Numerical Simulations of Drag Reducing Devices for Ground Vehicles

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Introduction

- Energy Resources Scarcity
- Oil Prices Fluctuations and Fuel Consumption
- Global Warming

Energy Resources Scarcity

- Increased Population
- Increased Consumption
- Limited Resources

Oil Price Fluctuations

- After the fuel crises in 1970, the US government started intensive research on reducing the fuel consumption if vehicles as it consist of 28% of the total energy consumed of the nation. A special concentration was done on heavy vehicles since they go through millions of mileages every year.
- Plan is to reduce drag by 25% by 2015.

Oil Price Fluctuations

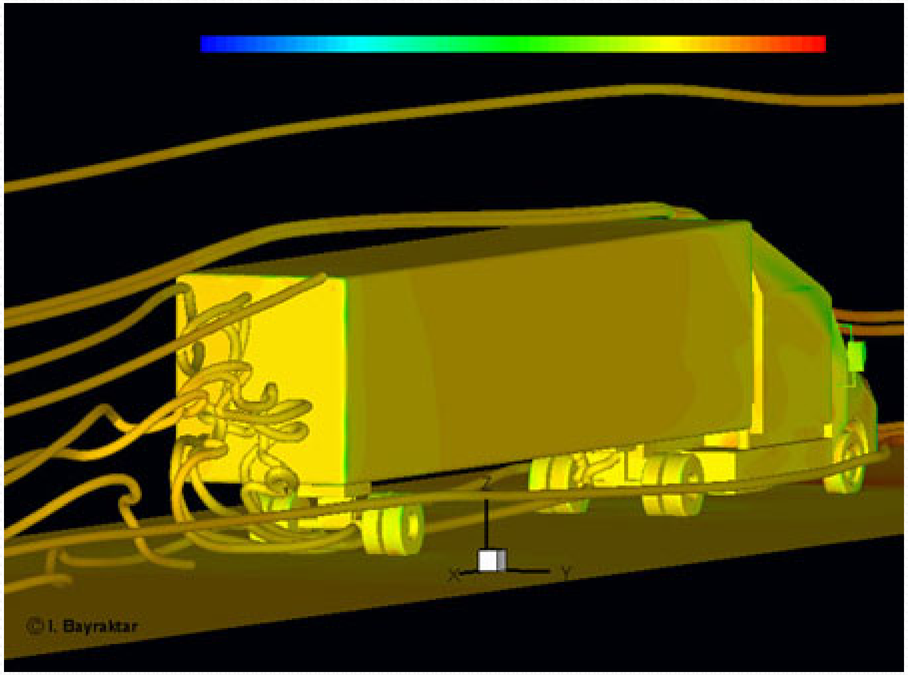
- “10 percent reduction in aerodynamic drag of the tractor trailer is equivalent to a reduction of 4100 $ per year per each truck.”
- In 1997, the fuel consumption of the Class 8 trucks reached 18 billion gallons in which 65% of this fuel consumption is wasted to overcome the aerodynamic drag.

Vehicle Losses

- Vehicles Aerodynamics
- Engine Losses
- Rolling Resistance Losses
- Drive System Losses

Drag

- What is drag?



Aerodynamics

- It is essential to work on all items to reduce drag to minimum.
- Aerodynamic has a major percentage in fuel consumption.
- The bulkier the vehicle, the less aerodynamically efficient it is.

Aerodynamics

- Many vehicle companies worked in corporation with research centers to find methods to reduce drag coefficient. Such as, Volkswagen, ATDynamics, Volvo etc.
- Reduction of small gaps
- Changing the shape of the vehicle to be aerodynamic

Aerodynamics

- Changing shape is not always a suitable solution especially for Heavy Vehicles.
  - Heavy vehicles shapes come mainly from the shape of the containers, which are boxy.

Aerodynamics

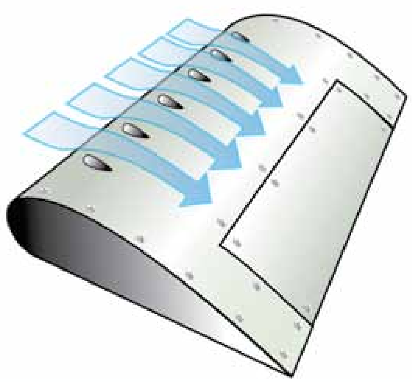
- Best method to reduce the drag is by adding drag reducing devices
- Drag reducing devices are mechanical equipment which direct the airflow in a better way to reduce the drag around the vehicle.

Drag Reducing Devices Examples

Drag Reducing Devices Examples (Front Heads)

Drag Reducing Devices (Vortex Generators)

Uncontrolled Turbulence



Controlled Vortices

Drag Reducing Devices Examples (Vortex Generators)

- Vortex Generators can be added on top of bottom of the body depending on where the turbulence is taking place..

Methods on reducing Drag (Platoon)

- Platoon concept is taken from the V-shape that birds take when migrating.
- the leading bird takes all the drag while the lagging ones handle less drag.

Platoons

- Traveling in Platoons saves a lot of money as drag reduction reaches up to 40 % on the third truck and 30 % drag reduction on the second truck.

Drag Reducing Devices (Skirts)

Aerodynamic Drag Facts

- Why is drag to be reduced
  - It reduces frictional losses on vehicles.
  - It reduces power needed to overcome the airflow.
  - It reduces the noise of wind separation.
  - It reduces fuel consumption.
  - It reduces surface damage.

Fuel Consumption Facts

- Why is fuel consumption to be reduced
  - Year 2002 statistics for combination trucks (tractor-trailers) on nation's highways showed the following figures:
    - 2.2 million trucks registered
    - 138.6 billion miles on nation's highways, 3-4% increase/yr
    - 26.5 billion gallons diesel fuel consumed, 4-5% increase/yr
    - 5.2 mpg, or 19.1 gallons/100 miles
    - 2.47 million barrels/day
    - 12-13% of total US petroleum usage (19.7×10^6 bbls/day)

Awareness

- Raises an Environmental awareness
- Companies’ Cash Awareness

The Aim of the Research

- This research's aim is to apply drag reducing devices that will reduce the drag forces on ground vehicles such as tractor-trailer, Hummer SUV and Ahmed car Model in order to reduce fuel consumption.
- Front and rear drag reducing devices are added to the sample vehicles and the effect on drag reduction is studied.
- The research is done using ANSYS Simulations v 11.0

Research Significance

- Environmental problems due to pollution are reduced.
- Fuel resources are saved for a longer period.

Research Objectives

- The application of Reynolds Averaged Navier Stoke's solver modules on the Tractor-Trailer, Hummer 2 and Ahmed car models.
- The application of Large Eddy Simulation on the tractor trailer, Hummer and Ahmed models.
- Validation of the results with experimental results of the tractor trailer, hummer and Ahmed vehicles.

Reynolds-Averaged Navier–Stokes (RANS)

- Three basic Models are used:
  - K-epsilon
  - RNG
  - SST

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\rho g_x+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\rho g_y+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\rho g_z+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)$$

RANS

- K-eps
  - the baseline of solving for kinetic energy k and turbulent dissipation ε
- Pros
  - Robust
  - Widely used
  - Easy to implement
  - Computationally cheap.
  - Valid for fully turbulent flows only.

K-epsilon

- CONS:
  - It performs poorly for complex flows involving severe pressure gradient, separation and strong streamline curvature.

RANS

- RNG
  - It is a mathematical technique that can be used to derive a turbulence model similar to the k-epsilon
  - Results in a modified form of the epsilon equation which attempts to account for the different scales of motion through changes to the production term.
  - RNG shows close results to k-epsilon ones.

RANS

- SST
  - It is a variant of the standard k–ω model.
  - It combines the original Wilcox k-Omega model for use near walls
  - Also uses the standard k–ε model away from walls using a blending function
  - The eddy viscosity formulation is modified to account for the transport effects of the principle turbulent shear stress.

RANS

- SST
- Pros
  - It gives highly accurate predictions of the onset
  - Highly accurate for calculating the amount of flow separation under adverse pressure gradients.
  - It is recommended for high accuracy boundary layer simulations.
- Cons
  - Its dependency on wall distance makes this less suitable for free shear flows compared to standard k-epsilon.
  - Requires mesh resolution near the wall.
  - A Reynolds Stress model may be more appropriate for flows with sudden changes in strain rate or rotating flows while the SST model may be more appropriate for separated flows.
  - It has no option to include compressibility.

LES

- What is LES
  - Large Eddy Simulation is a mathematical model for turbulence used in computational fluid dynamics.
  - Originally used to simulate atmospheric air currents
  - It resolves large scales of the flow field solution
    - better dependability than alternative approaches such as Reynolds-Averaged Navier-Stokes (RANS) methods.
    - It also models the smallest scales of the solution, rather than resolving them as direct numerical simulation.

The Need of Verification

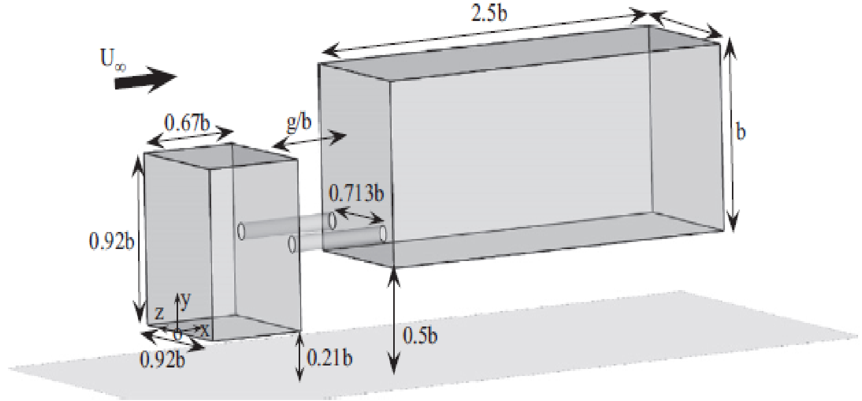
- Numerical Simulation gives different answers for different meshing grids, different processors and different Numerical Models.
- Comparison with experimental results is required.
- If numerical solution shows consistency with experimental; therefore, one can proceed with modifying the design considering appropriate meshing.

Vehicle Models

- Three Models:
  - Heavy Vehicle.
  - Sports Utility Vehicle.
  - Sedan Vehicle.

Geometric Model

- Is a simplified Tractor-Trailer.
- Excluding the wheels effect.



Meshing Grid

- Three meshing grids:
  - Course
  - Medium
  - Fine
- Tetrahedral meshing elements were used.

Results-Reference Paper

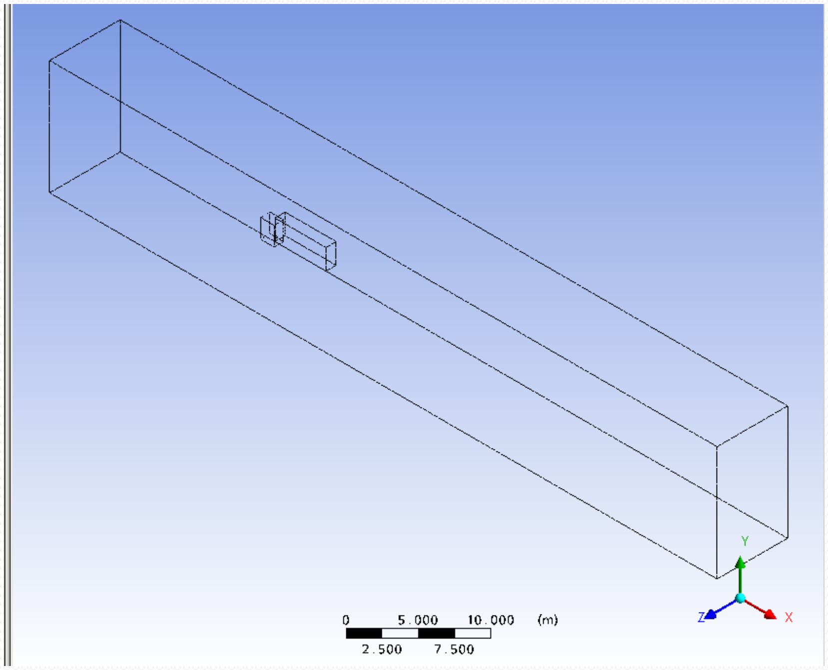
- Krajnovic [1] showed the following results:

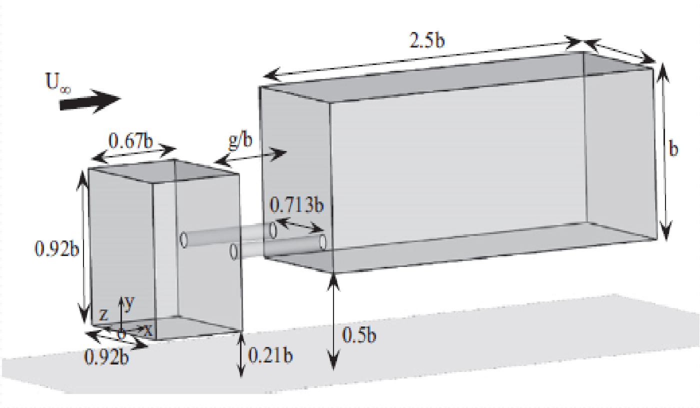
  - LES (13,000,000 Meshing elements)
    - Drag Coefficient = 0.79

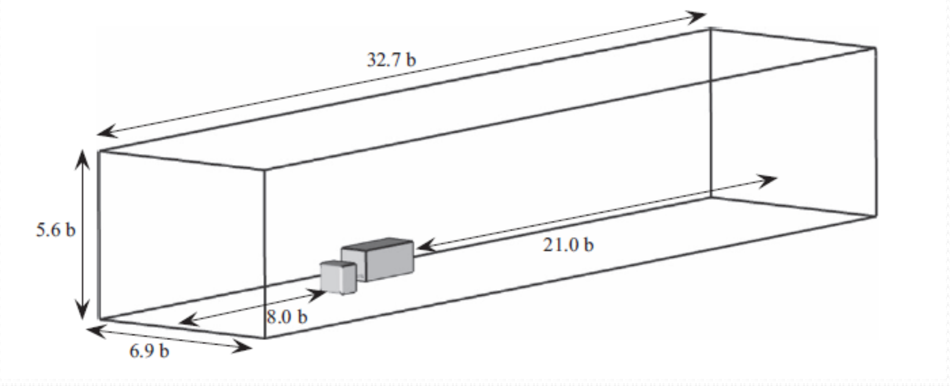
  - Experimental results
    - Drag Coefficient = 0.77

Geometric model

- This research's geometric model used is done with the following variables:





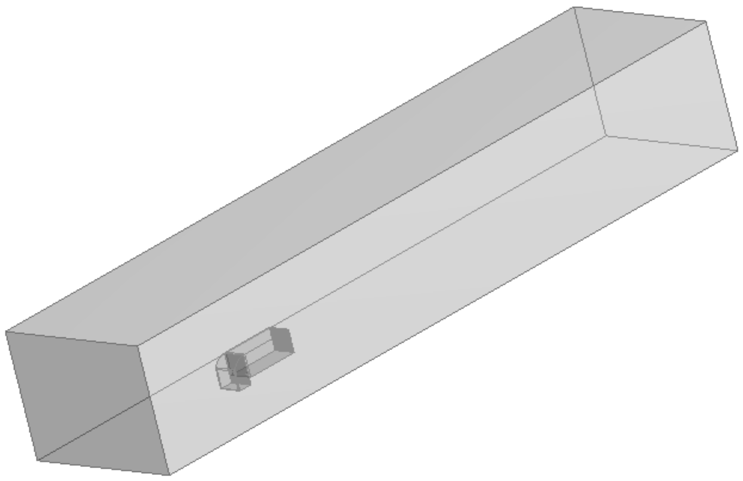


Meshing Grid-RANS

- For RANS, three different meshing elements number is used:
  - 1,300,000 (Coarse)
  - 1,600,000 (Medium)
  - 1,930,000 (Fine)
- All the elements were Tetrahedral as they fit better for our application.

