POLITECNICO DI MILANO

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Lateral wind effect on heavy truck approaching a bridge tower

Luigi SALATI Paolo SCHITO

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  - Target vehicle;
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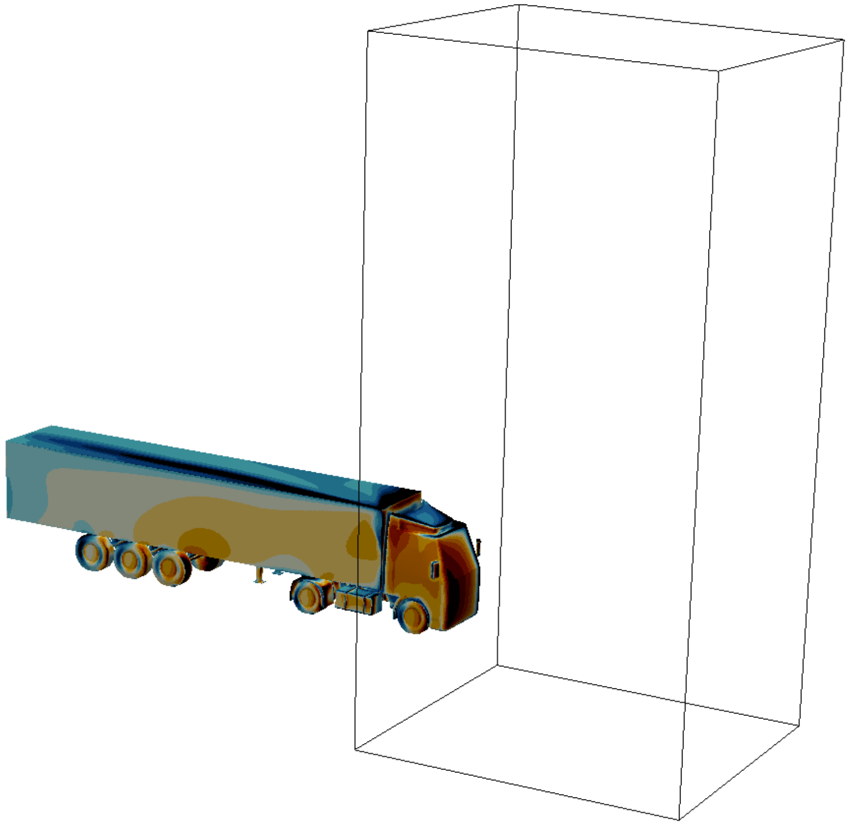


Introduction

- The aerodynamic of the heavy truck, in addition to the impact on the fuel consumption, is also important to prevent wind-induced accidents involve overturning (lateral wind).

- Heavy truck are particular sensitive to wind-induced dynamic instability compare with car due to their dimension.

- Due to the turbulence and to the complexity of the wakes generated from the interaction between the truck and the pier and **the relative motion between this two separate bodies** CFD study on this phenomena required really high HPC performances and high computational power.

- Two approach are used to study this phenomena:
  - Quasi-static approach (the overtaking maneuver is approximated as the sum of infinite steady-state simulation – no relative velocity between the objects);
  - Dynamic approach (dynamic mesh are required).

Overtaking between vehicle

The K parameter is defined as the ratio between Vr and V where:

Vr = relative velocity between overtaking and overtaken vehicle [m/s]

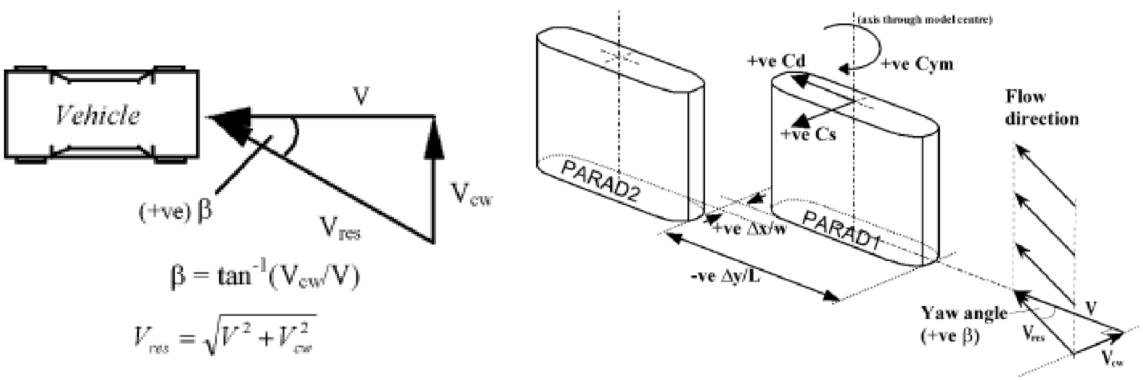
V = velocity of overtaken vehicle [m/s]

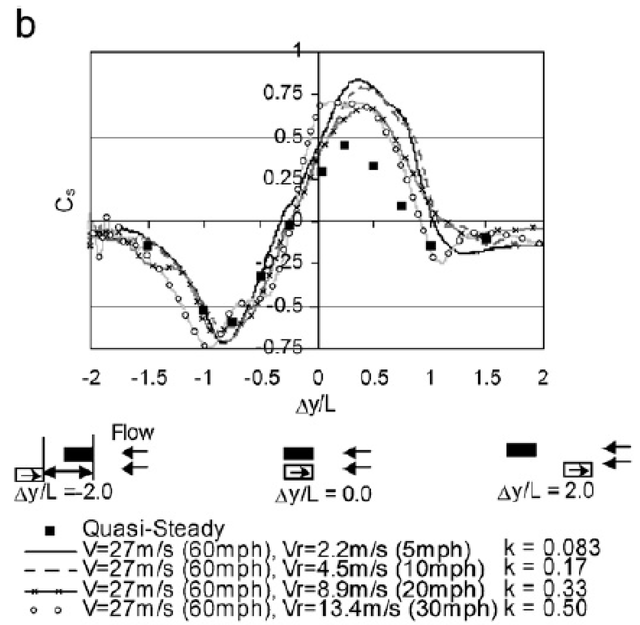
K= Vr/V

Under certain value of the k parameter the quasi-static approach have reasonable results.

- Corin et all.(2008) – scale 1:1

k<0,25-0,4 the quasi-static approach can be used



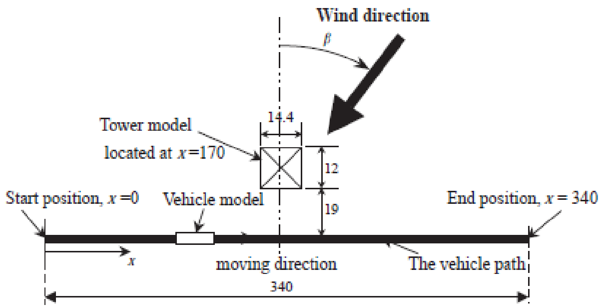


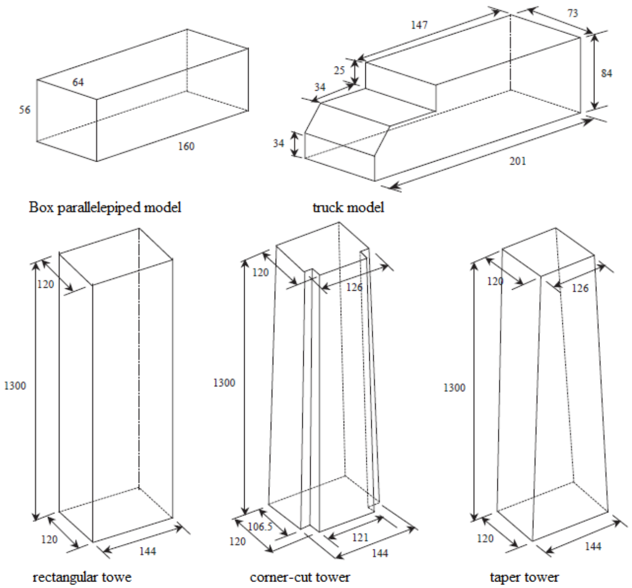
"A CFD investigation into the transient aerodynamic. forces on overtaking road vehicle models." R.J. Corin , L. He, R.G. Dominy. (2008).

