Discussion

The Author introducing his Paper, referred particularly to three aspects which he thought were of particular interest to the civil engineer. He exhibited a Wild self-reducing tacheometer together with its horizontal staff, and pointed out that contrary to what was said in the Paper, that particular model of tacheometer did provide the difference in height as well as the horizontal distance between two points. That was achieved by turning the wedges through 90 degrees, thus obtaining a sine-reduction in place of the cosine-reduction. In those cases where the vertical angle was large, a reduction correction was obtained from an auxiliary scale which rotated with the telescope.

A wedge attachment which fitted on to a "one-second" theodolite and which was made by a British firm was also demonstrated, together with an instrument which had been brought to the Author's notice since writing the Paper. That was the Ewing Stadialtimeter which had been made and was in use in Australia. It was not an instrument to be compared in accuracy with the full self-reducing tacheometer, but probably would meet a need so far as engineers' reconnaissance work was concerned.

The basic principle of the Stadialtimeter was similar to the well-known Hammer-Fennel device in which the image of a diagram of curved lines at varying distances apart, indicating the correct stadia interval at different angles of elevation, was brought by optical means into the field of the eyepiece. Mr Ewing's invention was an attachment that could be made to fit either vernier or microptic theodolites and was used with a vertical staff. It consisted of two units, a drum mounted in a box attached to a convenient part of the instrument, such as the upright of the theodolite, in such a position that the second unit, an optical sight, could be attached to the telescope or trunnion axis and made to observe the drum. The sighting mark was the virtual image of an illuminated pinhole which was seen in coincidence with the surface of the drum, which contained a series of curved lines representing the solutions of the usual reduction equations. After sighting the staff the drum was rotated on its axis until the intercept line, which was figured with the value $(S \times 100)$, was observed by the optical sight. The difference of level was then indicated on the external circular scale attached to the drum. The correction to be applied to the slope distance was obtained from a second set of curved lines which ran across the intercept lines.

Field reduction of reduced levels was greatly speeded up by the fact that the circular height scale was mounted on a friction fitting so that it could be turned relative to the drum. Thus the scale could be set to the reduced level of the theodolite station and all height observations made from that station would then be given as reduced levels. The Author had received no field reports of that instrument and felt that its accuracy might be very dependent upon the stability of the material used for the drum.

With the aid of lantern slides the Author then summarized his description of the Ni 2 level and illustrated the rather particular ground-control requirements needed for large-scale surveys from air photographs.

Mr P. E. Sleight said that many civil engineers like himself, who previously had thought that they were qualified to undertake surveying work must have been surprised to see the modern surveying instruments, which were magnificent pieces of work but which would be simply "boxes of tricks" to many engineers. The details which had been given of the modern methods used in surveying emphasized the fact that the young civil engineer should have a thoroughly sound knowledge of fundamental sciences, and particularly of applied physics.

One of the principal changes in the instruments used for astronomical work seemed to be in the speed and timing of observations. That had always been a difficulty in the past. It had not been possible to look at a watch and at the instrument at the same time, and it was not always possible to have a reliable observer.

One innovation which he applauded was the Star Almanac for Land Surveyors. It was much more convenient for observation and for finding out the data required, and much more useful than the Nautical Almanac, which some engineers found very trying to read.

The accuracy obtained in precise measurement over long distances was awe-inspiring. He was particularly interested in the statement that the 1951 measurement of the Ridge Way Base showed a disagreement of 0.0066 metre with the 1937 measurement of the same Base, which was equivalent to about $\frac{1}{4}$ inch in a total length of 7 miles. That was remarkable both for the modern measurement and for the original measurement.

The standardization of tapes in terms of electrical resistance was interesting, but it would appear that the difficulties of maintaining standard accuracy with the small variations in resistance might be as great as those of measuring the temperature of the tape, to which reference was made in the Paper. It was very unfortunate that invar suffered from instability in length, because it was otherwise most attractive in use. It was to be hoped that one day metallurgists would produce a material which was equally attractive but with better characteristics.

It was impossible to avoid referring to the electronic developments used in connexion with the measurement of long distances, since the developments that had taken place in the field were quite spectacular. Specialization in that branch seemed to be essential, and he doubted whether many civil engineers would be able to appreciate those developments without further knowledge of electronics.

