

Amelia Boettcher CFD 1703018

by Amelia Boettcher

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TIME SUBMITTED	28-JAN-2019 01:19AM (UTC+0000)	WORD COUNT	4210
SUBMISSION ID	99891647	CHARACTER COUNT	26329

Aerodynamic Vehicle Testing and Analysis

Computational Fluid Dynamics – M6X00408



ANSYS®

Amelia Boettcher (1703018)

BENG MECHANICAL AND MANUFACTURING ENGINEERING UWTSD

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CFD Techniques

Computational Fluid Dynamics is a dedicated approach for predicting fluid flow and the transfer of heat within a system. It refers to numerical methods which find solutions for intricate 3D time dependent scenarios. Navier-Stokes equations govern the principles of CFD with the backing of physics of fluids. The ANSYS solvers use the Finite Volume method within a mesh and calculates results for each cell created in the software. The aim of this work is to assess the aerodynamic performance of the MIRA reference vehicle demonstrating the use of CFD with ANSYS.

There are two groups of meshing methods, those applying to hexahedral cells and another group for tetrahedral shaped cells. 'Hex' cells can be meshed with Sweep, Multizone, Hex Dominant and CutCell (Fluent only) methods. 'Tet' cell meshing methods are Patch Conforming (Bottom up method) and Patch independent (Top down method). These can be used alone or in parallel to each other to find solutions of intricate geometries (CAE Associates Inc., 2019). Hex methods in general require more effort on the user end to satisfy particular geometric requirements but the mesh created is often more efficient than the alternative. Created elements in this assignment have been solely Tetrahedrons, using the Patch Independent method for its characteristics of the method described later.

MIRA Vehicle

The originally publicly funded company HORIBA MIRA have made several iterations of a reference car inside their full-scale wind tunnel facility as shown in Figure 1, are configured differently over the progressing years. An incredibly simplified design of a car shape is used as a reference for research and correlation. Le Good and Garry (Le Good & Garry, 2004) discuss the use of reference models for Automotive Aerodynamics and their advantages whilst comparing reference cars like the MIRA with the SAE model. For this assignment, the 1996 version will be considered the standard to be referenced and named MIRA. The wind tunnel is capable of aiding aerodynamic development and validation testing as the tunnel has 'guaranteed, repeatable conditions and lower overall developmental costs' (HORIBA MIRA, 2019).



Figure 1 MIRA Reference car, Dickinson M and Haynes T 2011



Figure 2 MIRA Environmental Vehicle Testing, 2015

Domain and Geometry

In Design Modeller, the domain size was chosen after an estimated guess of where areas of interest would occur in the domain, and it was amended once again after the wake regions had been calculated a single time.

Details View	
Details of Sketch1	
Sketch	Sketch1
Sketch Visibility	Show Sketch
Show Constraints?	No
Dimensions: 4	
☐ H1	20 m
☐ H3	20 m
☐ V4	4 m
☐ V5	3.95 m
Edges: 4	
Line	Ln7
Line	Ln8
Line	Ln9
Line	Ln10

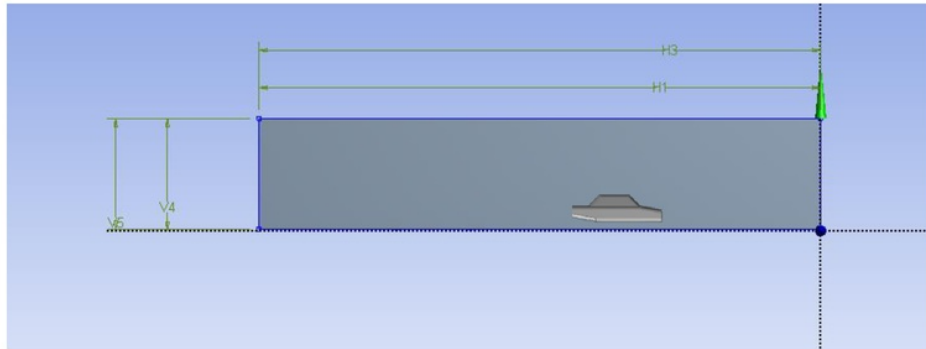


Figure 4 Dimensions of domain

Figure 3 Location of MIRA car in domain

In interview, Tudor (Tudor, 2018) says as a guide, the domain size must accommodate the length of the car three times behind the imported MIRA geometry file to fit in the length of the wake behind it, following this guide has been difficult as evidence of the wake reaching this far despite a high sensitivity in velocity applied shows that it did not reach that far. The MIRA car is as close to a generic 'perfect' car and is assumed to be unoccupied during test in the facilities wind tunnel. This generates the further assumption that the tyres are not compressed under weight and are therefore totally round. As this is not the case in the real world, the tyres in the geometry have been expelled from the domain by 5cm. The domain sizes for the analysis of the MIRA are shown in Figure 2 along with how

the 5cm of tyre compression was made. This in turn will assist in avoiding skewed elements in the mesh once it has been generated. Other means of avoiding skew underneath the wheels is to add 'chocks' either side allowing for bigger elements to form. Figure 3 shows the location of the MIRA within the domain after a Boolean has been created from the MIRA model as a tool and the domain space as the body with a depth of 3m. The depth dimension is to mimic the wind tunnel dimensions as found in the MIRA facility of Test section area of 15m length x 7.9m wide x 4.4m high with a cross sectional frontal area of 35m² (HORIBA MIRA, 2019).

Boundary Conditions

Inside the domain, the symmetry plane, opposite wall, floor and body of the car are treated as a wall (assumed to be 'non-slip') as found in the MIRA wind tunnel testing facility. It is assumed to be atmospheric pressure at approximately the same latitude and altitude. The inlet is located at the front of the MIRA's nose and the outlet is to the rear of the MIRA reference car with the velocity of the air stream being 20m/s coming in the horizontal x direction towards the front of the car.

Mesh and Quality

The Patch Independent method in Workbench was more appealing to use with the supplied MIRA geometry and for air flow analysis around the vehicle. It firstly creates a volume mesh which is then projected to the faces, then to the edges of the geometry in the domain interacting well with the prism layers created on the body. The first rough mesh began as 'All Tri' cells with maximum element size starting at 1m. This with the part setup as shown in Table 1. Features on the MIRA were set to a minimum size of 0.05 to capture relevant data as shown in Table 1 below.

