS FORCES ON THE STEERING CHARACTERISTICS OF THE CAR CASE STUDY AGH RACING RACE CAR

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ABSTRACT

At high speed, which is developed during the races, the ability to control the movement of the vehicle determines the winner. In order to obtain improvement, by use of the series of activities aimed at interference with the air flow, there was a tendency to provide increased downforce. As for the verification of the drivability and to simulate the behavior of the car on the track, during design phase the analysis was carried out by use of characteristics such as cornering stiffness, steer angle, understeer gradient, yaw and characteristic velocity.

KEYWORDS: Aerodynamics, Steering, Understeer, Oversteer, Neutralsteer

INTRODUCTION

Figure 1

The first race cars were primarily designed to achieve high maximum speeds, where the main objective was to minimize the drag force. However, the development of high-speed is associated with the lift force development, which negatively affects the stability of the vehicle. In order to improve the adhesion without a need to increase the weight, naturally the friction force was perceived as a solution. The thin airfoil theory developed in the aviation sector was successfully and under appropriate assumptions (proximity to the ground) used in the automotive industry. Aerodynamic profile of the car is based on the principle of an inverted aircraft wing. The issue mainly focuses on downforce, which might be generated by appropriately designed components. Therefore we can distinguish three models: Newtonian, Venturi and Bernoulli which bring the light to this phenomenon. In the Bernoulli equation, assuming turbulent free flow, stream of air is dissected on upper and lower side where is combined again at the end of the wing. Because the bottom profile is longer than the upper, which per unit of time is the long way, thus force higher speed under the wing, the increasing speed is connected with formation of low dynamics pressure area. Pressure difference between upper and lower profile is direct cause of downforce appearance. In the real environment, laminar flow is a state of utopia, however, some treatments such as breaking the wings on a larger number of elements (allowing to create the slot that provides energy to boundary layer on the surface of the wing) and the formation of the bending of a profile- which effect on increase of the downforce. The second one, Newtonian model is based on the transfer of momentum. The air stream in this case is reflected from the side and directed upward. In accordance with the principle of momentum and as a result of this action the wing achieve momentum which face downwards and backwards (drag force). The induced drag is then generated by the wings, thereby hinder the acceleration. Venturi effect uses the right of continuity of the stream and is used in the upstream portion of the aerodynamic chassis system which is a diffuser. Interference in the air flow results in increase of the pressure on the corresponding axle. This situation is especially evident during cornering. In the case where the rear axis carry more load, the front axle is not able to follow the path expected by a driver, thereby extending the radius-we deal with the effect of understeer. The opposite concept is oversteer where more susceptible to the occurrence of slip is a rear axle with much intense slip conditions. Increased pressure obtained through the interference with the flow of air results in more efficient acceleration, but a bad balance can lead to oversteer. The downforce discussed in the article in case of AGH car racing is obtained by the front, rear wing and the diffuser.

