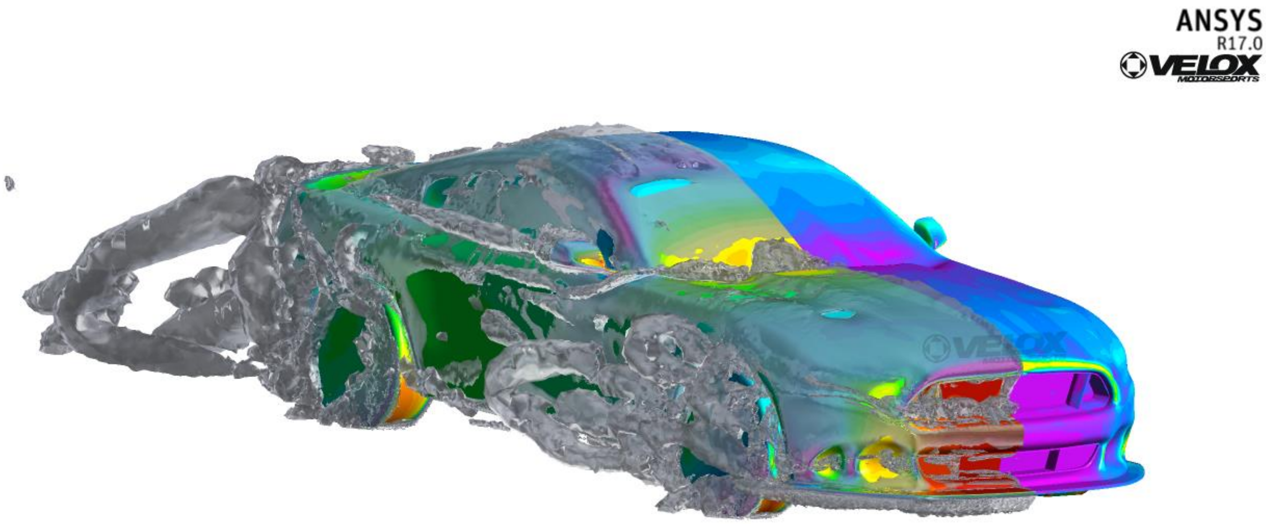
S550 Mustang

Performance Gain of Ventus1 Package



Author: Paul Lucas
Release Date: 2016/11/05
Approvals: P. Lucas, E. Hazen

Document Revisions

Rev	Date	Author	Description
1	2016/11/05	P. Lucas	Initial Release of Informative Packet
2	2017/08/07	P. Lucas	Company Name Change From Velox to Verus

Verus Engineering
Indianapolis, IN
sales@verus-engineering.com

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1. Executive Summary
   - Decreased lift
   - Drag decreased
   - Aerodynamic efficiency improved with the use of the Verus Engineering Ventus1 (Front Splitter, Rear Diffuser) Package

All work was done using ANSYS software: geometry preparation was completed using SpaceClaim, meshing was done with ANSYS Meshing, setup and solution was computed on ANSYS Fluent, and post-processing was completed in CFD-Post.

1.1. Coefficient Deltas

Cd	Cl	Aerodynamic Balance
-0.003	-0.155	41/59

Figure 1.1.1: Coefficient Deltas

1.2. Aerodynamic Forces

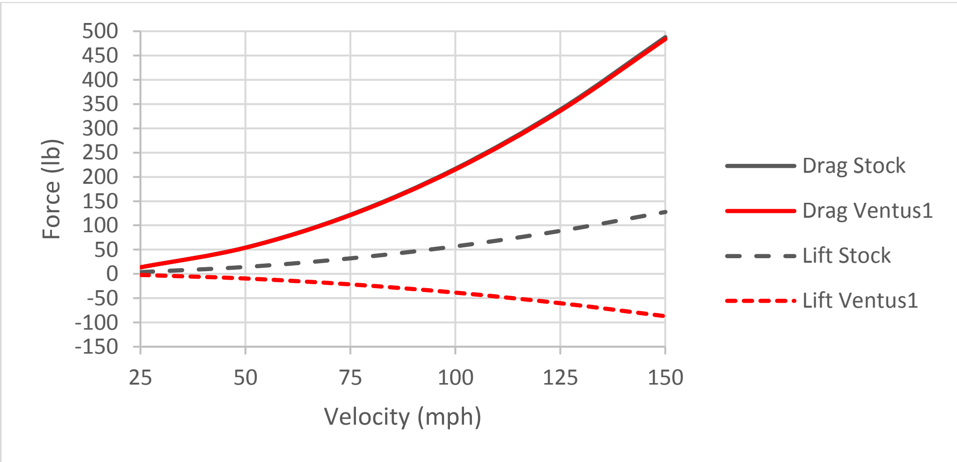

Figure 1.2.1: Aerodynamic Forces at Speed

1.3. Summary Plots

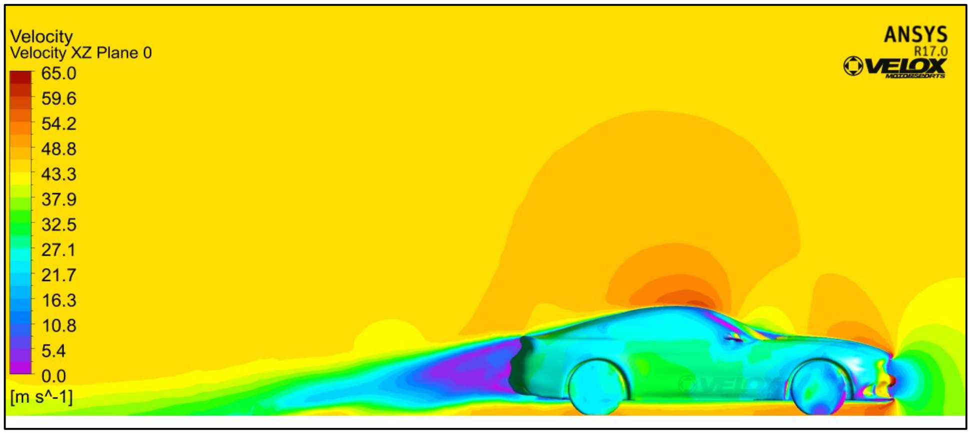

Figure 1.3.3: Stock Mustang – Velocity Cut Plane

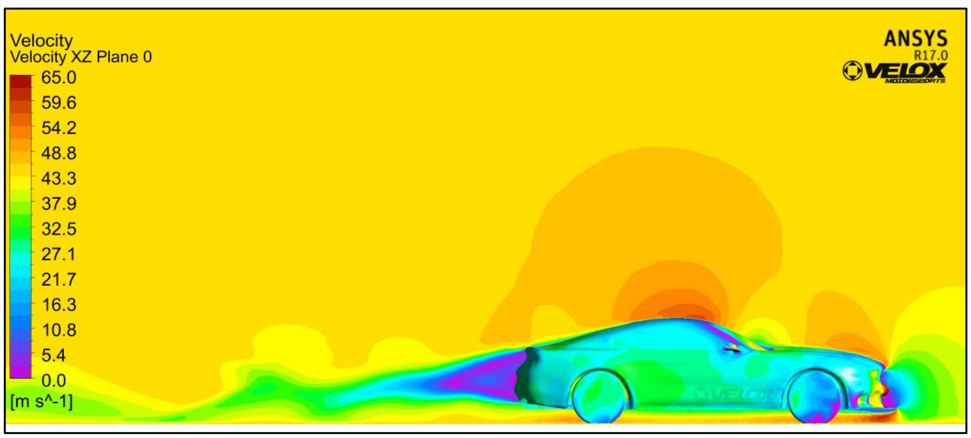

Figure 1.3.4: Ventus1 Mustang – Velocity Cut Plane

Comparing Figures 1.3.1-1.3.2, the rear wake changes. The velocity flow field is much cleaner coming off the diffuser than the factory car. The wake region shape dramatically changes between the two runs with the stock Mustang having a higher quantity of low velocity regions.

