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# Design Concept of Electric Vehicle



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## **Power and Mass Computations for Initial Vehicle Sizing**

Electric vehicles (HEVs) are expected to meet two performance criteria in order to compete successfully with conventional vehicles. The first criterion is the time required to accelerate from zero to 60 mph. The vehicles must also be able to negotiate a minimum grade at a constant speed. Argonne developed a model to compute power requirements associated with these criteria. Each drivetrain component is sized to meet the power requirements and its mass is then computed. The model is described in this section.

### **Power Requirements**

The procedure presented here estimates power requirements for accelerating on a flat road (no grade) and negotiating a grade represented by an angle  $\theta$  at a constant speed. We assume that the air is still and vehicles are not required to accelerate from a stop to the maximum speed up a hill or a ramp.



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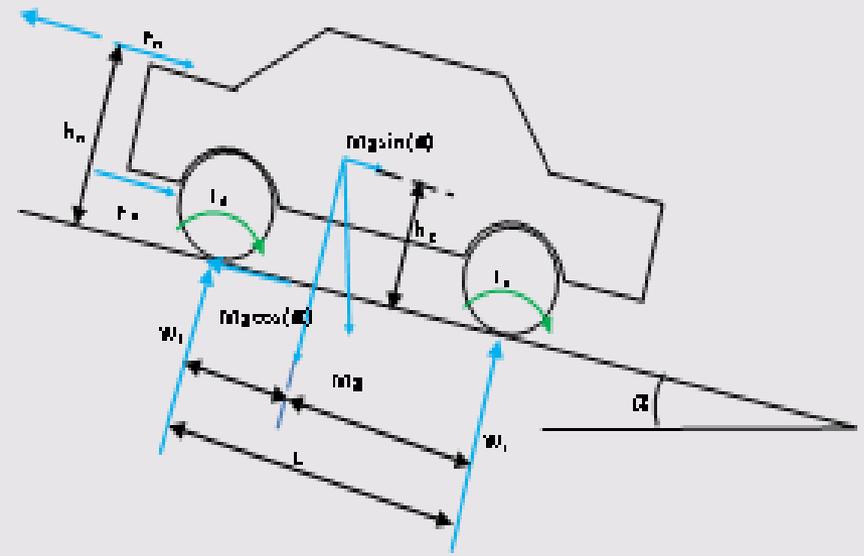
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## General description of vehicle movement

The vehicle motion can be completely determined by analysing the forces acting on it in the direction of motion. The forces acting on a vehicle, moving up a grade, are shown in **Figure**

1. The tractive force ( $F_t$ ) in the contact area between the tires of the driven wheels and the road surface propels the vehicle forward. The tractive force ( $F_t$ ) is produced by the power plant and transferred to the driving wheels via the transmission and the final drive. When the vehicle moves, it encounters a resistive force that tries to retard its motion. The resistive forces are

- Rolling resistance
- Aerodynamic drag
- Uphill resistance





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Using the Newton's second law of motion, the vehicle acceleration can be expressed as

$$\frac{dV}{dt} = \frac{\sum F_t - \sum F_{resistac}}{\delta M}$$

Where

$V$  = vehicle speed

$\sum Ft$  = total tractive effort [ $Nm$ ]

$\sum F_{resistance}$  = total resistance [ $Nm$ ]  $M$  = total mass of the vehicle [ $kg$ ]

$\delta$  = mass factor for converting the rotational inertias of rotating components into translational mass

## Rolling resistance

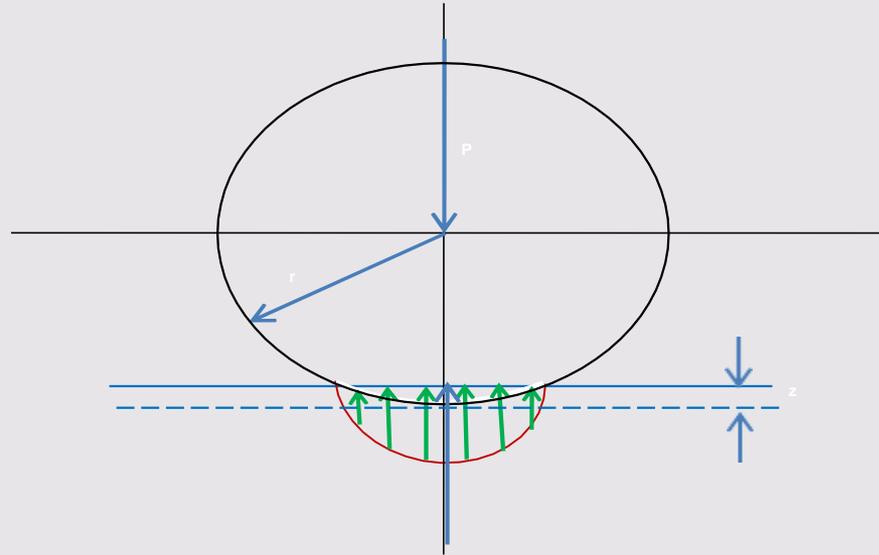
The rolling resistance of tires on hard surfaces is due to hysteresis in the tire material. In **Figure 2** a tire at standstill is shown. On this tire a force ( $\mathbf{P}$ ), is acting at its centre. The pressure in the contact area between the tire and the ground is distributed symmetrically to the centre line and the resulting reaction force ( $\mathbf{P}_z$ ) is aligned along  $\mathbf{P}$ .



