EXPERIMENTAL ASSESSMENT OF AIRFLOW PATTERNS OVER PICKUP TRUCK'S CARGO AREA USING BED COVERS

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Abstract - Automobiles take on various forms and interact with the surrounding air when in motion. This interaction, known as aerodynamics, studies how solid bodies influence the flow of air around them. The shape of these solid bodies plays a crucial role in determining their resistance to the airflow. Factors such as additional cargo and loads can significantly impact an automobile's aerodynamics, which is essential for safe transportation of people and goods. Despite stringent safety measures, vehicle-related accidents remain a significant concern. This study aims to investigate the effects of added cargo and covers on an automobile's performance. The introduction of these elements alters the vehicle's original shape and approved design for safe operation. To examine these changes, we conducted experiments using a 1:27 scale model of the F150 pickup truck, one of the most prevalent pickup trucks in the United States. Various loads with different shapes and weights were tested at a constant speed. The presence of additional freightage introduces unwanted drag or lift, resulting in reduced fuel efficiency and potentially unsafe driving conditions. To mitigate these effects, we employed an adjustable external shell on the F-150 pickup truck, creating a controlled aerodynamic configuration. The results were visualized using colored powder, serving as a medium to highlight the interaction of air with the vehicle's exterior. This paper contributes to standardizing the geometric design of external shells, considering the unique nature of each load and its placement on the vehicle. Additionally, it provides real-time data for comparison, aiming to enhance our understanding of the complex interplay between cargo, covers, and vehicle aerodynamics.

Keywords - Aerodynamics, CFD, Freightage, Pickup Cover.

I. INTRODUCTION

The transportation of goods in the United States in 2017 was largely attributed to the trucking industry at 71.6 percent or 10.4 trillion dollars [1]. The trucking industry is responsible for importing goods, and the improvement of aerodynamics on these vehicles will lead to a smoother transfer process. Greenhouse gas (GHG) emissions from transportation, account for about 29 percent of total U.S. greenhouse gas emissions, making it the largest contributor to U.S. GHG emissions [2]. Alam A. et. al. [3] states that the fuel consumption done by trucks traveling at about 62 mph is considered to be 52% of the total fuel provided to provide power to overcome aerodynamic drag. The aerodynamic drag on the vehicle, due to the presence of the cargo, leads to greater fuel consumption and eventually higher GHG emissions. This study explores the means of reducing the negative impacts due to the presence of cargo on trucks, that is, reducing the aerodynamic drag to impact the cargo transfer process. MU'AZU, J. et. al. [4] and Abdulwahab, A. [5] conclude that the air drag on a vehicle can impact its aerodynamics, by amplifying the vehicle's oscillation, causing roll-over accidents in strong crosswind situations due to the heavyweight of the vehicle. Soper, D., & Baker, C. [6] state that the cargo to be carried can be of different shapes and sizes, which makes it difficult to be characterized for the aerodynamic effects due to slipstream, which is essentially the disturbance in the air, encountering an object moving through it. There have been different approaches to the reduction of the increased aerodynamic drag, caused by bluff body freightage vehicles. A study done by Woodiga, S. et. al. [7] on the remodeling of a pick-up truck and SUV concluded that adding a roof spoiler contributes to about a 1 to 3 percent drag reduction only. Alam A. et.al.[8] claim that drag reduction is improved by adjusting the aerodynamic shape of the front end of the vehicle via the addition of external attachments. Östh, J.'s thesis paper [9] claims a drag reduction of 10% by placing an open cavity at the intersection between each freight cart of a regional train model. Šušteršič G. et.al.[10], conducted a study on the snaking stability of passenger cars with light cargo trailers weighing 130 kg, and concluded that it has negligible aerodynamic repercussions.