Part	Prism	Hexa-core	Maximum size	Height	Height ratio	Num layers	Tetra size ratio	Tetra width	Min size limit	Max deviation	Prism height limit factor	Prism growth law	Internal wall	Split wall	Passerouter
BODY	✓	✓	0	0	0	0	0	0	0	0	0	undefined	✓	✓	✓
CIELING	✓	✓	0	0	0	0	0	0	0	0	0	undefined	✓	✓	✓
FLOOR	✓	✓	0	0	0	0	0	0	0	0	0	undefined	✓	✓	✓
INLET	✓	✓	0	0	0	0	0	0	0	0	0	undefined	✓	✓	✓
MIRABOTTOM	✓	✓	0.05	0	0	5	0	0	0	0	0	undefined	✓	✓	✓
MIRAROSEFACE	✓	✓	0.05	0	0	5	0	0	0	0	0	undefined	✓	✓	✓
MIRARREARFACE	✓	✓	0.05	0	0	5	0	0	0	0	0	undefined	✓	✓	✓
MIRASIDES	✓	✓	0.05	0	0	5	0	0	0	0	0	undefined	✓	✓	✓
MIRATOP	✓	✓	0.05	0	0	5	0	0	0	0	0	undefined	✓	✓	✓
OPPOSITEWALL	✓	✓	0	0	0	0	0	0	0	0	0	undefined	✓	✓	✓
OUTLET	✓	✓	0	0	0	0	0	0	0	0	0	undefined	✓	✓	✓
SOLID_1	✓	✓	0	0	0	0	0	0	0	0	0	undefined	✓	✓	✓
SYMMETRYPLANE	✓	✓	0	0	0	0	0	0	0	0	0	undefined	✓	✓	✓

Table 1 Part Mesh Setup

After passing a geometry check, the element data was showing that there were not enough elements as expected as shown in Table 2 below. This proves numerically that the max element size needs to be smaller.

Element types :

NODE : 185
 LINE_2 : 1833
 TETRA_4 : 319909
 TRI_3 : 26482
 PENTA_6 : 61007
 QUAD_4 : 1350
 PYRA_5 : 63

Element parts :

BODY : 380979
 CIELING : 1431
 FLOOR : 4334

INLET : 232
 MIRABOTTOM : 3572
 MIRANOSEFACE : 186
 MIRAREARFACE : 441
 MIRASIDES : 1386
 MIRATOP : 6138
 OPPOSITEWALL : 2518
 OUTLET : 231
 SOLID_1_1 : 2018
 SYMMETRYPLANE : 6838
 WHEELS : 525
 Total elements : 410829
 Total nodes : 91616
 Min : -25 0.05 -6.1496e-017
 Max : 10 5 3

Table 2 Element Types

Starting off with five prism layers as shown in Table 1, a generous number to start with seemed to work well and was continued on to further iterations of the mesh. They provided enough data for the velocities along the surfaces without running into computer memory problems.

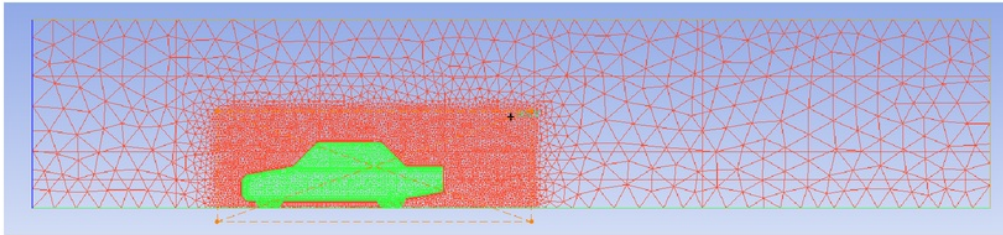


Figure 5 Mesh showing location of density boxes

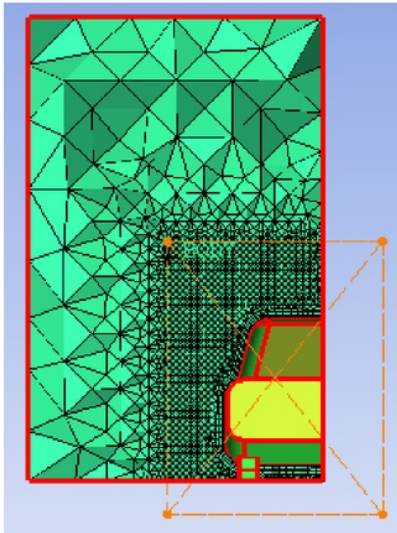


Figure 6 Cut of Mesh displaying location of density box

A density box was applied around the car and scaled up but moved to the rear in an attempt to capture data from the generated wake regions. A body point has been placed in the centre to make sure the software identifies the centre of the domain as the area to fill with elements that are more angular. The upsides of the Top Down meshing approach are beginning to show, as the mesh tents to 'pave over' edges with a well-structured mesh. The downsides are that it does not provide solutions to the differential Navier Stokes equations.

The profile of the volume mesh is shown in Figure 6, with ample space inside the density box to catch any traversing eddy currents being propelled out to the sides of the MIRA car.

Histograms of orthogonal quality and skew of the first mesh is not optimal, however satisfactory to achieve convergence. With 55% of elements being between 0.9-

0.95 and a mean of 0.89, global refinements would improve this globally. After a change of max element size to 0.75, better orthogonal quality data was found. The before and after of this change is shown in the Table 3 below.

<u>Max Element 1</u>	<u>Max Element 0.75</u>
Min = 0.291239, max = 1, mean = 0.891844928927	Min = 0.140812, max = 1, mean = 0.916794124965
424141 elements with the "Orthogonal Quality" diagnostic	1093168 elements with the "Orthogonal Quality" diagnostic
Histogram of Orthogonal Quality values	Histogram of Orthogonal Quality values
0.95 -> 1.0 : 33213 (7.831%)	0.95 -> 1.0 : 54785 (5.012%)
0.9 -> 0.95 : 231556 (54.594%)	0.9 -> 0.95 : 812838 (74.356%)
0.85 -> 0.9 : 52210 (12.310%)	0.85 -> 0.9 : 80152 (7.332%)
0.8 -> 0.85 : 46874 (11.052%)	0.8 -> 0.85 : 62928 (5.756%)
0.75 -> 0.8 : 24244 (5.716%)	0.75 -> 0.8 : 29319 (2.682%)
0.7 -> 0.75 : 16259 (3.833%)	0.7 -> 0.75 : 22976 (2.102%)
0.65 -> 0.7 : 9161 (2.160%)	0.65 -> 0.7 : 11909 (1.089%)
0.6 -> 0.65 : 5276 (1.244%)	0.6 -> 0.65 : 7649 (0.700%)
0.55 -> 0.6 : 3788 (0.893%)	0.55 -> 0.6 : 5643 (0.516%)
0.5 -> 0.55 : 1199 (0.283%)	0.5 -> 0.55 : 2476 (0.226%)
0.45 -> 0.5 : 313 (0.074%)	0.45 -> 0.5 : 1291 (0.118%)
0.4 -> 0.45 : 31 (0.007%)	0.4 -> 0.45 : 605 (0.055%)
0.35 -> 0.4 : 10 (0.002%)	0.35 -> 0.4 : 282 (0.026%)
0.3 -> 0.35 : 6 (0.001%)	0.3 -> 0.35 : 146 (0.013%)
0.25 -> 0.3 : 1 (0.000%)	0.25 -> 0.3 : 99 (0.009%)
0.2 -> 0.25 : 0 (0.000%)	0.2 -> 0.25 : 48 (0.004%)
0.15 -> 0.2 : 0 (0.000%)	0.15 -> 0.2 : 21 (0.002%)
0.1 -> 0.15 : 0 (0.000%)	0.1 -> 0.15 : 1 (0.000%)
0.05 -> 0.1 : 0 (0.000%)	0.05 -> 0.1 : 0 (0.000%)
0.0 -> 0.05 : 0 (0.000%)	0.0 -> 0.05 : 0 (0.000%)
Quality metrics criterion: Orthogonal Quality (Min 0.291239 Max 1)	Quality metrics criterion: Orthogonal Quality (Min 0.140812 Max 1)

Table 3 Orthogonal Quality

Skew results were mirrored the orthogonal quality improvements with a 3.84% reduction in skewed elements in the mesh from the same change as shown in Table 4 below.

