

# Simulation & Modelling Assignment Jake Mowbray

*by Jake Mowbray*

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Computational Fluid Dynamics: Ahmed Body Analysis

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### Abstract

The work aims to present and evaluate the results of computational fluid dynamic methods applied to the Ahmed body, 25-degree slant angle scenario through the use of the Ansys Workbench CFD package. Simulation runs are carried out in accordance with a meshing strategy for the purpose of validating measured lift and drag coefficients, the use of four turbulence models explore different interpretations of the configuration. A range of published material, specific to the Ahmed body scenario is utilised for the purpose of comparison.

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## Chapter 1 - The Essence of CFD

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Computational fluid dynamics is a specific science which operates through numerical analysis for the purpose of predicting fluid flow regimes. The successful utilization and application of CFD in conjunction with conventional methods can enable paramount development of structures affected by fluid flow. Ferziger and Peric (2002) suggest that CFD is being used more and more as an industrial design tool; however, they do acknowledge the need for CFD users to be well educated in numerical analysis and fluid mechanics. The need for user awareness during operation is proposed by Howard:

CFD has increased in importance and in accuracy; however, its predictions are never completely exact. Because many potential sources of error may be involved, one has to be very careful when interpreting the results produced by CFD techniques (Howard, 2012, p. 421).

The governing equations of CFD are based on the principles of Newton's laws and Reynold's theory, however taking the literal derivations are not suitable for application on countless finite elements. The equations are developed into differential form which account for many scenario descriptors: a perfect representation of a fluid's behavior will only be possible when every single affecting element can be included (Wah-Yen, et al., 2017). Anderson (2009) provides comprehensive work on CFD governing equation derivation and explains that various forms of the equations are required to obtain the most accurate result in a particular scenario.

The solving of aerodynamic coefficients with regards to the Ahmed body is a renowned CFD exercise, the simple car geometry is a standard in the automotive industry which is assessed for validation purposes (Guilmineau, 2008).

The CFD process includes:

- The definition of and environment, or geometry of which a fluid will flow through.
- The assignment of boundary conditions within the stated environment, velocity based inlets and pressure based outlets for example.
- The construction of a mesh within the bounds of the environment to which the software will apply the iterative solving process to each and every cell, or element.
- The CFD software will provide a solution after applying mathematical techniques.
- The solution will be post-processed to enable a visual representation of the predicted fluid flow to enable comparison and informed design decision making (Al-Baali & Farid, 2006).

## Chapter 2 - Investigation

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### Sim\_1 K-Epsilon Realizable Base

05/03/2019

The intention of an initial CFD simulation run is to define the fluid mechanics scenario by applying known conditions and assumptions of mesh refinement to obtain a ballpark result; this will provide some direction in terms of areas requiring further definition. A course global mesh of 0.1m is used.

A successful run of the initial simulation has yielded some sensible results which is an indication that the geometry, meshing and solver setups are correct. The solved coefficient values for lift and drag are 0.28407 and 0.46442 respectively, as shown in Figure 1. The values are in the region of the actual wind tunnel results, so to speak. They may not be an accurate interpretation of the true fluid mechanics; however, they are of the same numerical order which supports the assumption of a correct simulation setup. The Fluent results viewer is used to attain a general idea of airflow structures around the Ahmed body. Figure 2 clearly shows the 40m/s about the inlet which gradually reduces upon approach to the body. A higher velocity is seen about the front radius and rear slant separation points. The trailing wake is observed as a low velocity which increases towards the outlet. The presence of significantly jagged contours are noted; this is due to the course mesh used. The contours of static pressure shown in Figure 3 are as expected. It is noted that there is no change in pressure around the rear leg of the Ahmed body, this may indicate the need of further mesh refinement. The presence of an immediate backing up of pressure upon inlet along with a non-returning to zero pressure upon exit is also noted; this indicates the need for a larger fluid volume in front and behind the Ahmed body to allow for unhindered entry and fully diffused exit. Figure 4 shows the results of developing a familiarisation with the Ansys post processor; streamlines, swirling strength, volume rendering and contours of pressure are included to showcase the fluid behaviour display options.

| iter | continuity            | x-velocity | y-velocity | z-velocity | k          | epsilon    | C1-1       | Cd-1       | time/iter   |
|------|-----------------------|------------|------------|------------|------------|------------|------------|------------|-------------|
| 79   | solution is converged |            |            |            |            |            |            |            |             |
| 79   | 8.5588e-04            | 3.7784e-06 | 1.9828e-06 | 1.9470e-06 | 2.9610e-04 | 7.1491e-05 | 2.8403e-01 | 4.6436e-01 | 0:00:25 200 |
| 80   | solution is converged |            |            |            |            |            |            |            |             |
| 80   | 8.1169e-04            | 3.5769e-06 | 1.8925e-06 | 1.8634e-06 | 2.7452e-04 | 6.6212e-05 | 2.8407e-01 | 4.6442e-01 | 0:00:20 199 |

Figure 1- Sim\_1 Coefficient Values

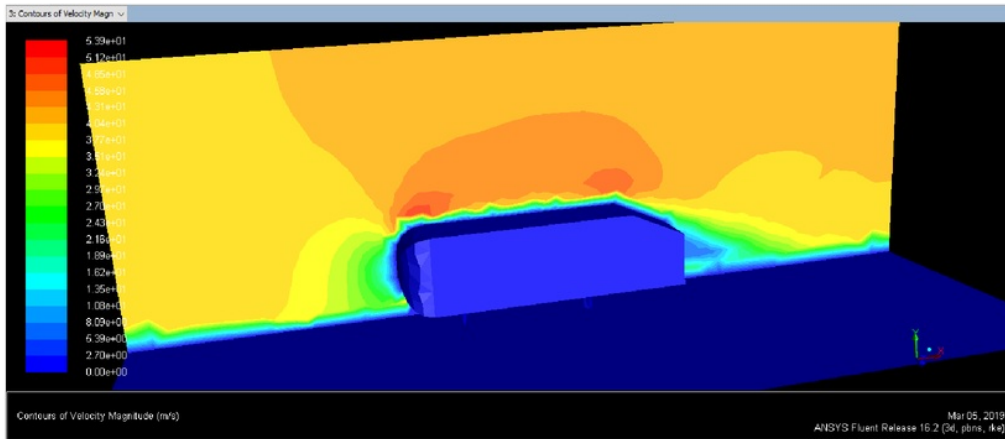


Figure 2 - Sim-1 Contours of Velocity Magnitude

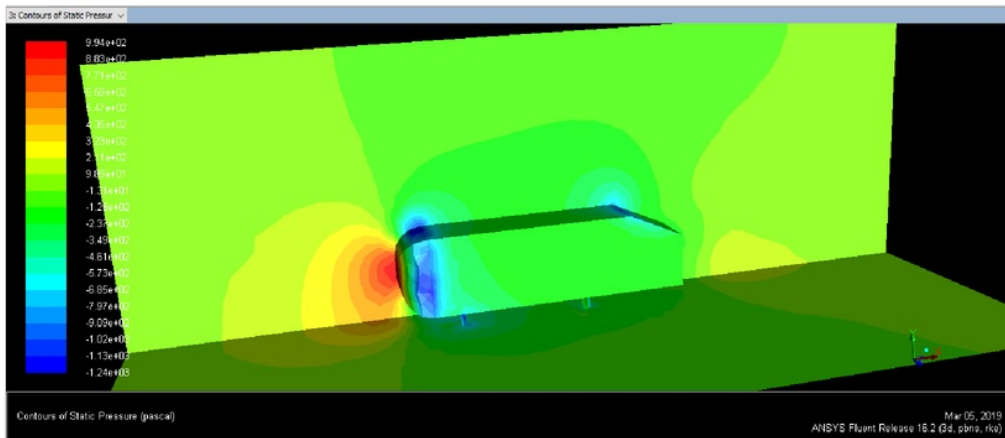


Figure 3 – Sim\_1 Contours of Static Pressure

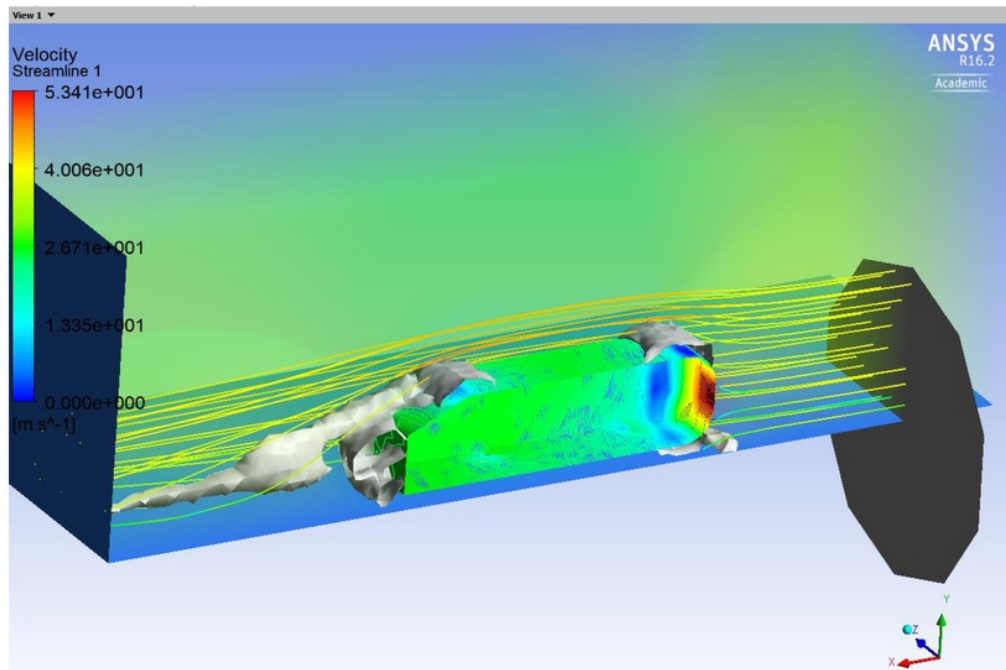


Figure 4 - Sim\_1 Post Processor Results

## Sim\_2 K-Epsilon Realizable Revised v1 12/03/2019

After consideration of the initial simulation results; the fluid volume dimensions are increased in length and height to, 6m long x 2m tall x 1m wide. The mesh view shown in Figure 5 highlights a large density box containing elements of 0.025m for the purpose of better capturing the flow structures about the Ahmed body. The lift and drag coefficient values are 0.35755 and 0.30896 respectively, they are again sensible and strikingly close to the actual wind tunnel values, Figure 6 (\*\*mesh ref\*\*) The nature of the air velocity is seen to be better developed in Figure 7; there is now sufficient volume in front of the Ahmed body, this enables the air to travel unhindered and maintain 40m/s for more than a meter. The wake region also seems to be captured sufficiently with regards to the settling of velocity on approach to the outlet. Figure 8 shows a slight backing up of pressure between the inlet and Ahmed body and a nominalised pressure towards the outlet. It is noted that the wake trail pressure diffusion is considerably near to the outlet; the trail may indeed be longer but the software is forcing a premature ramp down in pressure. The post processor results shown in Figure 9 clearly highlight unsettled air streams. The swirling discriminant is a method of identifying local vortex regions; the residual wake is captured and shown clearer than with streamlines. The ratio within the Ansys post processor for the swirling discriminant is set to 0.0758064 for this simulation and all further simulations to allow equivalent comparability.

