مجلة جامعة بني وليد للعلوم الإنسانية والتطبيقية
تصدر عن جامعة بني وليد – ليبيا
Website: https://jhas-bwu.com/index.php/bwjhas/index
العدد التاسع والعشرون، 2023

REDUCING DRAG IN TRUCK TRAILER USING NACA PROFILE

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تاريخ الاستلام: 2023-06-17   تاريخ القبول: 2023-06-27   تاريخ النشر : 2023-09-07

Abstract: Almost seventy percent of all goods are transported with the help of commercial vehicles with tractor-trailer combinations. Despite the fact that intensive aerodynamic studies have been taken into account for a few decades within the automotive industry. In theory the engine will only deliver fifty percent of the power to move the vehicle forward as the other fifty percent will be wasted against the significant and contrasting drag force. Computational Fluid Dynamics, often known as CFD, is a very powerful and effective tool which is used in engineering practice to find solutions to aerodynamic problems. The ANSYS Fluent (version 2016) software has been used to conduct the analysis throughout this paper and solidworks (version 2016) software to draw all model used. This article contains an in-depth study involving the usage of NACA aerofoil on the critical area of a trailer to help reduce the drag coefficient and hence exploit the fuel saving potential. Various different NACA aerofoils have been used in the study of the effectiveness of each profile for the given purpose. The best choice of NACA profile concluded from the CFD results is NACA 0012 with five parts attached to the truck trailer.

Keywords: (Aerodynamics, CFD, Truck Trailer)

Introduction

Commercial vehicles have not been the main area of research and application of aerodynamic advancements. The aerodynamic design of commercial/heavy vehicles has only been active for around thirty years [1]. Since commercial vehicles are the biggest fossil fuel consumers, most fleet operators are forced to improve the aerodynamic styling of their vehicles. Aerodynamic efficiency is directly proportional to the frontal area, the density of the head wind, the speed the vehicle is travelling at and the coefficient of drag, which is simply dependent on the shape of the vehicle.

It can be noticed from the above formula of drag force that at velocities higher than thirty miles per hour, drag force becomes significantly strong and hence important and up to fifty percent of engine power can be consumed to overcome this drag force.

At the present time, the tractor-semitrailer is one of the most common forms of transport. It plays a crucial role in cargo transportation because it is flexible and faster when compared with railway transportation [2].

One of the important ways which it used in order to conserve energy and to protect the global environment is improving the aerodynamic drag, so the main concern of the automotive industry is to reduce fuel consumption. The evolution of the vehicle body and the reduction of drag is fundamental for developing fuel consumption and driving performance so that it will increase the vehicle's capacity.

In spite of this, recent studies have shown that saving 3% in fuel consumption could be the result of reductions of 10% in aerodynamic drag [3].

In a lot of cases, the most dominant resistive forces for over 50% of overall resistance to motion are the drag force, thus it influences the fuel efficiency of the vehicle [4].

The one way that may be used to reduce fuel consumption for heavy vehicles can be attained by modifying truck shapes to reduce the aerodynamic resistance (drag) [5]. As result of that, the vehicle design is still a controlling worker when creating vehicle body shapes. In last year's achieved flow amendments and drag decreases without the need to change a physical shape by use an active flow control techniques [3], General, the flow field created around a vehicle shape, which it will influence the aerodynamic force system generated [4].

The drag of heavy vehicles is commonly decreased by using a range of methods, for example streamlining airflow, covering exposed under body structures, decreasing wake and flow separation, all of which could be achieved by cab and trailer mounted devices, for example cab roof and side fairings, trailer-front fairings and base-flaps. Despite the availability of these solutions, it not all these solutions have been exactly appropriate in the automotive industry, because there are some issues, such as cost, maintenance, safety and efficiency, which reduce the alternatives available to fleet operators [6].

The need for truck aerodynamic improvement was realized almost four decades ago when NASA's Dryden Flight Research Centre at Edward Sir Force Base started the research in this particular area. The initial work was carried out by Kenworth (1985) and proved the importance of cad-fairing adding onto the trailer in order to achieve reduced aerodynamic drag force.

Model Construction

Figure 1 shows the key dimensions of the semi-trailer model that was used in this analysis, which was created Solidworks V.2016. The height of the semi-trailer has been taken as a standard 4.2 m based on commonly found dimensions and was taken as the baseline configuration. The dimensions of the semi-trailer, wheels and ground clearance are typical of real conditions, the length of the semi-trailer 16.28 m, the width 2.6 m and the length of the trailer 12.73 m, with wheels diameter 0.5 m.