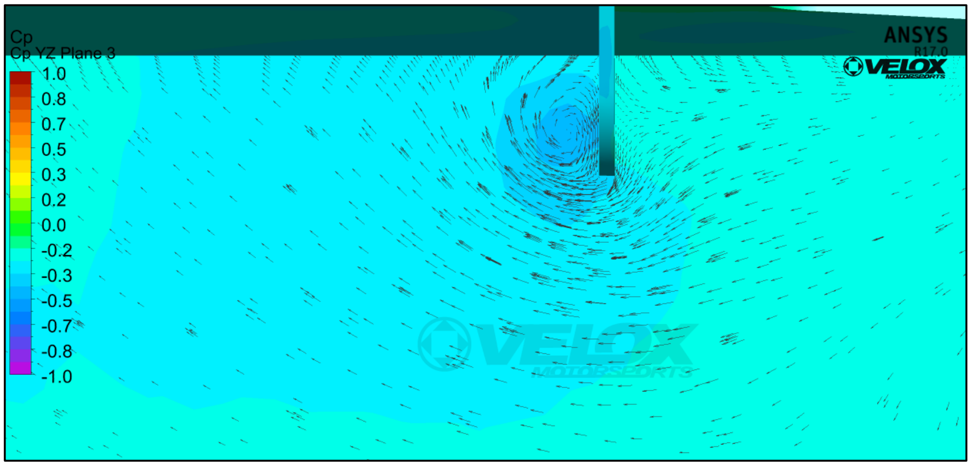

Figure 1.3.3: Vortex on the Velox Diffuser Strake

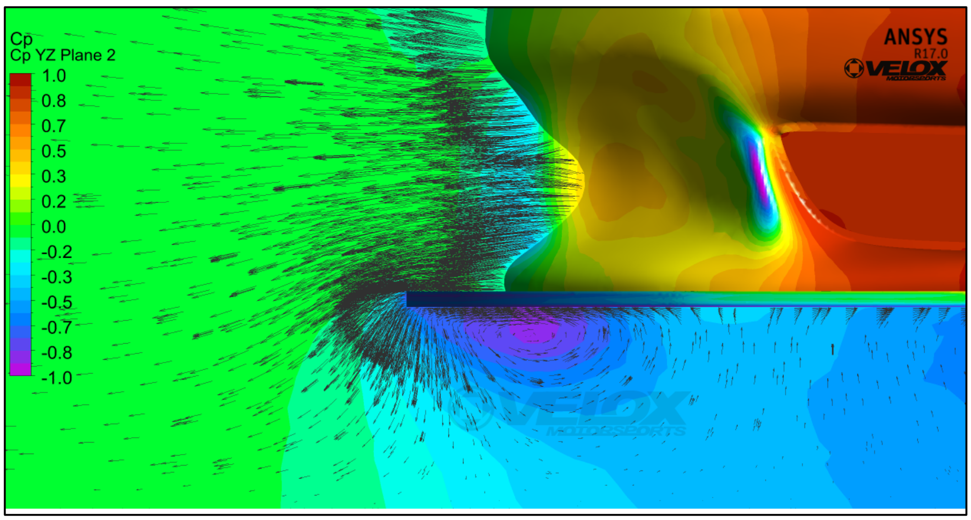

Figure 1.3.4: Vortex Formation under Splitter

Notice the vortex coming off of the stake in Figure 1.3.3. Vortices in these locations have a positive impact on diffuser performance. Also notice in Figure 1.3.4 the vortex traveling down the front splitter on the Ventus1 package. Vortex management is a key goal in all aerodynamic development at Verus Engineering.

2. ASSUMPTIONS

2.1. Geometry

In many automotive analysis cases, simplification of the geometry is required. Analyzing a fully detailed automotive case is usually not necessary, and much of the critical information we are after could get lost in the plethora of data. The proper approach to the analysis is to setup a simplified physical model. [1] In the automotive case, we isolate particular aspects of the system to capture and ensure we can set proper boundary conditions. In these cases, we are interested in the overall flow field around the Mustang and how the Ventus1 package improves the aerodynamic efficiency. The simplifications made were as follows:

- Solid wheel bodies
- Smooth underbody (except at rear bumper)
- Solid grill surface
- Removed door handles
- Removed antennae
- Removed all car panel gaps

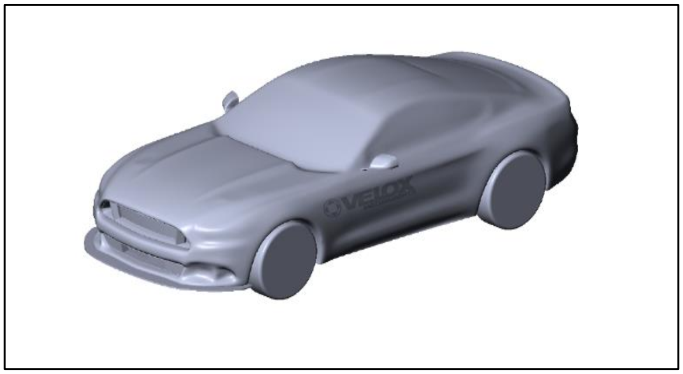

Figure 2.1.1: Geometry Simplifications – Front ISO

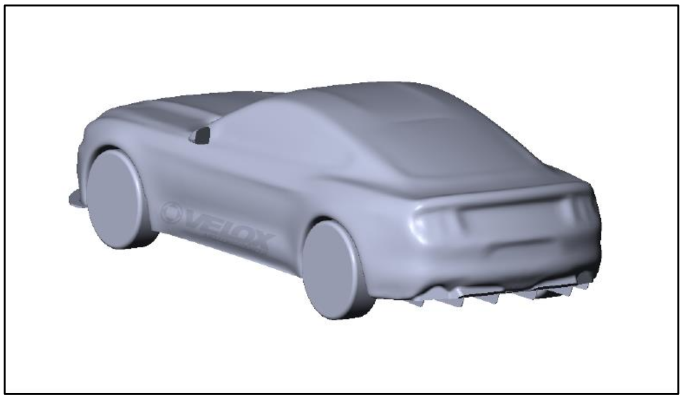

Figure 2.1.2: Geometry Simplifications – Rear ISO

2.2. Setup

Some physical effects are removed from the analysis because it is not necessary for these cases. We are looking at the overall flow field around the S550 Mustang, some of the physical models are left out. The simplifications made were as follows:

- No radiator flow
- No under hood flow
- No engine intake
- No exhaust flow

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3. MESH QUALITY AND METRICS

3.1. Metrics

A proper mesh is essential for a CFD analysis. With CFD, a poor mesh causes the simulation to not converge. Without convergence, the solution will never be reached, and without a good mesh, it is irresponsible to expect accurate results. Here at Verus Engineering we use two main metrics to evaluate mesh quality: skewness and orthogonal quality.