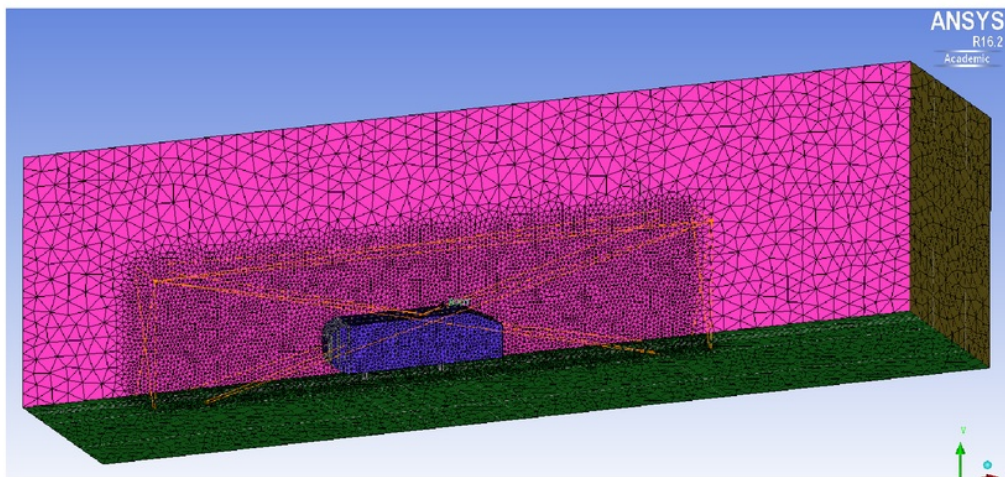


Figure 5 - Sim\_2 Mesh Revision

| iter  | continuity            | x-velocity | y-velocity | z-velocity | k          | epsilon    | C1-1       | Cd-1       | time/iter  |
|-------|-----------------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 133   | 1.8990e-03            | 2.6353e-06 | 1.3098e-06 | 1.3611e-06 | 4.3770e-04 | 1.3358e-04 | 3.5751e-01 | 3.0893e-01 | 0:02:09 67 |
| 134   | 1.0637e-03            | 2.5591e-06 | 1.2721e-06 | 1.3204e-06 | 4.2377e-04 | 1.2830e-04 | 3.5752e-01 | 3.0893e-01 | 0:02:08 66 |
| 135   | 1.0304e-03            | 2.4835e-06 | 1.2352e-06 | 1.2808e-06 | 4.1822e-04 | 1.2323e-04 | 3.5753e-01 | 3.0894e-01 | 0:02:07 65 |
| 136   | 1.0009e-03            | 2.4114e-06 | 1.1982e-06 | 1.2411e-06 | 3.9701e-04 | 1.1831e-04 | 3.5754e-01 | 3.0895e-01 | 0:02:06 64 |
| † 137 | solution is converged |            |            |            |            |            |            |            |            |
| 137   | 9.7175e-04            | 2.3420e-06 | 1.1629e-06 | 1.2016e-06 | 3.8413e-04 | 1.1353e-04 | 3.5755e-01 | 3.0896e-01 | 0:02:04 63 |

Figure 6 - Sim\_2 Coefficient Values

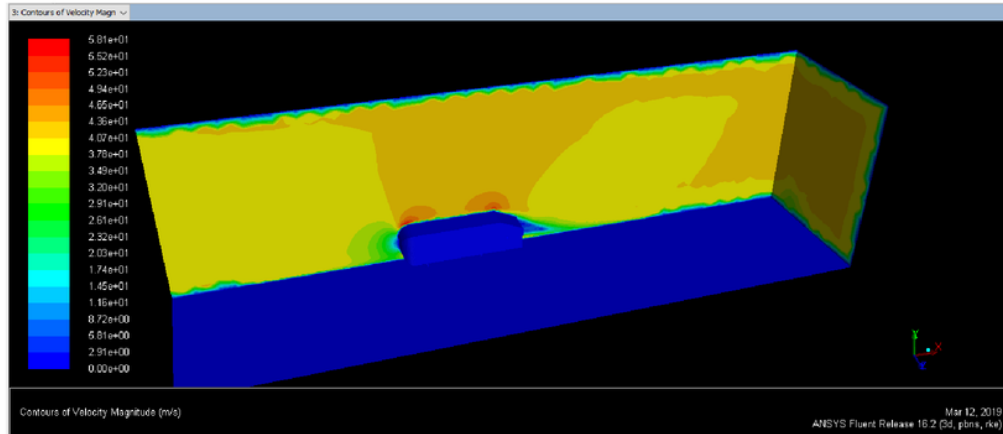


Figure 7 - Sim\_2 Contours of Velocity Magnitude

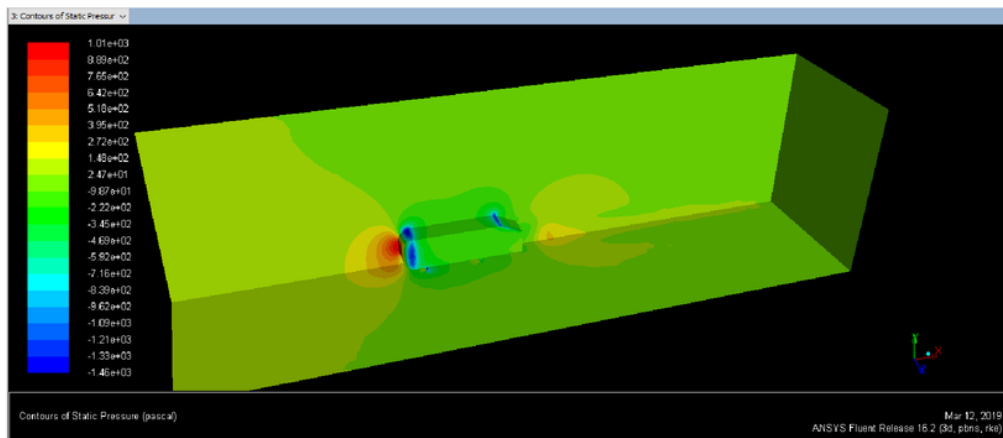


Figure 8 - Sim\_2 Contours of Static Pressure

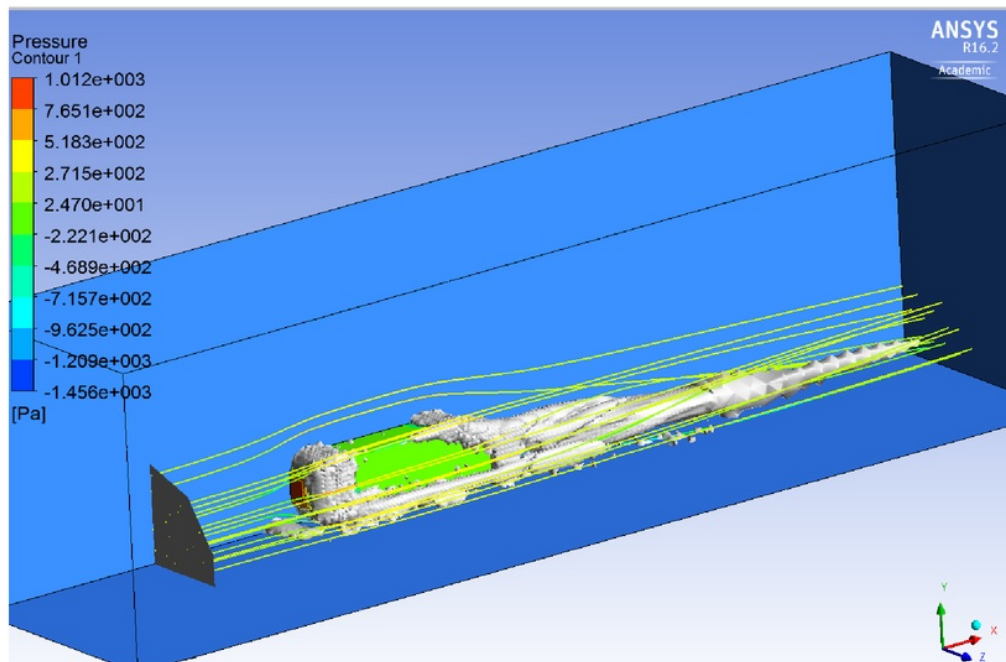


Figure 9 - Sim\_2 Post Processor Results

## Sim\_3 K-Epsilon Realizable Revised v2

12/03/2019

The length of the fluid volume is extended by 1.5m in response to the findings of the previous simulation, the observed disadvantage of this is an increase in per iteration solving time. The lift and drag coefficient values are 0.39892 and 0.35471 respectively, Figure 10. The flow structures surrounding the Ahmed body seem to be well captured on the whole, Figure 11 and Figure 12. Some velocity flux does remains and can be seen on the outlet face; be that as it may, the streamlines are seen to straighten out and the swirling discriminant is diminished before reaching the outlet. Therefore, the overall length of the geometry bounds will be reduced by 1 meter to conserve computational power and decrease the overall solving time.

| iter  | continuity            | x-velocity | y-velocity | z-velocity | k          | epsilon    | C1-1       | Cd-1       | time/iter  |
|-------|-----------------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 155   | 1.8570e-03            | 1.4887e-06 | 8.4675e-07 | 9.1233e-07 | 1.8623e-04 | 7.7255e-05 | 3.9916e-01 | 3.5479e-01 | 0:01:38 45 |
| 156   | 1.8932e-03            | 1.3714e-06 | 8.3191e-07 | 8.9446e-07 | 1.7953e-04 | 7.5181e-05 | 3.9908e-01 | 3.5476e-01 | 0:01:28 44 |
| 157   | 1.8153e-03            | 1.3438e-06 | 8.1970e-07 | 8.7795e-07 | 1.7321e-04 | 7.3778e-05 | 3.9891e-01 | 3.5473e-01 | 0:01:26 43 |
| † 158 | solution is converged |            |            |            |            |            |            |            |            |
| 158   | 9.9592e-04            | 1.3196e-06 | 8.0672e-07 | 8.6851e-07 | 1.6726e-04 | 7.2817e-05 | 3.9892e-01 | 3.5471e-01 | 0:01:24 42 |

