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Effects of Aerodynamic Characteristic at Different Velocity for Three Different Helmets and Neck Design Using Computational Fluid Dynamic Analysis

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Abstract: Helmet is one of the mechanism or safety element in motorcycle that protect motorcyclist from major injury in head and neck. Protective helmet may reduce the risk of death and head injury in motorcycle collision. However, there is still remain a large gap in knowledge regarding the effectiveness of different types of helmets in preventing injuries especially the one that relate to neck muscle strain occurs during riding. Most of the motorcyclist usually express their feeling of dissatisfaction with the fits of their helmets and it affected the posture of motorcyclist during riding. Bad posture of human caused different type of muscle strain on body. This study was focusing in research regardless neck strain during prolonged riding of motorcycle on a road. The main problem happened for air flow is how different type of helmet can cause the neck pain in motorcyclist since the different of velocity of air flow passing through may affect the muscle fatigue located on neck. In this research, the flow of air had simulated by using Computational Fluid Dynamics (CFD) software which is ANSYS-FLUENT to visualize the external flow streamline, which passed through the helmet model. It passed through three different helmets with three different velocities from 20m/s, 25m/s and 30m/s. The pressure distribution and velocity flow of helmet model are analyzed by representing it on streamlines and contour. As for the result, when the velocity is increase until 30m/s, it will create a low pressure at 266 Pa and very high velocity around the helmet. Thus, the turbulence rate in the region is very high. The result obtained shows the minimum average maximum principle elastic strain of neck occurs to the full-face helmet at 3.44×10-09. Full-face helmet meet the safest criteria compared to the other design in term of neck pain.

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1. Introduction

Helmets have been applied as a main part of protection, shielding the upper part of bodies especially sensitive region from incoming force and other penetration. The primary function of a helmet is to protect the head from skull fractures, and current helmets are usually effective in this regard. Another important function of motorcycle helmets is to prevent brain injuries, which can be quite serious. It can lead to long-term impairment or even death [1]. Main part of motorcycle safety is wearing helmet according to the existing law of local and foreign authority. Thus, wearing helmet allowing motorcyclist to contribute more on safety and avoid less injuries if accident happened

The neck becomes mechanically strained beyond its capability as a result of the combined weight of the helmet and head. A standard helmet weighing in at roughly 1.81 kg even a healthy neck might be weakened by a long ride. Other than that, an average head weight of 3.63 kg to 5.44 kg. A helmet also may contribute to stress on neck if it does not fit properly. Muscle cramp around the neck may occur if the helmet is too heavy. Some of helmet wearers express their feeling of dissatisfaction with the fits of their helmet [2].

Helmet is one of the safety elements that can protect the riders from severe injuries especially for the head during accident. Helmet can never be the solution toward the protection on the rider head only but the other part of human body needs to be considered the cause of the bigger problem. For a long time of riding there will be a several aspect or factor that need to be focus on especially when involving with safety. Other worldwide research has shown the protective effects of wearing a helmet in minimizing head and neck injuries. Nonetheless, some studies have suggested that wearing a helmet increases the risk of neck injuries [3]. This study analyzed the effect of different types of helmets onto the pain on the neck. Three basic of helmet design which are half-face, open-face and full-face helmets are being compared. The pain happened or experience by the motorcyclist can be interpreted in the form of stress and strain. For the sake of this study, three basic design of helmet and a model of human upper part body was designed in order to apply in the flow simulation using computational fluid analysis. The objective of this study is to select three helmet design according to the standard of helmet. Next, to analyze the effect of the aerodynamic characteristic at different velocity for three helmet design and lastly, to compared the most suitable form three design helmet according to the relationship between air flow, velocity flow, pressure, total deformation, stress and strain on the neck [4].

2. Materials and Methods

Proper methods and techniques should be followed to guarantee that the study achieves its aim. It is critical to define acceptable approach and right techniques for improved simulation and accurate analysis outcomes in a computationally based investigation [5]. This chapter's purpose is to outline our study approach and procedure in order to achieve the goal. The newly designed research tool was shown. The research is conducted to determine the relationship between motorcycle helmets including the type of helmet which are half-face, full-face and open-face with cervical spinal (neck) pain [6].

