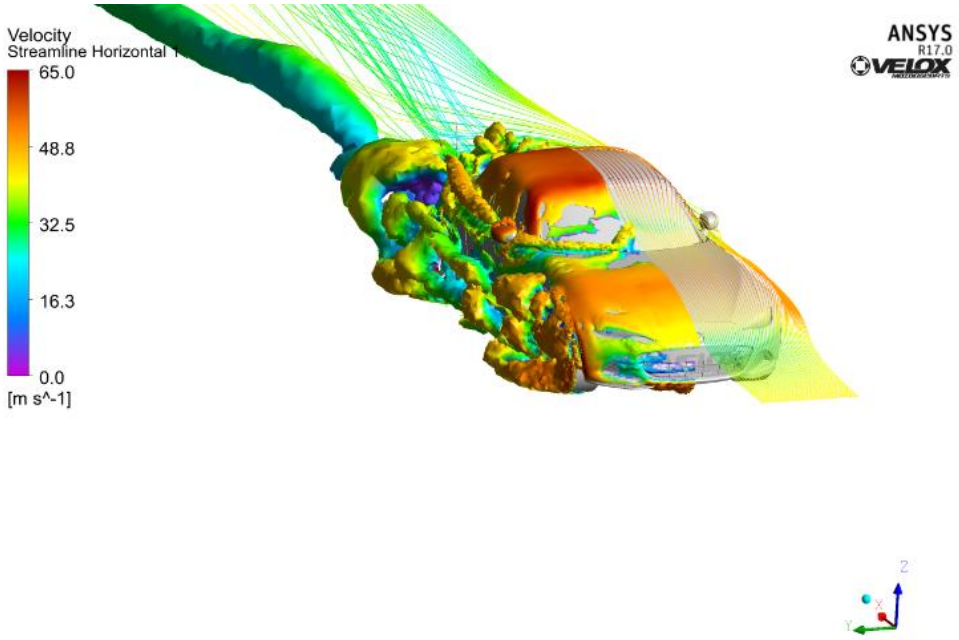
# ND Mazda Miata

## Performance Gain of a Rear Diffuser

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**Release Date**: 2016/09/21
**Approvals**: P. Lucas, E. Hazen

### Document Revisions

| Rev | Date | Author | Description |
|---|---|---|---|
| 1 | 2016/09/22 | P. Lucas | Issued for Release |
| 2 | 2017/08/07 | P. Lucas | Company Name Change From Velox to Verus |
| | | | |
| | | | |

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ND Mazda Miata – Performance Gain of Rear Diffuser

1. Executive Summary
   - Verus Engineering diffuser decreased overall lift of the ND Miata
   - Overall drag was decreased
   - Overall aerodynamic efficiency improved with the use of the Verus Engineering diffuser

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

### 1.1. Coefficient Deltas

| Cd | Cl | Aerodynamic Balance |
|---|---|---|
| -0.001 | -0.055 | No Change, 45/55 Bal |

Figure 1.1.1: Coefficient Deltas

### 1.2. Aerodynamic Forces

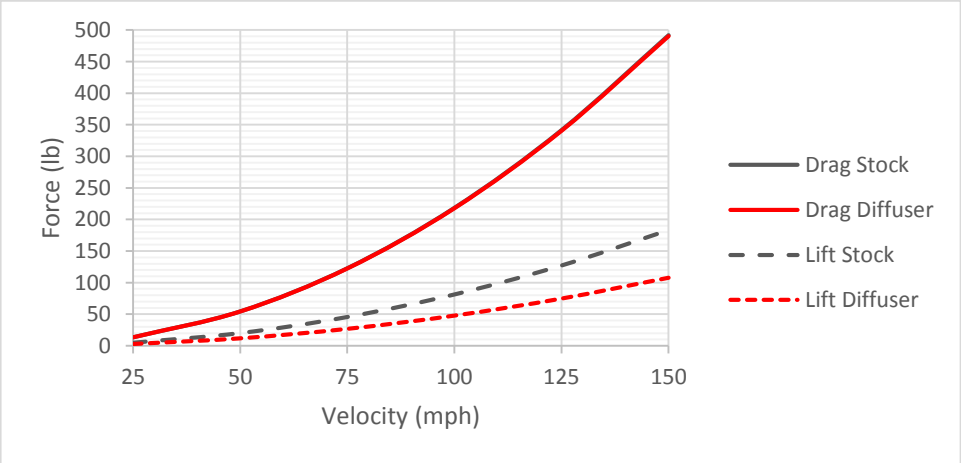


Figure 1.2.1: Aerodynamic Forces at Speed

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### 1.3. Summary Plots

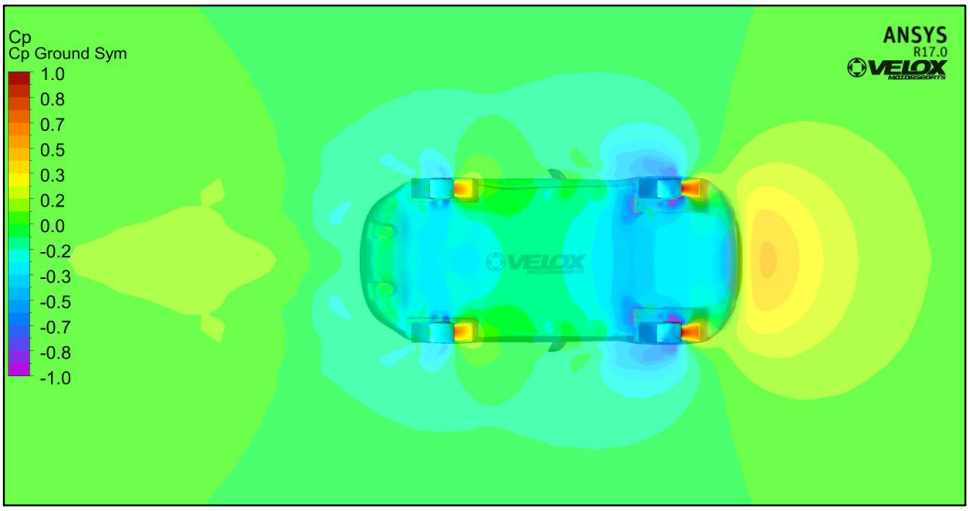


Figure 1.3.1: Stock Miata – Bottom Cp

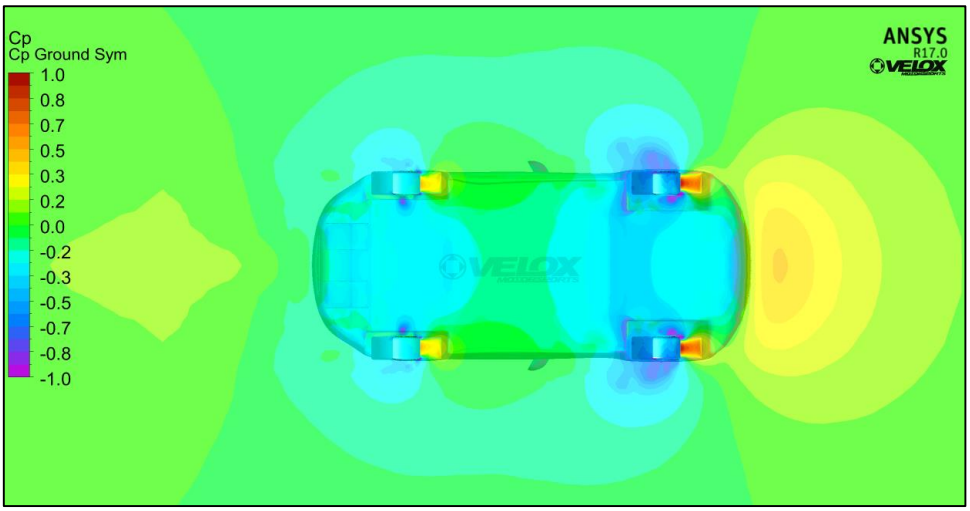


Figure 1.3.2: Diffuser Miata – Bottom Cp

Comparing Figures 1.3.1-1.3.2, the rear of the diffuser Miata model has a lower Cp (coefficient of pressure) value. A lower Cp value is pressure lower than freestream pressure. Lower pressure than freestream pressure creates downforce. The diffuser also creates a lower pressure zone in the middle of the Miata which is a common occurrence. The phenomenon is called a subsonic upstream disturbance.

