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Item Description: This is a draft manuscript of a lengthy report compiled by the RAF Bomber Command Operational Research Section, probably some time in 1945. The report was authored by Dr. Basil Dickins, a rising star in the field of physics who served as Section head during the war. Using a thematic approach it explores in excellent detail the challenges inherent in strategic bombing, making it a valuable source for both historians of air power and those studying Europe in the Second World War.

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CHAPTER 10

VISUAL BOMBING TRAINING

Introduction

Before January 1944, the O.R.S. took only a slight interest in the accuracy and use of bombsights. Data on the accuracy on practice bombing exercises were published monthly by the various Bomber Command groups in their summaries but although considerable doubt was felt as to the veracity of these figures the O.R.S. carried on no corresponding analysis. Up to this time the vast bulk of Bomber Command activity had been carried out by night and it was obvious from the magnitude of the bombing errors as assessed from night photographs that bombsight accuracy was a negligible factor in the overall accuracy of night bombing.

About the beginning of 1944 it became necessary to review this policy in view of the rather disappointing results achieved in attacks on special lightly defended targets in northern France. It should be made clear at this point that Bomber Command squadrons were almost completely equipped by this time with the Mark XIV bombsight, one notable exception being No. 617 Squadron of No. 5 Group which was fitted with the Stabilized Automatic Bombsight Mark II. On these raids the No. 617 Squadron results were generally satisfactory but the results obtained by the squadrons equipped with the Mark XIV sight were very poor, much poorer in fact than the figures quoted in the group monthly summaries for practice bombing accuracy. Moreover, the standard being achieved in practice with the Mark XIV (about 250 yards at 12-15,000 feet) was also very poor compared with the accuracy obtained in the development trials of the bombsight (120 yards at 12-15,000 feet). It was obvious therefore that the full capabilities of the Mark XIV bombsight were not being attained on operations and that there was an urgent need for the O.R.S. to investigate the discrepancy and discover its causes.

The order of the errors achieved with the bombsight on operations was known with some certainty although it was fully appreciated that part of the error was due to lack of a unique aiming point. Considerable doubt existed, however, about the practice bombing figures produced in the group monthly summaries. The precise method of analysis was not known but it was suspected that there was considerable laxity of treatment of gross errors and that poor exercises were frequently omitted altogether. A study of the published figures showed that there was a large component of wind finding error which partly explained the large difference between crew practice accuracy and development trial accuracy. It seemed, moreover, that the factor of

/wind-finding

wind-finding accuracy on operations might have a considerable bearing on the problems and it was decided to institute two parallel investigations i.e. firstly, a determination of winds used on operations against lightly defended targets and secondly, an analysis of practice bombing. Of these two investigations the second one forms the basis of the following section of the chapter.

Before a start could be made on the problem of analysing practice bombing results it was necessary to arrange for systematic returns of practice bombing results to be made by the various groups to O.R.S. Headquarters Bomber Command. An O.R.S. representative from the latter visited each of the groups in turn and discussed the layout of the returns and the data required for full analysis with the Group Bombing Leaders and the Group O.R.S. representatives. It was not possible to secure complete uniformity throughout the command because training policy at each group was the responsibility of the group Air Officer Commanding and it was inevitable that differences should occur. For example, although information on range results was available in a very convenient form in No. 5 Group, i.e. teleprinter forms direct from the range, it was always difficult to obtain adequate wind information from No. 5 Group.

Considerable progress was made on the analysis of practice results using these returns from the groups. The returns, however, showed many difficulties and revealed many faults in procedure both in the conduct and analysis of individual exercises and in the collective analysis of results on a squadron and group basis. The order of these factors given above corresponds with their relative importance and the method of approach to them by the O.R.S. will be discussed in the same order.

Conduct and Analysis of Bombing Exercises

It was found that the training instructions in force at the time were not very strictly adhered to but that they were more rigorously carried out in the Operational Training Units than in the squadrons. These instructions stated that a full practice should consist of dropping eight practice bombs from the same height and each on a different aircraft heading. The same wind, i.e. the best wind available, was to be used throughout the exercise and it was to be checked by taking a smoke puff wind during the exercise. Every effort was to be made to carry out exercises from a height greater than 10,000 feet.

Due to the varying degrees of enthusiasm for practice bombing in the groups the amount of practice bombing varied widely from group to group and from squadron to squadron. Due to the limited time available for practice caused by operational commitments and by bad weather, exercises were frequently curtailed and less than eight bombs

were dropped. It was frequently apparent that insufficient care was taken to spread out the aircraft heading on the individual bombing runs and the height of bombing was, generally, well below 10,000 feet. A most important omission, frequently apparent, was the failure to take a smoke puff wind thus making an exact analysis of the exercise impossible. There was considerable laxity in the recording of large errors on the range. Bombs which were off the range of the quadrants were often merely marked down as 'not recorded' and were not distinguishable from bombs which fell within range of the quadrants but were not recorded because of their failure to explode or for some other technical reason. The O.R.S. recommended a more rigid adherence to the training instructions for the conduct of exercises.

