EXPERIMENTAL STUDY ON DETERMINATION OF AERODYNAMIC RESISTANCE TO PROGRESS FOR ELECTRIC LOCOMOTIVE LE 060 EA1 OF 5100 KW

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This paper aims at making a comparative analysis regarding the influence of aerodynamic resistance to progress of electric locomotive LE 060 EA1 of 5100 kW for a range of situations encountered in exploitation. In this paper, experimental results are presented following a geometric modeling at 1:12 scale on a modular layout of the locomotive. Tests were made in the INCAS (National Institute of Research - Development Aerospace "Elie Carafoli") in the subsonic wind tunnel.

Keywords: aerodynamic, electric locomotive, experimental modeling

1. Introduction

The resistance to progress growth leads to increasing the necessary traction force. If the tractive force of the locomotive exceeds the limit of adhesion it can produce slippage of axles and there is danger of the stick-slip phenomenon, which has harmful effects on both the performance of locomotive traction as well as the requests from the drive system axles, [1], [2], [3].

General form of resistance to progress of railway vehicles, known as Davis' relationship [3], [4], [5], [6], [7]"

$$R_t = a + b \cdot v + c \cdot v^2 \tag{1}$$

where:

R_t – total resistance to progress of the train;

a – mechanical resistances at rolling caused by axle loads;

$b \cdot v$ – the resistances at non aerodynamic advancing;

$c \cdot v^2$ – the resistances at aerodynamic advancing ;

v – speed of the vehicle.

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Aerodynamic phenomena of a vehicle increase its resistance to displacement, the square of the velocity, fact which becomes more evident at high velocity.

Regarding the analysis on the resistances at advancing, caused by the aerodynamic phenomena, at electric rail vehicles they might decompose in:

- the resistances caused by design form of the box vehicle;
- the resistances caused by equipment located on the roof;
- the resistance caused by equipment between rolling plan and chassis plan.

Explanation of parameter “c” from second degree polynomial of Davis, for railway vehicles traveling at speeds up to 250 km / h, is done in the literature [8], [9], [10], [11], [12], [13], [14] with relation (2):

$$c = \frac{C_x \cdot S \cdot \rho}{2} \tag{2}$$

where:

C_x – air drag coefficient of sliding (also known as the coefficient of air penetration) (dimensionless);

S – front surface of the vehicle in cross section (m^2);

ρ – density of air moving vehicle(kg/m^3)

The front of the vehicle drag coefficient is determined by the equation:

$$C_x = \frac{2 \cdot F_x}{S \cdot \rho \cdot \bar{v}^2} \tag{3}$$

where:

F_x – the frontal sliding force (N);

$\bar{v}$ – velocity of the fluid (m/s)

In [15] the authors state that in a series of tests made in a “tunnel test” on TGV trains at a speed of 260 km/h, they found that “Of the total drag, the aerodynamic drag only on the train body is about 80%, the aerodynamic drag due to the pantograph system and other devices over the train is 17%, the rest drag of 3% is due to the mechanical drag caused by the brake system etc.”

In the same article, another study showed that ICE trains “in function cross section shape of the vehicle engine, its roof top equipment, those located between the chassis and running plane and the existence or not of hulls or skirts that conceal equipment outside (fig. 1 and 2) can result in reduced friction and consequently to lower air drag coefficient that goes into drag”

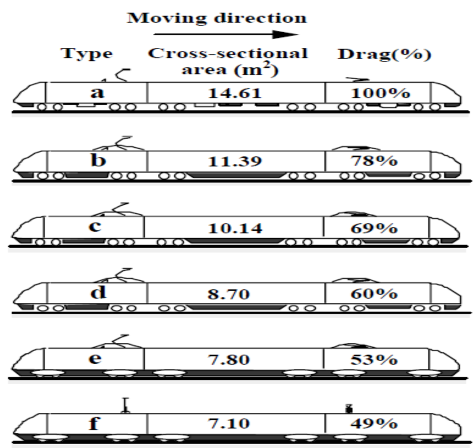

Fig. 1. "Aerodynamic drag on ICE (the hatching area is the device to smooth the structures underneath train"[15]

