Chapter 2
Landmark Revolutionary Inventions in Mechanical Engineering

Abstract In this chapter, important inventions in mechanical engineering since the advent of human civilization are discussed. The emphasis is on those inventions, which had long-lasting effect on the human civilization. Notable among them are wheel, cutting tool, internal combustion engine, railway, aircraft, refrigeration, and air-conditioning. These revolutionary inventions are still in use and have been undergoing through evolutionary changes. Inventions such as steam engine and Wootz steel are no longer used in the original form. Nevertheless, these inventions have paved the way for future inventions. The underlying principles of these inventions are also briefly described.

Keywords Mechanical engineering · Inventions · Wheel · Cutting tools · Ship · Aircraft · Windmill · Archimedes' screw · Steam engine · Railways · CNC machines · Wootz steel · 3D printing · Refrigeration and air-conditioning

2.1 Introduction

New inventions and their application to enhance the quality of human life is a continuous process since eternity. Mechanical engineering, being one of the oldest branches of engineering, pioneered many inventions that revolutionized the lifestyle of mankind. The roots of many latest gadgets and technologies can be dated back to thousands of years. A number of epoch-making inventions have taken place in mechanical engineering through the centuries. Continuous evolution and application of those inventions in various fields have resulted in industrialization, modern civilization, and better lifestyle. In this chapter, important revolutionary inventions and their impact on the civilization are discussed.

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2.2 Invention of Wheel

Invention of the wheel is indeed a landmark in the history of human civilization. It is one of the most ancient mechanical inventions of the world. The invention of wheel is considered such an important event that ‘reinventing the wheel’ has become a popular idiom for duplicating certain invention or finding. Wheel finds such as an important role in mechanical engineering, as fire in chemistry and money in economics. There are many evidences of existence of wheels in the early ages of civilization. However, the exact point of time of invention of wheel is yet unknown. It appears that the potters were the first ones to use wheels in 3500 BC for making earthen pots. The first ever wheel that was found in an archaeological excavation in Mesopotamia is believed to be a potter’s wheel. Some ancient paintings of wheeled carts and toys found in caves and potteries led to the belief that wheels were developed simultaneously in different places of the world. For example, wheels were used in Sumerian civilization, northern Caucasus, Central Europe, and Eurasian Steppes in the later part of the fourth millennium at around 3500–3350 BC (http://www.localhistories.org/techhist.html).

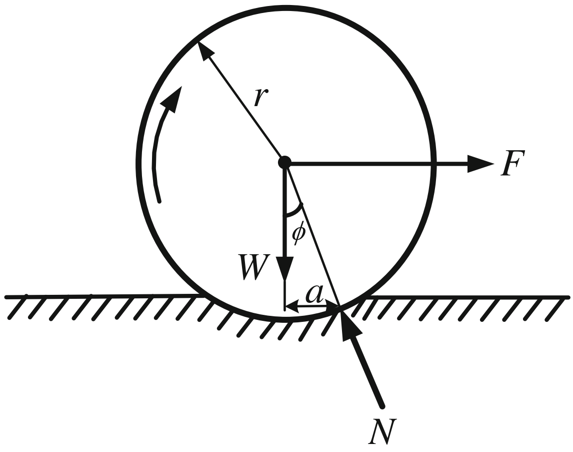
Although wheels were used for irrigation, milling grains, and pottery making for a long time, it was used for transportation around 300 years later after its invention (Anthony 2007). The earliest wheels were made from wood, a natural choice from the abundant trees in the forests. It is believed that initially wooden logs were used as rollers for moving heavy loads. With passage of time and continuous effort for modification, wheels were evolved from these rollers and used for transportation. The first use of wheel for transportation in chariots is dated back to 3200 BC in Mesopotamia. The idea of wheels with spokes led to the construction of lighter wheels. Spokes are the radial rods joining the wheel center to the outer wheel ring. In 2000 BC, the first wheel with spokes was invented in Egypt and used in chariots. From the ancient paintings and cave arts, it can be assumed that spoked wheels were used in toy carts and vehicles in Caucasus region, Central Europe, China, Indus Valley, and northwestern India around 2000 BC. Iron rims around a wheel were first introduced by the Celtics in 1000 BC (http://www.autoevolution.com/news/history-of-the-wheel-7334.html). A rim is the outer circular ring wound around a wheel attached to the outer ends of the spokes. Simple wooden spoked wheels were in use for a long time without major modification until 1802, when wire spokes with tension were invented. The rims of wire wheels are connected to the wheel center by the stiff wires in tension, e.g., bicycles’ wheels. G.F. Bauer took the first patent for it in 1802. In the nineteenth century, continuous improvement of the wheel has made it an indispensable part of modern technology and industrialization. With the onset of the Industrial Revolution, wheels were used in different mechanisms, starting with spinning wheel, water wheel, and propellers to more advanced forms in turbines, engines, flywheels, automobiles, jet engines, ships, clocks, toys, and computers.

2.2.1 Mechanics of Wheel Motion

A wheel rolls along a surface in contrast to sliding/dragging motion of flat objects along a surface. If the rolling takes place without slipping (and which is desirable most of the cases), it is called pure rolling. In pure rolling, the velocity of the contact point between roll and the ground surface is zero. The magnitude of velocity of a point on the wheel is proportional to distance of the point from the contact point measured in the vertical plane. It is easier to roll an object across a surface than slide, as rolling experiences less resistance from the surface than sliding. Rolling of a wheel reduces the frictional resistance to motion to a great extent. A perfectly rigid roll can undergo pure rolling motion on a perfectly rigid flat horizontal surface forever. The resistance to rolling will be zero in that case, and there need not be any friction between the roll and the horizontal surface. In practice, to eliminate slipping at the point of contact between the wheel and the surface, some amount of friction is required. However, in pure rolling, no energy is dissipated due to sliding friction as there is no relative motion between the roll and the surface on which it moves at the point of contact. Thus, theoretically, there is no upper limit on the sliding friction.

It is our experience that to sustain the rolling motion of a wheel, a moment is to be applied to the wheel by the application of a force or torque. This is due to deformable nature of wheel as well as the surface on which it moves. Existence of a contact point is an idealization. It is not possible to have the contact of wheel and the surface just at a point, as it will lead to infinite stress at the contact point. No matter how small, there is a contact area. Figure 2.1 shows a simple wheel of weight W that rolls along a surface (without slipping) due to the pulling force F. The deformation of the contact surface is exaggerated. The resultant force applied by the ground on to the wheel is N, which is inclined at an angle ϕ from the surface, but passes through the center of wheel for maintaining the equilibrium. It is

Fig. 2.1 A rolling wheel



to be noted that the resultant force due to the ground has line of action toward the leading side of the moving wheel. It is clear that the horizontal component of N will be equal to F if the wheel is moving without any horizontal component of the acceleration of its center of mass. The force F must be less than the limiting sliding frictional force. If the force F is more than the liming sliding frictional force, the wheel will skid. The force balance provides

$$F = N \sin \phi, \quad W = N \cos \phi. \tag{2.1}$$

Hence,

$$\tan \phi = \frac{F}{W} = \mu_r \approx \frac{a}{r}, \tag{2.2}$$

where r is the radius of the wheel and a is the horizontal distance between the point of the contact and the point through which the resultant of the ground forces passes. The variable μ_r in Eq. (2.2) is called the non-dimensional coefficient of rolling resistance (Shames 1997). The variable a is called the coefficient of rolling resistance. Compared to sliding friction, the rolling resistance is much lower. It depends on the nature of the surface, material of the wheel, material of the ground, the contact force, and the applied force/torque.

2.2.2 Uses of Wheel in Mechanical Engineering

Some important adaptations of a wheel used in mechanical engineering are gear, pulley, flywheel, turbine, grinding wheel, and automobile wheel. For transportation purpose, wheels are used in combination with axles. An axle is a cylindrical component on which either the wheel can be fixed or is free to rotate about the central axis of axle. If the wheel is fixed on the axle, the axle is supported on bearings and is free to rotate. In the wheels of railway car and some vehicles, the axle is fixed to the wheels and both wheel and the axle rotate in unison. In some vehicles, the axle is fixed on the vehicle and the wheels rotate around the axle. In order to reduce the friction at the wheel–axle interface, rolling-element bearings may be used.

Gears are the toothed wheels that are used for changing the speed and/or for amplifying the torque. Pulleys are used in conjunction with belts and perform the same function as gears. They can transmit power to a far distance. Nowadays, belt-pulley drives do not find much application as small motors can be easily fitted where required, avoiding the need of somewhat less efficient belt-pulley drives. Flywheels store energy in a part of cycle and release it in another part. The purpose is to avoid fluctuation in speed during a cycle. For example, in a mechanical punching press, a large amount of energy is required during punching operation, but there is very less energy requirement in another part of the cycle. A flywheel is fitted on the machine, which stores the energy in most part of the cycle in the form of rotational kinetic energy and releases it during punching operation. Thus, the punching can be accomplished with relatively smaller size of motor. A turbine converts hydraulic and thermal energy into rotational kinetic energy. The rotational kinetic energy of the turbine is transformed into electrical energy with the help of a generator. A grinding wheel is used to sharpen and shape various products. Here, the rotational kinetic energy of the grinding wheel is used to remove unwanted material from the workpiece.

2.3 Invention of Tools

In the modern times, tools in various forms have become necessities for mankind. A tool is used to either augment the human effort or replace it if powered by other source. It may not be possible to fix a nail by the blow of hand; a hammer is needed. A plow fitted on tractor can cut the earth of a form. Without proper tools, it would not have been possible to produce gadgets such as television, mobile phone, and computers, which have become a necessity for our day-to-day life. However, it is impossible to pinpoint exactly when the first tool was invented in the history of mankind. It is assumed that stones were used as tools by the early human during Stone Age. Broken sharp-edged rocks/stones were used for hunting and self-defense from the wild animals. Undoubtedly, stone tool and fire are the most ancient inventions in the history of human civilization. Tools played a vital role in the evolution of mankind.

