3.1 PHYSICS OF BASKETBALL PLAY

Sports and games in the recent past have undergone a phenomenal development due to the influence of Science and Technology. The availability of scientific tools for practice purpose and a realisation of the understanding and the application of principles of physics have enabled the athletes to improve their skills and achieve higher goals of excellence. It is a fact that athletes have benefited greatly from advances in sports medicine, training technique and equipment design. A detailed technical and statistical analysis of patterns of play have led to more sophisticated game strategies. However, the understanding and application of the physical principles involved in various sports and games are still in dearth and there is a need that this aspect should be fully developed.

The basketball game is a dynamic game involving various moves and in all these, a knowledge of the laws of physics involved is very much essential for a player to become a skilled player. In this section, the physical principles involved in various live situations are detailed. The principle of inertia plays a predominant role in the lay-up shot. The principle of inertia states that an object which is initially fixed with respect to a moving reference frame, if suddenly released continues to move with the same velocity as the reference frame at the instant it is released. A live illustration of this principle was provided by Galileo\textsuperscript{22} in his Dialogues Concerning the Two Chief World Systems in which he pointed out that a ball released from the top of the mast of a moving ship is seen to land at the foot of the
mast, and therefore must be moving horizontally as it falls with the same horizontal speed of the ship.

In the basketball game, the above phenomenon is involved in any shot put by the player on the run. To illustrate, consider an offensive player who breaks past the defense and dribbles the ball directly towards the basket as fast as he can for a lay-up. A few feet from the basket, he shoots the ball while still running. The inexperienced player will tend to push his shot towards the basket and the result is that the ball will overshoot the rim and or slam off the background with too great a speed. The player has failed to take inertia into account and by pushing his shot towards the basket, he has unwillingly added to the ball the velocity that the ball already possessed by virtue of the player's running motion. The proper way for him to take this shot is to shoot the ball vertically upward with respect to his own body (the ball has no horizontal component of motion in the moving reference frame) when he is about 2 to 3 feet from the basket. When this is done properly, the ball should arch nicely into the basket.

A similar situation arises when a player is moving cross court, parallel to the baseline, and takes a running (usually a hook shot) as he crosses the free-throw line. When the player is moving, say from left to right and aims his shot directly at the centre of the basket, the ball will continue its crosswise motion and will hit to the right of the centre of the basket. To compensate the inertia, the player must aim the shot at the left-hand side of the rim. An important aspect of basketball shooting is that the ball should be pushed by the fingertips rather than by the palm of one's hand. Shooting with the fingertips
gives the shooter much better control over the path of the shot. Also, a ball shot from the fingertips and released with a slight flick of the wrist obtains a backspin automatically. The effect of backspin on basketball shooting is very important and a shot with a backspin makes the shot softer and helps the shot to be lucky\textsuperscript{23}. The value of backspin in basketball shooting is the result of good physics rather than good luck. To understand this aspect let us make a simple analysis of what happens when a ball bounces. Let us consider three cases in which a moving ball strikes a horizontal surface with (1) no initial spin (2) a forward spin and (3) a backspin as shown in Fig. 3.1.1. In each case the ball has an initial translational velocity at some angle to the surface. We shall consider in the following analysis, only the horizontal component (parallel to the surface) of this velocity.

When the ball strikes the surface, a frictional force arises at the point of contact which alters both the translational and rotational motions of the ball. In general, there will be a transfer of energy between the translational and rotational modes, with an overall net loss in the total kinetic energy. At the simplest level, it is easy to determine in each case the direction of the frictional force and its effect on the motion of the ball. If the ball has no initial rotation (Fig. 3.1.1 a) then the frictional force opposes the forward translational motion. This force also creates a torque about the centre of gravity of the ball so that the ball gains angular momentum. Hence there is a loss of translational energy and an increase in rotational energy. Thus we expect a ball that is bounced forward with no initial spin to rebound with a forward spin and with slower translational speed.
Fig. 3.1.1 - Translational and rotational motion of basketball when it bounces on a rigid horizontal surface for various initial spin conditions.
When the ball is projected with an initial forward spin (Fig. 3.1.1 b), at the point of contact the rotational velocity will be opposite to the horizontal translational velocity component of the ball. If the spin rate is large enough the frictional force on contact will act in the forward direction. In this case, there will be an increase in the horizontal velocity and a decrease in the angular momentum and rotational energy will be converted to translational energy. The ball will appear to gain speed on the bounce and will skip forward at a lower angle to the ground.