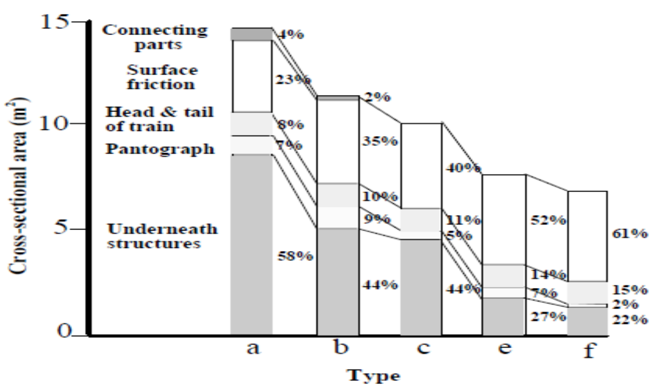

Fig. 2. "Aerodynamic drag components of ICE"[15]

2. Tests and analysis of results

In order to determine resistance to progress of the box and electrical equipment on railway vehicles we have made a geometric model on a 1:12 scale on type modular for electric locomotive LE 060 EA of 5100 kW which were introduced in INCAS (National Institute of Research - Development Aerospace "Elie Carafoli") subsonic wind tunnel (fig. 3).

The modularity of model has enabled us to phform 8 tests for various situations encountered in the operation of railway electric vehicles. These tests were conducted at values of velocity from 10 m/s to 55 m/s. A series of punctual tests, also, have been realized at a speed of 40 m/s respectively 55 m/s.

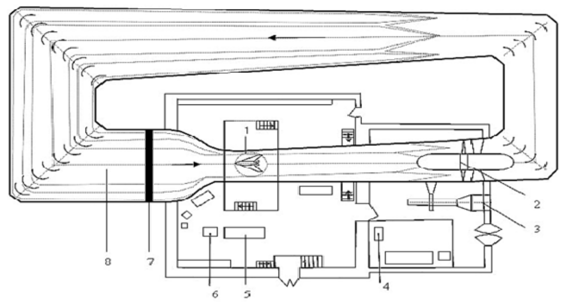

Fig. 3. The scheme of INCAS subsonic wind tunnel
1 - control room, 2 - motor, 3 - the engine cooling system, 4 - the power supply panel, 5 - the control panel, 6 - the control panel for motor, 7 - the section to minimize turbulence, 8 - quiet room

In the aerodynamic tunnel, the global loadings, aerodynamic forces and moments, due to the airflow in the experimental area are measured with an external balance, of pyramidal type with six components (fig. 4). Electrical signals are stored using a data acquisition system. The measured values are in counts (unit of a number, we can say impulses). To determine the actual values of forces and moments one needs to multiply with 6 constants, determined at calibration of balance. In this case only one measuring channel was used namely the channel appropriate for determination of resistance to progress.

Fig. 4. The extern balance of pyramidal type

The first test was conducted at a speed of 40 m / s, with scale model without equipment on roof. This was to determine the value of aerodynamic resistance to progress given only by the box (fig 5).

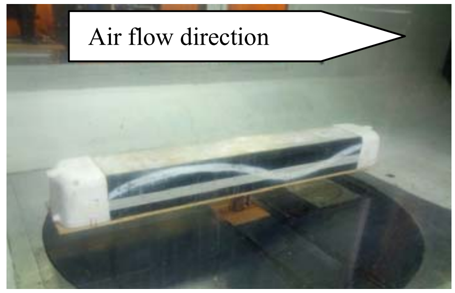

Fig. 5. Test no 1 – LE 5100kW without equipment's

Other tests were included and also the equipment on the roof of locomotive in various situations encountered in the operation of the locomotive (fig.6 to fig.12).

