LAWN BOWL DYNAMICS

by **Rob Judson**
July 2002

Choosing Bowls

Buying Second Hand

Novices need their own set of bowls as soon as they can afford them. They can achieve savings through buying second hand. However, if they are disinclined to bargain, they may do better to buy a new set. They have no choices regarding bowl size, etc if the seller has only one set available at the time and place. They should remember that the seller is unlikely to be an impartial adviser.

Prospective buyers should avoid bowls with extensive scratching of the running sole. Frequent driving on greens with gritty ditch beds often results in the scratching of spinning bowls. Bowlers should empty grit from their bowls cases regularly. Wear and tear over time or deliberate reshaping can affect the bias of bowls. Particularly if contemplating the purchase of used bowls of uncertain origin, they should have the set of bowls table-tested to ensure that they have complying bias.

Testing involves comparing the curvature of the entire path of each bowl in a set of any size as they traverse the table, with that of a 12.7 cm (size 5) master bowl. Table testing should show that each bowl in the set not only has bias exceeding the allowable minimum, but also has equal, or matching bias. The bias or turn of bowls should be marginally greater than that of the master or reference bowl. The margin provides an allowance for minor testing variables, and for a small reduction in bias due to wear.

Brand or Make

No one brand of bowl is technically superior to any other. All brands have exact raw material specifications. Their products have comparable running surface hardness and durability. The precision of bowl manufacturing processes is universally high.

Bowl Weight

Bowl sets are commonly made in several weights. Heavyweight bowls are about 4% heavier than medium weights of the same size. Extra-heavyweights are only about 3½% heavier than heavyweights of the same size. As no bowl may weigh more than 1.59 kg, the limit means extra heavyweight bowls are unavailable in the largest sizes.

These weight differences are not unimportant but they are not very large. Many bowlers lack the tactile sensitivity to detect the differences (just as many bowlers are unable to detect differences in the feel of right and of wrong bias). The claimed performance merits of bowls of a particular weight are sometimes so exaggerated that they are patently misleading. When asked for reasons for their choice, extra heavyweight bowl users commonly give unpersuasive responses. The marginally greater inertia of extra heavyweight bowls is of negligible benefit in attacking play.

The heavier the bowl, the greater is its stability in windy conditions or on small imperfections in the playing surface. However, bowlers using extra heavyweight bowls are obliged to work a little harder. Given that an extra-heavyweight is about 3% heavier than a heavyweight bowl, it experiences 3% more friction against the playing surface during its run. ('The force of friction is proportional to the perpendicular force between the surfaces in contact.') That 3% extra friction would translate into a corresponding reduction in run distance for a given delivery speed. To avoid short bowling, bowlers using extra heavyweight bowls must add 6% $((1 + 0.03)^2 - 1)$ to their delivery speeds.

Bowl Model

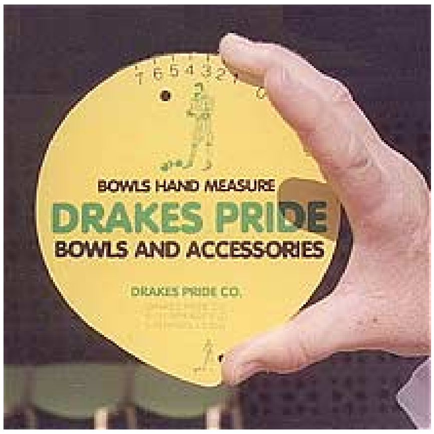
Modern bowls, sometimes called 'minimum bias' bowls, are an advantage where the pace of green exceeds 14 seconds. Their reduced aiming angle, relative to bowls with pre-1987 bias, brings the awareness of the object position in peripheral vision closer to the aiming line, thereby making judgment of delivery speed and aiming line relatively easier.

Some bowl models have paths of more even curvature than others. Some models have paths of less curvature until they approach the end of their run where the curvature increases, and overall bias requirements are achieved. Bowlers sometimes describe the shape of paths of different models of bowls with metaphors such as: bananas, crescent moons, hockey sticks, etc.

The similarities in the finishing paths of different bowl models are greater than observable differences. Experience at head directing or with comparisons using bowl delivery chutes tends to confirm those similarities. This is not to say that there are no differences in finishing paths; merely that they are commonly exaggerated. Particularly on fast greens, a reduced ‘hook’ in the finish of a bowl, makes drawing to the edge of the ditch or 'resting' against the front of a stationary bowl relatively easier to execute. On slower greens however, bowls with a ‘straighter’ finish could reduce the differences in tactical possibilities of forehand and backhand approaches into tight heads, thereby offering skips and thirds in particular, fewer options. For singles players, leads, and seconds, choice of bowl model is more a matter of personal preference than of necessity

Bowl Size

The most critical option when choosing bowls is bowl size. Arguably it is more important than all the other options combined. Bowl sizes, from smallest to largest are: 00, 0, 1,2,3,4,5,6, and 7. Diameters are in the range 115 to 130 mm. Handling comfort is the main consideration in choosing the size of a bowl. Any variation from the measured size should err on the side of being slightly small than too large. In most instances, bowls that are too large cause greater handling difficulty than bowls that are smaller than the measured size. Bowlers can estimate a suitable bowl size by encircling a bowl, so that the tips of middle fingers and thumbs approximately touch as in the left image.