Boundary Conditions.

- Boundary conditions-Tractor Trailer.
  - Inlet
    - U=24.4 m/s
  - Outlet
    - Pressure=0 Pa
  - Wall
  - Symmetry



Solver

- High resolution
- 100-150 runs
- RMS Error = 0.00001

Results-RANS

Grids	k-epsilon	RNG	SST
1.3 Million	0.911	0.907	0.931
1.6 Million	0.913	0.909	0.883
1.93 Million	0.849	0.843	0.876

RANS Cd Verification

- Error with experimental

Drag Error	K- eps	RNG	SST
1.3 M	15.4 %	15.14 %	17.3 %
1.6 M	15.6 %	15.32 %	12.7 %
1.93 M	9.29 %	8.6 %	12.12 %

LES geometric model

- Whole geometry-No symmetry required.
- Symmetry is not allowed.

LES mesh

- Two Meshing Grids
  - Coarse (140,000 elements)
  - Fine (1,700,000 elements)

LES solver

- 10 seconds
- 0.0001 per calculation
  - Cfl<1
- Automatic
- Central difference
- Backup results

Drag Coeff.

- Drag coefficient results

Drags	LES
0.140 M	0.83
1.7 M	0.81

Error with Experimental

Drags Error	LES
0.14 M	7.2 %
1.7 M	4.93 %

Errors with LES

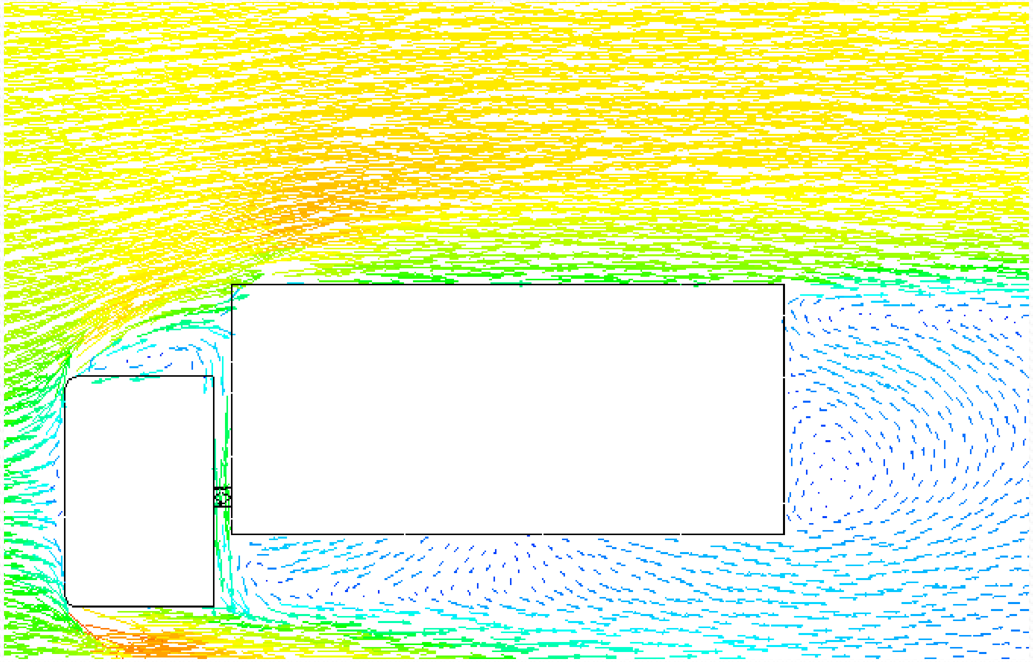
Drags Error	LES
0.14 M	4.45 %
1.7 M	2.1 %

Discussion of LES results

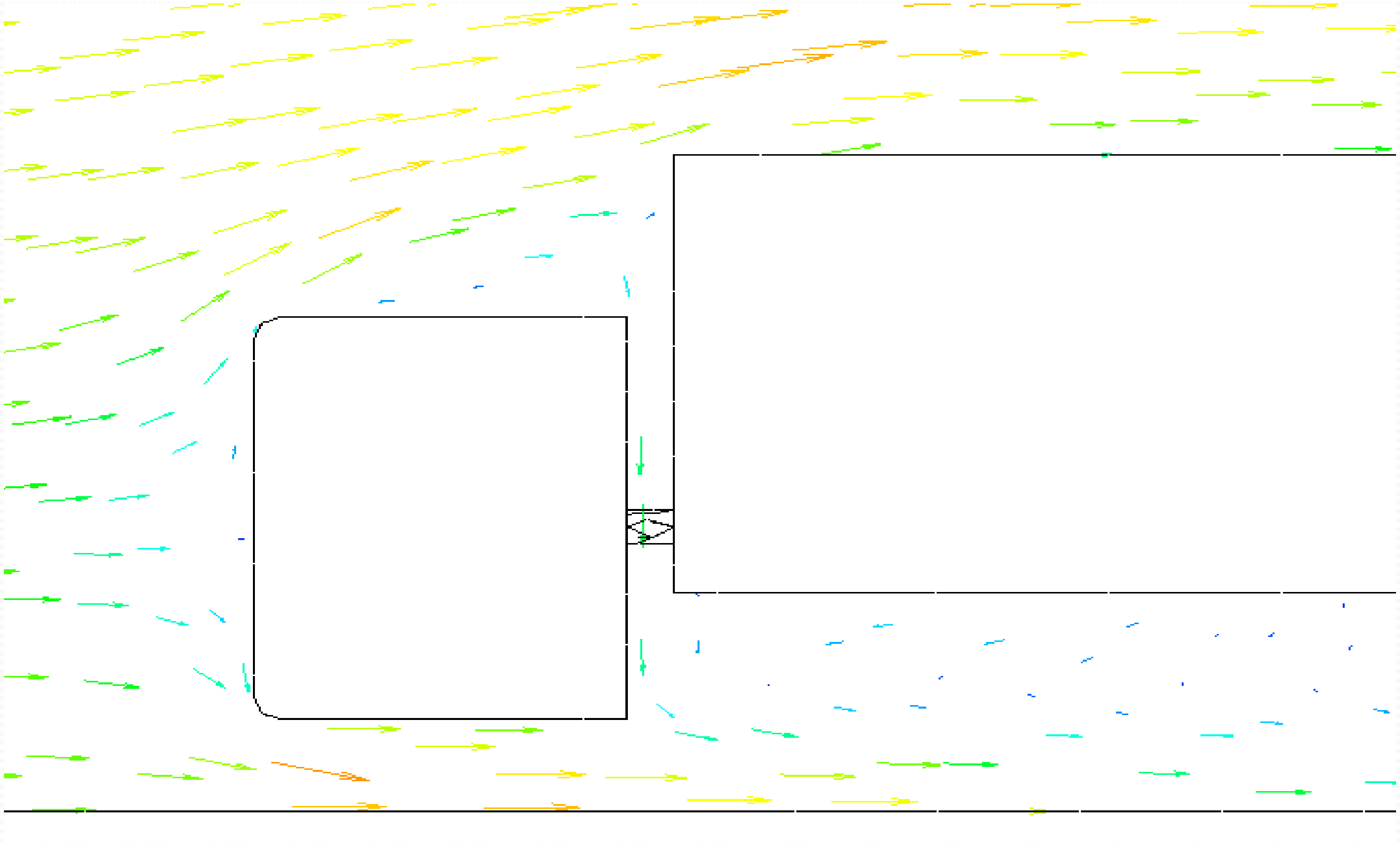
- The finer the grid, the closer the result is to the experimental results
- The LES coarse results showed more accurate results than those of the fine mesh RANS.
- The SST had the least close results to the experimental ones.

