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Comparison on Area of Throttle Bore Opening for Butterfly Throttle Body and Dual Plate Slider Throttle Body

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Abstract: Throttle body (TB) is a component that regulates air intake for internal combustion engines (ICE). The butterfly valve TB (BTB) is commonly used in most ICE vehicles. Previous researchers have discussed the issues of air turbulence and pressure loss caused by the butterfly valve. To address these issues, a new TB design, the Dual Plate Slider TB (DPSTB), was proposed to eliminate obstructions at wide open throttle (WOT) and maximize the TB bore opening. This study aims to compare the bore opening areas of the BTB and DPSTB. Mathematical analysis was validated using a TB model created with SolidWorks software. The BTB was analyzed at six different opening angles, while the DPSTB was examined at six different opening distances. Results show that the DPSTB provides a larger opening area in every condition observed, with no airflow obstruction at WOT. The opening area increased by 8.3, 3.5, 2.3, 1.7, 1.3, and 1.3 times respectively for valve opening conditions 1-6. These findings could inspire TB designers to explore new TB design packages for future ICE applications.

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Keywords: Throttle body, area of valve opening, mathematical analysis

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1. Introduction

In the realm of automotive technology, the air intake system for Internal Combustion Engines (ICE) employs valves to ensure the optimal amount of air is delivered to the ICE, thereby enhancing engine performance [1] and reducing vehicle emissions [2], [3]. Numerous research investigations have been conducted in this area, as highlighted in the review articles by Tahiruddin et al. [4]and Ashok et al. [5]. The majority of researchers have focused their studies on the Butterfly Throttle Body (BTB) concept, given its widespread use in passenger vehicles. The BTB is favored in passenger vehicles due to its simple structure and cost-effectiveness in manufacturing.

However, the concept of the gate valve TB, also known as Slider TB (STB), has been introduced specifically for high-speed vehicles [6], [7] and aircraft

[8]. STB is particularly advantageous for racing vehicles, as it operates predominantly at full engine load, offering unobstructed airflow at wide open throttle (WOT), thereby ensuring better airflow for combustion in the ICE [9], [10]. This concept was devised with the aim of maximizing air intake to achieve optimal combustion power [11].

The regulation of airflow across TB is commonly based on the valve opening area, allowing air to pass through to the ICE. Computational Fluid Dynamics (CFD) analysis aids researchers in comprehending airflow characteristics across TB, leading to proposed enhancements in various aspects [12], [13], [14]. Alternatively, mathematical analysis of the valve opening area can provide insights into valve opening characteristics that impact flow, potentially inspiring new TB design concepts.

Therefore, this study will encompass the following: First, both TB concepts, BTB, and Dual Plate Slider TB (DPSTB), were modelled using SolidWorks software. Second, the opening area for BTB and DPSTB was observed under six opening conditions and analysed using mathematical analysis, with the comparison presented in this study.

2. Modeling the BTB

Fig. 1 illustrates the BTB, which features a throttle bore cavity with a valve plate and shaft positioned in the centre of the bore. The plate's rotation controls the amount of air passing through the TB to the ICE. The valve opening area was measured at six different angles: 15°, 30°, 45°, 60°, 75°, and 90°. The 15° opening is considered the idle position, representing the minimum opening and a fail-safe closed condition in case of operation failure due to issues with the DC motor or gears [15]. The angles from 30° to 75° represent partial throttle openings, while maximum airflow is achieved at the 90° opening, known as WOT.

