Methods of Timing High-Speed Races.

By CECIL C. MASON.

IN the usual method of timing races with stop watches the errors can be divided into two main groups :

(1) Errors due to incorrect clock or watch rate, and also mechanical error due to incorrect starting and stopping or calibration.

(2) Errors due to inaccurate observation of the start or finish of the race ; including errors due to variations in the reaction times of the individual working the stop watch, that is, variation in the time between the mental observation and the mechanical response.

These errors are of different importance in short and long races. For example, in a very short race an actual error in the rate of the stop watch would cause errors quite negligible compared with many other probable errors, but, on the other hand, mechanical errors in starting and stopping the watch mechanism and in reading the dial due to inaccurate calibration are only important in short races. For short races, therefore, it is best to use a fiftieth-second stop watch, but for long races a greater over-all accuracy will often be obtained by using a fifth-second stop watch.

In an ordinary stop watch the motion is stopped by a light spring being pressed against the balance wheel ; and in motion the balance wheel in vibrating releases the escapement, and moves the hand forward one division every $\frac{1}{5}$ th second.¹ When stopped, therefore, it may be any interval of time from 0 to 0.2 sec. since the last movement of the hand : and when again released it may similarly be any interval from 0 to 0.2 sec. before the first movement occurs. On the assumption that the balance wheel on starting immediately gets into a steady state, we therefore see the true meaning of a stop watch reading $5\frac{1}{5}$ is that the interval is between 5.0 sec. and 5.4 sec., and any reading between these limits is almost equally probable. If, therefore, two observers use two different watches, and the second reads 5 sec. for this same event, neglecting other errors it is scientifically correct to assume the true interval is between 5.0 sec. and 5.2 sec. ; and so on, if several observers use several watches, the mean reading has quite possibly, if the readings mutually agree well, a real scientific accuracy exceeding $\frac{1}{5}$ second.

Calibration errors in stop watches are probably negligible apart from the centring error. However, in small cheap watches often less than $1\frac{1}{2}$ in. in diameter, where the dial is divided in 300 divisions of $\frac{1}{5}$ sec. each, the centre of the hand need only be 0.01 in. out of centre to give, in parts of the dial, an error of $\frac{1}{5}$ sec.

In the second class of error, the chief cause of observational error is due to the usual practice of observing different things at the start and finish of a race. Perhaps the observer starts his watch on

observing the flash of the pistol. This is a sudden event which cannot be anticipated, but must be closely watched for and awaited. Hence the watch is started after a delay due to the reaction time of the observer. However, in watching a runner approach a tape, the event can be exactly anticipated, and the observer can stop his watch almost exactly as the runner hits the tape. In this case there is no delay due to the reaction time of the observer. This can be proved by treating the second hand of a $\frac{1}{50}$ th sec. stop watch as the runner and stopping the watch as the hand reaches a chosen division. Therefore the correct way to time a race is to have similar signals for starting and finishing both timed by the same observer. For example, if the race is started by a pistol, then the finish should be signalled by a second pistol, fired by a practised observer watching the runner hit the tape. The timekeeper then times the interval between the pistol flashes, or stands equidistant from the two pistols and times the interval between the reports. Certainly this introduces a second observer, and so increases the chances of human error, but the method is more accurate than the usual practice, and we are left with the small observational error in firing the second pistol, and with the error due to variation in the timekeeper's reaction times in the two events. Alternatively, the timekeeper should know his mean reaction time, and when timing himself directly on starting pistol and finishing tape, he should add his mean reaction time to the watch readings. This reaction time varies from individual to individual, but is roughly constant for most individuals, and resulting errors can never be abolished so long as the timing mechanism is worked by human agency, except by multiplying the number of observers.

Several Swiss firms now make good stop watches with escapements beating fifty times a second. When testing mechanical fuses, I had an opportunity of making some hundreds of observations of my own timing errors in easy conditions for observation with $\frac{1}{50}$ sec. stop watch against a reliable mechanical record. I found my mean reaction time to be about 0.15 sec. or 0.16 sec. with a probable variation of 0.02 sec., and it could vary between 0.11 sec. and 0.20 sec. without my being in the least aware that I had been exceptionally quick or slow. When I was slower than 0.20 sec., I was usually aware that I had made a bad observation. These experiments did not distinguish between the different causes of error mentioned. The mean starting error of the watch in this case would be 0.01 sec., and the observational error as distinct from my reaction time was, I think, small and constant. I think, however, 0.02 sec. is not a large mean error to assume for the variation of reaction time in the average observer. Using a $\frac{1}{50}$ sec. watch, therefore, a single observer in the best conditions can hope for a mean probable error of 0.04 sec., or even 0.03 sec. with care and practice ;

¹ The following argument and conclusion equally apply to a complete watch, fitted with centre seconds hand with stop mechanism, since in this case the hand is worked by toothed wheels thrown in and out of gear, which can only engage in steps of a whole tooth.

but the error may easily be 0.06 sec., and in bad conditions even much greater, especially when the observation error is likely to be large.