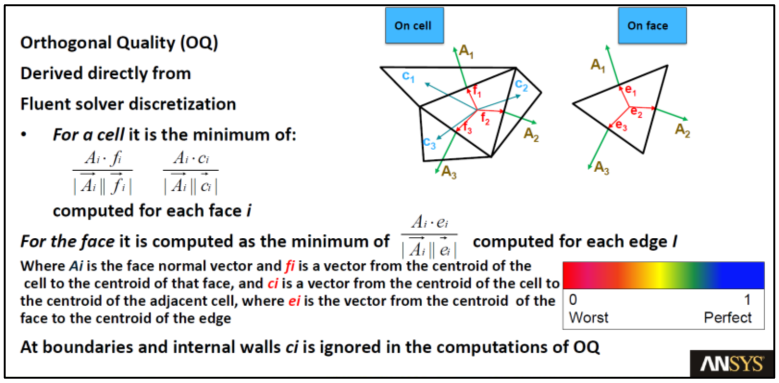

Figure 3.1.1: Orthogonal Quality Metrics

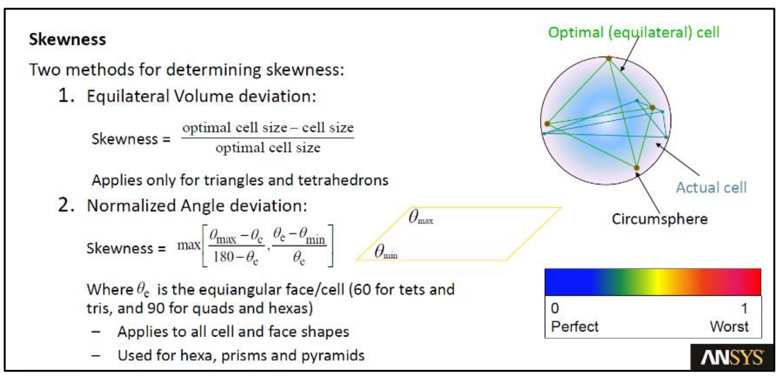

Figure 3.1.2: Skewness Quality Metrics

3.2. Quality

Low orthogonal quality and high skewness values are not recommended for a quality mesh. In general, we always want an orthogonal quality greater than 0.1 and skewness below 0.95. The value may differ depending on the physics and location of the cell.

Orthogonal Quality mesh metrics spectrum

Unacceptable	Bad	Acceptable	Good	Very good	Excellent
0-0.001	0.001-0.14	0.15-0.20	0.20-0.69	0.70-0.95	0.95-1.00

Figure 3.2.1: Orthogonal Quality Metrics

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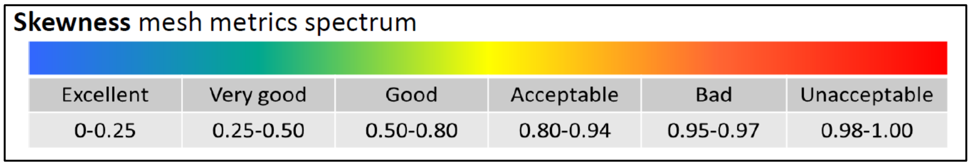
Skewness mesh metrics spectrum

Excellent	Very good	Good	Acceptable	Bad	Unacceptable
0-0.25	0.25-0.50	0.50-0.80	0.80-0.94	0.95-0.97	0.98-1.00

Figure 3.2.2: Skewness Quality Metrics

3.3. Types of Mesh

There are two main types of meshes, or grids: structured and unstructured. Structured grids generally have better convergence and higher accuracy with a more simple flow field. Unstructured grids are more commonly used for Verus Engineering applications since geometry and flow fields are complex.

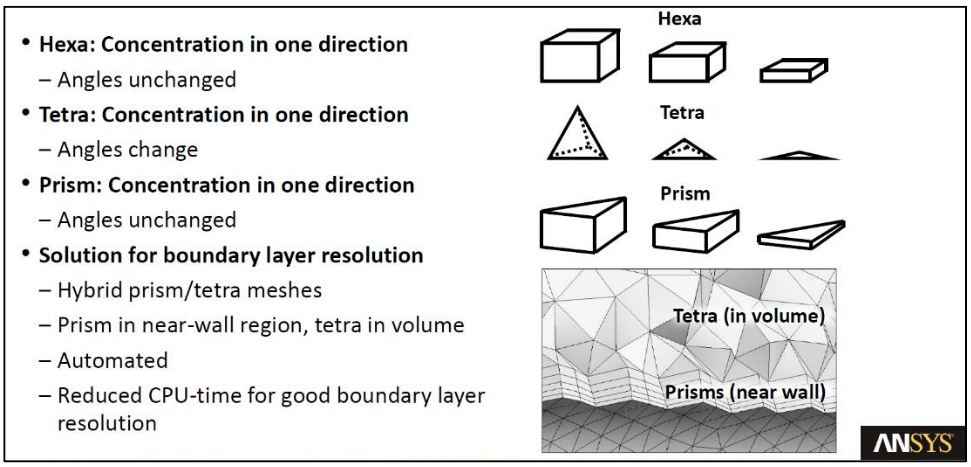

Figure 3.3.1: Hexahedral versus Tetrahedral

An unstructured mesh using prism layer for boundary layer resolution and tetrahedral in the volume was utilized for the S550 Mustang.

3.4. Mesh Quality of Mustang

All meshing is completed using ANSYS Meshing. Verus Engineering uses ANSYS Meshing to combine the strengths of ICEM CFD, TGRID, CFX-Mesh, and Gambit. ANSYS Meshing allows Verus Engineering to setup a quality grid for proper solution and convergence.

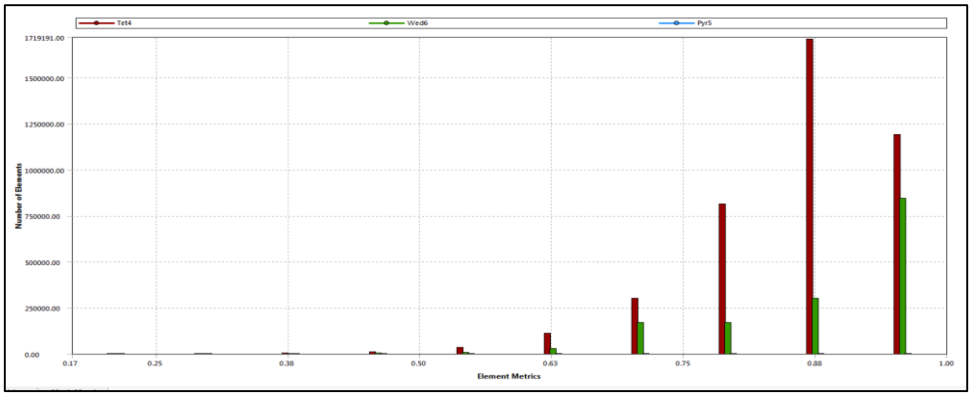

Figure 3.4.1: Mesh Quality of Mustang

Referring to Figure 3.4.1, orthogonal quality did not drop below 0.17. This is in the acceptable zone for the minimum orthogonal quality. The majority of the mesh is in the very good to excellent range.