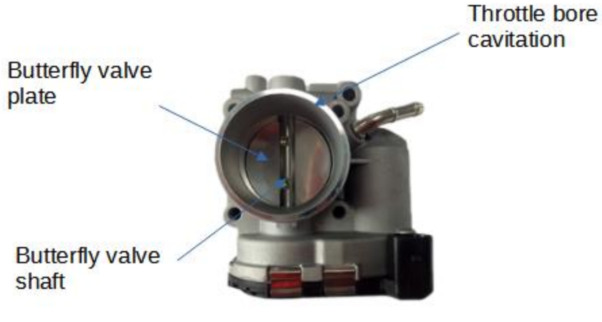

Fig. 1: Butterfly based electronic TB

In this study, a BTB with a 60 mm bore diameter and a valve plate thickness of 2 mm [16] was modelled using SolidWorks software to calculate the valve opening area through mathematical analysis. The model will be examined from the front view, focusing solely on the valve and the TB bore cavity. A mathematical approach will be used to determine the valve opening area. The parameters involved in the BTB model are area of valve plate, A_e and area of valve opening A_{cb} as shown in Fig. 2.

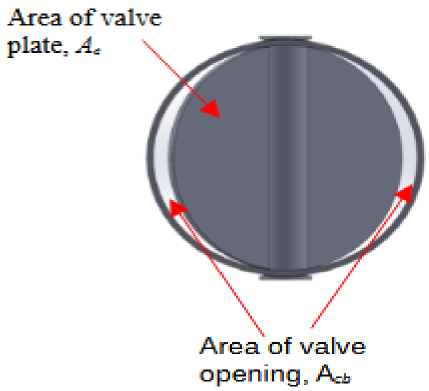

Fig. 2: Parameter observe from butterfly TB

2.1 Area of opening for BTB

From Fig.2, area of valve opening (A_c) is given as

$$A_c = A_{bore} - A_e \qquad (1)$$

where,

A_{bore} = Area of TB bore cavitation
A_e = Area of valve plate

Area of valve plate is equal to the area of ellipse as the butterfly plate formed an ellipse shape at the angle of front view. Ellipse consists of major axis *(y)* and minor axis *(x)* as shown in Fig. 3.

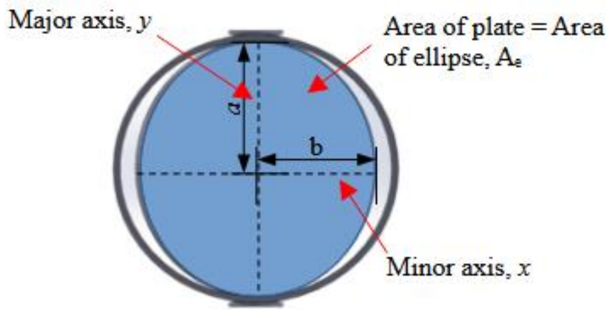

Fig. 3: Parameter of ellipse in BTB

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Referring to Fig. 3, Area of ellipse (A_e) is given as

$$A_e = \pi ab \quad (2)$$

where,

a = length at major axis
b = length at minor axis

To calculate the area of opening for BTB, SolidWorks measure tool was utilised to obtain the parameter needed from the model. Fig. 4 shows the measuring process done to BTB model with 15° angle of opening. Ellipse minor axis length of 58.47mm recorded from the model and formula of area for ellipse were adapted to calculate area of valve plate, A_e.

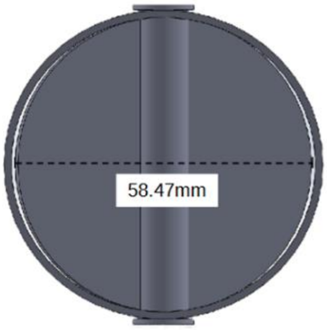

Fig. 4: Measuring the distance of plate opening using tools in SolidWorks

Area of TB bore cavitation A_{bore} is shown in Fig. 5, whereby the area is equal to the area of a full circle with radius, r is 30mm.

