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NUMERICAL SIMULATION ON REAR SPOILER ANGLE OF MINI MPV CAR FOR CONDUCTING STABILITY AND SAFETY

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Abstract -- *Spoiler attached on the rear part of a car can generate drag force and negative lift force, called downforce. This drag force can increase air resistance to the car, meanwhile, a negative lift force can improve the car's stability and safety. Refer to many researchers, the shape and the angle of the spoiler give different aerodynamic effects and therefore give a different value of drag force and lift force. Based on these facts, this study was focused on the analysis of different spoiler angle attached to a mini MPV car to drag and lift force generated by the spoiler. The method used in this study is a numerical simulation using the Computational Fluid Dynamics (CFD) technique. The analysis was carried out at different spoiler angle and car's speed. The spoiler angles are -20^o, -10^o, 0^o, 10^o, and 20^o. The car's speeds are 40 km/h, 60 km/h, 80 km/h, 100 km/h, and 120 km/h. Then the drag and lift force and their coefficient generated by different spoiler angles were being investigated at specified speeds. The result shows that higher spoiler angles generate higher drag and lower lift. Spoiler angles higher than 0^o generate negative lift force, otherwise generate positive lift force. Therefore, to increase a car's stability and safety, it is recommended to use a spoiler angle higher than 0^o. Based on the result, it is best to use spoiler angle 10^o because it generates negative lift force with -0.05 lift coefficient and 0,68 drag coefficient.*

Keywords: *Mini MPV car; Rear spoiler angle; Drag; Lift; Numerical simulation*

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INTRODUCTION

Along the times, transportation has increased in number due to the high demand for a mobile society. This phenome will potentially increase traffic accidents. According to a survey, traffic accidents have become the number 3 killer in Indonesia [1].

Many families in Indonesia choose mini Multi-Purpose Vehicle (MPV) cars as their daily transportation due to the spacious cabin of the cars and the ability of the cars to minimizing their fuel consumption but still have enough power to carry all family members [2]. However, mini MPV cars should be safe when used to carry all the family members in order to minimize traffic accidents. One aspect of the cars' safety is its stability on the road. It is influenced by the cars' body shapes and the aerodynamic phenomena along with the cars' bodies [3, 4, 5].

Drag and lift force are the two common forces in the aerodynamic study. Lift force is the most important concern to increase the car's stability, as lift force is the vertical force acting on a car's body. A higher lift force will lead to an accident because the car will be less stable [3, 6, 7]. Otherwise, a lower lift force will lead to safety because the car's stability improved. Meanwhile, the drag force is a resistance force acting on the car's body. A higher drag force will lead to higher air resistance to the car's body [8].

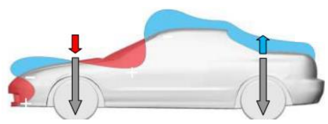


Figure 1. Pressure distribution along car's body due to its aerodynamic phenomena

Das & Riyad [8] have investigated the aerodynamic phenomena along a sedan-typed car using numerical simulation. A spoiler is attached on the rear part of the sedan to generate negative lift force called downforce, in order to increase its stability. The spoiler's angle of attack is modified to capture pressure distribution on the rear part of the sedan. The result shows that the spoiler can reduce flow separation in the rear part of the sedan, so the drag force reduced, and the high pressure in front of the spoiler can generate a negative lift force. Due to that reduction and negative lift force generation, the stability of the sedan increases.

Refer to Kurec et al. [9], rear spoilers attached to the body of the cars are one of many components that have a major influence on drag and lift force generation. They are used to achieve desired aerodynamics properties, in this case, the drag and lift force. They found that due to aerodynamic phenomena, pressure distribution along the car's body contributes downforce (negative lift force) to the front axle but lift force to rear axle, as shown in Figure 1. It makes the car to be unstable. Based on this reason, they researched to make the lift force at the rear axle to be negative and become downforce by adding a rear wing on top of the car's trunk alongside with a spoiler. The research was based on experiment and numerical simulation and the result shows that pressure distribution along with the car's body change. Using 20° rear wing and 55° spoiler increases downforce acting on the rear part of the car by 29%.

