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Analysis of Airflow Patterns and Pressure Distribution Characteristics on Cars with Variations of Under Front End Tilt Angle

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A B S T R A C T

The airflow across the underbody of the car will affect the lift and drag of a car. Part under front end car vehicle is one of the factors in the car that causes drag and also lift. This research was conducted to determine the airflow pattern and pressure distribution characteristics, such as static pressure, dynamic pressure, and pressure coefficient, which affect the performance of the test vehicle with variations in the angle of the under-front end. Experimental testing was carried out on 4 specimens, namely car vehicles with variations in tilt angles under front end 0°, 5°, 10°, and 15° inside the wind tunnel with a speed of 5.47 m/s. The results showed that the under front end of the 0° tilt angle is an area with low pressure, where the lift that occurs is relatively smaller than the under front end area which varies the angle of inclination. However, pressure fluctuations experienced by an angle of 10° are more stable than 0°.

1. Introduction

Many factors influence the making of a car. One of the factors is the shape of the car's body. One of the things that must be considered in the car body is the aerodynamics. One of the characteristics of aerodynamics is the airflow pattern that occurs due to the car body blocking the airflow so that there will be a change in pressure. The airflow pattern is greatly influenced by the shape of the car body, so the shape of the airflow pattern that is not streamlined will affect the speed of the car. A study shows the visualization of airflow patterns and pressure coefficients at various tilt angles of 0°, 5°, 10°, and 15° under rear end test car with an experimental method. The study found that the slope angle variation model under the rear end 5° the best of all test models because it has a low-pressure area in the rear area which is marked with Cp = -0.1, and on the under rear end has a smaller low-pressure area compared to other models.[1-5]

A study that conducts research on airflow patterns and static pressure distribution with variations in curvature roof without curvature, 600 mm, 1200 mm, and 2400 mm in test cars with experimental methods. Krishna got the result that the test car model with a roof 2400 mm curvature is better than other models due to the area blockage mass being smaller, namely at the ratio x/l=0.13 to x/l=0.26, the separation point occurs more delayed towards downstream with a value of x/l = 0.71 and a lower pressure coefficient with a value of Cp = 0.21, so that the resistance received is smaller. Studies that conduct research on airflow patterns and static pressure distribution on upper sidecars with the use of rounding on the non-curved variation, 200 mm, 400 mm, and 600 mm in front hood cars, with experimental methods, get the result that the use of rounding from 200 mm, 400 mm to 600 mm will further reduce forward bound vortex that happened so pressure drag can be reduced. In each model vehicle, there is an airflow stagnation point at the ratio x/l = 0. Flow separation occurs at a ratio x/l = 0.03 for vehicles without rounding and x/l ratio = 0.43 for vehicles with 200 mm, 400 rounding mm, and 600 mm. The use of rounding from 200 mm, 400 mm to 600 mm will cause a lower pressure coefficient value on the blockage mass, resulting in fluctuations in the value of the pressure coefficient, which is more stable towards the rear area, as well as reducing the vacuum in the wake area.[6-11] This study aimed to conduct research on airflow patterns on the sections under front end by varying the angle of inclination. Under front end or the lower front of the car is a part of the body that must be kept in mind because the lower part is a factor in the emergence of the lift force or the lifting force of the car at a certain speed.

2. Methods

This study is experimental research for the evaluation of the use of under front end on the vehicle for the airflow pattern and pressure distribution characteristics. The sedan-type vehicle model was chosen with a variation of the tilt angle under front end 0°, 5°, 10°, and 15°. The dependent variable in this study is dynamic pressure freestream, static pressure on body contours, pressure coefficient, and airflow pattern. The control variable in this study is the airflow velocity attest section constant 5.47 ± 0.01 m/s, and the air temperature attest section kept constant.