Figure 10 - Sim\_3 Coefficient Values

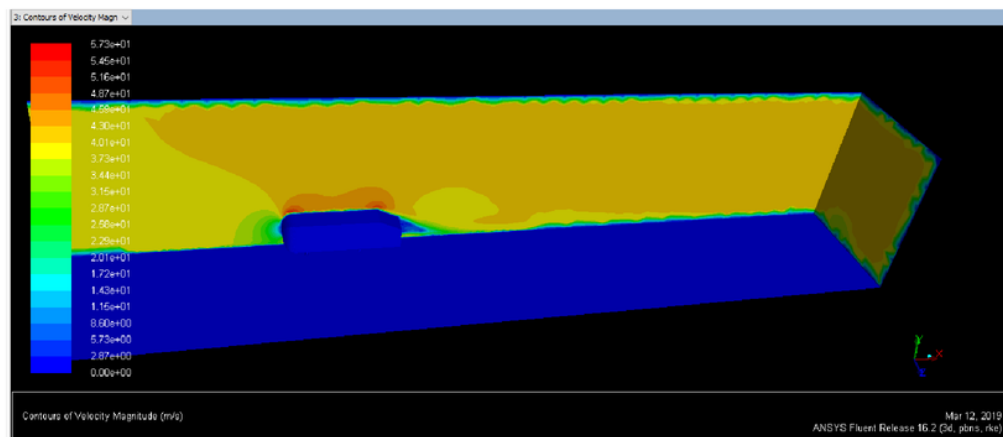


Figure 11 - Sim\_3 Contours of Velocity Magnitude

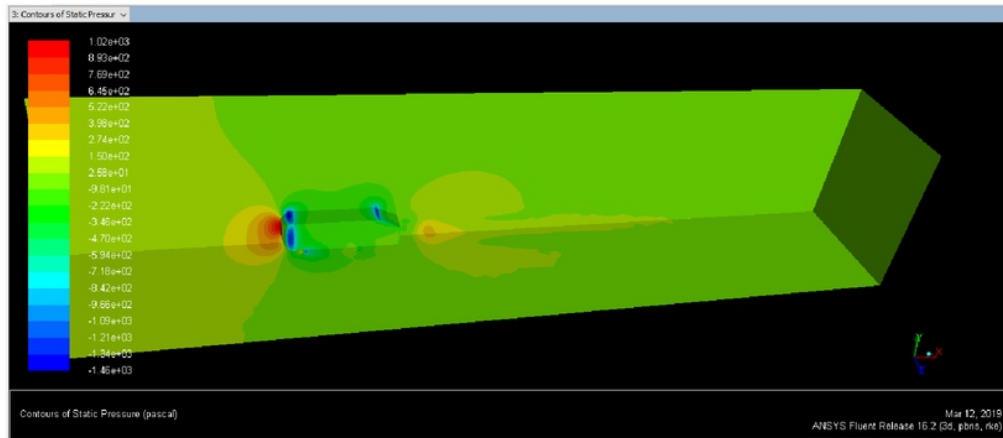


Figure 12 - Sim\_3 Contours of Static Pressure

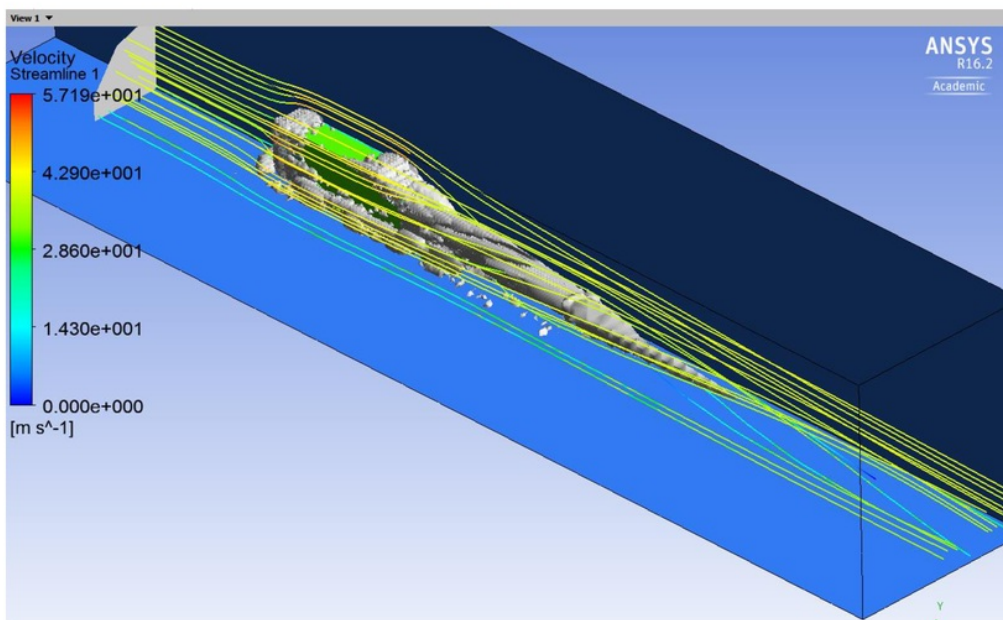


Figure 13 - Sim\_3 Post Processor Results

## Sim\_4 K-Epsilon Realizable Revised v3 &amp; 3 Prism Layers

19/03/2019

The simulation fluid domain geometry and mesh refinement has reached an acceptable position of compromise; in other words, the limits of the study have been calculated by the availability of time and computational power. The density box which encapsulates the whole Ahmed body has decreased in refinement to 0.04m and a new, smaller density box placed about the rear slant is set to a refinement value of 0.025m. Upon checking the orthogonal quality, aspect ratio and skew an unacceptable number of obscure cells are highlighted between the Ahmed body and the floor, shown in Figure 14. The challenge of creating a suitably structured mesh around a three dimensional body is considerable with the inclusion of curved faces. Blazek (2015) describes how the mesh is used as a guide for the governing equations and that the accuracy of the delivered solution is dependent on the quality of the mesh. Therefore, it is considered appropriate to analysis and initiate refinement of the skewed cells to assure solution accuracy. Ansys (2017) state that minimum orthogonal quality is to be more than 0.1, or maximum skewness to be less than 0.95. It is acknowledged that these values may differ depending on the constraints of the particular situation. To resolve the issue, an additional density box of value 0.015m is added to the area between the Ahmed body and the floor. The methodology behind utilising a finer mesh size is to ensure the tightly curved leg geometry is accurately captured, which lends itself towards accurately predicting the flow structures in that area. The results of further refinement are shown in Figure 15 and Figure 16; a handful of low quality cells remain with only two below target for orthogonal and some twenty below target for skew.

Lanfrit (2005) states that flat regions should be resolved using prismatic layers; this is to accurately capture the workings of the boundary layer. This area is described as the interaction layer between surface and fluid, as Douglas et al. states:

At the interface between a fluid and a surface in relative motion a condition known as 'no slip' dictates an equivalence between fluid and surface velocities. Away from the surface the fluid velocity rapidly increases; the zone in which this occurs is known as the boundary layer and its definitions is fundamental to all calculations of surface drag and viscous forces (Douglas, et al., 1995, p. 327).

Three prism layers of 0.01m height and 20% growth rate are applied to the floor and external surface of the Ahmed body in a specific effort to capture those boundary layer workings. The lift and drag coefficient values are 0.36385 and 0.35456 respectively, Figure 17. The pressure results shown in Figure 18 continue to display the backing up of pressure in front of the Ahmed body. A considerably larger fluid domain geometry would be required to address this matter; however, the additional

computational resource requirement as mentioned previous would impede the purpose of the investigation. Figure 19 clearly shows a swirling among the streamlines which identifies the c-pillar vortex, the swirling discriminant propagation about the rear slant seems to accurately locate the pillar's foundation through flow detachment (Vino, et al., 2005). It is noted that the introduction of prism layers has presented far greater detail of flow disturbances about the Ahmed body, particularly the front curves, legs and slant, shown in Figure 19. Figure 20 shows the varying velocities across the surfaces clearly and better defined separation points.

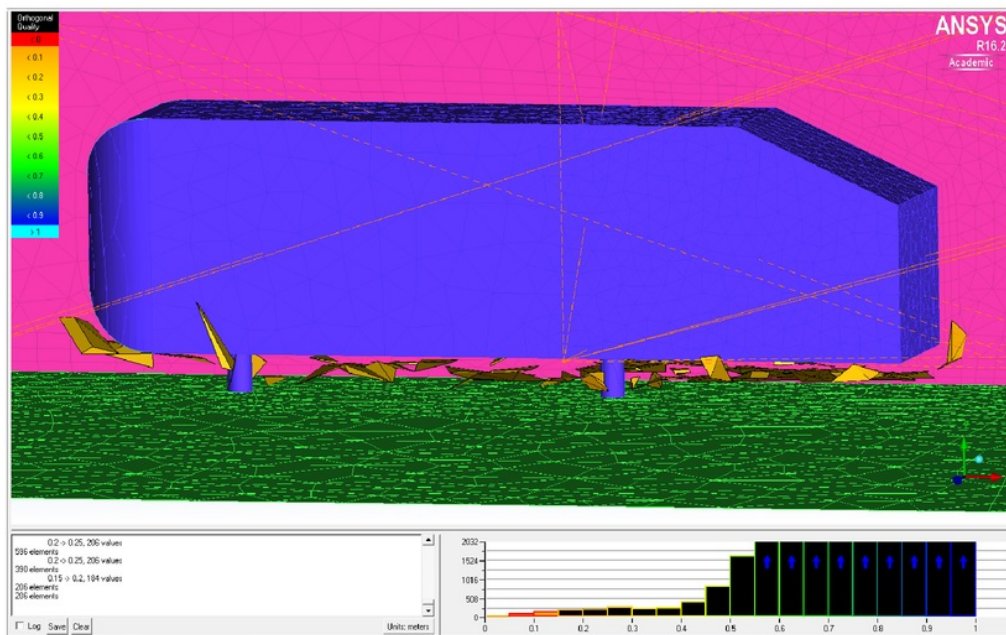


Figure 14 - Sim\_4 Orthogonal Quality

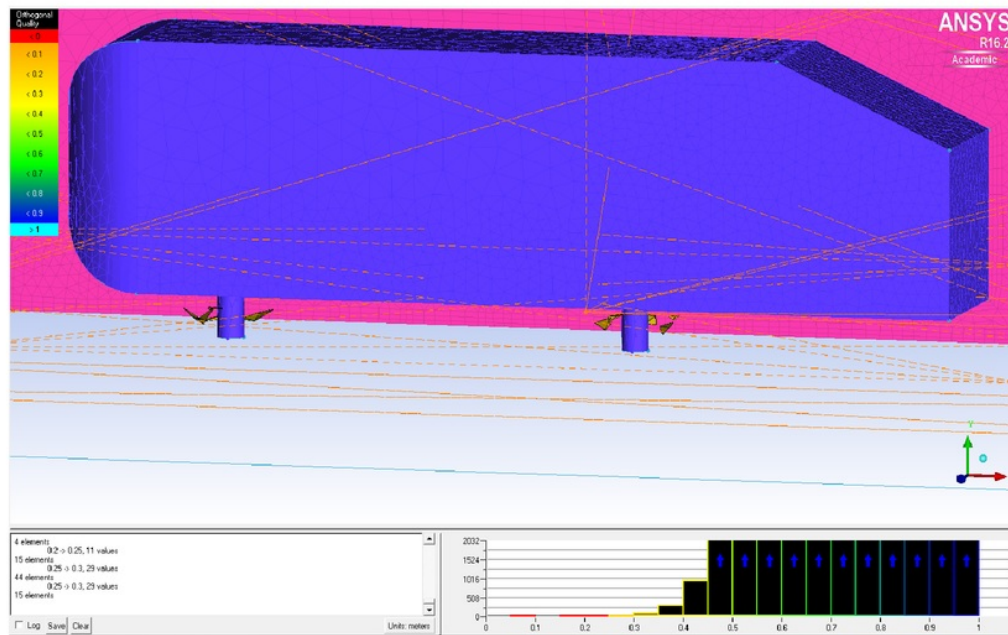


Figure 15 - Sim\_4 Orthogonal Quality Revised

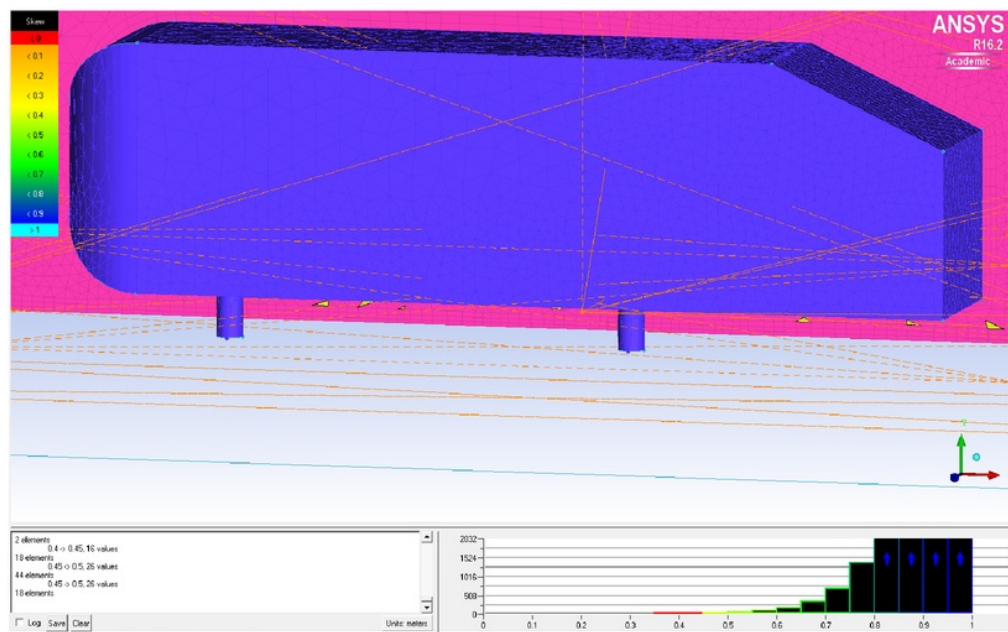


Figure 16 - Sim\_4 Skew

| iter  | continuity            | x-velocity | y-velocity | z-velocity | k          | epsilon    | C1-1       | Cd-1       | time/iter  |
|-------|-----------------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 188   | 1.2370e-03            | 2.8031e-06 | 1.1626e-06 | 1.1069e-06 | 7.3543e-04 | 3.3902e-04 | 3.6383e-01 | 3.5369e-01 | 0:00:52 12 |
| 189   | 1.1900e-03            | 2.7060e-06 | 1.1200e-06 | 1.0642e-06 | 7.2328e-04 | 3.3069e-04 | 3.6385e-01 | 3.5384e-01 | 0:00:47 11 |
| 190   | 1.1468e-03            | 2.6166e-06 | 1.0825e-06 | 1.0282e-06 | 7.1121e-04 | 3.2239e-04 | 3.6386e-01 | 3.5398e-01 | 0:00:42 10 |
| 191   | 1.1089e-03            | 2.5334e-06 | 1.0477e-06 | 9.9594e-07 | 6.9897e-04 | 3.1412e-04 | 3.6386e-01 | 3.5411e-01 | 0:00:38 9  |
| 192   | 1.0742e-03            | 2.4538e-06 | 1.0148e-06 | 9.6624e-07 | 6.8660e-04 | 3.0587e-04 | 3.6386e-01 | 3.5424e-01 | 0:00:33 8  |
| 193   | 1.0439e-03            | 2.3776e-06 | 9.8398e-07 | 9.3939e-07 | 6.7412e-04 | 2.9769e-04 | 3.6386e-01 | 3.5435e-01 | 0:00:29 7  |
| 194   | 1.0158e-03            | 2.3005e-06 | 9.5450e-07 | 9.1435e-07 | 6.6156e-04 | 2.8962e-04 | 3.6386e-01 | 3.5446e-01 | 0:00:25 6  |
| † 195 | solution is converged |            |            |            |            |            |            |            |            |
| 195   | 9.9036e-04            | 2.2246e-06 | 9.2622e-07 | 8.9115e-07 | 6.4899e-04 | 2.8170e-04 | 3.6385e-01 | 3.5456e-01 | 0:00:20 5  |