Tsai et al. [10] have studied another research conducted on aerodynamic effect due to the addition of a rear spoiler. They used different types of spoiler and investigated the drag and lift force generated by the spoilers. They also investigate the aero-acoustic phenomena due to the spoilers. The car modeled in their research is Honda S2000. They concluded that the spoiler or rear wing with the configuration shown in Figure 2 could generate a low lift force. Therefore, the stability of the car improved. The lift coefficient of the spoiler reaches -0.001. Minus sign indicates that the lift force generated is downward and considered as downforce.

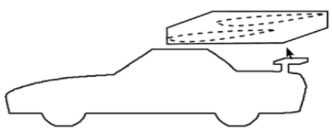


Figure 2. Spoiler or rear wing configuration attached on Honda S2000 [10]

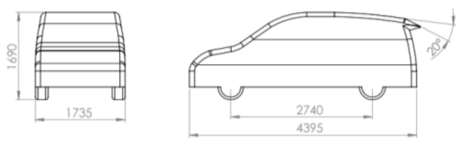
Many kinds of research of aerodynamic effect due to rear spoiler conducted by far used sedan-typed car as the modeled car, only a few types of research used non-sedan-typed cars, i.e., mini MPV car. Therefore, this study was focused on the aerodynamic effect of various spoiler angles attached on the rear top of the mini MPV car.

METHOD

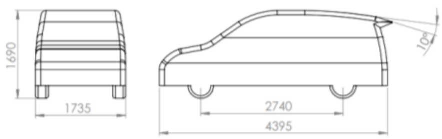
This study was conducted by numerical simulation using the Computational Fluid Dynamics (CFD) technique, because according to [11, 12, 13, 14], CFD can be used as fluid analysis tool with reliable result for complex body. Suzuki Ertiga is used as the modeled car; its dimension set up for modeling was based on the real specification from the company. Five rear spoiler angles were considered to study the aerodynamic effect due to the addition of the rear spoiler attached to the modeled car. The spoiler angles used in this study are listed in Table 1.

Table 1. Spoiler angle variations

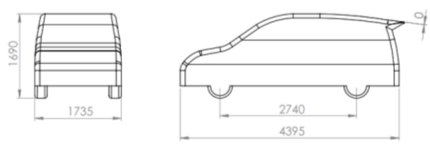
Variation	**Spoiler Angle [°]**
1	-20
2	-10
3	0
4	10
5	20



(a)



(b)



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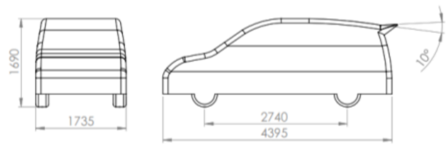
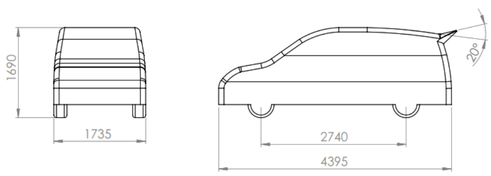


(d)



(e)

Figure 3. Different look of modeled car and their dimensions in millimeter with various spoiler angle (a) -20° (b) -10° (c) 0° (d) 10° (e) 20°

Figure 3 shows the different look of the modeled car with spoiler angle variations. As shown in Figure 3 and according to [6], the spoiler angle of 0º means the top of the spoiler straight with the top of the car. Spoiler angle higher than 0º means the top of the spoiler and the top of the car form an angle higher than 0º. Otherwise is vice versa.

Figure 4 shows the air domain and the boundary conditions applied to all variations. The rear part of the domain is longer than the front part in order to capture the flow streamline behind the modeled car. Front part of the air domain considered as inlet, rear part as an outlet, bottom part as no-slip wall, top and side parts as free slip walls. The car body considered as no-slip wall.

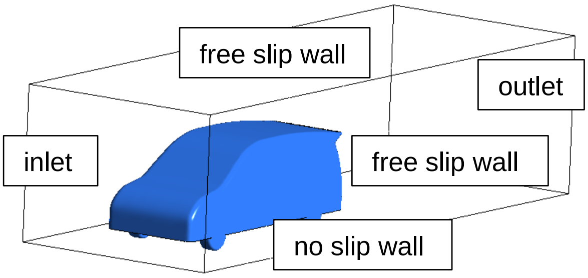


Figure 4. Air domain and boundary conditions

The air domain is set as air ideal gas with 30ºC temperature and 1 atm reference pressure. The inlet boundary is set at a normal speed. Five-speed values are to be applied to this study; they are 40 km/h, 60 km/h, 80 km/h, 100 km/h, and 120 km/h. The outlet boundary is set as relative static pressure with the value of 0 Pa. Based on [6] and [10], the turbulence model used to simulate aerodynamic along the car's body is Reynolds-Averaged Navier-Stokes (RANS). In this study, the turbulence model used is Shear Stress Transport (SST), which is a part of the RANS model. Convergence for each simulation was achieved if the residues for each simulation was less than or equal to 10^{-5} [15].

