Mechanics of Sport*

By Sir Gilbert Walker, C.S.I., F.R.S.

IN games with a ball in their most primitive stages, the ball may be simply a convenient lump to be thrown or hit; but effects of spin soon play their part. It is well known that Prof. P. E. Tait measured the starting speed of a golf ball and thought he had proved mathematically that its range could not be more than about two-thirds of the distance that his son proceeded to drive it. The cause lay in the upward force due to the under-spin, and the explanation of such an effect had been given by the late Lord Rayleigh, as well as in general terms by Sir Isaac Newton. Similar effects may be seen in a slice at golf, a swerve in cricket or baseball, or an American service at lawn-tennis.

Another game in which a swerve occurs is curling, and the path of a stone happens to have the same relation to its spin as that of a ball moving through the air. Now the bottom of a stone is not flat, but is hollowed, so that it is in contact with the ice over a circular line about 6 inches in diameter. Let us suppose that the direction of spin is such that the forward side is travelling towards the left. If we think of the sideways friction on the circle of contact, that in the front half of the circle is to the right and on the rear half to the left. Now the stone moves to the left, so the friction on the rear half must be the greater. But as the forward motion of the stone as a whole is retarded by friction on the ice, the pressure on the rear half must be less than that on the front half; and if the stone were moving over a glass plate the rear friction would be the less and the stone should swerve to the right. This actually happens. On ice, however, it swerves to the left and so there must be better lubrication on the front half, or greater pressure, than on the rear half. Now we know that when ice is not far from the melting point, pressure in excess of a critical value melts the ice and reduces the friction: it is this property that makes skating possible, for it produces a film of water between the skate and the ice. So there should be more melting in the front half; also a stone should refuse to curl when its pressure cannot melt the ice, that is, when it is very cold. This agrees with experience.

Curiously enough, there is yet another case in which rotation sets up deviation in the same direction as for a ball. It is that of a falling long strip of cardboard. As Maxwell pointed out, if a spin is started, the downward velocity will be least after the plane of the strip has passed through the horizontal and greatest after passing through the vertical. So the couples tending to increase the spin will be greater than those tending to decrease it; and the spin will grow. Also the horizontal forces will be greater after the vertical position has been passed through, and the sideways motion will appear. An example of this may be seen in the bull-roarer, an implement used in magical rites by primitive men over a large part of the earth. When the bull-roarer is twirled round, the string describes a cone on the side indicated by the theory, and when it has twisted so far that it must start untwisting, the cone shifts over to the other side.

Some effects of the 'nap' of a cloth may now be considered. A billiards player learns by experience that the path of a ball travelling slowly with much 'side', that is with a rapid spin about a vertical axis, will be diverted to the right or left according as the spinning motion on the right side is with or against the nap. The deflexion may be something like an inch in the length of the table. I have seen pages of mathematical analysis vainly devoted to the subject. But if we state the result in the form that the path bends away from the side on which the nap is being rubbed up and toward that on which it is being rubbed down, the explanation is obvious; for on the rubbed-up side the effective surface is higher than that on the stroked-down side, and the ball moves, as it were, on an inclined plane.

Let us consider now some of the weapons of primitive people. Slings and stones are still widely used, but the range of an arrow or a throwing spear is much greater than that of a stone of the same weight starting with the same speed. A few efforts to throw a wooden stick five feet long by hand will show that, unless precautions are taken, there is a marked tendency for it to travel in the stable transverse attitude with its length at right angles to its path, so that the range is poor in the extreme. For steady flight with the axis longitudinal we must either provide resistance in the rear end, as in an arrow, or put the centre of gravity forward, or spin the weapon about its axis; in a throwing spear both the latter devices are commonly employed. The natural way to give the spin is by wrapping the thumb and fingers round the spear, so that it rolls off the hand on release. The assegai is thrown in this way, and flies like an arrow from a bow; its penetration is very great.

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In the course of time, primitive peoples have developed two devices for throwing, the spear-thrower and the beckett. The former is a stick about two feet long and in its use the spear lies along the spear-thrower with its butt resting against a projecting peg. This makes possible an invaluable flick of the wrist and, strangely enough, imparts a considerable spin. This would be impossible if the spear were not slightly 'whippy', so that an imperceptible flick to one side in its slightly bent state will apply a couple about its longitudinal axis. I believe that a range of 150 yards can easily be attained in this way.

