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An External Aerodynamic Investigation: Motorcycle during a high-speed corner manoeuvre

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BEng Motorcycle Engineering

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Major Project / Dissertation

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Declaration of Authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has lead to the award of a degree.

Signed:

Date:

Abstract

This investigation evaluates the effects of the aerodynamic forces acting upon a sport styled motorcycle and rider geometry during a high speed, 60 degree lean angle cornering manoeuvre using the ANSYS computational fluid dynamics software.

The aspect of motorcycle aerodynamics during cornering is one not significantly covered in publicly available literature. Research explained in this paper provided a basis and validation for simulations to be set up in order to investigate into the improvement of motorcycle cornering forces using aerodynamic modifications.

Results were obtained through steady-state RANS simulation, using the k-epsilon turbulence model. Using a geometry based on the Yamaha R6 during a cornering manoeuvre. A constant speed of 27.7778 m/s with the lean angle of 60 degrees from vertical was used. Of which represented the motorcycles geometry during sector 4 of the Oulton park circuit.

Large flow separation and pressure concentration characteristics were originally observed, resulting in large lift and drag forces. Modifications involving vertically mounted air foils were applied along the geometry systematically, providing varied but effective results in reducing both drag and lift forces.

Acknowledgements

The author would like to thank technical advisors Tim Tudor and Owen Williams for their patience and expertise.

To Tim Tudor again, for not only being a fantastic technical supervisor, but also mentor, providing weekly meetings was key to this investigation and the increase in aerodynamic knowledge. Always finding extra time, if needed, to help and advise to the best of his ability.

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Acronyms

CAD – Computer Aided Design

CFD – Computational Fluid Dynamics

FIM - Fédération Internationale de Motocyclisme

COP – Centre of Pressure

CMM – Coordinate Measuring Machine

CT – Computerized Tomography

GPS – Global Positioning Sensor

IMU – Inertial Measurement Unit

BOI – Body of Influence

LBE – Lattice Boltzmann Equation

1.0 Introduction

1.1 Motorcycle Aerodynamics History



Figure 1.1.1 - Moto Guzzi "dustbin Fairing" (Phil West,

In an ever increasingly competitive industry that is motorcycle racing, significant technological advantages are becoming less so, and consequently more costly. Engine performance, materials, software, tyres and even rider protection have developed significantly over the past 20 years in order to give teams the competitive edge.

Considering the clear cost effective advantages it provided in Formula 1, aerodynamic designs were constantly being developed from the 1950's–1970's, purely focused on streamlining for straight-line speeds, but then seemed to halt in terms of development, rarely seeing designs and shapes significantly alter.



Figure 1.1.2 - Team Camel Yamaha (gold & goose, 2010.)

Originally aerodynamic fairings used on motorcycles, took the form of what was labelled '*dustbin fairings*', due to their shape shown in figure 1.1.1. These fairings as mentioned previously, were pioneered by NSU and Moto-Guzzi, (Spalding, 2017) and designed to create a teardrop shape to reduce any turbulence and produce a steady laminar air flow around the motorcycle and rider, thus reducing drag to improve straight-

line speed. However, due to the large cross-sectional area, any cross winds proved very dangerous to the lesser-developed "dustbin" fairings and therefore these types of fairings became condemned by the FIM when the uncovered front wheel regulations came in.



Figure1.1.3 - Ducati 2015 Wing (Moto DNA, 2015.)

Race bike fairings soon all became a very similar shape, (Figure 1.1.2) apart from the rare occasion, and did not develop significantly in the space of 30 years, until 2015.

2015 showed the first signs of aerodynamic development again in Grand Prix racing, when Ducati revealed wings based on the front of their motorcycle during pre-season

testing. Mainly focusing on straight line dynamics, these Wings soon became a wing/ Winglet combination in a dihedral orientation on the lower section of the bike shown in figure 1.1.3, the low positioning resulted in minimal effect on the CoP, but the orientation meant sacrificing extra drag force in turn for downforce to reduce front end lift and therefore increased rear tyre force under acceleration. This was acceptable at the time due to the power advantage the Ducati bike had over the rest of the field. (Spalding, 2017)

The rest of the manufacturers soon followed suit, realising the potential gains, developing an array of wings and winglets over the next two years. In 2017, it was announced that wings were to be banned for safety reasons and had to be incorporated into the fairing, leaving no uncovered protrusion.

However, in effect this increased the rate of aerodynamic development within a season. Due to the factory teams only having to homologate the external design of the fairings, also now allowed to assign different designs to each rider, this meant the wings inside could be modified as many times as they wanted. (As opposed to needing a set amount of homologated designs specified before the start of the season as previous.)

Therefore, it soon became evident that the wings and fairing designs were doing much more than just helping straight line speed and stability, confirmed with the introduction of asymmetrical designs, designed to have more of an effect during certain corners within a circuit. However, in argument to this, still couldn't have been applying large amounts of force upon the motorcycle, made clear by the fact that they were only being attached using pop rivets to the fairing, and not to the motorcycles chassis.

Due to the highly competitive industry of motorcycle manufacturing and the market influence at stake, the technology developed using these prototype machines are closely guarded secrets in order to prevent the opposition from gaining any advantage.

1.2 Aim

1.2.1 Focus on cornering

Therefore, the chosen aim of this investigation is to detect key characteristics of the airflow around a motorcycle and rider, during a cornering manoeuvre. Then use these findings to explore how the use of aerodynamic tools can be used to maximize the aerodynamic efficiency of the motorcycle and rider geometry during a high speed cornering manoeuvre in turn, increasing cornering ability.

Designs will follow the current FIM regulations and take into consideration marketability; although ideas produced will be prototype designs, a key aspect would be to produce designs that would still be practical to apply to production motorcycles.

1.3 Objectives

In order to measure success of this investigation, two main objectives have been specified:

- To increase down force through the contact patches without increasing lateral forces.
(reduce the lift effect created by the geometry of a cornering motorcycle/ rider)
- To reduce overall drag

These can both be measured and recorded in Newton's for each simulation using the reports section of the ANSYS fluent software.

1.4 Software used

Due to the vast cost of analogue simulation methods such as full-size wind tunnel testing and even scale wind tunnel testing, the method used to carry out this investigation will be a (digital) numerical simulation method known as CFD. CFD requires input data in order to set up an accurate simulation, and a solid body CAD model presented as an X.t File. Therefore, a number of software packages were used in order to achieve results, which include:

2D Data Analyser

2D Data Analyser is a telemetry system that provides an accurate visual representation of measurements and data taken from geometry sensors and accelerometers applied to the motorcycle. (2D, 2018)

GOM Inspect

GOM inspect software, mainly aimed at the quality control/inspection and product development market enables point clouds produced by CMM, CT and other scanning equipment, to be converted into solid body models. (GOM, 2018)

GOM Inspect will be used to convert either the scan or surface model of the motorcycle into a solid body model, which can be used in ANSYS Fluent.

Solid-Works

Solid works is a solid modelling CAD software, quickly becoming the industry standard.

Although Solid-Works is constantly adapting with many add-ins, its main use for this investigation will be to adapt the motorcycle geometry and use it to model aerodynamic features upon the geometry using the fundamental CAD modelling tools.

ANSYS Fluent

ANSYS fluent is one of the most powerful CFD simulation tools currently available. Including well-validated physical modelling capabilities, it is able to deliver fast, relatively accurate

results across a wide range of CFD and multi physics applications, resulting in it playing a huge part in the design of many aircraft, space shuttles and many other great engineering successes. (ANSYS, 2018)

ANSYS will be the key software used in this investigation, using settings from previous research; ANSYS fluent will be able to provide this project with considerably quick and accurate results; including visuals and force values, enabling the investigation to find what works and how to improve designs.

1.5 Time Management

Three main methods were used to plan the investigation to achieve the desired objectives, these were:

- Brain storm diagrams
- Flow charts
- Gantt charts

Brainstorms were an effective way of noting everything that needed to be done/ explored, and then once written down, a flow chart could then be produced to show the general route of development, (brainstorm and flow chart used can be seen in sections A2a and A2b of the appendices) of which then each idea/ section that made up each part within the flow chart could be planned for within the Gantt chart. The whole project was divided up into thirds in order to organise the planning in sync with university semesters.

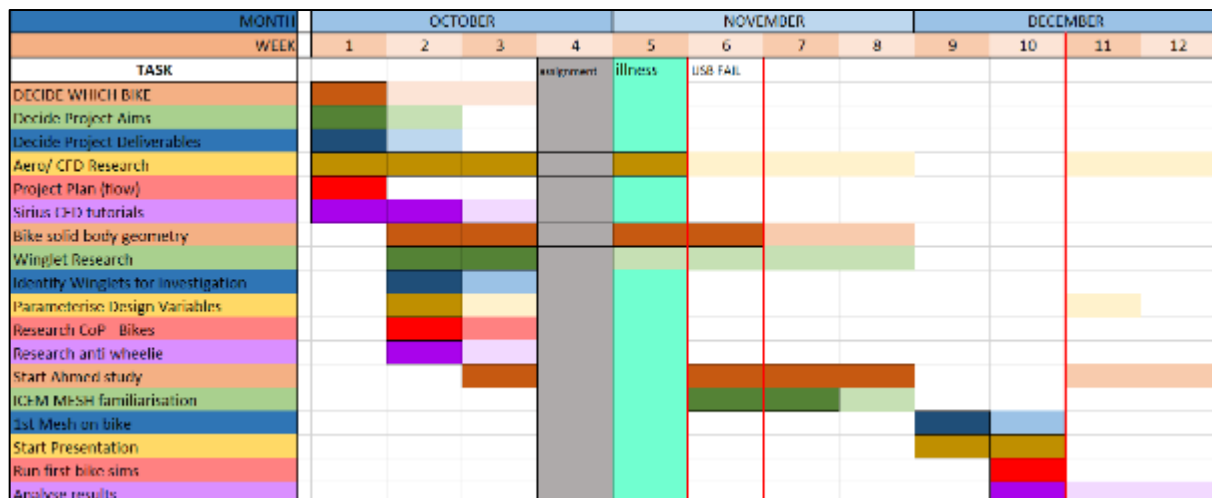


Figure 1.5.1 – semester 1 Gantt chart (A Shelton, 2017)

2.0 Research

2.1 Aerodynamics

2.1.1 Ahmed Body Study

Prior to this investigation, an Ahmed (bluff) Body study was carried out in order to validate findings. It was created and carried out through instruction of video tutorials created by YouTube profile *Sirius CFD*, recommended by the aerodynamics mentor/ Technical advisor overseeing this investigation, and a number of technical papers in addition. A total sum of 30 simulations were carried out personally and carefully recorded

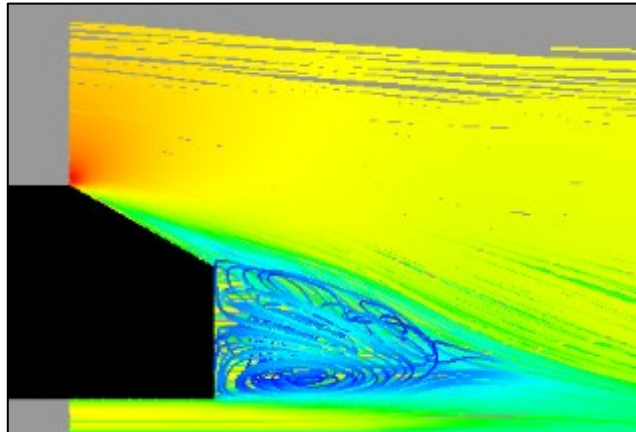


Figure 2.1.1 – Aerodynamic wake of an Ahmed Body (A Shelton. 2017)

within a spreadsheet noting each setting selection used throughout the domain creation – mesh creation – simulation set up process. Then the results were compared to the specified values given and validated by wind tunnel testing for those particular dimensions of Ahmed body in order to refine simulation settings. These 30 results were also enhanced by an extra 23 and 14 sets of results being taken into consideration recorded in the papers titled *Computational Fluid Dynamics: Ahmed Body Study* (Faulkner, 2017) (Cording, 2017) respectively (Result tables shown in A6 A7 and A8 of the appendices).

Totalling over 60 results, this provides a validated basis to reference, suitable for providing relatively accurate results for a bluff body aerodynamic investigation.

S.R Ahmed specified the Original Ahmed body study in 1984. Involving a simplified car based bluff body; the study involved testing two configurations of the geometry; one with a 25-degree rear slant and one with a 35-degree rear slant. Ahmed stated that findings showed 85% of the final drag value was caused by pressure drag, and was created by flow characteristics generated at the rear/ around the wake of the body. (Ahmed, 1984) Three main characteristics were observed by Ahmed:

- The recirculation area formed as the flow separates at the top of the vertical back surface of the model
- The recirculation area formed due to the separation at the base of the model.
- The pillar vortices that form as the vorticity in the side boundary layers roll up over the slant edges.

Since 1984, the Ahmed body geometry has gone through further analysis playing a key role in a number of other bluff body aerodynamic investigations, from further analysis based papers to modification investigations such as flaps.

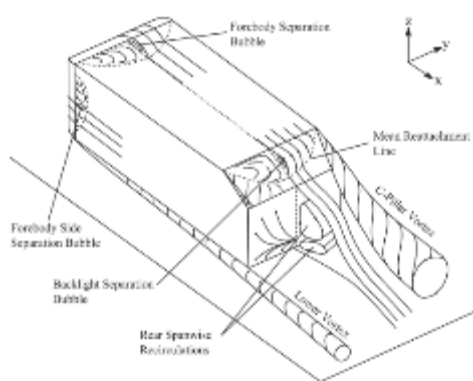


Figure 2.1.2 – Aerodynamic Effects on a Cornering Ahmed Body (J Keogh, 2004)

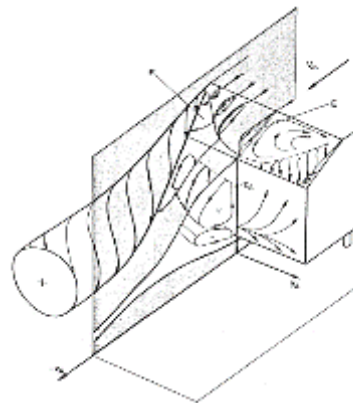


Figure 2.1.3 – Ahmed Body Wake (S.R. Ahmed, 1984)

Ahmed concluding findings

- It was found that up to 85 % of the total drag for a basic bluff body is pressure drag. Rest is friction drag.
- With attached flow over the frontal surface, the fore body contributes a maximum of 9 % to the pressure drag. Rest of the pressure drag is generated at the rear end.
- A pair of horseshoe vortices were found within the separation area behind the rear slant, also side edge vortices discovered.
- The strength of both sets of vortices in the separation bubble is significantly determined by base slant angle.
- A low drag rear end configuration induces a weak transverse flow in its wake.

“High drag generating flow is characterized by strong side edge vortices, a separation bubble on the base slant surface, and the separation bubble emanating from the vertical rear end base.”

“High drag flow, described under point 6 above, is unstable; the switch over to the stable low drag flow is accompanied by disappearance of strong vertical motion in the wake.” (Ahmed, 1984)

These findings will prove vital to the analysis of the motorcycle geometry. The characteristics mentioned above are relatable to the characteristics produced by the (bluff body) leg and torso of the motorcycle rider.

It is also suspected that transverse flow across the rear of the motorcycle enhances many negative aspects of how the flow behaves underneath the geometry and therefore can be reduced using designs taking into consideration S.R Ahmed's findings.

2.2 Previous Attempts

2.2.1 Tony Foale

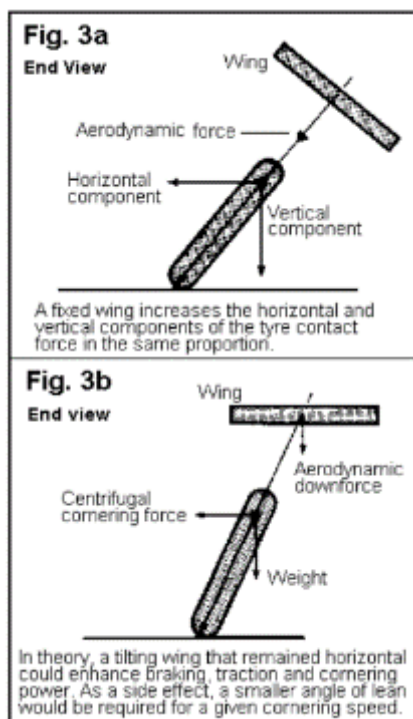


Figure 2.2.1 – Motorcycle Wing (T Foale, Not Stated)

The first suggestions of applying wings to a motorcycle known to this investigation came from the aerodynamic evaluation article by Tony Foale.

Although brief, the article explains how a fixed wing attached to a motorcycle would not only increase the downforce through the contact patches of the motorcycle, but when the motorcycle leans; also the lateral force. (Foale, Not stated)

Thereafter, a stabilised wing that remains horizontal is suggested, however not only are there handling dynamic flaws observed in this method, but it also does not adhere to the FIM regulations that any designs produced in this investigation follow.

Motorcycle aerodynamics isn't just about streamlining the motorcycle fairings in order to improve top speed, but much more can be achieved. However, does explain that motorcycle aerodynamic stability is not just as simple as ensuring the centre of pressure

is behind the centre of gravity, but involves a compromise between a combination of conflicting requirements, and therefore states that it has proven to be a complex task, of which even large manufacturers get wrong. (Foale, Not stated)

Journal Papers

There were found to be two credible previous attempts investigating the aerodynamic characteristics of a motorcycle whilst cornering that proved influential to this investigation.

2.2.2 Research Paper 1

“Computational Evaluation of Aerodynamic Forces on a Racing Motorcycle during High Speed Cornering.” (Van Dijk, 2015)

This investigation tended to focus slightly more on the computer aspect of the investigation, which proved insightful to just how much difference there can be, in terms of computing methods equations, power and the effect and limitations it can have on the results.

In terms of the physical geometry used, the aerodynamic adaptations tended to be more fairing based, and evaluating how the results varied through lean angle.

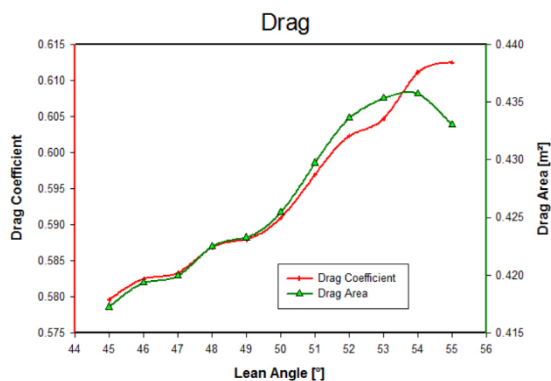


Figure 2.2.2 – Lean angle influence on drag value.
(T Van Dijk, 2015)

This strengthened the confidence in the choice of using such a high lean angle, as although it isn't at the maximum drag producing lean angle, it still provided evidence that there is plenty of improvement achievable.

