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AERODYNAMIC INTERACTION OF TWO VEHICLES IN SELECTED DRIVE MODES

AERODYNAMICKÁ INTERAKCE DVOU VOZIDEL PŘI VYBRANÝCH REŽIMECH JÍZDY

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Summary: Numerical simulation of two vehicles aerodynamical interaction in selected drive modes in this paper will be described. aerdynamical intaraction of two vehicles in selected drive modes

Key words: simulation, vehicles, Navier-Stokes equation, FEM, velocity, flow

Anotace: Článek se zabývá možnostmi využití hybridních pohonů v pozemní dopravě.

Klíčová slova: simulace, vozidlo, Navier-Stokesova rovnice, MKP, rychlost, proudění

INTRODUCTION

Aerodynamic forces, moments and stability depend on weather conditions and also on passed vehicles. Interaction arises by vehicle tandem motion (overtaking and passing) and grows by drive through tunnel, especially if the tunnel has only one tube for both directions. Vehicles aerodynamic interaction numerical simulation of selected drive modes in this paper will be described.

1. THEORETICAL FUNDAMENTS

Navier – Stokes equation (vector differential equation) describes flow of incompressible Newton liquid. Formula expresses the force balance actuating to element of flowing liquid (with friction). Formula only in simple cases can be solved analytically. More complicated cases must be solved numerically.

In this chapter are generally described various possible technical solutions to the hybrid drive and established the basic reasons, why it is best to deal with this drive concept for the specific use of land transport vehicles.

Navier-Stokes equation:

$$\frac{\partial u_i}{\partial t} + u_j \cdot \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho} \cdot \frac{\partial p}{\partial x_i} + \nu \cdot \frac{\partial^2 u_i}{\partial x_j^2} + f \qquad (1)$$

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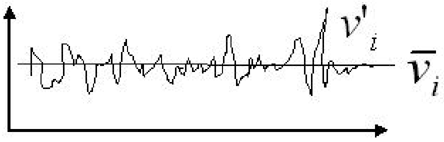
Navier-Stokes equations have universal validness, also for turbulent flow. For turbulent flow Navier-Stokes equations have only nostationary and aperiodic solutions. Direct solutions of Navier-Stokes equations for turbulent mode are extremely time-consuming. Usable models are based on simplified Navier-Stokes equations, where fluctuated instant velocity and pressure values are substituted by average values and real viscosity is substituted by turbulent viscosity (RANS-Reynolds Averaging Navier Stokes method).

- after averaging $u_i = \overline{u}_i + u_i'$



Averaged Navier-Stokes equation

$$\left(\frac{\partial \overline{u}_i}{\partial t} + \frac{\partial u_i'}{\partial t}\right) + \overline{u}_j \cdot \frac{\partial \overline{u}_i}{\partial x_j} + \overline{u}_j \cdot \frac{\partial u_i'}{\partial x_j} + u_j' \cdot \frac{\partial \overline{u}_i}{\partial x_j} + u_j' \cdot \frac{\partial u_i'}{\partial x_j} = -\frac{1}{\rho} \cdot \left(\frac{\partial \overline{p}}{\partial x_i} + \frac{\partial p'}{\partial x_i}\right) + \nu \cdot \left(\frac{\partial^2 \overline{u}_i}{\partial x_j^2} + \frac{\partial^2 u_i'}{\partial x_j^2}\right) + f$$

$$\frac{\partial \overline{u}_i}{\partial t} + \frac{\partial \left(\overline{u}_i \cdot \overline{u}_j\right)}{\partial x_j} + \frac{\partial \left(\overline{u_i' \cdot u_j'}\right)}{\partial x_j} = -\frac{1}{\rho} \cdot \frac{\partial \overline{p}}{\partial x_i} + \nu \cdot \frac{\partial^2 \overline{u}_i}{\partial x_j^2} + f$$

Boussinesq hypothesis

$$-\overline{u_i' \cdot u_j'} = \nu_t \cdot \left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i}\right) - \frac{2}{3} \cdot k \cdot \delta_{ij}$$

K - *ε* model of two equations was created by Jones and Laudner (1972) and elaborated by Laudner and Spalding (1974). This model of isotropic turbulence is standard for RANS numerical applications today. Isotropic coefficient of turbulent viscosity *K* comes from calculation of dynamic parameters – isotropic kinetic turbulent energy k (=½ $u_i\, u_i$ = ½ τ_{ii}) and dissipation of turbulent energy *ε*.

K - *ε* model in predeclared form is valid for flow in homogenous area (great Re) with full turbulence possibility.

