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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 16

MISCELLANEOUS INVESTIGATIONS CONCERNING BOMBER LOSSES

The Causes of Bomber Losses

In the previous chapter the various investigations which the O.R.S. made into the tactics employed by the Bomber Force with a view to keeping losses to a minimum were described. The O.R.S's investigations into the application of radio countermeasures and other protective devices used by the bombers will be discussed in Chapter 17. In order that development might proceed on the most profitable lines it was necessary to determine the causes of bomber losses, and at frequent intervals throughout the war the O.R.S. was asked to provide estimates of the relative proportions of losses to fighters, flak etc. The subject was an extremely difficult one. The proportions in fact varied from time to time and from target to target, but sufficiently accurate figures were obtained to enable the policy on radio countermeasures etc to be formulated.

The estimates of the proportions of aircraft lost to different causes were based on a number of sources of information, such as:-

(a) the observations of returning bombers

(b) the percentage of bombers attacked

(c) the percentage of bombers hit by flak

(d) interrogation of 'escapers' and 'evaders'.

The first attempt to assess the causes of bomber losses was based on a study of the observations made by returning aircrew. The method was used continually throughout the war to keep a watch on the situation, and also provided information on the positions at which losses occurred, which was of value in investigating tactics. There is no doubt that a high proportion of losses sustained were observed by other bombers, due largely to the high tendency for bombers to catch fire when successfully engaged by the enemy. The reports had, however, to be carefully cross-checked for time and position to avoid duplication and reporting of other incidents such as 'scarecrow' flares.

Taking all targets and all weather conditions, both of which influenced the loss rate, the O.R.S. reached the view in May 1942 that our losses which represented about four per cent of sorties despatched were distributed as follows:-

25% + to enemy fighter

25% + to flak

20% to causes other than enemy action.

Further study of the problem enabled the O.R.S. to state in November 1942 that non-enemy action losses were about 10 per cent of total losses, while the remaining 90 per cent appeared to be equally divided between fighter and flak.

In early 1943 an overall review of the losses sustained during 1942 was made in an endeavour to reach a firmer assessment of the proportion of the Command's losses due to various causes. The results were given in Bomber Command O.R.S. Report No. S91 (1) and considered only attacks on German targets. It must be remembered thatlosses varied with target attacked, type of aircraft, weather conditions and experience of the crew. Further, throughout the year there was a clear tendency for losses to rise, the rise being greater in some areas than others. As a result of all the information available at the time, the O.R.S. assessed bomber losses towards the end of the period to be as follows:-

to fighter	2½%	i.e.	55%
to flak	1½%	i.e.	30%
non-enemy action	½%	i.e.	15%
	4½%		100%

It should be mentioned, however, that whereas losses to fighter rose from about 1 per cent to 2½ per cent during the year, those due to flak were thought to remain at about 1½ per cent. This demonstrates the danger in ascribing a certain proportion of losses to one cause. Except under special circumstances such as low flying attacks and very bad weather, which on a few occasions resulted in losses well above average, the O.R.S. was confident that the variation in the loss rate was largely due to the varying success achieved by the fighters, the losses due to flak remaining at about 1 to 1½ per cent.

In mid-1943, a series of Orders of the day of Fliegerkorps XII for the period December 1942 to May 1943 was captured in Sicily, and A.D.I. (Science) produced a report (Air Scientific Intelligence Report No. 21) (2) analysing the details. They assessed the proportion of our losses due to fighters over

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(1) A.H.B./II/39/1/1.
(2) A.H.B./II/77/21.

the period as being 64 per cent. On a four and a half per cent loss rate this would credit about three per cent to the fighters.

One of the methods used for determining the loss rate due to different causes was discussed in Bomber Command O.R.S. Memorandum No. M.138.(1) In this method the correlation coefficient between the numbers of aircraft missing, numbers returning damaged by flak, and numbers having had combats with fighters was determined, and the regression equation connecting the three variables found. It was concluded that about three times as many aircraft were lost due to fighters as due to flak. This result suggested that the losses attributed to fighters in Bomber Command O.R.S. Report No. S.91 were(2) probably a little low, which agreed with the conclusions reached from the captured documents.

The relatively high proportion of losses allocated by the O.R.S. to flak was challenged by some of the A.A. authorities in this country, and a number of studies were made, particularly by the Army Operational Research Group to determine the relation between the number of strikes on returning bombers and the probable losses. These studies and the success of Allied A.A. all indicated that our losses due to flak should have been lower. The general view expressed in Memorandum No. M.143 (3) denied the certainty of the conclusions reached on the grounds that no allowance was made for the cumulative effects of several strikes not on the so-called vulnerable areas and the seriousness of the fire risk. While the difference was not large, at the most a half per cent, it is probable that the O.R.S. assessment of losses to flak was on the high side. This minor discrepancy was, however, unimportant, since the correct decisions, namely to counter the enemy fighters, had been taken on the information available and a general appreciation of the position.

As time went on, two further sources of information became available to the O.R.S. namely, messages from Prisoner of War Camps as to the way in which aircraft containing the personnel in the camps had been brought down, and the experience of aircrew shot down who succeeded in returning to this country. The results of an examination of the former are given in Memorandum No. M.137.(4) Very valuable information was obtained from the latter source, and,

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(2) A.H.B./II/39/1/1.
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(4) A.H.B./IIH/241/22/3.

as described below, the interrogation of such personnel became an O.R.S. responsibility.

Information from Returned Aircrew Survivors

When returned aircrew arrived in this country they were interrogated by the Air Intelligence branch, who issued a report. These reports were very interesting to the O.R.S., and when in May 1943 the Assistant Director of Intelligence (K) found it impossible to continue the interrogation, the O.R.S. decided that it was undesirable for the information to be lost and accordingly arranged to undertake the interrogations.