When the ball is thrown with a backspin, (Fig. 3.1.1 c), then the frictional force at the point of contact opposes both the translational and rotational motions of the ball and it will be larger than in the previous two cases. The result is a relatively large decrease (and possible reversal of direction) of both the translational and rotational motions. Consequently, a ball projected forward with backspin will lose considerable speed on the bounce and may even bounce backwards. The analysis indicates that a back spinning ball always experiences a greater decrease in translational energy and on total energy than a forward spinning ball. When the back spinning ball hits the rim or backboard it experiences a change in speed, spin and energy. This makes the shot "softer" and there is more likelihood of the ball dropping into the basket after it hits the rim.

A ball can be thrown with a sideways spin. When the ball hits a surface it will veer sharply to the left or right, depending on the spin direction. Good shooters learn to make effective use of spin. One example is the reverse lay-up in which a player dribbles along the
baseline and under the basket. As he come out from under the basket, he spins the ball upward against the backboard. On contact the ball veers sharply backward into the basket.

It is clear from the discussions presented above that shooting plays a key role in the basketball game. Equally important are the other basketball techniques such as footwork, jumping, and passing which are the prerequisites for achieving a situation to shoot the ball. In all these techniques, the principle of dynamics governing the actions of the body are utmost importance and a knowledge and application of these principles make a player more efficient and skillful. A detailed analysis of the physical principles involved in these techniques is presented below.

Quick starting and stopping, change of direction, feinting, manoeuvering and change of pace form the basis of successful basketball footwork. In all these tactics the control of the centre of gravity of the body and the application of force play a major role. The main objective of the various moves in foot work is to out-manoeuver an opponent. For quick starting in any direction, the stance determined by the work of Slater-Hamil should be used. That is, the defensive player must be ready to meet any manoeuver of his opponent. Hence it is necessary that the defensive player assumes a low crouch in a state of readiness so that he will not be easily feinted out of position. In some cases the defensive player may assume a position that tends to influence his opponent to move in a certain direction toward the sideline or toward the centre of the court or toward a teammate where he can be double-teamed. In such a situation the defensive player may
assume a staggered stance. This does not weaken his position. Instead it strengthens his position. Now he need not move as quickly in all directions because he has overshifted to force movement in a particular direction. As long as the defensive player maintains his state of readiness, his position is sound and is in a stable state of equilibrium.

Quick stopping, when running rapidly, requires a low position for the centre of gravity to reduce or eliminate the turning movement forward. To achieve this, one foot shall be placed ahead of the centre of gravity. A scoot or low hop with the bend of the knees provides better body control and places the player in a position to start off quickly in another direction by pushing from both feet. The speed with which the player is moving may require a very low crouch from which a recoil is necessary for quick starting. The low crouch in stopping also relieves the force on the feet because here force is traded for distance. When there were no give in the knees and at the hips, the feet would be subjected to a terrific pounding. The sequence in the execution of a stop after rapid motion is illustrated in Fig. 3.1.2.

