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A Numerical Study for the Flow and Dispersion Around Moving Cars and its Effect on the Dispersion of the Traffic Emitted Pollution within a Road Tunnel

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Introduction (1/3)

- The application of photo-catalytic materials on the walls and/or the ventilation system of Road Tunnels was proposed as an alternative, potential way for the reduction of traffic emitted NO_x
- In addition, the study of these effects on the dispersion in Road Tunnels will lead to better planning in the vicinity of emergency response scenarios
- As a first step, it was decided to study the dispersion inside Road Tunnels taking into account the aerodynamic effects due to the motion of vehicles
- The interaction between the Road Tunnel walls and the moving vehicles is expected to effect significantly the dispersion mechanism downstream of the moving vehicles

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Introduction (2/3)

- The main parameters expected to influence the dispersion inside the road tunnels were the number of vehicles, the type of the vehicles (passenger, HDV etc), the speed of the vehicles, the type of the tunnel (uni or bi-directional)
- As a first step a simple, relatively small road tunnel was selected, which had initially been proposed as a test bed for an experiment, in order to study the main features of the problem

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Introduction (3/3)

Traforo Uberto Tunnel Description

- Located in the heart of the city centre of Rome
- Bi – directional
- Three lanes, two for cars and one for buses

- Cars and buses are moving at opposite directions
- 347 m long
- 16 m wide

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Methodology (1/4)

Main features

- Solver: ANSYS CFX 5.7.1
- Mesh generator: ANSYS ICEN 5.1
- Vehicles approximated as stationary solid blocks with no tyres
- Car & Bus height 1.7 m & 3 m respectively
- Car & Bus length 4 m & 12 m respectively
- Car & Bus width 1.5 m & 2.5 m respectively
- Tunnel walls set as moving with fluid inlet velocity (50 km hr^{-1})
- No road tunnel roof longitudinal ventilation was assumed

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Methodology (2/4)

Main features

➢A series of both steady and unsteady 3D RANS simulations were completed

➢κ-ω Shear Stress Transport (SST) turbulence closure model with automatic wall functions was selected:

- ❑It can account foe the transport of the turbulent shear stress
- ❑It predicts well the onset and the amount of the flow separation under adverse pressure gradients

➢Discretization scheme: 2nd Order Upwind Difference

➢Car exhaust approximated as an area source (leeward face of the solid block approximating the car)

Methodology (3/4)

Main features

- Two sets of simulations were performed both for the moving cars and buses

- In each set two scenarios were assumed and investigated:
  - During the first ("Referenece") only one emitting vehicle was assumed present inside the tunnel
  - During the 2nd ("Car"), an additional 2nd moving vehicle was assumed to be present, in the wake region downstream of the leading one

Methodology (4/4)

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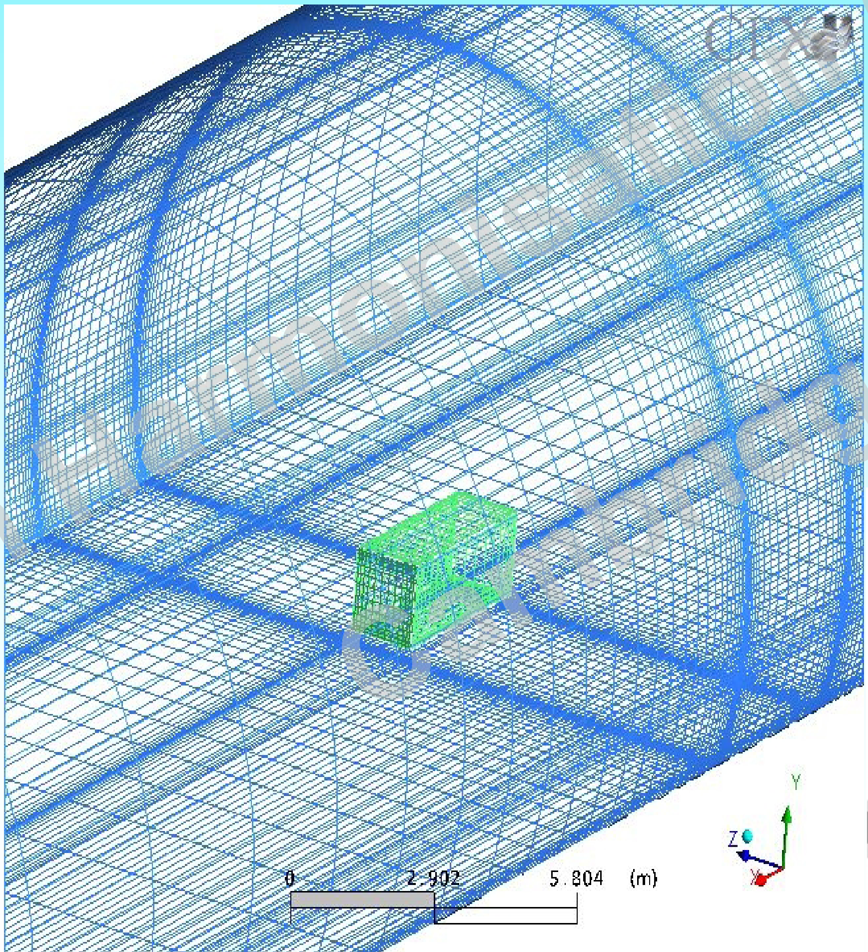
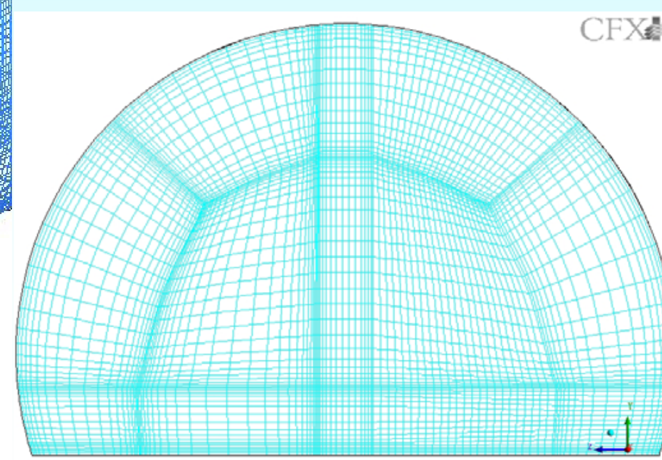
Mesh Specifications

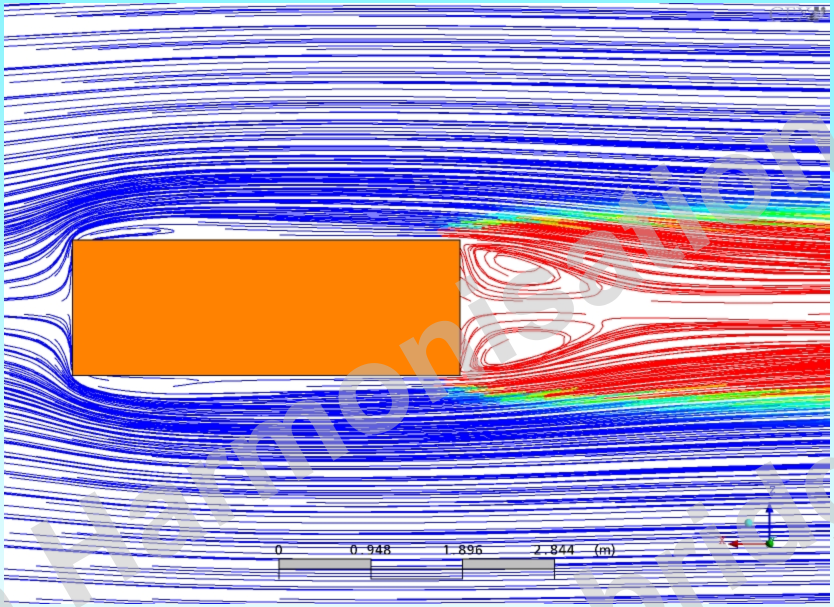


- Structured Hexa mesh
- Minimum cell: 0.05 m
- Expansion ratio: 1.2 – 1.3
- Total mesh size: 1200000
- O - grid concept applied



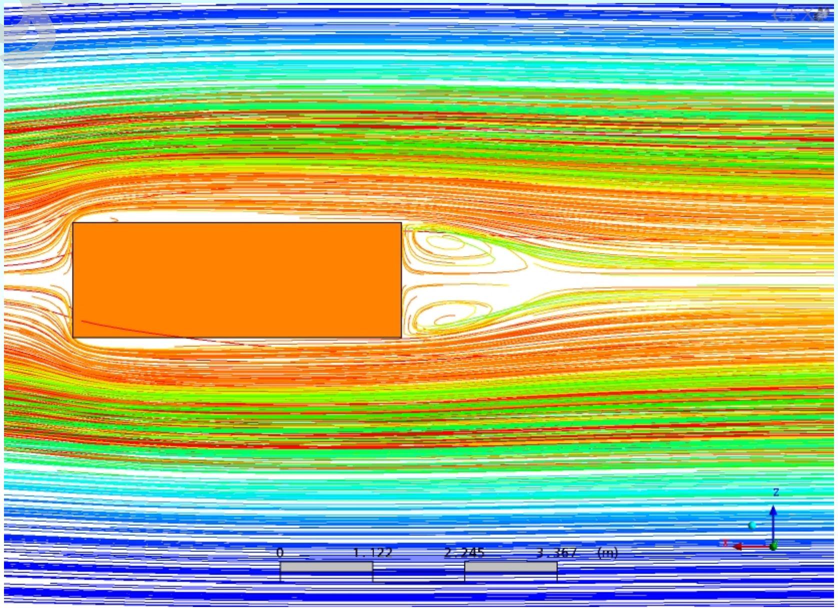
Moving cars

Horizontal Streamline plot



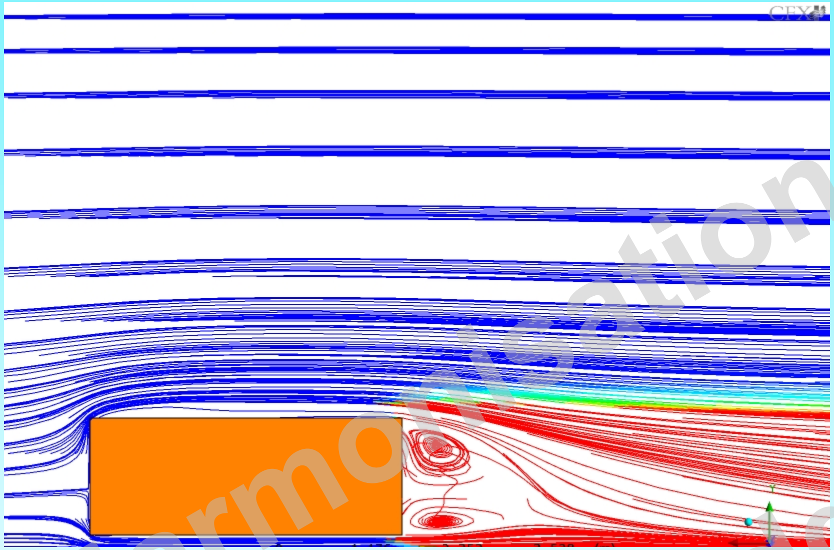
- Separation at both sides of the vehicle
- Main recirculation behind the vehicle with strong wake
- Flow symmetrical with respect to the longitudinal axis of the vehicle

- Velocity at the nose of the 2nd vehicle is severely affected by the wake of the 1st leading car
- Separation and recirculation zones as well as the wake region are larger in size (see below)



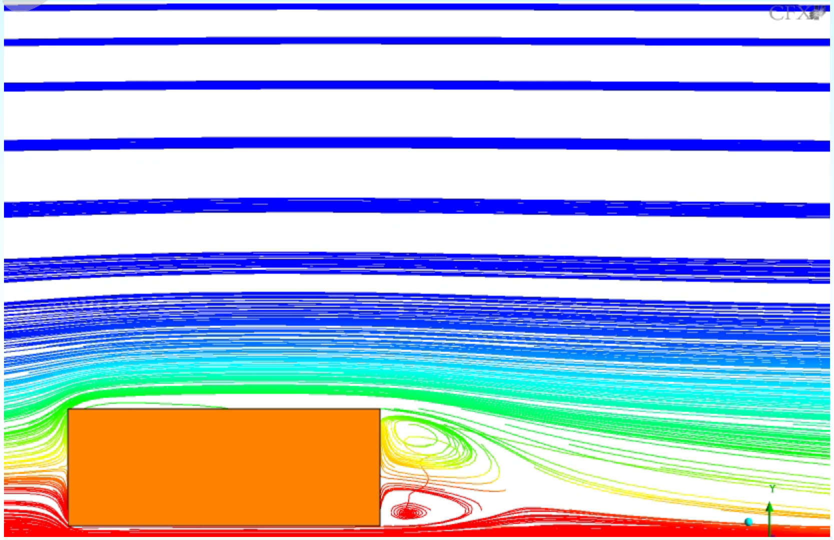
Moving cars

Vertical Streamline plot for the moving cars



- Separation on the nose of the vehicle with main recirculation behind the vehicle
- Flow asymmetrical with respect to the longitudinal axis of the vehicle

- Strong effect from the flow underneath the vehicle
- Flow pattern identical for the 2nd car