The method of contacting evaders and escapers was at a Personnel Reception Centre (P.R.C.) immediately on their return. They were asked to tell the full story of the flight up to reaching the ground after the final incident, and as much detail as possible was elucidated by careful questioning. The interrogators were briefed beforehand with a list of the types of information likely to be important, and were already experienced in the general tendencies of the loss of aircraft as well as being expert in some particular subject. The story was written up in narrative form and published with a limited circulation. (These reports were known as Bomber Command O.R.S. 'K' Reports of which 282 were issued).(1) The evader was also interrogated by Military Intelligence 9 concerning his adventures on the ground, and a separate report published.

After the liberation of France, a number of damaged aircraft managed to return behind the Allied lines before being abandoned. In the previous period these aircraft would have been 'missing' and any evaders would have been interrogated. As information regarding their experiences was of value, it was eventually arranged in December 1944 that these people should be interrogated at groups by the Intelligence personnel, and the reports sent on to the O.R.S.

With the ending of the German war and the extremely rapid return of repatriated P.O.Ws, it had to be considered whether these men ought to and could be interrogated. It was decided that not to do this would entail a loss of information, potentially valuable, concerning subjects such as fires

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(1) A.H.B./IIH/241/22/2.

in aircraft, and aircrew safety arrangements etc; much of this information having a probable bearing on future aircraft development. It was desirable that this interrogation should take place before the ex-P.O.W. went on leave as their stories were likely to be more factual than after continual repetition and possibly understandable exaggeration in the home circle. The organisation at the ~~[illegible]~~ P.R.Cs with a maximum duration of stay per man of 48 hours, had already been set up without our knowledge and we were therefore constrained to fit our interrogation into the existing scheme without any increase of time. The whole question had to be dealt with in great haste as the time that elapsed between our first hearing of the P.R.Cs and their opening was only just over a fortnight. During this period an organisation has to be devised, a questionnaire drawn up and printed and this had to be fitted to the system in use at the P.R.Cs when this was learnt. Consequently, it was not possible to consult other interested parties regarding the type of information to be asked for, and it was inevitable that some questions would arise later which might have been gone into in greater detail. This, however, had to be accepted as the price for getting any information at all.

Interrogation was carried out at three P.R.Cs:-

No. 106 P.R.C. at R.A.F. Station Cosford, for all British, Allied and Colonial personnel.

No. 11 and No. 12 P.D.R.Cs at Brighton and Hove, for Australian and New Zealand personnel.

No. 3 R.C.A.F. P.R.C. at Bournemouth for all Canadian personnel.

The following method of interrogation was used. The ex-P.O.Ws were received in parties of about 30. Each man was handed a printed pro-forma containing a few questions and space for a narrative of the last flight. A short explanation was given of the reasons for the questioning, and they were told how to fill up the form. As each man completed his form, it was read through hurriedly by the interrogator and, if necessary, a few supplementary questions were asked. This was a much less satisfactory method than that used originally for evaders and escapers, but it was all that was possible in the time. In one day, over 900 individuals were put through this process at Cosford; the information from this source was therefore not of the same quality as that obtained from evaders and escapers.

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Initially, officers from the O.R.S. carried out the interrogation, but owing to shortage of staff it was immediately found necessary to make other arrangements - R.A.F. Intelligence officers being made available by Command. One Squadron Leader and five other officers were posted to Cosford, and two officers to each of Bournemouth and Brighton/Hove. O.R.S. officers were also made available when required, and at one period the interrogation staff at Cosford was as high as 14 persons.

The O.R.S. interrogation commenced on 11 April 1945, and was stopped on 22 June 1945, as it was not considered worthwhile to keep on a staff for the very reduced flow of ex-P.O.Ws. During this time over 10,000 Bomber Command aircrew ex-P.O.Ws were interviewed, the figure being approximately 96 per cent of the total in this category who had passed through the P.R.Cs.

The information given in these questionnaires was then prepared for analysis. This was done by means of the Hollerith punch card system by which a 'master' number code system was drawn up covering all the specific points of information likely to be obtained. Each story was then examined and coded in the appropriate manner, all stories relating to one aircraft being treated as one. After checking and cross-checking the numbers were then registered on a card by punching holes in appropriate spaces. By feeding these cards through a special sorting machine any desired combination of information allowed for in the coding system could be obtained.

This was a laborious job involving a staff of from 15 to 30 coders codes for approximately six months. On completion, the system would allow of the answering of specific questions provided these have been covered by the original Master Code system. Any answers produced from this source was, however, subject to bias in favour of the less serious causes of loss, as only incidents from which there was at least one survivor story were covered.

Variation of Loss Rate with Type of Aircraft

Among the many factors which influenced the overall loss rate on a given operation was the composition of the force. Bomber Command always consisted of a variety of different aircraft and from the beginning of the O.R.S's activities attention was paid to the variation in the loss rate between different types of aircraft. The different types of aircraft were nomally distributed by groups. Some groups had only one type, while other had two types. The same type of aircraft was also to be found in more than one Group.

The difference in the loss rates was of great interest to many authorities including the Air Ministry, Ministry of Aircraft Production, and the Ministry of Production. It was clearly important to determine whether the differences were statistically significant and to ascertain the reasons for the differences.

It was apparent in 1941 that the loss rate of the Whitley was greater than that of the Wellington and the Hampden. One of the major differences between these types was the engines. The engines of the Whitley were liquid cooled, while those of the Wellington and Hampden were air-cooled. Theoretically, the vulnerability of liquid-cooled engines was greater than that of air-cooled engines and this was thought to be the most likely explanation. The differences in performance and size were not considered to be important factors although exhaust visibility which was greater in the case of the Whitley and would therefore lead to easier interception by fighters could not be ignored. The theory of engine vulnerability was supported by the fact that Wellington IIs, which had liquid-cooled engines had a greater loss rate than the Wellington Is. This question of engine vulnerability was of great interest particularly in the days of twin-engined aircraft, and the matter is discussed in detail in Chapter 19. Messrs. Rolls Royce naturally became very concerned at the results, and at a later stage in the war all Merlin engines damaged by enemy action were forwarded to the firm for detailed examination to see if anything could be done to reduce their vulnerability.