Van Dijk, also visually represented results well, which influenced this investigation as it enables the reader to clearly see the effects being investigated.

This investigation also showed how the simulation conditions could be adapted even more, in order to simulate exact cornering conditions through the application of rotational airflow through the domain.

2.2.3 Research Paper 2

“Motorcycle Cornering Improvement: An Aerodynamical Approach based on Flow Interference A Master Thesis in Fluid Mechanics.” (Sedlak, 2012)

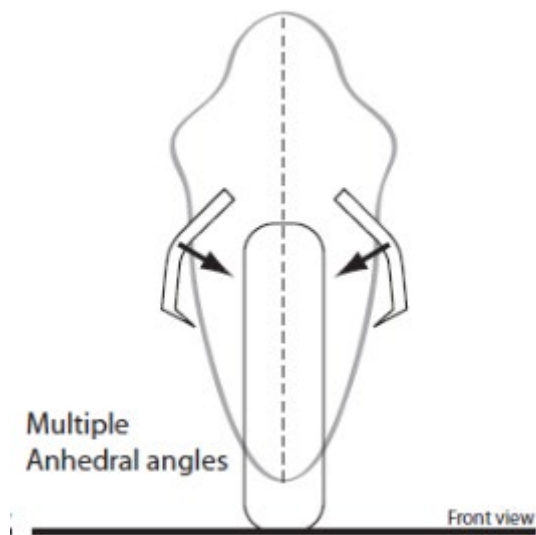


Figure 2.2.3 – Wing orientation Influence. (Sedlak, 2012)

Sedlaks investigation proved vital in saving time due to its analytical singular variable investigative approach. One example is that it provided information on wing interference, stating which shapes worked best at interrupting the flow, and the most effective distances away from the foil, which was used within this investigation.

It also provided the thought that encourage the wings in this investigation to be mounted vertically due to aiming to reduce lateral forces even further. (Shown in figure 2.2.3)

This investigation also applied the rotational airflow method, and was able to discuss its effects in terms of the winged geometry. It concluded that the rotational flow created a considerable difference in inner/outer effect up on the forces produced by the wings.

The conclusion also makes very clear that it is suspected that this approach may possibly have very different effects in the real dynamic situation, which due to the geometry in this investigation is also a significant consideration.

3.0 Methodology

3.1 Case Conditions Selection

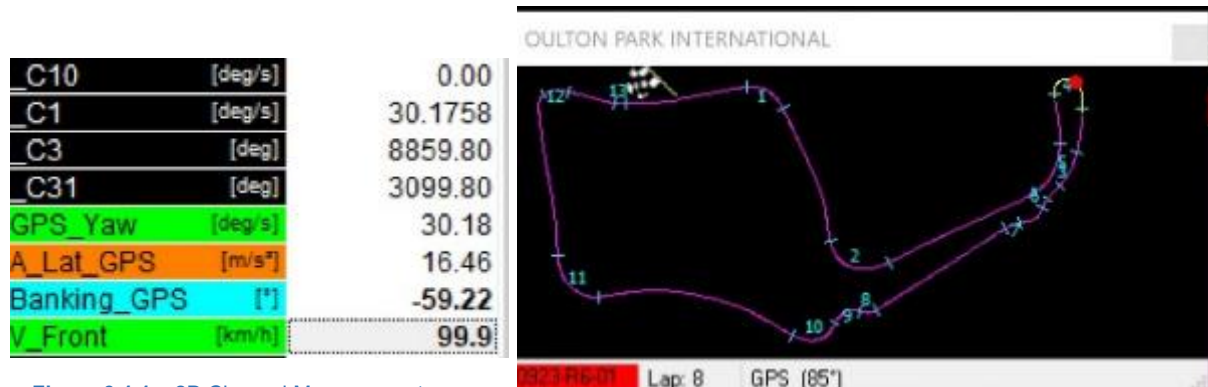


Figure 3.1.1 – 2D Channel Measurement

Bar (A Shelton, 2018)

Figure 3.1.2 – 2D Track Map. (A Shelton, 2018)

Team Orthrus Racing data from round two of the Thunder-sport GB 600 race at Oulton Park was used to specify simulation geometry.

Figures 3.1.1 and 3.1.2 above show the 2D software channel measurement bar, and the track map respectively. As you can see in figure 3.1.2, sector 4 of the Oulton park international circuit was chosen as a reference for the simulation geometry. This particular sector was chosen due to the corner allowing the highest lean angle of the lap of -59.22 degrees, indicating lean to the right, and a considerable amount of corner speed of 99.9 Km/h. It was important that these two factors were achieved due to:

Banking/ Lean angle – Modelling the highest lean angle, enabled the aerodynamic adaptations to be designed safely within remaining area of ground clearance. Avoiding all possibility of the adaptations interfering or encountering the road surface potentially causing an accident. This lean angle also meant that the rider would be in the ideal cornering body position, of which this investigation aims itself around.

Velocity – A higher geometry velocity means a higher rate of airflow over the motorcycle. This in turn, means that higher forces are acting upon the geometry, which will enable the investigation to determine the resulting aerodynamic effects much more clearly.

3.1.1 Data Validity/ Credibility

Two main conditions were taken from the 2D data mentioned above: velocity and lean angle. For this investigation, the data acquired is accurate enough due to only needing average values for set conditions. However, although the measuring equipment used such as GPS trackers, IMU's, potentiometers and wheel speed sensors are highly accurate at measuring singular parameters; it is worth stating for any future applications that these methods do not take into consideration dynamic variables. (Unless corrected via calculation files)

Examples of this follow below:

Velocity –

If measuring the wheel speed by the use of a wheel speed sensor, it does this by recording the number of pulses of a certain reference on the wheel (for example brake disc bolt) in relation to time. Which then uses the effective wheel radius specified to work out how far the bike has travelled in that time. However, this does not take into consideration the tyre aspect ratio. The aspect ratio of the tyre dictates that the effective radius is smaller when the motorcycle is leant over as opposed to larger when the motorcycle is travelling in a straight line. Therefore, this means that if the larger tyre diameter is used as reference, when the bike is leant over using the smaller radius of the tyre, the wheel speed calculated will be faster than the actual velocity of the bike and vice versa.

Banking/ lean angle –

Using GPS or accelerometers to measure the lean of the motorcycle in static/ level conditions can be highly accurate. However, these methods do not take into consideration the camber of the track. For example, from the normal that the measuring units are working in reference to, the bike lean angle could measure 80 degrees. But in reality, the camber of the road surface could be 20 degrees, in effect making the bike seem like it is leaning more than is physically possible.

3.2 Case Set-up

3.2.1 Geometry Reference/Creation

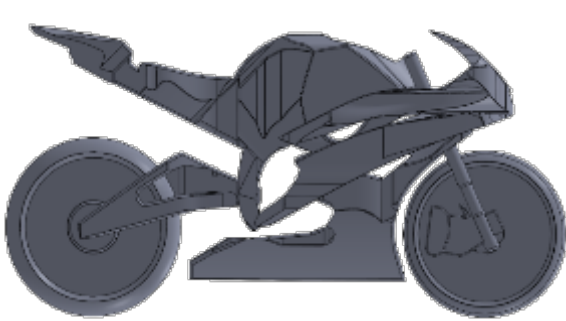


Figure 3.2.1 – Final motorcycle Geometry. (A Shelton, 2018)

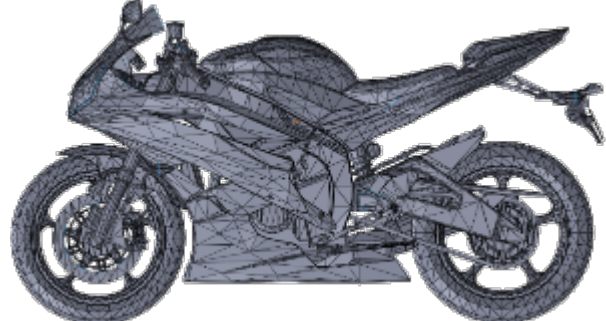


Figure 3.2.2 –Grab CAD R6. (A Shelton, 2018)

In order to make any designs relevant in case of future testing, it was important that the motorcycle geometry represented the Orthrus Racing Teams Yamaha R6, which would be the bike available when any practical testing would be carried out. It was felt that producing a generic motorcycle model, (very simplistic) would hinder the project when it came to the later practical stages. For example, the R6 clearly has very distinctively designed scoops running from the nose of the motorcycle, down its flank and towards the rear wheel. These were clearly created to have aerodynamic effect on the motorcycle. Therefore, future designs have to take into considerations these effects, so that they can either be taken into consideration to maximise the potential of the design, or to make sure that they don't reduce the potential of the design.

Figure 3.2.4 – 2017 R6. (Bennetts, 2016)



Figure 3.2.3 – Original R6 (MCS, 2005)

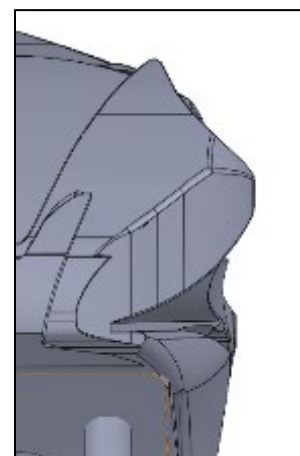


Figure 3.2.5 – Final Motorcycle Geometry. (A.Shelton, 2018)

The original model of the R6 was taken from Grab CAD, as this would have saved what resulted in multiple weeks of CAD experimentation. However, it was found that the original model was made up of both solid body parts and surface parts.

Surface parts are mainly created using scanning equipment and used for rendering and graphic design purposes. Surface parts are purely visual/reference and although can be seen, actually contain 0mm solid model thickness. This meant that the most important parts of the Grab CAD R6 model could not be recognised within the ANSYS modelling software.

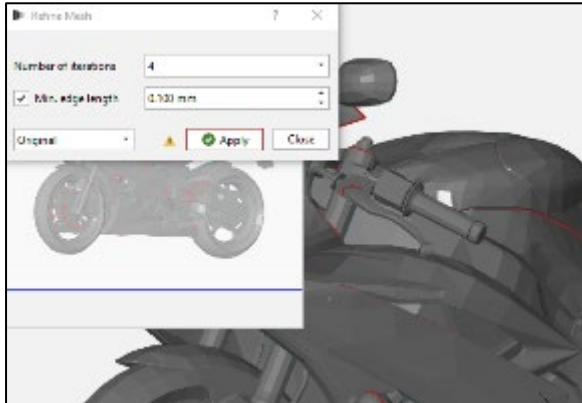


Figure 3.2.6 – Model Pre Mesh Refinement
(A.Shelton, 2018)

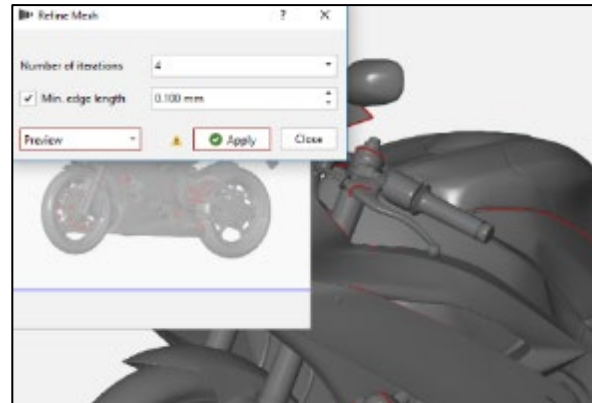


Figure 3.2.7– Model Post Mesh Refinement
(A.Shelton, 2018)

Figures 3.2.6 and 3.2.7 show the mesh refinement method used within the GOM Inspect software used to smooth the model. However, although the model looked smooth, how it actually achieved this was by breaking down every face, into even smaller faces. This meant that when it came to meshing the model every face within the model, would contain at least one element, resulting in large element numbers and due to the complex geometry shapes, increasing the chance of skewed elements/ reducing the element quality. Another method attempted within the GOM Inspect software, was by using a special tool that created contours using the geometry as reference. Although at the time it was not achieved, in reflection, if this process would to be carried out again, these contours could have been converted into a solid model with the use of 3D sketches and the swept boss feature within Solidworks.

Eventually the decision had to be made to produce the model using fundamental CAD modelling techniques. The model was divided into 8 separate models:

- Rider
- Lower Fairing
- Rear Wheel
- Front Wheel

- Forks
- Main body
- Front Fairing

The geometry was simplified significantly to the main fairing shapes, and most aerodynamically influential parts of the motorcycle. This was done as it enables a simpler mesh to be applied to the geometry, which improves mesh quality and reduces the cell skewness and therefore accuracy of the results.

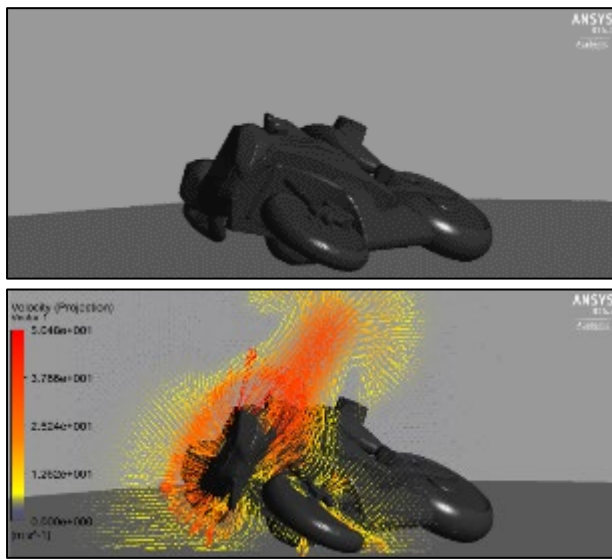


Figure 3.2.8– Model analysis (A.Shelton, 2018)

Figure 3.2.1 shows the initial model that was purely based on the R6 model shown in figure 3.2.3. It soon became apparent after analysing the results from the first test simulation that the model had to be altered. This was due to the design of the front section of the motorcycle fairing. As you can see in the top image, the R6 style wing protruded too far and created a scoop type effect. In the bottom image of figure 3.2.8, it shows how a spike of high velocity air, generating a vortex engulfs the front of the

tic would be significantly increasing drag (as shown in the results) due to effectively increasing the frontal area of the geometry. It would also reduce the effect the geometry of the outside of the model would have upon the simulation. Although in a real dynamic situation, this would happen, it would be nowhere near this scale. This is due to two reasons; the geometry is better designed to reduce this effect and the actual motorcycle has ducts extracting air through the centre of the front wheel surrounding, channelling air through the motorcycle's radiators. If the improved model did not reduce this, then the ducts may have had to be added.

Figures 3.2.9, 3.2.A and 3.2.8 show the final tested geometry, which was based more around figure 3.2.4 of which produced a reduced/ weaker vortex, and much more appropriate drag and lift values.

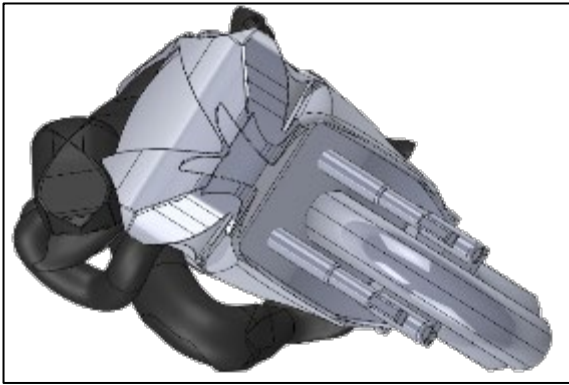


Figure 3.2.9 – Test Geometry Final Front. (A Shelton,

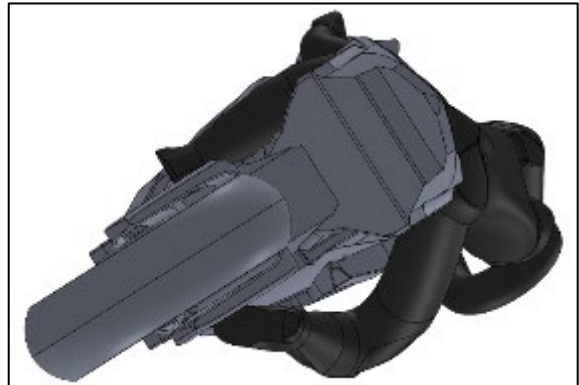


Figure 3.2.A– Test Geometry Final Rear (A Shelton,

The Rider was based on a Moto GP rider image and produced using a mixture of the swept boss base CAD method, and then creating sectional planes from each limb to create the feet and hands. It was also important that the rider had key parts such as the aerodynamic hump on the back, and the knee slider, as the aerodynamic effect around these parts would be important.

Specifying FIM Regulated work area

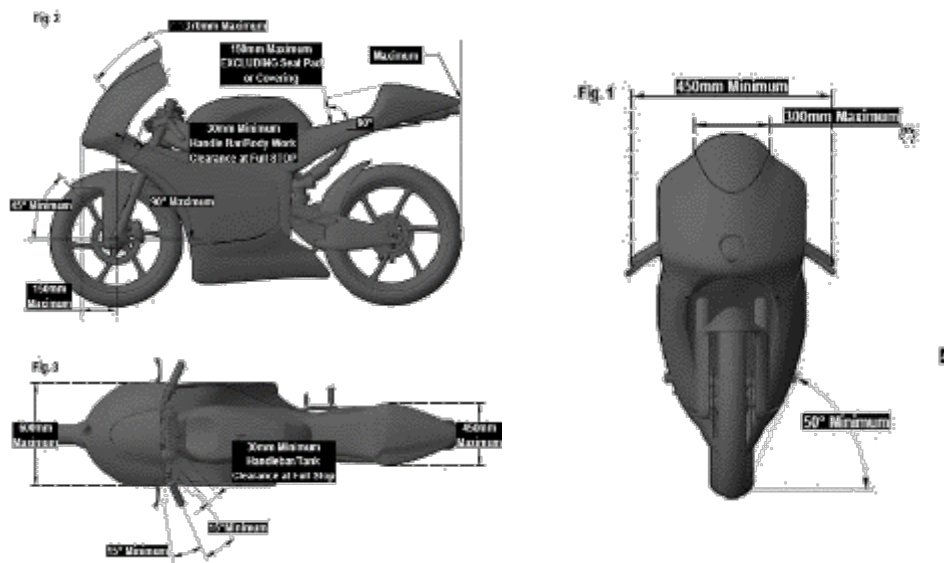


Figure 3.2.B – FIM Regulation. (FIM, 2017)

“4. When viewed from the side, it must be possible to see:

- a) At least **180 degrees of the rear wheel rim.**
- b) The whole of the front rim, other than the part **obscured by the mudguard, forks, brake parts or removable air-intake.**
- c) The rider, seated in a normal position with the exception of the forearms. Notes: No transparent material may be used to circumvent the above rules.

