CFD simulation of airflow through the throttle body of the air intake system applied to the Formula Student vehicle

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Abstract: *In this paper, a simulation of their flow through the throttle valve on the Formula Student vehicle was performed throttle valve is an element that, according to the regulations of the Formula Student competition, must be present in the intake installation of the vehicle's power unit if it is a competition in class IC. The correct design of the throttle is of great importance anchor or the power unit to work properly, but also to extract the maximum performance of the power unit itself, and thus of the competition vehicle as a whole. One of the main tasks of the throttle is to allow air to flow with as little resistance to flow as possible. For the CFD simulation in this work, ANSYS Fluent was used, which proved to be a very powerful tool in the CFD simulation of the throttle body.*
Keywords*: CFD, THROTTLE BODY, VEHICLE, IC ENGINES, FORMULA STUDENT*

1. Introduction

The Formula Student competition is getting more and more popular. This competition is very attractive because it provides students with a good springboard for employment in the automotive industry after graduation. The number of Formula Student teams is growing year by year. Students from universities around the world compete to design a small racing vehicle. The design of the air intake system together with the throttle body applied to Formula Student vehicles is a very current topic, as evidenced by a large number of articles on the mentioned topic [1-8]. This work is structured into six chapters. The first chapter is an introduction and this chapter outlines what is covered in each of the six chapters. The second chapter is related to the design of the throttle body and the limitations prescribed by the organizers of the Formula Student competition. The CFD analysis of the throttle body was performed in chapter three, while the results of the CFD analysis were presented in chapter four. Chapter 5 is the conclusion on the topic of the work itself, and chapter six lists the references used in the work.

2. Formula Student throttle body

2.1. Throttle body

In the Formula Student competition, the big challenge is designing the intake system for the engine. As the Formula Student competition uses engines that are installed on motorcycles, it is necessary to modify them. The main modifications relate to the adjustment of the intake and exhaust installation, the engine map, as well as the cooling system itself, and the fuel system. The possibility of changing some structural parts of the engine, such as modification of the engine pistons, and crankshaft, should also be considered. To consider the possibility of modifying the crankshaft, it is necessary to perform a dynamic analysis of the forces acting in the engine, which is preceded by a kinematic analysis. An example of kinematic analysis is given in Ref. [9] in which this analysis can be done very easily using CATIA software.

Electronic Fuel Injection (EFI) is an active system that adjusts fuel delivery for the internal combustion engine, and the carburetor is a passive system that controls the intake of the fuel and air mixture. Fuel delivery to the engine is managed by the engine control unit (ECU), which precisely controls the duration and time of fuel delivery through fuel injectors. It can be said that the throttle body is an air valve. The throttle body has the task of allowing air to enter the engine. The more air delivered in combination with the appropriate amount of fuel, the more power is obtained from the engine, theoretically. This would mean that the use of a larger diameter throttle body also means a larger amount of airflow, which is not always the best move. The diameter of the throttle body must be of the appropriate size according to the volume of the engine. If the throttle body diameter is too large, the air velocity is slow, but more air is sucked into the engine, while if the diameter is too small, the air velocity is faster, but not enough air can pass. If a forced-induction system is used, the diameter of the throttle body becomes less critical because the turbocharger or supercharger pushes air into the engine. A smaller throttle body can be used in a turbo setup because the air pressure and air density are approximately twice as high as in a naturally aspirated engine [10]. Figure 1 shows the barrel throttle body concept, which is very often used on Formula Student vehicles.

Fig. 1 *Barrel Throttle Valve [11]*

2.2. Throttle body restriction

Restrictions for the throttle body are given in the Formula Student Rulebook [12]. This regulation defines that the vehicle must be equipped with a throttle body, which can be of any size or design. The throttle must be activated by a mechanical foot pedal or rod system. Throttle position is defined as the percentage of time from fully closed 0% to open 100%. The mechanism of the throttle system must be protected from debris penetration to prevent jamming. Rulebook [12] defines two intake system configurations for naturally aspirated engines (Figure 2) and turbocharged or supercharged engines (Figure 3). Depending on which type of configuration is chosen, the position of the throttle body in the air intake system will also be defined. It is important to emphasize that in the case of using a turbocharged or supercharged configuration, a throttle body with a smaller diameter can be used compared to a configuration with naturally aspirated engines.