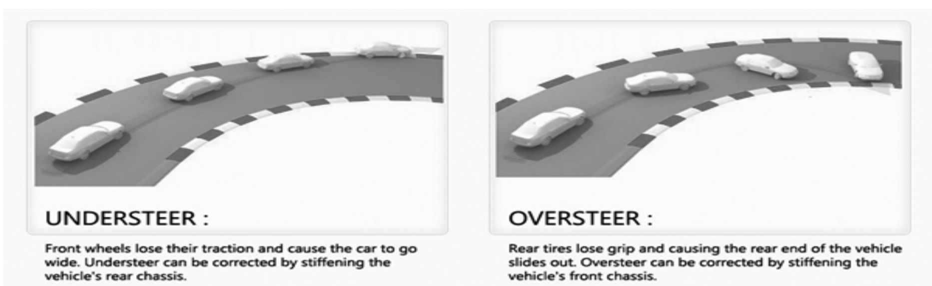

Figure 2

AGH RACING AERODYNAMIC PACKAGE

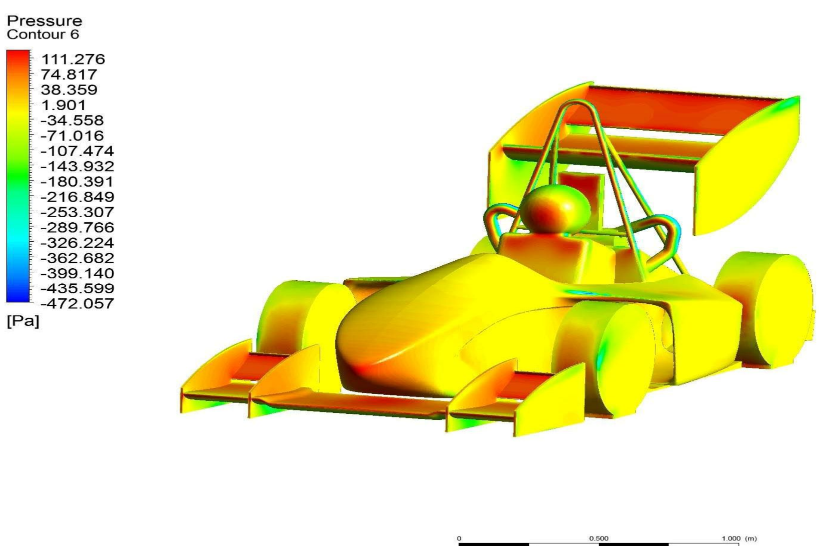

Figure 3

Bearing in mind that elements that gather most of the air flow and thus have a major impact on creation of downforce are connected with aerodynamic package which can be modified according to FSAE Rules- numerous operations were performed in order to optimize this area. For the purpose of maximize downforce and minimize drag force on the front, rear wings and airfoils, the characteristics such as shape or angle of attack were parameterized and the results of simulation were obtained by use of Ansys environment.

The graph below shows results of air flow simulation through the rear wing of our car in different configurations. First parameter P1 [degrees] stands for angle of attack of lower airfoil, P2 [degrees] for upper one. P3 [millimeters] shows height difference between lower and upper airfoil and P4 [millimeters] represents horizontal distance between them. P5 [N] and P6 [N] are desired results of each of our simulations and respectively indicates drag coefficient and generated downforce of our configuration. Highlighted line represents configuration chosen for our vehicle.

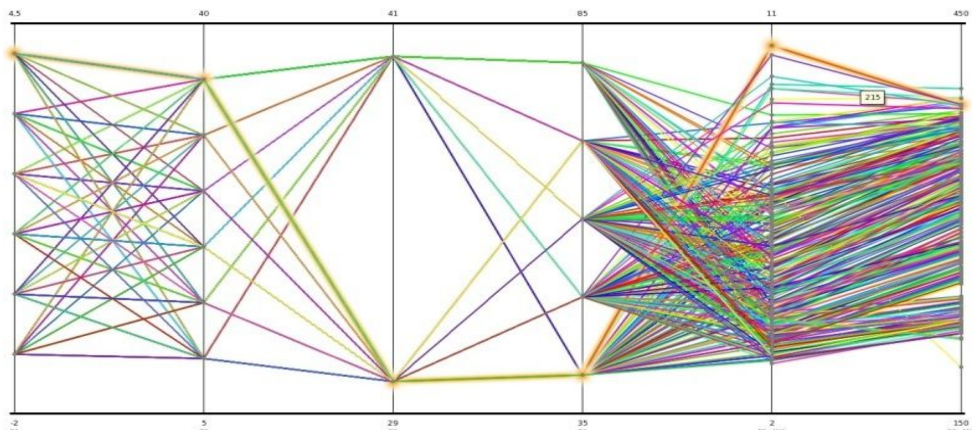

Figure 4

INFLUENCE OF AERODYNAMIC PACKAGE ON STEERING CHARACTERISTIC

To obtain center of gravity of our vehicle, virtual prototyping techniques were used to give shape, weight and desired material to our car. As the result of this operation, weight distribution was obtained. 48% of vehicles mass is concentrated in the front and 52% in the rear, values are measured assuming that car with driver weights 260[kg]. Neglecting aerodynamic package, the values of load on the front and the rear axles, are equal respectively 1248[N] and 1352[N].