2.1 Analysis of Helmet

The helmet is being analyzed through computational fluid analysis dynamics, (CFD)software and flow analysis is being done of various velocities. The velocities chosen for this research are 20m/s, 25m/s and 30m/s. Whilst whiplash can occur in crashes that happen at low speeds (up to 4.2 m/s) as well as those that happen at moderate to high speeds, it is more likely that fractured bones, brain injuries, and concussions will also occur in the latter. However, in crashes occurring at higher speeds, the activated crumple zone is present to possibly absorb the stress [7].

2.2 Model Preparation

This section focuses on the helmet construction with the human standard head. Modern helmets are constructed from plastic. Premium cost helmets are made with fiberglass reinforced with Kevlar or carbon fiber. This helmet design material was being made up by carbon fiber. The neck material is made of Nylon 6/6 (PA66) [8].

The design model of the helmet had been created by using Solidwoks 2020, with some basic feature. The models then were exported to ANSYS Workbench by converting the file into IGES format [9].

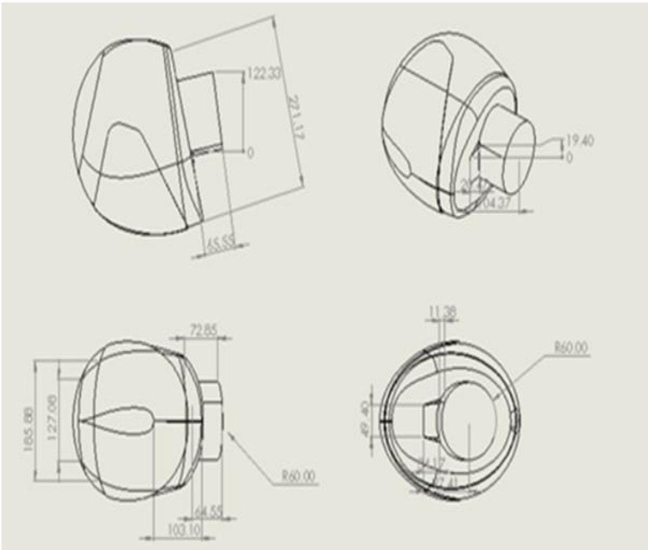

Fig. 1 - Orthographic drawing of full-face helmet

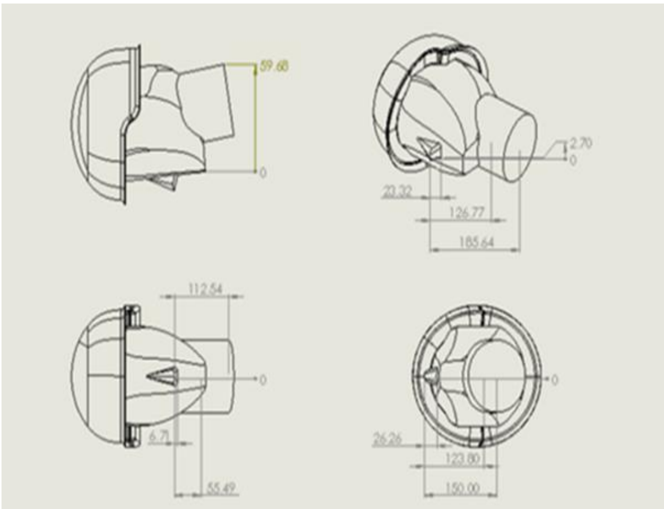

Fig. 2 - Orthographic drawing of half-face helmet

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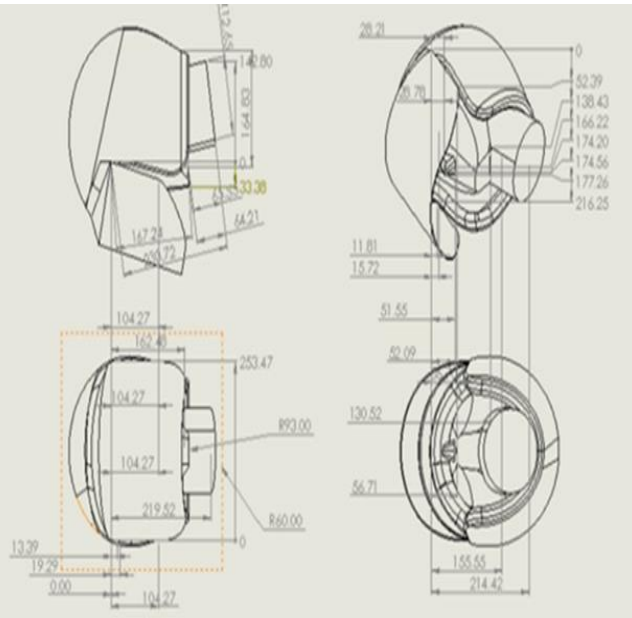

Fig. 3 - Orthographic Drawing of Open-face helmet

Figure 1, 2 and 3 shows the orthographic drawing of the helmet for three different types. The dimension of the helmet as be showed in the figure 1, 2 and 3 consists of its diameter, radius and the length.

2.3 Ansys Simulation Software

ANSYS is one of the parts in computational Fluid Dynamic (CFD) software. Most of CFD code such as ANSYS and other are now capable of producing reasonable aerodynamic flow predictions, they still rely on the user's knowledge and expert for setting up the model correctly, creating the right mesh, by having sufficient grid resolution and choosing the best numerical and physical models [10].