Covers for brake parts or wheels are not considered to be bodywork obstructing the view of wheel rims in regard to the above rules.

5. No part of the motorcycle may be **behind a line drawn vertically at the edge of the rear tyre.**

7. Mudguards are not compulsory. When fitted, front mudguards **must not extend:**

- a) **In front of a line drawn upwards and forwards at 45 degrees from a horizontal line through the front wheel spindle.**
- b) **Below a line drawn horizontally and to the rear of the front wheel spindle.** The mudguard mounts/brackets and fork-leg covers, close to the suspension leg and wheel spindle, and brake disc covers are not considered part of the mudguard.”

(FIM, 2017)

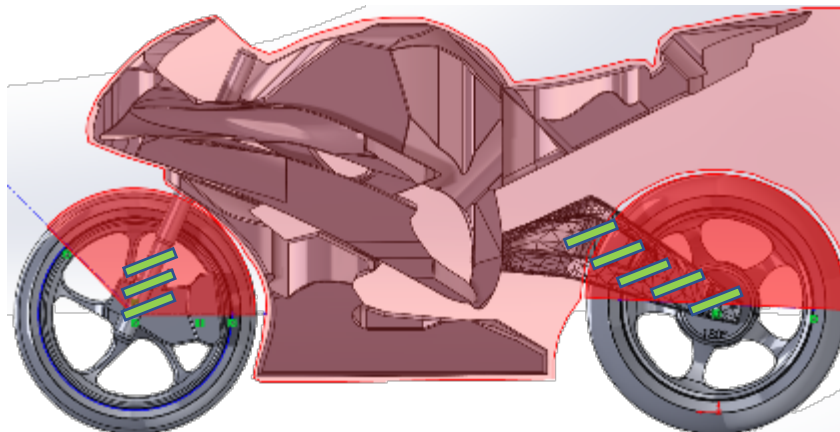


Figure 3.3.C—available adaptation space according to FIM. (A Shelton, 2018)



Figure 3.3.D – Fairing Adaptation Front and Rear. (A Shelton, 2018)

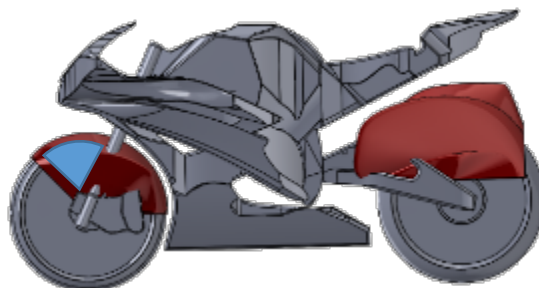


Figure 3.3.E – Fairing Adaptation Cross section. (A Shelton,

The original direction of the investigation, was aiming to apply horizontal wings to the un-sprung masses of the motorcycle. The theory behind this method, being that the forces are applied straight onto the un-sprung masses, and therefore not affect suspension systems.

However, it was advised by the technical supervisor that this investigation simply simulate wings in similar positions to what has already been produced, in order to interpret what has already been carried out by world leading motorcycle manufacturers, due to the incapability of having access to any of this prototype-tested information as mentioned in section 1.1.

Figures 3.3.C and 3.3.D above show an adapted version of the original geometry, with additional wheel huggers. These hugger type fairings were designed within the FIM regulation areas and towards the end of the investigation, in the hopes to improve the streamline effect of the geometry, and improve recirculation in order to reduce some of the negative effects discussed later in this investigation. However, due to inexperience within the ANSYS software, the model could not be transferred into the meshing stages of the set up, and therefore no results were obtained.

Upon reflection, if a revision of these fairings were to be carried out, part of the front fairing covering up the wheel, in front of the steering axis would be removed (shown by the blue section in figure 3.3.E). This is to help move the centre of pressure backwards, so that the fairing would steering into crosswinds.

3.2.2 Domain Creation

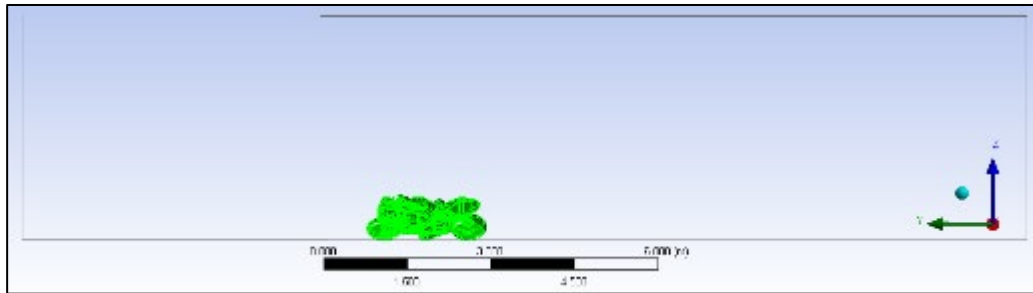


Figure 3.2.E– Fluid Domain. (A Shelton, 2018)

Figure 3.2.F above, shows the creation of the fluid/ computational domain. The first version was originally too short in front of the motorcycle geometry and would have been a large contributing factor to the differences in results between the initial geometry run and the finalised standard geometry run. (See results table in appendices A3) Reference from the Ahmed Body study was used to finalise the dimensions of the fluid domain geometry. For example using two vehicle lengths in front of the geometry and five vehicle lengths behind.

(SiriusCFD, 2012)

3.2.3 Boundary condition Application

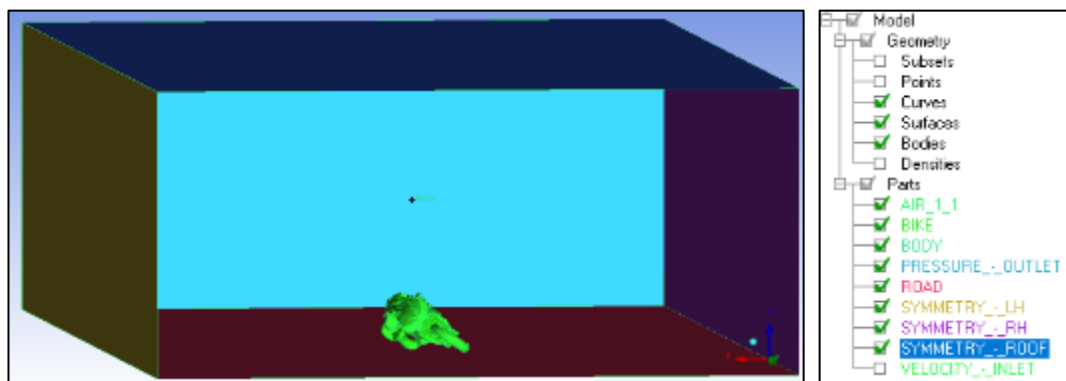


Figure 3.2.F– Boundary Condition Application. (A Shelton, 2018)

Figure 3.2.F shows boundary condition application. Labels are used to reference the geometry so that boundary conditions can be assigned when the geometry is transferred onto the Fluent solver module. What isn't shown in figure 3.2.F, is that the wings also became their own separate specified part. This was so that a smaller element size could be applied solely to the wings in order to accurately capture the crucial geometry of the wings.

3.2.4 Mesh Application

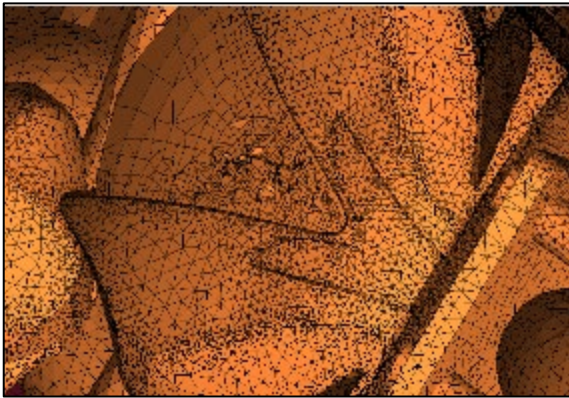


Figure 3.2.G – Hole in initial geometry (A.Shelton, 2018)

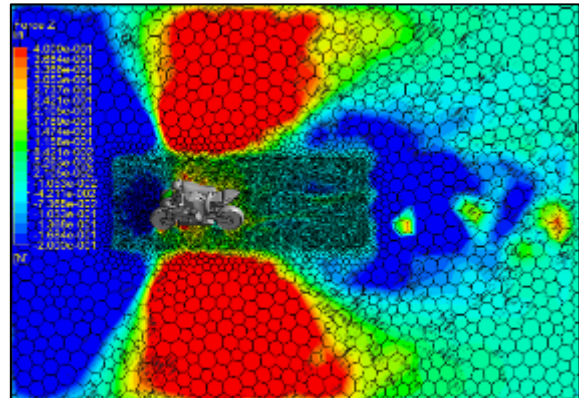


Figure 3.2.H – Fast Polyhedral element Growth Result (A.Shelton,

Holes

Figure 3.2.G above shows a problem discovered when the initial mesh was carried out. It shows that the specified element size was too big and therefore was unable to capture the geometry effectively within the model variance limit. This was due to the curvature of the front screen. In the centre of the image, you can see what are known as holes within the mesh. It was found that these could also be caused by existing file histories. For example, if a previous meshing file was still within the folder, when a new geometry was uploaded, it still tried to mesh the new geometry in reference to the old geometry. Therefore, if wings were moved or removed, this created large holes in the geometry that were difficult to fix.

These were a reoccurring problem throughout the whole of the investigation and are very time consuming and difficult to overcome. However, it was necessity as the case was not transferable into fluent with the holes still present. Therefore, three methods were found to work, these were:

Using the mesh repair tools-

These were only effective on very small insignificant holes in the geometry.

Creating parts to assign smaller element sizes-

This was effective, however the effect on the results of the runs were then questionable. As shown by the difference in result values from the initial simulation and the accepted standard simulation.

Using the standard run as a template-

Using the standard Simulation run as a template meant that the geometry had no winglets on it. Therefore, no holes were left when winglets were applied or moved as previously mentioned.

Polyhedral elements

Due to the complex geometry and therefore consequently the low quality of the mesh, the simulation wouldn't converge. Therefore, the tetrahedral mesh, had to be converted into polyhedral, as this reduces skewed meshes by joining tetrahedral elements together and therefore reducing the skewed angles that cause the inaccuracy. Polyhedral Mesh methods have also shown to reduce convergence times considerably, whilst still maintaining inaccuracy to be negligible. (M. Spiegel, 2010)

Bodies of Influence

Figure 3.2.G shows the initial meshing setup up. This consisted of specified boundary condition parts meshed as one entity, the bike geometry meshed as another, then also a body of influence based around the motorcycle geometry to surround the geometry with smaller elements in order to improve accuracy without filling the whole domain. However, as you can see in figure 3.2.H the sudden step up in mesh size, has a drastic effect on results when the mesh is converted to polyhedral elements. Therefore, in order to reduce this effect, the meshing set up was altered slightly, adding another BOI, however only applying it to the floor of the geometry. This meant that it captured the ground/ motorcycle interaction effectively, but also then proceeded to produce a steady growth in element size throughout the rest of the model as shown in figure 3.3.1.

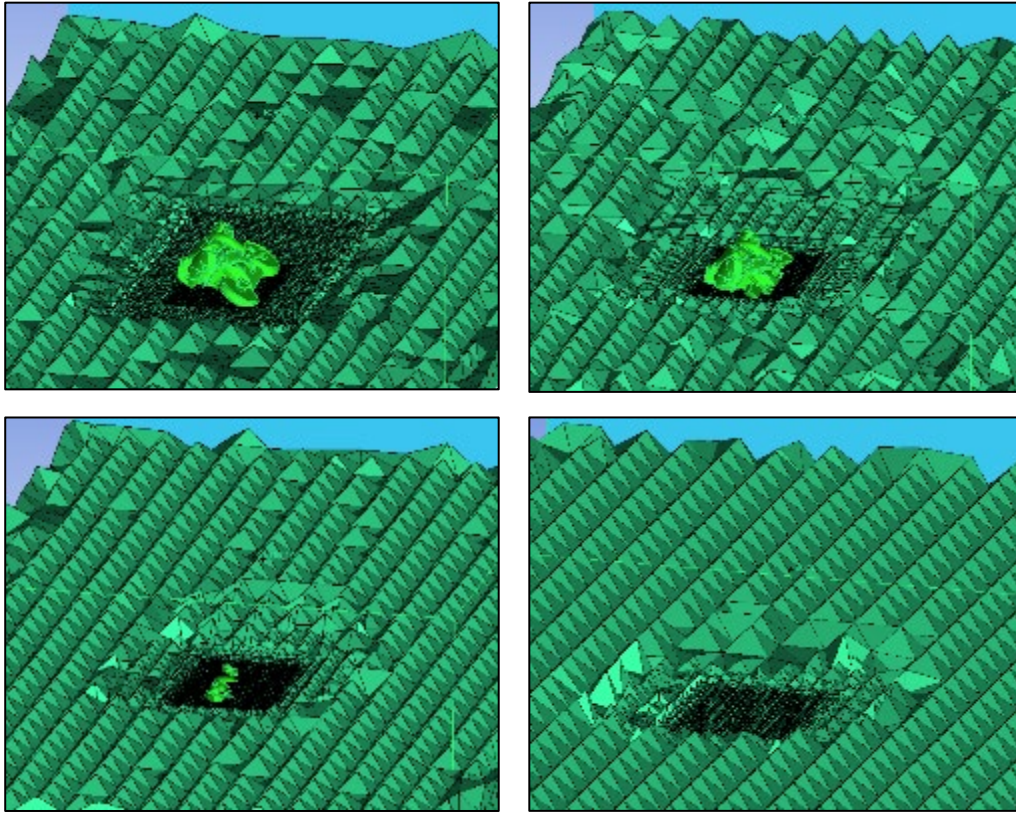


Figure 3.3.1 – slow element Growth Application (A.Shelton, 2018)

3.3 ANSYS Fluent

3.3.1 Simulation Method

The simulation set up was highly influenced by the Ahmed body study results, due to them both being similar in that they are steady-laminar flow, bluff body investigations.

As mentioned previously in section 2.1.1, the settings for the Ahmed body study were refined through an investigation process, accuracy being based on a set of credible lift and drag values, but also through the simulations ability to produce clear characteristics that the Ahmed body is well known for. Below is the list that was followed in order to set up the correct Fluent solver for each simulation:

Models-

- K epsilon – 2 equation
- Realizable
- Non equilibrium wall function

Cell zone Conditions-

- Pressure Outlet intensity viscosity ratio, 5%, 10%
- Velocity Inlet intensity viscosity ratio, 1%, 10% - 27.7778 in the –Y direction

Reference Values-

- Compute from Velocity Inlet
- Apply Frontal Area

Solution methods-

- Coupled, first 100 iterations, then all coupled for 400 iterations

Solution Control-

- Courant # - 50
- Momentum – 0.25
- Pressure – 0.25
- Turb Visc – 0.8 for first 100 iterations, then 0.95 for 400 iterations
- +3 x 0 onto the limits.

Monitors-

- Remove criterion and apply drag, lift and pressure monitors.

(Shelton, 2017)

Number of Iterations

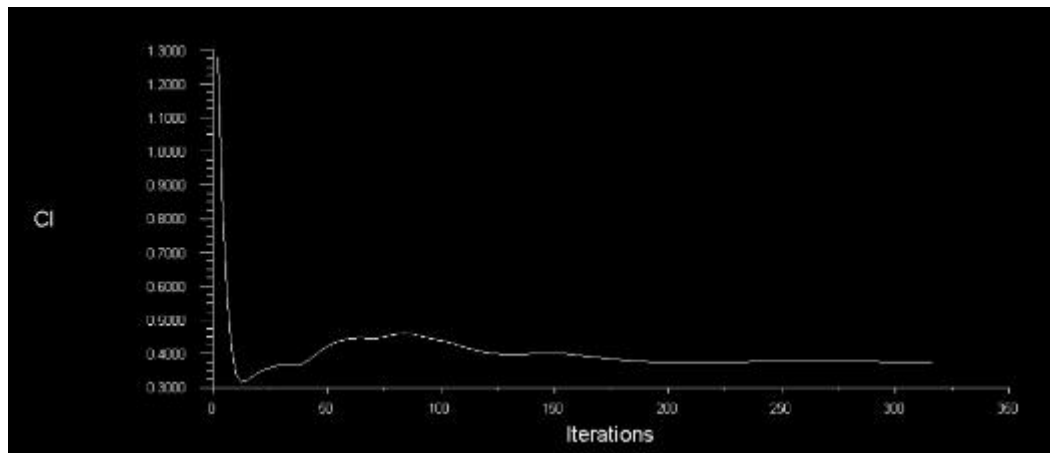


Figure 3.3.2 – Coefficient of Lift Convergence Graph (A.Shelton, 2018)

Figure 3.3.2 shows the coefficient of lift graph of simulation 19. Before simulation 19 the simulation process used, ran for 500 iterations. However, it was noticed during the single wing runs that the solution was commonly converging within 250 iterations. This can be seen by the graph flat lining. The choice was made to see if the increase to two wings made the simulation harder to converge, and although it did, 500 iterations was still too long. Therefore, the choice was made to reduce the simulation to 300 iterations in order to save time.

3.3.2 Limitations

The most common simulation method found to be used for these type of investigations as an alternative to the Navier – Stokes approach, is known as the Lattice Boltzmann method. This has been proven more effective than the Navier- stokes approach due to the method solves simulations through the technique of mathematically calculating the macroscopic fluid dynamic characteristics, movements and interactions of the minute particles that create flow. The Base equation used within this method is the LBE however is even more robust due to its ability to be extended in order to suit characteristics of specific cases. An extension found to suit external aerodynamics around automotive models, is called PowerFLOW. Due to the Digital Physics Method used by the /Boltzmann equation, a Cartesian structured grid is applied in which the element method called “Voxel” is used which enables to break down the case into a particle-by-particle approach making it highly accurate. (Angeletti, 2003)

Not only does this investigation not have access to these types of software extensions, but many of the investigations found in research, used computers with multiple processors and much more computer power than available to this investigation. Not only that but they also had the ability to leave simulations running for tens of hours in order to produce highly complex simulations. (Maduta, 2017) Therefore, it is to be noted that the accuracy of the findings in this investigation are simply limited, in comparison to other investigations out there, and findings should just be referenced to in terms of proof of concept.