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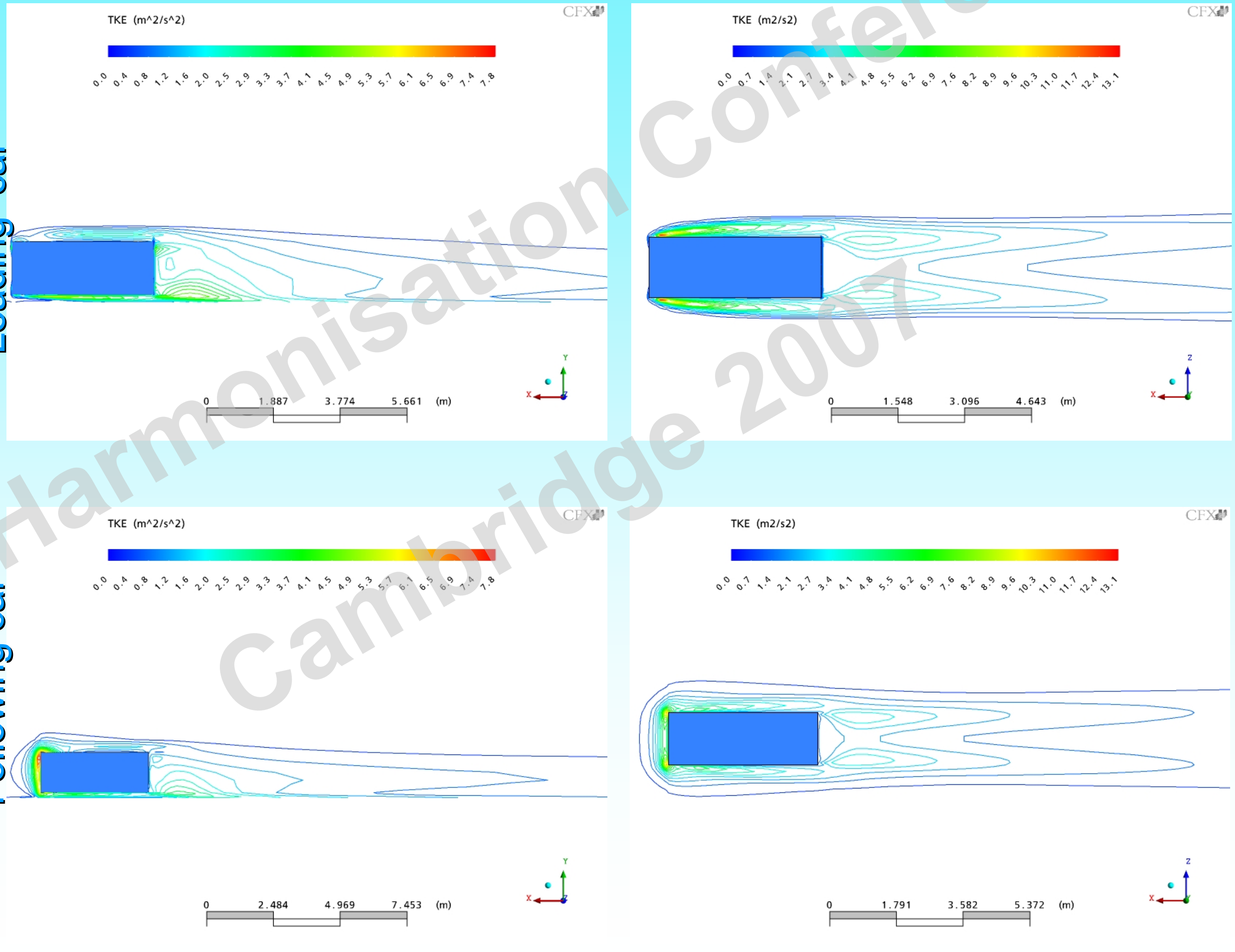
Moving cars

TKE (m^2/s^2)

Leading car

Following car



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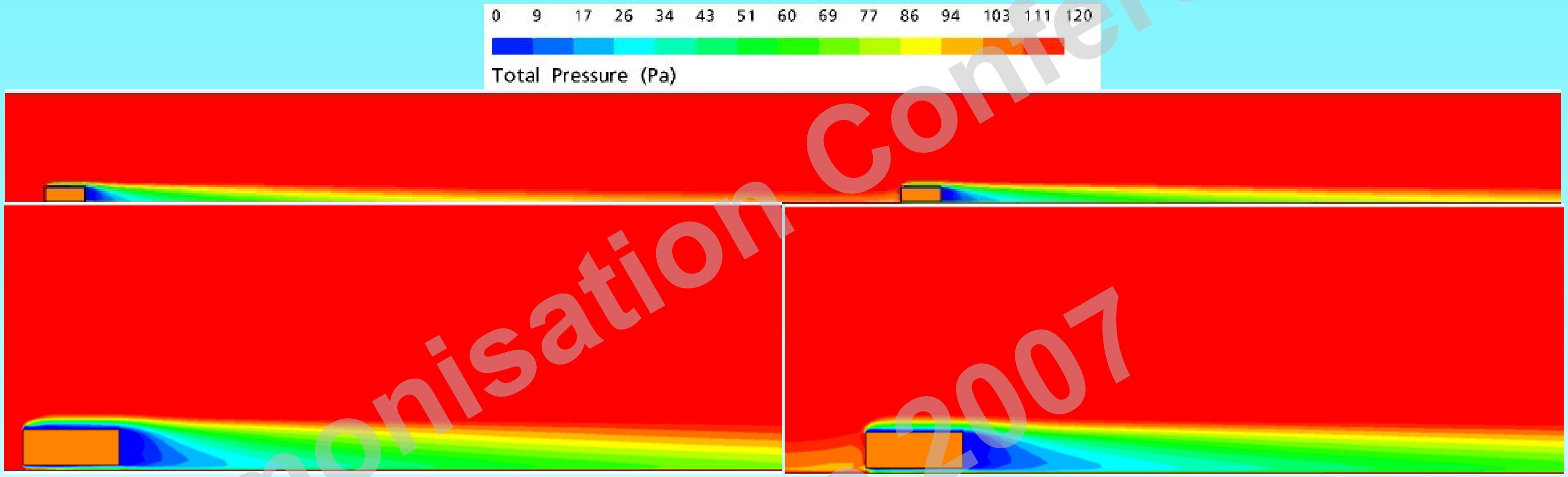
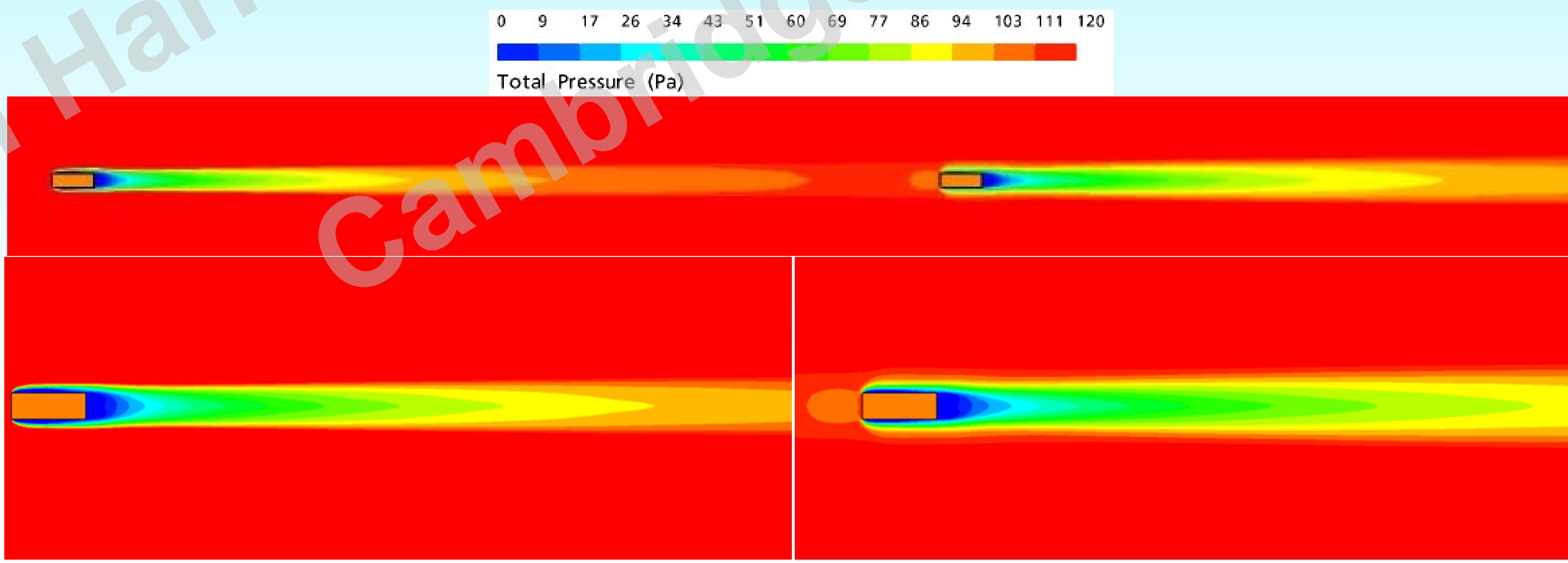
Moving Cars

Predicted pressure field





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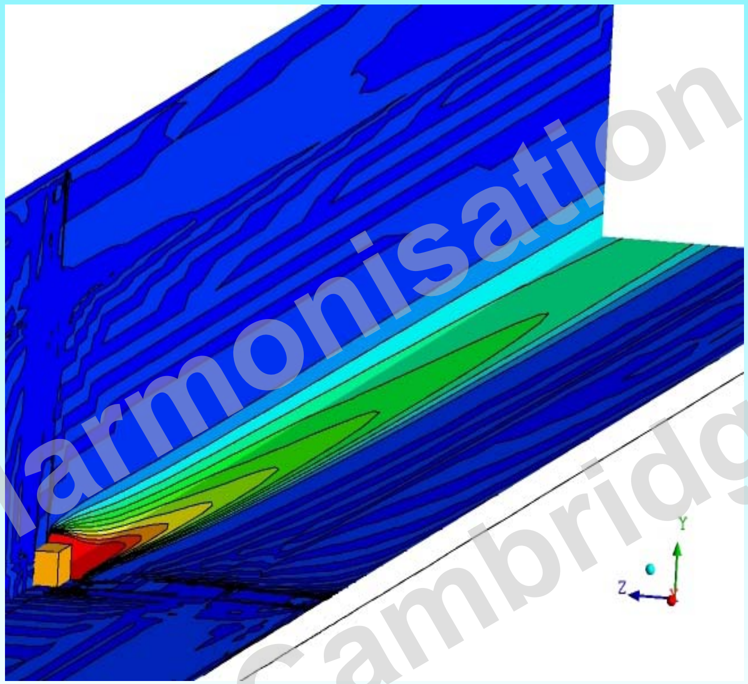
Moving Cars (5/11)

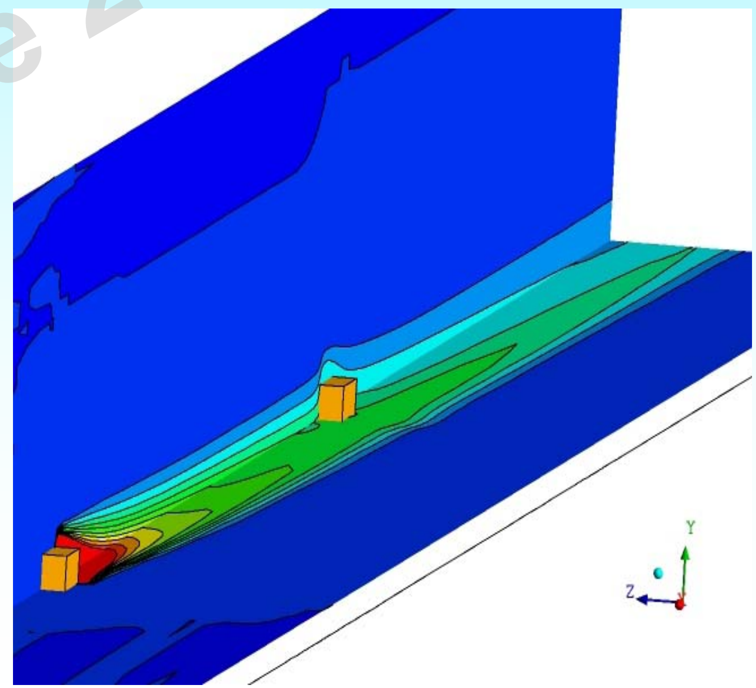
Predicted Concentration field (C*)