With several observers and several $\frac{1}{50}$ sec. watches, the probable error can be reduced to 0.02 sec. or less in the best conditions. The watch errors themselves, however, soon become large if a time interval exceeding a few minutes has to be recorded, as a fast escapement is necessarily very light, and therefore a bad regulator.

Using a $\frac{1}{5}$ sec. watch, a single observer cannot time an event with a mean probable error of less than 0.1 sec., even when the observation is properly made or corrected as above indicated, and I think, taking all errors into consideration, we shall not be far wrong in saying that the probable error is nearer 0.2 sec. than 0.1 sec. and that the error may be so large as 0.3 sec. without the observer being conscious of making a bad observation, and will certainly be from 0.1 sec. to 0.2 sec. too short if improperly observed and uncorrected.

Owing to the errors necessarily associated with the use of stop watches actuated by human agency, a demand arose many years ago for more accurate methods of timing, and recording chronographs have been used for many scientific purposes. The Cambridge Instrument Co., Ltd., for at least thirty years, has made a chronograph with three pens recording on a paper strip, and this instrument has been much used in laboratories for many purposes. The pens are moved by electromagnets, so that to obtain a record an electric current must be made or broken. One pen is actuated by a 50-period tuning-fork or by a seconds clock, and the other two pens are available for recording the instants at which electric currents are made or broken. With this instrument, without any particular care, accurate records of the making and breaking of the circuits may be taken to one-hundredth of a second, and as a current lasting for only one-thousandth of a second is sufficient to give a readable record on one pen when suitably adjusted, it is clear that by running the paper fast enough, the instrument itself is capable of giving readings to 0.001 sec.

For timing motor-car races a somewhat similar instrument made by Messrs. Thomas Mercer of St. Albans is now generally used. Messrs. Mercer are chronometer makers, and they have made a very convenient portable instrument comprising a three-pen chronograph and a chronometer giving seconds contacts, and the recording strip of paper is driven by clockwork. The recording pens are actuated by means of contacts placed on the track. These contacts are in the form of strips which are normally kept apart, but are pressed into contact by the wheels of any car passing over them. The chronograph is fitted with electromagnets of the Holden type. It is clear that the duration of the contacts caused by a car at high speed is exceedingly brief, so that the electromagnets operating the pens must give a very rapid response. The armatures are actually held against the poles by permanent magnets against the action of strong springs, and the springs can be adjusted so that

they are only just insufficient to pull the armatures off the poles. The current from the track contacts then passes through electromagnets which temporarily slightly demagnetise these permanent magnets, thus releasing the armatures, so that the pens move a full distance, even for a very brief current.

The defect of the arrangement, of course, is that it necessitates the re-setting of the pens before a second record can be taken. Hence an accidental contact might throw a pen out of action just as it was required. However, with ordinary electromagnet pen control, a succession of contact strips could be used at short intervals at the start and finish of the track. This would avoid the risk of one contact failing, if an uneven track caused a wheel to jump the contact, and it would eliminate doubts as to the correct interpretation of contacts, and by giving multiple records it would increase the mean accuracy. There is a distinct risk with the Holden magnets that the start is operated by a back wheel, and the finish by a front wheel, giving an error at 200 m.p.h. of 0.03 sec. or more. With the Holden type of magnet, it is also necessary for a short race that the start and finish of the race be recorded on two separate pens. This always gives a slight risk of error if precautions are not taken to see that the pens are exactly in line. Also, as the chronograph only gives contacts every half-second, it is important that the speed of the paper be quite uniform. Care must be taken, therefore, to see that the governor acts smoothly and does not cause hunting between a lesser and a greater limit of speed.

However, with this type of instrument it should be quite easy to obtain records with an error not exceeding 0.01 sec., which should be good enough for all practical purposes. Actually the readings can be easily taken to 0.0025 sec., and with care this accuracy might be obtained, but I doubt if the chronograph contacts are really reliable to this order of accuracy. With a car moving at 200 m.p.h., this only means an error of 9 in. in the position of the car: and the tracks must be straight and accurately measured if this accuracy in time is to be of value. These Mercer chronographs were used by Sir Henry Seagrave at Daytona Beach, Florida, and also by Capt. Malcolm Campbell at Verneuk Pans.