The accurate measurement of short distances was, however, something that the civil engineer should be informed upon, and in that field the tacheometric developments were probably the most important. The development of tacheometric instruments, as was shown by the Author, had taken place on the Continent. It was a pity that the Author had not

been able to refer to any British developments, such as had taken place some years ago, when a former Secretary of the Institution, Dr Jeffcott, introduced his self-reducing tacheometer. That instrument was not manufactured at the present time, but those who had used it in the past had found pleasure in the ingenuity of the design. Accuracies of about 1 in 5,000 were quoted in the Paper as being possible with modern instruments, whereas it had been customary in the past to think of 1 in 600 or 700 as being reasonably accurate for tacheometric measurements. The increased accuracy now possible was obtained with increased speed and with much less labour. The improvement in theodolites and levels, both optically and mechanically, had undoubtedly removed some of the spirit of adventure from surveying, and possibly the pupil engineer might regret the loss of some of his excuses for inaccurate readings.

The increasing use of aerial survey methods for map and plan reproduction, both in Great Britain and abroad, was sufficient evidence of the value of the development, and it was pleasing to note that the subject was being given a reasonable amount of space in most modern courses in surveying. Unfortunately, the equipment was not easy to use, it was very difficult to obtain, and one could not simply charter an aeroplane to undertake a little field work for students. The surveyor, however, had very good reason to thank the "Boffins" of the 1939-45 war for the continued development of those devices, which would undoubtedly increase the ease with which he could cover large distances.

In spite of all the modern developments in methods and in instruments, the civil engineer had still to carry out the usual routine tasks in his office; he had to set out straight lines, curves, right-angles, and plot levels, often with an old four-screw instrument.

Colonel M. O. Collins said that it might be of interest to mention an experiment which the Ordnance Survey had just finished, using tacheometers, and also to mention three items of development which they were pursuing.

So far as the tacheometers were concerned, the Survey had been carrying out an experiment for about a year, and they were now satisfied that they could do planimetric surveys to their standard of accuracy on the 1/1,250 scale with those instruments, provided that the control points on which the work was based were not more than 500 metres apart. The 1/1,250 scale was the largest scale on which the Ordnance Survey now worked. The results of the experiment showed that the cost of the work was slightly less when using the tacheometer, but there was very little difference, and certainly not sufficient to warrant a change-over in equipment and the re-training of personnel in a department as large as the Ordnance Survey. It had, however, been found in certain areas such as railway sidings, docks, and some factory areas, where horizontal measurement was difficult, that the tacheometer had great advantages, and it was being used for detailed survey in that special type of area. The Ordnance Survey had not

adopted the tachometer, but it was nevertheless a useful addition to the methods at present available for carrying out large-scale surveys.

With regard to the future, one of the interesting things about air survey was, as the Author had stated, how to provide the requisite control. A ground visit was expensive and added very considerably to the cost. The Ordnance Survey had therefore developed the stereocomparator method of providing control, which the Author had described. The department was satisfied that they could control their surveys on the 1/2,500 scale by stereocomparator means, and an experiment was now going on to see whether surveys on the larger scale of 1/1,250 could be controlled in the same manner. The area had been photographed and the control points selected, and the positions of those points would be obtained by normal traverse methods and also by stereocomparator; the results would be compared for accuracy and time in an attempt to analyse which was the best way of doing such a survey.

A further development which was related to the question of stereocomparator control was the application of modern machine-computing to survey problems. There were, broadly speaking, two types of digital computers, the mechanical and the electronic machines. Colonel Collins used the term "mechanical machine" to cover anything which mechanically sorted cards or added data on cards, and could even go so far as to multiply and divide. That type of machine was slow compared to the electronic machines. The work had to be inserted in a series of different stages, and the machines themselves had little or no memory.

The other type of machine was the electronic machine or, as it had been called, "the electronic brain." That worked rather faster. There were only two in Great Britain, namely the A.C.E. (Automatic Computing Engine) at the National Physical Laboratory, and the Ferranti machine at Manchester, which did work for outside interests. They had a considerable memory, and could add two 10-figure numbers together in one ten-millionth of a second. Unlike the mechanical machines, they became inefficient if they had to disgorge results half way through the computation, and that created difficulty.

The Ordnance Survey had now, with the help of the N.P.L., programmed the computation of the stereograms referred to by the Author, for computation by the A.C.E. The iterative solution of stereograms normally took a man with a desk-machine a day and a quarter; the A.C.E. solved it in 3 minutes, so that it was necessary to find a lengthy computation for the machine to do to make it worth while.