The prominent increase in fuel cost led to extensive studies based on fuel reduction. M.J. Bradley et. al. [11], investigated available technologies for fuel reduction leading to aerodynamic aid products [roof, side fairings, vortex generators, air dams] for reducing drag and achieving a 1% to 25% fuel reduction. The new safety factors are of prime importance, for vehicles with modified geometry. In a study performed by Abed A. et.al. [12], drag reduction is observed in varied bed geometry and covers with certain conditions [no cover, flat cover & inclined cover] generating lift and traction loss with potential for safety concerns. Their case with no cargo cover produced a remarkable 37.7% increase in lift versus the case on the inclined cover. Mukda, P. et. al. [13] also experimented with the effect of the drag coefficient on several vehicle types, resulting in internal recirculating flow within the cab of a pickup lowering fuel consumption. Their study proved

covering the wake of the truck could lead to a 5 - 33.3% reduction in the drag coefficient. Jongsoo Ha et.al. [14] performed an in-depth study of the pickup cab, testing lengths [175.2-233.4mm] and heights [26.2-65 mm]. The different geometries displayed an increase in drag for longer cab dimensions. J Abinesh et. al. [15] performed a study on a pick-up truck with a modified frontal area, ac vents, rear shape, and side mirrors. The modifications resulted in a drag reduction of 10% in comparison to the original model which in turn led to lower fuel consumption. Yang et. al. [16] performed aerodynamic modeling to relate a CFD model of a pick-up truck to a live experiment, and observed similar mean flows, thus, validating the experimental result via CFD. "Fleet Equipment [17]" performed a study with feedback generated from truck-drivers operating trucks with added modifications for drag reduction. The study side skirts were the most popular with positive feedback, among the various modifications explored.

Yesfalgn Damissie et. al. [18] creates models with modifications at the front and rear end of a bus resulting in the highest drag reduction. This model predicts a fuel consumption reduction of about 22.8% at 85-115 kmph. J Abinesh et. al. [15] used modified models with aerodynamic components to show drag reduction via Computational Fluid Dynamic software. This process validated that simple attachments can provide a proficient drag reduction without manufacturers requiring significant design changes.

Bhram Khalighi et. al. [19] performed an investigation on the feasibility of using CFDs for vehicle Aerodynamic problems. For unsteady application heavy runtime, the accuracy is not guaranteed. This caused the simulations to be based on steady with minor unsteady flow requiring up to thirty times less CPU hours with accurate results. The advantage of utilizing CFD methods is the ability to analyze and mathematically predict, without the heavy cost of full-scale live models. The presented literature utilized rigid static modification, however, hybrid or smart active modifications for drag reduction have not been largely explored. The presented literature has explored different optimization techniques for the aerodynamics of bluff body vehicles. The present study explores the effect of added attachments to the body of these vehicles. This paper aims to prove that there can be an optimal cover that can be added to cargo-carrying vehicles, which leads to studying the effect of aerodynamic drag, that in-turn affects the fuel consumption and the slipstream created by bluff bodies. Hence, a direct consequence of drag reduction is the increase in stability. This further encourages studies not limited to lowering fuel consumption but also exploring the aspect of increasing vehicle safety.

This paper addresses the following question:

"What's the effect of an additional external shell on a bluff body among freight transportation vehicles?" The investigation of the effects of an external shell led to the use of a model prototype of the vehicle with the aforementioned shell and colored fog to simulate an environment where aerodynamic drag can be visualized. The results indicated a significant impact of the external shell on the aerodynamic drag, which can in-turn lead to lower fuel-consumption and reduced slipstream.

I. Experimental Procedure

The experimental test is a visual representation of the airflow change due to pickup truck cargo covers. A 1:27 model of an actual 2019 Ford F-150 Crew Cab (Fig. 1.1) has been used. The tests are scaled to match 35, 55, and 75 miles per hour speeds. The speed limits reflect the nominal driving conditions within the city and highways. The test implements visual effects that helps to visually track the airflow as well as provides the much-needed insight for concentrated areas via the left-over residue.

The experiment is benchmarked for parameters without any covers and incorporates different added loads for pretesting understanding. The loads are represented by blocks in (Fig. 1.1.1-2.). The various scenarios explored in this study are as follows:

Test Models (model F-150)
1.1 No Cargo Cover
1.1.1 Large Block Load
1.1.2 Small Block Load
1.1.2.1 Standard Weight
1.1.2.2 Light Weight
1.2 Flat Cargo Cover
1.3 Hybrid Cargo Cover
1.4 Camper Cargo Cover

The different geometries in experimentation correspond to the flow changes due to size. The two small loads of different weights validate if any flow change is directly proportional to load weight. The following 3 model cargo covers are each tested under high-speed conditions. In Fig. 1.2-4. Respectively, the models are arranged from covering the flat cover height to flush with the roof of the pickup. The flow over the prototype for each test is observed from the rear of the truck bed and the concentrations are observed after the flow pattern has been obtained.