Figure 17 - Sim\_4 Coefficient Values

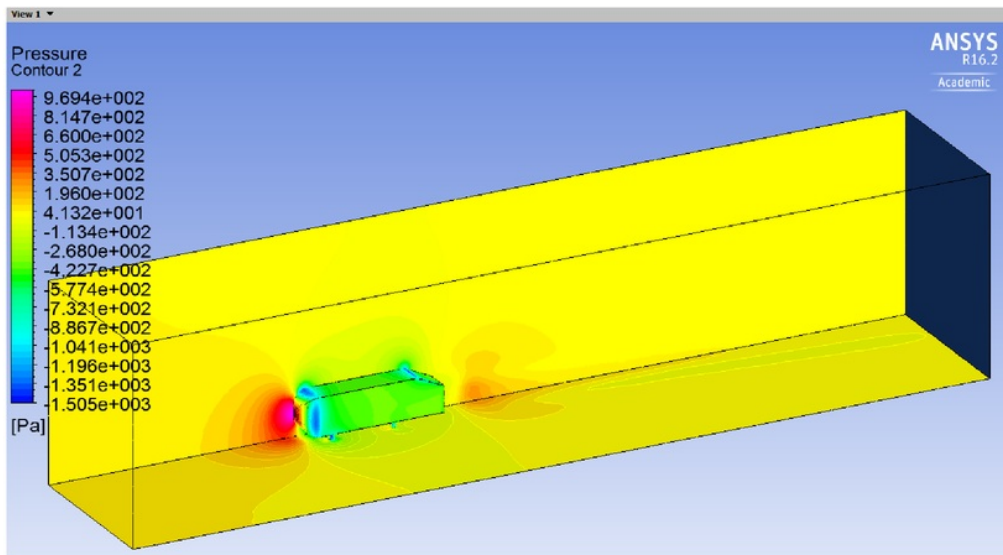


Figure 18 - Sim\_4 Post Processor Pressure Contours

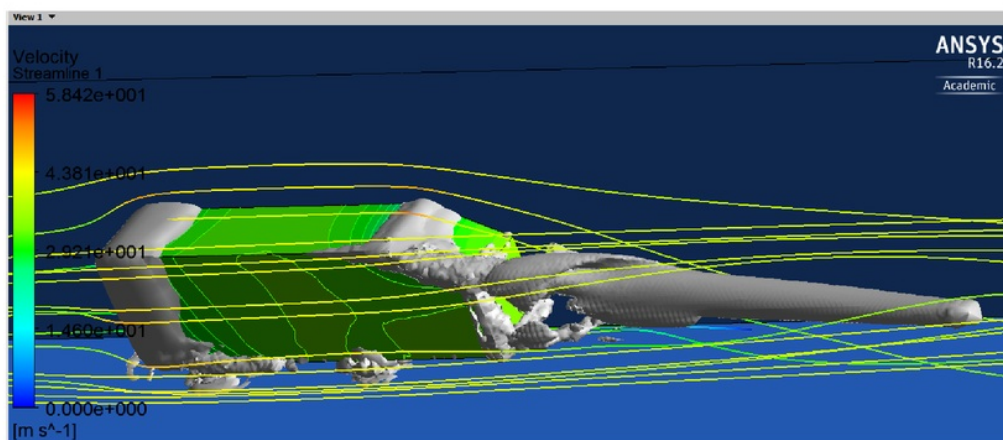


Figure 19 - Sim\_4 Post Processor Results

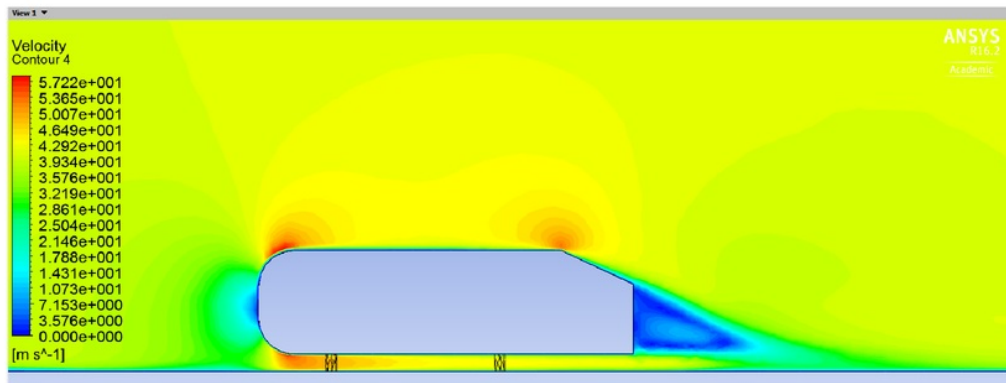


Figure 20 - Sim\_4 Post Processor Velocity

## Sim\_5 K-Epsilon Realizable 5 Prism Layers

26/03/2019

An increase to five prism layers is made in an effort to improve the coefficient values. This addition has resulted in the propagation of some poor quality elements in between the layers; shown through the orthogonal and skew analysis in Figure 21 and Figure 22 respectively. To address this, the initial prism layer height is limited to 0.001m with a 20% growth rate; this allows for a well-ordered mesh structure under the Ahmed body, shown in Figure 23. As shown in Figure 24, the lift coefficient failed to converge upon a solution; this may be a result of reducing the layer height. Instead of wasting resources on altering the mesh height it would be prudent to simply increase the number of layers. From studying the contours of static pressure, Figure 25. It would seem spurious pressure is present in the area approaching the lower curve of the Ahmed body front end; this is caused by poor meshing and will require redefinition.