Feinting consists of head, body, arm and foot moves. It is designed to deceive an opponent and cause him to act to his disadvantage. These movements are not likely to be effective if the centre of the gravity is thrown outside the base or too near the edge of the base in the direction of the feint. Hence there is a need for a compensating move that maintains equilibrium. To illustrate, let us consider a player who has the ball. If he steps back with the hope, as
Fig. 3.1.2 - Sequence in the execution of a stop after rapid motion. The knee and body bends cause the centre of gravity to drop. The centre of gravity is thrown to the rear as far as possible by the action of sitting on the heel.
a result of a previous manoeuver, of causing his opponent to move towards him to attack the ball so that the player with the ball, may dribble by, he must compensate for his move. This is done by bending forward at the waist as the foot drops back. In this posture the centre of gravity is kept towards the forward edge of his base and permits him to move in that direction more quickly. The feinting movements before a dribble are shown in Fig. 3.1.3. A head and shoulder feint in one direction is compensated for, by a dip of the opposite knee. This enables for a quick push in the opposite direction of the feint. Because of the dip of the knee the centre of gravity is prevented from moving in the direction of the feint. A stop by one foot, and an arm reach by a bend of the opposite knee, may be used to compensate for a thrust at the ball. This move prevents the centre of gravity from moving forward. As a result of this manoeuver if it is necessary for the defensive player to turn and move in the opposite direction from that of his thrust, he should throw his centre of gravity outside his base and directly backward by a deep knee bend of the back leg as forward leg pushes in that direction. Change of pace consists of an alternation of slowing down and speeding up. To slow down, one foot is put down ahead of the centre of gravity and the body straightens, but the knees may bend slightly. To speed up, the body is inclinded forward, the centre of gravity is thrown ahead of the foot, and the legs extend as they push off for speed. If the dribble indulges in the change of pace, he has to control the speed of advance of the ball. This can be done by changing angle at which the ball is pushed to the floor. To slow up, the angle of the line of the ball with the floor should be more nearly a right angle.
Fig. 3.1.3 - Feinting movements before a dribble. The secret of deception and the fast starting is to throw the centres of gravity forward as the player steps back.
Jumping is another important movement of basketball play. Several principles govern the jump. The jump will be higher if a player steps or hops before he takes off. This maneuver overcomes the inertia of the body and starts it in motion. Here the Newton's first law is involved. It also permits him to push off of the floor with greater force, which in turn will give greater height where Newton's third law is involved. The stamp of the foot by means of the hop before the jump not only increases the force of reaction between the foot and the floor, but the stamp stretches the muscles of the foot. This gives a more forceful elastic rebound. A muscle will contract faster with greater force immediately after being stretched. A slight flex of the knee and hip permits a more forceful action in the muscles that control the joints. The amount of the crouch will depend on the strength of the muscles. At the take-off, the arms should swing up hard to give momentum to the jump. If the take-off is from one foot, the thigh of the free leg should swing up hard. Just before the maximum height is reached, the leg should be extended downward sharply. The arm not used in reaching or tipping should be swung down in the same manner. This raises the position of the center of gravity in the body and thus gives more reach to the tipping hand.

All force and movement should be directed as nearly vertical as possible to make the effective force of the jump to become maximum. The principles outlined above should be followed when the jump is after the held ball or when the player is jumping to tip the ball at the basket. These principles suggest that a player at the basket should stay back far enough to be able to take a step before jumping. Manoeuvering to get a position from which this can be done
is quite important.

Jumping is of great importance in basketball and merits the special attention of players and coaches. The ability to out-jump an opponent often makes the difference between ball control and the lack of it. Even a fraction of an inch increase in the jump makes the critical difference. A proper calculation of the centre of gravity may add as much as 3 inches to the jump shows the importance of concentration on the principles governing the technique of the jump by the players and as well by the coaches.

Quickness in the movement of the ball is an important factor in basketball. Except in long passes, great force is not necessary for all other types of passes. In the case of long passes one has to take into account the effect of the air resistance. To prevent wide divergence of the ball from the intended direction, one has to control carefully the spin of the ball. For example, for passes of 12 m or more the ball should be thrown with a backspin directly opposite to the direction of the flight. As a result of spin imparted to the ball, the ball may take a curve and will be out of reach of the receiver. The curvature and the direction of the ball depend on the direction and the speed of the spin. The action of the ball as a result of spin imparted to the ball in different directions is illustrated in Fig. 3.1.4. In short passes, imparting maximum force is not significant but one has to look into the other factors which contribute to the speed of movement of body members.
A. The ball does not bounce high but moves forward faster as a result of forward spin given to it.

