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The Use of Tarpaulins on the Body of a Pickup Truck on Airflow Patterns and Pressure Distribution Characteristics: An Experimental Study

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ABSTRACT

The installation of tarpaulins on the body of pickup trucks is often used to protect goods from heat and rain, which affect airflow patterns, pressure distribution, and vehicle aerodynamics. This research was conducted to determine the airflow pattern and pressure distribution characteristics such as static pressure, dynamic pressure, and pressure coefficient that affect the performance of a tarpaulin-fitted pickup truck. Experimental tests were carried out on 6 specimens, namely pickup trucks without using a tarp or baseline, pickup trucks fitted with tonneau cover tarpaulins (type A), Aerocap tarpaulins with an angle of 0° (type B) and 12° (type C), and Cincing tarpaulins with foot angle of 30° (Type D) and 15° (Type E) in the wind tunnel at a speed of 5.47 m/s. The results showed that the more aerodynamic the use of tarpaulins resulted in a streamlined flow pattern, as shown by the use of 12° aerocap tarpaulins, which had more aerodynamic flow and the most stable fluctuations in the Cp value, blockage mass, and smaller obstacles compared to other pickup trucks.

1. Introduction

The use of motorized vehicles in Indonesia is increasing along with the times. Transportation or motorized vehicles on land that are commonly used daily are two-wheeled and four-wheeled. One of the most frequently used four-wheeled vehicles to facilitate human work in moving large amounts of goods is the pick-up truck. Pickup trucks are one of the four-wheeled vehicles that are in demand in Indonesia because they can transport goods in moderate quantities, not too little and not too much. Usually, these pickup trucks are used by individuals and business entities to transport goods such as food, livestock, cargo and even to sell products such as vegetables and household furniture. With its smaller size, it is more efficient if it is used to pass through narrow roads and bridges that are impossible for ordinary trucks to pass.[1]

Although the size of the pickup truck is smaller than the usual truck, it is also necessary to pay attention to the efficiency of fuel consumption, safety and comfort when using a pickup truck. This can be influenced by the aerodynamic factors of the vehicle. A study by Muchammad (2006) states that controlling aerodynamic forces on a pickup vehicle can also improve the performance of the vehicle.[2] The aerodynamic body shape of the pickup truck can reduce drag engine power to become the driving force for vehicle traction, maintaining vehicle stability, and saving fuel.

One of the aerodynamic characteristics is the airflow pattern that occurs due to the vehicle body blocking the airflow so that there will be a change in pressure.[3] Airflow patterns are influenced by the shape of the vehicle body itself. So that the airflow pattern that is not streamlined on the body will have an impact on vehicle speed and fuel consumption. In Indonesia, pick-up trucks are often fitted with tarpaulins to protect goods from rain and heat on the part of the pickup which affects the aerodynamic style. The emergence of this force resulting from the flow of air passing through various points on the pickup truck will produce a pressure difference. This pressure difference causes a different pressure distribution.

Pressure distribution is a fluctuation of the value of the pressure coefficient (C_p) caused by the mechanics of airflow that occurs and flows through various points on the surface of the vehicle body.[4] The value of C_p can be determined through the difference between the measurement of the static pressure on the body contour and the free stream static pressure divided by the free stream dynamic pressure.[5] This is why the use of tarpaulin variations on pickup trucks needs to be considered to reduce the occurrence of early wakes and separations, increase speed, save fuel, stabilize the vehicle and produce a streamlined flow pattern on the pickup truck body. The streamline around the vehicle body will have a very complex airflow pattern due to the shape of the vehicle body itself so that around the vehicle body there will be airflow disturbances. While the streamline at a greater distance from the vehicle body will form a parallel and undisturbed flow pattern.[6]

Research by Moussa shows that trucks with an aerocap using a fairing produce a lower C_d value than without using a fairing so that it can save fuel consumption and can optimize engine power.[7] Another study conducted by Adem (2010) stated that the use of additional equipment can reduce the drag coefficient compared to the baseline pickup truck.[8] data shows the highest Cd reduction of 19.84% and the highest CL reduction of 40.72% was achieved by a pickup truck using a 3D curved aerocap with a tilt angle of 12° This study was conducted to determine the airflow pattern and the characteristics of the vehicle pressure distribution such as static pressure, dynamic pressure, and pressure coefficient that affect the performance of the pickup truck if it is fitted with a tarp on the body.