2.3.1 Tools of Early Age

From the archaeological study of the Stone Age tools excavated from different parts all over the world, it is assumed that these tools date back to 5–2.6 million years before present. There are archaeological evidences of using wooden spears made from trees by early human about 5 million years ago. Perhaps the early human beings were in search of harder material as wood decayed soon and started using stone as it was easily available on the earth in caves, forests, and riverbanks. Around 2.8 million years ago, spears with stone blade and wooden handle were used. The very first stone tools found in Gona in Ethiopia were made from flint (Semaw et al. 2003). Flint (a form of quartz) was used as tool as it is hard and can be split to form sharp edges. Other types of stones were also used for making tools. The stone tool industry in its earliest form was called the Oldowan. The term Oldowan is taken from the name of a site in Tanzania. Oldowan tools were used about 2.6 million years back. Mostly hammering action was performed with these handheld stones. Other commonly used stone tools were hand axe, knife, scraper, chopper, anvil, wedge, etc. Primary objective of using these tools was for hunting animals for food, skinning them, and chopping their meat. Possibly, the tools were also used for felling the trees and cutting the fruits. At a later point of time, early human used the stone tools to sharpen the bones of the hunted animals and make pointed needles and fishhooks to catch fish and other water animals for food. In India, animal horns are used as musical instrument by certain sects of mendicants or saints. Evidences of using bone sickles for agriculture and bow drills for boring, drilling, and fire generation are found from the remains of early civilizations in different parts of the world. However, gathering knowledge about using stone as a tool, sharpening it by breaking, and splitting, making sharp points for arrows, drills, and spears required a very long period of time. Evolution of these tools was an extremely slow process spanning over millions of years.

The use of an advanced tool such as bow drill was an achievement in the prehistoric period. Stone tools were the only option up to 1.5 million years ago for human race. As civilization progressed, gradually improved techniques and materials were used for tool making. Innovation of the technique of smelting metal ore has ended the Stone Age and ushered in the Copper Age. The early human learnt to use copper ores by burning them for tool making. It is assumed that discovery and use of copper ore for making tools dated around 8000 BC. However, copper being a soft metal was not ideal for tools and weapons. In quest for improvement, blending of copper with tin gave birth to a much harder metal, bronze. Thus with the progression of metalworking, alloys such as bronze and brass (a mixture of copper and zinc) were discovered. Bronze became very useful for making tools, jewelry, and utensils. An entire period of early civilization starting around 3000 BC and spanning up to around 1000 BC is named as the Bronze Age. The discovery of metals and the use of metal smelting and casting technologies have given tool making a new height. The Bronze Age was succeeded by the Iron Age around 1500 BC. With the advancement of metalworking, iron with high melting point could be processed at elevated temperature and iron and its alloys were used for tool making. There were profound improvements in the design and quality of the tools. The use of copper, bronze, and iron has gradually replaced the stone, wood, and bone tools. With progress of Industrial Revolution, better technology, machines and materials have contributed to producing better tools. From the inception of the first stone tool, there is tremendous development in tool making, and now, different types of tools have innumerable applications in different fields.

2.3.2 Types of Tools

Tools in general have numerous types and applications. Stone and wooden tools are still in use for household purposes, e.g., stone milling wheel for grinding grains and wooden plow. Classification of tools is not an easy task as there are wide varieties of tools which may be manual and automatic. Some simple handheld cutting tools are knife, axe, sickle, saw, scissor, nail cutter, and razor blade, where there is a sharp cutting edge and the cutting is accomplished by shearing action. Some typical tools used in a mechanical engineering workshop are shown in Fig. 2.2. These include measuring tools, viz. try square, ruler, and vernier calliper. Lever can also be considered as a tool having mechanical advantage. It was also used in prehistoric times for digging, moving/lifting heavy loads, weighing, and irrigation. Pliers and wrenches are used to fit nuts and bolts by applying torque. Screwdrivers, drill bits, and milling cutters use both rotational as well as translational motion to achieve cutting action. A hammer is used to apply concentrated force, e.g., fixing a nail in the wall. Rulers, set squares, callipers, and different types of gauges are used for linear and angular measurements. Microscope and magnifying glasses are used for magnified view of an object. In a broader sense, household gadgets, mobile phones, computers, clocks, printers, sensors, etc., can also be considered as tools.

Applications of rotary as well as linear motion have given birth to many mechanical engineering tools, for example, different types of machine tools, cutting tools, and jigs and fixtures. The idea of partial rotary motion by the hand for digging or boring probably led to the inception of drilling tools. Bow drill was an important and essential tool used by early man for drilling and boring which was the basis for the modern drilling tools. Primitive lathe was developed from the idea of bow drill in the Eastern Mediterranean in around 1500 BC during Egyptian period (Burstall 1963). This can be considered as the first machine tool and was used for turning wood. During Greek and Roman periods, the primitive lathe was continuously modified and used for making furniture, spoked wheels, and ornaments. Modified forms of lathe were strap lathe, bow lathe, and pole and treadle (foot-operated) lathe. Greeks and Romans used to and fro motion of a stone plate over another for milling grains. Rotary hand mills with a wooden handle were used by the Romans

Fig. 2.2 Some tools of a mechanical workshop

for milling grains, where a stone wheel rotated on top of another with grains in between. With time and continuous improvement, the primitive machine tools were evolved into the sophisticated automated machine tools.

2.4 Ship

From time immemorial, mankind had been using waterways, which is the oldest means of transport on earth. Roadways, railways, and airways were developed much later. It is a long history of evolution of modern ships since the days when tree trunks and logs were used as boats. Although there are many subtle differences between a boat and a ship, the main difference is related to its size. The popular saying is that a boat cannot carry a ship, but a ship can carry a boat. Some terms related to boats and ships are explained in Sect. 2.4.1 followed by a brief history of their use and development in Sect. 2.4.2.

2.4.1 A Brief Introduction to Boats and Ships

Since ancient times, boats and ships have been used to transport passengers and cargo through waterways. They are also called naval vessels. The most primitive boat is the raft. It is flat in structure and thus highly stable, but may experience a lot of drag (resistance to forward motion). They cannot move at a very high speed. A dugout is a boat made from a hollowed tree trunk. A canoe is a lightweight narrow boat, typically pointed at both ends and open on the top. Dinghies are similar to canoe but are much wider.

For long-distance travel, sailboats and sailing ships were used. Sailboats and sailing ships are powered by means of sail that makes use of wind power. The sail is usually made of woven fabric and is supported by a mast. There can be more than one sail in a boat. Figure 2.3 shows the schematic of a typical sailboat. The important parts are labeled. The forward part of the boat is called the bow, and the back or aft-most part is called the stern. The rudder is used to steer the boat. The mainsail is the principal sail on a sailboat and is set on the aft-side of the main mast. The foot of the mainsail is supported by a spar called the boom. The mainsail creates the lift for the windward motion. The jib is also called foresail or headsail and helps to get lift in upwind direction. The hull is primarily the structural watertight body of a vessel. The line where the hull meets the water surface is called waterline. A horizontal structure called the deck forms the roof of the hull. The structure above the hull is called the superstructure. The rooms for the cargo and passenger can be below the deck. An extension of the hull that goes deeper into the water is called keel. It provides stability to the ship. A well-designed keel can provide the lift. A pulpit is a raised platform in the bow of certain boats.

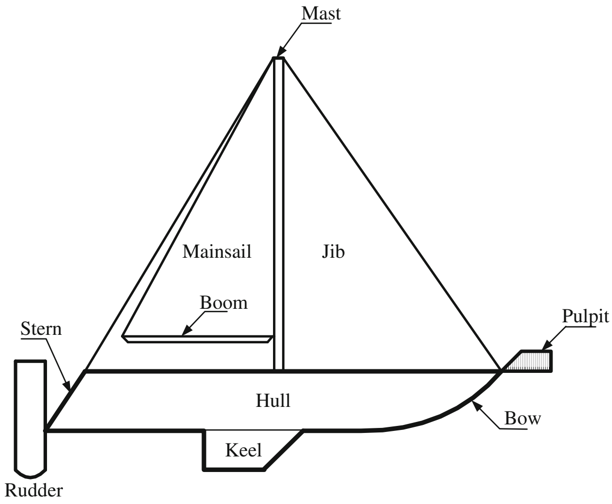


Fig. 2.3 A schematic of a typical sailboat

The boats can be driven by human power by means of oars. In past, in certain civilizations, slaves were employed to row the boats. Sometimes, the same boat had the provision for rowing and sailing. With the advent of steam engines, the dependency on wind and human power diminished in favor of boats and ships powered by thermal engines.

2.4.2 A Historical Note on Boats and Ships

It is impossible to ascertain who exactly invented the concept of using a boat or a ship. However, historians across the globe are of the opinion that the Egyptians were the first to use boats and ships for trade, travel, and exploration. There are archaeological evidences that Egyptians used wooden planks and dugout made of tree logs with sail and rows during the Bronze Age. The boat of Khufu, excavated in 1954 near a pyramid in Giza, dating back to 2500 BC, is an example of Egyptians shipbuilding expertise (Garrison 1999). Over the centuries, Greeks started exploring and colonizing the Mediterranean navigating in sea with boats/ships. Information of Greek sailors navigating to Western Europe, Great Britain, and Indian Ocean is found in history. There are evidences in history that ships were used for trading among northeast Africa, India, Sri Lanka, Persia, Rome, Arabian Peninsula, and many other places. In ancient times, there were skilled Indian shipbuilders as found from a panel excavated in Mohenjo Daro with the painting of a sailing ship. Although shipbuilding started in Japan in fifteenth century, the credit of using iron for ship building for the first time goes to Japan. In

1492, Christopher Columbus reached America from Palos de la Frontera, a Spanish province. In 1498, Vasco da Gama, a Portuguese explorer, reached India through the Indian Ocean from the Atlantic.

