

Part 66 Cat. B1 Module 2

PHYSICS

Vilnius-2017

we made give us a parallelogram rule for force decomposition - any force can be decomposed into two mutually perpendicular components, with magnitudes proportional to \sin and \cos function of appropriate angles.

In the example of inclined plane (**Fig. 2.2-9**) with length $L = 8 \text{ ft.}$ and height $h = 2 \text{ ft.}$, the rolling force

$$F_{Rol} = W \times \sin \alpha = 430 \times \frac{h}{L} = 430 \times \frac{2}{8} = 107.5 \text{ (lbs)}$$

is 4 times smaller than the weight due to inclined plane with smaller angle - with the use of calculator or trigonometric tables:

$$\sin \alpha = \frac{h}{L} = \frac{2}{8} = 0.25 \text{ and the angle } \alpha \approx 14.5^\circ$$

that is almost twice lower value than 30 degree (**Fig. 2.2-11**). That gives the effort almost two times smaller.

Pulley

Pulleys (**Fig. 2.2-12**) are simple machines in the form of a wheel mounted on a fixed axis and supported by a frame. The wheel, or disk, is normally grooved to accommodate a rope. The wheel is sometimes referred to as a "sheave" (sometimes "sheaf"). The frame that supports the wheel is called a block. A block and tackle consists of a pair of blocks. Each block contains one or more pulleys and a rope connecting the pulley or pulleys of each block.

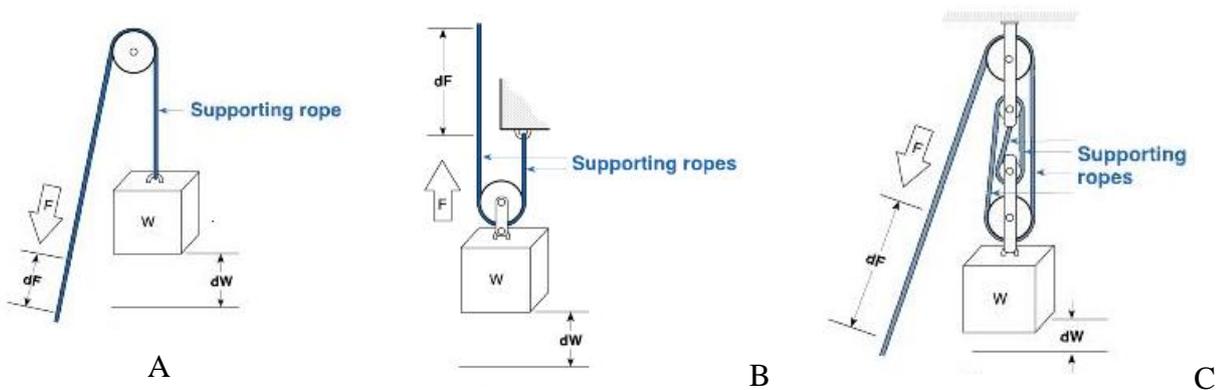


Figure 2.2-12. One section (A); two sections (B) and four sections (C) pulley

One section of supporting rope gives no mechanical advantage - only change in direction. Two sections of supporting rope give a mechanical advantage of 2 and four sections of supporting rope give a mechanical advantage of 4.

Mechanical Advantage of a Pulley

Mechanical advantage of a pulley is related to force decomposition (**Fig. 2.2-13**) as well as in inclined plane.



Figure 2.2-13. Pulley force decomposition

A single movable pulley (**Fig. 2.2-13A**) can be used to magnify the force exerted. The pulley is not fixed, and the rope is doubled. This leads to diminished effort, which is only $\frac{1}{2}$ of weight. The same effect is obtained when two sections are used as shown in the **Fig. 2.213B**. The lifting effort could be larger, if is directed by some angle to lifting direction.

Pulley as a Lever

A single fixed pulley is really a first-class lever with equal arms. The arms (**Fig. 2.2-14A**) are equal; hence the mechanical advantage is one. Thus, the force of the pull on the rope must be equal to the weight of the object being lifted ($R = E$). The only advantage of a single fixed pulley is to change the direction of the force, or pull on the rope.