Velocity Vectors

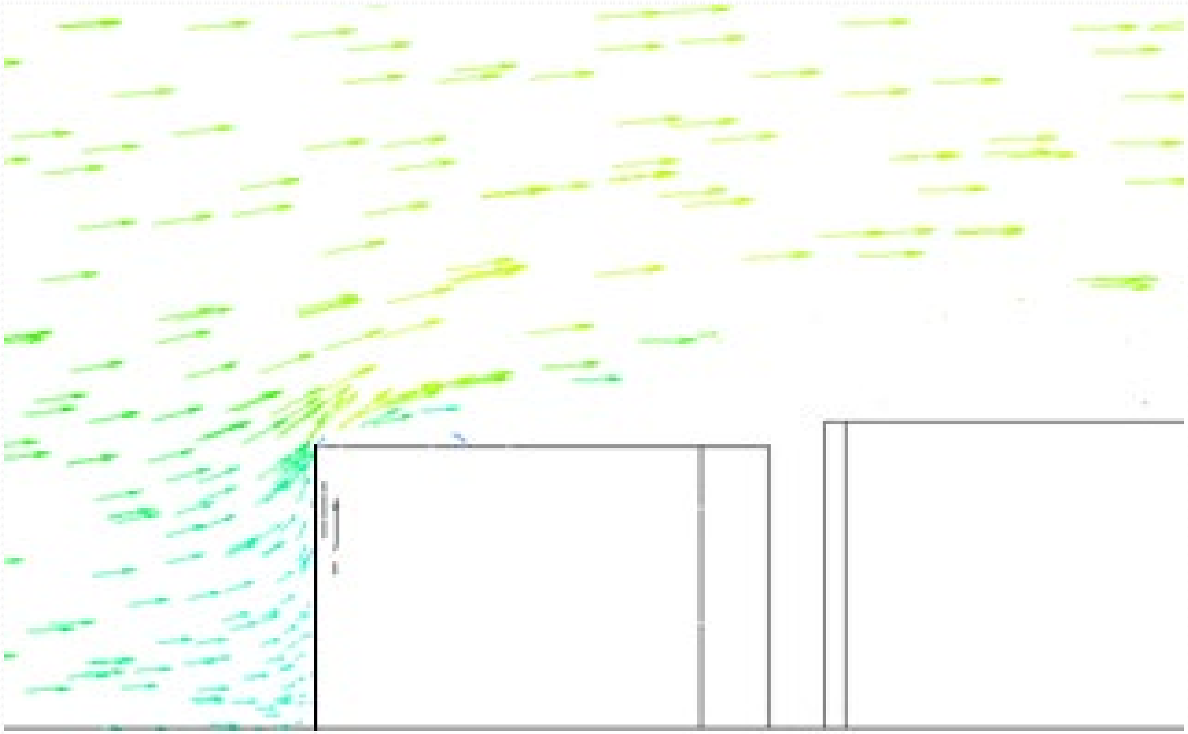
- Tractor Trailer-No DRD's



Velocity Vectors

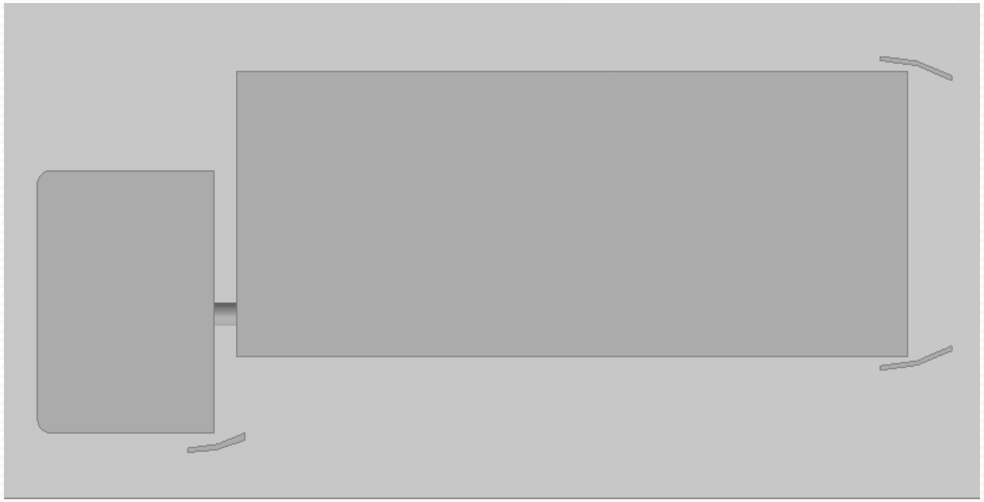


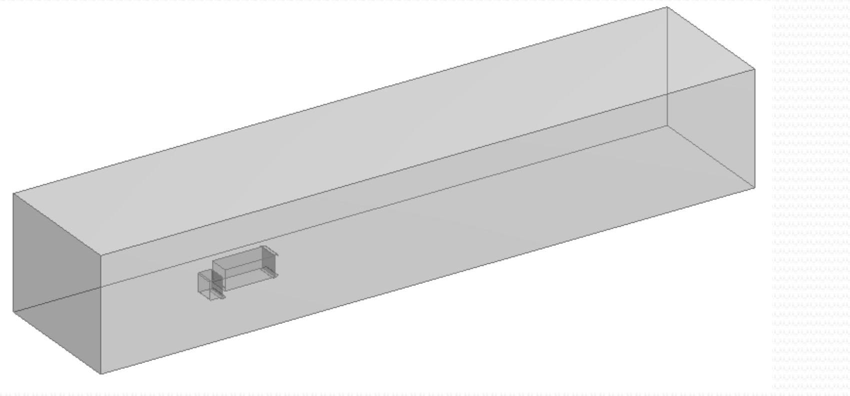
Velocity Vectors-Top View



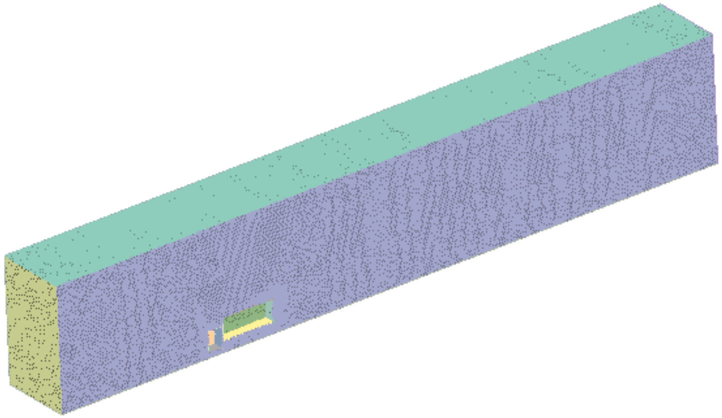
DRAG REDUCING DEVICES

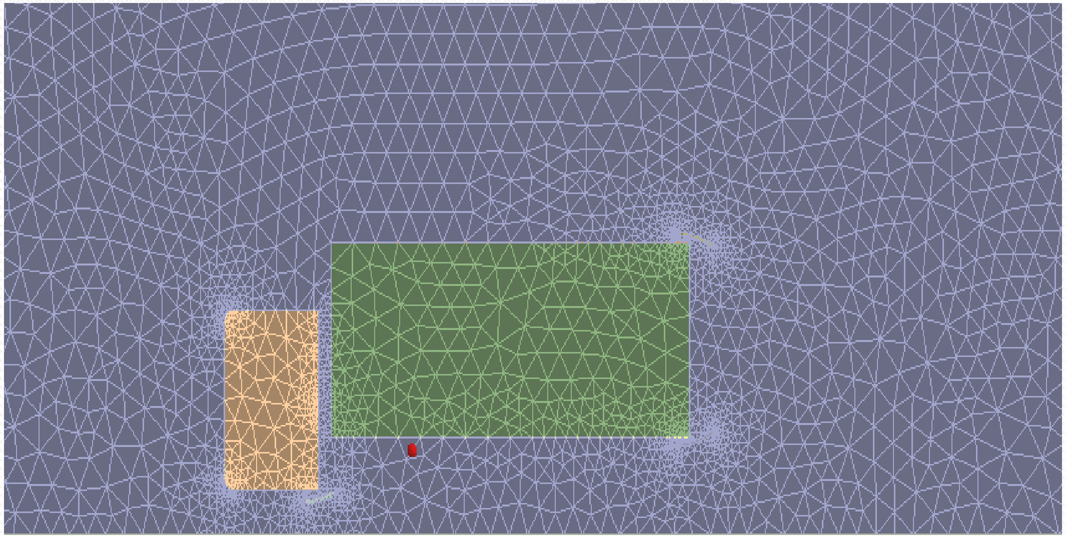
Rear DRD’s



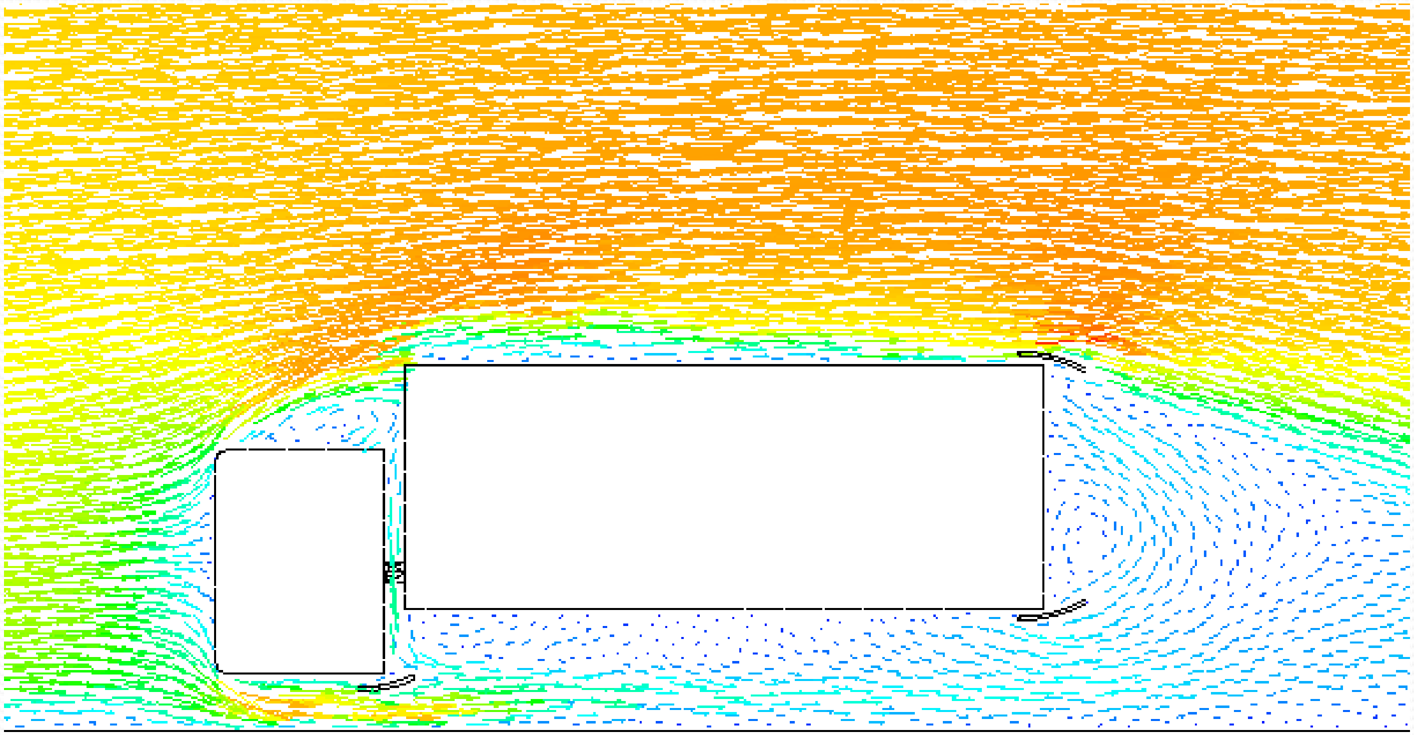


Meshing Grid

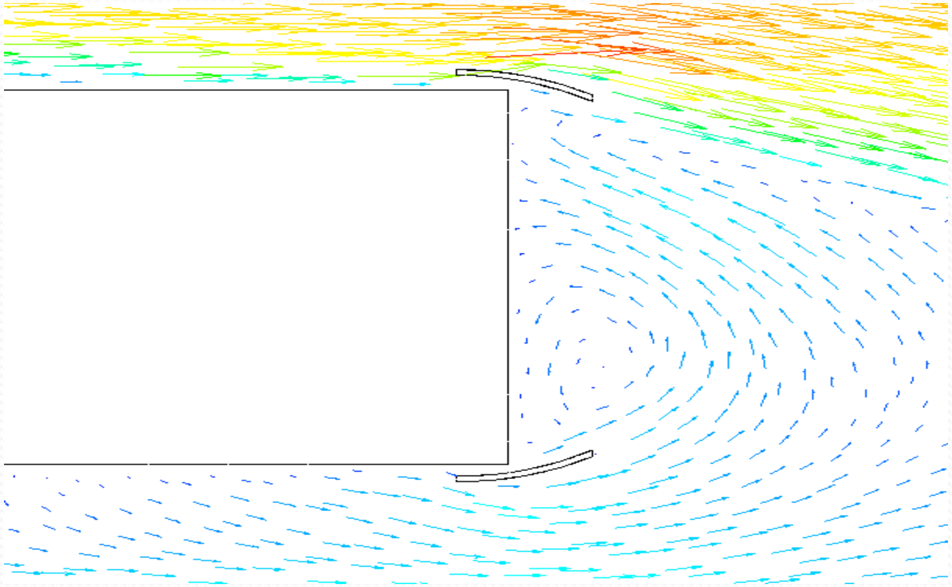


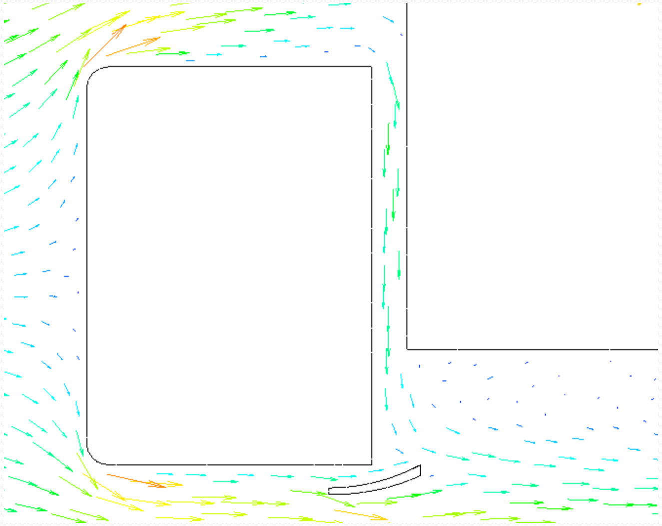


Velocity Vectors



Velocity Vectors-Rear DRD's

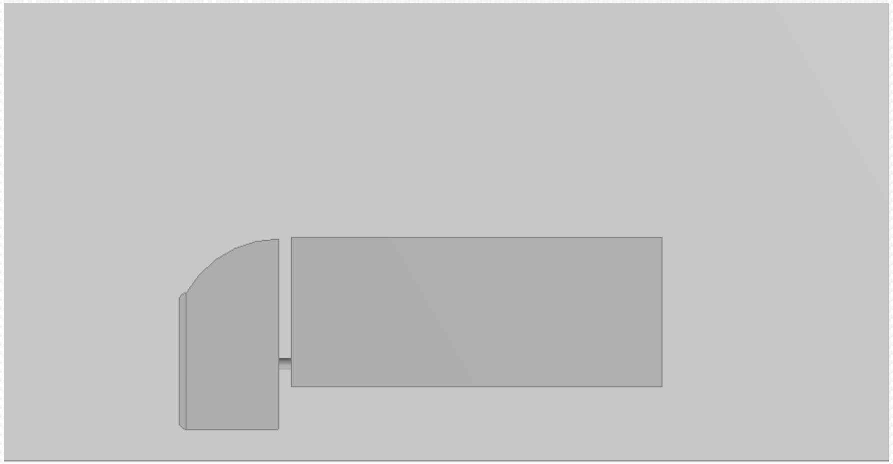


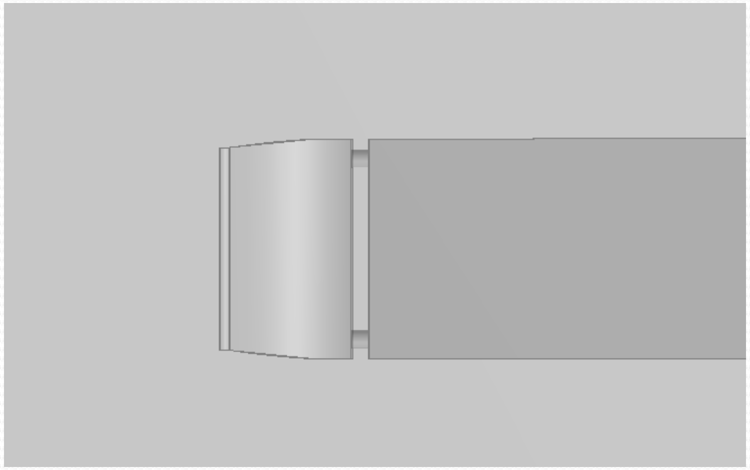


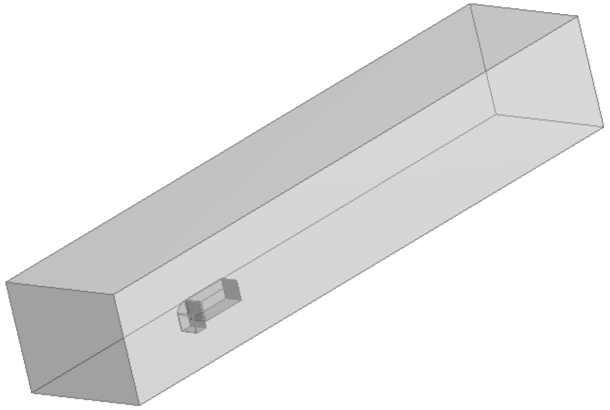
Results Summary-Rear DRD's

Rear	Mesh	CdxA
k-eps	Fine	0.778240616
	Mid	0.852425423
	Coarse	0.86362313
RNG	Fine	0.806234883
	Mid	0.828630297
	Coarse	0.860823703
SST	Fine	0.80483517
	Mid	0.80903431
	Coarse	0.81323345

