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EXPERIMENTAL ANALYSIS OF THE AIRFLOW AROUND PICK-UPS: A QUALITATIVE EVALUATION WITH VISUALIZATION METHODS

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Abstract. *This work is focused on the experimental evaluation of the aerodynamics from two simplified pickup models. One has sharp and flatted edges, and the other has rounded ones. Except this, they are equals. Nevertheless, this study has only a qualitative approach through visualization methods. Further analyses are being performed for the determination of flow patterns such as pressure distribution and velocities. Three visualization methods were considered: A simple path line visualization, smoke and tufts. Each method was properly chosen to give a different perspective of the airflow over the models, and to compare them. Two wind flow velocities were chosen for the analyses: sixteen and twenty-five meters per second, provided by a blown down closed-section and open-circuit wind tunnel. As expected, the results have shown that the flatted model has a higher detachment of the boundary layer, while the rounded one generates a smoother airflow. Further experiments may show that these characteristics will generate a higher drag coefficient to the flatted model. Also, the results for higher speed experiments have shown a more aggressivity in the wind flow, provoking a bigger recirculation zones in the front hood and other areas of the pick-ups.*

Keywords: *Aerodynamics, Pick-Up, Experimental, Flow Visualization, Boundary layer*

1. INTRODUCTION

Although it is possible to count less than ten big brands at the automobile industry, such as Volkswagen, Fiat and Citroen, due to the great level of market competition, it is one of the greatest industries of the engineering work. Thus, to be competitive, these brands have higher and higher investments in the search of new engineering improvements. In such, it is possible to say that their main goals are the reduction of the costs production and operation of their products, and maybe the most relevant matter, the aesthetics of the vehicle [1].

A relevant matter when a new model of an automobile is being concepted, is the fuel consumption [1]. Besides many factors, like the weight of the body and the engine type, the drag force is the head of the fuel consumption at higher speeds, while the frictional force is the preoccupation at lower ones. The drag force itself is very related to the shape of the model, because it affects its aerodynamics due to the boundary layer detachment and the ways that the air goes through the body. Therefore, when talking about aerodynamics, the objective is to search for means that characterizes how the flow acts over the body (vehicle). Hence, the study of this phenomenon may follow two lines, both very important for achieving a great result.

The first one is a quantitative study, where it is possible to find and numerically evaluate quantities like the velocity and pressure fields among other variables. The second one is a qualitative approach, where the analyses pass through a visualization method. At this, the objective is to see how the airflow interacts with the body shape. And, of course, both can be analyzed computationally and experimentally.

Both ways mentioned have their own particularities and must be brought together in order to fully represent the aerodynamic phenomenon desired. As an example, in one hand, the utilization of numerical analyses may provide a fully controllable environment where all the conditions are settled as desired. It allows tests at a constant temperature, air density and wind conditions, something difficult when performing a wind test at a long period of time. Of course, regarding the kind of test, small atmosphere changes are not highly prejudicial, however the more controllable is the ambient, the better. Also, a numerical simulation does not need all the infrastructure than an experimental test might need. In the other hand, complex geometries may require more elaborated meshes, that causes the necessity of more computational power and a high simulation time. And it has a great chance that, if the mesh is not built properly, the results would not correspond to the physic phenomenon itself.

Then, it is relevant to say that this work is the continuation of a previous study, both were performed at Centro de Pesquisa em Aerodinâmica Experimental – CPAERO (Experimental Aerodynamic Research Center), located at Universidade Federal de Uberlândia – UFU (Federal University of Uberlandia), where the goal was to describe and characterize the differences between the airflow of two simplified pick-up models. One has flatted shaped corners, full of live edges, and the other has rounded corners. The previous research [2] has investigated the problem mostly at a computational approach for both models. Thus, in matters of continuity, this work will reelevate the experimental approach with only visualization methods. For further and improved works on this subject, the quantitative approach will also be investigated.

