SECTION 4

ANGLE OF DELIVERY

In propelling a bowl, a player has a specific line of aim. Due to the simultaneous effect of the bias, the bowl does not maintain this line but it deviates to either side thereof. The reason for the deviation is because the force from the bias acts laterally to the direction of the propulsion.

To counteract the effect of the bias, a player must therefore aim at a certain angle off the direction in which the bowl is finally to be found. A new line joining the point of delivery to the position where the bowl ends is usually called the central line. There is an obvious angle between these two lines. The angle of delivery is the difference between the direction of propulsion and the ultimate line of the bowl.

In the game this angle of aim is often called *"grass"*. Bowlers are continually reminded that they need so much grass. What is actually implied when they are advised to use more grass is in fact that they ought to use a wider angle of aim in their delivery. The converse is true for excess grass.

4.1 CENTRIPETAL FORCE

When a cyclist goes round a bend he has to lean to one side creating a force in the direction in which he wishes the cycle to turn. This force is applied at a right angle to the direction in which the cyclist is travelling. This force is called **CENTRIPETAL FORCE**, and is given by the following formula

$$F = \frac{m\,v^2}{r}$$

where **m** is the mass of the cyclist/cycle combination, **v** is the linear velocity, and **r** is the radius of the bend. The formula is given for only

linear motion. Some necessary corrections can be added to include the rotary motion like that of the wheels of the cycle.

It is well-known that to increase the amount of turning, the cyclist must lean more to the side. This implies increasing **F** in the formula, which results in decreasing the value of **r**. When the radius is decreased, the cycle naturally turns sharper.

The journey of a bowl, which has both linear and rotational velocities, can be equated to the cyclist/cycle. The bias is a centripetal force pulling the bowl towards the center. From the formula, it can be seen that when **v** and naturally v^2 are large, **r** must be concomitantly large. A large radius means that the bowl travels along the circumference of a big circle. However when the velocity decreases, the radius of the arc along which the bowl travels must then simultaneously decrease. This relationship naturally assumes that the bias remains constant.

Anyone who has played bowls will have noticed that just after the bowl is delivered it has its maximum velocity, and travels nearly straight. Nearly straight really means along a circle with a big radius. As the velocity of the bowl decreases, the radius of the path decreases, and it turns quite sharply.

4.2 COMBINING COMPONENTS INTO A SINGLE VECTOR

The two existing forces, namely that from the propulsion by the player and that of the bias, have been examined individually. The next step is to study how they operate in tandem. There must be several ways in which to solve this problem. In this exercise they will be considered as **SIMULTANEOUS VECTORS**. As mentioned earlier, a vector is indicated by an arrow, which points in the appropriate direction and its length is proportional to its magnitude.

In section 3.4, a single vector was divided into two components. The reverse is when two components are combined and reduced to a single vector. Once again the parallelogram method is used. The components form the adjacent sides of the parallelogram. The diagonal, also called the resultant, represents the equivalent vector of the two original vectors.

When combining two vectors, both the direction and magnitude must obviously be stated in the same units. In the case of the direction this is simply given relative to a straight line joining the point of delivery to the position where the bowl ends, and as mentioned above is called the central line.

The bias of a bowl was measured as a force, and given in units of newtons. This means that the propulsion of a bowl by a player must also be given in these units. Propulsion was determined as energy, which was then converted to the equivalent amount of work. Work is not measured in newtons, and cannot be compared with the bias. However, work itself is a combination of the product of force and length. It is this force, measured in newtons, which is used as the second vector.

4.3 COMBINATION OF PROPULSION AND BIAS VECTORS

The bias continually produces an action at a right angle to the path that the bowl travels. As the central line shows the final position of the bowl, the overall action of the bias is at right angles to the central line.

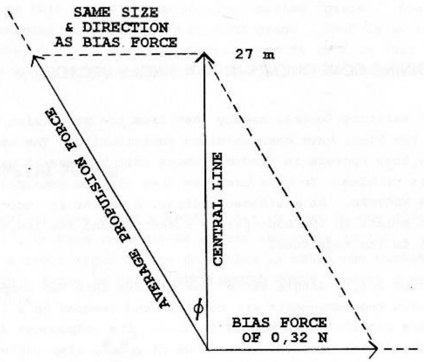

Figure 4.1. A diagram showing the simultaneous action of two forces. Φ denotes the angle of delivery. The magnitudes of the forces are not drawn on any scale.

The operation of two such vectors is shown in Figure 4.1. The angle between the aim of propulsion and the central line is the angle of delivery. In order to emphasize the angle the vectors were not drawn on the same scale. In this work the angle of delivery will be given the symbol Φ. Besides a parallelogram, an equivalent diagram of a right-angle triangle could also have been drawn. The size of the angle of aim is easier to determine from the triangle.

If the magnitudes of the two forces remain the same, the path followed by an object under their influence would be straight along the resultant. In this case in would also be the central line. However bowls do not travel straight down the green, but in a smooth arc. This is because the speed of the bowl and hence the kinetic energy is continually decreasing, and thus the equivalent force remaining from the propulsion decreasing in the same way.