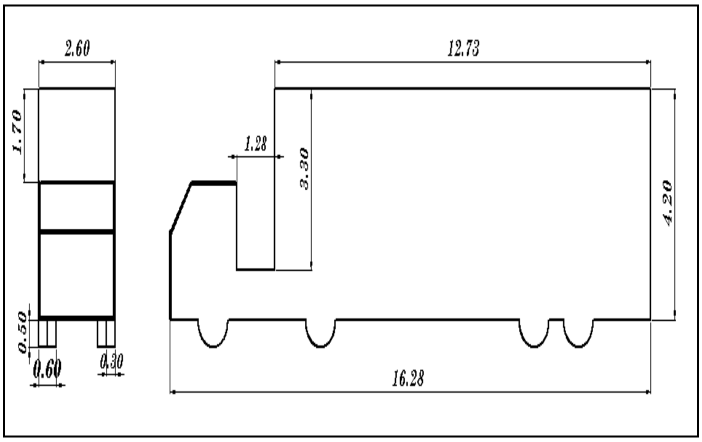


Fig. 1: The model dimensions by meter

The dimension of the NACA Airfoil, variations were created in the model by the application of the same foil, once with the usage of three equal splits, once with the usage of five equal splits and finally without any split along the entire height of the trailer end.

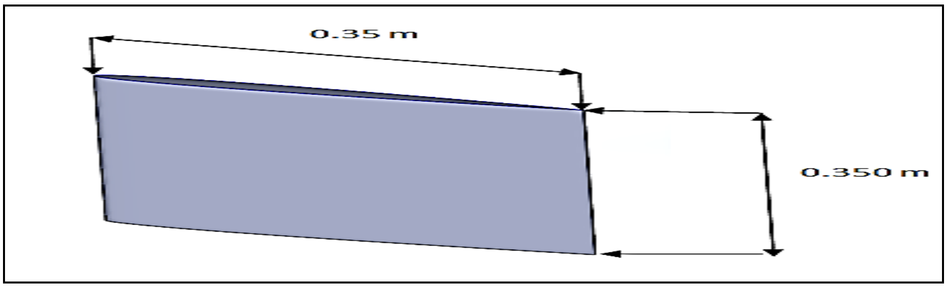


Fig. 2a: The NACA airfoil model 1

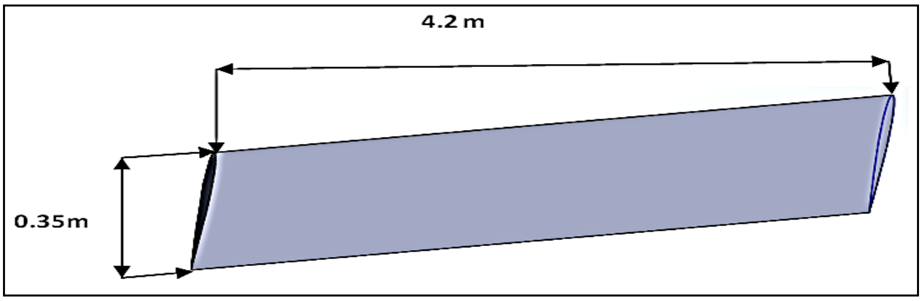


Fig. 2b: The NACA airfoil model 2

NACA Aerofoil Profiles

Three different NACA airfoils were used to analyses the effectiveness of each profile and its validity for the application. The three NACA airfoils used for the study are as given, NACA airfoil 0006, NACA airfoil 0012, and NACA airfoil 2412.

The semi-trailer with three NACA airfoils on each side of the semi-trailer.

The NACA length is 0.35 m and width 0.35 m, the gap between the NACA airfoil and the trailer is 0.2m, the position of the NACA airfoil on each side of the semi-trailer are one on the top and one on the bottom of the trailer and the last one was put in the middle, between the top and bottom NACA.

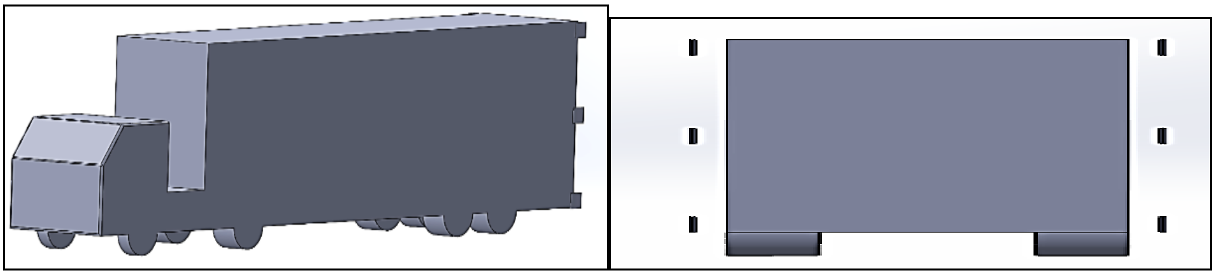


Fig. 3: The tractor trailer with three NACA profile

The semi-trailer with five NACA airfoils on each side of the semi-trailer.