•Presence of the 2nd car drives pollution to the two sides

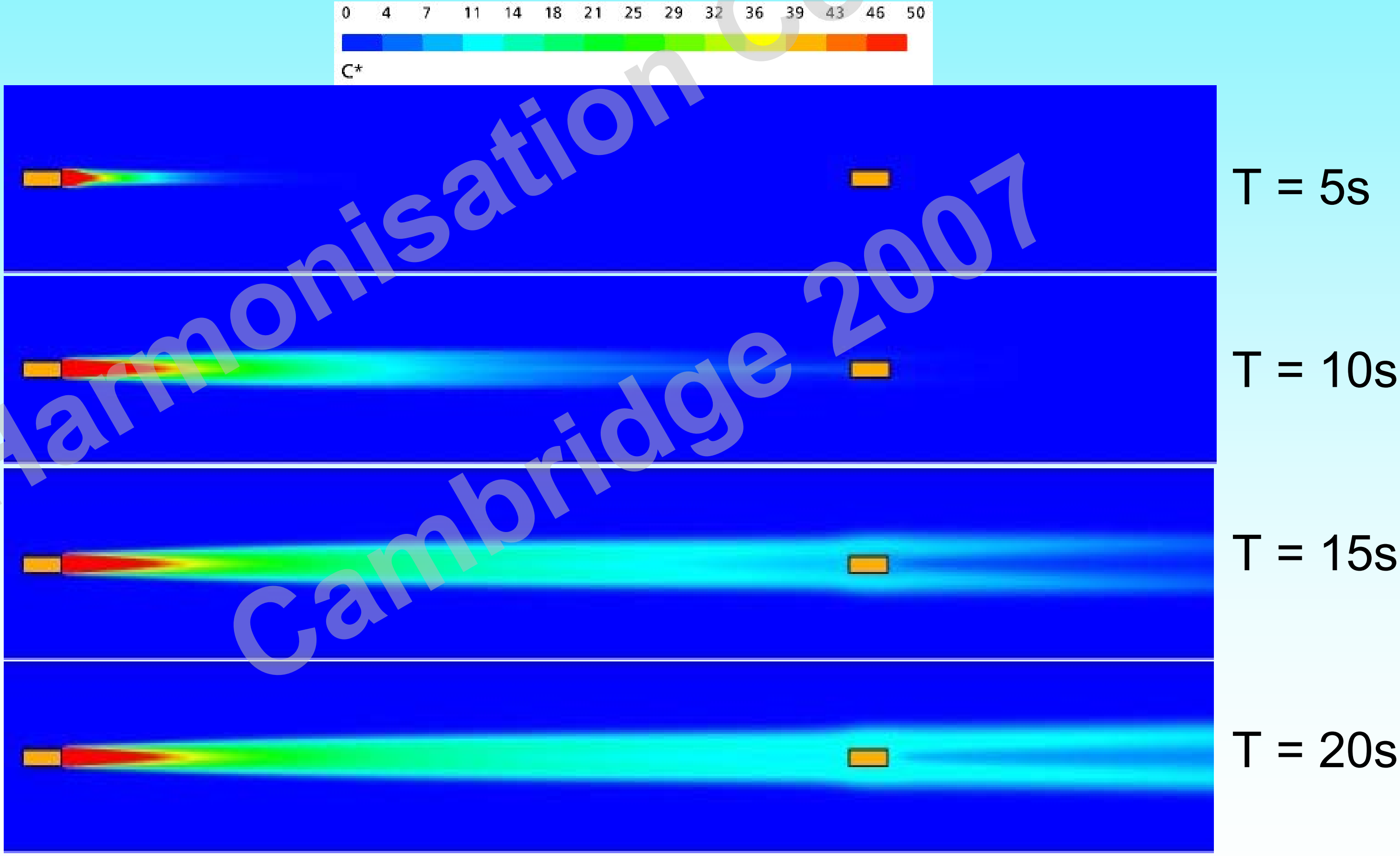
•Concentration in the wake of the 2nd car lower compared to the 1st scenario

Effect seems to be confined mainly within the wake region where increased mixing due to turbulence generated by the 2nd car is added to the existing one



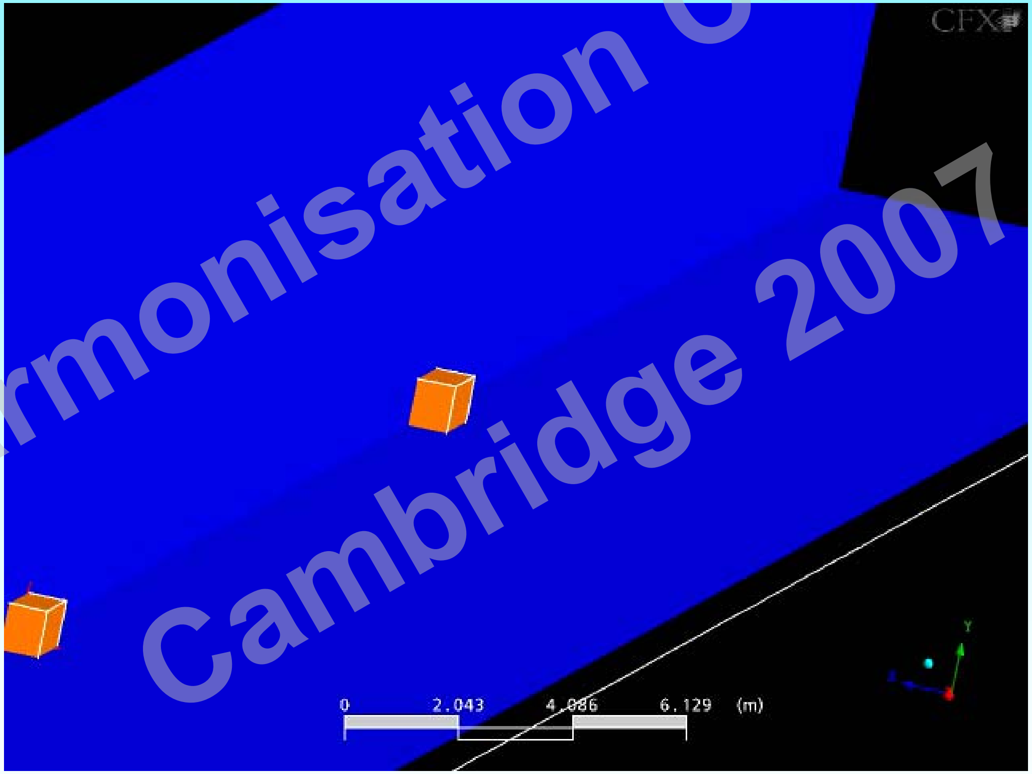
Moving Cars (6/11)

Predicted Concentration field development



Moving Cars (7/11)

Predicted Concentration field development



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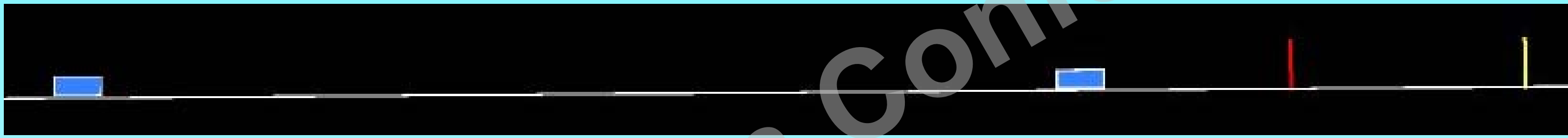
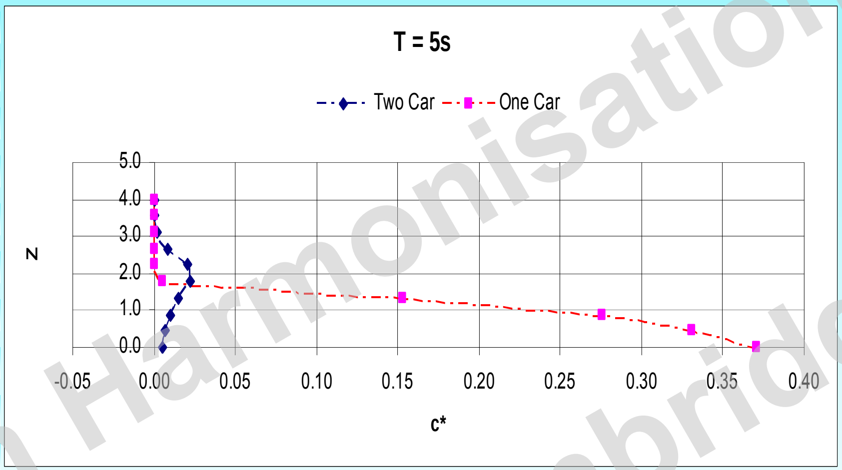
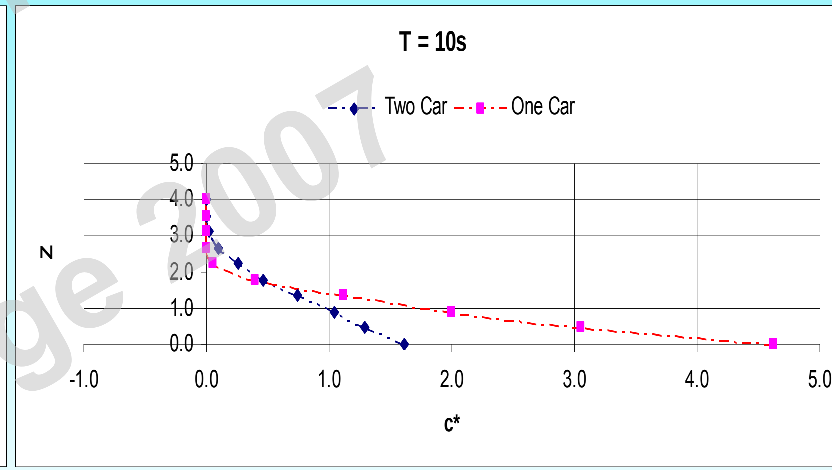
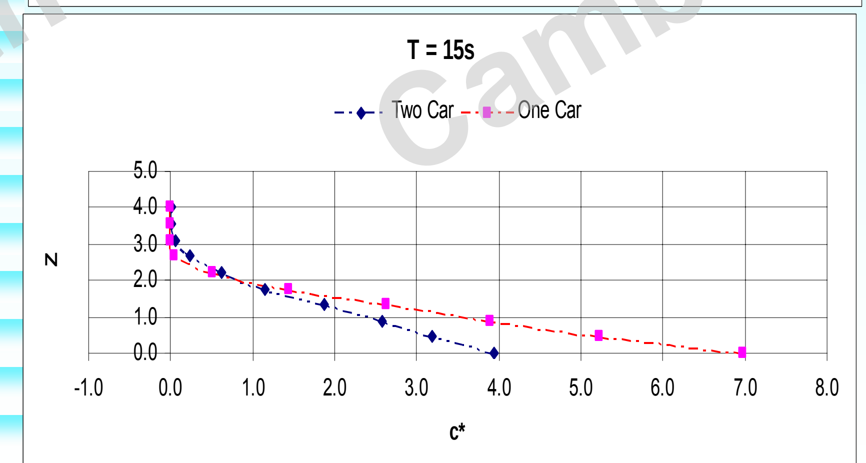
Moving Cars (8/11)

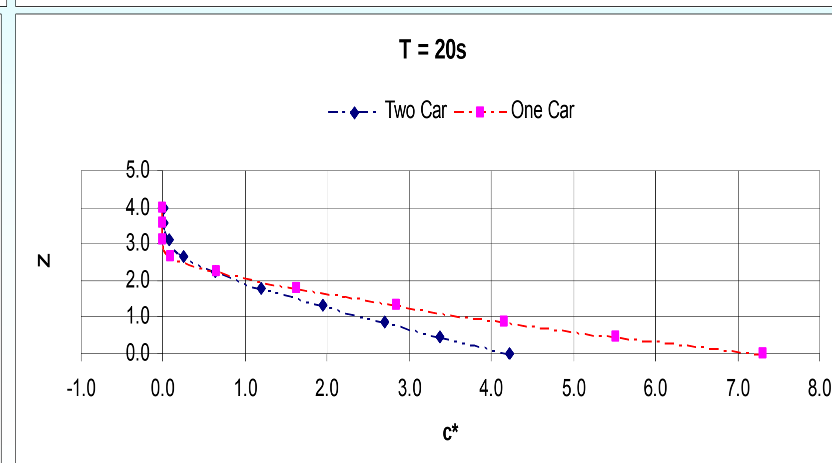
Non-Dimensional Concentration (C*)











