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The Effect of Inner Duct on Aerodynamic Noise of an Outside Rear View Mirror

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Abstract: Vehicle outside rear view mirror is one of the parts that produce aerodynamic noise. When the airflow gets contact with the body, aerodynamic noise produced as well as vibration noises caused by friction between air and the body. The study focused on the aerodynamic noise of vehicle outside rear view mirror produced during cruising or speeding. This research aims to analyze sound pressure level reduction by using different design of outside rear view mirror. SOLIDWORKS and ANSYS FLUENT computational fluid dynamics (CFD) simulation were used to design outside rear view mirror and analyze the aerodynamic noise. Boundary condition analysis and 3D modelling geometry were used as the method to conduct this project. This study involved two different outside rear view mirror designs which are the reference design and inner duct design. Each mirror was tested with 3 vehicle speeds: 110 km/h, 130 km/h and 150 km/h. Analysis shows that inner duct outside rear view mirror has lower sound pressure level produced compared to reference outside rear view mirror. An average, inner duct outside rear view mirror has 39.47 % noise reduction while reference outside rear view mirror has lower noise reduction which is 22.03 %. This can be concluded that inner duct outside rear view mirror is better design to reduce air resistance, surface area contacts and sound pressure level.

Keywords: Aerodynamic Noise, Outside Rear view mirror, computational fluid dynamic (CFD)

1. Introduction

Speed of the car does not depend, only on the engine's power but the exterior design of the car affects the speed too. In order to reach that speed level aerodynamic design is created. Until the last years, the vehicle design and shape are just the sign of fashion that usually has little concern with the car's aerodynamics. Due to the rate increase in the fuel prices, the first step was taken in the early 70s for aerodynamics in the development of the vehicles. So, with the advancement of engines in the automotive industry car speed is continuing to increase. The researchers are also looking at analyzing the drag and lift reduction and how these forces can be minimized that affect the road's efficiency and stability while running with the speed. Any improvement has its own consequences. One of the consequences is aerodynamic noise. Aerodynamic noise is a phenomenon related with high-speed operation. When new high speed line construction is designed, this sometimes leads to resistance on grounds of noise, even more so than on conventional lines [1-4]. Noise produced enter the vehicle through door windows. When the airflow gets contact with the body, aerodynamic noise produced and vibration noises caused by friction between air and the body. From an aerodynamic viewpoint, an outside rear view mirror outside a car is a bluff object with a large structural scale that is exposed in high-speed airflow.

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2. Methodology

This project consists of CFD simulation modelling of outside rear view mirror in SOLIDWORKS and boundary condition analysis using ANSYS FLUENT software. There are two models included in this project. The original design and another different design. Test and results are obtaining from different outside rear view mirror design. Both models were tested with three different vehicle speed which are 110 km/h, 130 km/h and 150 km/h. The humidity and temperature are constant for this project. The temperature is set to 23℃ and the humidity is set to 50%.

2.1 3D Modelling and Geometry of Outside Rear View Mirror

The aerodynamic noise radiation is calculated by using CFD commercial code FLUENT. In this study, there are two different of outside rear view mirror design to compare shape dependent aerodynamics effects. The first design is the original design of outside rear view mirror as shown in Figure 1. The second model design is the outside rear view mirror model that is designed by adding two inner ducts on the mirror as shown in Figure 2. Airflow passes from the leading edge of the mirror through the holes. Airflow rate become more stable and reduce the vorticity around the mirror, edge and gutter when the aerodynamic flow distributes by the inner duct. One modified outside rear-view mirror model is designed without reducing or changing the size of the original mirror.