In connection with this question it is of interest to record the statistics for losses over the period May to December 1941.

Liquid-cooled Engines		Air-cooled Engines	
Wellington II	3.08%	Wellington I	2.54%
Whitley	3.77%	Hampden	2.43%
Manchester	4.8%	Stirling	3.7%
Halifax	4.5%		

The number of sorties flown by the Manchester and four-engined Halifax and Stirlings to which the above statistics relate were admittedly very small but the same trend is apparent. The fact that the four-engined aircraft had higher losses than the corresponding twins was due to inexperience in operating these types. In fact, during the next few months

the Stirling loss rate became the lowest of any type and remained so for some time.

There was no doubt that the inferior flame damping arrangements on the Whitley was a contributory cause to its higher loss rate and great importance was attached to improving it. Much effort was expended by the M.A.P. on the development of better flame dampers but no great success was achieved. Incidentally, the flame dampers in the Stirlings were very good.

Once a bomber was shown to have sustained a higher loss rate than the average the obvious remedy was to discard it and cease production. This step could unfortunately not be taken without seriously affecting the intensity of the offensive and although future production could be influenced it was necessary to continue operating the inferior types.

In connection with the analysis of Whitley losses it was shown in Bomber Command O.R.S. Report No. 43 (1) that they increased relative to other types whenever the target necessitated crossing the searchlight belt, whereas against targets which did not involve crossing the belt, the losses were roughly the same as for other types. This supported the general view that an important contribution to the higher losses sustained by the Whitley was its lack of manoeuvrability.

The statistics quoted above indicated that the Manchester, which was coming along as a replacement to the Whitley, was not very promising. In the early months of 1942 no improvement on the early figures appeared, whereas the teething troubles of the Stirling were soon overcome. This was a serious matter and in Bomber Command O.R.S. Report No. 44 (2) a comparison was made of Manchester and Stirling loss rates. It was found that on nearly all groups of targets the Manchester sustained a considerably higher loss rate. Even on coastal targets in occupied territory where the loss rate was normally very small this aircraft sustained 3.8 per cent over the period September 1941 to March 1942. Such evidence/as was available indicated that the difference in loss rates of the two types was due to enemy action and therefore to the different vulnerabilities. There were two main differences; first the Manchester had only two liquid-cooled engines, whereas the Stirling had four air-cooled engines and, secondly the Manchester had two large

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(1) A.H.B./II/69/184.
(2) A.H.B./II/70/387.

petrol tanks whereas the Stirling had 14 small tanks. There was little doubt that these two important factors accounted for the difference in loss rate. The O.R.S. regarded compartmentation of the petrol tanks of great importance in connection with future types of aircraft. Clearly, the greater vulnerability of a liquid-cooled engine would be less important in the four-engined aircraft with which the Command would in future be equipped.

As the number of heavy bombers increased in the Command statistics regarding their losses become more reliable. The experience of the O.R.S. had shown, however, how dangerous it was to consider merely the monthly figures which were widely published. In order to make a proper comparison it was essential to take into account such factors as target, weather, and experience of the crews. Even so the overall statistics would indicate that a closer examination was desirable and from these it became apparent in early 1942 that all was not well with the Halifax. A comparison was made in Bomber Command O.R.S. Report No. 48 (1) between the loss rates of Stirlings and Halifaxes for the period July 1941 to June 1942. There was no doubt that the loss rate of the Halifax was about 50 per cent greater than that of the Stirling. On lightly defended targets there was no appreciable difference and it was concluded that the difference was entirely due to enemy action. It was noted that Halifaxes reported fewer combats than Stirlings, they reported fewer damaged by fighters but had about the same flak damage rate. This clearly suggested greater vulnerability to fighter attack and might well have been associated with the far greater visibility of the Halifax exhausts and its rather doubtful stability in making evasive turns.

Investigations to improve the flame damping were put in hand and consideration was given to the stability problem by the designers. As a result Halifaxes were later fitted with modified rudders. By the end of 1943 a sufficient number of sorties had been flown by Halifaxes fitted with modified rudders to enable an assessment to be attempted of its effect on the loss rate. A very searching investigation into all possible factors, however, failed to find any diminution of the loss rate due to the modification (Bomber Command O.R.S. Report No. S.114). (2) It should be recorded, however, that it was the general opinion of pilots that the modification improved the flying qualities of the aircraft.

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(1) A.H.B./II/70/328.
(2) A.H.B./II/39/1/1.

In the meantime, the losses of the Lancaster did not escape examination, for the Air Ministry had noted from the overall statistics issued by the War Room that the losses of Lancasters appeared to be approaching that of other types. There was no doubt that this aircraft which had been markedly superior in its loss rates since its introduction appeared in the spring of 1943 to have descended to the common level. The situation was examined by the O.R.S. and it was found that the trend could be partly explained by the fact that squadrons equipped with this aircraft were frequently engaged in more hazardous operations than the other types. (Bomber Command O.R.S. Report No. 69).(1)

Throughout the war it was always the case that one type of aircraft in Bomber Command had a higher loss rate than the others. For example, when the Stirling was the only heavy bomber, it had a much lower loss rate than the medium bomber, but as Halifaxes and Lancasters came along the Stirling became the Command's worst aircraft and at a later stage the Halifax was worse than the Lancaster. The Mosquito had the lowest loss rate of any, and the suggestion was made that a great expansion in the Mosquito force was desirable. The O.R.S. was not in favour of this proposal in view of the lack of room for navigational and bombing aids in the aircraft. The value of an aircraft to Bomber Command could not be judged entirely on loss rates. It was bombs on the target per casualty that really mattered, and there is little evidence of the bombing accuracy of the Mosquitos. They were, of course, essential to 'Oboe' operations and were a useful element in 'spoof' tactics. They also undoubtedly had a large nuisance value, e.g. they bombed Berlin nearly every night, but it seemed unlikely that a large force was worthwhile, particularly since to deliver the same bomb load many more aircraft and hence pilots and airfields etc. would be needed than in the case of Lancasters, even assuming the same accuracy. Further, no doubt a bigger force would attract more of the enemy's attention and certainly sustain higher losses.