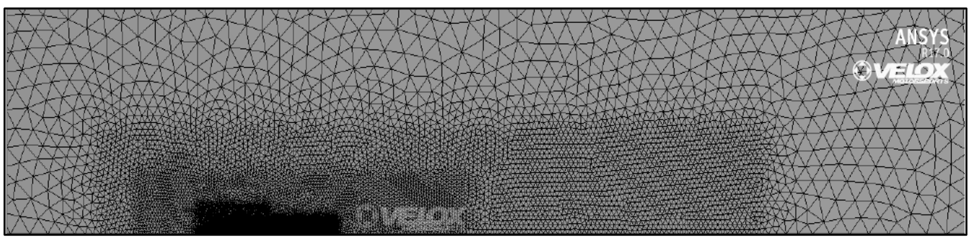

Figure 2.4.2: Mesh Wake Zone Refinement

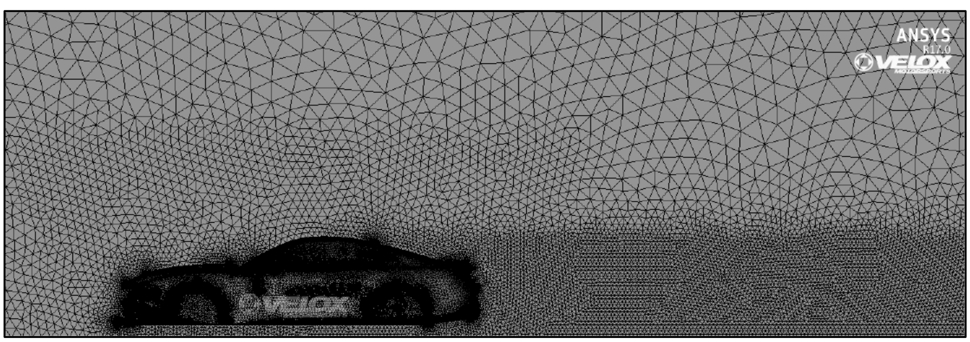

Figure 2.4.3: Mesh Wake Zone Refinement

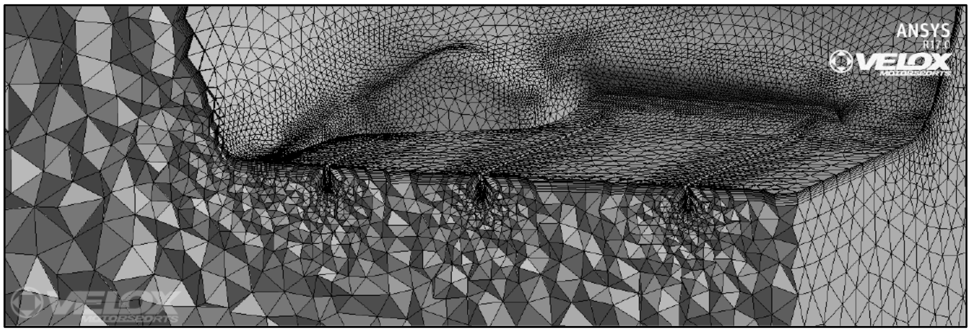

Figure 2.4.4: Mesh Section View at Diffuser

4. ANALYSIS SETUP

4.1. General

ANSYS Fluent – a finite volume discretization scheme - is used for solving all of Verus Engineering external aerodynamics cases. The solver used is the semi-implicit method for pressure-linked equations, SIMPLE. [2] These cases were solved using the steady-state method which ignores the higher order terms dealing with time.

4.2. Boundary Conditions

Boundary conditions are used to define the computational problem. Without boundaries, nothing can be solved, and proper boundary conditions are a must for an accurate analysis. A full understanding of the physics of the problem is a must. Computational Fluid Dynamics is today an equal partner with pure theory and pure experiment in the analysis and solution of fluid dynamic problems. [5] CFD only emulates the condition of the road and track, it does not reproduce it. Simulations inherently deviate from reality and it is often hard to quantify all the sources of error. The cases were solved using symmetry on the XZ Plane. This decreased the mesh quantity by cutting the computational domain in half, thus decreases the simulation time to convergence. Using symmetry on the XZ Plane is standard in the industry unless you are modeling yaw. The case is modeled using a virtual wind tunnel which is discretized and used as the fluid volume. The air then flows over the stationary car in the boundary. The ground and wind tunnel walls have the shear equal to zero to not have boundary layer growth which simulates the rolling road condition to have a proper flow regime. The wheels are setup as a rotational moving wall boundary.

Inlet	Inlet Condition	45 m/s
Outlet	Pressure Outlet Condition	0 Pa (Gauge)
Symmetry Plane	Symmetry	N/A
Ground	Wall Condition	Shear = 0
Wind Tunnel Walls	Wall Condition	Shear = 0
Mustang	Wall Condition	No Slip Shear
Wheels	Wall Condition	130 rad/s

Figure 3.2.1: Boundary Conditions

4.3. Turbulence Modeling

The majority of fluid flows in engineering cases are turbulent. Because of this, a proper turbulence model is needed for proper results and flow regimes. The k-omega SST turbulence model was used in these cases. The k-omega is great for solving flows in the viscous sublayer (boundary layer). The SST allows the model to solve free-stream area where the normal k-omega was too sensitive to free-stream turbulences. [3]

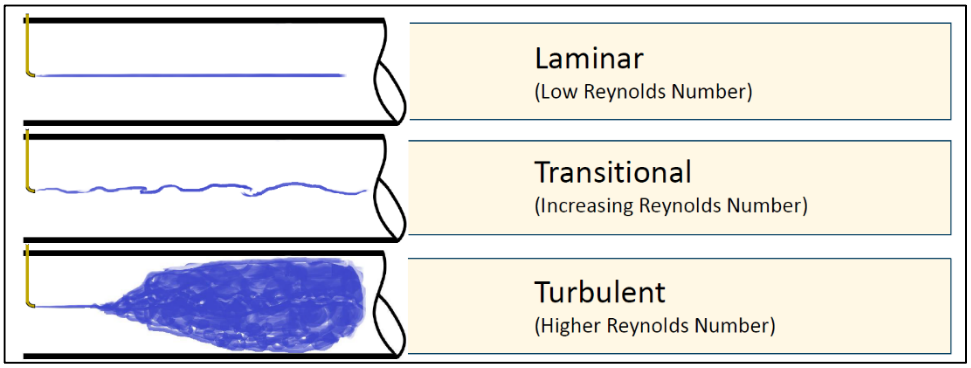

Figure 3.3.1: Flow Classifications

5. <u>Results</u>

5.1. Aerodynamic Coefficient Deltas

Deltas are what really matters when developing with simulations: whether it be CFD or wind tunnel testing. The delta is defined as the difference between the diffuser model coefficient and the stock model coefficient.

