caption to a figure comparing Frank Lloyd Wright's mile-high skyscraper (which was never built) to more familiar structures states that they are drawn to scale, and yet they are not. Such a neglect of detail jeopardizes an otherwise intriguing book, for the gloomy engineer has naturally to wonder about the details of those parts for which he must rely on the scientist. □

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Behind the birdies

Stephen Salter

The Physics of Golf. By Theodore P. Jorgensen. *American Institute of Physics/Oxford University Press: 1993.* Pp. 155. \$35, £27.50.

It was on grounds of national security that the Scottish Parliament introduced successive acts (1451, 1457 and 1491) banning the game of golf. The unprofitable use of land, the loss of productive working hours, the stresses on family life, the danger of apoplexy and the reduced attendance at kirk were factors but it was the distraction from archery practice that was decisive.

With advances in military technology, golf has been decriminalized in Scotland and many other countries. Golfing equipment with a street value estimated at \$13 billion a year is now sold quite openly. Jorgensen's book on the physics of golf offers no suggestions for treatment of addicts but may help us to understand their problems.

His model of the golf swing consists of two stiff hinged rods, one representing the arms of the player and the other the club. He presents the algebra to predict the behaviour of this model in terms of five torques on the golfer's arms. He supports the predictions with stroboscopic photographs of patches of reflective tape stuck to the club and to points on the body of the golfer. The observations are in good agreement despite the simplicity of the rigid two-rod model.

Many of the results are intriguing. For example, a marker on the head of a golfer will trace a curve that is as unique as his signature — a more enjoyable method of security identification than fingerprinting. In a good golf stroke the velocity of the golfer's hands decreases on contact with the ball, while that of the club head continues to increase. Similarly, a bull

whip makes a supersonic crack when most of it is static and all the kinetic energy has been transferred to the very tip.

Did you know that bull whips should have lead weights near the handle? Did you know that you can break the shaft of a club by not allowing your wrists to rotate? Did you know that a perfect ball would leave the tee at twice the speed of the club head? Good players achieve a ratio of 1.4 which suggests that there may still be room for design improvement.

Jorgensen calculates the instantaneous power delivery of human muscle and says that the amount of muscle needed (32 pounds or 15 kilograms) is far more than is available in arms and shoulders (he suggests that a visit to the butcher will confirm this). He argues that other muscles in the legs and back must be in use, passing energy through the arms.

The book contains enough experimental detail to allow readers to replicate results. An interesting example is the work of Peter Guthrie Tait in 1887 on ball spin. Working without electronic instruments or fast photography, he measured spin by attaching a flat ribbon to a golf ball and driving it into a nearby bank of thick clay. By counting the twists of ribbon, Tait calculated that the rate of spin was as much as 120 turns per second or 7,200 revolutions per minute, depending on the angle of the club face. Many people did not believe him.

despite the different weights of their heads and the fact that golfers like clubs of different lengths in their set. The method involves placing small weights at two places along the club shaft so that the total weight, the first moment and the second moment are the same. Small changes of weight, of the order of 1 gram, are involved. Good golfers seem to like the results.

A whole chapter is devoted to the laws of probability and their relationship to golf. The author collects data from the score cards of a pair of players over 20 games and calculates the probability of various scores. The Gaussian distribution strikes yet again. Twenty games — about 1,500 strokes — seem to be plenty to give the familiar smooth curves. Golf authorities have not so far devised a way of awarding non-integral handicaps. Jorgensen shows that this will prevent better players retaining an advantage.

Jorgensen writes for a wide readership ranging from nongolfing fellow physicists, who may find some of the verbal explanations rather laboured, to nonscientific golfers, who may wince at the algebra. He spans the gap with appendices for the heavier maths; readers should be tolerant.

Relaxed sportsmen in the United States will be less irritated than pedantic academics in Europe by the promiscuous mixture of physical units. Many results are given in inches, feet and yards with ounces and pounds for force. When

Jorgensen goes metric he uses grams and centimetres. Club makers use an extraordinary measure, the Lorythmic swing-weight scale, in which ounce-inches of moment about a point 12 inches from the grip end are divided into letter numbers in bands of 20 ounce-inches, which are then subdivided into numbered bands of 2 ounce-inches. We can be grateful to Jorgensen for a clear explanation.

It was rather mean of the publishers not to include one of Harold Edgerton's splendid flash photographs of a golf ball flattened to half its diameter: the peak force between club and ball can exceed 3,000 pounds — more than the weight of a family car. There is only one page of references and a three-page index, but this will not detract from one's enjoyment of the book.

Golfing addicts now need a psychologist to explain the ecstasy of hitting a golf ball exactly right. I can testify to the addictive power, managing such a hit once in 1958 and again in 1987. No wonder the Scottish Parliament needed more than one act. □

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Swinging both ways — woman golfer from *La Vie Parisienne*, 1908.

The rotation is produced in the fraction of a millisecond in which the ball is in contact with the club face. It has a profound influence on the flight of the ball because of the Magnus effect. The author explains how it can induce a lift force nearly as large as the gravitational weight of the ball.

Jorgensen explains how to match a set of clubs so that they all feel the same