It was a matter for speculation whether the lower loss rate of the Lancaster was due to the fact that the Halifax was more easily susceptible to interception and what the loss rate would have been had Bomber Command had a homogeneous force. There were a few operations on which only Lancasters were used and a comparison was made of their losses when operating alone

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(1) A.H.B./II/69/222

compared with those when they were operating in a mixed force. The results (Bomber Command O.R.S. Memo M) [1] showed that when operating alone the loss rate was increased by about 50 per cent and in fact appeared to be even higher than that of the mixed force. This was no doubt partly due to the lower level of saturation of the defences due to the small forces engaged but it seems very likely that the lower losses of the Lancasters on general operations was due partly to the presence of lower performance and more visible aircraft in the force.

Variation in Losses between Groups and Squadrons

Each group maintained its own careful watch on its loss rate and its O.R.S. representative carried out certain investigations. Among these were studies of the effect of operational experience on the loss rate which is discussed later on in this chapter. Comparisons were naturally made between the various groups although these were difficult to interpret since the types of aircraft were different. Nos. 4 and 6 Groups, however, were both equipped with Halifaxes and in an investigation made in 1943 it was clearly shown that the losses in No. 6 Group were significantly higher than those sustained by No. 4 Group (Bomber Command O.R.S. Report B.147.)[2] It was considered that this was most likely due to the lower experience of the group as a whole, since it had only been formed recently, and the lower experience of the crews. The report was sent to the Air Officer Commanding for consideration, and he requested the attachment of a member of the O.R.S. to carry out a more detailed study on the spot. (There was no resident O.R.S. representative at this group). A more detailed investigation was made and it was confirmed that the higher losses were due to inexperience and difficulties due to the formation of new squadrons and conversion to heavy bombers, which had reduced the amount of training done and instruction given within the individual squadrons. Appropriate steps were taken by the group headquarters to remedy the situation.

No. 4 Group, in their continual struggle to reduce their losses, suggested that one of the reasons that their Halifaxes sustained higher losses than the Lancaster might be because they were in the final wave of

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(1)
(2) A.H.B.(2) Unindexed.

the attack. Actually, the plan of attack usually involved both Halifax and Lancaster aircraft in the opening as well as the final phase of the attack, and it was possible to compare the losses in the different waves. It was found (Bomber Command O.R.S. Memo) (1) that the later Halifaxes had higher losses than those in the earlier wave, but in both cases they were higher than the losses sustained by the corresponding Lancaster waves. While, therefore, the position in the attack might have some effect and it was certainly worthwhile getting the Halifaxes away from the target as early as possible, the main difference in loss rate could certainly not be attributed to their allotted place in the attack.

As regards losses of individual squadrons, it was well-known that many experienced bomber crews had their own ideas on the right tactics to employ to ensure survival, and although a general tactical doctrine was taught throughout Bomber Command, such individuals naturally had an influence on the tactics adopted by individual members of their squadron. An investigation was accordingly made to determine how the actual overall losses sustained by Lancasters in Nos. 1 and 5 Groups should have been distributed if the chance of any aircraft being lost was entirely independent of the squadron to which it belonged. The results given in Bomber Command O.R.S. Memo M (2) show that while there was a slight tendency for extreme losses to be commoner and average losses to be rarer than expected by random chance, the tendency was quite insignificant. This analysis was repeated later for all squadrons in Bomber Command due allowance being made for the effect of type of aircraft, and it was found that apart from two particular squadrons, the losses were distributed as would have been expected from random chance (Bomber Command O.R.S. Memo M) (3)

The Effect on Experience on the Loss Rate

As indicated above, one of the factors affecting the loss rate was the experience of the crew and in the autumn of 1942, the O.R.S. started an investigation to determine the magnitude of this factor and to see if any change in the current policy for the employment of new crews was desirable. The need to allow crews to gain operational experience was well appreciated by the Command

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and the current policy was to send new pilots on a few operations as second pilot in an experienced crew in the first place and secondly to employ new crews on easy targets for their first few operations. It was desirable to determine the value of such experience and to check whether it was adequate to fit new crews for operations on main targets.

Attention was given first to Halifax squadrons since losses for this type were above the average. The results of the investigation given in Bomber Command O.R.S. Report No. B.116 (1) showed that the number of sorties which missing pilots carried out before becoming missing was dependent upon the number of second pilot or fresher trips they had made before becoming a captain or going on to main targets. Of those pilots who had become missing, those who had done under three second pilot or fresher trips had an average life of about two operations on main targets, but those who had done six second pilot or fresher trips had an average life of about eight operations. The investigation indicated that it was experience on flying Halifaxes which was important. As a result of this investigation, the Air Staff decided to give all Halifax pilots a series of training cross-country flights, two or three sorties as second pilots and two mining operations before sending them as captain on main targets.

An investigation on the effects of the pilot's experience on the casualty rate in No. 5 Group Lancasters (Report No. B.119) (2) was then made. It was found, contrary to the case of the Halifax, that the missing rate was independent of operational experience. It was pointed out that the missing rate of the Lancaster was at that time 2.9% and the chance of surviving 30 operations was therefore about 42%.

