

# Computing Gear Ratio Required For All-Terrain Vehicle

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**ABSTRACT:** Traction force is the necessary resistance offered by ground to the vehicle motion. Traction provides the firm grip that every vehicle needs for smooth manoeuvrability. But, wheels lose the grip with the ground, if the traction force is increased or decreased than the required value. Due to this, driver loses control of the vehicle. Hence, it is necessary for vehicle to move between the maximum and minimum traction values. Various factors and their forces affect the vehicle motion such as Coefficient of friction, Weight of the vehicle, Gradient and Air resistance.

**KEYWORDS:** Traction, Traction Torque, Vehicle Dynamics, Computation, Gear ratio.

## I. INTRODUCTION

Traction force is the resistance offered by the ground in the direction of the vehicle movement at the contact of tires and the ground. Because of this resistance, tires are able to grip the ground at all time and driver can control the vehicle smoothly. Like other resistances vehicle needs to overcome the traction force to move in the desired direction. This traction force acts at every wheel as you can observe in the figure 1 that represents a free body diagram of a wheel.

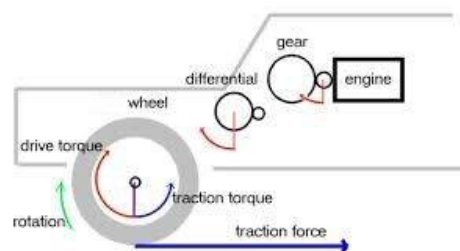


Figure 1 Forces acting on a wheel.

From the figure 1, you can clearly observe that driving torque and traction torque, generated from traction force, are in the opposite direction. Hence, driving torque must always be greater than the traction torque to move vehicle forward. The traction torque which a vehicle needs to overcome is the one associated with the minimum traction force. And this minimum traction force is nothing but rolling frictional force between a wheel and the ground. Along with the minimum traction force, there is a maximum traction force which is kinetic friction force. Formula for friction force:

$$\text{Force (F)} = \text{Coefficient of friction } (\mu) \times \text{Weight of the vehicle } (W=mxg)$$

A vehicle operates between these maximum and minimum values of traction force. If you provide driving force less than the rolling resistance, vehicle will not move. For example, when you push your car, until push force exceeds the rolling resistance car will not move forward. If driving force is more than the kinetic friction force, wheels will slip. For example, when a driver tries to get the car out of muddy region, tire rotates and digs out the mud from the ground. In this case, mud cannot provide the traction which matches starting torque of the vehicle.

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## II. RELATED WORK

### 1. Coefficient of Friction:

There are 2 types of coefficient of friction namely, rolling coefficient and sliding coefficient. From the table below, we select values of both coefficients of frictions.

Rolling Resistance Coefficients	
Conditions	Rolling resistance coefficient
Car tires on concrete or asphalt	0.013
Car tires on rolled gravel	0.02
Tar macadam	0.025
Unpaved road	0.05
Field	0.1–0.35
Truck tires on concrete or asphalt	0.006–0.01
Wheels on rail	0.001–0.002

Table 1: Rolling resistance coefficients

Average Values of Tractive Effort Coefficient on Various Roads		
Surface	Peak Values, $\mu_p$	Sliding Values, $\mu_s$
Asphalt and concrete (dry)	0.8–0.9	0.75
Concrete (wet)	0.8	0.7
Asphalt (wet)	0.5–0.7	0.45–0.6
Gravel	0.6	0.55
Earth road (dry)	0.68	0.65
Earth road (wet)	0.55	0.4–0.5
Snow (hard packed)	0.2	0.15
Ice	0.1	0.07

Table 2: Sliding resistance coefficients

Our case study is for all-terrain vehicle so we will consider maximum rolling resistance coefficient. Hence, we can consider maximum rolling resistance for the vehicle.

Rolling resistance coefficient = 0.05 (unpaved road)

Sliding resistance coefficient = 0.65 (Earth road)

### 2. Drag Coefficient:

Coefficient of drag depends on shape of the car and below table displays the drag coefficients corresponding to the car shape.

