CHAPTER 28

OPERATIONAL RESEARCH

AMONG the many new applications of science in the war of 1939-45 few had a more far-reaching influence on tactics than operational research. For the first time in history,[1] and at the instigation mainly of Professor Blackett,[2] the methods of scientific research were applied on a large scale to the study of the performance of new types of equipment and to the operations of war. There was no universally accepted definition for operational research, but one that met with fairly general acceptance was that put forward by Kittell, who described it as

> a scientific method of providing executive departments with a quantitative basis for decisions regarding operations under their control.[3]

In order to understand how the Australian Army and Air Force came to adopt operational research, and to appreciate the nature of its impact on their activities, it will be helpful to view these events against the background of the early history and achievements of operational research in the United Kingdom.

The story, as told by Sir Charles Goodeve, of its early close association with the Royal Air Force, not only reveals something of the nature and scope of operational research but also gives a hint why, when it came to be adopted in Australia, it should have exercised a greater influence on the air force than on either the army or the navy.

> Operational research was really born out of the Battle of Britain. As is well known, we had in 1940 few fighter aircraft compared with the number that would have been required to defend our shores against an air invader. We had very good fighter pilots and very good aircraft, but, with the equipment and methods used prior to 1940 it would have been impossible to obtain sufficient interceptions to defend our shores. The most important new feature that came in was, of course, radar. This equipment by giving ample warning, permitted the retention of aircraft on the ground until needed and then by plotting the positions of the enemy and defending aircraft, enabled a "ground control" to direct the aircraft to a position where the enemy could be sighted visually. The planning of this sequence of operations involved careful analysis of training and operational experiences and involved a full analysis of the technical possibilities of the equipment. But the process of combining these factors required mathematical calculations beyond the experience of the ordinary commanding officer. Accordingly a small party of half a dozen scientists was attached to Fighter Command to study and refine the deployment and the operational orders. These scientists learned to estimate which were the bad targets and which were the good, and to determine where and how our limited effort could best be expended. Their analyses formed the basis for the operation of the whole defence organisation of Britain. It is estimated that radar itself increased the possibility of interception by a factor of about ten; but that, in addition, this small operational research team increased the probability

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[1] Operational research was foreshadowed by F. W. Lanchester in *Aircraft in Warfare, the Dawn of the Fourth Arm* (1916).

[2] P. M. S. Blackett, FRS, MA, DSc. (Served RN in first world war.) Prof of Physics, Univ of Manchester, 1937-53, Imperial Coll of Science and Tech, London, since 1953. B. 18 Nov 1897.

[3] C. Kittell, *Science*, Vol. 151 (1947), p. 2719.

by a further factor of two, which together meant that the Air Force was made twenty times more powerful. The operational research contribution, a doubling, was out of all proportion to the amount of effort spent on the research.[4]

It would have been surprising indeed if knowledge of so rewarding an application of science had not spread to other members of the British Commonwealth and to the United States. Fortunately there was sufficiently close liaison between these countries and frequent interchange of scientists to permit the rapid diffusion of techniques such as operational research.

Two operational research groups were set up within the Australian Army, independently of one another and about the same time. While the initiating steps appear to have been taken more or less simultaneously, the first to begin work was the group sponsored by the Major-General Royal Artillery, Major-General J. S. Whitelaw. Attached, supposedly temporarily, to the M.G.R.A. Branch, the Army Operational Research Group under the leadership of Dr D. F. Martyn began its activities on 1st June 1942. The subsequent activities and influence of this group were, like those of the second group, determined to a large extent by their place in the military organisation.

It was essential for the success of an operational research team that it should be composed of men with a natural bent for such work and led by a scientist of really high calibre. In Britain, where the first valuable results came from the application of operational research to tactics and strategy, scientists worked in close contact with top executives and were in the confidence of commanders. They attended conferences at which orders were given, and had access to intelligence reports. Having no executive responsibilities the scientists were free to examine and analyse military operations dispassionately and critically, much as they were in the habit of examining problems in the laboratory.

Martyn had urged that his group should be attached to MacArthur's Headquarters so that it could function at the highest tactical and strategic level, but since the Americans had scientists of their own interested in work of this kind, nothing ever came of this suggestion. When, as will be described later, the second army operational research group was formed, some definition of their respective fields of work became essential. The result was that Martyn's group was restricted to weapon research in general and to radar in particular. This in itself was not necessarily a bad thing, and is mentioned here simply to explain the restricted nature of the program undertaken by the group, much of which could hardly be regarded as falling within the compass of operational research.

The new and complex technical equipment then coming into use by the army offered plenty of scope for weapon research. If, under the generally favourable circumstances that exist in a laboratory, it takes considerable time to get complex scientific equipment working efficiently, as it often does, it can be appreciated that in the field of battle, where the unexpected is always happening, radar equipment, for instance, would require

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[4] Sir Charles Goodeve, "Operations Research", *Nature*, Vol. 161 (1948), p. 377.

even more study. The presence of scientists in Darwin during February 1942, when Australian radar was first used against the enemy, made all the difference between success and failure in the use of the equipment.

By recruiting science graduates with honours in physics and mathematics, the Army Operational Research Group was gradually enlarged to fourteen members, most of whom retained their civilian status.[5] There seem to be several schools of thought about the necessity of this; those urging the wisdom of retaining civilian status do so in the belief that only in this way can the scientist talk freely to military commanders and chiefs of staff. Those maintaining the contrary view hold that close collaboration between commanders and scientists is not necessarily jeopardised by putting the scientist into uniform.

Martyn made no attempt to recruit men with engineering experience since the group was not to be concerned with design and maintenance but with the scientific principles involved in the efficient operational use of radar equipment. It was to concentrate on those irregularities in performance of new equipment which were outside the control of the design and maintenance staff. Members of the group who were posted to operational areas advised local commanders on the best tactical use of radar equipment and the best method of using information obtained from it. Operational scientists gave special attention to its general effectiveness rather than to its technical efficiency and freedom from breakdown, and also to the problem of eliminating interference between various types of radar equipment and communication services. In New Guinea, for example, it was found that English G.L. Mark II equipment caused serious interference with radio communication services up to a radius of about half a mile, a problem which apparently did not arise in England, where different communication techniques were employed. The Operational Research Group found the nature of the interference and developed a satisfactory remedy for it.