A further investigation into the effect of experience on No. 4 Group Halifax losses was made in 1943, in order to discover whether the position had changed since the previous investigation, but it was found that the casualty rate of pilots making their first two or three sorties in No. 4 Group Halifaxes remained high compared with that of more experienced pilots. Bomber Command O.R.S. Report No. B.160 (3) suggested that the effect could possibly be reduced by increased initial training in crews of the Halifax and by improving the handling qualities of the aircraft.

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(1) A.H.B.(2) unindexed.
(2) A.H.B.(2) unindexed.
(3) A.H.B.(2) unindexed.

Investigations by the O.R.S. representative at No. 5 Group had shown that there was a slight tendency for the loss rate to rise and then fall again during the middle of the operational tour, and the Air Officer Commanding No. 5 Group drew attention to this apparent trend for losses in No. 5 Group, and recommended refresher training in the middle of a tour. The O.R.S. was asked to investigate the matter for the Command as a whole and arranged for all Groups to render monthly returns, divided by type of aircraft, and giving for each major operation the number of sorties, early returns, crashes, attacks and combats, for each stage of crews operational experience. These returns were consolidated each month by the O.R.S. and separate notes issued for December 1943, and January and February 1944. After the March figures had been received, the returns were discontinued and a thorough analysis for all the four months was issued in Bomber Command O.R.S. Report No. S.187.(1) The investigation confirmed the higher missing rate amongst inexperienced crews and found that their crash rate, early return rate and combat rate was also high. The tendency for the loss rate to rise above the average just after the middle of the first operational tour, was also confirmed, but was not found to be so serious as had been suspected by No. 5 Group. The report stated that it was a matter of opinion how far training can be a substitute for operational experience, but that if there was any remedy for the high loss rate of inexperienced crews, it could only lie in increased and improved training. Accordingly, it was recommended that efforts should be made to increase the verisimilitude of operational training, and in particular that more long practice flights with fighter affiliation should be regularly included.

A new technique of analysis was developed for the above investigation. Each major operation was divided by operational group, type and mark of aircraft. These divisions were further sub-divided into five operational experience classes (0-5 Operations, 6-11 operations, 12-17 operations, 18-23 operations, 24-30 operations.) For each operation a separate missing rate was calculated for each division. The expected missing rate for each division was also calculated from the overall loss rate and the number of sorties flown in each experience class. If experience had no effect then this expected number would be equal to the actual number missing. The difference between these two figures thus served as

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(1) A.H.B./IIIC1/54/17(B).

a measure of the effect of experience, and by treating each operation and division separately the effect of different types of operation was largely eliminated.

Another investigation which brought out the importance of operational experience was made in response to a request from Air Ministry, to determine the maximum wastage rate a bomber force could stand during a sustained period of operations. The results were given in Bomber Command O.R.S. Memorandum No. M.44. (1) This investigation considered the cases in which types of aircraft had to be withdrawn from operations and pointed out that any rise in the casualty rate above a certain level is likely to diminish operational efficiency because of diminution produced in:-

(a) The general level of experience.

(b) The flow of operationally experienced instructors.

(c) The supply of suitable officers available as squadron and flight commanders and for specialists duties within the squadron.

The investigation showed that the permissible loss rate must be limited by the necessity of having a sufficiency of survivors at a late stage of the operational tour, and gave figures for the percentage of crews that survived a tour for a number of different average wastage rates. It concluded that a wastage rate in excess of seven per cent could not provide sufficient survivors to maintain efficiency in operations.

Aircrew Casualties directly due to Enemy Action in Bombers Returning from Night Operations

There was a feeling in the Command that personnel casualties were high and an investigation into the casualties among aircrew personnel directly due to enemy action was therefore made in February 1943 (Report No. S.77) (2) All available data was consulted, including medical officers' reports, raid reports, F.P. casualty signals and casualty forms. It was therefore possible to establish the circumstances of almost every incident. It was found that the number of casualties in returning bombers was low, and that there were, in fact, on the average 1,013 man sorties per casualty in returning bombers due to flak, and 1,150 man sorties per casualty due to fighters. The number of casualties per aircraft damaged due to flak was 0.07 and 0.05 per aircraft damaged by fighters.

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(1) A.H.B./IIH/241/22/3.
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These figures did not vary greatly between various types of aircraft. Analysis showed that the number of aircraft lost primarily due to death or severe injury to the pilot must be very small. About 20 per cent of all casualties were fatal or dangerous.

The subject of casualties amongst aircrew personnel directly due to enemy action was considered again in January 1944 when there was a widespread feeling, especially amongst the general public, that bomber crews ought to wear suits that would protect them against flak. It was felt that as the Americans were supplied with special armoured clothing, the British aircrews should be given the same protection. Analysis showed that the figures for casualties per man sorties were still low, 1,673 man sorties on the average being made for every man returning injured due to flak, and 1,309 for every man returning injured due to fighters. The casualties per aircraft damaged were more or less unchanged from the previous analysis. The investigation showed that the frequency of casualties amongst aircrew personnel was very small and had been unaltered by the removal of the main armoured bulkhead (see Chapter 19). It concluded that the use of the American type of flak jacket would only be effective in preventing one moderate or slight casualty per 100 man sorties, and that in view of its weight, with the fatigue it would produce, would be likely to do more harm than good. The paper also concluded that the American flak helmet might have prevented one head injury per 7,000 man sorties, and its use might be justified if it was not too heavy and cumbersome, if it did not produce fatigue and if the aircrew wished to use it. As a result of this investigation it was agreed that body armour should not be manufactured for aircrew personnel.

Further examination was made of the desirability of issuing crews with body armour when daylight operations started. However, it was still found that owing to the weight of the equipment, more aircrew personnel would be lost per unit weight of bombs dropped on Germany if the body armour were used than if it were not (Memorandum No. M.146) (1)

/Casualties .....

(1) A.H.B./IIH/241/22/3.