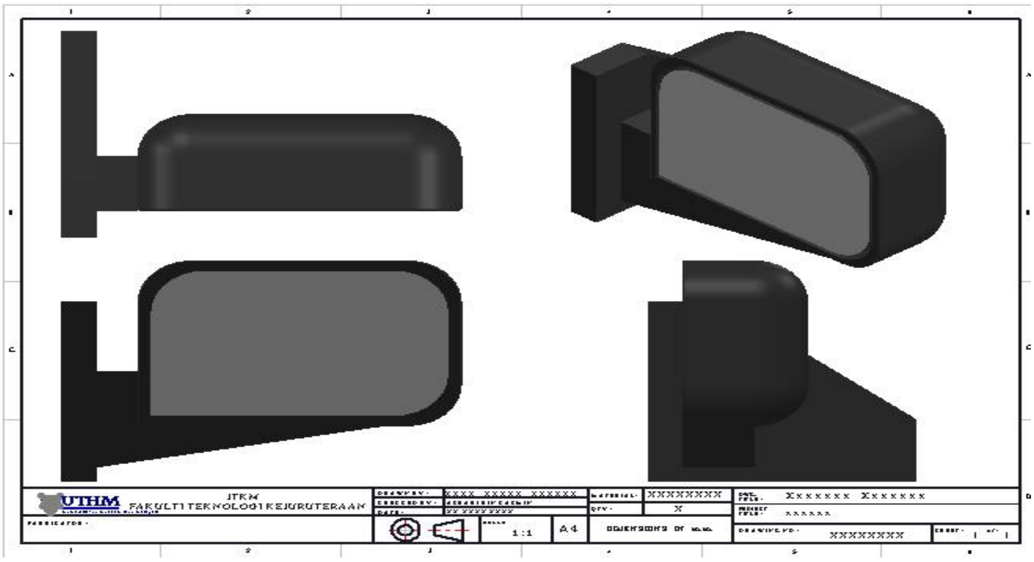

Fig. 1 - Reference outside rear view mirror

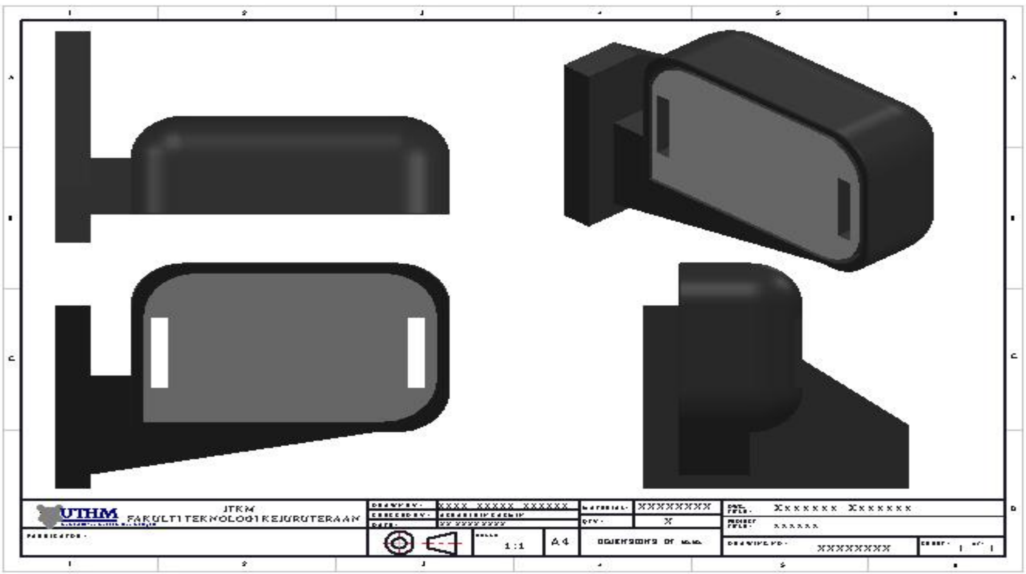

Fig. 2 - Inner duct outside rear view mirror

2.2 Boundary Condition and Analysis

In the CFD simulation, the aerodynamic performance of the two mirror models is compared by calculating the flow velocity and the sound pressure levels at three points which are the gutter, the edge and the centre of the mirror surface around the outside rear view mirror as shown in Figure 3.