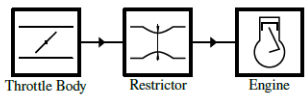

Fig 2. *Configuration for naturally aspirated engines [12]*

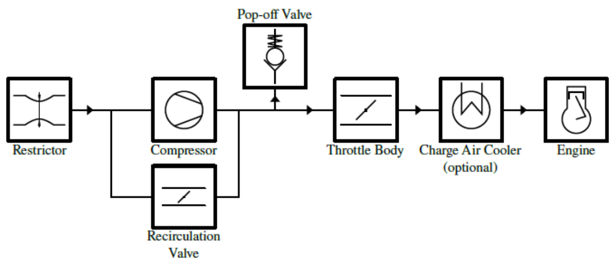

Fig 3. *Configuration for turbocharged or supercharged engines [12]*

3. CFD simulations of the throttle body

In this chapter, a CFD simulation of two throttle bodies was performed to see how the small geometrical difference between them affects the airflow. Figures 4 and 5 show two throttle bodies that were considered during the CFD simulation. Throttle body 2D geometries are shown in Figures 4 and 5. CFD simulation was performed for both throttle bodies at three characteristic positions, i.e. for positions of 50%, 75%, and 100% open throttle body. In Ansys Design Modeler

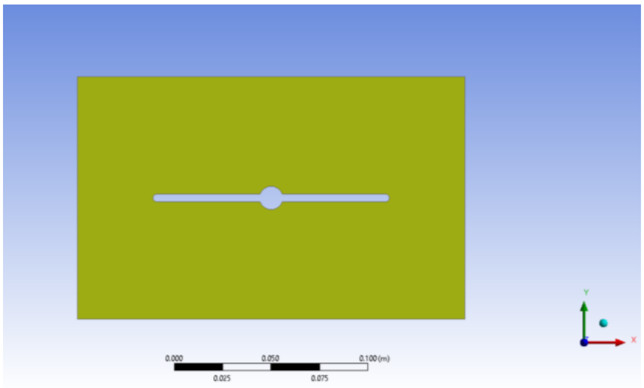

Fig 4. *Throttle body (concept) A*

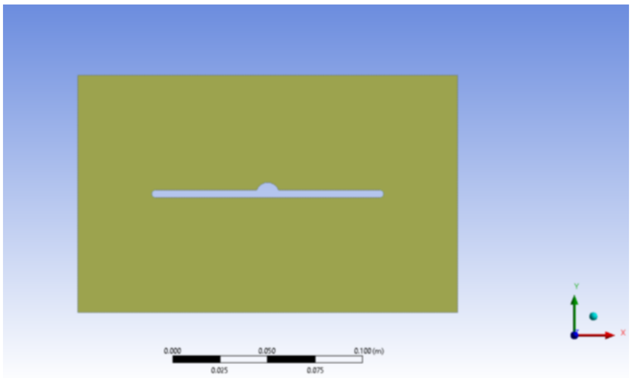

Fig. 5 *Throttle (body concept) B*

After generating the 2D geometry of the fluid domain, a mesh was generated for both types of the throttle body, which is shown in Figures 6 to 11. The first throttle body concept is labeled A and the numbers on the label indicate the position over the opening percentage, so we have A(100%), A(75%), and A(50%), where the percentages represent the position of 100%, 75%, 50% opening of the throttle body. It should be noted that 100% is a fully open throttle body and 0% is a fully closed throttle body. The same applies to concept B, so numerous values indicate the percentage of throttle body openness.

