COMPUTERISED ANALYSIS OF THE AIR RESISTANCE FOR A FORWARD MOVING VEHICLE

ANDREI ANDRAS[1], FLORIN DUMITRU POPESCU[2], ILDIKO BRÎNAŞ[3]

Abstract: The movement of a vehicle is determined by the use of the energy transmitted to the wheels, from the engine through the chain: gearbox - differential. Traction force, resistance forces and inertial forces determine the character of the vehicle's movement. In this paper, I approached the study of air resistance to the forward movement of a vehicle using the calculation technique. In this sense, we used the SOLIDWORKS® application with the help of which, using the model of a truck, we studied its aerodynamic behaviour in a virtual tunnel. We considered that a frontal air flow with a speed of 25 m/s (90 km/h) acts on the vehicle. The variation of the air speed in the direction of travel of the vehicle was determined. The obtained results were presented in the form of flow trajectories and in the form of sections corresponding to the reference planes. We also determined the variation of vorticity, as a quantity specific to fluid mechanics in order to highlight the intensity of circulation or the speed of air rotation, from the rear area of the vehicle.

Key words: Modelling, simulation, speed, force, vorticity.

1. AIR RESISTANCE TO THE FORWARD MOVEMENT OF VEHICLES

Air resistance F_a, is a force parallel to the road surface that acts on the vehicle in the opposite direction of its movement and is applied at a point located in the longitudinal plane of symmetry at a height h_a above the road (figure 1), called the frontal centre of pressure.

Vehicle aerodynamics studies the phenomena that occurs during the interaction between the vehicle and the surrounding air and uses the general principles of theoretical aerodynamics, limited only to the principles and analogies necessary to explain the propulsion process and the stability of the vehicle, related to the presence

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of air in relative motion. Establishing the parameters from the relationships used to calculate the air resistance and aerodynamic stability of the vehicle, as well as the study and choice of its optimal forms are done experimentally, in wind tunnels.

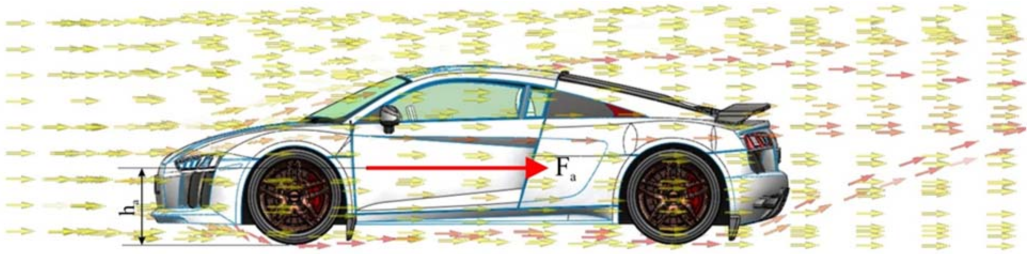

Fig.1 The action of air resistance

According to the theory of flow, if a solid moves in the air with translation speed v on the surface element of the surface $\mathrm{d}\Sigma$ of the solid, an elementary force $\mathrm{d}F_a$ given by the formula will act:

$$\mathrm{d}\vec{F}_a = \left(\vec{p}_0 - \vec{\tau}_0\right) \cdot \mathrm{d}A \tag{1}$$

where:

$\vec{p}_0$ is the normal unit effort vector;

$\vec{\tau}_0$ is the tangential unit effort vector;

$\mathrm{d}A$ is the area of the element $\mathrm{d}\Sigma$.

This system of elementary forces is reduced in relation to a fixed point in relation to the solid to a resultant force F_a and a resultant moment M_a given by the formulae:

$$\begin{aligned} \vec{F}_a &= \int_\Sigma \left(\vec{p}_0 - \vec{\tau}_0\right) \cdot \mathrm{d}A \\ \vec{M}_a &= \int_\Sigma \vec{r} \times \left(\vec{p}_0 - \vec{\tau}_0\right) \cdot \mathrm{d}A \end{aligned} \tag{2}$$

where:

$\vec{r}$ is the position vector of a current point on the surface.