The pick-up vehicle was chosen as the matter to be discussed due to its high importance at the market, as mentioned before. Almost every automobile manufacture has at least one model of pick-up to be offered for its double functionality. This kind of vehicle can be used for both personal interests and at a commercial point of view, as a low cargo unity. Thereby, the two simple model cited above were manufactured, using a MarkerBot® 3D printer from PLA filament of 1.75 mm-diameter. The body tests were designed in the software of solid construction CATIA®. Their dimensions were taken after a study performed by Silva-Pinto [3], where it took the measures of the most common pick-up models available at the Brazilian market, during the year of 2014, unifying them by an average of their values, to represent a mean external shape of a pickup vehicle. The software used to process the data was ImageJ®. The scale used due to the wind tunnel section was of 1:10. The Fig1. 1, created by and credited to Silva-Pinto [3] reveals the model's dimensions and at Fig.2 the two models are represented.

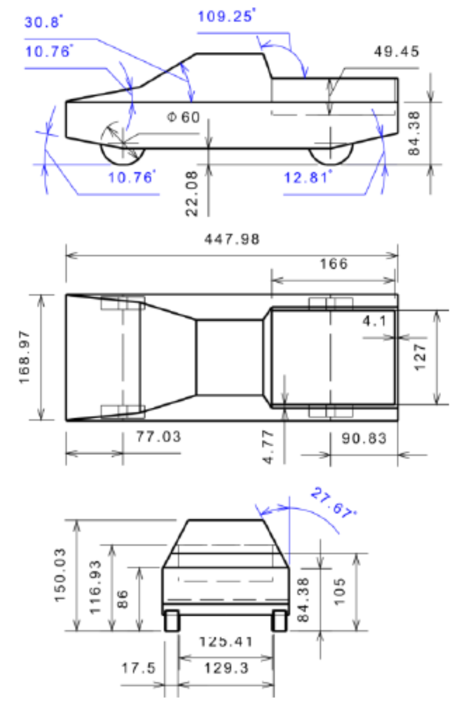

Figure 1: Test articles dimensions (mm). Source: Almeida, O. and Pinto, W.J.G.S., 2017.

Figure 2: Pickup test models. Right: Flatted. Right: Rounded

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The main idea of the project is to propose aerodynamic improvements to pickups models, with the aim of drag reduction. However, coming up with advanced ideas such as an aerodynamical dispositive to reduce drag without a fully comprehension of the problem may lead to mistaken conclusions. Thus, before that, it is highly recommended to start with more simple models. Then, a simplified version of this class of vehicle was chosen due to the need of a construction of a database, starting at first with a primitive version of the vehicle. Then, for future works, when its geometry will be well known, the insertion of more real features will be added to the model, such as air entrances, rear view mirrors, or rotational wheels. At the time, the testing body will be very alike a real pickup with all its geometrical components, then, aerodynamics improvements will be tested and proposed as discussed by Taniguchi,K. and all [4]. This explanate the chosen of the current model's configurations, as they are as simple as possible.

Finally, this paper, which, as mentioned before, is a part of a greater work, is the second step of the previous study. At this stage, the proposition is to provide the means for a qualitative evaluation of the problem, at an experimental approach, with several experiments. Furthermore, as different models were tested, it is possible to say that the first step of creating a more realistic model were performed when the flatted corner model was compared with the rounded one.

It is also important to emphasize that airflow visualizations are not that simple, since the air is, of course, not visible. It is possible to realize that each method applied here describes an aspect of the airflow over the body, and they need to be put together to give a better view of the situation. For an example, some of them give a three-dimensional approach, while others give a two dimensional one, and some can be compared themselves. Thus, three methods were applied: Path Line Visualization, Smoke visualization, and Tufts Visualization.

2. MATERIAL AND METHODS

The main equipment used in this study was a low-speed wind tunnel (TV-60), where a 25 hp electrical engine generates the mechanical power to spin a 12 bladed fan that is responsible to generate the airflow through a test section of 60x60 cm². This wind tunnel was built exclusively for CPAERO and counts with four wire-mesh screens and guide vanes after the fan that helps the decrease of the turbulence at the test section close to 0.6%. Also, the test section was built of acrylic, a transparent material that allows the visualization of the experiment from any side and angle as wanted. The maximum velocity at the test section is approximately of 28 m/s with minimum blocked ratio, not losing its blow cargo at five diameters after the test section.

The other equipment is much simple: a green table that has the exact height of the test section, a ball of an orange and white wool, a HD photographic camera, and a green board for auxiliary to the tuft's visualizations. The orange tufts and the green board and table colors were chosen to contrast with the black color of the models.

