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Maximium Velocity that a Vehicle can Attain without Skidding and Toppling While Taking a turn

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Abstract:- This paper compares the maximum turning velocity without skidding and toppling for a four wheel vehicle steered using either an all-four-wheel steering system, rear wheel steering system or an ordinary front wheel steering system. The maximum turning-velocity of a vehicle, the dimension of an automobile, and the surface condition of the road necessary to avoid skidding and toppling have been related mathematically with the help of equations. Maximum attainable velocity during turning has been analyzed utilizing these equations, in the above mentioned three different types of steering systems. In attaining maximum velocity for all the steering mechanisms, four different road radiuses have been considered. A maximum radius of curvature (12.42 meter), and a minimum radius of curvature (5.69 meter) and two other intermediate radii of curves (10.94meter and 8.06meter) have been taken. An optimization tool named genetic algorithm, which works based on Darwin's principle of natural selection, has been developed as an optimization tool to maximize the attainable velocity of a vehicle where no skidding and toppling will takes place.

Key words: *Ackermann steering geometry, opposite direction steering, parallel steering, optimization, genetic algorithm, skids, toppling.*

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I. INTRODUCTION

In a vehicle the steering mechanism helps the driver to maneuver. The primary function of the steering system is to allow the vehicle to take a turn. In conventional front wheel steering system, the rear wheels remain steady during turning while the front pair turns whereas, in rear wheel steering system the front wheels remain steady. A driver who negotiates a sharp turn in a hilly terrain may always wish the turn to be a larger radius or he has to reduce the speed of the car. Such desires of a driver could be satisfied if there were a four wheel steering mechanism instead of the conventional two wheel steering mechanism. Apart from the above mentioned two-wheeled steering system there is a concept of four-wheeled steering system in which the direction of turning of the front and rear wheels are either in opposite direction or in the same direction. In case of opposite direction steering mechanism, the rear wheels turn in a direction opposite to that of the front wheels. This type of steering is to be used when the car is to be turned at a low speed. In contrast, in the same direction steering mechanism, all the four wheels are turned in same direction. As a vehicle has always a chance to skid or topple, it is very much important to know the maximum speed at which an automobile may turn without derail before skidding or toppling takes place. As the turning of a car is a result of a combination of various parameters, an optimization technique has to be used to select the best combination from a set of available alternatives. A Genetic Algorithm, as an optimization tool, is used in the present study to achieve the maximum velocity by a four wheel steering system without skidding and toppling and also determines at which velocity no skidding and toppling will takes place for a particular vehicle. The specification of TATA NANO is taken as reference of a vehicle.

In this study a binary coded GA has been used to maximize the turning velocity while in cars running with three different types of steering mechanism. The mathematical models have been developed from the data of the road connecting between Hanumanthawaka to Simhachalam [1].

II. LITERATURE SURVEY

In a car, if engine can be said to be its heart, then steering mechanism is the eye which maneuver the car amidst traffic in a crowded street or round a sharp turn along the slopes of a hill. The present format of the steering mechanism, which has been patented by Rudolph Ackerman of England, is a geometric arrangement of linkages [2]. In order to maneuver a car, both the front wheels can be either turned equally or in-equally in the same direction. The former is known as parallel steering mechanism and the later is known as Ackerman Steering [3]. In Ackermann mechanism steering torques increase with increase in steering angle. The driver, thus, gets a feedback about the extent to which wheels are turned. There have been approaches where both of the front wheels as well as both of the rear wheels have been turned simultaneously [4]. There have been experiments on four wheel steering mechanism where all the wheels are mechanical engaged or disengaged during turning [5], turning by adjustable trapezoidal linkages [6], and also turning by mechatronics control [7]. Opposite wheel steering has been implemented and theoretically 41.13% and experimentally 50.43% reduction in turning radius has been observed [8]. Debnath et al.

optimizes the maximum skidding velocity and also shows that which wheel skids first [9].

While maneuvering a car, the turning velocity should depend upon the radius of the turn as well as the friction between the tyre and the track. Also, the driver has to turn the wheels to certain angle by turning the steering. In case of four wheel steering mechanism, both the front and rear wheels are to be turned. Thus to negotiate a turn effectively, the driver has to optimize the front wheel angle, rear wheel angle as well as the coefficient of friction between the road and the track. Apprehending that the velocity might not maximize along the steepest ascent path, a GA has been used in this study to optimize velocity, along with other constraints. The radii of curvature used in the study are based on the survey done by Murthy et al [1] at the hill top road from Hanumthawaka to Simachalam, Andhra Pradesh, India.