From fluid mechanics it is known that the resistance force exerted by the air on a body is proportional to the air density ρ, to the frontal surface A corresponding to the body and to the square of the displacement speed v_a, as follows:

$$F_a = \frac{1}{2} \cdot \rho \cdot c \cdot A \cdot v_a^2 \tag{3}$$

The aerodynamic forces and moments acting on the vehicle with respect to a reference system (X, Y, Z) whose origin is on the roadway, halfway between the axles, as shown in figure 2.

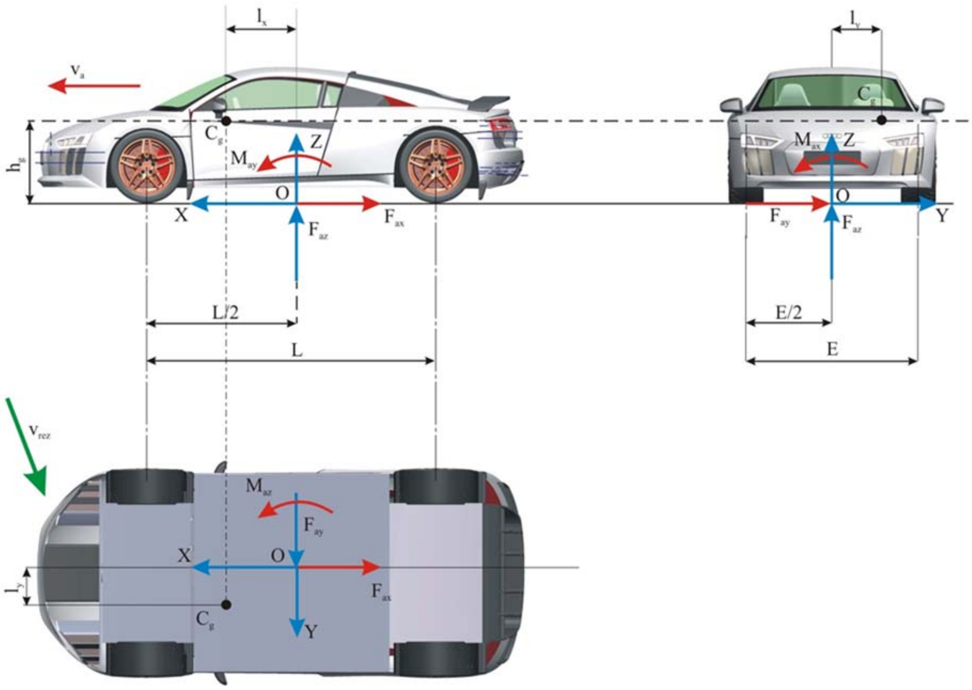

Fig.2 Aerodynamic forces and moments acting on the vehicle

From this figure it can be seen that the following aerodynamic forces act on the vehicle:

- air resistance in the direction of travel:

$$F_{ax} = \frac{1}{2} \cdot \rho \cdot c_x \cdot A \cdot v_a^2 \tag{4}$$

- lateral aerodynamic force:

$$F_{ay} = \frac{1}{2} \cdot \rho \cdot c_y \cdot A \cdot v_a^2 \tag{5}$$

- ascending or lifting force:

$$F_{az} = \frac{1}{2} \cdot \rho \cdot c_z \cdot A \cdot v_a^2 \tag{6}$$

where c_x, c_y and c_z are the air resistance coefficients in the X (moving direction), Y (lateral) and Z (bearing) directions, respectively.

If we reduce these forces at a certain point, three aerodynamic moments arise which are generated by normal pressures and specific frictional forces:

- the aerodynamic moment around the longitudinal axis or the aerodynamic roll moment:

$$M_{ay} = \frac{1}{2} \cdot \rho \cdot c_{my} \cdot A \cdot L \cdot v_a^2 \tag{7}$$

- the aerodynamic moment around the transverse axis or the aerodynamic pitch moment:

$$M_{ax} = \frac{1}{2} \cdot \rho \cdot c_{mx} \cdot A \cdot L \cdot v_a^2 \tag{8}$$

- the aerodynamic moment around the vertical axis or the aerodynamic turning moment:

$$M_{az} = \frac{1}{2} \cdot \rho \cdot c_{mz} \cdot A \cdot L \cdot v_a^2 \tag{9}$$

where: c_{mx} is the rolling moment coefficient, c_{my} is the pitching moment coefficient and c_{mz} is the gyration moment coefficient.