<u>Max Element 1</u>	<u>Max Element 0.75</u>
Min = 0.221309, max = 1, mean = 0.927639866617	Min = 0.174827, max = 1, mean = 0.923100339088
26990 elements with the "Skew" diagnostic	25952 elements with the "Skew" diagnostic
397151 elements for which this diagnostic is undefined	1067216 elements for which this diagnostic is undefined
Histogram of Skew values	Histogram of Skew values
0.95 -> 1.0 : 15267 (3.600%)	0.95 -> 1.0 : 13098 (1.198%)
0.9 -> 0.95 : 5523 (1.302%)	0.9 -> 0.95 : 6042 (0.553%)
0.85 -> 0.9 : 2663 (0.628%)	0.85 -> 0.9 : 3049 (0.279%)
0.8 -> 0.85 : 1242 (0.293%)	0.8 -> 0.85 : 1448 (0.132%)
0.75 -> 0.8 : 738 (0.174%)	0.75 -> 0.8 : 1167 (0.107%)
0.7 -> 0.75 : 496 (0.117%)	0.7 -> 0.75 : 488 (0.045%)
0.65 -> 0.7 : 427 (0.101%)	0.65 -> 0.7 : 260 (0.024%)
0.6 -> 0.65 : 273 (0.064%)	0.6 -> 0.65 : 147 (0.013%)
0.55 -> 0.6 : 156 (0.037%)	0.55 -> 0.6 : 109 (0.010%)
0.5 -> 0.55 : 100 (0.024%)	0.5 -> 0.55 : 55 (0.005%)
0.45 -> 0.5 : 65 (0.015%)	0.45 -> 0.5 : 31 (0.003%)
0.4 -> 0.45 : 28 (0.007%)	0.4 -> 0.45 : 28 (0.003%)
0.35 -> 0.4 : 6 (0.001%)	0.35 -> 0.4 : 14 (0.001%)
0.3 -> 0.35 : 0 (0.000%)	0.3 -> 0.35 : 12 (0.001%)
0.25 -> 0.3 : 4 (0.001%)	0.25 -> 0.3 : 3 (0.000%)
0.2 -> 0.25 : 2 (0.000%)	0.2 -> 0.25 : 0 (0.000%)
0.15 -> 0.2 : 0 (0.000%)	0.15 -> 0.2 : 1 (0.000%)
0.1 -> 0.15 : 0 (0.000%)	0.1 -> 0.15 : 0 (0.000%)
0.05 -> 0.1 : 0 (0.000%)	0.05 -> 0.1 : 0 (0.000%)
0.0 -> 0.05 : 0 (0.000%)	0.0 -> 0.05 : 0 (0.000%)
Quality metrics criterion: Skew (Min 0.221309 Max 1)	Quality metrics criterion: Skew (Min 0.174827 Max 1)

Table 4 Skew Quality

Results

The anticipated results for the coefficient of drag and lift generated are not expected to match that of the brief. This is down to lack of experience in the software and ability to perform the intended tasks. The improvement of air flow past the MIRA reference car within the wind tunnel should influence many factors in the real world. Fuel consumption can be improved by decreasing the drag, the car can be more comfortable with less noise caused by turbulence, better ventilation and passenger cooling.

The K Epsilon turbulence model has been relied upon here to be consistent and effective at calculating solutions for this case and in the future for when a geometric change is applied. It is a common turbulence model with the first transported variable of turbulent kinetic energy, K . The rate of dissipation energy, Epsilon, ϵ , is the second transported variable. For this model to work as intended, the assumption that turbulent viscosity is isotropic, with the same rate of deformation in all directions (Wilcox, 1998).

After 500 iterations in the solver, the software had converged at a solution at 245 iterations. The lines of C_d and C_l are not levelling out; therefore, one cannot instil complete trust in the results and must be treated as approximate values instead.

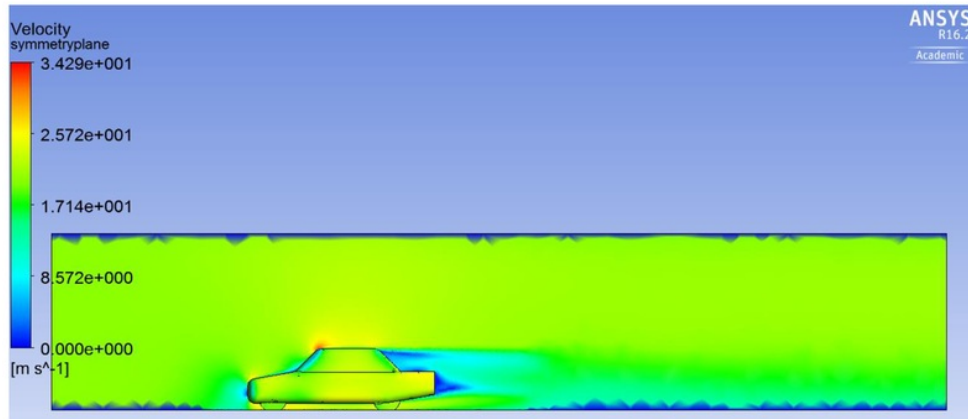
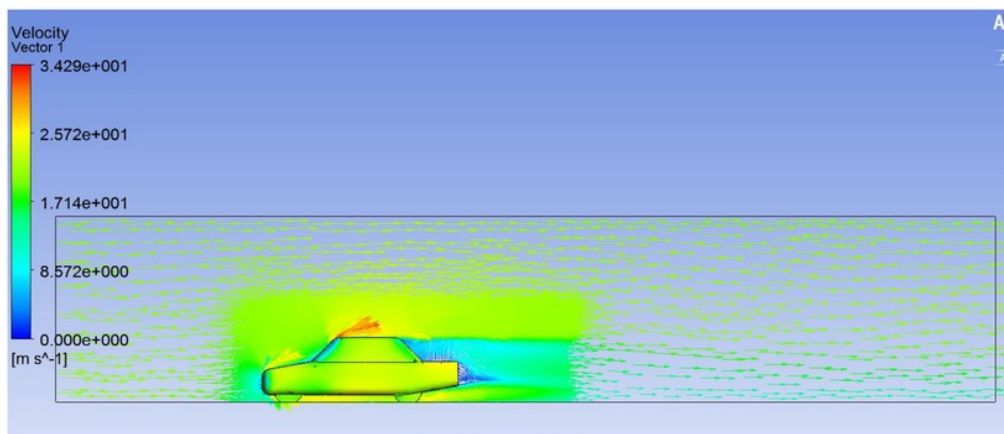
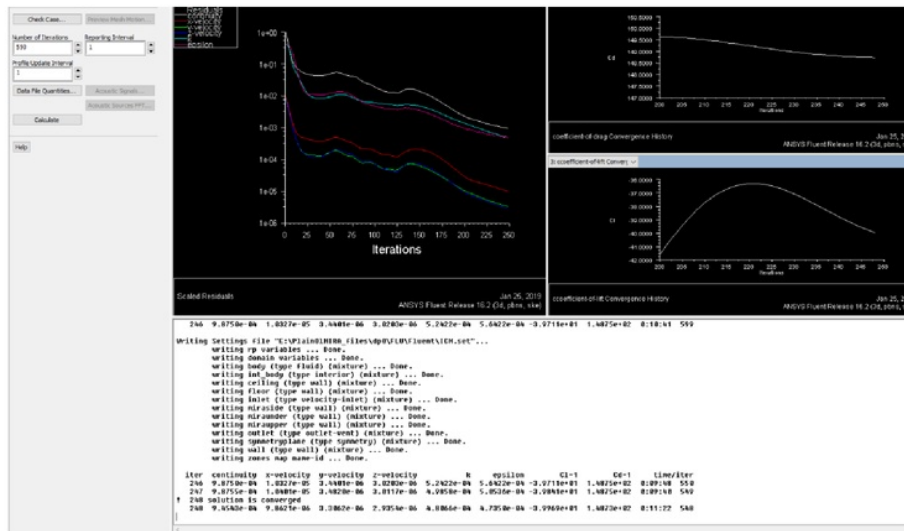