The primary aim of bombing analysis is to determine the cause of the bombing errors, and to recommend appropriate action for avoiding such errors. It follows, therefore, that the analysis, to be most effective, should be carried out as soon as possible after the actual exercise and that the crew of the aircraft should be on the spot to follow the analysis and assist in the interpretation of the results. It is obviously essential that the bombing leader, to supervise the analysis, must have a very sound knowledge of the bombsight and of the correct method of analysis. The existing publications covering bombing analysis did not, in the opinion of the O.R.S. , approach the problem of analysis from the best angle and it was suggested that a representation of the principles starting from the bomb-plot was required; in other words the analysis should be built up around the effects and not the causes. The O.R.S. therefore proceeded to investigate the current situation with respect to bombing analysis with the particular object of devising a general method of analysis on these lines.

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The uncertainty of the pseudo-wind vector error was stressed and the causes of the uncertainty given as the inaccuracy of the plotting of T2[1] and the unreliability of the position of the mean point of impact of eight bombs. It was suggested that the minimum pseudo-wind vector which could be considered significant was 60 yards.[2]

Owing to unreliability of the position of the M.P.I. and to the fact that certain large errors were not recorded, the O.R.S. considered that the pseudo-wind vector error could not be properly eliminated before proceeding to the next stage of the analysis.[3] It was therefore suggested that a second vector target, T3, should be obtained by vectoring out such known specific errors as:-

(a) Any error between that set on the bombsight and the correct setting based on the navigator's wind.

(b) Any error due to a known desynchronisation.

(c) The known trail of the instrument.

If all bombs were replotted about T3 and on a common heading, there would be, in general, a mean point of impact displaced from T3 demonstrating the presence of a line error, to port or starboard, and a range error, either undershoot or overshoot.[4] A simple method of performing the replotting was described and a series of tables was given which gave the possible causes of each of the possible observed results of analysis i.e. systematic line error, systematic range error, random line error and random range error.

Shortly after this paper was written the Mark XIV wind was introduced for use with the Mark XIV series of bombsights. This false wind was designed to correct the trail error mentioned above and therefore the arguments in favour of plotting T3 had to be reviewed. This step removed the greatest source of pseudo-vector error since the two remaining corrections were of infrequent occurrence, and it was therefore decided that it was practicable to rule out T3 altogether and to replot the bombs about the M.P.I. when analysing for range and line errors. When this point was settled all the suggestions and recommendations were embodied with some elaboration in a excellently produced booklet with many diagrams called 'Analysis of Bombing Errors with the Mark XIV Series of Bombsights'. This publication, issued by Training Branch, Bomber Command in July 1944, contained appendices fully explaining the Air Position Indicator method of finding a wind during bombing, the centroidal method of finding 'mean correct wind' using all available winds, diagrams of typical

(1) T2 - an imaginary point of aim associated with calculations to reduce the error to a standard basis.

(2) Bomber Cmd. O.R.S. Int.Mem. No. 13 'Assessment of Practice Bombing Accuracy. (Mark XIV Bombsight). (A.H.B./241/22/3).
(3) A.H.B./II/39/1/1 (Bomber Cmd. O.R.S. Rept. No. S.220).
(4) A.H.B./II/39/1/1 (Bomber Cmd. O.R.S. Rept. No. S.219).

plots showing typical errors (these were selected by the O.R.S. from actual bombing exercises) and several other relevant subjects. Certain of the material in the publication was provided by the Instrument Department of R.A.E., and also by the chief instructor of the Bomber Command Analysis school when it was formed. The issue of the publication served to standardise the general method of bombing analysis and to eliminate many of the undesirable practices which were in use. It also formed the basis for the courses of instruction on bombing analysis.

Whilst the O.R.S. had been engaged upon the work described above the Training Branch at Bomber Command had decided to form an Analysis School to instruct bombing leaders and others in the principles and sources of error of Mark XIV bombing. The bombing leaders' course at this Analysis School was largely built up around the Bomber Command Armament Note on Bombing Analysis.(1) The O.R.S. was in favour of establishing such a school and advanced the following suggestions as to its terms of reference.

(a) To determine the general lines along which practice bombing should be conducted throughout the Command.

(b) To design and standardise practice bombing returns by squadrons to groups and by groups to headquarters.

(c) To instruct unit bombing leaders in the principles of bombing analysis, and on the methods to be followed on squadrons.

(d) To maintain the Command's bombing accuracy records.

(e) To advise Bomber Command's Training Staff on any findings requiring policy action.

(c) and (e) were considered to be the two most important of these objects and the Bombing Analysis School was formed in July 1944 with these objects as its primary functions. It later assumed some work under heading (b) and (d) thus relieving the O.R.S. of a considerable amount of routine activity. This aspect of its work will be mentioned below under the heading of 'Collective Analysis'.

Collective Analysis

Before any improvement in the standard of accuracy of practice bombing could be attained it was essential to unify the system of bombing analysis and the method by which this was achieved has already been described. To detect the resulting improvement, however, a sound method of collective analysis was necessary and due to the smallness of the genuine trends over short periods the method chosen needed to be both accurate and sensitive. The search for such a

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(1) Bomber Cmd. Armament Training Notes, Pt.I, Bombing Serial No. 4.

method of analysis and, having decided upon one, to have it adopted by the Command was one of the major tasks of that section of the O.R.S. devoted to the study of practice bombing. Various systems were in use throughout the Command for the collective analysis of bombing results and all of them suffered from considerable sources of error particularly in respect of gross errors which were frequently left out of the analysis altogether. It was therefore impossible to compare, with any degree of confidence, average errors quoted by different groups.

