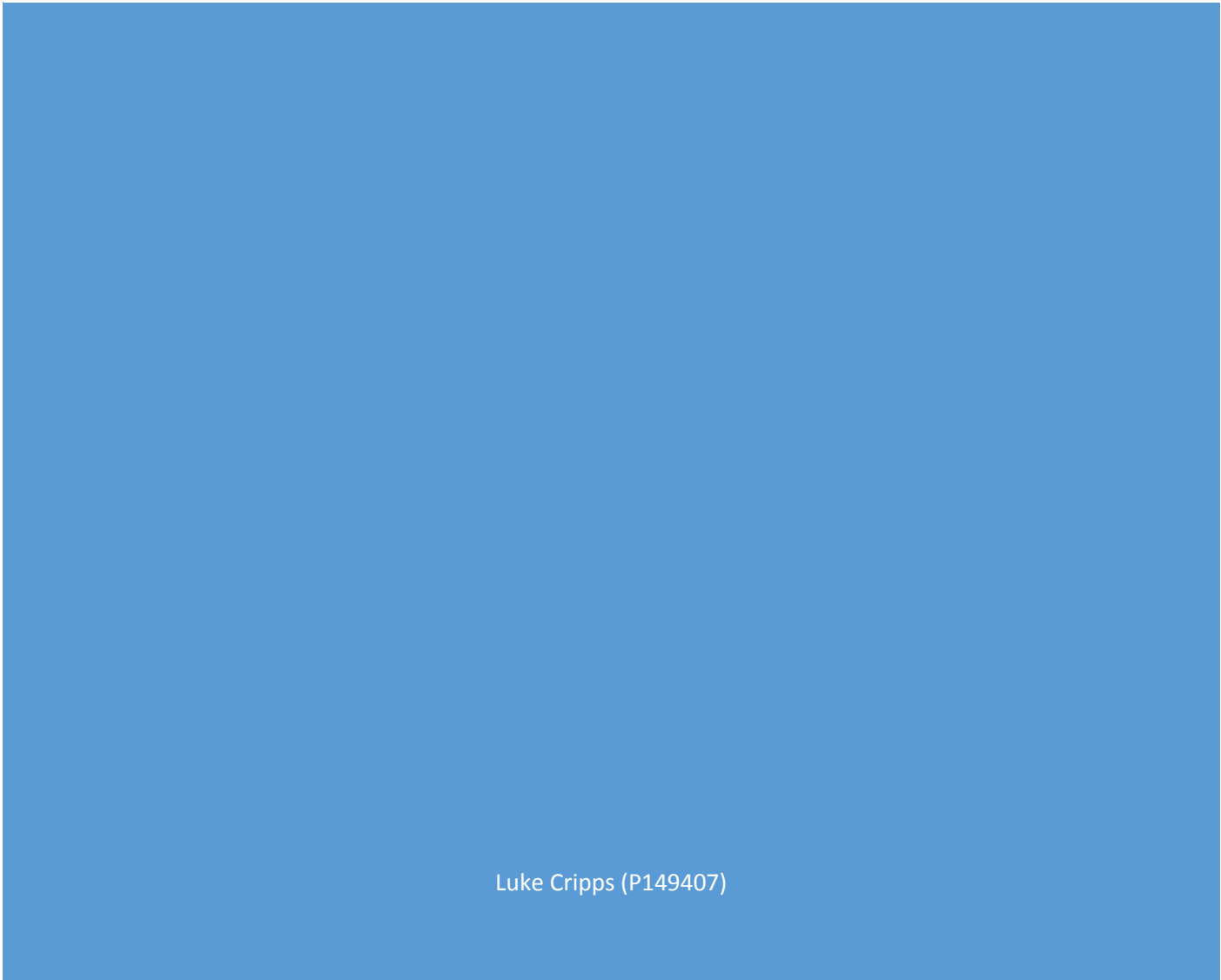




A PARAMETRIC INVESTIGATION TO VEHICLE GEOMETRY FEATURES ON EXTERNAL AERODYNAMIC PERFORMANCE



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This paper investigates the use of wind-tunnel testing and computational fluid dynamics on vehicles to explore how gains in aerodynamic performance can help improve fuel economy and consequently vehicle emissions. Using a reference geometry vehicle, tests will be carried out to first produce a validated case study, and henceforth, investigate the effect of varying vehicle shape; notchback; estate, as well as using aerodynamic devices; splitters; diffusers, has on the coefficient of drag and coefficient of lift. Validation being provided by wind-tunnel testing, also through data gathered from other studies.