3.4 Approach

3.4.1 Initial findings

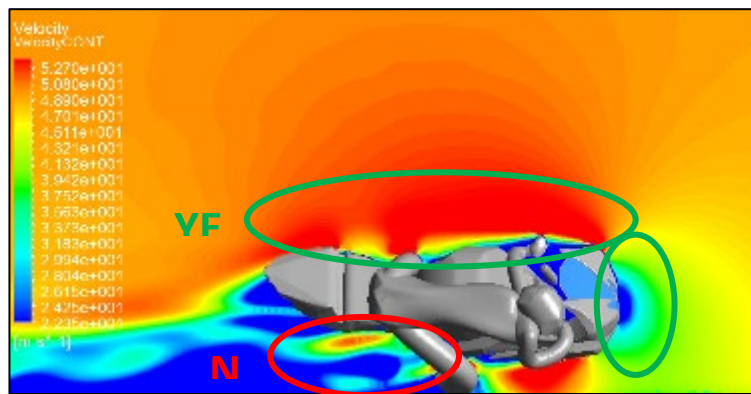


Figure 3.4.1 – Initial Standard Geometry Run Velocity Contour

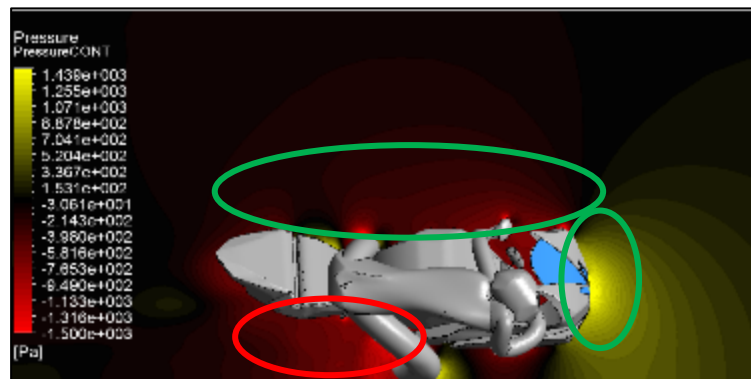


Figure 3.4.2 – Initial Standard Geometry Run Pressure Contour

Figures ### and ### above show the very first simulation of the original geometry. Although the geometry still had the scooping issue mentioned in section 3.2.1 of this report, rough conclusions could still be drawn in order to figure out how the airflow around the geometry was behaving. The first observation drawn, was that paired with the high lift result findings, it appeared that the geometry was working in a similar way to an air-foil.

The absence of pressure within the green highlights in figure 3.4.2 in relation to the high velocity shown in the green highlights in figure 3.4.1 follow the Bernoulli's theorem, of where low flow velocity is a resultant of high pressure and vice versa. (Lotha ET AL, 2018)

A pressure difference between the bottom and top of the foil or in this case, motorcycle, created by the blockage of airflow by the rider's leg clearly shows a strong concentration of high pressure underneath the motorcycle, of which many believe to apply to how airfoils provide lift. (Curley. ET AL, 2018)

It was later observed that, only the front half of motorcycle geometry obeyed this theory. The red highlights in both pictures show a distinct presence of low flow velocity and negative pressure. This lead to the general assumption that the lift effect was generated before the knee, but the majority of the drag was caused by an area of separation, known as pressure drag.

Van Dijk states, the lift effect only increases in proportion to the lean angle. (Van Dijck, 2015) Therefore due to the geometry used, this investigation will provide an insight into the maximum effect wings can provide.

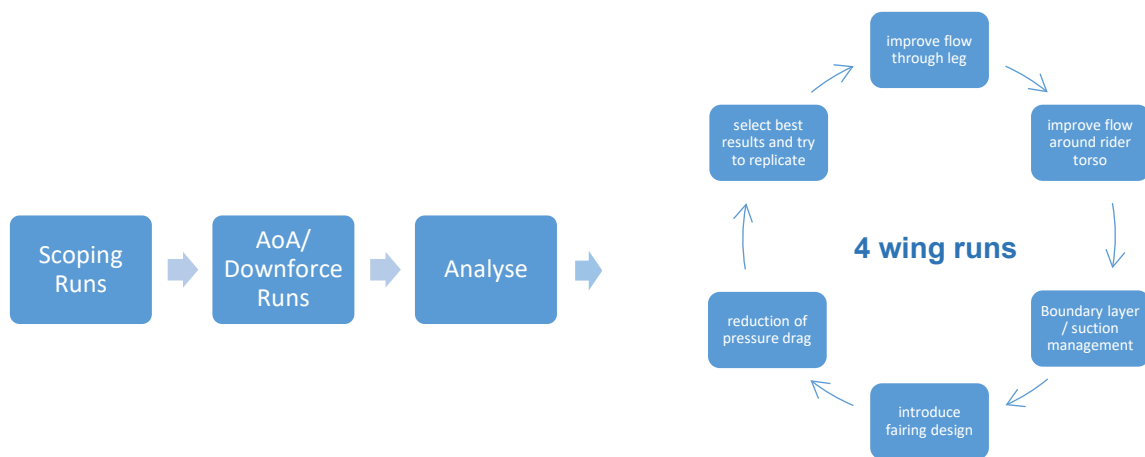


Figure 3.4.3 – Investigation Process (A.Shelton, 2018)

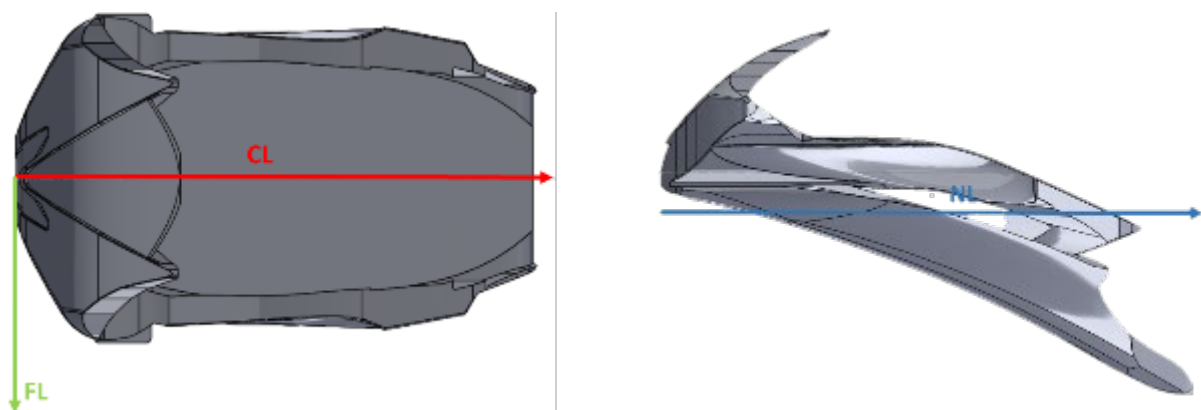


Figure3.4.4 – Foil Position Reference Lines (A.Shelton, 2018)

The simulation approach began with a number of “scope runs”, these scope runs were planned before hand and used the same 100mm wing design (shown in figure 3.4.5) to systematically work through each of the 4 specified variables:

- Wing distance from **FL** (mm)
- Wing distance from **NL** (mm)
- AOA (degrees from vertical)
- Wing distance from **CL** (mm)

For reference see figure 3.4.4

Then a preliminary analysis was carried out using graphs to visually represent results in order to give a rough idea of what areas and orientations were most effective, which could then be focused on more thoroughly.

3.4.2 Effective Runs

SIM #		Fd (N)	Fl (N)		Cd	Cl	IMPROVEMENT
60 DEGREE							Force reduction (N)
0		553.318	337.696		0.65723	0.40111	
0		165.066	111.539	276.605	0.61847	0.41792	
1		160.376	81.2504	241.627	0.5982	0.30306	34.977988
2		161.358	86.7097	248.067	0.60197	0.32349	28.537588
3		158.959	95.4913	254.45	0.59304	0.35626	22.154898
4		161.938	98.157	260.095	0.60418	0.36621	16.509669
5		163.46	97.457	260.917	0.60879	0.36297	15.68778
6		164.86	99.9343	264.794	0.614	0.37219	11.81045
7		162.794	92.268	255.062	0.60631	0.34364	21.54311
8		163.378	94.765	258.143	0.60848	0.35294	18.46178
9		160.474	95.9643	256.438	0.59767	0.35741	20.16648
10		162.465	102.261	264.726	0.60599	0.38143	11.87882
11		160.376	81.2504	241.627	0.5982	0.30306	34.977988
12		164.794	94.3712	259.165	0.61143	0.35015	17.439534
13		163.466	92.6824	256.148	0.60973	0.3457	20.456355

Figure 3.4.5 – Scope Runs and Their Results (A.Shelton, 2018)

Figure 3.4.5 above, shows the spreadsheet used to record the geometry parameters and their results on the drag force and lift force. It soon became apparent that the very first simulation provided the best results so far, reducing drag by nearly 5N and lift by close to 30N.

Figure 3.4.5 also shows that run 11, achieved the exact same results. Upon evaluation, it was concluded that due to the results not differing at all, this was an anomaly result. In speculation

this could have happened due to the incorrect geometry being loaded into the Fluent solver, as a result of using the geometry 1 simulation as a template.

What is clear even at this early stage in the investigation, is that the addition of singular wing/winglet combinations clearly have a positive effect on both aspects of aerodynamic efficiency of the motorcycle geometry during cornering.

3.4.3 Methods of improvement

After analysing the initial results, three main methods were decided in order to improve the drag and lift values:

Managing Flow Around Rider-

This method involves using angle of attack on the wings, in order to direct the flow around the rider. The top wing seemed effective at directing flow underneath the arm of the rider and around the torso. It is important that the flow is not directed onto surfaces that are at a high adjacent angle to the direction of flow, as this will cause vast concentrations of pressure and wake regions. (Hucho, 1986) AoA also has to be carefully monitored, as not to cause the foil to stall which will increase drag.

Improving Flow to Reduce Separation-

Hucho states, that the Reynolds number has a large influence on the size of the wake region of a bluff body, as shown in figure 5.1.4. (Hucho, 1986) It is believed that this effect may also be achieved by applying the correct distance between the air foil and leg, when the trailing edge is directly pointed towards the leg, and leading edge pointed directly into the direction of flow. Reduction of the separation area behind the leg in turn reduces the amount of suction, and increases the flow through and around the leg, reducing turbulence when the recirculating flow rejoins the inside airflow towards the rear of the motorcycle.

Wing Interference/ Downforce-

Sedlack concludes, that due to the cigar shape of the leg, it is considerably effective at interfering with the efficiency of the air foil, therefore it can be used to eliminate the effect of the inside wing.

4.0 Results

Due to the asymmetrical nature of this geometry, strong correlation of results aren't produced. This is caused by the asymmetrical rider body having a large effect on any flow going underneath the motorcycle. In short, the following results cannot be used for anything else, only in situation.

This makes it difficult when trying to evaluate the effectiveness of the control variables of the investigation. Therefore, this investigation relied more on research methods to find singular results. For example, it was found that the flatter cigar shape that a leg represents is more effective at destructively interfering with an airfoil, rather than a cylindrical shape. (Sedlak, 2012)

This however, has the positive effect of saving large amounts of time that would otherwise be used up producing more geometry and simulations.

Below, are three sets of graphs, produced by this investigations results, of which some conclusion can be drawn: (Note that all values were recorded using the NACA M27 foil)

4.1 Distance From CL

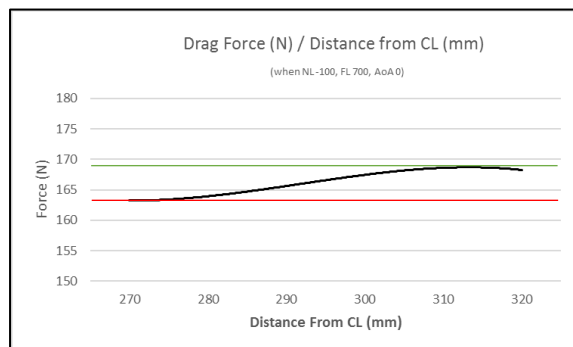


Figure 4.1.1 – Drag / CL Distance (A.Shelton, 2018)

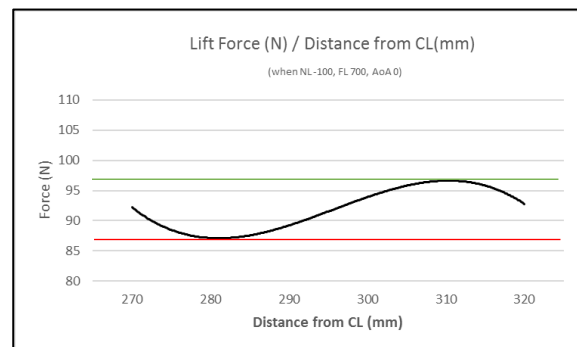


Figure 4.1.2 – Lift / CL Distance (A.Shelton, 2018)

Figure 4.1.1 above shows a graph of the relationship between the wing distance from the Centre Line (CL line) specified in section 3.4.1 and the overall drag force produced. As it clearly shows, the lowest drag force produced occurs at 270mm, this was the closest position tested to the CL line. This is to be due to it simply being so close to the main body of the geometry. Preliminary research suggested that the further away from the main body of the

geometry, the more effect the foil will have due to being situated in more direct/ un-disturbed air flow. (Molina, 2011)

Figure 4.1.2 shows the same relationship but with the overall lift force. As you can see the lowest lift, force provided occur when the wing was 280 mm away from CL. This is speculated to be due to it projecting flow around the rider's torso, and under the arm; improving flow and reducing pressure underneath the motorcycle rather than into the arm (shown by the results leading further away from the motorcycle) which would increase pressure.

4.2 Distance From FL

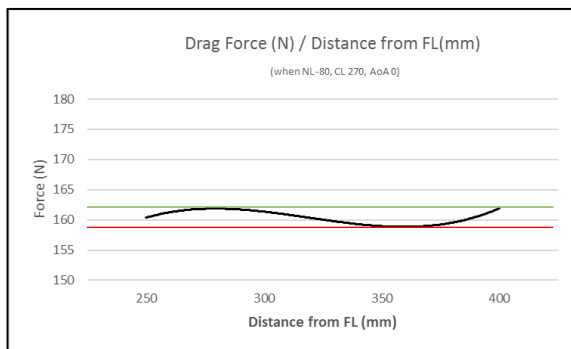


Figure 4.2.1 – Drag / FL Distance (A.Shelton, 2018)

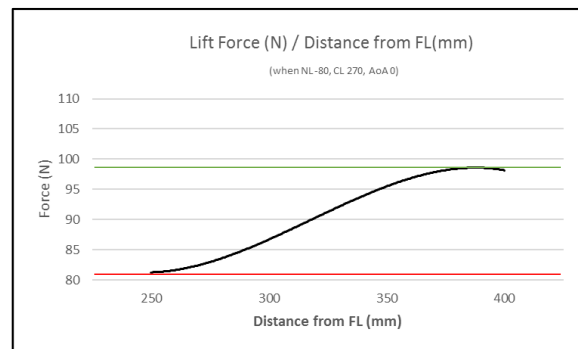


Figure 4.2.2 – Lift / FL Distance (A.Shelton, 2018)

Figure 4.2.1, shows the drag results according to wing distance from FL. As you can see the results, range is relatively small compared to the rest of the results. This is observed to be due to the position of the wing from NL. The results were taken when the NL distance was -80. This puts the wing in line with the gap in between the rider's leg and the motorcycle body. Therefore, it is assumed the wing did not have much effect in terms of directing flow around the rider.

Figure 4.2.2 shows a direct correlation that as the wing gets further away from the front of the motorcycle, the less effect it has in terms of reducing lift. This was due to the outside wing having a much more effective influence, by increasing the flow over the rider's outward leg, and therefore increasing the pressure difference below/ above the motorcycle.

4.3 Angle of Attack

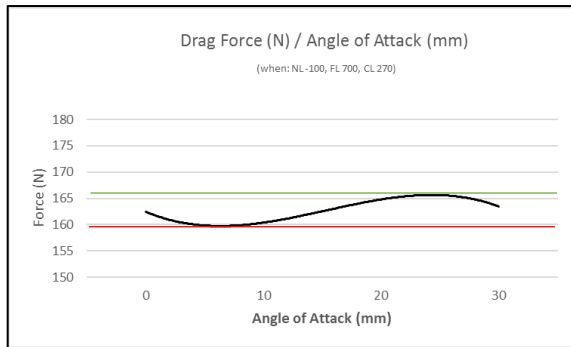


Figure 4.3.1 – Drag / AoA (A.Shelton, 2018)

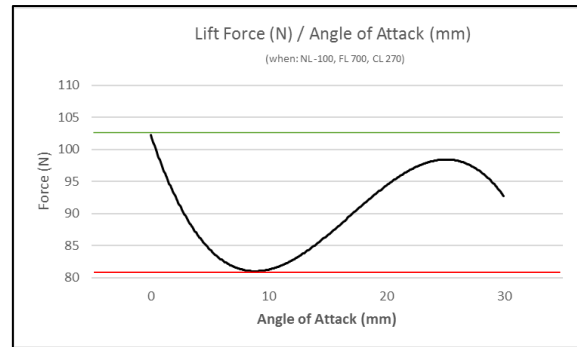


Figure 4.3.2 – Lift / AoA (A.Shelton, 2018)

Figure 4.3.1 above, shows that the NACA M27 foil was most efficient at reducing the overall drag of the motorcycle with around a 7-degree angle of attack, and then significantly increases up until the drag force value is higher than the standard geometry. This suggests that the foil produced separation at around 22 degrees.

Figure 4.3.2 on the right shows the resultant lift force in terms of angle of attack. However due to the vast range in results and the behaviour of the results, it was concluded that the rider body had far too much of an influence on the flow around the foil during these results, for any credible evaluations to be made.

