Mustansiriyah University
College of Engineering
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Digging Technology Branch

Equipment and Transportation Machine

Lecture two

(Power and Energy)

Definitions

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Power and Energy, Definitions

Mass: In general, mass is known as the measure of how much matter a body contains or the total number of subatomic particles in that object. Multiplying a man's mass by the pull of Earth's gravity, we'll get his weight. The mass is independent of a man's position in space. A body's mass on the moon is the same as its mass on Earth, because the number of atoms is the same. But, the Earth's gravitational pull, decreases as the body move farther away from the Earth. Therefore, the body can lose weight by changing elevation, but its mass remains the same.
Mass is important for calculating how quickly things accelerate when a force applied to them. What determines how fast a car can accelerate? It is probably known that a car accelerates slower if it has five passengers in it than if it has just one.

Force: weight is one type of force that everyone is familiar with is. This is the amount of force that the Earth exerts on a body. There are two interesting things about this force:
It pulls the body down, or, more exactly, toward the center of the Earth.
It is proportional to the body's mass. If the body have more mass, the Earth exerts a greater force on it.
When we throw a baseball, we apply a force to the ball, which makes it speed up. An airplane engine creates a force, which pushes the plane through the air. A car's tires exert a force on the ground, which pushes the car along.
Force causes acceleration. If we apply a force to a car (for example, by pushing on it with our hand), it will start to move. This may sound simple, but it is a very important fact. The movement of the car is governed by Isaac Newton's Second Law, which forms the foundation for classical mechanics. Newton's Second Law states that the acceleration (a) of an object is directly proportional to the force (F) applied, and inversely proportional to the object's mass (m). That is, the more force you apply to an object, the greater the rate of acceleration; and the more mass the object has, the lower the rate of acceleration. Newton's Second Law is usually summarized in equation form:

$a = F/m$, or $F = ma$

To honor Newton's achievement, the standard unit of force in the SI system was named the newton. One newton (N) of force is enough to accelerate 1 kilogram (kg) of mass at a rate of 1 meter per second squared (m/s^2). In fact, this is really how force and mass are defined. A kilogram is the amount of weight at which 1 N of force will accelerate at a rate of 1 m/s2. In English units, a slug is the amount of mass that 1 pound of force will accelerate at 1 ft/s^2, and a pound mass is the amount of mass that 1 lb. of force will accelerate at 32 $feet/s^2$.
The Earth exerts enough force to accelerate objects that are dropped at a rate of 9.8 m/s^2, or 32 $feet/s^2$. This gravitational force is often referred to as g in equations. If you drop something off a cliff, for each second it falls it will speed up by 9.8 m/s. So, if it falls for five seconds, it will reach a speed of 49 m/s. This is a pretty fast rate of acceleration. If a car accelerated this quickly, it would reach 60 miles per hour (97 km/h) in less than three seconds!

Common Units of Force:

SI: • newton (N) • 1 N = 0.225 lb.

English: • Pound (lb) • 1 lb. = 4.448 N

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Power and Energy, Definitions

Forces acting on a car

Usually, when we talk about force, there is more than one force involved, and these forces are applied in different directions. Let's look at a diagram of a car. When the car is sitting still, gravity exerts a downward force on the car (this force acts everywhere on the car, but for simplicity, we can draw the force at the car's center of mass). But the ground exerts an equal and opposite upward force on the tires, so the car does not move.

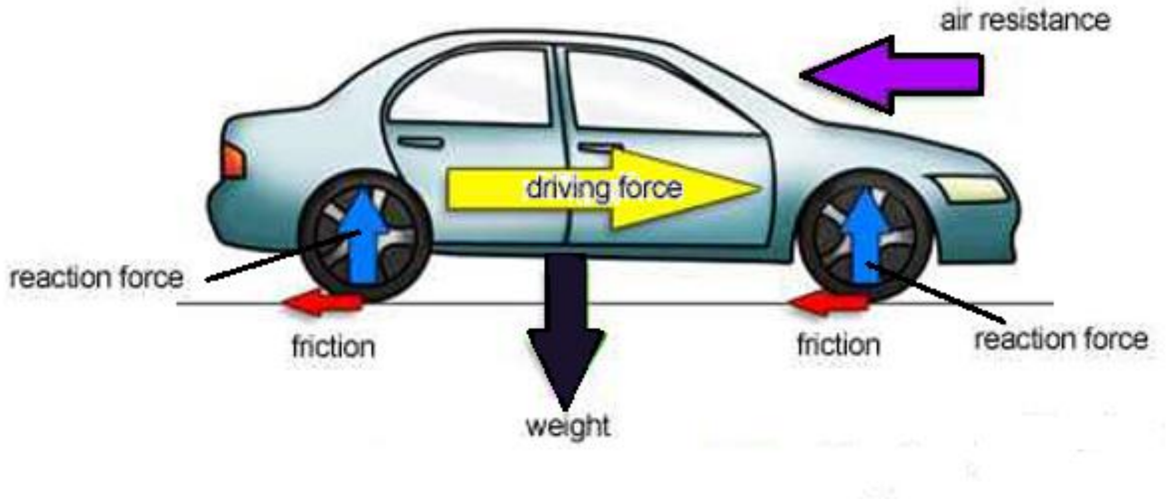

Figure 1: Forces acting on the car

There are several forces acting on the car, shown in (figure1) by the arrows.

• Gravity pulls down on the car.

• The reaction force from the road pushes up on the wheels.

• The driving force from the engine pushes the car along.

• There is friction between the road and the tires.

• Air resistance acts on the front of the car.

Resultant force

The resultant force is the sum of all the different forces acting on the car. You have to take account of the directions – the reaction forces on the wheels (blue arrows) add up to the same as the weight, so these cancel out. The driving force from the engine is in the opposite direction to the counter forces of friction and air resistance. When the car is increasing its speed then all these forces add to give a single resultant force forwards.