We now come to the problem of timing speed records of an aeroplane. In this case it is clearly impossible to have the aeroplane making its own contacts at the starting and finishing points, but again, as the aeroplane must make a flying start, accuracy can be obtained by increasing the number of observations, or in effect increasing the number of starting posts and correspondingly increasing the number of finishing posts; also, the number of observers can be increased with ease, as the aeroplane is bound to be high up and, therefore, visible over a large area. Therefore with, say, two chronographs, I do not think there should be any difficulty in obtaining results accurate to one-hundredth of a second, if the starting and finishing posts can be near enough together, so that both starting

and finishing can be recorded on the same chronograph. In this case the chronograph must not be fitted with Holden electromagnets, but must be of the usual type as fitted in the Cambridge instrument. The observer will then press a contact on observing the aeroplane cross each of a series of planes which can be defined by the observer looking through a small aperture and observing when the aeroplane crosses a series of wires.

The observer should be a good distance from the course, so that the series of planes forming the starting posts may be a reasonable distance apart to enable the observer to get a series of records without being hurried, and also it is desirable that these planes, which must all meet in the vertical line through the observer, should not be at too great an angle with each other, thus introducing complications in the calculations, and even errors, if the aeroplane is far off its course. Errors, however, would be eliminated by having an equal number of observers on each side of the course and taking the means, or, if the exact track of the aeroplane is recorded, proper corrections can be calculated.

We will now consider alternatives to this method suggested by the practice of other sciences. The most obvious parallel occurs in astronomy. It is one of the commonest observations to take transit times, that is to say, the time at which a certain star crosses the meridian. It is practically the same problem as that of obtaining the time at which an aeroplane crosses a certain plane in space. If the observer can get far enough away, it is easy to follow the aeroplane in a telescope, and with a suitable mounting the telescope can be rotated in the plane containing the observer and the course of the aeroplane so as to keep cross lines in the telescope sighted on the aeroplane. If contacts are placed upon the training mechanism, the instants at which the aeroplane crosses a series of planes can be recorded without any lag or error due to the reaction time of the observer, and the error due to inaccurate following of the aeroplane can be greatly reduced by having a whole series of contacts. The observer does not know when each contact is occurring; in other words, there is nothing to flurry the observer; he can concentrate his whole attention on smoothly following the aeroplane with the lines in the telescope.

Since writing the above, I have been able to discuss the problem with Mr. R. S. Capon, who is now superintendent of scientific research at the Royal Aircraft Establishment, South Farnborough, and he tells me that he was led by exactly similar reasoning to the method which has been in use for some time on the speed course at Martlesham. With a large object like an aeroplane the telescope is unnecessary and open sights were used. To commence with, a camera free to turn about a vertical axis was used at each station as a check. Open sights on the cameras were directed by each observer on the aeroplane, and an arrangement was fitted whereby the shutter of the camera is automatically tripped when the axis of the lens is directed to the starting (or finishing) point.

Simultaneously with the tripping of the shutter a recording pen marks the moving tape of the chronograph. Seconds from a reliable chronometer are marked on the tape by a third pen. The camera supplies information as to whether the observer has kept his sights correctly on the aeroplane. In this way it has been found that the method is normally so accurate that it is now usual to dispense with the taking of photographs and to rely on correct sighting by the observers (see *Jour. Roy. Aero. Soc.*, No. 194, vol. 31, February 1927).

A different method has been used for trial flights on the high-speed course at Calshot, mainly because certain apparatus happened to be available which could be applied to this problem without additional expenditure. The method has been worked out by Mr. Garner of the Royal Aircraft Establishment. In this case electrically driven Veeder counters are being used, operated from a tuning-fork giving ten complete vibrations per second. Two counters are used, one driven from a contact on one side of the fork and the second from a contact on the opposite side of the same limb of the fork. Hence the counters move forward alternately every twentieth of a second, each counter moving every tenth second. The problem in this case is simplified, as the Schneider Cup races start and finish at the same point. At the observation post a kinematograph camera is fixed in the starting (and finishing) plane, and the figures showing in the Veeder counters can be photographed simultaneously with any aeroplane crossing the observation plane. In this way, by running the kinematograph film at a fast speed, several pictures of the aeroplane are obtained, together with the readings of the two Veeder counters. From the photographs, the position of the aeroplane at start and finish and the time interval can be worked out with ample practical accuracy. The running of the tuning-fork can be checked immediately before and immediately after any flight.