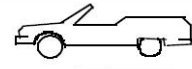



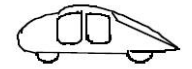


Vehicle Type	Coefficient of Aerodynamic Resistance
 Open convertible	0.5–0.7
 Van body	0.5–0.7
 Ponton body	0.4–0.55
 Wedge-shaped body; headlamps and bumpers are integrated into the body, covered underbody, optimized cooling air flow	0.3–0.4
 Headlamp and all wheels in body, covered underbody	0.2–0.25
 K-shaped (small breakway section)	0.23
 Optimum streamlined design	0.15–0.20
Trucks, road trains	0.8–1.5
Buses	0.6–0.7
Streamlined buses	0.3–0.4
Motorcycles	0.6–0.7

Table 3: Coefficient of drag

According to the shape of the car, coefficient of aerodynamic resistance is between 0.5 and 0.7. Hence, we consider coefficient of aerodynamic resistance as 0.6.

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### 3. Air density:

We are considering temperature as a variable on which the air density is dependent. Hence, below table shows us temperature and corresponding air density values.

AIR DENSITY AT STANDARD TEMPERATURE AND PRESSURE (STP)

Temperature °C	Temperature °F	Density, dry air [kg/m <sup>3</sup> ]	Maximum water content [kg/m <sup>3</sup> ]
-25	-13	1.423	
-20	-4	1.395	
-15	5	1.368	
-10	14	1.342	
-5	23	1.317	
0	32	1.292	0.005
5	41	1.269	0.007
10	50	1.247	0.009
15	59	1.225	0.013
20	68	1.204	0.017
25	77	1.184	0.023
30	86	1.165	0.030
35	95	1.146	0.039
40	104	1.127	0.051

STP = density of dry air at standard atmospheric pressure at sea level at 15°

Table 4: Air Density with Temperature

Vehicle will be working in hot environment so we consider the temperature as 35 degrees.

$$\text{Air density} = 1.146 \text{ kg/m}^3.$$

### 4. Engine properties:

Below table and graph shows the amount of torque available at corresponding engine RPM for Briggs and Stratton 305 cc engine.

Engine RPM	Engine Torque (N.m)
2000	10.68
2200	13.35
2400	18.56
2600	18.82
2800	19.09
3000	19.96
3200	18.82
3400	18.42
3600	18.02
3800	16.02

Table 5: Engine Torque vs. Engine RPM

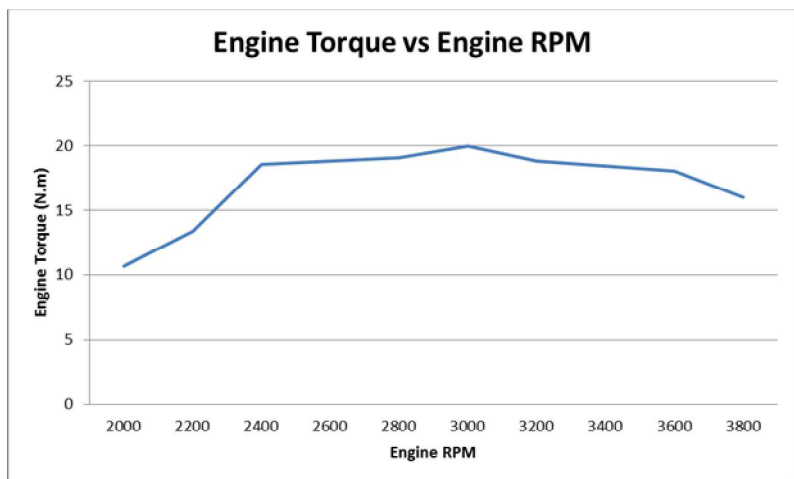


Figure 1: Engine Torque vs. Engine RPM

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## III. FORCES ACTING ON VEHICLE

Various forces act on a vehicle while driving and at rest condition. Traction force, Drag force and Gradient resistance are considered in the scope of this research paper. When considering traction it is not necessary to consider each wheel individually unless dynamic weight shifting is considered. Since, mass on each wheel adds up to total mass of the vehicle. Figure 2 represents following forces acting on a vehicle on gradient.