Had equipment remained static in principle and design it is reasonable to assume that the work of this group would have been completed in a relatively short time. As it was, there were changes not only in the equipment used by the Australian Army but also in that used by the enemy, with the result that there was a steady supply of problems. Among the most interesting were those caused by the phenomenon known as superrefraction.[6]

Spurious echoes often giving rise to false alarms were observed at almost every radar station in Australia. Once the origin of these anomalous echoes was understood it was possible to train operators to recognise them and thus avoid giving false alarms. These echoes were eventually traced to an abnormality in the propagation of radio waves which was caused

[5] Some members of the group who later visited operational areas did so in uniform. There they made contact with actual operational problems affecting all three Services.

[6] Whether this work on superrefraction can be called operational research is hardly a matter of debate. Most authorities would agree that it is not. The fact is that the vagaries of radar equipment arising from this cause formed the subject of much investigation by Martyn's group. Some reference, it is felt, should be made to this work if only to show what happens to an operational research group when it is not related to military commands as it should be.

by superrefraction. In a homogeneous medium, radio waves, like light, travel in perfectly straight lines, but on passing from one medium to another both radio and light waves undergo a bending, or refraction. Since, under normal conditions, the lower layers of the atmosphere are physically and optically denser than the upper layers, radio waves undergo a slight bending towards the earth, but nothing like enough to cause them to follow the earth's curvature for any appreciable distance.

Because it is optically much denser than dry air, water vapour in the atmosphere greatly influences the behaviour of radio waves. The presence of unusually large amounts of water vapour in the lower parts of the earth's atmosphere causes a correspondingly large refraction or bending of radio waves. This is known as superrefraction. It so interested Martyn that towards the end of the war its study became one of the main preoccupations of his group.

Superrefraction did not always produce spurious echoes; sometimes echoes were absent under conditions when they were expected. Theoretical considerations showed that when there were marked discontinuities in the humidity gradient of the atmosphere, high-frequency radio waves could be refracted in such a way as to produce "blind" zones in which a high-flying aircraft might be undetectable.[7] It was difficult to prove the existence of such blind zones with certainty since there were many other reasons, including the human factor, why aircraft should remain undetected in apparently favourable circumstances. The existence of blind zones was the probable explanation of the disappearance from radar view of the Japanese reconnaissance aircraft that flew over Sydney on the night of 4th April 1943. A Hudson which was searching for the aircraft was also intermittently lost to radar view.

While the diminution in range of a radar set for detecting *high-flying* aircraft owing to refraction effects could not at that time be so readily demonstrated, the extraordinary increase of range on low-lying objects arising from the same phenomenon was well established. Many abnormal echoes observed on radar screens were caused by reflection from objects such as hills or islands normally below the radar horizon, while a set whose normal range for the detection of a ship was only 20 miles, might suddenly be able to detect ships at a distance of 200 miles.

Superrefraction arises over sea or land when a mass of relatively cool and damp air underlies warm dry air, a condition which often occurs on the coast of north-west Australia.[8] Here the dry hot wind from the desert blows out over the sea and only the lowest layer becomes moist and cooled. The phenomenon is so strongly developed off Darwin that several times a month air warning sets (1.5 metres) operating there reported echoes from the coast of Timor, 300 to 500 miles away. Users of similar equipment near Broome, Western Australia, observed echoes from the coast of Java, 900 to 1,100 miles away. In February 1944 a high-flying Catalina was followed almost continually for a distance of

[7] This phenomenon finds a parallel in the total internal reflection of light.

[8] F. J. Kerr and J. K. Strachan, Radiophysics Laboratory Report RP 259/1, Aug 1945.

800 miles on its journey from Perth to Colombo by the air warning station at Geraldton.

A useful contribution to the knowledge of superrefraction was made by the R.A.A.F. and army stations round the coast of Australia and New Guinea when, following the suggestion of the operational research scientists, they made daily observations on the phenomenon as part of their regular duty. As with some of the data of meteorology, such widespread regular observations could hardly have been made in peace time owing to the prohibitive cost of maintaining so many stations at isolated points. The observations and their interpretation by radiophysicists were duly published and in this way became a useful by-product of wartime activities.[9]

The second army operational research group originated from an offer made by the War Office in London to the Chief of the Australian General Staff (General Northcott[1]) to send out a team of experts who had undergone special courses of instruction with the British Army Operational Research Group. Having obtained the approval of General Blamey, Northcott gratefully accepted the offer. The team, which reached Australia in July 1943, comprised Lieut-Colonel P. A. E. Jump, R.A., Major J. L. McCowen, R.E.M.E., and Captain G. G. Vickers, R.E.M.E. Northcott was advised that each member had specialised in a different field of military activity and that the best results would most likely be obtained by using them as a team.

The team's duties, as set out in an early memorandum, revealed a bias towards weapon study. They were (i) to collect factual and scientific data on the performance and tactical handling of equipment under operational conditions; (ii) to collate these data in order to provide scientifically based evidence to assist in the guidance of General Staff policy; (iii) to investigate the suitability of new equipment and tactics under development; (iv) to explore the need for new or modified types of equipment and to suggest basic specifications for such equipment.[2] Operational research had, of course, much wider application to military affairs than this list might suggest: it was applicable to problems of organisation, maintenance and training and to tactical studies in general. It was originally intended that the team should be attached to the General Staff, but after some top-level discussions it was finally placed within the Branch of the Master-General

[9] F. J. Kerr, "Radio Super-refraction in the Coastal Regions of Australia", *Aust Journal of Scientific Research,* Series A, Vol. 1 (1948), p. 433.