2.1 Path Line Visualization

The first method to be presented here has intended to demonstrate the evolution of the path line over the model, investigating how the flow path lines interacts with the body. Thus, the longitudinal symmetrical plane of the models was set to show this interaction, and tufts of sizes varying from thirty to eighty centimeters were used to simulate the air particles. Then, three points were planned: the first one finishes almost at the beginning of the pick-up's hood. The second goes a bit more far, reaching the hood's end. The last one goes further, to the very end of the model and a bit beyond. The points were named as P1, P2 and P3 respectively, and all of them start at the end of the wind tunnel section. Moreover, as said before, the motivation of this was to demonstrate the path lined flow. So, for each point, eleven tufts were attached to the end of the wind tunnel section at different vertical heights, and as the air blows, it is possible to visualize the wind behavior over the model as the tufts are attracted to de body.

The experiment was assembled with the vehicle model installed at the mentioned green table outside the wind tunnel section. So, placing the table right after the opened section, a green panel was attached behind it, so that the green ground and background could give a better contrast to the black model and orange tufts creating a great ambient to record the tests. Here it is substantial to emphasize that as the wind tunnel was projected to not lose its blow cargo until five diameters after the end of the tests section, the experiments were not affected by being performed after the end of the test-section.

Consequently, organizing the three pictures (one for each point) that were taken from the experiments in sequence (P1, P2, P3), make it possible to represent three sequential time intervals of the airflow. Then for every point, it was tested four experimental configurations: both the pick-ups rounded and flatted for the speeds of 16 and 25 meters per second. These velocities were chosen due to the previous data found at the past work [2], so that for future works, the comparison between the computational visualization with the experimental one shall be accomplished.

Obviously, the points location's ends were not chosen by chance. The first tufts for P1 finishes at the beginning of the hood, willing to properly demonstrate the boundary layer detachment located at that region, and how the rest of the airflow is affected by this phenomenon, analyzing the other tufts, that are longer than the ones mentioned before. P2 itself, was intentioned to demonstrate the development of the airflow after P1 until it reaches the end of the ceiling. Here, the goal was to see what may happen when the air goes over the hood after the recirculation zone and above the pickups front panel. Finally, P3 must have shown not only the airflow reaction at the end of the model, but also its response to the big recirculation zone that is an opened bed.

2.2 Smoke Visualization

The second method applied was the smoke visualization. The intention of this was to conceive a good notion of a tridimensional flow, differently from the previous one. In addition, it is possible to show how specific regions of the body reacts to the wind flow, generating recirculation zones and boundary layer detachments. Thus, this experiment is described by four points for the flatted and the rounded models. The first one gives a full lateral vision of the model; whose spotlights are the hood's beginning and the front part of the roof. The next point is the bed (open trunk) of the vehicle, for being an open cavity, which study proposition was pointed by Al-Garni et al [5]. The third and fourth points are focused at the roof's and at the bed's end, to give a perspective of the wind track from upward and downward. All the points were performed at the speed of 16 meters per second and were respectively named as P1, P2, P3 and P4.

Then, as from the previous experiment, this was also performed at the green table, after the end of the tests section, also willing to conceive a better contrast between the model, the background, and at this case, the smoke.

2.3 Tufts Visualization

The third method had the intention to capture how the wind flow lefts the disposition of the tufts that are attached all over the body. This will then show the ways of how the wind flow goes over the model. So, tufts of one and a half centimeters were utilized in order to capture a full lateral vision and a full superior vision of the pick-ups. The most remarkable part to be considered is the bed of the pick-up due to the enormous zone of recirculation that acts there. Another interesting perspective to be analyzed is the A-pillar, from the lateral view, where other recirculation zone happens. Thus, two points were captured for two wind velocities: the lateral and superior views for 16 and 25 meters per second, only for the rounded model. The flatted model experiment was performed at the previous work [3].

However, differently from the latest tests, this one was performed inside the wind tunnel section since camera shots from above the model were a requirement to analyze the phenomenon. Shots from the superior plane were not taken before because the point of interest at the previous experiments were planned to be captured only at the lateral plane. also, the white tufts were selected instead the orange ones as for this experiment, with no need of a background, the white tufts stand out over the orange ones.