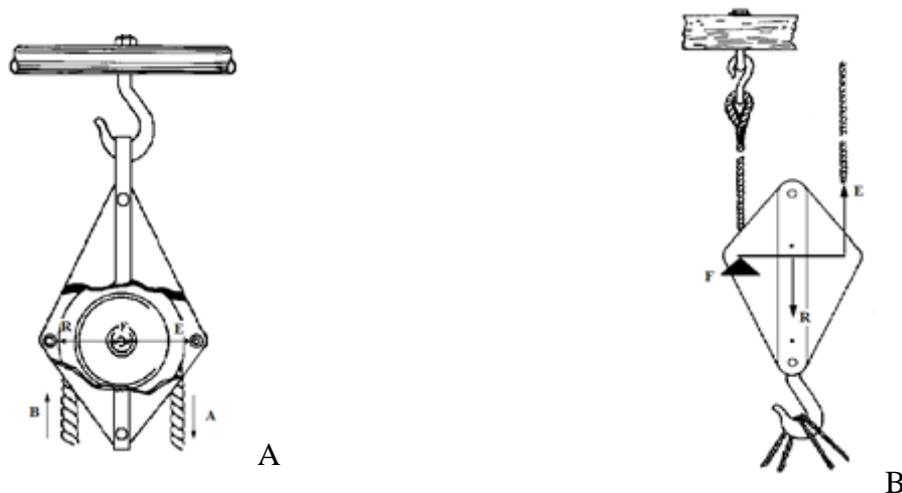


Figure 2.2-14. A single fixed (A) and movable (B) pulleys

Say, we need to subtract two vectors a and b . First make vector b negative ($-b$), by simply changing its direction, and then add those two vectors.

Acceleration of the Uniform Circular Motion

To derive the laws of circular motion the knowledge of vector addition, subtraction and motion laws will be applied. During circular motion the velocity vector permanently changes its direction as it is shown on **Fig. 2.2-49**. Two velocity vectors are named v_{Fin} (final velocity) and v_{In} (initial velocity). The points are on a circular path of radius r and divided by a distance s . This situation is modeled separately on the same circumference.

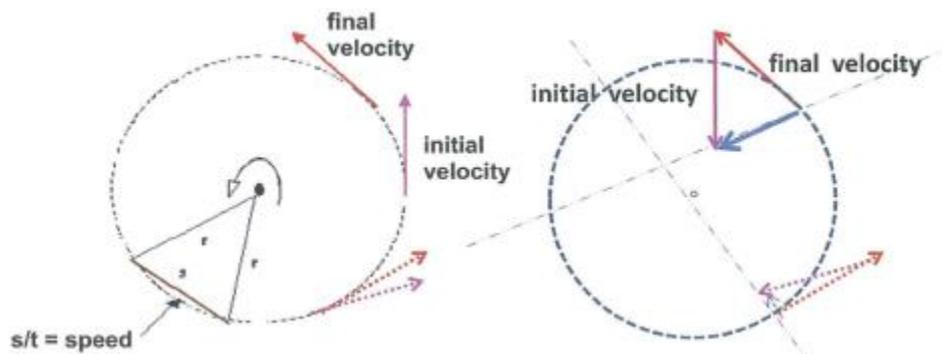


Figure 2.2-49. Circular rotation

The change in velocity vector's direction can be interpreted as motion under uniform acceleration which is described by the 1st law of motion. For this case it is:

$$\vec{v}_{fin} = \vec{v}_{in} + \vec{a}t$$

and

$$\vec{a} = \frac{\vec{v}_{fin} - \vec{v}_{in}}{t}.$$

If we represent the subtraction in vector form as it is done on **Fig. 2.2-49** (right), it is seen the vector

$$\vec{a}t = \vec{v}_{fin} - \vec{v}_{in}$$

is looking somewhere to the center of the circumference. If we bring the points closer as it is shown on the same picture, the direction of the $\vec{a}t$ changes and becomes the direction exactly to the center.

Therefore we have proved the statement about the centripetal nature of the acceleration of the circular motion. The other step is to derive the formula for centripetal acceleration. As we are interested in magnitudes mainly, the scalar form of the last equation shall be used:

$$|\vec{a}t| = |\vec{v}_{fin} - \vec{v}_{in}|$$

or

$$|\vec{a}|t = \Delta v.$$

In the beginning of this topic we chose the distance between the points being s . The radii to these points are perpendicular to velocity vectors. The logic conclusion is when the radius rotates by the

angle a , the direction between the velocities differs by the same angle. Both triangles formed by radii (background s) and by velocities (background Δv) are called like-looked with identical ratios between similar sites.

That allows forming a proportion:

$$\frac{s}{r} = \frac{at}{v}$$

As $s = vt$, the proportion can be transformed into:

$$a = \frac{s \times v}{r \times t} = \frac{vt \times v}{r \times t} = \frac{v^2}{r}$$

The magnitude of the acceleration is given by:

$$a = \frac{v^2}{r}$$

where v is the speed of the object and r is the radius of its path. This is an equation of centripetal acceleration with respect to velocity because the radius remains constant.

Centripetal Force

The acceleration of circular motion is usually considered to be due to an inward acting [force](#), which is known as the centripetal force. Centripetal force means “center seeking” force. It is the force that keeps an object in its uniform circular motion (**Fig. 2.2-50**).

