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COMPARATIVE RESEARCH OF A MOTOR CAR MOTION IN THE CASE OF THE LOSS OF CONTACT WITH THE ROAD SURFACE

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Abstract. The paper describes the car motion when the contact between its wheels and the road surface is lost. A simulation of such car motion was carried out using a mathematical package "Maple 6" for the two cases:
1) The car flies off a horizontal surface; 2) The car runs over a springboard.
The dependencies of the main parameters of motion (velocity V_a and distance S) upon the height H of the horizontal road step or upon the springboard height and its inclination angle (in the second case) α were found.
The work presents the graphs of these motion parameters and evaluates the influence of air resistance in both cases.

Keywords: inertia, air resistance, car velocity, car fly off distance, springboard, parameters of car motion.

1. Introduction

In car technical examinations (e.g. after road accidents) there sometimes arises the need of reconstructive calculations of the main car parameters [1]. When a car flies off the road or falls down from some other road construction the car is influenced by two forces: inertia (the propulsive force) and air resistance (the brake force). The investigator is interested mainly in such questions as how far the car can fly if it runs at speed V_a or what was car speed if it flew at distance S .

After the examination of work done on this subject the conclusions can be made, that many authors during simulation ignore the influence of air resistance on the parameters of a car motion when the car losses any contact with the road surface [2–4]. In such case the trajectory of a car motion is determined only by the car velocity at the moment of the contact loss and by the terrestrial gravitation which results in the fall down of the vehicle.

Other authors treat the car motion as a subject described by the energy equation for the rectilinear motion [5, 6]. But for the sake of simpler practical calculations some presumptions and conditions are often being introduced which, however, reduce the accuracy of results because of the simpler equivalent model.

References mainly are restricted by rather exhaustive analysis of the wheel – road interaction [7–10] while car flight off the road is almost not discussed.

Therefore, the goal of this work is the establishment of the main parameters of a car motion, laws of its alternation taking into account forces such as inertial, air resistance, when:

1) The car flies off a horizontal road;
2) The car runs over a springboard.

This paper also estimates the influence of air resistance on the car fly distance S for a given car speed V_a in both cases mentioned before.

In conclusions the found graphic dependencies between the main car motion parameters are analyzed and the results of this work are generalized.

2. Methods of research of car motion without contact with the road surface

For the examination of a vehicle motion without contact with the road surface of all its wheels a diagram of calculations of car motion is designed (see Fig 1). The car is considered as a material point c_m of its center of weight that "flies off" from a horizontal roadbed

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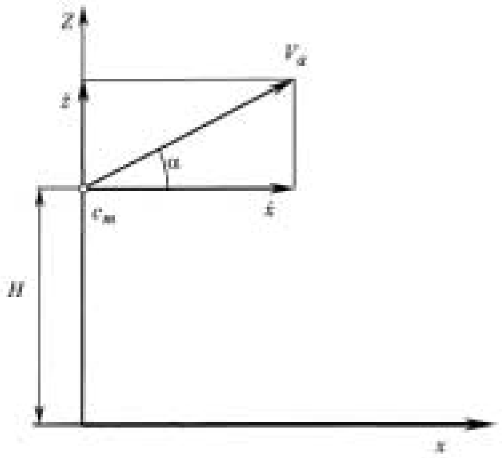

Fig 1. Diagram for calculiations of car motion

($\alpha = 0°$) with a given height H or runs over a springboard ($\alpha > 0°$).

With the help of the "Maple 6" mathematical package [11, 12] a program of calculations of the main car motion parameters (fly off distance $S\,(S = x)$, speed of motion V_a) taking into account inertial and air resistance forces was written for the cases:

1) $\alpha = 0°$;

2) $\alpha = 10°$.

In both cases the height H was fixed from which the car flies off (in the second case it was the height of the springboard).

The motion of the center of weight of the car is characterized by the following equations:

$$m\ddot{x} = -R_x,$$
$$m\ddot{z} = -R_z - mg. \quad (1)$$

$$R_x = \frac{1}{2}\rho \cdot A_x \cdot c_x \cdot \dot{x}\sqrt{\dot{x}^2 + \dot{z}^2},$$
$$R_z = \frac{1}{2}\rho \cdot A_z \cdot c_z \cdot \dot{z}\sqrt{\dot{x}^2 + \dot{z}^2}, \quad (2)$$

