Lateral wind effect on heavy truck approaching a bridge tower

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Content

- Introduction
- State of Art
- Case set-up
  - Target vehicle;
  - Overtaking maneuver;
  - Moving mesh strategy;
  - Numerical Model;
  - Boundary condition.
- Results
- Conclusion
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).
State of Art

Overtaking between vehicle

The K parameter is defined as the ratio between Vr and V where:
\[ V_r = \text{relative velocity between overtaking and overtaken vehicle [m/s]} \]
\[ V = \text{velocity of overtaken vehicle [m/s]} \]
\[ K = \frac{V_r}{V} \]

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

- Corin et al.(2008) – scale 1:1

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

State of Art

Overtaking an infrastructure

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

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

"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 previously 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°

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

Wind speed (m/s)

- Height (m)
- Wind speed (m/s)

Wind speed (m/s)

- Adimensionalized distance
- Wind speed (m/s)

- z = 1.0 m
- z = 2.0 m
- z = 3.0 m

Truck velocity 20 m/s

Wind velocity 10 m/s
Comparison between quasi-static approach and dynamic one: Forces acting on the vehicle

Quasi-static approach

\[ C_y = \frac{F_Y}{0.5 \rho (U_V^2 + U_W^2) A_{lat}} \]

\[ C_{Mz} = \frac{M_z}{0.5 \rho (U_V^2 + U_W^2) L A_{lat}} \]

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

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