When the car begins to accelerate, some new forces come into play. The rear wheels exert a force against the ground in a horizontal direction; this makes the car start to accelerate. When the car is moving slowly, almost all of the force goes into accelerating the car. The car resists this acceleration with a force that is equal to its mass multiplied by its acceleration. As it

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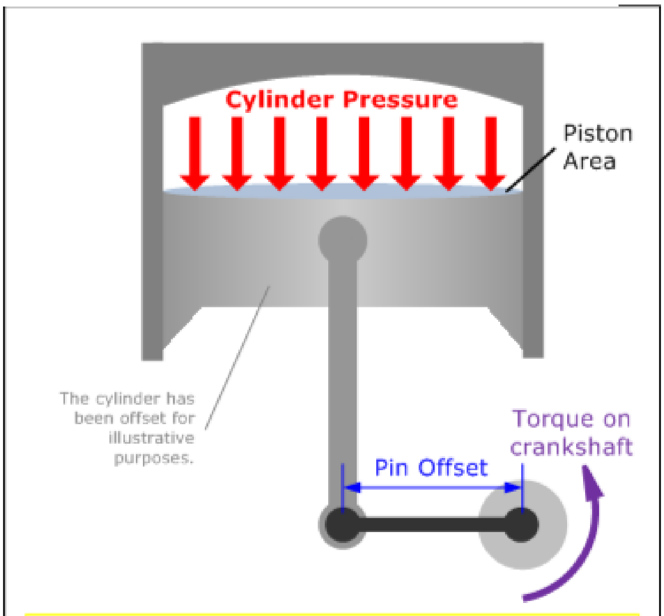
starts to move, the air exerts a force against the car, which grows larger as the car gains speed. This aerodynamic drag force acts in the opposite direction of the force of the tires, which is propelling the car, so it subtracts from that force, leaving less force available for acceleration. Eventually, the car will reach its top speed, the point at which it cannot accelerate any more. At this point, the driving force is equal to the aerodynamic drag, and no force is left over to accelerate the car.

Torque: Torque is a force that tends to rotate or turn things. You generate a torque any time you apply a force using a wrench. Tightening the lug nuts on your wheels is a good example. When you use a wrench, you apply a force to the handle. This force creates a torque on the lug nut, which tends to turn the lug nut. English units of torque are pound-inches or pound-feet; the SI unit is the Newton meter. Notice that the torque units contain a distance and a force. To calculate the torque, you just multiply the force by the distance from the center. In the case of the lug nuts, if the wrench is a foot long, and you put 200 pounds of force on it, you are generating 200 pound-feet of torque. If you use a 2-foot wrench, you only need to put 100 pounds of force on it to generate the same torque. A car engine creates torque and uses it to spin the crankshaft. This torque is created exactly the same way: A force is applied at a distance.

Let's take a close look at some of the engine parts (figure2):



Torque ∝ Cyl Pressure × Piston Area × Pin Offset
Torque ∝ Cyl Pressure × Displacement
∝ : varies with

Figure 2: Engine Torque

The combustion of gas in the cylinder creates pressure against the piston. That pressure creates a force on the piston, which pushes it down. The force is transmitted from the piston to the connecting rod, and from the connecting rod into the crankshaft. In Figure ٢, notice that the point where the connecting rod attaches to the crank shaft is some distance from the center of the shaft. The horizontal distance changes as the crankshaft spins, so the torque also changes, since torque equals force multiplied by distance.

Common Units of Torque SI:

- Newton meter (Nm)
- 1 Nm = 0.737 lb-ft English:
- Pound-inch (lb-in)
- 1 lb-in = 0.113 Nm
- Pound-foot (lb-ft)
- 1 lb-ft = 1.356 Nm

Work: In the physics sense. Work is simply the application of a force over a distance, with one catch -- the distance only counts if it is in the direction of the applied force. Lifting a weight from the ground and putting it on a shelf is a good example of work. The force is equal to the weight of the object, and the distance is equal to the height of the shelf. If the weight were in another room, and you had to pick it up and walk across the room before you put it on the shelf, you didn't do any more work than if the weight were sitting on the ground directly beneath the shelf. It may have felt like you did more work, but while you were walking with the weight you moved horizontally, while the force from the weight was vertical.

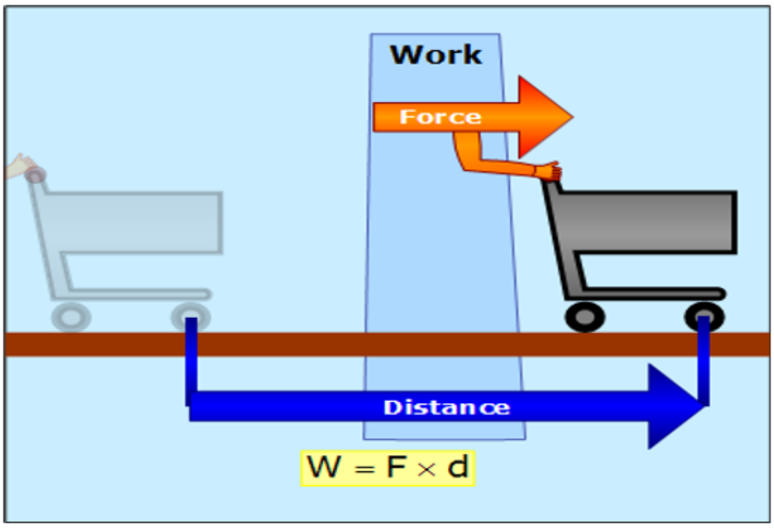


Figure 3: Work = Force x Distance

A car also does work. When it is moving, it has to apply a force to counter the forces of friction and aerodynamic drag. If it drives up a hill, it does the same kind of work that you do when lifting a weight. When it drives back down the hill, however, it gets back the work it did. The hill helps the car drive down. Work is energy that has been used. When you do work, you use energy. But sometimes the energy you use can be recovered. When the car drives up the hill, the work it does to get to the top helps it get back down. Work and energy are closely related. The units of work are the same as the units of energy, which we will discuss later.

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Common Units of Work

SI:

• Newton meter (Nm)
• 1 Nm = 0.737 lb-ft

English:

• Pound-inch (lb-in)
• 1 lb-in = 0.113 Nm
• Pound-foot (lb-ft)
• 1 lb-ft = 1.356 Nm

Power:

Power is a measure of how quickly work can be done. Using a lever, you may be able to generate 200 ft-lb of torque. But could you spin that lever 3,000 times per minute? That is exactly what your car engine does. The SI unit for power is the watt. A watt breaks down into other units that we have already talked about. One watt is equal to 1 Newton-meter per second (Nm/s). You can multiply the amount of torque in Newton-meters by the rotational speed in order to find the power in watts. Another way to look at power is as a unit of speed (m/s) combined with a unit of force (N). If you were pushing on something with a force of 1 N, and it moved at a speed of 1 m/s, your power output would be 1 watt.