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ND Mazda Miata – Performance Gain of Rear Diffuser

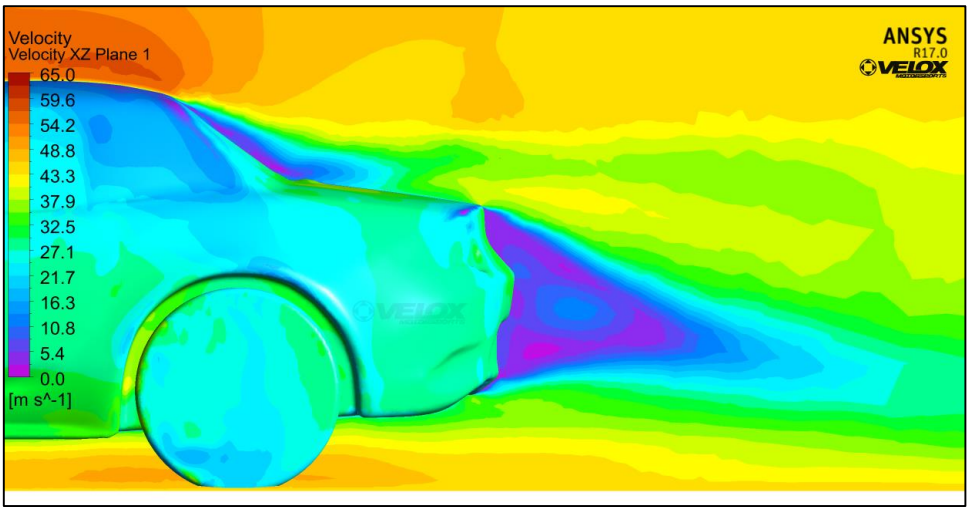


Figure 1.3.3: Stock Miata – Velocity Cut Plane

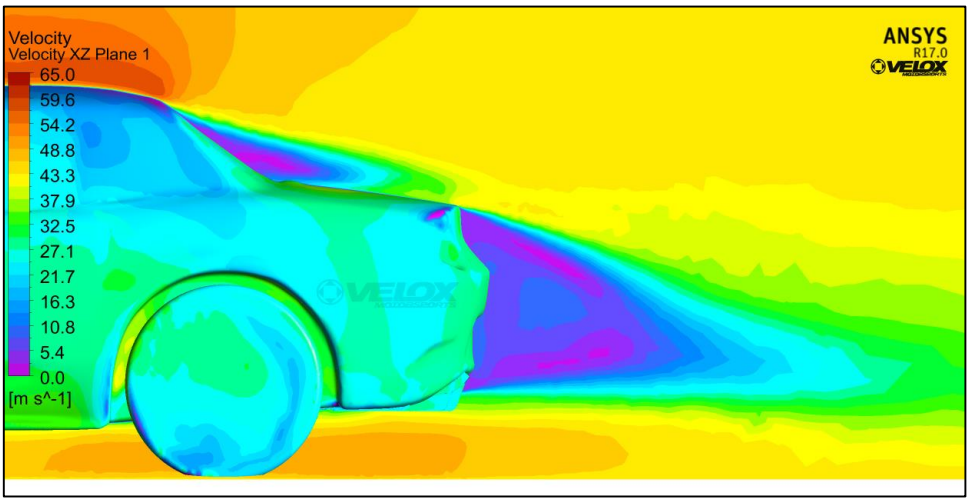


Figure 1.3.4: Diffuser Miata – Velocity Cut Plane

Comparing Figures 1.3.3-1.3.4, 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 Miata having a higher quantity of low-velocity regions. Also, note the change in the flow field of the rear window and trunk. Aerodynamic devices often change the flow field in other regions.

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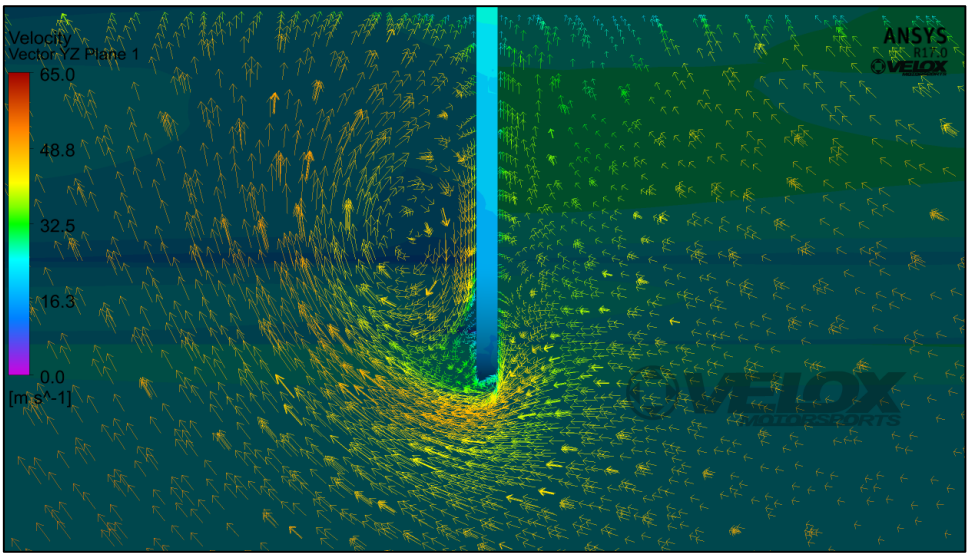


Figure 1.3.5: Vortex on the ND Miata Diffuser Strake

Notice the vortex coming off of the stake in Figure 1.3.5. Vortices in these locations have a positive impact on diffuser performance. We use this information to optimize our components quite often.

## 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 an 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 ND Miata and how the Verus Rear Diffuser improves the aerodynamic efficiency. The simplifications made were as follows:

- Solid wheel bodies
- Smooth underbody (no gaps or pockets)
- Solid grill surface
- Removed door handles
- Removed antennae
- Removed all car panel gaps

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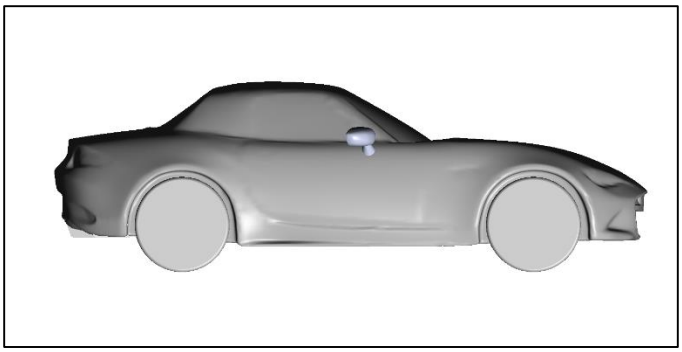

Figure 2.1.1: Geometry Simplifications – Side

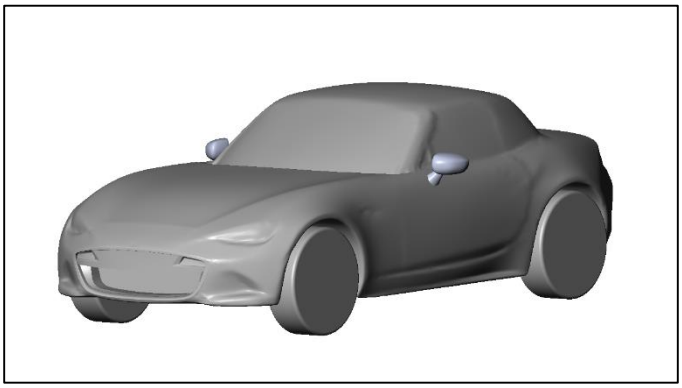

Figure 2.1.2: Geometry Simplifications – Isometric

### 2.2. Setup

Some physical components are removed from the analysis because it is not necessary for these cases. We are looking at the overall flow field around the ND Miata. As a result, the following simplifications were made to the model:

- No radiator flow
- No underhood flow
- No engine intake
- No exhaust flow

## 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. Furthermore, 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.