Early wooden boats were dugouts, rafts, and canoes (slender, open boats, tapering to a point at both ends). Before the invention of compass, navigation at sea was done by reading the positions of stars, the Sun, and the Moon. Gradually the use of mast, sail, and oars were introduced for proper steering, navigation, and sailing. However, main motive force for sailing was wind in these primitive ships. Better models of warships and merchant ships were developed by the Greeks with the modifications in the design of hull and the addition of top sail, keel, higher length-to-width ratio, and multiple oars and rowers. The theories on buoyancy, center of gravity, and equilibrium of floating bodies put forward by the great Greek scientist Archimedes (287 BC–212 BC) had revolutionized the field of fluid dynamics. 'Syrakosia' was the first three-mast ship in the world designed by Archimedes. Although some modifications were introduced in the design of ship building throughout the centuries, there were not many improvements until nineteenth century. The Industrial Revolution, invention of steam engine, improved propulsion techniques, and the use of iron for construction of ships brought about radical changes in the ship design. Mark Brunel (1769–1849), the French engineer, was the pioneer in introducing large ships made of iron with improved hull design emphasizing on the longitudinal strength of the ship. His son Isambard Kingdom Brunel (1806–1859) was also a great ship designer. 'The Great Eastern,' the largest steamship until twentieth century, built by Isambard Kingdom Brunel was the first ship designed based on the principles of hydrodynamics. Naval architecture and engineering reached a new height after the introduction and use of the concepts of metacenter, buoyancy force, Froude number, and wave resistance in hydrodynamics. The noteworthy works of Pierre Bouguer, William Froude, Mark Brunel, and many others in the nineteenth century are considered as the greatest contributions made in ship building and design. There were in-depth studies of hydrostatics, hydrodynamics, pitch, roll, drag of a vessel in water, effect of water, and wind resistance in naval engineering. Introduction of steam turbines for ship propulsion was indeed revolutionary, and HMS Viper and HMS Cobra were the first two ships to use steam turbine as prime mover in 1900 (Burstall 1963). In twentieth century, ship building progressed fast and there were boats and ships for trade, transportation, marine fishery, firefighting, rescue, explorations, military, luxury yachts, and many other functions. Gradually, superships such as very-large cargo carrier (VLCC) and ultra-large cargo carrier (ULCC) have come up for carrying petroleum, grains, minerals, and heavy goods. 'Fastship' is another improved variant of a cargo ship which is smaller and faster and carries the cargo within the hull.

Now, ships are designed using computer modeling and its dynamic properties and performance are simulated before manufacturing. There are tremendous improvements in design, materials used, propulsion system, and performance. Ship building has come a long way from the primitive dugouts made of tree to fully automated unmanned submarines used for undersea explorations.

One of the most severe accidents of shipping industry was the sinking of RMS Titanic. It was a huge ship and constructed by taking enough safety factor. It sank in the North Atlantic Ocean on April 15, 1912, after colliding with an iceberg on its maiden voyage from Southampton, UK, to New York, USA. Out of 2600 people on board, 1500 people perished in the water.

2.5 Windmills

A windmill converts the energy of wind into rotational kinetic energy. Natural wind is used as the prime mover for producing rotary power and for doing work. It contains some sails/blades that are rotated by wind, and the output is used for doing various works such as lifting water from wells, milling grains, sawing wood, and producing electricity. According to the historians, a wind organ designed by the Greek engineer Hero of Alexandria around first century is the first machine in history to use wind power (Burstall 1963). It is believed that wind was used to rotate prayer wheels in China around fourth century AD where radial sails were mounted to a vertical pole. However, windmills were used for doing works such as milling, pumping, and sawing wood around ninth century in the Far East, e.g., in Persia, Afghanistan, Asia, India, and China. Windmills were believed to come into existence in Europe much later, in the twelfth century in France and England. The earlier windmills had long vertical shafts with rectangular blades. Post mill (1180 AD) was such a vertical windmill used in Western Europe where sails/blades moved about a horizontal axis making a millstone rotate about a vertical axis to mill grains. Gears were used for power transmission from the sails to the millstone. Tower mill was another variant of windmill developed by fourteenth century which was more rigid and sturdy compared to the post mill. Up to the middle of the eighteenth century, use of windmills was very common for sawing, grinding, milling, and even for fans used in mines for ventilation. The construction detail of windmills, e.g., use of worm gears, bearings, fantails, and inclination of the sails, was indeed remarkable at that age. With the onset of Industrial Revolution, modifications of windmills took place with the use of bevel gears and cast iron in place of wood. There were continuous efforts to improve the design of sails/blades, and some designs were patented. Windmills were used by Stephen Hales for ventilating prisons and hospitals in 1752 (Armytage 1961). John Smeaton was the pioneer to conduct scientific study on windmill and published a paper in 1759 with the results of his experiments. He established a five-sail windmill in Leeds, England. However, during the period 1750–1850, there was a gradual transition from the use of windmills as prime movers to the use of steam engines. In 1784, the first steam power-driven flour mill was introduced and the trend set in. By the end of the eighteenth century and early part of the nineteenth century, small windmills were replaced by the steam-powered mills. However, large windmills (called wind turbines) were the next phase of modified windmills used for generation of electricity. Large windmills were also used for pumping water and called wind pump/engine.

The first wind turbine built by Professor James Blyth in Scotland in 1887 was followed by the construction of a number of wind turbines during the period 1887–1908 in various places in Cleveland, Ohio, and Denmark producing power from 5 to 25 kW (Cleveland 2007). Steel blades and towers replaced the earlier wooden counterparts in nineteenth-century windmills/turbines/pumps. In the twentieth century, wind power was tapped to a greater extent. A wind turbine constructed by Prof J.B. Wilbur of MIT and Palmer C. Putnam in Vermont in 1941 produced 1250 kW power. There were a number of successors constructing wind turbines/pumps around the world and a lot of modifications took place in their design and structure. In addition to producing electricity, some were extensively used for powering saw mills, grain mills, water pumping, irrigation, and agriculture across Europe, USA, Canada, Africa, and Australia. The power produced by the modern wind turbines ranges from about 20 kW to about 7 MW. Global warming, energy crisis, and fast-depleting fossil fuels have increased the importance of wind power as it is a renewable and environmentally friendly source of energy. Effort to tap wind energy is going on around the globe at the appropriate sites, for example, coastal areas and high altitude places where wind velocity is more.

According to Global Wind Energy Council (GWEC) report of 2014, the total installed wind power capacity in the world is 369, 553 MW (http://www.gwec.net/wp-content/uploads/2015/02/GWEC_GlobalWindStats2014_FINAL_10.2.2015.pdf). It was just 7600 MW in 1997. The share of five top nations in utilizing wind energy is as follows: PR China: 31 %, USA: 17.8 %, Germany: 10.6 %, Spain: 6.2 %, and India: 6.1 %. Modern wind turbines are classified as horizontal axis wind turbines and vertical axis wind turbines. In the horizontal axis wind turbines, the axis of rotation is horizontal. The number of blades may vary in different designs. Vertical axis wind turbines are called panemones. In these turbines, the main rotor shaft runs vertically and the plane of blade rotation is parallel to the wind direction. The advantage of these turbines is that the generator and the gear box can be placed at the bottom avoiding the need of tower and deep foundation. The blades need not be pointed in the wind direction unlike in horizontal axis wind turbine. Two designs of vertical axis wind turbine are common—the Savonius rotor and the Darrieus rotor. S.J. Savonius, a Finnish Scientist, invented the vertical axis Savonius rotor in 1922 (Savonius 1931). A schematic diagram of Savonius rotor wind turbine is shown in Fig. 2.4a. In this, two buckets are attached to a vertical shaft, such that the cross section resembles the letter S. It works due to the thrust force of the wind. The troposkein (a curve that a rope anchored at its ends assumes when spun along its long axis at constant angular velocity)-shaped Darrieus rotor was originally invented and patented by G.J.M. Darrieus, a French aeronautical engineer, in the year 1931 (Darrieus 1931). A schematic diagram of Darrieus rotor is shown in Fig. 2.4b. Various variants as well as combination of Savonius and Darrieus rotors are being used and researched.

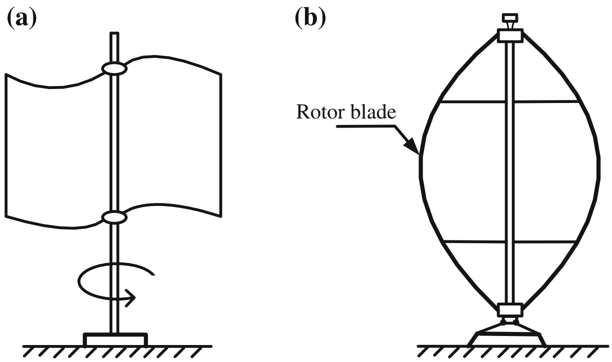


Fig. 2.4 Vertical axis wind turbine: **a** Savonius rotor and **b** Darrieus rotor

2.6 Archimedes' Screw

Screw is a mechanical element with helical spirals where both rotational and translational motion can be used to achieve the desired work. Archimedes, the great Greek scientist, first used the principle of screw to raise water in the third century BC. Therefore, the concept of screw, in particular screw as a system of raising water, is associated with Archimedes. In Archimedes' screw, water is pumped by turning a helical screw-shaped surface inside a hollow cylindrical shaft. With the rotation of the shaft and the helical surface, water gets carried up along the spiral and delivered at the end. In ancient times, Archimedes' screw was mainly used for irrigation, raising water, and draining water from mines and low lying areas. It was rotated manually or by a windmill. It is believed that Archimedes' screw was used for watering the Hanging Gardens of Babylon, one of the Seven Wonders of the World (Dalley and Oleson 2003). The geometry of an Archimedes screw is important for the volume of water to be lifted which depends on certain parameters such as the diameter, length and inclination of the outer cylinder, number of blades and their pitch and helix angle, water head, and the speed of rotation of the screw. The original Archimedes' screw had a wooden rotor with eight number of spiral blades with pitch equal to the circumference of the rotor, the length of the rotor being 16 times its diameter (Rorres 2000). An outer cylinder was constructed with wooden planks to cover the rotor blades. Depending on the height up to which water was to be lifted, the Archimedes' screw was placed inclined along the hypotenuse of a right-angled triangle with the bottom part immersed in water as shown in Fig. 2.5. With rotation of the blades, water got trapped in the helical blades and carried upward. Volume of water delivered per rotation can be increased by increasing the rotor blade diameter. Similarly, water delivered per unit time can be increased by increasing the speed of rotation.