III. METHODOLOGY AND EQUATIONS

As the velocity of a car needs to be controlled to avoid skidding while negotiating a sharp turn, the practical parameters were optimized using a GA. The mathematical equations in the corresponding sections derive the maximum attained velocity under certain constraints. The derivation has been considered under steady state turning condition.

3.1 Maximum Steering Angle Finding

The maximum steering angle$(d_f = 34^0)$, has been obtained from the specification of TATA NANO [10], as shown in Fig. 1.

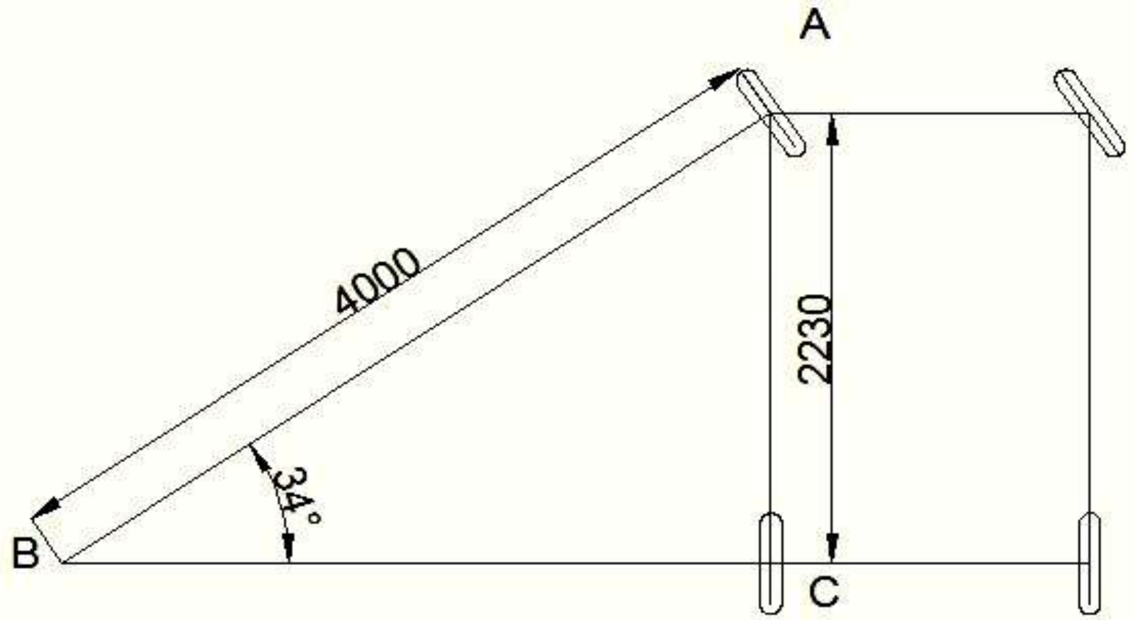

Fig. 1 Measurement of maximum steering angle

3.2 Condition to Resist Skidding

Let a vehicle (without any external load) be rotated about a point B (Fig. 1). The centrifugal force $(m\omega^2 r)$ of the vehicle will draw the vehicle away from the centre of rotation while frictional force $(\mu m g)$ between the wheels and the track will oppose this. For the purpose of analysis, centrifugal force here is assumed to be less than the frictional force to avoid skidding, thus

The condition for resisting skidding can be illustrated as:

Centrifugal force < Frictional force

$$m\omega^2 R < \mu m g$$

$$m\frac{v^2}{R^2}R < \mu m g$$

$$\frac{v^2}{R} < \mu g$$

$$v^2 < \mu g R \tag{1}$$

3.3 Condition for maximum skidding velocity during turning

While a car negotiates a turn, the velocity of all the four wheels will not be same, as the radii of these wheels from the centre of rotation are different. If the velocity of any of the wheel is greater than the velocity expressed in equation (1), the wheel will skid and thereby, the car will go out of balance.