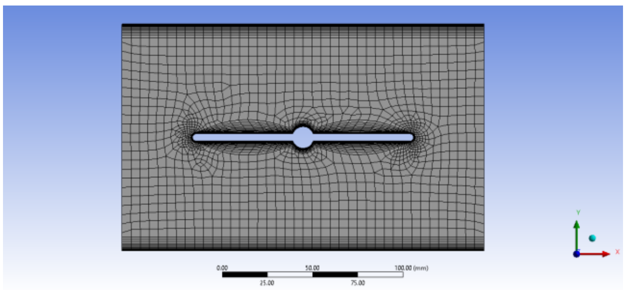

Fig. 6 *Mesh for Throttle body A(100%)*

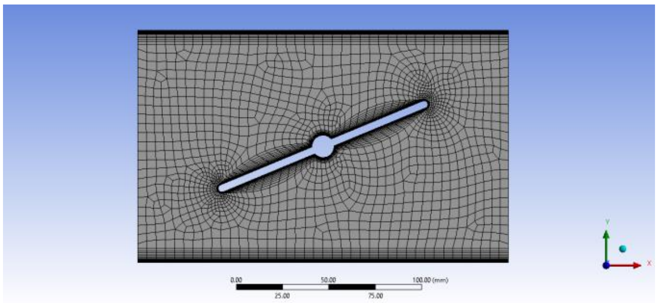

Fig. 7 *Mesh for Throttle body A(75%)*

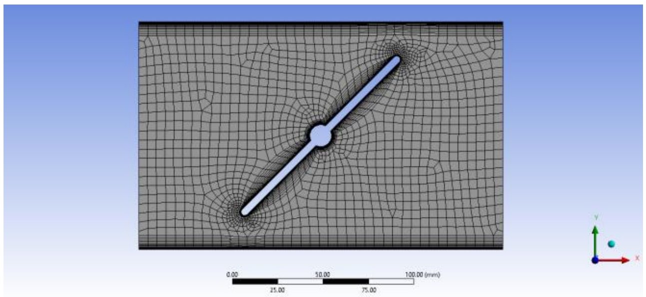

Fig. 8 *Mesh for Throttle body A(50%)*

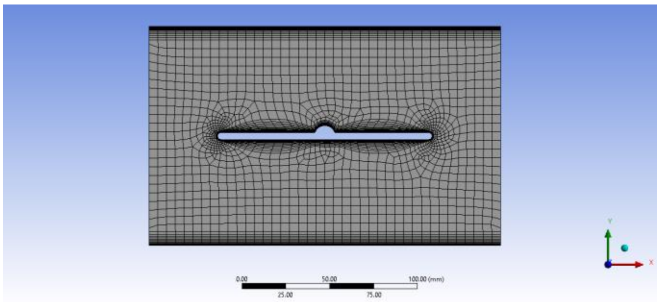

Fig. 9 *Mesh for Throttle body B(100%)*

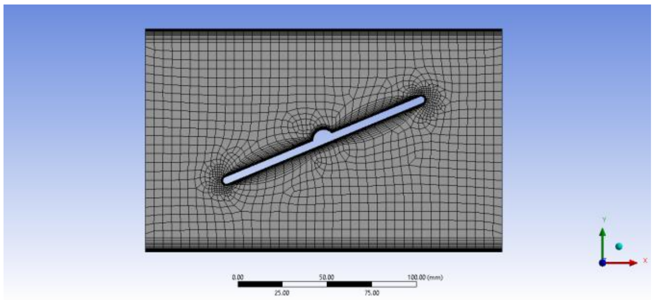

Fig. 10 *Mesh for Throttle body (B75%)*

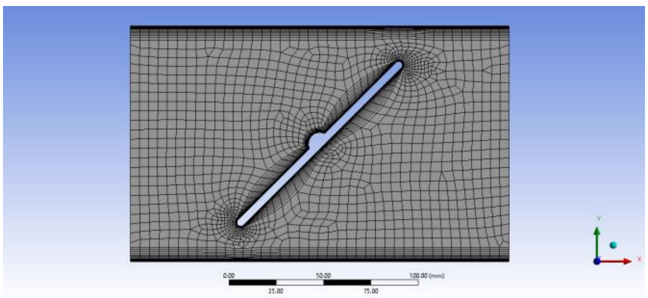

Fig. 11 *Mesh for Throttle body B(50%)*

Setting up the CFD simulation is what follows after generating the mesh. The standard k-epsilon turbulence model was used in the CFD simulation. After setting up the network, it is necessary to set the boundary conditions. Air was used as the fluid, and the pressure drop at the outlet compared to the inlet was simulated by 0.1 bar. A pressure of 1 bar was set at the inlet and 0.9 bar at the outlet. For each throttle body out of the three possible cases, it is necessary to define the inlet and outlet of the working fluid, and this is shown only in the example of a 100% throttle body for concepts A and B, in Figures 12 and 13 with the network (inlet - blue arrows, outlet red arrows).