Overtaking an infrastructure

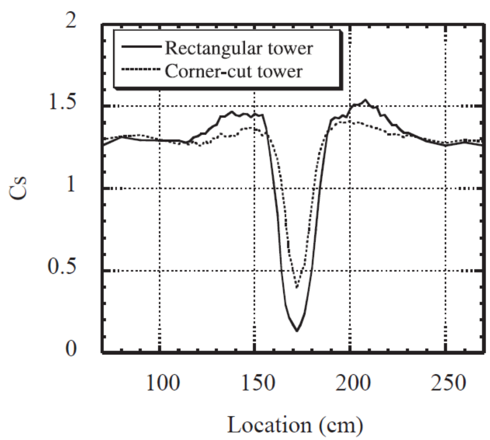
- ➢ Charuvisit et all.(2004) – scale 1:30

Vehicle speed = 3 m/s Wind speed = 3, 5,10 ,m/s

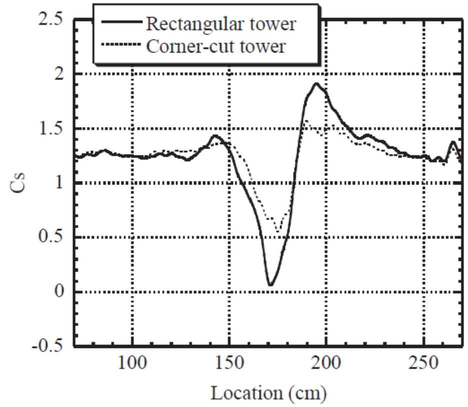




Quasi-static results



Dynamic results

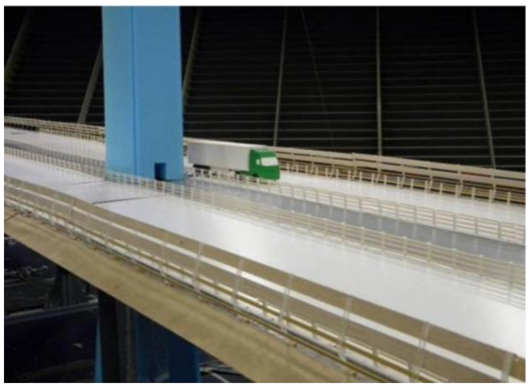


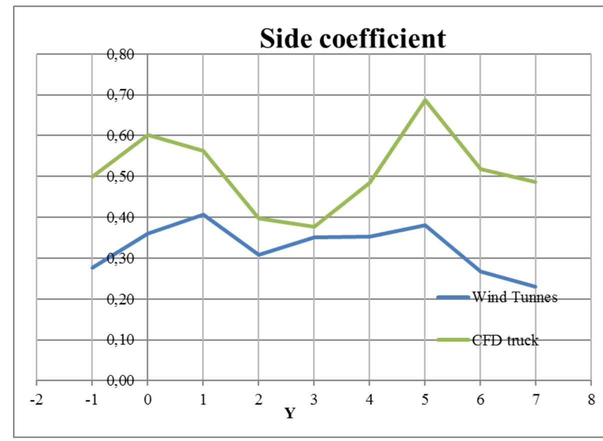
“Experimental and semi-analytical studies on the aerodynamic forces acting on a vehicle passing through the wake of a bridge tower in cross wind.” S. Charuvisit; K. Kimura ; Y. Fujino. (2004).

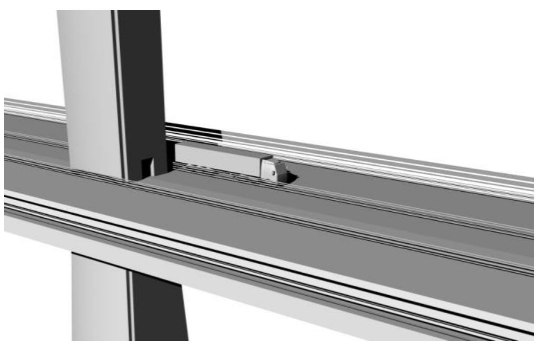
State of Art

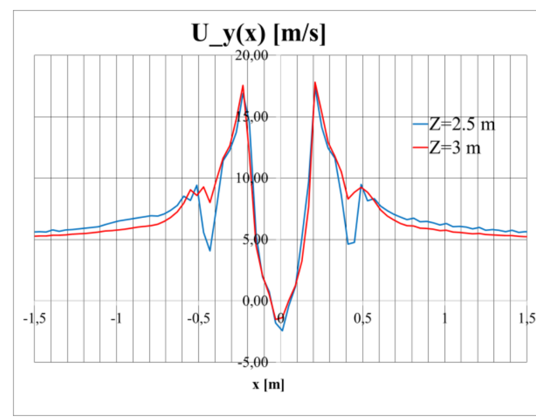
- Argentini at all. (2011)

Wind Tunnel Experiment to design lateral shielding
Bridge: Forth Replacement Crossing” (FRC) project
Quasi-static approach – scale 1:40
Wind speed 14 m/s





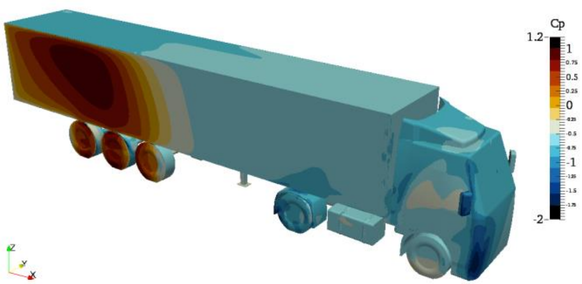


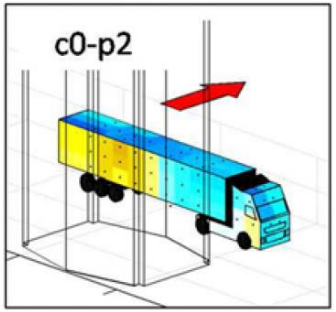


State of Art

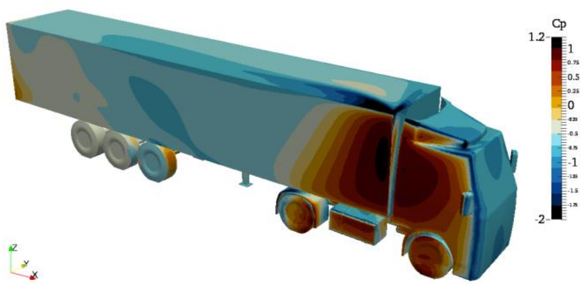
Pressure coeff. over the truck surface at the different relative position between the truck and the pylon

