# Editor's Preface

This title is the first in a series of volumes which will document the contribution of operational research in the Second World War. The Laurier Centre for Military Strategic and Disarmament Studies will publish the complete text of a number of original reports so that students of military history and operational research can have ready access to material of great significance.

The series is dedicated to the memory of Professor Ronnie Shephard who joined the Army Operational Research Group in 1942 and continued to work in military operational research until his death in 1995. Professor Shephard had a special interest in the early history of his discipline and collected thousands of reports on various aspects of wartime OR. This collection is now housed at the Laurier Centre. At the time of his death, Professor Shephard was working on a bibliography of operational research reports for the period 1938-1948 which will be published in this series.

The text of the report of No.2 Operational Research Section was reproduced from a pristine copy of the report held by the Library of the United States Military History Institute, Carlisle Barracks, Carlisle, PA. Most of the maps, diagrams and graphs have been redrawn for this edition by Mike Bechthold, but the content has not been altered. The index was prepared by Ian Miller. The book was designed by Michael Bechthold.

# Editor's Introduction

The work of No.2 Operational Research Section, which is the subject of the reports that follow, must be understood in the context of the studies carried out by the Army Operational Research Group both before and after the invasion of Northwest Europe. No.2 ORS obtained its personnel from the various sections of AORG in Britain and drew upon the work of hundreds of men and women who had built up an enormous body of knowledge. The purpose of this introduction is to provide a context within which the contribution of No.2 ORS may be better appreciated.

It is possible to trace aspects of operational research back to the First World War, especially to the work of A.V. Hill in anti-aircraft gunnery and Thomas Edison's statistical approach to evading submarine attack. But OR emerged as a reasonably distinct discipline as a consequence of experiments on the use of Range Direction Finding (RDF), or radar, in the Royal Air Force and in Anti-Aircraft Command.[1] The need to integrate data from radar stations and information from the ground Observer Corps with the systems of fighter aircraft direction and control challenged scientists to work out a method of analysing the performance of the entire air defence network. This led to the creation of a research section attached to Fighter Command and indirectly to the appointment of P.M.S. Blackett as Scientific Advisor to Lieutenant-General Sir Frederick Pile, the Commander-in-Chief of Anti-Aircraft Command.[2] The task confronting Blackett seemed as challenging as it was important. During the Battle of Britain it had become apparent that using AA guns against enemy aircraft was only slightly more effective than shaking fists at them. With the beginning of night bombing the need to increase the effectiveness of Anti-Aircraft Command became an even higher priority, but it was by no means certain this could be done. Ivor Evans has left an account of his introduction to field work which captures the atmosphere of the time. He was taken to an AA gun-site on the outskirts of London:

> On a flat piece of ground near the guns stood a wooden hut on a rotatable base, with aerial-bearing frames attached to it. Inside was a narrow bench on which three people could squeeze side by side, facing panels festooned with knobs and switches. In front of the central position was a device like pair of bicycle pedals at the top of a column, by means of which the hut could be rotated by hand. Two cathode ray tubes showed ghostly leaping signals on time bases. When the gain was turned up the radio noise was like a waving field of corn and the operators themselves referred to it as 'grass.'[3]

This device was the gun-laying radar, GL Mark 1, and it was supposed to provide the AA battery with an early warning of the approach of an aircraft and an estimate of range. Intended for daylight use, it provided no angle of sight, so bearing and elevation had to be obtained optically. There were plans to incorporate an elevation finding device in later marks of equipment, but nothing was ready in the fall of 1940 until L.H. Bedford of the Cossor manufacturing firm improvised an attachment which could be grafted on to the GL Mark 1. The elevation finder further complicated the task of AA batteries because it depended on a reflected signal from the ground. The levelness of the area, the soil type, the weather, the proximity of trees and huts, and perhaps other factors, affected the signal and each set had to be individually calibrated.[4]

Blackett initiated the creation of the AA Radio School at Petersham where J.A. Ratcliffe assembled a team of radar technicians from the Telecommunications Research Establishment (TRE) to act as field calibrators but Blackett was determined to go well beyond the provision of technical assistance and he decided to recruit a team of young scientists who would study the entire problem of anti-aircraft gunnery.[5]

David Keynes Hill, like his father, A.V. Hill, a physiologist, was the first recruit and he in turn persuaded his friend Andrew Huxley to come in with him.[6] Three physicists, Dr. A. Porter, F.R.N. Nabarro, and H.E. Butler were recommended by Blackett's colleagues. Ivor Evans, a recent physics graduate of University College, Cardiff, was the only candidate recruited from the "Central Register," an early attempt to identify the nation's scientific manpower. Blackett selected one non-scientist, 2nd Lieutenant G.W. Raybould, during a visit to the AA defences in the Derby-Nottingham area. Raybould, without any assistance, had devised a barrage procedure based on radar slant range measurements. He had been a surveyor in civilian life and his matter-of-fact approach to radar problems greatly impressed Blackett. Two young mathematicians, Mr. A.J. Skinner and Miss M. Keast, completed the team which assumed the name AA Command Research Group, but was generally referred to as "Blackett's Circus." Professor N.F. Mott, an outstanding theoretical physicist, consulted with the group and wrote a number of early reports.[7] Ivor Evans recalled that,

> In a bevy of very clever people the two outstanding individuals were the original members, Hill and Huxley. It would be a job to choose between them and it is hardly invidious to Hill that if I had to I would finally give the accolade to Huxley. He had an incredible mixture of theoretical and practical expertise. He had been trained as a physiologist, but he had a very wide knowledge of natural science in general. He was also a good mathematician. As if this wasn't enough he was also a born experimenter, very good with his hands. He could take a predictor to bits like a born mechanic...Both Hill and Huxley showed at this early age a marked and fully justified self-confidence that must have owed a lot to the milieu in which they had been brought up. As a pair they made an engaging contrast, Hill tall and gingery, dry and a little pedantic in manner, but with a quirky humour, and Huxley, more intense, dark and blue eyed, fluent and incisive in talk, given to occasional great gusts of laughter, to let you off lightly after delivering a knock-down argument.[8]

