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## Numerical Simulations of Drag-Reducing Devices for Ground Vehicles

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# 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 of vehicles as it consists 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

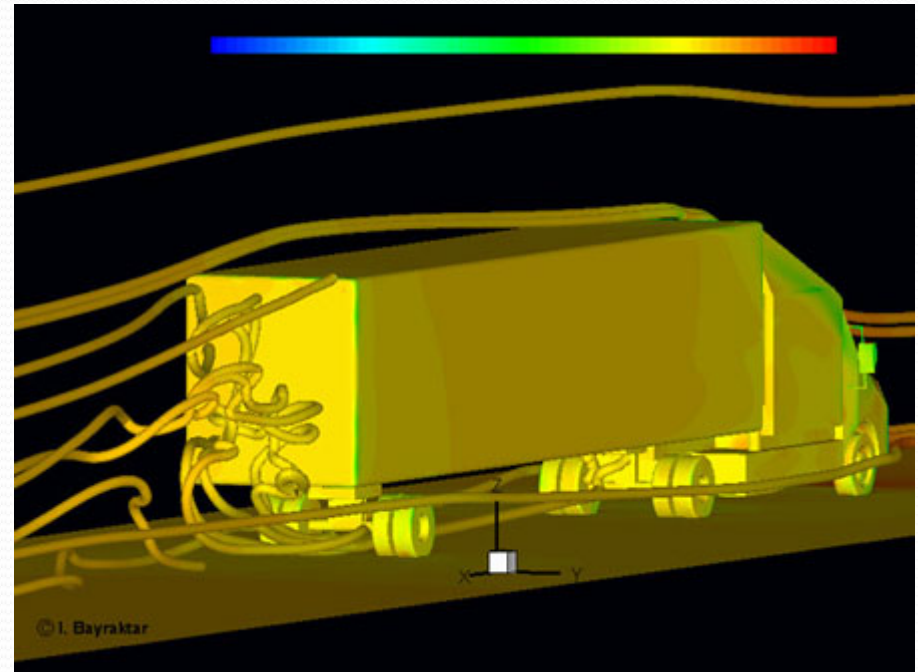
- “10 percent reduction in aerodynamic drag of the tractor trailer is equivalent to a reduction of 4100 \$ per year per each truck.”
- In 1997, the fuel consumption of the Class 8 trucks reached 18 billion gallons in which 65% of this fuel consumption is wasted to overcome the aerodynamic drag.

# 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



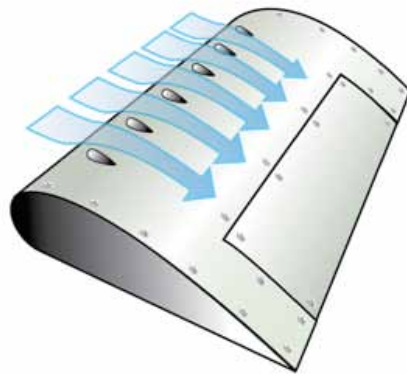
# Drag Reducing Devices Examples (Front Heads)



# 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 ( $19.7 \times 10^6$  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 Stokes'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  $\epsilon$
- 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  $k-\omega$  model.
  - It combines the original Wilcox  $k$ - $\Omega$  model for use near walls
  - Also uses the standard  $k-\epsilon$  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

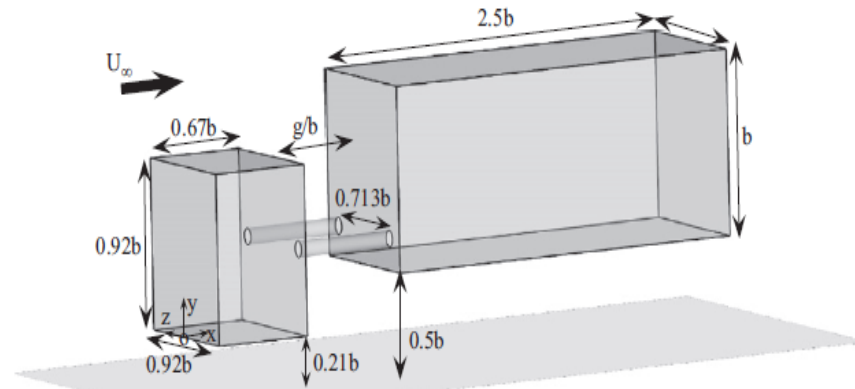
- Numerical Simulation gives different answers for different meshing grids, different processors and different Numerical Models.
- Comparison with experimental results is required.
- If numerical solution shows consistency with experimental; therefore, one can proceed with modifying the design considering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

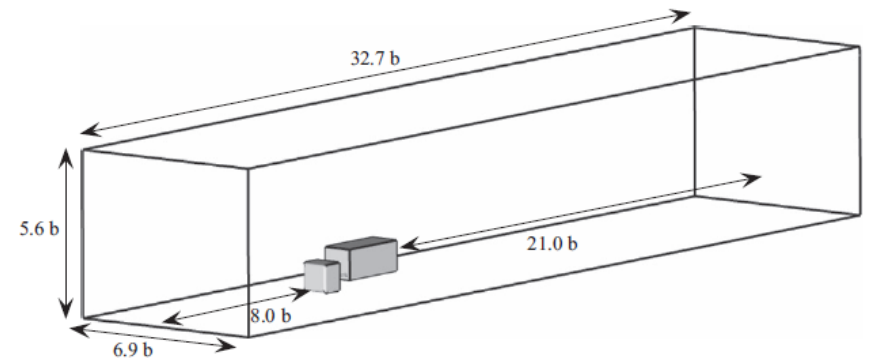
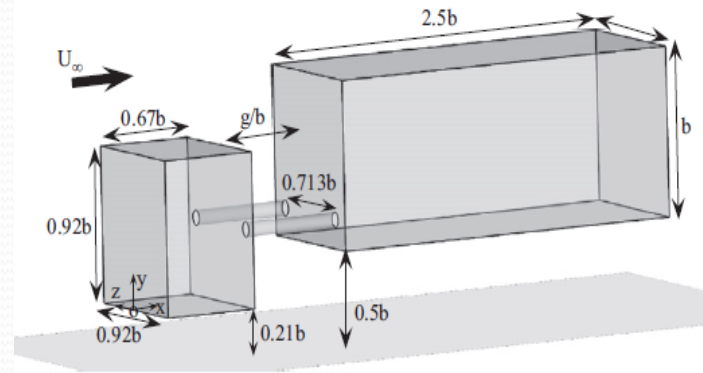
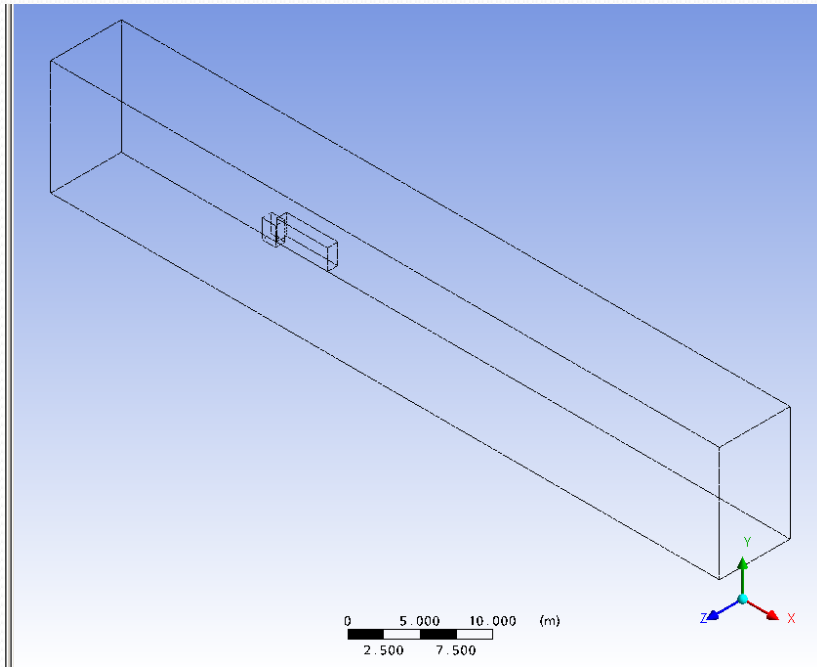
- Three meshing grids:
  - Course
  - Medium
  - Fine
- Tetrahedral meshing elements were used.

# 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:

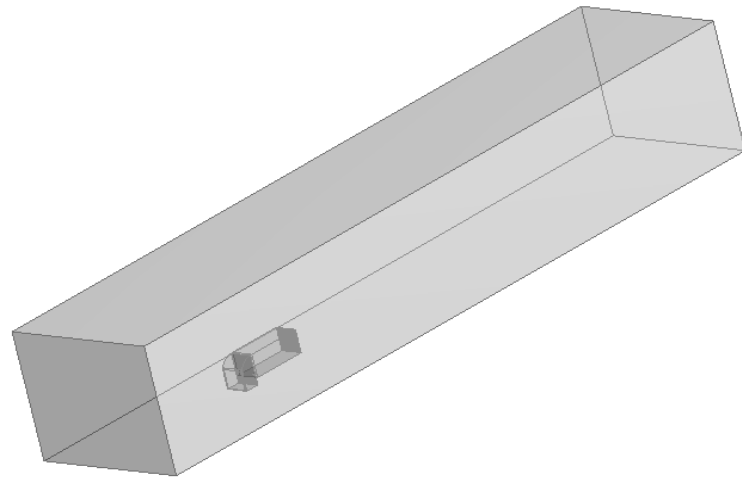


# Meshing Grid-RANS

- 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

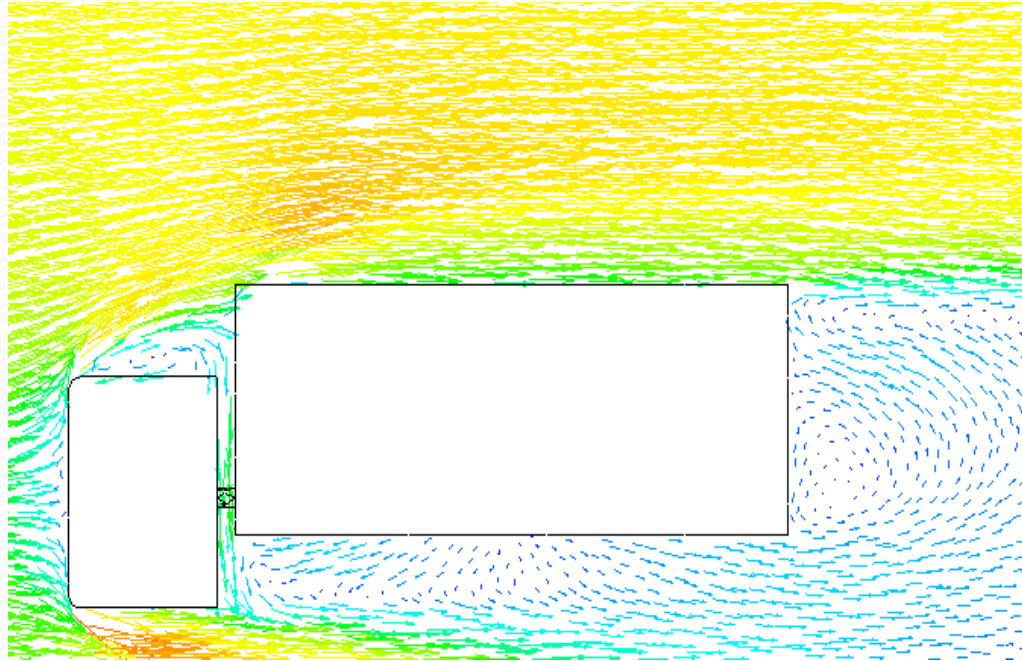
Drags Error	LES
0.14 M	4.45 %
1.7 M	2.1 %