As an interim measure designed to standardise the current procedure for collective analysis the O.R.S. made some recommendations on the subject in the paper on bombing analysis. Three definitions were given.(1)

> '(a) The individual crew error is the average error of all bombs dropped in an exercise converted to 20,000 feet.
>
> (b) The monthly squadron average is the average error of all bombs dropped by the squadrons during the month converted to 20,000 feet.
>
> (c) The monthly group average is the average error of all bombs dropped by the group during the month converted to 20,000 feet.'

The practice of taking the average of exercise averages to obtain squadron and group figures was condemned because of the varying number of bombs in each exercise. A standardised procedure for taking account of bombs which fell too far from the target to be measured was recommended, i.e. they were to be given an nominal error of 600 yards at 20,000 feet and included in the averaging process (at the same time the percentage of such bombs of the total number was to be kept). It was further recommended that the analysis should be undertaken at some central establishment and it was eventually undertaken as a subsidiary commitment by the Bomber Command Analysis School.

When a sufficient quantity of practice bombing results had been received by the O.R.S. a basic investigation was begun with two primary objects in view, firstly, to discover the causes of the poor accuracy achieved in the Squadrons and, secondly, to devise a sound method of collective analysis.(2) The second of these objects forms the basis of this section.

The distribution of crew errors, component errors, systematic line and range errors and component random errors over each 1000 feet height band were examined for a large number of practice exercises in which five or more bombs were dropped. It was found that the crew

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(1) Bomber Cmd. O.R.S. Int. Mem. No.17 'Analysis of Practice Bombing'. (A.H.B.2 unindexed)

(2) Bomber Cmd. O.R.S. Int. Mem. No.15 'Interim Report on the Analysis of Practice Bombing Errors with the Mark XIV Bombsight'.
(A.H.B./IIH/241/22/3).

errors within any one height band did not conform exactly to the Gaussian law of errors, there being rather more large errors than would be expected in such a distribution. It seemed therefore that the best direct parameter that could be calculated was the 50 per cent zone. At the same time it seemed that the main point of interest in this type of analysis was the density of bombs in the immediate vicinity of the target and that a parameter more directly based upon the assumption that the inner core of the bomb distribution was approximately a normal one - an assumption which was fairly well justified by later investigation was the best one to use. For each height band the number of bombs within circles of radii 100, 141, 200, 282 and 400 yards, centred on the target, were counted. From the theory of the normal distribution it was possible to obtain an estimate of the standard deviation of the distribution from the ratio of the numbers within successive circles. From the standard deviation the value of the total number of bombs comprising the normal distribution could be calculated and the excess of the observed total number of bombs over the calculated total number might be regarded as gross errors and expressed as a percentage of the total number dropped. The standard deviation could also be used to determine other parameters, e.g. 'the effective 50 per cent error' to describe the inner core of the distribution.

This idea was developed in a later unpublished paper on practice bombing errors with the Mark XIV bombsight.(1) This was a very full account of the progress of all aspects of analysis of practice bombing in the Command. At this stage, however, the development of the method of collective analysis is the only portion of this paper to be considered. The practice results for the period April to June 1944 were subdivided into groups, squadrons or heavy conversion units and into months. Height bands of 1,000 feet width were taken and the errors were classified, as before, into intervals of 100, 141, 200, 282, and 400 yards. Two parameters were quoted throughout the paper. The first, namely the overall 50 per cent error, was quite simply obtained by observation, i.e. in which interval the 50 per cent boundary occurred, and by interpolation to estimate at what point within the interval the exact limit of the 50 per cent region occurred. The second parameter, defined as the "effective 50 per cent error", was calculated on the assumption that the inner portions of of the distribution (i.e. of less than 300 yards radius) were normal. Four estimates of the 'effective 50 per cent error' were obtained

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(1) Bomber Cmd. Int. Memo. No. 14 'The Bombing Errors using the Mark XIV Vector Bombsight on practice'. (A.H.B./IIH/241/22/3).

from the four ratios of numbers of bombs corresponding to the following pairs of circles 100-141 yards, 141-200 yards, 200-282 yards and 282-400 yards. In a few cases the estimate of the 'effective 50 per cent error' from the 100-141 yards pair of circles was rather high due to a tendency of certain of the distributions (notably at 8000 feet and above) to be slightly hollow-centred. Apart from these odd cases the results obtained for the 'effective 50 per cent error' were less than the overall 50 per cent error as would be expected and yielded a positive percentage of gross errors. It was found that results obtained for small samples of bombs were most erratic and that to determine the 'effective 50 per cent error' with any confidence large samples were essential. This was achieved by a suitable widening of the height bands.