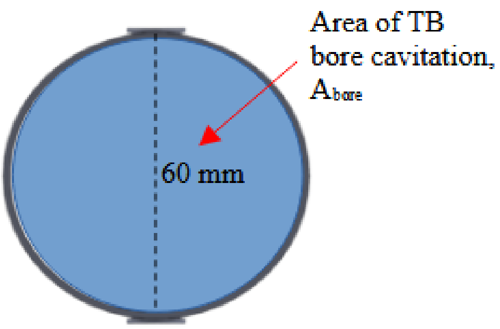

Fig. 5: Parameter of area for TB bore cavitation

Referring to Fig. 4, Area of TB bore cavitation (A_{bore}) is given as

$$A_{bore} = \pi r^2 \quad (3)$$

where,

r = radius of TB bore

Thus, area of valve opening *(A_c)* was calculated by utilizing formula (1), (2), and (3) and this mathematical analysis was repeated to calculate area of plate opening at angle of 30°, 45°, 60°, and 75°.

As for the valve opening angle of 90°, the valve is in WOT and from the front view it is observe that the area of the butterfly shaft can be calculated using the formula of trapezium area where it consists of base *(at)*, base *(bt)* and height *(ht)* as shows in Fig. 6. A very small area of curve at the shaft was assume to be zero as it is too small.

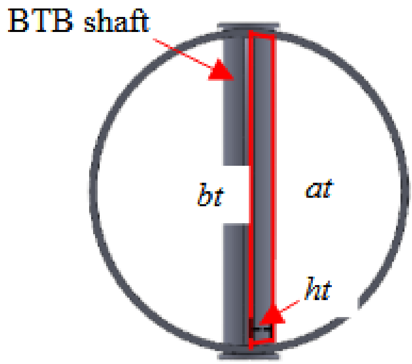

Fig. 6: Parameter of trapezium in BTB

Referring to Fig. 6, Area of trapezium ($A_{trapezium}$) is given as

$$A_{Trapezium} = \frac{1}{2}(at + bt)ht \quad (4)$$

where,

at = upper base length
bt = lower base length
ht = height of trapezium

From the SolidWorks model, butterfly shaft diameter was known to be 10 mm in thickness and butterfly shaft area was identified to be approximately similar to the area of two trapezium with the trapezium height of 5 mm as shown in Fig. 7.

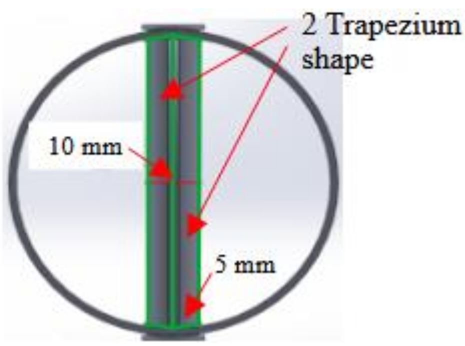

Fig. 7: Two trapezium is the area of the butterfly shaft

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Table 1 shows the findings on area calculated for each degree of throttle rotation observed in this study. At the angle of 15°, BTB was in the idle condition with area of opening 72.10mm^2. It is obvious that area of throttle plate decreases with respect to the angle rotation resulting in bigger area of opening on throttle bore, allowing more air to pass through the TB. Maximum airflow through TB was recorded at 90° angle with 2231.63mm^2 area of opening.

Table 1. Area opening on each degree rotation.

Area of Throttle Bore, A_{bore} ∏r2 (mm^2)	Angle of rotation (degree)	Area of throttle plate, A_e (mm^2)	Area of opening, A_c (mm^2)
2827.43	15	2755.33	72.10
	30	2495.68	331.75
	45	2065.91	761.52
	60	1495.24	1329.64
	75	822.78	1982.71
	90	595.80	2231.63

3. Modeling the DPSTB

As for the DPSTB, Fig. 8 shows the DPSTB concept proposed in this study. This concept employed two valves plate. The valve plates will slide in a opposite direction to each other creating a centre opening at the throttle bore cavitation allowing air to flow into ICE. Parameter involved is shown as the area of valve plate, $A_{plateDPSTB}$, Area of valve opening, A_{cDPSTB}, and Area of TB Bore cavitation, $A_{boreDPSTB}$

