ON THE SELF-PROPULSION CONDITIONS OF A PASSENGER CAR

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Abstract: *The resistance forces acting on a passenger car during motion include rolling resistance, aerodynamic resistance, grade resistance, and acceleration resistance. For a vehicle to achieve self-propulsion, the energy delivered by the engine must correspond to the torques and power required to overcome these resistances to motion*

Keywords*:* forces, resistance, motion, self-propulsion, passenger car

1.INTRODUCTION

The study of motion resistances is carried out for a sports passenger car with a seating capacity of two, designed to climb a maximum gradient of 16 degrees and capable of reaching a maximum speed of 262 km/h.

The forces acting on the vehicle during motion are of two types:

- **active forces** (acting in the same direction as the velocity);
- **resistive forces** (acting opposite to the direction of motion).

The resistive forces encountered during motion are:

- rolling resistance;
- aerodynamic resistance;
- grade resistance;
- acceleration resistance.

Due to the interaction between active and resistive forces, the vehicle may exhibit uniform, accelerated, or decelerated motion.

For a vehicle to be self-propelled, the energy supplied by the engine must match the torques and power required to overcome motion resistances. Therefore, it is necessary to define both the self-propulsion conditions and the physical causes and influencing factors associated with each resistance component.

2.ROLLING RESISTANCE

Rolling resistance R_r is a force generated by the rolling motion of the wheels on the road surface and is therefore a permanent force. Its physical causes include:

- deformation of the road surface;
- friction between tyre and road;
- hysteresis deformation of the tyre;
- suction effects caused by closed tread patterns on smooth surfaces.

The factors influencing rolling resistance R_r are:

- type and condition of the road surface;
- tyre inflation pressure;
- vehicle speed;
- tyre characteristics.

The calculation relationships for rolling resistance and the power required to overcome it are given by relations (1) and (2):

$$R_r = \mathrm{f} \cdot \sum_{i=1}^{Nr} Z_{ri} = \mathrm{f} \cdot G_a \cdot \cos \alpha \ \ [\mathrm{N}] \tag{1}$$

$$P_r = \mathrm{f} \cdot G_a \cdot \cos \alpha \cdot \mathrm{v} \ \ [\mathrm{KW}] \tag{2}$$

Where:

f – rolling resistance coefficient;
G_a – vehicle weight;
α – road inclination angle;
v – vehicle speed (m/s).

Table 1 presents the values of rolling resistance R_r and the required power P_r.

For the analysed vehicle, the following values were adopted: the rolling resistance coefficient $f = 0.018$ and the angle of inclination of the path $\alpha = 18°$.

Table 1. The values of rolling resistance Rr and power required to overcome Pr

V [km/h]	V [m/s]	Rr [N]	Pr [kW]
0	0	211.90	0
16.38	4.55	211.90	0.96
32.75	9.10	211.90	1.93
49.13	13.65	211.90	2.89
65.50	18.19	211.90	3.86
81.88	22.74	211.90	4.82
98.25	27.29	211.90	5.78
114.63	31.84	211.90	6.75
131.00	36.39	211.90	7.71
147.38	40.94	211.90	8.67
163.75	45.49	211.90	9.64
180.13	50.03	211.90	10.60
196.50	54.58	211.90	11.57
212.88	59.13	211.90	12.53
229.25	63.68	211.90	13.49
245.63	68.23	211.90	14.46
262.00	72.78	211.90	15.42

Fig. 1 shows the evolution of rolling resistance Rr as a function of speed. Fig. 2 shows the evolution of the power required to overcome the rolling resistance Rr as a function of speed.