Figure 7 Velocity Shown in Symmetry plane



It would have been more advantageous to thin out the vector arrows in Figure 9 to clearly see where the boundary layer separation occurs in front of the car. Therefore, one must estimate where it occurred using the same image but zoomed in. The red circle is the area that one believes is the point where boundary layer separation occurs which is apparently lower down the nose than the expected central area.

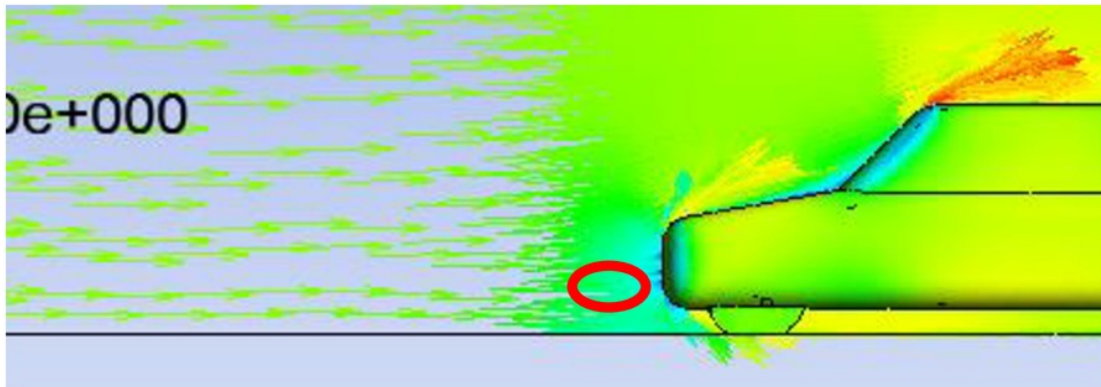


Figure 10 Boundary layer Split

There were no boundary layer separation bubbles formed in unexpected regions in the calculations of this car, this is because all the surfaces are incredibly smooth and rounded as to not cause this. Naturally, small regions behind the boot of the car show regions of separation happening at ambient pressure beneath the areas of turbulent mixing.

Figure 10 shows the airflow path in red of the highest velocity areas are above the cars roof underneath which are areas of green free stream velocity indicating that there could be a boundary layer separation bubble located there.

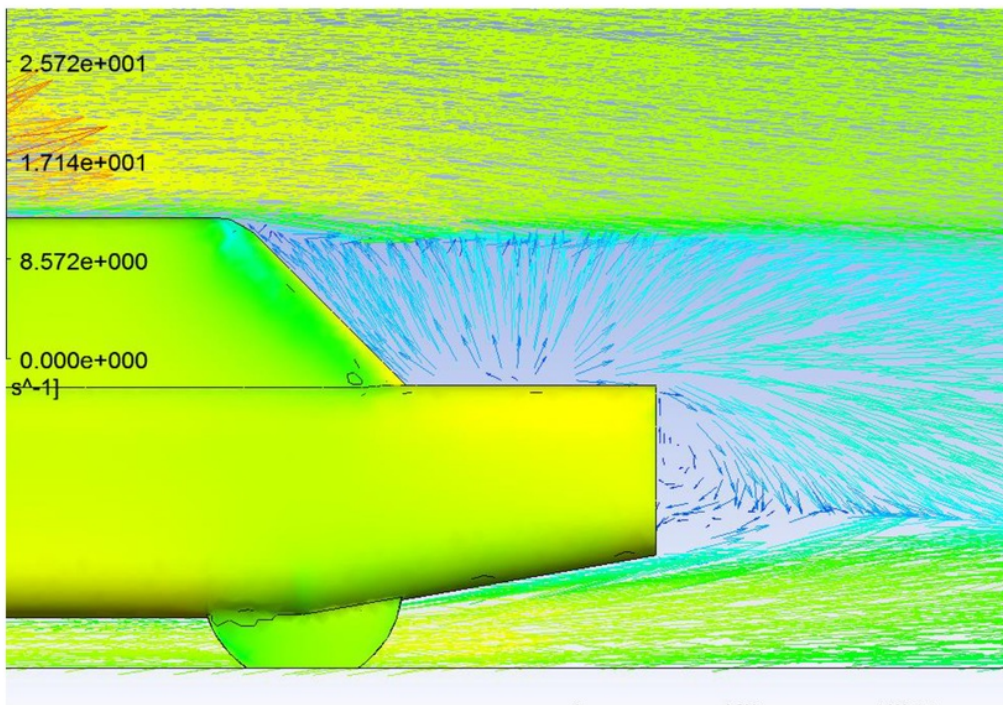


Figure 11 Turbulence in Vectors

This shows the effect of the viscous flow due to the shear stresses from the air 'sticking' to the cars surfaces. When the car is mirrored on its symmetry plane, the flow field around the sides of the car

are not expected to be symmetrical at the very rear end face of the car due to the interactions of multiple higher-pressure areas moving molecules towards each other accelerating some particles and not others. It was an oversight not to take a screen shot and prove this using sensitive tolerances with vectors of velocity.