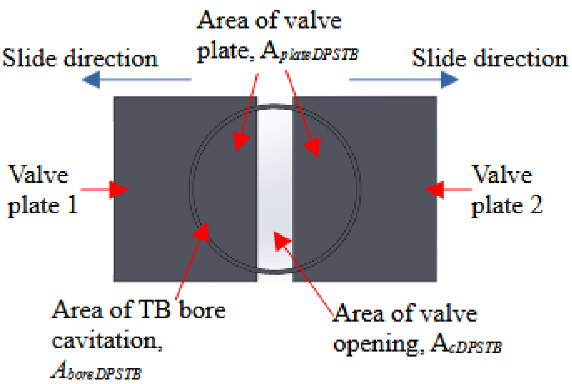

Fig. 8: Cross section of DPSTB opening

Using SolidWorks software, plate travel was assigned to six different opening distance of 5mm, 10mm, 15mm, 20mm, 25mm, and 30mm. Maximum plate travel of 30mm was the WOT condition on the DPSTB which is also equal to the radius of throttle bore cavitation and θ_s is the angle projected by the plate movement. Fig. 9 shows the parameter involve to obtain DPSTB area of valve opening which are area of sector A_s, area of triangle $A_{triangle}$, and area of valve plate $A_{plate\ DPSTB}$.

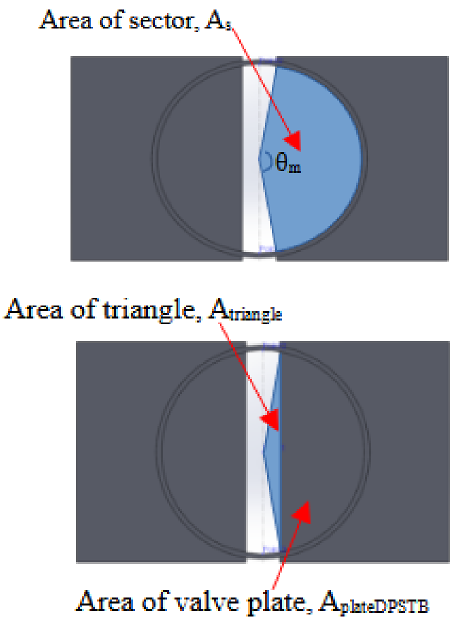

Fig. 9: Parameter observe in DPSTB

3.1 Area of opening for DPSTB

Referring to Fig. 9, mathematical analysis was performed to calculate both side of right and left throttle plates. Due to the symmetrical shape, calculating one side of throttle plate and multiply by two will manage to get both the plates area. Area of one valve plate ($A_{plateDPSTB}$) is given as

$$A_{plateDPSTB} = A_{sector} - A_{triangle} \tag{5}$$

where,

A_{sector} = Area of sector at angle θ
$A_{triangle}$ = Area of valve opening in triangle shape

To identify the Area of sector (A_{sector}), manipulated angle θ_s and manipulated distance (a_m) was obtain from SolidWorks model and radius of throttle bore, (R_{eff}) was known to be 30mm. Fig. 10 shows the parameter involves in findings the area of opening for DPSTB.

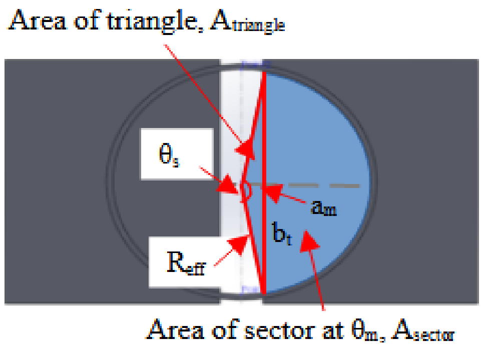

Fig. 10: Parameter involves in calculation of area for DPSTB

Referring to Fig. 10, area of sector (A_{sector}) is given as

$$A_{sector} = \frac{\theta_s}{360}\pi r^2 \qquad (6)$$

where,

θ_s = Sector angle
r = Radius of TB bore, R_{eff}

To define the sector angle (θ_s), the formula is given as

$$\theta_s = \cos^{-1}\frac{a_m}{R_{eff}} \qquad (7)$$

where,

a_m = Manipulated distance
R_{eff} = Radius of TB bore

Area of triangle ($A_{triangle}$) was determined by obtaining the height of triangle that also known as manipulated distance *(a_m)* and length of triangle side *(b_t)*, and angle of the triangle, θ_m as shown in Fig. 11.