# Discussion of LES results

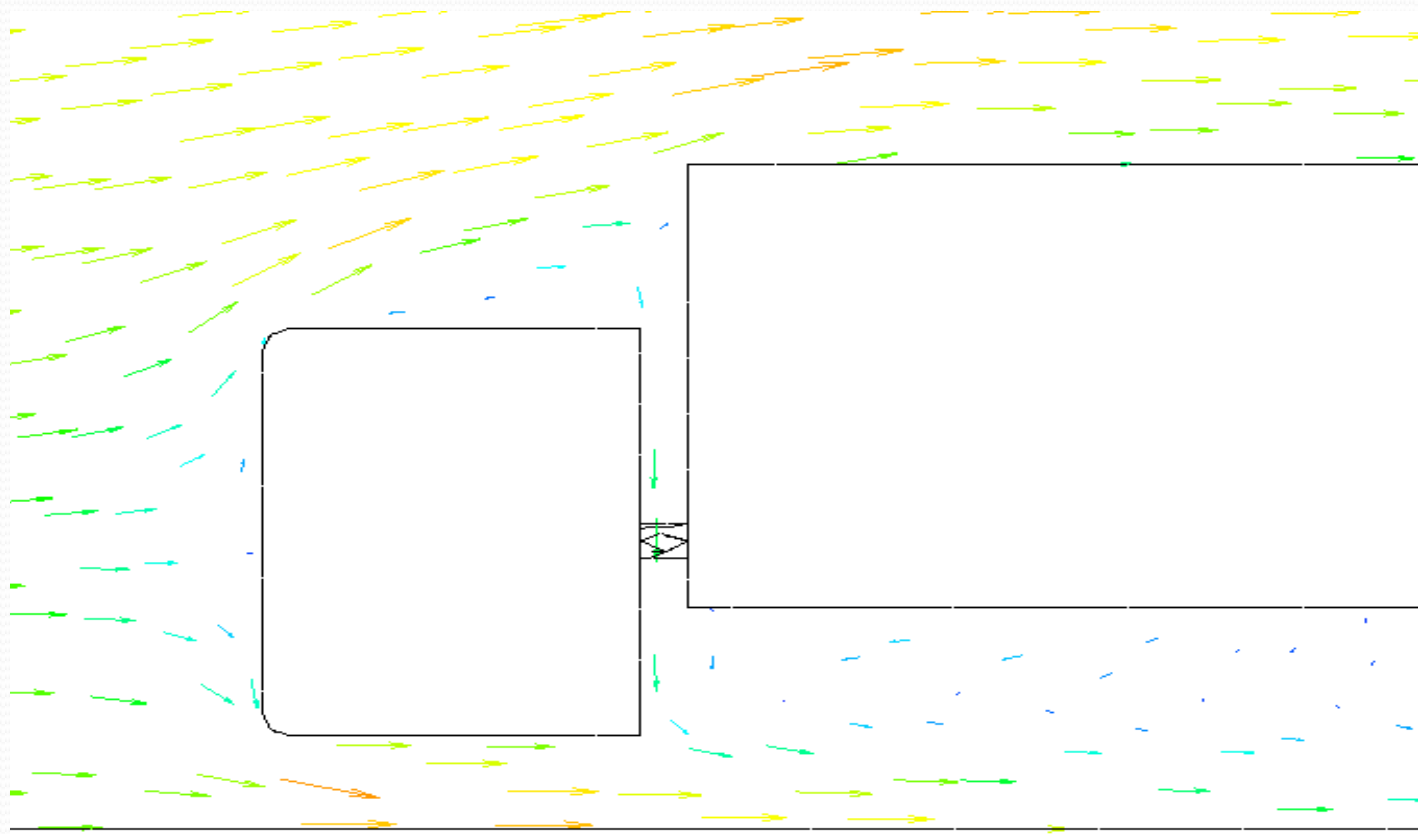
- The finer the grid, the closer the result is to the experimental results
- The LES coarse results showed more accurate results than those of the fine mesh RANS.
- The SST had the least close results to the experimental ones.

# Velocity Vectors

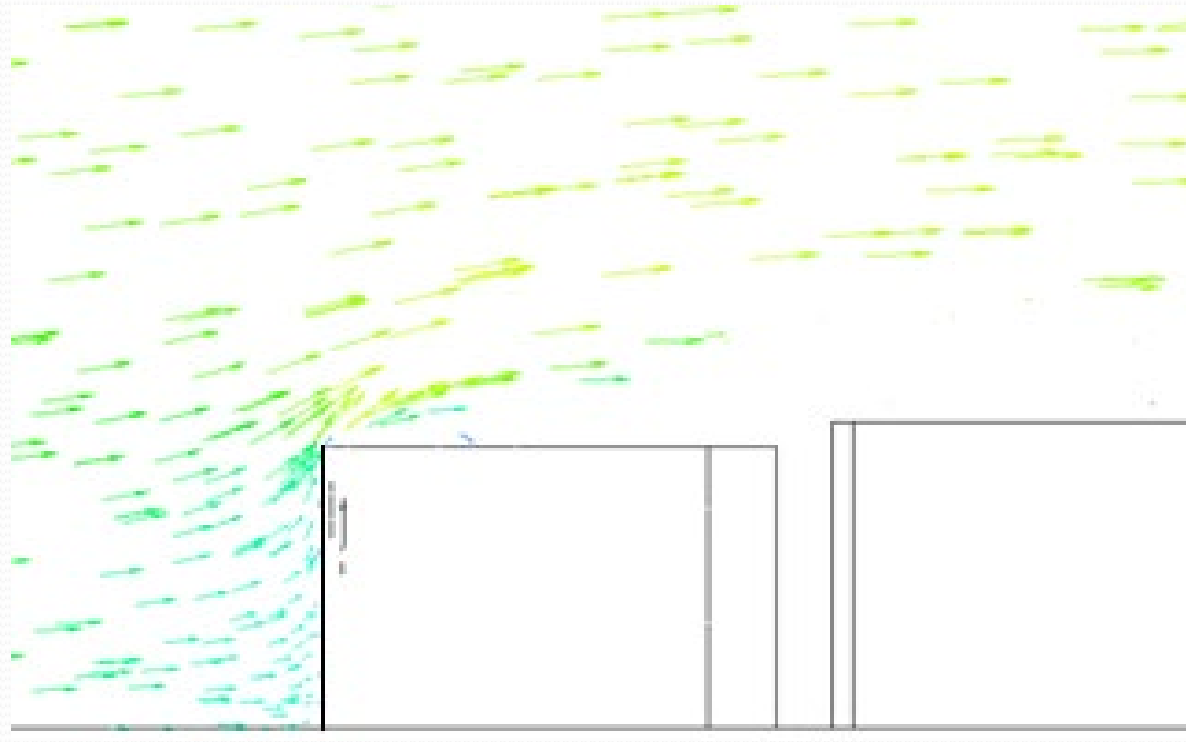
- Tractor Trailer-No DRD's



# Velocity Vectors



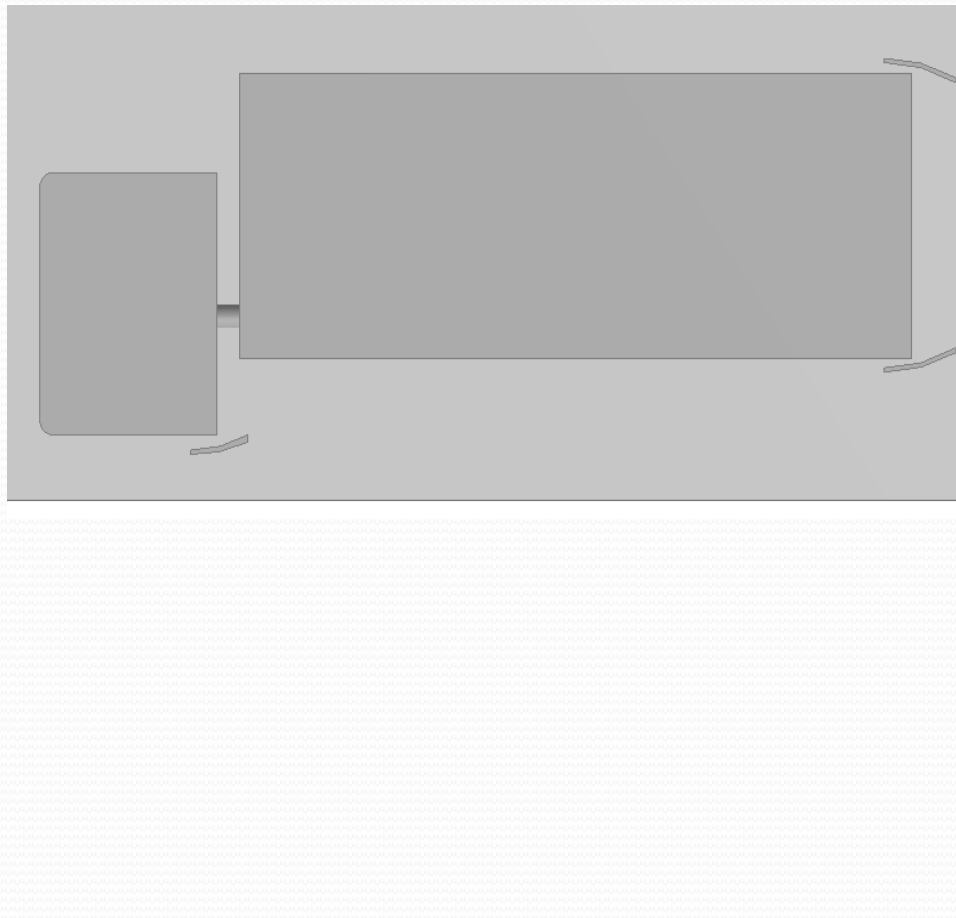
# Velocity Vectors-Top View



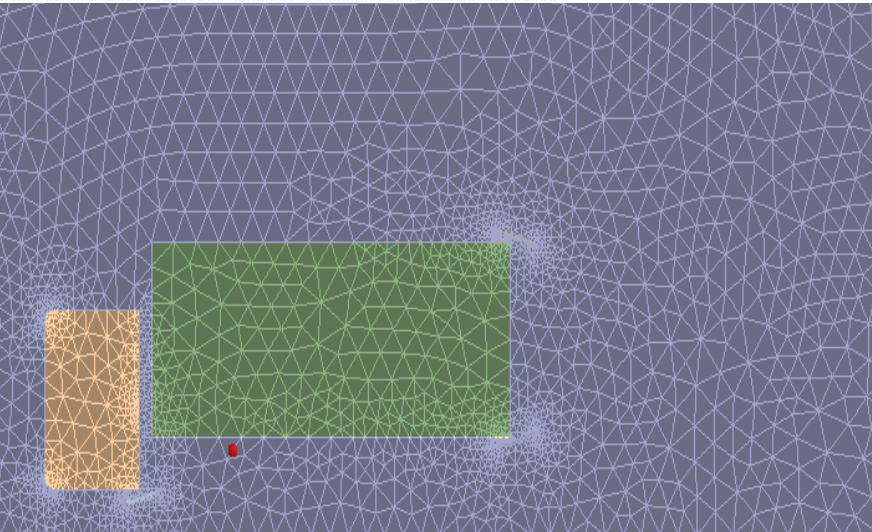
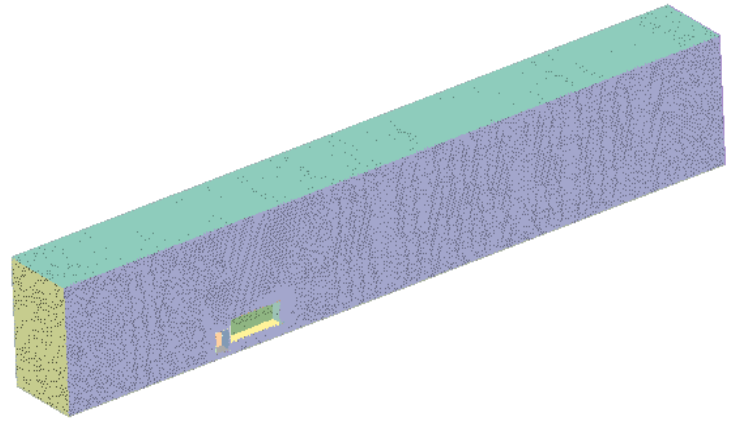


