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Gradeability for Automobiles

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Abstract: *The demand for transport has been growing rapidly and the footprints of roads have been widespread to areas which were previously inaccessible, especially hilly areas. Road inclinations are not always at zero. Vehicles should have the capability to take gradients even on full loads. The Gradeability of a vehicle is dependent on multiple factors such as the type of road surface, weight of the vehicle, tractive effort at the wheels, tire grip (at low speeds the aerodynamic drag is ignored). Since a vehicle should be ready to be driven on all types of terrains, tractive effort and tire grip become the deciding factors. This paper presents a method to determine the gradeability and enhance it to the required scale.*
Keywords: *gradeability, resistance, tractive effort, traction, traction diagram.*

I. Introduction

Gradeability is defined as the highest grade a vehicle can ascend maintaining a particular speed. When designing an automobile, various performance targets are kept in view, the major ones being weight, fuel economy, power, torque, speed, and acceleration, gradeability is given a lesser significance unless a special purpose vehicle is being designed like a Sports Utility Vehicle (**SUV**s) or other heavy duty vehicles. Urban vehicles do have to encounter situations where they might have to ascend slopes like a basement or a bridge. These situations might prove to become difficult for the driver when on full load, hence making it an important performance factor not only for Special Purpose vehicles but also to those driven in the urban land.

Gradeability is measured in multiple ways, mainly:

- As an angle of inclination to the horizontal (20˚, 30˚, 45˚, etc.).
- As a percentage of rise over run.
- As a ratio of one part run to some particular number of parts (1 in 20 meters, 1 in 50 feet, etc.)

II. Approach

The major factors affecting the Gradeability were discussed concisely above, going to the mechanic of the problem, a vehicle is subjected to three resistances chiefly, and they are, rolling resistance, gradient resistance and aerodynamic resistance. If a vehicle has to start rolling, it has to generate enough tractive force at the wheels to exceed these resistances.

1.1 Tractive force

It is the net force available at wheels. To determine this force we use the formula:

$$\frac{T_e \rho_t G}{R_r} \quad (1)$$

T_e: Torque at the engine
ρ_t: Transmission efficiency
G: gear ratio
R_r: rolling radius

1.2 Rolling resistance

This is the resisting force that opposes the rolling of the tires, which is caused due to non-elastic effects at the tire-road surface; it is given by the formula:

$$R_r = kW\cos\theta \quad (2)$$

k: coefficient of rolling resistance (.2 for loose sand)
W: weight of the vehicle in N
θ: Angle of inclination

1.3 Gradient resistance

When negotiating a slope, a component of weight acts against the direction of motion which is proportional to the angle of inclination of the road surface.

$$R_g = W sin\theta \quad (3)$$

1.4 **Aerodynamic Resistance**

Similarly, we consider the resistance offered from the air in the direction opposite to motion of the vehicle:

$$R_d = \frac{1}{2}\rho C_d A V^2 \quad (4)$$

ρ: Density of air (1.2kg/m^3)
C_d: Coefficient of drag ()
A: Projected area in m^2
V: velocity in m/s

1.5 **Total Resistance**

$$R = R_r + R_g + R_d \quad (5)$$

III. Case Study

The above approach can be explained with a case study of an All-Terrain Vehicle designed for competing at SAE BAJA INDIA and we draft a Traction Diagram to estimate the Gradeability of this vehicle.