The application of the principle of the Archimedes' screw is seen in many modern machines. For example, screw conveyors and rotary feeders are used to

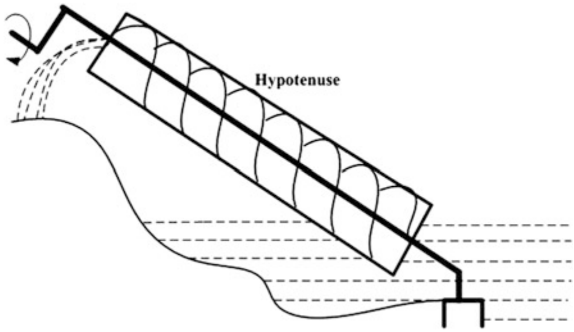


Fig. 2.5 Archimedes' screw

transfer both solids and liquids from one end of the conveyor to the other in industrial applications. It is widely used to drain wastewater with debris in treatment plants, rivers, and lakes. Archimedes' screw can also be used to run like a turbine, which can be coupled with generator for producing the electricity. Modified forms of Archimedes' screw are used in forming processes such as extrusion, injection molding, and die-casting. It also has application in the field of solid waste disposal where a large conveyor screw with decreasing pitch is used to compress the waste material. Same principle is used in the rotary screw air compressor.

2.7 Steam Engine

A steam engine performs mechanical work using steam as its source of power. Use of steam as driving power for machines and engines is indeed an act of revolution. The inception of the idea of using steam as motive power dates back to first century BC when the Greek engineer Hero of Alexandria developed the famous 'aeolipile,' the first device to use steam as power (Burstall 1963). A schematic diagram of aeolipile is shown in Fig. 2.6. It contained a sphere partially filled with water, and two outlets were placed at 180° to each other. The device fitted on a frame was heated over a fire. Boiling water in the sphere produced two opposite jets of steam through the outlets that kept the sphere rotating. Although, at that time, this device was invented as a toy, it illustrated the power of the steam. Aeolipile was not an efficient device.

A number of steam-operated devices were designed, experimented, and modified since its inception. The contributions of a number of persons, viz. della Porta, de Caus, Boyle, Marriotte, Otto von Guericke, Dennis Papin, and Thomas Savery, toward the study of air and steam were invaluable for the invention of the steam engine. The first steam-operated device designed professionally for practical purpose is the 'pulsometer pump' by Thomas Savery in 1698. This was a steam-operated pump used for excavation in mines. Savery's steam pump had no moving parts. Steam was admitted to an empty chamber and condensed. The

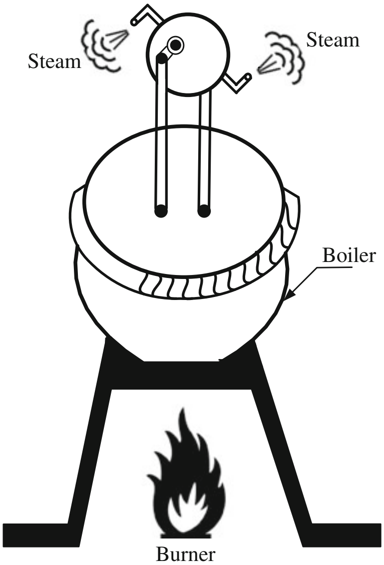


Fig. 2.6 A schematic of aeolipile

vacuum thus created drew wastewater from the bottom of the mine. However, it had disadvantages of low lift, high steam pressure, and propensity to accidents. Dennis Papin (1647-circa 1712) was a contemporary scientist who also experimented with condensed steam as a source of power. He is given the credit for using steam to move a piston within a cylinder for the first time. However, it was Thomas Newcomen (1664–1729) who first developed a practical steam engine with a piston and cylinder called Newcomen's atmospheric engine. The engine was developed in 1712 for raising the water in Dudley Castle, Staffordshire (Brown 2002). It had a piston in a cylinder which was attached by an iron chain to one end of a rocker beam that moved on a central pivot. At the other end of the rocker beam, another chain was attached to a plunger-type water pump. The rocker beam controlled the valves. Steam from the boiler entered the cylinder and condensed, thus creating the vacuum. The vacuum caused the piston to descend in the cylinder, which activated the plunger-type pump with the chain and rocker beam. Newcomen's steam engine worked at atmospheric pressure. Newcomen's invention was obviously influenced by the achievements in this field by his predecessors, viz. Savery (circa 1650–1715) and Denis Papin (1647-circa 1712) (Ainger 1829). There were considerable advancements in pumping water and air during this period. The act of using steam power to pump water was what made this engine unique. It was the first heat engine to be used as a source of mechanical power. In all the previous devices, manual and animal work, natural power from water wheels and windmills was used to get the driving force to produce mechanical work. Newcomen's steam engine opened the possibilities of freedom from dependence on nature and human being for doing mechanical work. It was a great success and widely used across Europe for pumping water, draining mines, and driving water wheels by 1750. It paved the way for all types of engines that were to follow using reciprocating piston to do work within a cylinder. It was undoubtedly the most significant invention in mechanical engineering that had accelerated the Industrial Revolution which set in from the middle of the eighteenth century. There were continuous efforts for improvements on the Newcoman's steam engine by the scientists John Smeaton and James Watt during the Industrial Revolution, which resulted in better versions in terms of thermal efficiency and horse power produced. A milestone in the history of steam engine was the modified version of the Newcomen's engine designed and patented by James Watt in 1781. It had a separate condenser and a double-acting cylinder–piston assembly that produced continued rotary motion. Moreover, it worked above atmospheric pressure. This engine was widely used to run the machines in the factories set up during Industrial Revolution (1750–1850). Watt succeeded in his efforts to provide rotary motion to his engine for driving factory machineries that enabled factories to be established away from the rivers (Rosen 2012). Earlier most of the factories were dependent on the flowing water of rivers for driving the water wheels.

Richard Trevithick (1771–1883) was the first to use a steam engine with a horizontal cylinder in 1803. This engine consisted as the basis for steam locomotives. By the end of nineteenth century, steam engine was used to drive vehicles and railway locomotives in addition to machineries in factories. Toward the end of the nineteenth century, steam turbines were introduced in the field of steam power. Steam turbines had less moving parts, could produce higher power, and were more efficient than reciprocating steam engine. Although a number of patents were provided for steam turbines during 1784–1884, Sir Charles Parsons (1854–1931) is credited for inventing the reaction turbine in 1884. During 1850–1900, many highly efficient steam engines were built, which were used in big ships, locomotives, and steam-operated road vehicles. The longest lasting steam engine used for road vehicle was the steam traction engine for carrying heavy loads. Steam engines and steam turbines were the dominant source of power until the early parts of the twentieth century. The contributions of some great scientific minds, viz. William Murdock, Arthur Woolf, George Stephenson, and Oliver Evans (in addition to those already mentioned above), are invaluable in the field of steam power. Although internal combustion engines and steam turbines have been replacing the steam engines in modern times, they can still be seen working at some places.

It is interesting to mention that the steam engine developed by Newcomen had an efficiency of 0.5 %. John Smeaton enhanced it to 1 %. Around 1885, the efficiency reached to 30 %. Theoretical thermodynamic efficiency of modern steam turbine may go up to 90 %.

2.8 Railways

The history of evolution of railways dates back to around 1600 when coal was transported in Britain by horse-driven wagons on wooden rails. They were in fact called tramways where a number of wagons were connected together and ran on wooden (and later on iron) rails. Wagons pulled by horses on tracks were used to transport people till nineteenth century. Mechanized railway was first used in England in the 1820s. After the development of steam engines, advances in railways and roadways progressed. There were continuous efforts to make steam engines smaller with higher power output so that they could be made mobile and used in vehicles. Although the father–son duo George Stephenson and Robert Stephenson are famous for inventing steam locomotive, the pioneering works of many contemporary scientists contributed toward the invention. Some early efforts were a prototype steam road locomotive by William Murdoch in Scotland in 1784 followed by a working model of a steam rail locomotive by John Fitch in the USA during the 1780s–1790s. Richard Trevithick was the first to invent and run a steam locomotive from Pendarren to South Wales in Britain in 1804 (Burstall 1963). It was in crude form and was not much reliable. However, it formed the foundation of modern locomotive engines for railways. Trevithick continued his efforts and developed a compact modified steam locomotive called ‘Catch Me Who Can’ in 1808. The locomotive had a speed of 19 km/h. Efforts continued with construction of more steam locomotives primarily for carrying coals from the collieries by Matthew Murray, Christopher Blackett, and William Hedley.