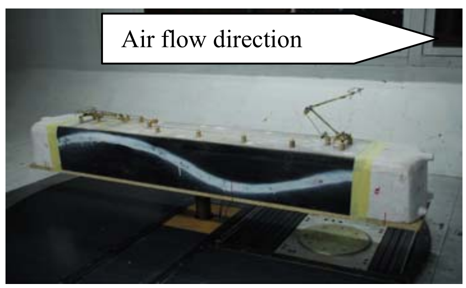

Fig. 6. Test no 2 – LE 5100kW with back pantograph high, meaning of air flow at the maximum working height and articulation arms towards the inside of locomotive

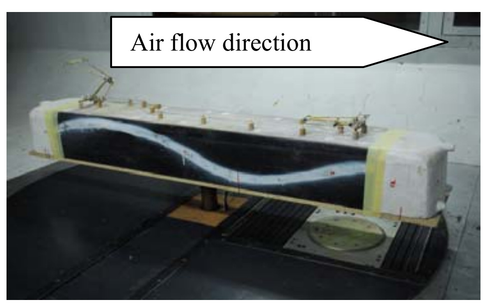

Fig. 7. Test no 3 – LE 5100kW with from the front pantograph high, meaning of air flow at the maximum working height and articulation arms towards the inside of locomotive

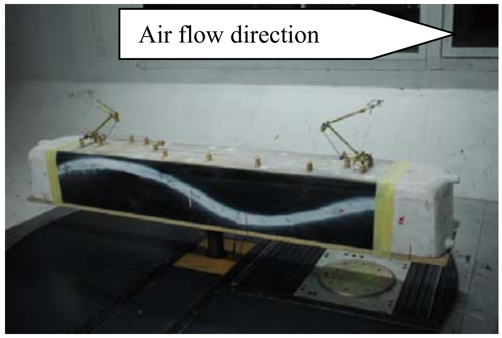

Fig. 8. Test no 4 – LE 5100kW with both pantographs raised at maximum working height and articulations of the arms towards the inside of locomotive

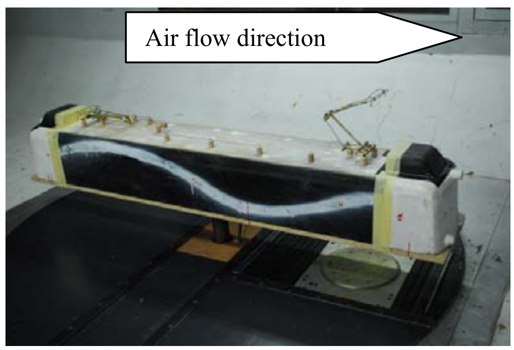

Fig. 9. Test no 5 – LE 5100kW with the back pantograph high, meaning of air flow at the maximum working height, articulation arms towards the inside of locomotive and air conditioning on box

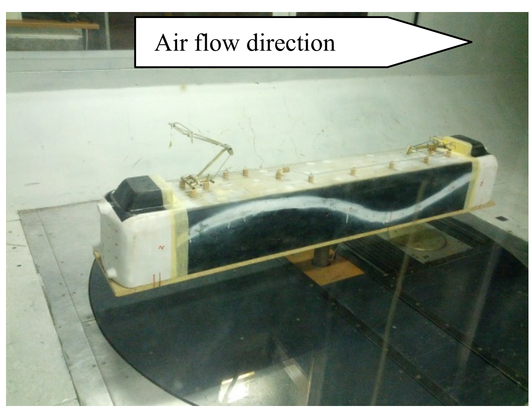

Fig. 10. Test no 6 – LE 5100kW with from the front pantograph high, meaning of air flow at the maximum working height, articulation arms towards the inside of locomotive and air conditioning on box

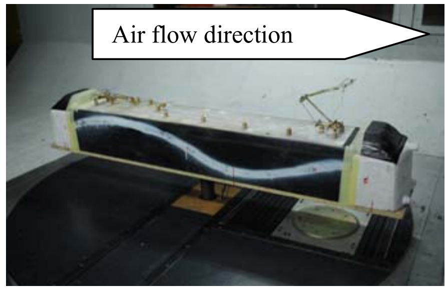

Fig. 11. Test no 7 – LE 5100kW with the back pantograph high, meaning of air flow at the maximum working height, articulation arms towards the inside of locomotive and air conditioning hull