The impact speed of the air v_{rez} is the result of combining the speed of the vehicle with the wind speed v_v, as shown in figure 3:

$$\vec{v}_{rez} = \vec{v}_a + \vec{v}_v \tag{10}$$

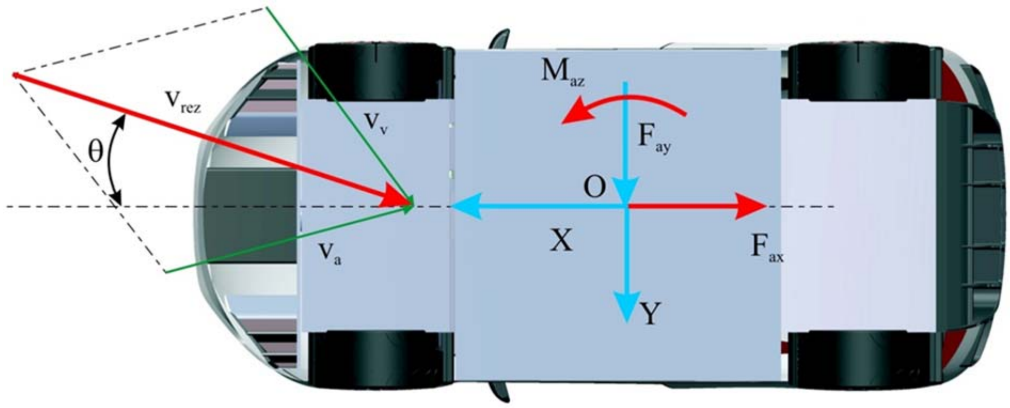

Fig.3 Impact speed of the air

The angle between the v_{rez} impact speed and the longitudinal axis of the vehicle is denoted by θ and is called the angle of incidence. The direction of the impact speed relative to the longitudinal axis of the vehicle depends on the direction of the wind and its direction of travel. Three special cases are usually considered in the calculations:

– the wind prevails from the front, respectively from the back, and θ=0 so that:

$$\vec{v}_{rez} = \vec{v}_a \pm \vec{v}_v \tag{11}$$

In this case, the power required to move the vehicle will increase or decrease depending on the direction of wind speed;

– the wind blows perpendicular to the longitudinal axis of the vehicle:

$$v_{rez} = \sqrt{v_a^2 + v_v^2} = \sqrt{1 + \left(\frac{v_v}{v_a}\right)^2} \tag{12}$$

where:

$$\mathrm{tg}(\theta) = \frac{v_v}{v_a} \tag{13}$$

– the wind speed is equal to zero:

$$v_{rez} = v_a \tag{14}$$

Figure 4 shows the variation of the v_{rez} impact speed and the angle of incidence θ, depending on the travel speed for different wind speeds v_v for the case when the wind speed is perpendicular to the vehicle travel speed. If the travel speed range between 0 and 10 m/s (0 and 36 km/h) is neglected (area in which the impact speed action on the vehicle is not too high), then the impact speed v_{rez} can be consider equal to the vehicle's speed of travel. It is also observed that at the normal travel speed between 20 and 30 m/s (72 and 108 km/h) the angle of incidence θ is between 5° and 20°, so in the calculations this angle can also be neglected.

Air density depends on air pressure and temperature. Thus, for 1 kg of air there is the formula:

$$\rho = \frac{p}{R \cdot T} \tag{15}$$

where:

- p - is the atmospheric pressure, N/m^2;
- T - is the absolute temperature, °K;
- R - is a characteristic constant for air, R = 29,27.

Under standard conditions (p_o=760 mmHg; t= 15°C; ρ=1,226 kg/m^3).