# **DRAG REDUCING DEVICES**

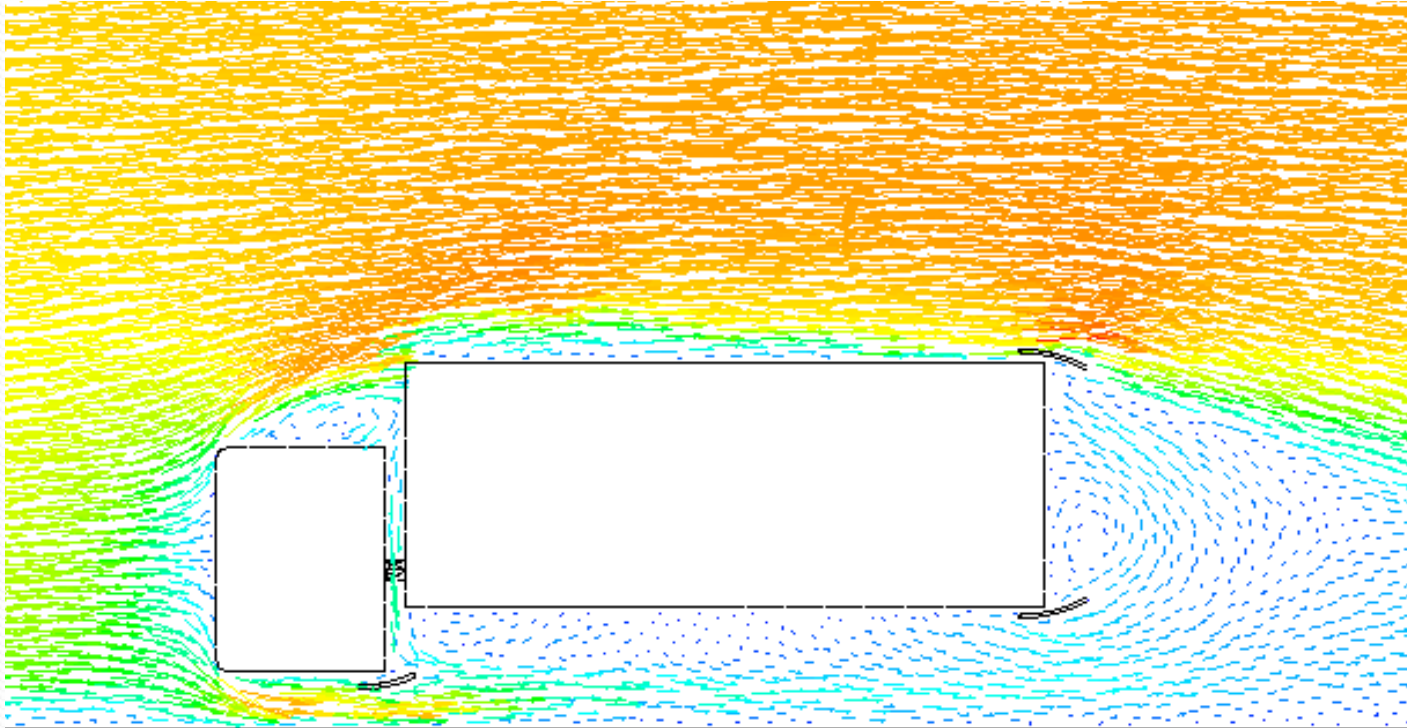
# Rear DRD's



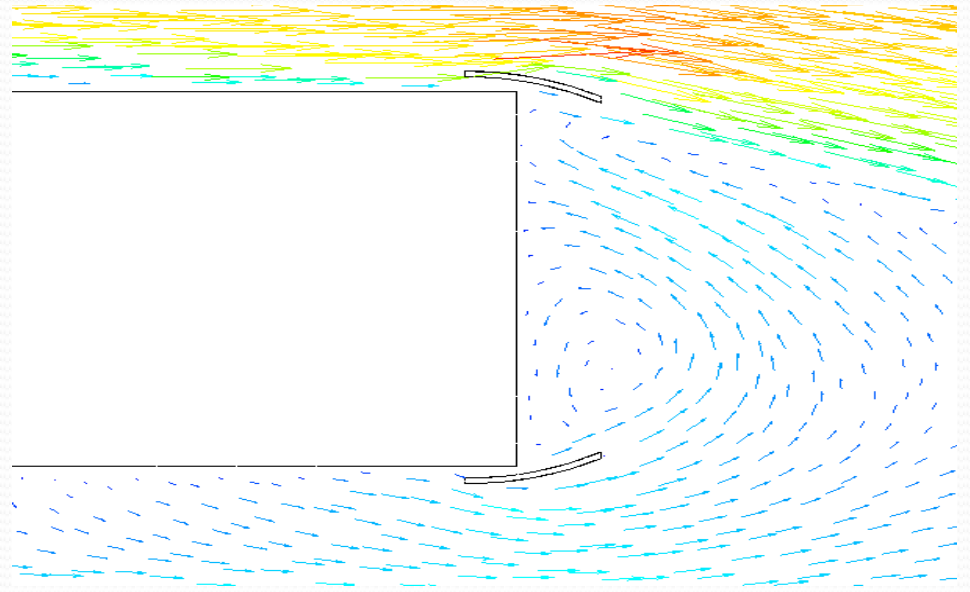
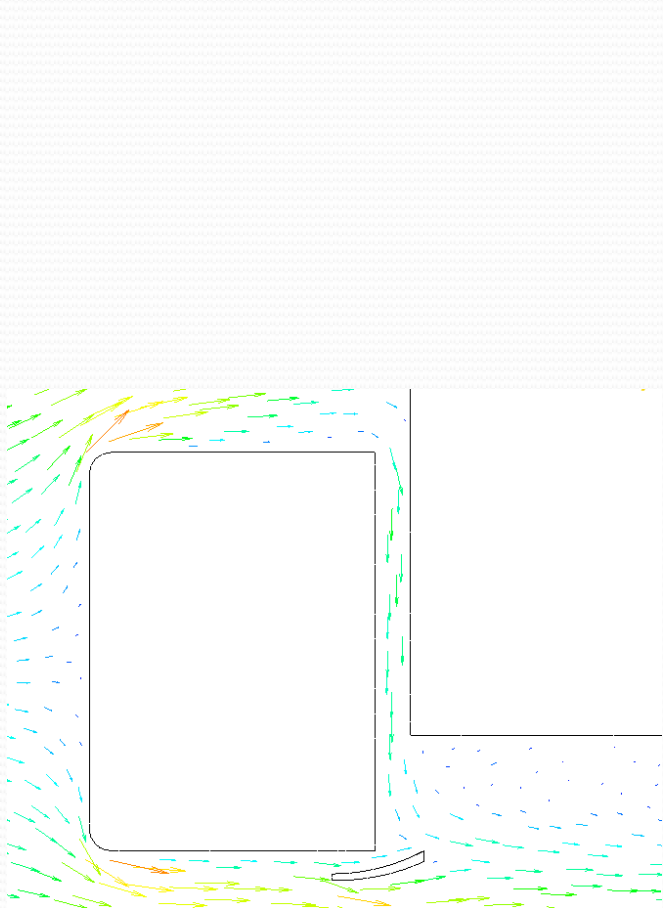
# Meshing Grid



# Velocity Vectors



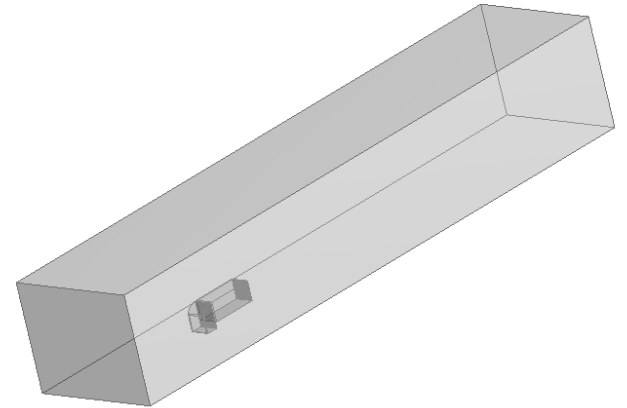
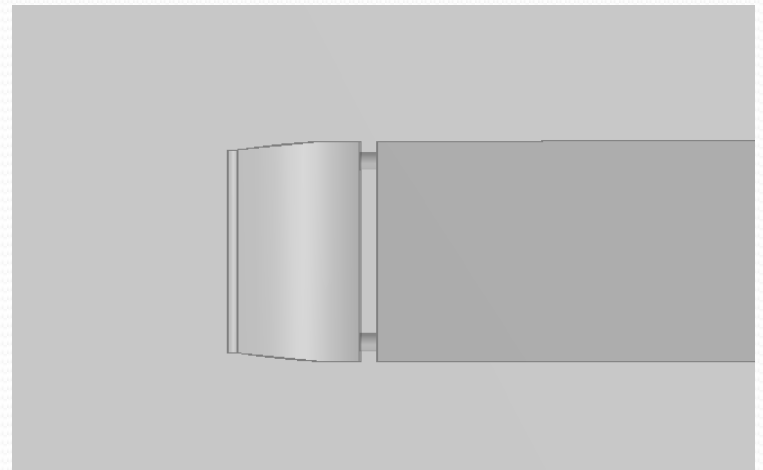
# Velocity Vectors-Rear DRD's



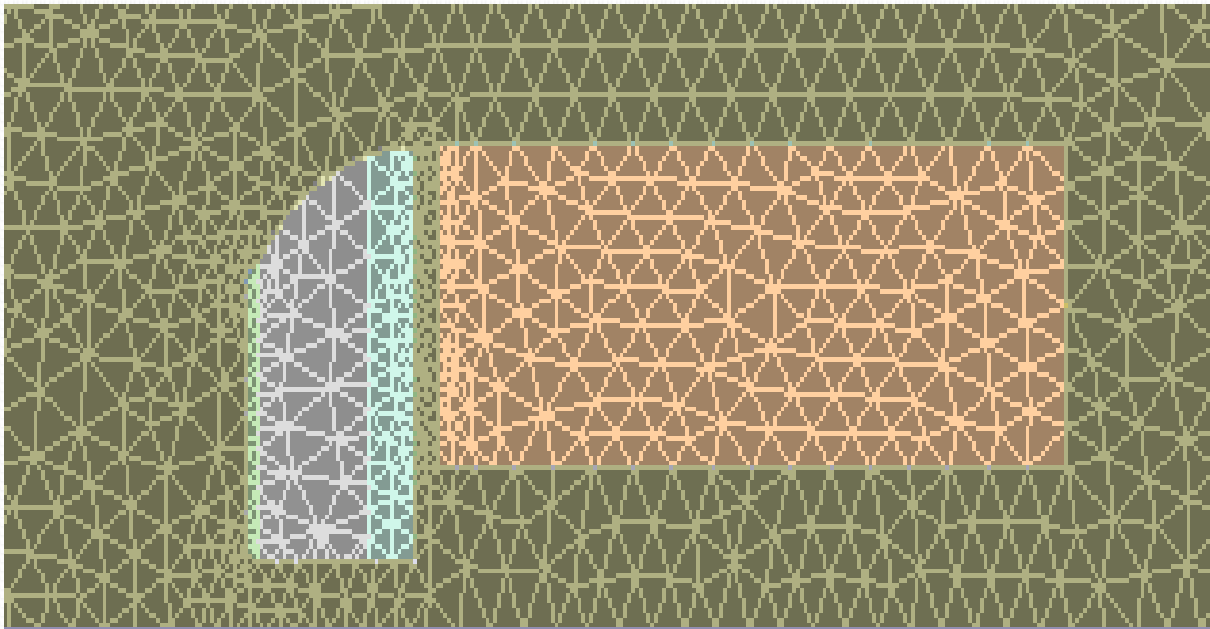
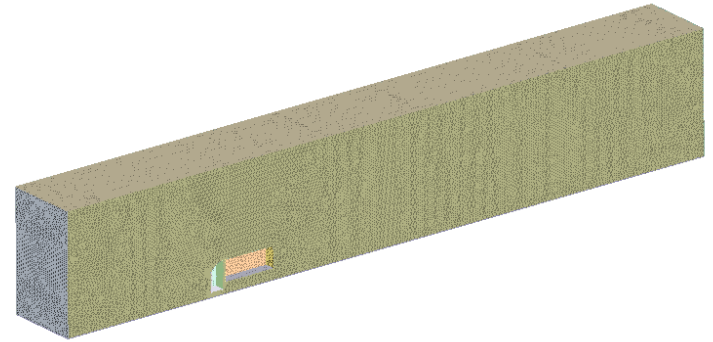
# Results Summary-Rear DRD's