The 'Circus' was divided into teams to work with the three London area anti-aircraft brigades. On Saturday mornings they met at Petersham with Ratcliffe and members of his research section to discuss new approaches to AA defence. These meetings began with a review of the week's work which was printed in a bulletin entitled *Scientific Operational Research*. This broad, experimental approach achieved a good deal. It was determined that if wire-netting mats, made of chicken wire, were placed around every receiver then only problems of ground level and soil composition remained. Raybould, and a hastily recruited Professor of Geology from Cambridge, established the best site locations, solving this problem. Andrew Huxley, who could turn from higher theory to a workshop bench with ease, modified the predictor used to lay the guns ahead of the target after Blackett noted that the existing predictor measured course and speed over too short a distance.[9]

These and many other innovations demonstrated what could be accomplished by a group of bright young scientists, but the basic problem of actually hitting enemy aircraft could not really be solved until better radar equipment, predictors, and fuses were available. In March of 1941 Blackett left to become Scientific Advisor to Coastal Command where he was to play a crucial role in the defeat of the U-boat. Blackett's departure placed the future of the 'Circus' in doubt and it was decided to combine the operational research group with Ratcliffe's wireless school. The Ministry of Supply, through the Air Defence Research and Development Establishment (ADRDE) took control of the combined sections.

This new enterprise, known initially as the Petersham Research Group, maintained separate units, one dealing with RDF development and the other with more general problems of AA fire control and analysis. L.E. Bayliss assumed control of the latter group which continued to study methods of optimizing AA fire with the available equipment.[10] The key innovation in this field was the development of a specially-equipped Recording Van which permitted the OR observer to monitor and film, for later study, the entire

sequence of an engagement with hostile aircraft. Recording vans were to play a vital role in the improvement of AA gunnery in time for the V-1 raids of 1944. In July 1941 J.A. Ratcliffe left Petersham to return to the Telecommunications Research Establishment, leaving the future of army OR in doubt once again.[11]

The War Office paid little attention to the development of operational research in the first years of the war. Weapon design for the army was the province of the Ministry of Supply and much of the work of Blackett's Circus seemed to be a natural extension of the equipment-development mandate of that ministry. But the scientific community in Britain included a large group of men who believed that scientists had much more to offer than purely technical advice. In his autobiography, Solly Zuckerman has described the meetings of the Tots dining club which provided a forum for discussions involving scientists and government officials. One such meeting led the publisher of Penguin Books to offer to publish a manifesto, issued in July 1940 as *Science at War*. Zuckerman, who put the book together, began it with the argument that,

> questions of strategy and tactics...should be a matter of direct scientific analysis...It is possible to reduce many of the factors in military operations to numerical values. Doing so provides problems capable of a definite solution. This has indeed been done to a certain extent with the tactical problems of naval and air fighting, but it could be extended to more. The scientific staff of the Services need to play a much larger part than they seem to do in the formulation and solution of strategical and tactical problems.

The ideas expressed in *Science at War* received wide distribution. A review in *Nature* by Julian Huxley argued that this "tract for the times" should be read by "every scientific worker." More than 20,000 copies were sold.[12]

The dining club, which included Blackett in its membership, continued to meet throughout 1941. These informal discussions of the role of science in war proved an important factor in persuading the War Office to take a more active interest in operational research but the Army Council, which included the directors of the various branches of the army, were not easily persuaded that civilian scientists could be of assistance. With the exception of the Director Royal Artillery, who had served previously at Anti-Aircraft Command, there was little enthusiasm for any expansion of scientific work in the army and positive opposition to the use of the term "operational" in the title of the ADRDE's operational research group.[13] Fortunately, Sir John Cockcroft, the Chief Superintendent of ADRDE, was an early advocate of operational research and he was determined to win the army over. He persuaded Lieutenant-Colonel B.F.J. Schonland to take charge of the new group, and counted on Schonland to overcome all opposition.[14]

Basil Schonland was an inspired choice. A graduate of Rhodes University College and Cambridge University, he had served with the Royal Engineers on the western front 1915-1918 and was twice mentioned-in-dispatches for bravery. By 1917 he commanded eight wireless stations, and when the war ended he was serving as a Chief Instructor, Wireless Communications. In 1919 Schonland went back to Cambridge, spending four years at the Cavendish Laboratory before returning to South Africa where he established an international reputation for his studies of thunderstorms and lightning.[15] Schonland had been one of the early investigators of cathode rays and the South African government invited him to take charge of the development and application of RDF for the South African armed forces. His team built their own radar sets for installation on the coast. This equipment was also used in the air defence of East Africa and the Middle East. Schonland was attached to General Wavell's headquarters in 1940 as RDF advisor. In early 1941 he was sent to Britain to examine developments in radar and purchase equipment on behalf of his government.[16]

Schonland's military background and scientific reputation were essential qualifications for his new job, but it was his personality that mattered most. Those who worked with Schonland invariably describe his ability to gain the confidence of senior and junior officers and of civilians and other ranks. He spoke with quiet authority but always encouraged his subordinates to speak frankly and to develop their own initiatives. According to D.K. Hill, who worked closely with him, Schonland was a good research

scientist who was interested in issues beyond his own field. He got on well with army officers, stayed above political and department intrigues, and learned to suffer fools gladly while maintaining his purpose.[17] Such men were rare indeed and army OR was very fortunate to obtain Schonland.