By placing the thumb of their bowling hand against the stop on a bowl size card indicator, bowlers can read their maximum size from the printed scale under the tip of the extended middle finger as in the right image.

A gripped bowl should not fall out of the hand when inverted. The grip should be secure and comfortable. Bowlers should feel that their bowls ideally suit them. They should choose their bowls from the range of options that they 'feel' are right for them. After size, the most important aspect of choice of bowls is the confidence with which bowlers own and use them.

Bowl Speed Mechanics

The Nature of Bowls Greens

Bowls greens are level rectangular surfaces up to 40 metres square. Many outdoor greens have playing surfaces of groomed natural grass. Surrounding the green is a ditch wide enough to trap bowls that overshoot the playing area. Ditches may also assist drainage of the green. The level of the green is at least 23cm lower than its immediate surrounds, or bank. The extension of the exposed face of the bank forms the outer limit of the ditch.

Pace of Green

Leafy, damp, soft greens have high friction and are 'slow'. Brownish, dry, firm, mown and rolled greens have low friction and are 'fast'. The harder surface of faster greens provides lower friction losses. Bowls thereby have lower rates of slowing down, or decelerating.

The pace of green is the measured time in course of a bowl that comes to rest 27 metres from the delivery point. Measurement of the pace requires merely a tape of adequate length and a digital watch. Different areas on a bowling green may yield different timings because of variations in grooming treatment, surface moisture content, etc. Head winds tend to assist the braking effect of the green and result in timings lower than those for windless conditions. Tail winds tend to have the opposite effect.

The required release velocity for a 27 metre run is 16.2 kilometres per hour when pace is 12 seconds, but only 10.8 kilometres per hour when pace is 18 seconds. On faster greens, bowls require lower release velocities (33% less in the examples given) to run a specified distance. Time (pace of green) equals distance (27 metres) divided by speed (mean velocity). The lower the required mean speed of a bowl to run a particular distance, the higher is the pace of green. Whatever the pace of green, bowls and jacks released at the same time and velocity will be in course for similar times and will run similar distances. The turning effect of bias is largely irrelevant to pace of green considerations.

Retarding Force of a Green

Readers know that a bowl or a jack in motion slows down and eventually comes to rest, even if not prematurely stopped by an object in its path. Natural grass and synthetic greens have elastic or deformable surfaces. The energy that propels a bowl dissipates by compressing the surface of the green along the bowl's path. A universal law of science is that energy cannot be created or destroyed. The mechanical energy of a moving bowl progressively converts into heat energy, which fractionally raises the green surface temperature under the moving bowl. In absorbing the mechanical energy of a bowl, a green presents a braking force.

From experiments with falling objects Galileo (1564-1642) found that gravity is a form of acceleration. Sir Isaac Newton (1643-1727) found that the force applied to a body of given mass is proportional to the imparted acceleration. This relationship applies generally, not just to instances where gravity is the acceleration force. Deceleration, or retardation, is negative acceleration and produces a braking force.

The general formula for calculating the friction force f of a green in bringing a bowl of mass m to rest is

$f = m \times a$, where a is the rate of deceleration of the bowl.

For a particular bowl, mass m is constant, so

$f \propto a$,

i.e. the rate of deceleration of a bowl is proportional to the friction force of the green that eventually brings a bowl to rest, where final velocity $v = 0$. The rate of deceleration of a bowl in motion is constant.

Bowl Deceleration Rate

Deceleration of a bowl in motion occurs at a constant rate. In these circumstances, the general formula for calculating the deceleration is:

$a = \frac{2S}{t^2}$, where S is the run distance, and t is the duration of the bowl's motion.

For a known pace of green, both S (27 metres) and t (pace of green in seconds) have known values and deceleration a calculates, as follows:

$a = \frac{2 \times 27}{t^2} = \frac{54}{T^2}$, where t is the measured pace.

Values of the decelerating effect for a range of green speeds is as follows:

Green Pace (secs)	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Bowl Deceleration a (m/sec^2)	1.10	0.84	0.67	0.54	0.47	0.38	0.32	0.28	0.24	0.21	0.19	0.17	0.15	0.14

The marginal extra weight of heavyweight (4%) and extra-heavyweight (3.5%) bowls causes extra surface contact area and friction. Such bowls would have marginally higher bowl deceleration rate for each pace of green. Bowl deceleration rates are of little direct value, but they constitute the basis for some interesting relationships.

A Method of Calculating the Pace of Green

Pace of green is calculable from a timed delivery over any measurable distance. The calculation requires a transposed version of the formula under the previous heading. The equivalent pace of green T for the standard 27-metre test distance becomes:

$T = \sqrt[2]{\frac{27 \times t^2}{S}}$, where t is the elapsed time and s is the measured run distance.

Bowl Delivery Speed

The formula for calculating the required delivery speed u of a bowl to run distance s is:

$u = \sqrt[2]{2as}$, where a is the deceleration rate of the bowl.