The other type of mechanization which the department was investigating was that of their level computations. That was not a problem for the A.C.E., but for the mechanical type of machine. Level computation was comparatively simple, and the main difficulty was the large volume of field data which had to be absorbed; it could be done quite satisfactorily by the punched-card type of machine.

One interesting fact which had been found in using the machines was that it was necessary to alter one's mathematics and the way in which one thought. The machine went the long way round. For many years surveyors, amongst others, had been trying to find short cuts; for example, logarithmic Tables of trigonometrical functions had been produced. The machines, however, could not refer to a Table; they had to produce the same answer from first principles, and that entailed an alteration in the method of solving a particular computation.

The Ordnance Survey were also finding that they might have to alter slightly the procedure in their field work to fit the new computation pattern. Colonel Collins mentioned that he believed that, certainly for organizations such as the Ordnance Survey, the modern machine-type of computing was going to come in a few years. The Ordnance Survey were trying to keep up-to-date so far as they could by contact with the people who were developing the machines, which at the moment were in no way completely developed.

The Ordnance Survey were also trying to develop a new levelling staff, a sectional duralumin staff of tubular construction. Colonel Collins felt that there was one point in instrument design which had arisen in that connexion which was of general interest. A high degree of precision had been achieved in dividing circles for angular measurement and in dividing steel tapes, but very largely there was a tendency to rely on the paint brush as the method of dividing staves, and that hardly gave the same degree of precision.

Mr B. F. J. Bradbeer observed that most civil engineers commenced their training with exercises in surveying, so that they might learn to appreciate an engineering problem, and that later in life they might be able to express their opinions on what should be done to improve an existing position, and do so with benefit to others. It was perhaps fortunate that many civil engineers had done some surveying, and were most likely to have studied geodesy in their college days, and therefore would be able to appreciate some of the finer points put forward by the Author.

The Paper presented to practising civil engineers a reminder and a valuable review of the latest developments, and gave them an opportunity to bring their thoughts up to date again. One aspect of the discussion which should be fruitful was that whereas they all tended nowadays to specialize more and more in their several directions, unless they came together occasionally and discussed those matters they could not learn to help each other; they could not derive the full benefit from those developments without contact and the opportunity to express their views.

The points in the Paper which chiefly attracted Mr Bradbeer were those concerned with modern methods of measurement of short distances. It was of interest from the point of view of the practising engineer to note the increasing awareness of surveyors of the difficulty of measuring on the ground in highly developed country. Moreover, on many occasions deci-

sions were demanded nowadays more rapidly than they had been in the past, and it was not possible to wait for a suitable season. It was often manifestly impossible to force a line through valuable crops, private enclosures, or dense vehicular traffic. He had seen the Ordnance Department at work in Lewes, which was noted for its traffic problems, and for some months he had scarcely seen a tape being used; almost the whole of the work had been done by tacheometric methods, or so he assumed.

In such circumstances as those of the close development to which he had referred, it seemed that optical measurement and/or survey from the air were the only methods available to the engineer and surveyor. An added advantage of those methods was that trial locations of, for example, railways, roads, or canals of some length, could be made without upsetting owners of property, who would otherwise be sensitive to the more obvious implications of a ground survey. The ground survey could cause a great deal of correspondence for no reason at all, and could give rise to a great deal of unnecessary "heart-burning" and waste of valuable time.

Mr Bradbeer had had an interesting experience at a public inquiry recently when challenged as to the authenticity of a proposed new road on the grounds that no surveyors had been seen in the district. Without disclosing too much information, he had been able to confirm that the survey had been adequately made—by air survey and tacheometric means. Several hundreds of miles of roads in Britain had been surveyed with the assistance of air survey and the value of that work would be more apparent were it not that those road schemes were unfortunately held in abeyance. Whilst some remarks had been made about the accuracy of contouring in some cases, he gathered that such discrepancies had been largely caused by the standard of ground control specified and paid for.

The Author had most opportunely emphasized that three-dimensional plotting required more detailed ground control than did planimetric work. By the modern methods described in the Paper it should be possible to specify standards of control suitable for the purpose in view, and if that was done, with liaison and proper understanding between the engineer and the air surveyor, satisfactory results should be obtained. It was comforting to read in the Paper that air survey was now recognized as an accepted branch of surveying. That was of interest to Mr Bradbeer because he had been for many years interested in photogrammetric methods, and there had been times when considerable doubts had been expressed about them.