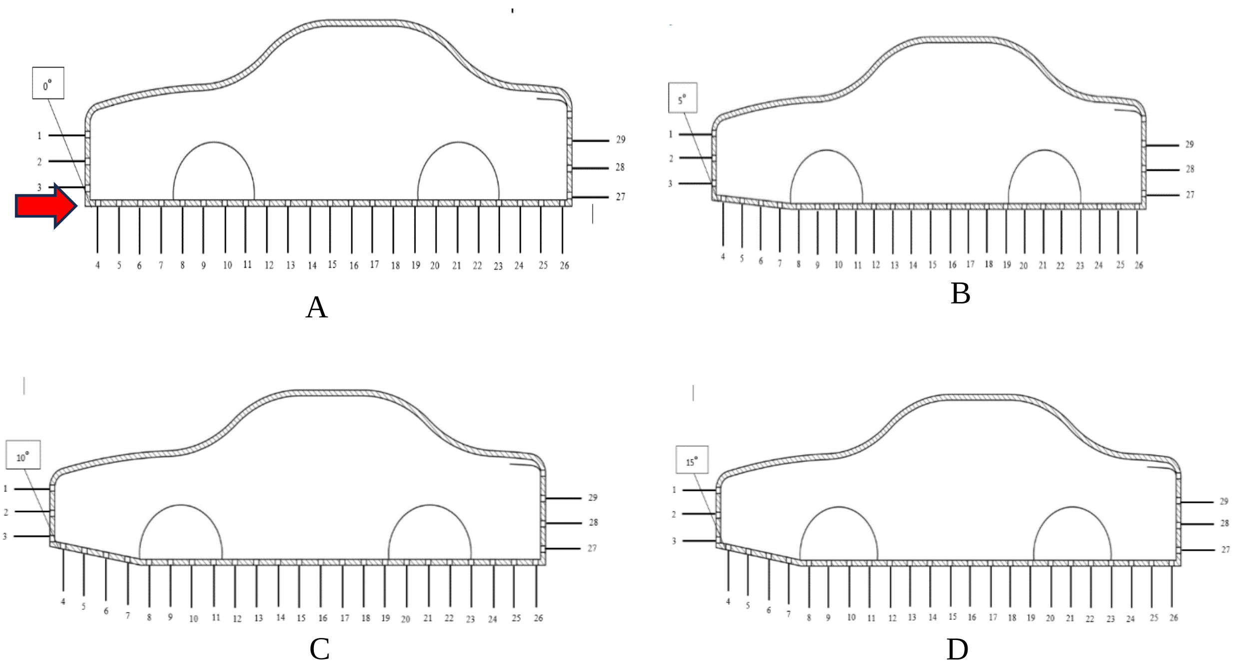


Figure 1. Under front end tilt variation angles are 0°, 5°, 10°, and 15°. A: angle 0°; B: angle 5°, C: angle 10° and D: angle 15°. Arrow red: under front end angle.

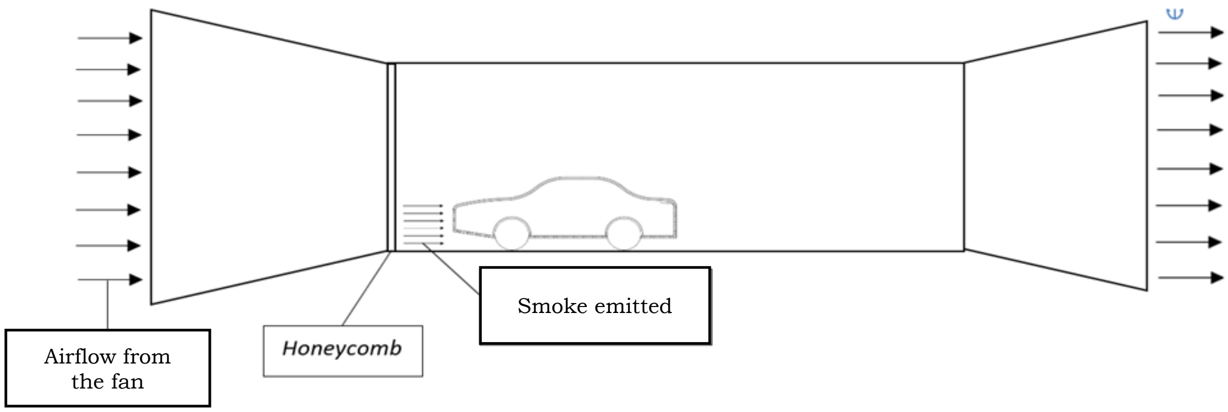


Figure 2. Schematic of research implementation.