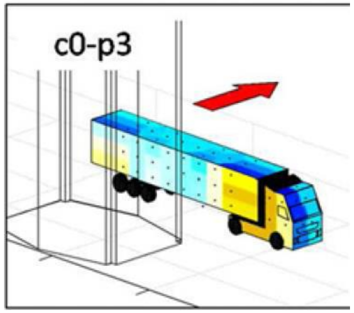
Y=2



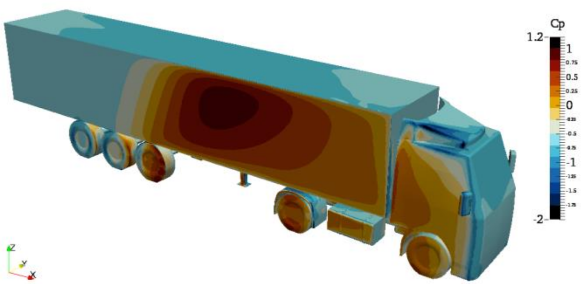


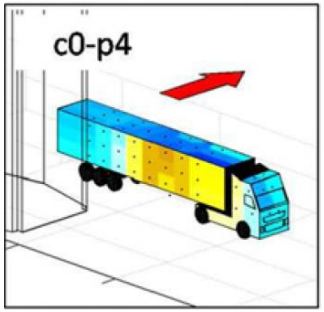
Y=3





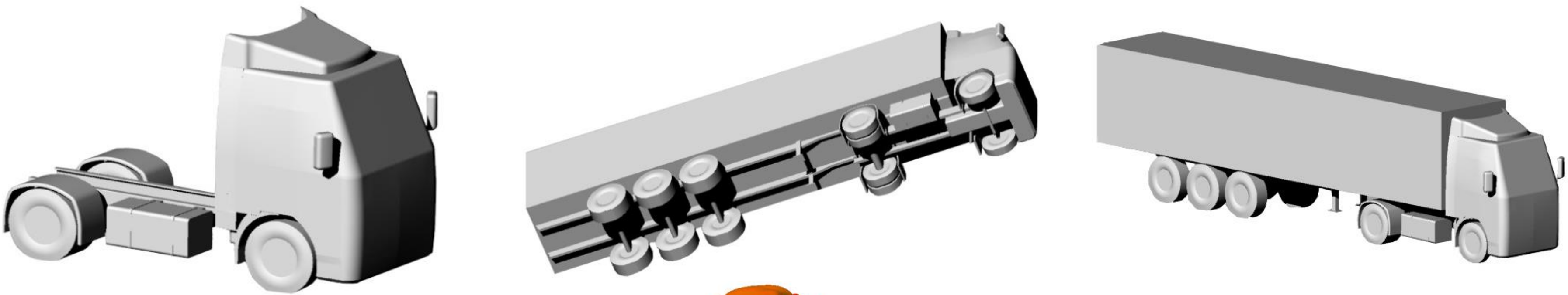
Y=4





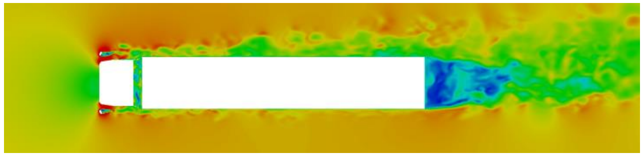
Target Vehicle

Truck geometry previous implemented to test the aerodynamics of heavy truck in front and cross-wind with DES turbulence model.

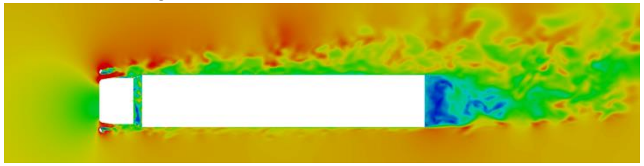


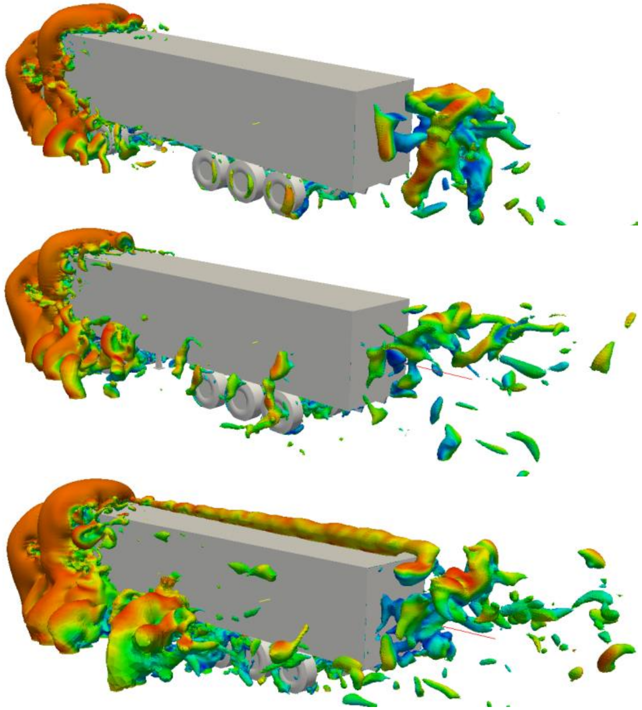
Yaw angle= 0°

Yaw angle= 5°



Yaw angle= 10°





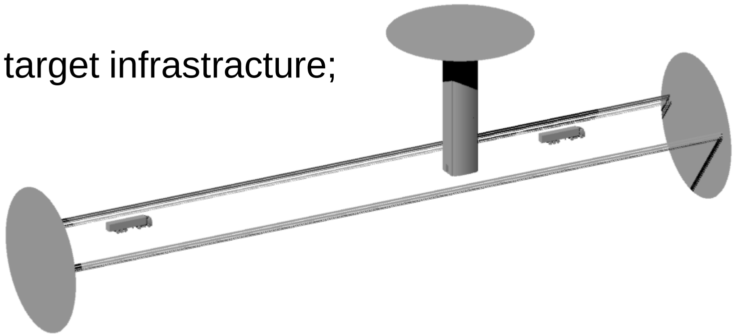
length	width	height
[m]	[m]	[m]
15,8	2,5	3,9

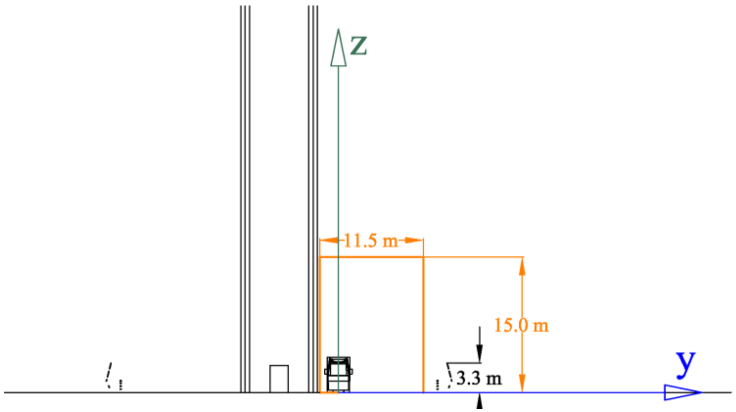
Heavy Truck Drag Reduction Obtained from Devices Installed on the Trailer." Salati, L., Cheli, F., and Schito, P.,SAE Int. J. Commer. Veh. 8(2):747

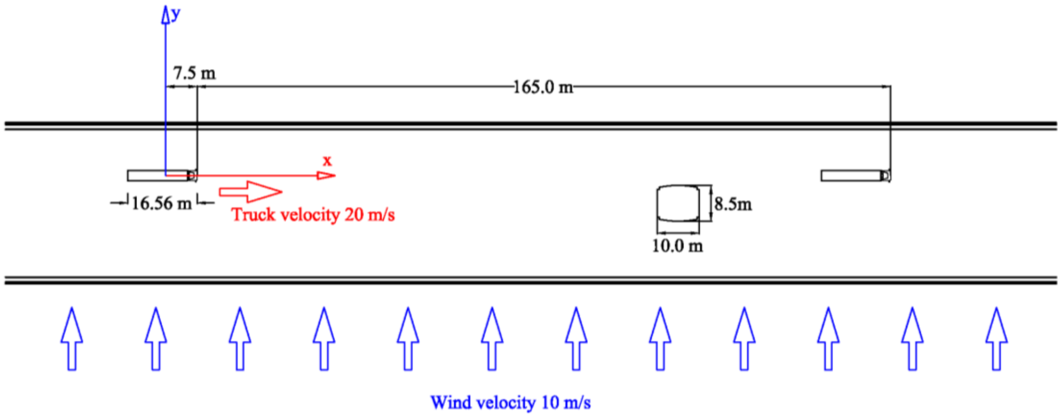
Overtaking maneuver

Simulation of a truck overtaking a pylon of a bridge in cross-wind:

- Pylon and lateral shield of the FRC project used as target infrastructure;
- The truck is moving at 20 m/s;
- Cross-wind velocity 10 m/s;
- Scale 1:1;
- Overtaking maneuver in 165 m.