The materials used for the cover are vinyl, wood planks, Velcro respectively. The covers were constructed by using 100% vinyl and wood pieces. Velcro was used to attach the covers to the top cover of the bed of the scaled model.

Experimenting in a tunnel provides a controlled environment for minimizing outside interferences. The setup was constructed by utilizing a large

cardboard box to emulate a tunnel with the additional placement of a fan within it. This fan blew in the direction of the F-150 [providing resistance to its speed], which had been secured to a placement plank with Velcro. Since we have a 1:27 scaled model, we had to make sure that the fan speeds towards the F-150 were reasonable, therefore aimed to have 35 mph, 55 mph, and 75 mph speeds respectively. A digital anemometer was used to measure the speeds accurately, which were achieved via the use of plastic nets.

Test Cases (Wind Speed)
1.1 No Cargo Cover (75 mph)
1.1.1 No load
1.2 No Cargo Cover (35 mph)
1.2.1 Small Block Load
1.2.2 Small Weighted Block Load
1.2.3 Large Block Load
1.3 No Cargo Cover (55 mph)
1.3.1 Small Block Load
1.3.2 Small Weighted Block Load
1.3.3 Large Block Load
1.4 No Cargo Cover (65 mph)
1.4.1 Small Block Load
1.4.2 Small Weighted Block Load
1.4.3 Large Block Load
1.5 Flat Cargo Cover (75 mph)
1.6 Hybrid Cargo Cover (75 mph)
1.7 Camper Cargo Cover (75 mph)

The other materials used for the test are blue-colored powder, large card-board box, cover, three different wooden blocks; two same size but different weight, one larger in size. The test involved 13 different cases, each used colored powder to create a visual for how the fluid flows against the F-150. We conducted a test with nothing on the bed of the F-150, then the blocks each had three tests, one at each speed, while the covers only had a test at the highest speed.



Fig. 1.1:1:27 model F-150



Fig.1.1.1-2.: Blocks- Large, Small & Small Lightweight



Fig.1.2:Cargo Area Flat Cover



Fig.1.3:Cargo Area Hybrid Cover



Fig. 1.4:Cargo Area Camper

II. SUCCESS

This experiment setup required finding a suitable model, setting accurate test parameters, and obtaining results. In the model-selection process, the literature review led us to the most common model in the United States of America; the Red 2019 Ford F-150 Crew Cab. This model is used by commercial and industry settings, hence, the Ford F-150 pickup truck is the best truck to analyze. In this experiment a Red 2019 Ford F-150 Crew Cab was used with a scale of 1:27. For the selected model prototype, the covers had to be designed with close similarity to the sold products.

This was achieved with modular attachments that allowed any change between test covers with ease. The material of the covers are coarse and were specifically selected to have larger concentrations of the residue to adhere. This material emphasized and created a better visual with the contrast of a dark color to the selected blue powder. The experiment was set up successfully with all the necessary items obtained. The test tunnel was set up to contain and funnel the flow of the wind created by the fan. The use of a large tunnel in scale to the model allowed accurate dispersion. Hence, we avoided the recirculation and obstruction, [due to smaller tunnels] tainting the results.

III. CHALLENGES

In the experimentation using scaled winds that matched the vehicle 1:27 ratio could not produce desirable concentrations. This is due to the scaled wind speeds not being strong enough to sweep and move the powder for residue imprintment. To resolve this challenge the simulated wind speeds were increased to deliver a visible flow of colored powder along the vehicle. The factor increased to 1:27 scale of 135 mph. This became the nominal test speed for all cases.

IV. RESULTS

In the experiment, the objective is to visualize patterns indicating the flow along the vehicle. The tests revealed imprinted patterns displaying airflow along the vehicle's surface area. This was shown by the leftover residue from each test conducted on each cargo cover. The imprint simulates the contact between the flowing air and the surfaces of the vehicle. Observing areas with a concentration of powder displays prominent locations with larger drag coefficients. This is used to determine the differences in drag coefficient between cases.