[1] Lt-Gen Sir John Northcott, KCMG, KCVO, CB. (Served 1st AIF.) GOC 1 Armd Div 1941-42; CGS AMF 1942-45; C-in-C BCOF Japan 1945-46. Governor of NSW since 1946. Regular soldier; b. Creswick, Vic, 24 Mar 1890.

[2] "The primary function of an operational research section is to obtain factual evidence in forward areas on both tactical and technical value of weapons and equipment. This evidence is obtained by:

(i) the collection and critical analysis of facts and quantitative data of military problems as opportunity offers and by critical appreciation of the effectiveness of new or modified weapons before or after they reach the user;

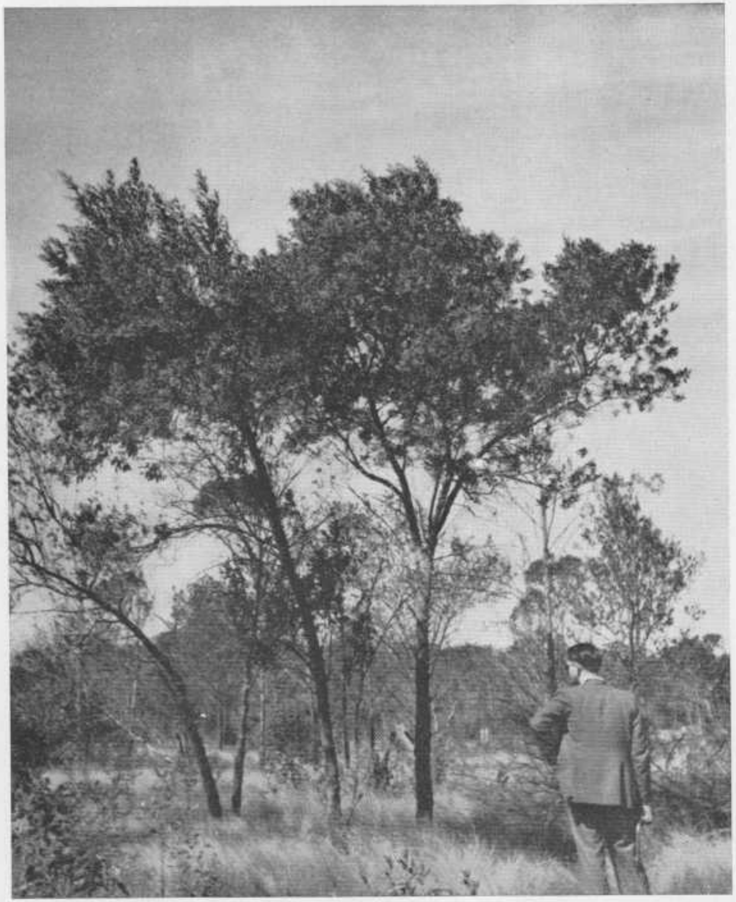
(ii) scientific assistance in the planning and reporting of trials and experiments carried out locally and in the solution of immediate problems, such as countering new enemy weapons or technique;

(iii) collection and critical analysis of eye-witness reports and opinions from both our own troops and prisoners of war."

From Appendix "B4" from the *Administration of the MGO Branch of the Staff, LHQ, and of the MGO Services 1944-* , Vol. 1.

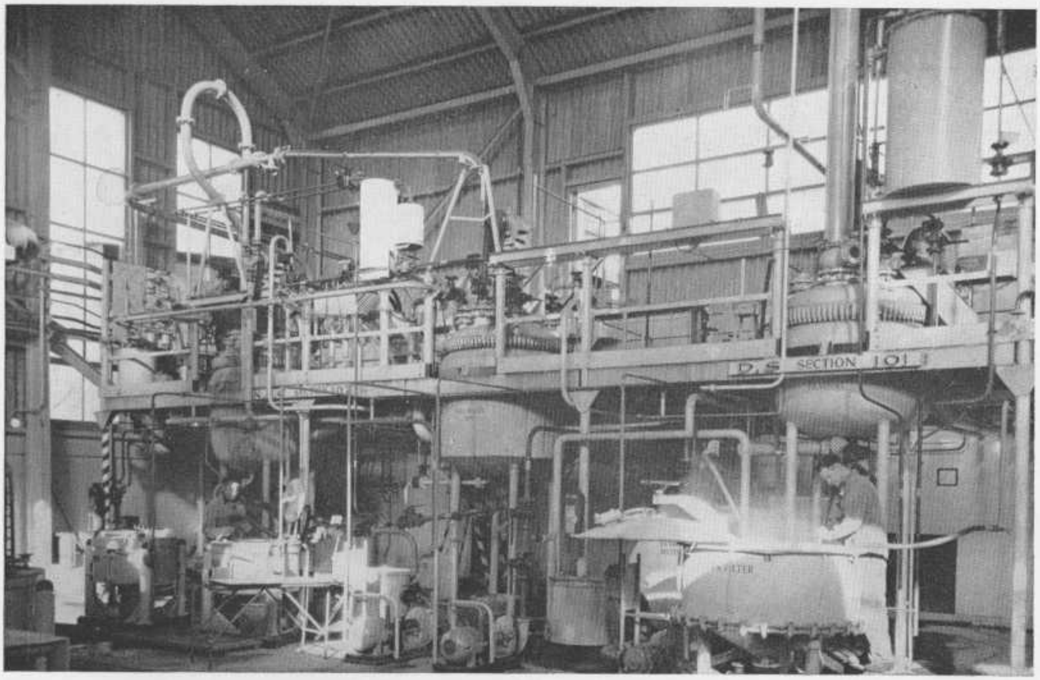
(*Division of Plant Industry*)

Leaf and flower of *Duboisia Leichhardtii*.



(*Division of Plant Industry*)

Duboisia Leichhardtii at Monogorilby, Queensland.