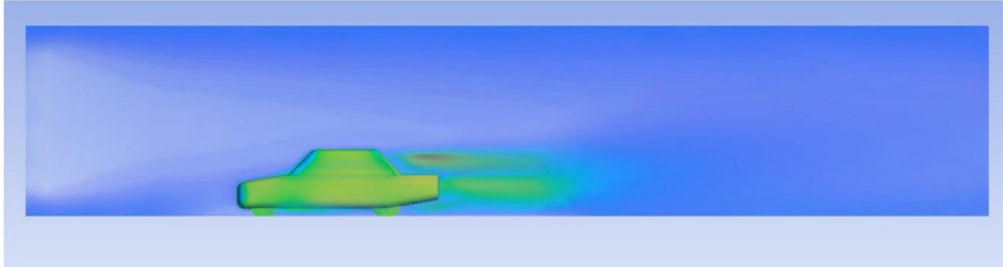


Figure 12 Forces

The stagnation points are indicated with areas of high pressure shown in red in Figures 13. A region of higher pressure on the flattest surface (nose of car) is correctly shown being stronger than the lesser red region on the windshield which is down to the resistance against the air flowing perpendicular to the high-pressure regions.

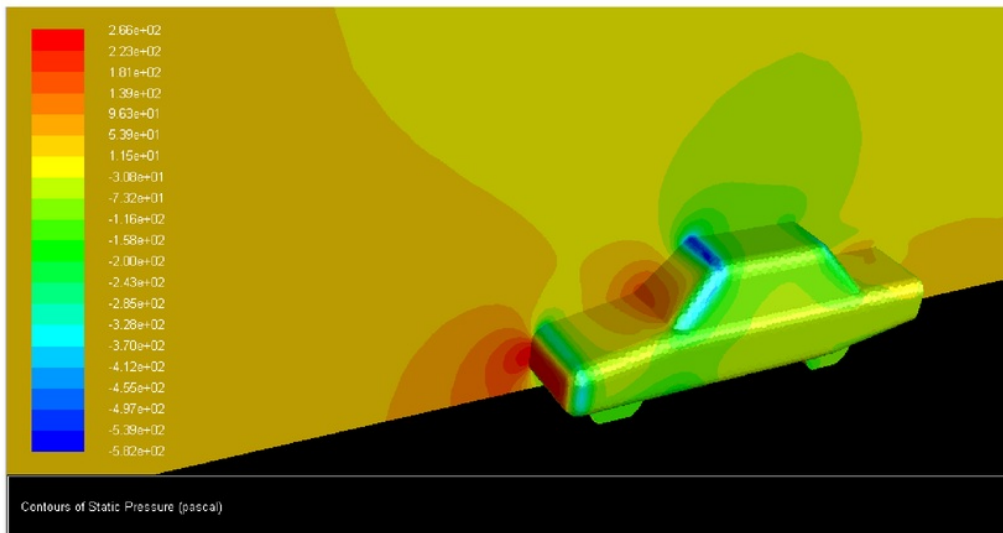


Figure 13 Contours of Static Pressure

The red windshield shown as the region of the highest pressure in Figure 13 shows downforce being applied. Nephograms of the car bodies surface and the symmetry plane have proved to be insightful of the results of the mesh. The area of low pressure at the front roof as shown in dark blue in Figure 13 is the region of the lowest pressure found in the domain. This can lead to an increase in vehicle speed and the decrease of pressure.

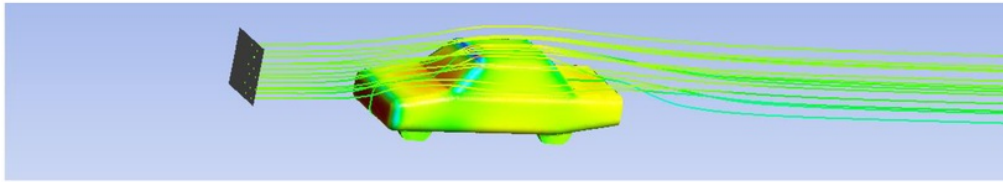


Figure 14 Ribbons showing the flow of air

The streamlines produced over the MIRA where they are curved, show pressure increases perpendicular to them. The lower back blue streamlines in figure 14 shows the free stream air flowing away from the vacuum behind the boot of the car caused by the drag then levelling out again in the wake region.

C_p and C_v

The results of the polyline pressure tap are clearly incomplete with data missing from the lower pressure tap. Comparing Figure 15 to a model Pressure distribution (Tudor, 2018) in Figures 16 the vague shapes and trend of the line can be fairly compared with peaks and dips occurring in similar areas along the x axis. Having the profile image of the MIRA car overlapped behind the pressure tap would stop the viewer having to assume what parts of the car are shown in the lines of the graph.