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ND Mazda Miata – Performance Gain of Rear Diffuser

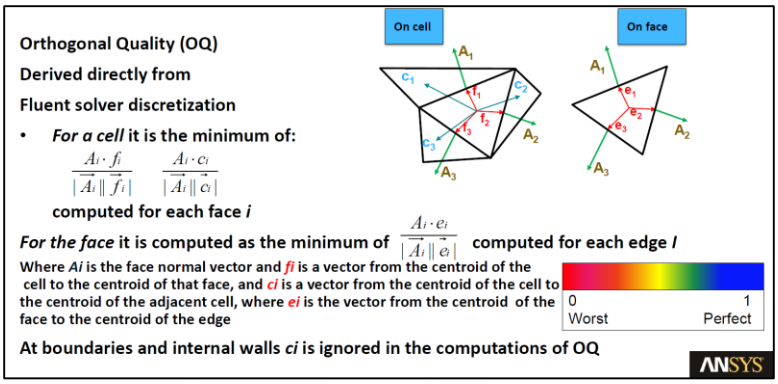


Figure 3.1.1: Orthogonal Quality Metrics

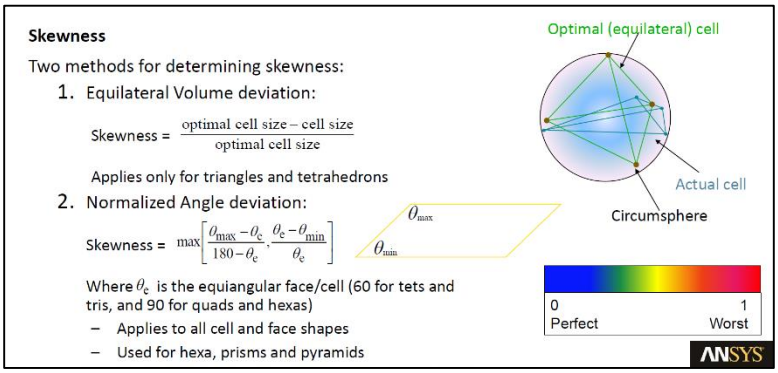


Figure 3.1.2: Skewness Quality Metrics

## 3.2. Quality

Low orthogonal quality and high skewness values are not recommended for a quality mesh. In general, we want an orthogonal quality greater than 0.1 and skewness below 0.95. This 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

**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

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### 3.3. Types of Mesh

There are two main mesh types, or grids: structured and unstructured. Unstructured grids are more commonly used for Verus Engineering applications since geometry and flow fields are complex.

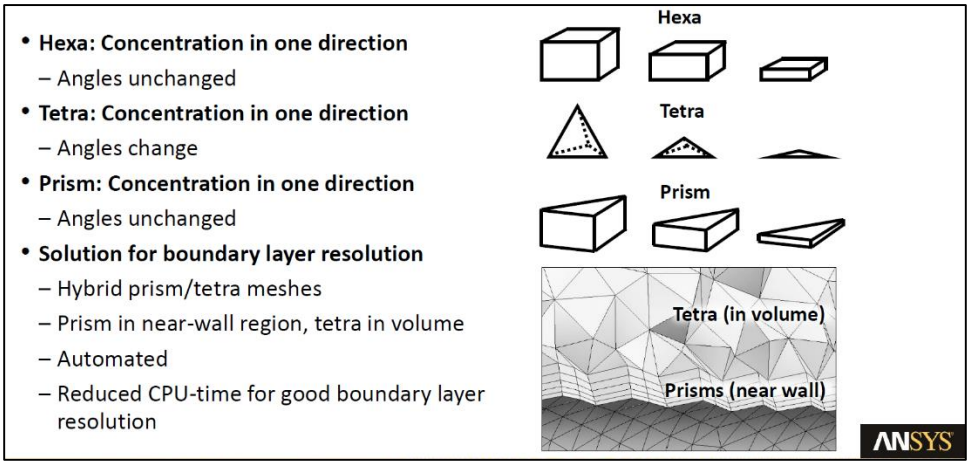


Figure 3.3.1: Hexahedral versus Tetrahedral

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

### 3.4. Mesh Quality of Miata

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 set up a quality grid for a proper solution and convergence.

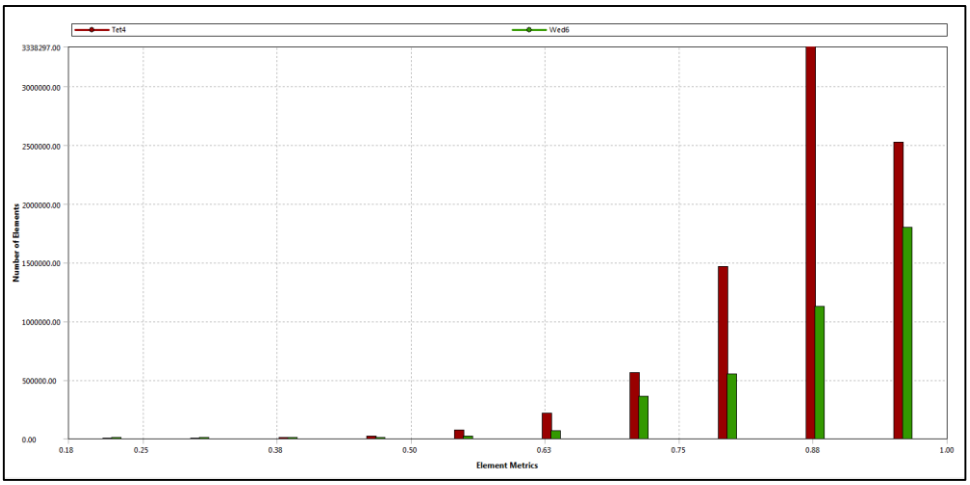


Figure 3.4.1: Mesh Quality of ND Miata

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Referring to Figure 3.4.1, orthogonal quality did not drop below 0.18. This is in the acceptable zone for orthogonal quality. The majority of the mesh is in the very good to excellent range.