The NACA has length of 0.35 m and width of 0.35 m, the gap between the NACA airfoil and the trailer is 0.2 m, the positions of the NACA airfoil on each side of the semi-trailer are two on the top and the bottom of the trailer and the last three were put between the top and bottom NACA, so as the distance between each NACA was 0.6125 m.

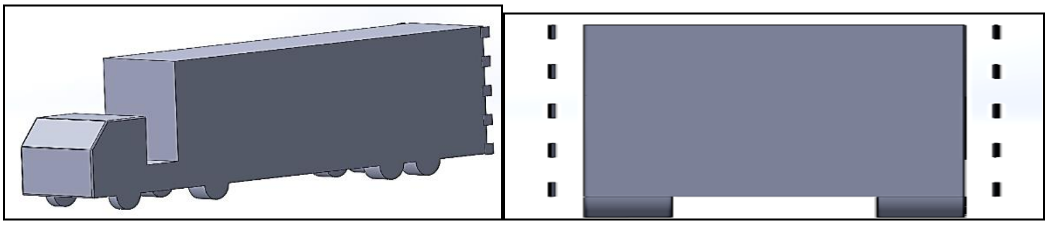


Fig. 4: The tractor trailer with Five NACA profile

The semi-trailer with one NACA airfoil on each side of the semi-trailer.

The NACA has width of 0.35 m and length of 4.2 m, the same as the length of the trailer of the truck, the gap between the NACA airfoil and the trailer is 0.2m.

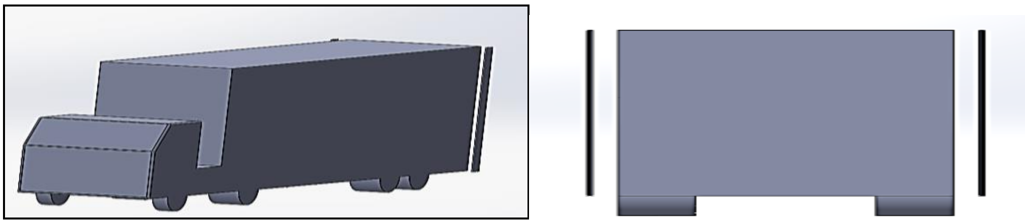


Fig. 5: The tractor trailer with one NACA profile

Computational Domain

The various models of the semitrailer formation under test were each imported into a three-dimensional, geometrically generated flow domain. The flow domain consisted of a rectangular cuboid volume containing the semitrailer model, as shown in the figure. The flow domain had a length of 260.48 m, such that the inlet of the flow domain was 5.L upstream and the outlet was 10.L of the semi-trailer models (where L is the total length of the semi-trailer model). The longitudinal side walls of this area were at a distance of 3.W from the model (where w is the total width of the semitrailer model), so the width of the flow area was 18.2 m, and the distance between the horizontal top wall of the area and the top of the semitrailer was 4.H (where H is the total height of the semitrailer model), so the height of the flow area was 22 m.