Moving Cars

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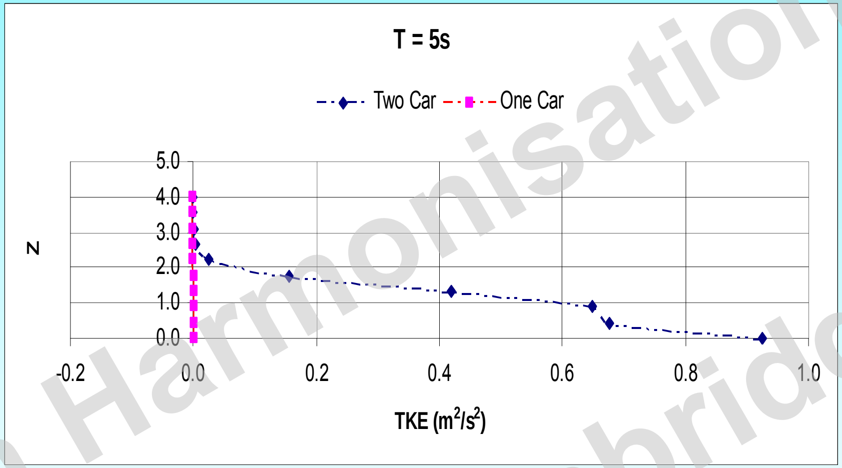
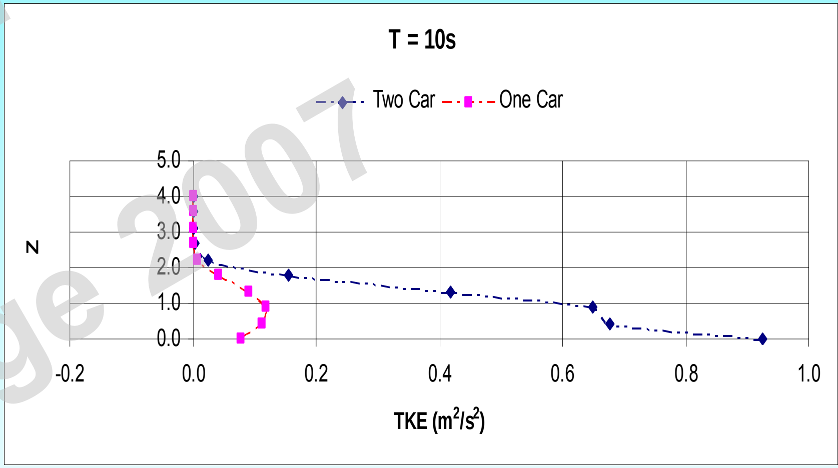
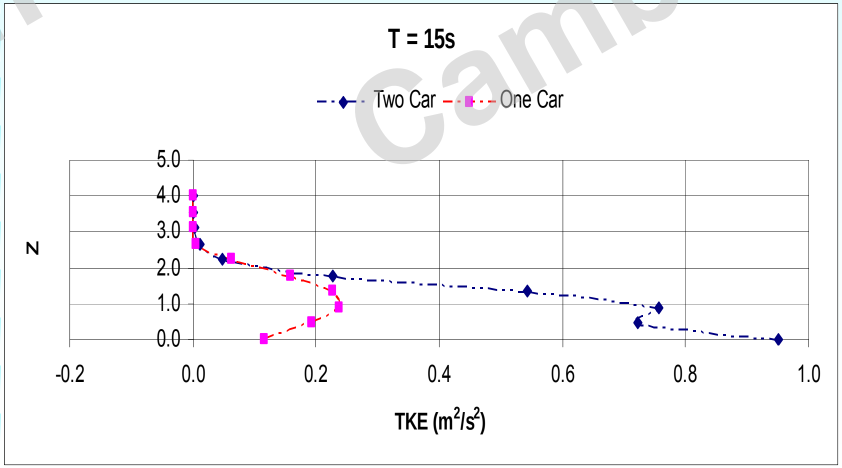
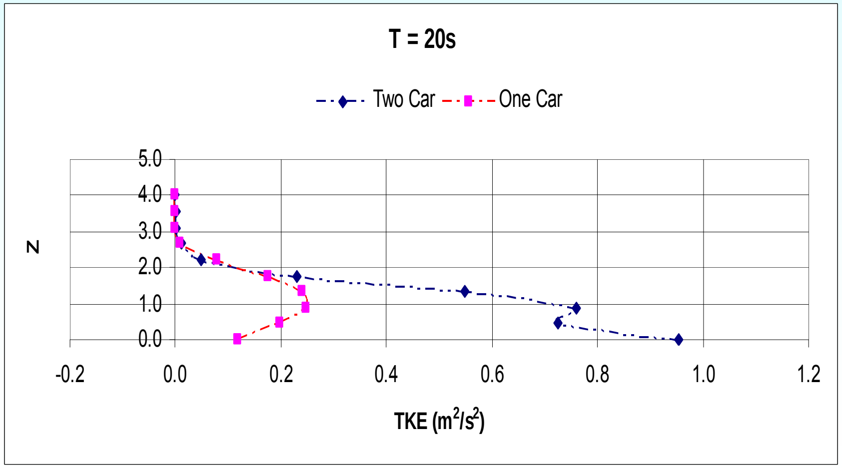
TKE (m^2/s^2)









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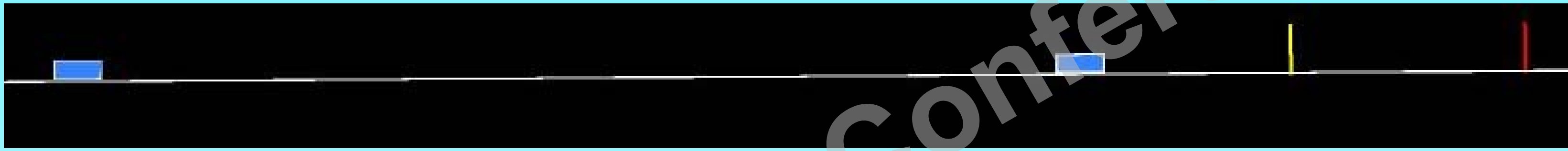
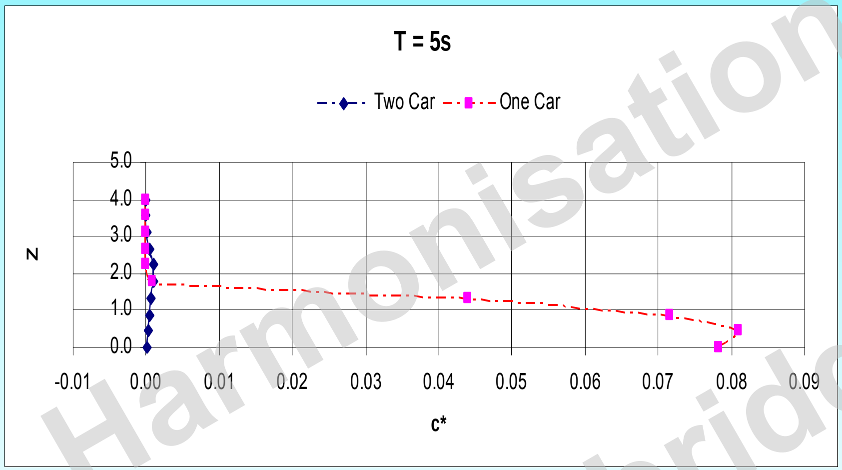
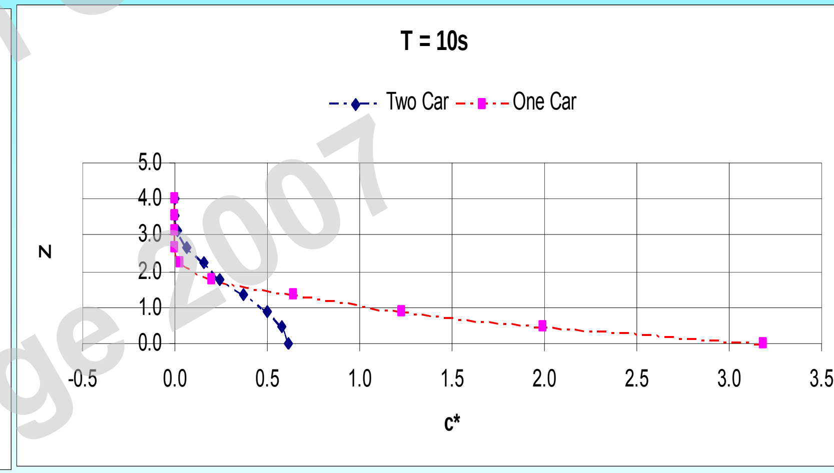
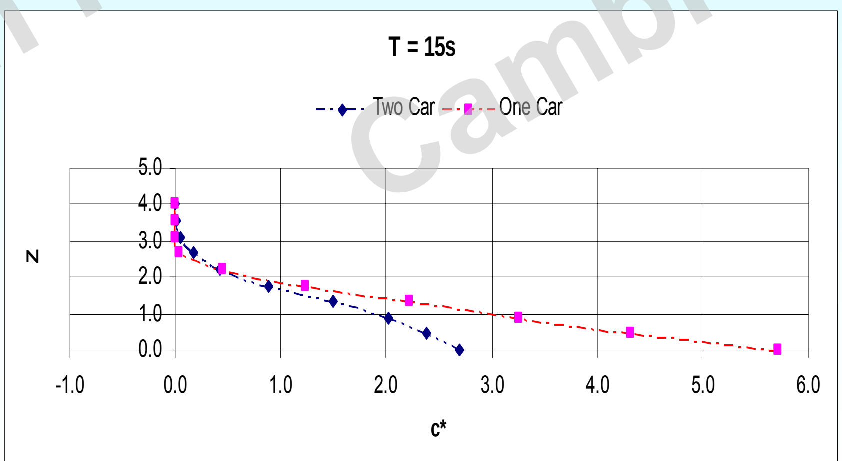
Moving Cars (10/11)

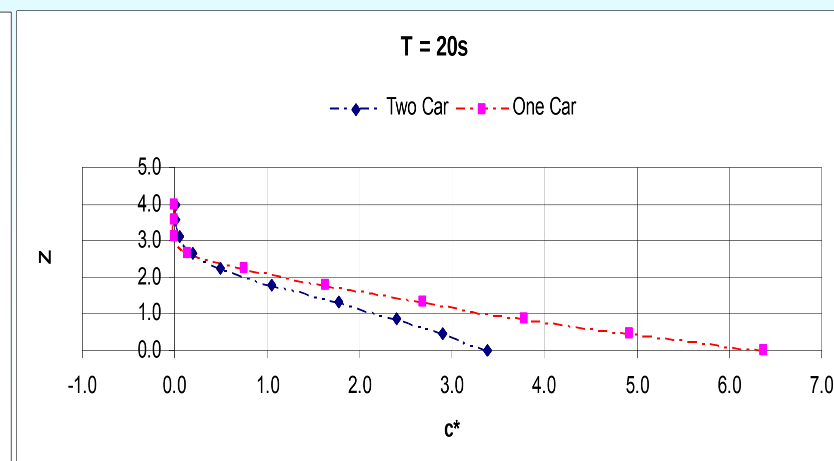
Non-Dimensional Concentration (C*)











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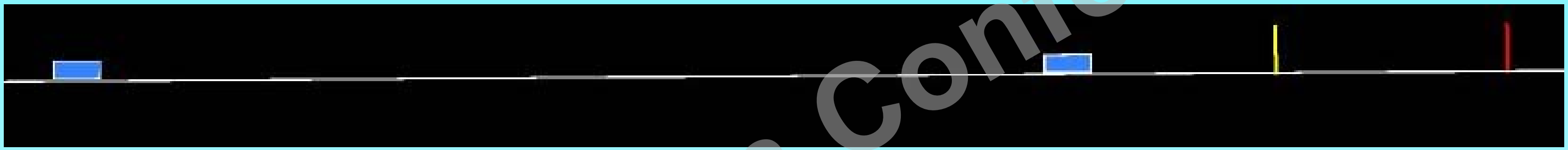
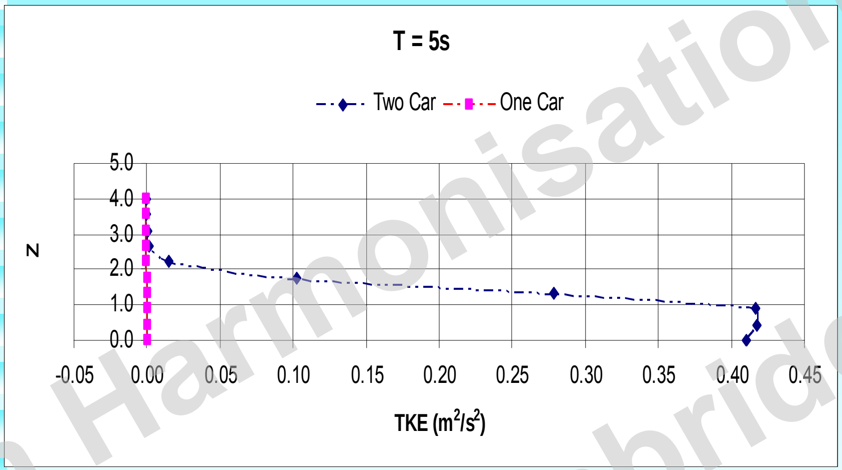
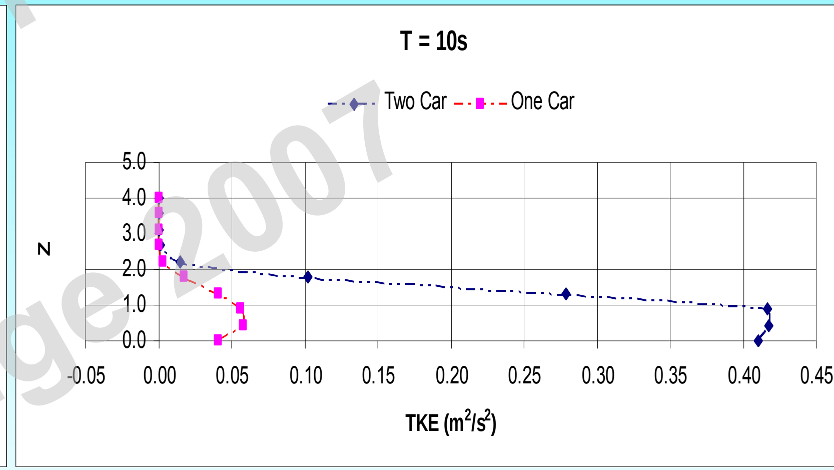
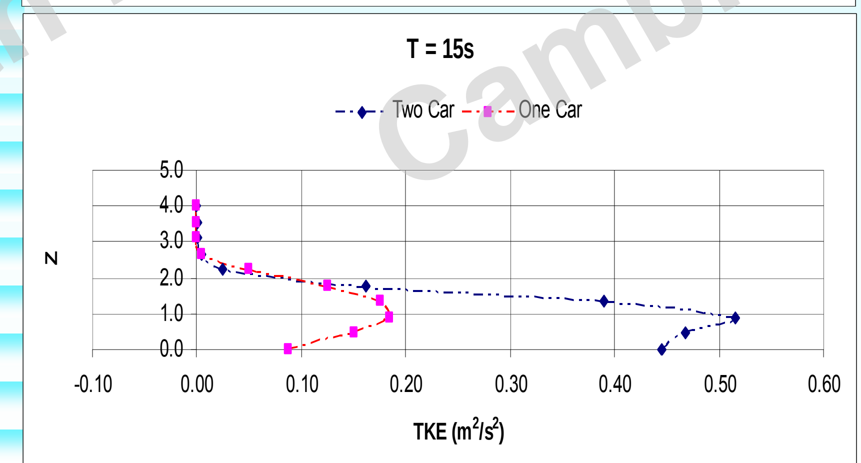
Moving Cars (11/11)