George Stephenson (1781–1848) built his first locomotive in 1813 for transporting coal in Killingworth Colliery. George Stephenson along with his son Robert Stephenson developed a number of improved steam locomotives and also concentrated on the issues relating to layout of railway track, signals, contact between wheel and track, and similar problems. The success story of practical railways started with the year 1825 when a railroad was opened from Stockton to Darlington with Stephenson’s steam locomotive called ‘Locomotion’ to carry coals. The ‘Rocket’ was another achievement by the Stephenson in 1829 which ran at about 48 km/h. The success of ‘Rocket’ was a landmark in the history of railways which opened the floodgates for construction of a number of railway lines in Britain. During 1830, a railway line was constructed by Stephenson between Liverpool and Manchester followed by a line constructed from London to Birmingham in 1838, which brought in the Railway Era in Britain. Another locomotive worth mentioning during this period is ‘The Lord of the Isles’ designed by Brunel for the Great Western Railway in 1841. In India, the first train ran between Mumbai and Thane in 1853.

Design of railway wheels were indeed challenging as they ran on rails. In the beginning of nineteenth century, rack-type tracks were developed on which a toothed wheel moved. However, it was difficult to use toothed wheels on rails. It took considerable efforts and experiments in the design of wheels for rails to realize that smooth rails in contact with the wheel rim could give sufficient friction to run the trains. Two types of wheel–rail combinations were initially used—flanged type and plated type. John Curr (circa 1756–1823) first introduced L-shaped flanged rails made with cast iron plates in 1776 (Roth and Divall 2015). Subsequently, the plate rail was introduced by Benjamin Outram and William Jessop in 1789. Initially, rails were made of a combination of wooden rails on transverse wooden sleepers. Later on, cast iron plates were laid on top of wood. These were replaced gradually by cast iron and steel rails for greater durability and safety. Around 1860, steel was used for making rails, which made it possible to carry heavy loads and run longer trains. Nowadays, steel rails with concrete or timber sleepers are common. Another challenge for expansion of railway lines was the construction of bridges on the rivers. With constructional and structural advancements in the field of civil engineering, more and more bridges were built on the rivers to meet this problem.

By the end of nineteenth century, more than 35,000 km of railway tracks were constructed in Britain and railways spread rapidly across the world in the twentieth century. It thus became the primary form of land transport all over the world for passengers and for carrying goods. Railways played a pivotal role in accelerating the Industrial Revolution. Railways continued to be used extensively in the twentieth century as it was cheap, could carry heavy goods, and convenient for long journey. Continuous efforts for improvement resulted in lightweight high-speed trains run by diesel engines and electricity. Nowadays, high-speed bullet train, sky train, and metro rails are common. Started in 2004, Shanghai Maglev (magnetic levitation) train is the fastest train with the maximum speed of around 430 km per hour (km/h). The fastest long-distance passenger train in the world is Jinghu High Speed Rail. It is a magnetic levitation train operating between Beijing and Shanghai at a speed of 300 km/h. The Chuo Shinkansen, a Japanese magnetic train, broke the world speed record for a passenger train in April 2015 (Reader's digest 2016). During a test run, it reached a speed of 603 km/h. Its planned top speed is 505 km/h, and it will connect Tokyo, Nagoya, and Osaka. It is expect to start from 2027.

2.9 Internal Combustion Engine

In internal combustion engines, the burning of fuel takes place in a closed combustion chamber that is an integral part of the engine and the combustion process releases high-temperature and high-pressure gases. Expansion of these hot gases is directly used to do work by acting on a piston or a rotor. It differs from the external combustion engine, where combustion takes place externally, e.g., in steam engine. In steam engine, water is heated separately in a boiler to produce steam, which is used to do work by actuating piston. The steam turbine is also a type of external combustion engine, where the steam generated in boiler is used to run rotor. In internal combustion engines, volatile fuels such as diesel, petrol, gasoline, natural gas, biodiesel are used, which release high amount of energy during combustion.

Invention of internal combustion engine (IC engine) is one of the most remarkable achievements in the history of mechanical engineering. Its invention has ushered in a new era in transportation. Internal combustion engines are widely used in automobiles, two-wheelers, aircrafts, locomotives, boats, and ships in addition to portable gadgets and machinery. It took scientific rigor and decades of research by a number of scientists to design a practical and efficient internal combustion engine. A host of professional engineers and scientists experimented and patented the designs of their IC engines but were not met with success. Early IC engines did not have the compression stroke, e.g., the engine built by Robert Street in 1794, which was in use for nearly a century (Davison 1957). The cylinder of the engine was opened at the top and closed at the bottom. Combustion was carried out at the bottom of the cylinder that moved the piston upward. Samuel Brown got patent for a compression-less IC engine in 1823 followed by Samuel Morey in 1826. By this time, Sadi Carnot, the father of thermodynamics, established the need for a compression stroke in IC engines for increasing efficiency. William Barnet tried to incorporate in-cylinder compression in his engine and patented it in 1838; however, it was not properly developed. Eugenio Barsanti and Felice Matteucci also met with similar fate in 1854. A commercially successful two-stroke IC engine developed by Etienne Lenoir in 1860 was similar in construction to horizontal double-acting steam engine, where combustion of gas–air mixture was used to do work in the place of steam. Lenoir's gas engine was capable of producing 0.5–3 hp power and was sold in hundreds in France. Nikolas Otto, the German scientist famous for inventing four stroke cycle (called Otto cycle), developed the Otto gas engine in 1876 with a compression stroke. The engine developed by Otto brought about phenomenal change in the history of IC engines. The success story of the Otto engine continued with selling of 45,000 engines in England, France, and the USA by 1885 (Burstall 1963). In 1880, Dugald Clark made some changes to Otto engine and invented the two-stroke IC engine. Dugald Clark is also credited for introducing supercharging of the working fluid. Subsequently, Atkinson cycle engine by James Atkinson was invented in 1882 with a higher efficiency than the Otto cycle. Early IC engines were used to run farm equipment, blowing blast furnaces, in pumping stations, and steel industries. Karl Benz was the first to build an IC engine based on Otto cycle to be used in automobile in 1879. Use of oil in IC engine in place of gas was also tried by many scientists. Daimler first made an IC engine to run on petrol for automobiles in 1884 where carburetor and electric spark were used for the first time. Another milestone in the history of IC engines was the invention of diesel engine by Rudolf Diesel in 1893. It had a higher thermal efficiency compared to its predecessors and successfully used for both stationary and automobile engines. Continuous efforts for improvements made IC engines more efficient, lightweight, smaller, cheaper, and most importantly reliable. Gradually, these engines were used in ships, aircraft, locomotives, automobiles, and power plants. Petrol engines were used for automobiles and aircraft and large diesel engines were used for stationary applications and ships, whereas high-speed diesel engines were used for heavy road vehicles and locomotives. The contributions of some great personalities such as Lanchester, Kettering, Daimler, Ford, Austin, and Morris are invaluable in the application of IC engines to automobile. Similarly, Wright brothers, Santos Dumont, Ellehammer, S.F. Cody, Hugo Junkers, and many others put efforts to fly aircraft with IC engines and gradually tasted success.

2.10 Aircraft, Rockets, and Satellites

From time immemorial, people dreamt of flying like birds and made innumerable attempts at it by attaching wings and flaps to their arms. In 1010, a monk named Oliver of Malmesbury became the first man to fly some distance with the aid of wings (Kalam and Singh 2015). He jumped from Malmesbury Abbey, England, and flew a short distance before crashing to the ground and causing injury to him. Realizing the impossibility of the effort, other means such as hot air balloons and hydrogen-filled balloons were tried by enthusiasts in 1783 where direction of flight was entirely controlled by the blowing wind. The basic principles of flying an aeroplane was first conceived by George Cayley (1773–1857) as early as 1799, and he made the scientific model of an aeroplane with a kite that had fixed wings and a movable tail. Inspired by Cayley's work, efforts and experiments went on by the scientists resulting in successful designs of gliders. Although control and steering posed problems, several manned flight in gliders and crude forms of planes were possible during the period 1849–1900 by some daring scientists. Some of the names worth mentioning are Octave Chanute, Otto Lilienthal, S.F. Cody, Felix du Temple, Francis Wenham, Horatio Phillips, Hiram Maxim, Santos Dumont, and many more for their invaluable contribution to the history of air travel. Based on the relentless efforts and scientific works of the predecessors, finally Wilbur Wright and Orville Wright, the two brothers of Ohio were able to achieve a successful flight on December 17, 1903, in North Carolina. It took them about four years and more than 200 models to reach this stage. Their aeroplane was made of canvas, wood, and a four cylinder IC engine of 12 HP power (Garrison 1999). Thus, Wright brothers had given wings to the age-old dream of mankind to fly in the sky.

Although Wright brothers' aeroplane was a landmark with its three-axis aerodynamic design, it was not up to the mark for commercial applications. Modifications on the existing design went on simultaneously by many scientists, and a variety of aeroplanes were constructed and tested up to 1908. Santos Dumont, Ellehammer, Hugo Junkers, Gabriel Voisin, Louis Blériot, and Henri Farman were some of the pioneers in commercialization of aircraft. The first person to fly as a passenger was Leon Delagrange, who rode with French pilot Henri Farman from a meadow outside of Paris in 1908 (http://www.avjobs.com/history/). On 25th July in 1909, Louis Blériot created history by crossing the English Channel in his aeroplane. With the advent of World War I (1914–1918) and the possibility of using aircraft in war, modifications in the design of aircraft took at an accelerated pace. Use of metals in aeroplane structure, higher speed, and height were some of the achievements. Fighter and bomber planes were extensively used during World War I. With ongoing research for improvements, gradually there were lighter, high-powered aeroplanes made of aluminum, fitted with wireless radio, gyroscope, superchargers, and cantilever wings, which were used for carrying passengers after the World War I. The aviation industry flourished with the events of flight across the Atlantic in 1919, beginning of an intercontinental flight service in 1921, and formation of several aviation companies. In 1929, the largest plane until then with 48-m-long wings made a flight with 169 passengers, which was a record that stayed intact for 20 years.