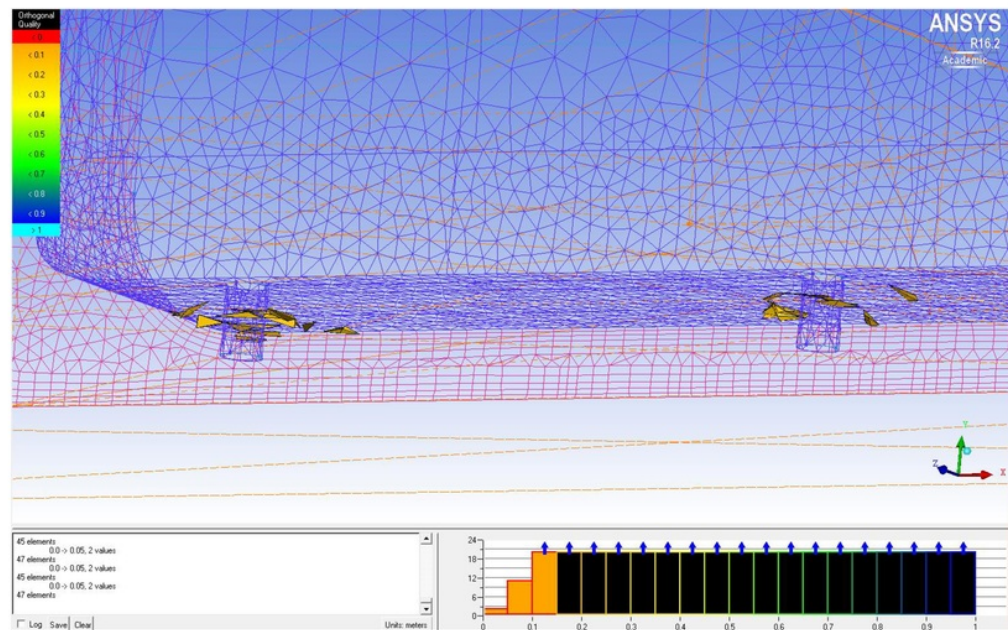


Figure 21 - Sim\_5 Orthogonal Quality

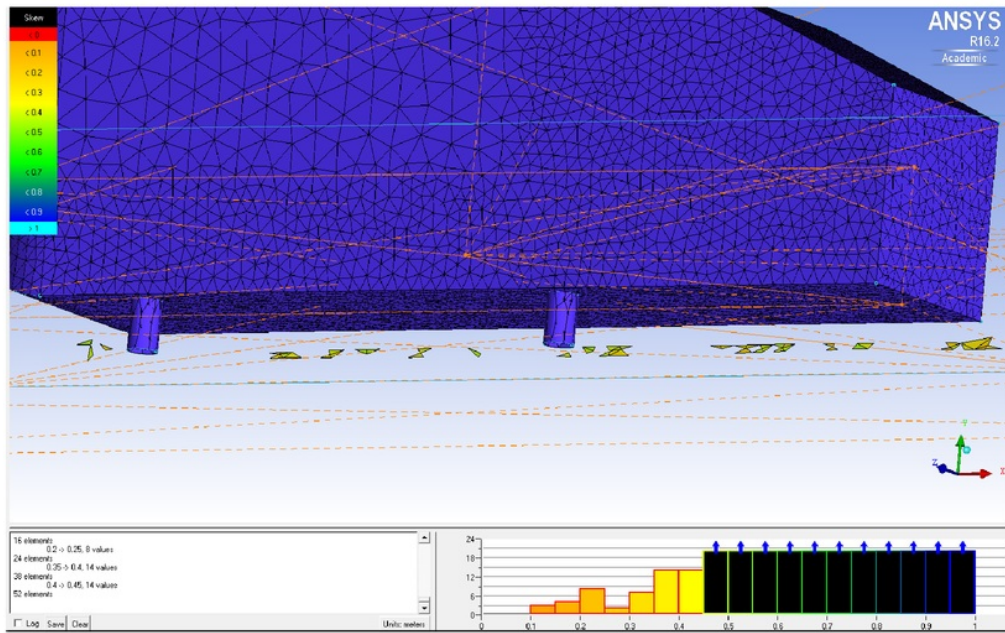


Figure 22 - Sim\_5 Skew

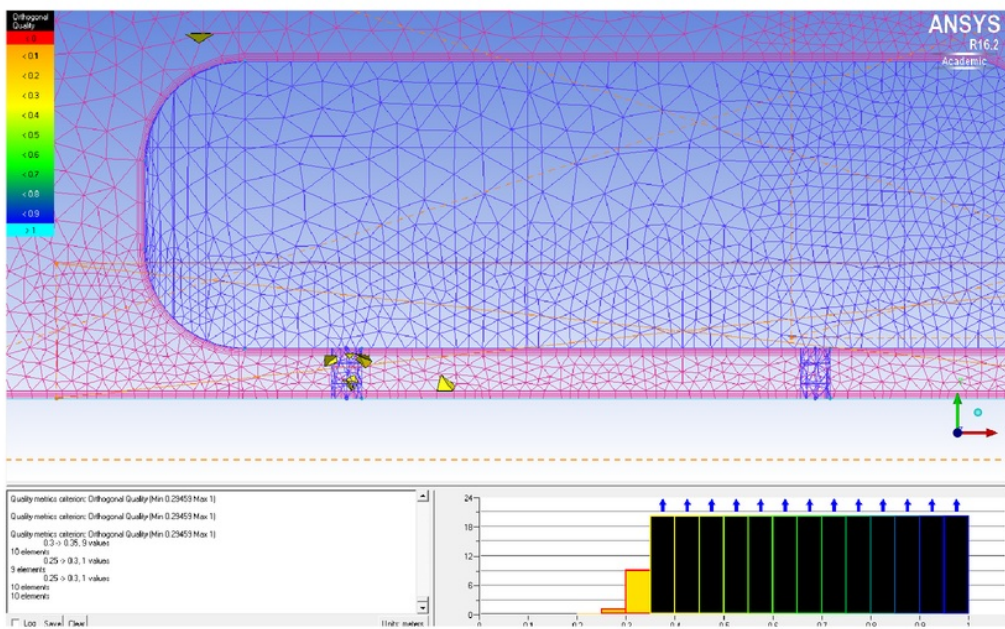


Figure 23 - Sim\_5 Orthogonal Quality Revisited

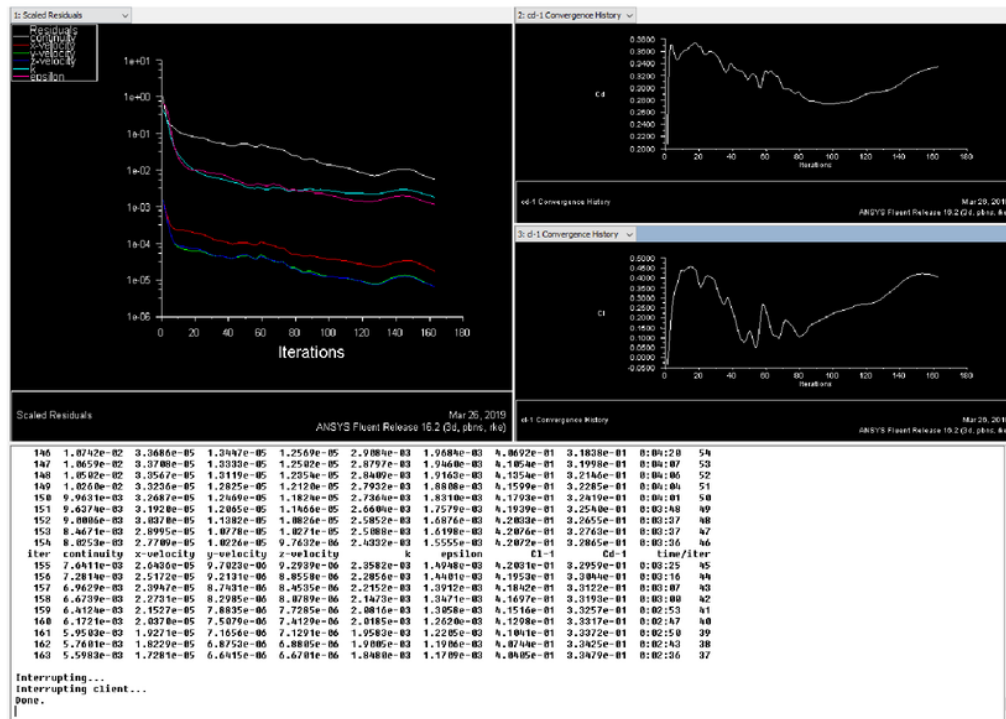


Figure 24 - Sim\_5 Results

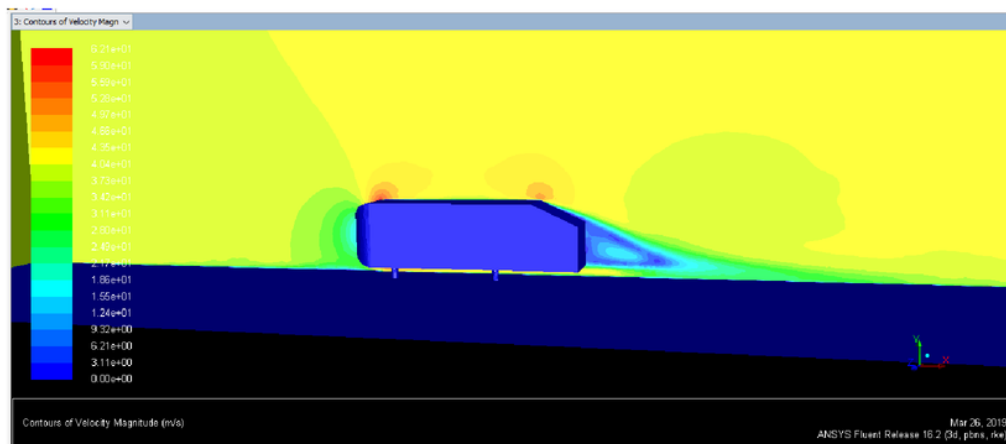


Figure 25 - Sim\_5 Post Processor

## Sim\_6 K-Epsilon Realizable 7 Prism Layers

26/03/2019

The introduction of seven prism layers is shown in Figure 26 along with a satisfactory assessment of skewed elements; the prism layers now occupy a substantial area beneath the Ahmed body while allowing sufficient area for effective mesh growth. The lift and drag coefficient values are 0.42732 and 0.34229 respectively, Figure 27. The results suggest that the drag coefficient is mainly influenced by the mesh density around the two fluid detachment points; as this figure has been stable throughout previous simulations (Afkhami, et al., 2009). The velocity results shown in Figure 28 are incoherent with the expectation; the work of Calise (2013) shows the velocity reduction and separation point about the underside of the Ahmed front face to be placed further towards the underside face, an increase in mesh density may remedy the issue.

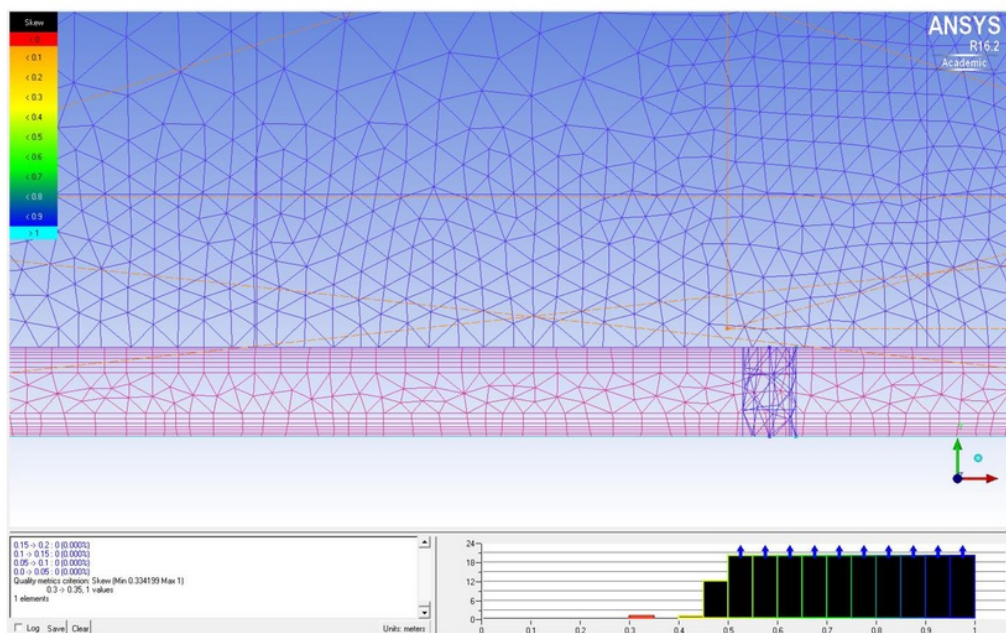


Figure 26 - Sim\_6 Skew

| iter                        | continuity | x-velocity | y-velocity | z-velocity | k          | epsilon    | Cl-1       | Cd-1       | time/iter   |
|-----------------------------|------------|------------|------------|------------|------------|------------|------------|------------|-------------|
| 233                         | 1.0485e-03 | 3.4471e-06 | 1.1300e-06 | 1.2091e-06 | 6.1836e-04 | 4.5618e-04 | 4.2735e-01 | 3.4186e-01 | 0:11:32 167 |
| 234                         | 1.0291e-03 | 3.3775e-06 | 1.1053e-06 | 1.1915e-06 | 6.0430e-04 | 4.4247e-04 | 4.2712e-01 | 3.4204e-01 | 0:11:23 166 |
| 235                         | 1.0098e-03 | 3.3122e-06 | 1.0780e-06 | 1.1694e-06 | 5.9035e-04 | 4.2835e-04 | 4.2712e-01 | 3.4218e-01 | 0:11:15 165 |
| ! 236 solution is converged |            |            |            |            |            |            |            |            |             |
| 236                         | 9.8944e-04 | 3.2493e-06 | 1.0503e-06 | 1.1460e-06 | 5.7665e-04 | 4.1711e-04 | 4.2732e-01 | 3.4229e-01 | 0:11:08 164 |

Figure 27 - Sim\_6 Coefficient Results

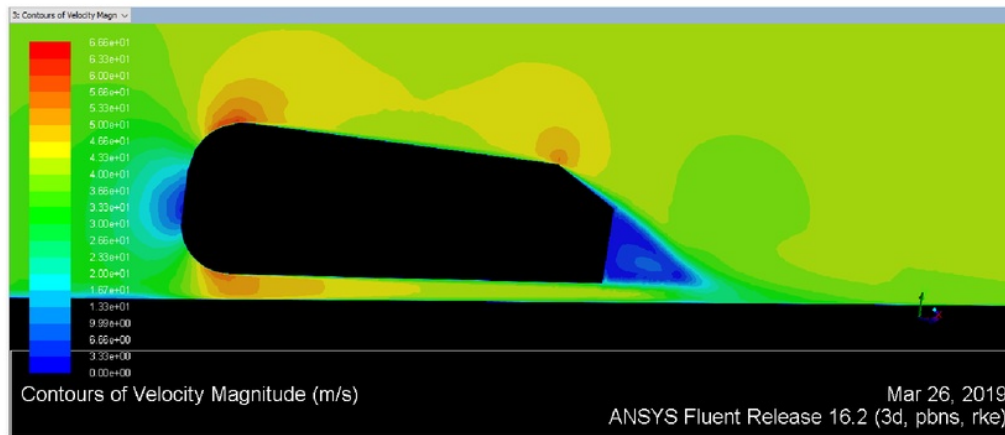


Figure 28 - Sim\_6 Contours of Velocity Magnitude

## Sim\_7 K-Epsilon Realizable 7 Prism Layers Revised

26/03/2019

The lower mesh density box refinement is amended to 0.01m to enable capture of fine fluid streams which may have a significant effect on the lift coefficient. The work of Mirzaei et al. (2015) presents findings from contrasting simulations which utilise course and fine grid configurations; they reiterate the point that a smaller grid will result in fewer areas of unresolved kinetic energy which yields a more complete and accurate coefficient. The orthogonal quality shown in Figure 29 is deemed acceptable. It is noted that visually, the mesh leading underneath the Ahmed body can be considered to be appropriate on comparison with published work (Serre, et al., 2013). The lift and drag coefficient values are 0.33258 and 0.32381 respectively, Figure 30. The lift coefficient value has improved considerably and it is noted that the velocity representation shown in Figure 31 yields what is expected more so than that of previous simulation runs. The Y X plane view shown in Figure 32 has been set to aid visual comparability of velocity with sequential runs. A satisfactory result has been obtained with regards to the validation process thus far.