A cuboid computational domain was used to obtain the CFD solution in this project as shown in Figure 4. The size of computational domain is 580 mm x 2000 mm x 800 mm considering the airflow rate and fields. The small part of the pillar, the gutter is included in the computational domain to minimize the aerodynamic effect on the mirror from the feature surrounding while driving because the vehicle body is in front and near to the outside rear view mirror.

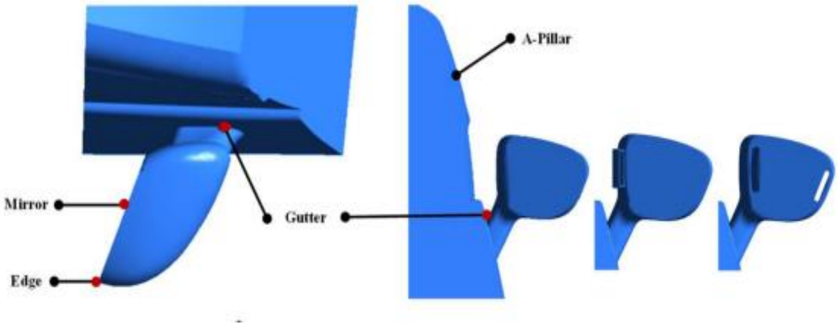

Fig. 3 - Edge, gutter and A pillar of the outside rear view mirror [2]

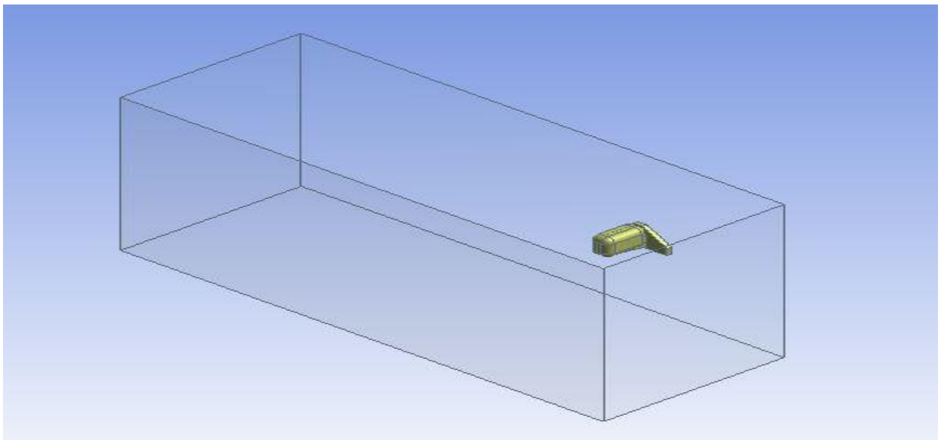

Fig. 4 - Computational domain

In the simulation, homogeneous velocity was applied through the inlet of the computational domain area and the homogeneous pressure was applied at the outlet of the computational domain as boundary condition considering the flow field. Besides that, stationary wall was also applied to the surfaces of the object and the computational domain. ANSYS Fluent was used to determine the computational dynamic analysis and using the environmental conditions such as the vehicle speeds, relative humidity and temperature of the inlet.

Standard k-epsilon turbulence model was used for the steady-state analysis. K-epsilon turbulence model was used to simulate mean flow for turbulent flow conditions. K-epsilon is the two-equation model that describe the turbulence of two transport equations. The k-ε two-equation turbulence model was used to obtain a steady solution of the flow field [5-6]. In this project, for aeroacoustic analysis a broadband source model of noise was applied. In contrast to the direct method and the integral Ffowcs-Williams & Hawkings (FW-H) method, the broadband noise source model does not require transient solutions to any governing fluid dynamics equations but requires the least computational resources [7].