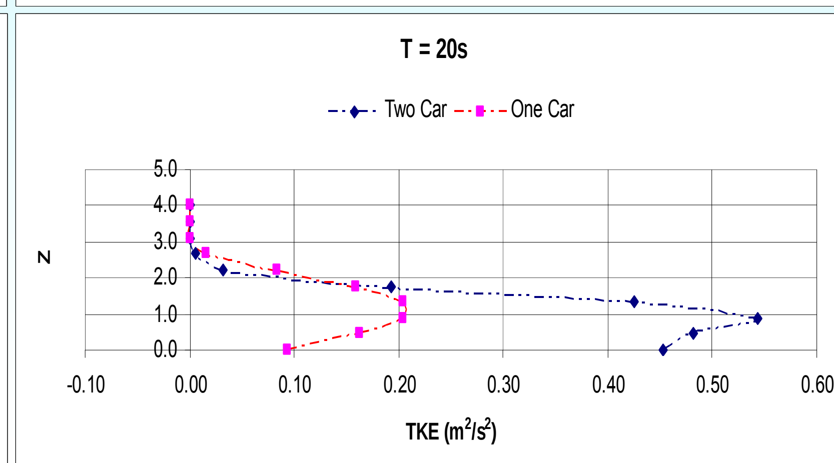
TKE (m^2/s^2)











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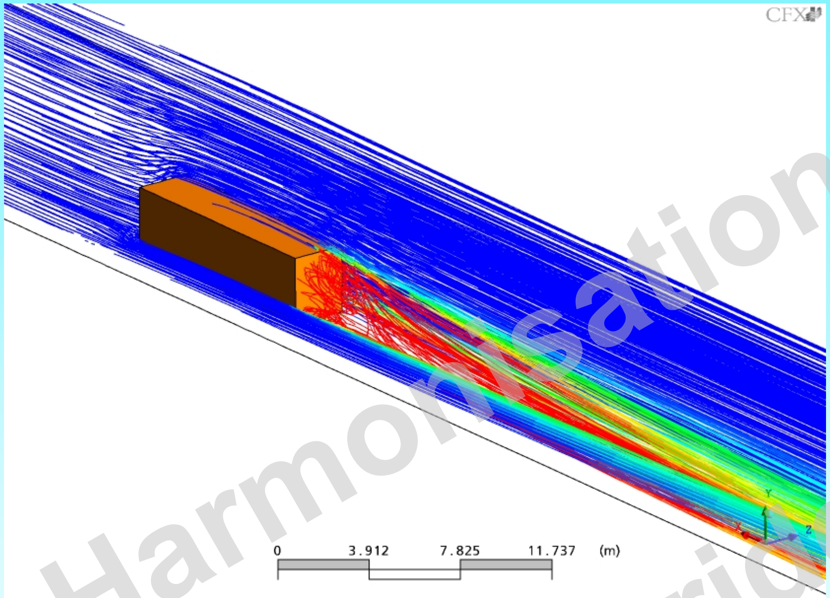
Moving buses (1/12)

Horizontal & Vertical Streamline plot



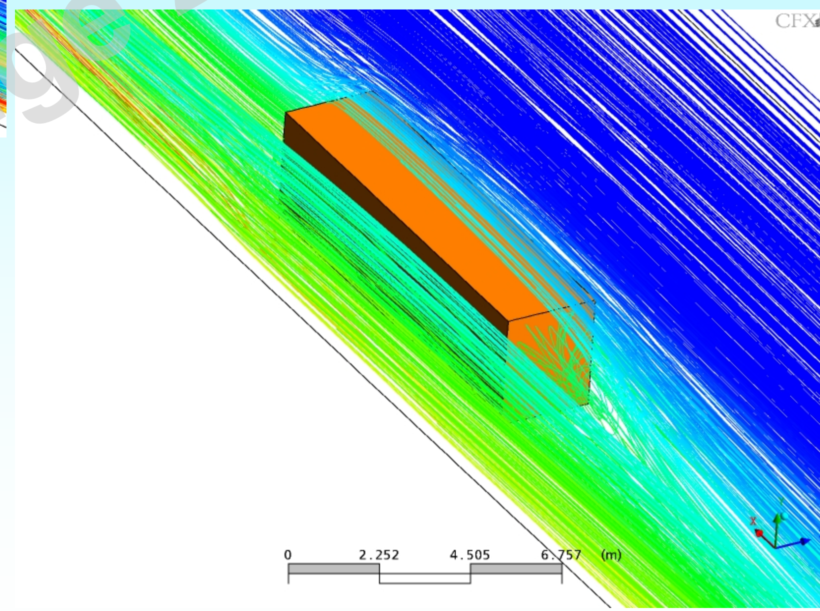
•Intense turbulent structures resulting in a strong wake downstream of the bus

•Flow is asymmetrical

•Strong Interaction between the tunnel wall and the bus

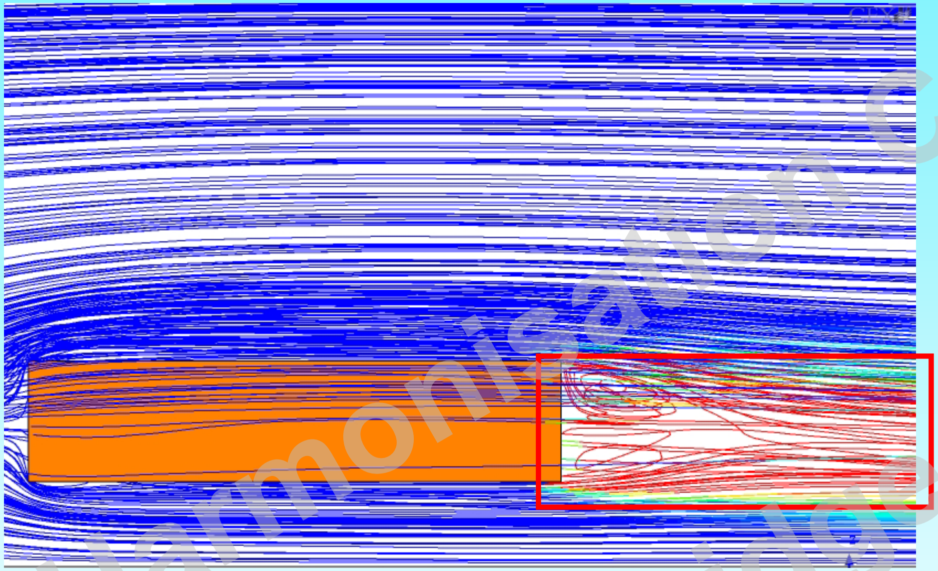
•Although flow pattern around the 2nd bus is identical the effect of the tunnel wall is even stronger

•The flow field is significantly affected by the wake of the 1st leading bus

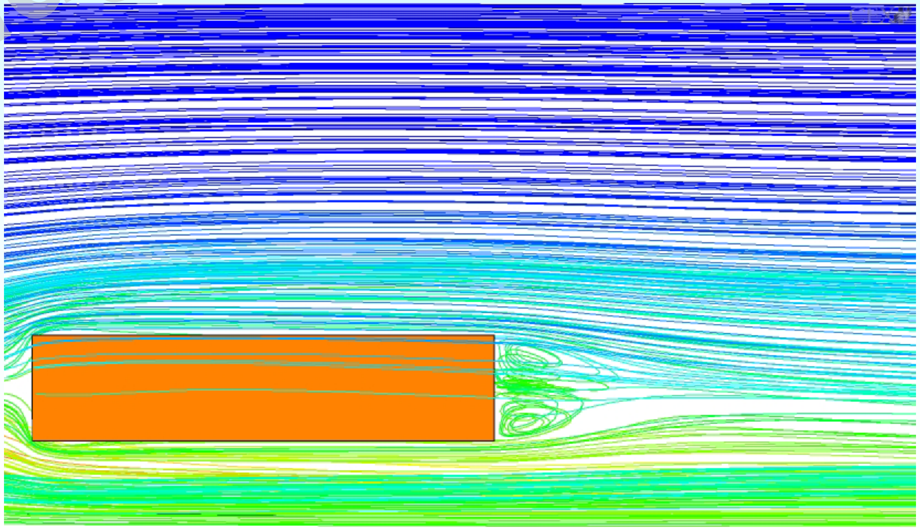


Moving buses

Horizontal Streamline plot



- Wake region asymmetrical
- Flow and pollution is driven towards the tunnel wall
- Separated boundary layer at the side, affected by the low pressure region close to the wall
- Flow field affected by the wall and the shifting in the direction of the flow in the wake region of the leading car
- In both cases the separated boundary layer at the side of the wall is probably flapping (hypothesis)



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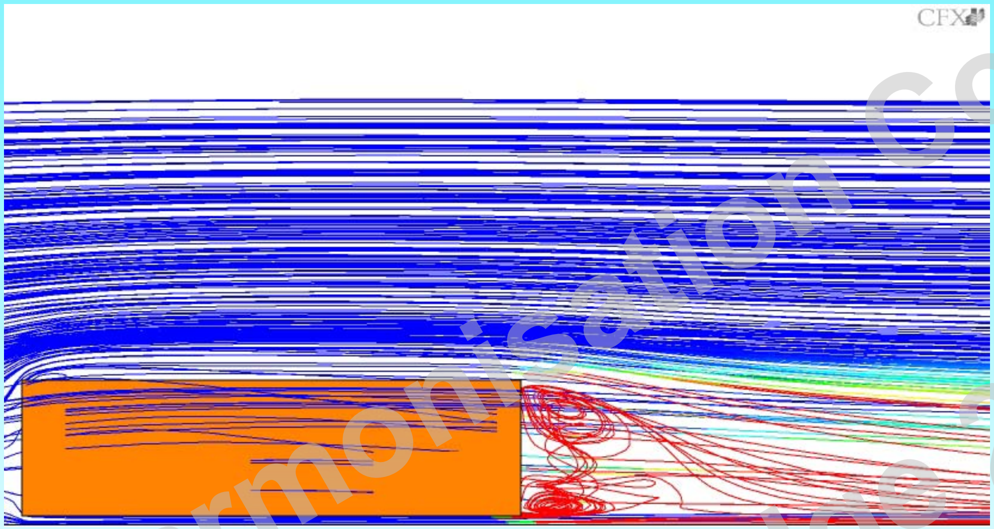
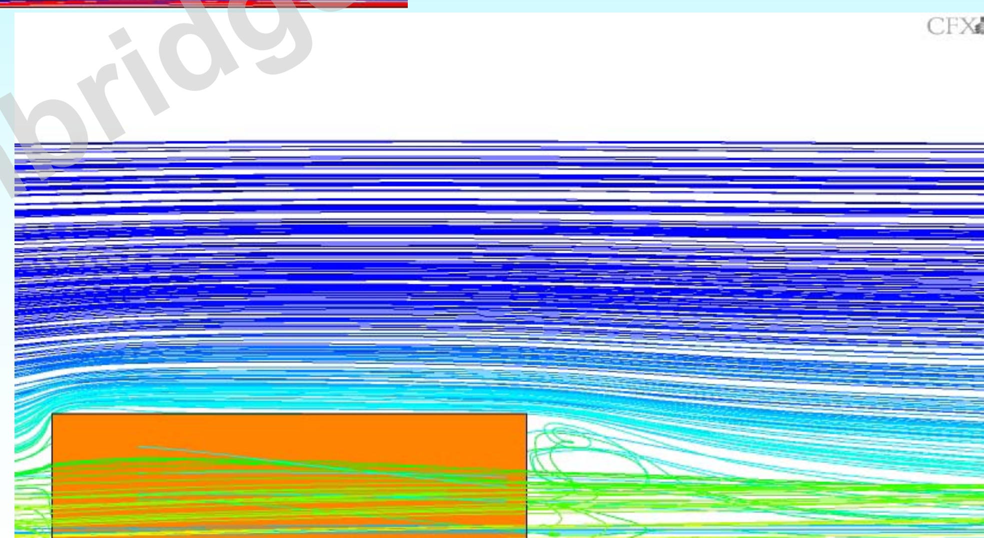
Moving buses

Vertical Streamline plot



- Separation at the roof of the vehicle
- Main recirculation downstream
- Strong effect from the flow underneath

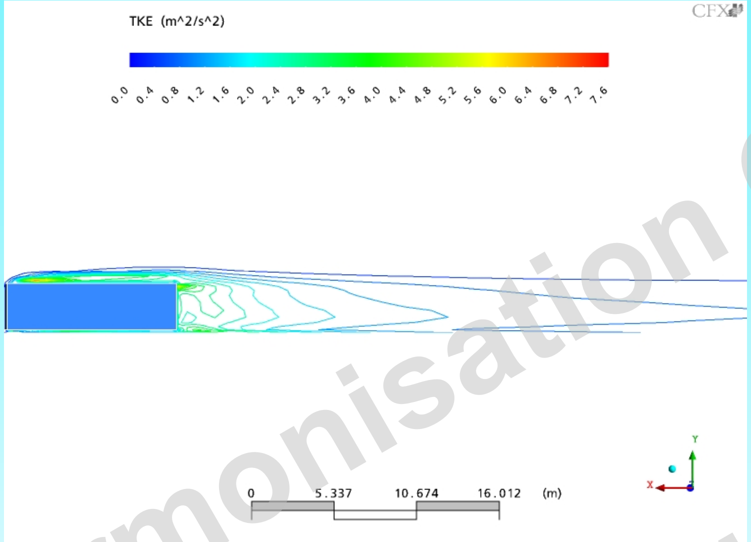
- Flow pattern identical for the 2nd car
- Wall effect present for both cases but stronger in the 2nd
- Pollution accumulated to the wall side