One of the values of the photogrammetric and air photography type of survey was that the photographs which were produced for the engineer gave not only the survey, but a considerable number of features which might be of the greatest value to him in the matter of land usage, the important question of severance, and with regard to land values when projecting a line such as a road or railway or aqueduct. A trained observer could deduce a great deal with regard to the state of the ground and the soil from such photographs. They were in that respect a permanent

record, and would also be a valuable record of the state of progress of a particular and perhaps complicated project at a particular instant.

Professor E. H. Thompson said that the analytical methods of aerial triangulation which the Author had described was of interest, not only for the large-scale surveying for which they had been used in the Ordnance Survey, but also in small-scale surveying, where it was necessary to provide aerial triangulation in a country which was inaccessible or difficult of access. A great deal of interest was being shown at the present time, and developments would, he hoped, be starting soon which included the development of a new instrument, a new stereocomparator, in which the recording of the observations and, possibly, also the mean of several observations, would be automatic, and thereby provide data in a form suitable for feeding to the automatic computer. That would further quicken the process of completing the triangulation. If that were successful, he was convinced that it would be the most economic and practical way of doing aerial triangulation, because the equipment, in spite of the cost of the electronic computer, was considerably cheaper than the expense involved if the work was done entirely with an automatic plotting machine of the type shown by the Author, since the computer, though expensive, would keep a great many considerably simpler instruments busy.

Colonel Collins had referred to work for the electronic computer. The output of the stereocomparator was very suitable for the electronic computer in the sense that the bulk of the computation, or the worst part of it, was that involved in a single pair of photographs, and the work was precisely the same for every pair of photographs. It was possible, therefore, to feed to the electronic computer the work required for pairs of photographs whether from one strip or from different strips in the same block or even from different blocks. The work was the same, and by a coding system it was possible to feed the results to the electronic computer in any order, and they could be put in the right order when the work came back again. In that way the worst part of the computation could be done, in a sense, piecemeal by collecting as much work as was necessary to keep the machine busy for a certain time and not worrying whether the work actually completed a particular strip or block. That made the computation considerably more flexible.

As Mr Sleight had said, the teaching of aerial survey was now being covered to some extent in courses, but it was difficult to cover it completely owing to the difficulty of learning about the various instruments used, and so on. That had been his experience during the comparatively short time he had been at University College. A diploma course in surveying was conducted there which taught all branches and lasted one year. He had come to the conclusion that it was quite inadequate to deal with photogrammetric methods, and the introduction of a photogrammetric course was being seriously considered, which would again last one year, and in which nothing but photogrammetry would be taught. The students taking such

a course would be expected to have a knowledge of the classical methods before being admitted, particularly if they were surveyors. Courses of that nature had been conducted on the Continent for a long time. One reason why those methods were not being applied in Great Britain so energetically as perhaps they should be, might be that young men were not being fully trained in them. He himself, and, he thought, all those who knew a little about the subject, had learnt it painfully by teaching themselves, and that was to some extent still the case today.

There was one point which he would like to make about the use of tachometric methods in the Ordnance Survey. It was perhaps a little unfair, as a comparison between ground-taping methods and tachometric methods, to compare the 1/1,250 surveys of Great Britain, which were to a large extent in towns, in which the taping was over extremely good ground. When the ground was bad and a certain amount of clearing was necessary, taping became difficult, and it might well be that the difference in speed and cost would be greater than Colonel Collins had indicated.

Professor Thompson was convinced that Great Britain had lagged behind the Continent in the production of novel instruments of various types, because the civil engineers in Great Britain appeared extremely reluctant to use any kind of instrument but the most conservative. Reference had been made that evening to the four-screw instrument, and the mere fact that it had been mentioned at all showed the sort of outlook which prevailed. On the Continent, on the other hand, the civil engineer had never hesitated to use the latest instrument.

Adherence to the use of older and more conventional instruments was a very short-sighted policy, because it was in fact far more expensive to use a cheap old-fashioned instrument rather than a costly modern instrument. The Ordnance Survey before the 1939-45 war had considered the question of the various orders of triangulation, and it had proved cheaper to use a theodolite of the modern type on the lower orders of triangulation, although its accuracy was not necessary for that work, rather than to use the old-fashioned instrument. The old-fashioned instrument was considerably cheaper in capital cost but required far more time to use; and it was in the time taken and not in the capital cost of the equipment that the cost of a survey went.