The method received one further modification of application rather than principle and that was the substitution of 'effective average error' for the 'effective 50 per cent error'. Since from the nature of the method the parameter actually obtained in the first instance is the "effective standard deviation" and since it is assumed that the core of the distribution is both circular and normal the deriviation of the 'effective average error' or the 'effective 50 per cent error' merely involves the multiplication of the standard deviation by appropriate constants. The method was described fully in an unpublished memorandum (1) in which a graph was given for converting the ratio of numbers of bombs within successive circles directly to 'effective average error'. A second graph for estimating the percentage of gross errors from the 'effective average error' was also given. A description of the method and its justification were also described in an Appendix to Bomber Command O.R.S. Report No. S.220. (2)

This method was never adopted officially in Bomber Command but when the Bomber Command Analysis School undertook the work of collective analysis they arranged all practice bombing errors in suitable height bands and in the appropriate error intervals (i.e. 100, 141, 200 yards etc.) so that the application of the method was possible with a minimum of labour. From the raw material supplied by the Analysis School the practice bombing results were subsequently analysed by the O.R.S. into 'effective average errors' and corresponding gross error percentages. From the middle of 1944 onwards this method was used by the O.R.S. for the study of inter-group and chronological variations.

Variation of Bombing Accuracy with height using the Mark XIV Bombsight

With a vector bombsight there is bound to be a deterioration of bombing accuracy with increase of height. At the same time it is necessary to compare bombing performances at different heights and to

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(1) Bomber Cmd. O.R.S. Int. Memo. No. 13 Assessment of Practice Bombing Accuracy (Mark XIV Bombsight). (A.H.B./IIH/241/22/3).
(2) A.H.B./II/30/1/1.

do this it is necessary to know the law governing the change of accuracy with height. Once the appropriate law is known the standard procedure is to convert all errors to a common height for purposes of comparison. This common height was originally 10,000 feet in Bomber Command but it was subsequently changed to 20,000 feet to facilitate the comparison of practice and operational bombing results. The height/error law used with the Mark IX bombsight and initially with the Mark XIV, was that the error was proportional to the square root of the height. This law was partly empirical and partly theoretical.

Early in 1944, shortly after the general introduction of the Mark XIV bombsight, the O.R.S. was dissatisfied with the square root law as it seemed from a study of practice bombing results that the conversion of errors from low heights seemed to lead to an underestimation of their accuracy. In May 1944 sufficient results had been analysed to make a closer study of the height/error variation possible. The overall 50 per cent error was plotted against height and attempts were made to fit the best curve, the choice lying between a parabola and a cubic. It was obvious that the accuracy at greater heights was greater than was indicated than the extrapolation of the parabola which fitted the lower results. Yet a significance test indicated that the parabola was as good a fit as the best-fitting cubic. The data on the higher height bands was scanty and so no conclusions were advanced at this stage. When the Bomber Command Armament Note on Bombing Analysis was issued a nomogram based on the original square root law was included in it. (1)

In August 1944 a similar investigation was carried out. The overall 50 per cent error was again the parameter used for the investigation. The overall 50 per cent error was plotted against height on logarithmic graph paper and the best-fitting straight line was drawn through the points. If the height/error variation is taken to be of the form

$$\frac{\text{Error1}}{\text{Error2}} = \frac{(\text{Height1})}{(\text{Height2})}^{A}$$

When A is a constant, then the slope of the best straight line is numerically equal to A. The spread of results was considerable and it was obvious that they could not yield a firmly established law yet, clearly, the variation was considerably less than would be expected with a square root law. The procedure was carried out for several groups over a period of two months and of the various indices obtained 0.36 was selected as being the most representative.

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(1) Bomber Cmd. Armament Training Notes, Pt.I, Bombing Serial No. 4.

A new height conversion nomogram was constructed on the basis of this new index and it was issued to units for general use in August 1944. The O.R.S. suggested that the variation would have to be closely studied with a view to amending the nomogram if a significantly different law were arrived at.

An investigation of the height/error variation in No. 4 Group's results for September 1944 by the method described above gave an index of 0.34 which was in quite good agreement with the previous results. On this occasion the 'effective 50 per cent error' was used to measure the variation.

In Bomber Command O.R.S. Report No. S.200 (1) a further attempt to check the accuracy of the index is described. A large sample of No. 5 Group results covering the period from July to November were used for the analysis. The results for each month were separated into 2000 feet height bands and for each band the 'effective average error' was determined. The 'effective average errors' were plotted against height on logarithmic graph paper and an index corresponding to each of the five months was obtained. They were as follows: July 0.23, August 0.31, September 0.25, October 0.34, November 0.30. The mean of these indices is 0.29 and apart from the July result the scatter about the mean is insignificant. The difference between these results and the results from the April to June sample which gave the index 0.36 was barely significant and it was not considered advisable to alter the nomogram at this stage. A suggestion was made that although the overall results between 2000 feet and 18,000 feet definitely indicated a variation less than the square root law, the variation between 12,000 feet and 20,000 feet might approximate more closely to the square root law. However, the available data were too scanty to investigate the suggestion thoroughly.

In August 1945 a scheme was devised to study the height/error variation thoroughly by means of special flights in which many of the variable factors, which may have tended to affect the validity of previous conclusions, were to be controlled. Amongst these factors the following were the most important -

(a) The same set of crews were to carry out all the necessary bombing.

(b) The division of effort with respect to height was to be made even amongst all the crews taking part.

(c) The collection of results was to be carefully supervised with a view to securing full data on all the bombs dropped.

/Windfinding

(1) A.H.B./II/39/1/1.