Figure 2 shows that the vehicle was initially placed in the test section at a distance of 5 cm from the honeycomb and 2.25 cm from the surface of the test section. Next, the air will flow through the fan to the test section. Furthermore, the smoke produced by the smoke machine will exit through the honeycomb, with a distance of 7.15 cm from the surface of the test section towards the body of the test vehicle. Next, input the tilt angle test specimen under the front end in the test section in the wind tunnel. Installation of Inclined tube manometer with test specimens and wall pressure tap on test section wind tunnel. Then, turn on the blower, measure the air speed using an anemometer to get a value of 5.47 ± 0.01 m/s then operate the wind tunnel. After 5 minutes, record the change in liquid spacing on an inclined tube manometer.

Data analysis was carried out to calculate the Reynolds Number, calculate the dynamic pressure of the airflow, process the "L" data on the inclined tube manometer be static pressure freestream as well as data processing "L" on the inclined tube manometer to set the static pressure on the contours of the test vehicle body.

3. Results and Discussion

From the measurement results in this study, the following fluid properties were obtained: Fluid velocity (V) = 5.47 m/s; fluid temperature (T) = 30.3°C; characteristic length (L) = 0.3 m; fluid density (ρ) = 1,163 kg/m^3; dynamic viscosity (μ) = 0,000018603 N.s/m^2; kinematic viscosity (υ) = 0,000016078 m^2/s. Then Reynolds number:

$$\text{Re} = \frac{\rho\, v\, D}{\mu} = \frac{1{,}163\ \text{kg/m}^3 . 5{,}47\ \text{m/s}.\ 0{,}35\ \text{m}}{0{,}000018603\ \text{N.s/m}^2} = 119.315$$

In this study, each specimen was tested with Refreestream the same one. In this study, the airspeed attest section Of the Wind tunnel is 5.47 m/s, and the fluid density is 1.163 kg/m^3, resulting in dynamic pressure freestream on wind tunnel countable:

$$\text{Pd}\infty = {}^{1}\!/_{2}\, \rho\, V_\infty{}^2 = {}^{1}\!/_{2}\ 1{,}163\ \text{kg}/m^3\ .\ (5{,}47\ \text{m/s})^2 = 17{,}399\ \text{N}/m^2 \text{ (relative pressure)}$$

Static pressure on the wall test section wind tunnel was determined by obtaining the maximum pressure value on the body contour surface. Based on the data obtained, the maximum pressure in each vehicle model is the fluid displacement distance (ΔL = 10 mm), and the maximum static pressure obtained on the contours of each vehicle model is 49.375 N/m^2. After obtaining the maximum pressure value on the static pressure contour of the wall test section can be calculated as follows:

$$P_0 = P_\infty + \frac{1}{2}\rho V^2$$

$$Ps_\infty = P_0 - \frac{1}{2}\rho V^2$$

$$Ps_\infty = 49{,}375\ \mathrm{N/m^2} - 17{,}399\ \mathrm{N/m^2}$$

$$Ps_\infty = 31{,}976\ \mathrm{N/m^2}$$

So the value of the static pressure of the wall test section is used to determine the value of Cp (coefficient of pressure) at all other measurement points on each vehicle model. In this test car, the static pressure of the fluid on the body contour is taken from the point leading edge up to a point trailing edge test vehicle body in the section underside vehicle. Static pressure on the contours of the vehicle body is measured with a pressure gauge viz inclined tube manometer with a tilt angle of 15°. Static pressure was measured on each model vehicle with a total of 29 point measurements on each test vehicle.

Table 1. Calculation results of changes in oil level (Δh) in each test model.