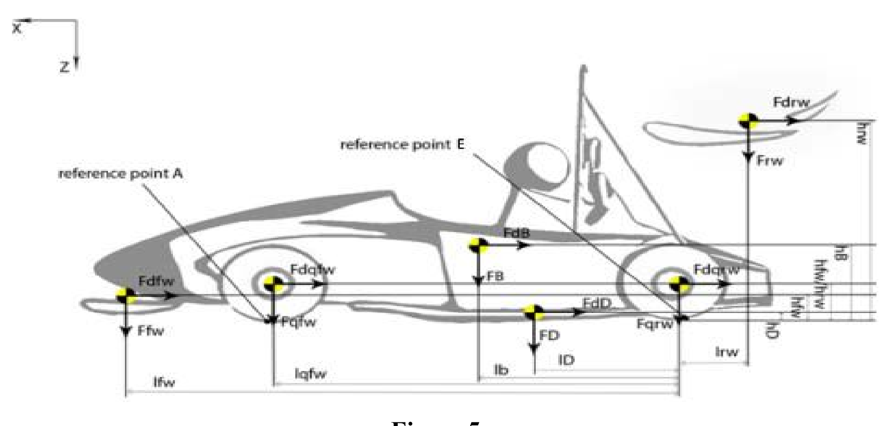

Figure 5

Table 1

Reference Point E	l_1 [m]	h_1 [m]	F [N]	Fd [N]
front wing /fw/	2,334696	0,125825	116,22	10,62
rearwing /rw/	-0,075749	1,115825	121,36	37,1
Diffuser /D/	0,741316	0,015825	30,22	2,66
Bodywork /B/	1,120436	0,395825	-59,62	53,42
front wheel /qf/	1,557406	0,144525	-11,9	8,94
rearwheel /qr/	-0,104544	0,144525	-12,34	14,66
refference point A	l_2[m]	h_2 [m]	F [N]	Fd [N]
front wing /fw/	0,731956	0,125825	116,22	10,62
rearwing /rw/	1,678489	1,115825	121,36	37,1
Diffuser /D/	0,861424	0,015825	30,22	2,66
Bodywork /B/	0,482304	0,395825	-59,62	53,42
front wheel /qf/	0,045334	0,144525	-11,9	8,94
rearwheel /qr/	1,60274	0,144525	-12,34	14,66

Table 1 shows values of downforce (F) and drag forces (F_d) being generated by each of element of aerodynamics package, where columns “l” and “h” stands for the distances between their centers of pressure in respect of two chosen points (A & E). They are located in contact points between the ground and the front and rear wheel. Such deployment enables calculation of load generated by aerodynamic package on the front and rear axis. Streamlined shape of the bodywork, generates negative downforce value (lift force), which property have negative influence on the handling of the whole vehicle. Downforce for vehicle with bodywork but without aerodynamic package, for front axis and by use of reference point E, is calculated using formula below (L-wheelbase, 1, 6[m]):

$$\frac{F_B \times l_{1B} - F_{dB} \times h_{1B} + F_{qf} \times l_{1qf} - F_{dqf} \times h_{1qf} + F_{qr} \times l_{1qr} - F_{dqr} \times h_{1qr}}{L} = F_f = -67{,}76N$$

For rear axis, by use of reference point A:

$$\frac{F_B \times l_{2B} + F_{dB} \times h_{2B} + F_{qf} \times l_{2qf} + F_{dqf} \times h_{2qf} + F_{qr} \times l_{2qr} + F_{dqr} \times h_{2qr}}{L} = F_r = -15{,}3\ N$$