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Windfinding

When the O.R.S. began to take an active interest in practice bombing the two most frequently used types of winds used for bombing were the navigator's wind and the 'met' forecast wind both of which were liable to considerable random errors. The effect of these inaccurate winds was to increase the crow errors considerably and, moreover, in the case of very inaccurate winds the vector error was sufficiently great to convert an otherwise normally aimed bomb into a gross error. In addition to the necessity of a good bombing wind it is of paramount importance in bombing analysis to have a good wind for anlysis purposes. A smoke-puff wind computed by the range party with a Hill's mirror[1] was the method laid down in the instructions. For a variety of reasons, however, smoke+puff winds were frequently not available. On such occasions the important step in bombing analysis of comparing the positions of the vector target and the M.P.I. of the bombs could not be carried out. An attempt was made to increase the number of smoke+puff winds taken but the difficulty of congestion on the range was, at times, insuperable.

Eventually an improved method of obtaining an anlysis wind using the standard A.P.I. was devised and a full description of the method is given in the Bomber Command Armament Note Part IV.[2] This method was explained to the Senior Air Staff Officer of No. 5 Group by a member of O.R.S. Bomber Command and he agreed to give the method a month's trial in the group. It proved so successful that it was adopted as standard procedure in the group. Moreover, in the following month, this method was extended in No. 5 Group to find a bombing wind, a 15 minute orbit being carried out on an easily identifiable object in the vicinity of the bombing range, the A.P.I. being read at the commencement and the end of the orbit. The wind was calculated from the difference between the two readings and was used throughout the exercise. The effects of this new method of windfinding upon the overall accuracy of No. 5 Group's practice bombing figures was shown in an appendix to Bomber Command O.R.S. Report No. S.220 on the importance of windfinding.[3] Over the period concerned the mean effective average errors (converted to 20,000 feet) for the whole of No. 5 Group were as follows:- April 210 yards, May 220 yards, June 213 yards, July 170 yards and August 175 yards. This very marked improvement which was equivalent to a reduction of the windfinding error of about 7 miles per hour, was maintained in subsequent months. No. 5 Group claimed by the middle of 1945 to have reduced the windfinding error on practice bombing to an average figure of 3 miles per hour using the 15 minute A.P.I. orbit method.

(1) Hills Mirror - A device used to project an image of a smoke puff on to a table and thus enable wind to be computed from the movement of the image.

(2) Bomber Cmd. Armament Training Notes, Pt.I, Bombing Serial No.4.

(3) A.H.B./II/39/1/1.

Another example of the value of this method was obtained in an analysis of the results of No. 4 Group's September practice bombing effort. During this month the No. 44 Base Squadrons had been using the A.P.I. method of obtaining a bombing wind and the remainder of the group had been using other methods. Since, otherwise, all squadrons were bombing under similar conditions the circumstances were favourable for a test of the efficiency of the A.P.I. method. The overall 50 per cent error for No. 44 Base was 207 yards (905 bombs) compared with a figure of 267 yards (1,020 bombs) for the rest of the group. It was presumed that most of this difference was due to more accurate windfinding. The A.P.I. method of obtaining winds both for analysis and bombing later became general in those Bomber Command squadrons which possessed the necessary equipment.

In the appendix on windfinding referred to above (1) a useful method of recording bombing winds was described and recommended for use at bases. The method was illustrated by three examples of A.P.I. winds found over a certain range on three particular days. It consisted of making a distribution of the winds in time and in height, the winds being represented in magnitude and direction by vectors. Where available the Met. Ballon Sonde wind was also inserted in the distribution as a dotted line the A.P.I. winds being represented by full lines. The effect of this arrangement of the wind data was to reveal the variations of windspeed and direction with time and height. It was obvious in certain cases that a particular wind vector differed so strongly with the trend in nearby cases that the reported bombing height must have been at fault. The usefulness of this method as a check on reported bombing heights as well as a record of bombing winds was stressed.

Causes of Gross Error

From the earliest attempts to analyse practice bombing results it was obvious that the errors must be divided into two separate and distinct categories i.e. normal and gross errors. Most of the analysis was confined to the normally aimed bombs and considerable progress was made with the systematic analysis of these errors. The gross errors, which amounted to approximately 20 per cent of all bombs dropped, were not studied so carefully, mainly because of lack of data on them (e.g. frequently the distance from the target was not known). Little was known of the precise causes of gross errors but it was thought that instrumental faults were probably the principal source of such errors. In

/April 1944

(1) A.H.B./II/39/1/1 (Bomber Cmd. O.R.S. Rept. No. S.220).

April 1944 an investigation into the causes of gross errors was carried out by the O.R.S.

The Training Branch had been rather disturbed by the increase in the number of irregular releases that were occurring on practice bombing ranges and they asked the O.R.S. to investigate the causes of them. (An irregularly released bomb is one which falls outside the danger area of a bombing range). Since such incidents are liable to cause public accidents full reports on them are submitted by units to Groups and by Groups to Air Ministry and Bomber Command. These reports give the magnitude of the bombing error and the Unit Bombing Leader's explanation of its cause. The collected reports therefore formed a very good basis for investigation of the principal causes of these errors.