Fig. 1.5: No Cargo Cover

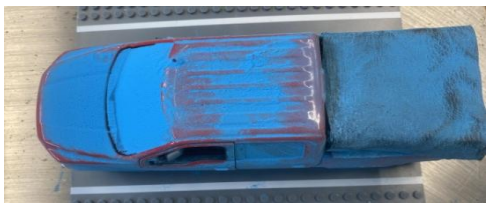


Fig.1.9: Flat Cargo Cover

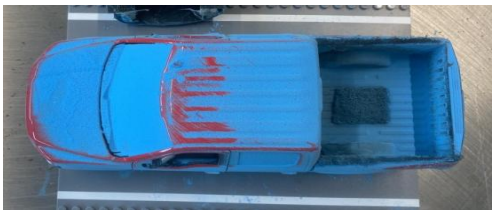


Fig.1.10:Hybrid Cargo Cover

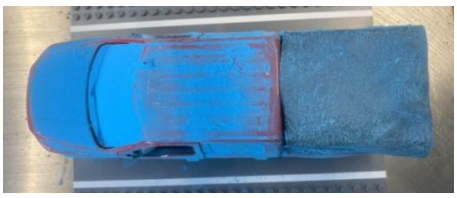


Fig.1.11: Camper Cargo Cover

The No Cargo Cover case as shown in Fig. 1.5 has leftover residue concentrations in the rear bed area. This shows recirculation of airflow occurring in the truck bed which increases drag coefficient. The Flatbed cover in Fig. 1.9 shows minimal interaction with the airflow. As the heights of the covers are increased, the coverage area increases as does the area interacting with airflow.

Analysis of Residue Attached to Cargo Area on F-150

For our analysis, we utilized five different cases for the 75 mph speed to show the amount of residue collected at the backend of the pick-up truck. The cases were the following:

Test Cases for Analysis (Wind Speed)
1.12 Case I no Cargo Cover nor Residue (75 mph)
1.13 Case II no Cargo Cover (75 mph)
1.14 Case III Flat Cargo Cover (75 mph)
1.15 Case IV Hybrid Cargo Cover (75 mph)
1.16 Case V Camper Cargo Cover (75 mph)

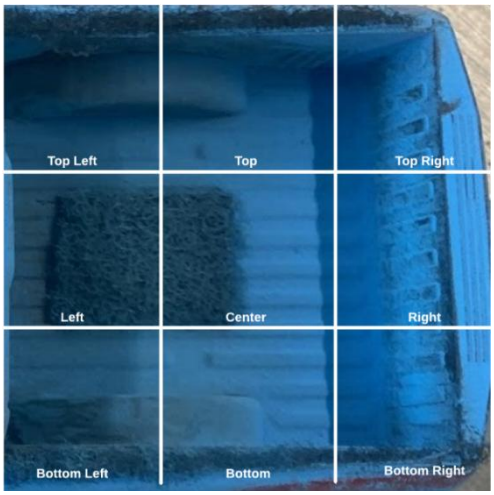


Fig. 1.12: Case I no Cargo Cover nor Residue (75 mph)

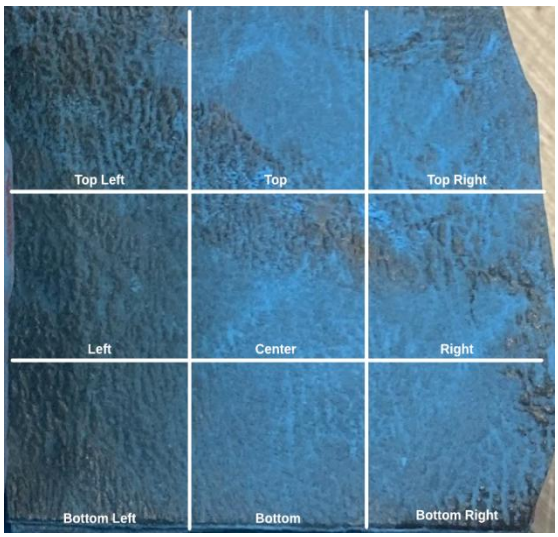


Fig. 1.13: Case II no Cargo Cover (75 mph)