CFD can be define into three classification process, which are pre-processing, processing and post-processing the simulation geometry. There is various type of analysis that can be used. This research however, concern only use ANSYS Fluent Static Structure since it is mainly related to fluid flow (air) and structure integrity on neck and helmet [11].

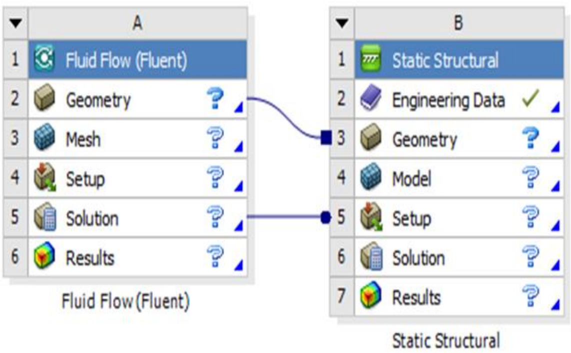

Fig. 4 - ANSYS Fluent Static Structure Simulation

Figure 4 shows the overall setup of ANSYS Fluent static structure simulation for the simulation of helmets and neck. Fluent static structure occurs when a fluid flow interacts with a solid structure and exert pressure and/or thermal loads onto the structure. Static structure analysis determines the displacement, stress, strain and forces in structures or component caused by loads that do not include significant inertia and damping effects.

2.4 Engineering Data

The physical properties of a substance refer to the state of the substance physically, independent of its chemical or mechanical makeup. These characteristics include mass, melting point and boiling temperatures, electrical and thermal conductivity, texture and density. All of these physical characteristic can be measured or observed [12].

Table 1 - Physical properties of Carbon Fibre (230 GPa)

Physical properties	Carbon Fibre (230 GPa)
Density(kgm-3)	1760
Tensile Modulus (GPa)	230
Poisson's Ratio	0.3
Shear Modulus (GPa)	5
Tensile Strength (MPa)	3530
Shear Strength (MPa)	-
Failure Elongation	1.50%

Table 1 show the physical properties of carbon fibre (230 GPa). Due too primarily to their high stiffness to weight ratio and high specific strength, carbon fibre are used extensively in structural applications [13]. Carbon fibre can typically be divided into three groups which are high strength, high modulus and intermediate modulus. A polymer that has undergone a carbonization procedure yields an organic precursor that is used to create carbon fibers. Carbon fibers make up the majority of carbon fibers used in automotive and aerospace applications [14].