Casualties Sustained in Crashes not due to Enemy Action among Aircrew over this Country

The casualty rate of different crew positions in non-enemy accidents over this country was considered in July 1944, with particular reference to casualties amongst air gunners. It was found (Memorandum M.145)(1) that casualties among pilots and gunners were somewhat greater than those among the rest of the crew, that aircraft of different types showed similar percentages of different categories of accidents, and that casualties per accident and per crew position showed no obvious variation between aircraft types.

The Fate of Aircrew in Aircraft that became Missing

In September 1943 a letter was received from the Air Officer Commanding No. 1 Group in which it was pointed out only a very small proportion of aircrew lost on night operations succeeded in returning to this country or became Prisoners of War, and that these proportions were decreasing. Fortunately, this question had already been considered by the O.R.S. in Memorandum No. M.137,(2) 'An Examination of two Special Sources of Information on the Causes of Our Losses', and the O.R.S. was able to advise the Air Staff that it appeared that the proportion of lost Lancaster crews who were taken prisoner was rather less than for other types, and that the decline reported o f the percentage of aircrew evading capture and returning to this country was probably due to the increasing use of Lancasters in the bomber force, to the German occupation of Southern France, and to the high proportion of bomber penetrations which had recently been made deep into Germany. A very extensive analysis of the available information as to the number of P.O.W's and the number of crews that were successful in returning to this country was then made (Report No. S.122).(3) This report pointed out that the proportion of missing aircrew that survived to become P.O.W's was 11 per cent for Lancasters, 17 per cent for Stirlings and 29 per cent for Halifaxes. The low rate for Lancasters was thought to be due to the fact that it was more difficult to escape from that aircraft owing to the greater difficulty in moving about in ~~this narrow aircraft~~ the narrow fuselage, to the small

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(2) A.H.B./IIH/241/22/3.
(3) A.H.B./II/39/1/1.

crews were either picked up by the coastal shipping or were seen from land. The inescapable conclusion was reached that many more ditchings must be taking place than the Command had been aware of. In consequence of this report, a letter was sent out to all aircrew impressing upon them the urgent necessity of transmitting when they thought there was any likelihood of their being forced to ditch, and steps were taken by the signals staff to ensure greater certainty of messages sent out being received.

Bomber Manoeuvres

The manoeuvres executed by bombers, particularly in the target area and on encounters with flak or enemy aircraft en route, were of great interest in the study of bombing accuracy and the effectiveness of evasive action. Such information was also needed to enable the degree of stabilisation of H2S to be determined. The first evidence was obtained by 'N' Section of the Central Interpretation Unit who developed a technique for deducing the form of manoeuvres in the target area from a study of the night photographs taken by bombers at the time of bomb release. This technique was worked out in 1942 and was applied to a small number of sorties on various operations during 1942 and 1943. The results were fragmentary, and suffered from the serious disadvantage that, with the camera cycle normally used, information could only be obtained concerning the manoeuvres taken after bombing, whereas the most important time was of course the period immediately before bombing. In May 1943 it was therefore suggested by the O.R.S. that the camera cycle in certain aircraft, and in particular in aircraft of the Pathfinder Force should be modified in such a way as to provide information covering the period of the run-up to the target; a simple method of making the modification was also put forward. This modified camera cycle was accepted by the Command, and on 22 May 1943 each group was instructed to make the modification in all the aircraft of one of its squadrons.

The diagrams obtained by the Central Interpretation Unit from the films exposed with the modified cycle were analysed by the O.R.S. and the results

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

are given in Memorandum M. (1) They confirmed the view which the Command had taken since the spring of 1943, that the evasive action taken by bombers in the target area was of a kind which would not reduce losses due to flak and if practised on the bombing run would prevent accurate bombing.

The necessary information having been obtained, the use of the modified cycle was discontinued throughout the Command on 28 October 1943. This was due mainly to the objection which had been raised by the Air Officer Commanding No. 8 Group, who claimed that the modified cycle distracted bomb-aimers during their search for the target. He felt, however, the need for obtaining further information on aircraft manoeuvres and asked that his aircraft might be equipped with the Type M Automatic Observer which had been developed by the Royal Aircraft Establishment.

This device, which could be installed in any aircraft equipped with blind flying instruments, produced a record of the movements of the aircraft during any required period not exceeding eight minutes. The record produced by the instrument was in the form of a cinematograph film, in which frames consisting of a photograph of a complete blind flying instrument panel were taken at intervals of one second. This form of presentation was not particularly well suited to the purpose of the O.R.S. but as there was little chance of obtaining a better instrument in reasonable time, it strongly supported its introduction.

It was agreed that the first ten observers off production should be given to No. 8 Group, and carried by bombers on operations so as to provide records of aircraft manoeuvres during a period of eight minutes up to and including the moment of bomb release. The first operational sortie carrying an observer was made on 2/3 October 1943, the target being Munich. The films exposed in the Auto Observers carried by No. 8 Group, were despatched to the O.R.S. for analysis. There were also a few films taken at the Bombing Development Unit in a Halifax performing standard manoeuvres, which were intended to assist in the analysis of the operational films. Before anything could be done with the films, it was necessary for the O.R.S. to reduce the results to graphical form. The method used in producing the

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graphs is fully described in 'Bomber Command Armament Training Notes, Bombing Note No. 8', published by the Training Branch on 31 December 1944. The graphs when produced were distributed to the Royal Aircraft Establishment, No. 8 Group, and the M.A.P. The O.R.S. intended to make a full-scale analysis of the results, but unfortunately the process of making and reproducing the graphs was laborious and slow, partly owing to the inherent disadvantages of this photographic type of record and partly owing to the poor quality of a large proportion of the films. It was impossible to produce the graphical records at the place and time at which they would have been most valuable, namely on the station from which the aircraft carrying the recorder operated, and within one or two days of the time of the operation recorded. The records were therefore not of much direct assistance to the individual squadrons, and crews who carried the observers, since the graphs usually arrived too latefor any clear memories to be retained of the conditions under which the films were taken.