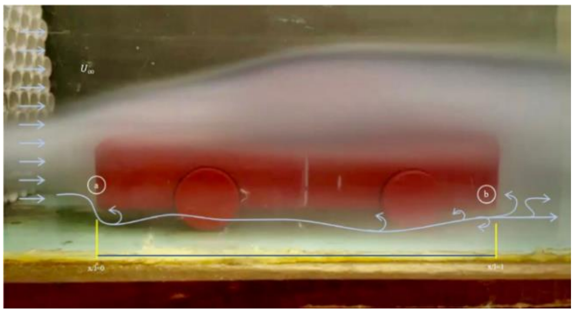
Measurement point	Δh (m) Tilt angle under front end			
	0°	5°	10°	15°
1	0,00650	0,00650	0,00650	0,00650
2	0,00845	0,00715	0,00650	0,00520
3	0,00650	0,00845	0,00650	0,00650
4	-0,00650	-0,00520	-0,00390	0,00195
5	-0,00390	-0,00195	0,00065	0,00130
6	-0,00195	-0,00065	0,00000	0,00065
7	-0,00195	-0,00065	-0,00130	-0,00195
8	-0,00130	-0,00130	-0,00130	-0,00130
9	-0,00195	-0,00195	-0,00195	-0,00195
10	-0,00130	-0,00455	-0,00130	-0,00195
11	-0,00195	-0,00325	-0,00195	-0,00195
12	-0,00065	-0,00130	-0,00130	-0,00130
13	-0,00130	-0,00130	-0,00195	-0,00130
14	-0,00065	-0,00195	-0,00130	-0,00130
15	-0,00130	-0,00195	-0,00130	-0,00065
16	-0,00065	-0,00065	-0,00065	-0,00065
17	-0,00195	-0,00390	-0,00195	-0,00130
18	-0,00130	-0,00130	-0,00065	-0,00065
19	-0,00130	-0,00195	-0,00195	-0,00195
20	-0,00065	-0,00195	-0,00195	-0,00130
21	-0,00390	-0,00195	-0,00260	-0,00195
22	-0,00195	-0,00260	-0,00390	-0,00195
23	-0,00260	-0,00390	-0,00260	-0,00260
24	-0,00260	-0,00260	-0,00455	-0,00260
25	-0,00260	-0,00163	-0,00325	-0,00455
26	-0,00260	-0,00520	-0,00325	-0,00390
27	-0,00260	-0,00455	-0,00390	-0,00325
28	-0,00325	-0,00390	-0,00260	-0,00325
29	-0,00325	-0,00455	-0,00325	-0,00325

Table 2. Calculation results of static pressure (Ps) on each body contour of the test model.

Measurement point	Ps (N/m^2) angle of inclination under front end			
	0°	5°	10°	15°
1	49,375	49,375	49,375	49,375
2	64,188	54,313	49,375	39,500
3	49,375	64,188	49,375	49,375
4	-49,375	-39,500	-29,625	14,813
5	-29,625	-14,813	4,938	9,875
6	-14,813	-4,938	0,000	4,938
7	-14,813	-4,938	-9,875	-14,813
8	-9,875	-9,875	-9,875	-9,875
9	-14,813	-14,813	-14,813	-14,813
10	-9,875	-34,563	-9,875	-14,813
11	-14,813	-24,688	-14,813	-14,813
12	-4,938	-9,875	-9,875	-9,875
13	-9,875	-9,875	-14,813	-9,875
14	-4,938	-14,813	-9,875	-9,875
15	-9,875	-14,813	-9,875	-4,938
16	-4,938	-4,938	-4,938	-4,938
17	-14,813	-29,625	-14,813	-9,875
18	-9,875	-9,875	-4,938	-4,938
19	-9,875	-14,813	-14,813	-14,813
20	-4,938	-14,813	-14,813	-9,875
21	-29,625	-14,813	-19,750	-14,813
22	-14,813	-19,750	-29,625	-14,813
23	-19,750	-29,625	-19,750	-19,750
24	-19,750	-19,750	-34,563	-19,750
25	-19,750	-12,344	-24,688	-34,563
26	-19,750	-39,500	-24,688	-29,625
27	-19,750	-34,563	-29,625	-24,688
28	-24,688	-29,625	-19,750	-24,688
29	-24,688	-34,563	-24,688	-24,688

Table 3. Results of the calculation of the pressure coefficient (Cp) in each test model.

Measurement point	Cp value under front end tilt angle			
	0°	5°	10°	15°
1	1,003	1,003	1,003	1,003
2	1,856	1,287	1,003	0,434
3	1,003	1,856	1,003	1,003
4	-4,688	-4,119	-3,550	-0,989
5	-3,550	-2,696	-1,558	-1,274
6	-2,696	-2,127	-1,843	-1,558
7	-2,696	-2,127	-2,412	-2,696
8	-2,412	-2,412	-2,412	-2,412
9	-2,696	-2,696	-2,696	-2,696
10	-2,412	-3,834	-2,412	-2,696
11	-2,696	-3,265	-2,696	-2,696
12	-2,127	-2,412	-2,412	-2,412
13	-2,412	-2,412	-2,696	-2,412
14	-2,127	-2,696	-2,412	-2,412
15	-2,412	-2,696	-2,412	-2,127
16	-2,127	-2,127	-2,127	-2,127
17	-2,696	-3,550	-2,696	-2,412
18	-2,412	-2,412	-2,127	-2,127
19	-2,412	-2,696	-2,696	-2,696
20	-2,127	-2,696	-2,696	-2,412
21	-3,550	-2,696	-2,981	-2,696
22	-2,696	-2,981	-3,550	-2,696
23	-2,981	-3,550	-2,981	-2,981
24	-2,981	-2,981	-3,834	-2,981
25	-2,981	-2,554	-3,265	-3,834
26	-2,981	-4,119	-3,265	-3,550
27	-2,981	-3,834	-3,550	-3,265
28	-3,265	-3,550	-2,981	-3,265
29	-3,265	-3,834	-3,265	-3,265