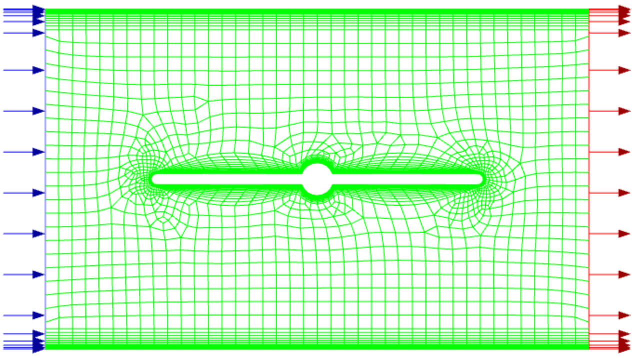

Fig. 12 *Inlet and outlet for 100% open Throttle body A*

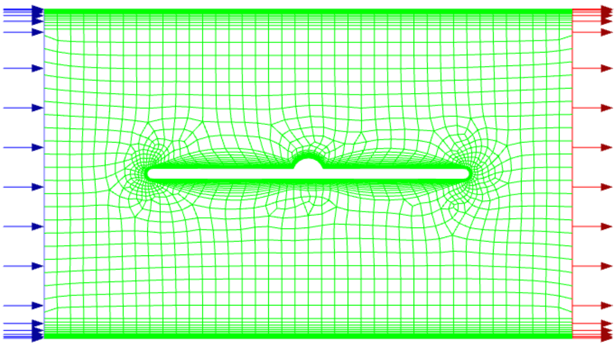

Fig. 13 *Inlet and outlet for 100% open Throttle body B*

4. Results

The results of CFD simulations of airflow through both throttle bodies A and B for three different opening positions are given in this chapter. Figures 14 to 19 show the contour of pressure for Throttle Body A and B for three positions.