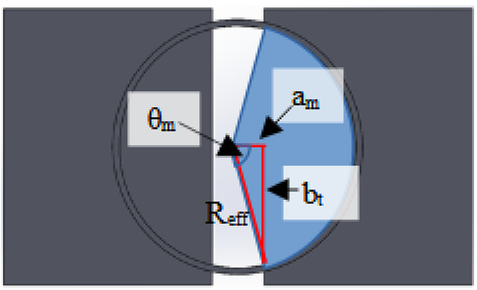

Fig. 11: Parameter of triangle in area of DPSTB

Referring to Fig. 11, area of triangle ($A_{triangle}$) is given as

$$A_{triangle} = \frac{1}{2}a_m b_t \qquad (8)$$

where,

a_m = Height of triangle / manipulated distance
b_t = Length of side triangle

For the length of side triangle b_t, is calculated by using the Theorem Pythagoras formula as given

$$b_t = \sqrt{(R_{eff})^2 - (a_m)^2} \qquad (9)$$

where,

R_{eff} = Radius of TB bore
a_m = Height of triangle / manipulated distance

SolidWorks measure was utilised to ensure the plate opening according to desired distance. Fig. 12 shows 5mm distance opening of the DPSTB plate set using SolidWorks. Each plate is set to opened at similar distance.

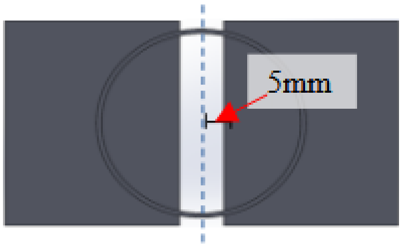

Fig. 12: Measuring process of 5mm opening distance for DPSTB

The calculation was done to obtain area of bore opening at plate travel distance of 5 mm, 10 mm, 15 mm, 20 mm, 25 mm and 30 mm. Table 2 shows the findings on each distance opening observed in this study. It is shown that maximum opening at WOT was calculated to be similar with the area of DPSTB bore which is 2827.43 mm^2.

Table 2. Area of opening for DPSTB.

Area of Throttle Bore, A ∏r^2 (mm^2)	Throttle plate travel distance (mm)	Bore opening distance (mm)	Area of opening, C (mm^2)
2827.43	5	10	597.23
	10	20	1177.27
	15	30	1721.87
	20	40	2207.89
	25	50	2602.27
	30	60	2827.43

4. Comparison on area of opening for BTB and DPSTB

Table 3 shows the comparison of bore opening area for BTB and DPSTB concept examine in this study. Cross section for the valves opening was shown in detail for each condition. BTB opening at WOT was only 2231.63mm^2 which was 595.8mm^2 less, compared to total area of bore opening which is 2827.43mm^2. This was due to the butterfly shaft existence at the centre of the TB bore.

Table 3. Comparison on valves area of opening.

	Butterfly TB			Dual plate Slider TB		
Condition	Opening angle	Cross section	Opening Area (mm^2)	Plate opening (mm)	Cross section	opening area (mm^2)
1	15		72.10	10		597.23
2	30		331.75	20		1177.27
3	45		761.52	30		1721.87
4	60		1329.64	40		2207.89
5	75		1982.71	50		2602.27
6	90		2231.63	60		2827.43

For the DPSTB concept, solid amount of 2827.43 mm^2 area opening was obtained at WOT. No obstruction at WOT as the throttle plate slide to side of the throttle bore. Each throttle plates will travel at the half distance of bore diameter to achieve this condition creating a centre throttle opening that will result in maximum air flow travel at the highest speed into the ICE as shown in Fig. 13. Velocity of the flow was at maximum speed on the centre of the cross section [17][18]. Thus, DPSTB concept will benefit the ICE intake system as the airflow entering combustion chamber without any obstruction and at the maximum velocity.