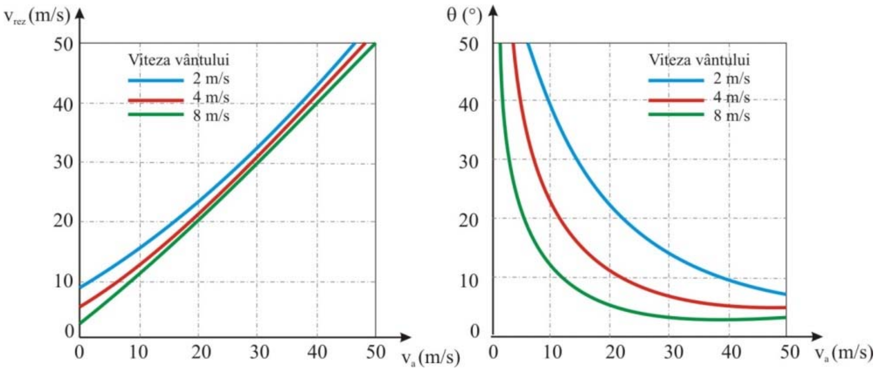

Fig.4 Impact speed and angle of incidence as a function of travel speed for different wind speeds

2. STUDY OF AIR RESISTANCE THROUGH NUMERICAL METHODS

2.1. The study model

To model the air resistance when a vehicle moves forward, we used the SOLIDWORKS® application, calling on the Flow Simulation menu. The study was carried out using the model in figure 5. From the point of view of the SOLIDWORKS® application, it is a part.

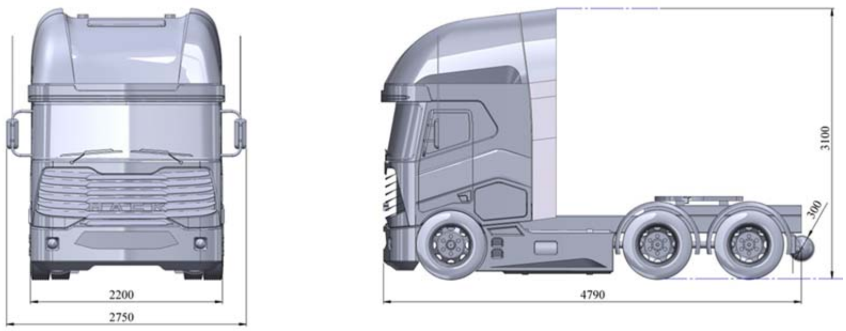

Fig.5 The model under analysis

2.2 Numerical analysis of air resistance

As can be seen in figure 6, the type of analysis is external, excluding both cavities without flow and internal spaces, the reference axis being Z.

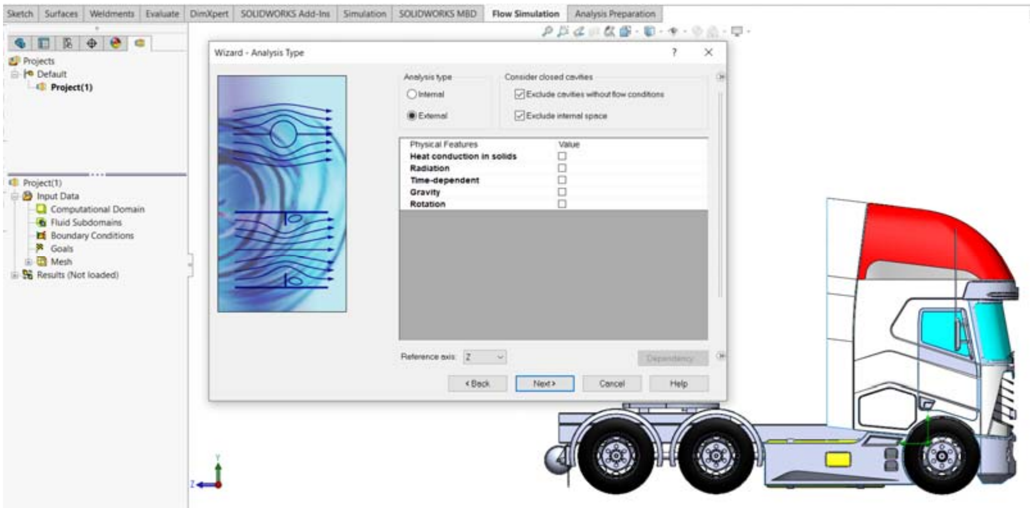

Fig.6 Establishing the type of analysis

Figure 7 contains information related to the type of fluid considered (in our case air), its flow being considered laminar and turbulent.