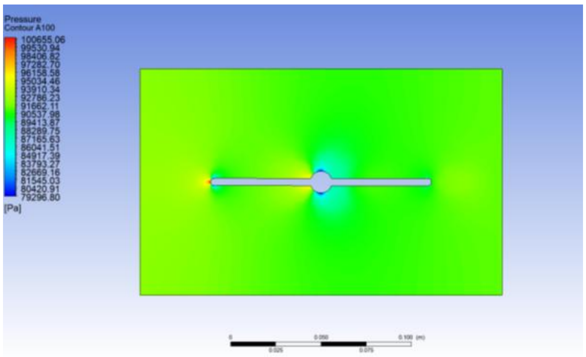

Fig. 14 *Pressure contour for Throttle body A(100%)*

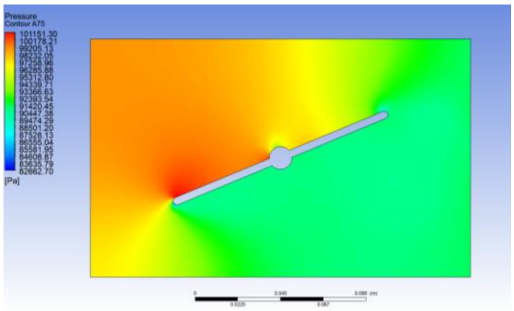

Fig. 15 *Pressure contour for Throttle body A(75%)*

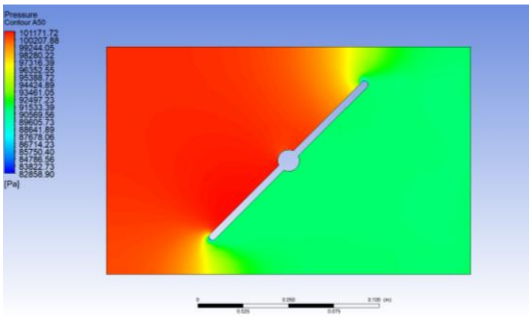

Fig. 16 *Pressure contour for Throttle body A(50%)*

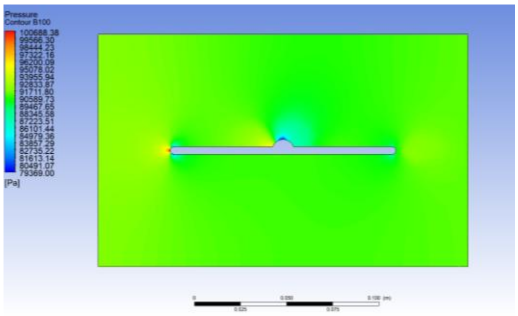

Fig. 17 *Pressure contour for Throttle body B(100%)*

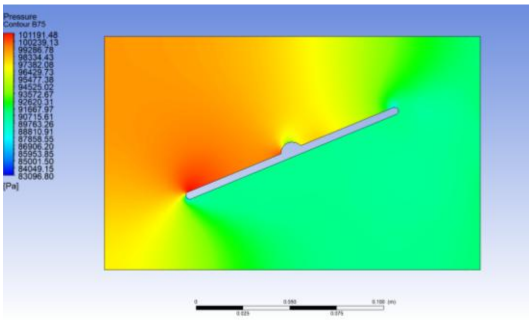

Fig. 18 *Pressure contour for Throttle body B(75%)*

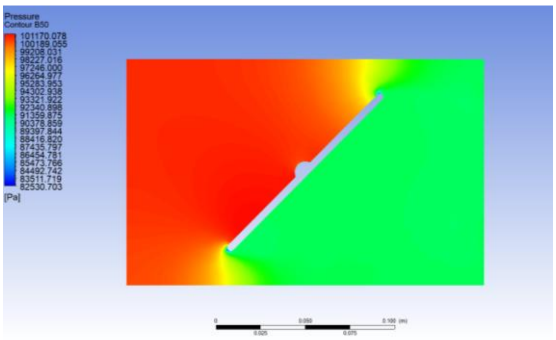

Fig. 19 *Pressure contour for Throttle body A(50%)*

Velocity contours for both throttle bodies and all three considered opening positions are also shown in this chapter. Figures 20 to 25 show velocity contours for the throttle body and opening positions.