Turbulent viscosity ν_t for *k* - *ε* model:

$$\nu_t = C_\mu \cdot \frac{k^2}{\varepsilon} \qquad \text{where: } \varepsilon = 2 \cdot \nu \cdot \frac{\partial \overline{u}_i}{\partial x_j} \cdot \frac{\partial \overline{u}_j}{\partial x_i}\,,\ k = \frac{1}{2} \cdot \overline{u_i \cdot u_i}$$

2. SIMULATION OF VEHICLE PASSING

Now, we are concerned to the two situations.

- Tandem motion, passing - double flow route, velocity 25 $m.s^{-1}$
- Tandem motion, overtaking – four lane route, velocity of overtaker 25 $m.s^{-1}$, velocity of overtaken 20 $m.s^{-1}$

CFD – Computational Fluid Dynamics software for the simulation of both situations has been used. The mesh for FEM was created in Ansys Gambit software, calculations and simulations was proceeded in Ansys Fluent 6.3.26 software.

2.1 Pre-processing

The mesh set, created in Gambit software, consists of two main domains, which are moving in opposite direction (*sliding mesh*). The basic elements are *squads* and mesh type is *pave*.

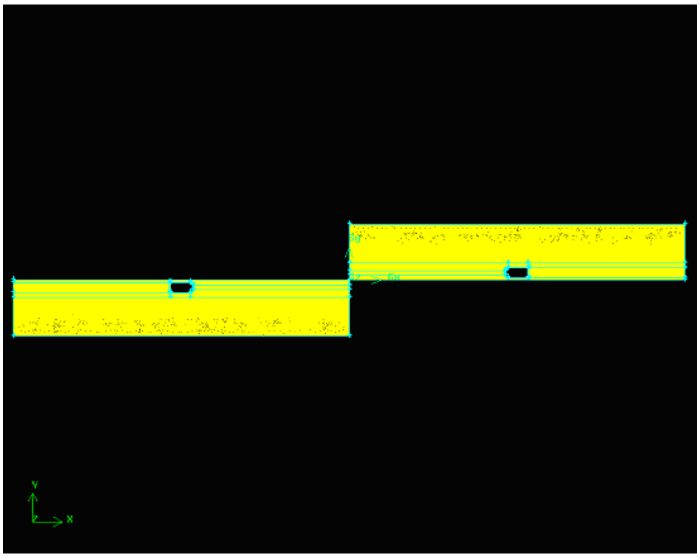


Fig. 1 - Mesh in Gambit software

Simplified vehicles models correspond with Skoda Fabia II dimensions. The model has length 4000 units and width 1650 units. Body shape matches Ahmed Body. The Gambit software has problems with creation of meshes with complicated geometry. Domain was decomposed to the few smaller domains due this reason, with rectangular geometry.

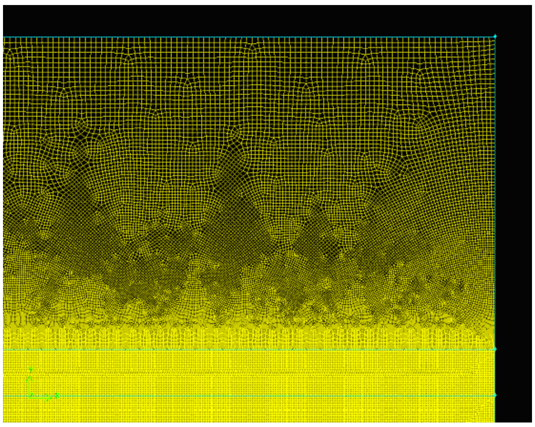


Fig. 2 - Mesh – „Growth rate“

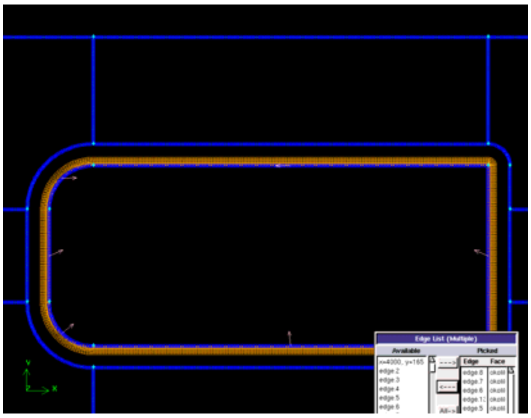


Fig. 3 - Mesh – „Boundary Layer“

2.2 Processing and post-processing

Because of the Gambit software cannot accept linear measures, corresponding scale factor in Fluent software must be set. The domain has length 120 meters and width 20 meters. The whole domain consists of two subdomains, which are in motion.