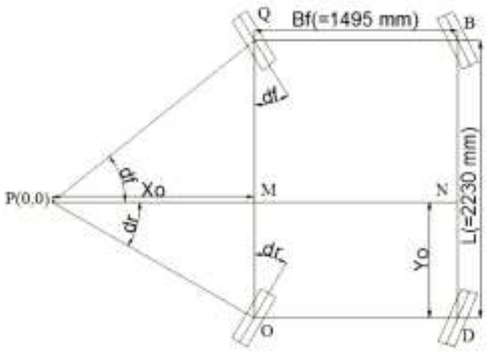

Fig. 2 Opposite wheel steering system

The schematic in Fig. 2 has been generated with the specifications of TATA NANO [10].

1. **Velocity of Front inner wheel**

$$v_{fi}^{2} < \mu g \sqrt{\left[\left\{\frac{l}{(\tan d_f + \tan d_r)}\right\}^2 + \left\{l - \frac{l \tan d_r}{(\tan d_f + \tan d_r)}\right\}^2\right]}$$

(2)

2. **Velocity of Outer front wheel**

$$v_{fo}^{2} < \mu g \sqrt{\left[\left\{\frac{l}{(\tan d_f + \tan d_r)} + b_f\right\}^2 + \left\{l - \frac{l \tan d_r}{(\tan d_f + \tan d_r)}\right\}^2\right]}$$

(3)

3. **Velocity of Inner rear wheel**

$$v_{ri}^{2} < \mu g \sqrt{\left[\left\{\frac{l}{(\tan d_f + \tan d_r)}\right\}^2 + \left\{\frac{l \tan d_r}{(\tan d_f + \tan d_r)}\right\}^2\right]}$$

(4)

4. **Velocity of Outer rear wheel**

$$v_{ro}^{2} < \mu g \sqrt{\left[\left\{\frac{l}{(\tan d_f + \tan d_r)} + b_f\right\}^2 + \left\{\frac{l \tan d_r}{(\tan d_f + \tan d_r)}\right\}^2\right]}$$

(5)

Subjected to:

$0.3 \leq \mu \leq 0.6$

$0 \leq d_f \leq 34$

$0 \leq d_r \leq 34$

3.4 Condition to Resist Toppling

Let a vehicle (without any external load) be rotated about a point B (Fig. 1). The body mass is considered to be uniformly distributed, so the height of the centre of gravity (CG) should be half of its height (in practical cases it is beneath the midpoint of the height).

If 'h' is the height and d_f is the wheel base of a vehicle, then the toppling velocity taking outer most point as the centre of topple, thus

The condition for resisting toppling can be illustrated as:

$$m\omega^2 R \frac{h}{2} < mg\frac{b_f}{2}$$

$$m\frac{v^2}{R^2} Rh < mgb_f$$

$$\frac{v^2}{R} < g\frac{b_f}{h}$$

$$v^2 < gR\frac{b_f}{h} \quad (6)$$

3.5 Condition for maximum toppling velocity during turning

While a car negotiates a turn, if the centre of gravity lies in the range of the surface area then no toppling will occur. If the CG comes out of beneath area then surely accidents will happen. Due to centrifugal force the CG tents to move away for the centre, and when CG goes beyond the surface covered by the four wheels then only toppling takes place. So from the centre of rotation the distance between the midpoint of the outer length of the car is the radius.

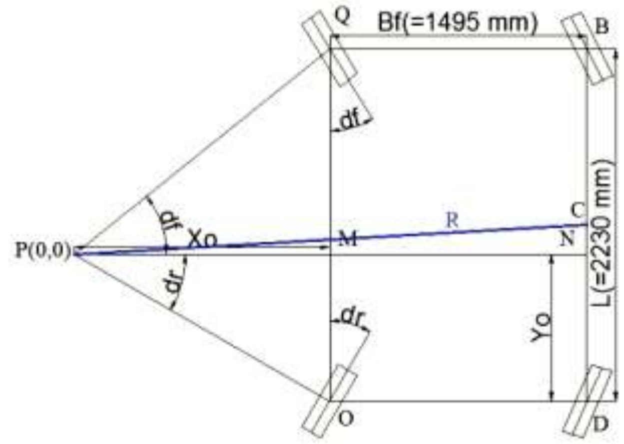

Fig. 3 Toppling radius in opposite wheel steering

Thus the toppling radius using Fig. 3 is as follow:

$$R_{toppling} = (x_0 + B_f)^2 + (\tfrac{l}{2} \sim y_0)^2 \quad (7)$$

And hence the toppling velocity becomes:

$$v_{toppling}^{2} < g\frac{b_f}{h}\{(x_0 + B_f)^2 + (\tfrac{l}{2} \sim y_0)^2\} \quad (8)$$