Sulphamerazine Plant. *(I.C.I.A.N.Z.)*

Executive Committee of Army Inventions Directorate, May 1945. Left to right: E. C. Allen, Dr R. v.d.R. Woolley, Cdr N. K. Calder, Sqn Ldr S. R. Bell, Dr A. S. Fitzpatrick, Brig J. W. A. O'Brien, L. J. Hartnett.

of the Ordnance, a disposition which almost certainly influenced the direction of the team's activities.

Overseas, operational research whether at the tactical and strategical level or at the level of weapon study, appears to have been most successful when applied to repetitive operations such as submarine hunting, convoying and bombing raids. If one may judge from the relevant reports and memoranda, the campaigns in the jungles and mountains of New Guinea offered little scope for operational research.

The following are only a few of the subjects studied, but they will serve to illustrate what the section and operational commanders who initiated investigations understood to be legitimate subjects for operational research. Much of the work done would, in the opinion of many operational research scientists, more properly belong to a testing establishment, since it consisted of what were primarily developmental trials.

At the beginning of August 1943 Jump and his colleagues went on to the forward areas in New Guinea, where they began a series of investigations, one of the first of which was a study of factors affecting the operational life of dry batteries.[3] The Scientific Mission which had visited New Guinea some months earlier had already looked into this question and had urged that manufacturing specifications for dry batteries should be altered to suit tropical conditions. Captain Vickers, who took up the study of this problem, found that in some instances batteries more than twelve months old were being issued to the troops in ignorance of the fact that storage for such a period, even under the best conditions in a temperate climate, would have greatly reduced their useful life. Manufacturers then knew very little about the effect on the shelf life of a battery of the high humidities combined with the high temperatures experienced in the tropics, though they were aware that shelf life was much shorter in tropical than in colder climates. While careful packing in sealed metal containers did much to ensure that batteries arrived in good condition up to the point of issue, the main difficulty was often experienced after this time: batteries of small portable wireless sets and mine detectors were often exposed to the most severe conditions, including complete immersion in water. Only after the operational researchers' recommendation that batteries should, when not in actual use, be carried in completely waterproof bags, was trouble from this source alleviated.

In due course the Operational Research Section was enlarged to include Australian officers with research and army experience. After it had been in the field about twelve months the original team of three British officers was replaced by another team from the United Kingdom, thus ensuring that the latest experience and techniques were available to the Australian section.

The Japanese, realising that they were unable to establish a continuous system of defence in long stretches of coastline in northern New Guinea,

[3] Operational Research Section Memo No. 18, "Factors Affecting the Operational Life of Dry Batteries in New Guinea" (1943).

concentrated their defences on beaches most obviously suited to landing operations. The outcome of this policy was that they left undefended a number of beaches that were naturally protected by a narrow knife-edge reef of coral running parallel to their length, in the belief that such beaches were impregnable. Except for this barrier many of these beaches were eminently suited to a landing operation. They were open to assault by shallow-draft vessels at high tide but were not accessible to major landing craft laden with vehicles and stores. The Operational Research Section undertook to investigate methods of breeching coral reefs in order to open up the possibilities of a tactical surprise.[4] After trying out several methods the team decided that experiments should be made with naval depth charges, but when application was made for help in securing the necessary charges, it was learned from the Naval Board that "the landing of assault troops on a beach being a naval responsibility, the removal of any obstruction in the water also becomes a naval responsibility". Thereafter the interest of the Operational Research Section in this project lapsed.

The problem of locating survivors of aircraft that had crashed in jungle and mountainous country was one that caused much concern in New Guinea. Its investigation became the joint responsibility of the Australian Jungle Training (Survival and Rescue) Unit and the Operational Research Section. So many aircraft were lost without trace that little was known about the geographic distribution of crashes, their preponderance, if any, at certain altitudes, on hillsides, or the frequency with which searching aircraft passed within range of survivors. Little or nothing was known of the proportion of survivors whose injuries would not have prevented them from using some signalling device, or of the number of occasions on which survivors had any idea of where they had come down.

In the face of these difficulties little headway was made with the problem. After critically examining ten methods of search, the Operational Research Section recommended that each should be given a trial, but could offer no suggestion which was most likely to succeed.[5] It is doubtful whether, in the circumstances, much more could have been done in the limited time given to the problem.

Nothing was known of the effect of firing small arms through kunai and other tall grasses that grow in profusion in New Guinea and other parts of the South-West Pacific Area. Trials to discover the effect of tall grasses

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[4] P. A. E. Jump, Notes on "The Breeching of Coral Reefs for the Passage of Major Landing Craft", ORS Memo No. 23.

[5] Major C. Powell and Capt J. A. Thornton, "The Location of Survivors of Crashed Aircraft in Jungle and Mountainous Country", Memorandum No. 34. The methods suggested were:

1. Radio transmission (SCR.536 handy talky, 5 miles' normal range).
2. Homing beacon for radio compass.
3. Radar homing beacon.
4. Radar air/sea rescue beacon.
5. I.F.F. (radar).
6. Radar reflector on captive balloon.
7. Captive balloon as visual marker.
8. Area marker for use at night (Krypton flashes visible at 20 miles).
9. Carrier pigeons. (These were successfully used in air/sea rescue in England.) Range in New Guinea 60-70 miles.
10. Robertson sun-flash signalling device.

All except (5) would have to be operated by a survivor, and carried down in the course of bailing out.

on the range and changes in angle of elevation of a bullet's trajectory were made in the Markham Valley (New Guinea). The differences in the performance of Bren, Vickers and Owen guns when fired through grass under various conditions were carefully analysed.[6]

In tests made on the Atherton Tablelands during the months of June, July and August 1944, a comparison was made of the accuracy for range of the 25-pounder Mark II and the Australian short modification of the same gun.[7] As was expected the short gun possessed neither the range nor the accuracy of the Mark II, but it was considered sufficient for the purposes for which it was intended.