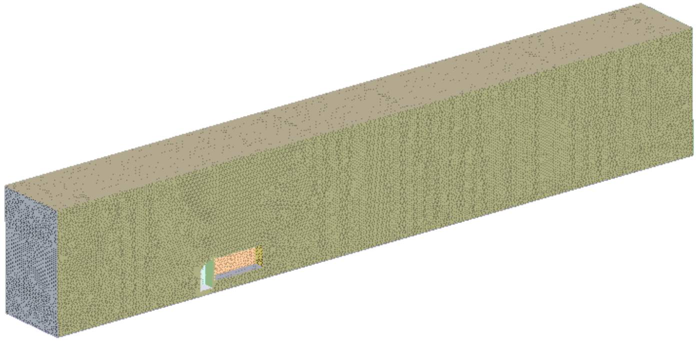
Front DRD’s

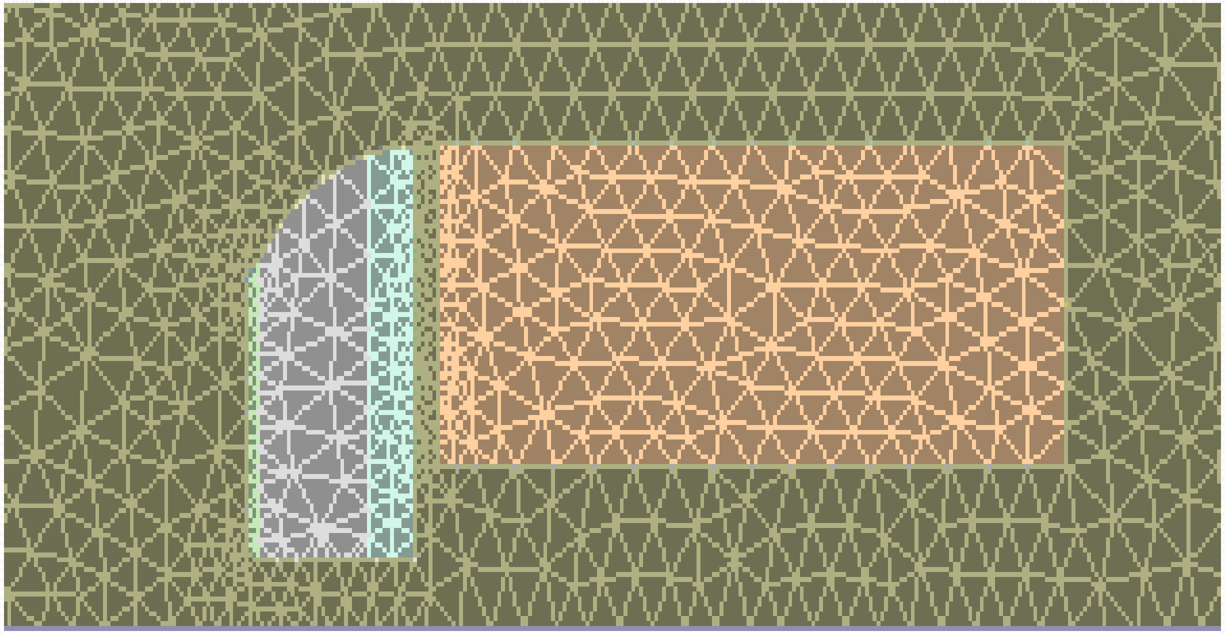




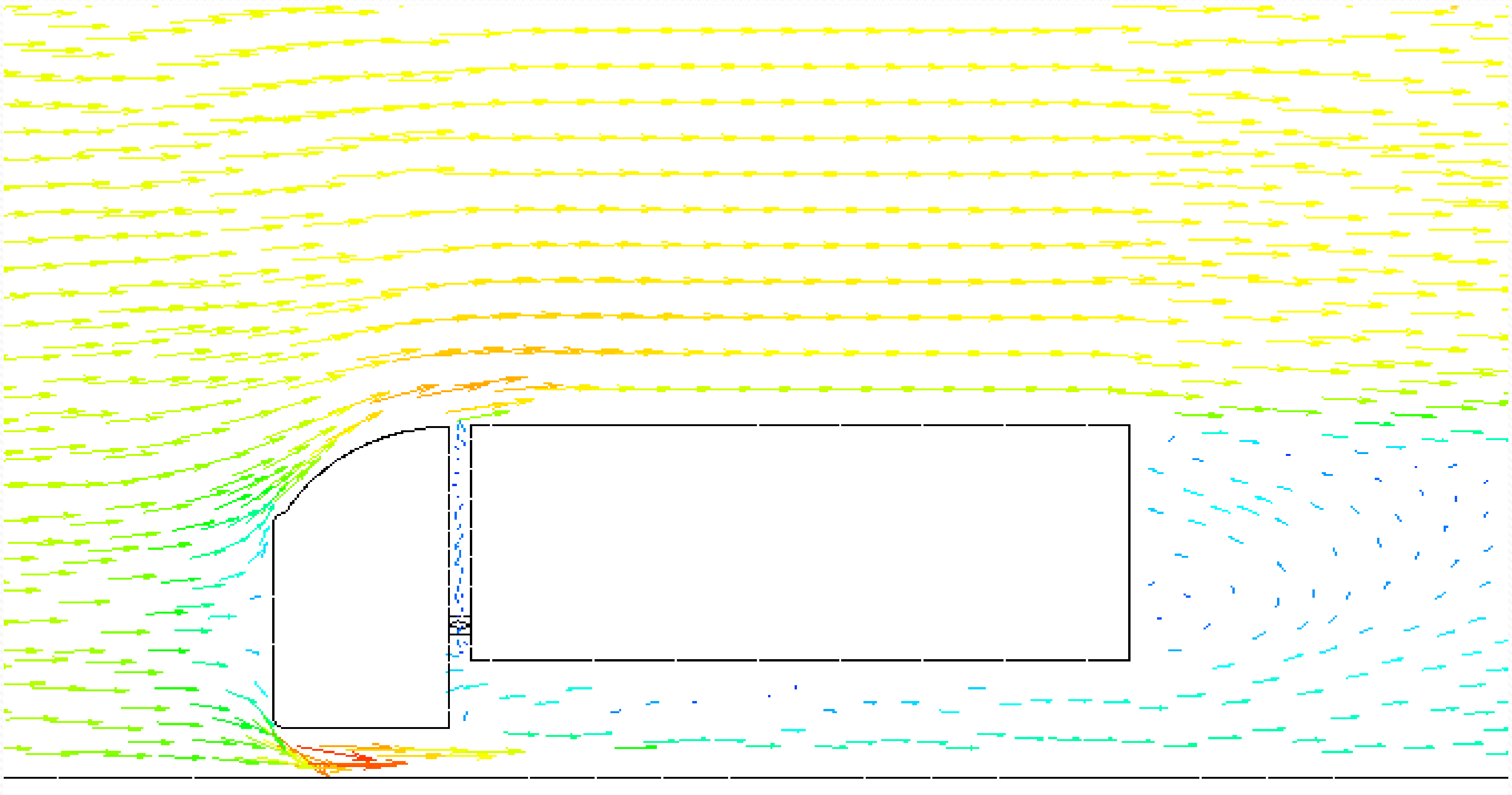


Meshing Grid

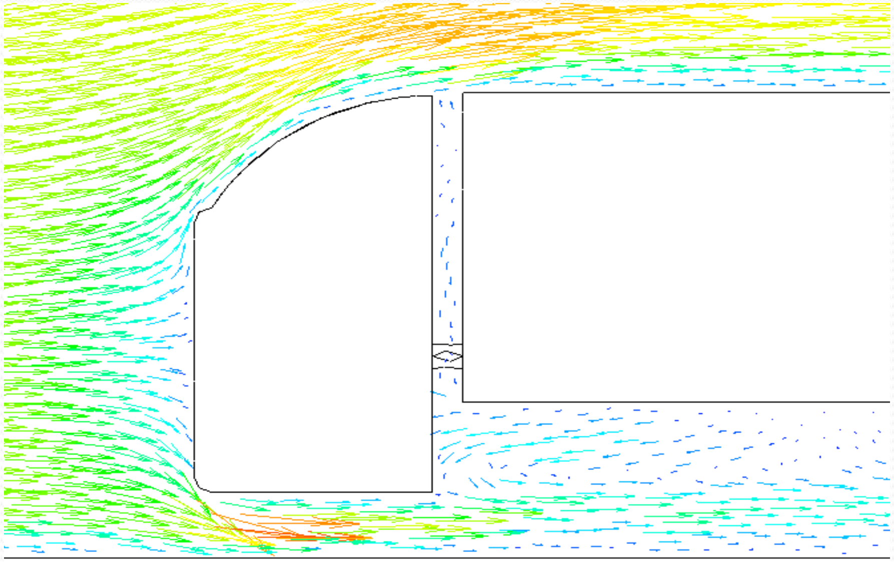


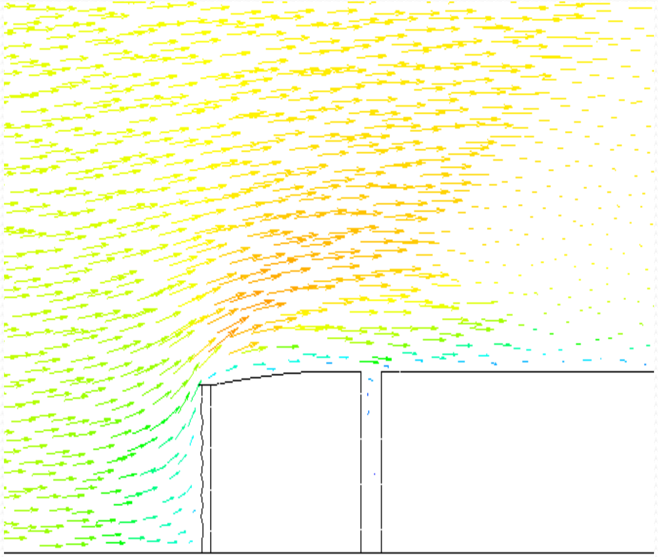


Velocity Vectors

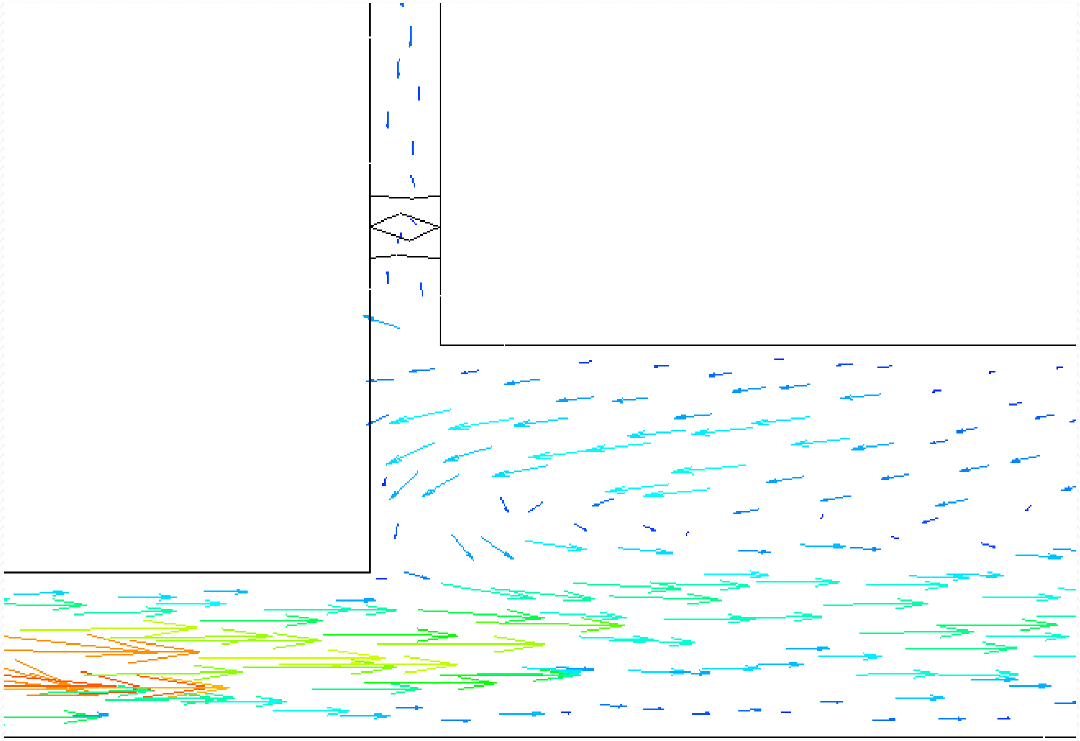


Velocity Vectors-Front DRD's





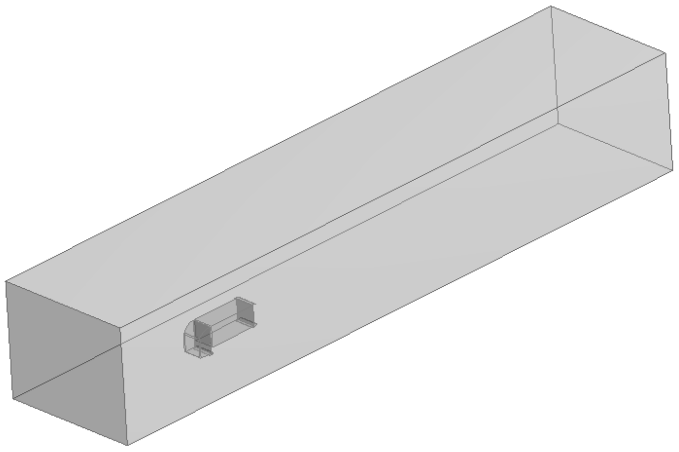
Improvement Needed

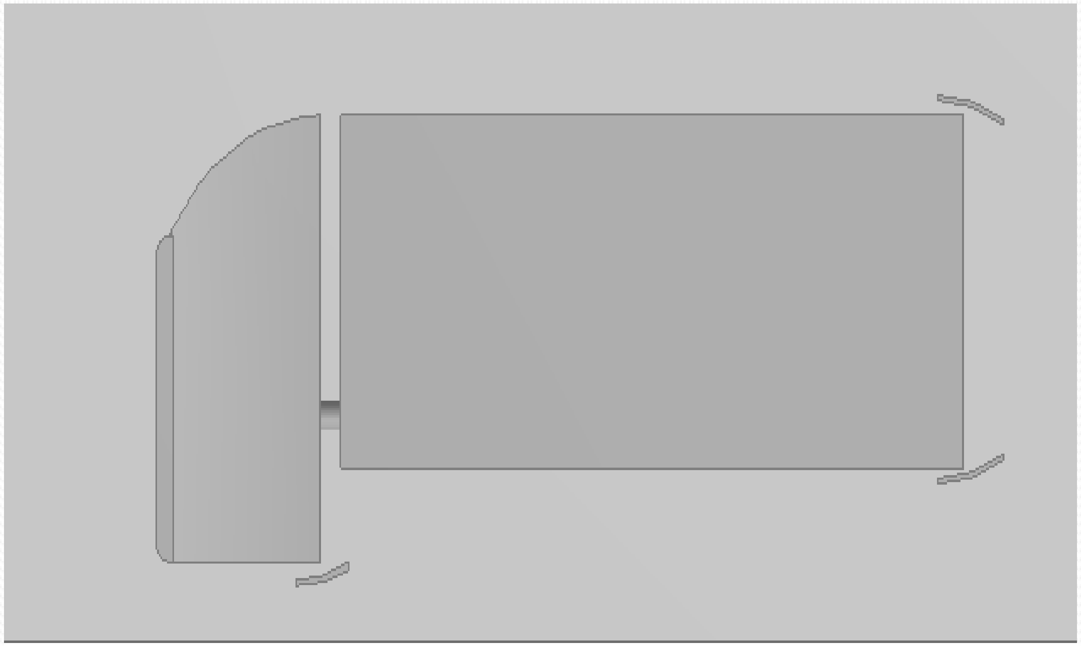


Results Summary-Front DRD's

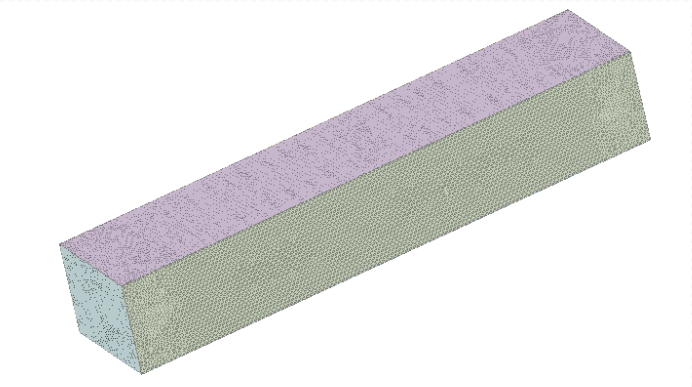
Front	Mesh	CdxA
k-eps	Fine	0.709654663
	Mid	0.711054376
	Coarse	-
RNG	Fine	0.704055809
	Mid	0.706855236
	Coarse	0.82583087
SST	Fine	0.718052943
	Mid	0.722252083
	Coarse	0.862923273