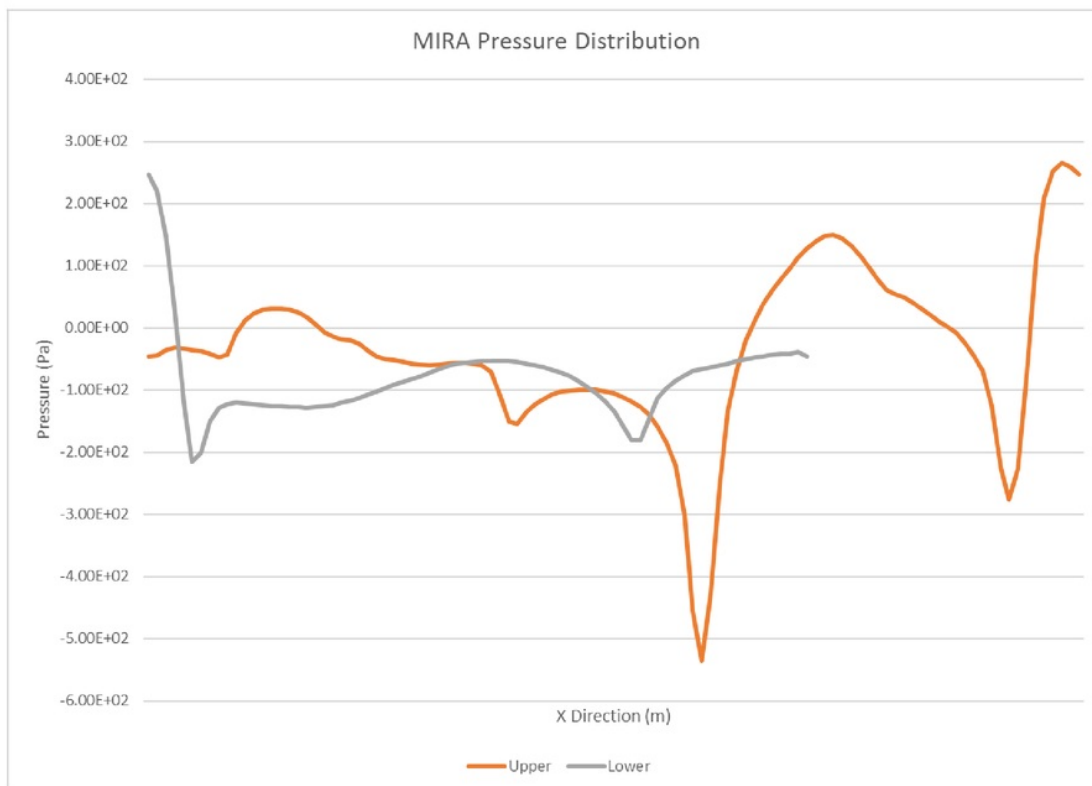


Figure 15 MIRA pressure Distribution

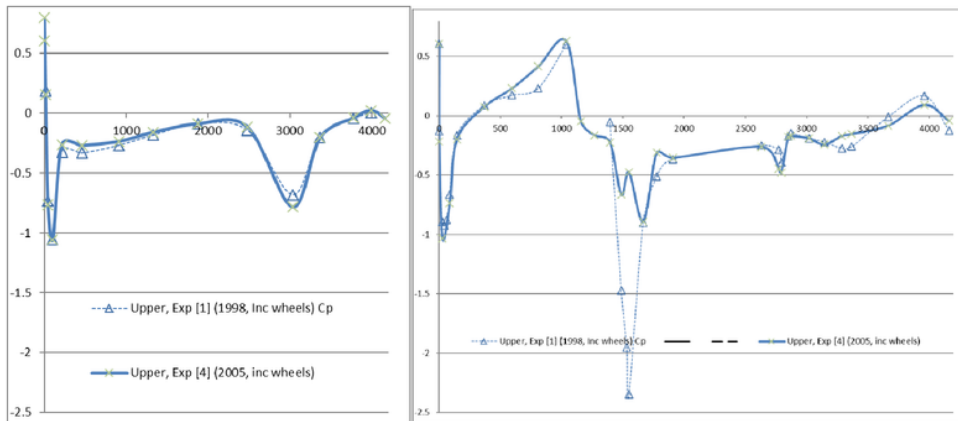


Figure 16 Tudor, T Surface Pressure Rakes Cp Upper surface, 2005

The Lower Pressure surface tap in Figure 15 does in fact show numerically that the front of the car has the highest-pressure region and is the same pressure as the highest pressure on the Upper surface. Negative pressure (vacuum) occurs from a high-pressure area at the front of the car, it then stays in the negative polarity till roof as indicated by the soft 'humped' curve. The extreme low-pressure regions on the Upper surface very clearly shows the area at which the boundary layer separates from the surface of the car. A zero value of pressure coefficient indicates that the local static conditions on the surface is equal to the pressure. Any values under zero display that the pressure is less than static at that point. Pressure coefficient being used as opposed to pressure values allows the aerodynamic performance of each of the models to be compared to each other directly. Pressure values rely entirely on flow velocity, largely the pressure coefficient is independent of speed over a broad range of flow velocities only if the flow pattern is not amended drastically. Body geometry characteristics are the only factors in determining the pressure profile of the MIRA.

Different values for the frontal area of the car are now made apparent from the lack of diligent handling of numbers. This once again makes data more difficult to compare to model data supplied. Normalised data has proven to be essential in this process. But the difference is not that substantial, so it may not affect the outcome.

Reference Values

Area (m2)

Density (kg/m3)

Enthalpy (j/kg)

Length (m)

Pressure (pascal)

Temperature (k)

Velocity (m/s)

Viscosity (kg/m-s)

Ratio of Specific Heats

Reference Values

Area (m2)

Density (kg/m3)

Enthalpy (j/kg)

Length (m)

Pressure (pascal)

Temperature (k)

Velocity (m/s)

Viscosity (kg/m-s)

Ratio of Specific Heats

Figure 17 Reference Values

Force Report		Forces - Direction Vector (1 0 0)					
Zone		Forces (n)			Coefficients		
		Pressure	Viscous	Total	Pressure	Viscous	
ceiling	1.22E-05	56.603989		56.604001	5.46E-08	0.25321016	0.25321
floor	0.002040887	53.363258		53.365299	9.13E-06	0.2387132	0.238722
mirabotto	19.363041	2.4503665		21.813407	0.086617901	0.010961378	0.097579
miranosef	36.559883	-3.60E-08		36.559883	0.16354561	-1.61E-10	0.163546
mirarearf	16.117065	7.80E-08		16.117066	0.072097476	3.49E-10	0.072097
mirasides	-3.0453341	1.0127628		-2.0325713	-0.013622883	0.004530455	-0.00909
miratop	-2.2223377	2.3478241		0.12548637	-0.009941322	0.010502668	0.000561
oppositev	0	90.461105		90.461105	0	0.40466532	0.404665
wheels	11.672615	0.068284221		11.740899	0.052215839	0.00030546	0.052521
Net	78.446986	206.30759		284.75458	0.3509218	0.92288864	1.27381

Figure 18 Force Report

The force report in Figure 18 shows the specific areas on the MIRA reference car that are of interest. The areas of viscous flow turn into a minus value along the MIRA sides according to the report, reasons and the theory behind why that is has not been identified but could be investigated further in the future.

Geometry changes

The changes to the original MIRA geometry are shown in Figure 19. An extruded cut from the top of the car downwards on the boot area has created a cavity. Most other settings remain the same.

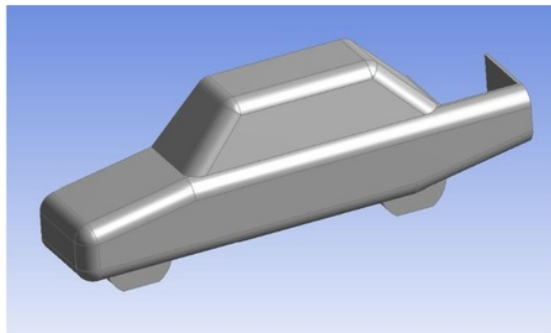


Figure 19 Geometrically amended MIRA

A cut through of the mesh of the geometrically amended MIRA reference car shows the changes made to the domain, the density box was contracted inwards as to concentrate on any disturbances caused by the 'tub' created at the rear of the car in Figures 20 and 21.

The mesh has some unexplained errors appearing on the opposite wall in the domain in Figure 23.