4.4 FORMULA FOR ANGLE OF DELIVERY

The angle of delivery can be determined from the triangle by using the Sin. law, namely

$$\text{Sin } \Phi = \frac{\text{Magnitude of Bias}}{\text{Magnitude of Propulsion Force}}$$

The value of the bias is known well enough. Therefore the problem when employing the formula would be to known what value to use for the propulsion force. As mentioned above this value is not constant. Its magnitude at the moment of delivery is known, and when it comes to rest it is obviously zero. There is a smooth decrease in the remaining propulsion force, and therefore it was decided to use the simple average of these two values.

The value of the force at the moment of delivery was determined in section 1, and can be given as

$$F = -1.4 \frac{mas}{l}$$

The average force is this expression divided by two.

By inserting the following values for the above parameters

Bias = 0,32 N
m = 1,59 kg
s = 27 m
l = 1,2 m

the formula pertaining to the angle of delivery reduces to

$$\sin \Phi = \frac{0,0128}{-a}$$

The formula has a negative sign in the denominator, namely **-a**. It should be noted that the values for **a**, as was shown in Table 1, are themselves negative. Therefore the entire value on the right-hand side of the equation is actually positive.

4.5 VALUES FOR ANGLES OF DELIVERY

The various angles of delivery for greens having different times were calculated from the formula above, and the results are given in Table 4.

Table 4. Table showing the angles of delivery that are obtained from using a bias force of 0,32 N and the previously determined propulsion forces from section 1.

Time of green	Acceleration	Propulsion force	Angle of delivery
9 s	-0,67 $m.s^{-2}$	33,4 N	1,10°
11	-0,45	22,4	1,64°
13	-0,32	16,0	2,29°
15	-0,24	12,0	3,05°
17	-0,19	9,36	3,92°
19	-0,15	7,49	4,90°
21	-0,12	6,13	5,99°

A section of the bank of a green is shown in Figure 4.2. Included in the figure are a few plates indicating the number of the rink, and also some boundary pegs. The distance between these pegs has to be between 5,0 and 5,8 m. A distance of 5,1 m was arbitrarily chosen for the drawing. When selecting their line of aim, many bowlers pick a point along the bank; for example like the point **P**.

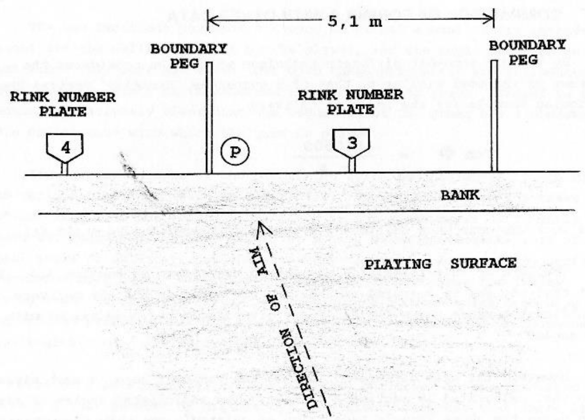

Figure 4.2. Drawing showing a section of the bank at the opposite end of the green, and the type of point some bowlers select when deciding on the appropriate angle of aim.

When playing on a green having a time of around 14-15 s, bowlers generally use a point of aim which is somewhere near the boundary peg. The distance between the number plate in the middle, and the boundary peg is half of 5,1 m. If the distance from the point of delivery to the bank is then 34 m, the angle of delivery is 4,3°. This is more than one degree bigger than the value that could be estimated from the table for this type of green. All the angles given in table are smaller than that what would be experienced in practice.

The major reason for the discrepancy is that the calculations in the table above do not take into account the fact that there is an extenuated swing by the bowl at the end of its journey. This topic will be discussed in section 5. As a result of this bowlers actually have to use a somewhat wider angle than those mentioned in Table 4.

4.6 COMPARISON OF FORMULA WITH OTHER DATA

By using a somewhat different technique wherein he considered the journey of the bowl similar to that of a gyroscope, Brearley[7] derived the following formula for the angle of delivery

$$\text{Tan}\ \Phi = \frac{0,0500}{-\ a}$$

This work was done when delivering a bowl a distance of 27,4 m (90 ft).

The form of this formula is similar to that given in section 4.4. The fact that the one is measured as Tan. and the other as Sin. is not very significant because these two functions give almost the same values with low angles.

However, the main difference is that the constant here is much bigger than that calculated in section 4.4 above. The anticipated angles of aim when using the above formula have being calculated[6], and they are naturally larger. For example on a 15 s green, the angle ought to be 11,8°.

4.7 ANGLE REQUIRED TO DELIVER A BOWL DIFFERENT LENGTHS

One of the most amazing things about the game of bowls is that while playing on a particular green, is that the line of delivery is always about the same irrespective of the distance that the bowl has to travel. This means that the angle of aim, Φ, is virtually constant. It naturally changes when playing on another surface.