The development of jet engine was initiated in 1930 when Frank Whittle demonstrated his high-velocity propulsion jet with a gas turbine and a centrifugal compressor in 1930. The first jet aircraft called Heinkel was developed in Germany in 1939 (Garrison 1999). Helicopters were developed in Germany in 1941 during World War II. Simultaneously, design of rockets also improved with the innovation of jet propulsion and advances in fluid dynamics. The jet engines and rockets used in World War II (1939–1945) had elevated the aeronautical industry from subsonic flight level to supersonic. There was a rapid growth of commercial aviation after the World War II with a number of commercial jet airliners ushering in the Jet Age. The Boeing 747 was the largest commercial supersonic passenger jet airliner launched in 1969. Tremendous improvements took place in military aircraft with the developments of long-range bombers, supersonic interceptor aircraft, surface-to-air missiles, and ballistic missiles. The USA, Soviet Russia, and other European nations all contributed to these developments.

Fueled by the advances in science and technology, men's imagination and the urge to know the unknown soared. Exploring the space was the next level attained in aerospace engineering in the 1950s and 1960s. Both the superpowers, the USA and Soviet Russia started space exploration programs and launched space satellites to gather information of the earth and the space hitherto considered impossible. The crowning glory of their programs included landing on the Moon, manned flight to orbit the Earth, launching space satellites, and developing space habitat. Yuri Alekseyevich Gagarin was the first human being to journey into outer space in April 1961. Neil Alden Armstrong was the first person to walk on the surface of the moon in July 1969. Twenty-first century brought in the digital era making it possible to design remote controlled automated and unmanned aircraft called unmanned aerial vehicles (UAV) to be used in wars, rescue operations, emergency, and dangerous missions. The latest feather in the cap is the flight by André Borschberg in a solar plane from Nagoya, Japan, to Honolulu, Hawaii, in 2015. Born on December 13, 1952, Borschberg is a Swiss businessman and pilot, who cofounded the Solar Impulse Project. Nowadays, several flying robots are being developed. Some of them are of the size of a fly.

2.11 CNC Machines

Automation is gaining prime importance in the modern industries to fulfill the need for improved productivity, quality, novelty, and variety in products. To address these issues, the use of computers has become necessary. Computer numerical control (CNC) can be defined as a form of programmable automation which is used for the operation of different machine tools. CNC machines are widely used by the industry where a program of instructions (codes) is stored in the memory of a computer. The computer acts as the controller for the functions to be performed by the machine as per the program of instructions. The programmer can edit, modify, and reprogram the codes as per the requirements. Before the use of computers, Numerical control (NC) machines were used where the program was fed to the machine with punch cards. NC machines were improved rapidly after the use of computers as the controlling unit and renamed as CNC machines. The CNC technology is widely used in machining processes such as turning, drilling, milling, and shaping. Once the complete program is fed and activated in the CNC controller, the machine automatically performs the machining operations to achieve the final component. The CNC controller directs the machine tool to perform various operations as per the program of instructions.

The history of NC technology dates back to the early part of the twentieth century. The first NC prototype machine was developed in 1952 in Massachusetts Institute of Technology (MIT) that used punched tap for feeding the programming instructions. The foundation of NC technique was laid by the pioneering works of John Parsons in 1940, when he tried to automatically generate a curve by providing coordinated motions to the tool path (Groover and Zimmers 1984). In 1948, Parsons developed a method of using punched cards containing the coordinate positions to control the tool path of a machine tool. He succeeded in generating the curved surface of a helicopter blade by directing the machine to move in small increments. Thus, NC technology was conceived for the first time and subsequently researched and advanced in the MIT. As the potential of NC technology for mass production and productivity was perceived, there was profound use of it among commercial machine tool manufacturers. Initially, punched tapes were used for feeding the programming instructions to the machine tools through the control unit. However, research continued as there were certain disadvantages with the conventional NC machines. When the programs were written on the punched tape, it took several passes of the tape to write a correct program, in addition to the tapes being fragile and prone to wear and tear. It was inflexible in terms of using varying speed and feed of machining operations. The machine control unit was not flexible and could not adapt to changes. With the advancements in the field of electronics, the disadvantages of the NC machines were removed over time. The new inventions of electronics, viz. miniature electronic tubes, solid-state circuits, and integrated circuits, were gradually used in NC machines making it better, smaller, and more reliable. Introduction of the computers has taken NC technology to a new height, and it came to be known as the CNC technology. The control units with punched cards in the NC machines were replaced by the computers in the CNC machines. Initial CNC machines used minicomputers in the 1960s. Computerized machine control unit led to software-based control on the machine which is very flexible. It enabled easier storing, editing, and changing of the programs, and better control and communication between the controller and the machine. Computers provided an easier programming environment and flexibility. Different programming languages such as G-codes, M-codes, and Automatically Programmed Tool (APT) were developed. The APT language is still in use in the industry, and it is also the basis of several modern programming languages. The use of CNC technology has led to higher state of automation, thus reducing the operator intervention. It can be operated automatically to produce components in large quantities, thus improving productivity. CNC technology has paved the way for computer-aided design (CAD) and computer-aided manufacturing (CAM) in the 1960s. CNC revolution accelerated in the 1970s and the 1980s with development of a number of CNC companies in the USA and Germany followed by Japan.

Manufacturing companies nowadays use CNC machines for producing better products as the competition have become very stiff. The latest CNC machines have microprocessor-based control system with feedback for higher efficiency. Adaptive control is possible in the microprocessor-based CNC machines for changing cutting environment. It incorporates feedback and optimal control through continuous monitoring and optimization of the machining parameters. Adaptive control is more accurate, precise, and advantageous for complex shapes. CNC software programs such as Enhanced Machine Controller (EMC) and Mach3 were made available as open source programs for personal use in 2003 (Groover and Zimmers 1984). Thus, CNC technology has revolutionized the manufacturing industry.

2.12 Wootz Steel

Steel, an alloy of iron and carbon, is the most widely used material in the history of metallurgy till date. The carbon in steel is in the form of iron carbide which enhances its strength and hardness. Although magnetite ore (Fe_3O_4) are abundant on the earth, melting magnetite to produce iron was a difficult task as iron has a high melting point. With the advancement of metalworking and design of better furnaces, iron could be processed at elevated temperature. It was discovered that iron mixed with carbon makes an alloy, steel, which has much higher strength compared to bronze. Soon iron and its alloys were used in all spheres of engineering and technology where strength was an important property for the working material.

Wootz steel was produced by Wootz process in India and Sri Lanka as early as first millennium (Garrison 1999). Wootz is the anglicization of ‘ukku,’ the Kannada word for steel (Srinivasan and Ranganathan 2004). There are evidences of production of crucible steel/Wootz steel in South India and Sri Lanka and exporting to Rome, Egypt, China, and Arab countries (Srinivasan 1994). The Arabs learnt this technique from India and used for making Damascus steel, another variety of high quality steel. The Damascus sword was famous for its sharpness. Recently, a wind-driven furnace was discovered along the coastline of Sri Lanka where monsoon wind of the Indian Ocean was used for natural draft to produce high carbon steel at around 1500 °C (Juleff 1996). Wootz process of making steel was developed by Indian blacksmiths where black magnetite ore was heated with bamboo charcoal in a clay crucible to produce carbon steel. Sometimes, wrought iron was first obtained by smelting the ore and then burnt with bamboo charcoal and certain plants containing carbon in a ceramic crucible up to 1200 °C. Smelting of wrought iron produced a high quality steel containing 1.5–2 % carbon. Wrought iron turned into austenite at the elevated temperature with the carbon atoms within its lattice structure which turned cementite after slow cooling. Cementite is turned into martensite by reheating and tempering, thus adding ductility and strength. In Wootz steel, a bandlike pattern is seen which is made by the precipitated iron carbides present in the martensite matrix.

As there were trade exchanges among the Asian and European countries, the technique of Wootz steel was learnt by the European traders around seventh century. British Royal Society tested and analyzed some samples of Wootz steel in 1790 with a motive of ascertaining its quality and possible production. Wootz steel played an important role in the field of metallurgy in Europe. The British Government in India prohibited the industry of Wootz steel in 1866 to reduce deforestation. Because of its high quality and novelty, efforts at reproduction of Wootz steel were tried by many metallurgists, e.g., Oleg Sherby, Jeff Wadsworth, Lawrence Livermore, J.D. Verhoeven, and Al Pendray in the twentieth century (Srinivasan 1994). The ancient technique of Wootz steel is not yet fully unveiled, and research is still going on to explore this advanced material hoping for a promising future.

2.13 Rapid Prototyping

In the present competitive market, manufacturing industry is faced with the challenges of product variety and customization combined with the requirement of enhanced product quality at lower cost. Automation is gaining prime importance in modern manufacturing industries to fulfill the above needs. The manufacturing industries have to innovate ways to reduce the time taken to design, manufacture, and market the product. There is continuous improvements and redesigning of products using CAD/CAM tools to meet the customer's demand. Recent technology such as rapid prototyping (RP) can directly fabricate a scale model of a part from 3D CAD model, thus enabling faster ways of manufacturing a part. Prototyping of a part is done prior to actual production to detect the design errors if any. In RP technique, need for prototype development is eliminated and scale models and parts are fabricated layer by layer by additive manufacturing process. Polymer powders such as polyamide, polyester, glass fiber-filled polymers, and aluminide are used in RP machines to form the layers. RP technique is also known as layered manufacturing. Although RP models are widely used for visualization and testing, it is also used for fabricating the actual parts.