F_f [N] -67,75847253	F_r [N] -15,29661029
W_{f+body} [N]	W_{r+body}[N]
1180,241527	1336,70339
[%]0,468	[%]0,531

There is decrease in load value on the front and rear axles, respectively with values of 67, 8[N] (1180[N]) and 15, 3[N] (1336[N]). It can be observed that weight distribution have moved to the front for about 1% (load distribution 47%/53%). What is more in given situation there are some justified efforts to create aerodynamic package with as great downforce as possible. Calculations are made by counting moments derived from downforce and drag force in respect to points A and E, and afterwards dividing it by value of wheelbase of vehicle in order to obtain the load on front and rear axis. In calculations, d’Alambert force is omitted, because it is assumed that while cornering driver is trying to keep constant velocity, hence the acceleration on that period of time is equal to zero, d’Alambert force is also equal to zero. Both of obtained loads on the front (83[N]) and rear (102[N]) axis generates positive downforce, and fulfill their role by increase of downforce to 1331,091 [N] on the front and 1453,654 [N] on the rear axis in comparison to the vehicle with bodywork installed only. Weight distribution is slightly moved into the front axis (W_f related to W_r)

$$\frac{F_{fw} \times l_{1fw} - F_{dfw} \times h_{1fw} + F_{rw} \times l_{1rw} - F_{drw} \times h_{1rw} + F_D \times l_{1d} - F_{dD} \times h_{1D} + F_B \times l_{1B} - F_{dB} \times h_{1B} + F_{sf} \times l_{1sf} - F_{dsf} \times h_{1sf} + F_{sr} \times l_{1sr} - F_{dsr} \times h_{1sr}}{L}$$

$$= F_f = 83{,}091\, N$$

$$\frac{-F_{fw} \times l_{2fw} + F_{dfw} \times h_{2fw} + F_{rw} \times l_{2rw} + F_{drw} \times h_{2rw} + F_D \times l_{2d} + F_{dD} \times h_{2D} + F_B \times l_{2B} + F_{dB} \times h_{2B} + F_{sf} \times l_{2sf} + F_{dsf} \times h_{2sf} + F_{sr} \times l_{2sr} + F_{dsr} \times h_{2sr}}{L}$$

$$= F_r = 101{,}65\, N$$

F_f [N] 83,091058	F_r [N] 101,653859
W_{f+aero} [N]	W_{r+aero} [N]
1331,091	1453,654
[%]0,478	[%]0,522

Next step to define the steering characteristic of the vehicle is to find the cornering stiffness (C_α [N/deg]). By this name we define the ratio of wheel lateral force (Fy [N]) to the slip angle (α [deg]). Wheel lateral force is perpendicular to vertical axis of the wheel while the camber angle is equal to zero, and its absolute value increases with increasing value of slip angle. Slip angle is a difference between direction of travel and direction of heading. Values for lateral force and slip angle may vary for the front and rear axis. By use of formula below, under assumption that slip angle does not exceed value of 5 degrees, with data from Tire Test Consortium on chosen tire cornering stiffness values have been calculated for both front and rear axis for vehicle with (+AERO) and without aerodynamic (+BODY) package.

$$C_\alpha = \frac{F_y}{\alpha} \text{ [N/deg]}$$

+AERO	Front	Rear	Slip angle	Front	Rear	Wheel Lateral	Front	Rear
$C\alpha_f$[N/deg]	240	-	(α)	5	-	Force	1200	-
$C\alpha_r$ [N/deg]	-	250	[degrees]	-	5	(F_y)[N]	-	1250

+BODY	Front	Rear	Slip Angle			Front	Rear	Wheel Lateral	Front	Rear
$C\alpha_f$[N/deg]	200		(α)			5	-	force	1000	-
$C\alpha_r$ [N/deg]		240	[degrees]			-	5	(F_y) [N]	-	1200

Cornering stiffness is about 20% larger on the front axis and 4% on the rear axis in the car with aerodynamic package (+AERO).