B. The ball bounces upward sharply and has its forward motion retarded as a result of reverse spin given to it.

C. The ball bounces to the left as a result of anti-clockwise spin given to it.

D. The ball bounces to the right as a result of clockwise spin imparted to it.

Fig. 3.1.4 - The action of the ball as a result of spin imparted to it in different directions.
The wrist snap is the primary source of force for passing the basketball. The other body movements used in throwing are relatively slower. In order to reduce the slower body movements to a maximum extent, in passing the ball to short distances, the ball is to be held with the wrists cocked and ready to release the ball. In the two hand pass, the ball should be held back against the chest with the elbow bent. Only the quick partial forward extension of the forearm and the wrist is necessary to develop sufficient force for the pass. For the one-hand pass, only a slight amount of upper arm rotation is necessary and there is no need for body rotation.

In the case of hook pass, in addition to other movements, rotation of the arm in a plane perpendicular to a sagittal section of the body is necessary. To offset the centrifugal force developed from the movement, the hand is laid around the ball with the ball rolled back on the forearm. In this way the ball can be controlled and prevented from flying off tangentially before the desired release point. Himieleski\textsuperscript{27} analysed the technique of hook pass and found it to impart greater velocity to the ball and hence was more difficult to block or intercept. The bounce pass is used to get the ball by an opponent by means of deflecting the ball off the floor. The principle of spin plays an important role in the bounce pass. When one desires that the ball should gain speed after hitting the floor, a forward spin is imparted to it. When he desires that the speed be retarded and the ball bounce high, a backspin is put on the ball. Backspin is used when bouncing the ball in front of a fast-moving player. The forward
speed of the ball is retarded and it bounces higher so that the receiver is able to catch the ball and still maintain his speed. Since bounce passes travel greater distances, the proportion of bad bounce passes made will be usually large. The studies by Raws indicate that the players mostly employ short passes and sparingly employ the bounce passes.

The basic principle involved in the jump shot is the accuracy in performance which is indirectly proportional to the number and size of the muscle used. The performance is more accurate if fewer muscles are used. The smaller the size of the muscle used, the greater would be the accuracy of performance. Fewer muscles come into play when one hand is used for shooting. If only the wrist and fingers and forearm are used to project the ball into the basket, then greater accuracy can be achieved because only a few muscles that are smaller in size and more sensitive ones are employed. The player must have sufficient strength to propel the ball into the basket with the proper arch. A large hand and strong fingers and strong wrist and arm muscles are the needed tools for this purpose. When a jump shot is attempted, there will be extreme muscular tension. The action of a muscle under extreme tension is uncontrollable and unpredictable. Inaccuracies creep into the action when extreme tension is necessary to execute the shot. At the movement of release, there is a need of a certain rigidity to the muscles to prevent recoil and to give direction. Prior to this entire action, the muscles should be free and relaxed.

The jump shot is used almost exclusively from all positions on the floor. If the shooter is dribbling or moving preparatory to the
jump, he should hop as he catches the ball. He can also avoid running and jump from both feet when shooting, thus achieving a higher jump from the force of both the legs. The jump should be in vertical direction to gain maximum height. The ball should be held in both hands until the arm thrust begins. This permits a pass-off at the last movement if necessary. The ball should not be released until the maximum height of the jump has been reached. The shooter's body is stationary at this point. He is better poised for his shot and the opponent is thrown off his timing in his effort to block the shot. Scolnick did an electrogoniometric and cinematographical analysis of the arm action of the jump shot by expert shooters and verified many of the above inferences.

Basketball shooting is the most important aspect of basketball play. In the shooting, the ball takes the path of a parabola. There may be some deviation from the parabolic trajectory due to air resistance, which will be about 5 to 10%. The dynamics of basketball shooting can be understood well by analysing the trajectory of the basketball considering it to be parabolic for all practical purposes, which is more so in the case of free throw shooting. This analysis will help to determine how one can take a best shot from any given location on the court including the free throw point. At a given distance from the basket, there are an infinite number of trajectories, each with a specific initial speed and launching angle, that connect the shooter's hand with the centre of the basket. It is a fact that most basketball players develop their shooting ability by trial and error and constant practice. Since the present study is aimed at
examining the correlation between the best trajectories developed by players as result of practice and theoretically feasible trajectories for a free throw shooting, a knowledge of the projectile motion of the basketball in basketball shooting is essential and hence is detailed below.