The specifications of the vehicle are as follows:

Table 1

Vehicle	BAJA SAE BUGGY
Power	10hp@3250rpm
Torque	19.66N-m@2800rpm
Weight	300kg
Tyre Radius	10.5inch/.2667m
Rolling radius (.96*R)	.256m
Frontal projected area	.7235m^2
Transmission efficiency	85%
Gearbox type	Sequential

Table 2

Gear	Gear ratio
1	31.48:1
2	18.70:1
3	11.40:1
4	7.66:1
Reverse	55.08:1

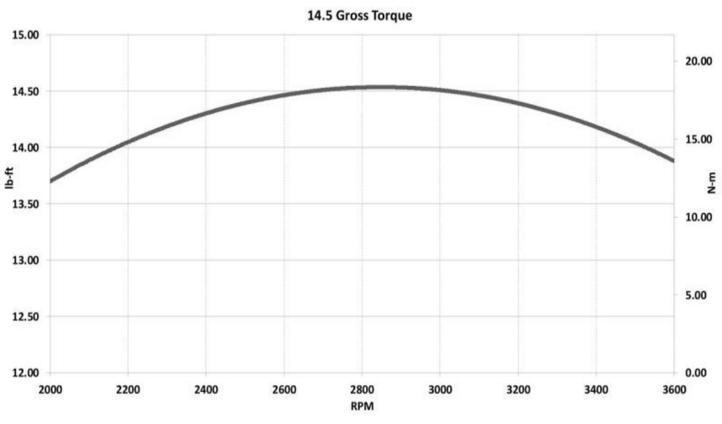

Fig. 1

1.6 **Tractive effort calculations**

Using equation (1) we calculate the tractive force at wheels for different gears.

Table 3

Gear	Tractive effort (N)
1	2055
2	1220
3	744
4	500
R	3595

1.7 **Calculations of different resistances**

1.7.1 Rolling resistance

The second step involves calculating the rolling resistance for different gradients, ranging from 0% to 100% using equation (2).

Table 4

Gradient (%)	R_r
0	588.6
20	577.5
40	546.8
60	504.7
80	457.7
100	416.42

1.7.2 Gradient resistance

The third step is to calculate the gradient resistance for different grades by using equation (3).

Table 5

Gradient (%)	R_g
0	0
20	577.17
40	1092.9
60	1515.75
80	1852.08
100	2081.01

1.7.3 Air resistance

The following table contains the drag force values

Table 6

Speed (kmph)	R_d
5	.629
10	2.516
15	5.652
20	10.06
25	15.726
30	22.43
35	30.76
40	40.117
45	50.87
50	62.8
55	76

1.7.4 Total resistance

For this, we take the values of all the resistances obtained at a particular gradient for different speeds and add them to get the total resistance. We tabulate this data for drafting the Traction Diagram later.

1.7.4.1 0% Gradient

Table 7

Speed	Traction
0	588.6
5	589.229
10	591.116
15	594.252
20	598.66
25	604.326
30	611.03
35	619.36
40	628.71
45	639.47
50	651.4
55	664.6

1.7.4.2 20% Gradient

Table 8

Speed	Traction
0	1154.67
5	1155.303
10	1157.19
15	1160.326
20	1164.734
25	1170.4
30	1177.04
35	1185.374
40	1194.374
45	1205.544
50	1217.474
55	1230.374

1.7.4.3 40% Gradient

Table 9

Speed	Traction
0	1639.7
5	1640.329
10	1642.216
15	1645.352
20	1649.76
25	1655.426
30	1662.13
35	1670.46
40	1679.817
45	1690.57
50	1702.15
55	1715.7

1.7.4.4 60% Gradient

Table 10

Speed	Traction
0	2020.45
5	2063.179
10	2064.706
15	2068.202
20	2072.61
25	2078.276
30	2084.98
35	2093.31
40	2102.667
45	2113.42
50	2125.35
55	2138.55

1.7.4.5 80% Gradient

Table 11

Speed	Traction
0	2211.5
5	2310.409
10	2312.296
15	2315.432
20	2319.84
25	2325.506
30	2332.21
35	2340.54
40	2349.897
45	2359.897
50	2372.58
55	2385.78

1.7.4.6 100% Gradient:

Table 12

Speed	Traction
5	2498.054
10	2499.946
15	2503.082
20	2507.49
25	2513.156
30	2519.86
35	2528.19
40	2537.54
45	2548.3
50	2560.23
55	2573.43

1.8 **Tractive force Available**

From the range of 2000-3600rpm the speed and traction available at different gears should be calculated. For this, the torque diagram (figure 1) for the engine should be referred to find the exact torque available at different intervals of engine speed.