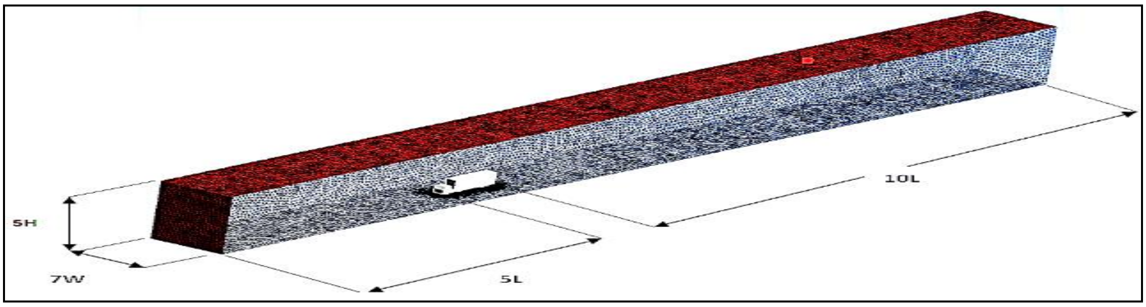


Fig. 6: Domain Geometry

Justification of Mesh

Mesh generation is the second step of CFD and is considered one of the main steps in CFD after the definition of the domain geometry. At this stage the CFD will divide the domain into a number of smaller elements, to resolve the flow physics within the domain geometry that has been created. This leads to the creation of a mesh (or grid) of cells overlying the whole domain geometry. The number of elements in the mesh within the computational domain will have an effect on the accuracy of a CFD solution, which means increasing the number of cells will increase the accuracy of the CFD solution [7]. The first step in the mesh before choose the correct size of mesh is a justification of mesh, which was used during the study as it holds a vital impact in the results in terms of not only the accuracy of results obtained, but also the computational time, which has been one of the most critical elements in the success of this article. This was achieved by using different elements of face size, so it was done by using the bigger element face size to domain and smaller elements face size to the body of the semi-trailer without NACA airfoil. The mesh independence test was done at meshes of 1.25 million, 2.5 million and 5.6 million with velocity of 40MPH (17.88m/s) and angular velocity of rotation wheels (35.76 rad/s) was used for this test. The results of the mesh independence test are shown in the table below.

Table. 1: The justification of mesh

Number of Case	Size of Mesh (m)			Number of elements	Force (N)			Drag coefficient
	Min	Max	Body of semi-trailer		Pressure	Viscous	Total	
1	0.1	1	0.165	1256890	2504	60	2504	1.057
2	0.1	1	0.07	2514836	2319	93	2413	1.019
3	0.02	1	0.04	5564584	2232	115	2348	0.99

It may be seen from the table that the accuracy of the results has been increased by increasing the number of elements. Mesh was chosen for this article with approximately 5.6 million elements, and also it has been used 12 million elements for model and the result was far less in comparison, that it was 0.9% difference with used 5.6 million elements. To save time required for the analysis, mesh with 5.6 million elements was selected as standard for all the remaining results for the article with a quality of mesh 96%.

Boundary Conditions

In this article, the velocity of the domain of the semi-trailer was defined as a velocity inlet with three different velocities at three different cases, which are 17.88 m/s (40 M/h), 22.35 m/s (50 M/p) and 25 m/s (56 M/h). The side face of the domain behind the model was defined as pressure outlet zero, and the bottom face of the domain flow was defined as moving wall by velocity 17.88 m/s (40 M/h), 22.35 m/s (50 M/p) and 25 m/s (56 M/h). The wheels of the domain flow were defined as rotation wheels with angular velocity as 35.76 rad/s, 44.7 rad/s and 50 rad/s. The figure 7 shows the names of all the faces of the semi-trailer.

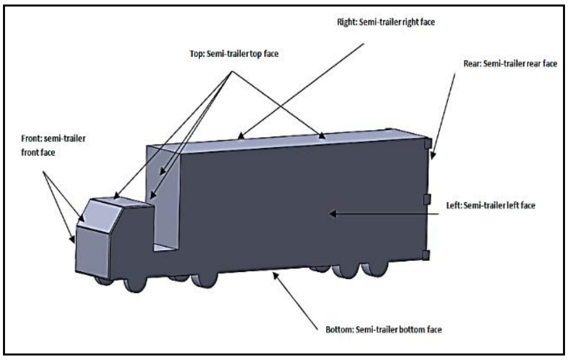


Fig. 7: Truck areas of aerodynamic interest

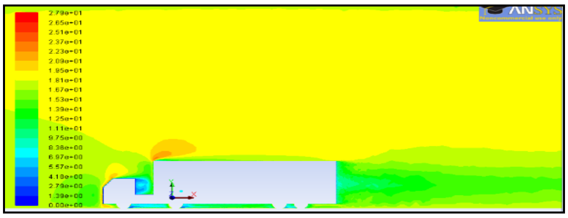
Results And Analysis

There have been rather interesting result trends found during the study, details of which can be found in next section. Data collection and representation has been carefully chosen to convey the results in the most direct manner. All the NACA foil profiles are compared side by side showing the drag force, density of air, frontal area of the commercial vehicle and, most importantly, the aerodynamic drag percentage reduction, which has been critical information since it highlights in black and white that which NACA foil is the most appropriate for the purpose within the NACA air foils used in this research.