The finite element mesh structure for the outside rear view mirror interior duct model is shown in Figure 5. In this study, a hybrid mesh with an external hex mesh and an internal box the automatic mesh function in the Commercial CFD code was generated around the mirror. Hybrid mesh generation was used because it exhibited the benefits of both structured and unstructured approaches to grid generation. Prismatic layers were adopted to catch boundary layers near no-slip walls, realizing strong orthogonality and clustering capabilities. Also, for complex geometries, this technique enables a single mesh to cover a computational domain. The versatility of the approaches allows the generation of automatic mesh accomplishments. In addition, the prismatic portion of a hybrid mesh reduces memory requirements and run times for a slow solver, compared to an all-tetrahedral mesh of the same resolution [8].

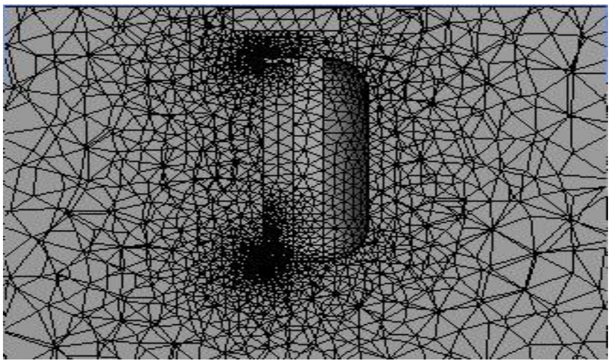

Fig. 5 - Element mesh structure for outside rear view mirror

CFD simulation started by creating the geometry which were reference outside rear view mirror and inner duct outside rear view mirror by using SOLIDWORKS software. The file was then saved in parasolid format. The geometry was imported to ANSYS Fluent in Design Modeler to create the enclosure which was the computational domain. The size of the computational domain was 580 mm x 2000 mm x 800 mm. Then, the mesh was generated. For the next step, in setup mode the model was set to k-epsilon turbulence equation and acoustic broadband noise sources. K-epsilon equation was used to simulate the mean flow characteristics for turbulent flow conditions. The material selection was set to aluminium and air because in this experiment air was used to demonstrate the simulation. The cell zone, the enclosure was set to 0 Pa pressure gauge to prevent reverse flow in the domain. Otherwise, the flow will be chaos in the domain. In boundary condition mode, the velocity of air from the inlet were set to 110 km/h, 130 km/h and 150 km/h based on the experiment scope. Then, the geometry mesh was initialized with hybrid initialization to determine the velocity and pressure fields of the simulation. Lastly, run calculation with number of iterations of 150. After getting the result, convergence was checked and analyzed. If the result succeed, next step will be proceeded and if the result was not succeeded, repeat the step from the beginning by checking the geometry mesh and the setup. After check the result and visualize, then collect the data and compare between inner duct model and reference model.

3. Results and Discussion

Table 1 show the velocity flow result at three different point according to the vehicle speeds and models.

Table 1- Simulation result of the velocity (km/h) at three different point according to vehicle speeds and models

Type	Vehicle Speed (km/h)	Gutter (km/h)	Mirror Surface (km/h)	Edge (km/h)	Average (km/h)	Edge-Gutter (km/h)
Reference Mirror	110	127.73	29.48	137.56	98.26	9.83
	130	162.68	34.85	173.31	123.61	10.63
	150	187.85	40.25	201.24	143.11	13.39
Inner Duct Mirror	110	142.06	40.57	152.21	111.61	10.15
	130	168.05	48.02	180.07	132.05	12.02
	150	194.65	55.62	208.55	152.94	13.90

Based on the result, velocity around the reference outside the rear-view mirror is lower than the velocity around the inner duct outside the rear-view mirror. This is because the line holes at the inner duct models allows more flow through the mirror. Small line holes create higher velocity because the air flows through the small surface area. Reference mirror have lower velocity because it has higher air resistance that block the air from pass through the mirror. Thus, creating higher sound pressure level.

Table 2 shows the sound pressure level result at three different point according to the vehicle speeds and models.