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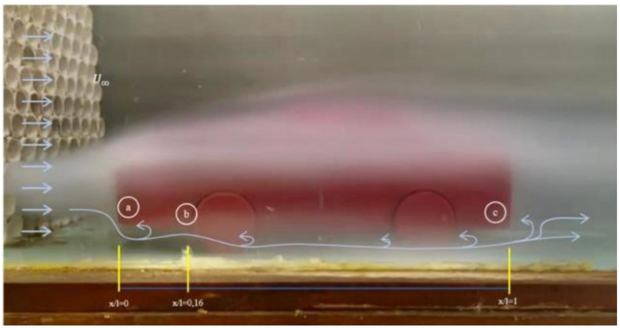

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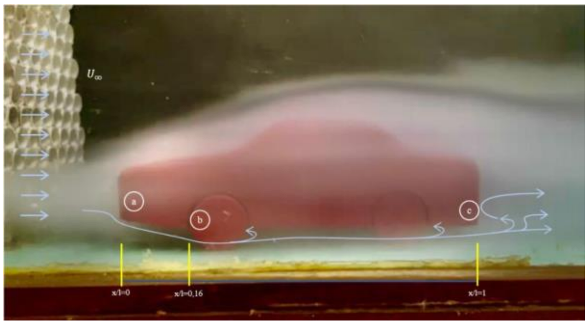

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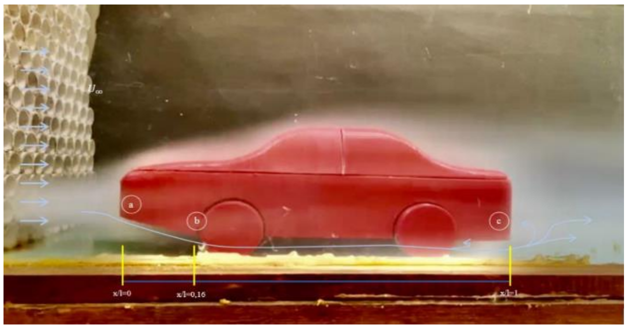

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Figure 3. Overview of airflow under front-end angles. A: angle 0 ^{o}; B: angle 5 ^{o}; C: angle 10 ^{o}; D: angle 15 ^{o}.

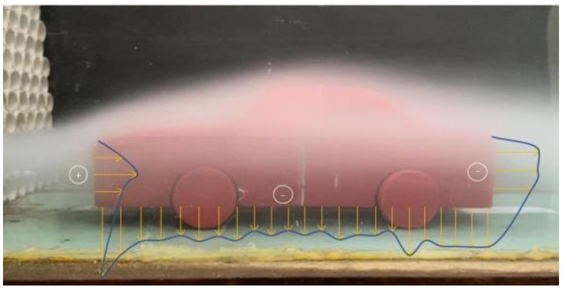
Figure 3. A. shows the airflow at an angle under the front end 0^{o}. The airflow moves from the leading edge to the trailing edge test vehicle. Point (a) is a stagnation point, where the airflow velocity v = 0 m/s. The stagnation point occurs at the ratio x/l=0, namely at measurement points 1 to 3. The separation point causes the occurrence adverse pressure gradient, which is marked by a flow that flows from back to front (backflow) at measurement points 4 to 5. The separation phenomenon occurs because the flow lines are no longer able to stick to follow the shape of the body surface and are pushed away towards free flow, and turbulence phenomena occur. Furthermore, at measurement points 6 to 26, airflow returns to the body due to a phenomenon of no-slip where, no matter how small, the viscosity of the airflow will not shift because the airflow is rubbing between the surface of the lower body contour and the surface test section. At point (b) is a low-pressure region (wake) occurring at measurement points 27 to 29.[12]