In this section the angle of delivery was determined from the combination of the bias of the bowl together with the propulsion force of the bowler. The magnitude of the bias is constant. Therefore as the angle

of delivery is virtually constant, it must follow that the delivery force is about the same irrespective of the distance a bowl travels along the green. This supports the suggestion in section 2 that the force used by bowlers during a game remains fairly uniform.

4.8 ROLE OF THE STATE OF BOWLING GREEN

The two important parameters needed to propel a bowl to its intended target are the delivery effort by the player, and the angle at which he must aim. This work has shown that both these parameters are influenced greatly by the state or retardation exercised by the green. Therefore it should be absolutely clear that the condition of the green has a profound role on the ease with which the game is played.

Simultaneous graphs of the propulsion force and the angle of aim for the various times are shown in Figure 4.3. The relevant data for these two actions show that the retardation caused by the green works differently on these two functions. A high retarding action means conveniently use of a small angle of delivery, but unfortunately requires a large effort during propulsion of a bowl. Naturally the opposite is also true for greens having small retarding effects. On such greens, modern rules regarding the reduced permitted bias in bowls, have gone someway in reducing undue high angles needed for deliveries.

The data in Figure 4.3 are not entirely correct. It was discussed in section 2 that because of differences in delivery lengths, that there is a tendency for the propulsion forces to become more constant. This means there is not as much variation as shown in the graph. Secondly, all the angles of aim ought to be bigger. This due to the fact that the bias of bowls increase as they near the end of their journey. This point will be discussed in section 5.

Summarizing the data means that there is a natural *"trade-off"* between these two parameters. The green ought neither to have such a high retardation that an undue effort is required to propel the bowl, nor should its retardation be so small that there is an unnecessary wide loop in the path that the bowl follows. Bowlers have a general *"comfort zone"* where they neither have to exert undue force, nor need an excessive angle in their delivery. This clearly indicates that probably the most important basic aspect for playing well-controlled bowls is to have good consistent surfaces.

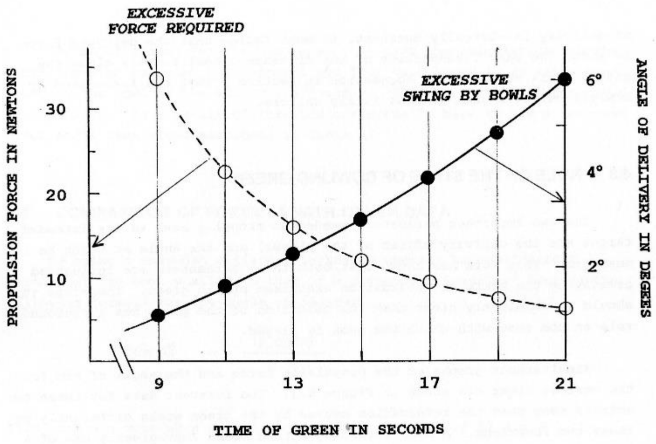

Figure 4.3. Diagram showing the contrasting effect that the time of the green has on the required propulsion force and angle of delivery.

REFERENCES

6. Rob Judson. *"Lawn Bowls Coaching"*. http://home.austarnet.com.au/coaching coaching@austarnet.com.au

7. M N Brearley and B A Bolt. Quart. J. Mech. & Appl. Maths., **XI** Part 3, 1958.

M N Brearley. Proc. Camb. Phil. Soc., **57** (1961) 131.

SECTION 5

BIAS OF TILTED BOWLS

In section 3 it was shown that the determination of the bias of a bowl is based on three factors. They are mass of the bowl, the position of the center of mass, and the distance that the center of mass is away from the perpendicular above the point where the bowl is in contact with the surface. Both the mass of bowl and the position of its center of mass are fixed.

In all the previous calculations the bowl was kept upright, and therefore the location of the perpendicular line above the point of contact, was fixed. This meant that the distance between this line and the center of mass remained the same, and the bias of a bowl was constant. In the example used this value was around 0,32 N.

When a bowl is tilted the position of the perpendicular line above the point of contact, shifts. The questions now is what is the distance between this line and the center of mass, and if it changes what is its consequential effect on the magnitude of the bias of a bowl. This is particularly important when the bowl tilts towards the bias side as it slows down near the end of its destination.

5.1 REASON FOR CHANGES IN THE MAGNITUDE OF BIAS

In Figure 5.1 (which is similar to Figure 3.2) a vertical line is drawn perpendicular to the tangent at the point where the bowl is in contact with the surface. By being perfectly round at this point, the tangent is simply the surface, and naturally the perpendicular will pass through the center from whence the circle was drawn.

If the bowl is now rotated 30° in an anti-clockwise direction, it changes its point of contact with a level surface. But by being perfectly round the tangent at this point is merely the new surface, and the perpendicular drawn at the point of contact, will again go through the center of the circle. As shown in Figure 5.1, the center of mass is still