Fig. 3 shows the rounded model with the attached tufts.

Figure 3: Rounded model setted for the tufts visualization experiment.

2.4 Wake-Vortices Visualization

The fourth and last method applied has intended to capture the wake structure that happens after the wind flow have already experienced the interaction with the vehicle but has not yet returned to the steady uniform regime. In order to accomplish that, it was arranged a square grid of the size of the test vertical section (60 x 60 cm) and divided in small squares of 2x2 cm. So, at each grid's intersections, a tuft of five centimeters was attached. Then, the model was placed inside the test section distant from an eighth of the total length of the body from the grid that was installed at the end of the wind tunnel test section. The wind flow velocity that was chosen to characterize this phenomenon was of 16 m/s to keep conformity with the latest experiments.

3. RESULTS AND DISCUSSIONS

As mentioned at Section 1, each method was focused at a particularity of the wind flow, willing to qualitatively demonstrate the fluid to body interaction. Hence, each method presents its own analyses and contribution to this work, and even some comparisons between the results of different applications shall be possible, as at some situations they emphasize de same part of the vehicle. Next are the results for the wind tunnel experiments, beginning with the Path Line Visualization. After the results are presented, they shall be discussed.

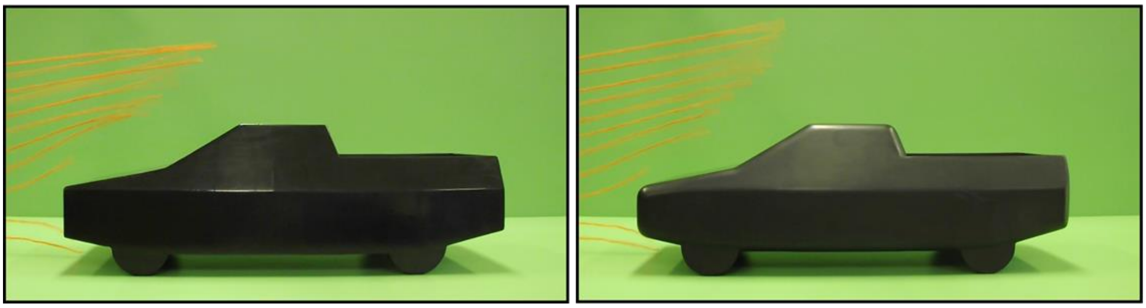

Figure 4: P1 for both models at 16 m/s. Left: Flatted. Right: Rounded.

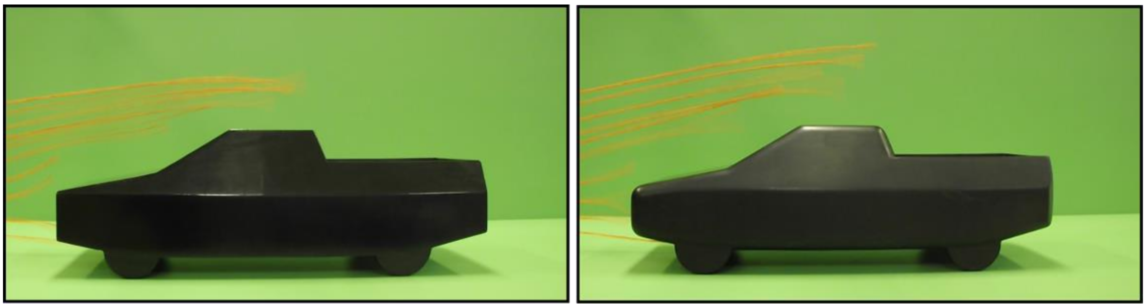

Figure 5: P2 for both models at 16 m/s. Left: Flatted. Right: Rounded.