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Table 2 - Physical properties of Nylon 6/6 (PA66)

Physical Properties	Nylon 6/6 (PA66)
Young's Modulus (GPa)	7.6
Poisson's Ratio	0.36
Yield Strength (MPa)	150
Tensile Strength (MPa)	140
Comp. Strength (MPa)	160
Density (kgm^{-3})	1400
Elongation	6.9%

Table 3.3 shows the physical properties of Nylon 6/6 (PA66). Nylon 6/6 has a characteristic of high lubricity, hydrocarbon resistance, and extremely balanced strength, ductility, and heat resistance. As strong as it is on its own, Nylon 6/6 may be made five times stronger and ten times stiffer by adding fillers, fiber, lubricants and impact modifiers. Materials can produce complicated structure with thick or thin walls thanks to its broad processing window [15].

3. Results and Discussion

This result discusses the validation as well as the results produced using CFD software, as well as the analysis derivation of each result. This chapter continues the product's development based on the technique presented in the previous chapter. Contour analysis, Streamline analysis, table analysis, and structure analysis. Structural analysis includes the total deformation, maximum principles stress and maximum principles elastic strain.

3.1 Grid Independent Test

Grid independent test is one of the important steps consider to be the one of the first result obtain apart from the project result. In order to build grids that work best, it is necessary to take into account the grid's shape, quality, and quantity. A component that affects the overall processing cost and the precision of the findings of simulation analysis is the number of grids. A considerable spatial discretization error is produced by coarse grids, which lowers the accuracy of the analysis's findings [16]. Calculation approach are important and should be similar or closely identical to the results as the mesh become finer, hence the term grid independence.

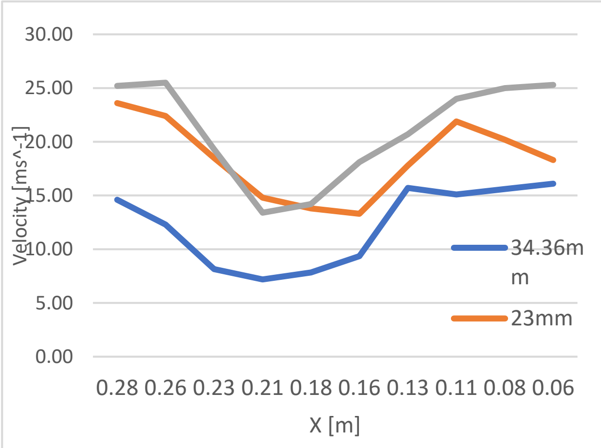

Fig. 5 – Grid independence test

Figure 5 above shows the velocity distributions for one of the models which is Full-face helmet with various of the element sizes. This model was selected to be a benchmark for the Grid Independent Test because of the less critical node could perform. Other than that, the velocity flow along the model shows quite stable velocity and the pressure shows a normal behavior value. This method required to setup the different element sizes of the element on the model. There are three element sizes which are 34.36 mm as a default element size from simulation, 23 mm and 10 mm. All of this model is run with the same value of velocity which is 20 m/s in order to get to compare the quality of meshing. The element size of 10 mm shows the most less percentage error after doing the calculation. The value calculated exhibit value less than 1 percent. As this model reach the grid independent, the cell size should be acceptable smaller. In effect of this selection there will be less error on the result afterward.

3.2 Velocity Distribution

In this analysis, the three helmets are determined their aerodynamic properties which one of it is velocity. This simulation can interpret the nature of the flow and also its structure. The flow structure that formed can be also known as velocity streamline. It is important to know that the flow happened to be formed around the object as it moved externally are very important and crucial which determined the aerodynamic characteristic of the object.