After simulations have been completed, drag forces (F_D) and lift forces (F_L) generated for each variation were used to calculate the drag coefficient (C_D) and lift coefficient (C_L), respectively. The calculation was based on [11][16] as stated in equation (1) and (2).

$$C_D = \frac{F_D}{0.5.\rho.v^2.A_D} \quad (1)$$

$$C_L = \frac{F_L}{0.5.\rho.v^2.A_L} \quad (2)$$

where ρ is air density at 30ºC, v is upstream air velocity located at the inlet, A_D is a frontal area, and A_L is a planform area. The frontal area is the projected area seen by a person looking toward the modeled car from a direction parallel to the upstream velocity v. Otherwise, the planform area is the projected area seen by a person looking toward the modeled car from a direction normal to the upstream velocity v.

Drag and lift coefficient are dimensionless parameters used to describe drag and lift force along a car's body. These parameters are widely used in the aerodynamic study [3, 11, 16, 17]. As stated in (1) and (2), higher drag and lift coefficient means higher drag and lift force, respectively [11,16, 17].

RESULTS AND DISCUSSION

Pressure distribution along with the modeled car with various rear spoiler angle are shown in Figure 5 to Figure 9. The figures show pressure distributions generated by numerical simulation with constant air velocity at 100 km/h. The pressure generated is classified as gage pressure, so pressure at 0 Pa means the pressure equal to reference pressure which is 1 atm. As shown in the figures, pressure on the front part of the car is high, because the air at 100 km/h velocity hit the front part of the car and generates stagnation pressure [11][16]. Otherwise, pressure on the rear part of the car is lower.

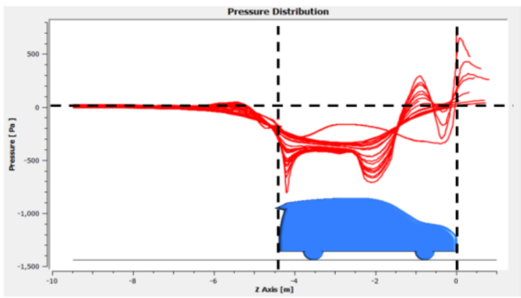


Figure 5. Pressure distribution along modeled car with -20º rear spoiler angle

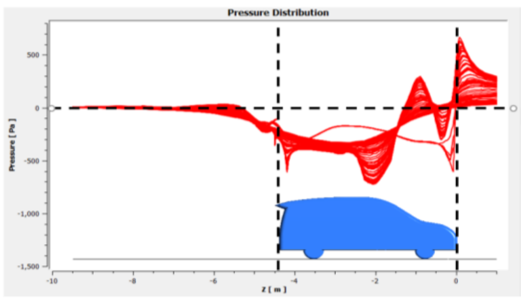


Figure 6. Pressure distribution along with a modeled car with -10º rear spoiler angle

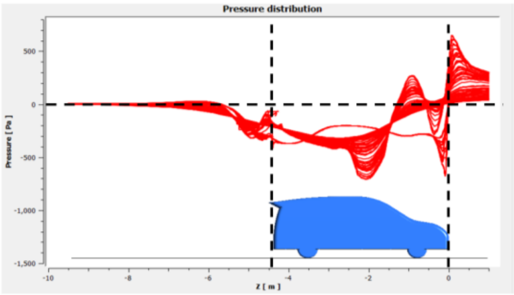


Figure 7. Pressure distribution along with a modeled car with 0º rear spoiler angle

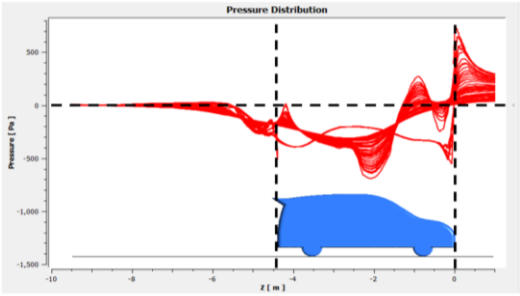


Figure 8. Pressure distribution along with a modeled car with 10º rear spoiler angle