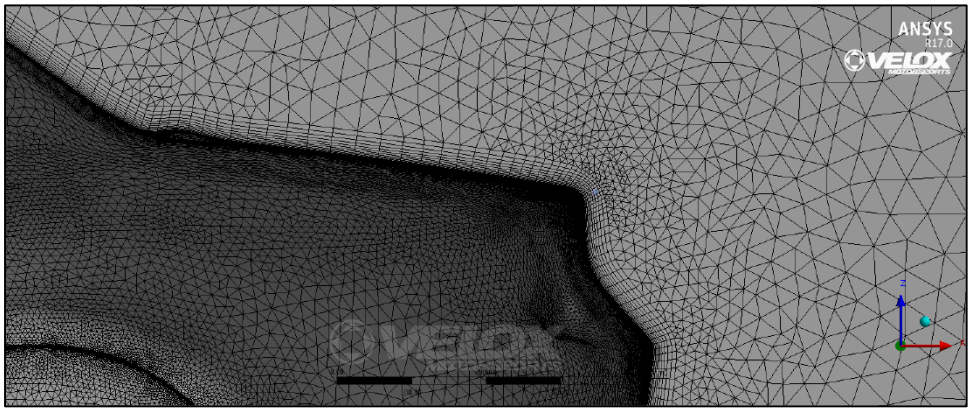


Figure 3.4.2: Mesh of the Rear of the Vehicle

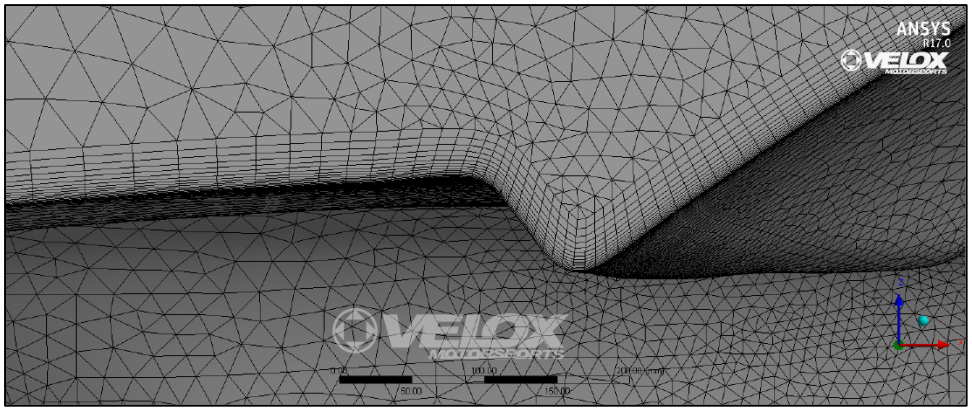


Figure 3.4.3: Mesh of the Hood to Windshield Interaction

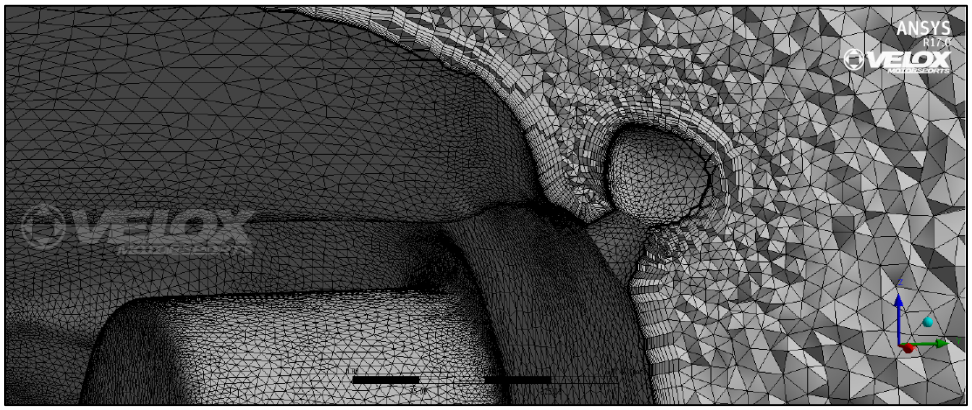


Figure 3.4.4: Mesh Section View around the Side Mirror

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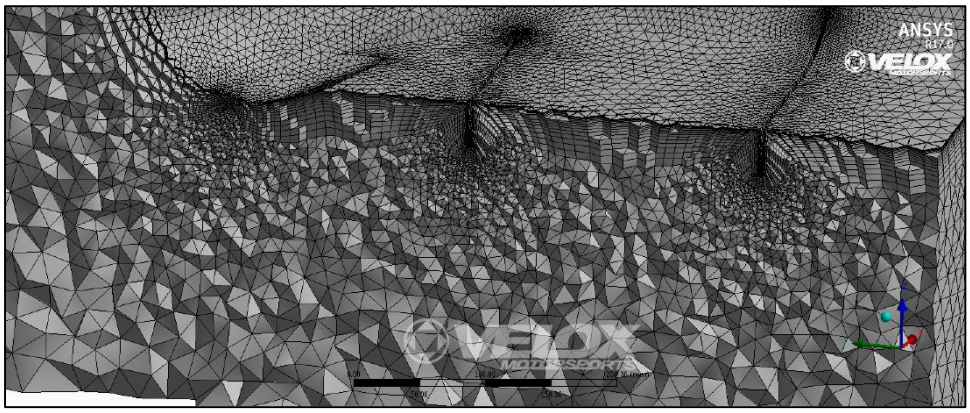


Figure 3.4.5: Mesh Section View of the Verus Engineering Diffuser

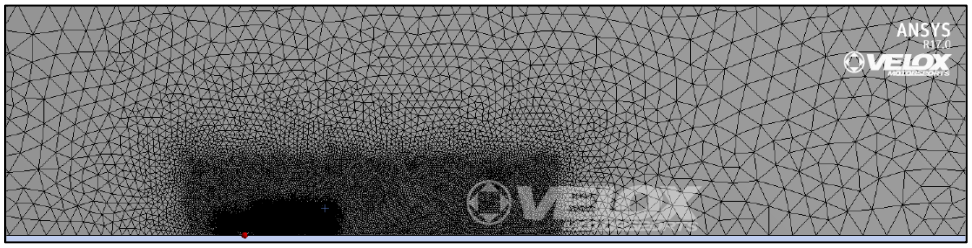


Figure 3.4.6: Mesh Wake Zone Refinement

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. Proper boundary conditions are a must for an accurate analysis. A full understanding of the physics of the problem is a must. CFD only emulates the condition of the road and track, it does not reproduce them. 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 set up as a rotational moving wall boundary.

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| | | |
|---|---|---|
| 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 |
| Miata | Wall Condition | No Slip Shear |
| Wheels | Wall Condition | 144 rad/s |

Figure 4.2.1: 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]

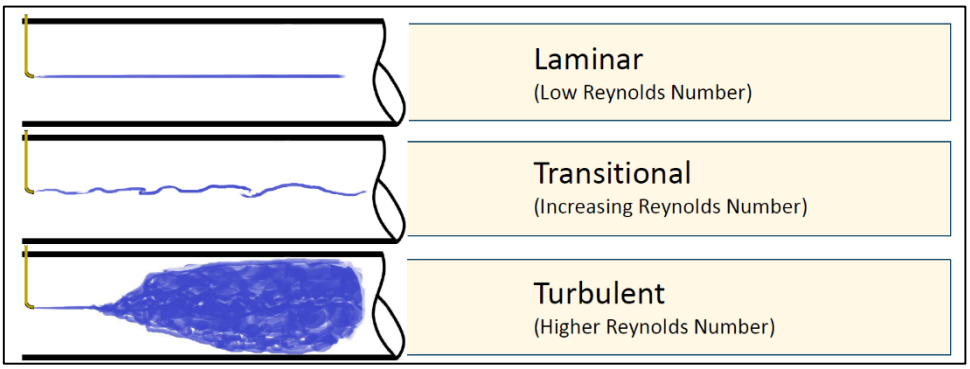


Figure 4.3.1: Flow Classifications

## 5. Results

### 5.1. Aerodynamic Coefficient Deltas

Deltas are what matter when dealing 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 |
|---|---|---|
| -0.001 | -0.055 | No Change, 45/55 Bal |

Figure 5.1.1: Aerodynamic Coefficient Deltas

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### 5.2. Aerodynamic Forces

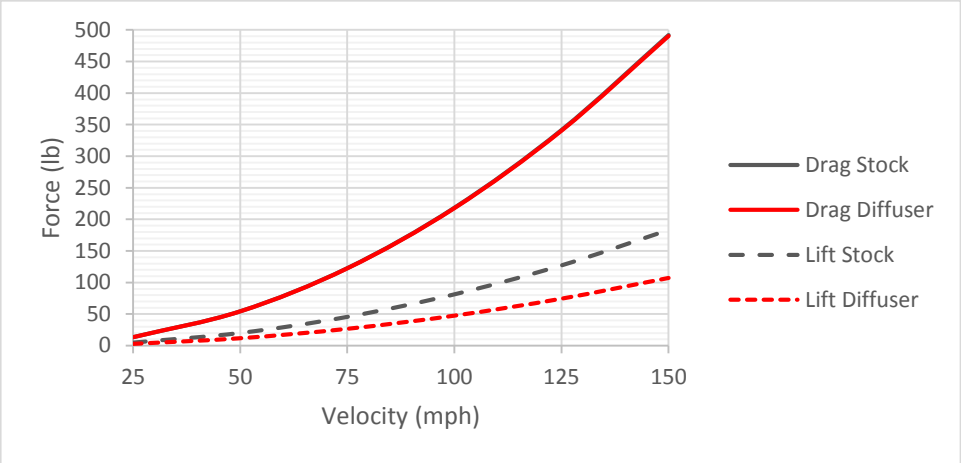


Figure 5.2.1: Aerodynamic Forces at Speed

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 ND Miata does not deviate from that standard. Notice Figure 5.2.1, the factory lift from the ND Miata is reduced.

### 5.3. Coefficient of Pressure Plots

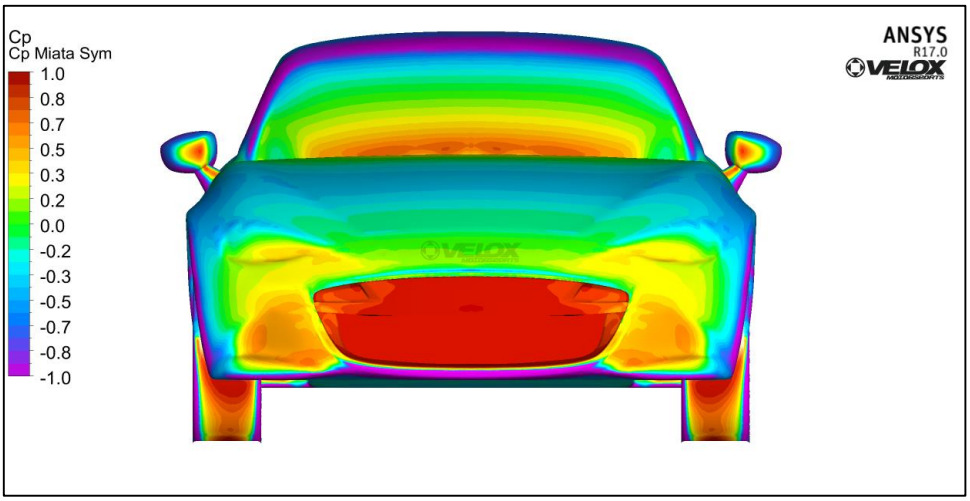


Figure 5.3.1: Cp Front

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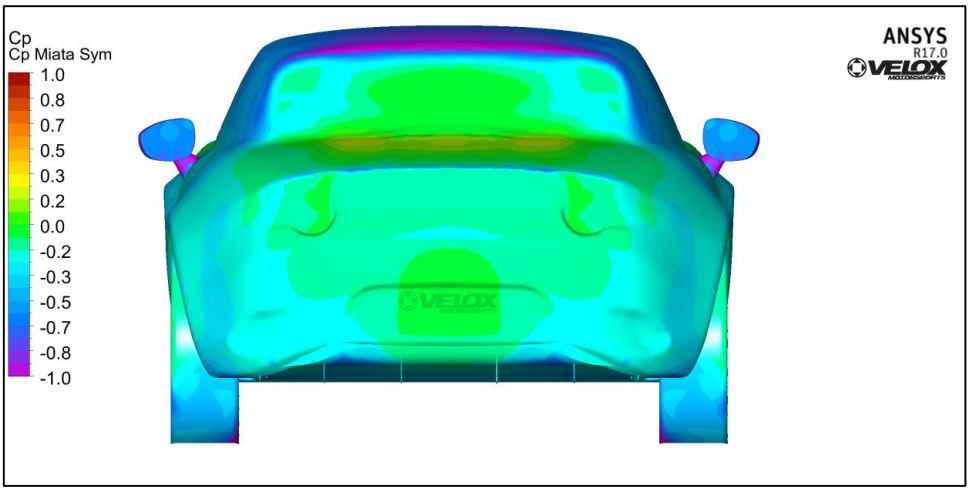