Between the spring of 1941 and mid-1942 the work of army operations research expanded slowly. Initially, Schonland could devote little time to OR as he was involved in the planning of the Bruneval raid which provided important information about German radar performance and he also continued to represent the South African Government for the selection and supply of RDF equipment. During these months L.E. Bayliss was effectively in charge and he was responsible for the formation of a separate group, soon to be known as ORS2, to study and advise on the efficient operation of coast-watching radar stations. The primary function of the new chain was to provide warning of the approach of German invasion craft, but it was used chiefly to protect coastal convoys from intruding German E-Boats. The OR team, drawing on their experience with the problems of anti-aircraft radar, controlled site selection and developed methods of training operators to get the maximum information from their sets. "Drills were invented to avoid radar's early shortcomings, methods of signal measurement, and the assessment of set performance were devised, also means of estimating vessel size."[18]

In July 1941 an experimental centimetric radar coast watching set was installed at Dover and ORS2 began to investigate its performance. The new equipment was "a great advance on previous sets in maximum range, discrimination, counting, and accuracy so that not even E-Boats could go between Calais and Boulogne undetected."[19] This did not prevent successful E-Boat attacks on convoys until the operators were trained to distinguish the various echoes and an accurate, speedy system of reporting was devised – classic operational research work.

By the fall of 1941 radar coverage at Dover denied the enemy local use of the Channel even at night. Unfortunately, at Ventnor, near Portsmouth, the set installed to monitor shipping across the Channel to Cherbourg was a failure. During the escape of the German warships *Scharnhorst* and *Gneisenau*, the Ventnor set was out of action due to fire damage but G.C. Varley, who was attempting to improve conditions at Ventnor on behalf of ORS2, reported "that it was almost certain that in the weather prevailing not even a high power set would have detected those ships from Ventnor, let alone a low power set which was badly down in performance."[20] A new set was installed two days after the German ships made good their escape.

In summarizing the work of ORS2 Varley wrote:

> This kind of operational research was a composite study of the performance of the instrument, the training of operators, and the use to which the information was put. It required close personal touch with the operators, and operational experience for the Experimental Officer, so that he could fully appreciate the operators' difficulties. It also required the status necessary to discuss problems of training and policy on equal terms with those officers responsible for it. For these duties civilian status was quite satisfactory and was perhaps better than uniform for interservice work.[21]

ORS2 also became involved in important studies on the accuracy of coastal artillery fire. A number of reports provided information on the factors which caused errors in predicted fire and these added significantly to the store of information AORG was acquiring on the general problem of improving the accuracy of all predicted fire, an issue of considerable importance to an army moving towards the restoration of an artillery-based land battle doctrine.[22]

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At the end of 1941 army operational research was still focussed on various aspects of radar gunnery but there was constant pressure to expand the scope of OR work. One reason for this growth of interest was the enormous success that Blackett was enjoying at Coastal Command where his analyses of air operations against U-boats were transforming tactical doctrine. In December 1941 Blackett wrote a brief paper, *Scientists at the Operational Level*, to inform the Admiralty of some of the developments

which had occurred in the operational research sections already established. This brief document, which Blackett described as "hurriedly and somewhat flippantly written," was widely circulated in all three British services and in the United States.[23]

The paper stressed the contribution scientists could make at the command level, the only place where direct access to "the real operational facts" was possible. "There is," Blackett wrote, "a strong general case for moving many of the best scientists from technical establishments to the operational commands."[24] The Admiralty responded by acquiring the services of Blackett and in May 1942 the Chief of the Imperial General Staff appointed Sir Charles Darwin[25] to the post of Scientific Advisor to the Army Council. Darwin had been on leave from the directorship of the National Physical Laboratory to improve Anglo-American scientific co-operation, especially with regard to the Manhattan project. Upon his return to England he took up the post at the War Office on the assurance that his terms of reference included the right "to suggest or examine from the scientific standpoint weapons or methods of waging war."[26]

Darwin and Schonland had much in common and there was little difficulty in establishing a relationship which allowed Darwin to use the operational research group as his field workers in Britain and overseas.[27] In January 1943 the War Office and the Ministry of Supply reached agreement on substantial changes in the title, status and mission of the group which clearly reflected new priorities. The title "Operational Research Group" was changed to "Army Operational Research Group" and the connection with the Air Defence Research and Development Establishment ended. As "Superintendent" AORG, Schonland came under the Ministry of Supply, for administrative purposes, but he was responsible to a committee chaired by the Scientific Advisor to the Army Council for policy. This committee authorized programmes at "a control meeting held at six-week intervals."[28]

The new charter specified a variety of duties for the AORG. It was (i) to investigate the performance of selected types of service equipment under the conditions obtained in field operations; (ii) to collaborate with design establishments in studying the performance and use of early models of new equipment; (iii) to investigate methods of using selected equipment; (iv) to analyse statistically the results of selected tactical methods, whether they involve the use of technical equipment or not; (v) to advise the War Office and the Commands upon the experimental planning of troop trials of equipment or tactical methods; (vi) to be represented by observers at troop trials; (vii) to carry out any other scientific investigations which may be approved.[29] Schonland had direct access to Directorates and Schools and to Commands in the United Kingdom. Reports on the results of investigations were to be published but the Scientific Advisor determined the external circulation list – for political as well as security reasons.[30] The new mandate for Army OR provided all that Darwin and Schonland had been asking for, and no time was lost in starting new projects and adding new sections.

Shortly after his appointment as Scientific Advisor, Darwin had agreed to a hastily-conceived scheme to send an OR section to the Middle East. The project went ahead even though no attempt had been made to gain the support of senior officers in that theatre of war. The team was attached to GHQ Middle East Forces and became a section of Staff Duties known as SD6. The new Commander-in-Chief, Lieutenant-General Harold Alexander, was a serious student of the kind of tactical problems the section wanted to address and he might have provided support but, in the preparations for El Alamein and the subsequent pursuit, 8th Army Headquarters insisted that officers from GHQ were not permitted to enter the battle zone. SD6 produced a few reports but its disappearance in 1943 was mourned by no one.[31] It had been an object lesson in how not to establish OR in the field.