The Auto Observers used in heavy aircraft of No. 8 Group produced 54 readable films, which were reduced to graphical form and published, the last being taken on 17/18 June 1944. The first 35 of these records were used by the R.A.E. in order to find how far flying conditions affected the accuracy of the release point as calculated by the Mark XIV bombsight; the results of this analysis were published in March 1944 as R.A.E. Technical Note No. Inst/844.(1) A similar detailed analysis was not undertaken by the O.R.S., since it did not appear that quantitative estimates of the various quantities recorded on the graphs would be of any value to the Command. The graphs were, however, valuable to the O.R.S. in providing a general picture of the type of manoeuvres carried out by bombers in the target area, so that arguments regarding the advantages and disadvantages of evasive action could be placed against a realistic background of information. In particular, the results were used in estimating the risk of collisions between bombers in the target area, and showed that the amount of evasive action taken was such as seriously to increase this risk. In the main, the Auto Observer graphs had the effect of strengthening the case for the policy of reducing evasive action over enemy territory, which policy the Command had been trying to enforce since the spring of 1943.

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In July 1944 it was suggested by the O.R.S. that the auto observer should be used to determine the magnitude of the flying errors of Mosquitos making a controlled bombing run with Oboe. It was a matter of some importance to decide whether the inaccuracies of Oboe bombing could be attributed to flying errors, or whether some unknown source of error was involved. Accordingly, a number of observers were issued to Nos. 105 and 109 Squadrons, with a modified form of D.R. compass dial to give greater accuracy in the reading of heading. The films taken were read by O.R.S., and the readings were set out in tabular form since greater accuracy was required than could conveniently be achieved in a graphical reproduction. The tables of readings were then analysed by the O.R.S. with the assistance of the Deputy Directorate of Science (Air Ministry), and the results of the analysis were published in Report No. S.202.(1) It was shown in that report that flying errors did in fact account for a large part but not quite all of the otherwise unexplained operational bombing inaccuracies. Later on, the tables of readings produced by the O.R.S. were analysed in greater detail by the A.W.A.S., and formed the basis for A.W.A. Report No.58, (2) which dealt with the operational performance of Oboe from a more theoretical point of view. The making of Auto Observer records in Mosquitos was finally discontinued at the end of October 1944.

In July 1944 all the existing auto observers were installed in Mosquitos of No. 8 Group, and it was decided that the replacements which were in production at the R.A.E. should not begiven to No. 8 Group but should be distributed among the other groups. Each group was to receive in the first place two Auto Observers, which were to be installed in heavy bombers so as to provide a picture of target manoeuvres among the main force similar to that obtained from No. 8 Group. The main force records began in August 1944, and the films were read by the O.R.S., and the results distributed as before in the form of graphs. Up till January 1945 fifty of these graphs were issued, covering both night and day operations. The release point errors caused in the Mark XIV bombsight computor by the manoeuvres recorded in these graphs were analysed by the R.A.E., the results being published in R.A.E. Technical Note No. Inst/901. (3) The analysis

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was similar to the previous R.A.F. analysis of the No. 8 graphs, and showed that the bombing errors due to the disturbance of the bombsight by evasive action were very considerably smaller in the main force than they had been in No. 8 Group a year earlier. Apart from this work by the R.A.E. the graphs were not studied in detail, but were used by the O.R.S. to keep a current check on the nature of evasive manoeuvres in the target area.

In view of the labour involved in interpreting and reproducing the auto/observer records, and the delay caused by concentrating all this work at the O.R.S., it was decided in November 1944 that the main force groups should read their own films. An instructional note was written by O.R.S. to enable the groups to take over the work. In January and February 1945 a final 14 records were produced by the Groups under the new system, and the graphs checked by the O.R.S. The number of auto observers in service was, however, decreasing through operational wastage, and new production had been stopped because the priority of the auto observer was not high enough to justify a curtailment of production of the Stabilised Automatic Bombsight Mark IIA with which it was competing. Thus, the making of Auto Observer records gradually petered out and eventually came to a stop in March 1945. A short summary of the trend of bomber manoeuvres up to that date was written by the O.R.S. at the request of the M.A.P., in order to assist the designers of the new Navigation Bombing Computer which was then in course of development. This summary, given in Memorandum No. M. entitled 'Information from Auto Observer Records and other Sources concerning the Amount of Evasive Action taken by Heavy Bombers on Operations',(1) includes the main conclusions which the O.R.S. was able to draw from the whole series of Auto Observer graphs.

Considering that the Auto Observer was practically the only source of detailed and objective information concerning the behaviour of bombers on operations, it is regrettable that so little real use was made by the O.R.S. of the information which it provided. It may be of value to enquire why this was so, with a view to formulating future requirements for devices of a

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similar kind. The most important failings of the Auto Observer were its unsuitability for large-scale use and its lack of adaptability to varying requirements. Both these faults arose from the fact that the instrument was designed for use in a research establishment for a specified purpose, and was never intended to be a standard operational equipment. For an Automatic Observer to be used on a large-scale in operational aircraft, it was essential that the instrument reading should be recorded directly as traces on a graph, and that there should be a high degree of flexibility in choosing the speed and duration of the record and the combination of instruments to be recorded.