4.4 Validation

SIM #	NOTES	MODEL	Ed (N)	Fl (N)		Cd	Cl	IMPROVEMENT
60 DEGREES LEAN @ 100 km/h STRAIGHT AIR FLOW								
0		Original	553.3184	337.6956		0.65723	0.401114	
0		Standard	165.0656	111.5392	276.6048	0.61847	0.417917	Force reduction (N)
13	Alternate AirFoil	NACA M27 - GEOM 13	163.466	92.68239	256.1484	0.609726	0.345704	20.456355
12VALID		NACA 4415 - GEOM 12	164.794	94.37121	259.1652	0.611435	0.350145	17.439534
13VALID		NACA 4415 - GEOM 13	163.466	92.68239	256.1484	0.609726	0.345704	20.456355
14		NACA M27 - GEOM 14	163.0601	85.12441	248.1845	0.608212	0.317513	28.420288
15		NACA M27 - GEOM 15	166.6771	92.65261	259.3297	0.621704	0.345593	17.275084
16		NACA M27 - GEOM 16	167.0509	91.07571	258.1266	0.624098	0.339711	18.47816
17		NACA M27 - GEOM 17	168.4577	97.75197	266.2097	0.623576	0.361846	10.395087
18		NACA M27 - GEOM 18	168.3327	92.63818	260.9709	0.623236	0.342984	15.633859
19		NACA M27 - GEOM 19			0			
			162.1595	100.7644	262.9239	0.604853	0.37585	13.68085
19 VALID	INDIVIDUAL FACE SIZING ADDED TO	NACA M27 - GEOM 19			0			
			165.5033	105.6043	271.3076	0.615722	0.39288	5.49718
20	Inflation layers added	NACA M27 - GEOM 20			0			
			164.8506	95.58057	261.5489	0.611637	0.331135	24.864554

Figure 4.4.1 – Geometry 19 VAL (A Shelton, 2018)

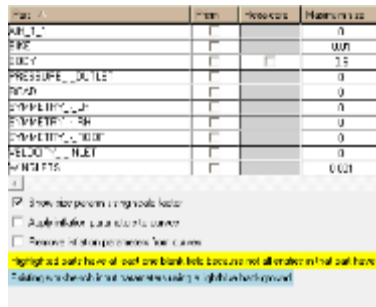


Figure 4.4.2 – Mesh Application (A Shelton,

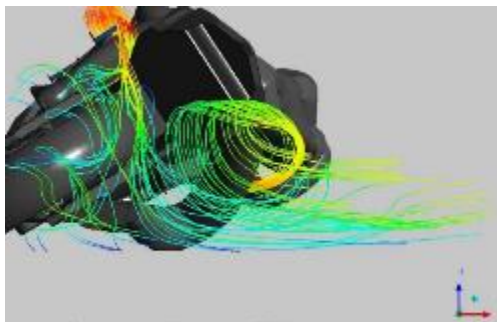


Figure 4.4.3 – Geometry 19 VAL (A Shelton,

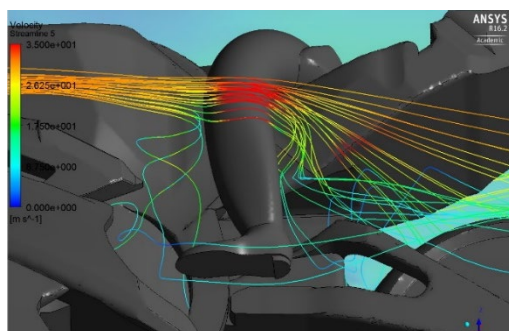


Figure 4.4.4 – Geometry 19 VAL (A Shelton, 2018)

As shown in figure 4.4.1 a number of validation runs were carried out throughout the investigation in order to maintain a level of credibility/ accuracy. Two validations are shown in the above image highlighted by the red outline, these included:

Testing to see if the alternate airfoil shape had any effect-

This was carried out on two separate runs, one at zero angle of attack, and another at 10 degrees; the runs were kept identical apart from the foil shape. The results showed no change in figures at all, indicating that the airfoil shape had no effect on the flow. However, in reflection this is now considered untrue due to the next validation criteria.

Testing to see if the mesh was capturing the geometry of the air foil-

Advice from the technical advisor of this investigation was followed, when changes were made to the mesh sizing, in order to capture the foil geometry better. This was due to noticing that the foils up to this point had cavities in the trailing edges. As shown in figure 4.4.1 this did increase the both results, which also reduces credibility of the first validation.

Figures 4.4.3 and 4.4.4 show a method of validation used through the investigation. Using the visual results to see if the numerical results ring true, can be very effective. In this example, you can clearly see that capturing the geometry of the airfoil, directed the flow of the air more into the riders outer leg creating turbulence. This would give a credible explanation into why such increases in drag were made.

5.0 Analysis

Although sometimes this method may not be effective, the main method used for analysing the results acquired was the use of ANSYS results' case comparison feature. Each run was saved fully, in order to be able to go back and make any adjustments, so in order to compare, the Case & Data file of the original standard geometry was simply loaded into the results of each run to easily compare.

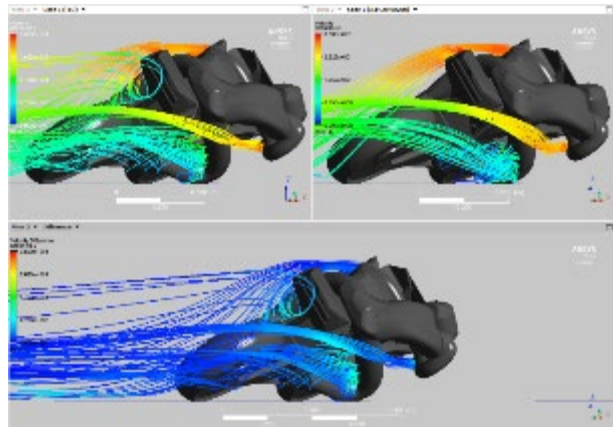


Figure 5.1 – Case Comparison. (A Shelton, 2018)

(As shown in figure 5.1)

The case comparison feature also enables a third window to be used that displays the difference in the two results by colour coordination. As you can see in figure 5.1 there is an increase in flow velocity through the leg of around 6.75 M/s indicated by the light blue colour.

Assumption:

It can be assumed that due to the cornering nature of the simulation, each result simulating a design that depends on inner wing cancelation will be skewed negatively, due to simulation set up using a flow inlet, which is straight and interacting with the geometry head on. This means that the usual effect of higher forces acting upon the outside of the motorcycle are not going to be applied. (Sedlak, 2012)

5.1 Resulting Effects upon static Geometry

5.1.1 Geometry 1

SIM #	Fd (N)	Fl (N)	Cd	Cl	IMPROVEMENT
60 DEGREE					Force reduction (N)
0	553.3184	337.6956	0.65723	0.401114	
0	165.0656	111.5392	0.2766048	0.61847	0.417917
1	160.3764	81.25038	0.2416268	0.598202	0.303063
					34.977988

Figure 5.1.1 – Geometry 1 Results. (A Shelton, 2018)

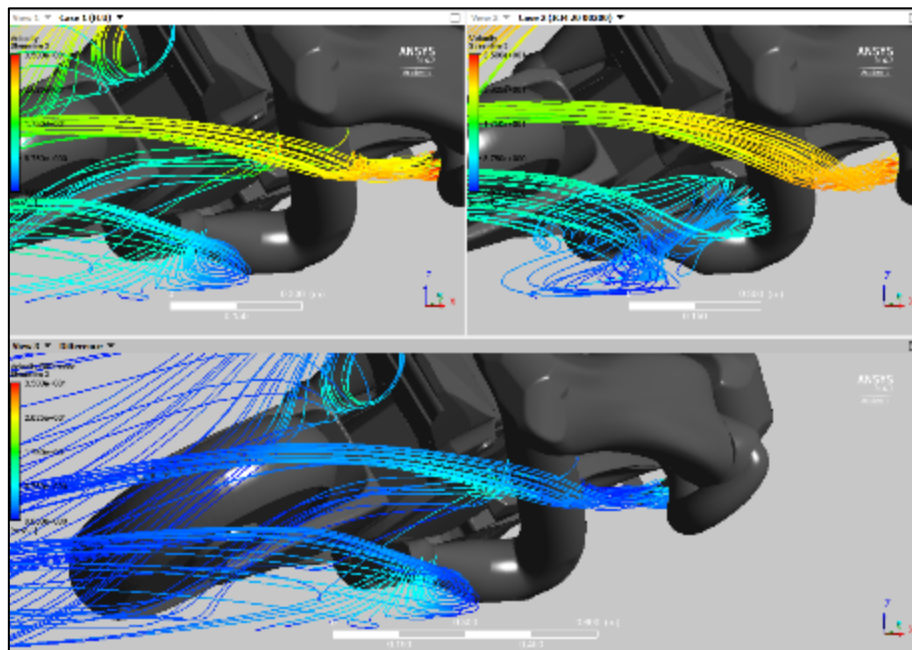


Figure 5.1.2– Geometry 1. (A Shelton, 2018)

Why did run 1 work so well?

Run 1, although only using one set of wings, managed to influence all aspects of flow interaction (mentioned in section 3.4) around the geometry. It has shown to do this, by using no angle of attack, which helped direct flow around the riders upper inside leg, (Not away from, which would produce a higher wing force) reducing the amount of separation caused behind the leg. (Hucho, 1986) Therefore the turbulent area (of which is proportional to drag (Ahmed, 1984)) apparent on the standard geometry (shown in the top right window of figure 5.1.2) is significantly reduced. (Shown in the top left window) the bottom window in figure 5.1.2 shows an increase in flow velocity of over 8 m/s where the flow lines are highlighted light blue.

The flow over the outside leg was also improved, and due to no angle of attack on the wing, it achieved this without creating too much of a recirculation angle, example of which is shown in the results of geometry 24. (Section 5.1.4)

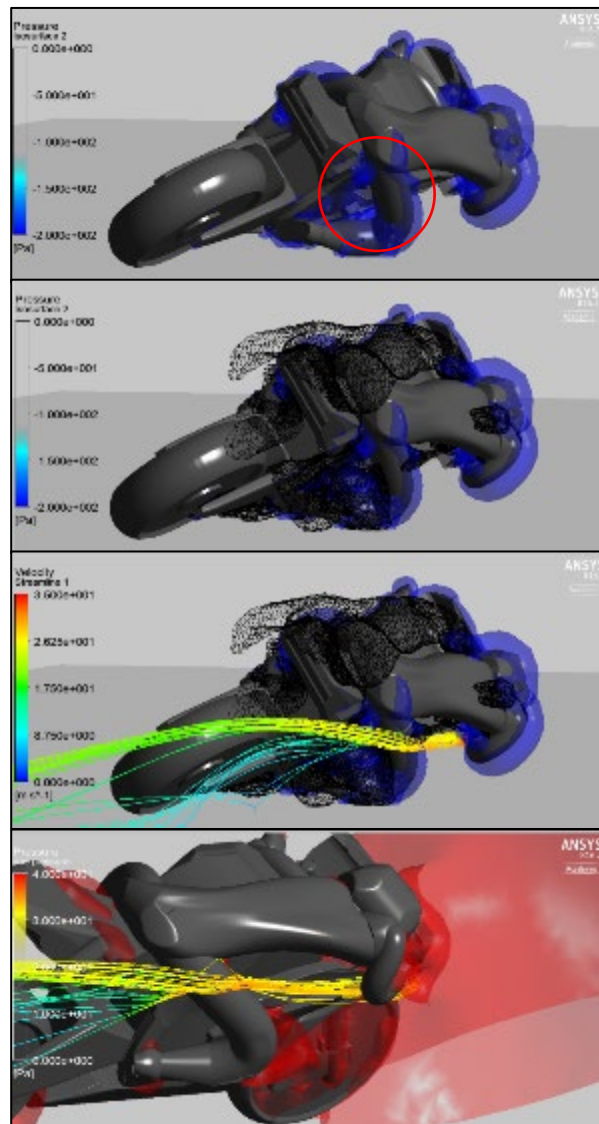


Figure 5.1.3 – Pressure/ turbulence reduction. (A Shelton, 2018)

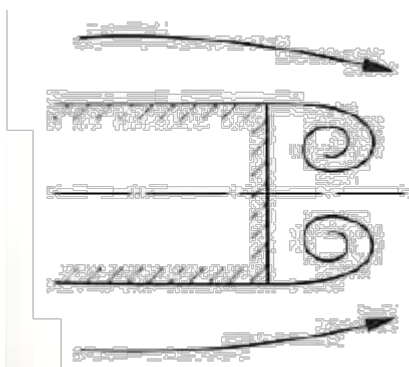


Figure 5.1.4 – Flow separation on a bluff body.
Separation line perpendicular. (W.Hucho, 1986)

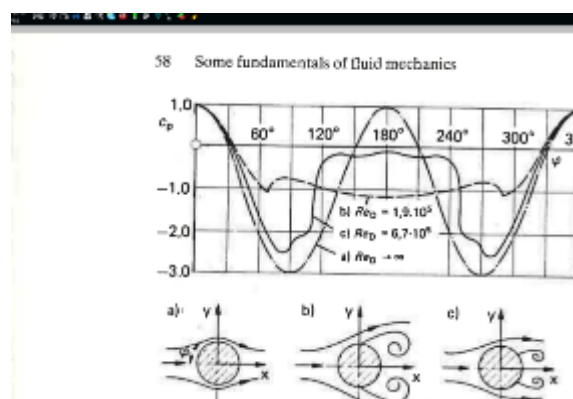


Figure 5.1.5 – streamline distribution at
different Reynolds numbers. (W.Hucho, 1986)

Figure 5.1.3 shows how the improved stream of flow under the riders torso, removes the positive and negative pressure concentrations (Blue and Red Iso Surfaces) and also as a result, the turbulence (shown as mesh) The positive pressure concentration at the front is believed to be a large contributing factor to the lift being produced, and the suction behind the leg creates turbulence, which is a source of pressure drag (Hucho, 1986) therefore this shows where a large contribution of the reduction in forces was created.

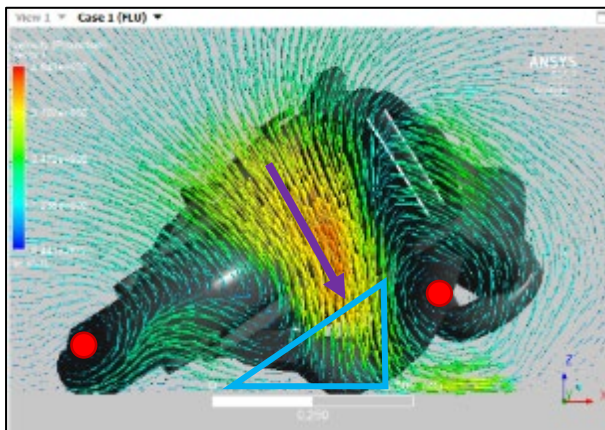


Figure 5.1.6 – Geometry 1. (A Shelton, 2018)

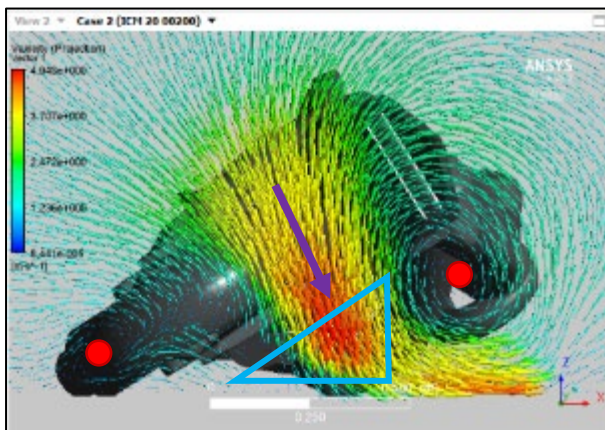


Figure 5.1.7 – Standard Geometry. (A Shelton, 2018)

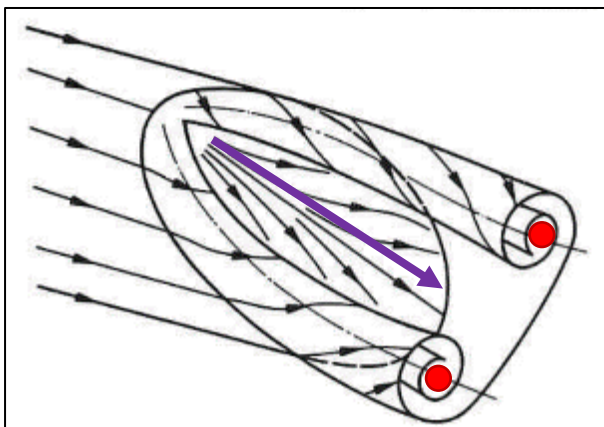


Figure 5.1.8 – Flow separation on a body with oblique blunt base. (W Hucho, 1986)

A good example of the flow effects around the motorcycle all interacting, is shown in figures 5.1.6, 5.1.7 and 5.1.A.

Figure 5.1.8 shows an effect called separation over an oblique-based body; however, this form of separation is different to the separation shown in figure 5.1.4, due to the separation lines being at an angle to the direction of flow, rather than perpendicular.

The motorcycle/ rider geometry displays both types of separation:

Behind the leg- (shown by the blue triangle)

Shows the bluff body type separation shown in figure 5.1.4 where the separation line is perpendicular to the flow direction and therefore produces vortices that's axis are also perpendicular to the flow resulting in relatively small velocity values. Due to this, vortex shedding occurs which results in an unsteady region, the kinetic force of the vortex field is lost, producing a total pressure loss in the region behind the leg of which the corresponding loss in kinetic energy is equal to the work of which is needed to overcome the pressure drag.

Rear of the motorcycle- (Shown by the Red dots and Purple Arrow)

Shows the type of separation previously mentioned and shown in figure 5.1.8 this type of separation as mentioned before is characterised by the separation lines being at a slight angle to the direction of flow, which cause the resulting vortices axis to be almost parallel to the direction of flow, which as a result, gives the vortices a considerable velocity component. This results in a steady three-dimensional flow separation characteristic flow, which to suction and the intense flow of the vortices, therefore pressure drag.