Consider the projectile motion of a body, shown in Fig. 3.1.5, projected in a uniform gravitational field. The body is projected with initial speed \( v_0 \) making an angle \( \theta_0 \) with the horizontal. At any time \( t \), the \( x \) and \( y \) coordinates of the projectile are given by

\[
\begin{align*}
x &= v_0 t \cos \theta_0 \\
y &= v_0 t \sin \theta_0 - \frac{1}{2} g t^2
\end{align*}
\]

where \( g \) represents the acceleration due to gravity and is taken as 9.8 \( \text{m s}^{-2} \). The velocity components of the projectile at any instant of time \( t \) are obtained by differentiating eqns. 3.1.1 and 3.1.2 with respect to time \( t \). Thus

\[
\begin{align*}
v_x &= \frac{dx}{dt} = v_0 \cos \theta_0 \\
v_y &= \frac{dy}{dt} = v_0 \sin \theta_0 - g t
\end{align*}
\]

The angle \( \theta \) made by the velocity vector of the projectile with the horizontal at any point on its path is given by the equation

\[
\tan \theta = \frac{v_y}{v_x}
\]
Fig. 3.1.5 - Projectile motion of a body.
From eqns. 3.1.3 and 3.1.4 we get
\[
\tan \Theta = \tan \Theta_0 - \frac{g t}{v_0 \cos \Theta_0} \quad \ldots \quad (3.1.6)
\]

From eqns. 3.1.1 and 3.1.2 we get
\[
\frac{y}{x} = \tan \Theta_0 - \frac{g t}{2 v_0 \cos \Theta_0} \quad \ldots \quad (3.1.7)
\]

or
\[
\frac{2y}{x} = 2 \tan \Theta_0 - \frac{g t}{v_0 \cos \Theta_0} \quad \ldots \quad (3.1.8)
\]

Rearranging, we get
\[
t = \left[ 2 \tan \Theta_0 - \frac{2y}{x} \right] \frac{v_0 \cos \Theta_0}{g} \quad \ldots \quad (3.1.9)
\]

Substituting eqn. 3.1.9 and eqn. 3.1.6 and simplifying we get
\[
\tan \Theta = \frac{2y}{x} - \tan \Theta_0 \quad \ldots \quad (3.1.10)
\]

Substituting the value of t from eqn. 3.1.9 in eqn. 3.1.1 and simplifying we get
\[
\frac{v_o^2}{2} = \frac{g x}{2 \cos^2 \Theta_0 \left[ \tan \Theta_0 - \frac{(2y/x)}{} \right]} \quad \ldots \quad (3.1.11)
\]

The highest point of the trajectory, \( y_{\text{max}} \), occurs when \( v_y = 0 \) and \( \tan \Theta = 0 \).
We have, applying kinematics of uniform motion,

\[ v_y^2 - (v_0 \sin \Theta_0)^2 = -2g y_{\text{max}} \]  \hspace{1cm} (3.1.12)

Since \( v_y = 0 \) when \( y = y_{\text{max}} \) we get

\[ -v_0^2 \sin^2 \Theta_0 = -2g y_{\text{max}} \]  \hspace{1cm} (3.1.13)

Therefore

\[ y_{\text{max}} = \frac{v_0^2 \sin \Theta_0}{2g} \]  \hspace{1cm} (3.1.14)

The eqns. 3.1.10, 3.1.11 and 3.1.14 describes the parabolic motion of a projectile in the absence of air resistance or other retarding forces. It may be mentioned here that the basketball is rather light in weight and has a relatively large surface area. As a result, the effect of air resistance on the projectile motion of the basketball is eventhough small but not negligible. Analysis on the effect of air resistance on the motion of the basketball when shot towards the basket indicates that the basketball trajectories deviate from the ideal parabolic path by about 5 to 10%. Nevertheless, the assumption of parabolic motion (ignoring air resistance) does not affect the qualitative findings. Hence eqn. 3.1.10, 3.1.11 and 3.1.14 may be used to describe the trajectory of a basketball.