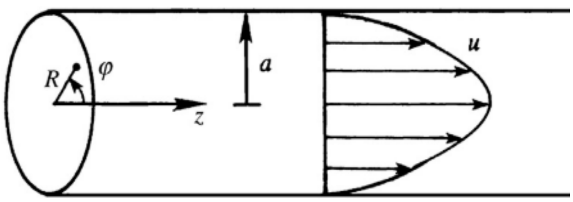

Fig. 13: Theory of flow in round pipe [17]

Fig. 14 shows the result of the comparison on area of opening for BTB and DPSTB. DPSTB offers better opening area compared to BTB which is 8.3, 3.5, 2.3, 1.7, 1.3, and 1.3 times more opening area respectively for condition 1-6 observes in this study.

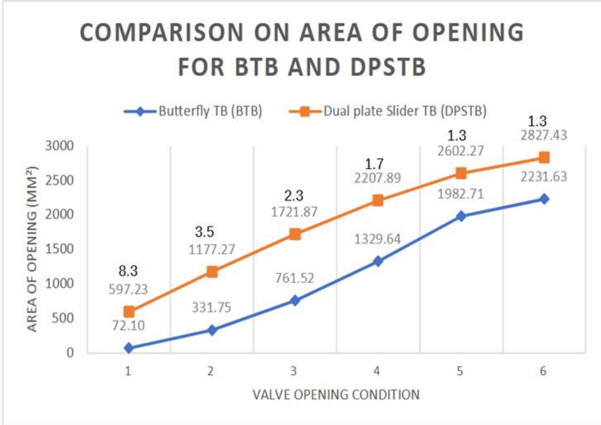

Fig. 14: Graph area of opening vs valve opening condition

5. Conclusion

Results shown that DPSTB offers bigger area of opening compared to BTB at each valve opening condition. Butterfly shaft existence at the centre of BTB bore was recognised as the reason of this findings. The originality of DPSTB was adapting centre flow opening concept to TB operation which was significant as various researchers explores the idea of centre opening TB concept [[19], [20], [21], [22]. For future study, further effort on development of DPSTB prototype is suggested to allow observation on the operation and characteristics of the DPSTB concept.

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References

[1] Fauzun and C. W. Yogiswara, “The effect of bellmouth radius and venturi restrictor length on the power and torque of BM-9’s engine,” *Evergreen*, vol. 8, no. 2, pp. 477–483, 2021, doi: 10.5109/4480732.

[2] I. B. Dalha, M. A. Said, Z. A. A. Karim, and S. E. D. Mohammed, “Effects of High CO2Contents on the Biogas/Diesel RCCI Combustion at Full Engine Load,” *Evergreen*, vol. 9, no. 1, pp. 49–55, 2022, doi: 10.5109/4774216.

[3] K. Adam and M. A. Wahid, “On the effects of tangential air inlets distribution configurations to the combustion characteristics of a direct injection liquid fueled swirl flameless combustor (Sfc),” *Evergreen*, vol. 8, no. 1, pp. 117–122, 2021, doi: 10.5109/4372267.

[4] M. F. R. Tahiruddin, F. A. Abdul Kadir, S. A. Shamsudin, F. Ahmad, H. Jamaluddin, and T. I. Mohamad, “Recent Publication Trends on Throttle Body Design,” *International Journal of Nanoelectronics and Materials*, vol. 15, no. March, pp. 523–543, 2022.

[5] B. Ashok, S. Denis Ashok, and C. Ramesh Kumar, “Trends and future perspectives of electronic throttle control system in a spark ignition engine,” *Annu Rev Control*, vol. 44, pp. 97–115, 2017, doi: https://doi.org/10.1016/j.arcontrol.2017.05.002.