An interesting way to figure out how much power you can output is to see how quickly you can run up a flight of stairs. Measure the height of a set of stairs that takes you up about three stories.

Time yourself while you run up the stairs as quickly as possible. Divide the height of the stairs by the time it took you to ascend them. This will give you your speed. For instance, if it took you 15 seconds to run up 10 meters, then your speed was 0.66 m/s (only your speed in the vertical direction is important). Now you need to figure out how much force you exerted over those 10 meters, and since the only thing you hauled up the stairs was yourself, this force is equal to your weight. To get the amount of power you output, multiply your weight by your speed.

Power (W) = (height of stairs (m) / Time to climb (s)) * weight (N)
Power (hp) = [(height of stairs (ft) / Time to climb (s)) * weight (lb)] / 550

Common Units of Power

SI:

Watts (W) , 1000 W = 1 kW
1 kW = 1.341 hp

English:

Horsepower (hp) ,1 hp = 0.746 kW

Energy:

If power is like the strength of a weightlifter, energy is like his endurance. Energy is a measure of how long we can sustain the output of power, or how much work we can do. Power is the rate at which we do the work. One common unit of energy is the kilowatt hour

Power and Energy, Definitions

(kWh). If we are using one kW of power, a kWh of energy will last one hour. If we use 10 kW of power, we will use up the kWh in just six minutes. There are two kinds of energy: potential and kinetic.

Potential Energy

Potential energy is waiting to be converted into power. Gasoline in a fuel tank, food in your stomach, a compressed spring, and a weight hanging from a tree are all examples of potential energy. The human body is a type of energy-conversion device. It converts food into power, which can be used to do work. A car engine converts gasoline into power, which can also be used to do work. A pendulum clock is a device that uses the energy stored in hanging weights to do work. When you lift an object higher, it gains potential energy. The higher you lift it, and the heavier it is, the more energy it gains. For example, if we lift a brick 1 inch, and drop it on the roof of a car, it won't do much damage. But if we lift the brick 100 feet and drop it on the car, it will put a huge dent in the roof. The same brick dropped from a greater height has much more energy. So, by increasing the height of an object, you increase its potential energy.

Let's go back to our experiment in which we ran up the stairs and found out how much power we used. There is another way to look at how we calculated our power: We calculated how much potential energy our body gained when we raised it up to a certain height. This amount of energy was the work we did by running up the stairs (force * distance, or our weight * the height of the stairs). We then calculated how long it took to do this work, and that's how we found out the power. Remember that power is the rate at which we do work. The formula to calculate the potential energy (PE) you gain when you increase your height is:

PE = Force * Distance In this case, the force is equal to your weight, which is your mass (m) * the acceleration of gravity (g) and the distance is equal to your height (h) change. So the formula can be written:

$PE = m*g*h$

Kinetic Energy

Kinetic energy is energy of motion. Objects that are moving, such as a vehicle, have kinetic energy (KE). If a car crashes into a wall at 5 mph, it shouldn't do much damage to the car. But if it hits the wall at 40 mph, the car will most likely be totaled. Kinetic energy is similar to potential energy. The more the object weighs, and the faster it is moving, the more kinetic energy it has. The formula for KE is:

$KE = 1/2*m*v^2$

Where m is the mass and v is the velocity.

One of the interesting things about kinetic energy is that it increases with the velocity squared. This means that if a car is going twice as fast, it has four times the energy. You may have noticed that your car accelerates much faster from 0 mph to 20 mph than it does from 40 mph to 60 mph. Let's compare how much kinetic energy is required at each of these speeds. At first glance, you might say that in each case, the car is increasing its speed by 20 mph, and so the energy required for each increase must be the same. But this is not so.

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We can calculate the kinetic energy required to go from 0 mph to 20 mph by calculating the KE at 20 mph and then subtracting the KE at 0 mph from that number. In this case, it would be

$1/2*m*20^2 - 1/2*m*0^2$.

Because the second part of the equation is 0,

$KE = 1/2*m*20^2$, or 200 m.

For the car going from 40 mph to 60 mph,

$KE = 1/2*m*60^2 - 1/2*m*40^2$; so

KE = 1,800 m - 800 m, or 1000 m.

Comparing the two results, we can see that it takes a KE of 1,000 m to go from 40 mph to 60 mph, whereas it only takes 200 m to go from 0 mph to 20 mph.

There are a lot of other factors involved in determining a car's acceleration, such as aerodynamic drag, which also increases with the velocity squared. Gear ratios determine how much of the engine's power is available at a particular speed, and traction is sometimes a limiting factor. So it's a lot more complicated than just doing a kinetic energy calculation, but that calculation does help to explain the difference in acceleration times.

Heat Energy

Heat energy is a form of energy which transfers among particles in a substance (or system) by means of kinetic energy of those particles. In other words, under kinetic theory, the heat is transferred by particles bouncing into each other.

In physical equations, the amount of heat transferred is usually denoted with the symbol Q.

Heat vs. Temperature

Note this crucial component to the above definition:

Heat always refers to the transfer of energy between systems (or bodies), not to energy contained within the systems (or bodies).

This can be very confusing, because we're used to in day-to-day conversation talking about heat as if it's contained in something. This distinction between heat and temperature is subtle, but very important.

Example: The iron is hot, so it's reasonable to say it must have a lot of heat in it. Reasonable, but it is wrong. It's more appropriate to say that it has a lot of energy in it (i.e. it has a high temperature), and touching it will cause that energy to transfer to your hand ... in the form of heat.

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Common Units of Energy

SI:

Newton meter (Nm)

1 Nm = 1 J

Joule (J)

1 J = 0.239 cal

Calorie (cal)

1 cal = 4.184 J

Watt hours (Wh)

1 Wh = 3,600 J

Kilowatt hours (kWh)

1 kWh = 1,000 Wh

1 kWh = 3,600,000 J

1 kWh = 3,412 BTU

English:

Foot - pound (ft lb)

1 ft lb = 1.356 Nm

British Thermal Unit (BTU)

1 BTU = 1,055 J

1 BTU = 0.0002931 kWh

Now that we know about potential energy and kinetic energy, we can do some interesting calculations. Let's figure out how high a pole-vaulter could jump if he had perfect technique. First we'll figure out his KE, and then we'll calculate how high he could vault if he used all of that KE to increase his height (and therefore his PE), without wasting any of it as it is described in figure 4.