here m – car mass (e.g., $m = 1100\,\text{kg}$ [13]); $\ddot{x}, \ddot{z}$ – car acceleration in the corresponding axial directions, in m/s^2; R_x, R_z – air resistance in directions of x and z axes; g – free fall acceleration, $g = 9{,}81\,\text{m/s}^2$; ρ – air density (e.g. $\rho = 1{,}22\ \text{kg/m}^3$; A_x, A_z – areas of car projections perpendicular to corresponding axes (e.g., $A_x \approx 1{,}9\ \text{m}^2$, $A_z \approx 8{,}0\,\text{m}^2$); c_x, c_z – car stream – line factors in the corresponding axial directions (e.g., $c_x = 0{,}50$, $c_z = 0{,}70$); $\dot{x}, \dot{z}$ – car speed in the corresponding axial directions, in m/s . For the simplicity of calculations it is accepted, that the car flight after the loss of the contact with the road is inertial, without rotation about x and z axis.

The first case ($\alpha = 0°$) researches the vehicle fly off the horizontal road at car speed V_a equal to 40, 80, 120, 160, 200,40, 280 km/h (higher values are considered as theoretical possible) and H variating from 1,0 m to 5,0 m (at steps equal to 1,0 m). Results of calculations (for H =1,0 m, H =5,0 m) are presented in Table 1, and dependencies of fly off distance on the car speed are presented in Fig 2 and Fig 3.

In the second case the springboard angle is $\alpha = 10°$, the springboard height H equals to 0,5 m and 1,0 m. The results for such values are presented in Table 2, and corresponding graphic dependencies – in Fig 4 and Fig 5.

Table 1. Results of calculations of motion parameters of a car flown off the horizontal road ($\alpha = 0°$, H =1 m and H =5 m)

Speed of car motion, m/s (km/h)	Without air resistance		With air resistance		Difference of the fly distance without and with air resistance ΔS, m	
	Fly distance S, m	Fly distance S, m	Fly distance S, m	Fly distance S, m	H =1,0 m	H = 5,0 m
	H =1,0 m	H = 5,0 m	H =1,0 m	H = 5,0 m		
11,11 (40)	5,037	11,27	5,016	11,22	0,021	0,050
22,22 (80)	10,06	22,56	10,03	22,43	0,030	0,130
33,33 (120)	15,13	33,93	15,05	33,65	0,080	0,280
44,44 (160)	20,23	45,35	20,07	44,87	0,160	0,480
55,56 (200)	25,26	56,83	25,09	56,10	0,170	0,730
66,67 (240)	30,40	68,36	30,10	67,31	0,300	1,050
77,78 (280)	35,41	79,94	35,12	78,53	0,290	1,410

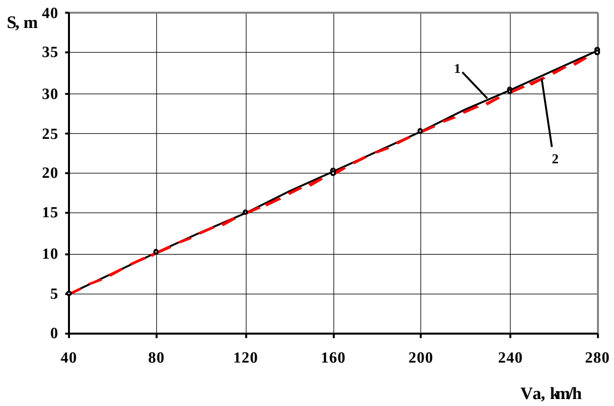

Fig 2. Car fly off distance S without (continuous line 1) and with (dotted line 2) taking into account the air resistance and $\alpha = 0°$, H=1,0 m

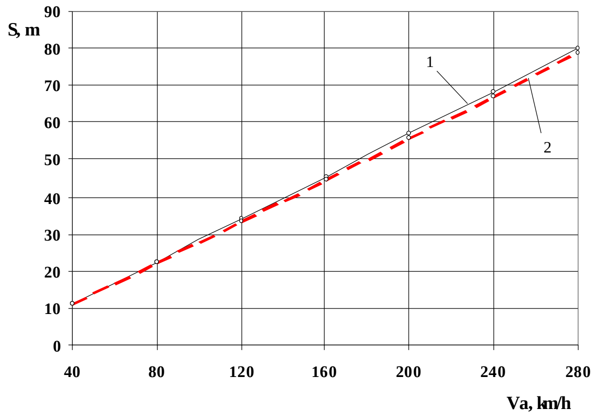

Fig 3. Car fly distance S without (continuous line 1) and with (dotted line 2) air resistance, when $\alpha = 0°$, H =5,0 m