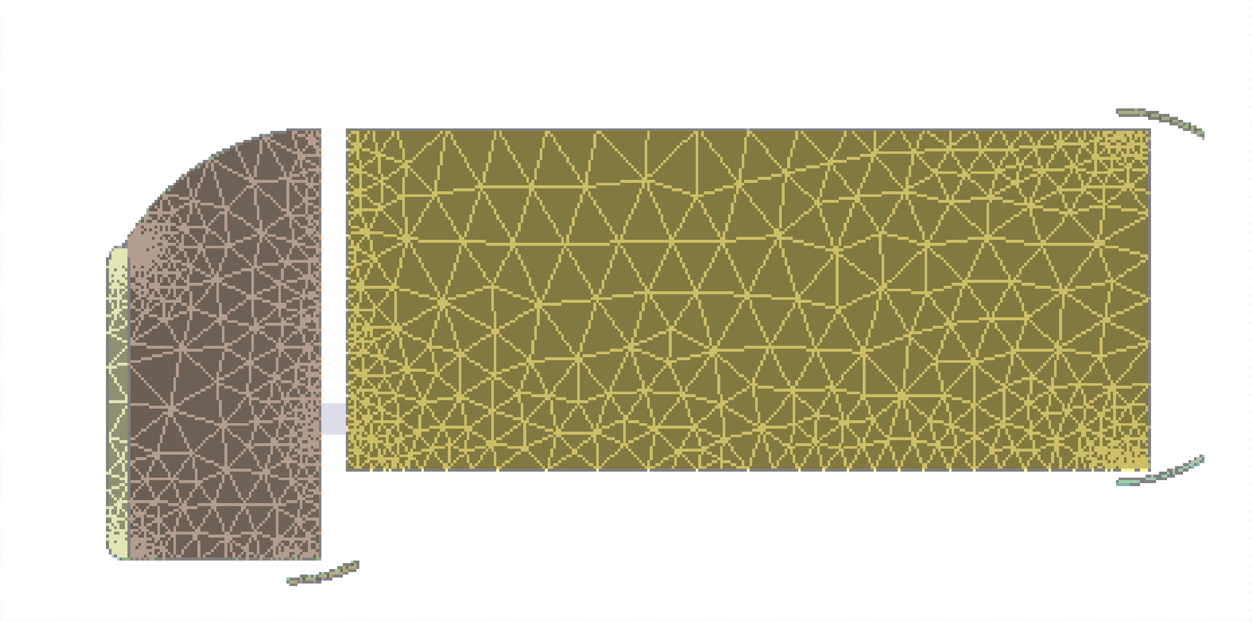
Full DRD's



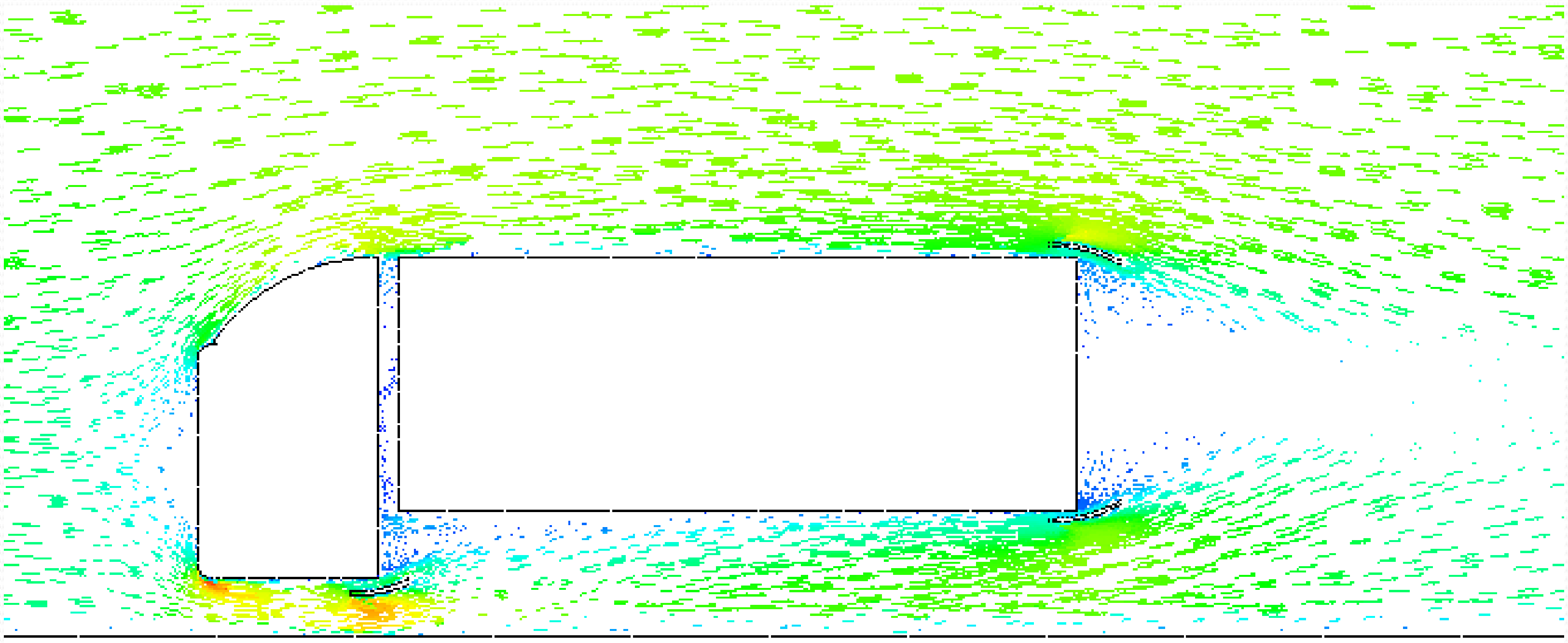


Meshing Grid

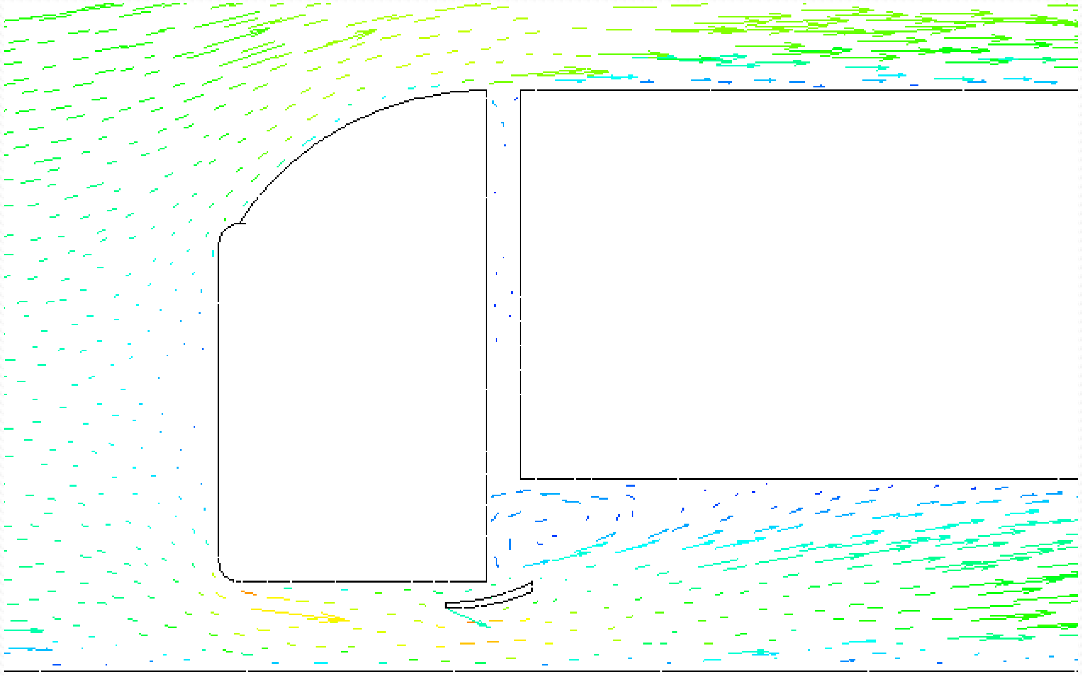


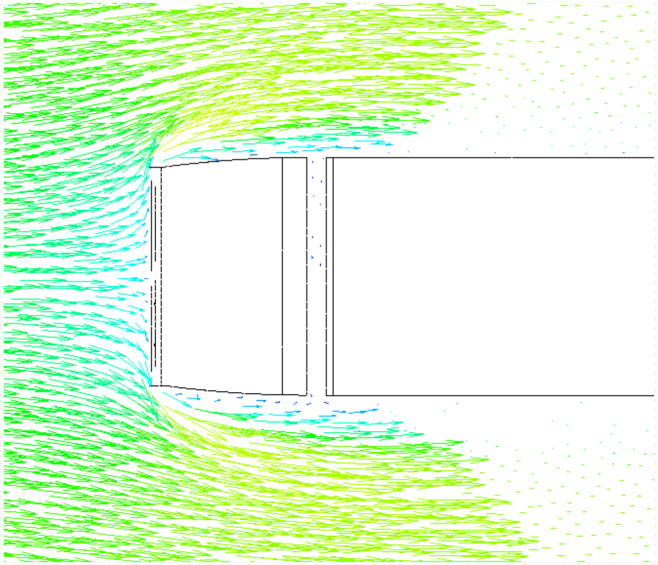


Velocity Vectors



Velocity Vectors-Full DRD's

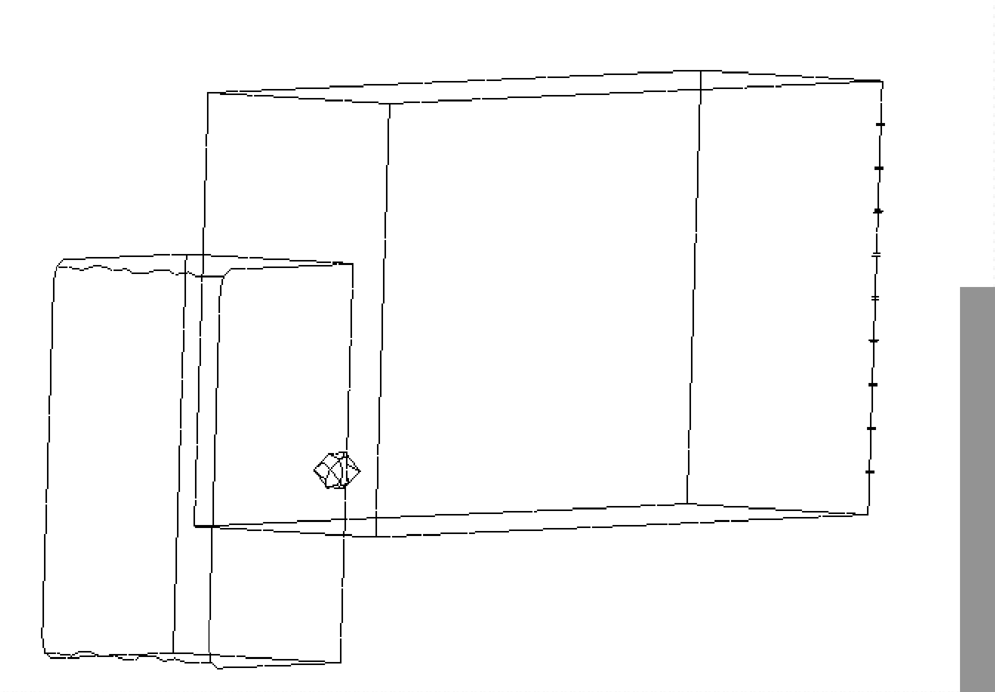


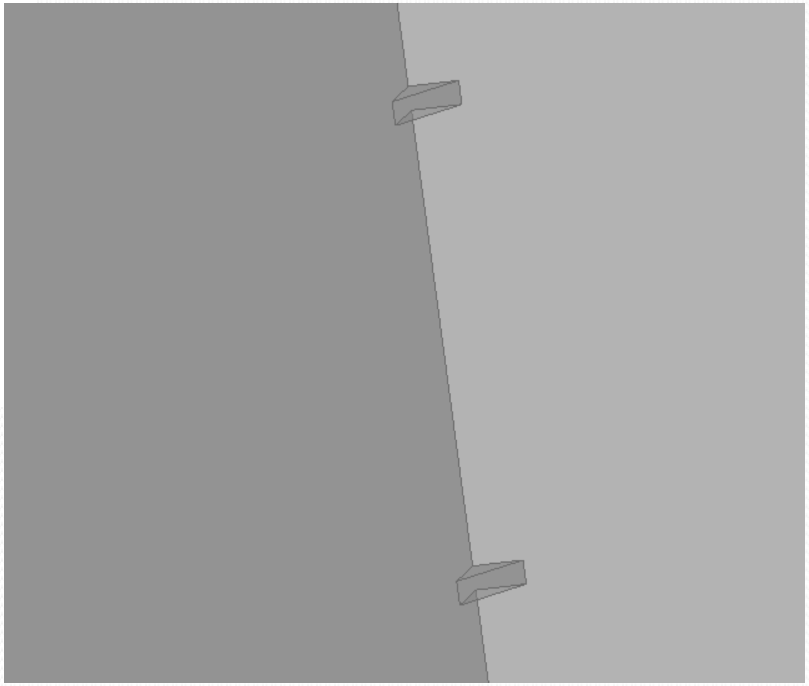


Results Summary-Full DRD’s

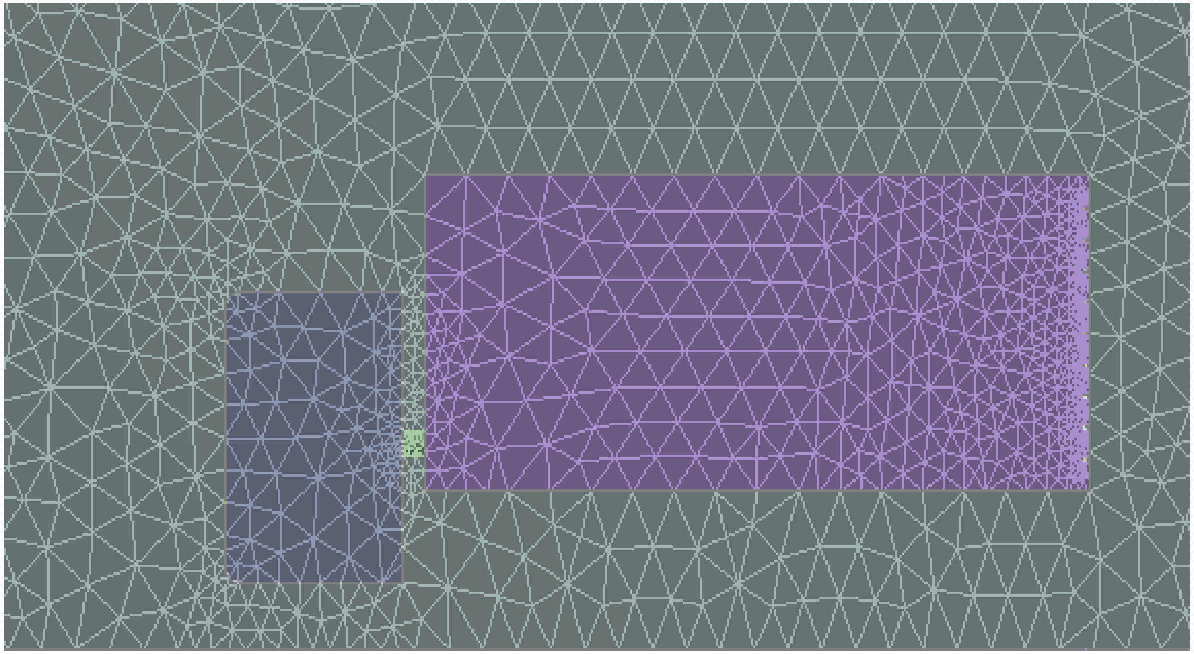
Full	Mesh	Cd
k-eps	Fine	0.713853803
	Mid	0.727151079
	Coarse	0.722252083
RNG	Fine	0.723651796
	Mid	0.735549359
	Coarse	0.735549359
SST	Fine	0.69096849
	Mid	0.708184964
	Coarse	0.708114978