Rapid Prototyping has emerged as a frontier technology in the early 1980s for its obvious benefits. It tremendously reduces the manufacturing lead time. As RP is an additive manufacturing process, need for tooling is eliminated and complex geometry can be directly manufactured from the 3D CAD model. Another contribution of RP to the conventional manufacturing industry is the rapid production of complex shaped tools which is not possible by conventional machining processes. This is called rapid tooling (RT) which is a natural extension of RP technique that enables design and fabrication of tools for casting, molding, and sheet metal-forming industries. Moreover, the product data in the 3D CAD model can be used for performance and cost analysis, engineering analysis regarding strength, structure, etc., customization of the product, and for interactive use during design and manufacturing stages. RP is preferred for customized products such as ear plugs for hearing aids, prosthetics of body parts, and cosmetic dentistry where the data from CT scan and MRI can be directly used for fabrication. It is profoundly used for artificial bone replacements in knee, jaw, and scalp in biomedical applications. RP is very important for the research and testing in the aerospace and missile industries. RP technique reduces the need to maintain a large inventory of parts. One can store the CAD model and rapidly e-manufacture the part on demand. The basic components of a RP system are 3D CAD or solid modeling software, RP machine and the related software for converting solid model data to instruction for the RP machine, and the post-processing equipment. A block diagram of the components of RP technology is shown in Fig. 2.7.

Different RP techniques available are Stereolithography Apparatus (SLA), Selective Laser Sintering (SLS®), Laminated Object Manufacturing (LOM™), Fused Deposition Modeling (FDM), Solid Ground Curing (SGC), and Inkjet printing techniques, Three-Dimensional Printing (3D Printing), and Ballistic Particle Manufacturing (BPM). The basic principle of these techniques is similar. First, the 3D solid model data is converted to.stl file format which is the input format for the RP machines. Then, the solid model is sliced into a number of 2D

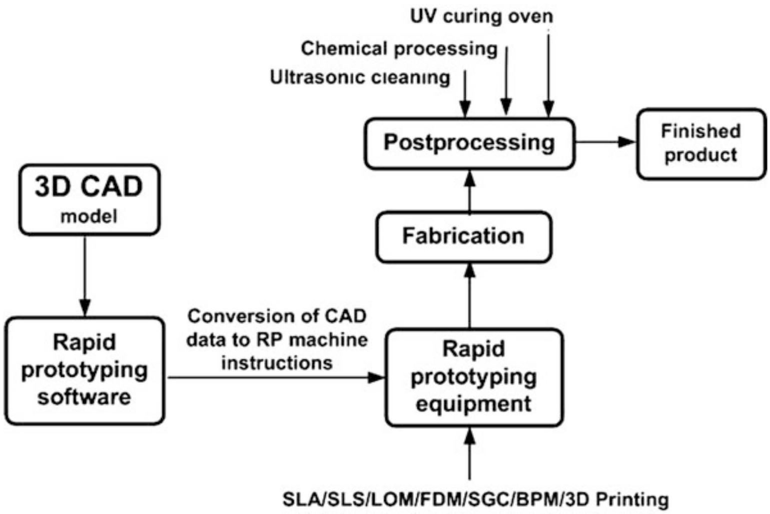


Fig. 2.7 The components of RP technology

cross-sectional layers and stacked using the bottom-up approach to fabricate the part. The part is then post-processed to rectify the defects. Initial RP machines were smaller in size and could produce small components. Large components were to be fabricated in parts and then glued. Currently, large machines are available for this purpose. RP technique has immense potential for the future and can be extended to other functions in engineering in addition to manufacturing. However, like all other techniques, RP too have its disadvantages, e.g., high cost of the machine and material, restricted part dimensions, and difficulty in accurate assembly of small sub-parts. Research is going on to bring in a new era of e-manufacturing by overcoming these difficulties (http://www.cc.utah.edu/~asn8200/rapid.html).

Nowadays, the word 3D printing is used synonymously with RP. 3D printing is a type of RP that uses a printer-type machine to make solid objects. Usually, 3D printers are easier to operate and inexpensive, but are able to produce smaller size of objects compared to a RP machine. It is envisaged that in near future, 3D printers will be as widespread and popular as the present-day computer printers. In the opinion of the authors of the present book, the term RP should be used for any technology that can develop a prototype in a short span of time; it need not be based on additive technology. On the other hand, the term 3D printing should be used for the technology that develops a product layer by layer, converting the digital image to real product.

2.14 Air-Conditioning and Refrigeration

Refrigeration is defined as the process of cooling and maintaining a temperature below that of the surroundings by the transfer of heat from one region at a lower temperature to another at a higher temperature. Refrigeration is carried out by providing external work/heat in the form of mechanical/electrical power and/or some heat. The immense importance of refrigeration is reflected by its innumerable applications. Some of them are freezer, refrigerator, and cold storage for processing, preservation, and distribution of food products, cryogenics in aerospace engineering, chemical, biomedical, and pharmaceutical industries, special applications such as cold treatment of metals, construction of artificial ice skating ring, and air-conditioning for human comfort, etc.

Air-conditioning (AC) is one of the applications of refrigeration technique to provide thermal comfort to living beings. Air-conditioning can be defined as the treatment of air by simultaneously controlling the parameters such as air temperature, humidity, air movement, odor, cleanliness, and ventilation of air to provide a more comfortable condition. It comprises cooling/heating, humidifying/dehumidifying, ventilating, and cleaning of air and circulating the same primarily to provide thermal comfort to people and to maintain a low-temperature environment for some applications such as operation theater, laboratory, pharmaceutical, and food processing industries. The conditioned air is supplied to buildings, houses, rooms, and vehicles.

The major types of refrigeration systems are as follows:

- Vapor compression refrigeration systems,
- Vapor absorption refrigeration systems,
- Gas/air cycle refrigeration systems,
- Solar energy based refrigeration systems, and
- Thermoelectric refrigeration systems.

The most widely used methods are the vapor compression refrigeration and vapor absorption refrigeration. The basic components of a vapor compression system consist of an evaporator, compressor, condenser, and an expansion valve as shown in Fig. 2.8a. The cooling effect is obtained by extracting heat by the vaporization of the refrigerant in the evaporator. The refrigerant vapor is then compressed in the compressor to a high pressure and passed through the condenser so that the vapor condenses into liquid by heat rejection to the heat sink. The high-pressure liquid refrigerant is then passed through an expansion valve to lower its pressure and temperature. The cycle repeats. The system requires input in the form of mechanical work. The vapor absorption system shown in Fig. 2.8b is similar to vapor compression system, except that the compressor is replaced by an absorber which dissolves the refrigerant in a suitable liquid. There is a liquid pump to increase the pressure of the mixture, and a vapor generator is used to extract the refrigerant vapor from the high-pressure liquid on heat addition. From vapor generator, the weakened refrigerant–absorbent solution is throttled back to absorber.

In gas/air cycle refrigeration, the working fluid is a gas/air that is compressed and expanded. Heat exchangers are used in place of condenser and evaporator. Using solar energy for refrigeration is given importance due to scarcity of fossil fuel energy sources. Solar energy-based vapor absorption refrigeration and air-conditioning are attempted using flat plate solar collectors. Recent method such as thermoelectric refrigeration is used in cryogenics and is still under research.

The history of refrigeration and air-conditioning is very long. In olden times, refrigeration and air-conditioning were achieved by the use of snow and ice and various means of natural cooling. In cold countries, ice-harvesting was done in winter and stored to be used in summer. Cooling of water by keeping in earthen pots is an age-old method where water evaporates through the pores of the pot absorbing the latent heat from the water. Evaporative cooling was used in ancient Egypt, Rome, and India by hanging straw mats in the windows that were wet with water. The evaporation of water cooled the air blowing through the window. Wind towers and flowing water ducts were some other methods used for cooling buildings.

The domestic refrigeration using natural ice in wooden insulated box was first used in 1803 and is still used by the street vendors. The era of artificial refrigeration started with the refrigerating machine (for making ice) made by the Scottish professor William Cullen in the year 1755 (Arora 2010). Invention of the first vapor compression mechanical refrigerator is credited to Jacob Perkins in 1834 (Burstall 1963). A number of patents were granted subsequently for inventing different vapor

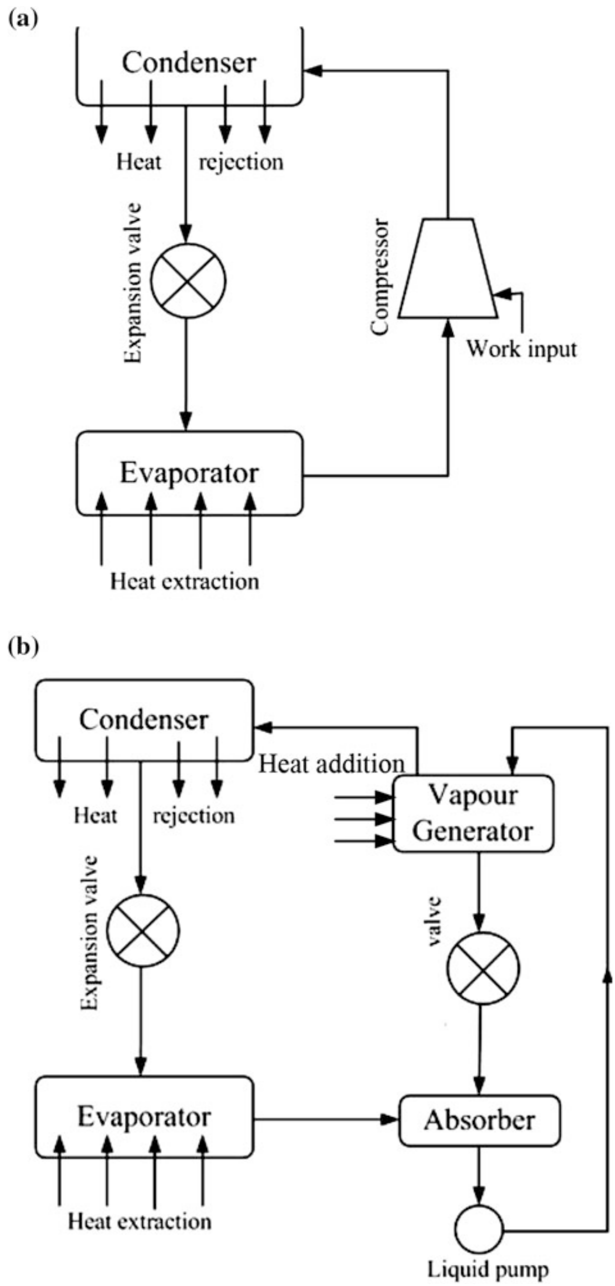


Fig. 2.8 Schematic of refrigeration system: **a** vapor compression and **b** vapor absorption