As you can see in figure 5.1.6, simply providing a stream of higher velocity flow, through the leg, reduces the unsteady separation. Therefore as a result provides a more effective teardrop shaped flow around the whole geometry, when interacting with the faster/ low angle recirculating flow around the outside of the motorcycle, which in turn reduces the angle/ component of the transverse flow around the rear of the motorcycle of which feeds the vortices. (Shown in figure 5.1.7)

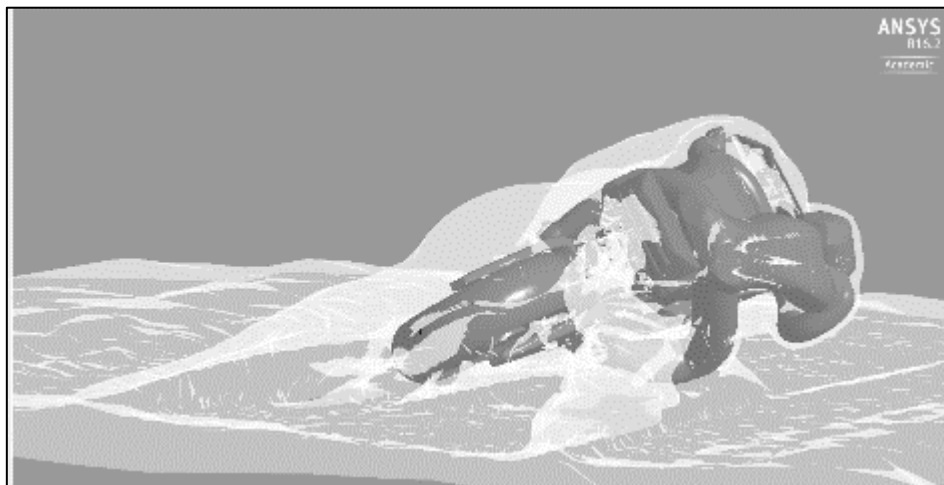


Figure 5.1.9 – Steady flow separation vortices. (A Shelton,

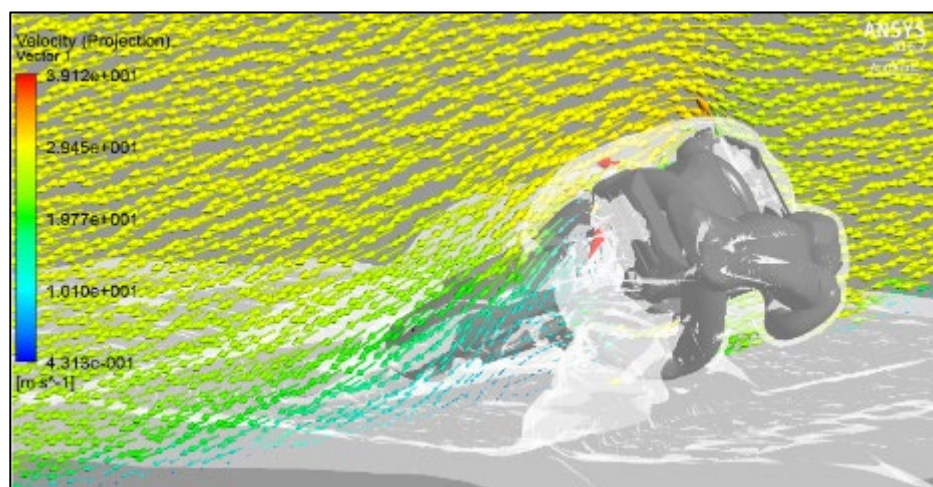


Figure 5.1.A – Oblique shape created by separation. (A Shelton,

5.1.2 Geometry 21

Geometry 21 provided the worst result of the investigation, actually increasing the negatively effecting forces by 16.16425 N this is believed to be due to the angle of attack of both wings to be set at 15 degrees from vertical. (See section A8 of the appendices for full geometry parameters)

SIM #	Fd (N)	Fl (N)		Cd	Cl	IMPROVEMENT
60 DEGREE						Force reduction (N)
21		0				
	170.3855	122.3835	292.769	0.627479	0.450702	-16.16425

Figure 5.1.B – Simulation 21 Result. (A Shelton, 2018)

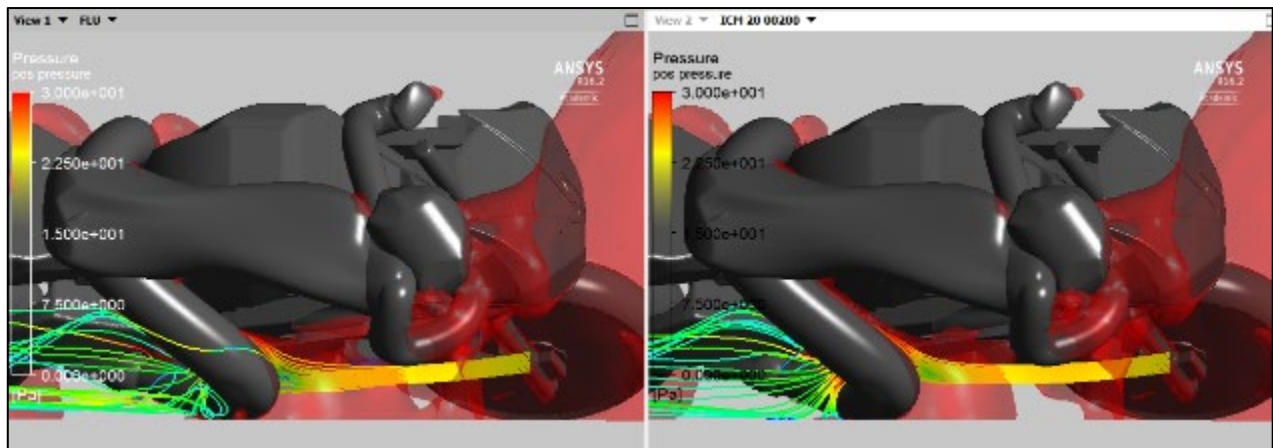


Figure 5.1.C – Increase in positive pressure. (A Shelton,

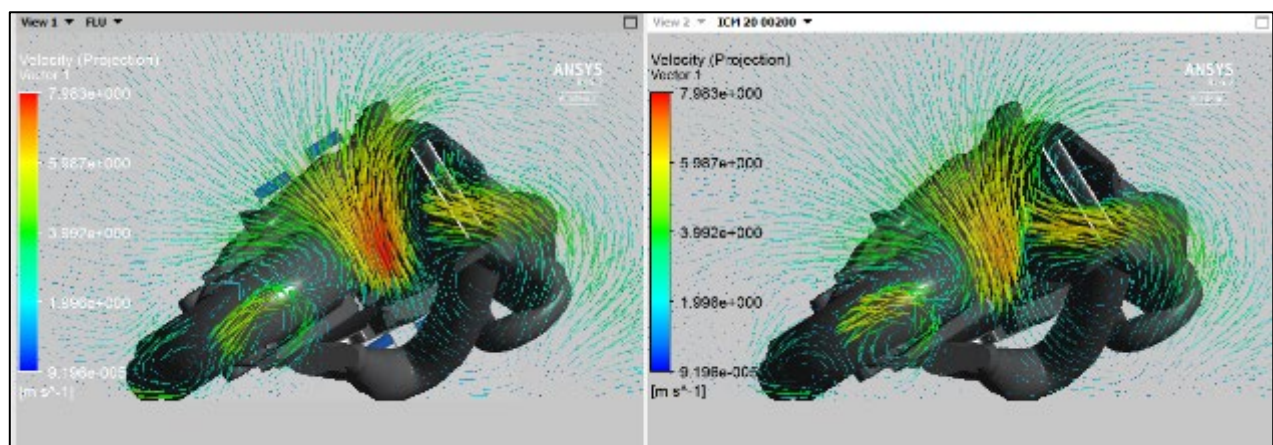


Figure 5.1.D – Increase in wake vortices. (A Shelton, 2018)

Figure 5.1.C shows how the sharp angle of attack applied to the lower wing, which directed flow directly into the steep gradient of the rider's leg, resulting in the high-pressure increase evident in the left window. This is believed to create the high lift value.

Figure 5.1.D shows an increase in steady flow separation vortices, which explained in section 5.1.1 means a higher amount of work has to be done in order to overcome the pressure drag created by such characteristics.

5.1.3 Geometry 24

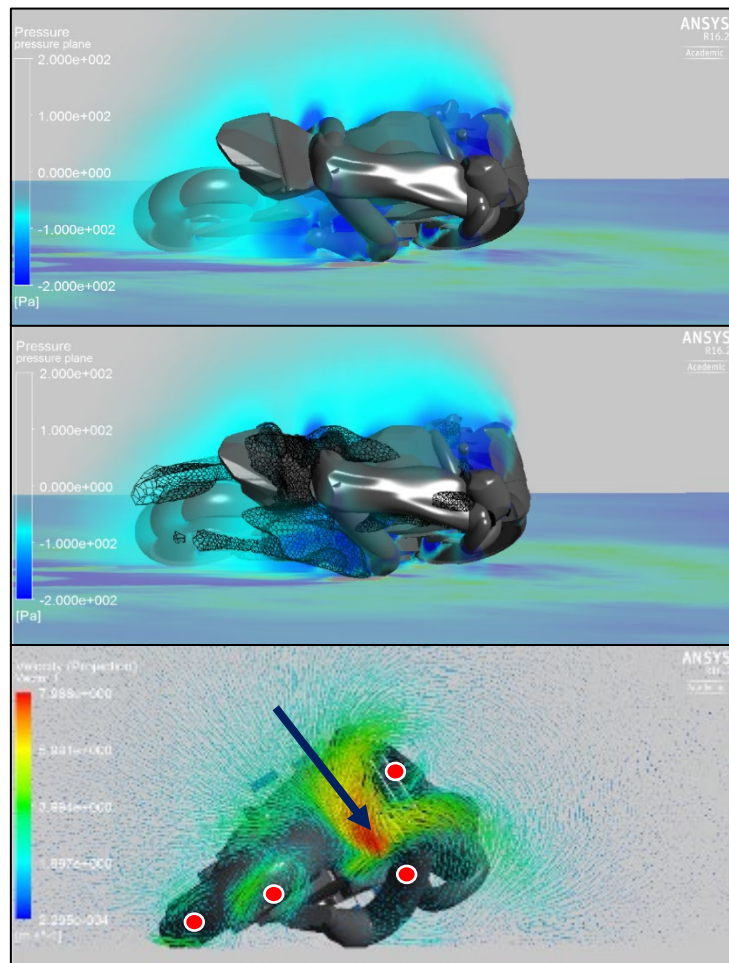


Figure 5.1.E – Geometry 24 (A.Shelton, 2018)

Findings showed that, although using the knee to interfere with the inside wing to reduce its effect was an effective method at producing downforce, (shown by simulations 14 – 18) both the increased angle of attack and larger distance from the CL factors were detrimental to the steady flow recirculation enhancing the steady separation characteristic produced in the wake of the geometry. This was due to the lack of flow through the leg that enables the steady circulation around the whole geometry. Instead, due to the absence of this flow injection, the

steep angle of steady flow recirculation/ separation produced by the outside wing, cuts through between the rear wheel and the seat unit, transversely across the rest of the airflow which then increases the intensity of the vortices. This can be compared with the same effect only weaker occurring on the standard geometry shown in section A9 of the appendices and contrasted to the successful reduction of this effect in 5.1.1.

6.0 Discussion

6.1 Discovering CAE Methods

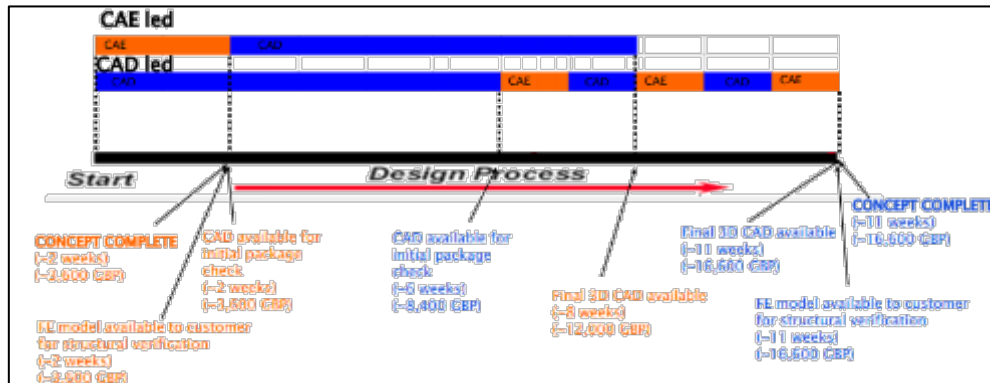


Figure 6.1.1 – CAE Led Design Process (K. Lake, 2018)

One of the major area for improvements of this investigation would be the investigation/ design process. The CAD led, singular parameter changing investigation style, was extremely time consuming, especially when software problems occurred.

Computer Aided Engineering has been a part of the engineering process for considerable amount of time. However, changing the order of the whole design process in order to be CAE led is a method quickly being adapted by many companies' due to the clear advantages it provides. Figure 6.1.1 above shows a timeline of both CAE led and CAD led design processes. Although it shows a generalised case, it is based on real life examples, and therefore shows just how much more effective a CAE led design process is. For example, advantages include:

- Overall whole design process shortened by 3 weeks
- Concept designs finalised 9 weeks quicker
- Better customer interaction and therefore approval due to FE model availability
- More than 4000 GBP saving

Topology Optimization is a key tool used in the CAE method, and with the recent advances in 3D printing and moulding processes, has already transformed the structural design process with great success. (Lake, 2018)

Topology Optimization works by providing the software with an objective. For example, in the case of a structural design, providing a load and direction that the structure has to withstand. Then, boundary conditions such as fixing points and available variable parameters such as maximum weight or wall thickness are applied within a specified design space. Then, the software using FEM will provide an organic styled structural solution according to the available design restrictions that can either be used directly by being converted into a CAM file or then used as reference for a CAD model to be designed to the machine methods available. 9/10 times this solution will be more efficient than any CAD led design by human.



Figure 6.1.2 – Internal CFD Topology Optimization (Dr Ing, 2009)

CFD topology optimization is currently used and available within the ANSYS software. However, according to research, seems only available to be applied to internal flow pipe-style CFD cases shown in figure 6.1.2. Therefore, it is felt that considering this technology was first being pioneered in 2009, external more aerodynamic aimed examples of this software could be close to being developed/ finalised. The results of this software being produced would benefit design process time significantly, as well as producing more organic/natural aesthetically pleasing designs. It is felt that the weight reduction and strength improvements could still be achieved however would not be within the same margin of improvements as the previous mentioned design aspects.

7.0 Conclusions

7.1 Was the solution effective and accurate?

In conclusion, the results retrieved from the investigation, clearly show a positive correlation for the relationship between the application of airfoils and reduction in negative cornering aerodynamic effects.

A reduction in 30 N of lift force is a considerable amount of force that will be applied downwards through the contact patches of the motorcycle thus improving grip and therefore cornering ability, which when applied to a large percentage of the track could significantly improve lap time. Considering the minute weight addition to the bike wings would make, a reduction in drag and lift is worth the addition.

However, this does not mean that this investigation has achieved anywhere near the maximum potential of wing application, due to the realisation of the larger aerodynamic affect happening towards the latter stages. It is suspected, that taking more into consideration the separation effect when applying wings, will have a much more responsive effect.

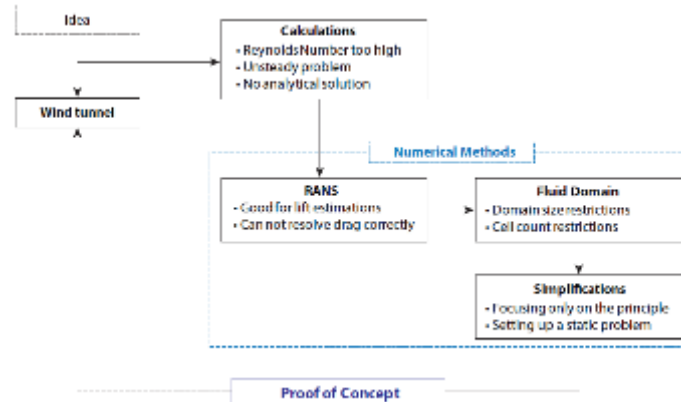


Figure 7.1 – CFD Proof of concept (Sedlak, 2012)

Figure 7.1 above shows how the findings of this investigation are to be taken as a proof of concept, and that in order to validate actual real life dynamic results; these simulations are to be used as a complimentary form of testing in conjunction with real life wind tunnel and track testing. (Hucho, 1986) (Sedlak, 2012)

7.1 Evaluation

7.1.1 Maximising the Potential of Workbench

Due to the temperamental behaviour of the ANSYS software, with my lack of experience with the software, a lot of time was wasted due to invalid runs caused by either incorrect geometry being loaded into the solver, or by general incorrect data being transferred through each module within the workbench software. It was suggested that the simulations were to be set up from scratch each time. Although I did try this, due to the lengths of time it took to mesh and run the simulations, if any mistakes were made in either of the three set up modules, it became apparent that this was not only giving me different results, but also just adding even more time to the problem I was already experiencing and therefore becoming detrimental to the investigation.

Therefore, I took the time to research and pay more attention to the workbench aspect of the ANSYS software, in order to be able to use the workbench feature as intended, by making a template and then swapping each progressive model into the first module and then transferring the data through each step. This meant that it removed any possibility of incorrect/ different set up, and eliminating any anomaly results.

Although this did sacrifice time during this investigation, it was felt that for industry and any other future purposes, my personal efficiency of using the ANSYS software has now vastly improved.

In reflection, the ANSYS AIM software may have been a better selection of software for short term/ time sensitive use, as it includes aid intended for less frequent users. (ANSYS, 2018)

7.1.2 Self Evaluation

It is felt that although I have worked none stop and incredibly hard in order to create this investigation, it lacks the credibility in its results, due to the lack of in-dynamic investigation.

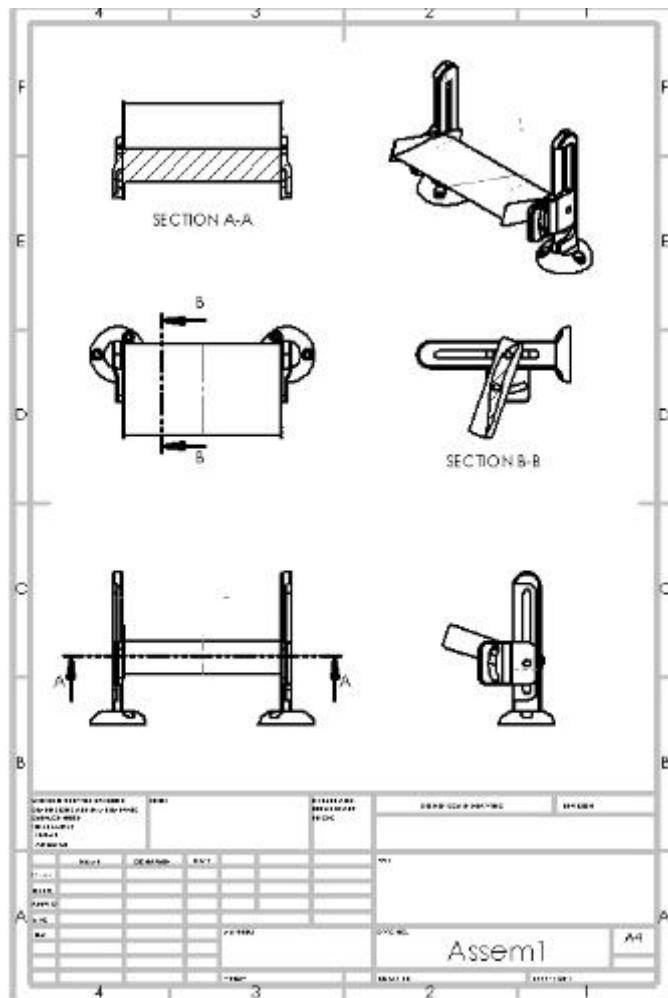
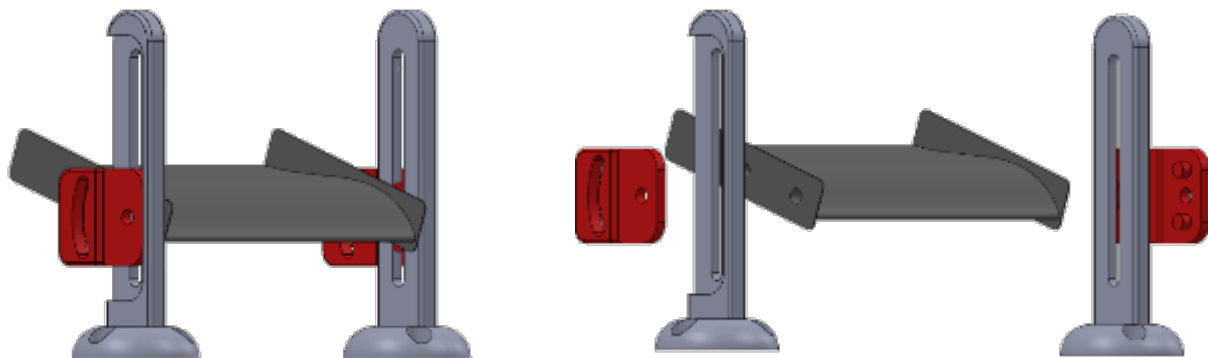
Additions could have been made to the simulation, of which could have improved the accuracy of results significantly, however were not applied due to running out of time.