This method is really only suitable when a race finishes at the starting-point, as there would be difficulties in synchronising Veeder counters at two separate observation posts. Generally, the method is not so accurate as Mr. Capon's, but it is no doubt attractive to persons who like to see instruments reading on actual dials in preference to having to measure up records.²

As a variant on Mr. Capon's method, which avoids turning the camera, and eliminates errors due to lag in working the shutters, I would suggest fixing the camera so that its position is very accurately known, and taking a single photograph when the aeroplane is known to be in the field. Behind the plate I should put a photoelectric cell which would record instantaneously on a chrono-

² Since this was written, it seems that a slight modification has been introduced for use on the straight three-kilometre speed course at Calshot. Instead of Veeder counters outside the camera, rotating discs controlled from the tuning fork are fitted in cameras at each end of the course, both cameras being electrically connected to the same fork. Thus shadow photographs of numbers perforated in the discs are obtained in the successive kinema photographs. The method for a short course is undoubtedly very accurate, as the position of the aircraft can be worked out from the photographs with any accuracy justified by the speed of the photographs.

graph through suitable amplifiers, or photographically with a string galvanometer, the exact moment of the exposure of the plate, and from the plate itself one could calculate with sufficient accuracy the exact distance of the aeroplane from the true starting or finishing post. This, however, considerably increases the cost of the required apparatus.

Mr. Capon has also patented (see Patent No. 279,959) an alternative method which is capable of very great accuracy. In this method a camera is placed at each observation post with the lens

pointed normally to the course. A film is moved at constant speed in each camera across a narrow slot. In this way a continuous photograph is obtained of a narrow strip defining the starting (or finishing) plane. Any object crossing the plane is therefore recorded, more or less distorted, however, depending on its speed and that of the film. The films can be synchronised and marked with regular time intervals by means of sparks in spark-gaps near the slots, or by other suitable means.

Experimental Method in Psychology.¹

By F. C. BARTLETT.

THE position which psychology occupies to-day in relation to the other biological sciences, both theoretical and applied, is due directly to its adoption of experimental method. Yet if the psychologist is asked to point out any single unshakable discovery of first-rate psychological importance, based directly and wholly upon experiment, his attempts to answer the question are always regarded as unsatisfactory.

As is known, the earliest experimentalists in psychology were physicists and physiologists, most of them with a strong bent towards philosophy in their outlook. They set up a standard which in various ways has cramped and confined experimental psychology ever since. When a physicist approaches a problem in which he has to state how a stimulus affects any kind of response, he is bound to lay the burden of explanation upon the stimulus. When the physiologist approaches the same type of problem, his emphasis is equally bound to be mainly upon the response side of the relationship. This he perfectly legitimately isolates so far as possible, trying to state its characteristics in terms of the functions of the mechanism immediately concerned.

These are precisely the type of problem that the psychologist has most often attempted to carry over into his own field. Let us consider one point which grew out of the early experimental work on psychophysical methods. Fechner believed that all the content of experience, from the relatively simple sensation to the most complex reasoning content, was definitely measurable. Mainly as a result of his own observations, but aided also by the earlier work of Weber, he thought he could demonstrate this experimentally by showing that stimulus intensities and sensation intensities are related by a definite principle, the value of the unit sensation varying with the modality of stimulation. In order to establish the zero point for a sensation of given mode, and also the series of just noticeable differences piled up from this point by increase of the stimulus, he carried out a wonderful and patient series of experiments. He employed and somewhat improved Weber's method of 'limits'; he developed the method of 'mean error', but he relied mainly upon the method, already proposed by

Vierordt, of 'right and wrong' cases. This raised the problem of the doubtful judgments.

A controversy grew up which has proceeded voluminously ever since, though at the moment it seems nearly to have worn itself out. Broadly, four plans for dealing with these 'doubtful' judgments have been proposed and followed:

(a) to divide them equally between 'right' and 'wrong' cases;

(b) to ignore them;

(c) definitely to instruct the observer to 'guess' when he is uncertain and then, if doubt still persists, to lump all cases together with 'guesses of greater' and 'guesses of less' as constituting an area within which stimulus variations have no corresponding sensation differences;

(d) to prohibit the observer from being doubtful.

All these devices ignore the very points which are psychologically the most interesting and important. First they tend to treat each judgment in the series as equally and independently significant, the function of the immediate stimulus. This is certainly wrong. Secondly, no judgment of this type is the expression of a simple stimulus-response situation, but of a stimulus-attitude-response situation. To demand guesses and to prohibit doubt both alike determine an *attitude* of observation which spreads over the whole experimental situation, affecting judgments which are assigned certainty just as much as the others.

When an observer enters into an experimental situation, he brings with him propensities, tendencies, preformed organised systematic modes of response, the preformed cumulative organised effect of a mass of past discriminations. The stimulus, the situation that is presented, hits off some of these. They appear in him as an 'attitude', and it is under the active control of this that he makes his responses. Only when we know more about how this is set up and about its precise effect upon the responses made, can we safely give to the latter the necessary weighting which makes their statistical treatment genuinely significant. I think that the psychophysical methods, studied from this point of view, will yet yield some enormously important results.

If the physicist in his approach to the stimulus-reaction type of problem tends to treat the stimulus regarded objectively as the main point of interest,

¹ From the presidential address to Section J (Psychology) of the British Association, delivered at Cape Town on July 26.