2.2.1 Evaluation of mode "Tandem motion, passing"

When are two vehicles passing, the vehicle faces are in one line, x/L = 1, aerodynamic drag coefficient c_d is falling down and lateral force hardly rises. Both vehicles pushing the pressure field, which take effect to the vehicles (grow of lateral force).

When are two vehicles alongside, x/L = O, aerodynamic drag coefficient c_d is minimal and comes rising. The lateral force is falling down and comes to zero.

When the vehicle body tails are in one line, x/L = -1, aerodynamic drag coefficient c_d is maximal and comes to standard level. The lateral force is growing to negative values and lateral force oscillates because of turbulence separation. The wakes are in interaction. Both wakes are in wave motion and aerodynamic characteristics oscillate.

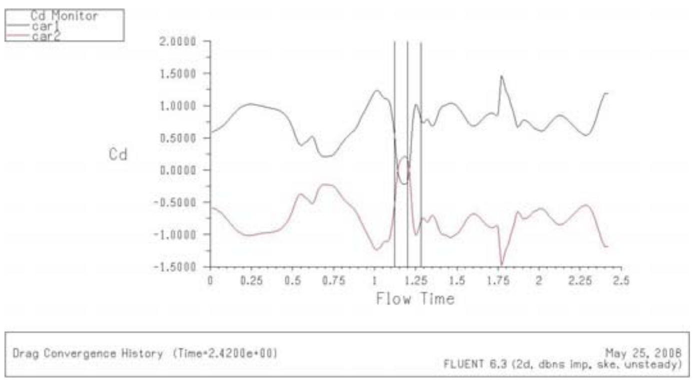


Fig. 4 - Tandem motion, passing - aerodynamic drag coefficient

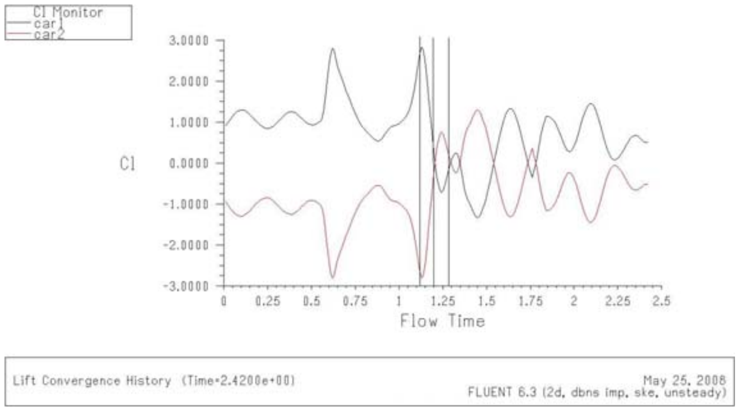


Fig. 5 - Tandem motion, passing – lateral force

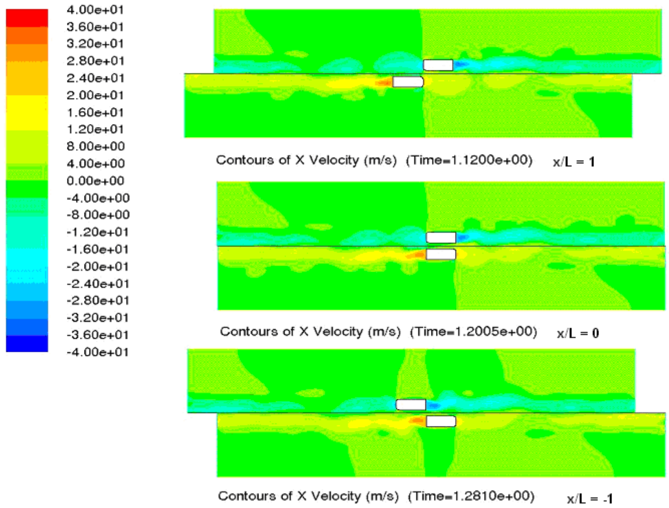


Fig. 6 - Position x/L = 1, 0, -1 passing

2.2.2 Evaluation of mode "Tandem motion, overtaking"

When are two vehicles overtaking, the vehicle *car1* body tail and vehicle *car2* face are in one line, x/L = 1, aerodynamic drag coefficients of both vehicles c_d rise, especially for *car1* and is maximal. Lateral force of the *car1* hardly rises and of the *car2* falls down.

When are two vehicles alongside, x/L = O, aerodynamic drag coefficient c_d is minimal and has the same level for both vehicles. The lateral force is falling down for both vehicles.