3.6 Constraints during optimization

In order to obtain the maximum achievable velocity in a particular wheel without skidding, the velocity represented by corresponding equations from (2) to (5), and for without toppling the velocity represented by the equation (8) has to be maximized subject to the following constraints: coefficient of friction between wheel and road ($0.3 \le \mu \le 0.6$), front steering angle ($0 \le d_f \le 34$) and rear steering angle($0 \le d_r \le 34$). In dry road the minimum tire-road friction coefficient, μ_{min}should be greater than 0.2 and the maximum tire-road friction coefficient, μ_{max} is 0.6, so to minimize the risk of skidding the μ_{min} and μ_{max} has been taken as 0.3 and 0.6 respectively [11]. The range of front steering angle (d_f)and rear steering angle (d_r)is kept between 0^o and 34^o (refer section 3.2).

When a vehicle starts to take a turn the initial load acts on both of the front wheels. The load gradually shifts on to the outer wheels leaving the rear inner wheel with less frictional force compared to the other three wheels. In such a case there is every possibility that the skidding will first take place in the rear inner wheel. Due to this reason maximum velocity of the inner rear wheel of the car has been considered as the limiting case velocity beyond which the rear wheel skids to de-stabilize the car.

3.7 Optimization

In this study a binary coded GA has been utilized to optimize the parameters within their domain as it is the most commonly used optimization tool. The flow chart of the performed GA is shown in Fig. 3.

3.8 GA Parameter Settings

The performance of genetic search depends on GA parameters, such as probability of crossover (P_c), probability of mutation (P_m), population size (N) and generation (G). Crossover probability has been taken as 0.5 (i.e. uniform crossover). Probability of mutation has been varied from 0.0833 to 0.25 and population size has been varied up to 150 [11]. Four bits are assigned for each variable (such as front steering angle, rear angle and co-efficient of friction). Mutation is generally kept fixed during the initial parametric study. Randomly 1 to 3 bits has been picked from a string of 12 bits converting mutation probability to 1/12, 2/12 and 3/12 respectively. The maximum number of generation has been varied up to 150 to obtain greater accuracy fitness (velocity). This investigation is made in three stages taking P_c as constant as discussed below.

Step 1: At P_c= 0.5, fixing N and G both at 100, P_m has been varied from 0.0833 to 0.25. The minimum value of the P_m whose corresponding fitness value was highest has been selected.

Step 2: Fixing P_m at that selected value, N has been varied (between 50 to 150) by keeping G as 100. The minimum value of the N whose corresponding fitness value was highest has been selected.

Step 3: In this step, P_m and N has been kept constant and G has been varied. It has been observed that velocity attains its maximum at a particular generation, which is considered to be the best, and does not improve further with any increase in the number of generation. These fittest parameters-P_m, N and G as discussed in Step 1 to Step 3, are the optimal parameters.