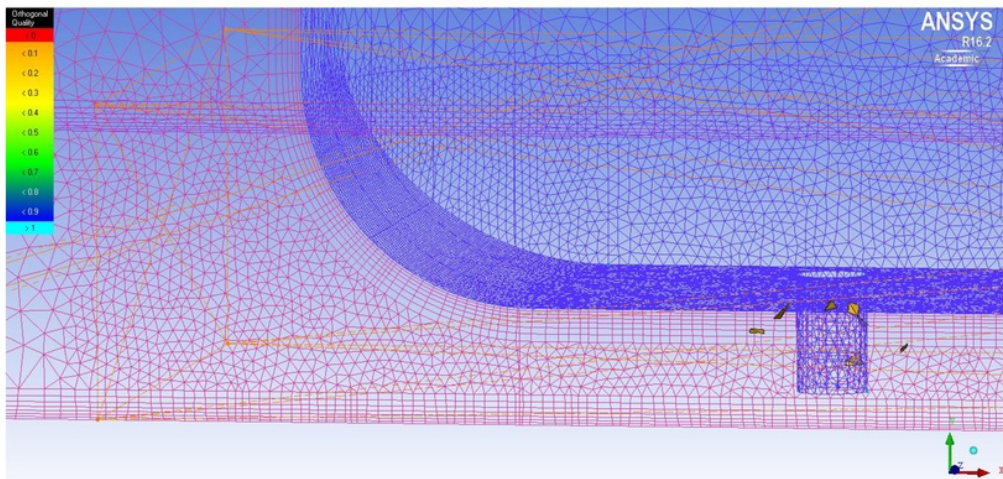


Figure 29 - Sim\_7 Orthogonal Quality

| iter                        | continuity | x-velocity | y-velocity | z-velocity | k          | epsilon    | Cl-1       | Cd-1       | time/iter  |
|-----------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 144                         | 1.1337e-03 | 5.3250e-06 | 2.3948e-06 | 2.5288e-06 | 5.5693e-04 | 3.0667e-04 | 3.3166e-01 | 3.2325e-01 | 0:02:39 56 |
| 145                         | 1.1157e-03 | 5.2448e-06 | 2.3669e-06 | 2.4822e-06 | 5.4589e-04 | 3.0095e-04 | 3.3180e-01 | 3.2333e-01 | 0:02:38 55 |
| 146                         | 1.0951e-03 | 5.1620e-06 | 2.3385e-06 | 2.4395e-06 | 5.3488e-04 | 2.9506e-04 | 3.3192e-01 | 3.2340e-01 | 0:02:37 54 |
| 147                         | 1.0765e-03 | 5.0830e-06 | 2.3100e-06 | 2.3960e-06 | 5.2389e-04 | 2.8905e-04 | 3.3204e-01 | 3.2347e-01 | 0:02:24 53 |
| 148                         | 1.0603e-03 | 4.9960e-06 | 2.2819e-06 | 2.3549e-06 | 5.1275e-04 | 2.8290e-04 | 3.3215e-01 | 3.2354e-01 | 0:02:24 52 |
| 149                         | 1.0439e-03 | 4.9082e-06 | 2.2526e-06 | 2.3117e-06 | 5.0181e-04 | 2.7687e-04 | 3.3226e-01 | 3.2361e-01 | 0:02:24 51 |
| 150                         | 1.0279e-03 | 4.8191e-06 | 2.2219e-06 | 2.2692e-06 | 4.9093e-04 | 2.7106e-04 | 3.3236e-01 | 3.2368e-01 | 0:02:23 50 |
| 151                         | 1.0115e-03 | 4.7305e-06 | 2.1892e-06 | 2.2244e-06 | 4.8016e-04 | 2.6562e-04 | 3.3247e-01 | 3.2375e-01 | 0:02:21 49 |
| † 152 solution is converged |            |            |            |            |            |            |            |            |            |
| 152                         | 9.9482e-04 | 4.6436e-06 | 2.1567e-06 | 2.1803e-06 | 4.6955e-04 | 2.6034e-04 | 3.3258e-01 | 3.2381e-01 | 0:02:10 48 |

Figure 30 - Sim\_7 Coefficient Results

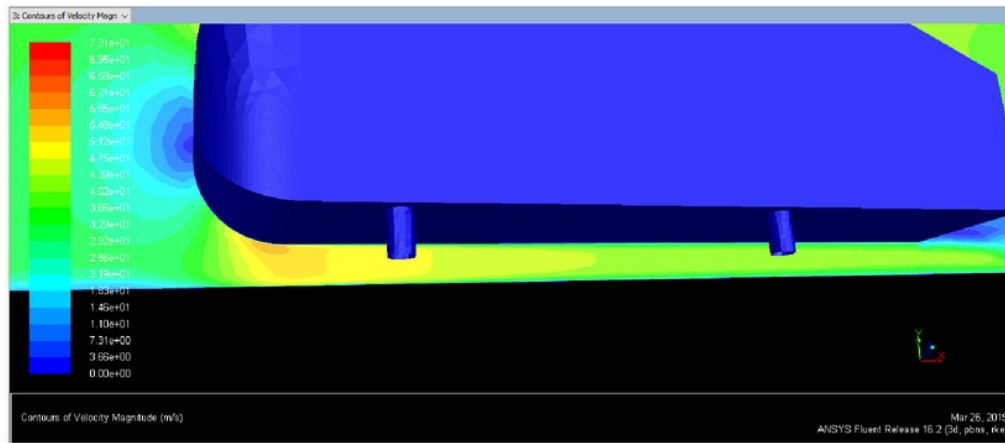


Figure 31 - Sim\_7 Contours of Velocity Magnitude

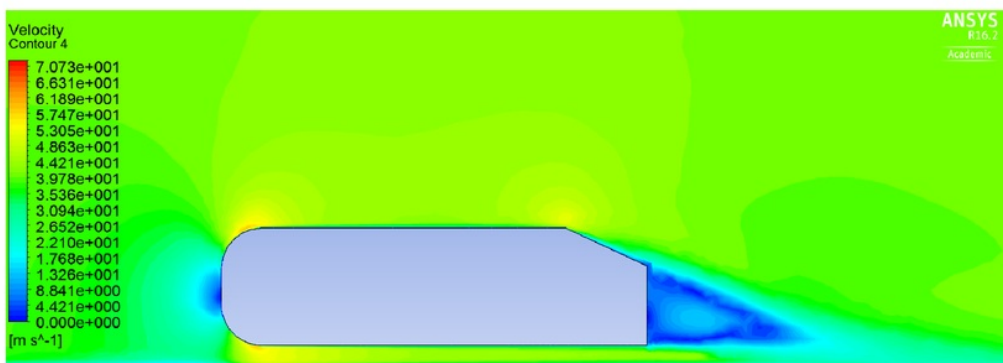


Figure 32 - Sim\_7 Post Processor Results

## Sim\_8 K-Epsilon Standard

02/04/2019

To test the computational representation for the given situation further, the turbulence model is changed to assess whether accuracy will improve. If so, the updated solver may be better suited to the given situation. Yilmaz et al. (2017) present the output variance between three K-Epsilon solvers among others. The work explains the importance of identifying trends to enable appropriate selection; the Reynolds stress solver is stated to be particularly suitable toward accurately representing highly swirling flow. The lift and drag coefficient values are 0.3543 and 0.34202 respectively, shown in Figure 33. It is observed that the lift coefficient has now moved within 0.0093 of the wind tunnel value, however the drag coefficient has moved away by a factor of two. The representations shown in Figure 35, Figure 36, Figure 37 and Figure 38 are configured to provide comparability with further simulation runs.

|     |            |                                                                                         |
|-----|------------|-----------------------------------------------------------------------------------------|
| !   | 129        | solution is converged                                                                   |
| 129 | 9.9165e-04 | 4.8646e-06 2.2826e-06 2.1754e-06 4.0554e-04 2.4381e-04 3.5430e-01 3.4202e-01 0:04:08 71 |