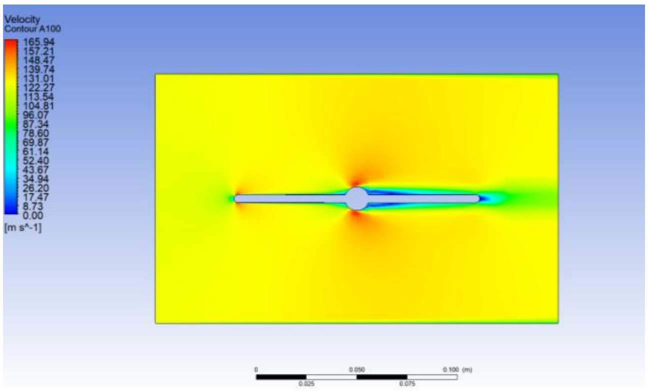

Fig. 20 *Velocity contour for Throttle body A(100%)*

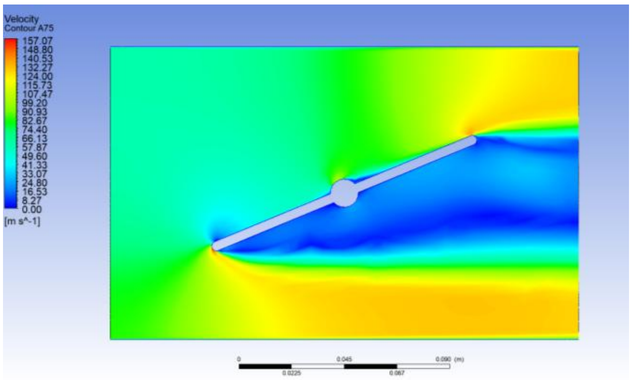

Fig. 21 *Velocity contour for Throttle body A(75%)*

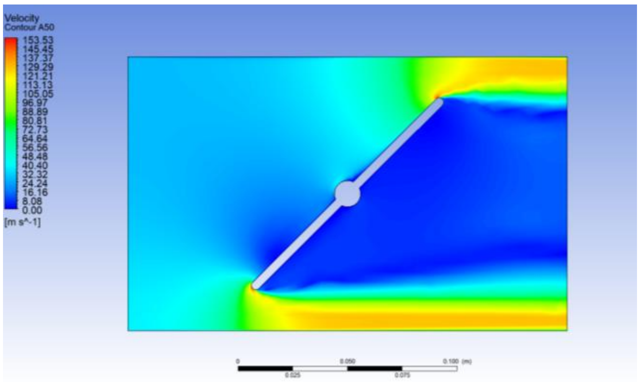

Fig. 22 *Velocity contour for Throttle body A(50%)*

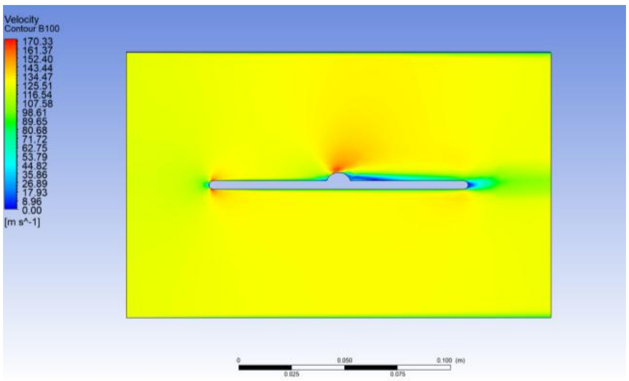

Fig. 23 *Velocity contour for Throttle body B(100%)*

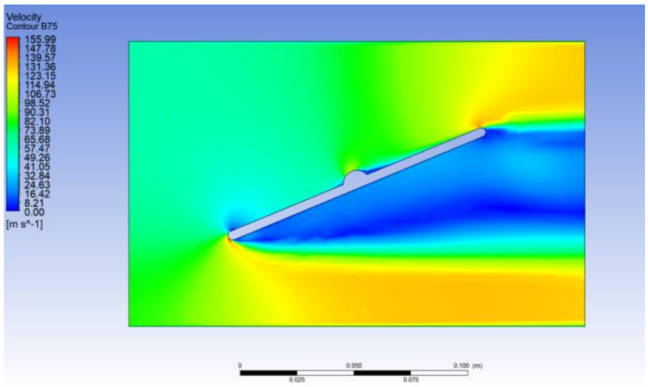

Fig. 24 *Velocity contour for Throttle body B(75%)*

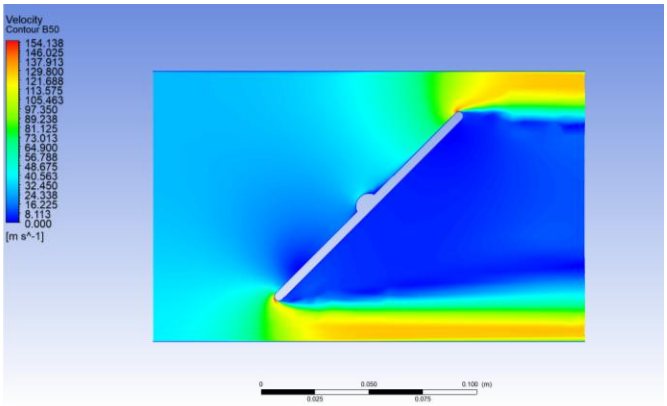

Fig. 25 *Velocity contour for Throttle body B(50%)*

For an easier overview of the results related to max velocity, a diagram is given in Figure 26.

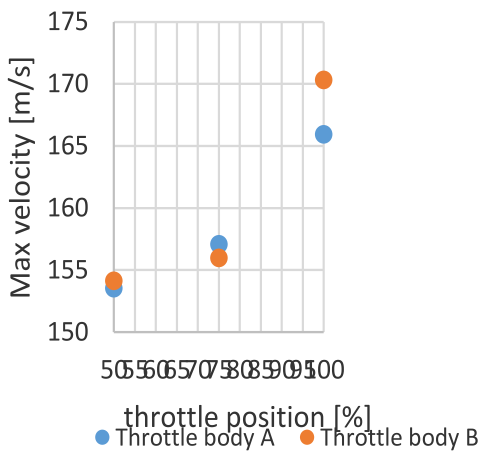

Fig. 26 *Maximum velocity in the throttle body*

From the previous analysis, it can be concluded that these two throttle bodies are very similar geometrically, and practically similar in results as well. Throttle body B has a higher maximum speed value at full opening (100%). which is logical because it has a smaller surface that creates an obstacle to airflow. A slightly higher maximum speed is achieved by throttle body B even at 50% opening, while at 75% opening the maximum speed is higher with throttle body A.

5. Conclusion

CFD simulation is a standard part of serious engineering practical analysis not only in the automotive industry but also in all other industries dealing with fluids. In the paper itself, it was shown that even if the design of the throttle body is slightly different, the results can differ to a great extent. In this case, it is shown in the example of velocity and pressure at the full opening of throttle body A and B. Investigating the fluid flow in the throttle body can be a very complex job, especially if the considered problem is examined in detail. It has been shown that very simple CFD simulations can simulate the real situation in the example of the throttle body. In the end, it should be emphasized that the biggest influence on the flow is the throttle body's diameter. Special attention should be paid to the correct dimensioning of the throttle body, but also to the shape itself, as well as to the choice of material from which it will be produced. As Formula Student teams are limited by budget, the vast majority decide to make their throttle body design, so CFD simulation can be of great help in choosing a better design.

6. References

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