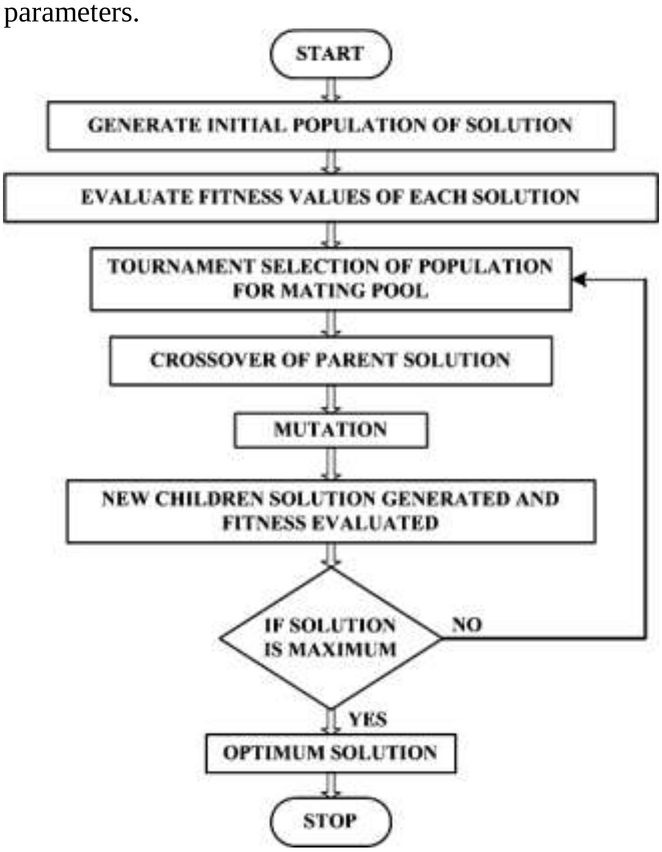

Fig. 4 Flow chart of GA

IV. RESULTS AND DISCUSSION

Previous investigations on four wheel steering focused only in minimizing turning radius, which was projected for driving in less speed. In this work, for a particular radius of curvature of road, maximum achievable speed of a car before skidding has been observed.

After the parametric study the optimal parameters came out as following: Crossover probability, P_c = 0.5; Mutation probability, P_m = 0.15; Population size, N = 130; Generation, G = 80.

These optimal GA parameters have been used to determine the maximum velocity of the rear inner wheel, beyond which the car is likely to skid. Table 1 compares the result of maximum velocities as observed amongst conventional front wheel steering, rear wheel steering and combination of both the steering for given a sharp radius of turn along with their corresponding front angle, rear angle and coefficient of friction obtained by the developed GA. The GA optimized the coefficient of friction to be 0.6 which is the maximum within the range. At a glance it can be seen, in Fig. 5 that in all the cases maximum skidding velocity is achieved when the car is steered by its rear wheels. Table 2 shows the percentage of skidding velocity increasing in rear wheel steering and opposite wheel steering as compared to ordinary steering system. While in Fig. 6, in all the cases maximum toppling velocity is achieved when the car is steered by its rear wheels. Table 4 shows the percentage of toppling velocity increasing in rear wheel steering and opposite wheel steering as compared to ordinary steering system.

Table 1 Skidding Velocity of the car

Radius of the road=5.69 meter				
Type	Maximum velocity [km/hr]	Front angle	Rear angle	Friction
Only front wheel steering	14.5170	18.3332	0	0.6
Only rear wheel steering	15.4924	0	18.3332	0.6
Combination of both	15.1962	9.1666	9.1666	0.6
Radius of the road=8.06 meter				
Only front wheel steering	20.6090	13.5679	0	0.6
Only rear wheel steering	21.3073	0	13.5679	0.6
Combination of both	21.1048	6.7839	6.7839	0.6
Radius of the road=10.94 meter				
Only front wheel steering	27.8036	10.3542	0	0.6
Only rear wheel steering	28.3251	0	10.3542	0.6
Combination of both	28.1788	5.1771	5.1771	0.6
Radius of the road=12.42 meter				
Only front wheel steering	31.4625	9.2364	0	0.6
Only rear wheel steering	31.9243	0	9.2364	0.6
Combination of both	31.7962	4.6182	4.6182	0.6

Table 2 Percentage of skidding velocity increasing

	Radius of the road			
STEERING TYPE	5.69 meter	8.06 meter	10.94 meter	12.42 meter
Only rear wheel steering	6.72%	3.39%	1.88%	1.47%
Combination of both	4.68%	2.4%	1.35%	1.06%