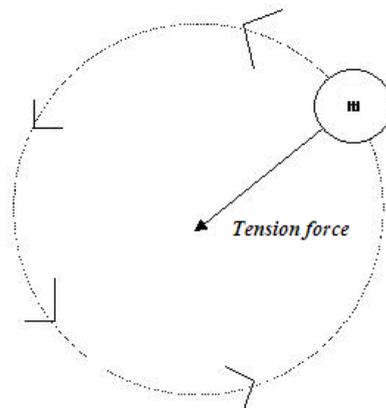


Figure 2.2-50. Tension as the centripetal force (a mass on a string)

The centripetal force can be provided by many different things, such as tension (as in a string), and friction (as between a tire and the road).

An example of tension being the centripetal force is tying a mass onto a string and spinning it around in a horizontal circle above your head. The tension force is the centripetal force because it is the only force keeping the object in uniform circular motion.

The m is the mass of the object, and the tension force is the centripetal force because it is keeping the object in uniform circular motion. If the rope is cut the object would continue to move in the direction of the velocity (**Fig. 2.2-51**).

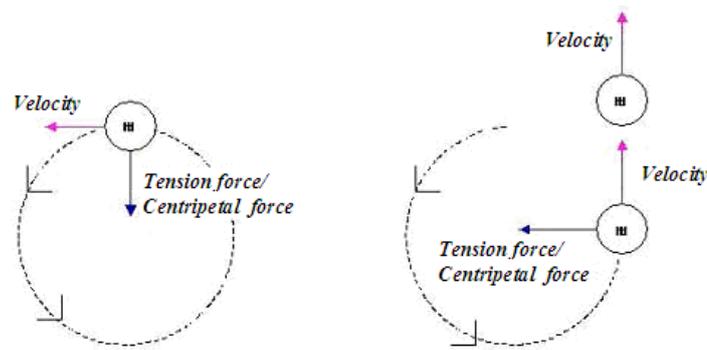


Figure 2.2-51. The object would continue to move in the direction of the velocity

The string holding mass m is cut about $\frac{3}{4}$ of the way (**Fig. 2.2-51** - right). After the string is cut, the tension force/centripetal force are no longer acting upon the object so there is no force holding the object in uniform circular motion. Therefore it continues going in the direction when it was last in contact with the force.

Similar to the tension force, the friction force between the tires of a car and the road is the centripetal force because it keeps the car moving in a circular path.

Centrifugal Force

An object traveling in a circle behaves as if it is experiencing an outward force. This force is known as the centrifugal force (**Fig. 2.2-52**).

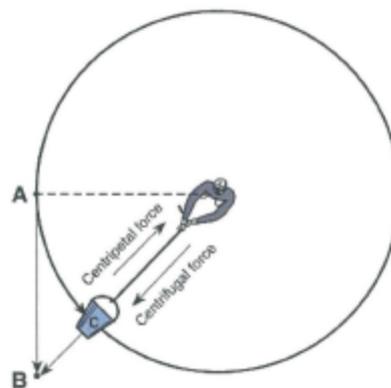


Figure 2.2-52. Centrifugal and centripetal forces

The bucket of water (**Fig. 2.2-52**) is trying to obey Newton's 1st law and travel in a straight line from point A to point B. But the rope holds it along the curved path A to C. The resultant vector CB is the centrifugal force, and this is the force that holds water in the bucket.

It is important to note that the centrifugal force does not actually exist. Nevertheless, it appears quite real to the object being rotated. Since the centrifugal force appears so real, it is often very useful to use as if it were real.

The centrifugal force is calculated as

$$F_{Centrifugal} = m \times a = m \frac{v^2}{r}.$$

Fluid Resistance

In fluid dynamics, *drag* (sometimes called *fluid resistance*) is the force that resists the movement of a solid object through a fluid (a liquid or gas).

An object moving through a gas or liquid experiences a force in direction opposite to its motion.

Terminal velocity is achieved when the drag force is equal in magnitude but opposite in direction to the force propelling the object. **Fig. 2.2-75** shows a sphere in Stokes flow.

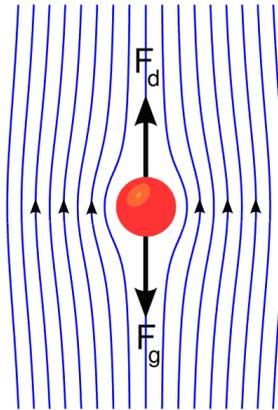


Figure 2.2-75. A sphere in Stokes flow

F_g is gravity force. Small arrows show direction of movement of fluid relative to sphere. Large arrows show direction and magnitude of equal and opposite forces on the sphere, which has stopped accelerating and is moving at terminal velocity.

For a solid object moving through a fluid, the drag is the component of the net aerodynamic or hydrodynamic force acting in the direction of the movement. The component perpendicular to this direction is considered lift.

In aerodynamics, *lift-induced drag* or sometimes *drag due to lift*, is a *drag* force which occurs whenever a lifting body or a wing of finite span generates lift (**Fig. 2.2-76**). With other parameters remaining the same, as the angle of attack increases, induced drag increases.