Before Darwin knew the fate of SD6 he decided to post a scientific officer to First British Army in Tunisia. David Hill had been attached to his office examining issues like the ideal bombing pattern for enemy interdiction and Darwin decided to send him to North Africa. Hill was given the rank of Major on the General List and put on a ship to Algiers. He went "with instructions to investigate this, that, and

the other" but without any staff and without any position at First Army Headquarters. Hill was unable to make any headway with the operations branch and in April 1943 he joined forces with SD6 just before it was disbanded.[32]

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Darwin and Schonland devoted considerable effort to establishing contact with officers in the various branches of Home Command. The Royal Armoured Corp's Armoured Fighting Vehicle School at Lulworth had welcomed a Medical Research Council proposal to create a physiology lab to study tank design in relation to crew efficiency and fatigue. The lab was set up by Omond M. Solandt,[33] a Canadian physiologist who had been doing graduate work at Cambridge. Solandt, a bright, inquisitive, and very confident young man, quickly developed questions about all aspects of tank design and tactics. Many of his ideas seemed to make sense to armoured corps officers and in July 1942 the School permitted Solandt to collaborate with Schonland's operational research group in studies on a broad range of armour development questions. The Lulworth group became ORS4 (Armoured Fighting Vehicles, Field and Anti-Tank Artillery).

Solandt's initial ORG report analysed crew casualties in the Mark III Matilda Infantry Tank during the first El Alamein battle, July 1942. Other work focussed on methods of ranging, firing on the move and the German all-around vision cupola.[34] Studies comparing the gunsights used in German and British tanks led to important results and an object lesson in OR methods. Solandt recalled this investigation as one of the highlights of his time at Lulworth. The problem presented to Solandt was that "the Germans had introduced a new tank gunsight which was vastly superior to the British sight." Tank crews in the desert were sure that it was the new sight that made it possible for the Germans to knock out British tanks at long range before they were themselves in danger. However, careful measurements showed the British gunsight was accurate. The German sight was similarly tested and found to be inferior. "We were therefore forced," Solandt wrote, "to treat it as an operations research rather than a technical problem..."[35]

Solandt's team studied "the whole weapon system" undertaking "first class fundamental research which shed light on the whole process of aiming a gun and which subsequently produced important improvements in various aiming systems."[36] None of this research solved the immediate problem of what was actually happening in the desert. It was not until 1943 that firing tests against captured German tanks revealed the existence of face hardened armour which existing British shot could not penetrate.[37]

Solandt's work on specific problems in tank design and tactics became the basis of AORS4(a), "Tank Gunnery and Armour and Mobility of Tanks." A new unit AORS4(b) "Anti-Tank and Field Gunnery" was established at the School of Artillery, Larkhill. The tank section at Lulworth spent a good deal of time in the first half of 1943 on experiments designed to improve tank gunnery at medium and long range. British armoured doctrine persisted in the view that tank guns were to be used to engage other tanks and work was concentrated on attempts to find out why this mission was so difficult to accomplish. Major John G. Wallace produced two detailed reports on methods of estimating range and sighting while Major H.A. Sargeaunt worked on preparing firing tests for gunners and the development of new firing gear.[38]

Solandt was determined to educate the armoured corps about the proper role of his research team and in early 1943 he prepared a "Lecture on Tank Operational Research."[39] The purposes of OR, he insisted, were threefold: to study the use of tanks and improve tactical handling; to improve tank design – both in minor details and in general specifications; and to improve the training of tank crews. To accomplish these goals a good deal of information, not currently available, was necessary. For example, he asked, "What type of target does a tank usually engage? Is the current British view that tanks mainly engage other tanks correct?" If so, the selection of the 6-pounder, "a specialized armour piercing weapon

with a short barrel life, small HE shell and no smoke shell" makes sense. But what of the American view that tanks must have a multi-purpose gun because they engage a variety of targets?

Next he pointed out that the School had no useful information on the ranges at which tanks ordinarily engaged targets. "Is this range," he asked, "limited by an ability to see the target, ability to hit the target, or ability to damage it?" Turning to the question of tank armour he noted that there was no reliable information on which weapon knocks out the majority of our tanks or whether there were particular weak spots? Were tank tracks particularly vulnerable? If so it would be necessary to add skirting plates to protect the tracks. Other basic questions also need to be answered if OR was to make a full contribution. The mechanical reliability of tanks under various conditions must be known and the type of defects identified.

Solandt reminded his listeners of the contributions OR had already made. He recalled that early reports from the desert fighting had suggested that crew casualties were largely due to burns. This had led to "an orgy of designing clothing that would protect crews against flaming petrol." Major A.L. Chute of the Royal Canadian Army Medical Corps had gone out to the Middle East in March 1941 to study the physiological side of tank warfare on behalf of the Medical Research Council. Chute established that there were very few cases of severe burns and light burns were limited to the exposed areas of the body so even the lightest clothing would prevent them. A study of burnt-out tanks had determined that "fires in the fighting chamber were not primarily petrol fires but were due to the ignition of cordite stowed in the tank." This report led to the armouring of ammunition stowage bins and a decline in the incidence of interior fires. Exterior fires, which were higher in British and American tanks, appeared to be due to the use of gasoline engines instead of the diesel engines favoured by the Germans.[40]

These examples of operational research were an indication of what could be accomplished if information was available. The Scientific Advisor was impressed with Solandt's work and asked him to prepare a paper on the "Progress of British Tank Design" for the Army Council. A decision had been made to increase production of the Cromwell and Darwin wished to have an independent evaluation of this policy. Solandt provided a point-by-point comparison of the Cromwell with the American Sherman tank. Much had been made of the superior speed and thicker armour of the Cromwell but it suffered from an extremely cramped crew compartment (40 per cent smaller than the Sherman) which meant no gun larger than the 6-pounder could be fitted. The crew areas were also difficult to ventilate or heat. The slightly greater thickness of armour plating on the sides and rear of the turret was valuable but the designers had provided large flat roof surfaces on the hull which were thinly armoured and vulnerable to high explosive gun fire. Indeed, the Ordnance Board had found that a 25-pounder HE shell would knock out a Cromwell. Other serious problems involving the reliability of the engine and other mechanical components remained to be solved.[41] The Churchill tank, the only other British model likely to be available in 1944, had different but equally serious problems.[42]