2. Methods

This research is experimental. This study will analyze the effect of installing tarpaulin on the body of a pickup truck with several variations of tarpaulin on airflow patterns and pressure distribution characteristics with experimental studies in one wind tunnel unit. The independent variables in this study were a pickup truck without tarpaulin, a pickup truck with a tonneau cover (type A), a pickup truck with an aerocap tarpaulin with an inclined angle of 0° (type B), a pickup truck with an aerocap tarpaulin with an inclined angle of 12° (type C). pickup trucks with cincing tarps with a 30° foot angle (type D), and pickup trucks with cincing tarps with a 15°foot angle (Type E). The dependent variables in this study are freestream static pressure, dynamic freestream on the body contour, pressure coefficient ($C_{p)}$), and airflow patterns. The control variable is the airflow velocity in the test section which is constant at 5.47 m/s and the air temperature in the test section is kept constant. The tools used in this research are wind tunnel, hot wire anemometer, inclined tube manometer, smoke machine and camera. The test specimen in this study was a Mitsubishi L300 pickup truck model which was printed using 3D printing using polylactic acid (PLA) material.

The research procedure used a constant speed of ± 5.47 m/s. In the test, testing will be carried out on 41 points consisting of 30 points on the upper side and 11 points on the underside, where each of these points will be analyzed for its effect. The distance between points on the upper side is ± 17 mm and ± 30 mm on the underside. Data analysis was carried out with the following process; taking pictures from video visualization of airflow patterns and processing into images of analysis of airflow phenomena. Then calculate the Reynolds number and the dynamic pressure of the airflow. Next, processing the "L" data on the inclined tube manometer into a freestream and static pressure system arrangement of static pressure on the body contours of the test pickup truck. Next, the pressure coefficient is calculated.

3. Results and Discussion

Recording and analysis of visualization of airflow patterns

In this study, the media which is used to assist the process of visualizing the pattern of an airflow across the body of the model vehicle is the smoke produced by the smoke machine. The following is a visualization image of the working fluid flow that crosses the contours of the test model vehicle body, which is obtained from the results of the visualization of the airflow pattern. The research carried out obtained 6 visualizations of the working fluid flow of the pickup truck test model with variations in the use of tarpaulins, namely without tarpaulin (baseline), tonneau cover tarpaulin (type A), 0° aerocap tarpaulin (type B), 12° aerocap tarpaulin (type C), 30° cincing tarp (type D), and 15° cincing tarp (type E) (Figure 1).