[6] Saxonparts.com, “BMW M10 Slide Throttle 44mm - SaxonParts,” Saxonparts.com. Accessed: Apr. 01, 2022. [Online]. Available: https://www.saxonparts.com/product/bmw-m10-slide-throttle-44mm/

[7] G. Stroes, “DTM S14 Slide Throttle Bodies,” e30sport.net. Accessed: Feb. 24, 2022. [Online]. Available: http://www.e30sport.net/tech_articles/engine-tech/dtm_slides/index.htm

[8] C. Series, “The study of slide-valve throttle orifice ’ s geometry influence on control surface actuator ’ s dynamical capabilities of maneuverable aircraft The study of slide-valve throttle orifice ’ s geometry influence on control surface actuator ’ s dynamical cap,” 2021, doi: 10.1088/1742-6596/1958/1/012003.

[9] J. Coxon, “The Slide Throttle,” High Power Media. Accessed: May 18, 2021. [Online]. Available: https://www.highpowermedia.com/Archive/the-slide-throttle

[10] G. Rowswell, “Fast car throttle bodies guide,” Fast Car. Accessed: May 17, 2021. [Online]. Available: https://www.fastcar.co.uk/tuning/fast-car-throttle-bodies-guide/

[11] W. Ashraf, S. Khedr, A. Diab, and H. Elzaabalawy, “Effect of Replacement of Butterfly Throttle Body by Barrel Throttle Body on Mass Flow Rate using CFD,” in *SAE Technical Papers*, Mar. 2017. doi: 10.4271/2017-01-1078.

[12] M. H. Abd Ghapar, “The effect of slide type throttle on an intake flow of a throttle body unit,” 2021.

[13] W. N. M. Z. Wan Mohd Zakri, “The effect of iris valve concept on an intake flow of a throttle, throttle body unit,” 2021.

[14] N. A. Che Hashim, “The effect of billet-barrel type throttle on an intake flow of a throttle body unit,” 2021.

[15] M. Mcharek, T. Azib, M. Hammadi, C. Larouci, and J.-Y. J.-Y. J. Y. Choley, “Multiphysical design approach for automotive electronic throttle body,” *IEEE Transactions on Industrial Electronics*, vol. 67, no. 8, pp. 6752–6761, Aug. 2020, doi: 10.1109/TIE.2019.2939999.

[16] Bosch Engineering, “Electronic Throttle Body,” Bosch Motorsport. Accessed: May 18, 2022. [Online]. Available: https://www.bosch-motorsport.com/content/downloads/Raceparts/en-GB/51017995147518219.html#/Tabs=51023243/

[17] D. R. D. Pijush K. Kundu, Ira M. Cohen, *Chapter-9-Laminar-Flow_2016_Fluid-Mechanics-Sixth-Edition-*, 6th ed. Academic Press, 2016. doi: 10.1016/B978-0-12-405935-1.00009-5.

[18] Cashco, *Fluid Flow Basics of Throttling Valves*. 2011.

[19] G. John, “Variable throttle valve,” Patent US6712040B1. Accessed: Apr. 01, 2022. [Online]. Available: https://worldwide.espacenet.com/patent/search/family/031993762/publication/US6712040B1?q=pn%3DUS6712040B1

[20] J. Isbester Thomas, “Clamshell-type hydraulic flow control gate,” Patent US3998426A. Accessed: Apr. 01, 2022. [Online]. Available: https://worldwide.espacenet.com/patent/search/family/024380559/publication/US3998426A?q=pn%3DUS3998426A

[21] T. Waits C, “Centerflow throttle valve,” Patent US2014352657A1. Accessed: Apr. 01, 2022. [Online]. Available: https://worldwide.espacenet.com/patent/search/family/051983708/publication/US2014352657A1?q=pn%3DUS2014352657A1

[22] K. Banis, “Throttle valve for internal combustion engines,” Patent LV15411B. Accessed: Apr. 01, 2022. [Online]. Available: https://worldwide.espacenet.com/patent/search/family/061622652/publication/LV15411B?q=pn%3DLV15411B

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