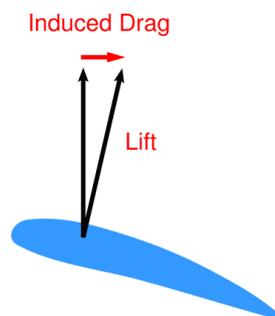


Figure 2.2-76. Induced drag

In aviation, induced drag tends to be greater at lower speeds because a high angle of attack is required to maintain lift, creating more drag. However, as speed increases the induced drag becomes much

less, but parasitic drag increases because the fluid is flowing faster around protruding objects increasing friction or drag (**Fig. 2.2-77**).

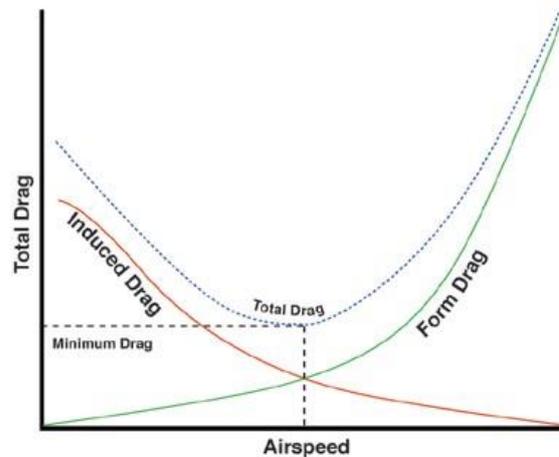


Figure 2.2-77. Drag dependence on airspeed

The combined overall drag curve shows a minimum at some airspeed - an aircraft flying at this speed will be at or close to its optimal efficiency. Pilots will use this speed to maximize endurance (minimum fuel consumption), or maximize gliding range in the event of an engine failure.

Streamlines

Fluid flow is described in general by a vector field in three (for steady flows) dimensions.

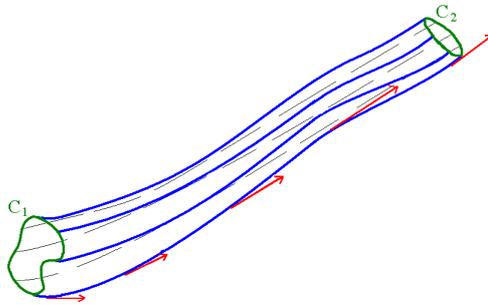


Figure 2.2-78. Fluid flow and streamlines

Solid blue lines and broken grey lines (**Fig. 2.2-78**) represent the streamlines. The red arrows show the direction and magnitude of the flow velocity. These arrows are tangential to the streamline. The groups of streamlines enclose the green curves (C_1 and C_2) to form a stream tube. *Streamlines* are a family of curves that are instantaneously tangent to the velocity vector of the flow. This means that if a point is picked then at that point the flow moves in a certain direction. Moving a small distance along this direction and then finding out where the flow now points would draw out a streamline.

on the surroundings. That is, all the energy which comes into the system comes back out; the internal energy and thus the temperature of the system remain constant.

Combustion Energy Cycles

The thermodynamics cycles used in internal combustion reciprocating engines are the Otto Cycle (the ideal cycle for spark-ignition engines) and the Diesel Cycle (the ideal cycle for compression-ignition engines).

Otto Cycle

The Otto Cycle (**Fig. 2.3-21**) consists of ingestion ($0 \rightarrow 1$), adiabatic compression ($1 \rightarrow 2$), heat addition at $V = \text{const}$ ($2 \rightarrow 3$), adiabatic expansion ($3 \rightarrow 4$) and rejection of heat at $V = \text{const}$ ($4 \rightarrow 1$).

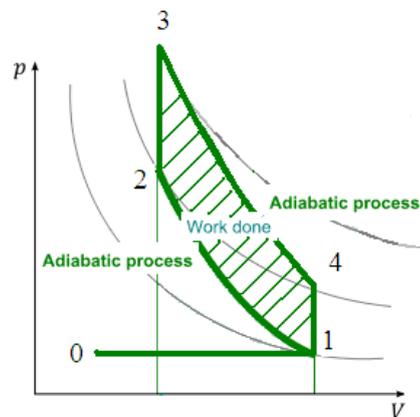


Figure 2.3-21. The graph of Otto Cycle

The Otto cycle is characterized by four strokes or straight movements alternately, back and forth, of a piston inside a cylinder:

1. Intake (induction) stroke;
2. Compression stroke;
3. Power (combustion) stroke;
4. Exhaust stroke.

The cycle (**Fig. 2.3-22A**) begins at top dead center (TDC), when the piston is furthest away from the crankshaft. On the first stroke (*intake* - **Fig. 2.3-22B**) of the piston, a mixture of fuel and air is drawn into the cylinder through the intake (inlet) port. The intake (inlet) valve (or valves) then close(s) and the following stroke (*compression* - **Fig. 2.3-22C**) compresses the fuel-air mixture.