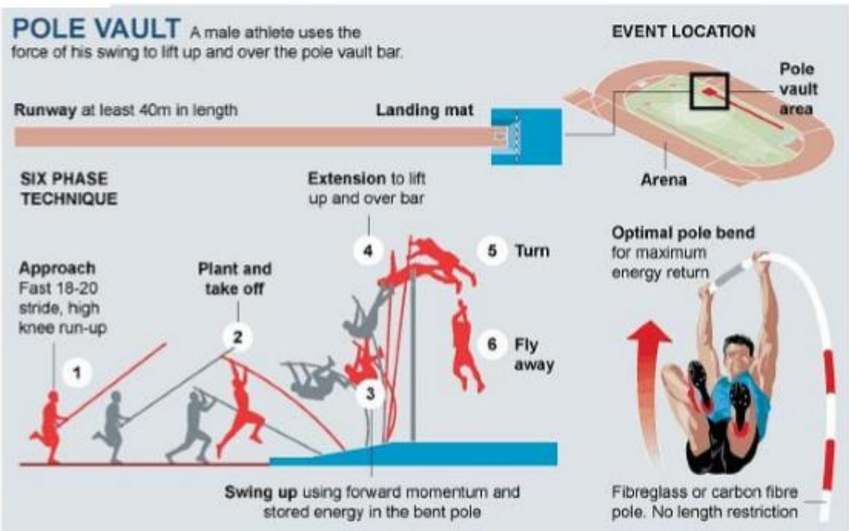

Figure 4: Pole Vault

If he converted all of his KE to PE, then we can solve the equation by setting them equal to each other:

$1/2*m*v^2 = m*g*h$

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Since mass is on both sides of the equation, we can eliminate this term. This makes sense because both KE and PE increase with increasing mass, so if the runner is heavier, his PE and KE both increase. So we'll eliminate the mass term and rearrange things a little to solve for h:

$1/2*v^2 / g = h$

Let's say our pole-vaulter can run as fast as anyone in the world. Right now, the world record for running 100 m is just under 10 seconds. That gives a velocity of 10 m/s. We also know that the acceleration due to gravity is 9.8 m/s^2. So now we can solve for the height:

$h=1/2*10^2 / 9.8 = 5.1$ meters

Vehicle Performance

Manufacturers use many terms to describe the performance of vehicles — horsepower, torque, gradeability, turning radius, side-slope stability and others. Here is a brief guide to help users understand what some of these terms really mean in everyday operation.

Horsepower. It is a unit of measurement of power (the rate at which work is done). There are many different standards and types of horsepower. Most countries now use the SI unit *watt* for measurement of power.

A horsepower is a totally arbitrary measurement – dreamt up by James Watt when trying to compare the effectiveness of his steam engines against the horses they were replacing. One horsepower was deemed to be the equivalent of one horse lifting 33,000 pounds over one foot in one minute on the surface of the Earth.
One horsepower equals 745.7 watts (0.7457 kW), though very few countries use this measurement – only really being popular in Australia and South Africa. After all, who wants to say their 400hp sports car only has 298 kW?

Engines are rated in brake horsepower produced at a specific engine speed. This is called the rated horsepower. The maximum horsepower usually is the same as the rated horsepower, although it may be higher. The governed horsepower is measured at the governed engine speed and may be lower than the rated or maximum horsepower. Horsepower helps determine how fast the vehicle can go with a specific load under specific operating conditions such as grade, rolling resistance and head winds. The parasitic horsepower is the amount of power diverted, or lost, to various components before the engine horsepower reaches the driving tires. Fans, alternators, air and air-conditioning compressors, and other engine-driven components divert horsepower. Friction in the transmission and rear axle gearing does, too. Pumps operated in the pump-and-roll mode divert horsepower. The more horsepower that gets diverted to run components, the less horsepower there is to move the vehicle.

Petrol engines can typically run at higher engine speeds than diesel engines and develop less torque in the lower ranges – most is made at the higher end of the rev-range which is why petrol engines are often said to feel more exciting because the driver must hold on to gears longer to access maximum acceleration. That’s why petrol-driven racing cars usually rev really highly.

Torque. Engines also are rated in the maximum foot-pounds of torque produced at a specific engine speed. This is called the peak torque. The peak torque occurs at an engine speed that is much lower than the governed engine speed. Torque helps determine the grade the vehicle can climb with a specific load under specific operating conditions such as tire size, total gear reduction and rolling resistance. This is called gradeability. The vehicle speed while climbing that grade is determined by the engine rpm, total gear reduction and tire size. To climb a steeper grade at the same speed, the vehicle needs more engine torque. To climb a steeper grade at a faster speed, the vehicle needs more engine torque delivered at a higher engine rpm, which means more engine horsepower. The old trucker's rule of thumb is "torque determines the grade, horsepower determines the speed.

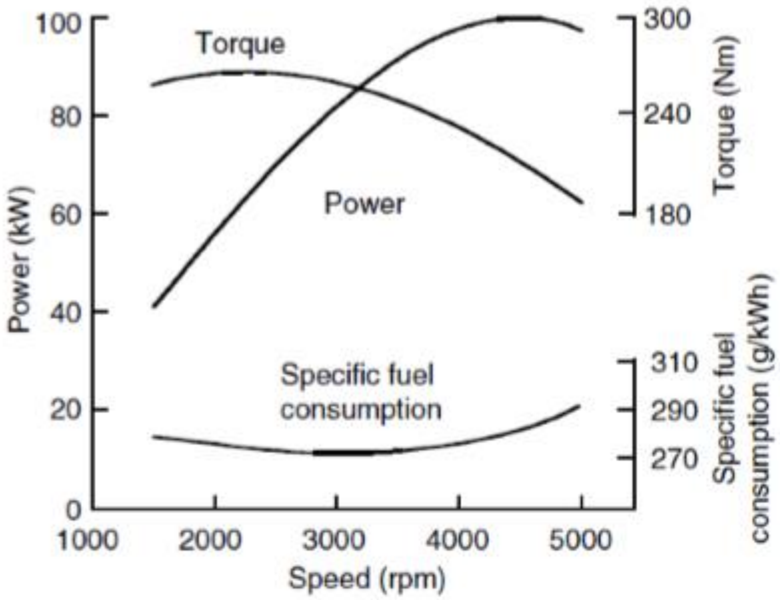

Figure 5: Typical performance characteristics of gasoline engines

<u>Engine speed.</u> Engine speed is measured in revolutions per minute. The governed rpm is the maximum allowable engine speed. The cruising rpm is lower than the governed and is usually the point of best fuel economy and all-around engine response. It is the recommended engine rpm for prolonged driving. The peak torque rpm is the point of maximum torque and is usually the lowest recommended engine speed when the vehicle is moving. In general, if two engines have the same horsepower, the one with significantly higher governed rpm will have a lower peak torque. Be aware of this when comparing engines and be sure to check both horsepower and torque.