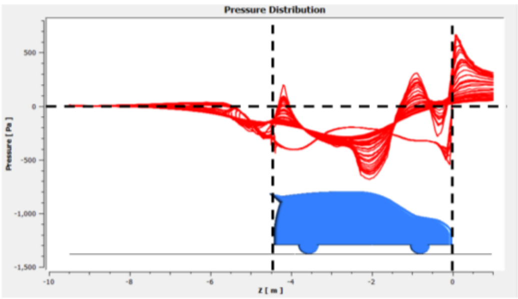


Figure 9. Pressure distribution along with a modeled car with 20º rear spoiler angle

Pressure on the rear part of the car is lower because there is flow separation, as shown in Figure 10. This flow separation generates low pressure, and because of that, a pressure difference between the front part and the rear part of the car occurred [11]. The pressure different then generates a drag force. Drag forces generated along the car's body are shown in Figure 11. Figure 11 shows that higher velocity generates a higher drag force, so drag force at 120 km/h velocity is the highest drag force. Otherwise, the drag force at 40 km/h is the lowest among the others. Figure 11 also shows that a higher spoiler angle generates a higher drag force, so drag force generated by the spoiler at 20º angle is the highest among the other angles. These increases are more visible at high speed (100 km/h and 120 km/h) because the drag force due to pressure difference is proportional to velocity.

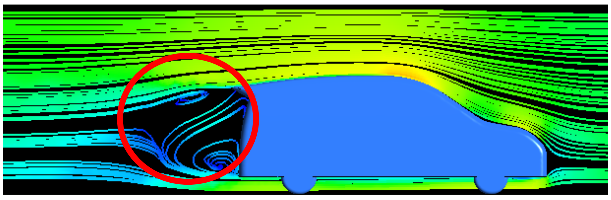


Figure 10. Flow separation behind the car

Nevertheless, as shown in Figure 11, drag force decreases at an angle -20º to -10º. Therefore, at an angle less than 0º, the drag force will decrease if the angle increase.

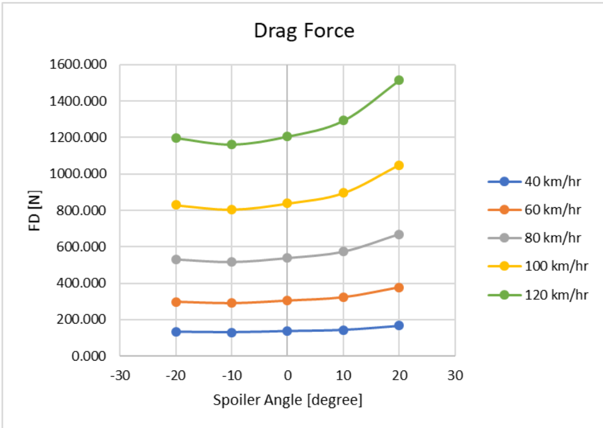


Figure 11. Drag forces generated along the car's body with various rear spoiler angle and speed

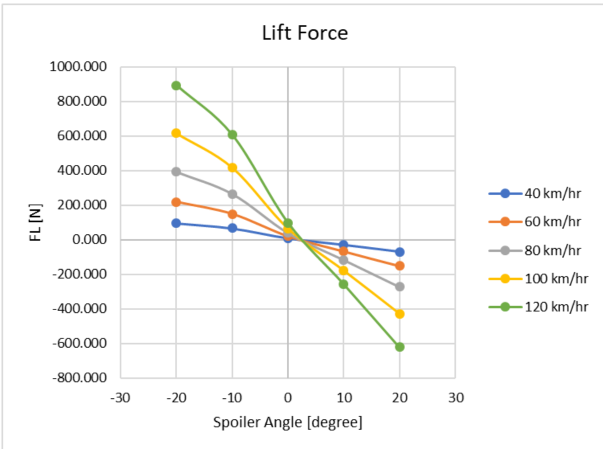


Figure 12. Lift forces generated along the car's body with various rear spoiler angle and speed

As shown in Figure 5 to Figure 9, the spoiler angle at 20º generates more positive pressure on the front part of the spoiler than other angles. Therefore, the lift force generated by the spoiler is the minimum among the others [4]. The condition is recognized clearly in Figure 12. Figure 12 shows that at a certain speed, higher spoiler angles generate lower lift force. These phenomena are more visible at a higher speed than lower speed because lift forces generated due to pressure acting on the car's body are proportional to velocity.