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

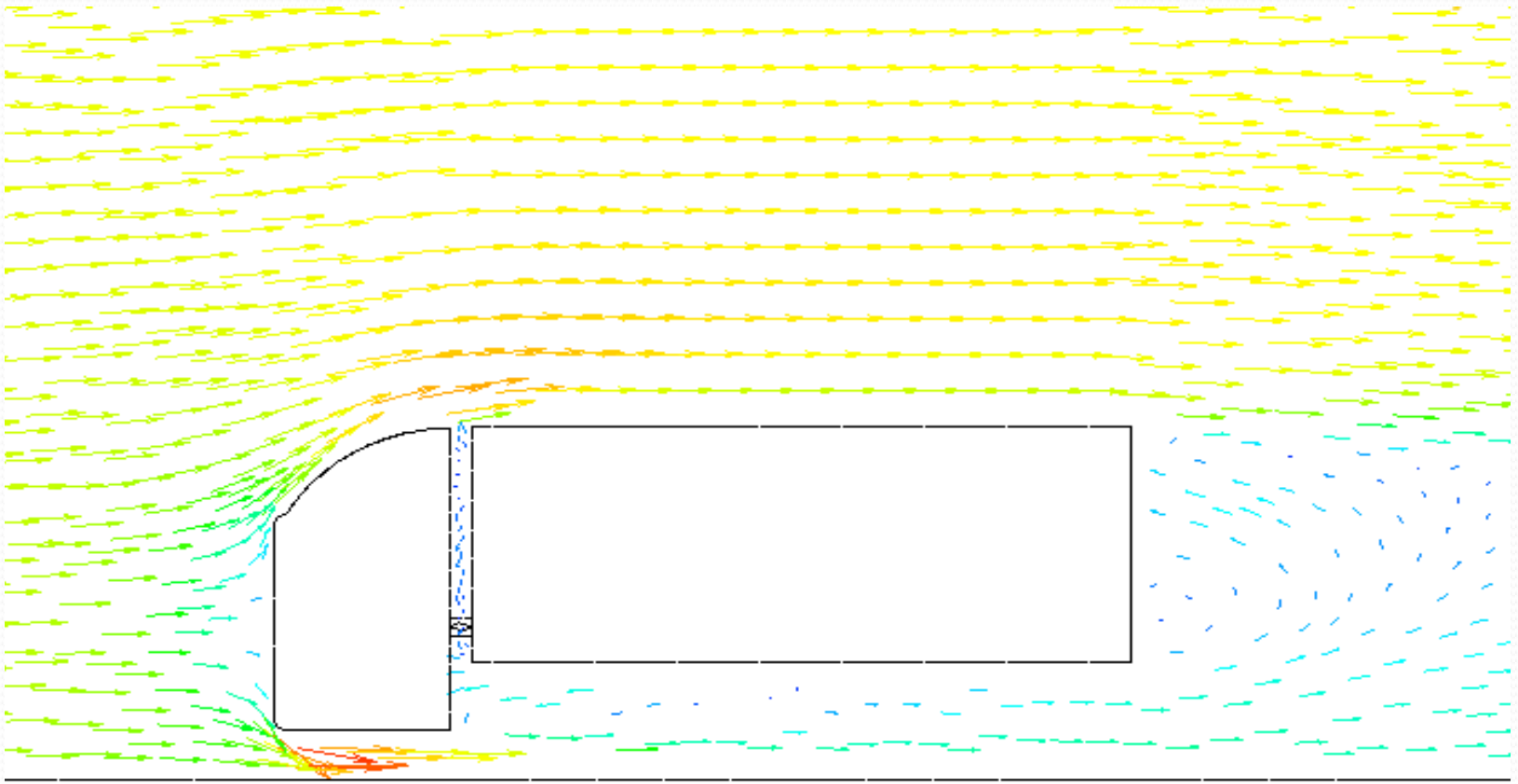
# Front DRD's



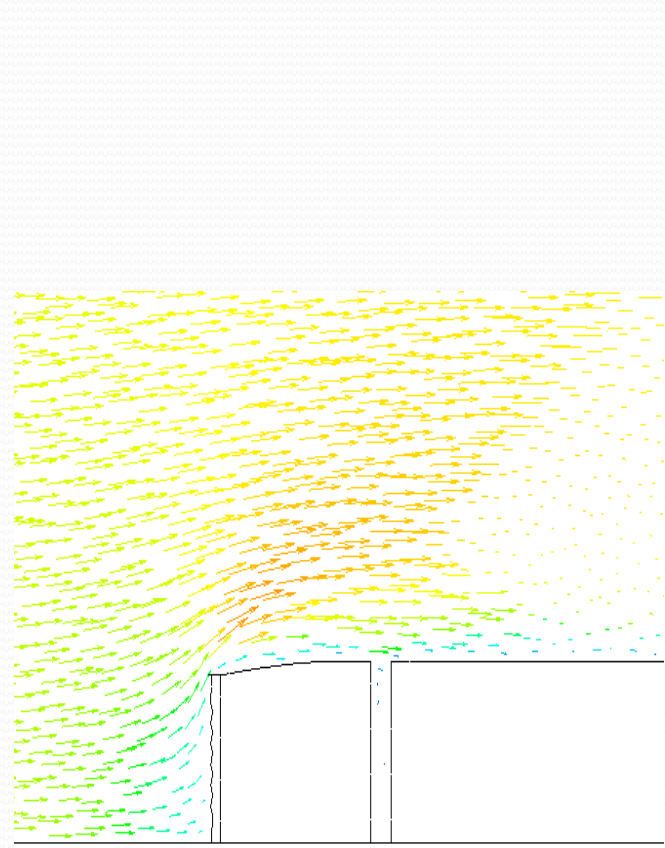
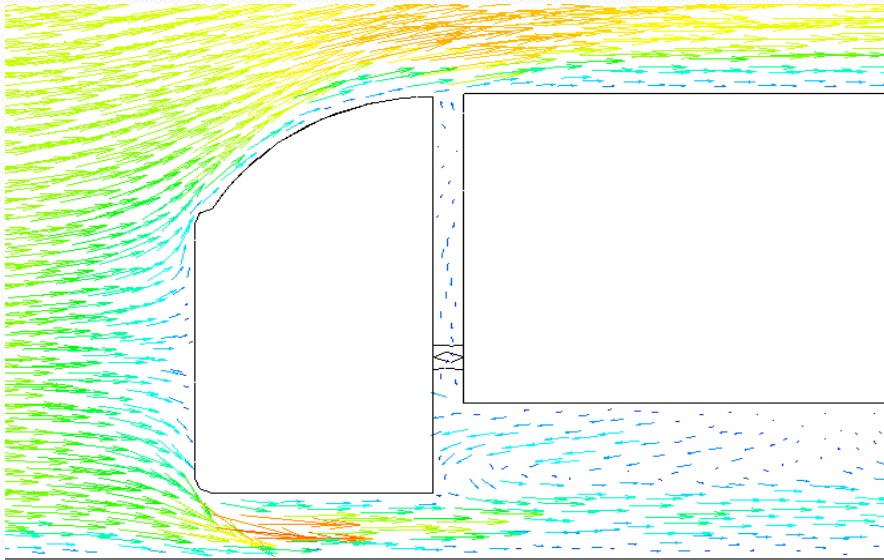
# Meshing Grid