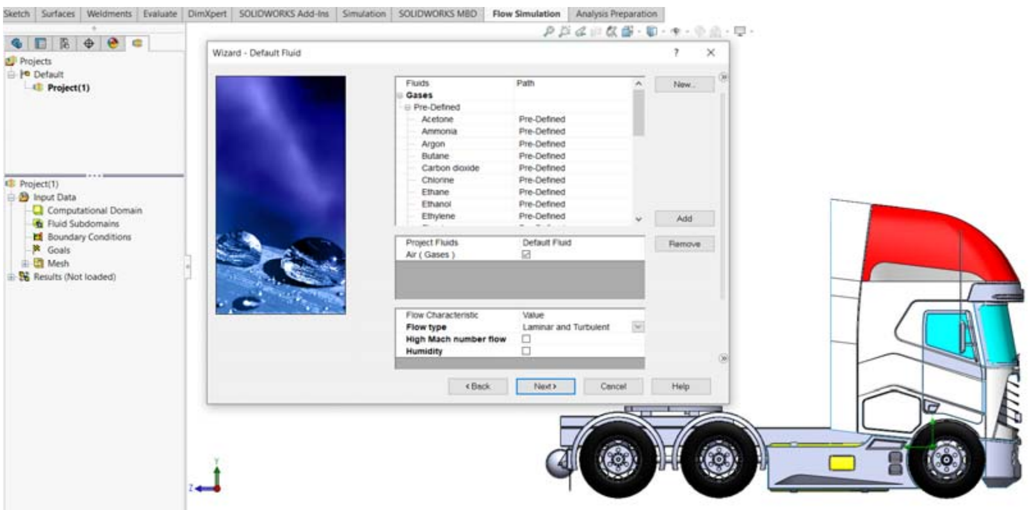

Fig.7 Establishing the type of fluid and the type of flow

We considered the vehicle to be moving at a speed of 90 km/h (25 m/s) along the Z axis (figure 8).

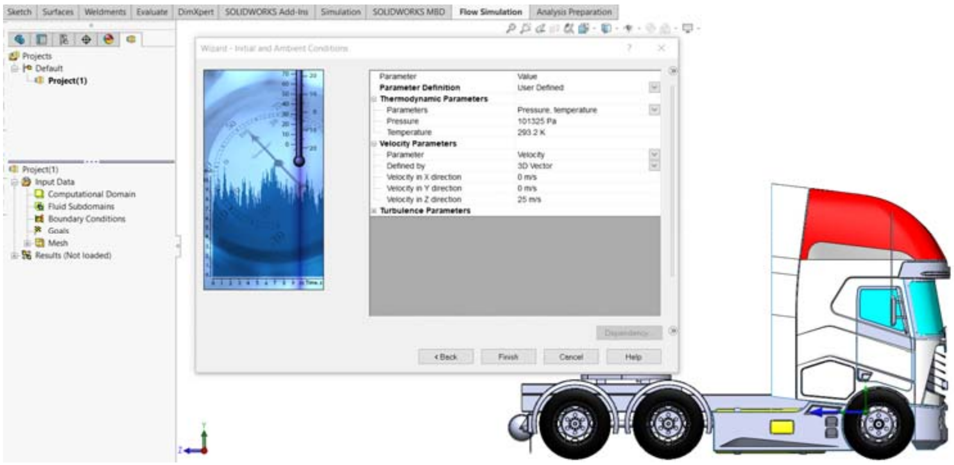

Fig.8 Establishing the speed of the vehicle

Figure 9 shows the volume of the domain for which the simulation was performed. It will be sectioned by planes, parallel to the basic ones (frontal, side and top) in order to highlight the variation of relative air speed.