He asked civil engineers, therefore, to give the modern instruments a trial and to consider that, however much higher the cost might appear than that of the customary instruments, in the long run it would pay to use them and, by giving the instrument maker a market, it would enable him to feel that he could develop unconventional instruments with a reasonable hope of being able to make a living, which up to now in Great Britain had been quite impossible. It had not been impossible on the Continent, however, where the introduction of a new instrument resulted in large sales to civil engineers.

Mr E. W. Cuthbert observed that there was too much of a gulf between the surveyor and the man at the other end of the tape. With modern methods of surveying, as well as with the classical ones, the result was dependent equally upon the man who assisted the surveyor and on the surveyor himself. Not enough attention was given to the training of chain-men. He knew of a survey which was going on in London where the progress was very slow. It had to be done at night, owing to the traffic during the day, and only old age pensioners could be found to act as chain-men; they could not stand up to the severe winter weather when most survey work seemed to be done. When a young man could be obtained, he was often not so reliable as an older one.

So far as civil engineering work was concerned, it was most important that the surveyor should be thoroughly conversant with the objects of his survey. A good deal of misdirected effort was put into finding out details and obtaining information which were not of real use in designing and setting out the work, and it was often found, when the surveyor returned to his office, that he had missed a tie-point which was important in setting out a road or railway, or had not noted services such as drains, etc. The surveyor should know exactly what he had to produce, and he should also know what degree of accuracy was expected of him. There were cases in which great effort had been devoted to producing accurate measurements of buildings which were going to be demolished within the first few weeks of the job, whereas things which were essential had not been measured accurately.

Under the heading "Linear Measurement—Long Distances" the Author had referred to the fact "that in air conditions of 85° F. a steel tape has shown an expansion appropriate to a temperature of 20° higher than the air temperature." That would represent an error of $\frac{3}{80}$ inch in 100 feet, which was probably acceptable for most civil engineering purposes. It would be interesting, however, if the Author would say a little more about the possibility of standardizing the tapes in terms of their electrical resistance where great accuracy was required.

With regard to the Bergstrand geodimeter, it would be interesting to know the effect of the atmospheric conditions on those long measurements and what sort of percentage errors resulted from local differences in temperature and pressure on a very long line. He would also like to know whether it was difficult to align mirrors on the photo-electric cell and whether they remained correctly aligned as the refraction varied over a long line. It seemed to him that there must be a considerable flickering effect, and that a relatively small mirror or photo-electric cell might lose its target.

It was startling to realize the extent to which the surveyor was dependent upon the spirit-level, a fact to which the Author had referred. Mr Cuthbert wondered how the glass tubes of spirit levels of any specified curvature were accurately manufactured. Any information which the Author could give on that subject would be of interest.

With regard to air survey, Mr Cuthbert's experience had been limited to seeing the results of one air survey on a suburban line of London Transport. He agreed that up to a scale of approximately 1/500—or, in railway terms, 40 feet to the inch—the results could be produced with sufficient accuracy for many purposes, but it must be remembered that with many surveys for railway purposes, although the actual plotting was not to a scale much greater than 40 or 20 feet to the inch, the tie-points were surveyed to a great degree of accuracy, and when the points were co-ordinated, they were relied upon in many calculations for curves and the setting out of the works generally. That could not be done by scaling the plan of a survey plotted to 40 feet to the inch; with the combined errors of the photography, the plotting, the inking-in, and scaling, the accuracy was probably of the order of 6 inches on the ground. That must be borne in mind in deciding whether an air survey would pay, when compared with the traditional type of survey with a closed traverse running along each side of the railway, which was plotted after calculating the co-ordinates of the traverse stations.

In many railway works, much of the detail could not be seen in the air photograph. Platform edges were often obscured by overhanging platform roofs, and platform structures could not be surveyed directly from the air; bridge piers and the faces of abutments were often hidden by vegetation, and a certain amount of detailed inspection on the site had to be done by the surveyors to identify signals and to obtain details of drains and so on. There were cases, therefore, where a survey from the air for railway works would not be a good proposition even on an electrified line, where direct measurements across tracks were very difficult.