Figure 3. B. shows the airflow at an angle under the front end 5^{o}. The airflow moves from the leading edge to the trailing edge test vehicle. Point (a) is a stagnation point, where the airflow velocity v = 0 m/s. The stagnation point occurs at the ratio x/l=0, namely at measurement points 1 to 3. The phenomenon occurs in the forward bound vortex in the front area because not all pressure measurement points in the front area or the ratio x/l=0, the vehicle has a value of Cp = 1. At this point, the ratio x/l=0 also exists Separation point causes the occurrence of an adverse pressure gradient which is marked by a flow that flows from back to front (backflow) at measurement points 4 to 5. The separation phenomenon occurs because the flow line is no longer able to stick to follow the shape of the body surface, so the airflow experiences turbulence, but due to the 5° angle, the turbulence is minimal compared to the test vehicle without angles. At point (b), the ratio x/l=0.16 has a smaller separation point because of the 5° angle. Furthermore, at measurement point 8 to 26, airflow returns to the body due to a phenomenon of no-slip where no matter how small, the viscosity of the airflow will not shift because the airflow is rubbing between the surface of the lower body contour and the

surface test section. At point (c) is a low-pressure region (wake) occurring at measurement points 27 to 29.[13]

Figure 3. C. shows the airflow at an under front end angle of 10^{o}. The airflow moves from the leading edge to the trailing edge test vehicle. Point (a) is a stagnation point, where the airflow velocity v = 0 m/s. The stagnation point occurs at the ratio x/l=0, namely at measurement points 1 to 3. At the ratio point x/l=0, there is also a Separation point at measurement point 4. The separation phenomenon occurs because the flow line is no longer able to stick to follow the shape of the body surface. At point (b), the ratio x/l=0.16, the 10° angle experiences a smaller separation than the front of the car body, and turbulence also occurs due to the angle at measurement points 8 and 9. Furthermore, at measurement points, 10 to 26 air flows back to the body because of the phenomenon of no-slip, where no matter how small, the viscosity of the airflow will not shift because the airflow is rubbing between the surface of the lower body contour and the surface test section. At point (c) is a low-pressure region (wake) occurring at measurement points 27 to 29.[14]

Figure 3. D. shows the airflow at an under front end angle of 15^{o}. The airflow moves from the leading edge to the trailing edge test vehicle. Point (a) is a stagnation point, where the airflow velocity v = 0 m/s. The stagnation point occurs at the ratio x/l=0, namely at measurement points 1 to 3. At point (a) at the ratio x/l=0, there is a small point of separation due to the slope angle of 15°, which causes airflow that is able to stick to follow the contours of the body. At point (b) at the ratio x/l=0.16, there is a small separation point, then at 8 to 26 measurement points, the airflow returns to the body due to the phenomenon of no-slip where no matter how small the viscosity of the airflow will not shift because the airflow is rubbing between the surface of the lower body contour and the surface test section. At point (c) is a low-pressure region (wake) occurring at measurement points 27 to 29.[15]



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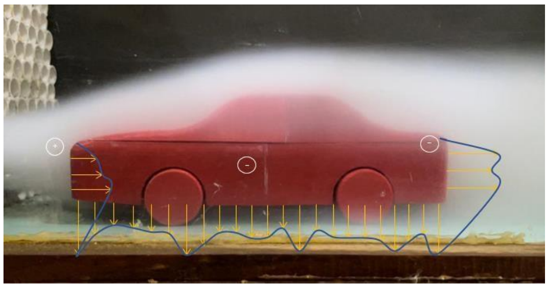

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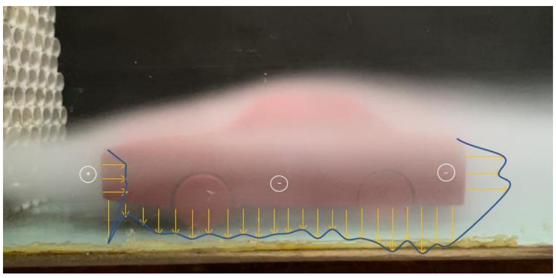

C

D

Figure 4. Pressure distribution of the test model with an angle under front end. A: angle 0^{o}; B: angle 5^{o}; C: angle 10^{o}; D: angle 15^{o}.