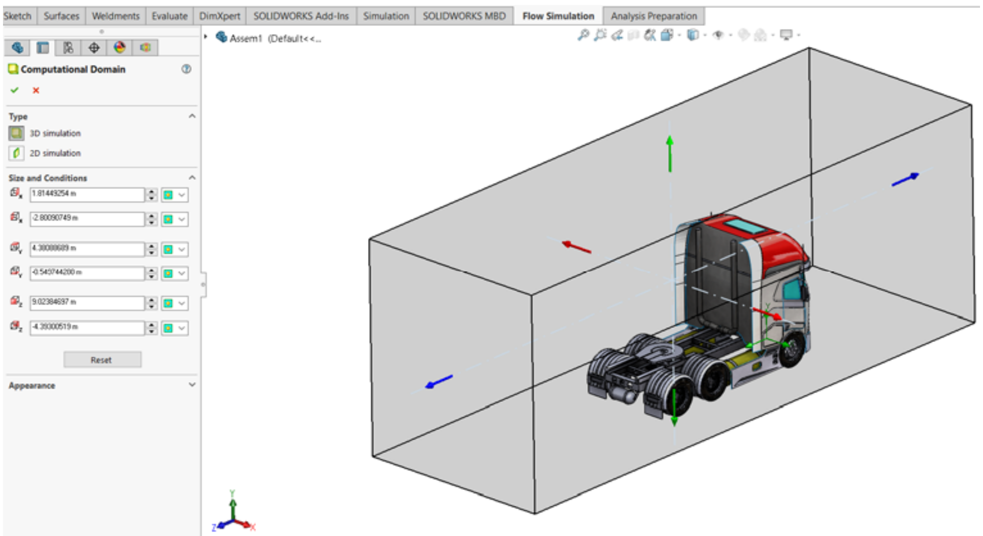

Fig.9 The volume of the domain for which the simulation was performed

After performing the calculations related to the air resistance simulation, we obtained the results that are presented in graphic form in figures 10-14. They represent the variation of relative air speed in the form of flow trajectories and in the form of a section.

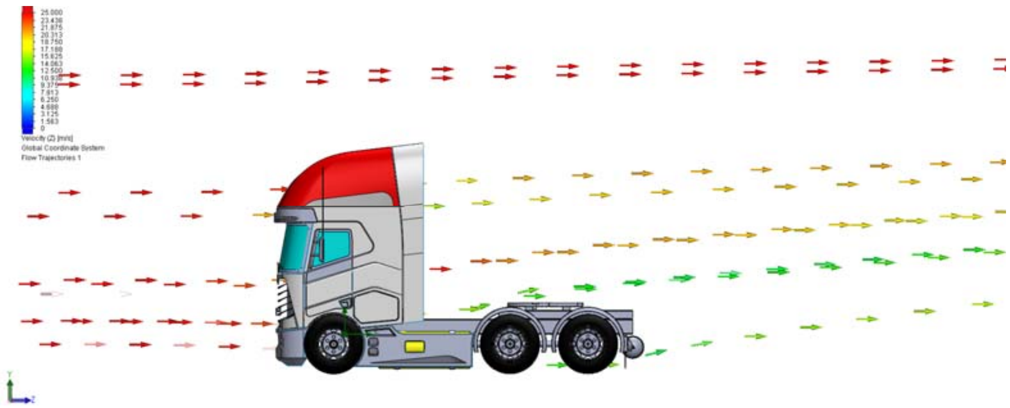

Fig.10 Variation of the relative air velocity in the Z direction (flow trajectories) in the lateral plane

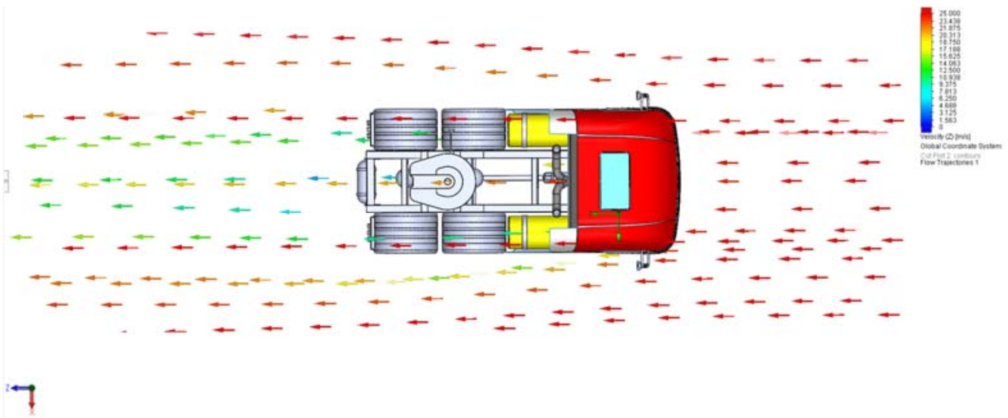

Fig.11 Variation of the relative air speed in the Z direction (flow trajectories) in the upper plane