Table 2- Simulation result of the sound pressure level (dB) at three different point according to vehicle speeds and models

Type	Vehicle Speed (km/h)	Gutter (dB) (A)	Mirror Surface (dB)	Edge (dB) (B)	Gutter-Edge (dB)	(A-B)/A (%)
Reference Mirror	110	52.53	26.26	32.83	19.7	37.5
	130	80.92	57.80	69.36	11.56	14.3
	150	84.88	60.63	72.75	12.13	14.3
Inner Duct Mirror	110	49.90	22.66	26.44	23.46	47.0
	130	57.20	32.69	36.77	20.43	35.7
	150	60.57	34.61	38.94	21.63	35.7

Based on the result, inner duct outside rear view mirror has lower sound pressure level around the mirror compared to reference outside rear view mirror. The aerodynamic noise produced around gutter and edge decreased. However, the aerodynamic noise increases as the vehicle speeds increases too. The sound pressure did not cross each other because of the inner duct. When the high velocity flows through the inner duct, lower sound pressure level produced. Higher air flow through the edge and gutter causing the air density increases, thus increasing the sound pressure level. Reference outside rear view mirror has higher sound pressure level because of the pressure fluctuations by the change of velocity and air density that cause difference vorticities around gutter and trailing edge of the mirror surface. This outcome agrees well with previous studies stating that the intrinsic noise of the mirror sounds like a whistle, emitting pressure fluctuations near the trailing edges of the mirror housing [6] and a noticeable shift in the vortex of the A-pillar [9].

Figure 6 shows that inner duct side view mirror has lower drag coefficient compared to reference outside rear view mirror. Figure 7 shows that inner duct has lower drag force compared to reference mirror. This is because when the velocity increase, the drag force is increases too. Drag coefficient is directly proportional to drag force. Inner duct outside rear view mirror has lower drag force compared to reference outside rear view mirror because inner duct reduces the air resistance and less surface contact between the air and the mirror body. The density of air flow does affect the drag coefficient. Drag coefficient increases as the density of the sound pressure level increases.

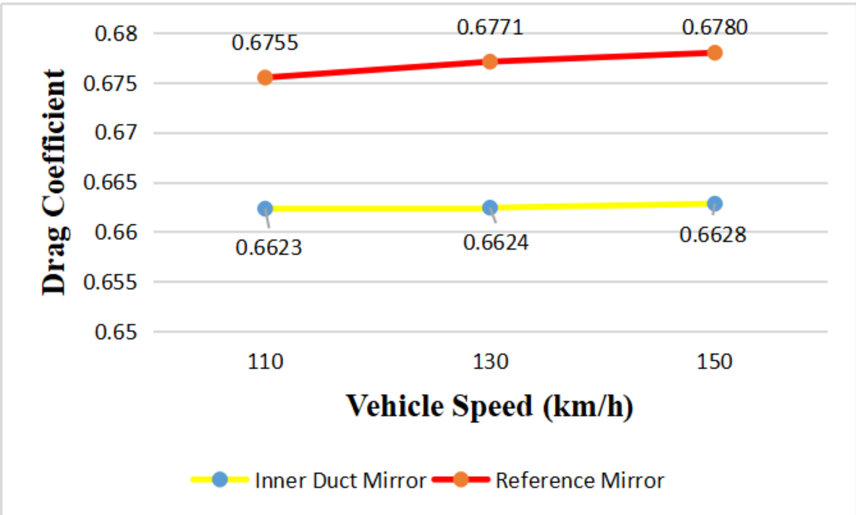

Fig. 6 - Graft drag coefficient against vehicle speeds (km/h) (a) first picture; (b) second picture