Flow Velocity Variation

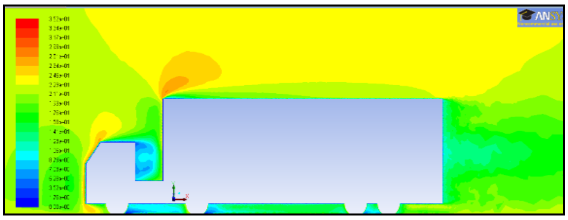
Three different flow velocities were used to ensure the in-depth study corresponding to the effect of flow velocity change with the maximum flow velocity used as the maximum motorway speed limit for commercial vehicles in the UK.

The three flow velocities used for the analysis are as follows 17.88 m/s (40mph), 22.35 m/s (50mph), and 25.03 m/s (56mph).



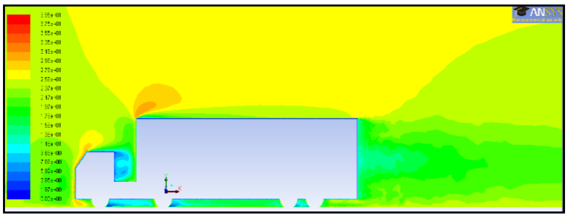
With Five NACA0012

Fig. 8: Contours of velocity magnitude, Semi-trailer at velocity of 17.88 m/s



With Five NACA0012

Fig. 9: Contours of velocity magnitude, Semi-trailer at velocity of 22.35 m/s



With Five NACA0012

Fig. 10: Contours of velocity magnitude, Semi-trailer at velocity of 25 m/s

The tables below are contained the data collected from CFD results and other calculations for various speeds suggested.

Table 2: shows different velocities with various DRAG and drag coefficient reading

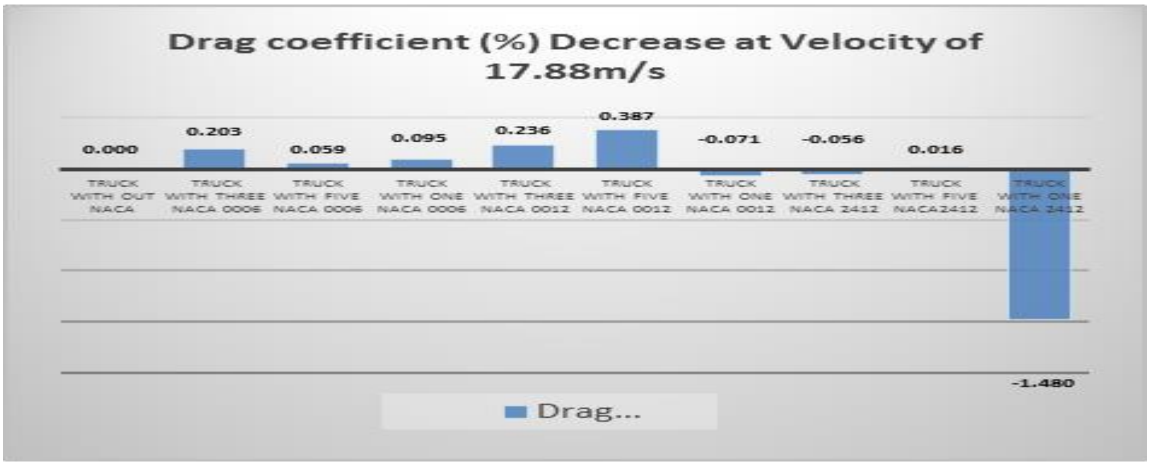
Velocity = 17.88 m/s					
Type of NACA	**Drag (N)**	**Air density (kg/m3)**	**Area (m sq.)**	**Drag coefficient**	**Drag coefficient (%) Decrease**
Truck without NACA	2348	1.225	12.09	0.992	0.000
Truck with three NACA 0006	2351	1.225	12.13	0.990	0.203
Truck with five NACA 0006	2360	1.225	12.16	0.991	0.059
Truck with one NACA 0006	2362	1.225	12.17	0.991	0.095
Truck with three NACA 0012	2359	1.225	12.17	0.990	0.236
Truck with five NACA 0012	2367	1.225	12.23	0.988	0.387
Truck with one NACA 0012	2384	1.225	12.26	0.993	-0.071
Truck with three NACA 2412	2366	1.225	12.17	0.993	-0.056