VG DRD’s

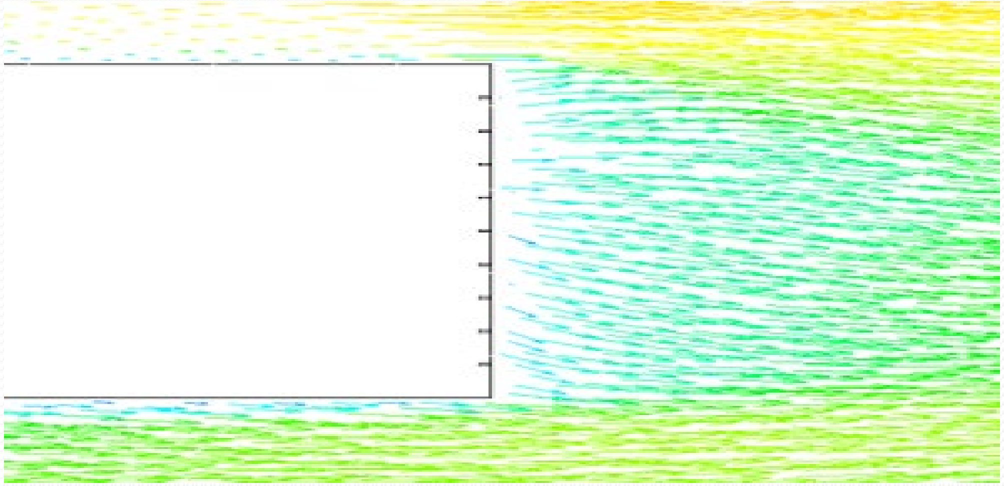




Meshing Grid



Velocity Vectors



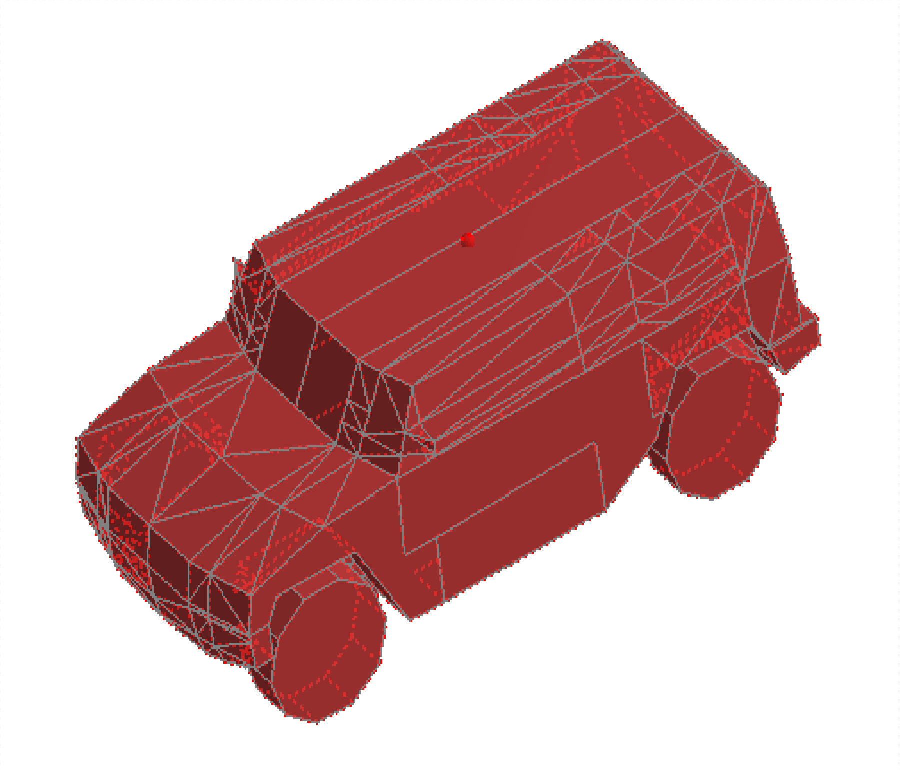
Results Summary-VG DRD's

VG	Mesh	Cd
k-eps	Fine	0.842207516
RNG	Fine	0.828630297
SST	Fine	0.84682657

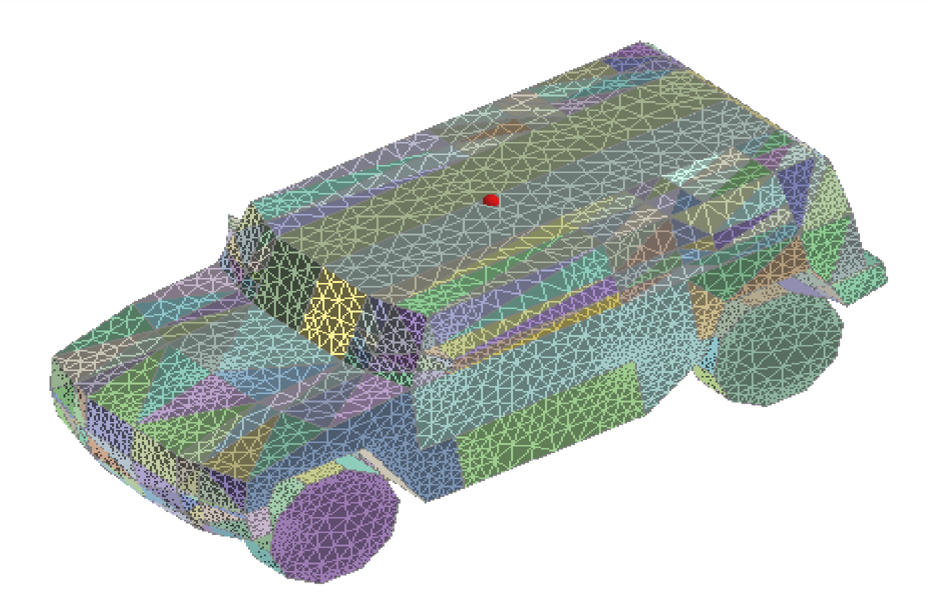
Cd Reduction for Tractor Trailer

Model	CdxA Reduction %
Tractor Trailer	
Front	17%
Rear	8.7%
Full	21%
VG	1.6%

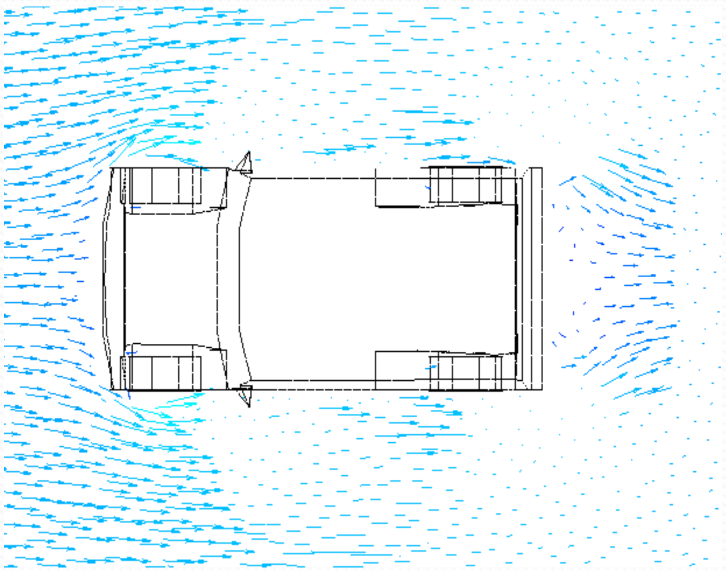
SUV-Hummer



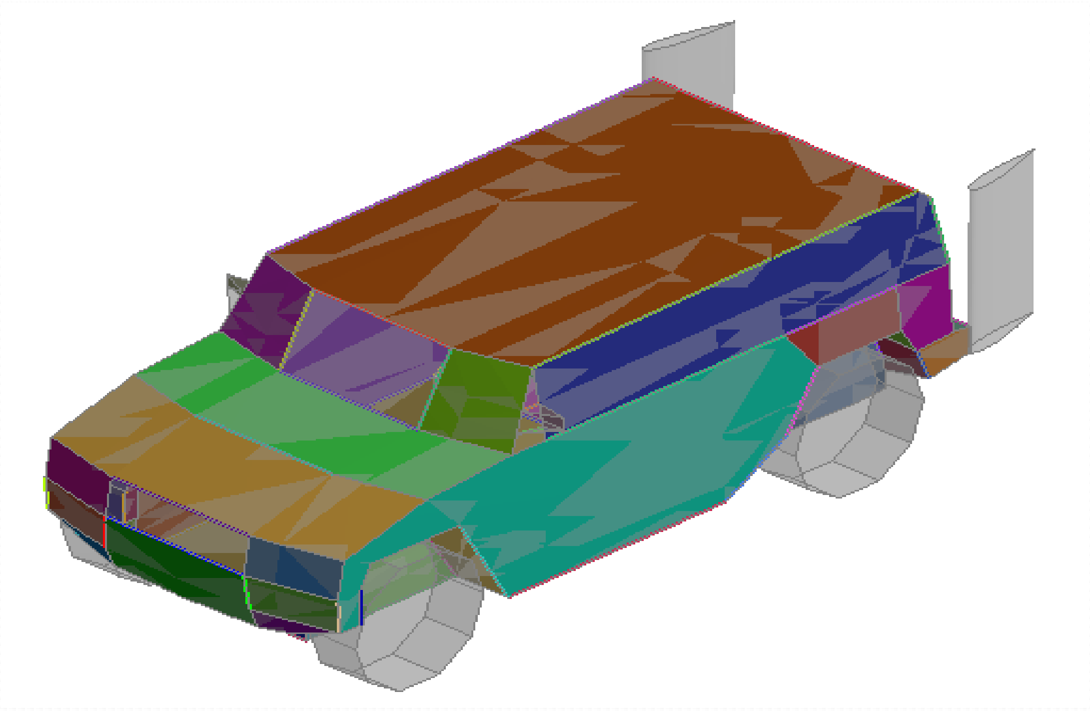
Meshing Grid



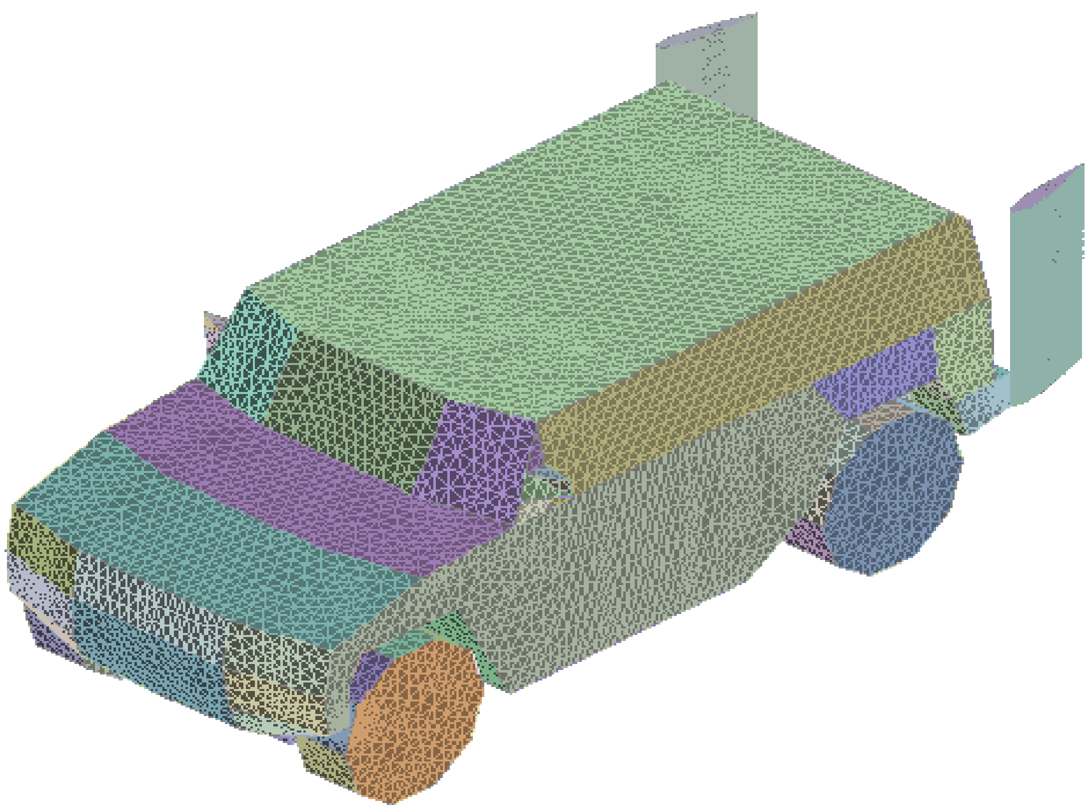
Velocity Vectors



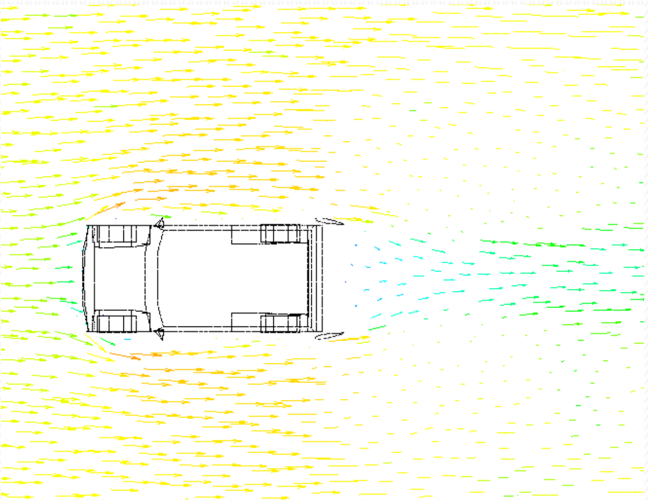
SUV-Hummer with DRD’s