Solandt concluded that the British tank models under development were likely to prove less effective than the Sherman tank. There was little point in encouraging British tank factories to continue producing inferior designs. He suggested two possible remedies: manufacture American designs in this country or recall Col. G.M. McLeod Ross[43] from America to begin work on an entirely new tank. Further attempts to modify existing designs would simply waste "the productive effort of the workmen in British factories."[44] The report won the support of the Scientific Advisor but it was not possible to stop British production. The development of the Cromwell and the Churchill continued while attempts were made to remedy the worst defects. Both tanks were produced in relatively large numbers during 1943 and 1944 and were used to equip one of the British armoured divisions and several of the independent armoured brigades in Second British Army. However, Sherman tanks, from American production, accounted for at least two-thirds of the medium tanks employed by 21 Army Group including the only ones with an effective armour-piercing gun, the 17-pounder equipped Sherman "Firefly."[45]

AORS4 played a very large role in trials designed to test the operational performance of the Sherman and in the development of the 17-pounder gun. Work on the 75 mm Sherman took place at Lulworth

under the direction of H.A. "Tony" Sargeaunt[46] who combined a great deal of practical experience in tank design and development with a good analytical mind. Sargeaunt was also able to establish excellent relations with armoured corps officers both at Lulworth and in the field.[47]

A separate sub-section, AORS4(b) was created to study the performance of anti-tank guns, including the 17-pounder. Located at the artillery school, Larkhill, the group undertook numerous studies designed to improve the accuracy of 6- and 17-pounder towed anti-tank guns. Much attention was devoted to the various sights available as well as to the perennial problems of estimating and correcting for range and dispersion of fire. This work was of considerable value to the armoured corps when the decision to mount the 17-pounder in the Sherman was made and the section was active in studying Firefly gunnery in 1944.[48]

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A completely new OR section developed out of Schonland's friendship with Major-General "Boy" Browning, the airborne commander, established during the planning of the Bruneval raid. Browning readily agreed to Schonland's suggestion that both the technical and tactical problems of airborne warfare might benefit from "the advice of a resident scientist."[49] Schonland selected Lieutenant Michael Swann, a young officer who had recently returned from a posting as a radar advisor in Iceland. Swann had begun a science degree at Cambridge in 1938. In the summer of 1939 he went on a student expedition to Iceland to do "some reasonably respectable biology." The outbreak of war kept the students trapped in Iceland throughout the fall and winter. When Swann reached Cambridge in 1940 he took advantage of the wartime opportunity to complete a Zoology degree in 18 months and then enlisted in the army as a private. During the personnel selection interview Swann admitted to a knowledge of Icelandic and was assigned to the Intelligence Corps. Shortly afterwards a former schoolmaster "who had been approached by the War Office to find some bright people," asked Swann if he was interested in a new job in what turned out to be radar. Swann spent several months at Petersham before his Icelandic experience caught up with him again and he was ordered to join a group studying conditions of arctic warfare. On his return to England in the summer of 1942 he had an extensive interview with Schonland who asked "a lot of sensible questions" and then sent him off to the airborne division to do operational research for them.[50]

Swann's first report dealt with the transport and employment of 20 mm and 40 mm guns. A second investigation explored "Special Aids in Night Operations" initiating work which would continue in AORS5 and other sections for the balance of the war. Swann relied on the test results of the RAF Physiological laboratory which had worked on night vision for pilots. He prepared a note on "Training for Night Operations" which was issued to all airborne troops. It stressed methods of attaining night adaptation and emphasized the necessity of avoiding the use of bright lights.[51]

Swann was soon joined by David Bayly Pike. In the summer of 1941 Pike, an acting Headmaster and thus in a reserved occupation, decided to join the army. As it happened C.P. Snow was interviewing "for very special jobs" that day. Pike was accepted for a 13-week course at Petersham even though Snow thought his University of London External degree in Geography scarcely qualified as science. Pike did very well in the radar course and worked successfully at a variety of anti-aircraft tasks before Schonland sent him to join Swann.[52]

It had become apparent that the biggest single problem facing airborne troops was the difficulty of marking landing and supply drop zones. A great deal of AORG work was devoted to this and much time and energy was spent on infra-red detectors and other devices. After 1942 the best hope appeared to be a radar beacon which pathfinder troops could set up for later aircraft to "home" onto. The system was known as "Rebecca-Eureka," "Rebecca" being the airborne receiver and "Eureka" the radar beacon.

These devices had been produced by the Telecommunications Research Establishment. The task of operational research under David Pike was to find out how the equipment worked under field conditions and how it could best be used. Pike demonstrated that there were serious practical problems with signal

strength. Careful siting and spacing of the beacons was also of vital importance.[53] Improved versions of Rebecca-Eureka were developed and a miniaturized Eureka beacon played an important role in Normandy on D-Day.[54]

In early 1943 AORS5 moved to Airborne Forces Headquarters and then to the Airborne Forces Development Centre where research focussed on a variety of essentially technical problems. Perhaps the most important work was the section's crusade for the substitution of dark orange filters for the blue material used on army torches (flashlights). A scientific officer at the Ministry of Supply had pointed out the damaging effects of blue light on night vision but no new requirement was forthcoming from the War Office. AORS5 acquired enough dark orange filter material for 6th Airborne Division but when 1st Airborne was ordered to the Mediterranean, the section had to draw on its petty cash to purchase a new supply and "cut it to size for the whole force in a small workshop at Ablington House." The history of AORS5 ruefully records that this "was the only way in which the official inertia and obstruction could be circumvented.[55]

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Michael Swann was sent to the School of Infantry at Barnard Castle in Yorkshire to begin AORS6 (Infantry Weapons and Tactics). He was well received by the staff though they did not know quite what to do with a twenty-three-year-old Captain in the Royal Electrical and Mechanical Engineers who proposed to analyse their equipment and tactical methods.[56] Basic infantry weapons were tested carefully by many other army organizations, including the Small Arms School at Bisley. The school itself examined tactics so the contribution OR could make was not immediately apparent.