Problems:

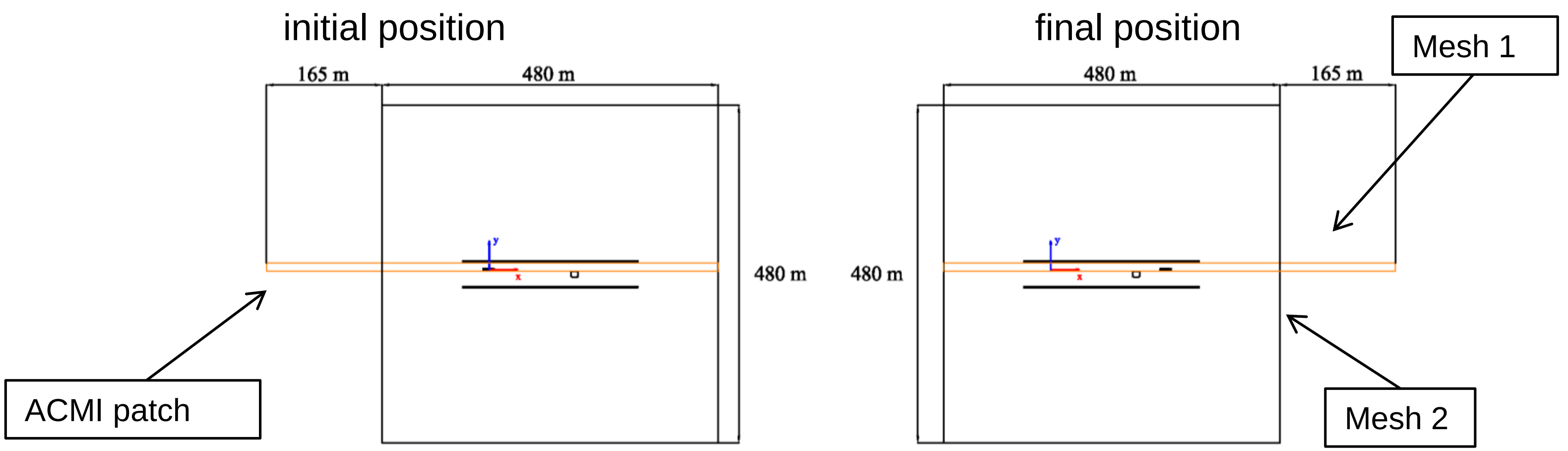
1. Simulation of the relative motion between the vehicle and the infrastructure (Solid Body Motion + ACMI Interface).
2. The different dimensional scale of the two object in the domain: the heavy truck and the bridge (suitable mesh generation).

Moving mesh strategy

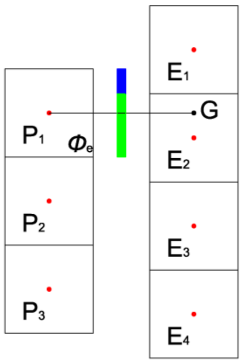
Rigid motion of the cells of the mesh, without changing their topology.

ADVANTAGES:

- Same mesh quality at any time step;
- Considerable saving in computational resources.



It is required to manage, the flow-field exchange, between the two part of the domain: the stationary one and the one in movement: Arbitrary Coupled Mesh Interface (ACMI).



AMI-ACMI Interface

$$\Phi_e = \Phi_G + (1 - \alpha)\,\Phi_P$$

$$\alpha = \frac{x_e - x_P}{x_G - x_P}$$

$$\Phi_G = \sum_i \alpha_i \Phi\, E_i$$

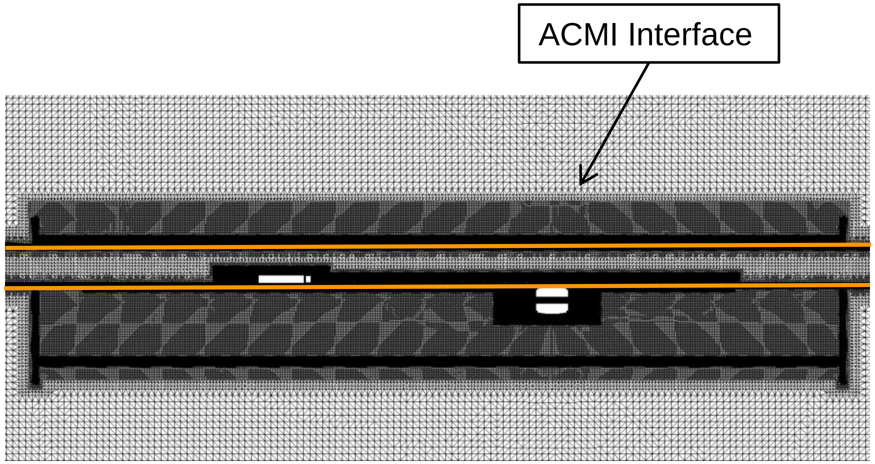
$$\alpha_i = \frac{A_i}{A}$$

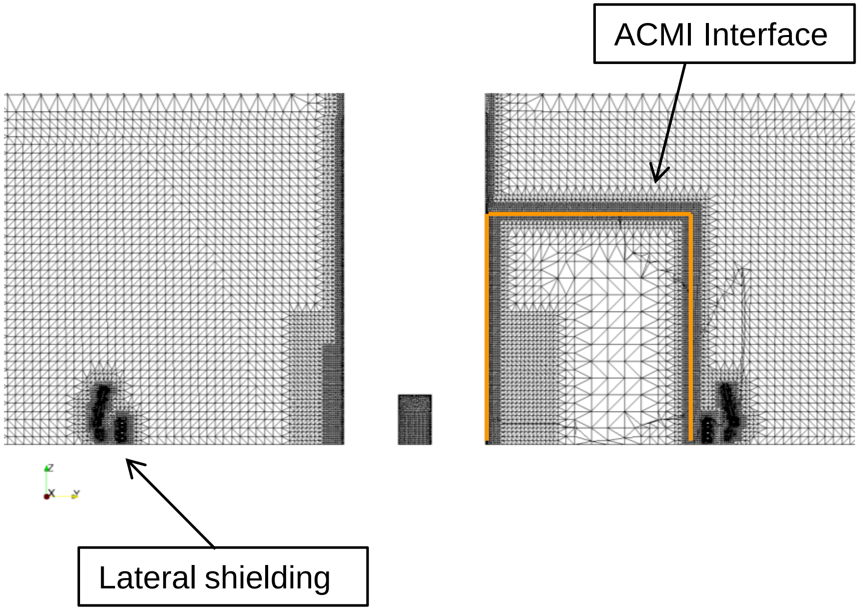
In the AMI procedure, each face accepts contributions from partially overlapping faces from the neighbour patch, with the *weights* defining the contribution as a fraction of the intersecting areas.

ACMI is an AMI patch in which two patches are partially overlap.