These irregular releases did not, of course, include all gross errors and, in fact, they constituted only a very small percentage of them. The errors analysed by the O.R.S. ranged in value from 500 yards to two and a half miles with one error of six miles, the mean height of dropping being 9,500 feet, whereas the usual boundary between normal and gross errors was in the region of 300 yards at this height. Moreover it is possible that the irregular releases did not represent even a typical sample of gross errors being confined to the larger values. However it was thought reasonable to suppose that the causes of the irregular releases would bear a fairly close resemblance to the causes of gross errors in general. It seemed, therefore, that the proposed investigation would fulfill the dual purpose of providing the Training Branch with a basis for remedial action on the subject of irregular releases and at the same time of filling a gap in our knowledge of the causes of practice bombing inaccuracy.

A total of 346 incidents which occurred in Nos. 6, 7, 91 and 92 Groups during January, February and March 1945 were analysed.(1) The causes of the incidents were divided into a number of appropriate headings and tabulated by causes, groups and months. The complete total of incidents due to each of the various causes was calculated. These totals were the most useful ones as the individual group and monthly totals were too small to yield significant conclusions although some of the more obvious inter-group comparisons were pointed out.

It was found that the two most frequent causes of irregular releases were airbomber faults (principally 'incorrect line of sight', 'failure to carry out correct levelling procedure' and, sic, 'poor bombing') and bombsight faults which together amounted to rather more than 50 per cent of the total.

Faults due directly to various members of the aircrew (i.e. pilot, navigator and airbomber) together amounted to 35 per cent of

(1) A.H.B./39/1/1 (Bomber Cmd. O.R.S. Rept. No. S.219).

35 per cent of the total. Since 10.6 per cent were due to weather and may be considered as unavoidable and 13.1 per cent were not classified it was obvious that far more gross errors than had been imagined were due to manipulative errors. In designing the new categorisation scheme for practice bombing which is described later in this chapter this fact influenced the decision to include gross errors in each exercise score.

The errors of the bombsight were broken down into smaller categories based on its separate functions and the principal source of large errors within the bombsight were found to be poor suction and faulty gyros which amounted to five per cent of the total.

The report provided a basis for action by the Training Branch in a drive to reduce the frequency of irregular releases.(1)

Operational Training Unit Bombing

By the beginning of 1945 the accuracy of bombing by fully trained crews using a vector bombsight had been thoroughly investigated by the O.R.S. Standardised methods of bombing analysis had been introduced and these had been of value in raising the quality of bombing accuracy throughout the operational groups. When the investigation into bombing accuracy was begun a number of operational training unit bombing results were received by the O.R.S. At this time operational training units were not equipped with complete Mark XIV bombsights and were bombing with sighting heads only. A superficial analysis of these results showed them to be somewhat better than current operational squadron practice figures. However, it was not thought worthwhile to carry out an extensive analysis of operational training unit bombing until the complete Mark XIV bombsight was being used by operational training unit crews.

In January 1945 an investigation into operational training unit bombing was made by the O.R.S., the bombing records of twelve crews from No. 24 Operational Training Unit, Honeybone being used as the source of bombing data.(2) Added interest was lent to the investigation by the fact that the T1 bombsight (i.e. the American version of the Mark XIV) was used by the operational training units though it was not anticipated that any conclusions concerning the bombsight would be reached on the strength of this analysis.

The method of analysis was similar to that used for the operational group results. The bombing effort was divided into height bands and into the usual error intervals, i.e. less than

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(1) A.H.B./II/39/1/1 (Bomber Cmd. O.R.S. Rept. No. S.219).
(2) Bomber Cmd. O.R.S. Int. Memo. No. 16 (Accuracy of Bombing by O.T.U. crews using the T.1 Bombsight). (A.H.B./IIH/241/22/3).

100, 141, 200, 282 and 400 yards. For each height band an effective average error and a gross error percentage were quoted. An overall converted accuracy figure of 267 yards at 20,000 feet was obtained. This was significantly worse than the current operational squadron figures and it was suggested that the difference was large due to the more accurate windfinding techniques in use on the squadrons.

The sample of bombs analysed consisted of almost exactly equal night and day figures. The accuracy achieved on night and day bombing was compared and the night accuracy was found to be significantly better than day accuracy (effective average errors at 20,000 feet were 247 yards and 278 yards respectively). No such significant differences had been observed from the results of operational squadrons. It was suggested that the illuminated target and lack of other distractions in the vicinity of the target might be the operative factors in the case of operational training unit crews. Another noteworthy result was that the gross error percentages lay between two per cent and four per cent, much lower figures than were obtained on squadrons.

In spite of the smallness of the sample of the bombs an attempt was made to measure the height/error variation by the method described in the section dealing with the height/error investigations. The index obtained was 0.22, a very low figure, indicating that for this sample of results the accuracy did not fall off so rapidly with increase of height as it did normally in the operational groups, but due to the smallness of the sample no significance could be attached to the results.

Despite these interesting differences which might have repaid further investigation no more work was done on operational training unit analysis by the O.R.S.

Crew Categorisation

In the latter half of 1944 an attempt was made by No. 5 Group and afterwards by other groups to categorise crews in terms of their practice bombing accuracy. Generally speaking the two main reasons for these attempts were:-

(a) To establish an approximate order of merit amongst crews with a view to selecting the best ones for key jobs such as marking and 'backing-up' on operations.

(b) To stimulate interest in practice bombing by providing crews with a reasonable tangible degree of improvement to aim at.