The staff of the school provided Swann with a list of minor problems which amounted to requests for information. In a document, dated 10 February 1943, he dealt with such issues as dud mortar bombs. A large number of those manufactured before December 1941 were known to be faulty and he reported that they could be returned for newer ammunition which "should prove much more satisfactory." Proposals for a bayonet for the Sten Gun had been rejected, he noted, because the gun was not "sufficiently robust." The "Scientific Advisor's Branch" was, he had been told, fully aware of the problems with officers' weapons. An "American carbine and a silenced .22 automatic pistol" were to be sent to the school for trials. The "grave shortage of watches" was also "fully realized" and attempts were being made to purchase them from "every possible source, even, it is understood, by buying 2,000 from a second hand jeweller's shop in Baghdad."

Swann commented next on the current state of the debate over assault jerkins which the school strongly preferred to the existing web equipment. He also reported on a problem which British infantry had complained bitterly about since the beginning of the war – the smoke emitted by mortar shells which made identifying mortar locations so easy for the enemy. The smoke was due to the fact that cordite, the only available smokeless propellant, could not be machine filled. A new kind of propellant was being tested but, "any new type will not be available for some time."[57]

None of this news was terribly helpful or had much to do with OR. If Swann was to be more than a liaison officer with good connections he would have to find work for himself. Fortunately, Swann was a self-starter with unlimited confidence in his own abilities. One of his earliest memoranda outlined the current state of knowledge about night operations based on his experience with airborne troops. "This paper," he explained, "is really intended to serve as a basis for argument. It is suggested that the whole subject be reviewed and discussed, and the army's needs and requirements in Night Fighting be made known."

The memorandum provided a summary of Swann's notes for the airborne division on night vision and listed a variety of special aids including whistles "which simulate natural noises," infra-red and ultra-violet light, and luminous paints. He also included an appendix on "Measurement and Prediction

of Darkness and Ranges of Visibility" which emphasized the possibility of determining "what times and on what nights a particular job can be done" and at "what ranges men, tanks, etc. can be seen and recognized."[58] The study of night fighting was to become one of the major projects of AORS6 in 1943 and 1944.

Swann was joined by two other young scientists, Alan J. Skinner and R.W. Nurse. Together they studied the infantry sledge, coloured smoke, the lethality of mines, the fragmentation of mortar shells, the lethality and stopping power of bullets and the performance of the Bren light machine gun. The Bren was the key to firepower for the infantry section and AORS6 organized a number of trials hoping to optimize the use of the weapon. One study examined means of engaging groups of attackers at short range. The approved method called for aimed bursts of four or five shots. This did not make sense to Swann and he arranged a new trial. Targets were set up spaced at four and eight feet and at ranges of 100 and 200 yards. The Guards' demonstration platoon and one from the Dorset Regiment did the shooting and results confirmed Swann's instinct that traversing fire was the most effective method until the range shortened drastically. Single shots were the next most efficient, while bursts were the least effective at all ranges. Objections that too much ammunition would be expended were checked and it was found that over a 30-second period traversing used only two more Bren magazines than firing by bursts. Since such fire would only be used in situations where the expenditure of ammunition was of secondary importance this was judged not significant.[59]

Swann shared Schonland's belief that OR had to address tactical questions and in April 1943 he prepared another discussion paper for the staff of the Infantry School titled "Note on Bombardment." The report drew upon previous research on the lethality, or lack thereof, of bombs and artillery fire directed at entrenched troops and identified a number of questions that an OR team in an operational theatre could investigate.[60] This work was to become the principle activity of No.1 ORS, the overseas section established for the Italian theatre.

A much more controversial project was also initiated in April, the study of the use of white phosphorous as an anti-personnel weapon. While phosphorous-filled bombs for the 3-inch mortar were already in use to produce smoke screens, it had been suggested that, "in view of the ineffectiveness of ordinary ground-burst high explosives against dug-in troops...splashes of burning phosphorus" might be used against men in slit-trenches. The OR section prepared targets consisting of 4'x4' squares of asbestos wall board and established that a single mortar bomb produced 980 large splashes spread over an area of 2700 square feet. It appeared that the smoke and its choking effect would heighten the impact of white phosphorus on morale.

The memorandum noted suggestions that white phosphorous "should not be tried out in battle and thereby given away like tanks and gas in the last War." Instead, large scale production of shells and extensive trials in England must precede its introduction to the battlefield. This, it was concluded, "would need the complete approval of everyone" including the War Cabinet. The section did suggest ways of using white phosphorus in small controlled experiments on the battlefields but further trials were confined to asbestos targets.[61]

In the fall of 1943 AORS6 was given the task of conducting trials with the PIAT (Projector, Infantry, Anti-Tank). The tactical instructions issued by the Small Arms Training Directorate simply stated that, because of low muzzle velocity, effective range was limited to 115 yards and recommended that great attention be paid to concealment. Tanks were to be engaged from the flank or the rear. The School of Infantry needed to know a good deal more than this before issuing tactical advice.

Swann arranged for a series of trials, the first of which was tragically marred by the death of an NCO who was struck by the brass cartridge which was fired back along the spigot tube.[62] This accident led to a modification of the cartridge case which rendered it less lethal. The trials showed that, within 100 yards range, well-trained crews could hit a tank moving at 10 mph 70 per cent of the time when it was receding, 55 per cent when it was crossing, and 40 per cent when it was approaching. The poor

performance on approaching targets "seemed to be due to the sense of hurry." A hit did not necessarily mean the tank would be stopped. Not all hits detonated because of oblique impacts and since hits from a hollow charge projectile simply punched a hole through the armour, bombs which failed to strike the engine or crew compartments were unlikely to have much effect. The PIAT did not have sufficient accuracy to strike any particular part of a tank so it was vital to make sure as many hits as possible were obtained on a single target.

