Analysis of the action of the aerodynamic resistances on an electric multiple unit train type

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Abstract. The present paper aims to analyse how aerodynamic resistances acting on an electric multiple unit train type are distributed during the movement. For this we considered a model, the case of the on an electric multiple unit train type that is in the operation of a railway company in Romania. Starting from the aspects mentioned in the literature, on how the aerodynamic resistances vary (it is directly proportional to the square of the displacement velocity), an initial estimation of the values of these forces is pursued. In the second step, it is performed an analysis of the airflow around the vehicle. To observe the evolution of aerodynamic resistances, the numerical simulation of airflow is used. In this sense, it has gone from the constructive shape of the train (which has been modelled in geometric form in 3D format) to its use in a specialized air flow simulation program. In this way the aerodynamic resistances acting on the train during the its movement are estimated.

1. Introduction
Technological development from over the past decades has allowed the transport system to increase vehicle speeds. While maintaining this trend, the same can be seen for vehicles in the rail transport sector. Under these circumstances, the determination and analysis of the forces acting on the moving vehicles are gaining more attention. The manifestation of this interest starts from the production and transmission of the traction force, continues with the analysis of the forces and the reactions at the level of contact between the wheels and the way of rolling, at the study of the forces of resistance of moving who opposing the movement of the vehicle and finally, in the braking process.

As regards the link between the forces acting on a moving vehicle, it is expressed in the literature [1-6] through the relationship (1).

\[ F_{0(v)} - \sum R_{t(v)} - F_{f(v)} \leq F_{a(v)} \]  

(1)

where: \( F_{0(v)} \) [kN] - is the traction force developed by the power equipment in the motor vehicle, with are acting in the direction of vehicle movement; \( \Sigma R_{t(v)} \) [kN] - is the sum of the resisting forces opposing the movement of the vehicle; \( F_{f(v)} \) [kN] - is the action of the braking force when the vehicle is to be stopped (in this case, the traction force must be canceled) or the reduction of the travel speed; \( F_{a(v)} \) [kN] - represents the adhesion limit force at the contact between the wheel and the tread.

To observe the effects of the aerodynamic forces acting on a moving vehicle, it is first necessary to see how the resistances of moving of the vehicle can be determined. Inside a railway vehicle are mounted equipments which can be in rotational motion and/ or in translation motion, but also suspension elements (both elastic and damping (which can be both viscous or dry friction). At the
level of the contact between the wheel and the rail tread, rolling friction occurs. In this condition it is quite complicated to establishing a mathematical relationship that takes all these aspects into account. To determine the values of the resistance forces, it is using the experimental methods. The most commonly used method in this regard is the free launch of the vehicle. However, in the literature [6-14], it is clear that the first person who has established an empirical mathematical relationship, which has allowed the determination of the sum of the resistance forces of moving, with a fairly good accuracy (in the case of a railway vehicle) was WJ Davis in 1926. He was the one who for the first time specified that the values of these forces are increasing with the square of the speed of movement. In this way Davis formula is generalized as a second-order polynomial function (2).

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

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].

Practically this relationship shows that the sum of the resistant forces comprises three basic components, namely: the strengths given by the inertia of the vehicle, the resisting forces occurring during running as mechanical and rolling friction in the bearings and the resistance forces caused by the friction with the air.

2 Case study

Although much of the Romanian rail passenger transport is made by means of classical trains consisting of a motors vehicle (locomotive) and several towed vehicles, in the last years began to use and the electric multiples train type.

For the case study of this article, we considered one such the electric multiple train type. First, we see the values of the resistance forces of moving and how they are decomposed on the three components given by Davis's empirical relationship. In the second part of the study, it will be dedicated to analyzing the aerodynamic resistances resulting from airflow simulation. Taking into account the constructive characteristics of the vehicles, which are included in the composition of this multiples electric train, and the results obtained from the series of experiments carried out within the framework of the Romanian Railway Authority for putting into circulation, at ring from Făurei, is estimated the empirical values of the Davis coefficients. For this with the punctual results obtained from the experiment, it is graphically plotted the sum of the forces that are resistant of moving (figure 1) and then the trendline of this graph is established. In this way, the characteristic equation of the amount of the sum of resistance forces of moving vehicle in the form of a second-order polynomial function is deduced. The constants of this function become practically the corresponding values of Davis coefficients according to the data presented in Table 1.