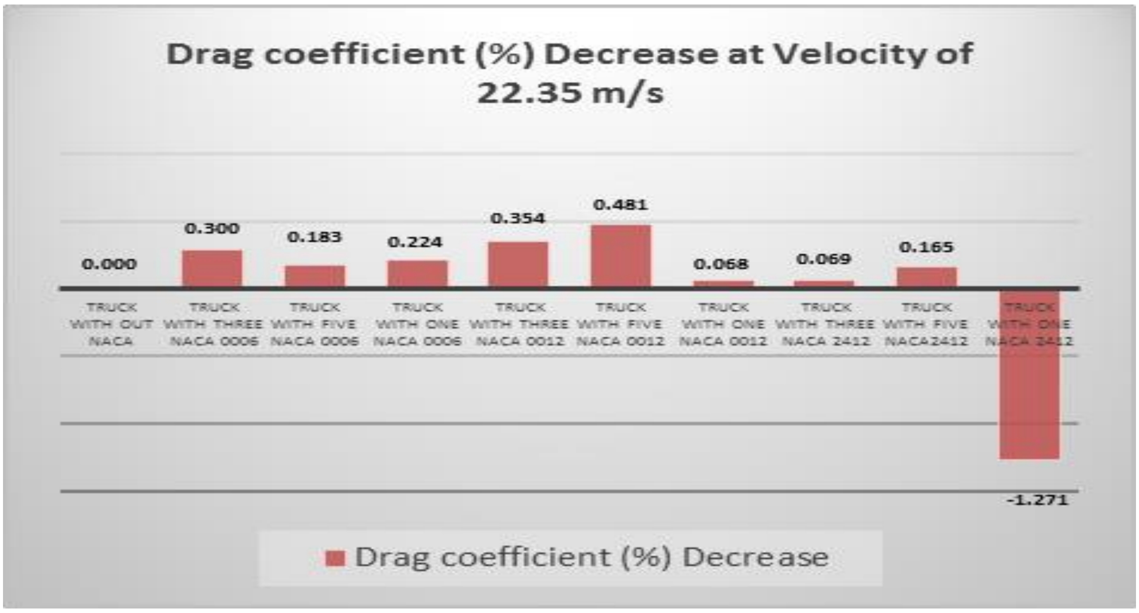
Type of NACA	Drag (N)	Air density (kg/m3)	Area (m sq.)	Drag coefficient	Drag coefficient (%) Decrease
Truck with five NACA24 12	2376	1.225	12.23	0.992	0.016
Truck with one NACA 2412	2418	1.225	12.26	1.007	- 1.480
Velocity 22.35 = m/s					
Type of NACA	**Drag (N)**	**Air density (kg/m3)**	**Area (m sq.)**	**Drag coefficient**	**Drag coefficient (%) Decrease**
Truck without NACA	3657	1.225	12.09	0.989	0.000
Truck with three NACA 0006	3659	1.225	12.13	0.986	0.300
Truck with five NACA 0006	3672	1.225	12.16	0.987	0.183
Truck with one NACA 0006	3675	1.225	12.17	0.987	0.224
Truck with three NACA 0012	3671	1.225	12.17	0.985	0.354
Truck with five NACA 0012	3684	1.225	12.23	0.984	0.481
Truck with one NACA 0012	3708	1.225	12.26	0.988	0.068
Truck with three NACA 2412	3682	1.225	12.17	0.988	0.069
Truck with five NACA24 12	3696	1.225	12.23	0.987	0.165
Truck with one NACA 2412	3759	1.225	12.26	1.001	- 1.271
Velocity = 25 m/s					
Type of NACA	**Drag (N)**	**Air density (kg/m3)**	**Area (m sq.)**	**Drag coefficient**	**Drag coefficient (%) Decrease**
Truck without NACA	4569	1.225	12.09	0.987	0.000

Truck with three NACA 0006	4571	1.225	12.13	0.984	0.310
Truck with five NACA 0006	4586	1.225	12.16	0.985	0.202
Truck with one NACA 0006	4590	1.225	12.17	0.985	0.239
Truck with three NACA 0012	4584	1.225	12.17	0.983	0.402
Truck with five NACA 0012	4601	1.225	12.23	0.982	0.511
Truck with one NACA 0012	4632	1.225	12.26	0.987	0.089
Truck with three NACA 2412	4599	1.225	12.17	0.986	0.095
Truck with five NACA24 12	4616	1.225	12.23	0.985	0.201
Truck with one NACA 2412	4693	1.225	12.26	0.999	-1.201

Individual Effects and Velocity Effect

Tables and the charts below show that the drag coefficient (%) decrease at various velocities. Indeed, the best NACA profile showed good results is NACA 0012 with five parts distributed at the back of truck-trailer. As can be seen from fig. 11 the values percentage of drag coefficient decrease are 0.387 % at speed of 17.88 m/s, and 0.481 % at speed of 22.35 m/s, and 0.511 % at speed of 25 m/s. Actually, it can be concluded that the drag coefficient % decreases more at high speed suggested.