Note that the lift force is pointing upward. Therefore, to improve the car's stability, the lift force should be negative to form downforce. As shown in Figure 12, downforce generated when the rear spoiler angles are at 10º and 20º. Based on this fact, a downforce will be generated if the angle more than 0º.

As mentioned before, the drag and lift force coefficient is widely used in aerodynamics study because they are dimensionless, so they are not affected by velocity but still affected by the shape of the car [11]. Figure 13 and Figure 14 show the drag and lift coefficient generated by the simulation, respectively.

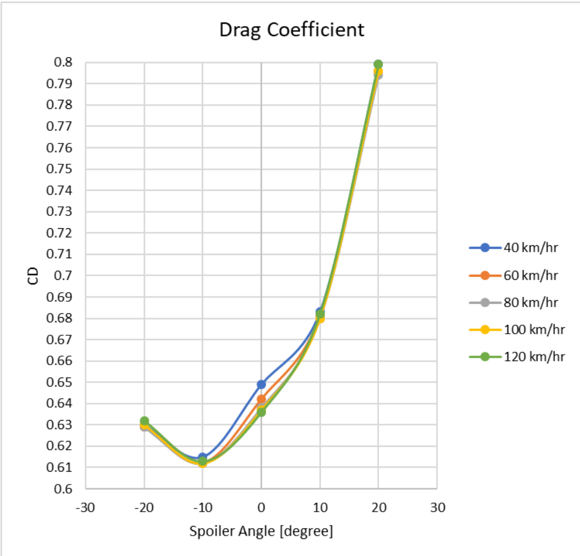


Figure 13. Drag coefficient generated along the car's body with various rear spoiler angle and speed

As shown in Figure 13, higher rear spoiler angles generate a higher drag coefficient. Otherwise, Figure 14 shows that the higher rear spoiler angle generates a lower lift coefficient. The condition is a dilemma because a lower lift coefficient will lead to a more stable car but the lower the lift coefficient, the higher the drag coefficient. In terms of fuel consumption, the lower drag coefficient is better because air resistance will be lower. Thus, part of the energy generated due to fuel consumption used against air resistance will below. Otherwise, a higher drag coefficient will increase air resistance and therefore part of the energy generated due to fuel consumption used against air resistance will be high [18].

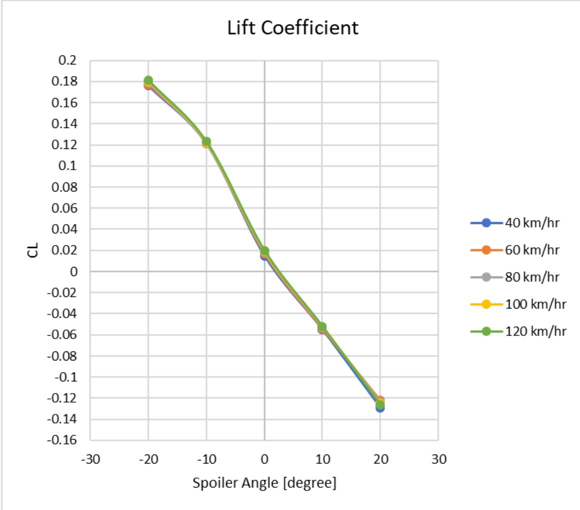


Figure 14. Lift coefficient generated along the car's body with various rear spoiler angle and speed

According to Figure 13 and Figure 14, The best spoiler angle is 10º because it generates negative lift force with -0.05 lift coefficient and 0,68 drag coefficient. The angle generates negative lift force, which is good to increase the car's stability and safety, and the drag force generated is not high as spoiler angle 20º. For comparison, at a speed of 100 km/h, the increase in drag force between spoiler angle 10º and 20º is 17,0588%.

CONCLUSION

Rear spoiler angle will affect the aerodynamics effect of the car. Higher spoiler angles will generate higher drag and lower lift. Higher drag will lead to higher air resistance and lower lift will lead to the car's stability improvement. According to the result, the best spoiler angle is 10º because it generates negative lift force with -0.05 lift coefficient and 0,68 drag coefficient. The angle generates negative lift force, which is good to increase the car's stability and safety.