I feel I have excelled in the ability shown, to learn new software to a professional level, and I feel that CAD modelling skills have improved significantly since the initial geometry design.

I feel that I have shown the ability to create an investigation in a systematic and professional way, carrying it out efficiently showing practical ability.

In contrast, one aspect I feel I could improve significantly on, is not allowing a lack of confidence to prevent me from either trying new methods or asking for help. This has affected the investigation significantly numerous times, and I feel will hinder my development in the future.

7.2 Further Work



The images above and to the left, show a model designed and produced completely by myself with the intention of testing. The model was successfully 3D printed, and designed in order to provide a solution to a problem discovered during this investigation; that there seems to be no time and expense efficient way of testing aerodynamic methods during a testing weekend. These wings are design to be able to be applied to many positions on most motorcycles with little or no adaptation. The wings are adjustable in height and angle of attack, which would provide great diversity of testing the effects of wings applied to a motorcycle.

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Images

Figure 1.1.1 -

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Figure 1.1.2 -

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Figure 1.1.3 -

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M.McVeigh, *Moto GP Winglets*, MotoDNA.Net, Oct 13, 2015.

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Figure 2.1.2 -

Aerodynamic Effects on a Cornering Ahmed Body.

J Keogh ET AL, The aerodynamic effects on a cornering Ahmed body, School of Mechanical and Manufacturing Engineering, UNSW, Sydney, 2004. PDF.

Figure 2.2.3 -

Lean angle influence on drag value.

T. Van Dijk, Computational Evaluation of Aerodynamic Forces on a Racing Motorcycle during High Speed Cornering, SAE INTERNATIONAL, 2015. PDF.

Figure 3.2.3 -

Original R6.

MCS, *Yamaha YZF-600*, motorcyclespecs.com, 2005.

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Figure 3.2.4 -

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Figure 6.1.1 -

CAE Led Design Process.

K. Lake, *CAE in the product life cycle*, UWTSD Swansea, 2018.

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Figure 6.1.2 -

Internal CFD Topology Optimization.

Dr Ing ET AL, CFD Topology Optimization of Automotive Components, 4th European Automotive Simulation Conference, 2009. PDF.

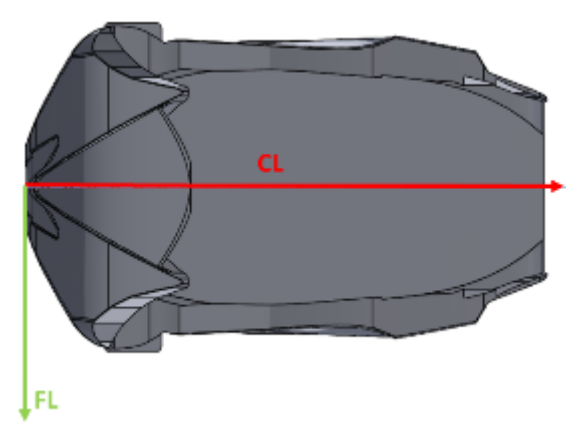
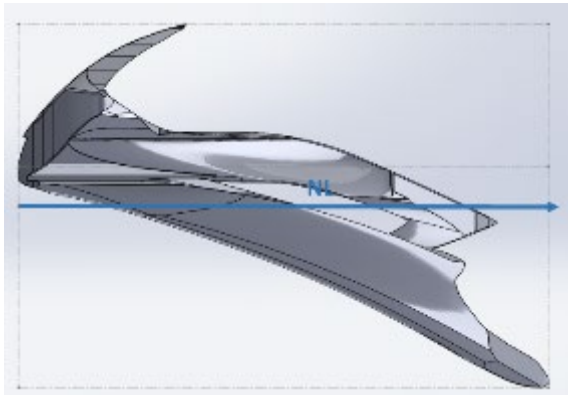
Figure 7.1 -

CFD Proof of Concept.

V. Sedlak, Motorcycle Cornering Improvement: An Aerodynamical Approach based on Flow Interference. PDF. 2012.

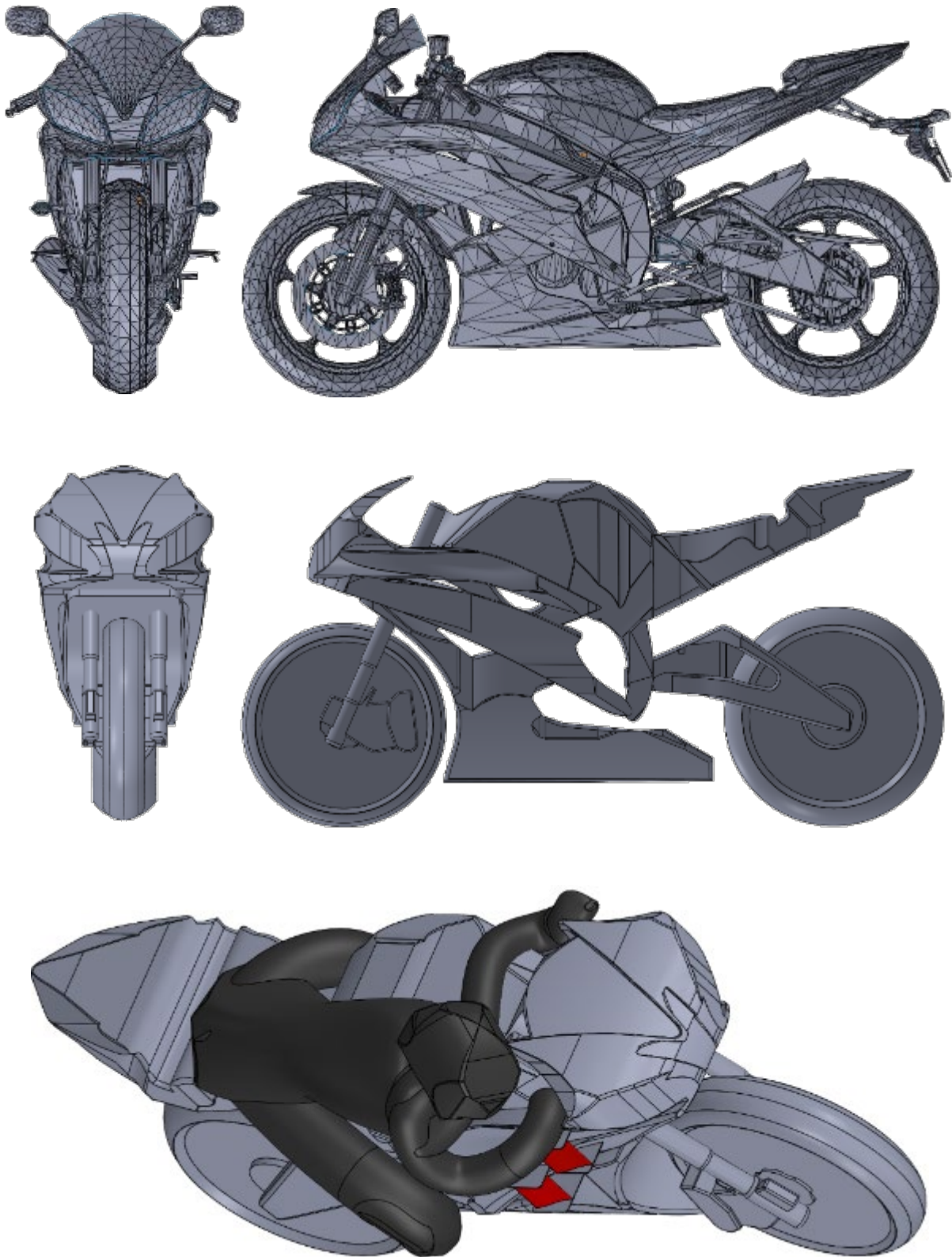
Appendices

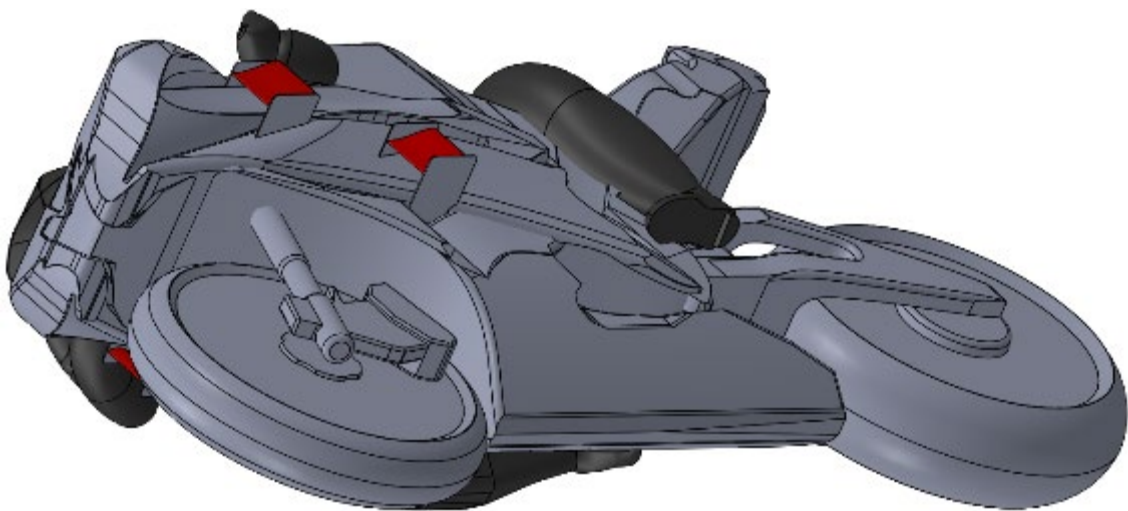
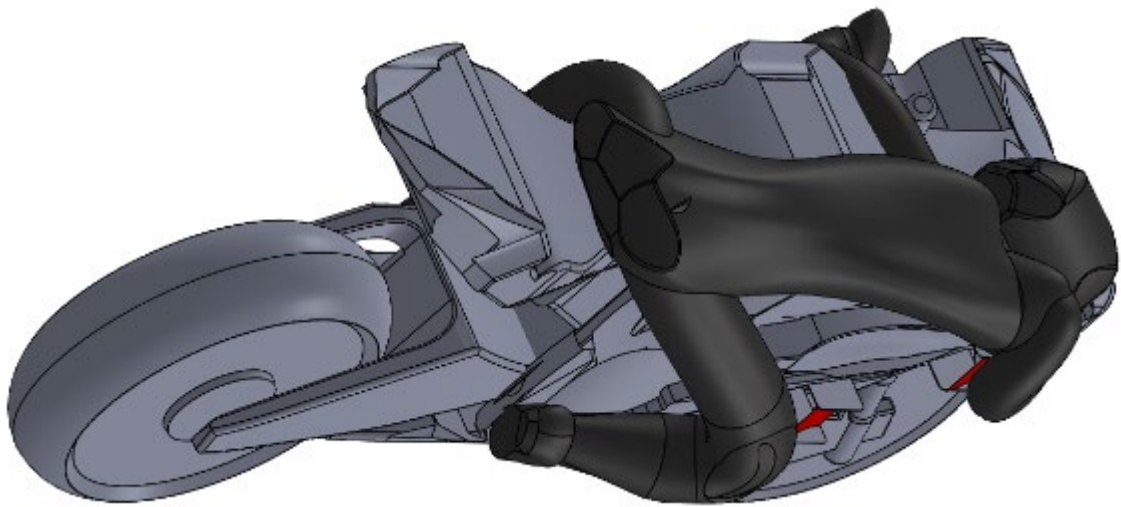
A1



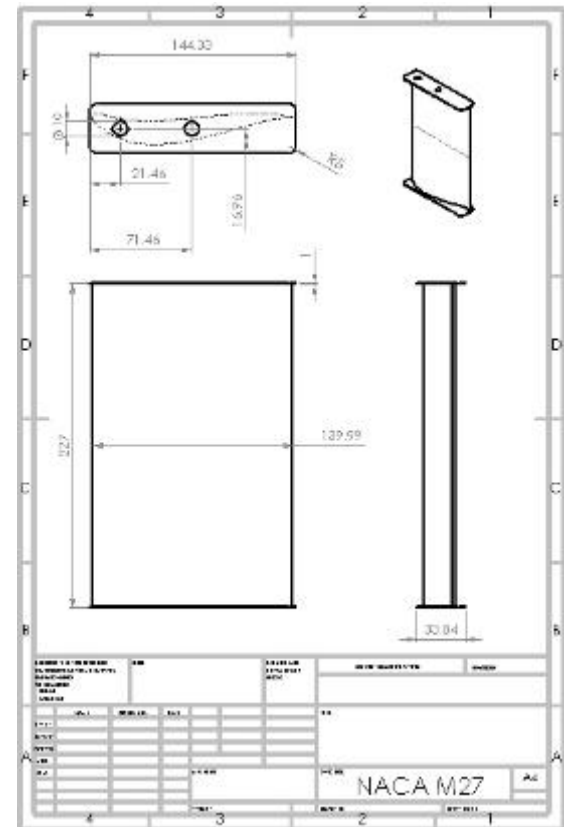
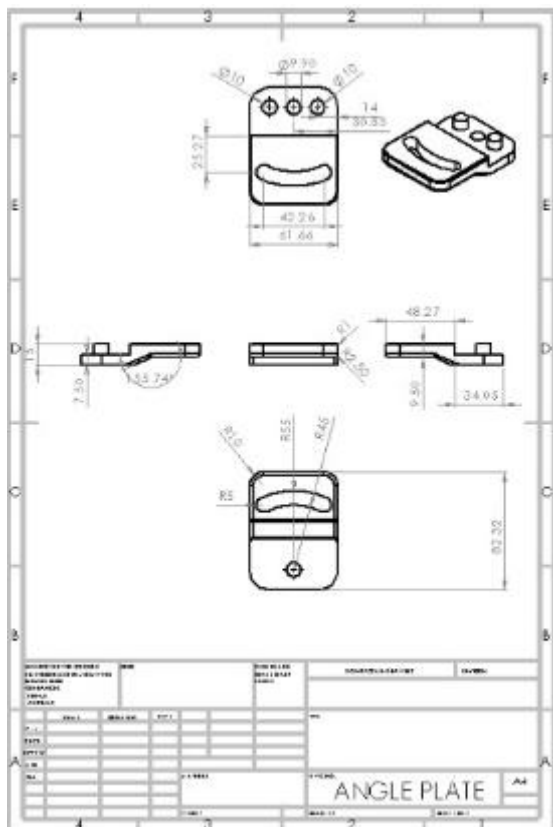
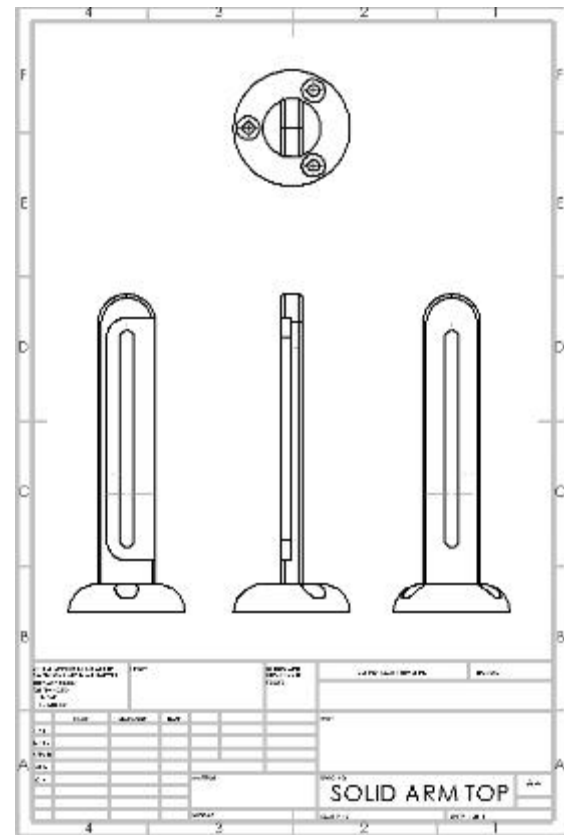
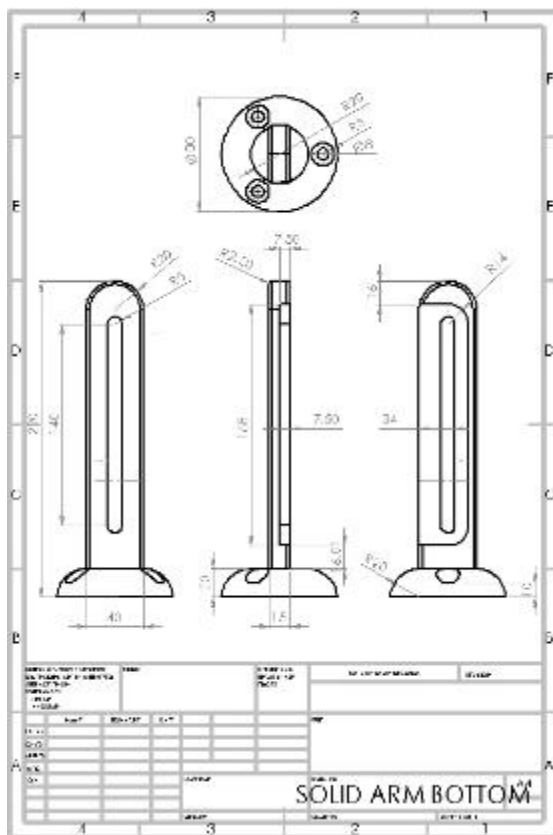
SIM #	NOTES	MODEL	Wing	WING DISTANCE FROM FL (mm)	WING DISTANCE FROM NL (mm)	Wing A (degrees from vertical)	WING DISTANCE FROM CL (mm)	WING LENGTH (mm)	FD (in)	FL (in)	CD	CL	IMPROVEMENT Force reduction (%)
0		Standard	none	-	-	-	-	-	553.32	337.7	0.0572	0.4071	
1		NACA M27 - GEOM 1	#1	250	80	0	270	100	165.07	115.4	0.0665	0.4179	34.977886
2		NACA M27 - GEOM 2	#1	300	80	0	270	100	160.38	112.56	0.0582	0.3031	29.537506
3		NACA M27 - GEOM 3	#1	350	80	0	270	100	161.96	88.71	0.002	0.3235	22.527038
4		NACA M27 - GEOM 4	#1	400	80	0	270	100	160.96	95.497	0.003	0.3583	16.520663
5		NACA M27 - GEOM 5	#1	450	80	0	270	100	161.94	98.657	0.0042	0.3662	15.620663
6		NACA M27 - GEOM 6	#1	500	-100	0	270	100	163.49	97.457	0.0002	0.3631	15.007778
7		NACA M27 - GEOM 7	#1	550	-100	0	270	100	164.06	99.324	0.004	0.3722	11.87345
8		NACA M27 - GEOM 8	#1	600	-100	0	270	100	163.38	94.785	0.0066	0.3529	18.46178
9		NACA M27 - GEOM 9	#1	650	-100	0	270	100	160.47	95.964	0.0077	0.3574	20.4648
10		NACA M27 - GEOM 10	#1	700	-100	0	270	100	162.47	102.26	0.006	0.3814	11.87382
11		NACA M27 - GEOM 11	#1	700	-100	10	270	100	160.38	81.25	0.0062	0.3031	34.977886
12		NACA M27 - GEOM 12	#1	700	-100	20	270	100	164.79	94.371	0.014	0.3501	17.435634
13		NACA M27 - GEOM 13	#1	700	-100	30	270	100	163.47	92.882	0.007	0.3457	20.456365
14		NACA M27 - GEOM 14	#1	600	-100	40	280	100	164.79	94.371	0.014	0.3501	17.435634
15		NACA M27 - GEOM 15	#1	700	-100	50	290	100	163.08	85.124	0.0062	0.3175	28.450365
16		NACA M27 - GEOM 16	#1	700	-100	60	300	100	168.68	92.853	0.027	0.3458	17.275084
17		NACA M27 - GEOM 17	#1	700	-100	70	310	100	167.05	91.076	0.023	0.3397	18.47618
18		NACA M27 - GEOM 18	#1	700	-100	80	320	100	168.49	97.752	0.028	0.3676	10.395067
19		NACA M27 - GEOM 19	#1	250	80	0	270	100	168.33	92.638	0.026	0.343	15.653659
19		NACA M27 - GEOM 19	#2	450	-100	0	240	100	162.86	100.76	0.0048	0.3753	13.66065
19		NACA M27 - GEOM 19	#3	-	-	-	-	-	165.5	105.6	0.057	0.3923	5.43716
20		NACA M27 - GEOM 20	#1	250	80	10	270	100	164.95	96.69	0.071	0.3271	24.354561
21		NACA M27 - GEOM 21	#1	450	-100	0	250	100	164.95	96.69	0.071	0.3271	24.354561
21		NACA M27 - GEOM 21	#2	250	80	15	270	100	164.95	96.69	0.071	0.3271	24.354561
22		NACA M27 - GEOM 22	#1	350	80	0	270	100	170.39	122.36	0.0276	0.4507	-18.76425
22		NACA M27 - GEOM 22	#2	600	-100	0	270	100	168.83	106	0.0268	0.3929	17.7862
23		NACA M27 - GEOM 23	#1	350	80	10	270	100	165.43	105.22	0.035	0.39	5.99922
24		NACA M27 - GEOM 24	#1	250	80	10	270	100	168.57	108.36	0.0225	0.4038	-1.32751
25		NACA M27 - GEOM 25	#1	250	80	5	270	100	166.36	102.63	0.0163	0.3902	7.97897
26		NACA M27 - GEOM 26	#1	250	80	5	270	100	164.39	101.29	0.0086	0.375	10.50428
27		NACA M27 - GEOM 27	#1	250	80	10	270	100	164.39	103.57	0.0197	0.3876	8.47326