compression refrigeration machines using different refrigerants to John Gorrie (1845), James Harrison (1857), Charles Tellier (1864), David Boyle (1871), John Enright (1876), and many more (http://www.nptel.ac.in/courses/112105129/pdf/RAC%20%20Lecture%201.pdf). Refrigerated railroad cars were first used in the USA using ice to lower the temperature of the railway compartments in 1840. The early refrigerants used were mainly ether, alcohol, sulfur dioxide, methyl chloride, methylene chloride, etc. Carl Von Linde (1842–1934) first used ammonia as the refrigerant in his ice-making machine in 1876. The first vapor absorption refrigeration with ammonia was developed by Ferdinand Carré (1824–1900) in 1860 and was widely used up to the 1920s. Freon was the new refrigerant used in the early part of the twentieth century that replaced ammonia. The modern refrigerators use hydrofluorocarbon (HFC) and chlorofluorocarbon (CFC) as refrigerants. The first commercial domestic refrigerator was made by General Electric Company, USA, in 1911 and then other companies in Japan and Europe followed suit. The refrigerator based on vapor absorption principle proposed by Platen and Munters was first made by Electrolux Company in 1931. The first dual temperature refrigerator with two chambers was introduced in 1939. The development of air-conditioning is due to the pioneering work of the American scientist Willis Carrier who invented the first air conditioner in 1902. It rapidly grew based on the research of many scientists and was in wide used by 1930. Air-conditioning was in use in private homes in the USA by 1933. Modern air-conditioning is based on vapor compression or vapor absorption methods for cooling and heating of space. Air-conditioning is now widely used in residential and commercial buildings; in textiles, such as printing, manufacturing, and photographic industries; in computer rooms, such as power plants; and in mobile applications such as as railways, automobiles, and aircrafts. In modern lifestyle, refrigerator and air conditioners are the part and parcel of day-to-day life.

2.15 Mechatronic Products

Mechatronics refers to the synergistic integration of mechanical engineering with electronics, electrical engineering, and control engineering supported by computer engineering, information technology, and telecommunication engineering for better design, manufacture, and operation of products and processes. As suggested by W. Bolton, ‘a mechatronic system is not just a marriage of electrical and mechanical systems and is more than just a control system; it is a complete integration of all of them. It can be considered to be the application of computer-based digital control techniques, through electronic and electric interfaces, to mechanical engineering problems (Bolton 2006). The most important characteristic of a mechatronic system is its ability to process and communicate information in different types of signals, viz. mechanical, electrical, hydraulic, pneumatic, optical, chemical, and biological. Mechatronics can be classified into several key areas, for example, robotics, intelligent motion control, automation, actuators and sensors, modeling and design, electronics and optoelectronics, etc.

The idea of automatic control of a mechanical system originated by the end of the nineteenth century fueled by the progress in different field of engineering during the Industrial Revolution. During World War II, automatic control systems advanced with the design of various war-related gadgets such as automatic airplane pilots, gun-positioning systems, and radar. Before the 1960s, most of the industrial products and equipment were based on mechanical principles. However, the evolution of mechatronics started in the 1960s with the progress in the fields of electronics, development of microprocessors, NC technique, semiconductors, and integrated circuits. During the 1970s, there was a change in the technology of products and equipment with incorporation of electronic components with the mechanical systems. It is when the term 'mechatronics' was first coined for such products by Tetsuro Mori, an engineer in Yaskawa Electric Corporation in Japan in 1969.

During the early 1970s, mechatronic products such as automatic door opener, vending machines, dot matrix printer, and autofocus camera were developed. Gradually, the advances in control theory, computation technology, servo technology, microprocessors, and integrated circuits enabled design of products such as NC machine tools, sewing machine, digital watch, push button telephones, electronic typewriter, photocopiers, automatic washers and dryers, rice cookers, and automatic ovens. Mechatronics played a pivotal role in development in robotics in the 1970s. The 1980s saw the progress in information technology, and microprocessors were embedded into mechanical systems to improve performance, for example, antilock braking system. Digital computers were integral for control systems. Controlling and functioning of machines became much easier by the use of computer hardware and software enabling manufacturing of a product with high accuracy, for example, CNC machines. Finally, since the 1990s, there has been tremendous progress in the field of mechatronics and it is applied in robotics, flexible manufacturing systems (FMS), CAD/CAM, automated guided vehicles (AGV), data communication systems, multi-point fuel ignition, and digital engine control in automobiles, smartphones, microwave ovens, dish washers, vacuum cleaners, televisions, cameras and camcorders, video recorders, central heating controls, bar coding machines, automatic teller machines (ATM), and the list goes on. The latest addition to the list is biometrics, automatic climate control, automatic unmanned vehicles, microbots, etc. Future of mechatronics has extreme potential as the application area of mechatronics encompasses all spheres of human lifestyle.

2.16 Conclusion

In this chapter, some revolutionary mechanical engineering inventions have been discussed. Starting from wheel to mechatronic products, the technology has been continuously evolving. The mechanical engineering is a very dynamic discipline of engineering. New technologies have been replacing the old. Electronics watches have replaced the mechanical watches. The belt-pulley drive, cam follower, and even gears are phasing out in favor of sophisticated motors and control systems. However, the basic philosophy of mechanical engineering remains same. It tends to make machine, equipment, and tool for enhancing the capabilities of human being.

References

Ainger, A. (1829). On the early history of steam engine. *Journal of Franklin Institute, IV*(6), 361–370.

Anthony, D. W. (2007). *The Horse, the wheel and language: How Bronze-age riders from the Eurasian stepps shaped the modern world*. Princeton: Princeton University Press.

Armytage, W. H. G. (1961). *A social history of engineering*. Massachusetts: The MIT Press.

Arora, R. C. (2010). *Refrigeration and air conditioning*. New Delhi, India: PHI Learning Private Limited.

Bolton, W. (2006). *Mechatronics-electronic control systems in mechanical and electrical engineering* (3rd ed.). Delhi: Pearson Education, Dorling Kindersley (India) Pvt. Ltd.

Brown, R. (2002). *Society and economy in modern Britain 1700–1850*, Taylor & Francis.

Burstall, A. F. (1963). *A history of mechanical engineering*. London: Faber and Faber.

Cleveland, C. J. (Ed.) (2007). History of wind energy. In: *Encyclopedia of energy* (Vol. 6, pp. 421–422), Elsevier.

Dalley, S., & Oleson, J. P. (2003). Sennacherib, archimedes, and the water screw: The context of invention in the ancient world. *Technology and Culture, 44*, 1–26.

Darrieus, G. J. M. (1931). Turbine having its rotating shaft transverse to the flow of the current. US Patent no. 1835018.

Davison, C. S. C. (1957). The internal-combustion engine. *Journal of the American Society of Naval Engineers, 69*, 148–152.

Garrison, E. (1999). *A history of engineering and technology-artful methods*. Florida: CRC Press.

Groover, M. P., & Zimmers, E. W, Jr. (1984). *CAD/CAM: Computer-aided design and manufacturing*. USA: Printice Hall of India Private Limited.

Juleff, J. (1996). An ancient wind powered iron smelting technology in Sri Lanka. *Nature, 379*, 60–62.

Kalam, A. P. G. A., & Singh, S. P. (2015). *Reignited: Scientific pathways to a brighter future*. Gurgaon, India: Puffin Books.

Reader's digest (2016, March). All abroad! eight long (and iconic) train tips, pp. 66–67.

Rorres, C. (2000). The turn of the screw: Optimal design of an Archimedes screw. *Journal of Hydraulic Engineering, 126*(1), 72–80.

Rosen, W. (2012). *The most powerful idea in the world: A story of steam*. Industry and Invention: University Of Chicago Press.

Roth, R., & Divall, C. (Eds.). (2015). *From rail to road and back again?: A century of transport competition and interdependency*. England: Ashgate Publishing Limited.

Savonius, S. J. (1931). The S-rotor and its application. *Journal of Mechanical Engineering, 53*(5), 333–338.

Semaw, S., Rogers, M. J., Quade, J., Renne, P. R., Butler, R. F., Domínguez-Rodrigo, M., et al. (2003). 2.6-million-year-old stone tools and associated bones from OGS-6 and OGS-7, Gona, Afar, Ethiopia. *Journal of Human Evolution, 45*, 169–177.

Shames, I. H. (1997). *Engineering mechanics—statics and dynamics*. Singapore: Pearson Education.

Srinivasan, S. (1994). Wootz crucible steel: A newly discovered production site in South India. *Papers from the Institute of Archaeology, 5*, 49–59.

Srinivasan, S., & Ranganathan, S. (2004). *India's legendary wootz steel: An advanced material of the ancient world*. Bangalore and Indian Institute of Science, Bangalore: National Institute of Advanced Studies.

Retrieved September 15, 2015, from http://www.autoevolution.com/news/history-of-the-wheel-7334.html.

Retrieved March 17, 2016, from http://www.avjobs.com/history/.

Retrieved August 24, 2015, from http://www.cc.utah.edu/~asn8200/rapid.html.

Retrieved March 15, 2016, from http://www.gwec.net/wp-content/uploads/2015/02/GWEC_GlobalWindStats2014_FINAL_10.2.2015.pdf.

Retrieved September 3, 2015, from http://www.localhistories.org/techhist.html.

Retrieved August 22, 2015, from http://nptel.ac.in/courses/112105129/pdf/RAC%20%20Lecture%201.pdf.