When the, the vehicle *car1* face and vehicle *car2* body tail are in one line, x/L = -1, aerodynamic drag coefficient c_d is falling down and is minimal for both vehicles and oscillates. Lateral force of the *car1* rises because of *car2* wake and consequently falls to normal level. Lateral force of the *car2* rises, comes to normal level and oscillates. Aerodynamic characteristics oscillate.

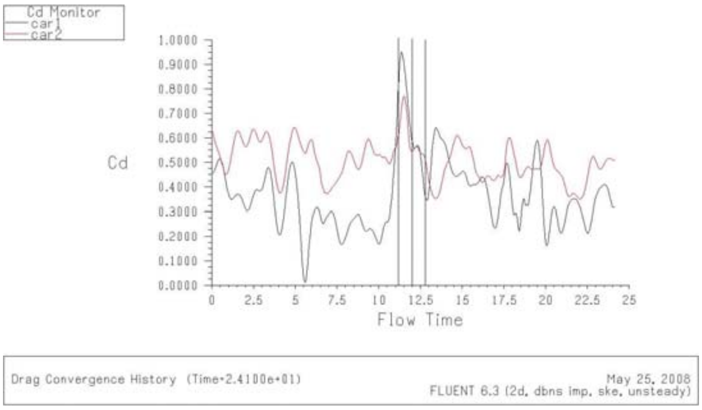


Fig. 7 - Tandem motion, overtaking - aerodynamic drag coefficient

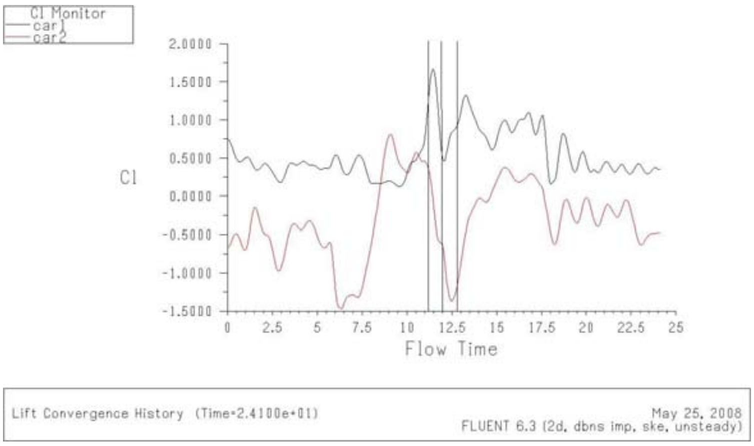


Fig. 8 - Tandem motion, overtaking – lateral force

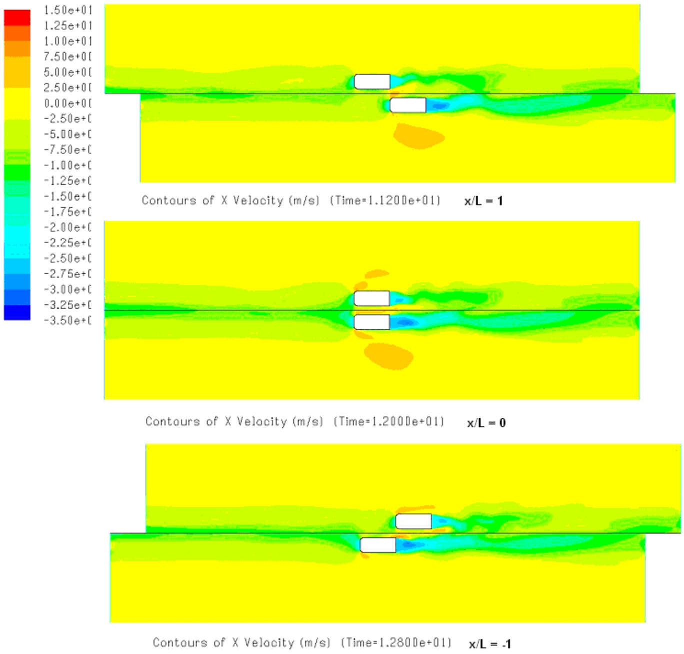


Fig. 9 - Position x/L = 1, 0, -1, overtaking

3. CONCLUSION

Vehicles aerodynamic interaction numerical simulation of selected drive modes in this paper has been described. Two situations by Fluent software have been simulated, at first tandem motion of vehicles (passing), at second tandem motion of vehicles (overtaking). Simulated results have influence to yawing moment and every driver time to time in common life must during overtaking revise the direct course. These simulations can be used to improve the vehicle aerodynamic design towards the better transport safety.

LITERATURE

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