Study on the aerodynamic force which acts in the case of a train type multiple unit electric

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Abstract. This paper seeks to analyse the values of the aerodynamic resistance forces occurring during the movement of a train type multiple unit electric while are running in Romania. Taking into account what has been said so far in the literature, regarding the fact that the aerodynamic forces acting on the vehicles are directly proportional to the square of the traveling speed, it is intended to estimate the values of these forces in the case of the proposed train for analysis. An exact determination is difficult to achieve and requires very high costs in terms of both the measuring equipment and the actual realization of the experiment. To avoid this, we will opt for a numerical analysis of aerodynamic force measurements. In this regard, the geometric shape of the train will be first modelled and then inserted into an airflow simulation program.

1. Introduction
Increasing the travel speeds of railway vehicles (trains) implies, among other things, the problem of studying the phenomena and forces generated by air friction. Practically, this friction between the surrounding air and the vehicle is transposed to the rolling stock as the aerodynamic force acting during its travel.

Obtaining high aerodynamic forces during travel will directly lead to a significant increase in the energy consumption required for this process [1-3]. This consumption will further have implications on the efficiency of the transport system as a whole.

Another aspect that needs to be considered, once with increasing travel speeds, is the level of noise produced and the degree to which it influences the environment [4].

A few studies [4-12] have pointed out that the aerodynamic performance of a train (both classic and one high-speed), are closely related to the constructive form thereof, and the environment in which they move.

In order to highlight these aspects, a number of constructive elements can be identified which have a particular importance in studying aerodynamic performances, such as: the length of the front part of the train (the nose of the train), the rolling equipment area, the passage from one vehicle to the other, the arrangement of the equipment on the vehicle body.

Regarding the environment in which the movement is carried out, three frequently analysed situations are identified in the literature. A first situation is when the train movement is carried out under normal atmospheric conditions. A second situation is when the railway vehicles are moving in
an atmosphere in which gusts of wind blow. And in the third situation regarding the environment in which the displacement it is when then the vehicles are circulating in the tunnel.

This paper aims at analysing the variation in the values of the aerodynamic forces occurring during the movement of a multiple train-type electric unit (EMU) that is used in Romania and which circulates under normal atmospheric conditions.

2. Theoretical aspects of aerodynamic forces

Regardless of the type of train and its shape, the resistances to moving of them are determined by the frictional forces occurring while traveling on the tread of rail. These frictions can be both mechanical and airborne.

At present, it is well known that the sum of the resistance depends on the speed of the vehicles. More precisely with the square of this speed.

The one who first envisioned and presented a mathematical formula for determining the variation values mode of the resistances to moving, taking into account the previously mentioned, for the railway vehicles, was J.W. Davis. According to this, the variance of the resistances to moving is determined by the equation (1), which is written in the form of a second-degree polynomial functions.

\[ \sum R_{t(v)} = A + B \cdot v + C \cdot v^2 \]  

where: \( \Sigma R_{t(v)} \) [N] - the sum of the total rolling resistance of a railway vehicle; \( A \) - the mechanical rolling resistance (inertia) [N]; \( B \) - the coefficient of non-aerodynamic resistance of moving vehicle N/(km/h); \( C \) - the drag coefficient determined by aerodynamic phenomena N/(km/h)^2; \( v \) - vehicle speed [km/h].

According to SR EN 14067-1 of 2004, the aerodynamic force acting on a railway vehicle decomposes on the three coordinates of the Cartesian reference system, in the based at equation (2). There was thus obtained, the aerodynamic drag force \( F_x = F_{dreg} \) [N], the lateral friction force with the air \( F_y = F_{side} \) [N] and lifting force \( F_z = F_{lift} \) [N]:

\[ (F_x, F_y, F_z) = (F_{dreg}, F_{side}, F_{lift}) = \frac{\rho \cdot U_x^2 \cdot S_{tr}}{2} \cdot (C_{dreg} \cdot C_{side} \cdot C_{lift}) \]  

where: \( \rho \) [kg/m^3] - is the air density, \( U_x \) [m/s] is the free stream velocity, \( S_{tr} \) [m^2] - is the vehicle (train) surface area and \( C_{dreg}, C_{side}, C_{lift} \) - are the dimensionless coefficients corresponding to each of the forces.

Within the same standard (besides the aerodynamic forces) the aerodynamic moments acting on the vehicles are stipulated, in the based at equation (3) \( M_x = M_{roll} \) [Nm] – rolling moment, \( M_y = M_{pitch} \) [Nm] – pitching moment, \( M_z = M_{hunt} \) [Nm] – hunting moment) and the pressure coefficient equation, equation (4).

\[ (M_x, M_y, M_z) = (M_{roll}, M_{pitch}, M_{hunt}) = \frac{\rho \cdot U_x^2 \cdot S_{tr}}{2} \cdot (C_{roll} \cdot C_{pitch} \cdot C_{hunt}) \]

\[ C_p = \frac{2 \cdot (p - p_{\infty})}{\rho \cdot U_x^2} \]
where: $l_r$ [m] - is the length of the vehicle (train), $C_{roll}$, $C_{pitch}$, $C_{hant}$ - are the dimensionless coefficients corresponding to each of the moments, $P$ [Pa] is the local static pressure and $p_{\infty}$ [Pa] is the free stream static pressure.

Taking into account the above mentioned, the aerodynamic forces acting on a multiple electric unit train will be analysed.

3. Simulation of airflow
Starting from the vehicle's overall constructional characteristics and the shape of the electric multiple unit train analysed (Hyperion train), it is first modelled in the geometrically shaped in 3D format at the 1:1 scale, according to the figure 1.