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1.0 Introduction

Vehicle shapes have a massive effect on the drag and lift characteristics of a car, due to the external aerodynamic forces that are acting on it. These characteristics are becoming more crucial in the design of vehicles because of the stricter measures placed on carbon dioxide emissions, and other toxic compounds produced by the internal combustion engine, through the Euro six and the fore coming Euro 7 standards, as described by RAC, 2018. This is due to the drag being a factor in a vehicles fuel economy, meaning that an improvement in fuel economy would reduce the emissions produced as less fuel would be needed to be used in the combustion process, documented by Keith Douglass, N.D.

The most basic car shapes used in the automotive industry would be; estate; fastback; notch and pickup. Each shape influences the coefficient of drag produced by the vehicle. Below are some examples of coefficient of drag values for different cars, using a variety of vehicle shapes, provided by Angelina I. Heft, 2012:

	Estate Back	Notchback	Fastback
Audi	0.288	0.260	0.259 ²
BMW	0.257	0.248	- ³
DrivAer	0.319	0.277	0.275

Table 1 - Coefficient of drag values for a variety of vehicle shapes

Vehicle shape is not the only feature that affects the drag and lift of a vehicle. Aerodynamic devices also play a role in the overall effect of the drag and lift characteristics. Splitters and rear wing spoilers, just to name a few, are some of these devices that can affect these characteristics, as stated by Renan Francisco Soares, 2018.

The overall aims looking ahead are:

- To investigate how the difference in vehicle shape affects the coefficient of drag and coefficient of lift.
- To investigate the impact, positive or negative, of adding aerodynamic devices to the vehicle in response to the coefficient of drag and coefficient of lift.

The aims will be investigated using computational fluid dynamics (CFD) and through wind tunnel testing. Graphs for the coefficient of drag and lift will be produced for each variant of the vehicle.

2.0 Research

2.1 Background

2.1.1 Relevance to Industry

One major factor why the automotive industry is interested into looking at reducing the drag acting on a vehicle is that drag has an influence on fuel economy. If a vehicle has a high coefficient of drag, then the fuel economy of that vehicle will be worse when compared to another car with a lower coefficient of drag. An example of this would be the Honda Jazz. The graph below shows how when the coefficient of drag is improved, so does the fuel economy. Figure produced by Kentaro Machida, 2015:

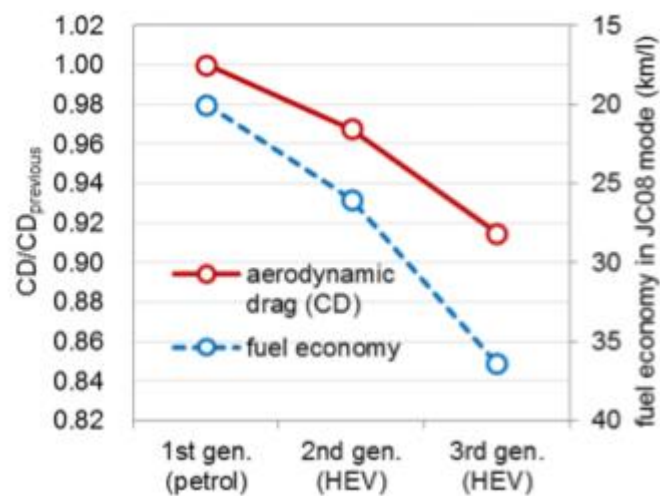


Figure 1 - A graph showing the correlation between the coefficient of drag and fuel economy for the new generations of the Honda Jazz

This increase in fuel economy has a link to the carbon dioxide emissions produced by a vehicle. With an increase in fuel economy, a reduction in the carbon dioxide produced is the result, as illustrated in the following graph, produced by Keith Douglass, N.D.