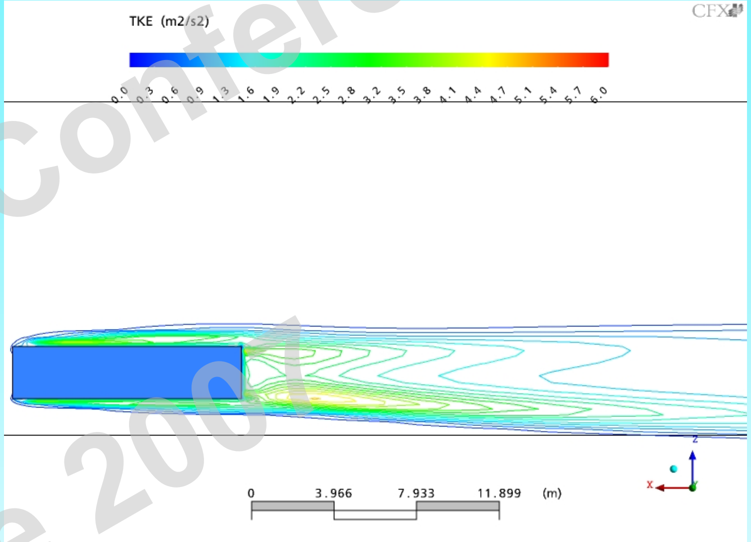


Moving buses (4/12)

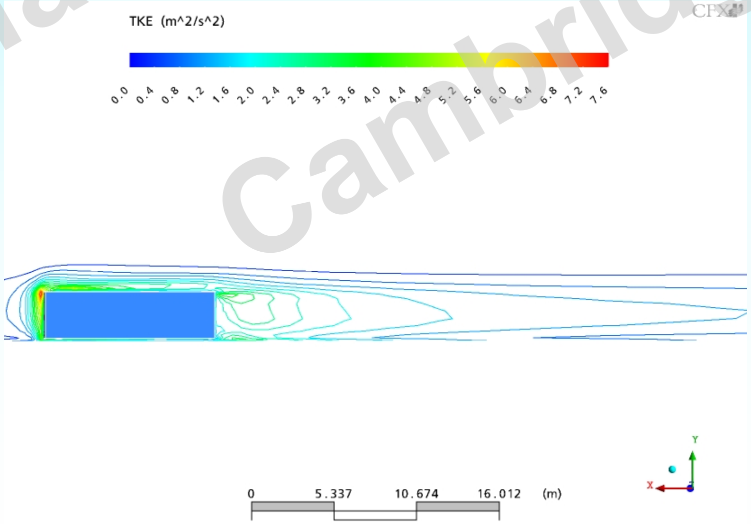
TKE (m^2/s^2)

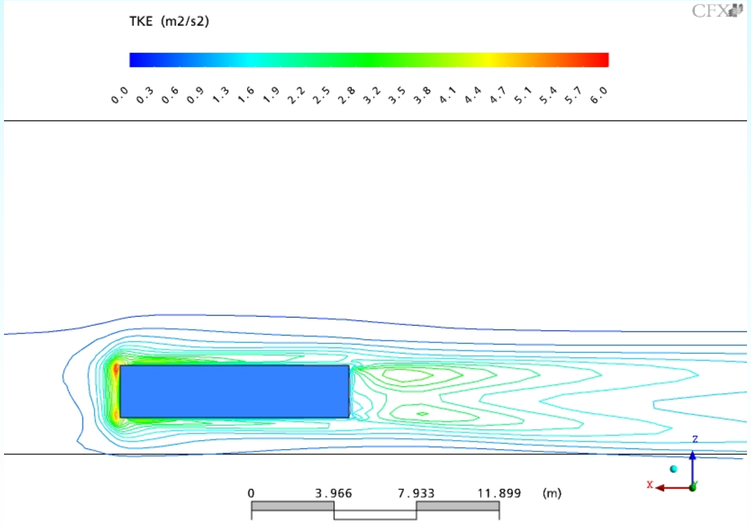
Leading bus





Following bus





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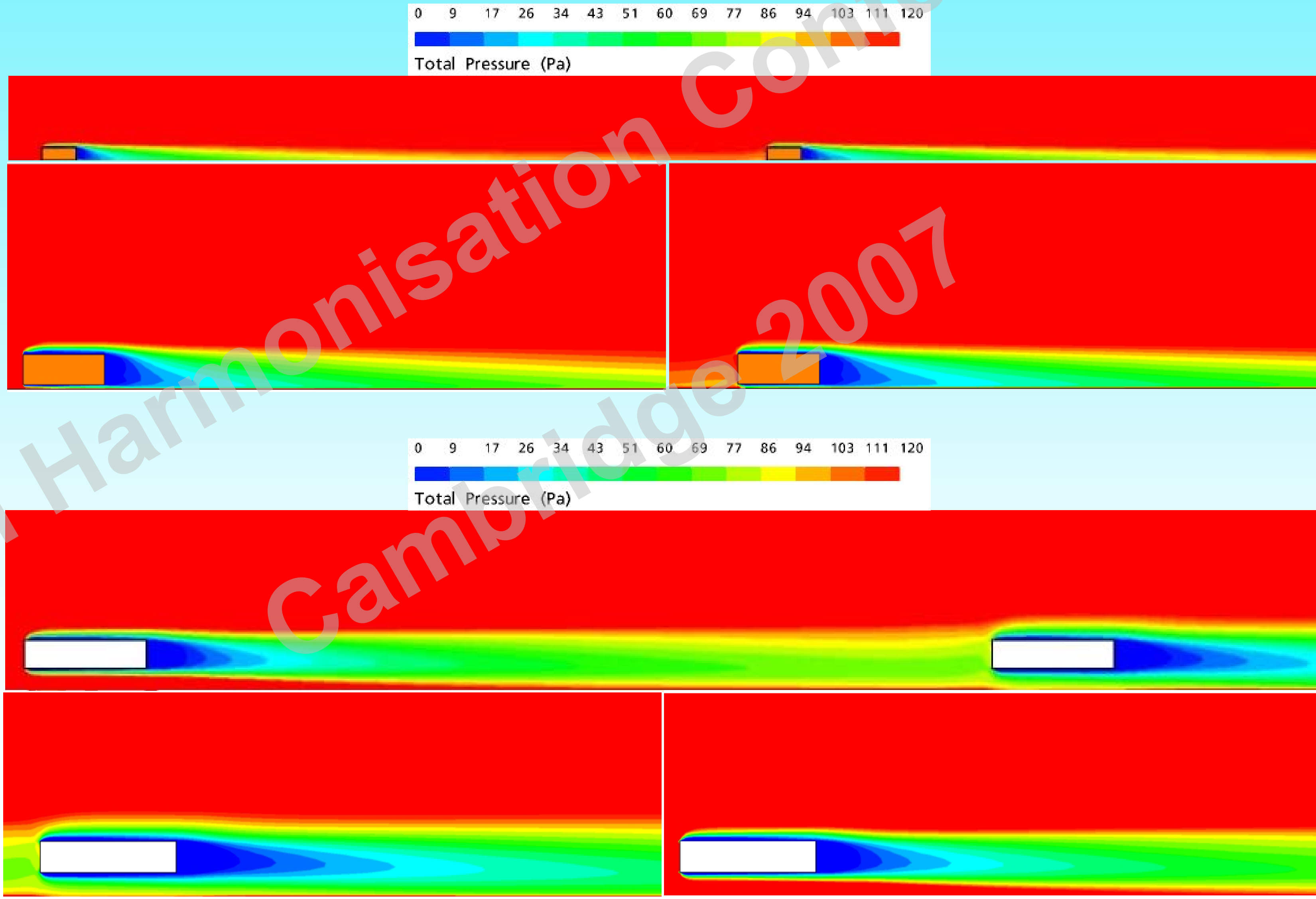
Moving buses

Predicted pressure field



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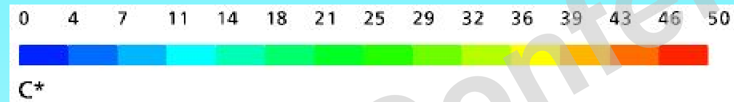
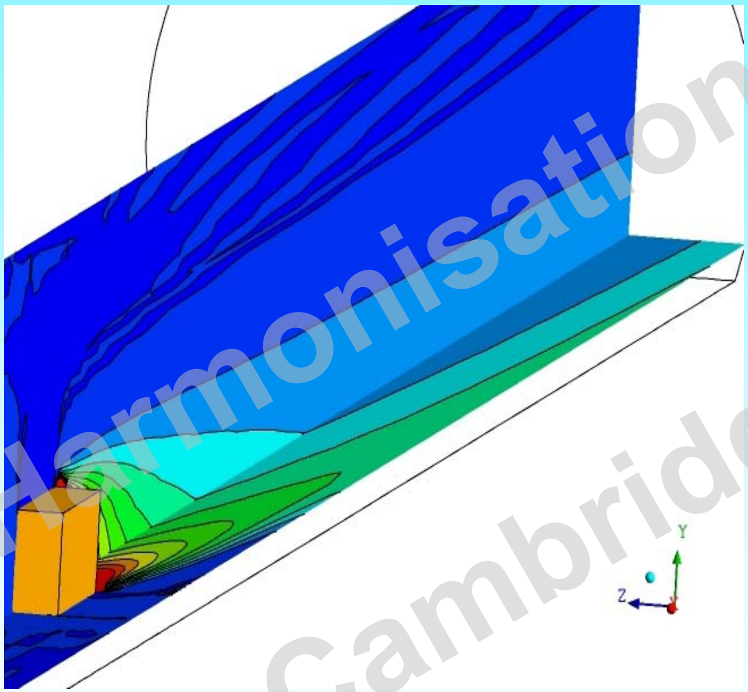
Moving buses (6/12)

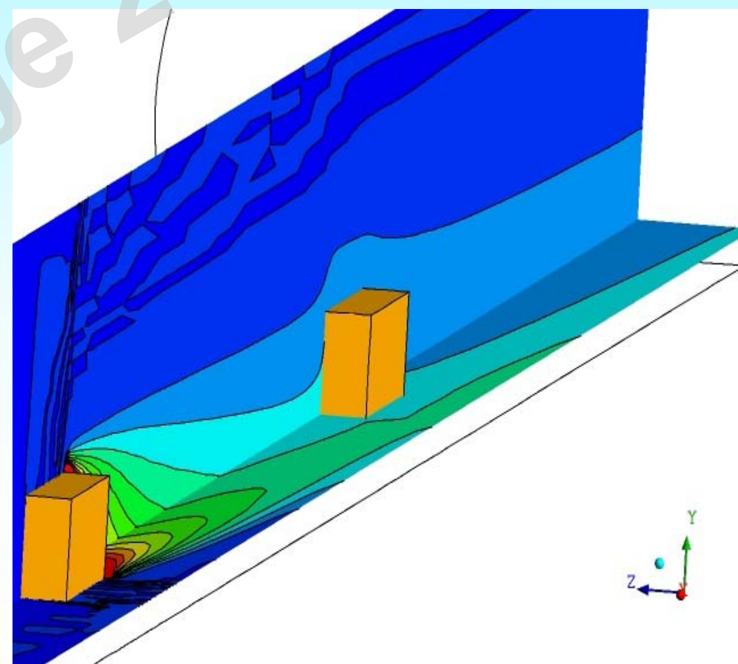
Predicted concentration field (C*)





Separation about tail gives rise to transient aerodynamic forces due to pressure disturbances propagating alongside the wake

Entrapment to the wall side wake region with higher than expected concentrations in locations in the wake region compared to the single bus



Moving buses

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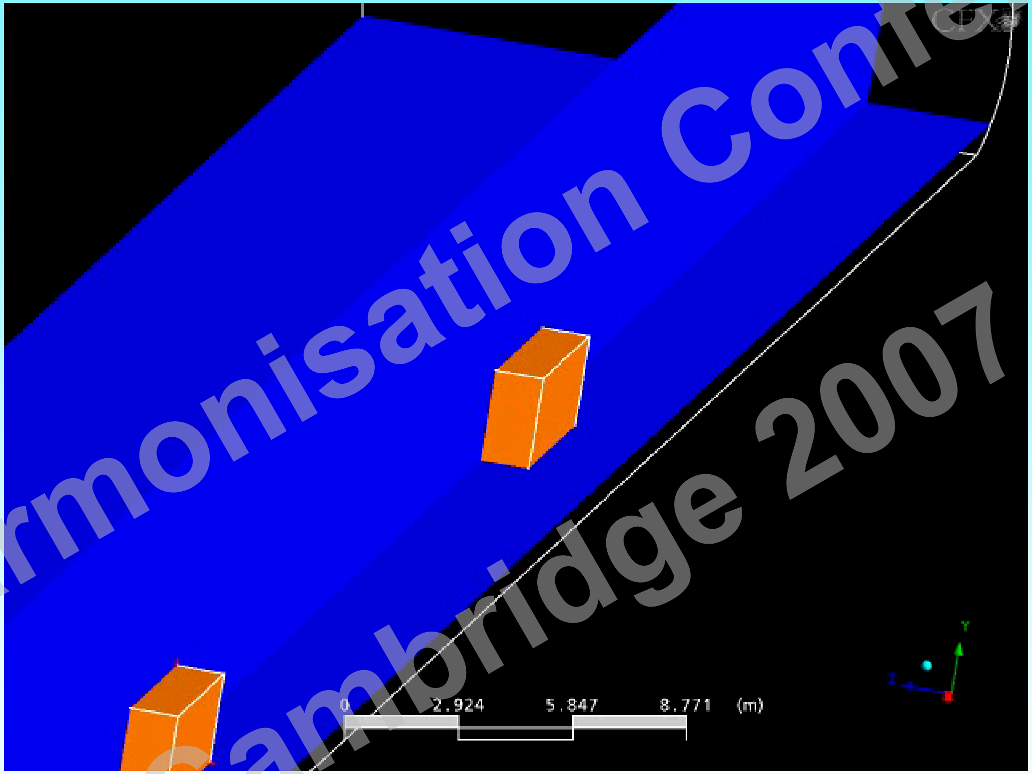
Predicted Concentration field development