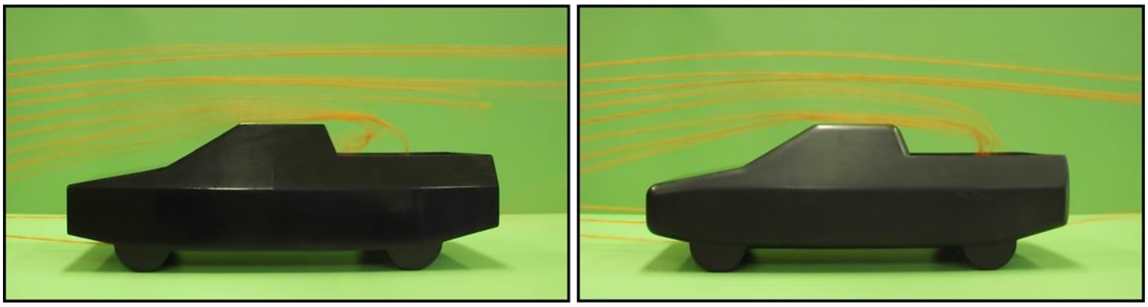

Figure 6: P3 for both models at 16 m/s. Left: Flatted. Right: Rounded.

Figure 7: P1 for both models at 25 m/s. Left: Flatted. Right: Rounded.

Figure 8: P2 for both models at 25 m/s. Left: Flatted. Right: Rounded.

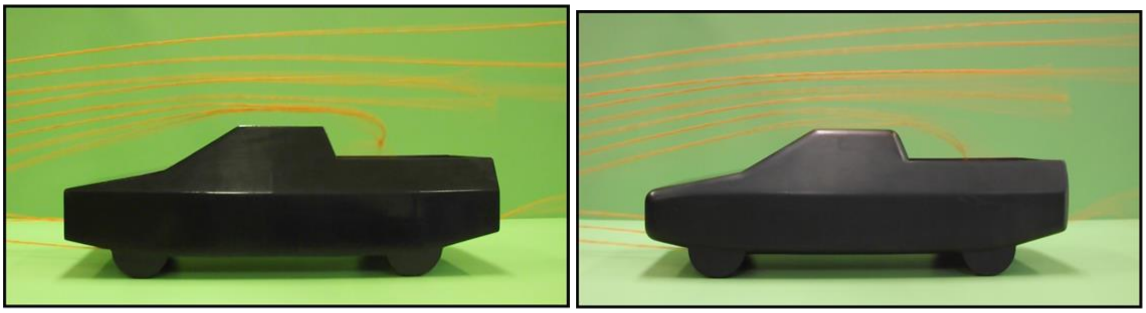

Figure 9: P3 for both models at 25 m/s. Left: Flatted. Right: Rounded.

The analyses of this experiment can be made in three perspectives. The first one is focused at the evolution of the airflow as it interacts with the vehicle, comparing the series of three pictures – P1, P2, P3 – for any velocity or model (flat or rounded). The second must reveal the differences between the velocities that the air was subjected to, while the third is about the differences caused by the rounded corners in contrast with the flatted ones. Thus, from the first perspective, it is possible to see that the as the air flow evolution begins with an interaction with the pickup's front hood, where a boundary layer detachment happens, shown by the way that tufts rise over it. Then, at P2 the attraction between the tufts and the body, as they advance from front hood until the ceiling, is very remarkable in such, the phenomenon is evidenced by the flatted 16 m/s picture, where the tufts (located next to the body) shape are equivalent to the pickup shape. This is evidenced by curvature they perform when reaching the hood, the front panel and the ceiling. Finally, at P3, while the upper tufts continue their movement, scaping from the vehicle, the mid ones stay trapped onto it at the big recirculation zone caused by the open cavity of the bodywork. Also, the lower tufts go below the body, and when they reach its and, they go upwards, as they are attracted to the body's surface. About the velocity's perspective, it was noticed that at 16 m/s, the tufts attraction to the body is more prominent since the flow is more stable. Lastly, when comparing the two models, it is noticeable that the rounded corner vehicle offers a smoother interaction of flow to superficies. This fact is more evident spotlighting the superficies transition areas, such as the hood to font panel or this to the ceiling.