Army interest in operational research lapsed at the end of the war and was not revived until 1952 when Mr Blunden was appointed Chief Scientific Adviser to the Army. In 1953 Blunden visited London to investigate the best way of setting up a scientific organisation within the Australian Army. His principal conclusion was that operational research should form the basis of scientific advice at the executive level, and on the strength of this he set about building up an appropriate organisation. It is interesting to note that among the first subjects chosen for investigation were the Wiles steam cooker and the Owen gun.

In Australia the R.A.A.F. appears to have taken operational research more seriously than the army and to have tackled it along broader and sounder lines, giving it a more appropriate position within its organisation.[8] As against this, the R.A.A.F. was slower in adopting it. From 1942 onwards scientists in the C.S.I.R. and the universities had attempted to interest the air force in operational research, but a firm decision to undertake it was not made until late in 1943.[9] This decision was reached after conversations between Sir Henry Tizard (then Scientific Adviser to the Air Council of Great Britain) and Air Commodore McCauley[1] (Deputy Chief of Air Staff, R.A.A.F.), in which Tizard strongly urged the Australian air force authorities to make more use of their technological and scientific resources.

Steps were immediately taken to bring together a team of suitably experienced research workers—no easy task since at this late period of the war most scientists had already gone into other Service and civilian organisations. Squadron Leader Davis,[2] a highly competent young mathematician of Sydney University, began some preliminary administrative work at Air Force Headquarters, Melbourne. In the meantime the British Air Ministry, at the request of the Australian Air Board, arranged to lend

[6] Lt-Col H. Dickson, Memo No. 33: "The Effect of Small Arms in Tall Grass".

[7] Memo No. 45, ORS (Aust), "Range Accuracy of the Quick-firing 25-pdr Mark II and of the 25-pdr (short) Mark I Aust".

[8] I am indebted to W Cdr J. C. Bower and Sqn Ldr A. D. Thomas for helpful discussion in connection with this section.

[9] The introduction of operational research into the RAAF was promulgated in Air Force Confidential Order A4, 18 Jan 1944.

[1] Air Marshal Sir John McCauley, KBE, CB. Dep Chief of Air Staff RAAF 1942-44, 1946-47; Air Cmdre Ops 2 TAF, European Theatre, 1944-45; Chief of Staff BCOF, Japan, 1947-49; Chief of Air Staff RAAF 1954-57. B. Sydney, 18 Mar 1899.

[2] W Cdr C. S. Davis, DFC; MSc, PhD. RAF 1940-42; RAAF 1942-46; Professor of Mathematics, Univ of Q'land, since 1956. Of Strathfield, NSW; b. 15 Apr 1916.

the services of two Australian scientists (Dr Bower[3] and Dr Miller[4]) who had been working as operational research officers in the R.A.F., Middle East and South-East Asia Air Force Commands. While on their way to Australia these officers visited air force operational research organisations in Canada and the United States. Bower, with a strong background of scientific training and of experience in the R.A.F., became the leader of the new organisation. Miller took charge of the section at R.A.A.F. Command, and Davis was appointed to the section in New Guinea. Later, when the war moved from New Guinea up into the islands, a section was started in the First Tactical Air Force area under Squadron Leader Loveday.[5]

These different sections were always part of the Air Staff. Operational research section leaders were themselves directly responsible at R.A.A.F. Headquarters to the Chief of the Air Staff, and at commands to the Air Officer Commanding. They had no executive responsibility and so were free to devote their energies to research.

Since different scientific disciplines were likely to be called upon in operational reseach, well-balanced teams included men with different backgrounds—physicists, chemists, mathematicians, biologists and psychologists. The R.A.A.F. teams built up by 1945 were well organised in this respect. A natural consequence of the fact that operational research grew out of the first attempts to study the military efficiency of radar was that the first teams were made up mainly of physicists and mathematicians. As the scope of operational research widened, it became necessary to recruit men whose training lay in fields other than the exact sciences. Thus biologists were often found particularly effective in collecting the personal stories needed in tactical studies; in investigating the efficiency of personnel it was logical to employ psychologists.

Not until early in 1945 was an adequate staff recruited and trained. In the meantime the different sectional leaders did the best they could with the staffs at their disposal and succeeded in obtaining some interesting results in widely differing spheres of activity.

As the R.A.A.F. authorities conceived it, operational research covered not only combat operations but any operation within the Service. Research activities fell into three main groups:

(*a*) those directed towards providing assistance in the formulation of future operational requirements in the planning, strategy and tactics of operations and improving the combat efficiency of the air force;

(*b*) those directed towards helping administrators achieve maximum working efficiency of the air force: how best to distribute resources of manpower, equipment, buildings and aircraft in order to achieve the objectives of the service;

(*c*) those directed towards problems relating to personnel: health and efficiency, selection, training methods, training assessment and morale.

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[3] W Cdr J. C. Bower, MSc, PhD. O i/c Operational Research Section, RAF HQ, Middle East, 1942-43, RAAF 1944-45. Of Heidelberg, Vic; b. Melbourne, 3 Oct 1911.

[4] Sqn Ldr A. R. Miller, MA, MSc, PhD; RAFVR. Research physicist; of Cambridge, Eng; b. 4 Sep 1915.

[5] Sqn Ldr N. J. Loveday, MA; RAAF. Company director; of Brisbane; b. Rosewood, Q'land, 5 Dec 1914.

Researches which had the most profound effect on the efficiency of waging war came mostly under (*a*). Examples illustrative of each of these groups will be given to indicate the range of interest and the extent to which the R.A.A.F. made use of operational research.