For example, in first gear, at 2000rpm, the torque available at engine output is 13.7N-m, by putting this in equation (1); we get the tractive force at the wheels.

Also, convert the angular velocity to linear velocity.

(Using the formula: $\frac{\pi DN}{G}$).

1.8.1 First gear

Table 13

Speed	**Traction**
6.45	1941.41
7.1	1991.058
7.74	2026.491
8.39	2047.605
9.038	2065.374
9.684	2047.605
10.329	2040.602
10.91	2012.067
11.62	1962.732

1.8.2 Second gear

Table 14

Speed	**Traction**
10.846	1168.118
11.93	1197.991
13.0152	1219.311
14.099	1232.015
15.18	1242.706
16.269	1232.015
17.35	1227.801
18.43	1210.632
19.52	1180.948

1.8.3 Third gear

Table 15

Speed	**Traction**
17.9	703.025
19.7	721.004
21.49	733.83
23.28	741.481
25.07	747.916
26.86	741.481
28.65	738.945
30.45	728.612
32.24	710.747

1.8.4 Fourth gear

Table 16

Speed	**Traction**
26.656	472.33
29.32	484.416
31.98	493.036
34.65	498.173
37.318	502.496
39.98	498.173
42.64	496.469

45.3152	489.527
47.98	477.524

1.9 **Traction diagram**

After the calculation of Tractive effort required and Tractive effort available are done and tabulated, the last step is to use this data to create a graph called Traction Diagram, which is a measure to check the climbing performance of an automobile. The Traction available and traction required are plotted as a function of the vehicle speed.

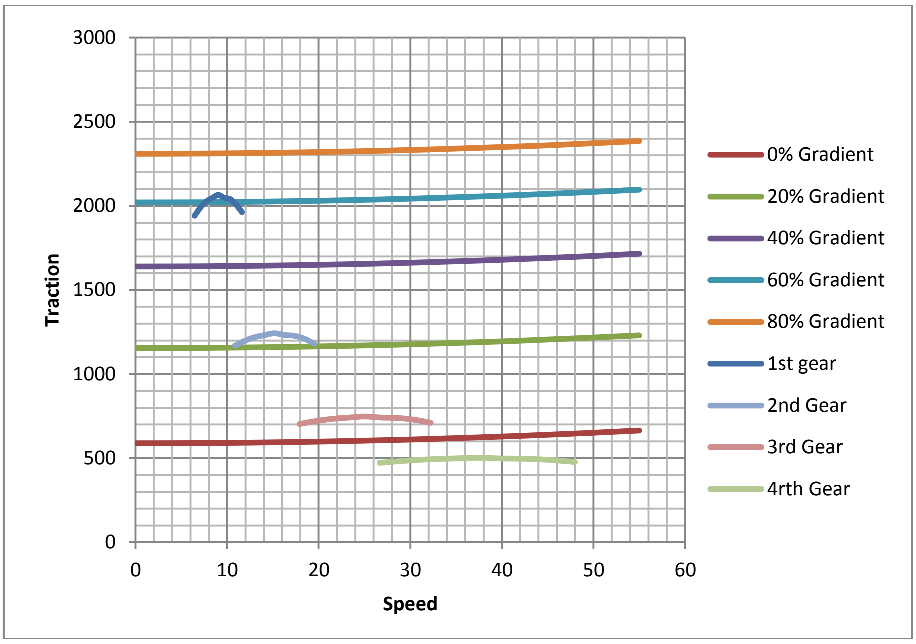

Fig. 2

1.1 **Results**

The gradeability can be calculated from the above graph, which is 64% for this vehicle.

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