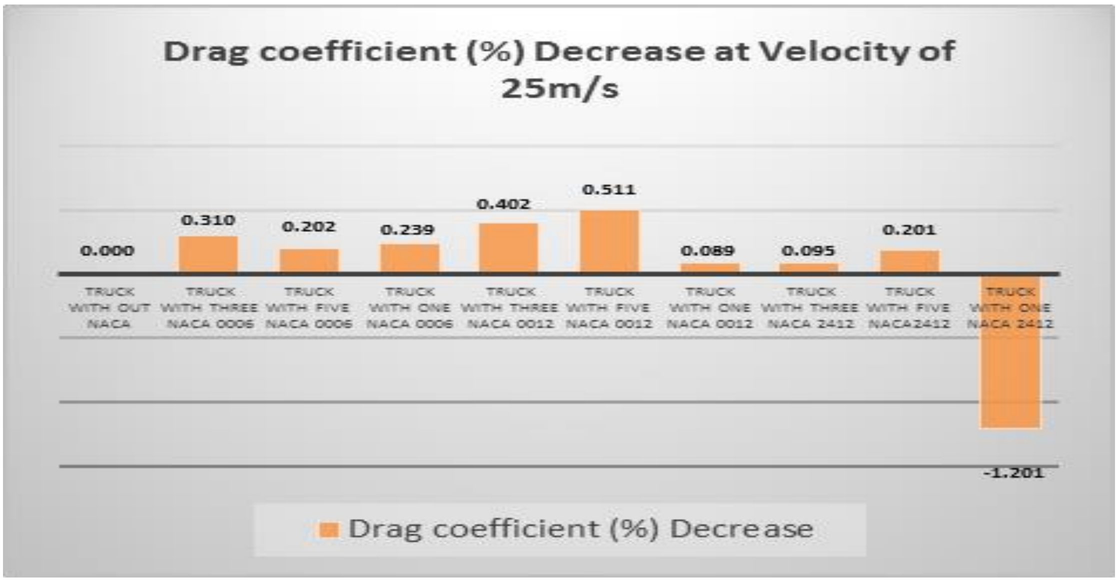
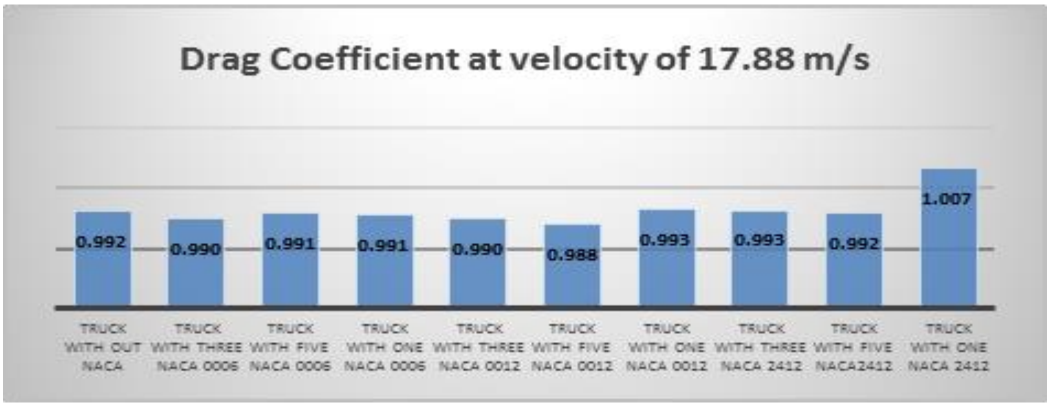
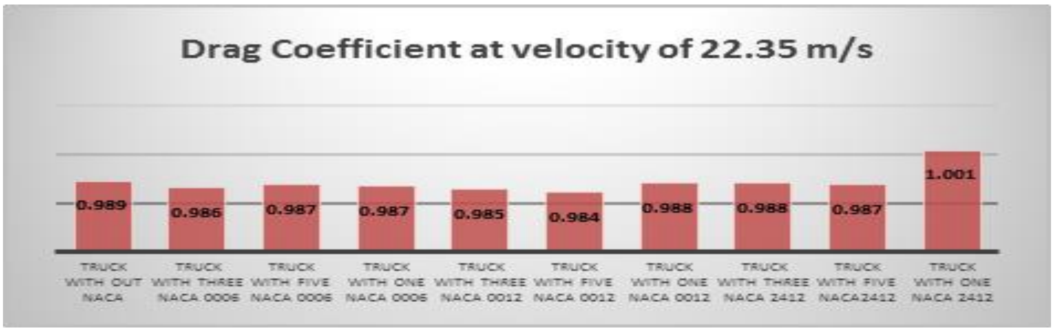


Fig. 11: Shows drag coefficient (%) decrease at velocities of (17.88 m/s, 22.35 m/s, and 25 m/s) respectively.