Figure 5.3.2: Cp Rear

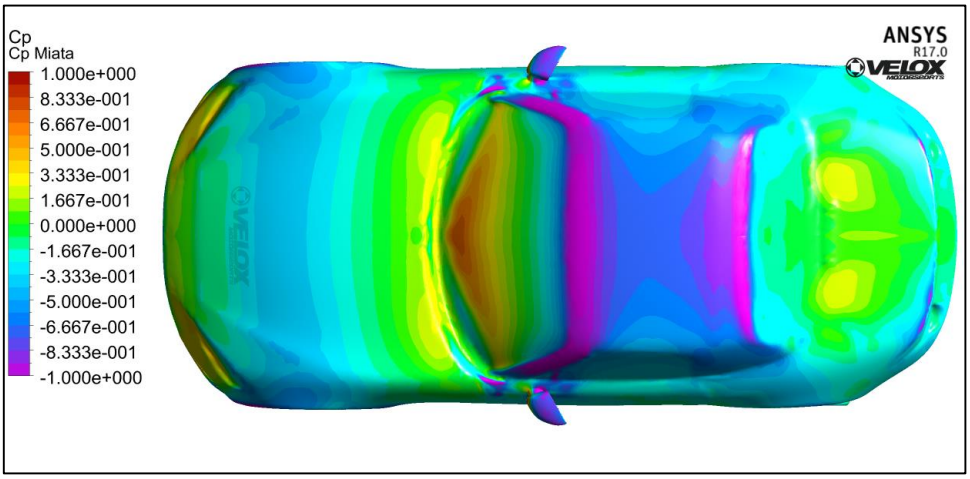


Figure 5.3.3: Cp Top

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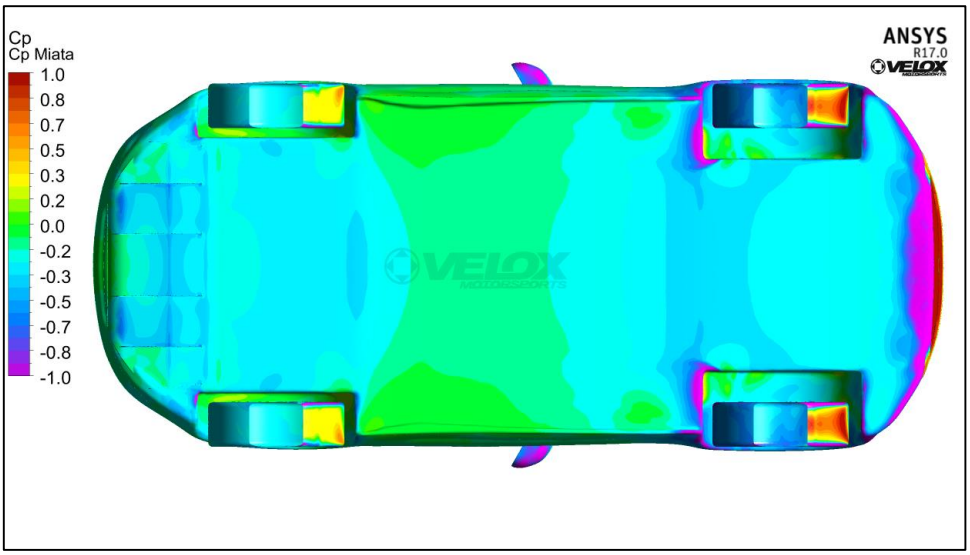


Figure 5.3.4: Cp Bottom

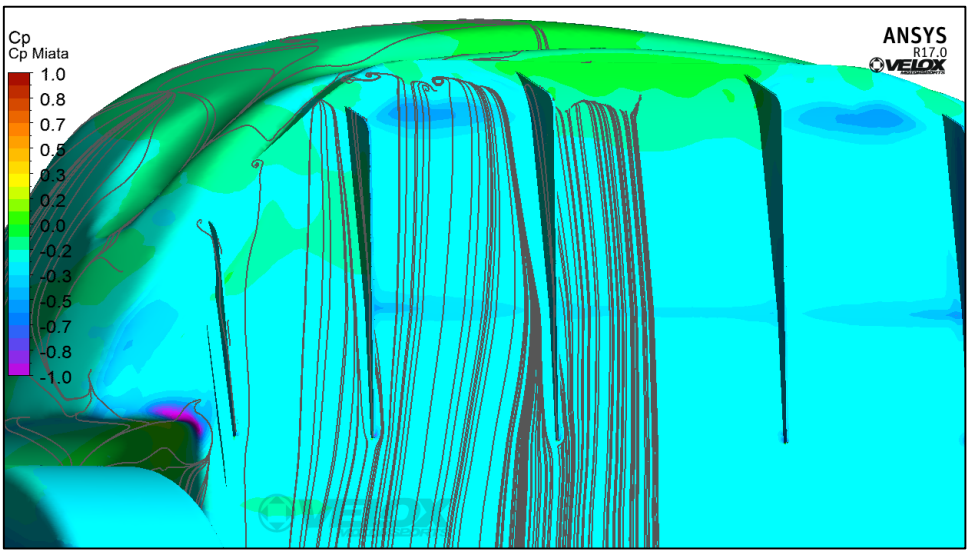


Figure 5.3.5: Cp Diffuser with Surface Streamlines

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### 5.4. Velocity Plots

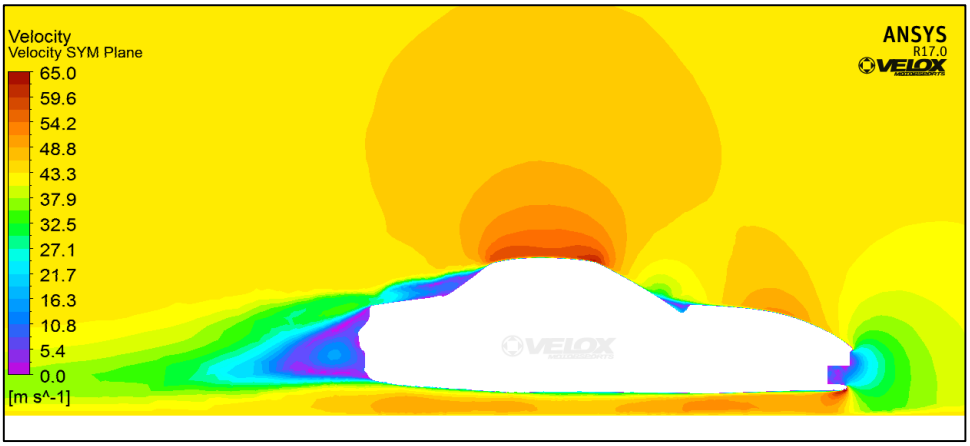


Figure 5.4.1: Velocity Plot Symmetry Plane

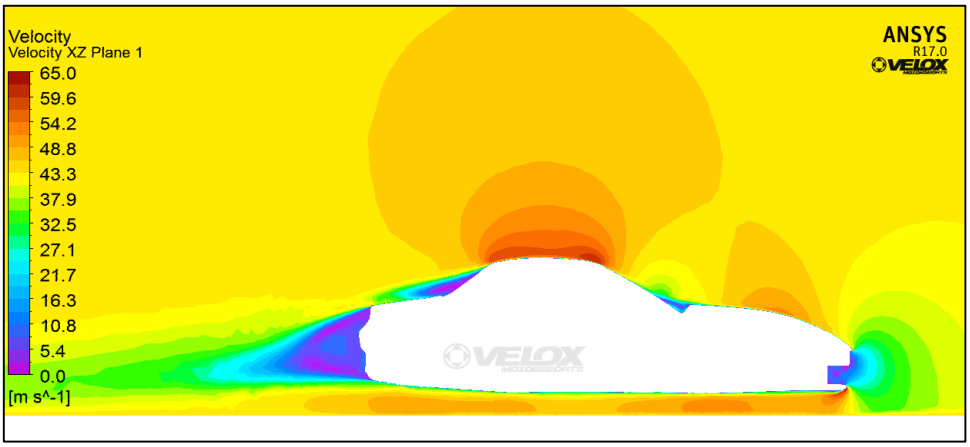


Figure 5.4.2: Velocity Plot XZ Plane 1 (Offset from Sym Plane 0.1m)