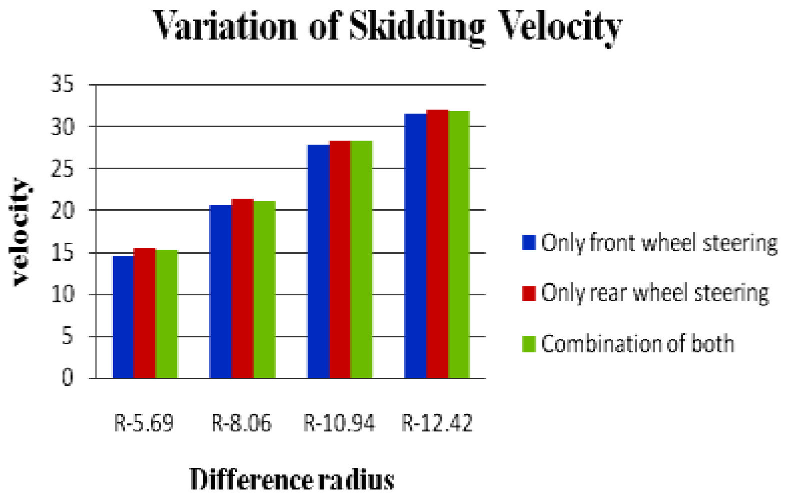

Fig. 5 Different Skidding Velocity at different radius

Table 3 Toppling Velocity of the car

Type	Maximum velocity [km/hr]	Front angle	Rear angle	Friction
Radius of the road=5.69 meter				
Only front wheel steering	26.4011	18.3332	0	0.58
Only rear wheel steering	28.2421	0	18.3332	0.4400
Combination of both	27.4820	9.1666	9.3246	0.6
Radius of the road=8.06 meter				
Only front wheel steering	34.3313	13.5679	0	0.58
Only rear wheel steering	39.7664	0	13.5679	0.4400
Combination of both	35.1134	6.7839	6.8671	0.6
Radius of the road=10.94 meter				
Only front wheel steering	43.7229	10.3542	0	0.58
Only rear wheel steering	44.8585	0	10.3542	0.4400
Combination of both	44.2966	5.1771	5.2240	0.6
Radius of the road=12.42 meter				
Only front wheel steering	48.5050	9.2364	0	0.58
Only rear wheel steering	49.5911	0	9.2364	0.4400
Combination of both	49.0041	4.6551	4.6182	0.6

Table 4 Percentage of toppling velocity increasing

	Radius of the road			
STEERING TYPE	5.69 meter	8.06 meter	10.94 meter	12.42 meter
Only rear wheel steering	6.97%	15.83%	2.59%	2.23%
Combination of both	4.09%	2.27%	1.31%	1.02%

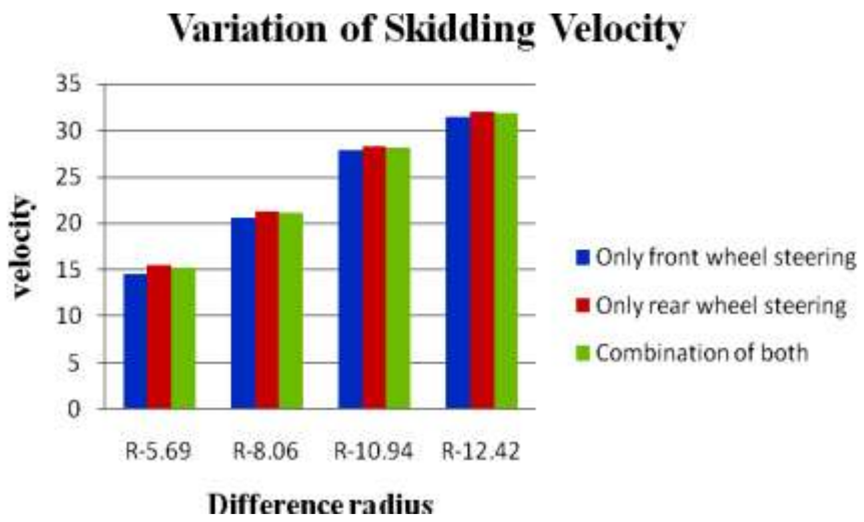

Fig. 6 Different Toppling Velocity at different radius

V. CONCLUSIONS

(a) It has been observed that rear wheel steering system can achieve greater velocity than opposite wheel steering and front wheel steering system. (b) The maximum attainable speed of any car in hilly roads of smaller radius of curvature can be found out; following that driver can stably run the car. (c) It has been found that the maximum velocity attained without skidding using rear wheel steering mechanism can be 9.1% greater than the conventional front wheel steering and 8.5% greater than opposite steering in four wheel steering mechanism. (d) always the toppling velocity is more than the skidding velocity. So, the skidding velocity of the vehicle is the maximum achievable speed of a car.

NOMENCLATURE

df=front angle;
l=Legth of the car;
h=Height of the car;
g=Gravitational force;
m= mass of the body;
Pc=crossover probability;
G=number of generation;
dr=Rear angle;
bf=Wheel base of the car;
v=Velocity;
μ= frictional coefficient of rear and tyre;
Pm=mutation probability;
N=number of population;
GA=geometrical algorithm

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