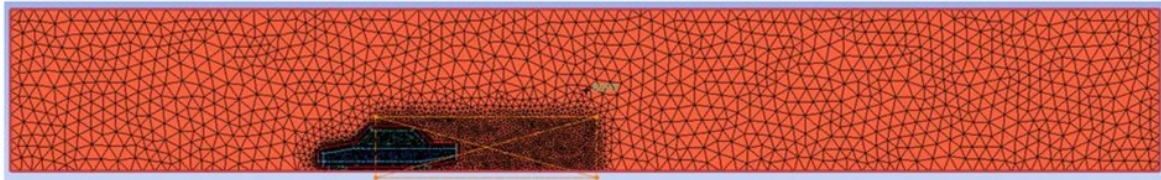


Figure 20 Mesh with alternative location of density box

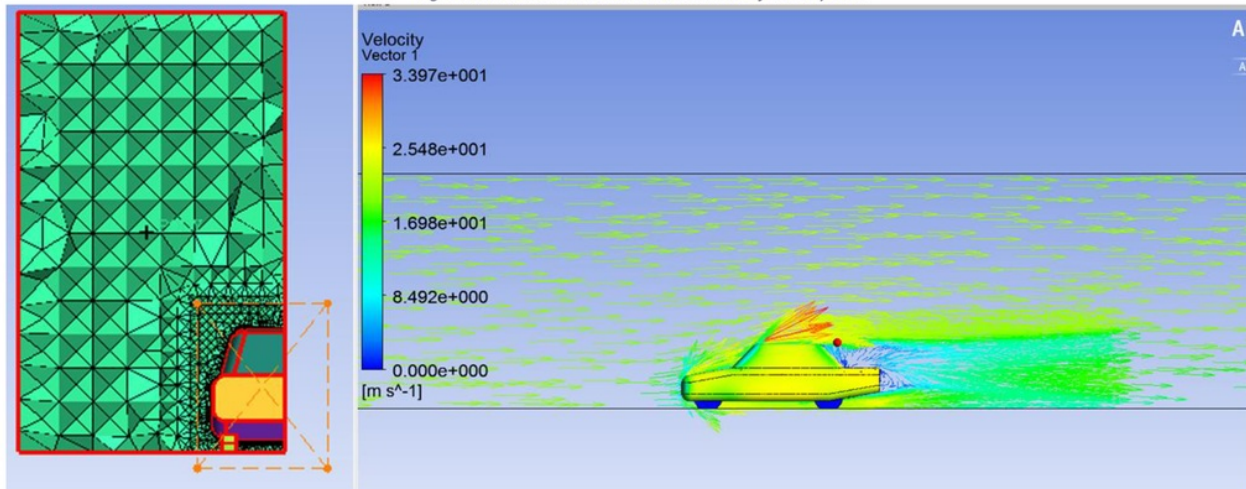


Figure 22 Volume Mesh

Figure 21 Vector lines

There are no obvious reasons that this has occurred as it is on a flat surface thus should be easy for a mesh to be generated. The velocity vectors on the roof of the modified car are off beat to the original, with far higher velocities being recorded on the scale. The vectors in this image also show the arrows traversing through the domain past the boundaries, this function did not work previously. It shows a stunted reflection of what is occurring on the bonnet of the car. This could be by cause of the wheels not functioning as intended in the model enabling the physics to act differently in the domain as they would never show as having no velocity on the surface.

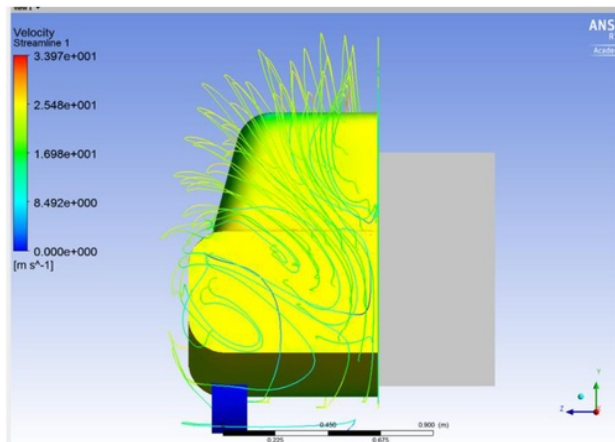


Figure 23 Ribbons showing turbulent flow at rear

Using Ribbons in a velocity streamline view from the rear of the car, the vortices are admirably shown despite the inability to mirror the car along the symmetry plane.

This is indicating that Base Drag is occurring being caused by depression on the back of the MIRA. To reduce this, one would need to taper the end part of the body rounding the geometry to increase the pressure on the region.

The ribbons also show the air 'dipping' into the cavity created at the rear in Figures 24 and 25. The colour code for velocity decreasing is telling us that the air is slowing down before it enters then exits the trough. This could be because it is rolling off the top of some eddy currents produced and therefore having experienced friction with them.

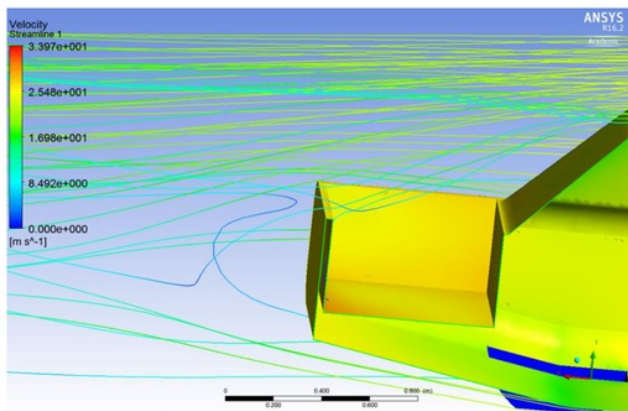


Figure 27 Flow in Cavity

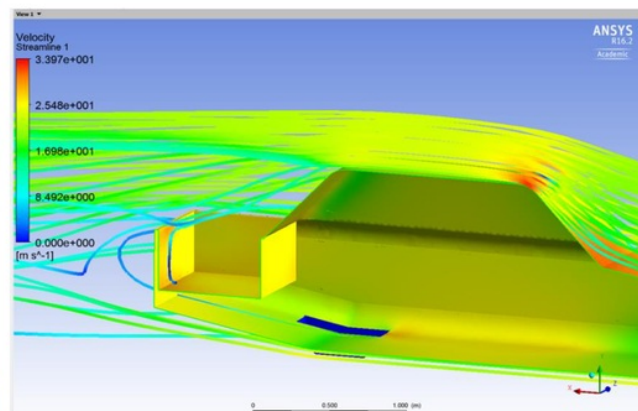


Figure 24 Increased ribbon size

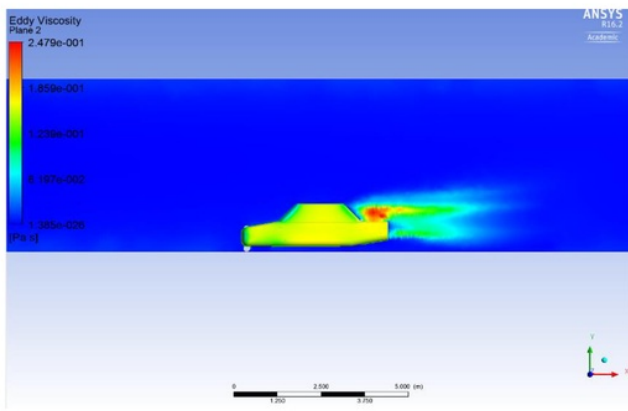


Figure 26 Eddy Viscosity

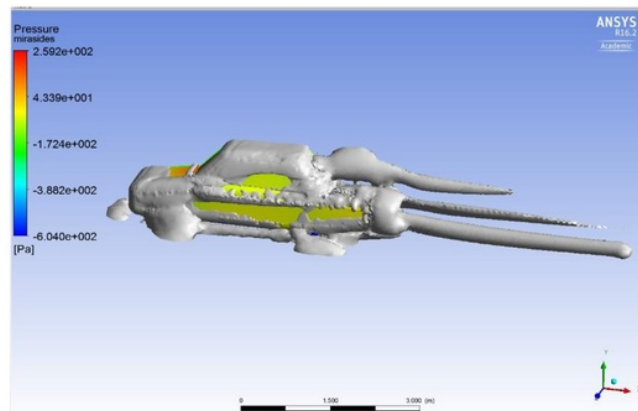


Figure 25 Pressure areas

The reason as to why the pressure distribution graph looks better upon geometric change to the MIRA is probably down to having used the software more thoroughly over time.