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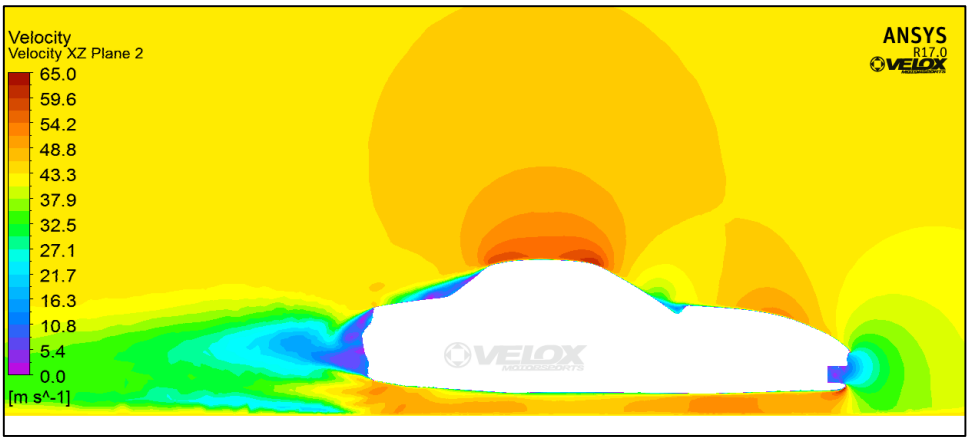


Figure 5.4.3: Velocity Plot XZ Plane 2 (Offset from Sym Plane 0.3m)

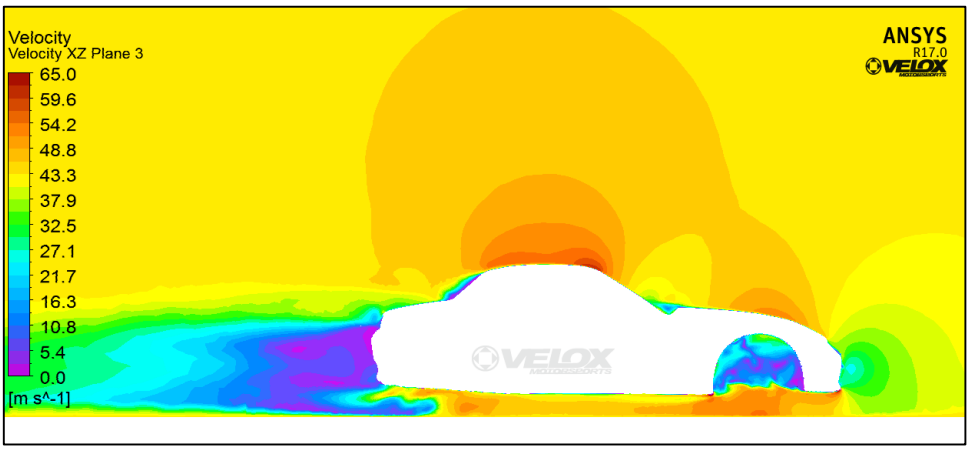


Figure 5.4.4: Velocity Plot XZ Plane 3 (Offset from Sym Plane 0.5m)

## 5.5. Vector Plots

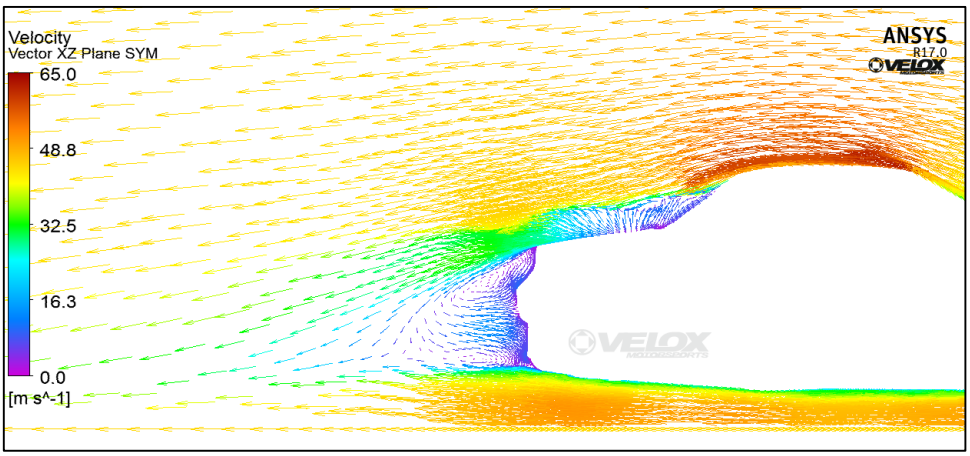


Figure 5.5.1: Vector Plot Symmetry Plane

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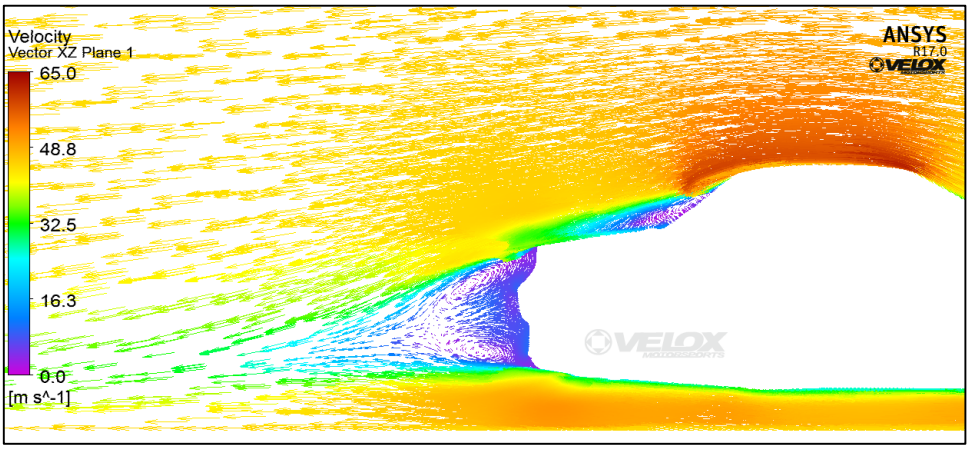


Figure 5.5.2: Vector Plot XZ Plane 1 (Offset from Sym Plane 0.1m)

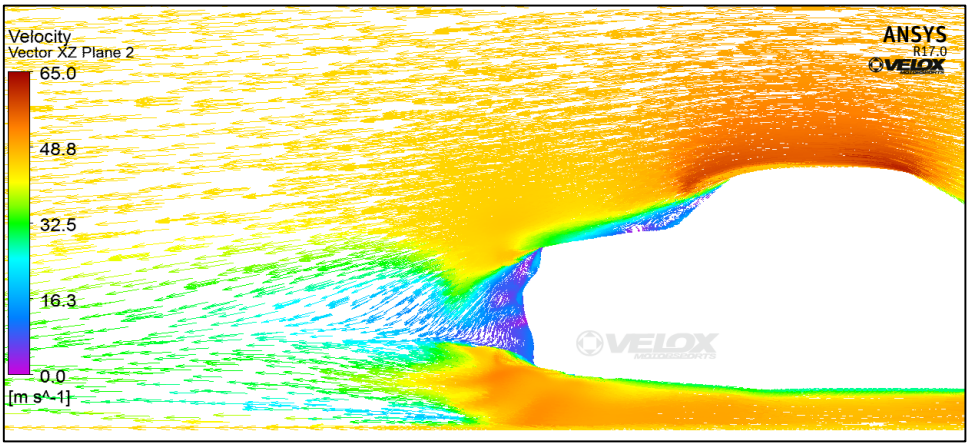


Figure 5.5.3: Vector Plot XZ Plane 2 (Offset from Sym Plane 0.3m)