Having calculated values of loads on the front and rear vehicle axis (including aerodynamic package and not taking it into account), as well as cornering stiffness, it is possible to obtain steer angle (δ [deg]) which in case of AGH Racing vehicle is examined on the front axis it is an angle in which front wheels should be swerved in such way that vehicle which moves with speed V is able to overcome corner with radius R. By use of the formula below, using average speed and radius of turn during FSAE competitions (respectively 15[m/s] and 8[m]), steer angle is calculated as follows:

$$\delta = 57{,}3\frac{L}{R} + \left(\frac{Wf}{C_{\propto F}} - \frac{Wr}{C_{\propto R}}\right)\frac{V^2}{gR}\text{ [deg]}$$

L- wheelbase, W_f load on front axis, W_r – load on rear axis, $C_{\alpha f}$ – cornering stiffness front, $C_{\alpha r}$ – cornering stiffness rear, R – radius of turn, V – forward speed

δ +aero[deg]	10,7093369
δ +body[deg]	12,43131263

As it can be seen, calculated values of steer angle for a vehicle with and without aerodynamic package show that there is 2 degrees improvement in overcoming the same corner. Understeer gradient (K [deg/g]) describes how the steer angle changes with vehicles lateral acceleration and radius of turn. It is the main factor to determine steering characteristics of the vehicle (assuming movement on a constant radius turn).

If value of K is equal to zero (K=0) vehicle is considered as natural steer – it means that no change in steer angle is needed as the speed is varying. From the physical point of view, neutral steering case corresponds to the balance of the vehicle in such way that the "force" generated by lateral acceleration causes the same slip angle at both front and rear wheels. For K values greater than zero (K>0) understeer is considered – steer angle increase with the speed in proportion to K times lateral acceleration. It increases linearly with lateral acceleration and with the square of the speed. In understeer case front wheels tends to slip sideways to a greater extent than at the rear wheels.

For K less than zero (K<0) vehicle is over steer, steer angle decrease along with increase of speed. It causes slip angle of rear wheels to increase more than at the front wheels. The outward drift at the rear of the vehicle turns the front wheels inward. $\frac{\delta - 57{,}3\frac{L}{R}}{a_y} = K$ [Degrees/g]

L-wheelbase

R-radius of turn

a_y- lateral acceleration, 6, 56[g]

K +aero [deg/g]	6,70932526
K –body [deg/g]	8,431300987

Obtained values of understeer gradient shows that vehicle in both cases is considered to be understeer. With gain of acceleration, steer angle of vehicle with aerodynamics package requires about almost 2 degrees/g smaller correction, which means that in case of presence of aerodynamic package there is 7% improvement in controlling the cornering ability. Another important indicator is Yaw velocity. It describes vehicle motion around its yaw axis. In other words it simply includes information how the direction of heading is changing in respect to the steer angle. It is the basic visual measure for driver to predict vehicles behavior while cornering.

$$Y = 57{,}3\frac{V}{R}$$

Yaw velocity (Y) +aero [deg/s]	10,032134
Yaw velocity (Y)+body [deg/s]	8,6424904

In case of AGH Racing race car, 18% improvement can be noticed.

Characteristic velocity describes the speed at which understeer vehicle with no lateral acceleration have half less steering control than in case of neutral steer vehicle. It is expressed by formula below, and mainly depends on Understeer gradient (K).

$$V_{char} = \sqrt{57{,}3L\frac{g}{K}}\ \text{[m/s]}$$

L-wheelbase

g-gravity constant

K-understeer gradient

Vchar +aero [m/s]	11,58197074
Vchar+body [m/s]	10,33176668

In case of a car with the aerodynamic package improvement can be noticed-decrease in steering control is obtained while driving 1, 2[m/s] faster.

CONCLUSIONS

In this paper, the analyses of steering characteristics were performed in order to obtain the evaluation of applied aerodynamic solutions. From these studies the information was obtained that the car is characterized by understeer, and the vast majority of properties has improved, thereby the ability to control the vehicle has improved.

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