Indicated horsepower

Indicated horsepower (ihp or hp_i) is the theoretical power of a reciprocating engine if it is completely frictionless in converting the expanding gas energy (piston pressure × displacement) in the cylinders. It is calculated from the pressures developed in the cylinders, measured by a device called an engine indicator – hence indicated horsepower. As the piston advances throughout its stroke, the pressure against the piston generally decreases, and the indicator device usually generates a graph of pressure vs stroke within the working cylinder. From this graph the amount of work performed during the piston stroke may be calculated.

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Indicated horsepower, unlike later measures such as shaft horsepower (shp or hp_s) and brake horsepower (bhb or hp_b), it did not take into account power losses due to the machinery internal frictional losses, such as a piston sliding within the cylinder, plus bearing friction, transmission and gear box friction, etc.

Brake horsepower

Brake horsepower (bhp or hp_b) is the power measured at the crankshaft just outside the engine, before the losses of power caused by the gearbox and drive train.

In Europe, the DIN 70020 standard tests the engine fitted with all ancillaries and exhaust system as used in the car. The older American standard (SAE gross horsepower, referred to as bhp) used an engine without alternator, water pump, and other auxiliary components such as power steering pump, muffled exhaust system, etc., so the figures were higher than the European figures for the same engine. The newer American standard (referred to as SAE net horsepower) tests an engine with all the auxiliary components (see "Engine power test standards" below).

Brake refers to the device which was used to load an engine and hold it at a desired rotational speed. During testing, the output torque and rotational speed were measured to determine the brake horsepower. Horsepower was originally measured and calculated by use of the "indicator diagram" (a James Watt invention of the late 18th century), and later by means of a Prony brake connected to the engine's output shaft. More recently, an electrical brake dynamometer is used instead of a Prony brake. Although the output delivered to the drive wheels is less than that obtainable at the engine's crankshaft, use of a chassis dynamometer gives an indication of an engine's "real world" horsepower after losses in the drive train and gearbox.

Shaft horsepower

Shaft horsepower (shp) is the power delivered to a propeller shaft, a turbine shaft – or to an output shaft of an automotive transmission. This shaft horsepower can be measured with a torque (torsion) meter, or estimated from the horsepower at the crankshaft and a standard figure for the losses in the transmission (typical figures are around 10%). While shaft horsepower is a common rating for jet engines, industrial turbines, and some marine applications, it is not commonly used in the internal-combustion-engine automobile industry because of the need to estimate losses in the transmission; instead, this industry in the USA typically uses SAE certified net power, which is measured at the engine's crankshaft, and so does not account for losses in the transmission.

Wheel horsepower

Motor vehicle dynamometers can measure wheel horsepower (whp), which is the effective, true horsepower delivered to the driving wheel(s), representing the actual power available to accelerate the vehicle after all losses in the drive train, and all parasitic losses such as pumps, fans, alternator, muffled exhaust, etc. The vehicle is generally attached to the dynamometer and accelerates a large roller and Power Absorbing Unit which is driven by the vehicle's drive

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wheel(s). The actual power is then computer calculated based on the rotational inertia of the roller, its resultant acceleration rates and power applied by the Power Absorbing Unit. Some motor vehicle (and motorbike) dynamometers can also be purely inertia-based where the power output is calculated from measuring the acceleration of a roller drum with a known rotational inertia and known parasitic frictional losses of the roller drum's bearings.

The Power and Torque at any RPM are related according to

Power (hp) = Torque (Nm) × π × RPM/22,380. This relationship means that because RPM keeps rising, even as the torque falls off, the power keeps rising up to a point.