The required delivery speeds of bowls to run a particular distance on a green of a particular pace appear in the adjacent table.

Required Delivery Speed (kph)

	Green Pace (sec)				
Head Distance (m)	**10**	**12**	**14**	**16**	**18**
21	17.1	14.3	12.2	10.7	9.5
24	18.3	15.3	13.1	11.5	10.2
27	19.4	16.2	13.9	12.2	10.8
31	20.8	17.4	14.9	13.0	11.6
36	22.4	18.7	16.0	14.0	12.5

On very fast greens, bowlers tend to feel that they attain necessary run distances by doing little more than allowing their bowls to trickle out of their hands. Nevertheless for a run distance of 28 metres on a 20 second green, a bowl delivered at less than 10 km/hr will stop short.

A transposition of the previous formula takes the following form:

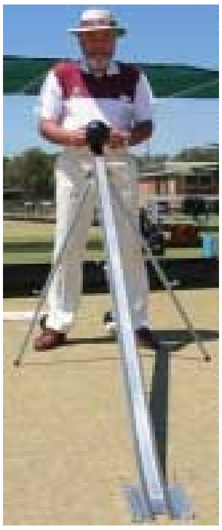
$$s = \frac{U^2}{2a}$$

In unchanged environmental conditions the value of ***2a*** is constant so $s \propto u^2$, i.e., run distance of a bowl is proportional to the square of the delivery speed. Therefore any error in run distance of a bowl is proportional to the square of any error in delivery speed. For example, on an 11 second green, a 28 metre run distance requires a bowl delivery speed of 5 m/sec. Suppose the actual delivery speed is 5.25 m/sec, which is a 5% error. The extra run distance obtained is proportional to the square of the error:

$$s = 28 \times \frac{105 \times 105}{100 \times 100} = 30.87 \ m$$

Thus the extra 5% of delivery speed produces an extra 2.87m of bowl run, which constitutes a 10.3 % error in the result. This compounding effect of delivery speed errors makes accuracy in distance more difficult to learn and master than accuracy in delivery line. Driving speeds of leading bowlers measured on police speed guns as a novelty feature at bowls carnivals commonly show values in the 30-50 km/hr range. Delivery speeds for drives are typically about 3 times those of draw shots.

Delivery of a Bowl from a Chute



Testing of bowls requires a consistent and controllable mechanism for launching the bowls. The most commonly used device is an inclined ramp with a narrow track for providing fine control over launching direction. Following its release from an elevated point on an inclined chute, a bowl accelerates as it rolls downward under the influence of gravity.

Tables used for bowls testing allow test runs in the range 8 - 11 metres. Their fast surfaces have an equivalent pace in the range 21.5 to 27 seconds. The combination of short runs and fast surfaces requires only short, low launching chutes.

Required Elevations for Chute Deliveries

The exit speed ***u*** of a solid sphere (such as a bowls jack) launched from elevation ***h*** on an inclined chute is available from the general formula

$$u^2 = \sqrt{2}hg$$

Lawn bowls are oblate spheroids. Although they lack the spherical symmetry of jacks, the angular momentum they develop in rolling down a chute does not significantly differ from that of equivalent spheres. Therefore the mechanical behaviour of bowls conforms quite closely with the general formula.

Transposition of the previous formula to calculate the required elevation ***h*** of a bowl for an exit speed ***u*** produces

$$h = \frac{U^2}{\sqrt{2} \cdot g} = \frac{0.7u^2}{g}$$

(approx), where ***g*** is gravitational acceleration (981 cm/sec^2)

Experimental run distances required may exceed the length and width of a bowling green. Run distances of bowls of nearly 55 metres are achievable by setting up a chute diagonally in one corner of a green. Variations in pace of green will correspondingly affect run distances.

By combining the formulas for ***a***, ***u*** and ***h*** (above) and substituting for ***a*** and ***u***, another formula for calculating required elevation ***h*** emerges:

Required Delivery Chute Elevation (m)

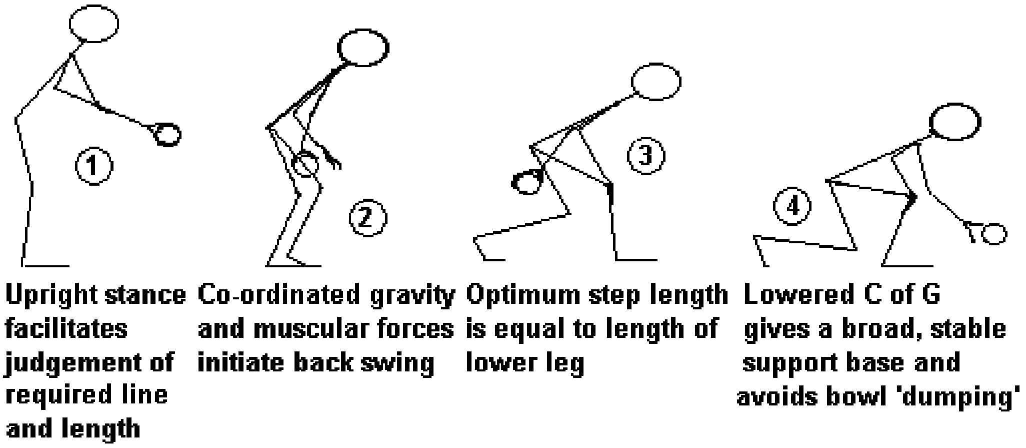
	Green Pace (sec)				
Head Distance (m)	**10**	**12**	**14**	**16**	**18**
21	1.63	1.14	0.83	0.64	0.50
24	1.87	1.30	0.95	0.73	0.58
27	2.10	1.46	1.07	0.82	0.65
31	2.41	1.68	1.23	0.94	0.74
36	2.80	1.95	1.43	1.09	0.86