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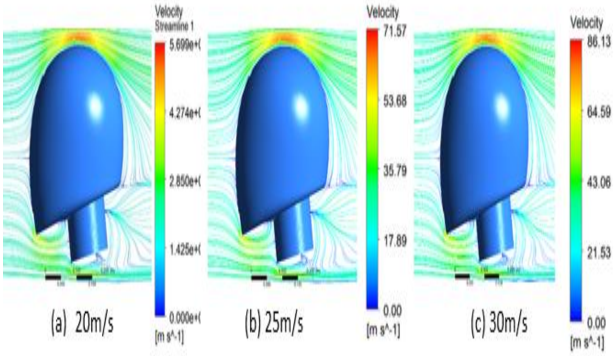

Fig. 6 - Full-face helmet Velocity distribution (a) 20m/s (b) 25m/s (c) 30m/s

For this simulation the object is well known of their aerodynamic design for the purpose of performance without left out the safety element. The velocity profiles of the distribution of the air flow around the Full-face helmet is shown in the Figure 6 While in an unstable flow this equivalence does not exist, in a steady flow this streamline pattern is similar to the flow lines or path-line that characteristic the track of the fluid particles within a Lagrangian description of the flow field [17]. As the fluid flow past the helmet which was set stationary. The fluid flow of air at an instant time flow from inlet until reach the surface of the helmet at the velocity of 20m/s.

From the figure 6, the velocity of air that flow through the helmet increase along with the increase in the velocity distribution. Velocity distribution formed highest at upstream level of the full-face helmet on 30ms-1 also affecting the number of air streamline. This phenomenon causing increase in streamline merging at that point.

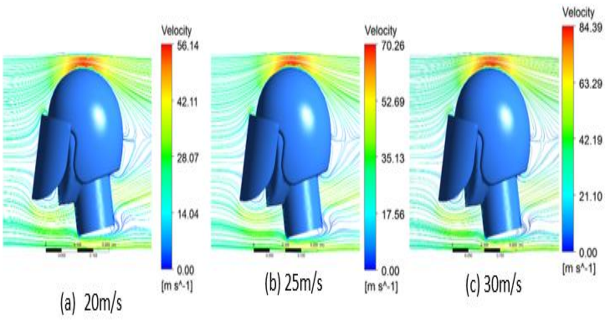

Fig. 7 - Open-face helmet velocity distribution (a) 20m/s (b) 25m/s (c) 30m/s

Figure 7 above display the velocity profile of the air flow distribution around the Half Face Helmet. The streamline pattern is comparable to the flow lines or path-lines that characterize the track of the fluid particles within the flow field of the steady flow field. In a steady flow, however this equivalence does not exist in an unstable flow. The helmet, which was immobile, was passed by the fluid. Air is moving at a rate of 20m/s from the inlet to the surface of the helmet at any given moment.

From figure 7, the velocity distribution occurs at maximum value of 84.39ms-1. The high velocity produce at the upstream of the helmet affecting the quantity of air streamlines. Thus, the movement of head front and backward will be slightly less compared to full-face helmet.

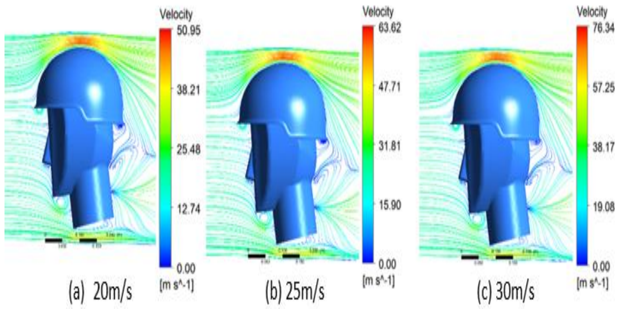

Fig. 8 - Half-face helmet Velocity distribution (a) 20m/s (b) 25m/s (c) 30m/s

Form the figure 8 above, the model of Half face helmet shows the result of quite big different from the other two model. These is because the model exhibits unique design which caused the velocity streamline flow differ from others. The flow behind the head shows the turbulent flow. The flow can be classified as the turbulent flow. Other than that, from the front part of the model, there are stagnation point and turbulent flow. Instability can be interpreted formed in the front as the flow are distributed far from the smooth line or laminar flow. The flow that flow from inlet reached the stagnation point split uneven velocity causing by the surface of the human head. For the matter of time, frequent or increase in the magnitude of the velocity of air can cause the injury for the muscle related to the face.