Following, the results from the Smoke Visualization are described:

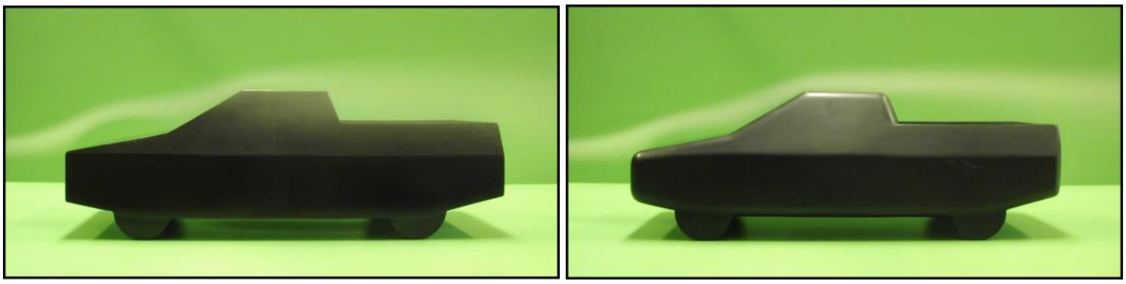

Figure 10: P1 for both models at 16 m/s. Left: Flatted. Right: Rounded.

Figure 11: P2 for both models at 16 m/s. Left: Flatted. Right: Rounded.

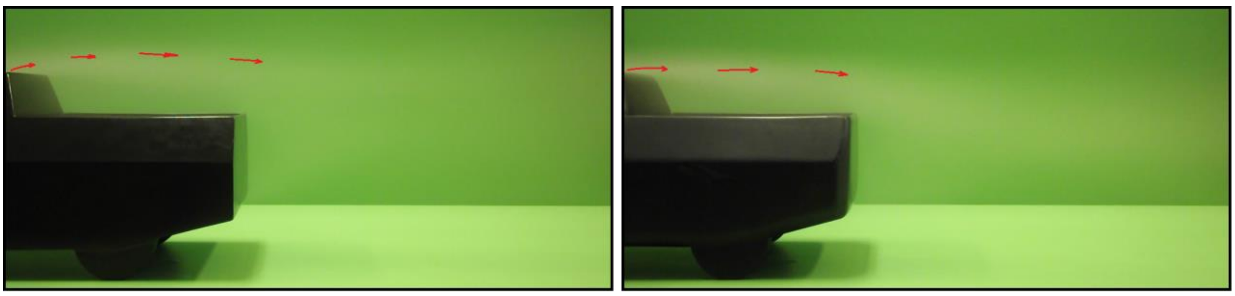

Figure 12: P3 for both models at 16 m/s. Left: Flatted. Right: Rounded.

Figure 13: P4 for both models at 16 m/s. Left: Flatted. Right: Rounded.

Before analyzing these results, it is important to clarify that, even with all the efforts to capture the best photographs as possible, due to the laboratory luminosity and camera capability, the pictures quality got impaired. However, in locus the airflow pattern was observed in all the smoke visualization experiments. Thus, to help understanding the flow behavior, arrows were included in the pictures to demonstrate the flow direction.

As presented, the focus of the last experiment was to demonstrate the evolution of the airflow as it goes through the vehicle. Tough some phenomenon particularities could be characterized; they are now truly evidenced by the smoke visualization results. The first point, for instance, shows a full lateral view of the pickup where the points of interests are the front hood, the front panel and the ceiling, and here the comparisons are about the distinctions of the two models. Thereby, at the front hood, the boundary layer detachment that was already noticed, is now really perceived, as well as it happens to the difference between the flat and the rounded models. It is remarkable that for the flatted model, the boundary layer detachment is more severe, causing even a curvature at the profile due to the discontinuity provoked by the edges. The same happens to the transition between the hood and the front panel. However, at the transition between the front panel and the ceiling, no apparent differences were noticed.

At P2, the bigger recirculation zone that occurs in both pickups, located at the opened trunk, was the focus. Yet here there was no notable distinction between the models, the qualitative registration of this phenomenon is required, in order to have a sight about how it occurs, as it is pointed as one of the great causes of the drag force increment at this class of vehicle when compared with another class as cars. As already said, the opened bed can be compared with an opened cavity, causing the recirculation, and this turns out more severe because of the sudden end of the vehicle surface. This could be smoothed by the utilization of an airfoil, as studied by Taniguchi [6].

P3 and P4 have intended to demonstrate what happens when the airflow does not meet the vehicle surface anymore, and to present the qualitative contrast between both models – Fig.12 and Fig.13. Thus, the wind particles try to continue to be attached to the body, but as this is impossible, it follows the body shape tendency, as shown by P4, where the airflow goes up, due to the inclination of the inferior surface of the vehicle. For P3, as there is no more surface, the air particle next to it begins to move down, causing then the recirculation zone of P2. The particles located more further, continue the forward movement. This phenomenon was also denounced at the path line visualization.