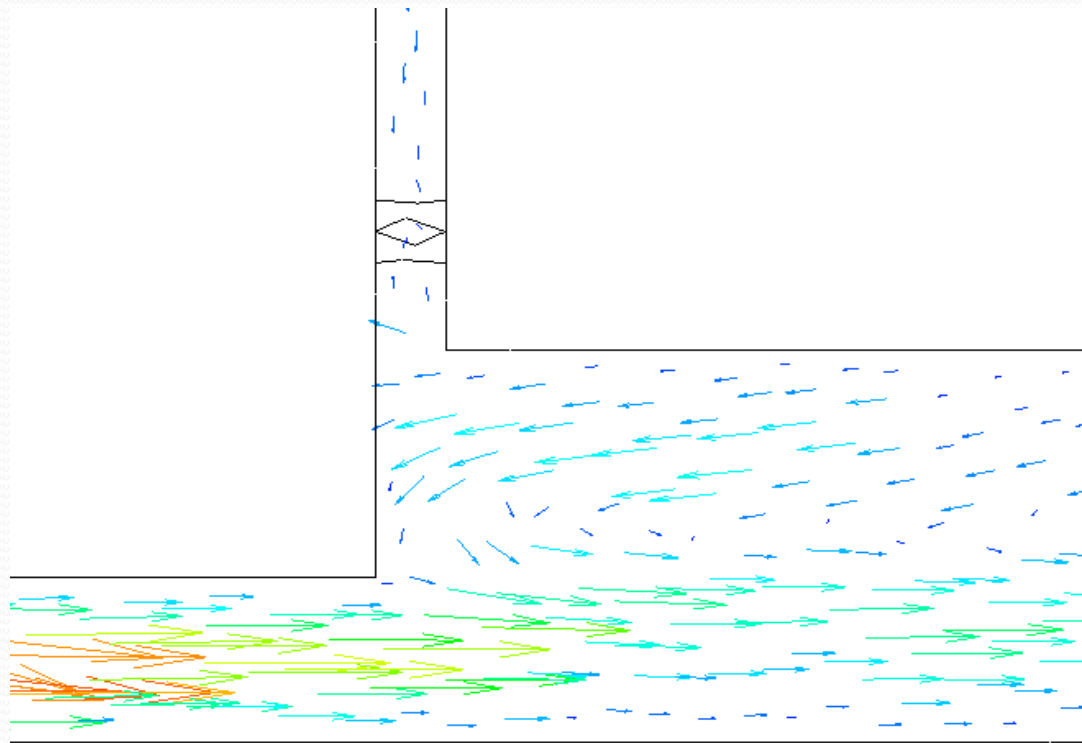
# Velocity Vectors



# Velocity Vectors-Front DRD's



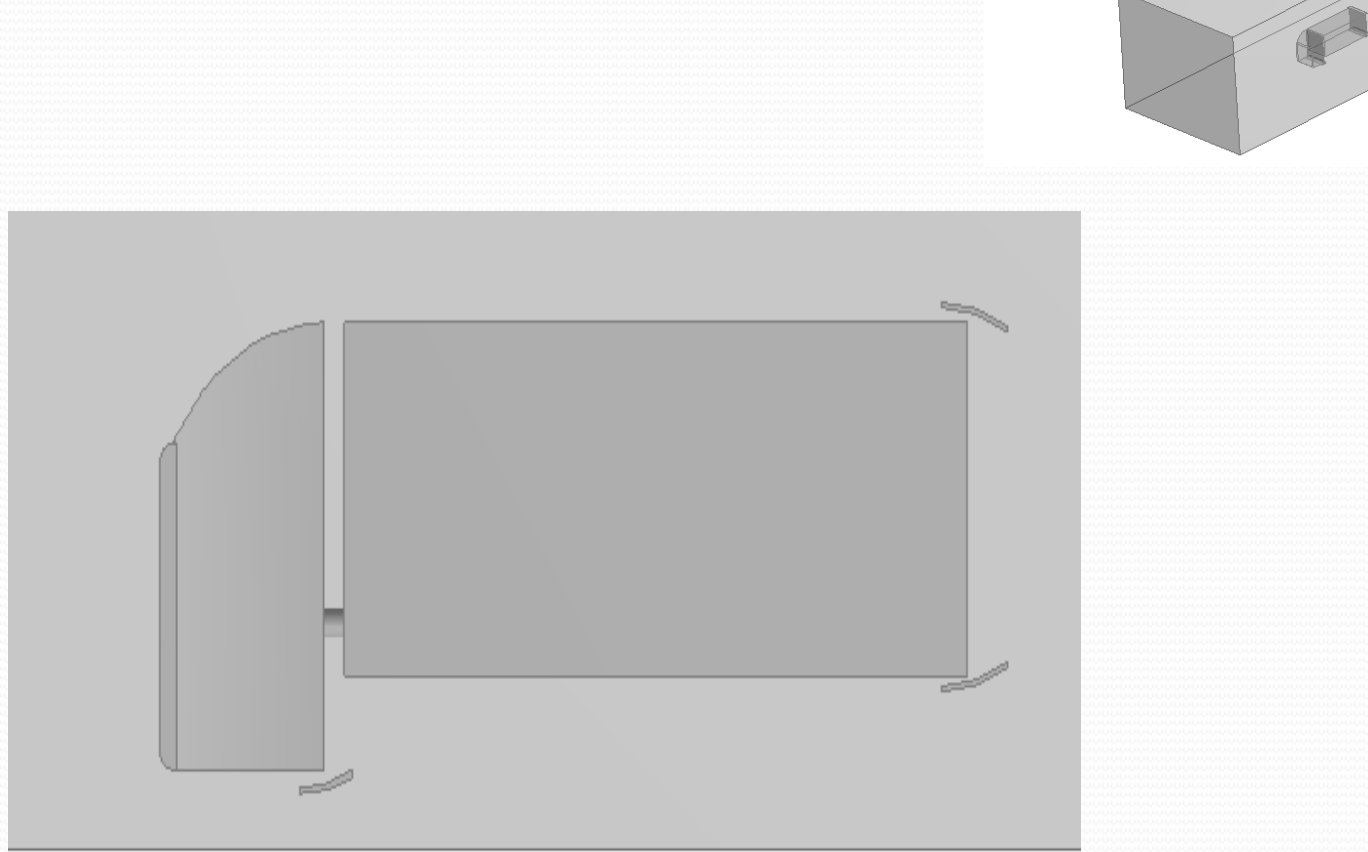
# Improvement Needed



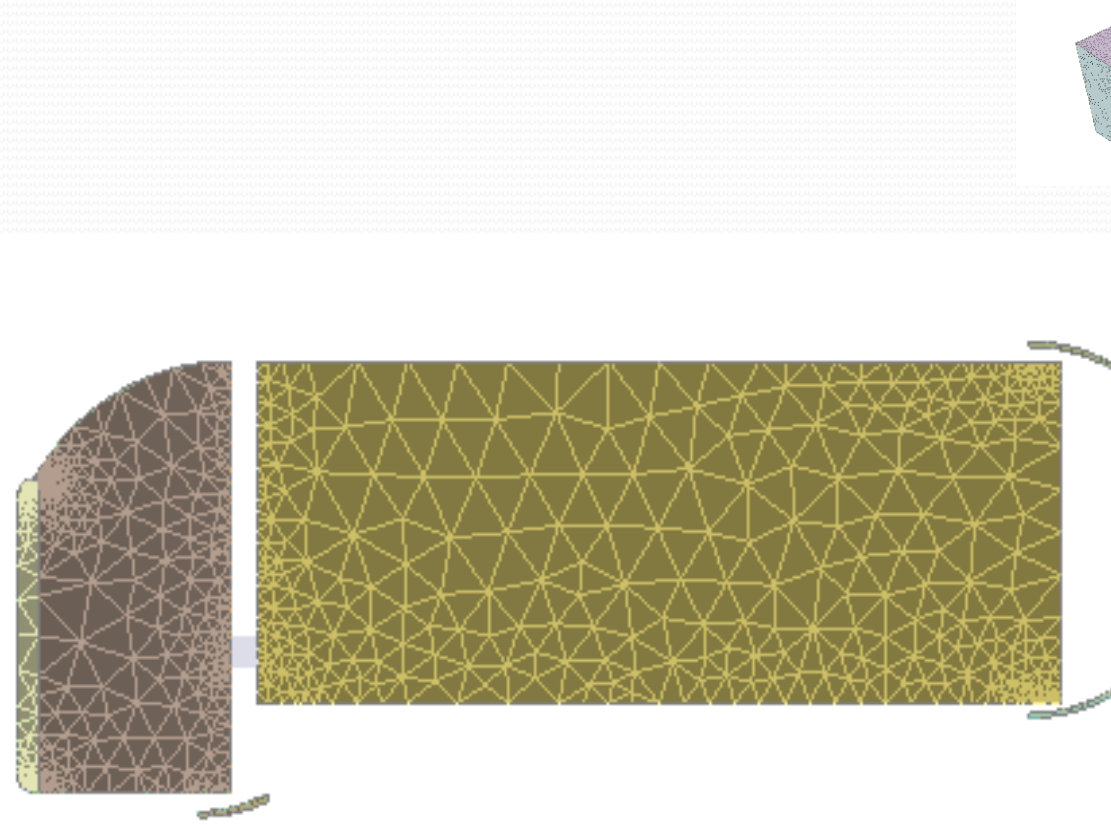
# Results Summary-Front DRD's

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

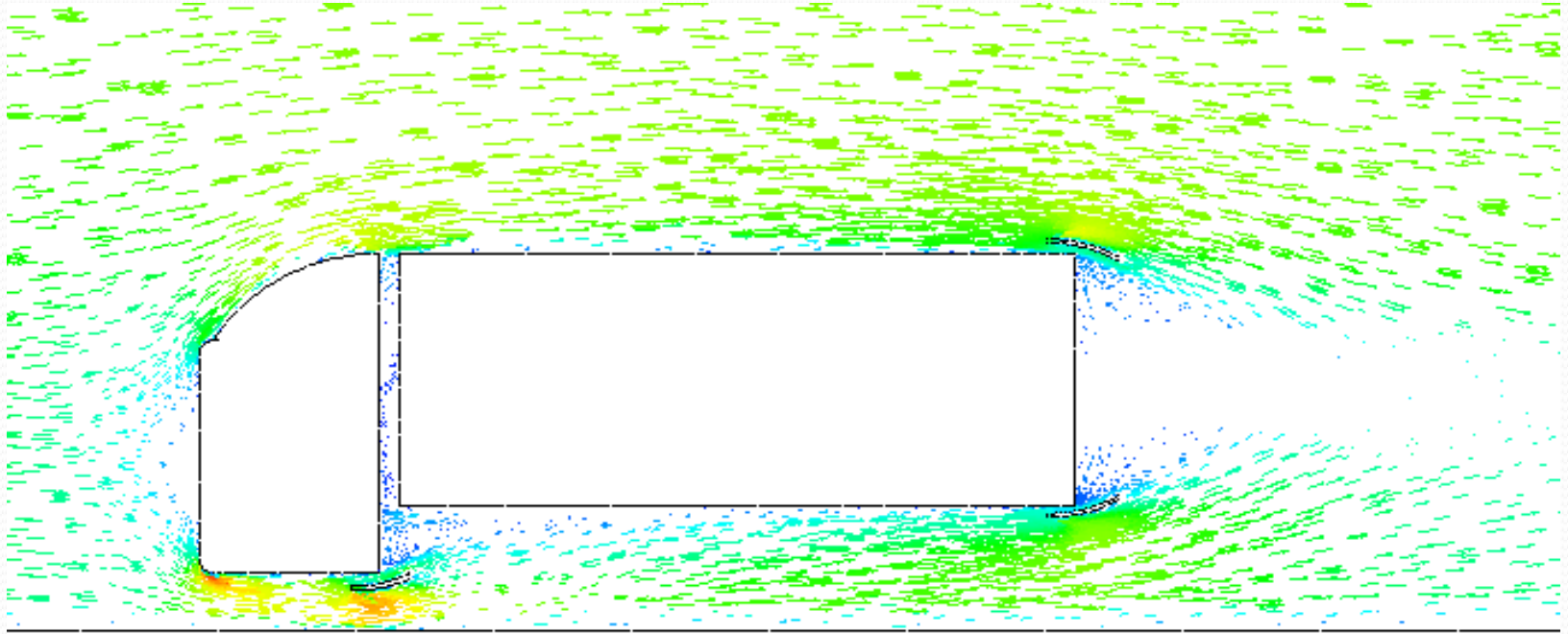
# Full DRD's



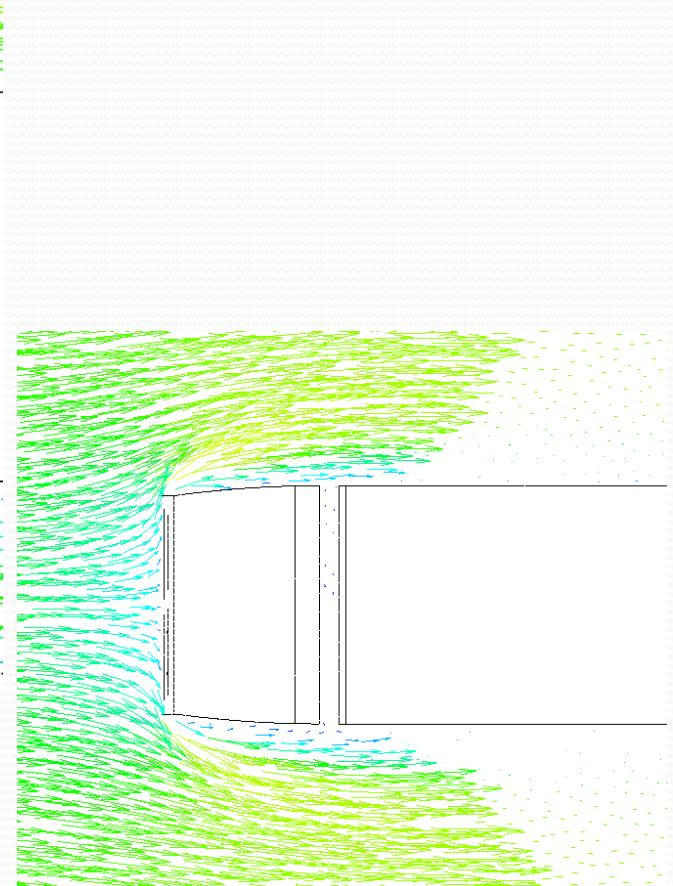
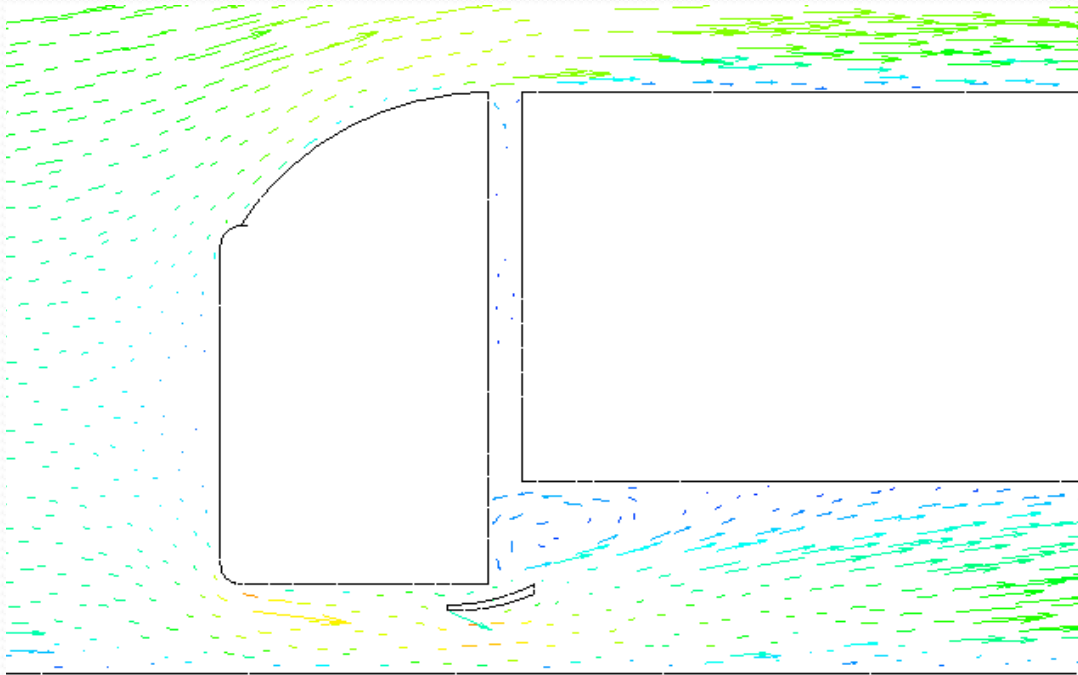
# Meshing Grid



# Velocity Vectors



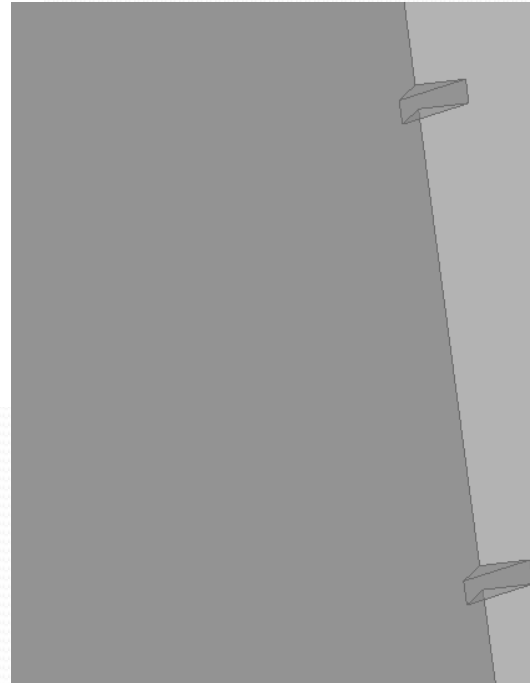
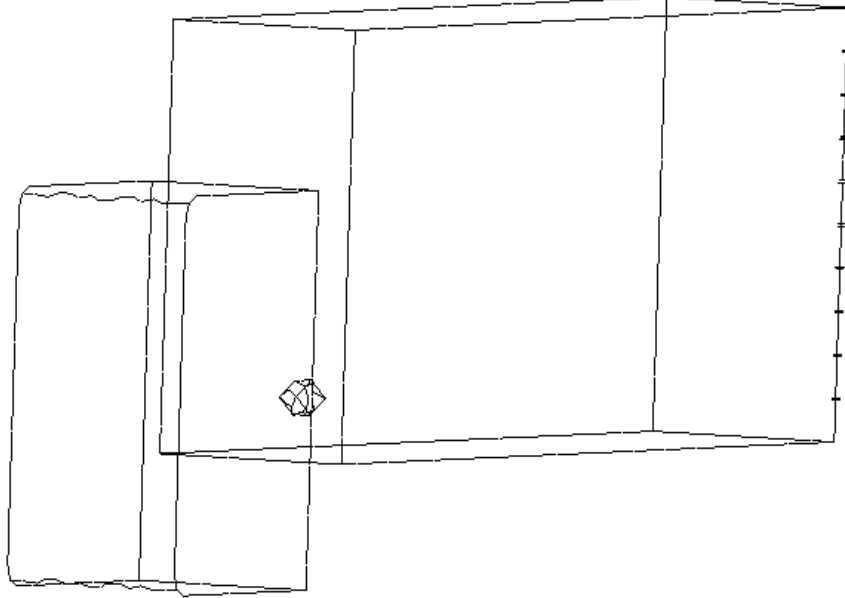
# Velocity Vectors-Full DRD's