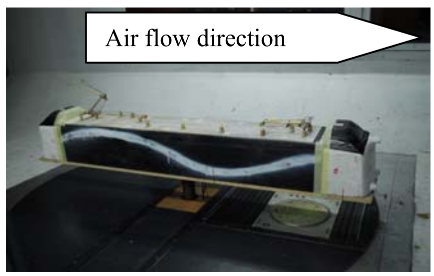

Fig. 12. Test no 8 – LE 5100kW with from the front pantograph high, meaning of air flow at the maximum working height, articulation arms towards the inside of locomotive and air conditioning hull

The results obtained from testing on the geometric model of the locomotive at scale for aerodynamic resistance to advancement are given in Table 1

After processing the experimental data at a speed of movement with 40m/s (144km/h - value of the 140km/h representing the maximum speed with which the locomotive is able to circulate on magistral lines) one can make a series of comparisons on aerodynamic resistance to advancement, namely:

1. The equipment on the locomotive roof (pantograph, isolators on the roof automatic, switch) creates turbulences, leading thus to increase of aerodynamic resistance to advancement (fig.13). Depending on the situations encountered in locomotive of operation, this equipment determines a proportional increase aerodynamic drag at the advancement, in this case ranging between 22,99% and 37,45% (fig.14).
2. It can be seen that increasing the cross-section area of the locomotive, aerodynamic resistance to advancement increase also (Fig. 15), as it is said in the literature. In this case, this increase can reach up to 9.045% (fig.16).

Table 1

Experimental results

Nr. exp.	**R_{ia} [ct]**	**R_{ia} [daN]**	**Test**	**v [m/s]**
1	809	2,7652	Test 1	40
2	75	0,2564	Test 2	10
3	154	0,5264		15
4	269	0,9194		20
5	410	1,4014		25
6	585	1,9995		30
7	796	2,7207		35
8	995	3,4009		40
9	1257	4,2964		45
10	1554	5,3116		50
11	1869	6,3882		55
12	1023	3,4966	Test 3	40
13	1931	6,6002		55
14	1016	3,4727	Test 4	40
15	1930	6,5967		55
16	1011	3,4556	Test 5	40
17	1934	6,6104		55
18	1029	3,5171	Test 6	40
19	1959	6,6959		55
20	78	0,2666	Test 7	10
21	164	0,5606		15
22	285	0,9741		20
23	439	1,5005		25
24	636	2,1738		30
25	866	2,96		35
26	1085	3,7085		40
27	1377	4,7066		45
28	1724	5,8926		50
29	2127	7,2701		55
30	1112	3,8008	Test 8	40
31	2150	7,3487		55

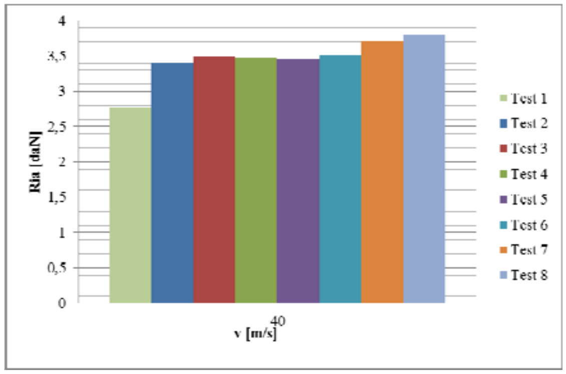

Fig. 13. The aerodynamic resistance to advancement of LE5100kW

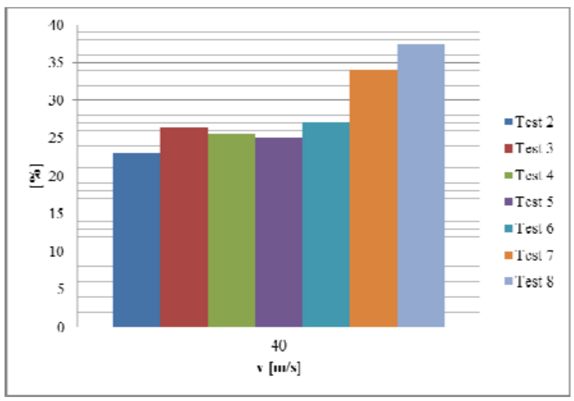

Fig. 14. Increase percentages of aerodynamic resistance caused by equipment located on the locomotive