Next follows the result from the Tufts Visualization method, as described by Fig. 14 and 15:

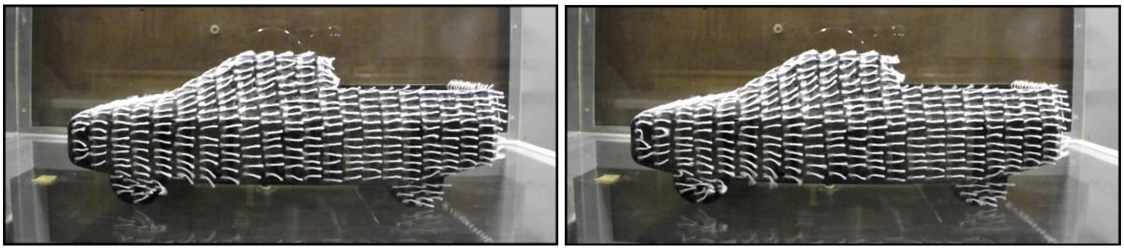

Figure 14: Tufts Visualization for the Rounded model, lateral view. Left: 16 m/s. Right: 25 m/s

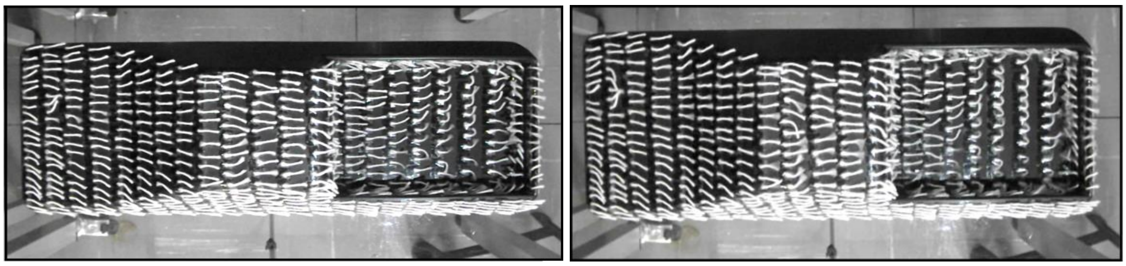

Figure 15: Tufts Visualization for the Rounded model, superior view. Left: 16 m/s. Right: 25 m/s

For the third method, what matters is the way the airflow leaves the disposal of the tufts. Its almost like the airflow leaves an impression in the tufts, revealing its interaction with the vehicle. Thus, this experiment was necessary to complete the other visualizations analyses. At this, the comparisons are between the velocity's differences, as only the rounded model was experimented for this work. The flatted model was already tested by Almeida-Pinto [3]. Hence, P1 shows the lateral view, that brings to knowledge two airflow behaviors: the one acting on the A-Pillar, where it is remarkable the tufts contrapositions, revealing the vortices that this region is submitted to, and the other, that reveals the wind separation that acts on the vehicles lateral since the upper part of the lateral is inclined, and the lower is not. For P2, the analyses are similar, once the spotlights are also the wind separation acting at the superior body parts (hood, front panel and ceiling) and the pickup bed. Thus, it became clear that when this kind of vehicle submitted to 25 m/s, the airflow separation over it is more brutal if compared to the 16 m/s wind speed, as denounced by the tufts separation at the lateral view, at the hood and at the front panel. Also, at the bed and at the lateral panel is also remarkable that for the higher wind velocity, the tufts disposal is left in a more lifted and curved way, revealing a more severe recirculation as the wind blows. At the ceiling, though no apparent difference has been noticed.

And for the last experiment, the results for the wake-vortices visualization are presented and illustrated by Fig.16.

The final experiment does not actually complete the latest ones and can be analyzed in a separated way. Thus, as already explained, its point of interest was to demonstrate the two symmetrical vortices that are formed by de development of the wake structure after the airflow contact with the vehicle ends. Although both models were tested, and the vortices could really be noticed, the contrast between their structures (of both models) did not show a remarkable difference. Further experiments, that shall be performed with means to quantitatively describe the phenomenon might show it.