$$h = \frac{7.8s}{t^2}$$ ***(approx)***, where ***s*** is the required run distance and ***t*** is the pace of green.

The adjacent table shows the required release height (cm) on a delivery chute for a bowl according to the required run distance and the pace of green.

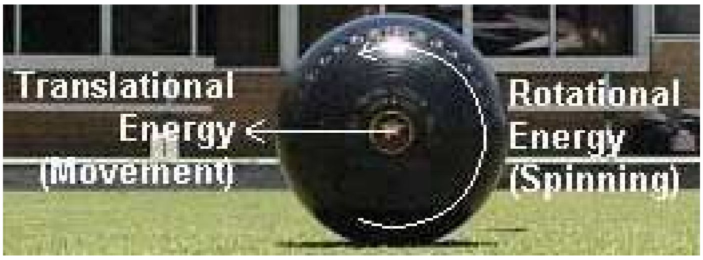
Elevation in Manual Deliveries

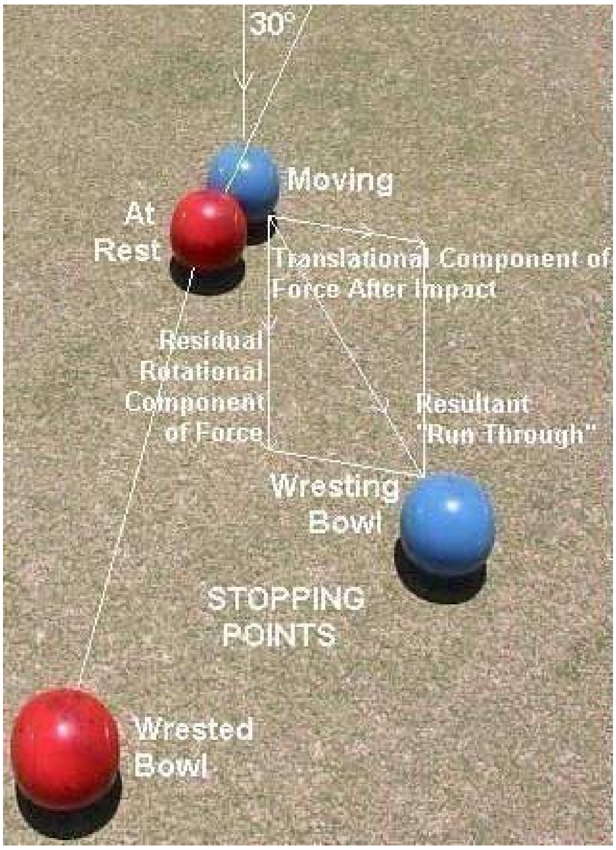
Bowlers commonly use gravitational force in generating required bowl delivery speeds like the method shown in the following figures (1) to (4). They elevate the bowl in the set up (1). They use some gravitational energy to augment muscular force in producing the back swing (2). On completing the back swing (3) the bowl might have only about half of its initial elevation as bowlers bend their bodies into the delivery posture. Bowlers use muscular force augmented by gravitational energy again in producing the forward or delivery swing (4).



Bowl Impacts - Wresting and 'Run Through'

The mass of a bowl in course not only changes position but also spins. Thus it has translational energy (movement) and rotational energy (spinning).





As a bowl leaves an inclined chute, there is a relatively smooth transition as it begins its run along the green. However a manually delivered bowl has no rotational energy as it contacts the green. It is not possible to impart topspin. Therefore a manually delivered bowl initially skids as some of its translational energy converts to rotational energy. The conversion of energy continues until the bowl has angular velocity, or spinning speed, at which skidding stops. Bowlers intuitively impart the total energy required to deliver a bowl that will run a particular distance in given circumstances.

A bowl has about 7 times the mass of a jack. If a bowl collides with a stationery jack, little variation in speed or direction of the bowl's movement may be perceptible. The jack will tend to move in a direction opposite to that of the point of impact. If a jack collides with a bowl at rest, negligible movement of the bowl may occur.

'Impact' refers to the mechanical action of a bowl in motion (impacting or wresting bowl) on a bowl at rest (impacted or wrested bowl). The last paragraph but one indicated that a bowl in course has translational energy (movement) and rotational energy (spinning). Upon impact, the wresting bowl may retain much of its spinning energy, but may transfer much of its energy of motion to the wrested bowl, forcing it to move.