Figure 33 - Sim\_8 Coefficient Results

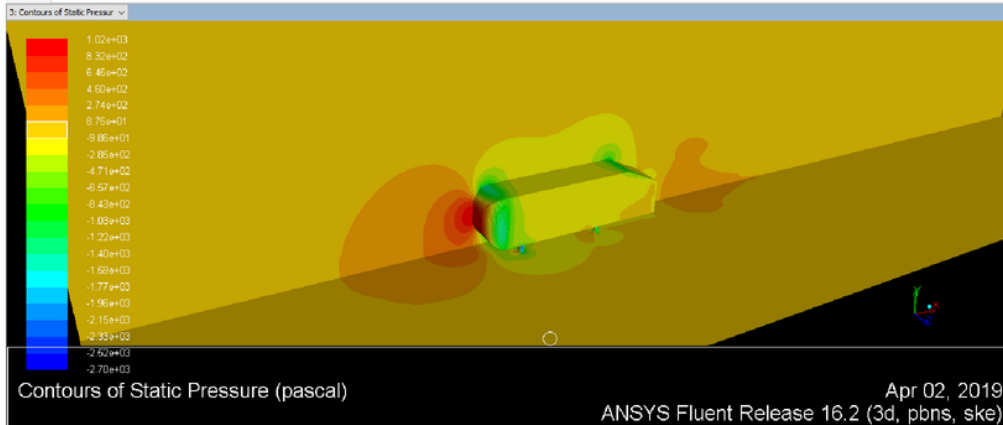


Figure 34 - Sim\_8 Contours of Static Pressure

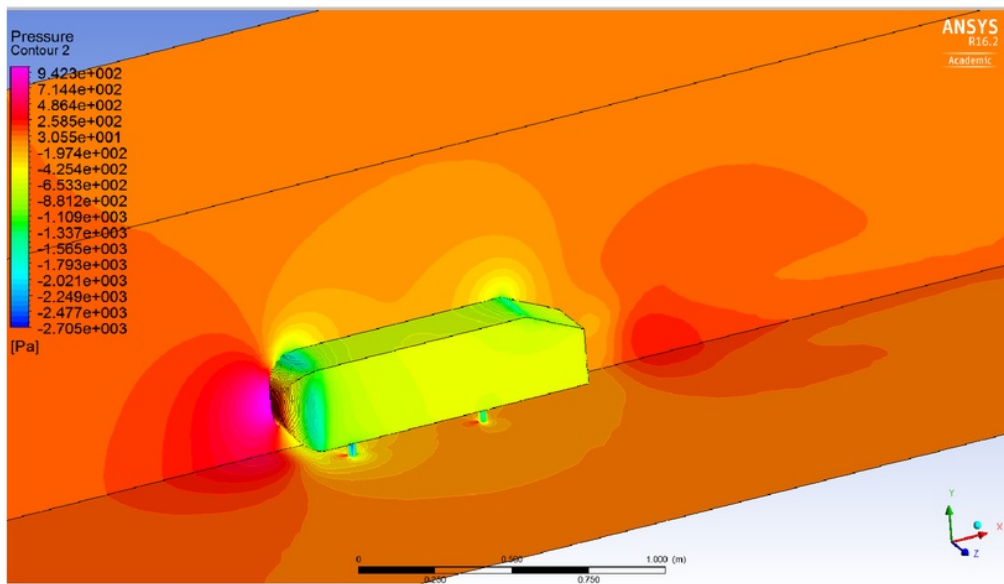


Figure 35 - Sim\_8 Post Processor Pressure

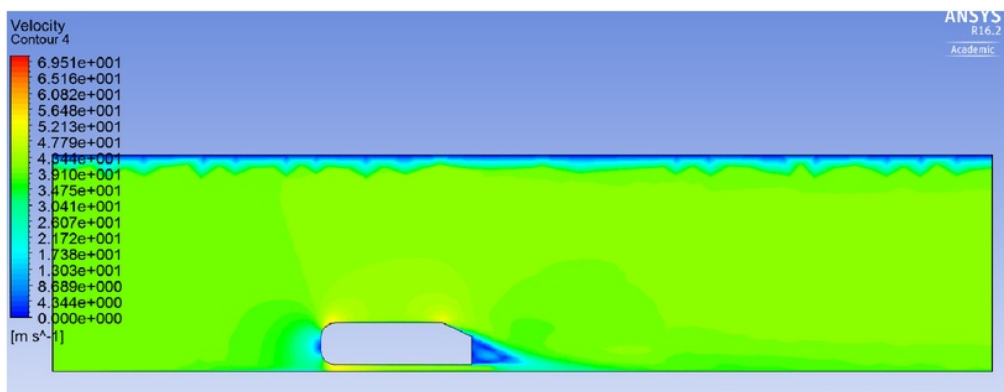


Figure 36 - Sim\_8 Post Processor Velocity

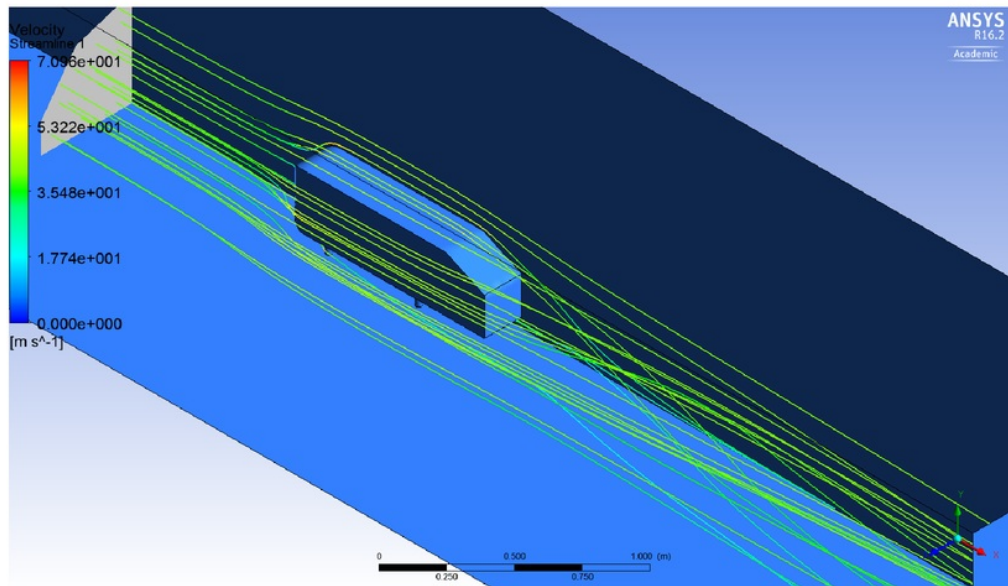


Figure 37 - Sim\_8 Post Processor Streamlines

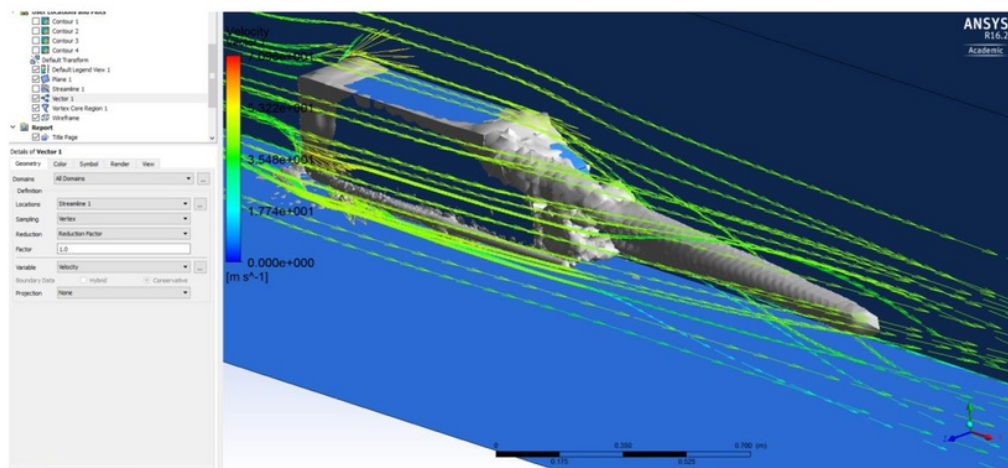


Figure 38 - Sim\_8 Post Processor Vortex Core Region

### Sim\_9 K-Omega Standard

02/04/2019

The lift and drag coefficient values are 0.32329 and 0.32619 respectively, shown in Figure 39. On the whole, no considerable improvement is observed with the K-Omega Standard solver. The representations shown in Figure 40, Figure 41, Figure 42 and Figure 43 are very similar to those of the previous run.

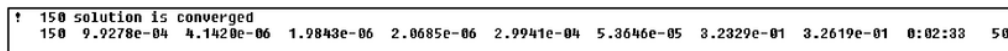


Figure 39 - Sim\_9 Coefficient Results

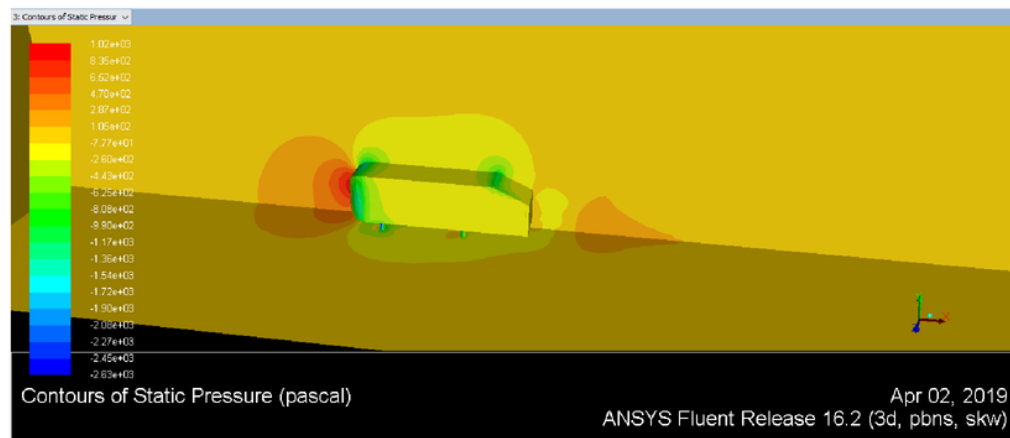


Figure 40 - Sim\_9 Contours of Static Pressure

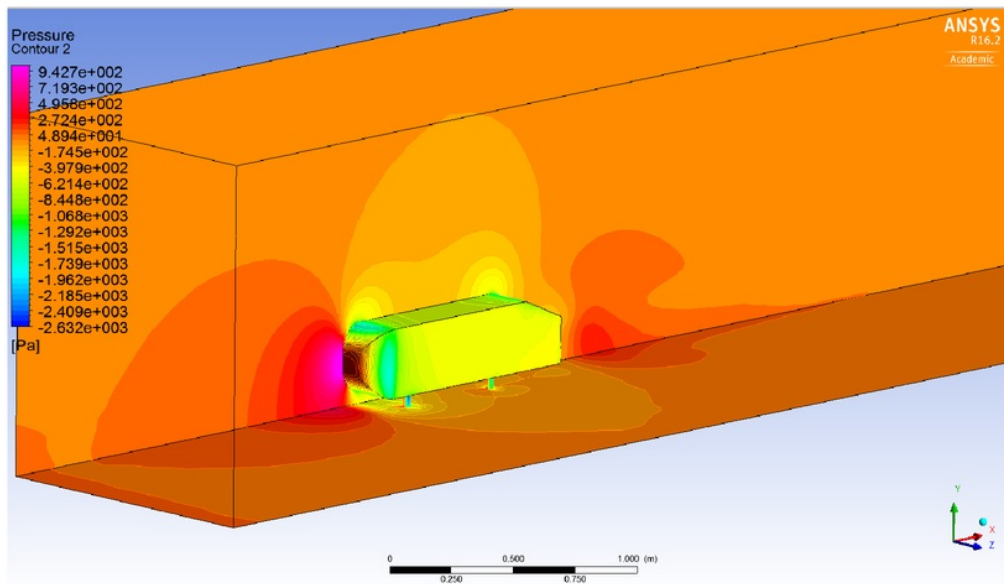


Figure 41 - Sim\_9 Post Processor Pressure

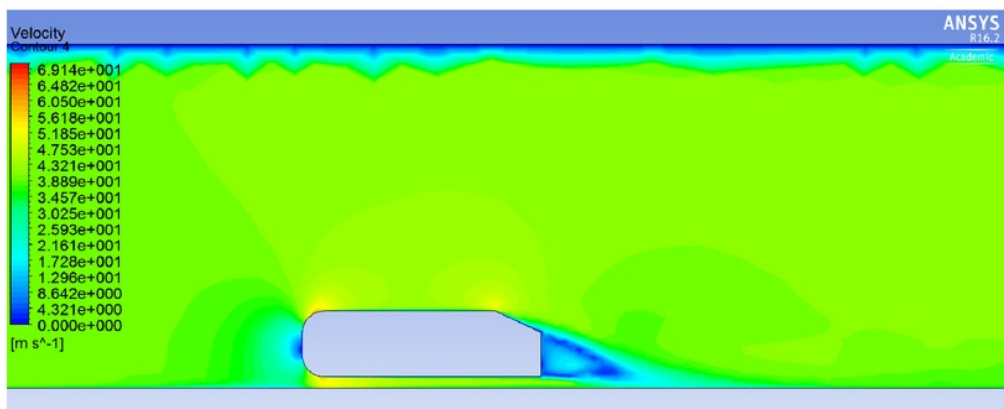


Figure 42 - Sim\_9 Post Processor Velocity

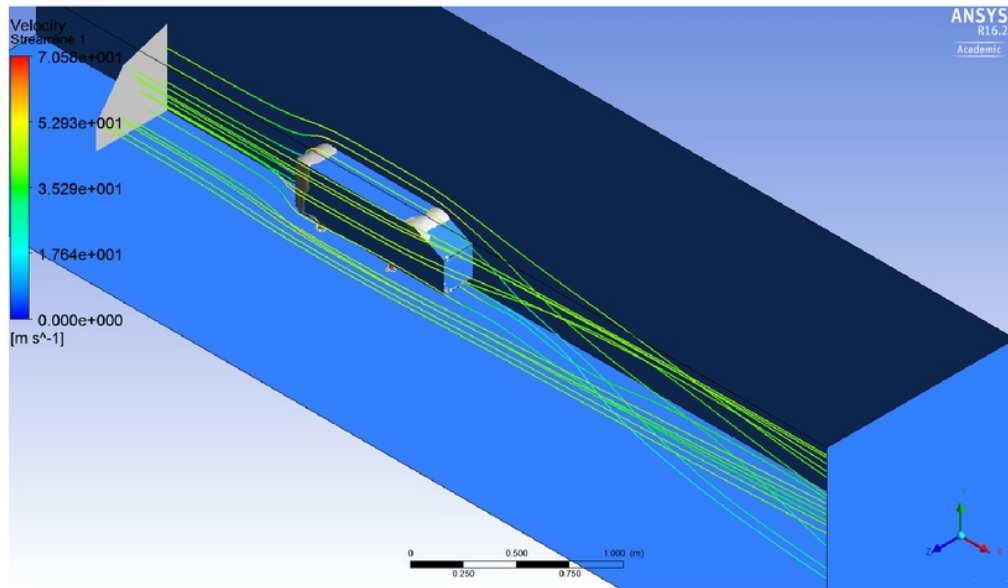


Figure 43 - Sim\_9 Post Processor Streamlines

## Sim\_10 K-Omega SST

02/04/2019

The lift and drag coefficient values are 0.29317 and 0.33536 respectively, shown in Figure 44. Again, it is observed that the coefficient values have moved away from the wind tunnel values. The representations shown in Figure 45, Figure 46 and Figure 47 are very similar to those of the previous two runs.

| iter  | continuity            | x-velocity | y-velocity | z-velocity | k          | omega      | Cl-1       | Cd-1       | time/iter  |
|-------|-----------------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 111   | 1.2977e-03            | 5.7626e-06 | 2.8404e-06 | 2.6220e-06 | 5.8637e-04 | 1.0081e-04 | 2.9120e-01 | 3.3501e-01 | 0:04:15 89 |
| 112   | 1.2399e-03            | 5.4884e-06 | 2.7066e-06 | 2.4870e-06 | 5.6407e-04 | 9.7695e-05 | 2.9126e-01 | 3.3497e-01 | 0:04:14 88 |
| 113   | 1.1908e-03            | 5.2109e-06 | 2.5855e-06 | 2.3686e-06 | 5.4241e-04 | 9.4741e-05 | 2.9151e-01 | 3.3494e-01 | 0:04:13 87 |
| 114   | 1.1489e-03            | 4.9564e-06 | 2.4732e-06 | 2.2707e-06 | 5.2244e-04 | 9.1975e-05 | 2.9190e-01 | 3.3494e-01 | 0:04:12 86 |
| 115   | 1.1178e-03            | 4.7435e-06 | 2.3911e-06 | 2.2025e-06 | 5.0441e-04 | 8.9431e-05 | 2.9233e-01 | 3.3497e-01 | 0:04:10 85 |
| 116   | 1.0924e-03            | 4.5986e-06 | 2.3361e-06 | 2.1601e-06 | 4.8788e-04 | 8.6919e-05 | 2.9275e-01 | 3.3503e-01 | 0:04:08 84 |
| 117   | 1.0756e-03            | 4.4960e-06 | 2.2942e-06 | 2.1310e-06 | 4.7274e-04 | 8.4480e-05 | 2.9307e-01 | 3.3510e-01 | 0:04:06 83 |
| 118   | 1.0578e-03            | 4.4227e-06 | 2.2525e-06 | 2.1043e-06 | 4.5882e-04 | 8.2069e-05 | 2.9327e-01 | 3.3510e-01 | 0:04:04 82 |
| 119   | 1.0412e-03            | 4.3573e-06 | 2.2092e-06 | 2.0703e-06 | 4.4528e-04 | 7.9681e-05 | 2.9334e-01 | 3.3526e-01 | 0:04:17 81 |
| 120   | 1.0209e-03            | 4.2962e-06 | 2.1562e-06 | 2.0307e-06 | 4.3175e-04 | 7.7349e-05 | 2.9330e-01 | 3.3532e-01 | 0:04:11 80 |
| † 121 | solution is converged |            |            |            |            |            |            |            |            |
| 121   | 9.9809e-04            | 4.2221e-06 | 2.0915e-06 | 1.9808e-06 | 4.1832e-04 | 7.5122e-05 | 2.9317e-01 | 3.3536e-01 | 0:04:06 79 |