Finally, the results obtained from the data acquired shall be summarized. Thus, from P1 of the Path Line method, the front hood boundary layer detachment was observed. This was then evidenced by the smoke P1 test. Also, both ways have shown that the flatted model induces a more critical detachment, probably caused by the sharp edges. Then, the first three tests accordingly spotlight the great recirculation zone at the body hood. This phenomenon is clearly demonstrated when these tests are brought together. At the Path Line, the tufts reveal the way the airflow that was attached to the surface of the ceiling now tends to curve, penetrating in the bed cavity. Then the smoke tests show the air recirculation there, and the third method implies on the movement the airflow follows during the recirculation state by way the tufts became disposed. About this, future tests are already programed to reveal the pressure fields that acts on the region, willingly to better characterizes the phenomenon with quantitative data. Also, it is thought to place a body cover, and test it again to investigate the differences between the covered model against the opened one, in terms of visualization and drag evaluation. And at last, analyzing together P3 for the Path Line and P3 and P4 for the smoke methodology, the disposal of the airflow at and after the body ends is also revealed, as both methods show the same results.

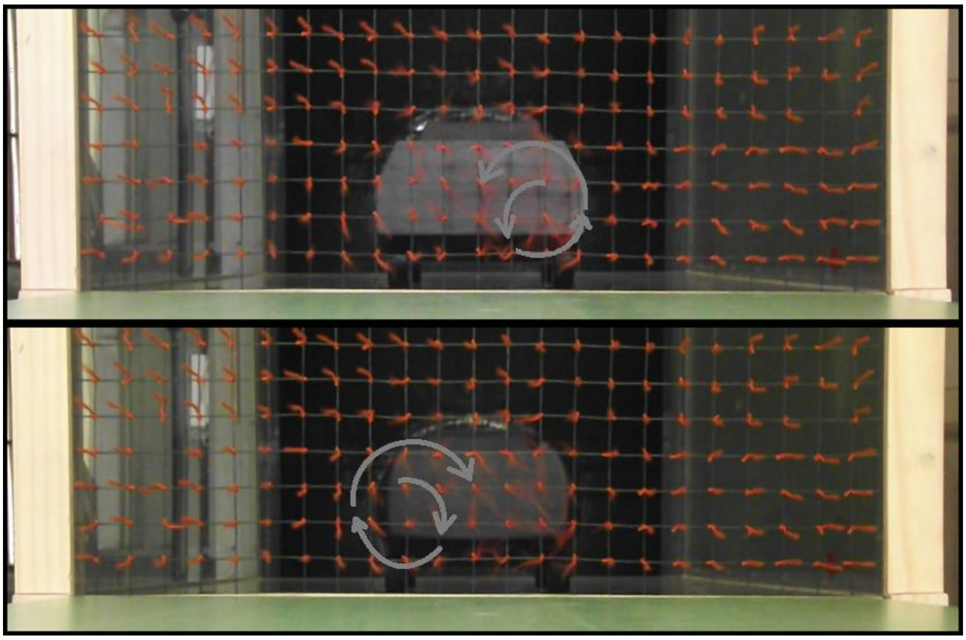

Figure 16: Wake-vortices visualization for 16 m/s. Upper: Flat. Down: Rounded.

4. CONCLUDING & REMARKS

The next stages of this work shall concern the quantitative approach. So, the models will be tested under anemometric and pressure distribution so that the wind velocity profile shall be acquired. Moreover, the models will also be tested in terms of drag coefficient evaluation with the help of an aerodynamic balance. Then, in order to finish the study about the contrast between the rounded and flatted models, the CFD simulation performed at past works must be placed to compare the experimental and computational results in terms of qualitative and quantitative evaluation. After all, the differences between both models' analyses could be considered completed, and the effect of how the smoothness of the rounded model may impact the flow pattern and its aerodynamics characteristics.

As described in the last paragraph it may conclude the first phase of the aerodynamics study of pickups vehicles and for consequence, the first step of the database creation. Then, the next phase continues with the creation of the database. The next model, already being developed, shall contain the wheels-housing and wheels that are fix by axis onto the model, as separated bodies, but only for the rounded prototype. Then all the experiments shall be replayed, so that the airflow patterns could be compared to the results accomplished at phase one of this work. This process is thought to continue until the database is completed.

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