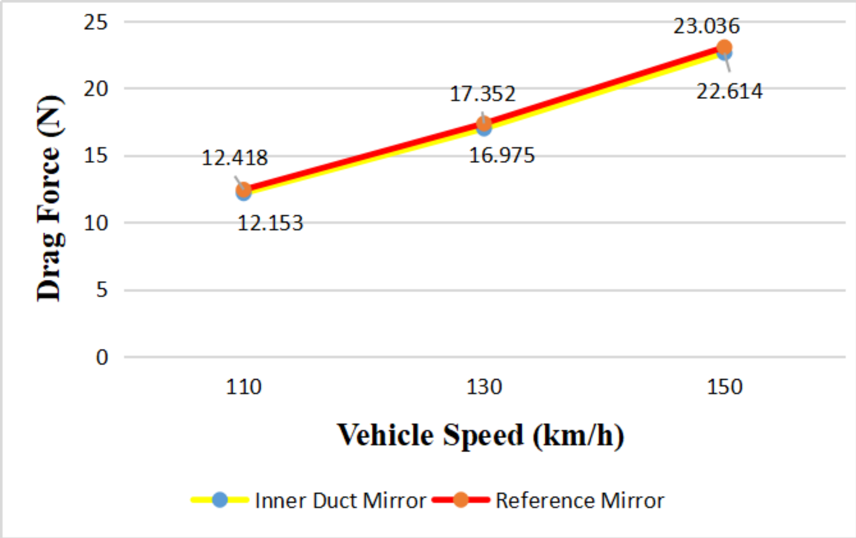

Fig. 7 - Graft drag force (N) against vehicle speeds (km/h)

4. Conclusion

As the finding, the inner duct outside the rear-view mirror has higher velocity than the reference outside rear view mirror but lower sound pressure level. This is because air that flow through the inner duct has higher velocity as the size of the inner is small. That higher velocity creates lower sound pressure level. The drag force and drag coefficient of the inner duct outside rear view mirror are lower than reference outside rear view mirror because inner duct reduces the surface contact between the air and the mirror body besides reduce the air resistance. This can be concluded that inner duct outside rear view mirror is better in reducing the sound pressure level compared to the reference mirror.

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References

[1] Thompson, D. J., Jones, C., & Gautier, P.-E. (2009). Railway noise and vibration mechanisms, modelling and means of control. Elsevier

[2] Yee San, C., & Mustaffa, N. (2019). Evaluation of SI Engine Fuelled by Liquefied Petroleum Gas on Performance and Emission Using 1D Simulation. Fuel, Mixture Formation and Combustion Process, 1(1)

[3] Ansari, A., Mustaffa, N., Khalid, A., & Jaat, N. (2019). Evaluation of Mixing Characteristics of Liquefied Petroleum Gas (LPG) at Different Injector Location. Fuel, Mixture Formation and Combustion Process, 1(2)

[4] Baharol Maji, D. S., & Mustaffa, N. (2021). CFD Analysis of Rear-Spoilers Effectiveness on Sedan Vehicle in Compliance with Malaysia National Speed Limit. Fuel, Mixture Formation and Combustion Process, 3(1)

[5] Chu, Y.-J., Shin, Y.-S., & Lee, S.-Y. (2018). Aerodynamic Analysis and Noise-Reducing Design of an Outside Rear View Mirror. Applied Sciences, 8(4), 519. https://doi.org/10.3390/app8040519

[6] Rinoshika, A., & Watanabe, S. (2010). Orthogonal wavelet decomposition of turbulent structures behind a vehicle external mirror. Experimental Thermal and Fluid Science, 34(8), 1389–1397. https://doi.org/10.1016/j.expthermflusci.2010.06.013

[7] ANSYS, Inc. (2016) ANSYS Fluent User's Guide, Release 17.2. - References - Scientific Research Publishing. https://www.scirp.org/reference/ReferencesPapers.aspx?ReferenceID=2172161

[8] Ito, Y., & Nakahashi, K. (2004). Improvements in the reliability and quality of unstructured hybrid mesh generation. International Journal for Numerical Methods in Fluids, 45(1), 79–108. https://doi.org/10.1002/fld.669

[9] Watkins, S., & Oswald, G. (1999). The flow field of automobile add-ons — with particular reference to the vibration of external mirrors. Journal of Wind Engineering and Industrial Aerodynamics, 83(1-3), 541–554. https://doi.org/10.1016/s0167-6105(99)00100-2