Commanders were supplied with a factual analysis of operations under their control. An example of this was an analysis made of the amount of flying and the resulting casualties in three types of aircraft: the Kittyhawk, Boomerang and Spitfire.[6] Kittyhawks, usually employed in low-level strafing on bombing attacks against Japanese ground installations and small ships, paradoxically suffered more casualties in the forward areas when engaged in non-operational flights—that is, flights other than those against the enemy—than when flying on combat missions. The number both of flying hours and of sorties was taken as the basis for comparison. Casualties were in fact more closely related to the number of sorties made than to the actual time of flying. The reason for this was that for all types of single-engined aircraft a high proportion of casualties was sustained in the vicinity of the target area owing to enemy anti-aircraft fire and fighter aircraft, and at the base during landing and take-off. In other words, there were small periods of time for which an aircraft was exposed to risk, which were independent of the number of hours occupied in flying to and from the target area. Another point of some interest which emerged from statistical analysis was that Japanese anti-aircraft fire was more than twice as dangerous as their fighter aircraft.

For the purpose of estimating the rate at which aircraft should be supplied to keep pace with losses, an investigation was undertaken by the section with the cooperation of other sections at Air Force Headquarters, in particular the Records Section of the Directorate of Organisation. It was established that the incidence of non-operational casualties, reckoned on the basis of hours flown, was markedly less in rear than in forward areas; that the proportion of casualties experienced in operational and non-operational flights varied with the kind of aircraft; that of the different kinds of operational flying in New Guinea none was more hazardous than tactical reconnaissance—aircraft so engaged suffered a higher proportion of casualties than occurred with any other single-engined R.A.A.F. fighter aircraft in any other role or in any other part of the South-West Pacific Area. When these findings had been collated it was possible to estimate the rate at which aircraft should be replaced.

Perhaps the most important piece of operational research was that carried out by Miller on the sea-mining operations directed against harbours of Japanese-occupied islands to the north of Australia by Squadrons 11, 20 and 43 of the R.A.A.F. during the period April 1943 to April 1944.[7]

The South-West Pacific Area offered few targets of the kind which, from European experience, could be regarded as conventional objects for attack by an air force. Throughout the war in the Pacific and South-East

[6] ORS Report No. AR8, "Effort and Casualties in RAAF Squadrons Equipped with Single-engined Aircraft".

[7] A. R. Miller, "Mine-laying Operations of the RAAF, 22 April 1943 to 30 April 1944", Reports Nos. BR.2 and BR.8, OR Section HQ RAAF Comd, Allied Air Forces, SWPA.

Asia there were no large industrial cities, no chemical engineering plants, no networks of railways and marshalling yards, no large-scale engineering works such as bridges and viaducts which could be destroyed from the air with telling effect on the enemy's ability to wage war. In Western Europe the most crippling of all attacks were those directed against communications networks upon which depended production of the weapons and equipment of war and their supply to the fighting forces.

Despite the great differences between the two theatres of war, one principle of warfare underlying the use of air power was just as valid for the Pacific region as it was for Western Europe. Stated briefly, it was to disrupt the enemy's communications by direct attack and by isolating him from supplies of fuel. The different tactics used to achieve this aim were dictated by the totally different terrain—a land mass in the European theatre, and in the Pacific a vast expanse of sea studded with islands. The task of the R.A.A.F. was to prevent the Japanese from using the sea lanes of the Pacific. This it did by cooping up their ships in the harbours.

Quantitative studies of sea-mining operations were directed to answering two main questions: what proportion of the total activities of the three squadrons was devoted to mining, and what precisely were the results of the operations. The answer to the first question was found to be that irrespective of whether activity was measured by the number of sorties or by flying hours, the proportion devoted to sea mining was roughly 20 per cent of the total, as is shown in the accompanying table.

	Per cent of the total no. of	
Duty	Sorties	Flying hours
Minelaying	20.5	20.8
Bombing	17.6	18.2
General reconnaissance	16.4	18.3
Convoy escort	41.4	38.6
Miscellaneous	4.1	4.1

Distribution of effort—Squadrons Nos. 11, 20 and 43.

The answer to the second question was convincing and conclusive: 230 sorties against 18 harbours had resulted in the closing of 10 harbours for periods up to 5 weeks, the sinking of about 60,000 tons of shipping, and the damaging of about 75,000 tons. It was estimated that if the cargoes of these sunken ships had been dispersed among airfields and dumps, their destruction would have required something like 12,000 sorties from 20 squadrons. Since these results were achieved with what was equivalent to half a squadron occupied full time, it meant that minelaying was forty times as effective as the bombing of land targets. Moreover, this estimate took no account of enemy losses due to damaged shipping, to the diversion of effort to minesweeping, and to the loss of war production resulting from dislocation of sea communications. When these indirect effects were taken into account sea-mining operations appeared to have been about 100 times as destructive to the enemy as an equal number of bombing missions against land targets would have been. Not only was sea-mining a highly effective method of harassing the enemy, it was also one that achieved results with relatively small loss to the attacking force, as the accompanying table will show.

Form of attack	Period	No. of sorties per missing aircraft	Aircraft lost per ship sunk	Aircraft lost per ship sunk or seriously damaged
Low level 600 ft	Mar 1941 Jun 1942	6.2	2.65	1.23
Medium level 4,000 ft	Jul 1942 Mar 1943	25	3.33	2.0
Torpedo	Mar 1941 Aug 1943	5.0	3.65	1.73
Minelaying (Europe)	Jan 1943 Jun 1943	28	1.0	0.85
Minelaying (RAAF, SWPA)	Apr 1943 Apr 1944	77	0.23	0.13

Comparison of different methods of attack on sea communications.

This illuminating analysis had its share in causing the R.A.A.F. to concentrate a much larger part of its effort on minelaying. The immediate result of these mining operations was that Japanese ships were often blown up when entering or leaving a harbour. Consequently the Japanese would then close the harbour in question for days or even weeks while the approaches to it were swept for mines. This immobilised all shipping in the harbour and all that was due to arrive there during the time spent on sweeping operations. The shipping available to the enemy was thereby substantially reduced, and the replenishment of stores and weapons was delayed.

Fewer aircraft were lost for each ship sunk or seriously damaged on these minelaying operations than on any other operation, and the results achieved were out of all proportion to the effort in manpower and materials put into them.

