Using ANSYS CFX in Formula Student Racing

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SYNOPSIS

This paper deals with the aerodynamic simulation of race cars for the Formula Student series of the TU Graz Racing Team. Included are simulation results of the car of 2008 (TANKIA 2008) and 2009 (TANKIA 2009) made by Ansys CFX, as well as some comparisons with experiments made on the car of 2008. The underbody concept, introduced in 2008, was investigated by its own. The other presented simulations were performed on the full vehicle.
1. INTRODUCTION

The Formula Student is a global design competition for students, in which over 400 universities teams from all over the world design, calculate, simulate and finally build a formula race car. The competition consists of seven single events, in which students can get 1000 points at most. Three of them are static, where the students have to defend their car from a technological and an economical point of view, the other four ones are dynamic, where the team has to show, how good their car performs on the race track.

The average speed in the Formula Student is about 50 km/h and top speeds are about 120 km/h. Thus aerodynamic is not of first order priority. Anyway, especially since the top teams are quite close together, aerodynamic may cause the little advantage to finally become the winner over all.

Since the installed engine power of about 75 kW is sufficient enough, the drag of aerodynamic elements can gain a certain limit. This is shown in a simplified way by figure 2, calculated by (1), skipping the rolling resistance, as well as power needed for acceleration. Since there are always flat courses, no climbing resistance has to be considered.

\[ P_D = \frac{1}{2} \cdot \rho \cdot A \cdot C_D \cdot v^3 \]  

\[ (m_{car} + m_{driver}) \cdot \frac{v^2}{R} = (m_{car} + m_{driver}) \cdot g \cdot \mu + \frac{1}{2} \cdot \rho \cdot A \cdot C_L \cdot v^2 \cdot \mu \]  

Figure 2: Drag power vs. Speed

The actual limitation of aerodynamic elements is given by the weight of the elements being applied. As can be seen in figure 3, you can gain the same or a higher curve speed with a car, having a lower lift coefficient but having a lower weight as well. This was calculated by (2).
2. TANKIA 2008

2.1 The Underbody Concept

In 2008, the underbody concept was introduced. Therefore about 20 different diffuser geometries were investigated. Those geometries were firstly modelled on their own with a simplified model. Finally the best one was adjusted to the full vehicle. This profile can be seen in figure 4 and 5. In order to increase downforce, Gurney flaps are added at the backside.
By choosing the underbody construction as aerodynamic package, the principles of operation of the 'Ground Effect' have to be displayed. By creating a reversed wing profile, air velocities which are twice as high as $U_\infty$ are possible.

![Figure 5: Simplified Modell](image)

With these simplified, but very effective simulations we obtained a lift force of about 150 N at an air speed of 14 m/s. Further on the whole chassis with the attached underbody was simulated.

### 2.2 Model 2008

Caused by reasons of calculation resources, the model is made up as a symmetric half vehicle model. Nevertheless this represents a quite good assumption, since the car is almost symmetric.

The side bags are closed, but in the simulation it is assumed, that there is a negative mass flow at the side bag inlet and a positive one at the outlets. Since the air can get out of the side bag at two positions, the outlet mass flow splits up.

The wheel rotation is simply modelled by applying a wall with a rotational speed, related to the applied vehicle speed.

The CFD model as well as the actual TANKIA 2008 can be seen in figure 6.
2.3 Boundary Conditions

The investigated speeds are 14 m/s and 30 m/s, since those represent eminent speeds and pretty little high speed curves occur in the courses of the Formula Student. The bottom surface, representing the ground, is modelled as a wall with the same wall speed as the air speed. The other boundaries are the velocity inlet, symmetry plane and openings.

As mentioned above, the tyres got an applied rotational speed, calculated by the applied air velocity and the tyre diameter.

At the side bag inlets a negative mass flow of 0.25 kg/s is applied (outlet), what was investigated at a test bench for the engine coolers. The same mass flow is applied as a positive one (inlet) at the outlets of the side bags, 65% of it gets out at the backside, and 35% at the side bag gills.
2.4 Simulation results

In figure 7 you can see the results obtained with the used model. Especially at the bottom you can see the low pressure area, causing the downforce. At the backside of the car big vortices occur.

![Figure 7: Pressure distribution TANKIA 2008](image-url)

![Figure 7: Velocity distribution TANKIA 2008](image-url)
2.5 Test results

In order to proof the increased curve speed with the underbody a test was made with the actual car. Therefore the driver drove with increasing speed at a constant radius of 20 m with the inner front wheel, as can be seen in figure 8.

Figure 8: Track while the test

In figure 9 you can see, that the obtainable G-force with the underbody construction increased significantly. Thus higher curve speeds are possible.

Figure 9: Speed vs. G-force
3. TANKIA 2009

3.1 Model

The Model of the TANKIA 2009 is more sophisticated than the one of its precursor, but it is still a symmetric half vehicle model. The side bags are modelled as in reality, in order to get a realistic flow through and around them. Thus it can be investigated, besides other things, how efficient the side bag gills are.

As mentioned above, in the season 2008 there was a test bench for the engine coolers in order to get the right position of the coolers, the size of the inlets and the angle of the inlet plates for the cooler inflow. In order to skip this test bench in 2009 we compared the results of the simulation with the gained results of the test bench in 2008. The same coolers are used and the adjustment is mainly the same. Thus those results can be compared doubtless. Within the new car, we measured finally the temperature of the cooling fluid, which was basically the same as in 2008. In figure 10 the used CFD-modell and the actual car can be seen.

![Figure 10: CFD-modell and actual TANKIA 2009](image)

3.2 Boundary Conditions

The TANKIA 2009 was investigated at speeds of 14 m/s and 30 m/s, what represents the average speed and top speed for fast curves respectively. The ground was again modelled as a moving ground and the wheels, represented by walls, got applied an angular velocity according to the applied air speeds.

We set a mass flow of 0.25 kg/s through each cooler, in which the air is heated up to 70°C. The mass flow, getting out and in again is constant, in order to fulfill the continuity equation.
3.3 Simulation Results

In figure 11 you can see the low pressure area at the middle of the car, which produces the wanted downforce. Caused by changed rules for the chassis of Formula Student race cars in 2009, we had to construct an expanded and higher chassis. This causes higher vortices at the cars backside, as you can see in figure 12. The obtained downforce is not as much as in 2008, but even with the smaller area of the underbody, caused by the rule changes, it is quite good.

![Figure 11: Pressure bottom](image1)

![Figure 12: Wake region with big turbulence](image2)
In figure 13 you can see the temperature distribution caused by the introduced heat of the engine coolers. We tried to get some of the air, flowing through the cooler, out of the side bags with gills at them. Up to a certain level it was possible, but there occurred a backflow at the third one. In further constructions we will lay more stress on getting rid of it.

4. CONCLUSION

From 2008 to 2009 the rules of the Formula Student series have been changed significantly. E.g. the templates for the chassis have been enlarged a lot. As a result, the preconditions for the aerodynamic of the car got worse, while the importance of the suspension increased. Nevertheless, the diffuser is still an effective way of increasing the lift coefficient and thus the possible curve speeds with little increase of the weight, especially since it represents as well the lower wall of the side bags.

Increasing the lift coefficient and thus curve speeds is significant and justifies the little increase of weight of about 3 kg, as shown with the TANKIA 2008, which became Formula SAE world champion in May 2009.