Bowlers sometimes deliberately play impact shots. They sometimes use the term 'wresting shots' to describe attempts at forcing a bowl at rest either into or out of the 'scoring zone'. They sometimes use terms like 'follow-through' or 'run-through' to describe a wresting bowl that displaces a stationary bowl yet retains sufficient momentum to advance to a tactically advantageous position in the scoring zone. Because of the tactical possibilities, the basic mechanics of bowl impacts are worth consideration.

Contrary to the expectations of some bowlers, experiments show that the distance and direction that the wresting and wrested bowls move after impact is virtually unaffected by whether the bowl at rest is on its 'side' or is 'upright' when impact occurs. The main variables that determine distance and direction of subsequent movement are impact speed and angle of impact. The tolerance for error in impact speed is typically about ± 2%. An impact speed error of ± 2% translates into a run distance error of ± 4%, or about ± 1 metre. In the context of ‘yard-on’ shots, an error of a metre would usually result in failure to achieve the tactical objective. For both wresting shots and follow-through shots, the tolerance for error in delivery line is typically less than one quarter of a degree. An error outside the latter tolerance means missing the targeted bowl altogether. Therefore, accuracy of delivery line is usually more critical than bowl speed accuracy. In any case, tactical success of wresting shots or follow-through shots typically has rather small margins for error.

In explanation of wresting shots and follow-through shots, the term 'Notional Run' is the extra distance that a bowl would have rolled before coming to rest had its course been unobstructed.. The term 'Impact angle' is the angle between a line through the point of impact and the alignment of 'full-face' or 'dead-centre' impact. Thus the angle of full-face impact is 0°, and the angle of oblique impacts cannot exceed 90°. 'Wrested Distance' or 'Follow-Through Distance' is the distance that the corresponding bowl moves after impact before coming to rest. 'Wrested Angle' or 'Follow-Through angle' is the angle between the direction that the corresponding bowl moves after impact and the direction of 'Notional Run'.

Wresting Shots

Impact Angle	0° (‘full-face’)	30° (about. 5 cm ‘off-line’)	50° (about 9 cm ‘off-line’)
Wrested Angle*	About 0°	16–20°	44–46°
Wrested-Distance	45-49% of Notional Run	41-47% of Notional Run	22-30% of Notional Run
(∴) Required Notional Run	About twice the required wresting distance	About twice the required wresting distance	About 3 – 4 times the required wresting distance

**The Wrested Angle tends to be of similar size to the Impact Angle*

‘Follow Through’ or ‘Run Through’ Shots

After impact, the retained rotational energy of the wresting bowl retains a component of momentum in the direction of

Impact Angle	0° (‘full-face’)	30° (about 5 cm ‘off-line’)	50° (about 9 cm ‘off-line’)
RT/FT Angle*	About 0°	7–10°	16–25°
RT/FT-Distance	18-19% of Notional Run	30-32% of Notional Run	58-59% of Notional Run
(∴) Required NotionalRun	About 5 – 6 times the required run-through distance	About 3 times the required run-through distance	About 1½–1¾ times the required run-through distance

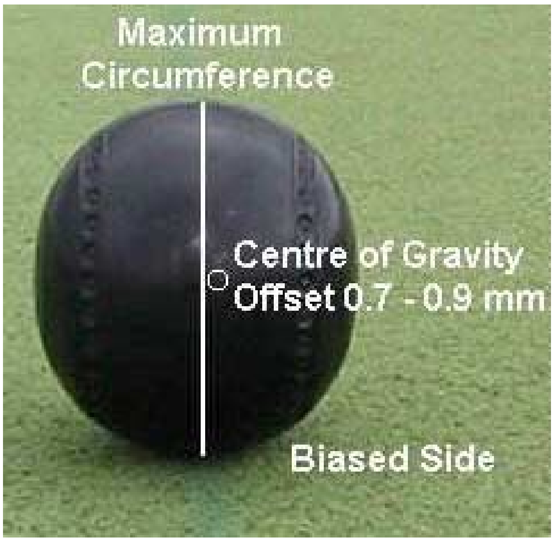
motion before impact. The remaining translational energy produces a component of movement of the wresting bowl at right angles to a line from its centre to the impact point. The resultant of these two components defines the direction and distance of follow-through.

Delivery Angle Mechanics

Static Characteristics of Bowls

Lawn bowls are spheroids with greater curvature near their running sole, or plane of maximum circumference, than near the poles of their spinning axis. Small rings, or 'discs', engraved around these poles identify their locations. Because of their shape, bowls are statically unstable except when resting on either of their discs. On a firm surface, unsupported bowls will topple and rock into a stable position. On an uneven or deformable surface such as a leafy bowling green, they may rest stably other than on one of their discs if the area of contact extends under their centres of gravity.