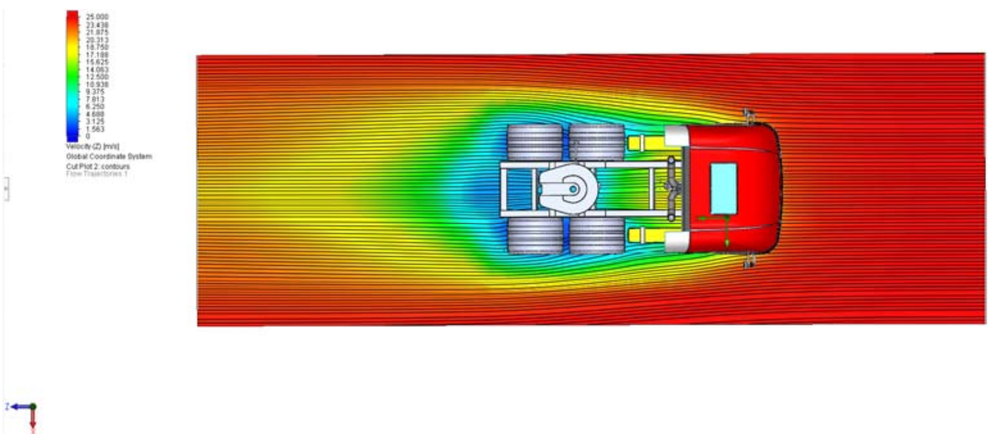

Fig.12 The variation of the relative air speed in the Z direction (in section, with flow lines highlighted) in the upper plane

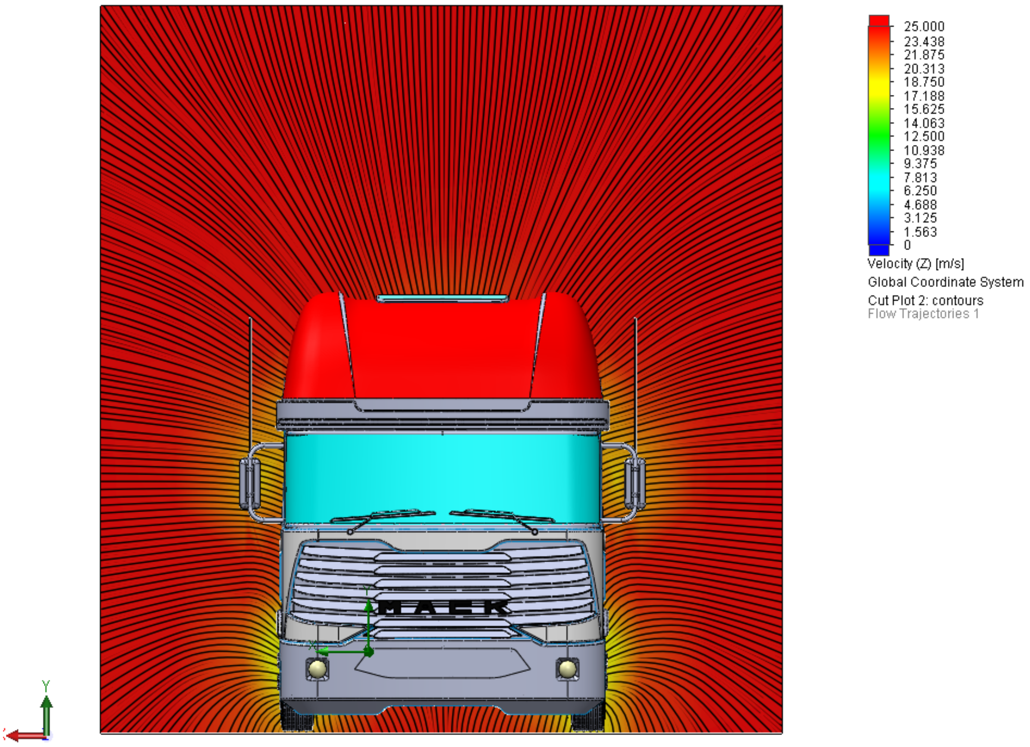

Fig.13 The variation of the relative air speed in the Z direction (in section, with flow lines highlighted) in the frontal plane