Cd	Cl	Aerodynamic Balance
-0.003	-0.155	41/59

Figure 5.1.1: Aerodynamic Coefficient Deltas

5.2. Aerodynamic Forces

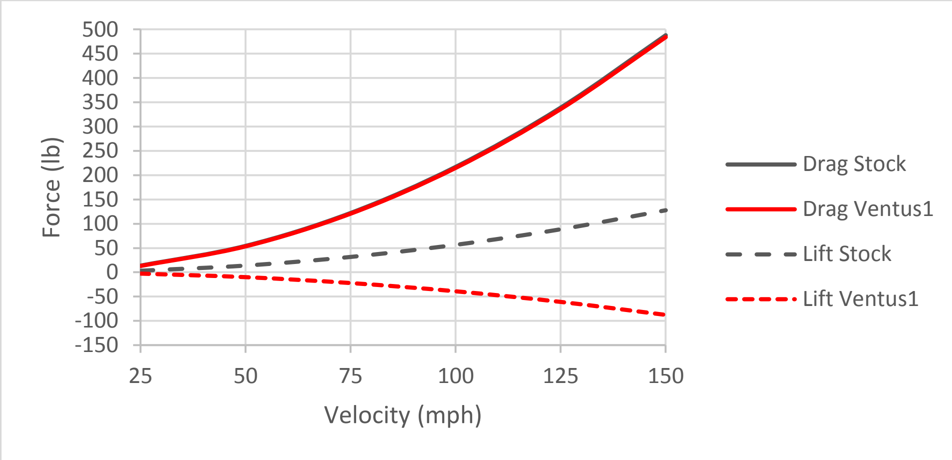

Figure 5.2.1: Aerodynamic Forces at Speed

Aerodynamic forces change with the square of velocity. That is why a solid downforce number cannot be given unless it is at a specific speed. Most OEM road vehicles create lift from the factory, and the Ford Mustang is in that category. Notice Figure 5.2.1, the factory lift from the Mustang is greatly reduced with the Ventus1 package.

5.3. Coefficient of Pressure & Wall Shear Plots

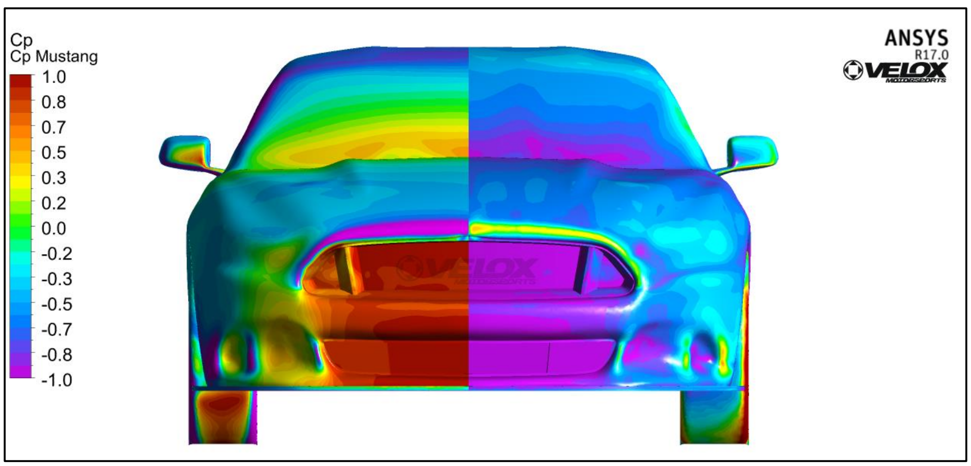

Figure 5.3.1: Cp & Wall Shear Front

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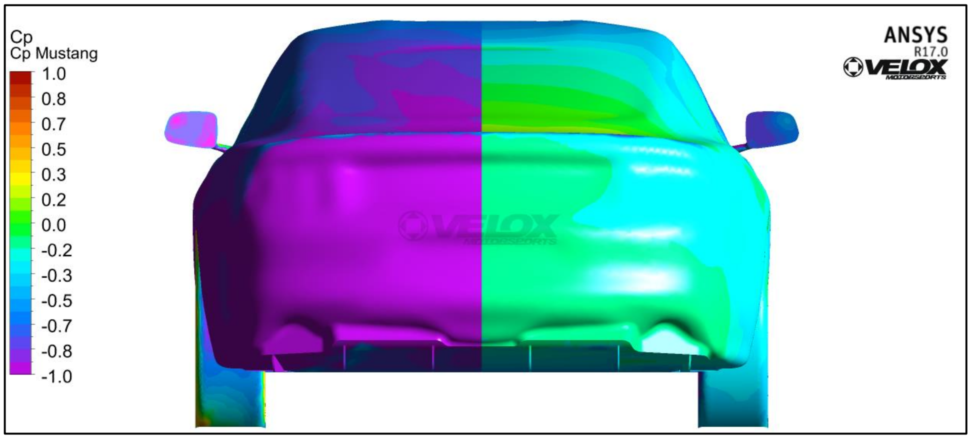