Moving buses

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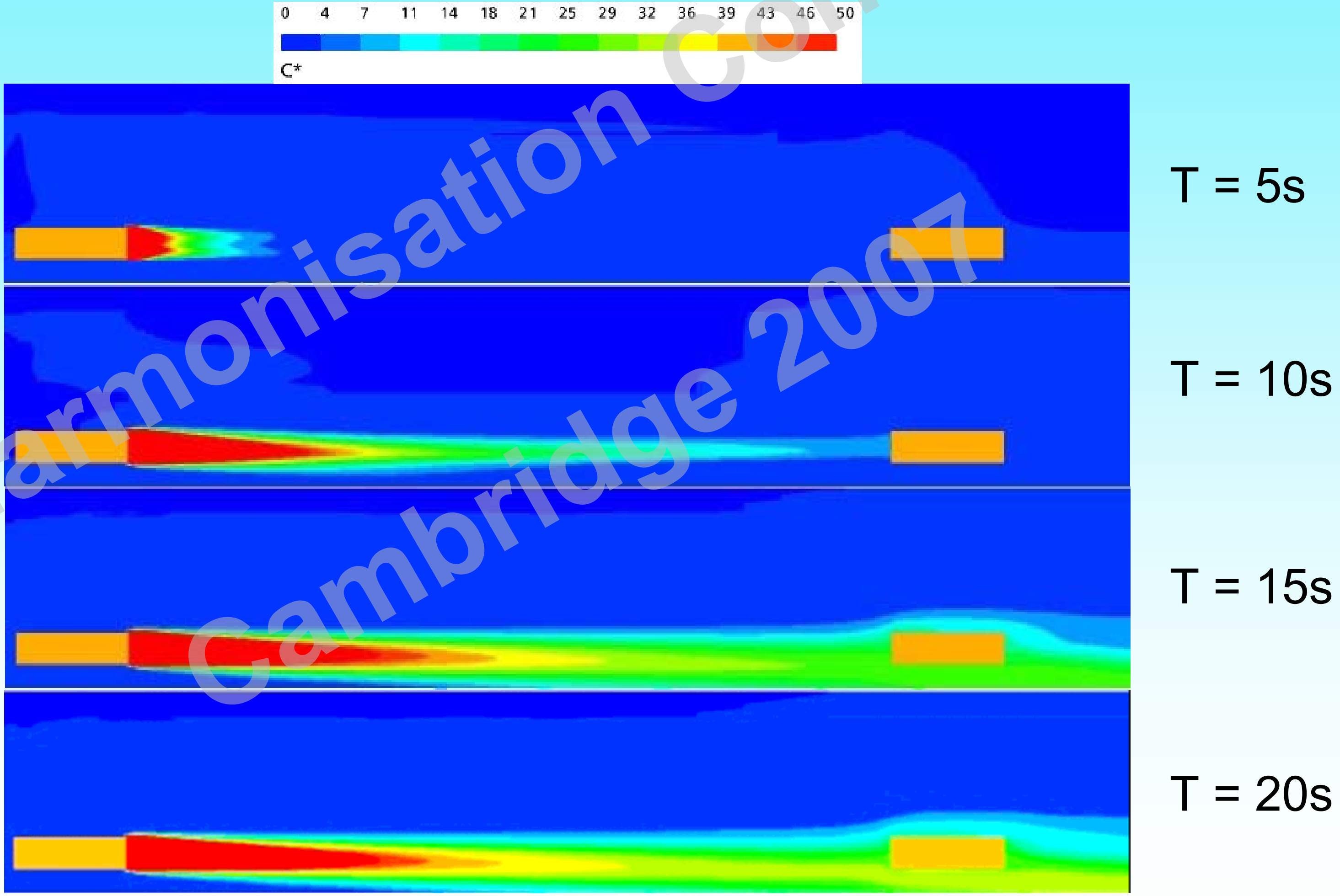
Predicted Concentration field development



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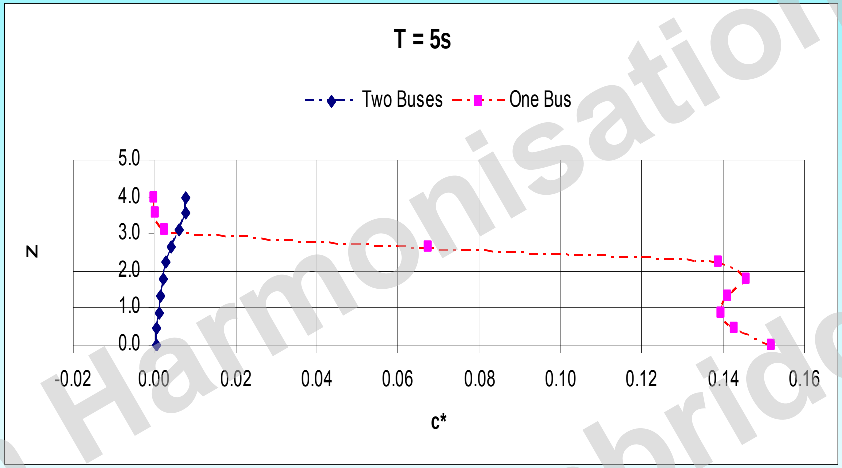
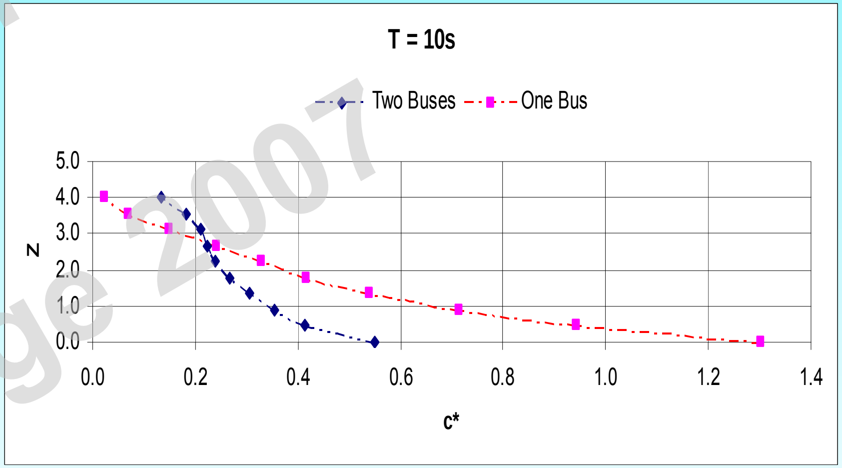
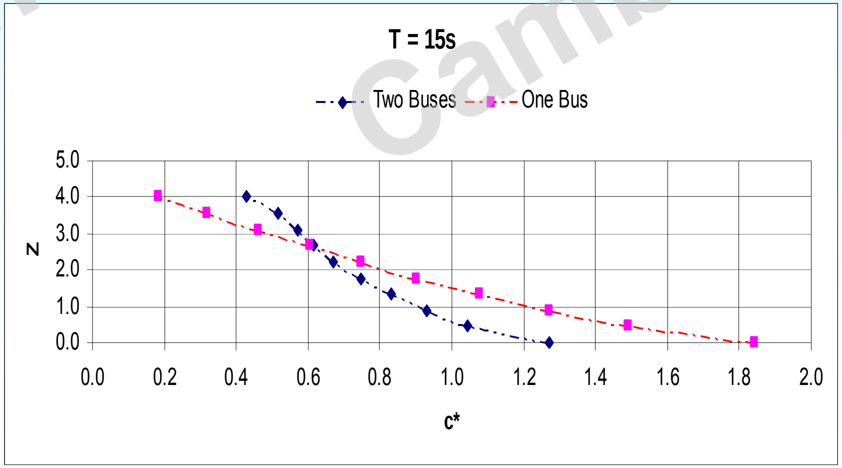
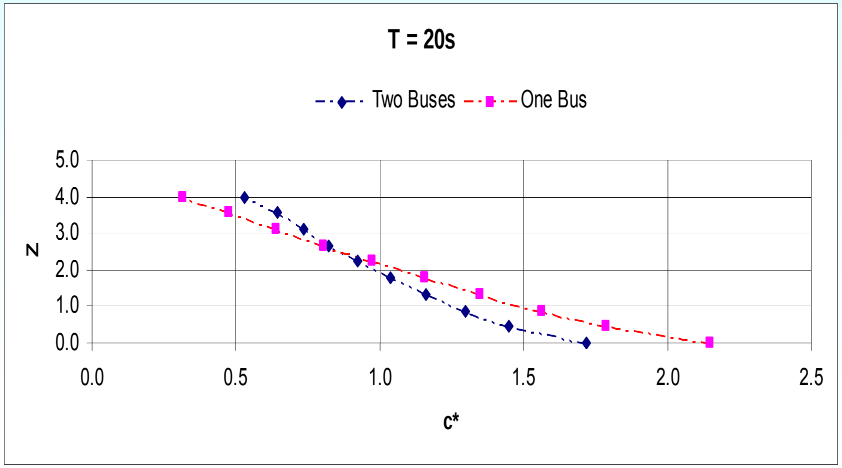
Moving Buses (9/12)

Non-Dimensional Concentration (C*)









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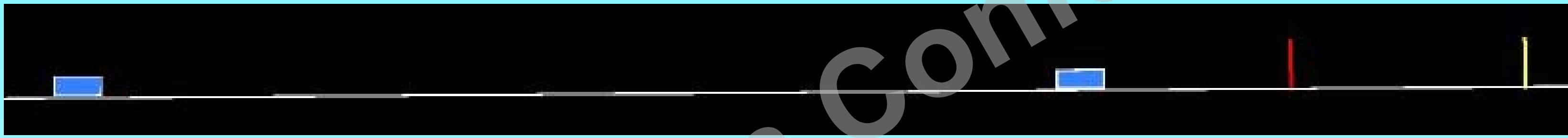
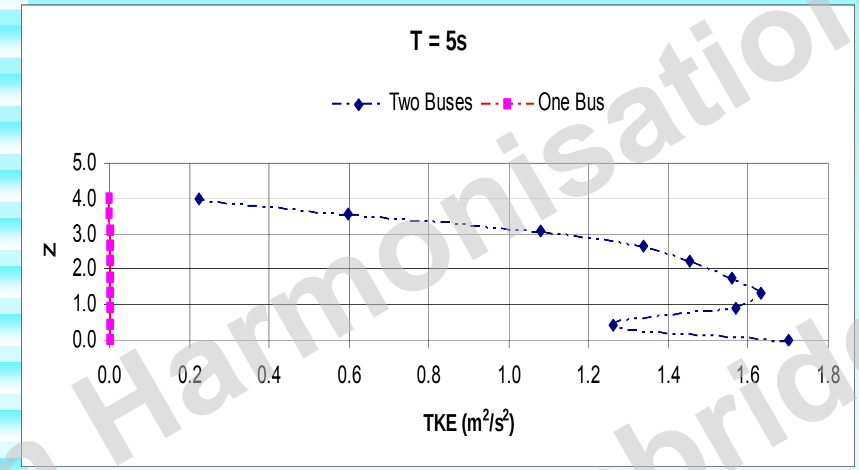
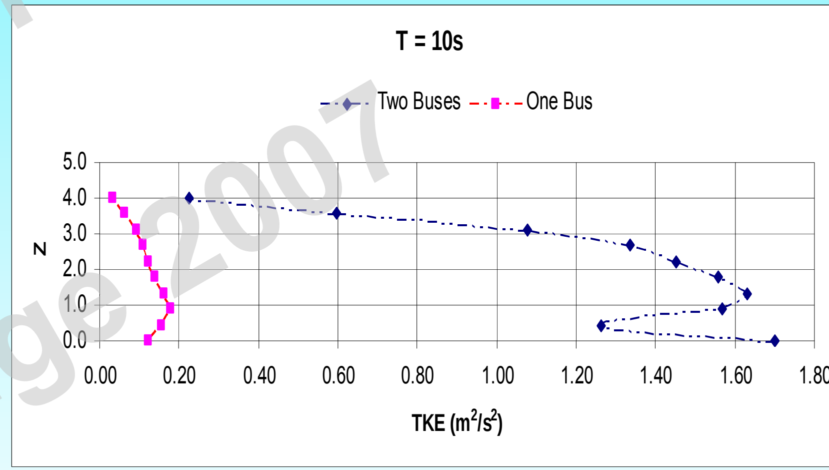
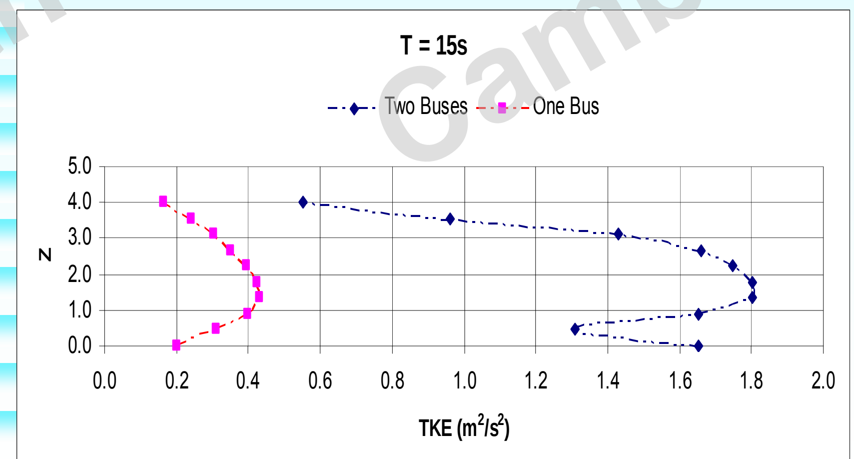
Moving Buses (10/12)