The velocity of the helmet specific detailed shows that the high value of velocity formed in the upper part of the helmet with the velocity of 76.34 m/s. This show by the all three model. One of the biggest different happened to be classified from these three models are the formation of the flow on the behind of the helmet. The flow of unsteady in the back of the helmet can be one of the factors that support the neck pain.

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3.3 Comparison of Velocity Distribution across Helmets Type

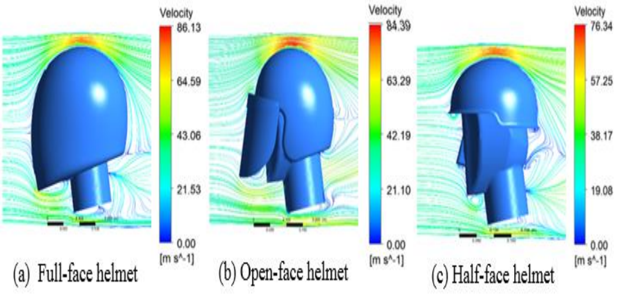

Fig. 9 - Comparison of Velocity distribution (a) Full-face helmet (b) Open-face helmet (c) Half-face helmet

Figure 9 shows the different velocity distribution on three types of helmets. These helmets produce different value of velocity at the same point which at upstream level. The maximum velocity value for full-face helmet is 86.13 ms-1 while for open-face helmet, maximum velocity value is 84.39ms-1. The least velocity value is at half-face helmet which is 76.34ms-1. As velocity distribution increase, the streamline also increases. The drag force produced will decrease thus low stress produce.

3.4 Wake Formation

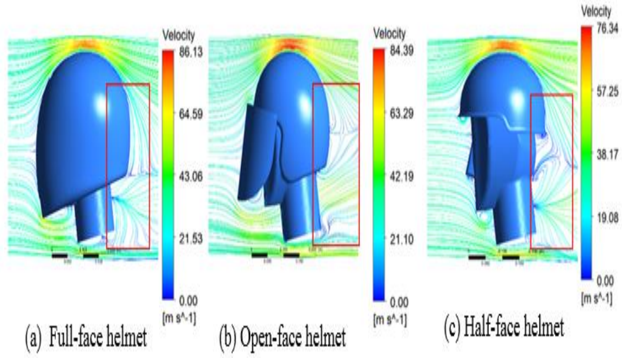

Fig. 10 - Wake formation (a) Full-face helmet (b) Open-face helmet (c) Half-face helmet

Figure 10 shows the flow pattern over the front and back of the helmet are quite different. In the front, the flow smoothly passes over the helmet, but in the wake flow is usually highly unsteady and large eddies or vortices are shed downstream. The large eddies are formed at a regular frequency and they produced pressure disturbances in the flow. Wake formation are more obvious in half-face helmet rather in the full-face helmet and open-face helmet. As the wake formation increase, the drag force also increases.

The wake formation are differ for the full-face helmet and open-face helmet. For full-face helmet, the formation formed on the neck and helmet while for the open-face helmet the formation was formed on the helmet only. This can be describe that open-face helmet provide less drag forces compared to the full-face helmet.

3.5 Pressure Distribution

In the physical sciences, pressure is defined as the stress at a point within a confined fluid or the perpendicular force per unit area. Pressure and velocity are inversely proportional to each other. If pressure increase, the velocity decrease to keep the algebraic sum of the potential energy, kinetic energy, and pressure constant.