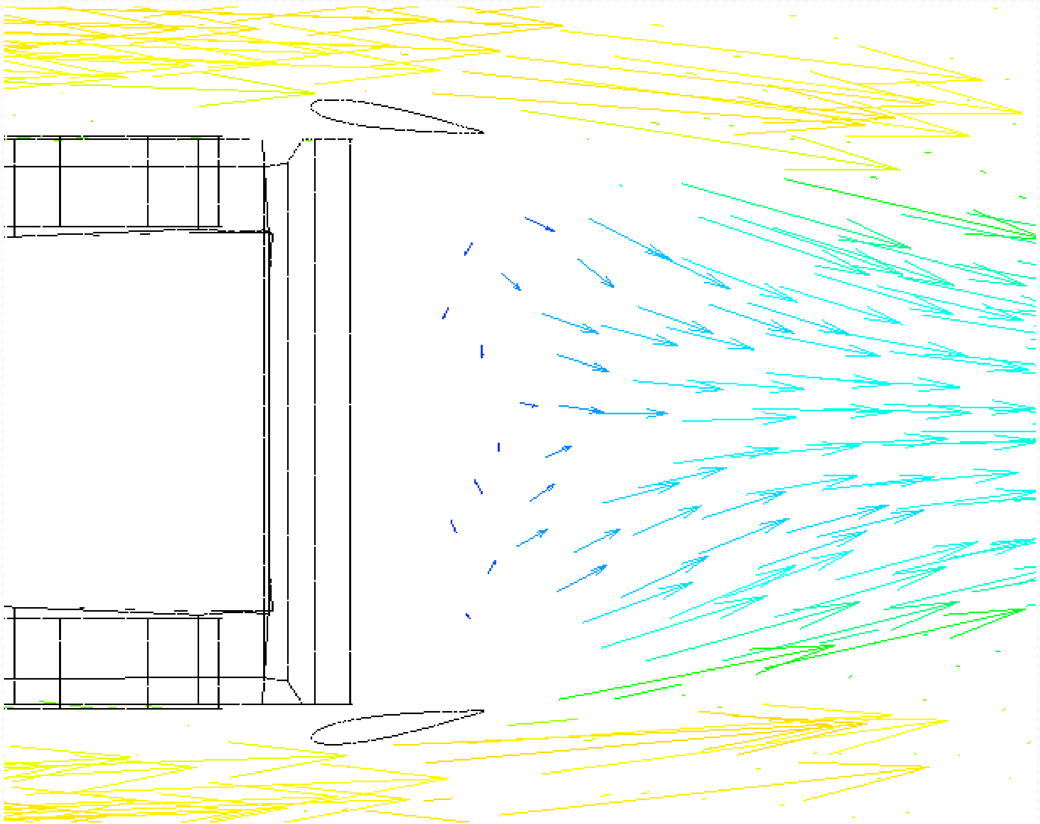


Meshing Grid



Velocity Vectors



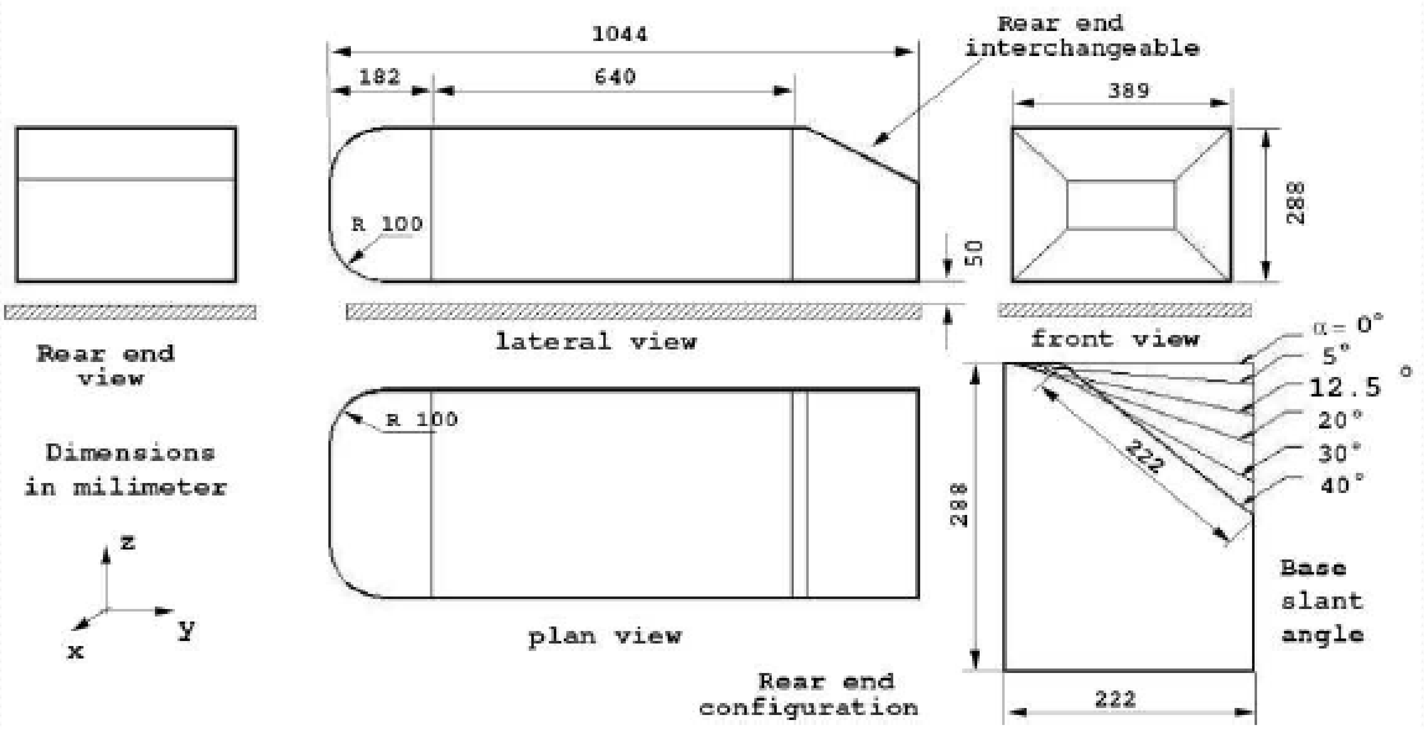


Results-Hummer

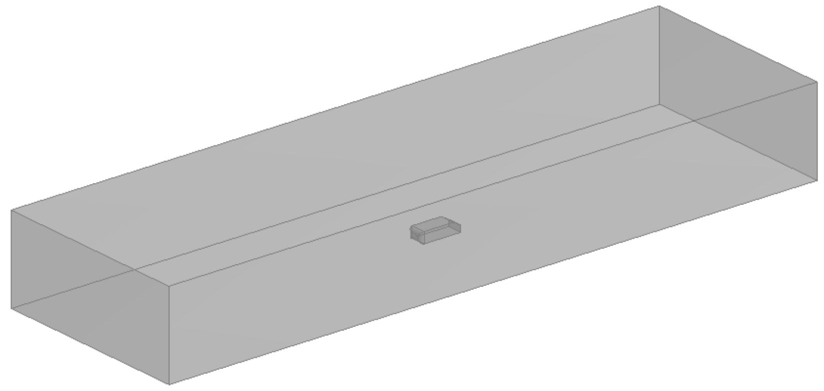
H_2	CdxA
No vane	0.603
With Vane	0.5776

Sedan-Ahmed Car Model

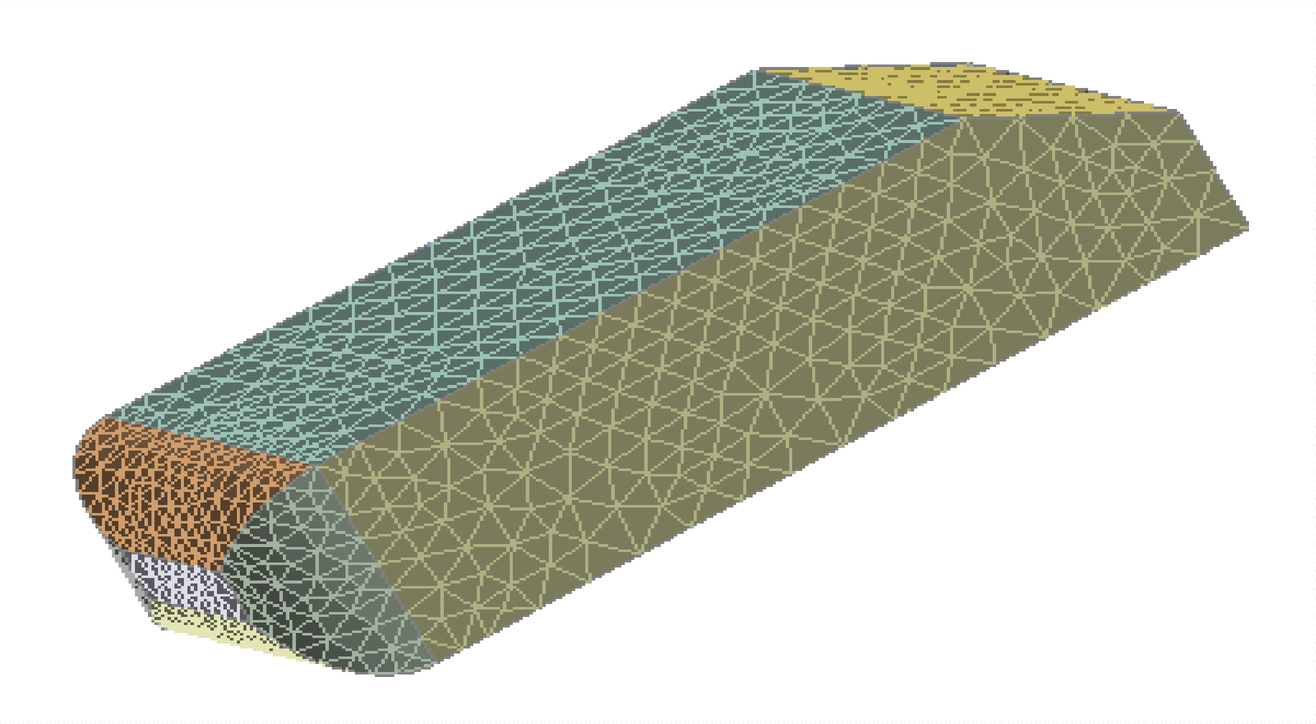
- General Dimensions



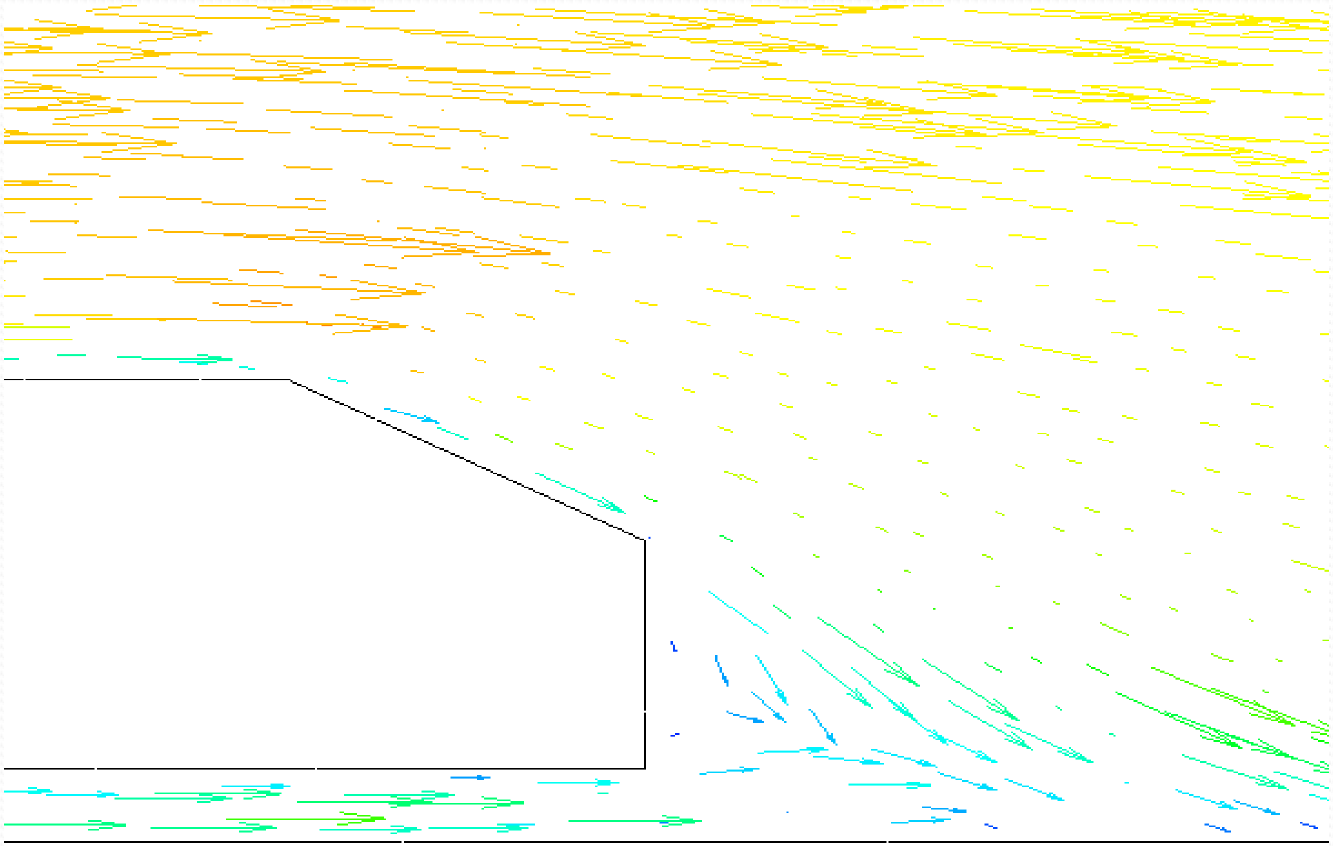
Ahmed Model-No DRD’s



Meshing Grid



Velocity Vectors



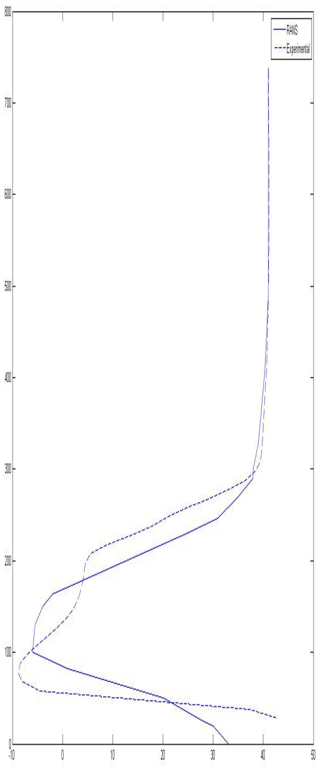
Ahmed Model-No DRD's

- Cd Summary

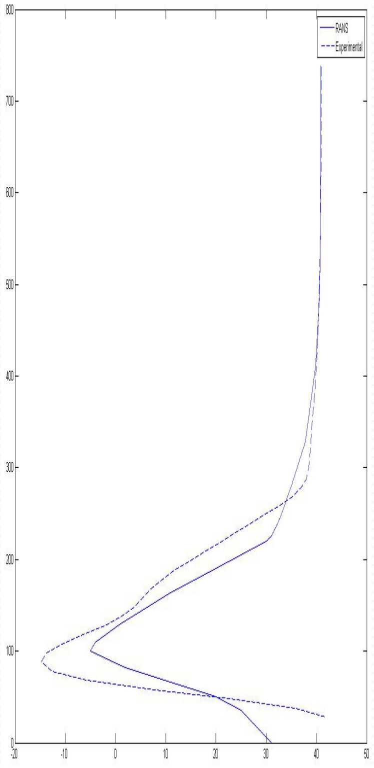
Ahmed No Wing	Mesh	CdxA
k-eps	Fine	0.391571324
	Coarse	0.430465634
RNG	Fine	-
	Coarse	0.4301681
SST	Fine	0.404001634
	Coarse	0.434730289