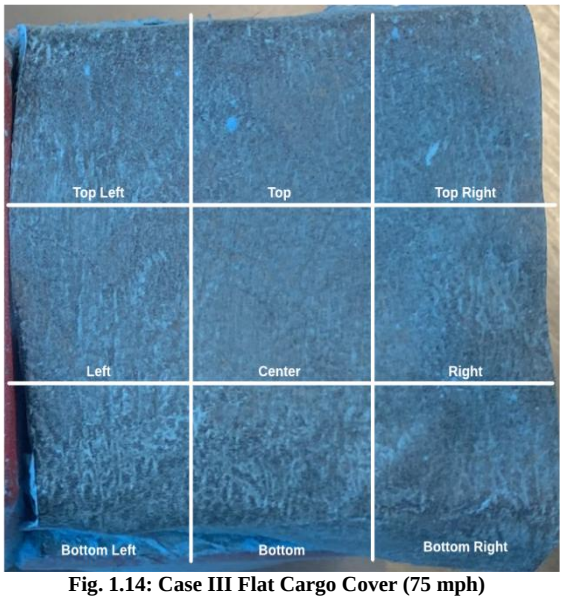


Fig. 1.14: Case III Flat Cargo Cover (75 mph)

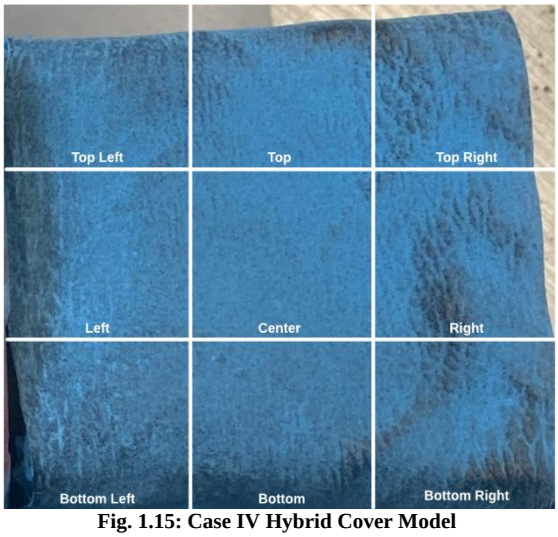


Fig. 1.15: Case IV Hybrid Cover Model

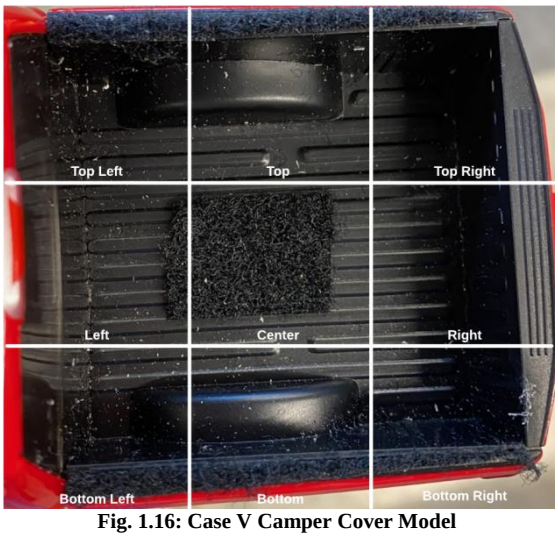


Fig. 1.16: Case V Camper Cover Model

We created a measurement system of the amount of residue that remained on the backend of the F-150 after each experiment. We did this by comparing the grid selection of cases I-V to one another, respective to the same area of selection. We considered the amount of residue on each section to be indicative of the amount of drag that the section is experiencing. To represent our comparison, we generated Table I and the chart shown in Fig. 1.17. The following defines the criteria by which we measured residue:

Key:

0: Little to no residue on the grid selection
1: Residue is barely visible on the grid selection
2: Residue is not entirely coating the grid selection and has not become clumped on the groves of the backend.
3: Residue has not entirely coated the grid selection but has become clumped in the crevices of the backend.
4: Residue has entirely covered the grid selection and has become clumped in the crevices of the backend.
5: Residue has entirely covered the grid selection and has left an even coating on the backend.