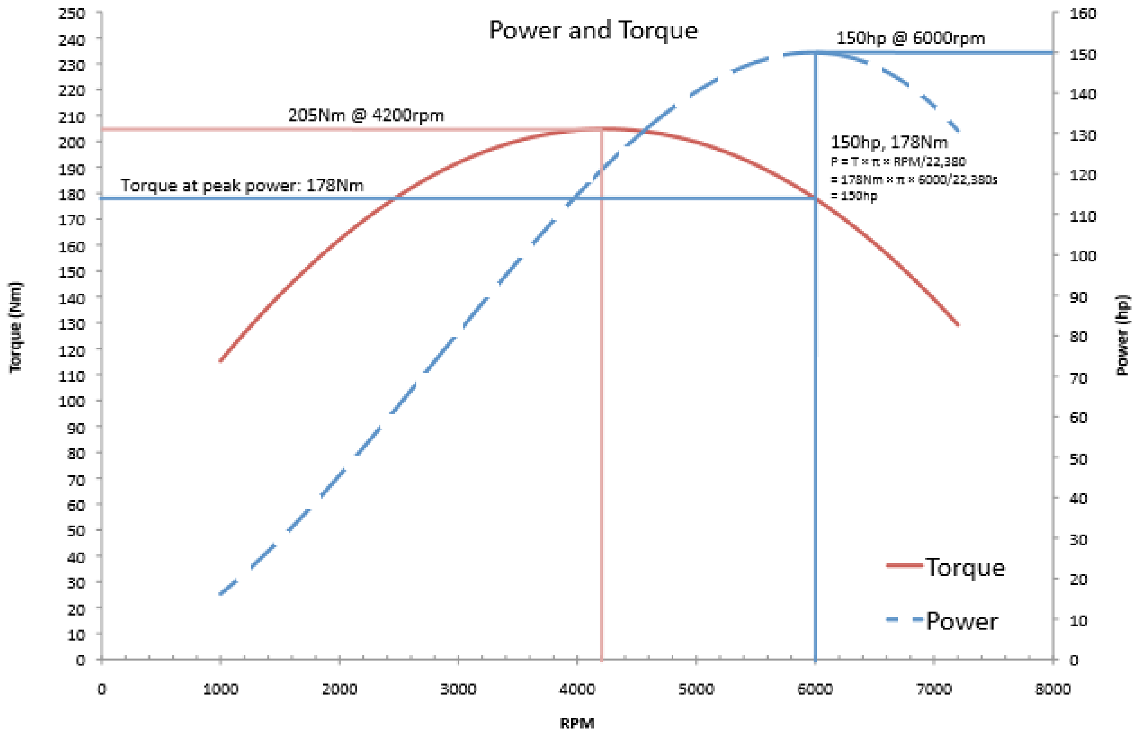

Figure 6: Power vs Torque in hypothetical car

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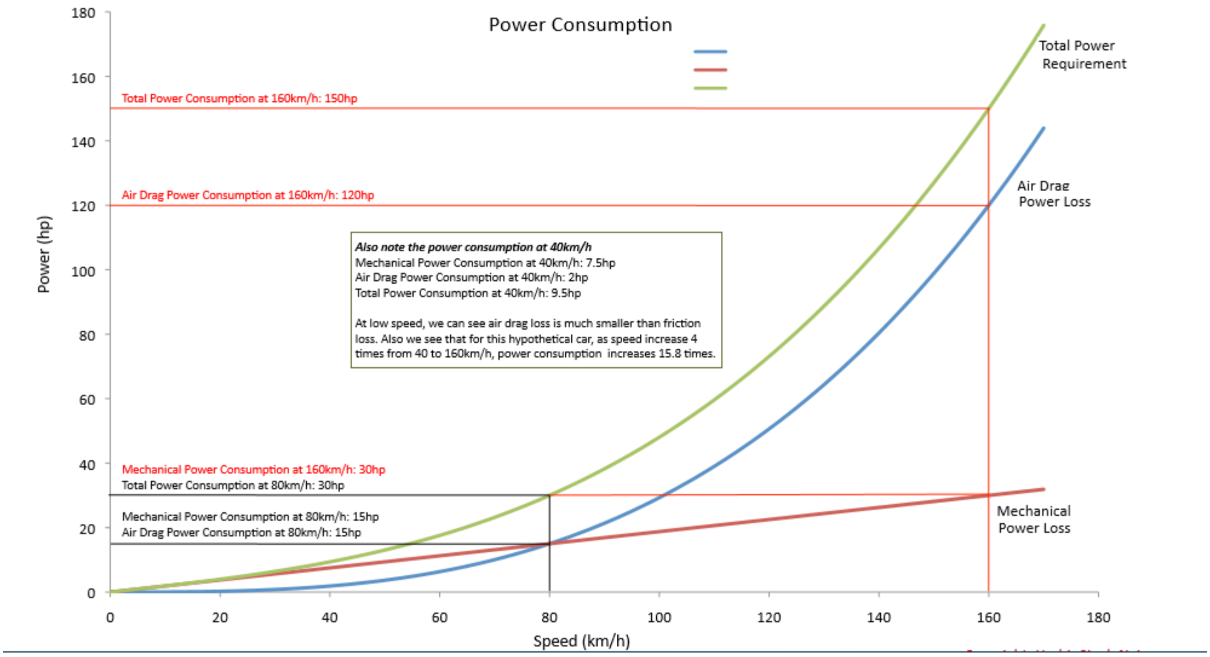
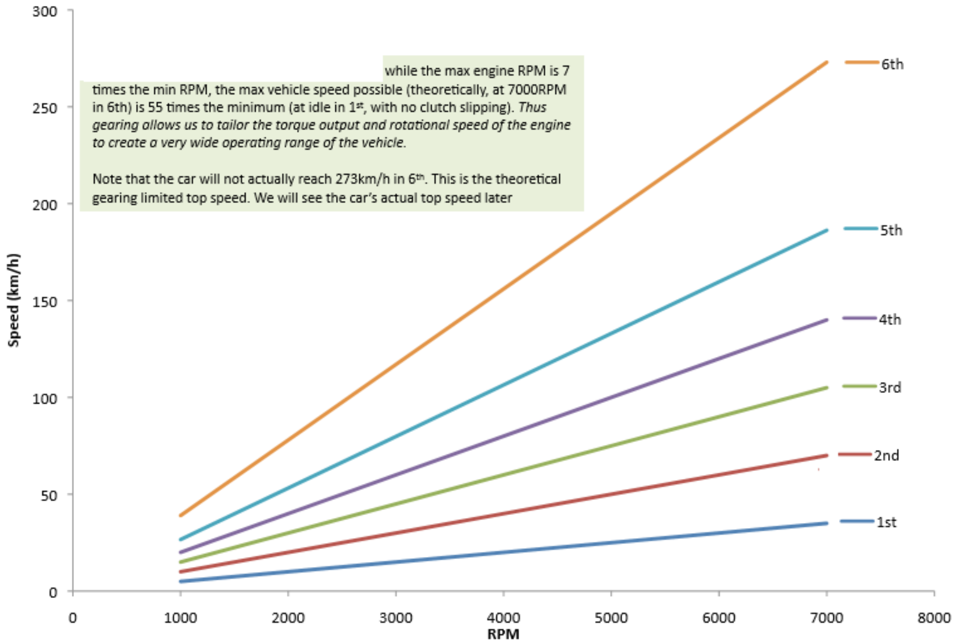


Figure 7: Power consumption in a hypothetical car



Gear	Vehicle Speed per 1000 engine RPM
1st	5 km/h
2nd	10 km/h
3rd	15 km/h
4th	20 km/h
5th	26.6 km/h
6th	39 km/h