At R.A.A.F. Headquarters operational research men concentrated on problems of administration. One of the first of such problems put up to them by Air Commodore McCauley was that of finding the most efficient way of providing relief for personnel after a reasonable tour of duty in the tropics.

While the importance of giving air crews periodic rests from active flying was fully recognised, McCauley was convinced that it was equally necessary, especially in the tropics, to give periodical relief to ground staff, and in order to conserve manpower he was naturally anxious that this should be done in the most efficient manner possible. Not every man in the rear areas was available for relieving those in forward areas; some were disqualified by age, a key position, or unfitness for service in tropical areas.[8] The problem was to discover how best to apportion the time to be spent in travel to and from the forward areas and the period of the tour of duty. In answer the Operational Research Section provided a simple formula by means of which the Personnel Branch was readily able to implement a policy of relieving ground staff in the most efficient manner.

The accompanying table, worked out from the formula, illustrates the interplay of the three most significant factors—(*a*) tour of duty in forward areas, (*b*) tour of duty in rear areas, and (*c*) time of transit—affecting the size of the forces which could be maintained in forward areas.

Factors affecting the availability of personnel in forward areas

	Tour of duty in forward areas	Tour of duty in rear areas	Time of transit	Maximum percentage of establishment in North
a	24 months	12 months	14 days	57
b	15 „	12 „	14 „	45.5
c	12 „	12 „	14 „	40.0
d	15 „	6 „	14 „	61.0
e	15 „	1 „	14 „	86
f	15 „	12 „	1 month	44
g	15 „	12 „	3 „	39.5

Obviously the length of the tour of duty in the rear areas had to be kept low if the forward strength was to be kept high. On the other hand, when only a moderate strength was required forward, tours of duty in forward and rear areas could be made of comparable duration. The fact that the time of transit was not a particularly sensitive factor (compare lines *b*, *f* and *g* of the table) did not mean that it could be left out of account; for example, under the extreme conditions stated in line *g* of the table, 15 per cent of personnel were in transit, which was far too high.

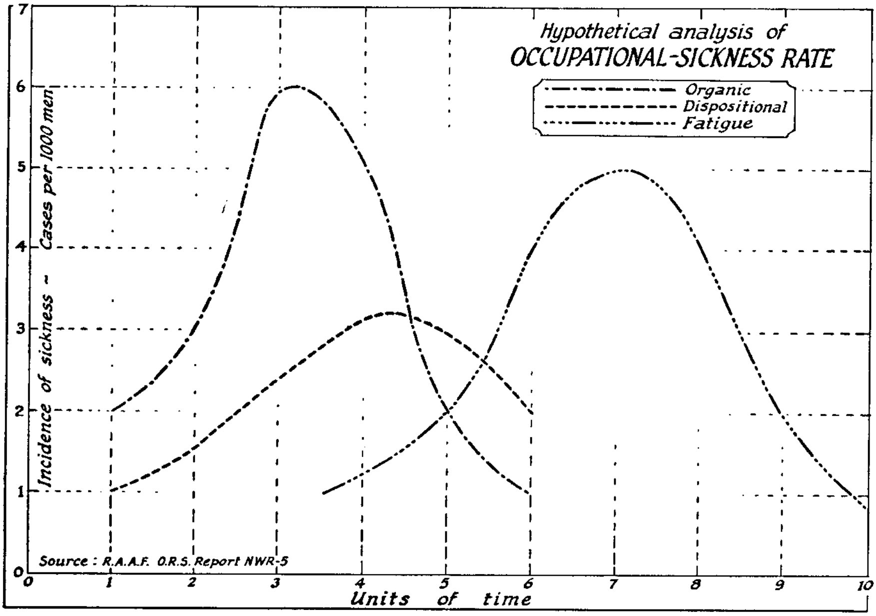
The formula was applied in detail (with appropriate modifications where necessary) to determine possible relative tours of duty in forward and rear areas for each of the 100 or so trades in the R.A.A.F. It is worth noting that this study had a lasting influence on posting policy in the R.A.A.F.; it survived the 1939-45 war and was used in the Korean war.

In another attempt to help administrative officers make the most efficient use of limited supplies of manpower, operational researchers analysed medical statistics to discover the nature and incidence of the different kinds of occupational sickness.[9] Any disorder arising directly from working conditions, whether organic or psychological, was classified as occupational sickness. Organic disorders were those affecting the parts of the body involved in a particular task, and included eyestrain, conjunctivitis, otitis and haemorrhoids. Psychological disorders were divided into two groups: (*a*) dispositional—those constitutionally predisposing states which resulted in conversion hysteria or anxiety states; (*b*) fatigue—neuropsychic dis-

[8] ORS RAAF Report No. AR.2, "Planned Relief". These men totalled 9,900, made up of: unfit, 2,550; under age, 3,050; over age, 1,150; compassionate posting, 650; men in key positions, 2,500.

[9] ORS RAAF Report NWR.5, "Notes on the Analysis of Occupational Sickness".

orders such as headaches, general debility and insomnia, caused by working too long at the one task. The incidence of each of these types of occupational sickness in any large group of people was found to vary in a characteristic way: the number suffering from organic complaints reached a maximum first; then followed dispositional and fatigue disorders. The accompanying figure shows an idealised form of the curves for each type.



A high proportion of dispositional sickness was considered to indicate a need for revising methods of selection at recruitment. The time that elapsed before fatigue disorders reached a maximum was suggested as indicating the length of the period beyond which a person should not be kept on the one job. If kept beyond this period the chances of a rapid recovery were seriously reduced. Recommendations were based on the individual curves because very little could be deduced from the complete occupational sickness curve. The administrative staff was left to formulate its policies in the light of the statistical analyses.