In February 1945 an instruction of the subject of crew categorisation was issued by the Training Branch of Bomber Command; the purpose of the instruction was to standarise the categorisation of crews throughout the Command and it defined the method of procedure to be adopted at the operational training unit, heavy conversion unit and operational stages.

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The method laid down was extremely simple. It consisted merely of taking the average of the crew errors on the three most recent exercises converted to 20,000 feet and categorising according to the following criteria:-

Category A — Errors up to 120 yards.

Category B — Errors between 121 yards and 200 yards.

Category C — Errors between 201 yards and 280 yards.

Category D — Errors greater than 280 yards.

At the same time the O.R.S. was asked to initiate an investigation into the working of this scheme and to assess its value. It seemed likely that it would be most difficult to estimate the usefulness of the scheme in so far as heading (b) above was concerned and that the opinion of bombing leaders and others connected with the active employment of the method would have to be accepted. Although there were some serious and fundamental objections to the method on purely theoretical grounds it was decided to carry out an investigation into the actual operation of the method in practice, and into the extent to which it answered the requirement stated under heading (a) above.

O.R.S. representatives visited Nos. 4, 5 and 7 Groups and collected a considerable quantity of data on the practice bombing history of a number of crews. This data was in the form of the results of all the practice bombing exercises carried out by the crews concerned during their careers with the Groups. The average crew error and converted crew error as calculated by the Groups was also recorded.

The first stage of the analysis was to re-compute the average crew errors and to conver these averages to 20,000 feet. A comparison of these figures as calculated by the O.R.S. with the group figures revealed some remarkable differences. It was found that nearly 20 per cent of the converted averages as obtained from the groups had errors exceeding ten yards and that there was a distinct negative bias attached to these errors (nearly 15 per cent of the errors over ten yards were negative i.e. less than the correct value).

The corrected converted averages were then grouped in threes and the averages of these sets of three (i.e. the measure used to determine category) were calculated for all the available crews. A histogram illustrating the frequency distribution of these averages of sets of three was drawn and a normal curve was fitted to the results. The following percentage frequencies of occurrence of categories was found:-

/Category A

Category A	0 - 120 yards	2.1%
Category B	120 - 200 yards	51.5%
Category C	201 - 280 yards	37.5%
Category D	Over 281 yards	8.9%

It seemed obvious that such a distribution of categories was unnecessarily coarse and, while it was probably a sound idea to have a small 'expert' class, the division of all crews into, effectively, two categories resulted in little better than an 'above and below average' classification. Further research into this method of categorisation seemed likely to be unfruitful and so the O.R.S. summarised its comments on it and devised an alternative categorisation scheme specifically designed to cover the criticism made of the original method.(1) The main criticisms were:-

(a) No account was taken of gross errors.

(b) No credit was given for chronological improvement.

(c) No account was taken of fluctuation between exercises or, in other words, no credit was given for consistency.

(d) The category boundaries were arranged in such a way that the distribution of the crews between categories was unequal and unsystematic.

(e) The percentage of serious mistakes (mistakes greater than ten yards) made by bombing analysis officers in deriving the average crew error and in converting it to 20,000 feet was nearly 20 per cent. (It should be noted, however, that this was not a criticism of the method but of its application).

The proposed new system gave to each crew a score based upon three separate factors, i.e. (1) the value of the mean radial average value per exercise (ii) the degree of fluctuation between exercises (iii) the rate of improvement. Gross errors were accounted for by giving a fixed value of 400 yards at 20,000 feet to all converted errors of over 400 yards.

Five exercises were deemed necessary for categorisation and the procedure was, briefly, as follows. Converted average radial error (Y axis) was plotted against exercise value (X axis) for the first to the fifth exercise and the regression line of average radial error on exercise value was drawn. The slope of this regression line (in yards per exercise) was taken as the factor of improvement. The average of the differences between each average radial radial errors and the values of the Y ordinate of the regression line at the corresponding points was taken at the fluctuation factor. This factor corresponded to the

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(1) A.H.B./IIH/258/5/9 (Bomber Cmd. O.R.S. Rept No. 139).

average difference between actual results and expected results the latter being taken as lying on the regression line. The mean of the five average radial errors was the third factor.

These calculations were performed on 93 sets of five successive exercises taken from the Nos. 4, 5, and 7 Group sample mentioned above and frequency distributions of improvement, fluctuation and mean factors were constructed. After a close examination of the mean and standard deviation of each of these distributions it was decided that each of the three factors must be given unit weight in the score if anomalies were to be avoided.

On this basis the scores for the 93 cases were calculated and expressed in the form of a frequency distribution. This distribution was then divided up into suitable bands for categorising the scores, the basis being that categories A and D should each comprise 1/6th of the total and Categories B and C should each have 1/3rd of the total. The resulting boundaries were:-

Category A	less than 245 yards
Category B	246 - 295 yards.
Category C	296 - 320 yards.
Category D	greater than 320 yards.

The provisional nature of this grouping and the necessity of checking it with further data were stressed.

The possible application of this method to a wider sphere of training activities was mentioned briefly in the report.(1) The new scheme received the provisional approval of Training Branch at Bomber Command in August 1945 and the report on it was published with a covering letter from them asking groups and other formations for their comments on it.