The two-man crews at the Infantry School could get off five well aimed shots at crossing and receding tanks and three at approaching ones, but only one detonation in three appeared likely to be capable of stopping a tank. Swann concluded that PIATs "can only be effective when grouped for a single tactical task." He also recommended an increase in the number of bombs carried by a team. Perhaps the most interesting finding contradicted the view that "fire should be held till the tank was well in range, to make sure of a kill." Even at short ranges the PIAT could not be aimed to hit a vulnerable spot and it was more important to get off as many shots as possible so fire should be opened "as soon as the tank is within range."[63]

AORS6 continued to conduct trials on the PIAT examining its suitability for holing walls and in street fighting but attention was soon shifted to the performance of British and German mortars. During the fighting in North Africa and the early stages of the Italian campaign the German 81 mm mortar had proven vastly superior to the British 3-inch mortar, outranging it by more than 1000 yards. By the end of 1943 this gap had been overcome but the poor reputation of the 3-inch mortar lived on. AORS6 conducted a number of trials with both mortars and the results demonstrated that the stepped-up 3-inch mortar using the Mk.IV Cast Iron bomb was in fact superior to its German counterpart with a higher rate of fire and a greater lethal effect. The problem of visible smoke from the British mortar which had made firing positions difficult to conceal had also been solved. AORS6 tested the new propellant and concluded that there was now (December 1943) "little to choose between this and the German propellant." This reassurance could not be extended to the question of accuracy. German mortar crews were provided with a larger variety of charges which meant that, especially at shorter ranges, greater accuracy was possible. The provision of a similar range of charges to British mortar crews was recommended.[64]

Swann kept turning from essentially technical trials of equipment to tactical methods. At least three discussion papers produced by AORS6 under his direction demonstrated the benefits of a systematic approach to a battle doctrine which had developed by trial and error. The first of these, simply titled "The Infantry Battle,"[65] was described as "nothing more than a rough sketch of the Infantry battle made from the comments and descriptions in *Current Reports from Overseas* and *Notes From Theatres of War*." Swann's intention in writing the paper was to ensure that everyone at the School of Infantry used a common vocabulary with an agreed upon meaning. He hoped that a description of the difficulties encountered in each stage of the battle would allow the OR section and the school's instructing staff to work towards solving some of the problems.

A review of the available reports made it evident that the carefully planned (never less than five days) set-piece attack, based on shooting the infantry on to their objective with a creeping artillery barrage, had become the norm in North Africa and Italy. The available information made it clear that problems did not cease when the infantry had captured the objective. If the infantry did not "get off the objective immediately, and follow through to a second or third objective...at least 1000 yards," in-depth enemy artillery and mortar fire which had been previously registered on the position caused heavy casualties and prepared the ground for counter-attacks which the enemy inevitably staged "within an hour or two." Troops in the Mediterranean theatre had learned the necessity of getting anti-tank guns and the artillery FOO (Forward Observation Officer) up front as soon as possible. Quick production of minefields was also important as was the principle "dig or die." Swann noted that infantry-tank co-operation appeared "to have been patchy and tactics not very well worked out." Tanks had been preceded by infantry and had functioned essentially as a mobile platform for artillery and machine guns. The main function of air support "has been to confer immunity from air attack...Bombing forward troops

does not seem to have been effective" in the Mediterranean. With "The Infantry Battle" as a basis for discussion, AORS6 proceeded to examine specific issues. A study of the German use of reverse slope positions, which had become standard practice after "the venue of the fighting changed to the undulating or mountainous ground in Tunisia, Sicily, and South Italy," offered a detailed analysis of seven phases of such attacks. Nothing in existing doctrine addressed the fact that the main body of the enemy's defence was secure from observation in such positions and it was therefore impossible "to eliminate or neutralize the defenders by means of accurate mortar or artillery fire." The advantages of reverse slope positions were lessened in night attacks, or when the ridge could be attacked sideways, but the practical solutions also seemed to lie in the greater use of armour and in air attacks. The possibilities of using close support aircraft to reconnoitre and/or attack reverse slopes should be considered "or reconsidered" the report concluded.[66] These common-sense papers did not add anything that was not already known but the systematic approach to the various stages of a battle helped to clarify everyone's thinking.

The OR section's study of the way in which riflemen used the Lee-Enfield rifle and the low level of accuracy achieved with it at longer ranges, by average soldiers, persuaded Swann to advocate measures to greatly increase the fire-power of the infantry section. Two solutions were offered: the substitution of the Sten gun for the rifle for all but one or two men who would act as snipers; or the creation of two Bren gun groups, each of five men. This argument was rooted in the evidence that most combat took place at ranges of less than 200 yards. It offered strong support for similar proposals made by the Director of Infantry but no changes in the organization or equipment of the infantry section was forthcoming.[67]

AORS6 had a significant impact on the School of Infantry, and the army's preparations for the invasion of France. The views of the section were treated seriously by the School and the Director of Infantry circulated the reports and memoranda to divisional battle schools. It seems clear that AORS6 had a measurable impact upon the development of infantry battle doctrine in 1943 and 1944 and certainly influenced No.2 ORS in Northwest Europe.[68]

* * * * *

Three of the four other new sections established in 1943 were intended to pursue intensive research on problems which had been uncovered in earlier studies. Neville Mott of Bristol University had been associated with army OR since the Blackett period lending his talents as a theorist to the solution of radar problems. Together with one of his students, F.R.N. Narbarro, he turned his attention to studies of the effectiveness of artillery fire. In February 1943, Narbarro wrote a "Draft Program for ORS7 – Lethal Effect of Weapons."[69] The same month Mott produced studies of the "Penetration of Fragments into Armour" and the "Vulnerable Area for the 25 pdr Shell."[70]

Throughout the rest of 1943 work on the lethality of British projectiles laid a firm foundation for understanding the potential effectiveness of various weapons. In August of 1943 a member of the Mott-Narbarro group published "The Influence of Ground Cover on the Performance of HE Projectiles."[71] This report demonstrated that even slight undulations in the ground dramatically reduced the lethality of existing high explosive shells. A follow-up study which measured the exposed area of men in entrenched positions raised further questions about the actual impact of field artillery fire leading AORS7 to investigate the accuracy of such fire. This work was accomplished in association with AORS4 and their work formed the basis of the research carried out by OR sections in the field.