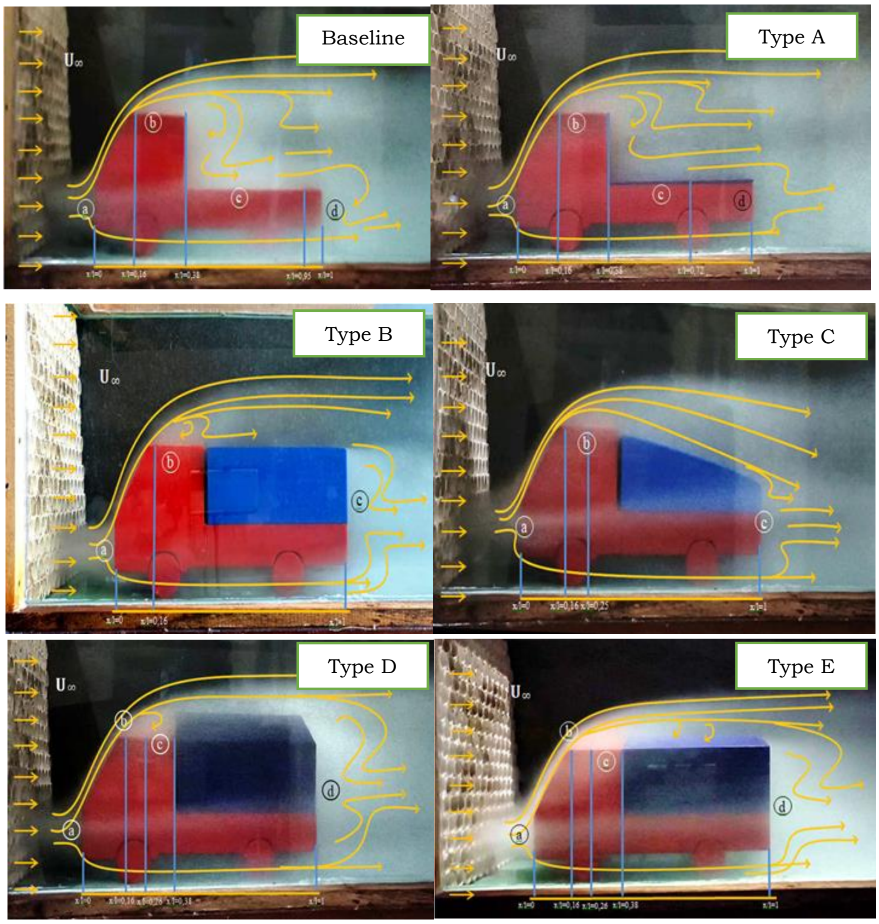

Figure 1. Visualization of working fluid flow on each pickup truck model. Description: Baseline: truck model without tarpaulin; type A (tonneau cover tarpaulin pickup truck); type B (aerocap tarpaulin model pickup truck 0^{o}); aerocap tarpaulin model pickup truck 12^{o}); type D (cincing tarpaulin model pickup truck 30^{o}), type E (cincing tarpaulin model pickup truck 15^{o}).

Air moves from the leading edge to the trailing edge of the test vehicle. Point a is the stagnation point, where the airflow velocity v = 0 m/s. Point b is the separation point that occurs at the ratio x/l=0.16. At point (b) a truck without a cover (baseline) which causes an adverse pressure gradient is indicated by the back-to-front flow. The separation phenomenon occurs because the flow lines are no longer able to adhere to the shape of the body surface and are pushed away toward free flow. Furthermore, at point (c) at a ratio of x/l=0.38 to a ratio of x/l=0.95 the flow that flows in the tub section produces blockage mass which causes a large and thick circulation as indicated by thick white smoke that accumulates in the tub section. This circulation is caused by the pressure difference between the empty pickup and the surrounding air. Point (d) is a region of low pressure (wake). Streams flowing below experience less impact separation area due to the shape of the pickup truck bottom and friction from the road.

The separation phenomenon in type A trucks occurs because the flow line is no longer able to adhere to the shape of the body surface and is pushed away toward free flow. Furthermore, at point (c) at a ratio of x/l=0.38 to a ratio of x/l=0.72 the flow that flows in the body produces a blockage mass that is smaller than a pickup truck without a tarpaulin. With the addition of a tonneau cover tarpaulin, it shows a reduction in circulation that occurs in the body of the pickup truck, which is indicated by the white smoke which is thinner and does not accumulate too much in the body. Point (d) is an area of low pressure (wake) and is more regular than without the use of tarpaulin.

At point (c) the type B pickup truck creates a lower wake area that is greater than the use of other tarpaulins. This is because the use of square and large tarpaulins causes the airflow behind to have a larger wake distance according to the shape of the tarpaulin itself.

The separation phenomenon in the type C pickup truck model occurs because the flow line is no longer able to adhere to the shape of the body surface and is pushed away toward free flow. Furthermore, at the ratio x/l = 0.25 a reattachment line occurs. Then at point (c), it produces the smallest low-pressure area (wake) compared to other pickup trucks. This is due to the aerodynamic shape of the tarpaulin so that it follows the airflow pattern.

In the type D pickup truck model, point (c) at the ratio x/l=0.26 to x/l=0.38 mass blockage occurs due to the cincing tarpaulin blocking the flow so that it can increase drag. This can be seen from the thick white smoke that accumulates at point (c). Then at point (d) a fairly large low-pressure area (wake) is formed due to the use of large and not aerodynamic tarpaulins.

Furthermore, on the type E pickup truck model, point (c) in the ratio x/l=0.26 to x/l=0.38 blockage mass occurs due to the cincing tarpaulin that blocks the flow but the shape is smaller than the 30°foot angle cincing tarp. Then at point (d), a large low-pressure area (wake) but it is still smaller than the 30° foot angle cincing tarp.