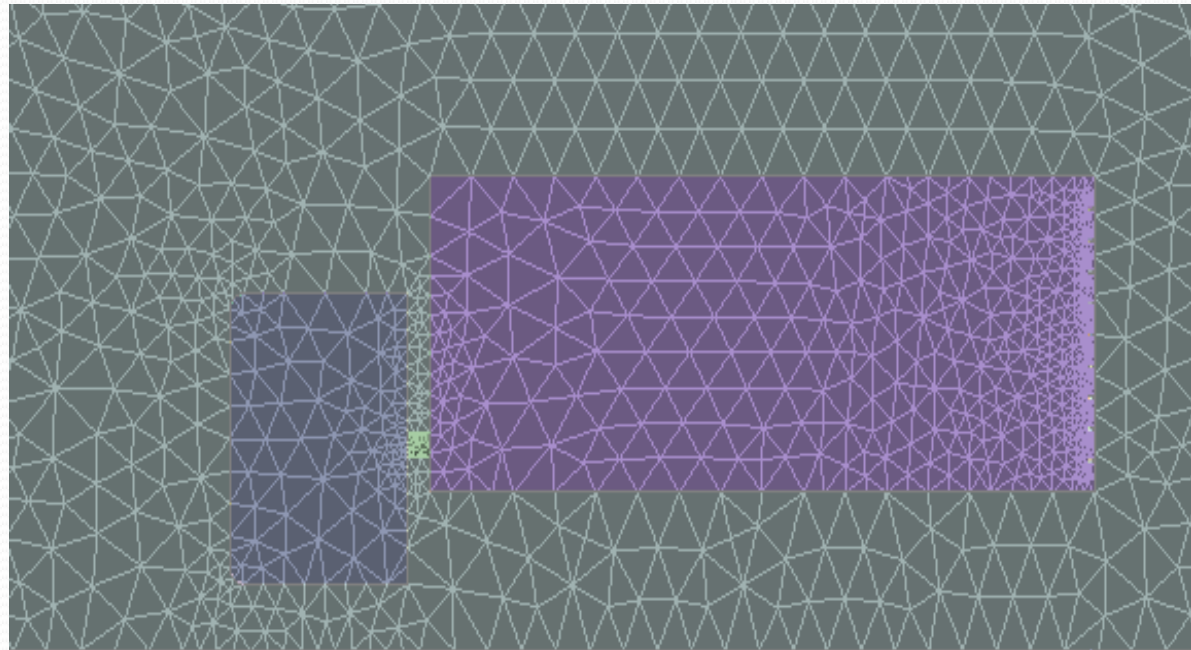
# Results Summary-Full DRD's

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

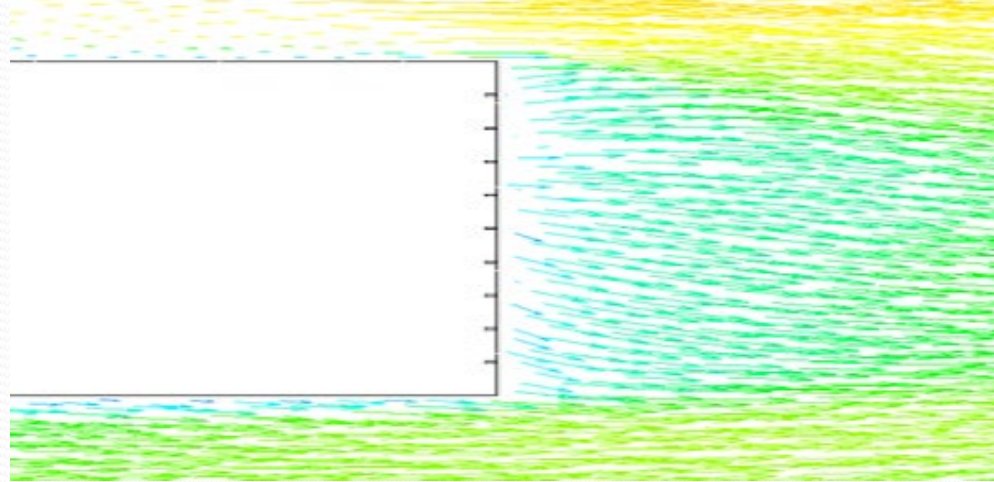
# VG DRD's



# Meshing Grid



# Velocity Vectors



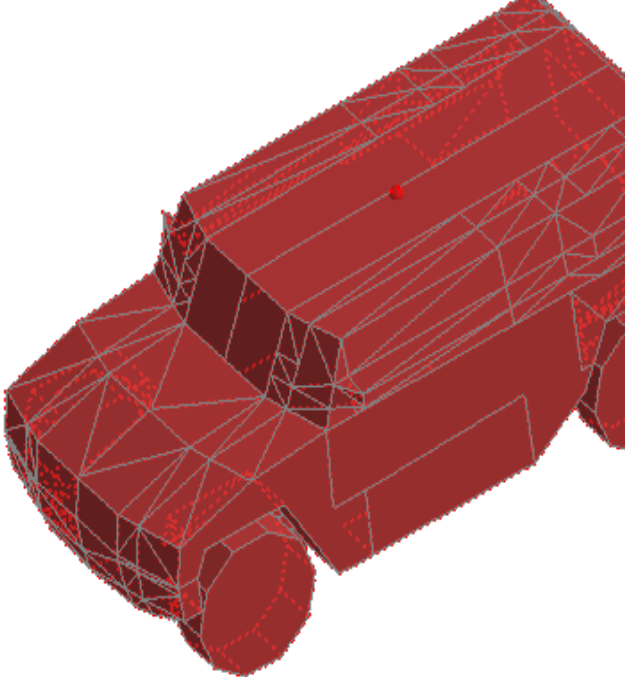
# Results Summary-VG DRD's

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

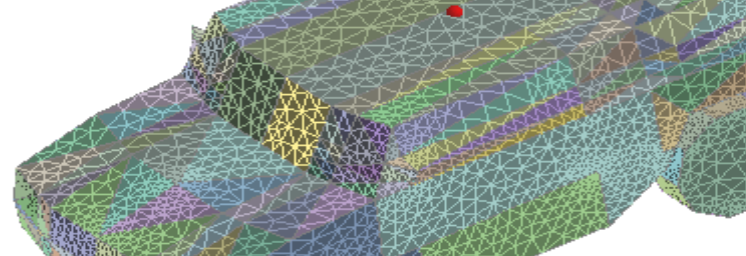
# Cd Reduction for Tractor Trailer

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