The path of a successful shot in the absence of air resistance is illustrated in Fig. 3.1.6. It has a trajectory which leaves the shooter's hand with an initial speed \( v_0 \) and launching angle
Fig. 3.1.6 - The path of a successful shot in the absence of air resistance.
\( \theta_0 \) and passes through the point \((x = L, y = h)\) where \(L\) is the horizontal distance from the point of release to the centre of the basket and \(h\) is the vertical distance between the rim of the basket and the point of release. Eqn. 3.1.11 becomes

\[
\frac{v_0^2}{2} = \frac{gL}{2 \cos \theta_0 (\tan \theta_0 - h/L)} \quad \ldots (3.1.15)
\]

In the above equation \(v_0\) and \(\theta_0\) are the variables. For any given launching angle \(\theta_0\), there exists an unique positive value of \(v_0\) that will give the desired trajectory. Eqn. 3.1.15 hence describes a family of parabolas that connect the point of release with the centre of the basket. For a given \(h\) and \(L\) the relationship between \(v_0\) and \(\theta_0\) is represented graphically in Fig. 3.1.7, which is based on Eqn. 3.1.15. There exists an unique minimum initial speed for every \((h, L)\) combination. The minimum speed \(v_{om}\) occurs at \(\theta_{om}\) and can be obtained by evaluating \((d v_0)/ (d \theta_0)\) at \(\theta_0 = \theta_{om}\) and equating it to zero. The \(\theta_{om}\) value can be given by

\[
\theta_{om} = 45^\circ + (1/2) \arctan h/L \quad \ldots (3.1.16)
\]

or

\[
\tan \theta_{om} = h/L + (1 + h^2/L^2)^{1/2} \quad \ldots (3.1.17)
\]

Substituting Eqn. 3.1.7, in Eqn. 3.1.15 and simplifying we get
Out of all the possible trajectories linking the point of release to the centre of the basket, there exists only one launching angle \( \Theta_{om} \) which gives the minimum speed trajectory. The curve shown in Fig. 3.1.6 is symmetrical about a vertical axis through \( \Theta_{om} \). \( v_o \) is finite and real only if \( \Theta \) lies in the range \( 90^\circ > \Theta > \arctan h/L \).

There exists another constraint on the allowed values of \( \Theta_o \) because of the fact that the ball must drop into the basket. This is possible if the ball is on the descending part of its parabolic trajectory by the time it reaches the basket. This criterion can be mathematically stated by defining the angle of entry \( \Theta_e \) as the angle between the horizontal and the tangent to the trajectory as the ball crosses the plane of the rim as illustrated in Fig. 3.1.5.

Eqn. 3.1.10 can be used to obtain an expression for \( \Theta_e \). Since \( \Theta_o \) is measured positively above the horizontal we have

\[
2h/L - \tan \Theta_o = \tan \Theta = \tan (\Theta_e) = -\tan \Theta_e
\]

or

\[
\tan \Theta_e = \tan \Theta_o - 2h/L
\]

Hence the condition required to be satisfied for the ball to be on the descent when it reaches the basket is that \( \Theta_o \gg 2h/L \).
Apart from the restriction defined by Eqn. 3.1.20 on $\Theta_q$, there are other restrictions on $\Theta_q$ which are detailed below.

As per the standard, the diameter of the basket is 0.45 m. The circumference of the basketball lies in between 0.75 m to 0.78 m. Hence the diameter of the basketball is about 0.23 m, which is slightly more than half the diameter of the basket. In view of this, for a successful shot the centre of the ball need not pass through the exact centre of the basket. It is enough if the ball passes through in such a way clearing both the front and the back rims. Hence there exists a margin for error in shooting the horizontal distance $L$ by a maximum of $\pm \Delta L$ and the ball will still go into the basket. However, the margin of error disappears if $\Theta_e$ is equal to $32^\circ$. If $\Theta_e$ is less than $32^\circ$ the ball cannot clear both the rims. Still, the ball may bounce off the rim or basket or both and rebound into the basket. In this situation the shot is not a clean shot even though a point is scored. Hence the minimum launching angle $\Theta_{oL}$ is given by

$$\tan \Theta_{oL} = \tan 32^\circ + 2h/L = 0.62 + 2 h/L \quad \ldots \quad (3.1.21)$$

Therefore for a successful shot $\Theta_o$ must lie in the range $\Theta_{oL} \leq \Theta_o \leq 90^\circ$. For every angle $\Theta_o$ lying within this range there exists a specific launching speed that will make the ball pass through the centre of the basket.