Results of fluid measurement with test equipment

Based on measurements with test equipment, data obtained; fluid velocity (V) = 5.47 m/s, fluid temperature (T) = 31.3°C, and hydraulic diameter (D) = 0.35 m. By knowing the fluid temperature, the fluid density (ρ) = 1.160 kg/m^3**,** dynamic viscosity (μ) = 0,000018613 N.s/m^2, and kinematic viscosity (v) = 0,000016078 m^2/s. Then the Reynolds number can be calculated as follows;

$$Re = \frac{v\,D}{\mu} = \frac{1.160\ kg/m^3\ .5.47\ ms\ .0.35\ m}{0.000018613\ N.s/m^2} = 119{,}315$$

Furthermore, each specimen was tested with the same Re freestream. In this study, the air velocity in the test section in the wind tunnel is 5.47 m/s and the fluid density is 1.160 kg/m^3 so that the freestream dynamic pressure in the wind tunnel can be calculated as follows;

$$P_{d\infty} = {}^{1}\!/_{2}\, \rho\, U_\infty{}^2 = {}^{1}\!/_{2}\ 1{,}160\ \text{kg}/m^3\ .\ (5{,}47\ \text{m/s})^2 = 17{,}354\text{N}/m^2\ \text{(relative dynamic pressure)}$$

Static pressure on the wind tunnel test section wall is determined by obtaining the stagnation pressure value at the front contour of the pickup truck body. Based on the stagnation pressure data on the front of each pickup truck model, the fluid displacement distance (Δ= 13.5 mm) and the stagnation pressure on the contour of each vehicle model is 26.507 N/m².

After obtaining the stagnation pressure value on the front contour, the static pressure of the test section wall can be calculated as follows

$$P_0 = P_{s\infty} + \frac{1}{2}\,\rho\,{U_\infty}^2$$

$$P_{s\infty} = P_0 - \frac{1}{2}\,\rho\,{U_\infty}^2$$

$$P_{s\infty} = 26{,}507\ \mathrm{N/m^2} - 17{,}354\ \ \mathrm{N/m^2}$$

$$P_{s\infty} = 9{,}153\ \mathrm{N/m^2}$$

So that the static pressure value of the test section wall is used to determine the value of Cp (Pressure coefficient) at all other measurement points in each vehicle model.

Determination of the pressure coefficient (Cp) on the model pickup truck

The pressure coefficient is calculated by the following equation;

$$C_p = \frac{P_s - P_{s\infty}}{P_{d\infty}} = \frac{26{,}507\ N/m^2 - (9{,}153\ N/m^2)}{17{,}354\ N/m^2} = 1$$

Figure 2 shows the distribution of the pressure coefficient on the upper side which is combined into 1 graph. In the front area the ratio x/l = 0, the maximum Cp value is Cp = 1 which indicates the occurrence of a stagnation point, where the maximum airflow pressure and air velocity v = 0 m/s. The value of Cp at a ratio of x/l=0 is not all worth =1, this is because there is a forward bound vortex phenomenon at the front of the pickup truck.

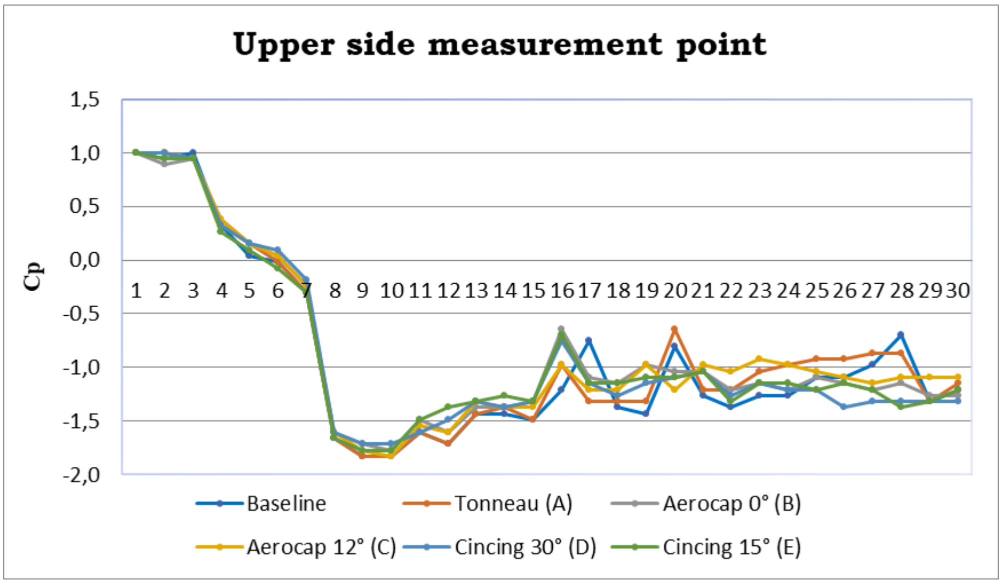

Figure 2. Graphics of upper side Cp combined.