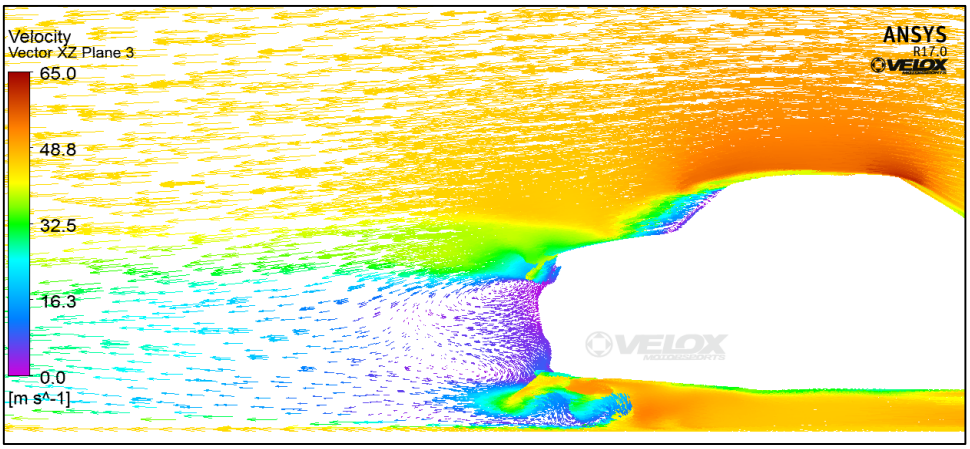


Figure 5.5.4: Vector Plot XZ Plane 3 (Offset from Sym Plane 0.5m)

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### 5.6. Turbulent Kinetic Energy Plots

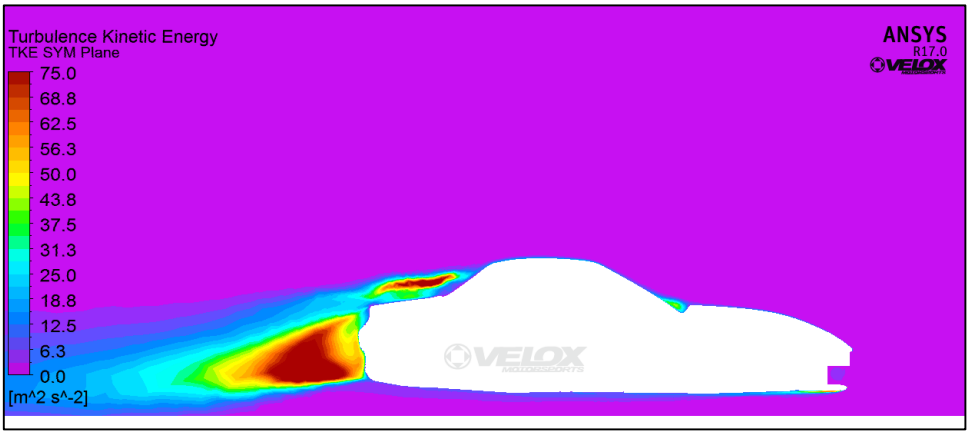


Figure 5.6.1: TKE Plot Symmetry Plane

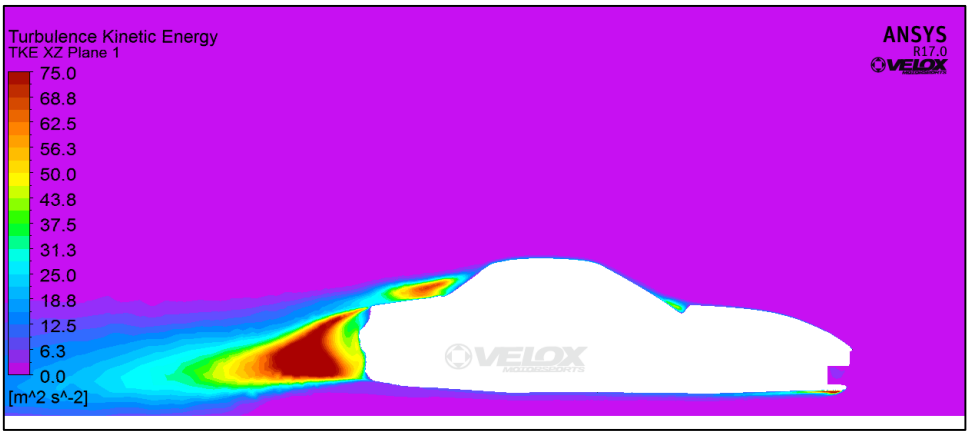


Figure 5.6.2: TKE Plot XZ Plane 1 (Offset from Sym Plane 0.1m)

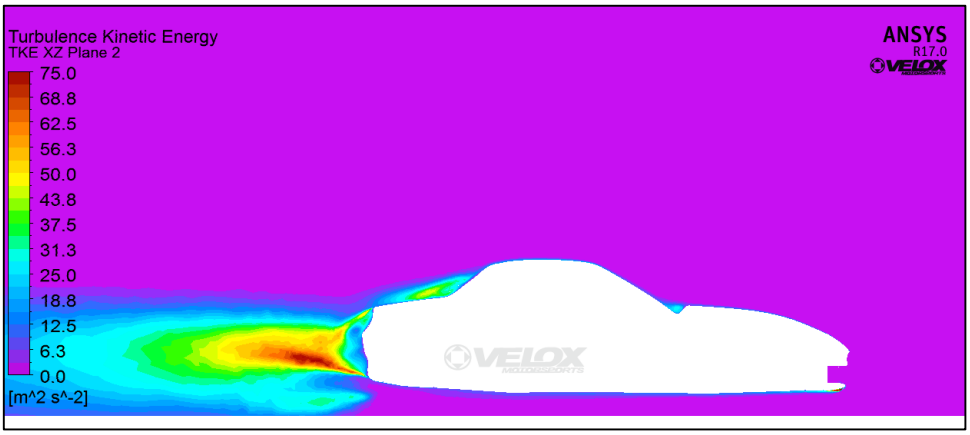


Figure 5.6.3: TKE Plot XZ Plane 2 (Offset from Sym Plane 0.3m)

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ND Mazda Miata – Performance Gain of Rear Diffuser

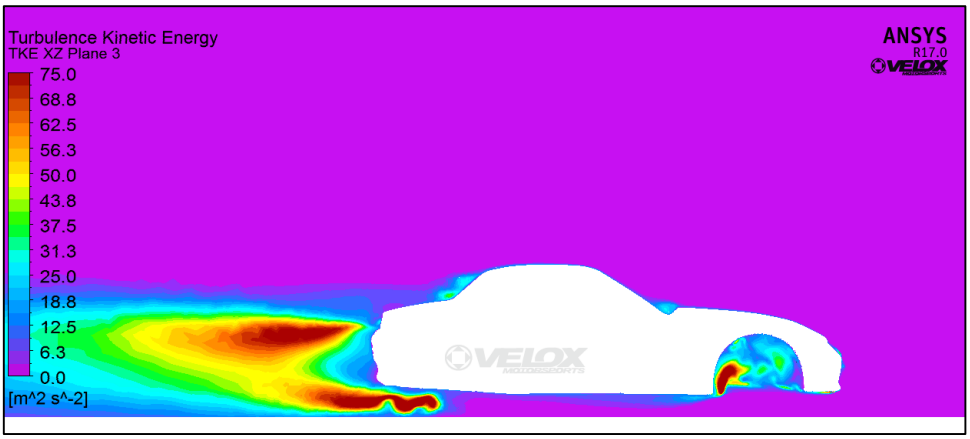


Figure 5.6.4: TKE Plot XZ Plane 3 (Offset from Sym Plane 0.5m)