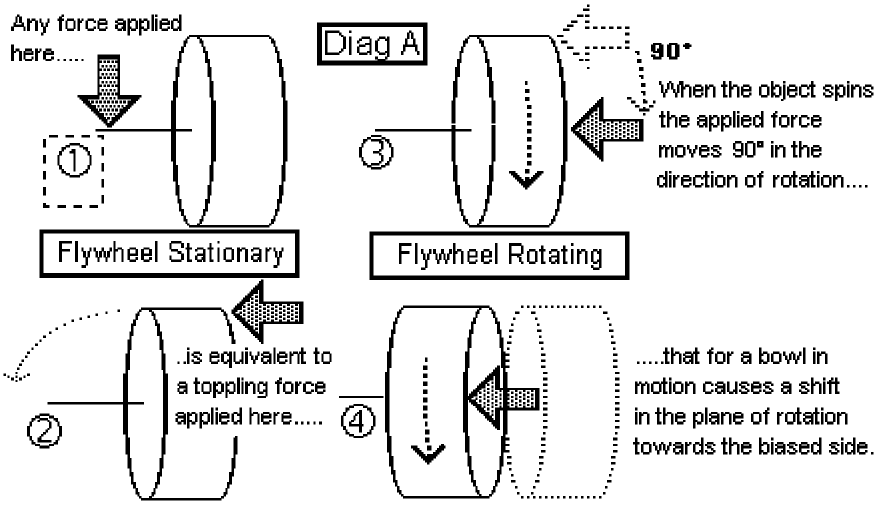
Manufacturers mould and shape bowls so that there is fractionally more mass on one side of the bowl. This shaping moves the centre of gravity away from the bowl's plane of maximum circumference. The C of G offset of a bowl with the old (pre-1987) bias is about 0.9 mm. Modern bowls have an offset of about 0.75 mm.



This offset provides an arm for a moment of toppling force created by the bowl's own weight. The moment of force is equivalent to a weight of about 23 grams tugging downward at the small disc. This moment of force constitutes the bias of the bowl. The slightly reduced C of G offset of modern bowls gives them less bias. Bowls placed with their running sole on a firm surface invariably topple towards the smaller ring, or biased side.

The asymmetric shape of a bowl creates asymmetric weight distribution. This unequal weight distribution creates a bias. Readers can readily demonstrate this with a tennis ball and a piece of blu-tack© about the size of a pea. Roll the unmodified tennis ball along a level surface and it runs straight, like a jack. Now apply the lump of blu-tack© to the tennis ball. Grip the ball with the blu-tack© facing the forehand or backhand side. The weight of the blu-tack© is enough to create a bias. The tennis ball will follow a parabolic path just like a biased bowl. Note that the procedure did nothing to alter the shape or contour of the running surface. The lop-sided weight distribution creates the bias and turns the tennis ball. Alteration of contour of a bowl will affect bias if it changes the asymmetry of weight distribution along the spinning axis of the bowl.

Mechanics of Bias



Rotating objects such as flywheels and bowls in motion share some common physical properties as shown in diagram A in the adjacent image. In drawings 1 and 2 the object is stationary. Drawing 1 shows how a downward force at one end of the rotational axis tends to topple the object. Drawing 2 shows an equivalent effect results from a horizontal force applied from the opposite side near the top edge of the object. If the object rotates, gyroscopic effects apply. The toppling force at the top edge moves 90° in the direction of rotation, as shown in drawing 3. This causes the object to change its plane of rotation instead of toppling, as shown in drawing 4.

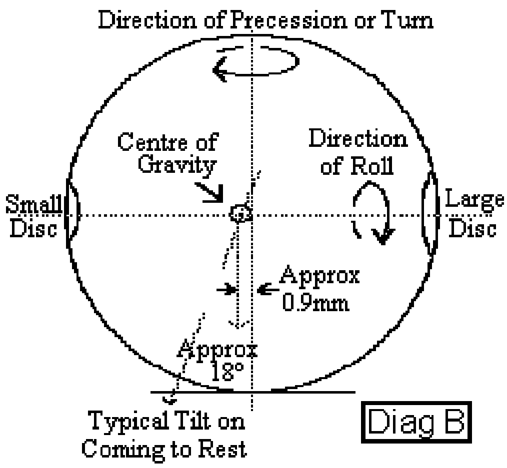
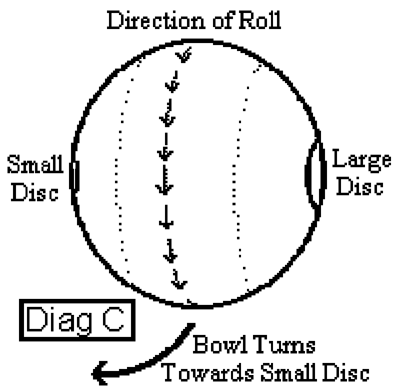
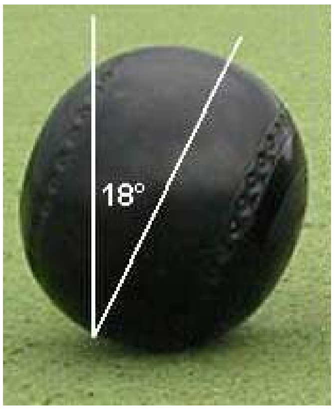