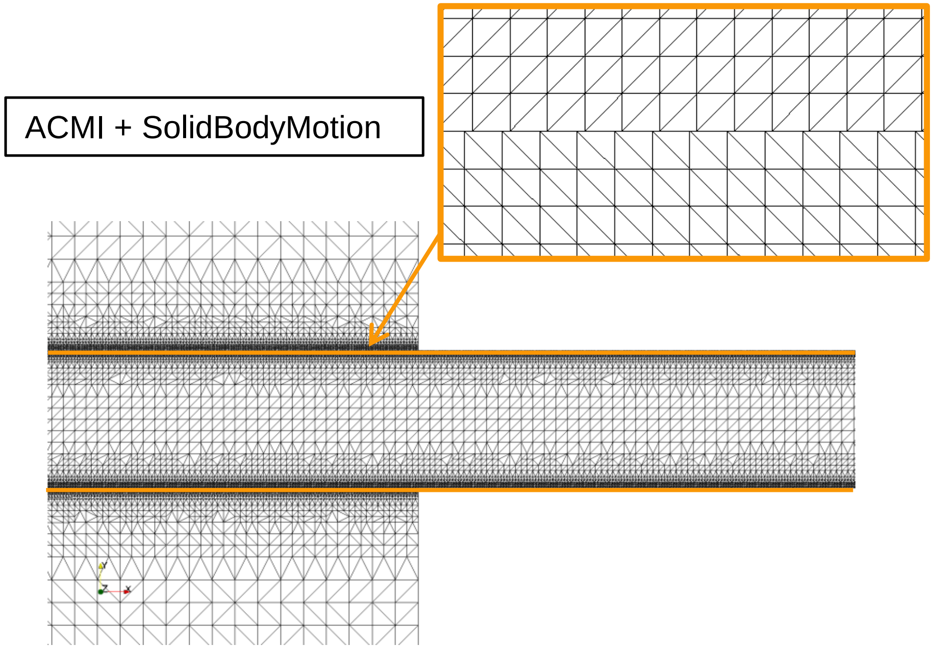
Numerical model

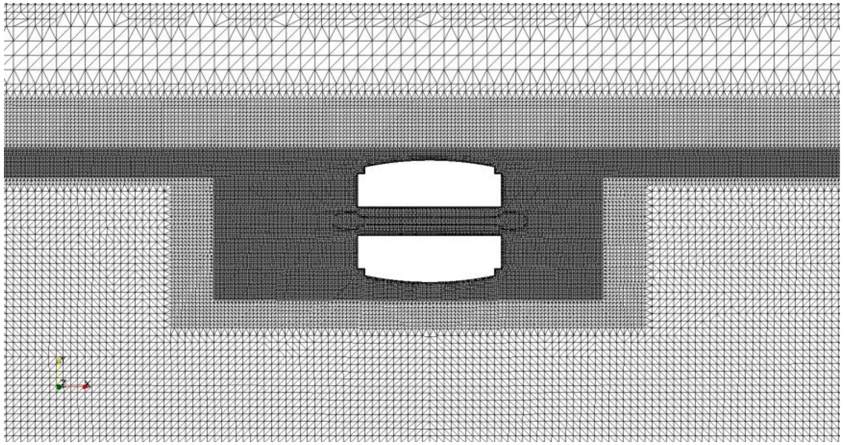
- CFD solver: OpenFOAM;
- Mesh: OpenFOAM - snappyHexMesh (around 55,5 millions elements);
- Fully Cartesian grid;
- Several main rectangular volumetric controls, one inside the other are designed to refine the grid around the truck, the pylon and the shielding;
- Layer where added around the whole vehicle and the pylon;
- Approximation of the contact area wheel/ground.





Numerical model

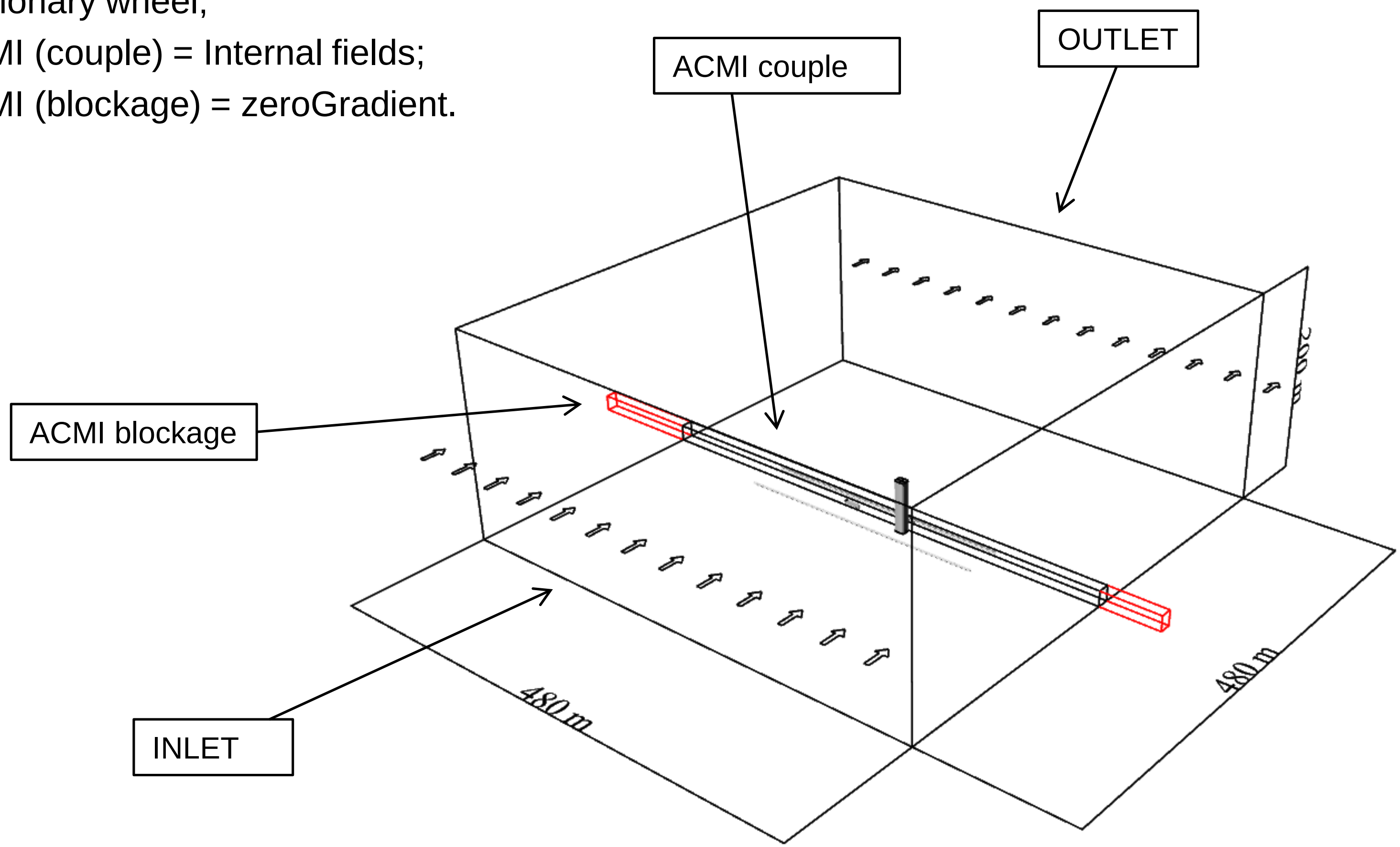




- Time variant incompressible RANS equations are solved;
- Time step = 0,0005 sec;
- Turbulence model k- ω SST;
- PIMPLE algorithm is used for coupling pressure and velocity.

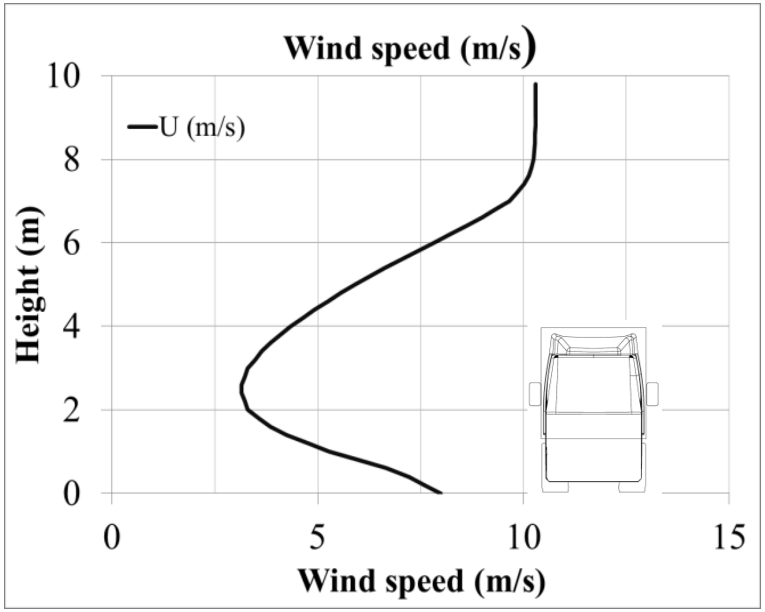
Boundary condition

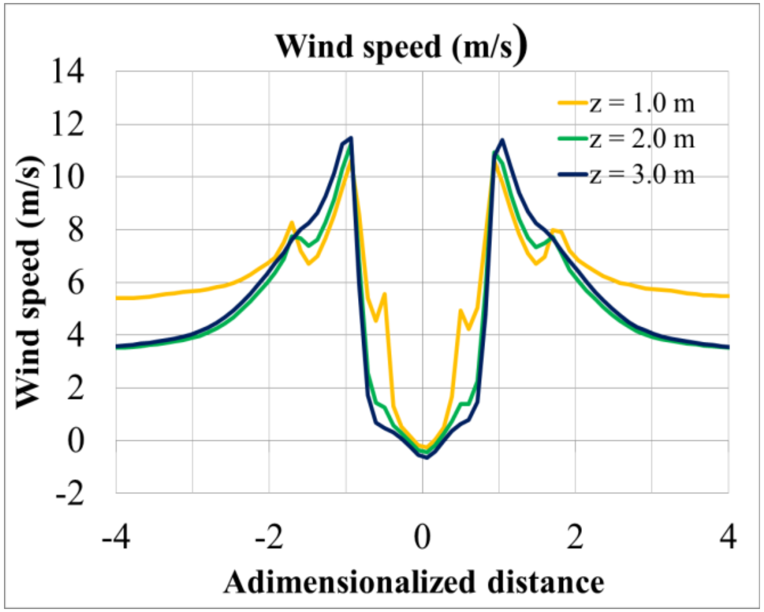
- V=10 m/s inlet
- Zero pressure is set up at the outlet and slip wall is used for top, bottom and lateral boundaries.
- Truck = movingWallVelocity;
- Pylon = fixedValue;
- Stationary wheel;
- ACMI (couple) = Internal fields;
- ACMI (blockage) = zeroGradient.