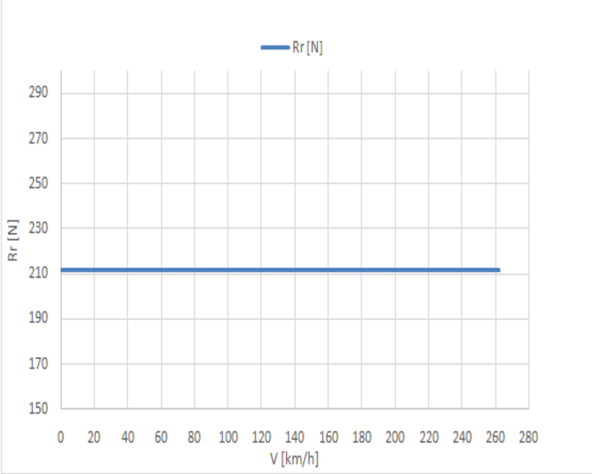

Fig.1. Evolution Rr as a function of speed

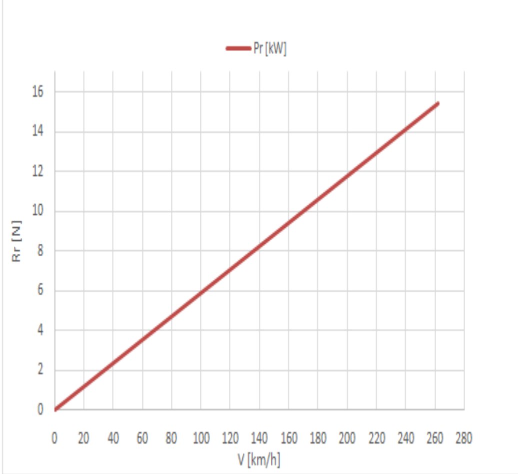

Fig.2. Evolution P_r as a function of speed

3. AERODYNAMIC RESISTANCE

Vehicle aerodynamics addresses the phenomena occurring between the moving vehicle and the surrounding air.

Aerodynamics studies:

- air resistance and methods for its reduction;
- airflow inside the vehicle;
- interaction effects with air in terms of stability and adhesion, as well as methods for improvement.

Vehicle shape significantly influences aerodynamic performance, quantified by the drag coefficient c_x.

The aerodynamic resistance and the power required to overcome it are calculated using standard relations:

$$R_a = \frac{1}{2} \cdot \rho \cdot c_x \cdot A \cdot v^2 \ \ [N] \quad (3)$$

$$P_a = R_a \cdot v \ [kw] \quad (4)$$

Where:
ρ – air density;
c_x – air resistance coefficient ;
A – maximum cross sectional area (A = B*H);
v – vehicle speed (m/s).
For the studied vehicle: c_x = 0,28; ρ = 1,225 kg/m³; A = 2415 mm^2;

The resulting values of aerodynamic resistance R_a and required power P_a are presented in Table 2.

Table 2. The values obtained for air resistance Ra
and for the power required to overcome it Pa

V [km/h]	V [m/s]	Ra [N]	Pa [kW]
0	0	0	0
16.38	4.549	5.793	0.026
32.75	9.097	23.170	0.211
49.13	13.646	52.133	0.711
65.50	18.194	92.681	1.686
81.88	22.743	144.815	3.294
98.25	27.292	208.533	5.691
114.63	31.840	283.836	9.037
131.00	36.389	370.725	13.490
147.38	40.938	469.199	19.208
163.75	45.486	579.258	26.348
180.13	50.035	700.902	35.069
196.50	54.583	834.132	45.530
212.88	59.132	978.946	57.887
229.25	63.681	1135.346	72.299
245.63	68.229	1303.331	88.925
262.00	72.778	1482.901	107.922

Fig. 3 şi Fig. 4 show the variation of air resistance R_a and the power required to overcome it P_a as a function of travel speed.

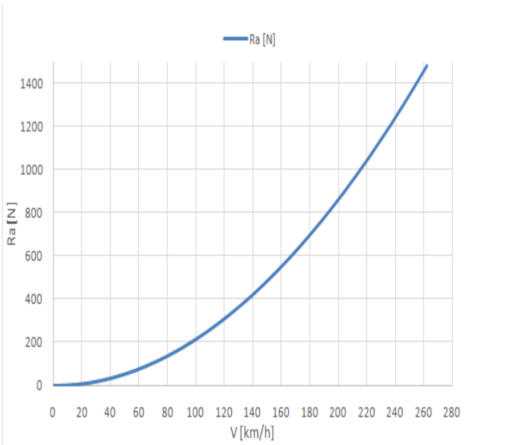

Fig. 3. Evolution of Ra as a function of speed

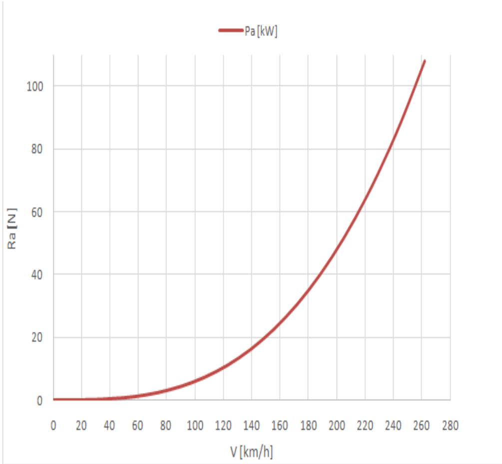

Fig. 4. Evolution of Pa as a function of speed

4.RESISTANCE TO CLIMBING THE SLOPE

When climbing a slope, the gravitational force generates a component R_p opposite to the direction of motion. This force acts as a driving force during descent and a resistive force during ascent.

The formulated resistance values for different slope inclinations are:

$$R_p = m_a \cdot g \cdot \sin\alpha \ \ [N] \quad (5)$$

For small inclinations (<17°), the approximation $\sin\alpha \approx \tan\alpha$ can be used.