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REFERENCES

[1] E. Susanto and Y. Gunardi, "Disain dan Implementasi Pengendali Lampu Jarak Jauh dan Dekat Pada Kendaraan Bermotor Secara Otomatis," *SINERGI*, vol. 17, pp. 225–230, 2013.

[2] H. Pranoto, D. Feriyanto, and S. Zakaria, "Performance and Exhaust Gas Temperature Investigation of Ceramic, Metallic and FeCrAl Catalytic Converter in Gasoline Engine," *SINERGI*, vol. 23, no. 1, pp. 11–16, 2019. DOI: 10.22441/sinergi.2019.1.002

[3] J. Katz, "Aerodynamics of Race Cars," *Annu. Rev. Fluid Mech.*, vol. 38, no. 1, pp. 27–63, January 2006. DOI: 10.1146/annurev.fluid.38.050304.092016

[4] S. J. Kim, C. H. Yoo, and H. K. Kim, "Vulnerability assessment for the hazards of crosswinds when vehicles cross a bridge deck," *J. Wind Eng. Ind. Aerodyn.*, vol. 156, pp. 62–71, September 2016. DOI: 10.1016/j.weia.2016.07.005

[5] E. Jacuzzi and K. Granlund, "Passive flow control for drag reduction in vehicle platoons," *J. Wind Eng. Ind. Aerodyn.*, vol. 189, pp. 104–117, June 2019. DOI: 10.1016/j.weia.2019.03.001

[6] C. S. Yuan, S. Mansor, and M. A. Abdullah, "Effect of spoiler angle on the aerodynamic performance of hatchback model," *Int. J. Appl. Eng. Res.*, vol. 12, no. 22, pp. 12927–12933, 2017.

[7] S. Y. Cheng, K. Y. Chin, S. Mansor, and A. B. Abd Rahman, "Experimental study of yaw angle effect on the aerodynamic characteristics of a road vehicle fitted with a rear spoiler," *J. Wind Eng. Ind. Aerodyn.*, vol. 184, no. July 2018, pp. 305–312, January 2019. DOI: 10.1016/j.weia.2018.11.033

[8] R. C. Das and M. Riyad, "CFD analysis of passenger vehicleat various angle of rear end spoiler," *Procedia Eng.*, vol. 194, pp. 160–165, 2017. DOI: 10.1016/j.proeng.2017.08.130

[9] K. Kurec, M. Remer, T. Mayer, S. Tudruj, and J. Piechna, "Flow control for a car-mounted rear wing," *Int. J. Mech. Sci.*, vol. 152, pp. 384–399, March 2019. DOI: 10.1016/j.ijmecsci.2018.12.034

[10] C. H. Tsai, L. M. Fu, C. H. Tai, Y. L. Huang, and J. C. Leong, "Computational aero-acoustic analysis of a passenger car with a rear spoiler," *Appl. Math. Model.*, vol. 33, no. 9, pp. 3661–3673, September 2009. DOI: 10.1016/j.apm.2008.12.004

[11] B. M. Munson, T. H. Okiishi, W. W. Huebsch, and A. P. Rothmayer, *Fundamentals of Fluid Mechanics*. New York: John Wiley & Sons, Inc, 2013.

[12] H. Lomax, T. H. Pulliam, and D. W. Zingg, *Fundamentals of Computational Fluid Dynamics*. Toronto: University of Toronto Institute Aerospace Studies, 1999.

[13] W. Versteeg, H. K. Malalasekera, *An Introduction to Parallel Computational Fluid Dynamics*. Harlow: Pearson Education Limited, 2007.

[14] M. Lanfrit, "Best practice guidelines for handling Automotive External Aerodynamics with FLUENT," *Fluent*, vol. 2, pp. 1–14, February 2005.

[15] ANSYS. Inc, *ANSYS CFX - Solver Modelling Guide*, Pittsburgh, 2013.

[16] Y. A. Cengel and J. M. Cimbala, *Fluid Mechanics Fundamentals and Application*. New York: McGraw-Hill, 2006.

[17] E. L. Houghton and P. W. Carpenter, *Aerodynamics for Engineering Students*. Oxford: Butterworth Heinemann, 2003.

[18] S. M. Rakibul Hassan, T. Islam, M. Ali, and M. Q. Islam, "Numerical study on aerodynamic drag reduction of racing cars," *Procedia Eng.*, vol. 90, pp. 308–313, 2014. DOI: 10.1016/j.proeng.2014.11.854