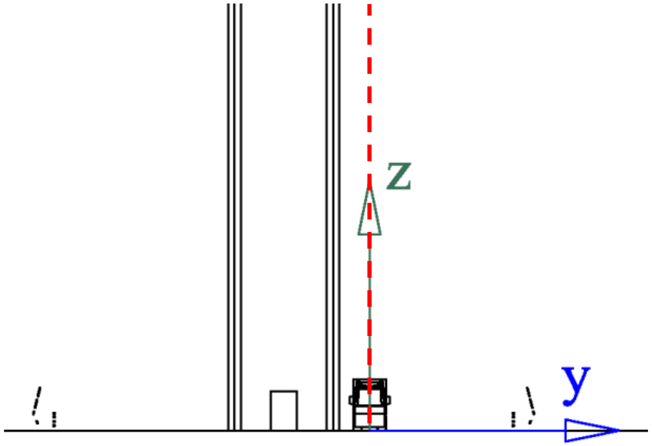


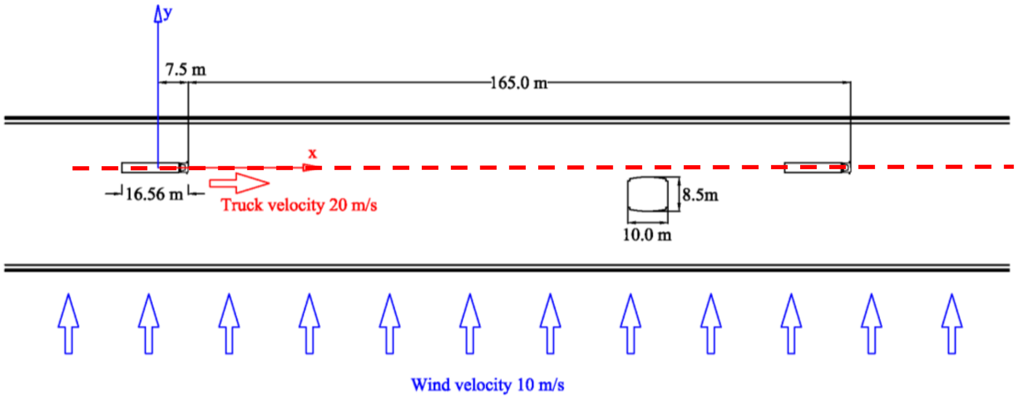
CFD results

Wind velocity: first lane downwind





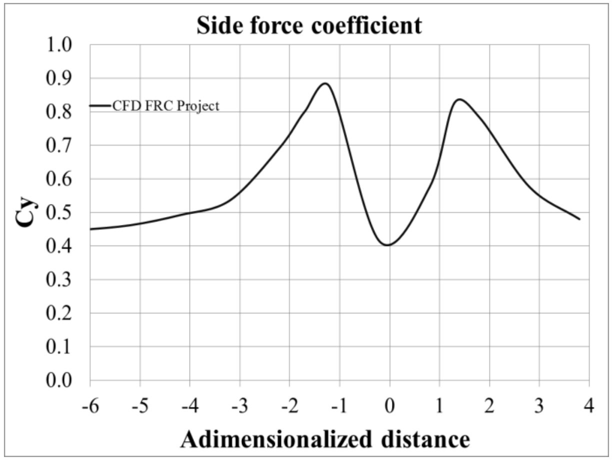


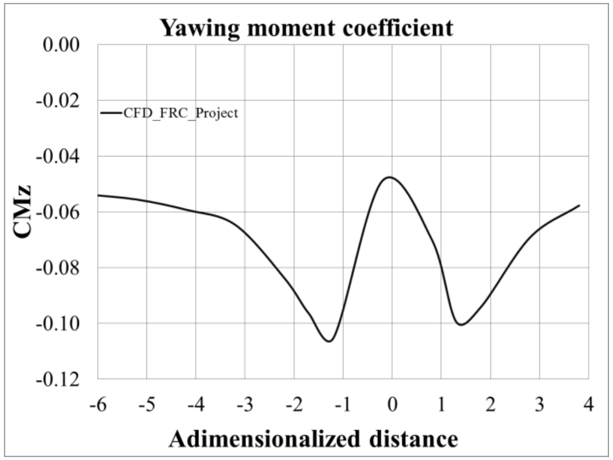


CFD results

Comparison between quasi-static approach and dynamic one: Forces acting on the vehicle

Quasi-static approach

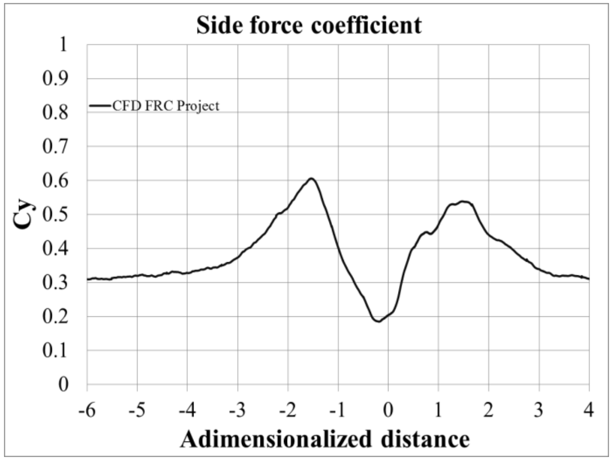


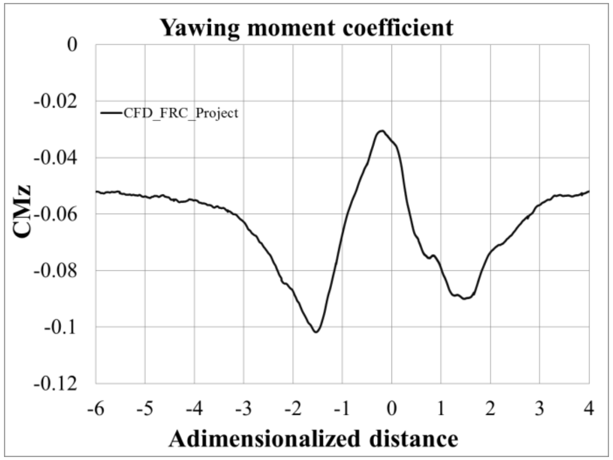


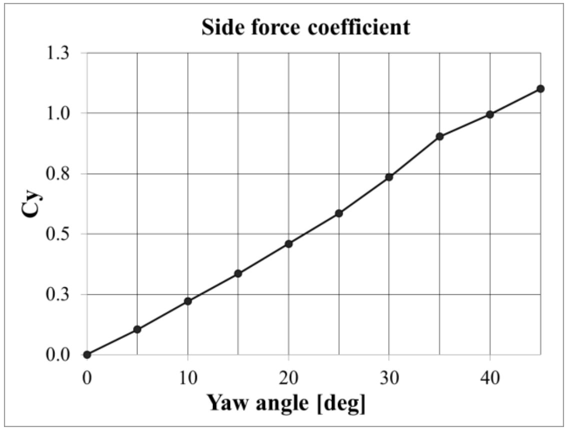
$$C_y = \frac{F_Y}{0,5*\rho*(U_V^2+U_W^2)*A_{lat}}$$

$$CM_Z = \frac{M_Z}{0,5*\rho*(U_V^2+U_W^2)*L*A_{lat}}$$

Dynamic approach







CFD results

Comparison between the CFD simulation and the wind tunnel test of Charuvisit et all.