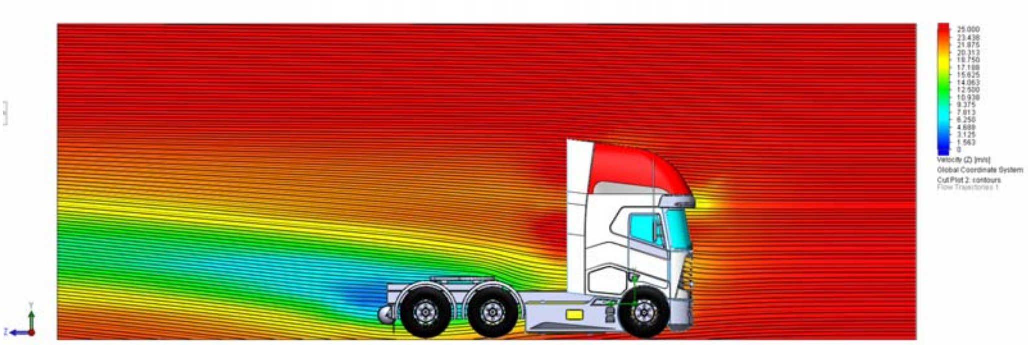

Fig.14 The variation of the relative air speed in the Z direction (in section, with flow lines highlighted) in the lateral plane

In figure 15, we presented the vorticity, as a quantity specific to fluid mechanics in order to highlight the intensity of circulation or the speed of air rotation, from the rear area of the vehicle.

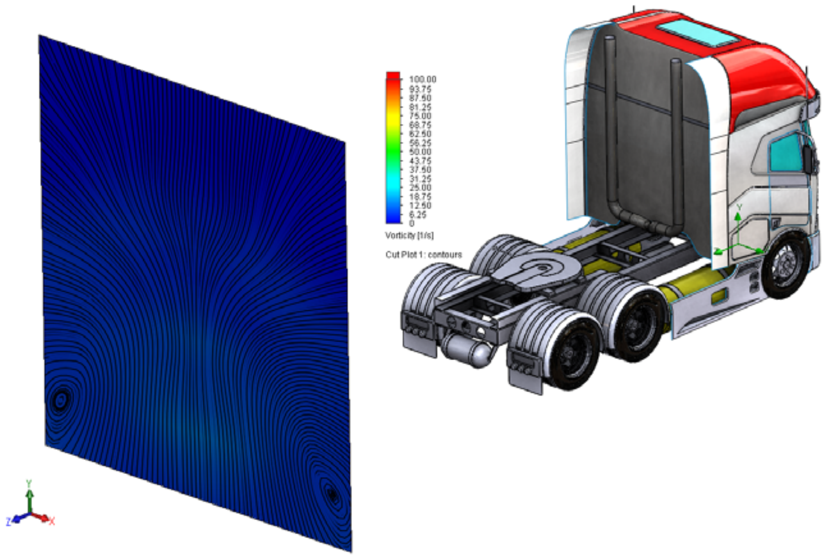

Fig.15 Vorticity at the limit of the calculation domain

CONCLUSIONS

We performed the study of air resistance when a vehicle moves forward using numerical methods with the help of SOLIDWORKS (Flow Simulation). For this, we created a virtual wind tunnel in which the vehicle is stationary, with the air acting on it frontally at a speed of 90 km/h (25 m/s). We opted for an external simulation, for which the volume of the analysed domain represents the volume of the wind tunnel. The external flows take place around the bodies and differ from the internal flows known as channel flows, in that the space, theoretically boundless, must be limited to a domain, which must have a linear dimension several times larger than the body. The variation of the air speed in the direction of travel of the vehicle was determined. The obtained results were presented both in the form of flow trajectories and in the form of sections corresponding to the reference planes. We also determined the variation of vorticity, as a quantity specific to fluid mechanics in order to highlight the intensity of circulation or the speed of air rotation, from the rear area of the vehicle. Both for speed and for vorticity, the variation diagrams obtained are consistent with those presented in specialized manuals.

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