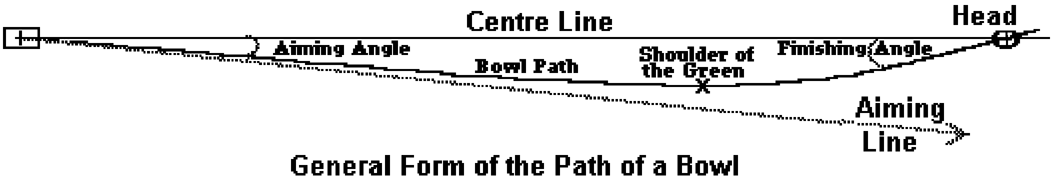
Diagram B shows how the same principle applies to biased lawn bowls. It shows the cross section of a bowl advancing towards the reader. The moment of the weight of the bowl acting downward from the offset centre of gravity creates a toppling force. This moment of force has a tendency to topple the bowl towards the reader's left. However as the bowl rotates towards the reader, gyroscopic effects cause the force to move 90° so that it acts from right to left at the leading point of the bowl's plane of rotation. This causes the bowl to turn to the reader's left towards its smaller disc as in diagram C.





As a bowl follows its characteristic curved path, it progressively tilts towards its biased side. The angle of tilt as a bowl comes to rest is about 18°. At that point the centre of gravity is above the point of surface contact. The bowl then either remains at the angle, or rolls over on to its small disc.

A bowl's total turn, or 'precession', depends on the offset of its centre of gravity. As a bowl slows down, its rate of turn proportionally increases. The rate of turn also depends on the profile of its running sole. Bowls of all sizes of a particular model have profiles similar to one another, but different to those of other models or manufacturers. The profile of the running sole affects the shape of a bowl's path, i.e. the relative position of the shoulder, and the sharpness of the finishing angle, both of which appear in the following diagram.



General Form of the Path of a Bowl

Some bowlers believe that different grass varieties or different playing surfaces (synthetic or lawn) affect the line of a bowl. However, evenly groomed surfaces of equal pace will all result in similar bowl performances. If a particular type of grass appears to affect bowl performance differently, testing will show that the pace has changed.

Any cross wind present will tend to align with the horizontal arrow in flywheel diagram A (2). If its direction is from right to left in that diagram, it acts with the bias of the bowl and increases the amount of turn. If its direction is from left to right, it acts against the bias of the bowl and reduces the amount of turn.

Bowl Aiming Angle

Aiming line is the required direction of delivery to offset the turn of a bowl due to its bias. Aiming angle is simply the angle at the point of delivery that the aiming line makes with a straight line to the object position in the head.

Irrespective of size, all bowls should have a bias not less than that of a standard test bowl, and all bowls in a particular set should have the same bias. However different types of bowls have different amounts of bias. Bowls with the 'old' (pre 1987) bias required an approximate aiming angle as follows:

$$A = \frac{1}{\arctan \frac{.05}{a}}$$

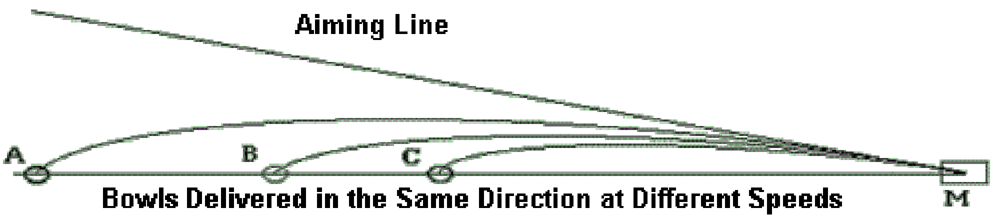
, where A is the angle (radians), and a is the rate of deceleration (m/sec²) of the bowl.

The faster the green, the greater is the required aiming angle to offset the bias. Use of the preceding formula produces the aiming angles in the last row of the following table for a range of green speeds:

Green Pace (secs)	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Bowl Deceleration a (m/sec²)	1.10	0.84	0.67	0.54	0.47	0.38	0.32	0.28	0.24	0.21	0.19	0.17	0.15	0.14
Aiming Angle A (degrees)	2.6	3.4	4.3	5.3	6.4	7.6	8.9	10.3	11.8	13.3	15.0	16.7	18.5	20.3

In 1987, bowls authorities approved a master bowl of reduced bias that replaced the existing (pre-1987) reference bowl. The reduction in bias was about 18%. So bowls manufactured to the newer bias standard require aiming angles of about 82% (approx 4/5ths) of corresponding aiming angles of older bowls. Bowl manufacturers introduced a range of new models with the reduced bias. Licensed bowl testers use the same master bowl for table testing of bowl sets of any size. Allowable bias is the same irrespective of bowl size. Some bowlers mistakenly believe that small bowls have more turn or bias than larger bowls.