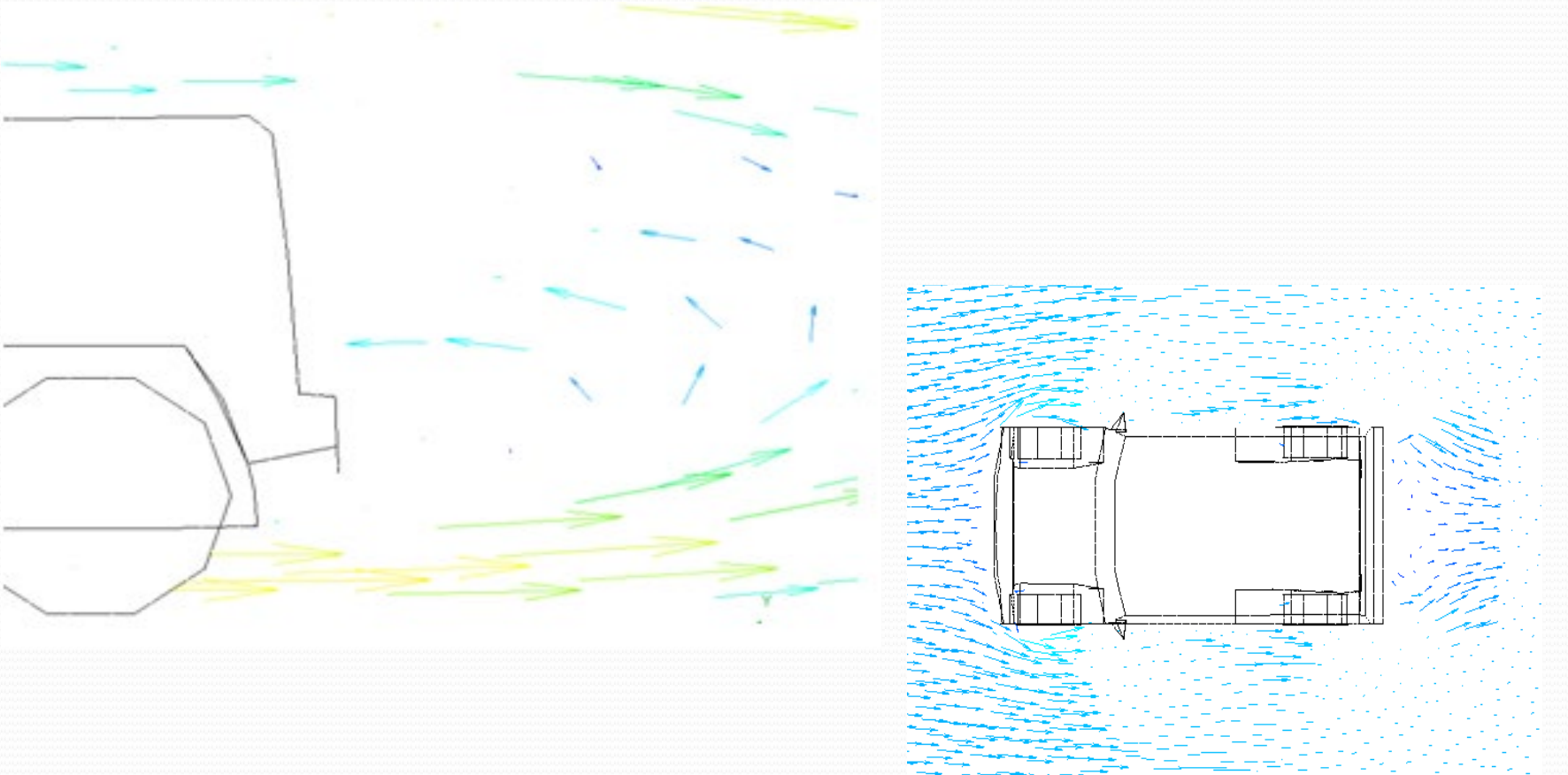
# SUV-Hummer



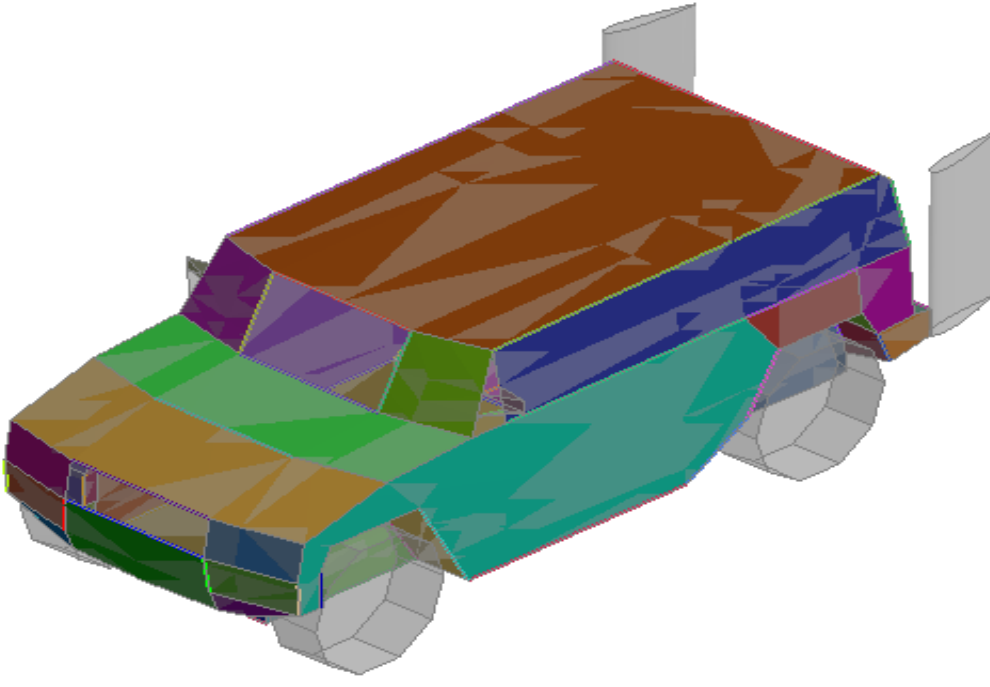
# Meshing Grid



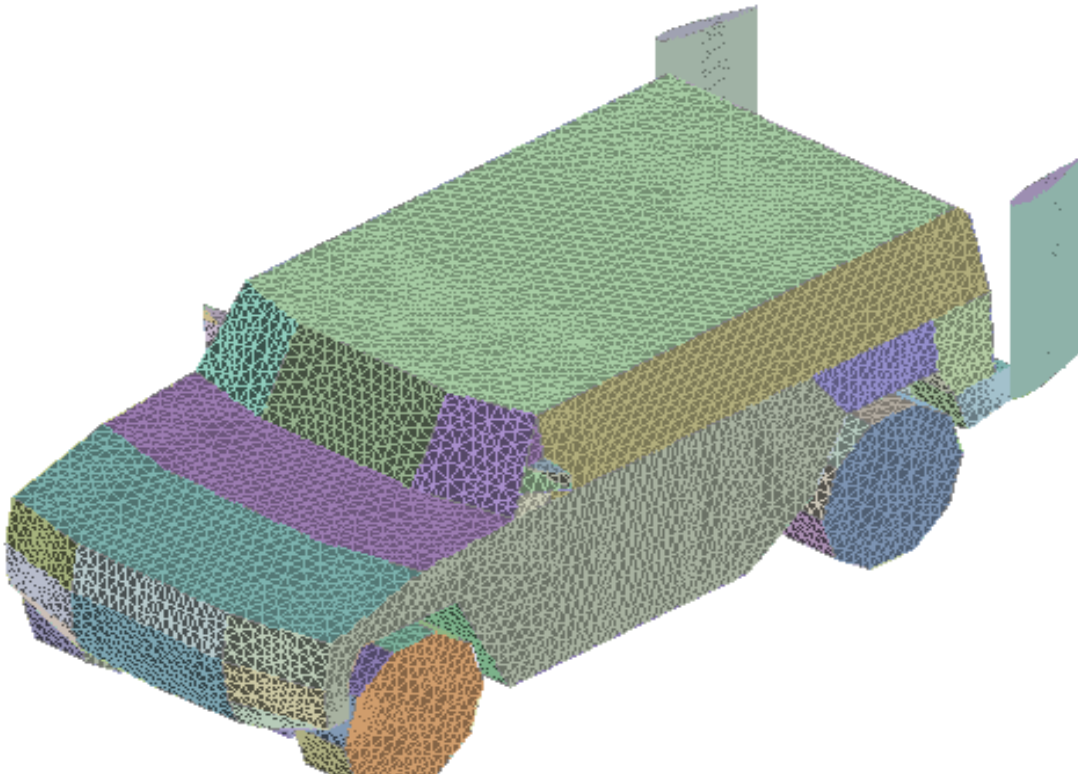
# Velocity Vectors



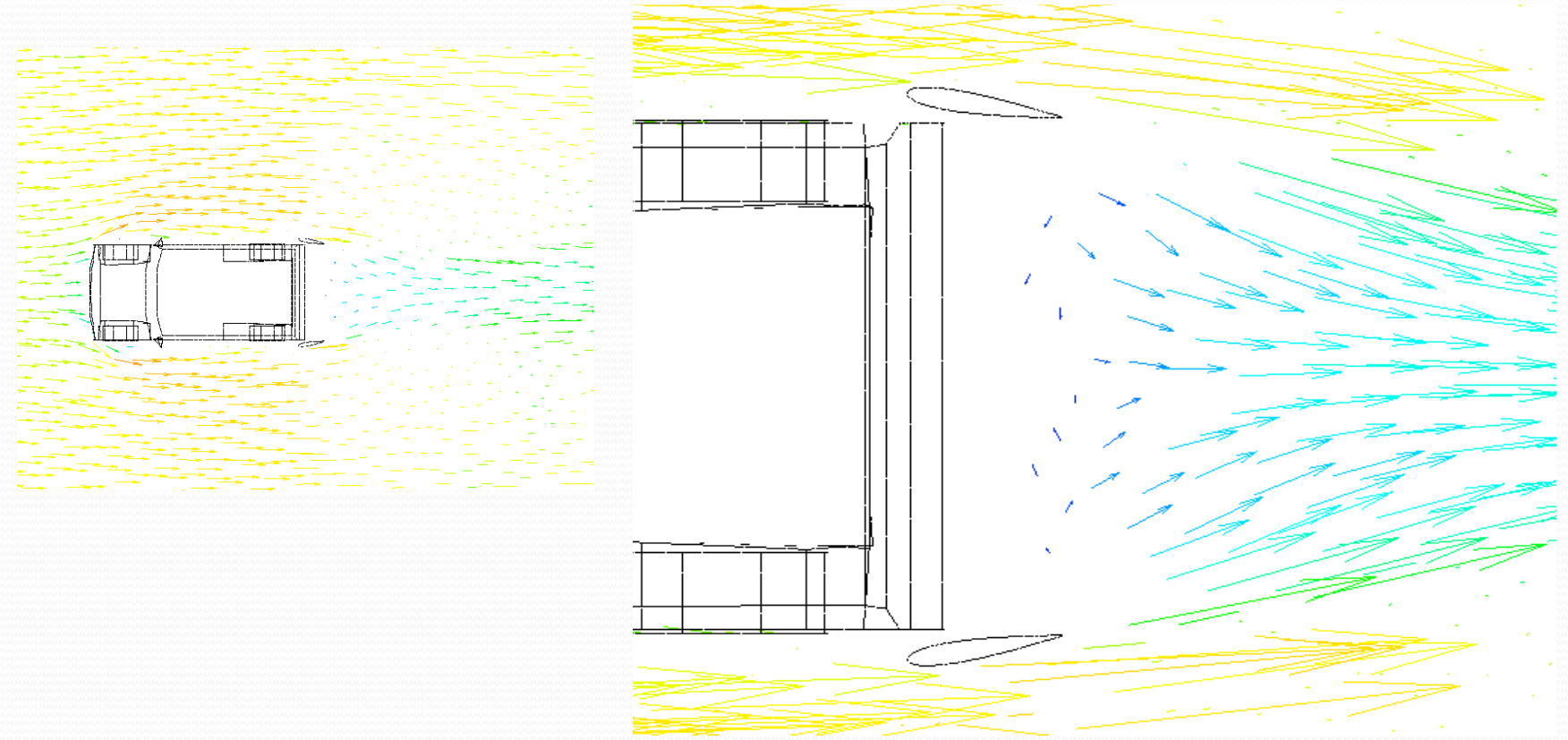
# SUV-Hummer with DRD's



# Meshing Grid



# Velocity Vectors

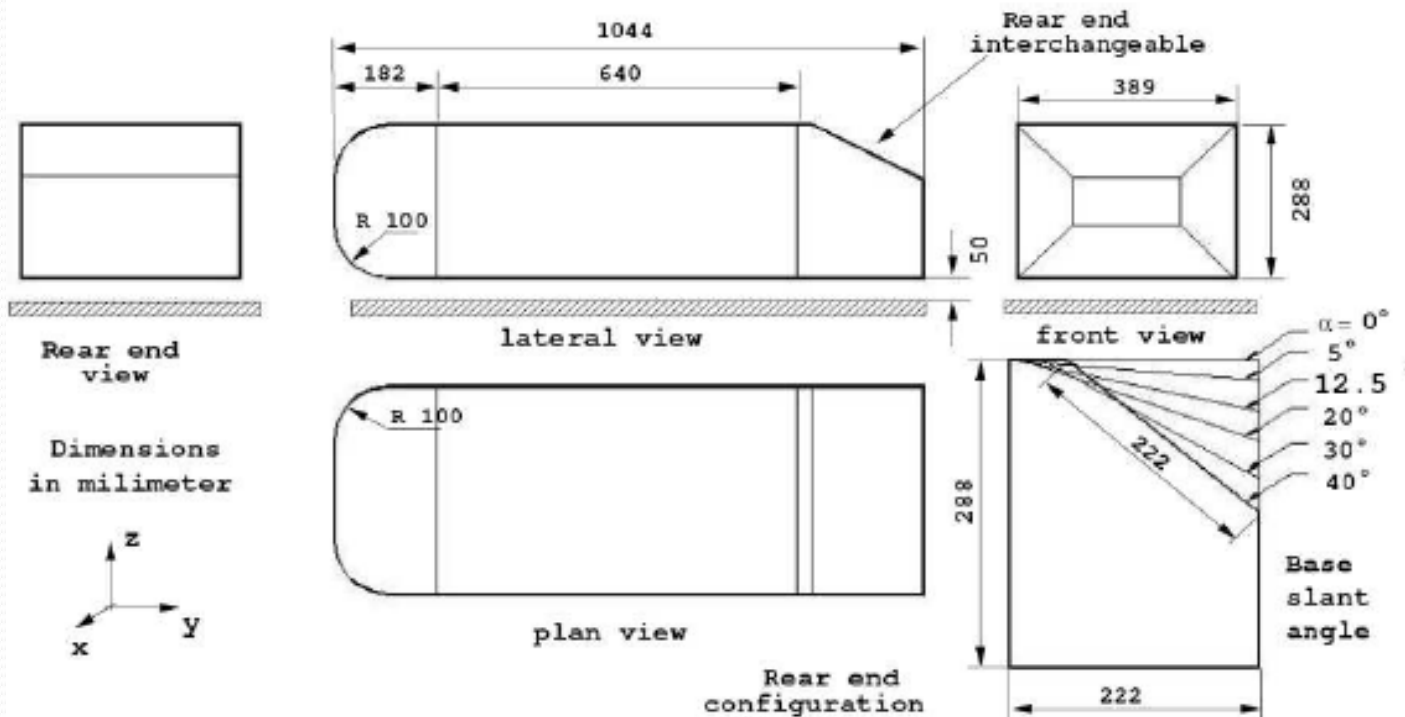


# Results-Hummer

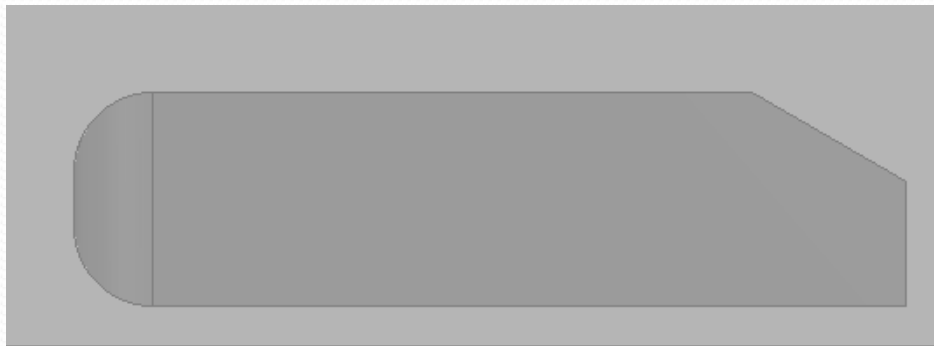
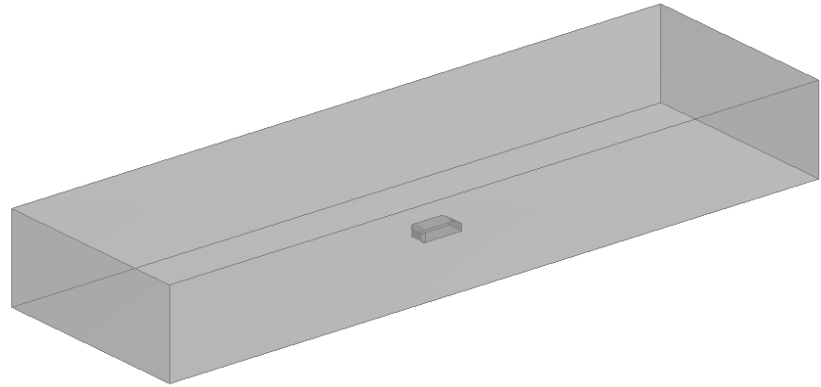
H <sub>2</sub>	CdxA
No vane	0.603
With Vane	0.5776