The air-fuel mixture is then ignited (*ignition* - **Fig. 2.3-22D**), usually by a spark plug for a gasoline or Otto cycle engine or by the heat and pressure of compression for a Diesel cycle or compression ignition engine, at approximately the top of the compression stroke. The resulting expansion of burning gases then forces the piston downward for the third stroke (*power* - **Fig. 2.3-22E**) and the

fourth and final stroke (*exhaust* - **Fig. 2.3-22F**) evacuates the spent exhaust gases from the cylinder past the then-open exhaust valve or valves, through the exhaust port.

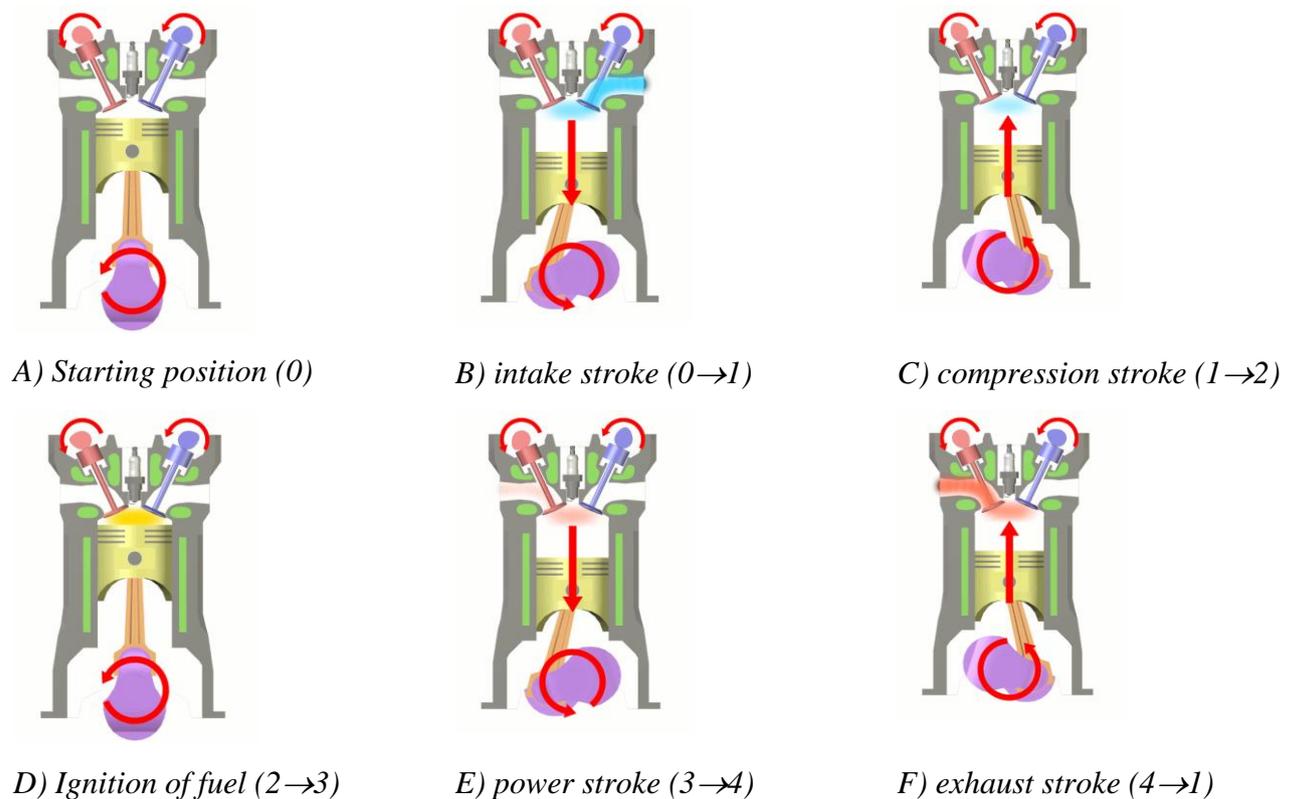


Figure 2.3-22. Four-stroke cycle (Otto cycle)

Diesel Cycle

The *Diesel cycle* approximates the pressure and volume of the combustion chamber of the *Diesel engine*, invented by Rudolph Diesel in 1897 (**Fig. 2.3-23**).