CFD simulation

Scale 1:1

Wind speed 10 m/s

Vehicle speed 20 m/s

Yaw angle of 12°

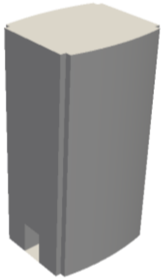
Charuvisit et all. experiment

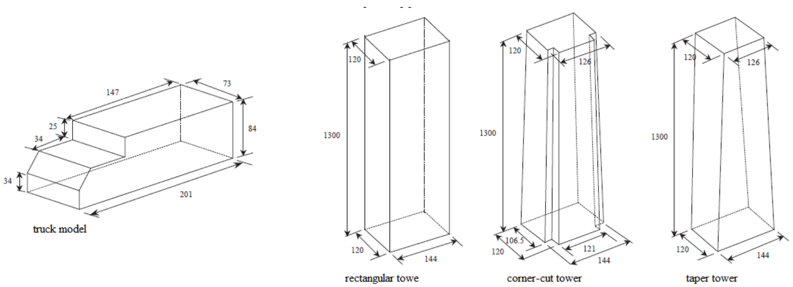
Scale 1:30

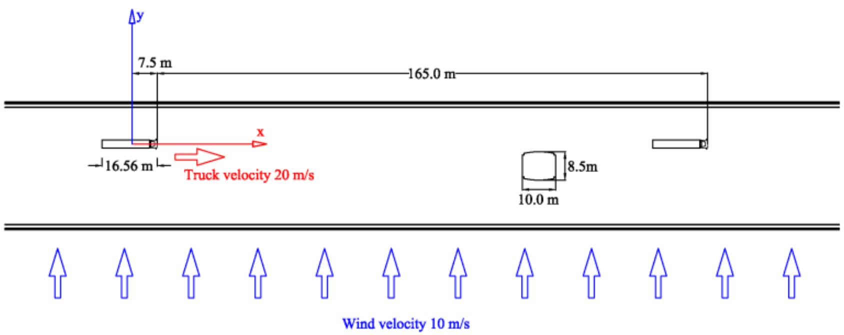
Wind speed 3.5, 5, 10 m/s

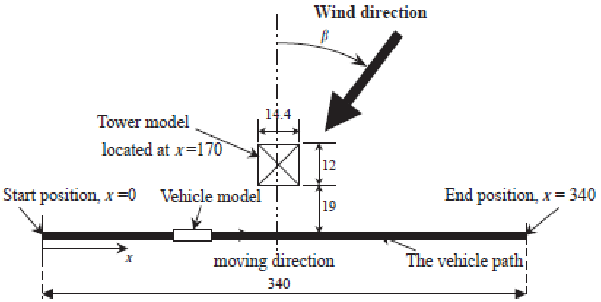
Vehicle speed 3 m/s

Yaw angle of 50°, 60° , 73°









CFD results

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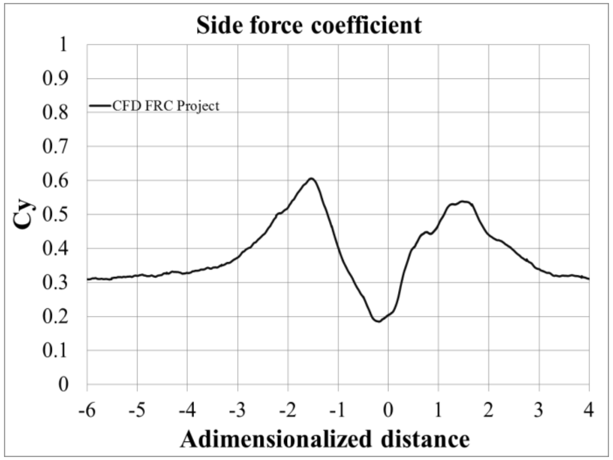
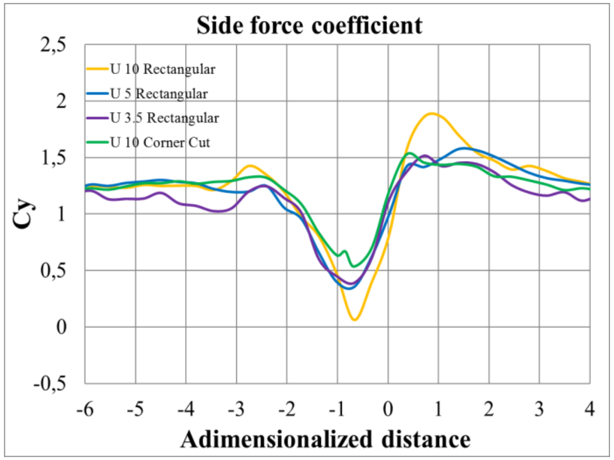
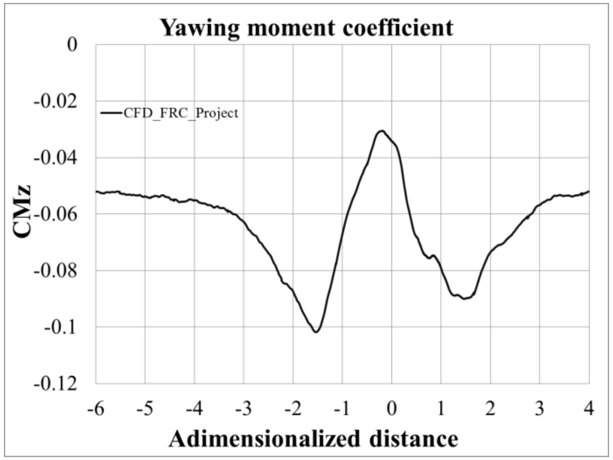
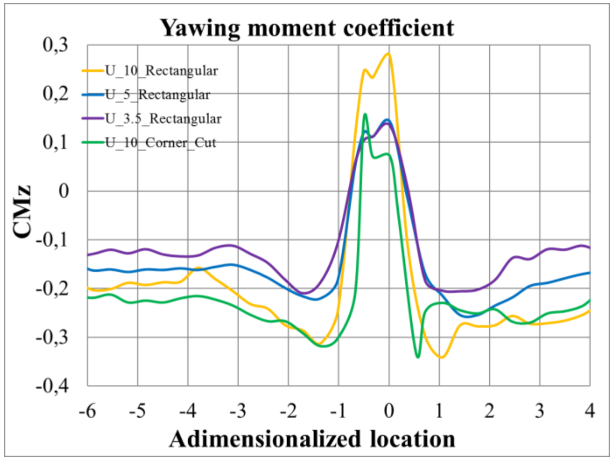
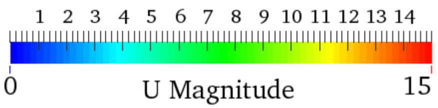








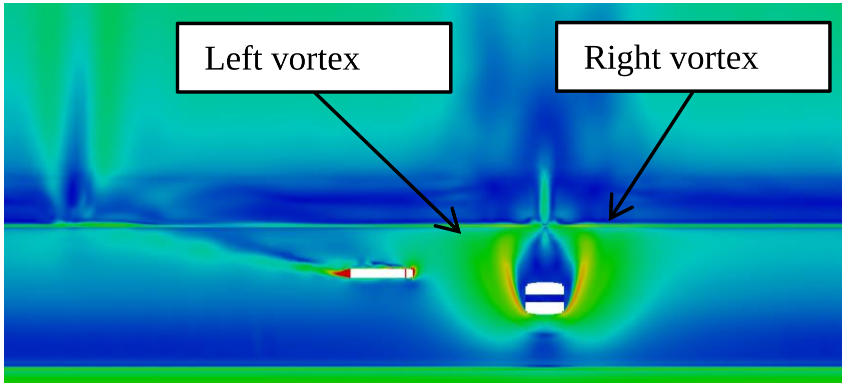
CFD results



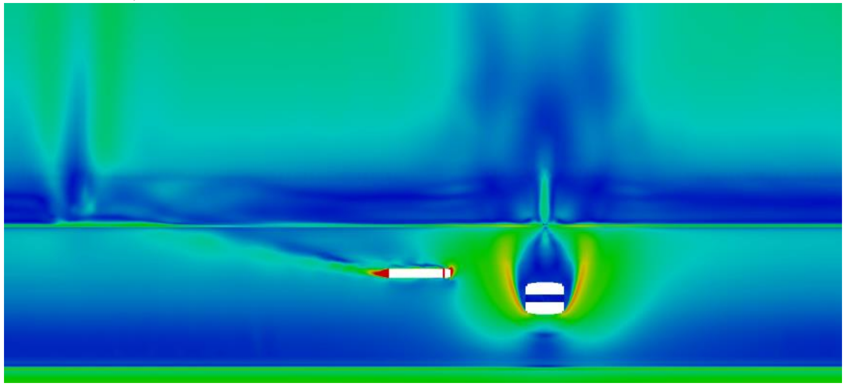
Flow field analysis during the overturning maneuver