Although cross winds affect the aiming angle, the run distance s does not. As the following figure shows, bowls delivered in the same direction at different speeds will come to rest in a straight line:



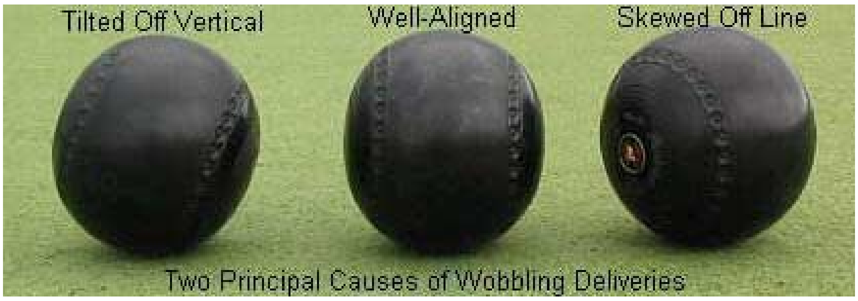
Bowls Delivered in the Same Direction at Different Speeds Will Come to Rest in a Straight Line

Fast attacking deliveries require a reduced aiming angle. Bowl speed and aiming angle combinations vary not only with tactical requirements but also from one type of bowl to another. Bowlers can succeed with controlled speed by drawing to an imaginary jack beyond the target so that the expected path of a bowl will traverse the target's location.

The slower the green speed, the larger is the aiming angle required by a fast attacking delivery to an object bowl in the head. The longer a bowl is in motion, the more its bias makes it turn. Bowlers tend to drive with an individually comfortable and consistent rhythm and pace. For a particular driving speed, a bowl on a slower green experiences greater friction, greater deceleration, lower impact speed and greater time in course from mat to target. The greater time in course allows greater turn, so the bowl requires a greater aiming angle. Drives on slower greens using aiming lines suited to faster greens, will run narrow and miss the target by typically up to a metre.

Bowl Wobble

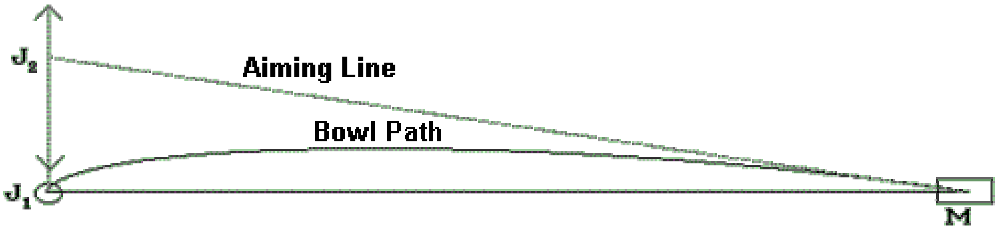
There are two principal causes of bowl wobble. Wobble occurs if the coaxial engraved rings of the bowl are not parallel with the direction of delivery. The spinning axis is thereby not square to the delivery line. Wobble also occurs if the engraved rings are tilted instead of being vertical. These conditions appear in the following figure:



Bowls canted left or right or skewed left or right to the same degree will all wobble identically. A correctly aligned bowl will wobble if wrist or finger movement occurs during delivery or if a bowler applies propelling force other than through its centre. In either case the bowl is likely to begin its course either off square or tilted.

Wobble is an unstable condition that generally damps out while a bowl is in course. A driven bowl might wobble until it strikes its target or enters the front ditch. The slower the green, the quicker wobble dissipates. While wobble persists, it effectively reduces the offset of the bowl's centre of gravity. Consequently wobbling bowls turn less than normal. Random wobble causes random bowling accuracy. Some bowlers grip the bowl in a canted position for delivering a drive. They force a wobble, which makes their bowl follow a straighter line. There is no way of imparting a sustained tilt for the run of a bowl.

Length of Curved Path



In the preceding diagram, J_1 represents a jack. Line MJ_1 is the direct line to J_1, and is readily measurable. The diagram also shows the superimposed path of a bowl. The length of the curved path to J_1 is equal to the length of MJ_2, where J_2 is the point on the aiming line that is 'jack high'. The length of MJ_2, and therefore the run of the bowl is:

$MJ_1 \div \cos A$, where A is the aiming angle.

The extra run distances of Classic Deluxe bowls along their curved path, compared with the direct distance to their final position appear in the adjacent table. The extra run is much smaller than many bowlers suppose. The extra run of bowls with the new (1987) bias is even less than the values in the table.

Extra Run of Bowl (w/ pre-1987 bias)
In Reaching Destination by Curved Path
Compared with Direct Distance (cms)

	Green Pace (sec)				
Head Distance (m)	**10**	**12**	**14**	**16**	**18**
21	9	19	34	58	92
24	10	21	39	67	106
27	12	24	44	75	119
31	13	27	51	86	136
36	15	32	59	100	159

On 'fast' greens, bowls leave the centre line of the rink by several metres before they draw in again. Some bowlers intuitively speculate that the total extra distance travelled by bowls is several metres. The actual run distance of a bowl can be found by dropping markers as it passes, extending a cord from marker to marker, and then measuring the straightened cord after the bowl comes to rest. The curved path of a test delivery to measure pace of green on, for example, an 18 second green will exceed the direct distance (27 metres) by no more than 119 cm, or about 4.5%. On a 12 second green the actual difference would be only 24 cm, or less than 1%.