![Geometric 3D shape of the Hyperion train (dimensions in mm).](image1)

In addition, a sector of the railway structures a type embankment, it was modelled in the 3D format, figure 2. This structure contains the basic elements such as: the ballast bed, crossbeams and rails.

![Geometric 3D shape of the railway (dimensions in mm).](image2)

With the two geometric models built in 3D format, a geometrical assembly was made so that, through it, to can be could simulate the displacement conditions of a train on a railway track, as can be seen from figure 3.

Based on this assemblage, simulation of the flow of air flowing next to the vehicle during its deposition will be performed. Simulation of air flow is made for eleven-point values of train speed, within the range from 0 km/h to 200 km/h. These steadily maintained speeds start at a value of: 5m/s and end at 55m/s, with a successive increase of 5m/s.

To simulate the airflow, we started from the situation when the train is moving under normal atmospheric of pressure and temperature conditions (101325 Pa and 293.2 K). Based on this general consideration, a volume of air was defined in which to simulate, as follows:
- for the vertical direction, the volume is limited by a plan at the beginning of the ballast bed and a second plane located 15 m from the first;
- for the transverse direction, the volume was delimited by two symmetrical planes at 10 m from the median longitudinal plane of the vehicle and of the railway;
- regarding the delineation in the longitudinal direction were considered two symmetrical planes at 50 m from the transverse plane of the vehicle.

In the case of the airflow simulation, besides the vehicle, and without regard to the structure of the railway, the vertical delimitation is carried out starting from a plane situated at the level of the running surface (the wheel-rail contact plane) of the vehicle’s.

The flow simulation program uses parallelepipedal elements forms mesh both for volume of air and as well as in the train volume at the level of the boundary layer. It uses for turbulent flow analysis, the k-ε model where the equations of Favre Navier-Stokes are used.

As a result of the simulation of the flow of air, we can see: in figure 3 the dynamic air pressure distribution in the longitudinal section of the train, at an air velocity of 55 m/s, and in figure 4 the pressures exerted on the train surface, at the same rate of air flow rate.

![Figure 3](image1.png)

**Figure 3.** Distribution of dynamic air pressure in the longitudinal section of the train.

![Figure 4](image2.png)

**Figure 4.** Air pressure exerted on the train surface.

Taking into account the eleven values of the air velocities considered, in the figure 5 shows the evolution of the aerodynamic forces obtained during the simulations performed.

The stabilized values resulting from the simulations performed regarding aerodynamic resistance obtained for the eleven individual point analysed are centralized in table 1.

| Speed v [m/s] | 5   | 10  | 15  | 20  | 25  | 30  | 35  | 40  | 45  | 50  | 55  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| F_{x,Hy,c} [N]| 99.3| 392.1| 876.6| 1545.1| 2415.1| 3462.0| 4704.3| 6122.4| 7767.8| 9575.8| 11588.4|
| F_{y,Hy,c} [N]| -12.0| -47.9| -106.0| -193.2| -343.6| -489.5| -597.3| -761.9| -1089.7| -1253.0| -1672.0|
| F_{z,Hy,c} [N]| 20.6| 79.6| 188.6| 334.6| 525.3| 754.9| 1043.5| 1333.6| 1689.2| 2108.6| 2561.2|
Figure 5. Variation of aerodynamic forces during flow simulation.

For the simulated air flow near the train without considering the geometric model of the railway, the stabilized values obtained are centralized in table 2.

Table 2. The stabilized values of the aerodynamic forces resulting from the simulation of the air flow near train, without regard to the structure of the railway.

| Speed v [m/s] | 5   | 10  | 15  | 20  | 25  | 30  | 35  | 40  | 45  | 50  | 55  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| F_{x,Hy} [N]  | 140.8 | 554.1 | 1240.5 | 2202.0 | 3438.7 | 4944.5 | 6698.4 | 8766.8 | 11073.5 | 11081.7 | 11069.0 |
| F_{y,Hy} [N]  | -1.9 | -1.1 | -5.7 | -32.7 | -4.8 | -67.9 | -9.1 | -114.4 | -100.1 | 7.4 | -100.4 |
| F_{z,Hy} [N]  | 69.2 | 277.4 | 625.9 | 1106.6 | 1722.8 | 2484.1 | 3416.7 | 4423.8 | 5612.4 | 5675.7 | 5674.0 |

In figure 6 provides a comparative analysis between: aerodynamic forces obtained as a result of the air flow simulations performed for a vehicle moving on a railway and the values obtained in the case from the air flow simulation of the same vehicle, but at which is not considered part of railway infrastructure.

Figure 6. Influencing the infrastructure of the railway.
4. Conclusions
As expected for the Hyperion train, the aerodynamic forces of the train grow with the speed of travel (see tables 1 and 2).

After the 3D geometric modelling of the train (figure 1) and of a railway sector on which this is moving (figure 2), are done simulation regarding the air flow near the vehicle in a well-defined volume (figure 3).

The distribution of dynamic air pressure in the vehicle's median section has the highest values in the upper frontal area due to the upward routing of the flow lines, and in the back of train and the railways plane, these pressures have the lowest values, as can be seen in figure 3.

It can also be seen that the distribution of pressures on the vehicle surface is greatly influenced by its discontinuities. The highest-pressure values appear at the front, significant values are also in the area of running gear, equipment located on the body and in the area of vehicle interconnection (see figure 4).

During airflow simulation, it can be observed that the average aerodynamic forces stabilize at certain values, as shown in figure 5.

Making a percentage comparison between aerodynamic force values, obtained when the train under consideration is moving on a railway sector, in which does not take into account the track infrastructure and the situation in which this is considered, it is noted that the infrastructure elements positively influence the air flow near the train, in the sense that these forces decrease with an average performance of about 35% (see figure 6).

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