# Sedan-Ahmed Car Model

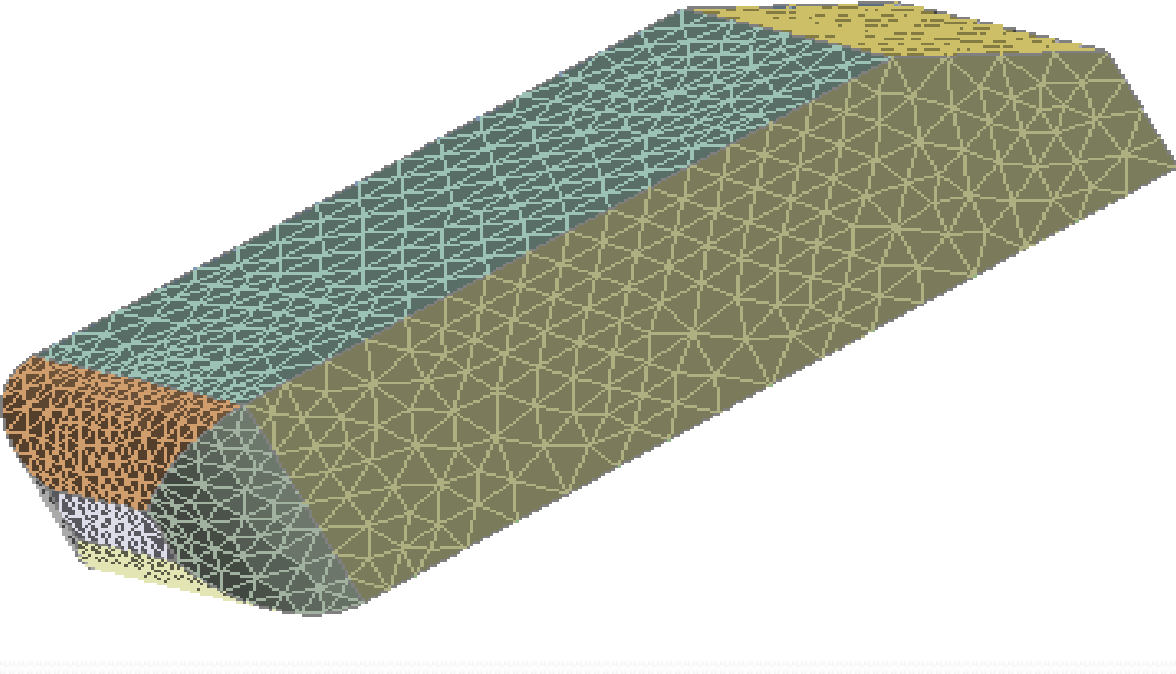
- General Dimensions



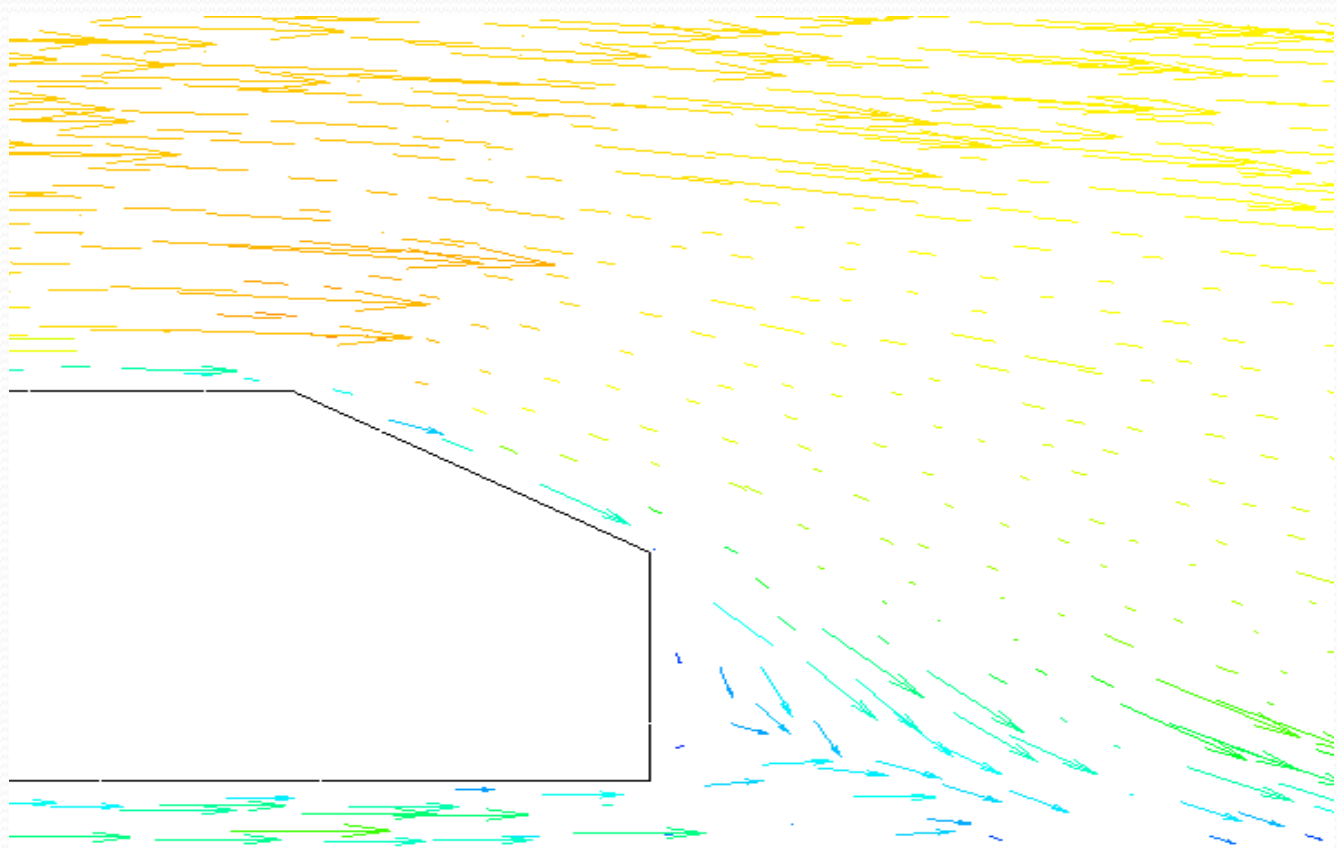
# Ahmed Model-No DRD's



# Meshing Grid



# Velocity Vectors



# Ahmed Model-No DRD's

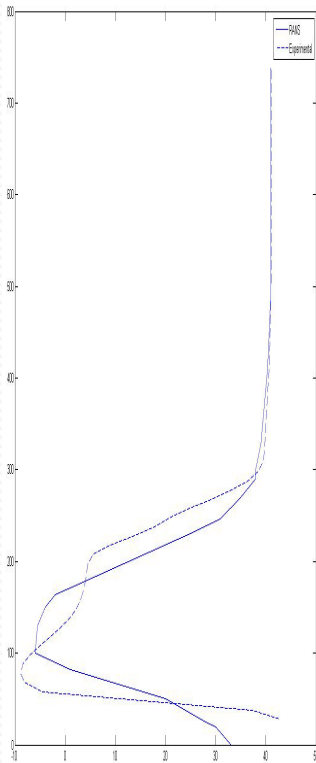
- Cd Summary

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

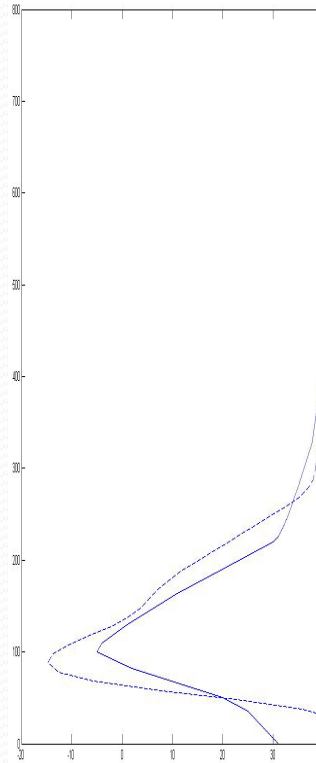
# Verification



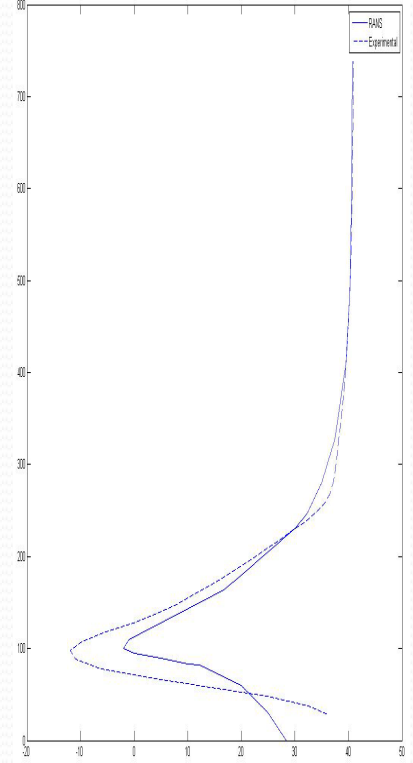
38 mm



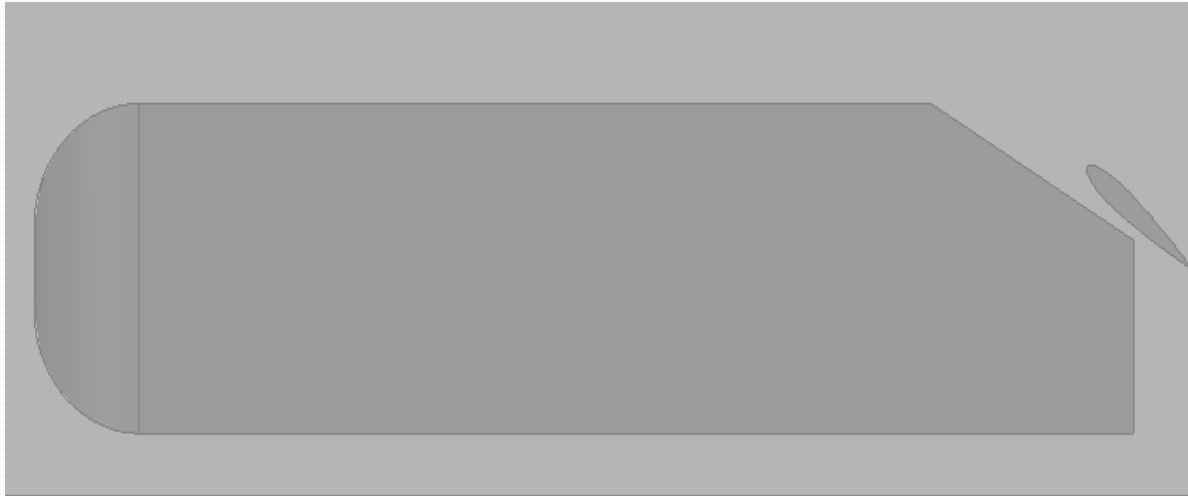
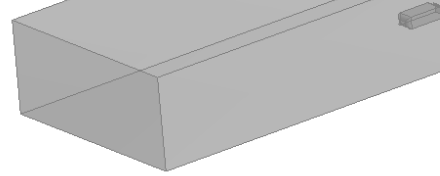
88 mm



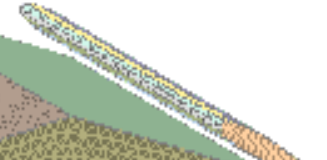
138 mm



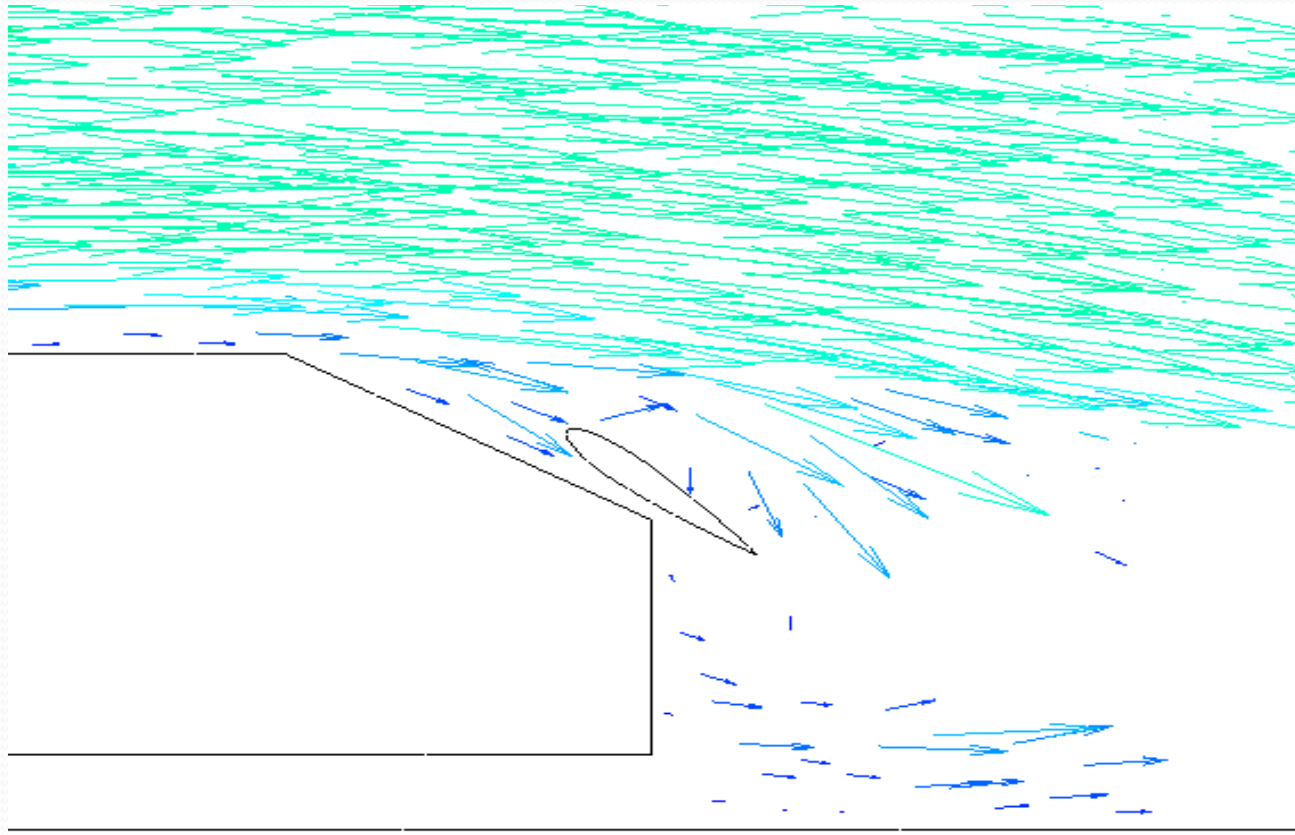
# Ahmed Model-Rear Wing



# Meshing Grid



# Velocity Vectors

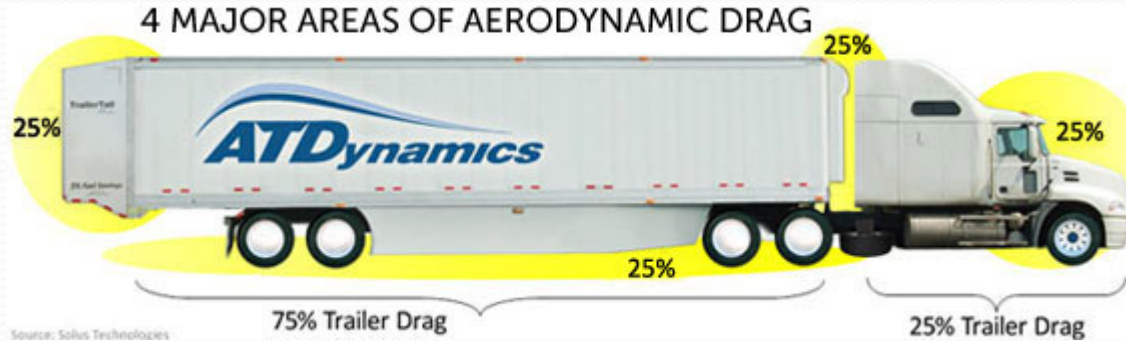


# Cd Summary Results

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%

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- Thank you for listening.



- Looking forward for your questions and comments.