Grid Section	Case I	Case II	Case III	Case IV	Case V
Top Left	0.1	5	2	3	4
Top	0.1	5	2.7	3.2	4
Top Right	0.1	5	3	3	4
Left	0.1	5	2	3.1	4
Center	0.1	5	2.5	4.3	4
Right	0.1	5	2.7	2.7	3.7
Bottom Left	0.1	5	2	3.7	4.3
Bottom	0.1	5	3.7	3.9	4.3
Bottom Right	0.1	5	2.5	2.8	4

TABLE I Residue per Grid Section from Cases I-V

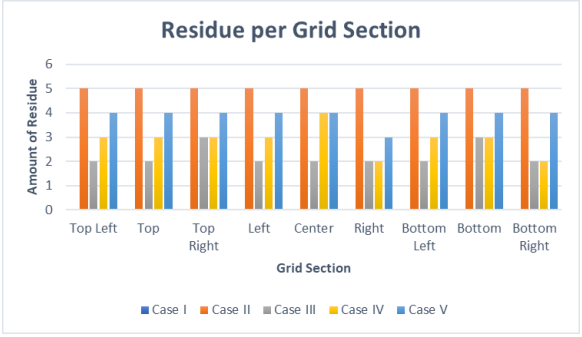


Fig. 1.17: Residue per Grid Section Chart Analysis

If we use case I and case II as a minimum and maximum situation respectively, we are able to make comparisons for the cover cases III-V. When taking the top left grid selection into consideration, we found that this particular area had a point difference between every cover case, we attribute this to the nearness of this selection to the back windowpane of the pick-up. As the height of the cover increased as did the amount of residue on the top left section. The same correlation can be found in the top grid section as there was an increase in between cases. With the top right grid section, we noticed that in cases III and IV, the amount of residue was equal, suggesting that in this section of the cover, there is a similarity in the amount of drag that is experienced. The left grid section showed a similar trend to that of the top left. At the center of the grid section, there was a similar amount of residue as the top section for case III, a similar amount for case V, but a much larger amount for case IV. This is likely due to how the residue shifted towards the center as it impacted the covers on the truck during experimentation, creating a section with excess residue, depicting how the drag becomes concentrated on the center of the covers. The right grid section was similar to that of the top right section, with the exception that there was an overall reduction in the amount of residue for cases III, IV, and V. This means that there was a smaller concentration of residue, and thus drag, on the right grid section for these cases. For the bottom left grid section, in cases III, IV, and V, a similar amount of residue was found as in the previous left grid sections for the same case The bottom grid section had a similaramount of concentrated residue compared to the top right grid section. This identifies these areas as sections with a high amount of drag for each of the cover cases, likely due to the number of crevices in this particular section. The bottom right grid section has a large reduction in residue for cases III and IV in comparison to the bottom grid section. This is likely due to most of the residue being collected on the bottom grid section, reducing the amount of residue that flows to the bottom right grid section.

V. CONCLUSION

This experimental study was conducted to understand the flow on the backend of a truck and the difference that is made when using different types of covers to protect cargo. We sought to make a hybrid between a traditional camper and a flat cover that would result in compromising the aerodynamic drag that was less than the camper but slightly greater than the flat cover. Through our experimental testing, we were able to see how the grid sections top, top right, right, bottom, and bottom right are similar in the amount of residue present for the flat cover and the hybrid cover. For all sections except for the center, the camper cover resulted in the greatest amount of residue. As we are attributing the amount of residue measured to the amount of aerodynamic drag experienced in that particular section, we are able to prove our hypothesis through our experimental testing.

Future Work

To expand upon our study, we want to use Computational Fluid Dynamics to simulate the five cases with the three speeds to provide theoretical data that will support our experimental data. We would also like to research a material that will allow for the hybrid model to shape itself to the size that is needed to appropriately encompass the cargo that is present in the bed of the truck. This material would need to be able to influence the reduction of aerodynamic drag.

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