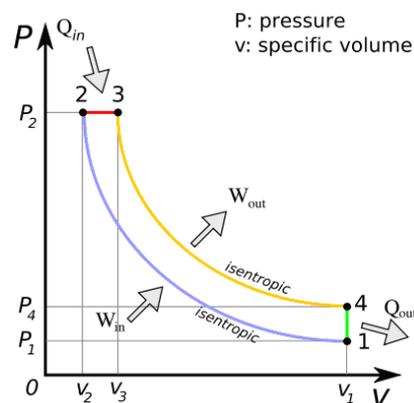


Figure 2.3-23. The graph of Diesel cycle

It is characterized by having $P = \text{const}$ during the "combustion" phase. This opposes the Otto cycle which is an idealization of the process in a gasoline engine, approximating the real behavior with $V = \text{const}$ during that phase.

The processes during the Diesel cycle are:

- Process 1 to 2 is isentropic compression (blue);
- Process 2 to 3 is reversible constant pressure heating (red);
- Process 3 to 4 is isentropic expansion (yellow);
- Process 4 to 1 is reversible constant volume cooling (green).

The diesel is a heat engine - it converts heat into work:

- Work in (W_{in}) is done by the piston compressing the working fluid;
- Heat in (Q_{in}) is done by the combustion of the fuel;
- Work out (W_{out}) is done by the working fluid expanding on to the piston, this produces usable torque;
- Heat out (Q_{out}) is done by venting the air.

This cycle (**Fig. 2.3-23**) refers to a compression ignition engine drawing in air by its piston, or by a mechanically driven supercharger or exhaust driven turbocharger. As air is compressed, its temperature rises from adiabatic compression until the piston reaches the top of its compression stroke. At that point fuel is injected directly into the cylinder and ignites immediately. Note that in thermodynamics, an *isentropic process* is any reversible adiabatic process.

Brayton Cycle

The *Brayton Cycle* is a thermodynamic cycle that describes the workings of the gas turbine engine, basis of the jet engine and others.

The term Brayton cycle has more recently been given to the gas turbine engine. This has three components – compressor, combustion chamber and turbine (**Fig. 2.3-24**):

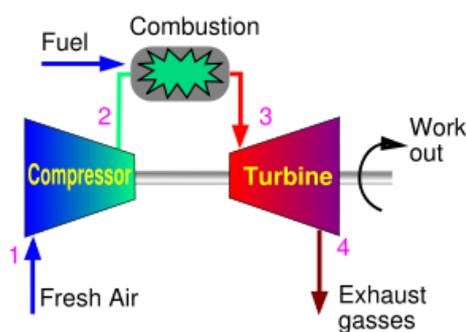


Figure 2.3-24. Schematics of the gas turbine engine

The three components on **Fig. 2.3-24** are gas compressor; a burner (or combustion chamber) and an expansion turbine.

Lenses and Optical Instruments

Magnifying glasses or lenses have been in use for centuries and were well known to the Greeks and medieval Arabs. Lenses of many different types play an important part in our own everyday life. Apart from the benefit of spectacles which enable millions of people to read in comfort, our lives would be vastly changed if we had no cameras, projectors, microscopes or telescopes, all of which function by means of lenses.

Not all lenses can be used as magnifying glasses. There are some, used in opera glasses and in spectacles for short-sighted persons, which always give a diminished, erect virtual image. These are referred to as concave or diverging lenses, while magnifying glasses are called convex or converging lenses. The two types can be readily distinguished from one another; converging lenses are thickest in the middle while diverging lenses are thinnest in the middle. **Fig. 2.4-28** illustrates some of the more common types of lenses.

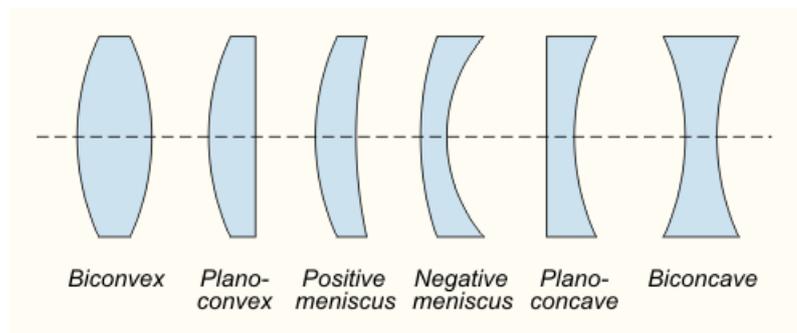


Figure 2.4-28. Types of lenses

There are several types of lenses. They are classified by the curvature of the two optical surfaces. A lens is *biconvex* (or *double convex*, or just *convex*) if both surfaces are convex. A lens with two concave surfaces is *biconcave* (or just *concave*). If one of the surfaces is flat, the lens is *piano-convex* or *piano-concave* depending on the curvature of the other surface. A lens with one convex and one concave side is *convex-concave* or *meniscus*. It is this type of lens that is most commonly used in corrective lenses.