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$$Fr = Mg F_r \cos(\alpha)$$

where

$P$  = Normal load acting on the centre of the rolling wheel [N]

$f_r$  = rolling resistance coefficient

$\alpha$  = road angle [radians]



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## **Aerodynamic drag**

A vehicle traveling at a particular speed in air encounters a force resisting its motion. This force is known as aerodynamic drag.

$$F_w = \frac{1}{2} * \rho * A_f * C_D * V^2$$

where

$\rho$  =density of air

$A_f$  =vehicle frontal area

$V^2$ = vehicle speed

$C_D$ = drag coefficient

## **Grading resistance**

When a vehicle goes up or down a slope, its weight produces a component of force that is always directed downwards, This force component opposes the forward motion, i.e. the grade climbing.



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When the vehicle goes down the grade, this force component aids the vehicle motion. The grading resistance can be expressed as

$$F_g = Mg \sin(\alpha)$$

Where

$M$  = mass of vehicle [ $kg$ ]

$g$  = acceleration constant [ $m / s^2$ ]

$\alpha$  = road angle [ $radians$ ]

## Acceleration resistance

In addition to the driving resistance occurring in steady state motion, inertial forces also occur during acceleration and braking. The total mass of the vehicle and the inertial mass of those rotating parts of the drive accelerated or braked are the factors influencing the resistance to acceleration:

$$F_a = \lambda * M * \frac{dv}{dt}$$

where

$\lambda$  = rotational inertia constant

$M$  = mass of the vehicle [ $kg$ ]

$V$  = speed of the vehicle [ $m / s$ ]



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Total driving resistance The traction force ( $F_t$ ) required at the drive wheels is made up of the driving resistance forces and is defined as

$$F_{resistance} = F_r + F_w + F_g + F_a$$

$$F_{resistance} = Mg F_r \cos(\alpha) + \frac{1}{2} * \rho * A_f * C_D * V^2 + Mg \sin(\alpha) + F_a = \lambda * M * \frac{dv}{dt}$$

power required ( $P_{req}$ ):

$$P_{req} = F_{resistance} * V$$

## Drive train tractive effort and vehicle speed

After having dealt with the configuration of the drivetrain, this section deals with the **tractive effort**. The torque transmitted from the power plant to the driven wheels ( $T_w$ ) is given by

$$T_w = i_g i_o \eta_t T_p$$

Where

$i_g$  = gear ratio of the transmission

$i_o$  = gear ratio of the final drive

$\eta_t$  = efficiency of the driveline from the power plant to the driven wheels

$T_p$  = torque output from the power plant [Nm]



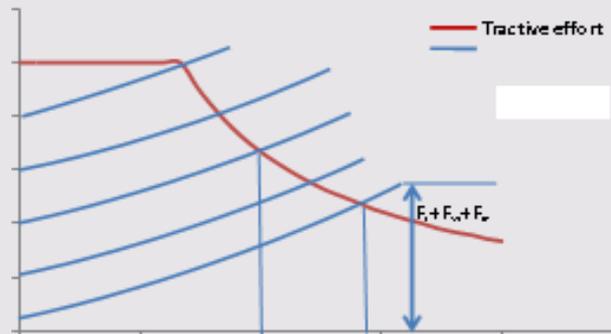
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**Maximum Cruising Speed** The maximum speed of a vehicle is defined as the constant cruising speed that the vehicle can achieve with full power plant load on a flat road. The maximum speed of a vehicle is determined by the equilibrium between the tractive effort of the vehicle and the resistance and maximum speed of the power plant and gear ratios of the transmission.

The vehicle reaches its maximum speed when the tractive effort, represented by the left hand side term, equals the resistance, represented by the right hand side. The intersection of the tractive effort curve and the resistance curve is the maximum speed of the vehicle,



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## *Gradeability*

Gradeability is defined as the grade angle that the vehicle can negotiate at a certain constant speed. For heavy commercial vehicles the gradeability is usually defined as the maximum grade angle that the vehicle can overcome in the whole speed range

## *Acceleration Performance*

The acceleration of a vehicle is defined by its acceleration time and distance covered from zero speed to a certain high speed on a level ground.