Another study of administrative interest was one relating to the nature and causes of operational inefficiency in signals workers. Extreme examples taken from statistical records showed that it was possible, under the worst conditions, for a teleprinter to make as many as 200 to 250 errors a day, of which 85 per cent might be serious; that under similar conditions cypher assistants could make as many as 120 errors a day.[1] When it is remembered that operators were selected on the grounds of their apparent

[1] The situation was not quite so bad as these figures might suggest. They included typographical errors in text or heading, altering the sense of the word or text; incorrect abbreviation of names of units in addresses; incorrect procedure in setting out the signal. Also it is to be noted that 50 per cent of the serious errors were picked up and corrected by the operator.

fitness for the job, the need for investigating the causes of inefficiency of this degree is clearly apparent. The usefulness of the most nearly perfect signalling equipment could be seriously offset by failure of the human element.

The staff of the Melbourne wireless telegraphy station at Camberwell was chosen as the subject of study because its numbers were large enough to give statistically significant results. In the beginning operational research officers attempted to discover the extent of the variations in efficiency and the principal factors responsible for them. Errors were least numerous during the evening shift (4 o'clock to 11.15), while about equal numbers occurred during the other two shifts (11.15 to 7.30 a.m. and 7.30 to 4 p.m.). As far as could be judged, efficiency increased with pressure of work. There was no sign that operators were extended to the limit of their capacity. Operators working on the same shift for a six-day week were least efficient on the second and fifth days. From this it was concluded that it did not much matter whether a two-day or six-day shift system was used. Male operators working under similar conditions were not significantly more efficient than female operators.

Fatigue, which to the operational research worker meant reduction in efficiency as a result of occupational or temperamental unsuitability, was compounded of two factors: boredom and occupational debility.[2] Boredom was caused by lack of interest-value in the work itself, or by too little work. Its cure lay partly in the provision of proper rest pauses, the value of which had been recognised many years before. The causes of occupational debility were traced to unsatisfactory shift systems, poor working conditions, incorrect "social" treatment of workers, and too long a tour of duty. All these conditions, once diagnosed, could be remedied.

Conditions met with among the signals workers were typical of many routine, repetitive jobs, and the conclusions drawn from these statistical studies were considered to have a fairly wide application in the R.A.A.F.

One of the last wartime studies undertaken by the headquarters group of the Operational Research Section concerned the problems of demobilisation. A critical examination of the "point system", a method then in use for deciding the order in which men were to be discharged, revealed a number of weaknesses, the chief of which was that it took no heed of the labour market. The operational research team divided all servicemen into five occupational groups:

1. Those whose jobs were being kept for them or who through their own endeavour had been able to find jobs or had decided to start a business of their own.
2. Those with qualifications required by essential industries, and for whom there was an immediate demand.
3. Those who wished to resume interrupted training or who had been chosen to begin training at universities and technical colleges.
4. Those with the qualifications for group 2 but for whom positions could not immediately be found.
5. The remainder, for whom no positions were immediately vacant.

[2] The term "debility" was used to cover any type of health disorder which could be closely associated with the work of the operator.

A census was taken of 45,170 persons from Western Australia, Queensland and Victoria, and a group of 32,000 was selected at random to discover how they were distributed among the five groups. Group 5, comprising about 50 per cent, constituted the "labour pool" upon which operational researchers urged that the machinery for rehabilitation, vocational guidance and other benefits for ex-servicemen should be focused. This report did in fact provide valuable guidance for the administrative sections of the R.A.A.F., and was acted upon. Most of the results of this kind of operational research seemed just plain commonsense—in fact this branch of science has been called quantitative commonsense. One basis on which to judge the probable value of operational research is the definiteness of the recommendations made as a result of it; in this respect much of the work done by the R.A.A.F. compared favourably with that done overseas.

It is important to emphasise that operational research scientists were always available for day-to-day advice, and senior officers did in fact frequently use them most effectively as scientific advisers. The advantage to an officer planning some specific operation of being able to rely on substantiated facts rather than on opinion or prejudice, needs no emphasis. The role of scientific adviser steadily became a more important function of the operational research worker as the war proceeded.

Frequently data accumulated by operational research workers provided the basis for Service training or educational manuals. Among the most valuable of these manuals was one prepared by the Operational Research Section of the R.A.A.F., describing the principles of radar, the performance of typical radar equipments, and their operational efficiency. In other ways, for example by making their services available as lecturers, operational research officers assisted in the training of servicemen.

There can be no doubt that operational research influenced wartime policy of the R.A.A.F. to a sufficient degree—at a late stage in the war at least—to justify its existence. It is equally certain, however, that had the section been established earlier and recruited to its full strength in 1943 the value of its efforts would have been much greater. Through the work of Bower, Miller, Davis and Loveday, operational research won the good opinion of many air force administrators. Interest in operational research, though at a reduced level of activity, was sustained after the war and results obtained earlier were applied to the fighting in Korea in the early fifties. The R.A.A.F. had learned to appreciate the contribution that the scientist could make to its general activities. Concrete evidence of this was provided by the appointment of Squadron Leader Thomas[3] as scientific adviser on operational research to the Chief of Air Staff—the first appointment of its kind in the Australian armed Services.

In Britain and the United States operational research was successfully applied, after the war, to the problems of industry—to the running of transport systems, civil aviation and traffic problems, as well as to many

[3] Sqn Ldr A. D. Thomas, MSc; RAAF. Communications engineer; of Burwood, NSW; b. Richmond, Eng, 13 Jun 1921.

other fields of activity. Despite the useful work done in the R.A.A.F., there were long delays in applying the technique to Australia's peacetime activities. Bowen's study of the problems relating to the stacking of aircraft over an airport,[4] and Muncey and Hutson's work on floor temperatures[5] were among the first applications of the technique to civilian problems.

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[4] E. G. Bowen, "Operational Research into the Air Traffic Problem", *Journal of the Institute of Navigation,* Vol. 1 (1948), p. 338.

[5] R. W. Muncey and J. M. Hutson, "The Effect of Floor on Foot Temperature", *Aust Journal of Applied Science,* Vol. 4 (1953), p. 395.