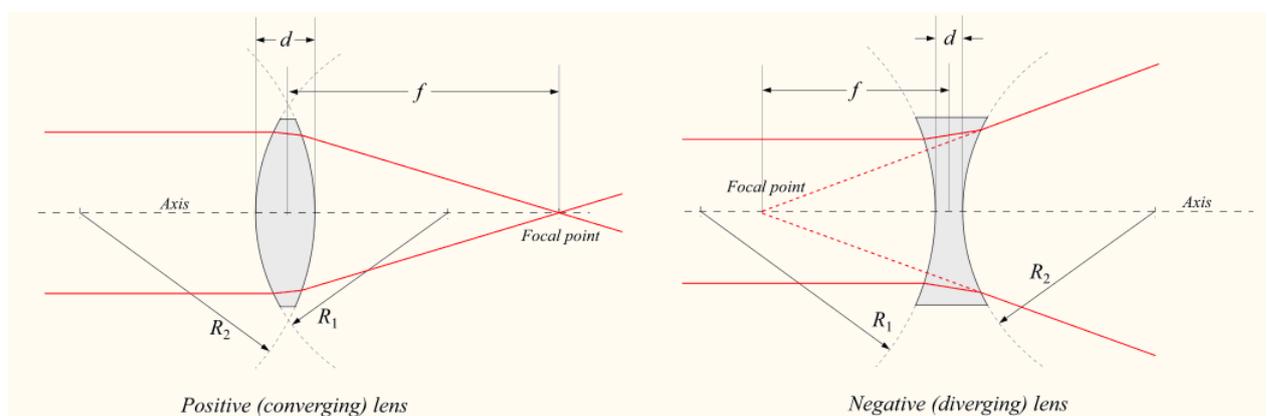


Figure 2.4-29. Parameters of lenses

Lenses are similar to mirrors to some extent. The principal axis of a lens is the line joining the centers of curvature of its surfaces (**Fig. 2.4-29**).

If a parallel beam of light, parallel to the principal axis is incident on a converging lens, the rays, after passing through the lens, all converge to a point on the axis which is called the principal focus, F . In the case of a diverging lens the rays will spread out after passing through the lens, as if diverging from a focus behind the lens.

In the case of a diverging lens the rays will spread out after passing through the lens, as if diverging from a focus behind the lens. The lens is thus called a *negative* or *diverging* lens.

The principal focus is thus real for a converging lens and virtual for a diverging lens (**Fig. 2.4-29**).

In spherical mirrors the point focus is obtained only for rays which are very close to the axis. The same hold true for lenses. Thus, the principal focus of a lens is that point on the principal axis which all rays originally parallel and close to the axis converge, or from which diverge, after passing through the lens.

The center of the lens is called the optical center. The focal length f of a lens is the distance between the optical center and the principal focus F . A lens has two principal focuses - one on either side of the lens, F and F' .

The value d is the thickness of the lens (the distance along the lens axis between the two surface vertices). R_1 is the radius of curvature of the lens surface closest to the light source; R_2 is the radius of curvature of the lens surface farthest from the light source.

Lenses Compared With Prisms

A lens may be regarded as being made up of a very large number of portions of triangular prisms, the angles of which decrease from the edge of the lens to its center (**Fig. 2.4-30**).

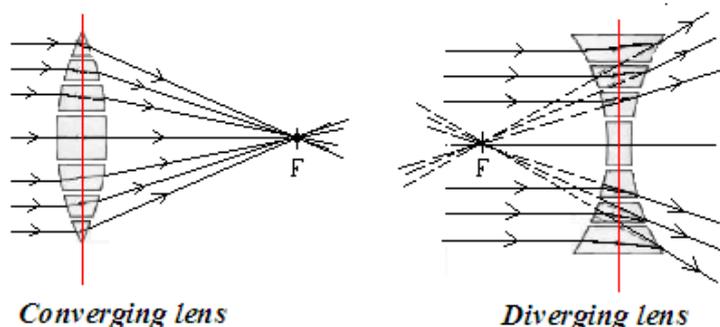


Figure 2.4-30. Lenses compared with prisms

Each prism (**Fig. 2.4-30**) with increasing angle deviates light strongly. Such prisms are closer to the principal axis in diverging lenses and to the edge in the case of converging lens.

Interference of Circular Waves

If two ball-ended dippers are attached to the vibrator of the ripple tank, two sets of circular ripples are sent out which pass through one another (**Fig. 2.5-14**).