On the other hand, he knew of one job on a railway where a survey from the air would have been ideal. A survey had been in hand for a proposed depot on what was largely agricultural land, and the only places where extreme accuracy was needed from the point of view of setting out were where the new depot tracks made a junction with the existing main line. The remainder of the topographical features consisted of hedge lines, country lanes, and watercourses across fields. Those could have been surveyed very well from the air, and much time would have been saved. He concluded that it was necessary to bear in mind to what use the survey was to be put before deciding whether it should be an air survey or not.

Mr T. K. Chaplin asked whether the Author could give some idea of the accuracy of radar altimeter surveys from aircraft in relation to elevations obtained from trimetrogon aerial photography, and whether there was any practical method of using radar to measure an aircraft's true elevation as well as its position, and thereby avoid dependence on altimeter observations.

He also asked whether the Zeiss Ni 2 level was sufficiently robust to be carried by a lorry over rough roads. Was any trouble caused by temperature differences within the supports of the compensator? Slight variations

of temperature might conceivably produce disproportionate effects on the angle of the compensator. When working at the extremes of the range of the compensator, did any slight error of focusing cause trouble resulting from the considerable angle of incidence of the light-rays on the cross-hairs?

Mr P. G. Mott dealing with a point raised by Mr Cuthbert on the use of air survey for large-scale plans, explained that the photogrammetrist overcame the difficulty of detail screened by station roofs and bridges, etc., by laying down markers before photography at specially selected points. Those markers showed up clearly on the air photographs and were later used by the ground parties to establish fixed lines from which the missing detail could be completed by simple offset measurements. With the aid of the markers and the large amount of detail which existed on a photogrammetric plan when it came from the plotting machine it was a comparatively simple matter for the ground surveyor to add the remainder, and such work could be carried out very rapidly.

He confirmed that, under present conditions photogrammetry could give a limiting accuracy of ± 4 to 6 inches on the ground. Greater co-ordinate precision than that could be obtained only by conventional methods of ground survey.

One point which did not appear to have been mentioned by the Author or in the discussion concerned the medium on which engineering surveys were plotted. Engineers were still inclined to adhere to the use of tracing linen and Whatman paper and the employment of cheap reproduction processes such as the so-called "true-to-scale" process, which was a complete misnomer. It often happened that the value of a survey carried out with great accuracy was completely vitiated in its subsequent use by the dimensionally unstable medium on which it was plotted and reproduced. That was quite unnecessary because there existed excellent proprietary media which had negligible distortion characteristics and, in addition, provided a better drawing surface with far greater transparency than any of the old-established materials.

It was true that a special problem arose in the case of railway plans which dealt with long sections of line involving a difficult storage problem. The present practice in that type of survey was to use rolls of Holland-backed Whatman paper, which was subject to considerable movement with changes of temperature and humidity. In the photogrammetric method that difficulty was partially offset at plotting stage by the fact that each stereogram was treated separately on four points of control, so that the error if it existed was not cumulative over a long strip. It was also customary to establish a very long line-scale after seasoning of the paper before use; it could be used to scale long distances on the plan and would expand on contact with the paper. Nevertheless, railway engineers would undoubtedly gain a better accuracy if a more stable medium could be found to meet their requirements.

Mr W. P. S. Cockle, speaking on the subject of railway surveys to large

scale, expressed the hope that those who were carrying out air surveys of that type would be able, within a few years, to provide a survey at 20 feet to the inch, which was what was really required; a 40-foot-to-the-inch survey was mainly of topographical value. Also the wisest plan was not, as had been suggested, to have a control traverse round the neighbouring streets, which was not the slightest use to the engineer and which the air-photography firms would not even bother to print on the survey which they provided, but to establish the control traverse down the railway itself. Between the important points, it was purely topographical and one worked to 40 feet to the inch, no calculations being involved; but when one came to bridges, railway stations, and junction work, one could enlarge that survey over short distances by the use of the tape to 8 feet to the inch or any larger scale desired, the whole being tied-in exactly to the aerial survey plotted at 40 feet to the inch. That had been done, and it seemed to be the only way to make an air survey of use to the civil engineer in the calculations required for alterations to existing railways.

* * **Mr T. Convey** referred to the early work of Dr B. A. Gould (in Cambridge, Massachusetts, 1875), followed by that of Professor A. A. Nicholson, J. E. Sears, and H. Barrell of the National Physical Laboratory, and others on the use of light-waves as standards of length. Later developments in that field had arisen from the investigations of Eric Bergstrand, in Norway, in the use of high-frequency light signalling, as referred to in the Paper. Could the Author indicate broadly the degree of progress which had been made in Great Britain so far.