The Effect of Icing on Bomber Command Operations

The first main investigation undertaken by the O.R.S. into the effect of icing on Bomber Command operations was an attempt to find the effect of icing conditions on the percentage of aircraft missing. The results are given in Bomber Command O.R.S. Report No. 42 (1) which gives the percentage of sorties of aircraft of various types missing on icing and non-icing nights. The data showed that the proportions of sorties missing have been about the same when icing conditions were present or absent, except in the case of Wellington Ic's before December 1941, whose losses were much higher under icing conditions. This difference disappeared after the introduction of alcoholised fuel, in December 1941. The other types of aircraft in use in the Command had always had effective means for preventing carburettor icing, but the Wellington Ic's did not before the introduction of alcoholic fuel. It therefore appeared that the prevention of carburettor icing was very important and that this could be done by the use of alcoholised fuel. It may be mentioned that interrogation of repatriated Prisoners of War after the war showed that a large number of Wellington Ic's were, in fact, lost due to engine icing, and that few aircraft of other types were lost in this way.

The next main icing investigation carried out was an attempt to discover whether or not 'Kilfrost' de-icing paste was advantageous. This paste was in general use throughout the Command, although some discretion

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(1) A.H.B./IIK/10/46B.

was allowed to squadron commanders. The substance had, however, to be spread evenly over the aircraft and this required a large number of man-hours. The substance consisted of a paste to be applied smoothly to the edges of the wings and control surfaces, the idea being that any ice forming on the paste would break away with some of the paste before any great weight of ice had been built up. Also, the presence of soluble salts in the paste was supposed to lower the freezing point of the water impinging thereon and so reducing the incidence of ice formation. Preliminary experiments in its discontinuation showed no significant effect, so sanction was obtained for a large-scale experiment whereby half the operational force would use 'Kilfrost' on the leading edges of all wing and control surfaces, while the other half would use it on the leading edges of control surfaces only.

The preliminary results showed that there was no significant difference in the percentage of abortive sorties in the two classes, and it was therefore suggested that, since no obviously adverse effects were accruing from the use of 'Kilfrost' on the control surfaces only, and since the data available was still inadequate for a thorough test, it would be worthwhile continuing the investigation for some time. This was agreed.

After a further period it was still found difficult to draw firm conclusions, but it was felt that if 'Kilfrost' had been advantageous it would have shown a definite result. In view of the disadvantages in its use - weight penalty of 30 pounds, manpower requirement of 15 hours, difficulty of smooth application, possibility that rough application might disturb the airflow and assist ice accretion, and no apparent advantage under conditions of heavy icing - it was recommended (Bomber Command O.R.S. Memorandum No. 133, 'The use of "Kilfrost" De-icing Paste on Operational Aircraft') [1] that:-

(a) the use of 'Kilfrost' paste on the leading edges of all mainplanes be discontinued

(b) the use of 'Kilfrost' paste on the leading edges of control surfaces be continued.

In October 1943, a general report on icing was prepared covering the period October 1941 to June 1943. The basis of this work was to separate

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operational nights into those on which icing of any type was reported and those on which none was reported. Data were obtained from operational records, and special ice accretion reports concerning sorties, aircraft missing, G.C.I. activity, attacks, flak losses, reasons for abortive sorties, types of defect and types of icing, temperatures, methods of escape from icing conditions. This information was treated in a variety of ways. Owing to some doubt regarding the soundness of the original basis, i.e. the split into icing and non-icing nights and to other difficulties, this report was not issued for general circulation. The results of the investigation, which were given in Bomber Command O.R.S. Memorandum No. M.134,(1) were as follows.

(a) The abortive rate was greater on icing than on non-icing nights and this difference was somewhat greater in winter than in summer.

(b) Examination of the somewhat limited evidence available did not show that the enemy defence activity, either in night fighters or flak, had been markedly affected by icing conditions. There was also no obvious tendency for losses to either night fighters or flak to increase under icing conditions.

(c) A large number of different troubles were reported by aircrews on icing nights, but these were re-grouped wherever possible according to the most likely type of countermeasure which might have been taken. The results showed the need for improvement in the following fields:- wing icing, engine and propeller icing, lubricant and hydraulic fluid troubles due to increasing viscosity at low temperatures, pitot head icing, and windscreen icing. Wing icing was the most severe, amounting to over one third of reported cases, but lubricant and hydraulic troubles, engine and propeller icing and pitot head icing were also of some magnitude.

(d) The Lancaster was shown to be in general less affected by icing than other types of aircraft. The Stirling was more affected by wing icing, probably owing to its lower maximum height which could often render it unable to make use of climbing as a method of evading icing conditions. Halifax aircraft showed a high increase in the abortive rate on icing nights which was probably due in the main to wing icing.

(e) A consideration of the action taken by different types of aircraft when icing conditions were encountered again, showed the Lancaster to be somewhat superior to the other types.

(f) The temperatures at which various forms of icing occured were examined and a number of troubles were reported down to temperatures as low as minus 23°C.

A number of attempts were made to find the proportion of aircraft lost due to icing at various times, but except for the investigation mentioned earlier, in which it was found that a large number of Wellington Ic's were lost, very little direct evidence of losses due to this cause was found, and it was concluded that they must be very small, as otherwise such evidence

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would have been available. This question together with others relating to the effects of icing on bomber operations, was considered at an Air Ministry meeting held on 19 April 1944. At this meeting the O.R.S. stated that members of the crews of some 150 aircraft lost on bombing raids had been interviewed in connection with the investigations into the causes of losses. In no case was icing the cause of loss. There was no other evidence of losses due to icing recently, although such losses did occur up to 18 months prior to this conference, especially of Wellingtons. It was considered that the performance of the heavy bombers with engine de-icing as was then provided was such that not more than 1 per cent of all losses could be due to icing. The policy of Bomber Command was to avoid flying in icing cloud conditions, but if it became necessary for the aircraft to fly in all weathers, the icing losses would undoubtedly increase.

Various attempts were made to assess the weight of de-icing equipment that it was economic to carry in bomber aircraft, and the results of some of these investigations were given in Internal Memoranda Nos. 135 (1) and 136 (2).

(1) A.H.B./IIH/241/22/3.
(2) A.H.B./IIH/241/22/3.