- $F_w$  = Air resistance
- $F_{tr}$  &  $F_{tr}$  = Rolling resistance at front and rear wheel
- $M_v g \sin \alpha$  = Gradient resistance
- $M_v g$  = Weight of the vehicle
- $W_f$  &  $W_r$  = Normal reaction at front and rear wheel
- $\alpha$  = Gradient angle
- $\mu$  = Coefficient of friction

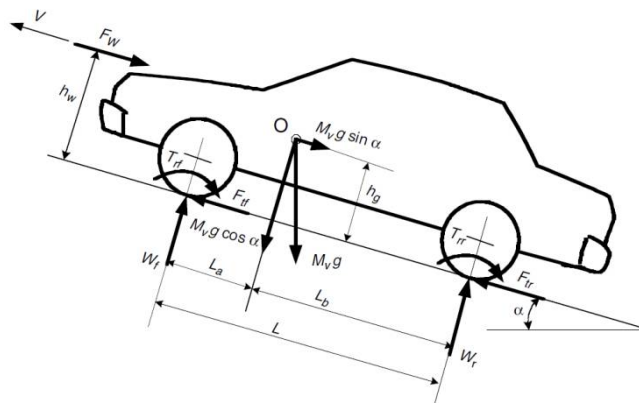


Figure 2: Forces acting on a vehicle

## IV. FORMULAE

Following are the formulae used in in this paper:

- Gradient resistance =  $M_v \times g \times \sin \alpha$
- Air resistance =  $0.5 \times \rho \times A_f \times C_D \times (V + V_w)^2$
- Rolling resistance =  $\mu \times M_v \times g \times \cos \alpha$
- Torque = Force x Radius
- Gear ratio = Wheel Torque / Engine Torque
- Gear ratio = Engine RPM / Wheel RPM
- Wheel RPM = (Wheel Velocity (m/s) x 60) / (2 x  $\pi$  x Tyre radius)
- nth term of Geometric progression ( $t_n$ ) =  $a(r)^{(n-1)}$

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## V. CASE STUDY

We are taking a case study of a BAJA all-terrain vehicle to calculate ratio of powertrain required to incline 30 degree gradient and has maximum velocity of 80kmph.

Consider following parameters related to the scenario:

- Mass of the vehicle ( $M_v$ ) = 300kg
- Gravitational constant ( $g$ ) = 9.81 m/s<sup>2</sup>
- Gradient angle ( $\alpha$ ) = 30 degrees
- Coefficient of friction (rolling) = 0.05
- Coefficient of friction (sliding) = 0.65
- Air density ( $\rho$ ) = 1.146 kg/m<sup>3</sup>
- Frontal Area ( $A_f$ ) = 1sq.m.
- Coefficient of aerodynamic drag ( $C_D$ ) = 0.6
- Speed of the wind ( $V_w$ ) = 5 kmph = 1.39 m/s<sup>2</sup>
- Tyre Radius = 0.2921 m

### Calculations:

- Gradient resistance =  $M_v \times g \times \sin\alpha$   
=  $300 \times 9.81 \times \sin(30)$   
= 1471.50 N.
- Air resistance =  $0.5 \times \rho \times A_f \times C_D \times (V+V_w)^2$   
=  $0.5 \times 1.146 \times 1 \times 0.6 \times (1.39)^2$   
= 0.66 N (Negligible)
- Rolling resistance =  $\mu \times M_v \times g \times \cos\alpha$   
=  $0.05 \times 300 \times 9.81 \times \cos(30)$   
= 127.43 N
- Minimum torque = (Rolling resistance + Gradient resistance) x Tyre radius  
=  $(127.43 + 1471.50) \times 0.2921$   
= 467.04 N.m
- Sliding resistance =  $\mu \times M_v \times g \times \cos\alpha$   
=  $0.65 \times 300 \times 9.81 \times \cos(30)$   
= 1656.62 N
- Maximum torque = (Sliding resistance + Gradient resistance) x Tyre radius  
=  $(1656.62 + 1471.50) \times 0.2921$   
= 913.72 N.m
- Ideal 1<sup>st</sup> gear ratio:  
Consider we want to engage the gear at 3000 RPM to provide maximum allowed torque at the wheel to get maximum acceleration.  
  