### 5.7. Diffuser Plots

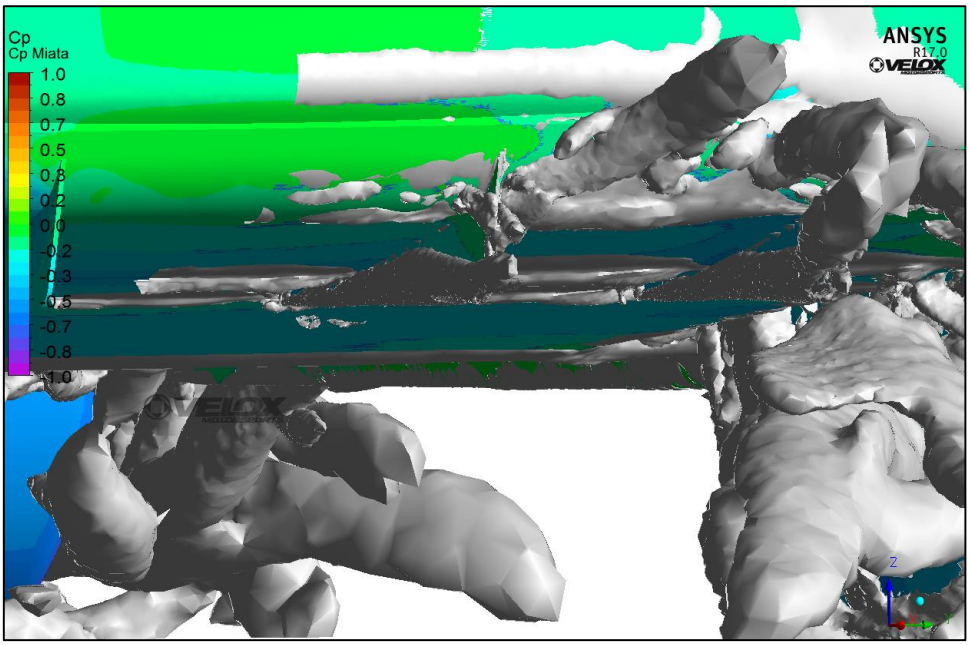


Figure 5.7.1: Q-Criterion Displays Vortices off the Diffuser

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ND Mazda Miata – Performance Gain of Rear Diffuser

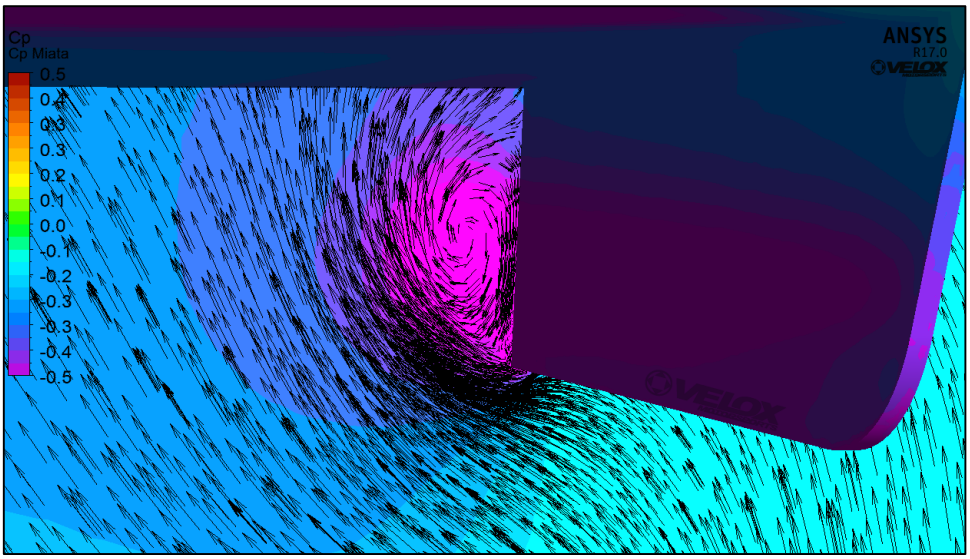


Figure 5.7.2: Vortex Formation on Strake

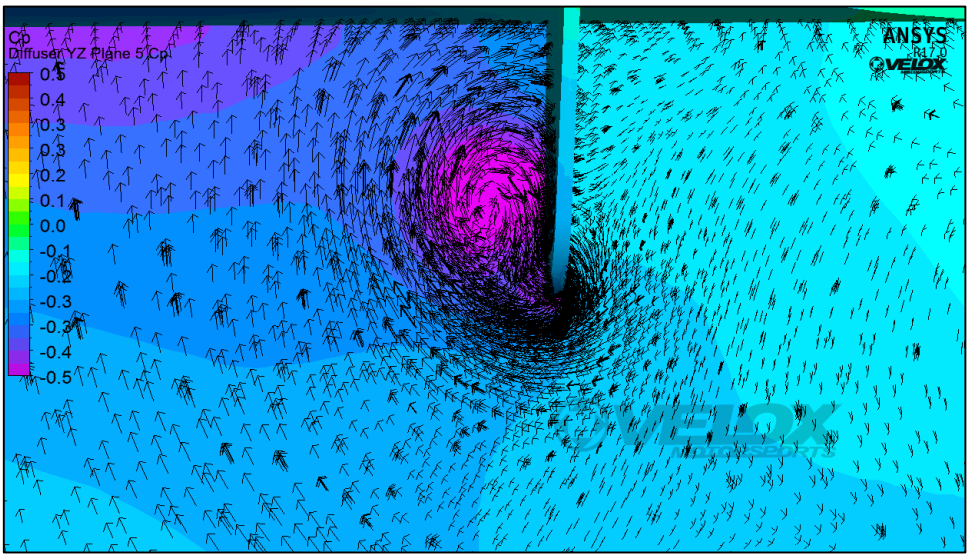


Figure 5.7.3: Vortex Formation on Strake

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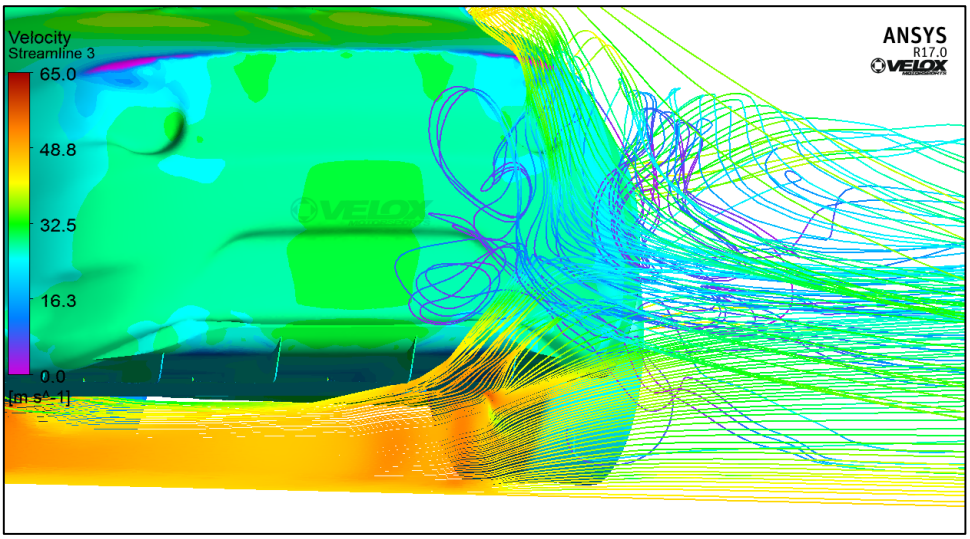


Figure 5.7.4: Streamlines Off the Diffuser

Notice on Figures 5.7.2-5.7.3 the vortex forming on the strake. In the core of the vortex is a low-pressure zone. These vortices help to keep flow attached on the rear diffuser. Figure 5.7.1 makes spotting vortices off the car easier. This helps us tremendously when focusing on optimizing components. The flow stays attached going up the diffuser in part from the strake vortices that can be seen in Figure 5.7.4.

## 6. ERRORS IN SIMULATION

### 6.1. Physical Model

Some of the errors in the physical model were discussed in Geometry Assumptions. The substitution of a CAD model from a real physical model is an inevitable source of error. The CAD model only also represents part of the physical system. Other errors are either represented with boundary conditions or are 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 a grid convergence study. [4]

## 7. VALIDATION

### 7.1. Physical Testing

Physical testing of the diffuser is the next step for validation. With the physical part on the ND Miata, pressure taps will be used in an array on the surface of the diffuser. These will be used to correlate the data from CFD. From there, flow vis will be used to compare to the wall shear stress vectors. With these two physical tests, we can compare results to our CFD analysis. At this time, validation of the analysis can be completed.

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8. CONCLUSION

The Verus Engineering diffuser decreased the overall lift and reduced drag of the ND Miata. Since the diffuser 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 where the diffuser is located and also created a lower pressure zone in the middle of the chassis. This equated to a very little change in aerodynamic balance. The Verus Engineering diffuser helps the ND Miata get more from the tires at the track and also increases gas mileage on a daily driver. The diffuser will be great on either a normal daily driver or a track rat.

In the future, we will be looking into improved performance with an aggressive diffuser for the ND Miata. We will use what we learned from this analysis and improve upon it. Stay tuned for future products and updates.

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## 9. REFERENCES

[1] Zikanov, Oleg. *Essential Computational Fluid Dynamics*. 1st Edition. Joh 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).
[4] Slater, John. 2008. Uncertainty and Error in CFD Simulations. https://www.grc.nasa.gov/WWW/wind/valid/tutorial/errors.html (Acessed 2016-09-20).

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