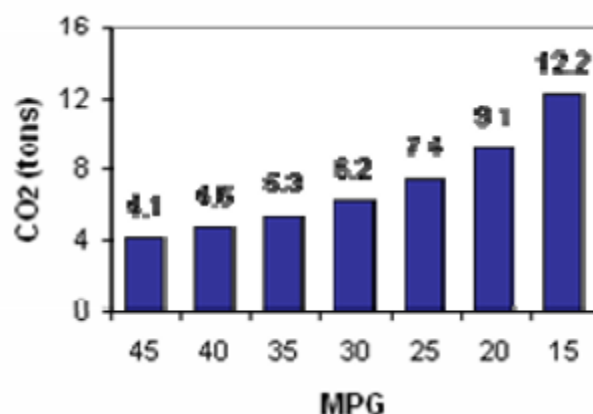


Figure 2 - A graph showing the correlation between fuel economy and carbon dioxide production

2.1.2 Aerodynamic Fundamentals

Bernoulli's Equation, as stated by Princeton, N.D:

$$p + \frac{1}{2}\rho V^2 + \rho gh = \text{constant}$$

p = Pressure

ρ = Density

V^2 = Velocity

g = Gravitational Constant

h = Elevation

Some assumptions are made, according to Katz, 2016:

- The points where the pressure is acting lie on a streamline
- The viscosity of the fluid used is constant
- Friction is not observable in the system

Reynolds number, as stated by Nuclear Power, N.D, is the ratio of inertial forces to viscous forces. It is an adequate parameter for predicting if a flow condition will be laminar or turbulent.

$$RE = \frac{\rho \times V \times D}{\mu}$$

RE = Reynolds Number

ρ = Density of fluid

V = Velocity of fluid

D = Diameter of fluid

μ = Viscosity of fluid

Engineering Toolbox, 2003

Boundary Layers

As a vehicle moves through a fluid, the molecules of air near the surface of the vehicle start to move around as they have been disturbed. Aerodynamic forces are therefore generated between the fluid and the surface of the vehicle, as declared by Hall, 2015. The fluid closest to the surface of the vehicle will have no velocity. As the layers of fluid travel further away from the surface, the velocity of the fluid will increase, as there will be less collisions between the molecules, as clarified by Technical F1 Dictionary, N.D. Once there are no collisions between the molecules, this is classed as the boundary layer. The viscosity and compressibility of the fluid are the two main factors in the position of the boundary layer.

Boundary layers can either be laminar or turbulent, dependent on the value for Reynolds number. A lower value for Reynolds number illustrates a laminar flow, where a higher Reynolds number would mean the opposite, a turbulent flow, as mentioned by Mclean, 2012.

Separation

Flow separation occurs when the boundary layer of a vehicle has travelled against an adverse pressure gradient for long enough that the velocity of the boundary layer when compared to the vehicle retards to zero, as defined by Clancy, 1975. The flow of the fluid detaches from the vehicle's surface and inherits the forms of eddies and vortices. This type of separation leads to increased drag affecting the vehicle's performance.

Boundary layer separation occurs when a boundary layer becomes separate from the surface of the vehicle, and becomes a broad wake, as explained by White, 2011. This type of separation occurs when the boundary layer closest to the surface of the vehicle has its direction of motion reversed, Wilcox, 2000.

Lift and Drag

Drag is a force that an object, vehicle is subjected to that provides a resistance to the direction of motion, as defined by Electropaedia, 2005. The drag force acts parallel to the motion of the fluid, meaning it will operate in the same direction.

Lift is a force that acts perpendicular to the flow of fluid that the vehicle is passing through, explained by Hall, 2015. As this lift force can act perpendicular, being a vector quantity, the force will either try to lift the vehicle up and work against gravity, or its magnitude will be in the other direction, acting as downforce to push the vehicle into the ground.

2.2 Current Studies

2.2.1 Aerodynamic Studies and Vehicles

Reference shapes

With stricter measures being placed on carbon dioxide production and having the link between the coefficient of drag and better fuel economy, as mentioned on page 3, the use of reference shapes to help improve the coefficient of drag for vehicles is becoming more vital. Using these reference shapes will mean the aerodynamic characteristics that either benefit or hinder gains in fuel economy and therefore emissions can be tested, and verified, as expressed by Angelina I. Heft, 2012.

There are numerous different vehicle geometry models that have been created to help in the investigation into reducing the coefficient of drag:

- Ahmed Model
 - NRCC/SAE Model
 - Rover Bluff Body Model
 - Pininfarina Reference Car
 - MIRA Reference Car
- Geoffrey M. Le Good, 2004

The Ahmed geometry was originally developed for vehicle wake investigations and was designed in mind so when an experiment was conducted, there would be only one aerodynamic feature, as seen in the diagram below, that would be assessed, justified by Strachan R.K, 2007:

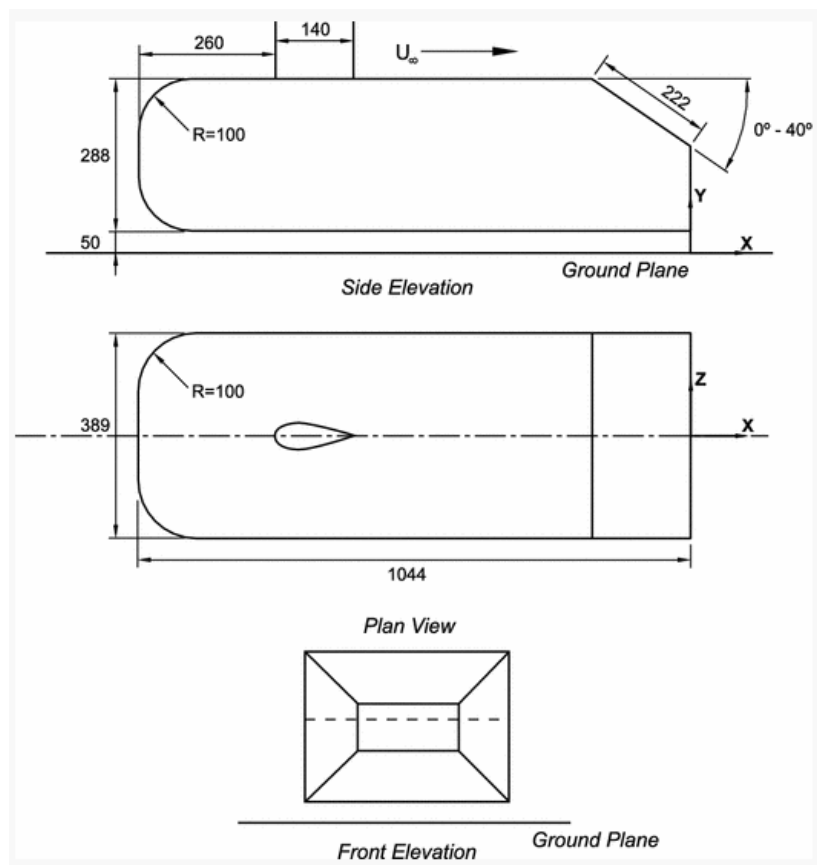


Figure 3 - The Ahmed geometry model

NRCC geometry was configured to exhibit attached or separated flows on American cars and trucks. This geometry, amongst others, was used to investigate the effect of aerodynamic drag against longitudinal position inside a wind tunnel, tests carried out by Garry K.P, 1994. Below is a diagram of the NRCC reference geometry, provided by D Wood, 2014:

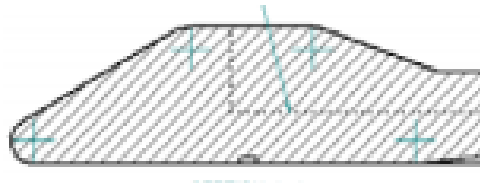


Figure 4 - The NRCC/SAE geometry model

The rover model was designed to assist in investigations on how changing vehicle shapes would affect the aerodynamic forces, as explained by Geoffrey M. Le Good, 2004. The Rover geometry has interchangeable slits at the rear so that the angle of slope can be changed. Below is a diagram of the Rover reference geometry, shown by Howell, 1994:

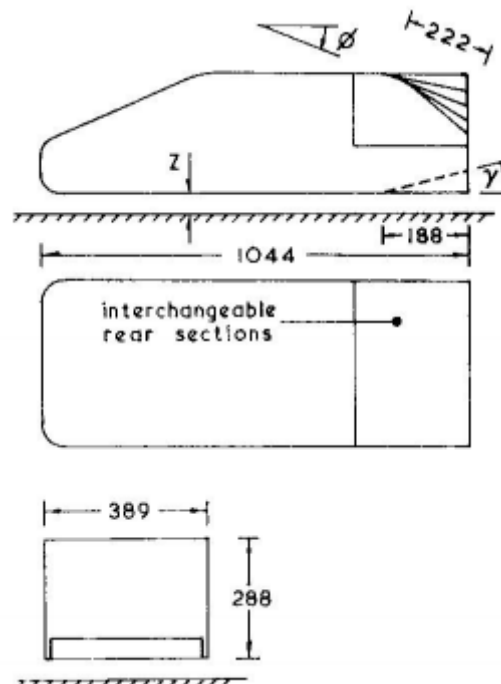


Figure 5 - The Rover reference geometry

The Pininfarina reference geometry, is the first of the models to have wheels included in the design. This means that results taken from using this reference geometry would be more accurate, due to interaction between the underside of the car being referenced as well, as detailed by Geoffrey M. Le Good, 2004. A illustration of the reference geometry is shown below, also provided by Geoffrey M. Le Good, 2004:

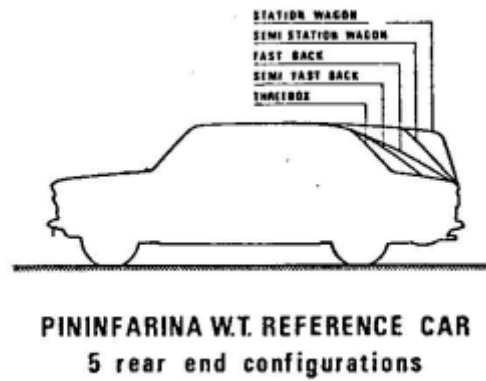


Figure 6 - The Pininfarina reference geometry

The MIRA reference car, the most well-known reference geometry in the automotive industry. It is used to calibrate the MIRA wind-tunnel every three months. It has been used for numerous investigations with relevance to wind-tunnel testing, and CFD investigations, as used by Yingchao Zhang, 2014. Below is a diagram of the MIRA reference car used in two configurations, created by Pruthviraj Mohanrao Palaskar, 2016:

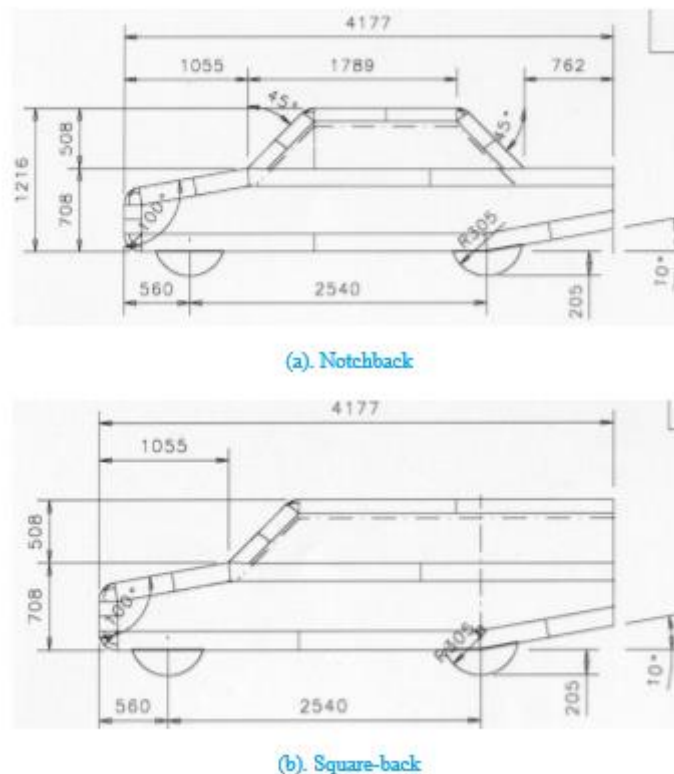


Figure 7 - Two configurations of the MIRA reference car

2.2.2 MIRA Reference Car Studies

As the MIRA reference car is the most used car geometry out of the ones talked about above, there are some studies out in the world where the need for the geometry is being used. Jeffrey Hoffman, 2001, has used the MIRA reference car to see if the coefficient of drag changes when different vehicle shapes are used. While this is not the primary aim of investigations completed by Hoffman, data has been gathered that will be useful during investigations into the aims mentioned above.

Another study carried out by Yingchao Zhang, 2014, investigates the optimum aerodynamic shape for a vehicle using the MIRA reference car as its reference geometry. All of the components of the vehicle were looked at and tested, to compare where most of the resistance, drag was created. Both papers produce data which can be used as a validation method for the aims of this investigation.

2.3 Methods

2.3.1 CFD Process

Computational fluid dynamics, CFD, has been used for many years in designing stage of a vehicle's development to evaluate its aerodynamic performance. This then leads to the design of the vehicle changing to minimize the aerodynamic drag resisting the car's movement, as expressed by Yingchao Zhang, 2014. The equations of fluid dynamics are the conservation laws of mass, momentum and energy. When using CFD, these conservation laws are called the Navier-Stokes equations, justified by Kronbichler, 2010. The programme needed to calculate the results for investigations is called Ansys. The following flow chart illustrates the general process for using the software to generate value for coefficient of lift and drag, inspiration provided from Francesco Mariani, 2016 and Stephane Cyr, 2011:

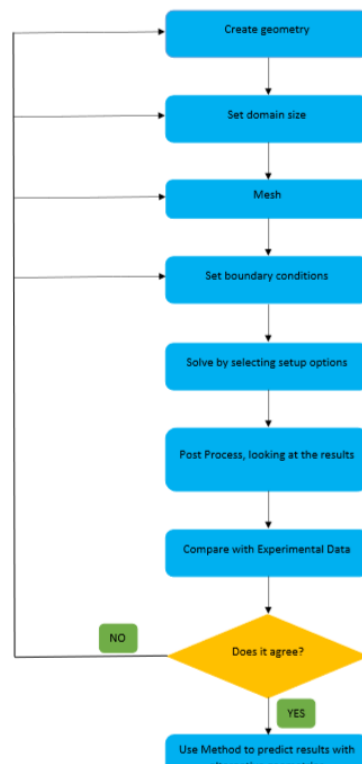


Figure 8 - A flow chart illustrating the process of using CFD

2.3.2 CFD Methods for External Aerodynamics

When looking at external aerodynamic features; diffusers; splitters; rear wings, a similar process is used to calculate results for the coefficient of lift and drag. Once the baseline study has been varied, the geometry is changed, to include one of the features stated above. For example, when testing a front splitter, the size of the splitter can make a difference to the drag generated, as shown in the graph below, created by Renan Francisco Soares, 2018:

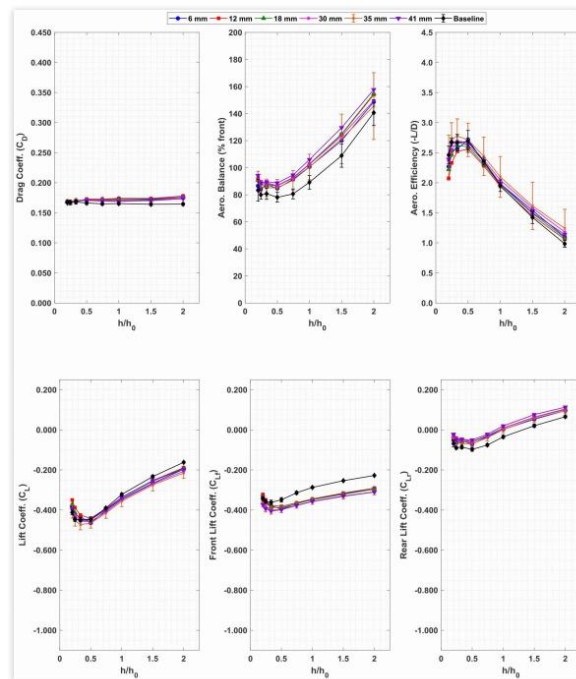


Figure 9 - Various graphs illustrating how splitter sizes affects coefficient of drag and lift values

2.3.3 Validation Case

In order to generate results, a validated baseline model needs to be generated. If the baseline study cannot be validated, then results cannot be used. The validation can be made using existing studies, or through experimental data. Once a baseline study has been made, so that the data can be verified, the results should be similar to ones shown below, produced by Renan Francisco Soares, 2015:

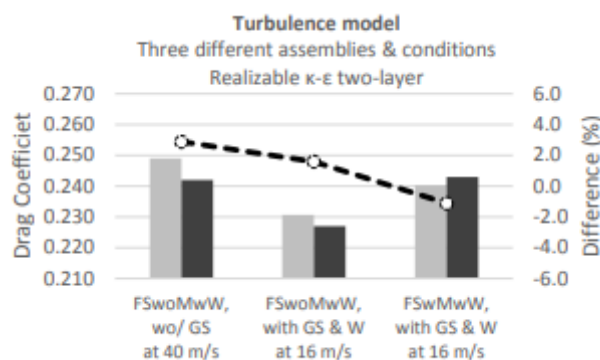


Figure 10 - A Graph illustrating coefficient of drag values against different assemblies

2.3.4 Wind-tunnel

Wind-tunnel testing is a way of validating results by means of an experimental procedure. The specification of the wind-tunnel available for testing is available at <http://discoverarmfield.com/media/transfer/doc/c2.pdf>.

3.0 Conclusion

Drag has a clear role in the effect of resistance to motion, which is why it is an issue that needs investigating. The use of the MIRA reference car is justified by the number of studies use it for testing. The next steps are to further validate a baseline case study by changing vehicle shape, and consequently, investigate how adding aerodynamic devices affects the coefficient of drag and lift.

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