Gear ratio = Wheel Torque / Engine Torque  
=  $913.72 / 19.96$   
= 45.77
- Ideal 4<sup>th</sup> gear ratio:  
For the BAJA all-terrain vehicle, generally maximum velocity of 80 kmph is sufficient. Hence, maximum velocity will be at maximum engine RPM i.e.3800.

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$$\begin{aligned} \text{Wheel RPM} &= (\text{Wheel Velocity (m/s)} \times 60) / (2 \times \pi \times \text{Tyre radius}) \\ &= (80 \times 5 \times 60 / 18) / (2 \times 3.14 \times 0.2921) \\ &= 751 \end{aligned}$$

$$\begin{aligned} \text{Gear ratio} &= \text{Engine RPM} / \text{Wheel RPM} \\ &= 3800 / 751 \\ &= 5.22 \end{aligned}$$

- Ideal intermediate gear ratios:

Main problem with any type of gears is the loss of power while transmission. There is an unobtainable (wasted) power due to stepped traction-speed characteristics given by the mechanical transmission relative to the ideal one with continuous power transmission. The problem constraints represent the mathematical relations between different gearbox ratios. The optimal solution of the problem proves that choosing the gear ratios according to the geometric progression gives the global minimum wasted power.

Hence considering that the required gear ratios are in geometric progression we can calculate the intermediate gear ratios,

$$\text{Ideal 1}^{\text{st}} \text{ gear Ratio} = 45.7:1$$

$$\text{Ideal 4}^{\text{th}} \text{ Gear ratio} = 5.22:1$$

Both of these gear ratios must be in the geometric progressive series. We know, any nth term in such sequence is given by,

$$t_n = a(r)^{(n-1)}$$

Where,

a = First term

r = Common ratio

n = Number of gear

For our purpose a = 5.22 (ideal gear ratio) and n = 4(fourth gear)

$$45.77 = 5.22 * (r)^{(4-1)}$$

$$r = 2.06$$

The intermediate gears ideally have to be in such progression as well.

By using above equation we can calculate the 2nd and the 3rd gear ratios.

$$\begin{aligned} \text{Ideal 2}^{\text{nd}} \text{ gear } (t_2) &= 5.22 \times (2.06)^{(2-1)} \\ &= 10.76 \end{aligned}$$

$$\begin{aligned} \text{Ideal 3}^{\text{rd}} \text{ gear } (t_3) &= 5.22 \times (2.06)^{(3-1)} \\ &= 22.15 \end{aligned}$$

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## VI. RESULT

We calculated the minimum torque required to move the vehicle and maximum torque that can be provided to wheels without wheel-spin at 30 degrees gradient. From this range of torque, we were able to find out ideal gear ratios for BAJA all-terrain vehicle. These obtained values were very useful in guiding us to select a proper powertrain system for our vehicle.

Gear	Required Gear Ratio	Available Gear Ratio
1 <sup>st</sup>	45.3 :1	41.57:1
2nd	21.94 : 1	18.7:1
3rd	10.7 :1	11.38 : 1
4th	5.22 :1	7.04 : 1

Table 6: Gear ratios

We were able to find a gearbox that sufficiently fulfilled our vehicle's requirements. This gearbox had integrated clutch and differential, so the total gear ratio was the multiple of clutch gear ratio, gearbox ratio and differential gear ratio. Though it is not an exact match, it provides the needed acceleration and velocity.

## VII. CONCLUSION

We calculate the gear ratios by first deciding the environment in which the vehicle will move. From these fixed parameters, traction values are computed to get a range of force or torque that can be provided at wheels. From the formulae, it is clear that as gradient increases tractive effort increases and so the minimum torque required for moving the vehicle. When provided torque exceeds maximum torque value, wheel will slide instead of rolling which will reduce the efficiency of the vehicle and increase the wear of the tyre.

Weight shifting during acceleration and braking contributes to the tractive effort. Apart from this, aerodynamic drag adds into the resistance at high speeds. But, inertia of the vehicle opposes the resistance. Hence, tractive effort and torque required varies in dynamic conditions.

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