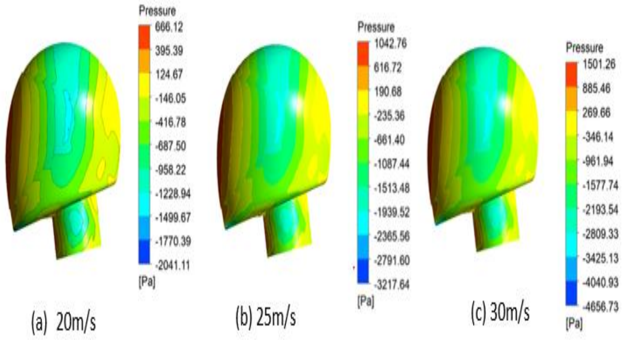

Fig. 11 - Full-face helmet pressure distribution

From figure 11 the pressure formed as there are the velocity of the air move from the inlet touch the model at velocity of 20 m/s. the pressure at their maximum value on the point or area at which there are low velocity of air. The fluid particle on the mid-section of the helmet at the stagnation point happened to produce the fluid to completely stop. As this occur, the pressure rising completely and instantly at where the point of in contact. Mathematical observation from this point, the velocity of the air can be valued as zero m/s. the velocity had a chance to be separated equally on the surface after the impact. The impact may be high due to the velocity but the pressure is more influenced at this point. The major problem could be more catastrophic if the whiplash phenomenon or can be known as the high velocity of air at very short time. When the air flow streamline moves downstream, the velocity is about to again decreasing velocity magnitude. This can be shown that the pressure starts to build up to about 266 Pa. In the context of human behavior, the sudden or frequent movement of this situation of speed could be affecting the human neck support and muscle.

Figure 12 above shows the pressure distribution of open-face helmet for three different velocity. The pressure created as the air moved from the inlet to the model at a speed of 20m/s is shown in the above Figure12. The pressure reached its maximum value at the location or region where the air velocity was low. At the point of stagnation, a fluid particle on the middle of the helmet caused the fluid to stop altogether. As this happens, the pressure instantaneously and totally increases at the site of contact. The air's velocity may now be calculated mathematically to be zero meters per second. After the hit, the air's velocity had a chance to be distributed equally on the surface.

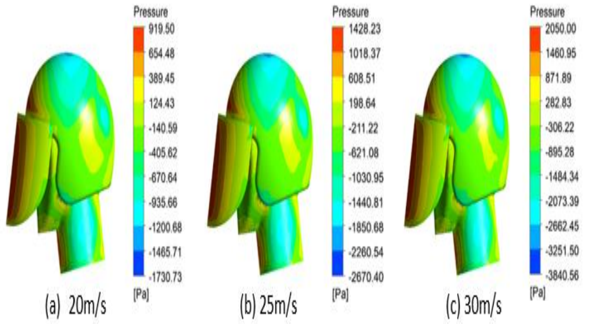

Fig. 12 - Open-face helmet Pressure distribution (a) 20m/s (b) 25m/s (c) 30m/s

The velocity may provide a high impacted, however the pressure is being affected more at this time. The main issues can become more severe if the whiplash phenomenon or high velocity in a brief period of time occurs.

Additionally, because the action at the stagnation point is less affected by air velocity in this condition, pressure is spread evenly and consistently. However, after the flow effect on the helmet's front portion, there are also significant effect on the center surface and the back of the helmet. As the liquid circulates around the helmet at the constant velocity, pressure is continually created in a consistent way. The figure above demonstrates how the color of the pressure contour varies at its upper part, which is 90°. Since the air is moving at its fastest speed at this location, the pressure is at its lowest point.

The velocity is about to gain decrease in magnitude as the air flow streamline moves downstream. This demonstrates that the pressure began to increase about 266 Pa. The human neck support and muscle may be impacted by the sudden or the frequent movement of this scenario of speed in the context of human behavior.

Figure 13 above shows the three conditions of an applied value of velocity from 20m/s, 25m/s and 30m/s affecting on the model pressure. The pressure produced on the model formed. Apart from the other model, this model does not consist of visor that can protect the surface of head. The flow on the front of the head can be unsteady flow. The pressure point at the front part of the helmet is about to be distributed scatted and non-uniformly.