Tables and coming charts showed drag coefficient at different velocities. It's clear that the lowest drag coefficient appointed at truck with five NACA 0012 compared to other models of NACA shapes attached to the truck. Fig. 12 shows that, the lowest drag coefficient for the truck with five NACA 0012 is 0.988 at velocity of 17.88 m/s, and the lowest drag coefficient for the truck with five NACA 0012 is 0.984 at velocity of 22.35 m/s, and the lowest drag coefficient for the truck with five NACA 0012 is 0.982 at velocity of 25 m/s. where it can be concluded that, the best choice of NACA profile for the truck trailer is NACA 0012 with five parts attached to truck trailer.





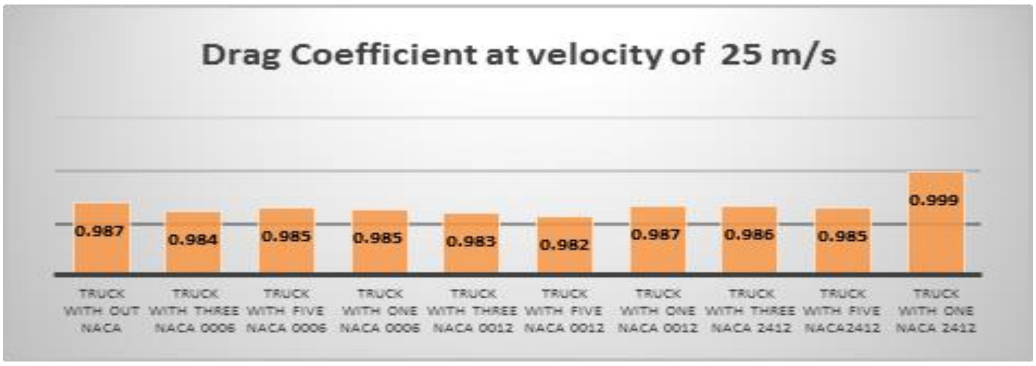


Fig. 12: Shows drag coefficient at velocities of (17.88 m/s, 22.35 m/s, and 25 m/s) respectively.

CFD Results Validation

Since it is a novel concept, unfortunately the study cannot be directly validated with the desired accuracy. However, the magnitude of the total impact involving both the effect of velocity on the aerodynamic drag on commercial vehicles and the range of NACA airfoils can be compared to match the trends. As the results suggest, the application of NACA airfoil has a considerable beneficial effect on the commercial vehicle's aerodynamics and significantly helps to reduce aerodynamic drag, and hence the fuel economy can be increased with the usage of this phenomenon. It can also be noticed that the NACA feature has a far greater impact on higher velocity, hence maximum benefit can be obtained at the top speed limit of 56 mph.

Conclusion

The results from the article involve the baseline model with the incorporation of cab fairing. This was important as it represents the best industry practice for further aerodynamic improvement of the vehicle design, in this case the trailer aerodynamic efficiency against drag force. Now another novel concept is being applied to significantly reduce the wake region with the help of NACA airfoils. Airfoils help to keep the flow attached to the foil and hence dipping more into the wake region before the flow separates from the rear end of the trailer. Once the wake region or rear end turbulence region is decreased significantly in area, drag force onto the trailer will also be achieved, which has been proven through results obtained with the help of CFD analysis for this article.

The conclusions which can be drawn after the study has been carried out to reduce aerodynamic drag using NACA airfoil can be described in the following points:

1) Aerodynamic drag can be significantly reduced with the application of NACA airfoil onto the body of the trailer near the wake region.

2) As proved with the in-depth CFD analyses, NACA airfoil provides the benefit of reducing aerodynamic drag and hence helps to reduce fuel consumption.

3) It can be seen that, by usage of NACA airfoils, drag force is increased due to increment of the front area of the vehicle and the drag coefficient is increased simultaneously. Therefore, with presence of NACA airfoil, an unusual and inverse relationship between drag force and drag coefficient is established.

4) The best choice of NACA profile concluded from the CFD results is NACA 0012 with five parts attached to the truck trailer.

Abbreviations and Acronyms

CFD	Computational Fluid Dynamic
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
MPA	Meter Per Hour
m	Meter
s	second
rad	radian
L	The total length of the semi-trailer model
W	The total width of the semi-trailer model
H	The total height of the semi-trailer model

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