Improvement with Practice of Crews using the Mark XIV Bombsight

Although it is obvious that there is a considerable improvement in the accuracy of a crew's bombing from the operational training unit to the operational stage there was some doubt as to whether operational crews continued to improve during their careers on squadrons. An opportunity to investigate this problem arose out of the analysis of categorisation scores.(2)

A large quantity of data had been collected from groups covering the practice bombing histories of about ninety crews. These data were divided into two sets, one covering a number of crews through the heavy conversion unit stage (No. 7 Group) through to the operational stage (No. 5 Group) and the other set covering a number of No. 4 Group crews, most of whom had completed at least one

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(1) A.H.B./IIH/258/5/9 (Bomber Cmd. O.R.S. Rept. No. 139).
(2) A.H.B./II/39/1/1 (Bomber Cmd. O.R.S. Rept. No. S.225).

tour. The two sets were analysed separately and since errors from the target only were available the analysis was, of course, confined to crew errors.

All bombing errors were converted to 20,000 feet and those which were greater than 400 yards when converted were rejected as gross errors; the average of the remaining errors for each exercise was taken as the mean radial error for the exercise concerned. Then the average of all mean radial errors of all first exercises, all second exercises etc. were calculated. This gave, in effect, a series of measures of the average accuracy (i.e. overall mean radial error) achieved on successive exercises. These measures were plotted out separately for the two sets of data with overall mean radial error as the Y axis and exercise number as the X axis. A marked downward trend was noticeable in both graphs indicating systematic improvement with practice. Although such improvement cannot continue indefinitely it was thought reasonable to fit regression lines (i.e. regression of overall mean radial error on exercise number) to the data, provided that no attempt was made to extrapolate the regression lines beyond the limits of the data used. The slopes of these regression lines were regarded as measuring the systematic trend of the results and they showed improvement of five yards per exercise (over 12 exercises) for No. 4 Group crews and three yards per exercise (over 11 exercises) for Nos. 5 and 7 Group crews. The greater improvement rate for No. 4 Group crews is partly explained by the much higher initial results in the case of No. 4 Group (compare Y coordinates in each case when X = 0: No. 4 Group 221 yards and 7 Group 181 yards) which afforded them greater scope for improvement.

It was thus established that amongst operational crews practice bombing accuracy continued to improve at least up to the twelfth exercise and as few crews performed as many as twelve exercises further practice bombing was likely to be profitable. It was, unfortunately, impossible to examine the data to find out how much of the improvement was due to bombing, flying and wind-finding improvements because bomb-fall plots and wind-finding data were not available.

An investigation into the alteration of frequency of occurrence of gross errors with practice was carried out using a method similar to that described for the mean radial errors. A small decrease of gross error percentage with the practice was revealed but the result was not statistically significant.

/Practice bombing .....

Practice bombing Accuracy with the Stabilised Automatic Bombsight Mark IIA

The estimation of bombing accuracy achieved on practice with the stabilised automatic bombsight was never such a difficult problem as the assessment of Mark XIV results. The sight was in use in one squadron only, i.e. No. 617 Squadron and the quantity of practice bombing results was small and correspondingly manageable. Moreover the results were received regularly by the O.R.S. in the form of teleprinter signals direct from the bombing range. A detailed investigation was made into the practice results achieved by No. 617 Squadron during the period from March to October 1944 and the results of this investigation were published in December 1944.(1)

The total sample of bombing errors available for analysis consisted of more than a thousand bombs. These were subdivided into 2000 feet height bands and into five periods i.e. March-April, June-mid-July, mid-July-August, September and October, each of the periods containing approximately 200 bombs.

The average error for each height band and each period was calculated. In the calculation of these averages, errors over 400 yards which amounted to between two per cent and three per cent of the total, were omitted and counted as gross errors. The overall average error was about 100 yards and the mean height of dropping was approximately 12000 feet; the average error was remarkably constant throughout the eight months period. The average error achieved on practice was slightly poorer than the service trial figure of 110 yards for the height band 17,000-21,000 feet.

The variation of accuracy with height was examined and although the results up to mid-July showed no significant variation there was a significant decrease in accuracy with height during the last three months of the period.

The most important observations were made from a set of plots of bombs on line and range axes. These plots were based upon the September and October results and were for heights of 8,000, 10,000 and 12,000 feet. They revealed a very marked, significant overshoot of 33 yards at 8,000 feet, eight yards at 10,000 feet and 12 yards at 12,000 feet. There was also a small systematic port tendency which was not significant. Moreover the random errors were much greater across in line than in range, the ratio of the line to range standard deviations being 1.4.

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(1) A.H.B./II/39/1/1 (Bomber Cmd. O.R.S. Rept. No. S.190).

The following recommendations were made -

' (a) Crews should be made aware that their tracking errors are worse than their range errors and, therefore, rather more attention must be paid to them.

(b) An allowance should be made for the overshoot. An immediate approximate cure would be to use a different terminal velocity scale.

(c) In view of the uncertainties of the ballistics of practice bombs at high altitudes it is suggested that some practice is done with 250 pound general purpose bombs which have well established and good ballistics to check the presence or absence of a systematic overshoot.'

A similar analysis to that described above was again carried out in April 1945 on the data for the proceeding three months. The average error was slightly poorer than before being 113 yards for a mean height of dropping of 12,000 feet. There was again a small systematic overshoot but it was not significant and the random range and line errors were almost exactly equal.