Figure8: vehicle speed vs engine rpm for six speed ratios

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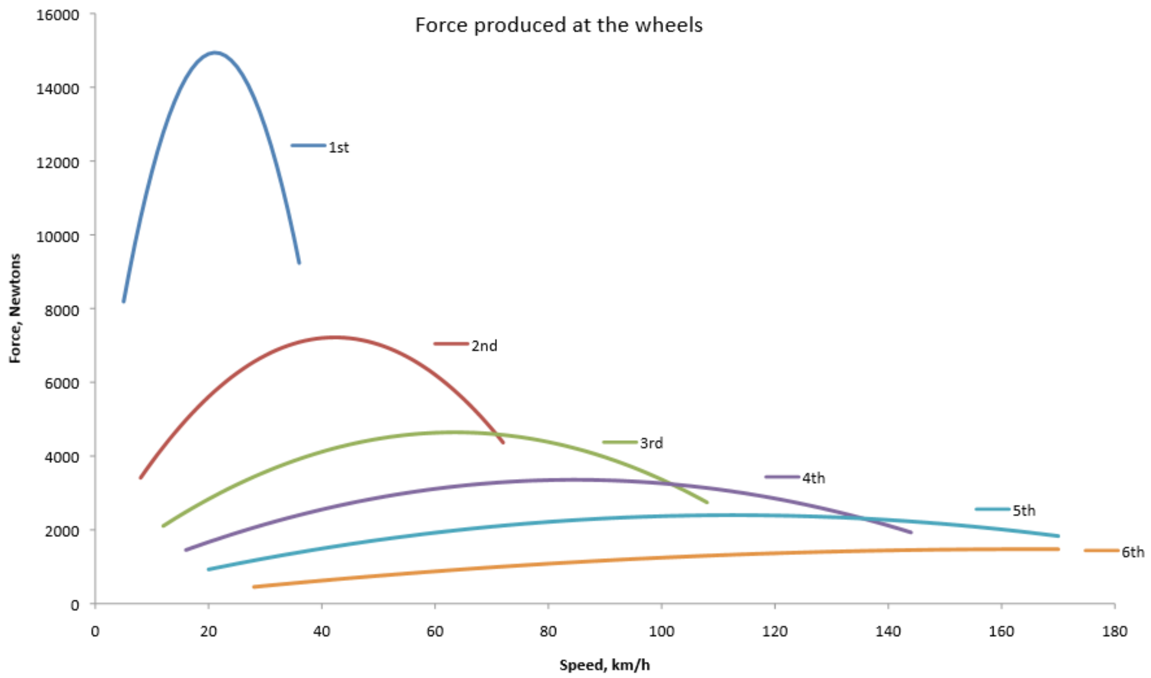

Figure9: produced force at the wheels for six speed ratios

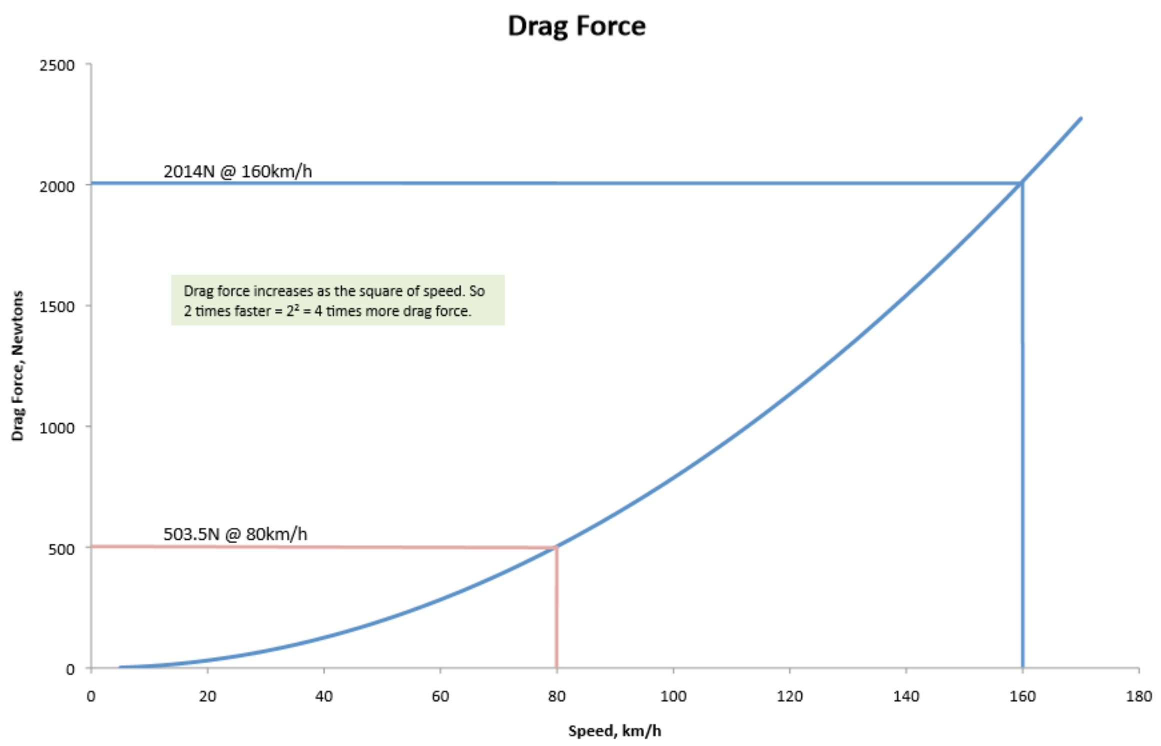

Figure 10: Drag force vs speed

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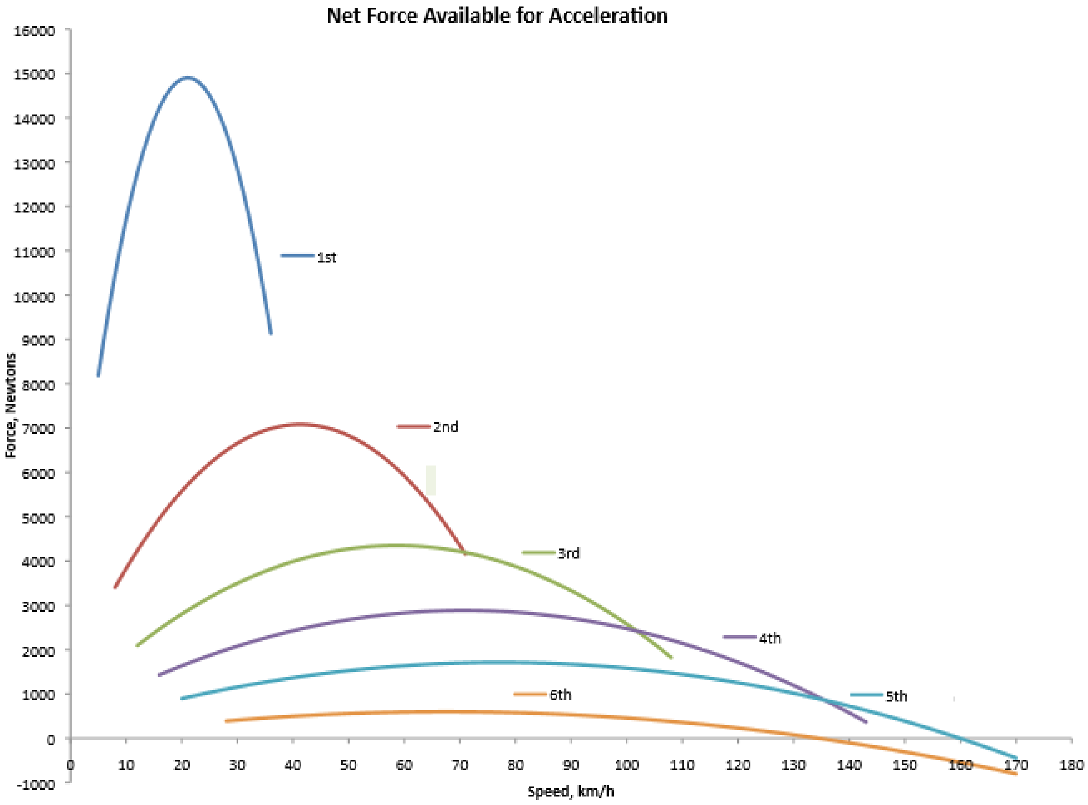