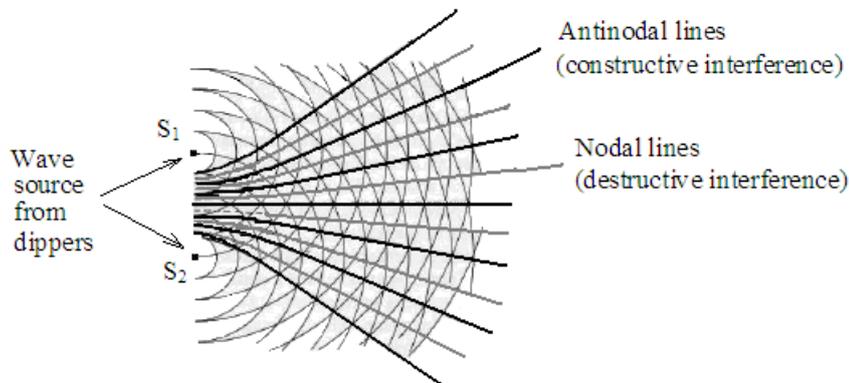


Figure 2.5-14. Interference of circular wave

Where the two waves are superposed in the same phase, e.g., crest on crest, we get lines of increased disturbance or constructive interference. These are called the nodal lines. In between these are the nodal lines along which the waves are exactly out of phase, e.g., the crests of one are superposed on the troughs of the other. Here, provided the amplitudes of the two waves are the same, we now get zero resultant disturbance of the water surface, or destructive interference.

A similar to **Fig. 2.5-14** interference pattern is obtained if either a straight or a circular wave is incident on a vertical barrier having two small apertures. In this case, interference takes place between the emerging diffracted waves.

If imagine that the two water wave sources of **Fig. 2.5-14** were replaced by two point light sources then, if light is a form of wave motion, similar constructive and destructive interference to occur should be expected (**Fig. 2.5-15**). There will be increased brightness along the antinodal lines and darkness along the nodal lines.

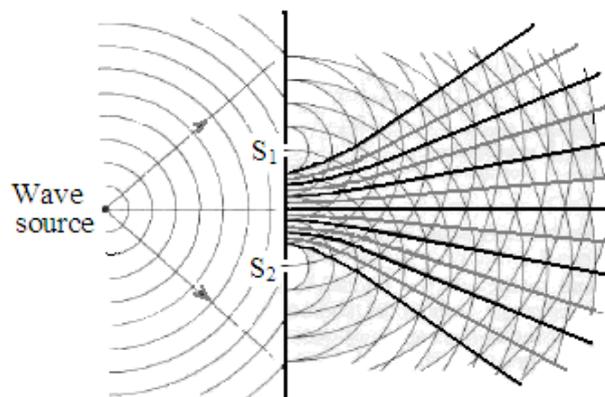


Figure 2.5-15. Interference of water waves diffracted from narrow openings

At the beginning of the nineteenth century, Thomas Young did, in fact, perform such an experiment using the light diffracted from two pinholes and obtained series of light and dark bands or interference fringes on a screen placed in the path of the light. This was very strong evidence for the wave theory of light. Later he repeated the experiment using the light from two narrow parallel slits, with similar results.

Sound and Longitudinal Waves

Sound is transmitted through gases, plasma, and liquids as longitudinal waves, also called compression waves. Through solids, however, it can be transmitted as both *longitudinal* and *transverse* waves.

Longitudinal sound waves are waves of alternating pressure deviations from the equilibrium pressure, causing local regions of compression and rarefaction (**Fig. 2.5-16**).

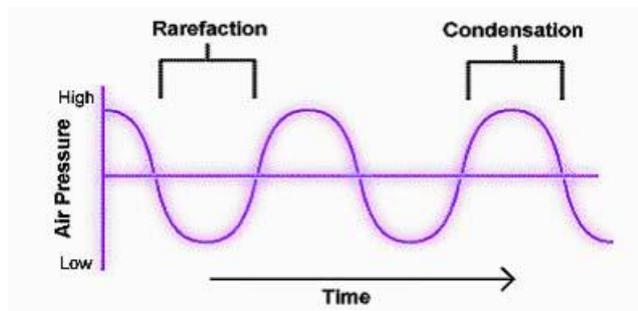


Figure 2.5-16. Sound wave compressions and rarefactions

Every day, the world around us is awash with sounds, from the rustling of leaves to the roaring of engines. All of these sounds interact with one another, and with all the elements and obstacles of their environment.

But what do we hear really?

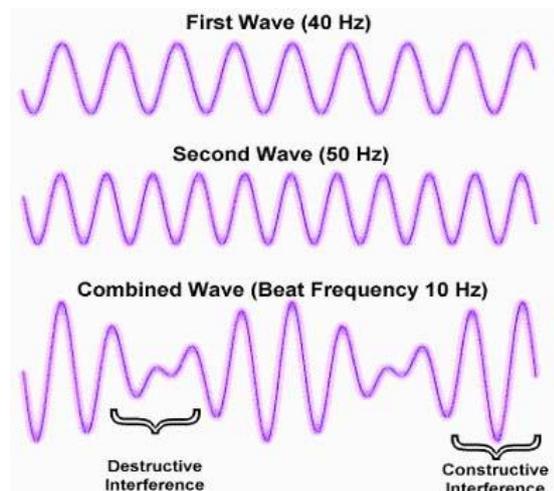


Figure 2.5-17. Principles of sound formation