Magnitude velocity at the plane z = 2.6 m

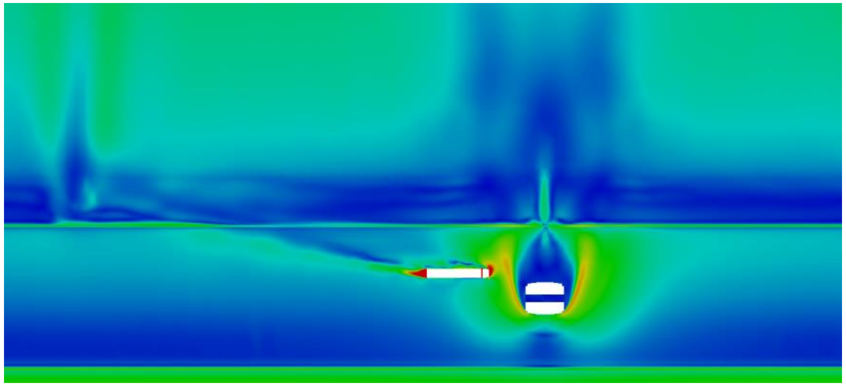
Time = 4 sec.



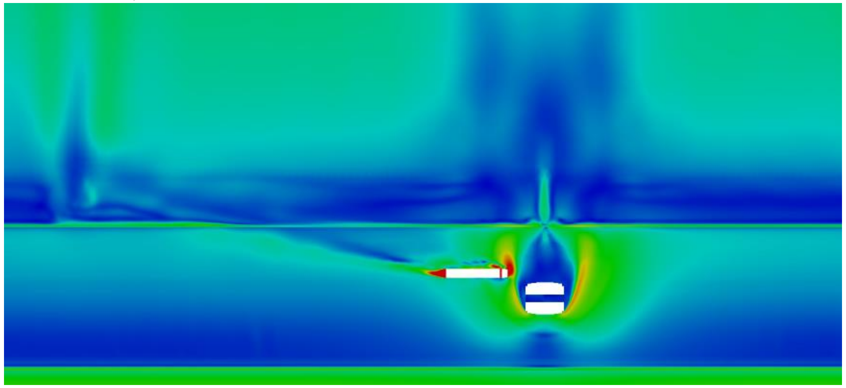
Time = 4,5 sec.



Time = 5 sec.

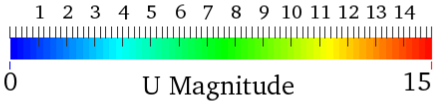


Time = 5,25 sec.



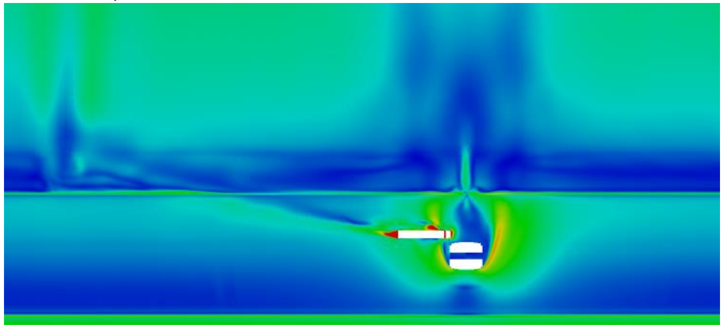
CFD results

Flow field analysis during the overturning maneuver

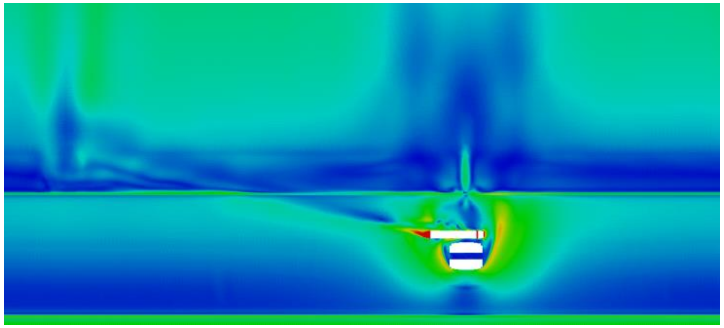


Magnitude velocity at the plane z = 2.6 m

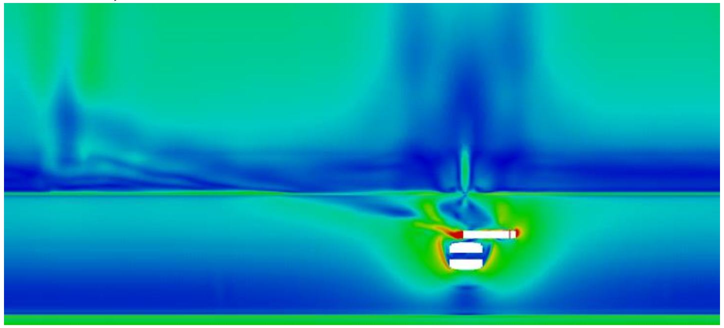
Time = 5,5 sec.



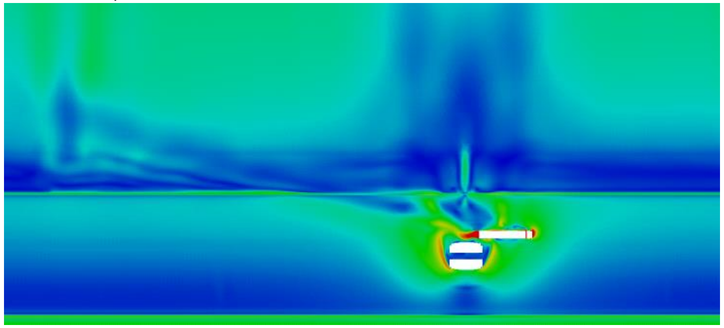
Time = 6 sec.



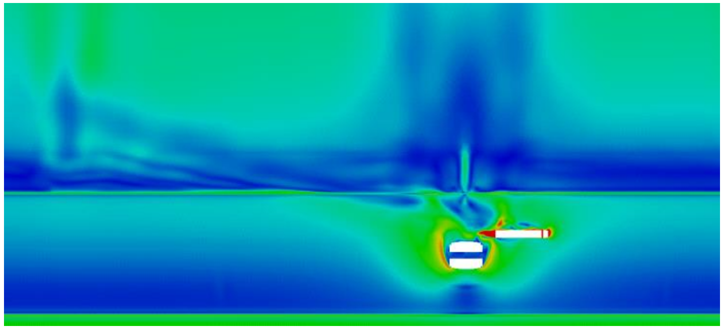
Time = 6,5 sec.



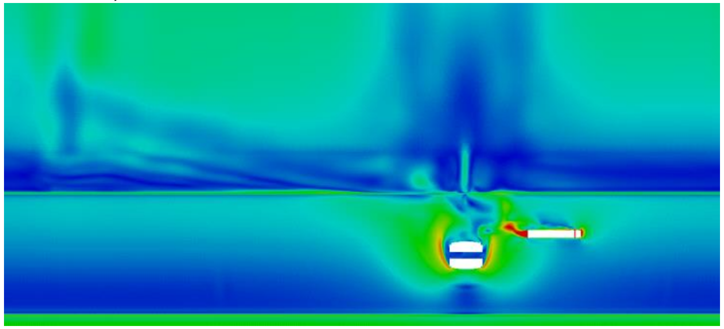
Time = 6,75 sec.



Time = 7 sec.



Time = 7,5 sec.



Conclusion

- The SolidBodyMotion + ACMI are capable to predict the aerodynamic forces acting on the vehicle during the overtaking maneuver compare to previous experimental results
- The quasi-static approach predict lower aerodynamic forces compare with the dynamic one;
- More precise numerical model as DES or LES can predict more turbulences an higher aerodynamic forces;
- A different moving strategy can be used to avoid the ACMI issue in the continuity .