A4





A5



A6

Run No.	No. Elements	No. Nodes	Max Element Size	Min Element Size	Max No. Across Gap
1	1925004	2898940	250	1	5
2	1905196	2868119	250	1	5
3	1905196	2868119	250	1	5
4	1905196	2868119	250	1	5
5	1905196	2868119	250	1	5
6	1905196	2868119	250	1	5
7	1925004	2898940	250	1	5
8	1831784	2804964	250	1	5
9	1912191	2773568	250	1	5
10	1911228	2824248	250	1	5
11	1602581	2452110	250	1	5
12	2330913	3454501	250	1	5
13	1607482	2358133	250	1	5

Run No.	Growth Rate	Inflation layers		Iterations	Method	Viscous Model	Wall Function
		Geometry	Domain				
1	1.2	5	5	600	Coupled	R K - Epsilon	NE
2	1.2	5	5	600	Coupled	R K - Epsilon	NE
3	1.2	5	5	600	Simple	R K - Epsilon	NE
4	1.2	5	5	600	Coupled	R K - Epsilon	Scalable
5	1.2	5	5	600	Coupled	R K - Epsilon	Standard
6	1.2	5	5	600	Coupled	K - Omega	N/A
7	1.2	5	5	600	Coupled	SST	N/A
8	1.2	6	6	600	Coupled	R K - Epsilon	NE
9	1.2	3	3	600	Coupled	R K - Epsilon	NE
10	1.2	4	4	600	Coupled	R K - Epsilon	NE
11	1.2	5	5	400	Coupled	R K - Epsilon	NE
12	1.2	5	5	400	Coupled	R K - Epsilon	NE
13	1.2	3	3	400	Coupled	R K - Epsilon	NE

Run No.	Results		
	CI % Accuracy	Cd% Accuracy	AVG% Accuracy.
1	11.26086957	3.177257525	7.219063545
2	1.55942029	2.35451505	1.95696767
3	16.68695652	17.67558528	17.1812709
4	3.179710145	0.324414716	1.75206243
5	2.605797101	0.401337793	1.503567447
6	3.469565217	1.240802676	2.355183946
7	14.77971014	4.528428094	9.654069119
8	3.055072464	2.096989967	2.576031215
9	1.669565217	1.936454849	1.803010033
10	1.562318841	1.983277592	1.772798216
11	0.31884058	2.157190635	1.238015608
12	0.397101449	2.214046823	1.305574136
13	1.426086957	1.558528428	1.492307692
14	8657	354.5	4505.75

A7

Methodology Stage	Notes	Model Run	Domain Element Size (m)	Wakebox Element Size (m)	Underbox Element Size (m)	Face Sizing (m)		No. of Elements	No. of Nodes	Body of Influence (BOI)				Underbody base	Wake box	Growth Rate	No. of Iteration Layers
						Long	Absurd			H	L	W	L from absurd (m)				
Flux stage - Vary isos model, scheme + wall function		Original	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
		2	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
		3	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
		4	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
		5	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
		6	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
		7	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
		8	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
		9	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
		10	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
Meshing stage - vary element size	v element size 30%	11	1.00E-03	7.00E-04	7.00E-04	1.40E-03	7.00E-03	5,030,014	1,026,413	0.5	2.5	0.35	1.044	Y	Y	1.2	5
	w element size 30%	12	1.49E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	1,040,790	242,870	0.5	2.5	0.35	1.044	Y	Y	1.2	5
	h inflation to 0	13	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	1,955,735	473,617	0.5	2.5	0.35	1.044	Y	Y	1.2	9
	v inflation to 1	14	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,770	396,515	0.5	2.5	0.35	1.044	Y	Y	1.2	1
Domain Geometry to increase bodies of influence	h domains by 30%	15	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	3,029,537	412,438	0.5	2.5	0.35	1.044	Y	Y	1.2	5
	v domains by 30%	16	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	1,890,827	423,402	0.5	2.5	0.35	1.044	Y	Y	1.2	5
	No under and wake box. No BOI	17	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	1,633,757	359,420	0.5	2.5	0.35	1.044	N	N	1.2	5
No. of iterations needed to converge		18	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	608,990	172,525	-	-	-	-	N	N	1.2	5
		19	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
		20	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
		21	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
Start Angle - 35°		22	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,039,335	428,177	0.5	2.5	0.35	1.044	Y	Y	1.2	5
	Run with best 25° setup	23	1.50E-03	1.00E-03	1.00E-03	2.00E-03	1.00E-02	2,035,414	427,451	0.5	2.5	0.35	1.044	Y	Y	1.2	5

Viscous Model or turbulence model	Wall Function	No. of Iterations	Solver	Velocity of Inlet (m/s)	Start Angle (degrees)	Cd	Ct
R k-epsilon	Non-Equilibrium	600	Coupled	20	25	0.24054	0.35813
S k-epsilon	Non-Equilibrium	600	Coupled	20	25	0.31761	0.37305
S k-omega	Non-Equilibrium	600	Coupled	20	25	0.25860	0.38029
k-omega SST	-	600	Coupled	20	25	0.24927	0.33384
RSM	Non-Equilibrium	600	Coupled	20	25	0.27885	0.30665
R k-epsilon	Standard Wall	600	Coupled	20	25	0.2394	0.25802
R k-epsilon	Scalable Wall	600	Coupled	20	25	0.25805	0.38065
R k-epsilon	Non-Equilibrium	600	Simple	20	25	0.31433	0.31561
R k-epsilon	Non-Equilibrium	600	Simple	20	25	F.T.C	F.T.C
R k-epsilon	Non-Equilibrium	600	FSO	20	25	I.L.C	I.L.C
R k-epsilon	Standard Wall	300	Coupled	20	25	0.30198	0.35856
R k-epsilon	Standard Wall	300	Coupled	20	25	0.30600	0.35153
R k-epsilon	Standard Wall	300	Coupled	20	25	0.30453	0.36774
R k-epsilon	Standard Wall	300	Coupled	20	25	0.30558	0.35555
R k-epsilon	Standard Wall	300	Coupled	20	25	0.30347	0.36158
R k-epsilon	Standard Wall	300	Coupled	20	25	0.31781	0.3692
R k-epsilon	Standard Wall	300	Coupled	20	25	0.35025	0.30504
R k-epsilon	Standard Wall	300	Coupled	20	25	0.4201	0.30838
k-omega SST	-	500	Coupled	20	25	0.26807	0.30661
k-omega SST	-	550	Coupled	20	25	0.25049	0.3143
k-omega SST	-	650	Coupled	20	25	0.25054	0.34257
k-omega SST	-	700	Coupled	20	25	0.30233	0.34752
R k-epsilon	Standard Wall	600	Coupled	20	35	0.32604	0.25074

Global Project Overview - Q3 2024												
Project Details		Financials			Operational Metrics			Compliance & Risk			Reporting	
ID	Name	Budget (USD)	Actual (USD)	Variance (%)	Progress (%)	Quality Score	Defect Rate	Audit Status	Risk Level	Last Update	Owner	
001	Alpha Initiative	1,200,000	1,150,000	4.2%	85%	92	0.5%	Compliant	Low	2024-09-15	John Doe	
002	Beta Initiative	800,000	820,000	2.5%	70%	88	0.8%	Minor Issues	Medium	2024-09-10	Jane Smith	
003	Gamma Initiative	500,000	480,000	4.0%	90%	95	0.2%	Compliant	Low	2024-09-18	Mike Chen	
004	Delta Initiative	300,000	310,000	3.3%	60%	85	1.0%	Needs Review	Medium	2024-09-12	Sarah Lee	
005	Epsilon Initiative	200,000	190,000	5.0%	95%	98	0.1%	Compliant	Low	2024-09-16	David Kim	
006	Zeta Initiative	150,000	160,000	6.7%	50%	80	1.5%	Significant Issues	High	2024-09-08	Emily White	
007	Eta Initiative	100,000	95,000	5.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Chris Brown	
008	Theta Initiative	75,000	78,000	4.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-11	Alex Green	
009	Iota Initiative	50,000	48,000	4.0%	90%	95	0.2%	Compliant	Low	2024-09-17	Nina Black	
010	Kappa Initiative	25,000	26,000	4.0%	60%	80	0.9%	Needs Review	Medium	2024-09-09	Sam Blue	
011	Lambda Initiative	15,000	14,000	6.7%	80%	90	0.3%	Compliant	Low	2024-09-13	Rachel Red	
012	Mu Initiative	10,000	11,000	10.0%	50%	75	1.2%	Significant Issues	High	2024-09-07	Kevin Purple	
013	Nu Initiative	5,000	4,500	10.0%	90%	95	0.2%	Compliant	Low	2024-09-15	Liam Yellow	
014	Xi Initiative	3,000	3,200	6.7%	70%	85	0.6%	Minor Issues	Medium	2024-09-12	Mia Pink	
015	Omicron Initiative	2,000	1,800	10.0%	95%	98	0.1%	Compliant	Low	2024-09-16	Noah Grey	
016	Pi Initiative	1,500	1,600	6.7%	60%	80	0.9%	Needs Review	Medium	2024-09-09	Olivia Cyan	
017	Rho Initiative	1,000	950	5.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Peter Magenta	
018	Sigma Initiative	750	780	4.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-11	Quinn Olive	
019	Tau Initiative	500	480	4.0%	90%	95	0.2%	Compliant	Low	2024-09-17	Ryan Teal	
020	Upsilon Initiative	250	260	4.0%	60%	80	0.9%	Needs Review	Medium	2024-09-08	Sophia Gold	
021	Phi Initiative	150	140	6.7%	80%	90	0.3%	Compliant	Low	2024-09-13	Thomas Silver	
022	Chi Initiative	100	110	10.0%	50%	75	1.2%	Significant Issues	High	2024-09-07	Uma Bronze	
023	Psi Initiative	50	45	10.0%	90%	95	0.2%	Compliant	Low	2024-09-15	Victor Copper	
024	Omega Initiative	30	32	6.7%	70%	85	0.6%	Minor Issues	Medium	2024-09-12	Wendy Nickel	
025	Unlabeled	20	21	5.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Xavier Zinc	
026	Unlabeled	15	16	6.7%	60%	80	0.9%	Needs Review	Medium	2024-09-09	Yara Tin	
027	Unlabeled	10	9	10.0%	95%	98	0.1%	Compliant	Low	2024-09-16	Zoe Lead	
028	Unlabeled	5	6	20.0%	50%	70	1.5%	Significant Issues	High	2024-09-05	Adam Platinum	
029	Unlabeled	3	3	0.0%	80%	90	0.3%	Compliant	Low	2024-09-13	Eve Silver	
030	Unlabeled	2	2	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-11	Frank Gold	
031	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-17	Grace Copper	
032	Unlabeled	1	1	0.0%	60%	80	0.9%	Needs Review	Medium	2024-09-08	Henry Nickel	
033	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Ivy Zinc	
034	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-12	Jack Tin	
035	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-16	Karen Lead	
036	Unlabeled	1	1	0.0%	50%	75	1.2%	Significant Issues	High	2024-09-06	Liam Platinum	
037	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-13	Mia Silver	
038	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-11	Noah Gold	
039	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-17	Nora Copper	
040	Unlabeled	1	1	0.0%	60%	80	0.9%	Needs Review	Medium	2024-09-08	Oliver Nickel	
041	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Peter Zinc	
042	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-12	Quinn Tin	
043	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-16	Ryan Lead	
044	Unlabeled	1	1	0.0%	50%	75	1.2%	Significant Issues	High	2024-09-06	Sarah Platinum	
045	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-13	Thomas Silver	
046	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-11	Uma Gold	
047	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-17	Victor Copper	
048	Unlabeled	1	1	0.0%	60%	80	0.9%	Needs Review	Medium	2024-09-08	Wendy Nickel	
049	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Xavier Zinc	
050	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-12	Yara Tin	
051	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-16	Zoe Lead	
052	Unlabeled	1	1	0.0%	50%	75	1.2%	Significant Issues	High	2024-09-06	Adam Platinum	
053	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-13	Eve Silver	
054	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-11	Frank Gold	
055	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-17	Grace Copper	
056	Unlabeled	1	1	0.0%	60%	80	0.9%	Needs Review	Medium	2024-09-08	Henry Nickel	
057	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Ivy Zinc	
058	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-12	Jack Tin	
059	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-16	Karen Lead	
060	Unlabeled	1	1	0.0%	50%	75	1.2%	Significant Issues	High	2024-09-06	Liam Platinum	
061	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-13	Mia Silver	
062	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-11	Noah Gold	
063	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-17	Nora Copper	
064	Unlabeled	1	1	0.0%	60%	80	0.9%	Needs Review	Medium	2024-09-08	Oliver Nickel	
065	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Peter Zinc	
066	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-12	Quinn Tin	
067	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-16	Ryan Lead	
068	Unlabeled	1	1	0.0%	50%	75	1.2%	Significant Issues	High	2024-09-06	Sarah Platinum	
069	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-13	Thomas Silver	
070	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-11	Uma Gold	
071	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-17	Victor Copper	
072	Unlabeled	1	1	0.0%	60%	80	0.9%	Needs Review	Medium	2024-09-08	Wendy Nickel	
073	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Xavier Zinc	
074	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-12	Yara Tin	
075	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-16	Zoe Lead	
076	Unlabeled	1	1	0.0%	50%	75	1.2%	Significant Issues	High	2024-09-06	Adam Platinum	
077	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-13	Eve Silver	
078	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-11	Frank Gold	
079	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-17	Grace Copper	
080	Unlabeled	1	1	0.0%	60%	80	0.9%	Needs Review	Medium	2024-09-08	Henry Nickel	
081	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Ivy Zinc	
082	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-12	Jack Tin	
083	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-16	Karen Lead	
084	Unlabeled	1	1	0.0%	50%	75	1.2%	Significant Issues	High	2024-09-06	Liam Platinum	
085	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-13	Mia Silver	
086	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-11	Noah Gold	
087	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-17	Nora Copper	
088	Unlabeled	1	1	0.0%	60%	80	0.9%	Needs Review	Medium	2024-09-08	Oliver Nickel	
089	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Peter Zinc	
090	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-12	Quinn Tin	
091	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-16	Ryan Lead	
092	Unlabeled	1	1	0.0%	50%	75	1.2%	Significant Issues	High	2024-09-06	Sarah Platinum	
093	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-13	Thomas Silver	
094	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-11	Uma Gold	
095	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-17	Victor Copper	
096	Unlabeled	1	1	0.0%	60%	80	0.9%	Needs Review	Medium	2024-09-08	Wendy Nickel	
097	Unlabeled	1	1	0.0%	80%	90	0.3%	Compliant	Low	2024-09-14	Xavier Zinc	
098	Unlabeled	1	1	0.0%	70%	85	0.6%	Minor Issues	Medium	2024-09-12	Yara Tin	
099	Unlabeled	1	1	0.0%	90%	95	0.2%	Compliant	Low	2024-09-16	Zoe Lead	
100	Unlabeled	1	1	0.0%	50%	75	1.2%	Significant Issues	High	2024-09-06	Adam Platinum	

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