Figure 11: net acceleration force

This chart tells us some very interesting things

1. The force available for acceleration is highest in the lowest gears, so acceleration in those gears will be strongest
2. Drag force has little impact at low speeds, but at high speeds, it significantly cuts down on net force, even making it negative
3. This car's top speed is 160km/h. That is the highest speed the car can reach before net force reaches zero.
4. Top speed is reached in 5th. In 6th, the net force drops below zero at 135km/h, meaning that is the top speed of the car in 6th because it can accelerate no more.
5. If you shift from 5th to 6th at 160, the car will start to slow down, because the drag force will exceed the thrust force of the engine, causing acceleration in the opposite direction, or deceleration.
6. Another interesting thing. When accelerating in 3rd gear, you will get better acceleration if you shift to 4th at 102km/h (6670rpm), rather than reaching the 7200rpm redline because at 102 km/h, net force in 3rd drops below that in 4th. Something similar happens in 4th at 136km/h. Depending on the torque curve, gearing and drag, the optimal shift point can be well below redline!!
7. The lowest gears have by far the greatest amount of net force available for acceleration due to the multiplying effects of gearing and the low aerodynamic drag. In higher gears at high speeds, drag really depresses the amount of force available
8. Cars are hyper responsive to the throttle (both adding and reducing) in the lowest gears, because slight changes in speed produce huge changes in net force. The gentle slopes of the high gears show why cars are much smoother in throttle response in higher gears, approaching considerable sluggishness in the highest gears, where little change in force happens and so little throttle response is felt. Strong throttle response in lower gears also happens because so much more force is available to produce acceleration. In this hypothetical car, peak force and thus peak acceleration in 1st is nearly 25 times higher than in 6th
9. Peak net force approximately happens at the torque peak, except in higher gears where drag force depresses the net available force. In this example, in 4th gear, the peak net force occurs at 71km/h, where the engine is turning 3550rpm, well below the torque peak of 4200rpm. This is because as the car goes past 71km/h, the increase in drag force is greater than the increase in thrust produced by the increase torque

Lecture two

Power and Energy, Definitions

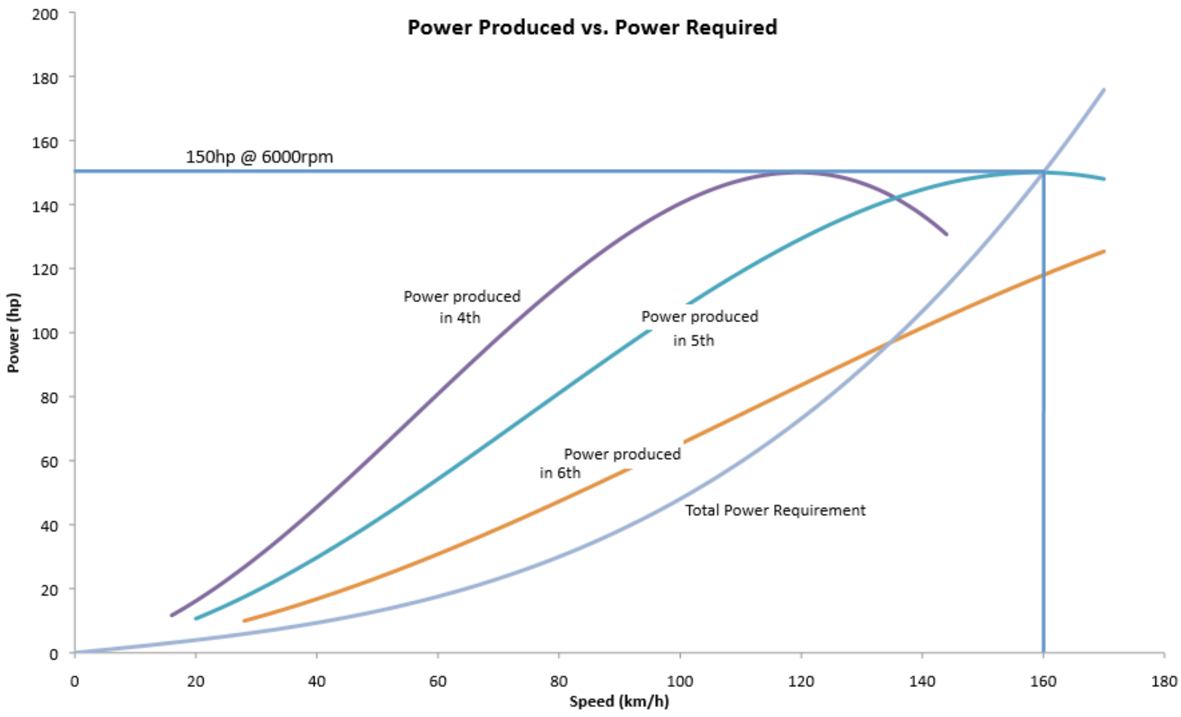

Figure12: Required and Produced Power

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1- Vehicle fundamentals. Istanbul technic university.
2- Harbir Singh Nain , Understanding power, torque and gearing.
3- CNG United/Electric Auto Shop, Unit 7, force, power, torque and energy.