Verification

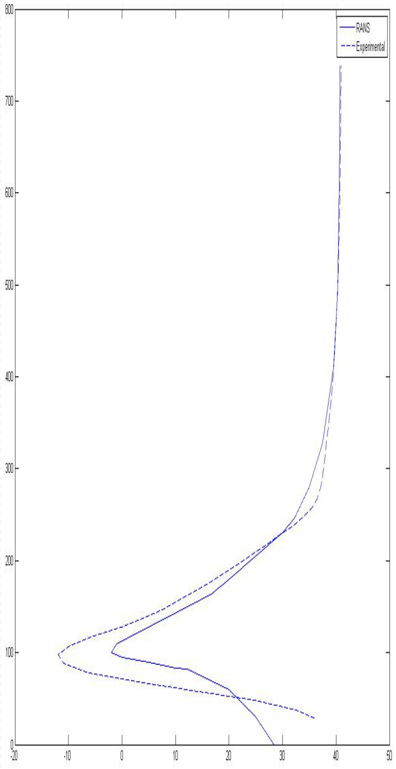
- 38 mm



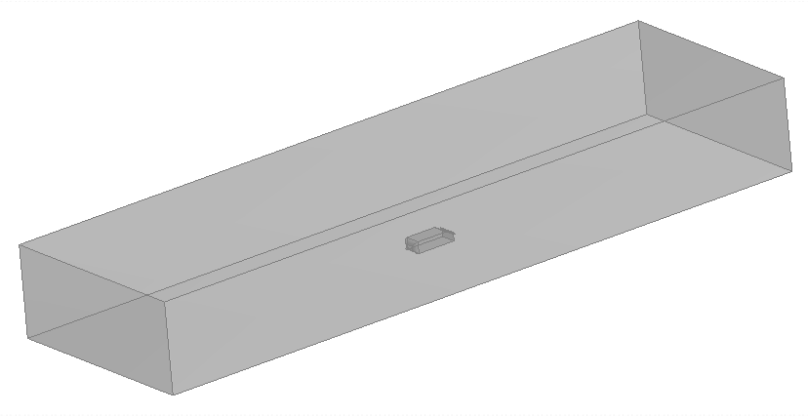
88 mm

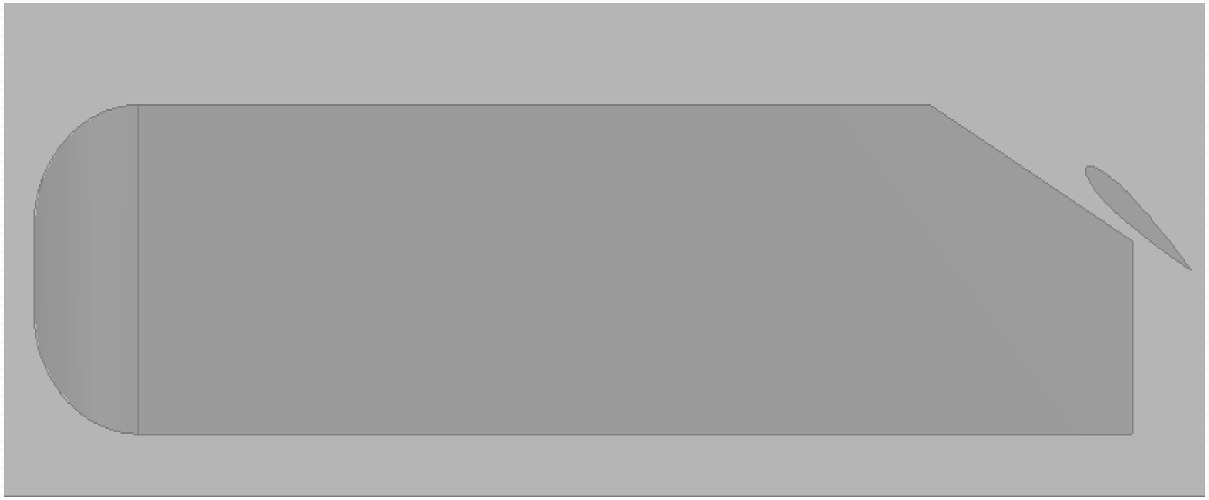


138 mm

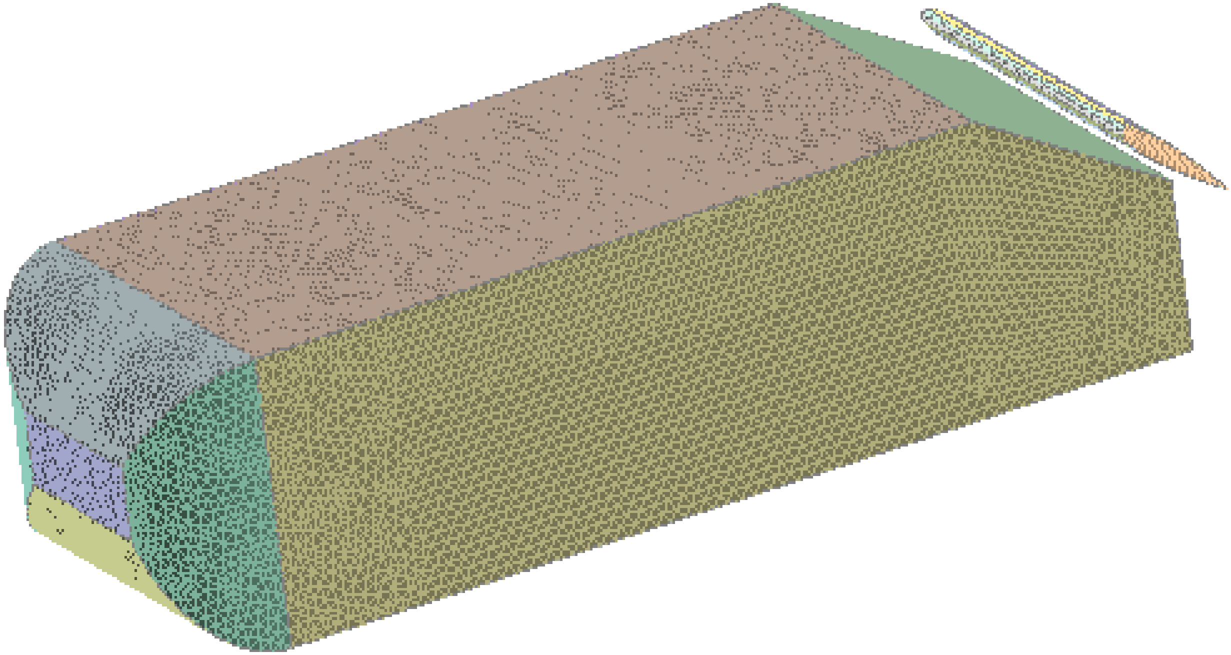


Ahmed Model-Rear Wing

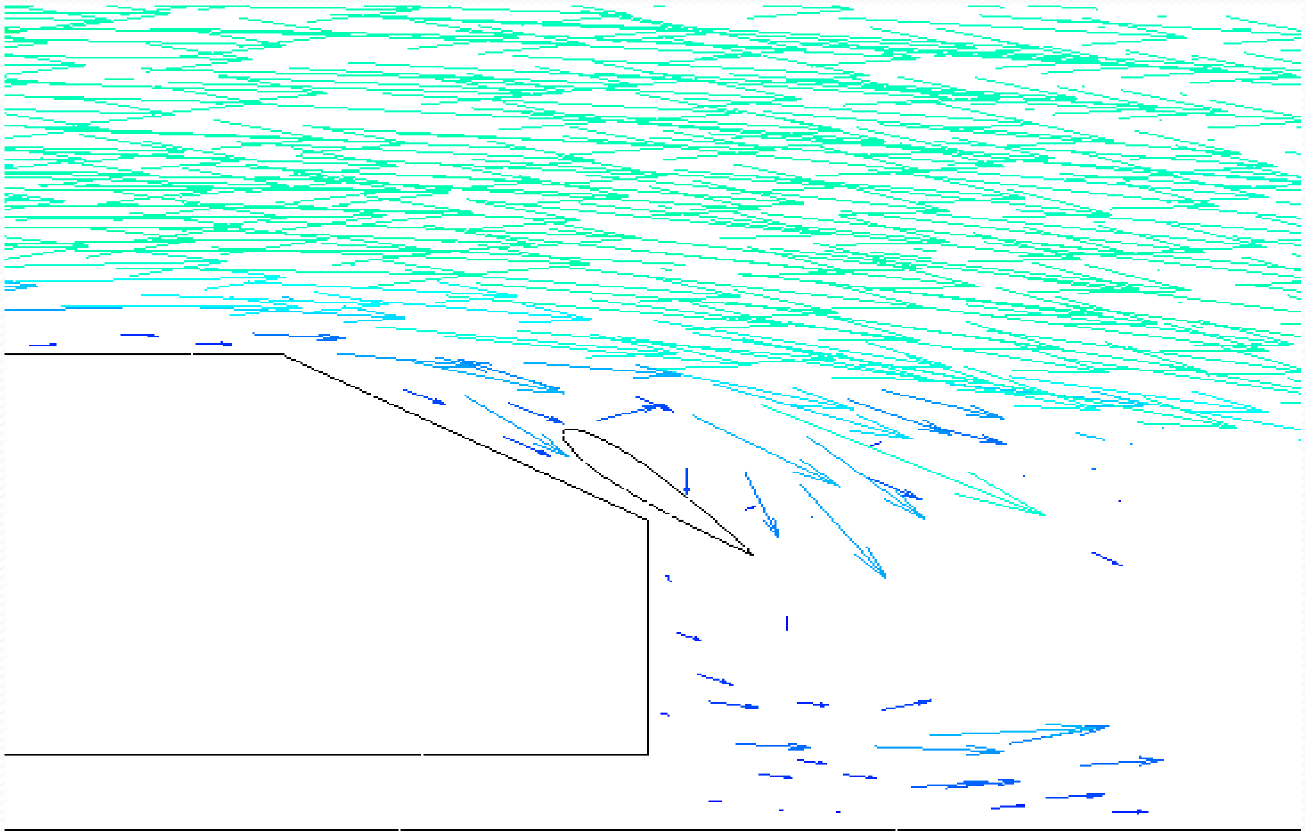




Meshing Grid



Velocity Vectors

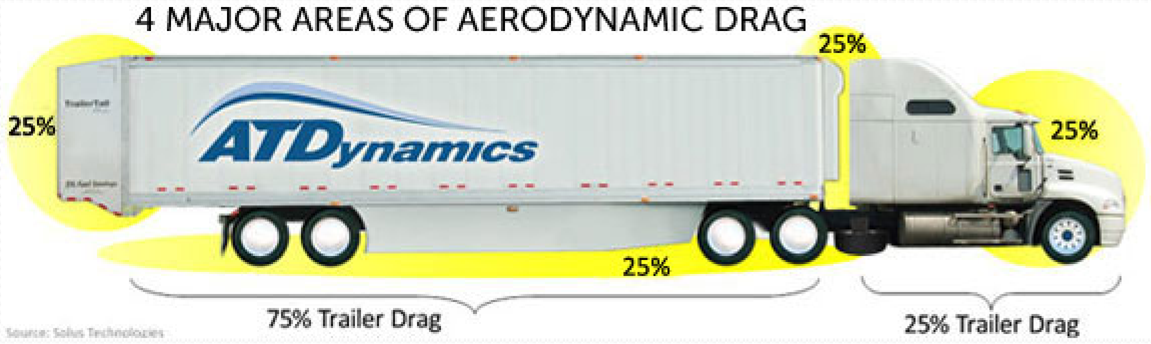


Cd Summary Results

Ahmed with wing	Mesh	CdxA
k-eps	Fine	0.35
	Coarse	0.36
RNG	Fine	0.356
	Coarse	0.408
SST	Fine	0.38
	Coarse	0.401

Future Work

- Optimization of the vanes



- Use of a more complicated geometry

Conclusion

- The drag coefficient of a truck trailer model is studied.
- Using different models in ANSYS
  - RANS
  - LES.
- LES showed results with less error than RANS.

Conclusion

- Tractor Trailer:
  - Rear DRD's: Reduced Drag by 8.7%
  - Front DRD's: Reduced Drag by 17%
  - Full DRD's: Reduced Drag by 21%
  - VG DRD's: Reduced Drag by 1.6%
- SUV:
  - Rear Directing Vanes: Reduced Drag by 4.2%
- Ahmed:
  - Rear Directing Vanes: Reduced Drag by 10%

References

Bibliography

[1] ABDULLAH. Al Garni, L. P. (2010). Experimental Study of a Pickup truck Near Wake. *Journal of Wind Engineering and Industrial Aerodynamics*, 13.

[2] CA. Gilkson, H. T. (2009). An Experimental and Computational Study of the Aerodynamic and Passive Ventilation Charecteristics of Small Livestock Trailers. *Journal of Wind Engineering and Industrial Aerodynamics*, 11.

[3] J.Bettle, A. H. (2002). A Computational Study of the Aerodynamic Forces acting on a tractor trailer vehicle on a bridge in cross-wind. *University of New Brunswick*, 20.

[4] Krajnovic, J. O. (2011). The Flow around a trailer-truck model studied by Large Eddy Simulation. *Journal of Wind Engineering and Industrial Aerodynamics*, 12.

[5] Makoto Tsubokura, T. N. (2010). Large Eddy Simulation on the Unsteady aerodynamic response of a road vehicle in Transient Crosswinds. *International Journal of Heat and Fluid Flow*, 12.

[6] Md. Mahbubar Rahman, M. M. (2007). Numerical Investigation of Unsteady Flow Past A Circular Cylinder 2-D-Finite Volume Method. *Jounrla of Naval Architecture and Marine Engineering*, 16.

[7] Menter, R. (1993). Zonal Two Equation k-epsilon Turbulence Models for Aerodynamic Flows. *AIAA Journal*.

[8] Moin, P. (2002). Advances in Large Eddy Simulation Methodology for Complex Flows . *International Journal of Heat and Fluid Flow*, 11.

[9] QI Xiao-ni, L. Y.-q. (2011). Experimental and Numerical Studies of Aerodynamic Performance of Trucks. *Science Journal*, 7.

[10] Sinisa Krajnovic, J. F. (2011). Numerical Simulation of the Flow Around a simplified Vehicle Model With Active Flow Control. *International Journal of Heat and Fluid Flow*, 9.

- Thank you for listening.

- Looking forward for your questions and comments.