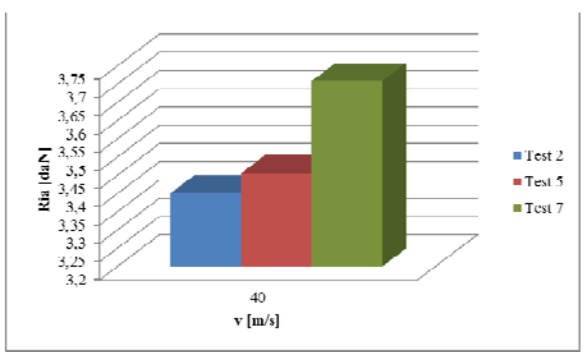

Fig. 15. The aerodynamic resistances to advancement given by increasing the cross-section area of LE5100kW

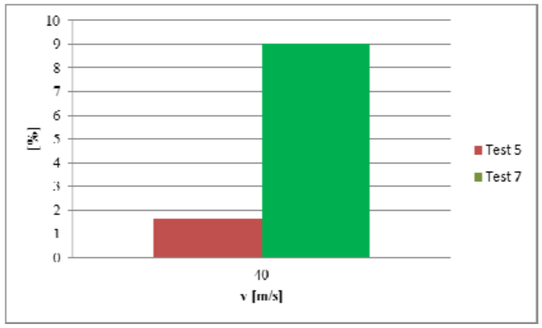

Fig. 16. The percentage increase in aerodynamic drag at forward due to increasing cross-section area of LE5100kW

Regarding the speed variation in the range of 10 m/s and 55 m/s, it is found that increasing the cross-section area causes an increase in the aerodynamic resistances to advancement (fig.17) which is between 4% and 13.8% (fig.18).

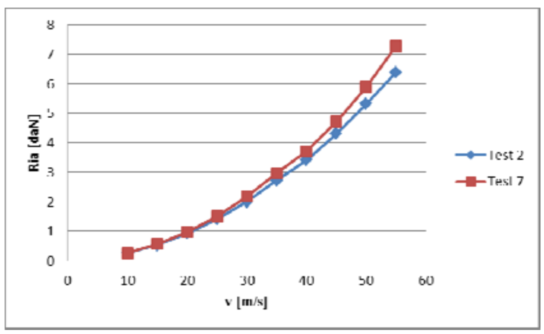

Fig. 17. Variation of aerodynamic resistance to advancement with travel speed

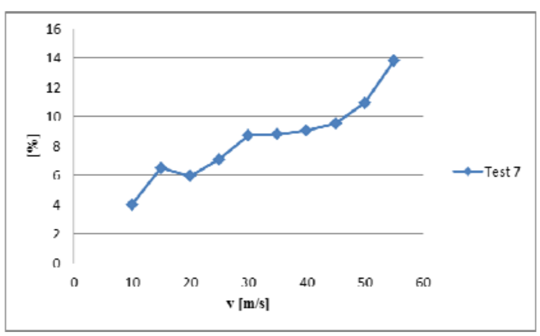

Fig. 18. Variation of increase percentages of the aerodynamic resistance to advancement with travel speed given increasing the cross-section area

3. Conclusions

After testing in subsonic tunnel within INCAS (National Institute of Research - Development Aerospace "Elie Carafoli"), of the geometric model on a 1:12 scale of electric locomotive LE 060 EA of 5100 kW, it appears that for the analysis of aerodynamic resistance to advancement, equipment placed on this, determine percentage increases up to 22,99% if using in current mod vehicle.

Incremental upgrades, which led to increased cross-section area, by fitting in the ends of locomotive, on the roof, of the air conditioned, necessary to the climate in the driving posts, involves an increase in aerodynamic drag by a further 1.61%, compared to using in the current mod and their careen, on entire cockpit, to an increase of 9.05%.

These analyzes have not been done before on electric railway traction vehicles in Romania. As stated, modernizations have increased aerodynamic resistance to advancement that lead implicitly in an increase in the power consumption required for towing of a certain tonnage

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