The Author, in reply to the various questions that had not been answered during the discussion, said that Mr J. S. Clark of the Metrology Division of the N.P.L. was working on the standardization of tapes in terms of their electrical resistances and a Paper would be published in the next number of *The Empire Survey Review* (July 1953). In the meantime it could be stated that the Directorate of Colonial Surveys had borrowed the N.P.L. apparatus, which consisted of a piece of invar wire (of the same brand as the field tapes to be used) stretched on a wooden frame and connected across a Wheatstone Bridge. That piece of invar had been standardized by resistance methods at the N.P.L. and its resistance would be determined in the field at the time when the field tape was in use. It could be said that it was impracticable to determine the resistance of the field tape itself in the field satisfactorily, but a resistance thermometer made of the same material as the field tape would give a much closer result than any mercurial thermometer.

Concerning the accuracy of the geodimeter measurements, undoubtedly a very important controlling factor was the value taken for the velocity of light as compared with the true value in the atmospheric conditions at the time. That value depended upon the index of refraction for the particular

* * This contribution was submitted in writing upon the closure of the oral discussion.—SEC. I.C.E.

medium, which varied with the pressure, temperature, and, to a certain extent, the humidity of the air. Bergstrand claimed that errors of 1°C . in temperature, 3 millimetres of mercury in pressure, and 40 millimetres of mercury in humidity would each produce errors in the computed index of refraction of about 1 part in a million, and in his most recent determination of the velocity of the light he gave the m.s.e. of his value of μ as $\pm 0.000,000,2$. Provided that the atmospheric conditions were recorded as carefully as conditions would permit, and their effects allowed for, errors in velocity due to small errors in deduced refractive indices would be negligible.

The Author had seen no mention in the published accounts of difficulties in alignment caused by the effect of flickering.

Mr Cuthbert had asked for more information on the manufacture of glass tubes for precise spirit-levels. Such information was not readily available in detail in standard text books on surveying and could be best obtained by a visit to one of the instrument makers. The glass tube was first placed on a bar and that bar was then bent to the necessary curvature, after which the grinding was done with an abrasive, by a reciprocating movement along the bar and a rotation about the axis of the glass tube. For very sensitive bubbles the grinding motion was done by hand, solely by rotating about the axis and not along it. Extreme care was then taken in cleaning the tube and filtering the liquid, before the final sealing off.

The question of the accuracy of radar altimetry surveys in conjunction with trimetrogon photography had been raised by Mr Chaplin. That combination was a particular case of small-scale survey that had been used in Canada, well outside the limits of engineering survey, for which the exceptionally wide cover of the trimetrogon cameras and the rapid and approximate results of the Airborne Profile Recorder were particularly suited, namely the production of the 1/1,000,000 Aeronautical Charts with contours at 500-foot vertical interval.

The A.P.R. was used particularly in Canada and the United States for making profile surveys for transmission lines, railway and road strip maps, and for radio link surveys. The electronic part of the apparatus (a parabolic antenna, on the underside of the aircraft, projected a narrow radar beam downwards, and the time of the return of the reflected beam was recorded), which was subject to the limitations already referred to, gave the depth of the ground profile below the aircraft and the value of such a record depended entirely upon knowing the height of the aircraft. Where no ground control existed that could be correlated with the accompanying photographic strips, that datum had to be barometric, the unknown fluctuations of which directly affected the accuracy of the whole method. Advantage was taken of the known relationship * of wind velocity, wind

* If v is the component of wind along the track, the slope of the pressure surface in the direction of the track is given by $\tan \alpha = \frac{2\omega \sin \phi \times v}{g}$ where ω = angular velocity of the earth, ϕ = latitude, g = acceleration due to gravity.

direction, and the pressure contours, by recording the changes of drift angle of the aircraft, and applying a correction to the barometric datum. After such corrections had been applied and use had been made of any other control points, accuracies of ± 10 feet had been claimed in Canada.

Answers to questions dealing with the Zeiss Ni 2 level were tentative, but after a year of use in several tropical countries, no criticisms had been received on its lack of robustness or on difficulties arising from fluctuating temperatures. The wires of the compensator consisted of a magnetic non-rusting steel and all the light metals used in its construction were eloxadized.

The reply to Mr Convey's question was that work on the use of light waves as standards of length was being continued at the N.P.L. and reference had been made in the bibliography to Dr Essen's work in that connexion.