Figure 44 - Sim\_10 Coefficient Results

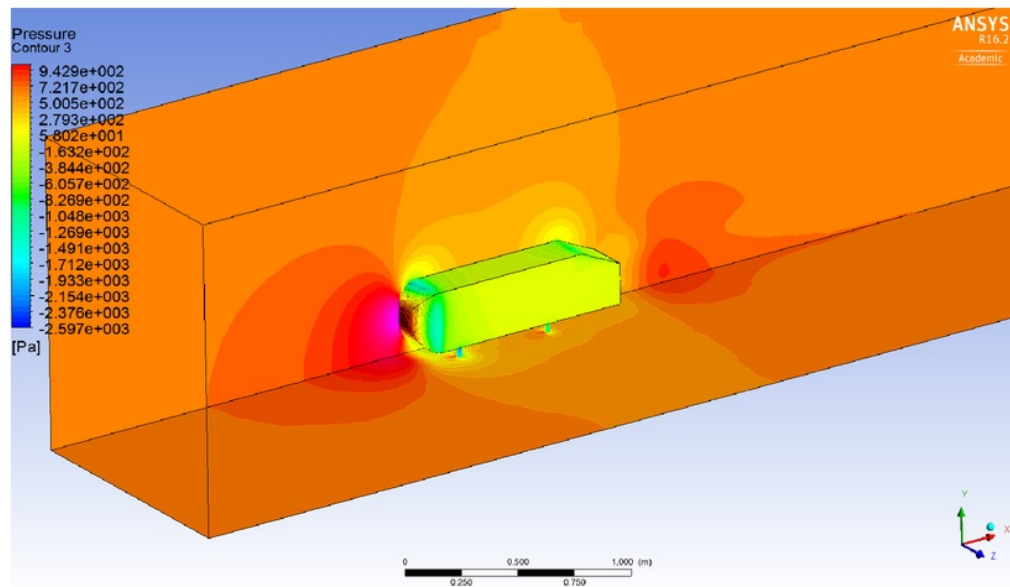


Figure 45 - Sim\_10 Post Processor Pressure

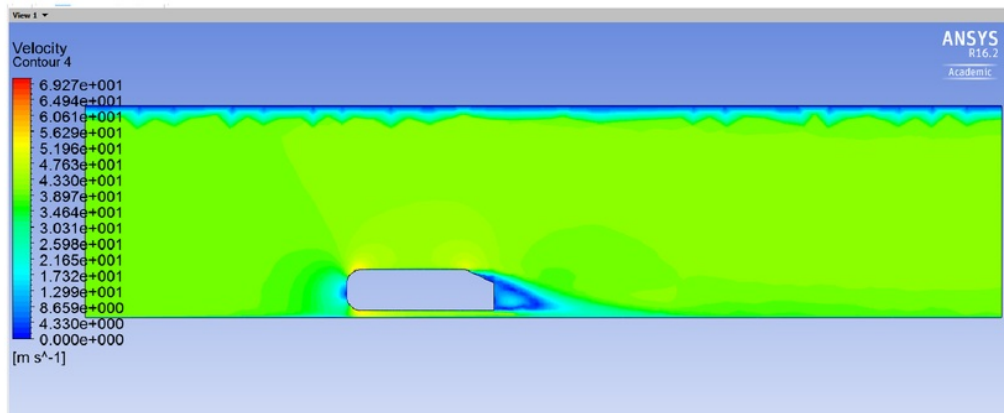


Figure 46 - Sim\_10 Post Processor Velocity

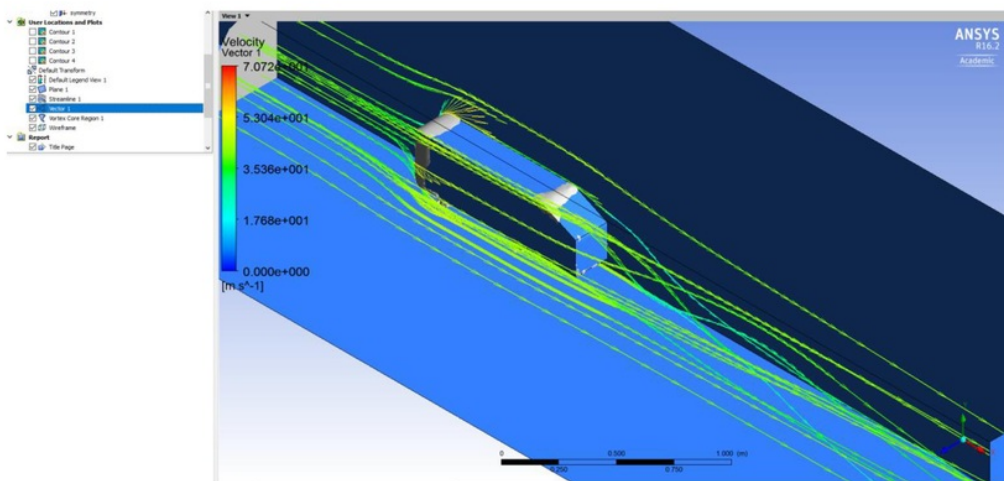


Figure 47 - Sim\_10 Post Processor Streamlines

### Chapter 3 - Results

The coefficient values obtained from ten simulation runs are presented in Figure 48. Sim\_2 provides the nearest values to the wind tunnel investigation; considering the lack of prism layers and only a single density box, the obtained result may not be a true representations of the actual fluid flow. It is much more likely that Sim\_8 is a truer representation; by way of following a guided meshing strategy the results are far more realistic (Lanfrit, 2005). The expected flow structures about the rear slant are easily recognisable with utilisation of the vortex core region option, Figure 38. The graph points shown in Figure 49 give a clear indication of the difficulty experienced in pinning down the lift coefficient when compared to the drag; the Sim\_1 point is omitted from contemplation due to it being a ballpark run.

| #      | Simulation Run                                   | Coefficient value: |         | Difference between Sim_# and actual: |         |
|--------|--------------------------------------------------|--------------------|---------|--------------------------------------|---------|
|        |                                                  | Lift               | Drag    | Lift                                 | Drag    |
| Sim_1  | K-Epsilon Realizable Base                        | 0.28407            | 0.46442 | -0.06093                             | 0.16542 |
| Sim_2  | K-Epsilon Realizable Revised v1                  | 0.35755            | 0.30896 | 0.01255                              | 0.00996 |
| Sim_3  | K-Epsilon Realizable Revised v2                  | 0.39892            | 0.35471 | 0.05392                              | 0.05571 |
| Sim_4  | K-Epsilon Realizable Revised v3 & 3 Prism Layers | 0.36385            | 0.35456 | 0.01885                              | 0.05556 |
| Sim_5  | K-Epsilon Realizable 5 Prism Layers              | 0.40405            | 0.33479 | 0.05905                              | 0.03579 |
| Sim_6  | K-Epsilon Realizable 7 Prism Layers              | 0.42732            | 0.34229 | 0.08232                              | 0.04329 |
| Sim_7  | K-Epsilon Realizable 7 Prism Layers Revisited    | 0.33258            | 0.32381 | -0.01242                             | 0.02481 |
| Sim_8  | K-Epsilon Standard                               | 0.35430            | 0.34202 | 0.0093                               | 0.04302 |
| Sim_9  | K-Omega Standard                                 | 0.32329            | 0.32619 | -0.02171                             | 0.02719 |
| Sim_10 | K-Omega SST                                      | 0.29317            | 0.33536 | -0.05183                             | 0.03636 |
|        |                                                  |                    |         |                                      |         |
|        | Actual Recorded Wind Tunnel Values               | 0.345              | 0.299   |                                      |         |

Figure 48 - Coefficient Results Table

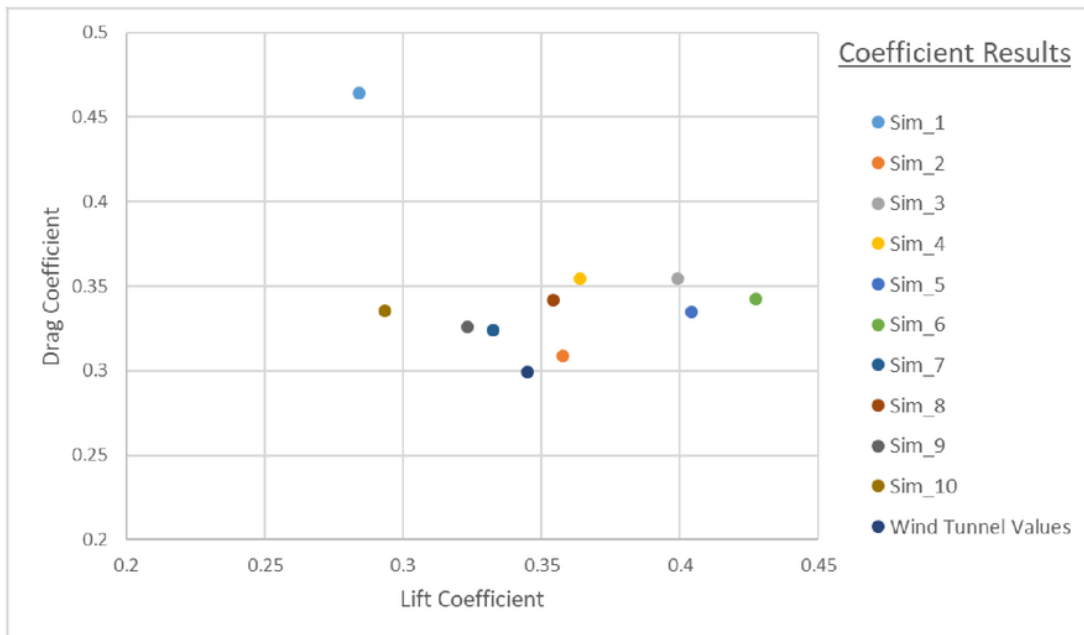


Figure 49 - Coefficient Results Graph

## Conclusion

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The airflow structures associated with the Ahmed body have been assessed, and an attempt has been made to validate the CFD configuration against actual wind tunnel measured coefficients. It is determined that the K-Omega Standard turbulence model would be best suited for further investigation with regards to the stated configuration. Resource constraints have limited the overall strategy development, however considerations for the future would include revisiting the mesh definition with the K-Omega Standard model. An increase in the fluid volume geometry would also be worth further investigation, as published study geometries are around twice as large (Tunay, et al., 2004). To increase accuracy further it would be appropriate to check the non-dimensional length,  $y^+$ . The value represents the element size near volume walls and turbulence models have stated limits for this. Tailoring the element size to suit the turbulence model parameters will ensure regions are not left unresolved (Douglas, et al., 1995). Tunay et al. (2004) state Reynold's number will influence the magnitude of wake structures following the rear slant; hence, a more involved turbulence model is also proposed. It is noted that the simulation results are generally, in agreement with the wind tunnel measurements and that trends of strategy alterations were reasonably well predicted. It is clear to see from research, that CFD is a powerful tool with limitless application in the engineering sector.

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