Table 3 presents grade resistance values for various inclination angles, while Figure 5 illustrates its variation.

Table 3. R_P values

α [˚]	Rp [N]
0	0
1	205.45
2	410.84
3	616.10
4	821.17
5	1026.00
6	1230.51
7	1434.65
8	1638.35
9	1841.55
10	2044.19
11	2246.20
12	2447.54
13	2648.12
14	2847.90
15	3046.82
16	3244.80

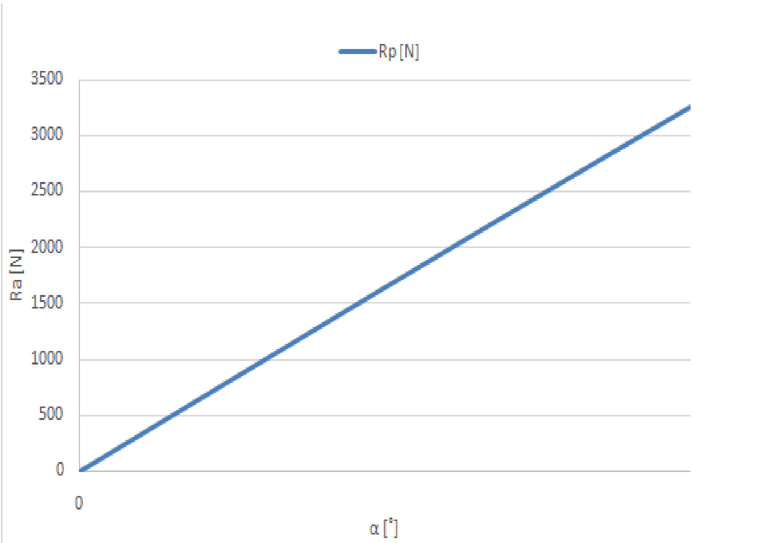

Fig. 5. Evolution of Rp with angle α

5. STARTING RESISTANCE

Starting resistance occurs when the car has an accelerated movement.
The starting resistance formula is as follows

$$R_d = m_a \cdot \delta \cdot \frac{dv}{dt} \quad [N] \tag{6}$$

Where:
δ – the coefficient of rotating masses;
$a = dv/dt$ –the acceleration of the car s translational movement
For the analysed vehicle, **δ1 = 1,04 was adopted.**

6. GENERAL EQUATION OF RECTILINEAR MOTION

To establish the general motion equation, the vehicle is considered to move rectilinearly with positive acceleration on a road inclined at angle α.

The dynamic equilibrium equation is:

$$F_R = R_r + R_a + R_p + R_d \quad [N] \tag{7}$$

where:
F_R – active force;
R_r, R_a, R_p, R_d – resistive forces.

The analytical expression of the wheel force is:

$$F_R = \frac{M \cdot i_{tr} \cdot \eta_t}{r_r} = \frac{P \cdot \eta_t}{v} \quad [N] \tag{8}$$

where:

- M – the moment from a point on the exterior feature;
- P – power under the same conditions;
- η_t –transmission efficiency;
- i_{tr} – report of transmission;
- r_r - rolling radius;

Depending on the conditions of self-propelled there are 3 particular cases of the general equation of motion, namely :

a) Travel at full speed

The maximum speed is obtained when α = 0°. Under these conditions, the acceleration is 0 and the equation has the form:

$$F_{R_{v\,max}} = G_a \cdot f + \frac{1}{2} \cdot \rho \cdot C_x \cdot A \cdot v_{max}^2 \ [N] \tag{9}$$

b) Traveling on a track with maximum longitudinal inclination or minimum specific resistance

Considering that the slope is maximum, the travel speeds are small, so the air resistance is negligible in relation to the other forces. From this it follows that the equation takes the form:

$$F_{R\Psi_{max}} = G_a \cdot \Psi_{max} \quad [N] \tag{10}$$

where: Ψ – total path resistance coefficient (Ψ = f * sin α + cos α);

c) Starting from a standstill with maximum acceleration:

It is obtained when α = 0° şi V_0 = 0 m/s. Under these conditions, Ra = 0 and the equation has the form:iar ecuaţia are forma:

$$F_{R_{a1\,max}} = G_a \cdot f + m_a \cdot \delta_1 \cdot \left(\frac{dv}{dt}\right)_{1max} \quad [N] \qquad (11)$$

For the studied vehicle a_{1max} = 2,2 m/s² **.**

According to relations 9, 10 and 11, the following values result:

$F_{R_{v\,max}}$ [N]	1694.797
$F_{R_{\Psi_{max}}}$ [N]	3448.490461
$F_{R_{a1\,max}}$ [N]	3331.896

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