Figure 4.A. Pressure distribution of the test model with an angle under front end angle of 0^0, in the front area is a stagnation point) where the maximum value of Cp=1. Furthermore, at point 4, there is a flow separation phenomenon with a value of Cp = -1.602. This occurs, as a result, forward-bound vortex happening to the front area until the flow is no longer able to experience reattachment. The significantly low value of Cp from measurement points 4 to 5 indicates high airflow velocity caused by flow separation. At the 6th measurement point, the Cp value has increased in a positive direction up to the 20th measurement point with a Cp value = -0.583, this phenomenon indicates the occurrence of blockage mass, and the airflow returns closer to the surface of the body. Increasing the value of Cp, there will be a decrease in speed. The Cp value again decreased at measurement point 21 with a value of Cp = -1.149. At measurement point 22, the Cp value increased, namely -0.809, but the Cp value again decreased at point 23 to point 26 stably with Cp = -0.923. At point 27 to point 29, the value of Cp has again decreased in a negative direction which causes a phenomenon to occur in that area wake at the back of the car.[16]

Figure 4.B. Pressure distribution of the test model with an under front end angle of 5^0, in the front area is a stagnation point where the maximum value of Cp = 1. On the front, there is a phenomenon of the forward bound vortex as evidenced by the Cp value in the front area or the ratio x/l=0, not all of which have a value of 1. Furthermore, at point 4 there is a phenomenon of flow separation with a value of Cp=-1.376. This occurs because a forward-bound vortex occurs in the front area so that the flow is no longer able to experience reattachment. The significantly low value of Cp from measurement point 4 indicates high airflow velocity. Caused by the flow separation. At measurement point 5 with a value of Cp = -0.809, it has increased in a positive direction up to measurement point 7 with a value of Cp = -0.583. This phenomenon indicates a blockage mass, and airflow is returning closer to the surface of the body. Increasing the value of Cp, there will be a decrease in speed. The Cp value again decreased at measurement point 7 to point 12 with a value of Cp = -1.036 which indicates high airflow velocity. At measurement point 12, the Cp value increased in a positive direction up to point 16 with a Cp value = -0.583 and again experienced a decrease in Cp value at point 17 with a Cp value = -1.149. At point 18, the Cp value increases to point 21 with a Cp value = -0.809. At points 22 to 23, the Cp value again decreased in a negative direction with a Cp value = -1.149 and again increased at point 24 with a Cp value = -0.923. At points 25 to 29, the Cp value decreases with a Cp value = -1.262 which causes the wake phenomenon to occur in the area behind the car.[17]

Figure 4.C. Pressure distribution of the test model with an under front end angle of 10^0, in the front area is a stagnation point where the maximum value is Cp=0.663. On the front, namely points 1 to 3, there is a forward bound vortex phenomenon as evidenced by the Cp value in the front area or the ratio x/l=0, not all of which have a value of 1. Furthermore, at point 4, there is a flow separation phenomenon with a value of Cp=-1.149. This happened because of the forward bound vortex that occurs in the front area so that the flow is no longer able to experience reattachment. At point 5, the Cp value increased by -0.356 but again decreased the Cp value up to measurement point 9. At measurement points 9 to 20, the Cp value fluctuated, and the Cp value began to decrease from point 21 to point 24 and again experienced the Cp value increases at points 25 to 26 measurement points. The Cp value again decreases in a negative direction at points 27 to 29, which makes the area a wake phenomenon.[18]

Figure 4.D. Pressure distribution of the test model with an under front end angle of 15^0, in the front area is a stagnation point where the maximum value is Cp=0.663. Furthermore, at point 4, there is a phenomenon of flow separation with a value of Cp = -0.13 and continues to experience a decrease in the value of Cp at point 7 with a value of = -0.809. At points 8 to 18, there is an increase in the value of Cp with a value = -0.583. This phenomenon indicates the

occurrence of blockage mass, and the airflow returns closer to the surface of the body and again decreases the Cp value at point 19 to point 25, which causes the phenomenon to wake. The Cp value again increased in a positive direction at points 26 to 27 and stabilized up to point 29 with a Cp value = -1.306.[19,20]

4. Conclusion

Under front end 0° tilt angle is an area with low pressure, where the lift force that occurs is relatively smaller compared to the under front end, which has a tilt angle. However, the pressure fluctuation experienced by the 10° tilt angle is more stable compared to the 0° angle.

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