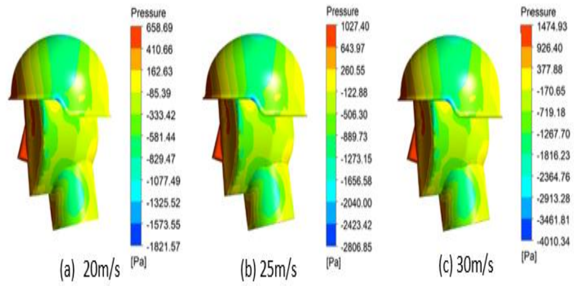

Fig. 13 - Half-face helmet Pressure distribution (a) 20m/s (b) 25m/s (c) 30m/s

The contour of the light blue formed on the neck of the human model are slightly differ from the model of helmet Open Face helmet. The light blue contour indicated the low pressure formed on the neck are less than in the open face helmet. The velocity of the air at this part are high thus the pressure will be low. On the other hand, there are formation of the high value of pressure on the front part of the neck. This can affect the movement of the helmet and the neck.

3.6 Maximum Principle Elastic Strain

Table 3 - Maximum Principle Elastic Strain of Helmets and Neck

	Velocity [m/s]	Minimum [mm/mm]	Maximum [mm/mm]	Average [mm/mm]	Maximum occur on
Full-face helmet	20m/s	-2.26×10^{-09}	1.86×10^{-05}	1.03×10^{-06}	Neck
	25m/s	-9.83×10^{-09}	7.02×10^{-06}	3.74×10^{-07}	Neck
	30m/s	-1.82×10^{-09}	7.62×10^{-08}	3.44×10^{-09}	Neck
Open-face helmet	20m/s	-8.85×10^{-09}	3.49×10^{-06}	2.18×10^{-07}	Neck
	25m/s	-1.36×10^{-08}	5.42×10^{-06}	3.38×10^{-07}	Neck
	30m/s	-1.96×10^{-08}	7.76×10^{-06}	4.85×10^{-07}	Neck
Half-face helmet	20m/s	-3.20×10^{-08}	4.08×10^{-07}	8.35×10^{-09}	Neck
	25m/s	-4.88×10^{-08}	6.33×10^{-07}	1.29×10^{-08}	Neck
	30m/s	-7.02×10^{-08}	9.10×10^{-07}	1.87×10^{-08}	Neck

Table 3 above shows the value of minimum and maximum elastic strain formation on the helmet and the neck of the model. These values are done by applying the pressure of air to the model. pressure and velocity of the inlet air that flow through the model gives such a difference in the unit values of the elastic strain formed. Full-face helmet from this result shows the least value of elastic strain compared to the other models. This is happened because of the design of the helmet are far less complexity and the stagnation point formed on the front

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part of the helmet are producing evenly split of the air. The formation of the turbulence flow on the back of the helmet are also less.

According to the theory of maximum principles strain, the failure of a material or component will occur when the maximum value of principle strain developed in the body exceeds the limiting value of strain. The result obtained shows the minimum average maximum principle elastic strain of neck occurs to the full-face helmet at 3.44×10-09. In conclusion, the aerodynamic forces including the velocity and pressure distribution that affect to the different type of models causing a significant large due to the design of the helmets itself. This study suggested that the use of Full-face helmet meet the safest criteria compared to the other design in term of neck pain. The future of this study should be more concern on analyze the prolonged used that could causing more fatality

4. Conclusion

In this study, Computational Fluid Dynamic (CFD) ANSYS using one-way coupling of the Fluid-Solid Interaction (FSI) approach. This method typically describes the pure mapping of physical properties resulting from the analysis of a fluid-model to another solid-model. This study examined the effect of air flow on the different type of helmet and neck pain. The analysis of the maximum principles elastic strain is shown in various velocity of air affecting the human neck. Different type of helmet design exhibits different value of the fluid flow of air and then the other parameters which could also affecting the integrity of the structure. This can be examined through the flow condition and the structure analysis in static structure simulation.

This study has successfully design 3 helmets according to the standard design through Solidwork. It was found out that full face helmet had a highest velocity distribution which is 86.13 m/s. This high velocity flow produced around the helmet caused low drag force and also low strain value. other than that, the data of maximum principles elastic strain shows the lower value of average elastic strain happened on the neck of full-face helmet. Thus, this study suggest that the full-face helmet has the best design compared to open-face and half-face helmet. The finding of this simulation required more detail perspective in doing the research which could lead to more accurate result. These predictions are taught to be help solving problem not only in the matter of engineering but also for the public safety and health.

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