The beckett is a short cord wrapped around the spear and also the first finger of the thrower's hand. It enables the wrist to be freely used and gives the valuable spin. The Roman *pilum* was thrown in this way with a thong called *amentum*.

A boomerang can to-day be looked on as an anticipation of the 'autogiro'; for as with the horizontal fan of the autogiro, its rotation provides support similar to that of the wings of an aeroplane. The couples necessary for its steering are produced partly by the warping of its plane and partly by the lack of symmetry in its cross-section. Returning boomerangs may describe paths of various types; we may have several circuits in front, or a figure of eight. But for an ordinary missile to be thrown at an animal, the shape is designed to give a straight and very flat trajectory. Its efficiency is considerable; when my range with a cricket ball weighing $4\frac{3}{4}$ oz. was seventy yards I could throw a straight-going boomerang weighing twice as much a distance of 185 yards. One of my literary friends used to maintain that a boomerang alighted rotating faster than when it left the thrower's hand; and I used to reply, with the cocksureness of a mathematician, that such a thing was impossible. But we are now familiar with the way in which, except in recent patterns, the rotation of the fan of an autogiro was provided, not by the direct drive of an engine, but by the forward rush of the machine through the air. So my literary friend was not far wrong.

A well-known tool of the Stone Age is the adze, of which the head, or celt, may have a curious property; when placed on a fixed plate of clean glass it may spin in one direction but not in the other. The celt is oval and at the point of contact with the plate the lines of curvature are not, in general, precisely parallel with the dynamical axes—the axes based on the distribution of matter. There is rotational asymmetry, and this shows itself when the celt is spun. Theory brings out another paradox; when tapped at one end rotation is set up, and the direction of this may be reversed merely by raising the centre of gravity.

Let us now turn to some problems of the motion of living beings. The art of swimming has been revolutionized by copying primitive peoples in methods so obvious that we ought to have thought of them. Thus in 1892 the record for the mile was 29 min. 25 sec.; it is now 21 min. 7 sec., an improvement of about forty per cent. In the crawl stroke the body is horizontal instead of sloping, so that the resistance is reduced and the energy is nearly all spent in propulsion, whereas much was spent in keeping the head out of the water. In it, also, useless resistance is not caused by moving the arms forward or sideways in the water, instead of backwards, and the legs, which are not well designed for propulsion, remain nearly straight; their movement, whether the flutter or the scissors, is made three or four times to one of the arms and has a very small range; its object is largely that of controlling the position of the body.

We will now consider a high jump. A good performer crosses the bar in a nearly horizontal attitude, so that as he approaches it vertically he would, unless something occurred, turn through another right angle in descending and alight nearly upside down. In fact he learns to make violent contortions to avoid a dangerous descent. Perhaps the best exponent of this art is the cat, which, if suspended by the paws with its back only a few inches above a table and released, will fall on its feet. It performs the whole operation of rotation in the air in about a quarter of a second. This can be illustrated by mounting a platform able to rotate without appreciable friction, when, by repeated use of the arms, a man can turn his body completely round as often as he wishes, although at no instant is there the slightest angular momentum about the vertical.

Another theme is that of sailing flight. In the tropics when the sun has sufficiently heated the earth's surface, we see kites and vultures flapping their way upwards until about fifty feet above ground; and then, having reached an up-current, their labours cease and they soar in spirals to a height of perhaps 2,000 feet; they may wander at will all day and descend at sunset. At the first glance it would appear from the inclination of the wings that the up-current would drive the bird backwards, not forwards, but on plotting the motion of the bird relative to the air and remembering that its wings are slotted the paradox is solved.

I believe that the mechanical efficiency of a modern sailplane easily beats that of a vulture, the flight of which is handicapped by carrying much flesh; so that in the tropics a skilful and experienced pilot should be able to roam all day at will. But even in our comparatively feeble European sunshine, the distance record is 313 miles and a height of more than 19,000 feet has been reached.