Figure 5.3.2: Cp & Wall Shear Rear

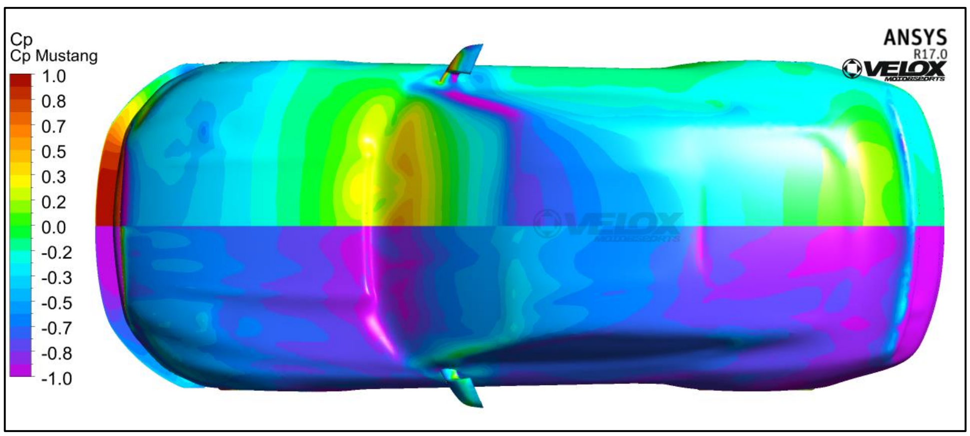

Figure 5.3.3: Cp & Wall Shear Top

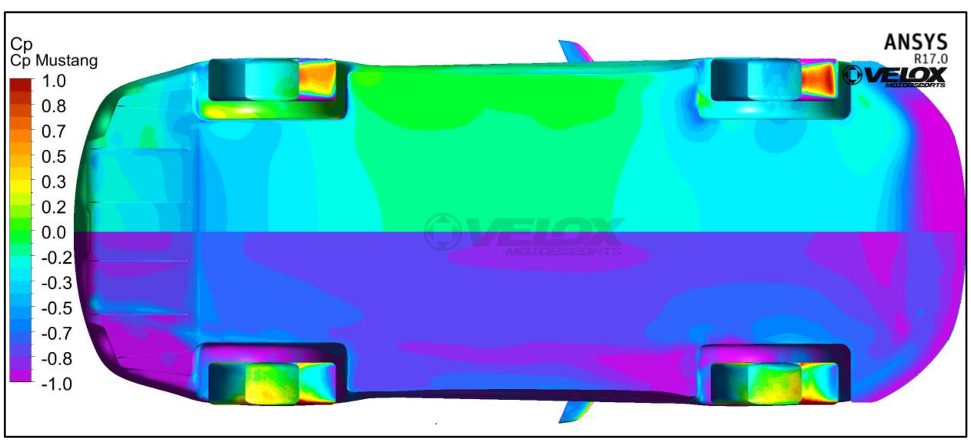

Figure 5.3.4: Cp & Wall Shear Bottom

5.4. Velocity Plots

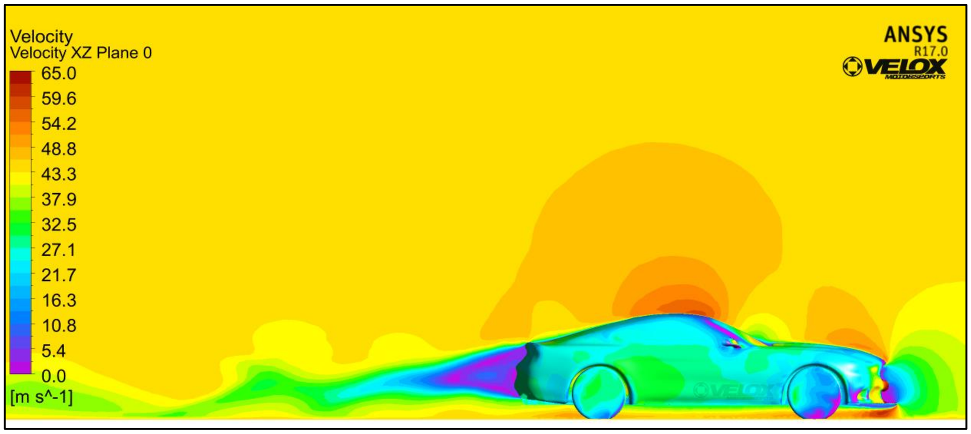

Figure 5.4.1: Velocity Plot Symmetry Plane

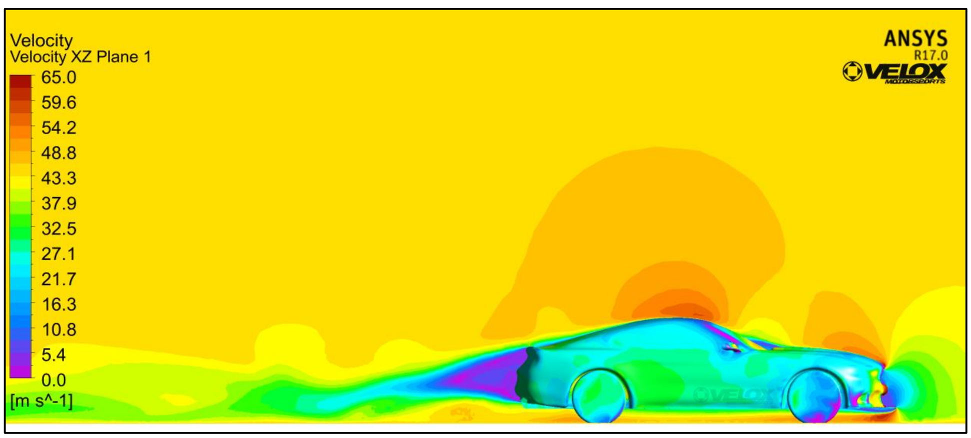

Figure 5.4.2: Velocity Plot XZ Plane 1 (Offset from Sym Plane 0.1m)

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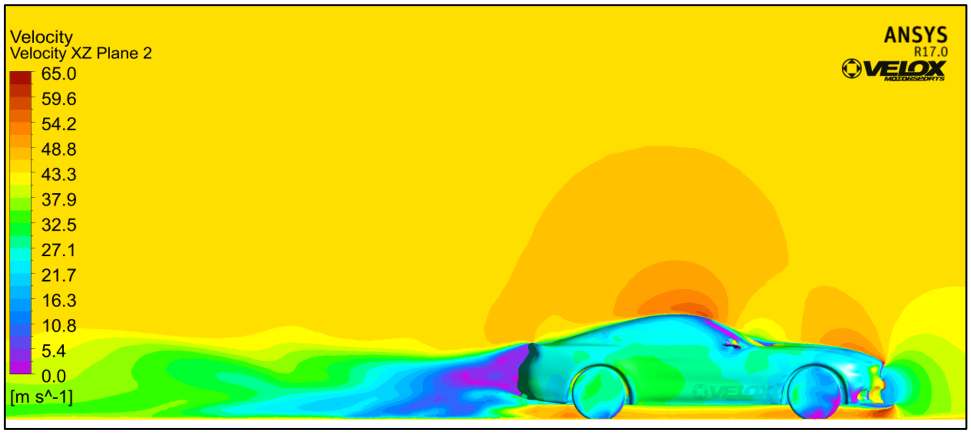

Figure 5.4.3: Velocity Plot XZ Plane 2 (Offset from Sym Plane 0.3m)

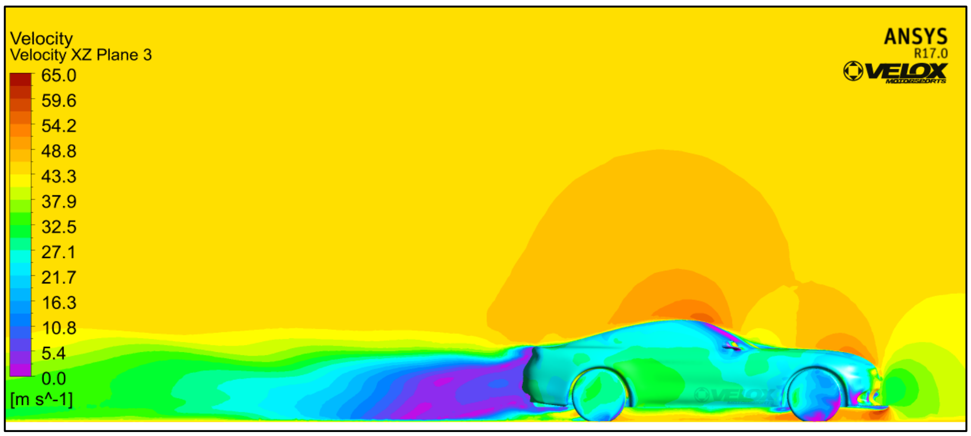

Figure 5.4.4: Velocity Plot XZ Plane 3 (Offset from Sym Plane 0.5m)