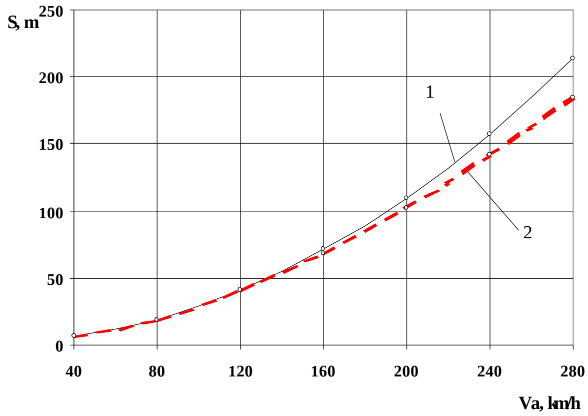

Fig 4. Car fly distance S without (line 1) and with (line 2) air resistance, when $\alpha = 10°$, H =0,5 m

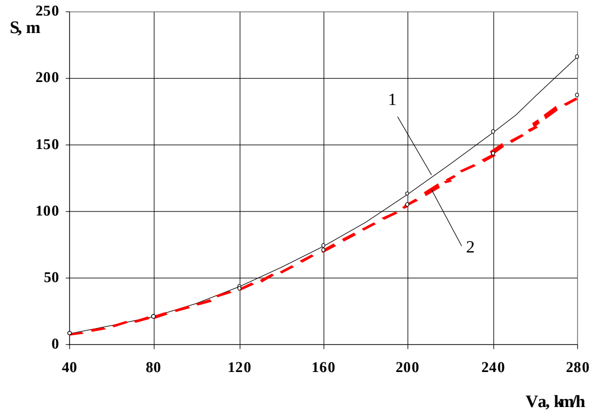

Fig 5. Car fly distance S without (line 1) and with (line 2) air resistance, when $\alpha = 10°$, H=1,0 m

Table 2. Results of calculations of motion parameters of a car running over the springboard ($\alpha = 10°$, $H = 0{,}5$ m and $H = 1{,}0$ m)

Speed of car motion, m/s (km/h)	Without air resistance		With air resistance		Difference of the fly distance without and with air resistance ΔS, m	
	Fly distance S, m, $H = 0{,}5$ m	Fly distance S, m, $H = 1{,}0$ m	Fly distance S, m, $H = 0{,}5$ m	Fly distance S, m, $H = 1{,}0$ m	$H = 0{,}5$ m	$H = 1{,}0$ m
11,11 (40)	6,254	7,540	6,247	7,533	0,007	0,007
22,22 (80)	19,69	21,71	19,50	21,53	0,19	0,18
33,33 (120)	41,38	43,75	40,29	42,66	1,09	1,09
44,44 (160)	71,58	74,12	68,13	70,73	3,45	3,39
55,56 (200)	110,4	113,0	102,2	105,0	8,20	8,00
66,67 (240)	157,8	160,5	141,5	144,3	16,30	16,20
77,78 (280)	213,7	216,5	184,9	187,9	28,80	28,60

3. Conclusions

1. From the analysis of the results of calculations and the shown graphs for the example, given with comments to formula (1), (2) we see that the influence of air resistance on the fly off distance of the car, flying off the horizontal road is as follows: when both the height H of the car fly off and the car speed V_a increase, differ-

ence ΔS for cases without and with taking into account air resistance equals to from $\approx 0{,}020$ m (V_a=40 km/h, H=1,0 m) and $\approx 0{,}290$ m (V_a=280 km/h, H=1,0 m) to $\approx 0{,}050$ m (V_a=40 km/h, H=5,0 m) and $\approx 1{,}41$ m (V_a=280 km/h, H=5,0 m).

2. In the case, when a car runs over the springboard, difference ΔS of fly distances without and with taking into account air resistance at low speed (100–120 km/h) also is not considerable ($\Delta S \approx 0{,}19 \div 1{,}09$ m at H=0,5 m) and $\Delta S \approx 0{,}18$ m at H=1,0 m). As the car speed increases, difference ΔS increases more intensively – at speed equal to 280 km/h ΔS reaches $\approx 28{,}80$ m for H=0,5 m and $\approx 28{,}60$ m for $H = 1{,}0$ m. The increase of the fly distance following the speed increase can be explained as the result of increase of air resistance to the car running over the springboard because of increased car projection area on to the frontal plane, if compared with the case when the car flies off the horizontal road surface (when $\alpha = 0°$).

3. Based on the results it can be affirmed that for the cases analyzed above (when $\alpha = 0°$ and $\alpha = 10°$), at low speed, that is mainly met in the out – of – town roads (up to 120 km/h) the influence of air resistance on the parameters of car motion is not considerable and has no decisive significance.

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