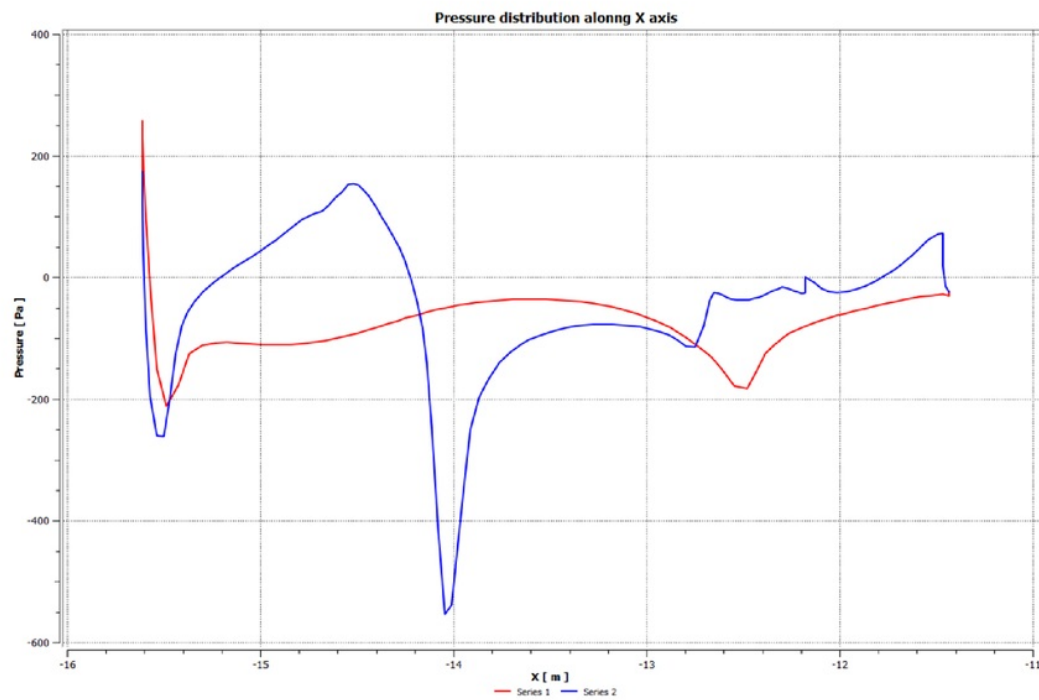


Figure 28 Pressure Distribution along the x axis of MIRA with geometrical change

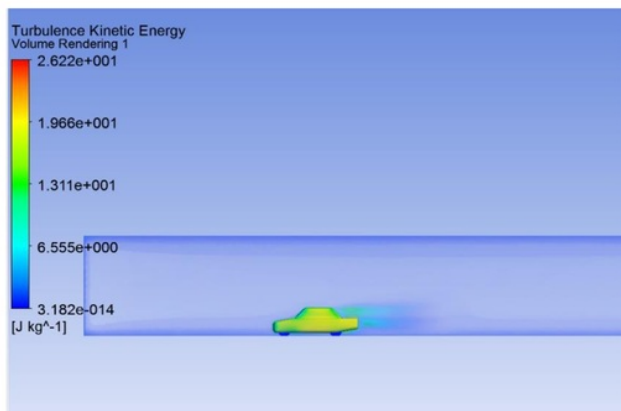


Figure 30 Volume rendering of Turbulence

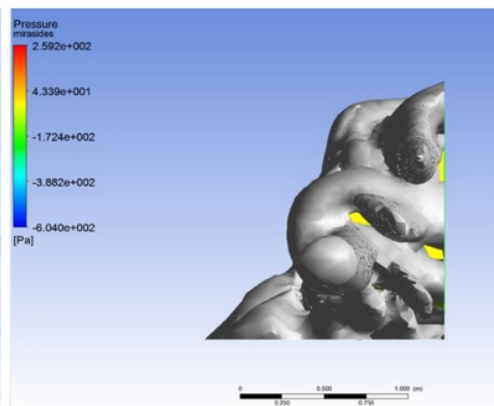


Figure 29 Quality of Turbulence

Conclusions

A finer mesh will always provide better computational results, the large geometric change was a good decision as results are differentiable with ease. Inconsistent data also provides inconsistent incomparable results which are rendered useless. Figure 29 shows poor quality, grainy and pixelated image of the turbulence to provide information on the areas that it is needed the most, which would require additional density boxes to assist in the endeavour of finding the affects of the geometrical change applied to the MIRA reference car.

Improvements

Improvements that could be made to the project include but are not limited to; approaching the analysis with an optimisation strategy. Due to having no experience or exposure to the software the methods of recording work and making amendments to models were patchy and inconsistent, at best. Viewing the analysis from a manufacturing approach, a matrix of Design of Experiments like Ahmad (Ahmad, 2010) has done could have been created, using effectively-collected data as its focus. The scope of the project should have been narrowed down to focus on analysing aerodynamic devices on the results generated rather than evaluating the mesh and its improvements in relation to the vehicles performance. Further optimisation of the geometry could have been made with a goal in mind, to reduce turbulence, to be able to increase vehicle speed, or to track the Reynolds number to distinguish laminar and turbulent flow in the domain, however changing the geometry without an inclination of the outcome was a bad decision and should have been planned out in theory further before execution.

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Figure 1 Dickinson, M and Haynes, 2011 MIRA Reference car, photograph, Warwick University viewed 5 January 2019
https://warwick.ac.uk/fac/sci/wmg/research/lcvtp/news/hevc11/ws12_review_may11.pdf

Figure 2 MIRA Ltd. 2015 MIRA Environmental Vehicle Testing, digital image, YouTube viewed 5 January 2019 <https://www.youtube.com/watch?v=riBYKAInfTs>

Figure 3 Boettcher A, 2019 MIRA Ansys, digital image, University of Wales Trinity Saint David 20 January 2019

Figures 4-29 Boettcher A, 2019 MIRA Ansys, digital image, University of Wales Trinity Saint David 20 January 2019

Table 1 Part Mesh Setup, Boettcher A, 2019 MIRA Ansys, Table, University of Wales Trinity Saint David 20 January 2019

Table 2 Element Types, Boettcher A, 2019 MIRA Ansys, Table, University of Wales Trinity Saint David 20 January 2019

Table 3 Orthogonal Quality, Boettcher A, 2019 MIRA Ansys, Table, University of Wales Trinity Saint David 20 January 2019

Table 4 Skew Quality, Boettcher A, 2019 MIRA Ansys, Table, University of Wales Trinity Saint David

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