5.5. Turbulent Kinetic Energy Plots

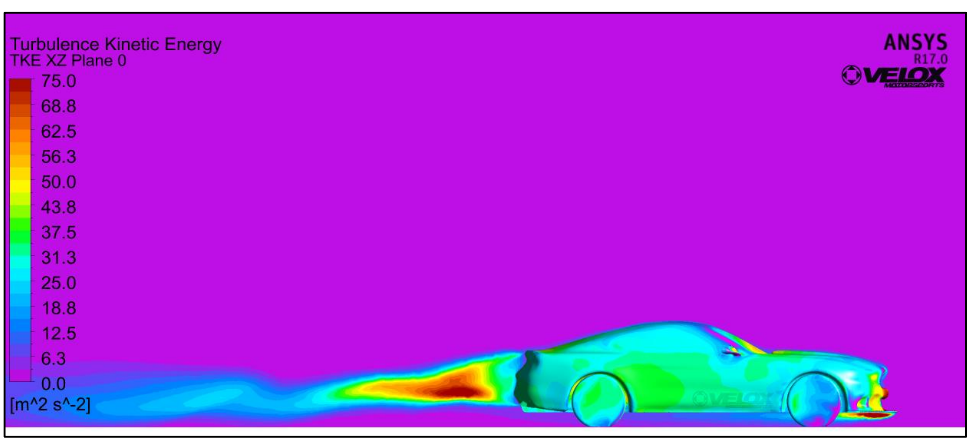

Figure 5.5.1: TKE Plot Symmetry Plane

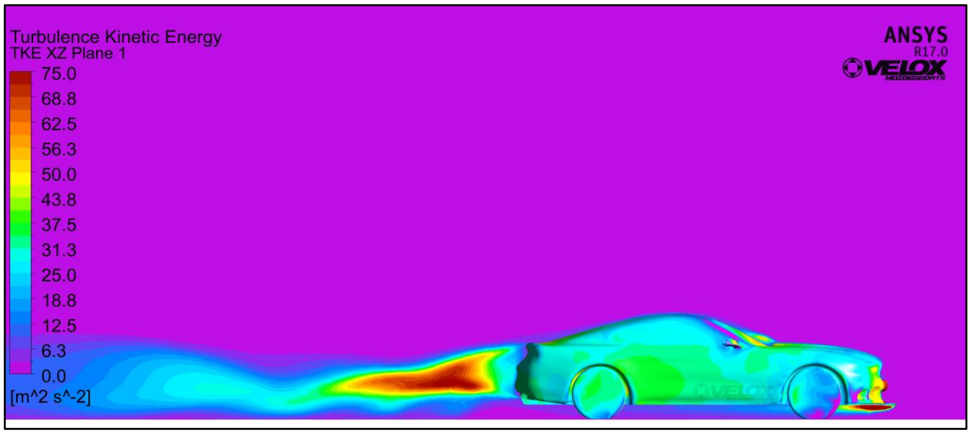

Figure 5.5.2: TKE Plot XZ Plane 1 (Offset from Sym Plane 0.1m)

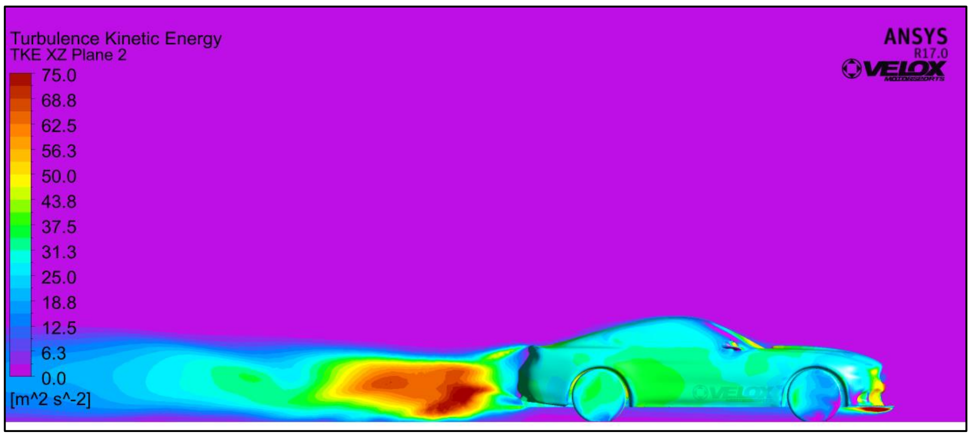

Figure 5.5.3: TKE Plot XZ Plane 2 (Offset from Sym Plane 0.3m)

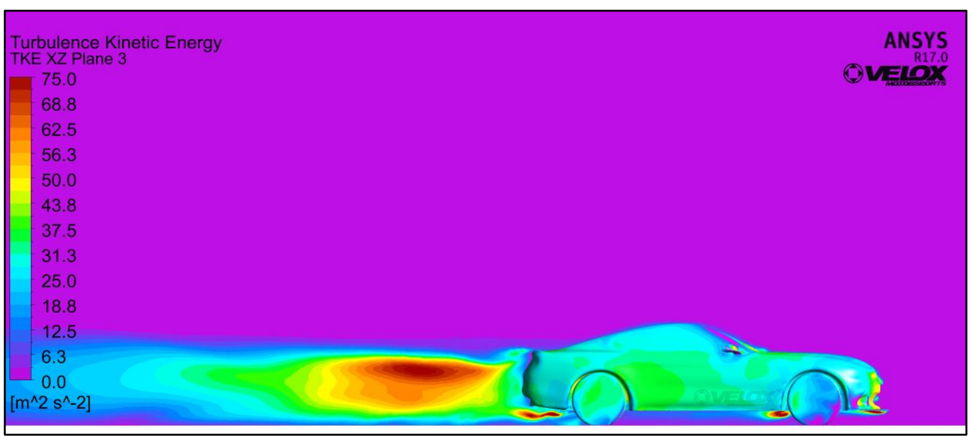

Figure 5.5.4: TKE Plot XZ Plane 3 (Offset from Sym Plane 0.5m)