Table 1. Davis coefficients according to the characteristic equation for the sum of the forces of the train moving.

| Vehicle type | A [N] | B [N/(km/h)] | C [N/(km/h)^2] |
|--------------|-------|--------------|----------------|
| Hyperion     | 746.8 | 20.7         | 0.7            |

To see what the variance of the components of the sum of the resistance forces of moving vehicle is (figure 1), it will be broken down into the three large components, according to Davis's relationship. Further on Figure 2 shows a percentage analysis of the degree of influence of these components on the total sum of the resistance force at moving.
3. Simulation of airflow

Starting from the constructional features of the gauge and the shape of the electric multiple units train analyzed (Hyperion train), it is first modeled in the geometrically shaped in 3D format at the 1:1 scale, according to the figure 3.

With this model, the airflow simulation on beside the vehicle is made for 12-point values of the train speed in the range of 0 km/h to 200 km/h. These constant values are: 1m/s, 5m/s, 10m/s, 15m/s, 20m/s, 25m/s, 30m/s, 55m/s.

To conduct airflow simulation, we started from the general consideration of the train moving under normal atmospheric conditions on pressure and temperature (pressure 101325 Pa and temperature...
293.2 K). Following this general consideration, a volume of air was defined in which the simulation was made, as shown in Figure 4, so:
- for the vertical direction, the volume is bounded by a plane located at the runway surface and a second plane located at 15 m from the first;
- for the transverse direction, the volume was delimited by two symmetrical planes at 12 m from the median longitudinal plane of the vehicle;
- regarding the delineation in the longitudinal direction were considered two planes at 40 m and 50 m respectively from to transverse plane.

![Figure 4. Volume delimitation about simulating airflow for the Hyperion 3D model.](image)

The flow simulation program uses parallelepipedal elements forms mesh both for volume and the surface of the train. 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, we can see: in Figure 5 the dynamic air pressure distribution in the longitudinal section of the train for an air velocity of 45 m / s, and in Figure 6 the pressures exerted on the train surface, also for the same value of the air flow rate.

Taking into account the twelve values of the air velocities considered, in the figure 7 shows the evolution of the aerodynamic resistances obtained during the simulations performed.

The stabilized values resulting from the simulations performed regarding aerodynamic resistance obtained for the 12-individual point analyzed are centralized in Table 2 and Table 3.

![Figure 5. Distribution of dynamic air pressure in the longitudinal section of the train.](image)
Figure 6. Air pressure exerted on the train surface

Figure 7. Variation of aerodynamic resistances during flow simulation

Table 2. The stabilized values of the aerodynamic resistances resulting from the simulation from $v = \left[ \frac{K}{55} \right] m/s$.

| Speed $v$ [m/s] | 1 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
|-----------------|---|---|----|----|----|----|----|----|----|----|----|----|
| $F_{a_{-THyp}}$ [N] | 6.34 | 156.90 | 619.67 | 1389.41 | 2464.66 | 3846.10 | 5533.86 | 7519.46 | 9820.44 | 12414.97 | 12450.62 | 12438.94 |

In Figure 8, it is made a comparative analysis between: the aerodynamic resistances obtained as a result of the airflow simulations performed on the vehicle and the corresponding values determined by Davis's empirical relationship.

Figure 8. Evolution during simulations of aerodynamic resistances of the train.
4. Conclusions

As was to be expected and in the case the Hyperion train the resistance to moving increase with the square of its speed of travel. This has also been demonstrated by drawing the graph of these forces resulting from the tests carried out by the Romanian Railway Authority (see Figure 1). It is noticed that the percentage of the resistance aerodynamic forces has a significant influence starting with speeds exceeding 35 km / h. At the maximum allowable train speed, the percentage of the resistance aerodynamic forces exceeds 80% of the total sum of the train resistance forces at moving (see Figure 2).

Following the 3D geometric modeling of the train and to realize the airflow simulation next to it, can be seen that the distribution of pressures on the vehicle surface is greatly influenced by its discontinuities. At the front, the highest values of pressure occur, significant values are also present in the area of rolling stock (at the bogies), equipment located on the body and in the interconnection area of the vehicles (see Figure 6).

By comparing the percentages of aerodynamic resistances resulting from the use of the two methods of analysis, it can be observed that in the case of simulated air flow in the vicinity of the vehicle, the results obtained are lower than in the case determined by Davis’ relationship. The explanation of this aspect can be determined by the general conditions imposed (the simulation did not take into account the disturbances which may occur with the wind gusts, the atmospheric environment considered in the simulation being an ideal one - the laboratory), but also the way it is made meshing the volume and boundary layer elements. It can be seen in figure 8 that the abnormalities between the two methods are approximately 30% for the range of travel speeds ranging from 0 km/h to 160 km/h (maximum train speed). For higher rated speeds (where an extrapolation on Davis's relationship has been made) deviations are over 45%.

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