In view of the fact that the diameter of the ball being less than the diameter of the basket, we also have a margin for error for the minimum correct speed $v_o$ by $\pm \Delta v$ wherein the ball still goes into
the basket. Similarly there is also a margin of error for the launching angle $\Theta_0$ by $\Delta \Theta$ when the ball is projected with the correct launching speed so that the ball still goes through the basket. The two margins for error $\Delta v$ and $\Delta \Theta$ serve as criteria for selecting the best trajectory. The larger the margins for error for a given shooting angle the more freedom the shooter has to deviate from the precise values of $v_0$ and $\Theta_0$ required for a centre-of-basket trajectory.

Since the basketball shooting is a three dimensional phenomenon there exists another margin for error called lateral margin for error. The margin for error in later angle $\Delta \psi$ is given by $^{31}$.

$$\tan \Delta \psi = \frac{0.36}{(h^2 + L^2)^{1/2}} \quad \cdots (3.1.22)$$

The analysis of the principles of physics involved in basketball play shows that for a clean shot there are various factors that determine the correct launching angle, launching speed apart from the practice and skill of the player. These aspects are examined in the present study indepth in the case of free throw shooting.
3.2 DESIGN DETAILS OF THE EXPERIMENTAL SETUP USED TO DETERMINE THE SHOOTING ANGLE IN FREE THROW SHOOTING

The apparatus used to determine the shooting angle is designed and fabricated indigenously in the Central Workshop of Sri Krishnadevaraya University, Anantapur. The details along with the dimensions of the apparatus are shown schematically in Fig. 3.2.1.

The apparatus consists of a semicircular transparent perspex sheet (S) having a thickness of 3 mm and radius of 0.5 m. The perspex sheet is rigidly fixed to a semicircular iron frame (F), of width of 2.5 cm and thickness of 0.5 cm. On the curvature of the circular sheet 180 equally spaced markings are made to give the angular scale from $\theta^\circ$ to $180^\circ$. At the centre of the semicircular sheet a pointer (P) made up of aluminium is attached which can be freely moved over the circular scale.

A galvanized zinc tube (IT) of outer diameter 3.5 cm and length 1.20 m is welded to the semicircular frame at its centre. This tube goes freely into another galvanized zinc tube (OT) of inner diameter 4 cm and length 1.5 m. This tube is welded to a tripod stand arrangement (TS) as shown in Fig. 3.2.1. The entire apparatus has stable equilibrium when kept vertically standing on the base (tripod stand). The height of the circular scale can be raised or lowered by moving the inner tubing I and can be fixed for any desired height using the screw S.
Fig. 3.2.1 - SS: Semicircular Scale; P : Aluminium pointer
F : Iron frame; IT : Inner Tube (length 1.2 m);
OT : Outer Tube (length 1.5 m); S : Screw
TS : Table stand.
3.3 METHOD OF MEASUREMENT OF SHOOTING ANGLE

Shooting angle is the angle made by the tangent to the trajectory of the ball at the point of release to the horizontal. To measure this angle (also called as the launching angle) in free throw shooting, the apparatus described in Section 3.2 is placed closed to the player and the height of the circular scale is adjusted by changing the length of IT and fixed by the screw S such that the point of release of the ball coincides with the centre of the circular scale. When the shooter just shoots the ball into the basket the pointer P on the circular scale is moved simultaneously on the scale and fixed at that angle, the direction of which coincides with the tangent to the trajectory at the point of release. The investigator practiced in exact fixing of this launching angle on each subject (i.e. the player in the actual test measurement) a number of times (about 25 to 30 shots) till perfect skill is achieved and later the test measurements are recorded.