5.6. Ventus1 Plots

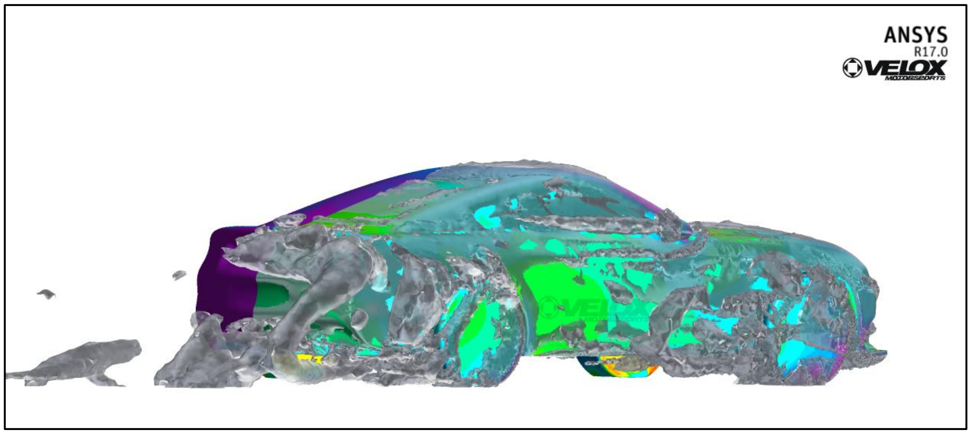

Figure 5.7.1: Q-Criterion Displays Vortices off the Mustang

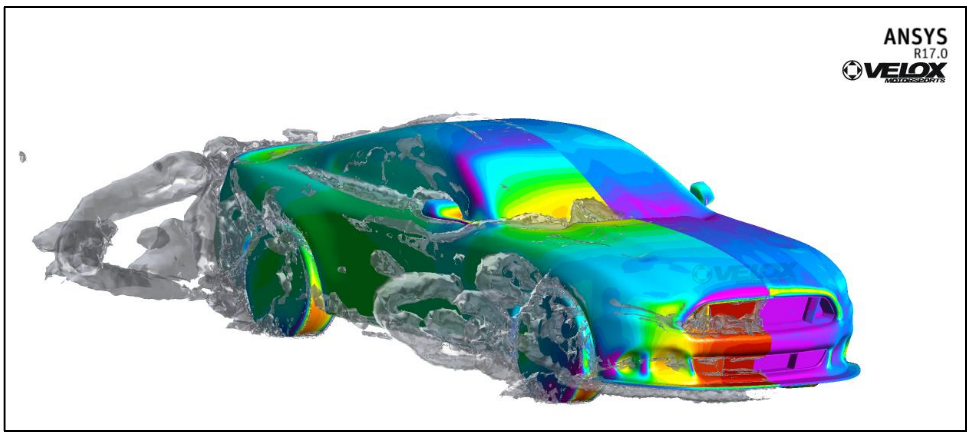

Figure 5.7.2: Q-Criterion Displays Vortices Forming on Splitter

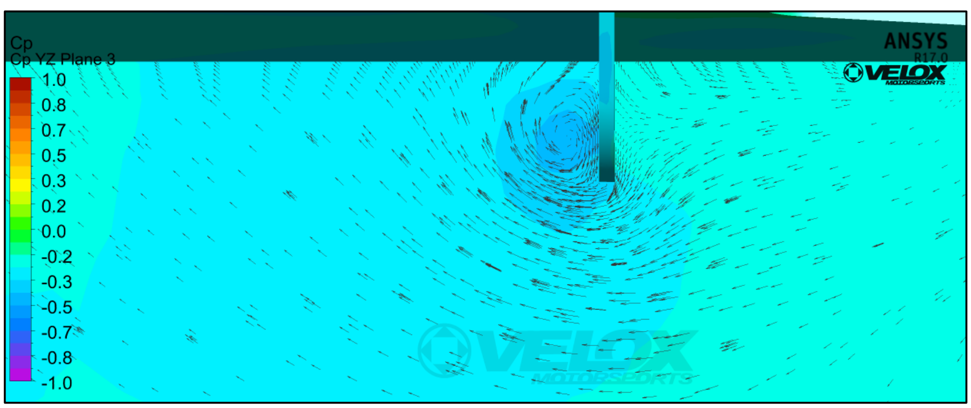

Figure 5.7.3: Vortex Formation on Strake

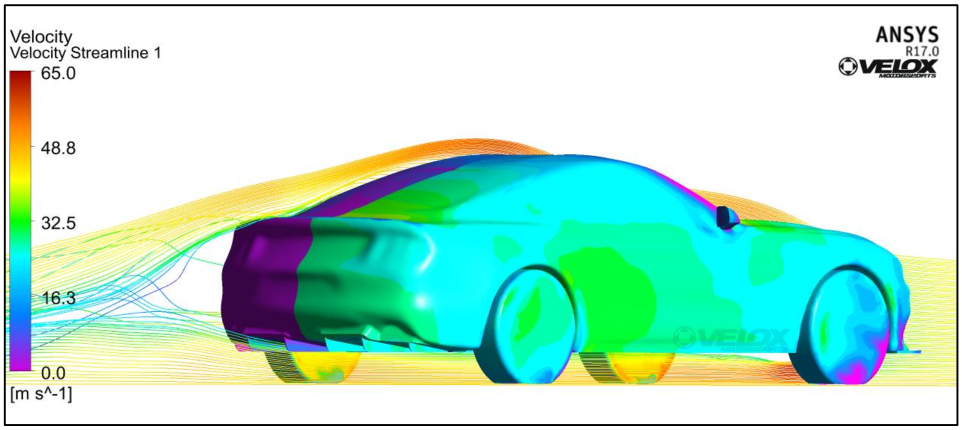

Figure 5.7.4: Streamlines Off the Diffuser

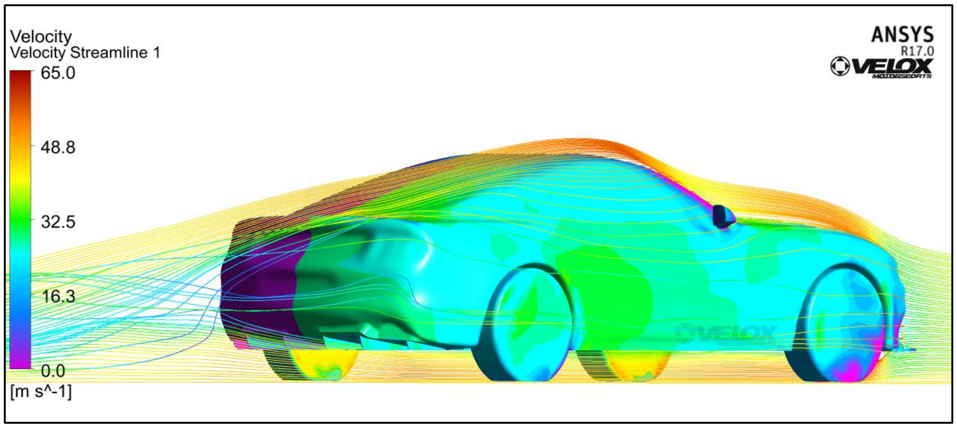

Figure 5.7.5: Streamlines Off the Diffuser

Notice on Figures 5.7.1 & 5.7.3 the vortex forming on the strake. In the core of the vortex is a low pressure zone. These vortices help to keep flow attached vehicle components. Figure 5.7.1 makes spotting vortices off the car easier, and this helps when optimization of parts occur. The flow stays attached going up the diffuser in part from the strake vortices that can be seen in Figure 5.7.4 & 5.7.5. Figures 5.7.2 show the flow regime off the front splitter. Vortices formed on the edges of the splitter which help create downforce to balance the downforce from the diffuser.

6. ERRORS IN SIMULATION

6.1. Physical Model

Some of the errors in the physical model was discussed in Geometry Assumptions. The substitution of a CAD model from a real physical model in an inevitable source of error. The CAD model only also represents part of the physical system, others are either represented with boundary conditions or left out of the analysis.

6.2. Discretization Error

Discretization errors are those errors that occur from the representation of the governing flow equations and other physical models as algebraic expressions in a discrete domain of space and time. As the mesh is refined, the solution should become less sensitive to discretization error. These errors can be analyzed using grid convergence study. [4]

7. CONCLUSION

The Verus Engineering Ventus1 package decreased the overall lift and reduced drag of the S550 Mustang. Since the diffuser and splitter decreased lift and reduced drag, the overall aerodynamic efficiency was improved. The diffuser helped create vortices that kept flow attached to the diffuser surface. The diffuser created a low pressure zone in the rear while the splitter created a low pressure zone in the front. This equated to a well-proportioned aerodynamic balance. The Verus Engineering Ventus1 package helps the Mustang get more from the tires at the track and also increases gas mileage on a daily driver. The Ventus1 package will be great on either a normal daily driver or a track queen.

8. REFERENCES

[1] Zikanov, Oleg. *Essential Computational Fluid Dynamics*. 1st Edition. John Wiley & Sons, Inc., 2010.
[2] Patankar, Suhas. Numerical Heat Transfer and Fluid Flow. 1st Edition. Hemisphere Publishing Corporation, 1980.
[3] Menter, Florian. Improved Two-Equation k-w Turbulence Models for Aerodynamic Flows. NASA Technical Memorandum, no. 103975 (1992).
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[5] Anderson, John. *Computation Fluid Dynamics*. 1st Edition. McGraw-Hill, Inc., 1995.