Stable Cp values are produced by a pickup truck using a 12° aerocap tarpaulin so that the flow pattern is more aerodynamic and there is minimal blockage mass. In addition to producing a streamlined flow pattern, the use of 12° aerocap tarpaulin also resulted in a smaller wake area at the rear of the pickup truck as evidenced by the Cp= -1.093 value which was greater than the use of other tarpaulins. This is supported by previous studies that used the CFD method so that they mutually reinforce the results of the two methods (experimental and CFD).[8]

Meanwhile, unstable Cp values were produced in pickup trucks without tarpaulin, tonneau cover tarpaulin, 30° cincing tarpaulin and 15° cincing which indicated the occurrence of blockage mass. The use of 30° cincing and 15° cincing tarps resulted in a more complex flow where bound vortex and blockage mass occurred at the front of the tarpaulin which obstructed the airflow pattern resulting in large resistance, streamlined and irregular flow. The largest wake area occurred in the use of 30° cincing tarpaulin as evidenced by the smallest value of Cp= -1.319 due to the non-aerodynamic shape of the tall and large tarpaulin.

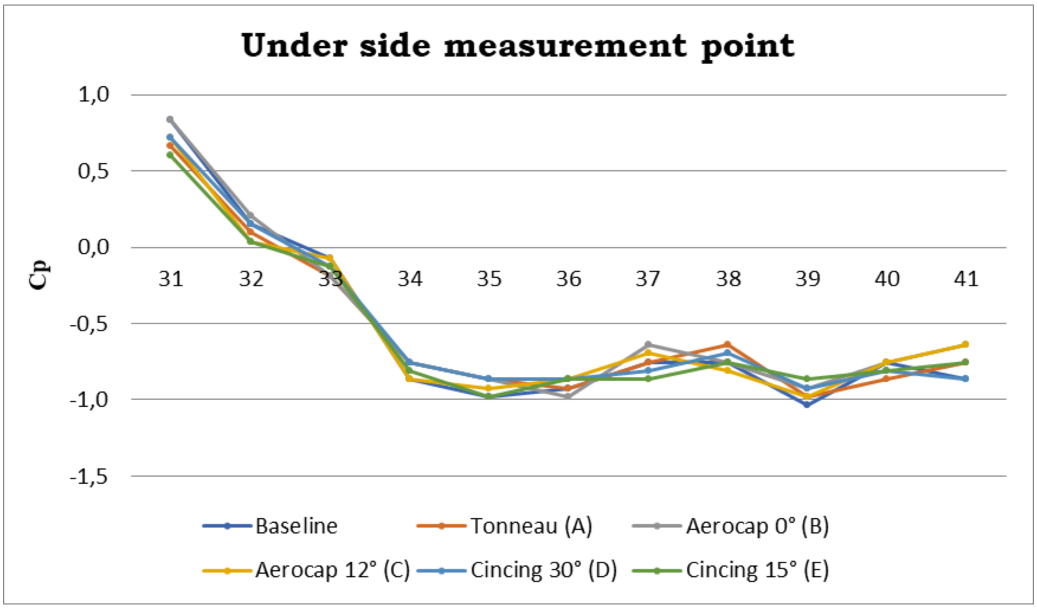

Figure 3. Graphics of under side Cp combined.

Figure 3 describes the distribution of the pressure coefficient on the underside which is combined into 1 graph, from the graph above it can be seen that there is no significant change in the value of Cp on each underside of the pickup truck due to the shape of the bottom of each pickup truck test model is no different. This shows that the measurements on all the pickup truck model tests are consistent and accurate. Where on the underside, the Cp value of the measurement points 31 and 32 on each pickup truck is positive, then there is an increase in speed from point 33 to point 36 due to a decrease in the Cp value towards the negative. In the rear area at point 41, the largest Cp value is produced, namely by a 12° aerocap tarpaulin pickup truck where the airflow approaches the lower body contour, while the smallest Cp value is produced by a 30° cincing pickup truck where the airflow is away from the lower body contour.

4. Conclusion

Based on the results of the study, it can be concluded that the more aerodynamic use of tarpaulins results in a streamlined flow pattern, as shown by the use of 12° aerocap tarpaulins which have more aerodynamic flow than other pickup trucks. The use of tarpaulin variations affects the value of the static pressure distribution along the pickup truck body as indicated by unstable fluctuations in the Cp value due to blockage mass on the baseline and tonneau cover pickup trucks. The fluctuation of the Cp value of the 12° aerocap tarpaulin pickup truck is the most stable, the blockage mass and the resistance that occurs are smaller.

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