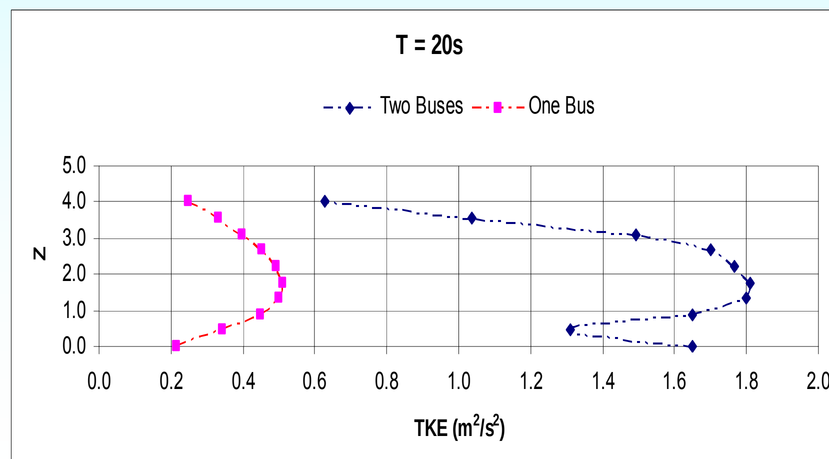
TKE (m^2/s^2)











Moving Buses (11/12)

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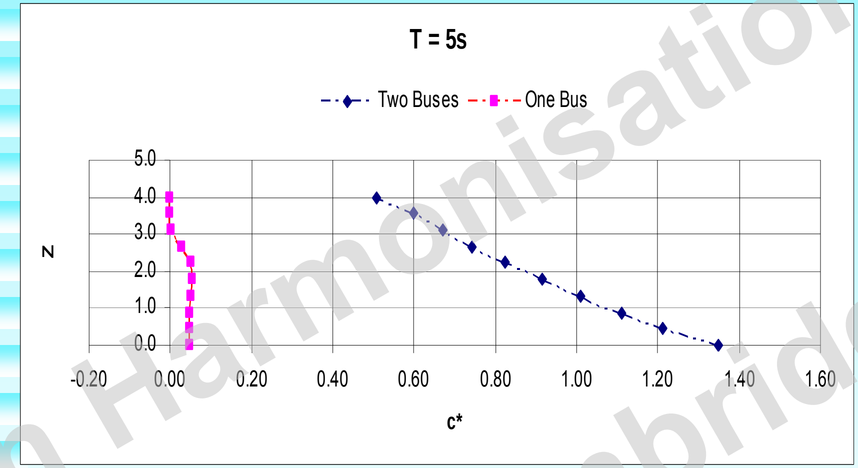
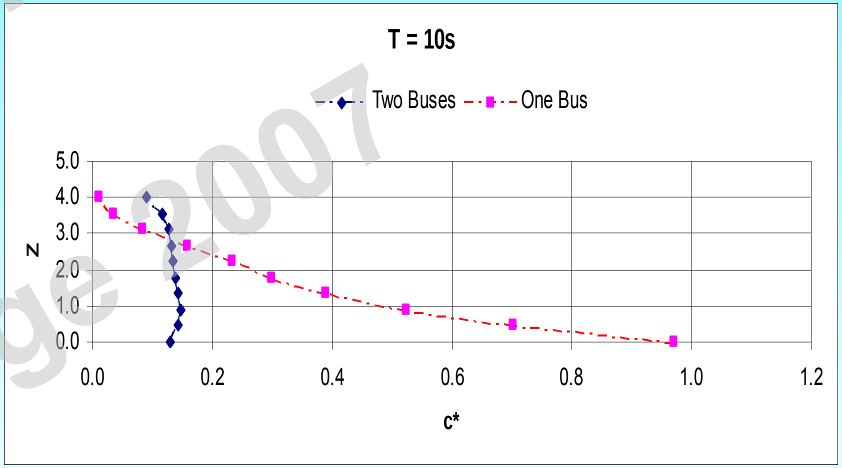
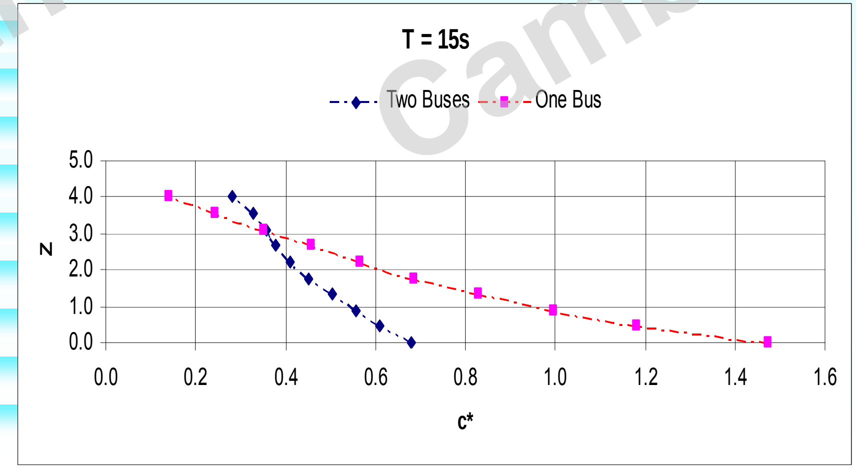
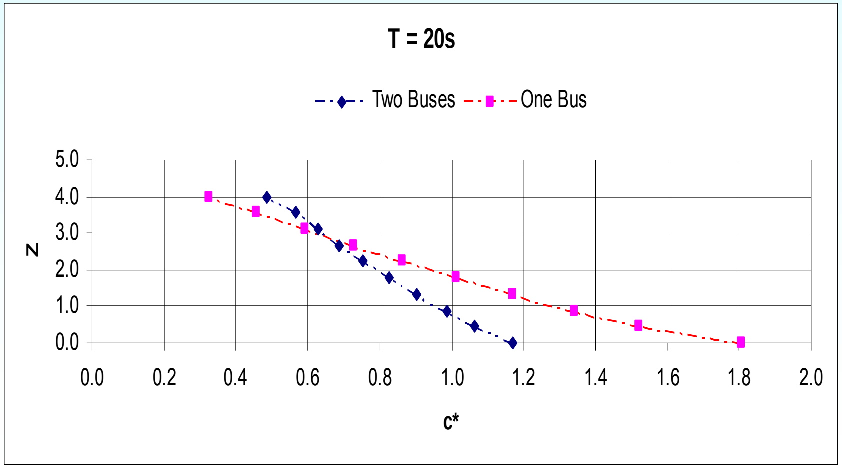
Non-Dimensional Concentration (C*)









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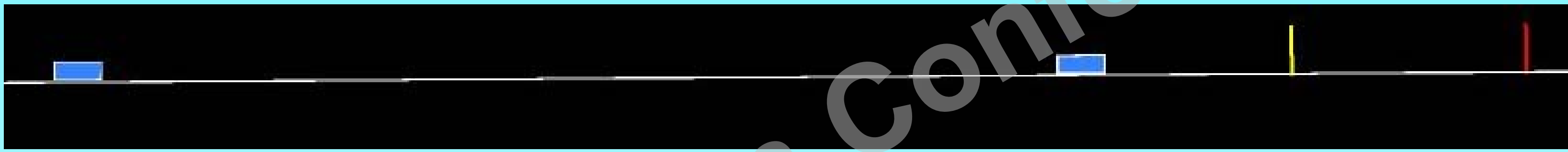
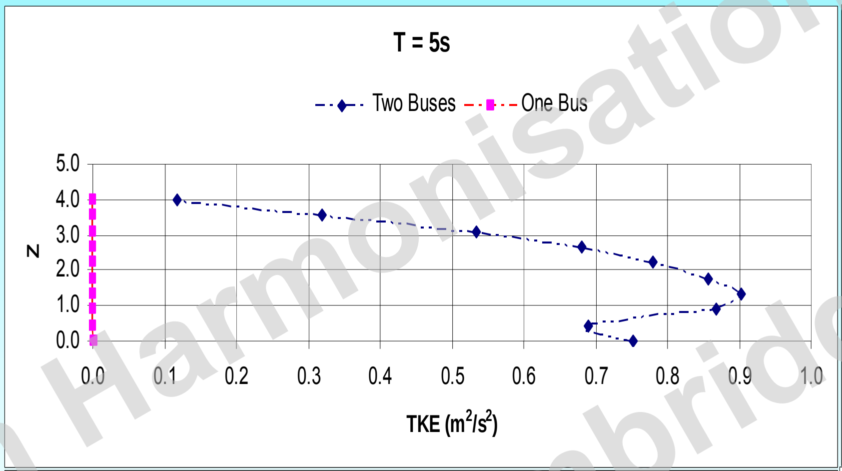
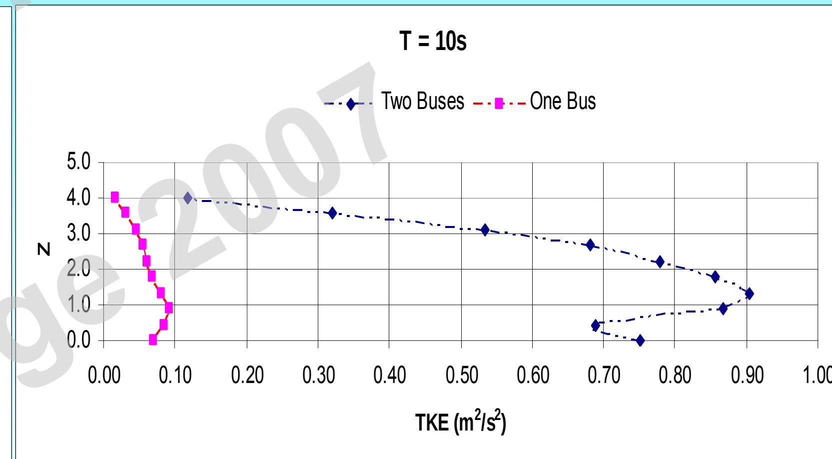
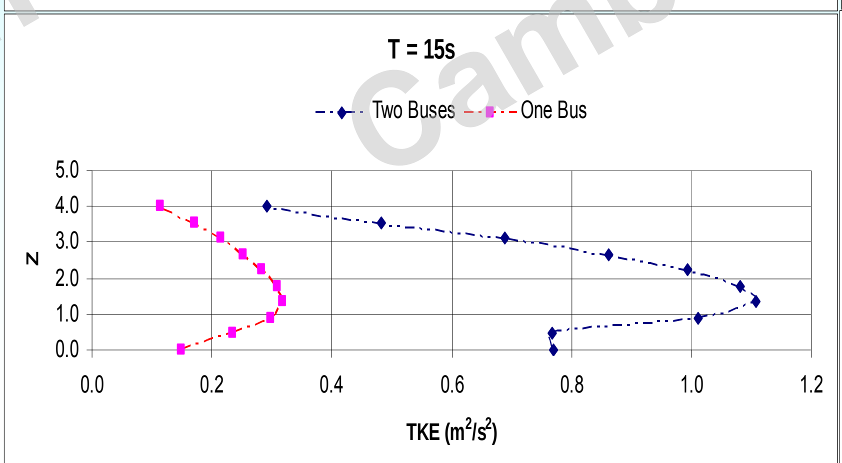
Moving Buses (12/12)

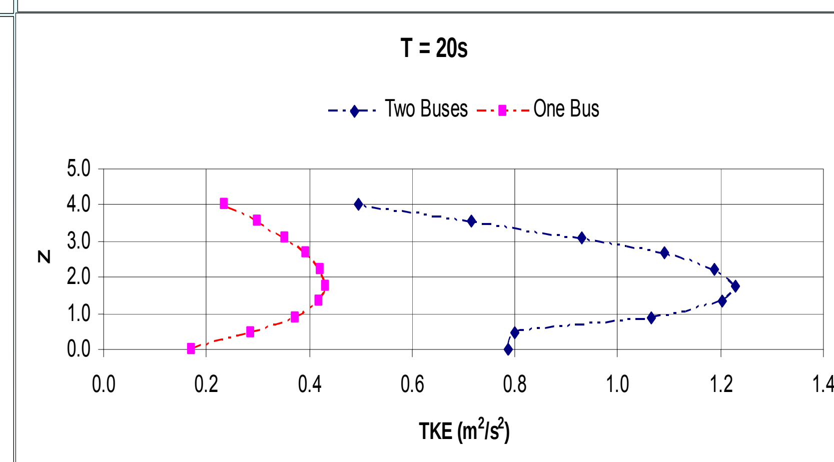
TKE (m^2/s^2)











Conclusions & future work (1/2)

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- Strong dependency of the dispersion mechanism on the complex aerodynamic effects due to the motion of vehicles

- Depending on the position of the moving vehicle inside the tunnel, the concentrations of traffic emitted pollution at specific locations, which lie in the wake of those moving vehicles can be affected

- For the moving car case, the increased mixing levels in the wake region of the 2nd car results in considerably lower concentrations compared to the single car

- For the moving bus case, interaction between the boundary layer separation at the wall side of the vehicle models and the tunnel wall lead to increased predicted TKE in the wall side wake region

Conclusions & future work (2/2)

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- This could be attributed to the aerodynamic forcing due to the continuous pressure disturbances propagating along the tunnel wall-side of the wake region of the 2nd following bus
- In cases with combined bi-directional motion with higher number of vehicles acting, the combined aerodynamic effect is expected to influence the dispersion even further
- Future work will include :
    - The actual number of the moving vehicles
    - A more realistic shape of the moving vehicles
    - LES modelling, which is necessary due to the unsteady nature of the aerodynamic effects