AORS8 operated as three relatively autonomous sub-sections, "Mines and Obstacles," "Special Optical Aids and Visual Problems," and "Flame Throwers." The work of this latter sub-section had a significant impact on the development and early deployment of the Wasp and Crocodile flame-throwing equipment, two of the most effective weapons available to Allied infantry in the entire war.[72] AORS9 concentrated on time and motion studies producing numerous reports designed to improve the speed and safety factors involved in such tasks as refuelling flame throwers, laying mines and handling ammunition in depots.[73]

The Battle Analysis group, AORS10, grew out of a "Fire Effect Committee" chaired by Sir Charles Ellis, who succeeded Darwin as Scientific Advisor in 1943. As the date for "Overlord" approached, Ellis was drawn into the raging debate over the use of heavy bombers in support of the D-Day landings. A directive from the War Office Joint Technical Warfare Committee required "that the morale effects of heavy bombardment be studied," as there was reason to believe that these were "of greater importance than the lethal and material effects."[74] Ellis and Narbarro, representing AORG, went to the United States to examine American records of the attacks on the Gilbert and Marshall Islands. They were persuaded that an analysis of the relationship between the weight of the bombardment and the number of casualties among the assault troops could be determined. Narbarro was placed in charge of AORS10 which began work on the impact of the preliminary bombardment on three battles which were part of operations to cross the Garigliano River in Italy during January 1944.[75]

The work of AORS10 was carried out in England from routine planning and operational records, but Darwin and Ellis continued to press for the establishment of sections which would function in the actual theatre of war. Throughout the fall of 1942 Darwin tried to overcome resistance to the expansion of operational research onto the battlefield. As one of his colleagues put it,

> It was not easy to make headway: operational research was a new baby in a family which was already over large...the extra member was not popular and but for the determination of the Scientific Advisor might well have been starved out of existence in its early life.[76]

Authorization to form OR sections for all overseas theatres was granted in November 1942 but it was not until June 1943 that No.1 ORS (Italy) was in place.

Eighth Army in Italy was no more hospitable to operational research than it had been in North Africa. Of the 15 reports prepared by the section, 12 dealt with questions related to the accuracy and effectiveness of artillery fire, an issue of some importance. There was, however, no mechanism for impressing the results of these studies on local commanders. As one critic explained,

> A new type of unit has great difficulty in making good headway unless it is lucky enough to have a powerful sponsor. In No.1 ORS' case there was no such person and work was undertaken in a somewhat haphazard manner.[77]

Two Canadian officers served with the section, Captain H.H. Clayton, Royal Canadian Artillery and Lieutenant-Colonel A.B. Dove, Royal Canadian Engineers. Like their British counterparts they found the work frustrating though Clayton finally won the attention of Eighth Army Headquarters by a study of the drying rates of soils in the Po Valley. After the war he recalled,

> We found ourselves in the unenviable position of being regarded at 8th Army H.Q. as experts on tank going, while being ourselves acutely conscious of initially knowing nothing and of having little time to find out what was knowable. However we retained our reputations for luckily that spring was very dry in Northern Italy so that tanks could go almost anywhere.[78]

* * * * *

No.2 ORS, formed in July 1943 to serve with 21 Army Group, was headed for a similar fate when Ellis intervened to try and establish a firm basis for operational research in Northwest Europe. In the long run-up to D-Day the small OR section worked chiefly as a liaison group between army staff officers and technical specialists in the AORG. Important work on the control of communications in the bridgehead, where radio and radar sets of every conceivable kind would be operating in close proximity, was underway. Equally vital work on AA defences for the beaches and Mulberry artificial harbours was also in progress,[79] but Army OR had not begun to deal with the kind of complex battlefield questions that Ellis knew operational research should address.

Ellis advocated a three-tiered system for 21 Army Group. First, he wanted a Scientific Advisor appointed as senior officer with ready access to the Chief of Staff. Second, he requested an OR section with its own establishment including sufficient vehicles and clerical staff. The third tier would be the AORG in England, especially AORG 10, the Battle Analysis group.[80] Late in 1943 Ellis wrote to the newly-appointed commander of 21 Army Group, General Bernard Montgomery, asking if Montgomery would "like a small team of scientists to observe his battles." Monty's full reaction to this inquiry from an unknown civilian can only be imagined but he was said to have replied with a five word message, "I observe my own battles."[81]

Montgomery did not, however, veto Ellis' plan. The formal link with AORG in England was quite impossible, as Monty would not allow "outsiders" access to operational information, but he raised no objection to the addition of a Scientific Advisor to his staff or to the expansion of the OR Section. Ellis' choice for the position, Basil Schonland, had a military background, great common sense and considerable presence. When approached about the project he was hard at work on the decoy attack on the Pas de Calais and other aspects of electronic warfare. Schonland had long been "unhappy about the highly technical turn the Operational Research Section had taken." He accepted the position on the condition that this could be changed and the promise that Ellis would make available "any member of AORG whom I wanted, in uniform and at short notice."[82]

Schonland was given the rank of Brigadier which, at least theoretically, placed him on an equal footing with the heads of Monty's intelligence and operations sections. He found that "Freddie," Lieutenant-General Frederic de Guingand, Montgomery's Chief of Staff, was "kind, courteous and accessible."[83] His fellow Brigadiers had been told that he was there "to solve difficult problems for them" and they seemed quite willing to try him out. In a 1951 memoir Schonland noted that the "solving of conundrums" was an important subsidiary function of the Scientific Advisor. Most of the puzzles were deadly serious and technically complex. Others were more easily solved. When intelligence officers asked whether the enemy could "electrify the sea" by running leads from local power stations into the ocean at the landing beaches, Schonland assured them that this was impossible.[84]

For Schonland the principal function of the Scientific Advisor was to promote the application of operational research to the battlefield and to ensure that the recommendations of the OR teams were acted upon. As a first step he and his successor as Superintendent of AORG, Omond Solandt, selected "the best men available" to strengthen No.2 ORS. Patrick Johnson,[85] an Oxford Physics Don who had served with the OR group in the Middle East, was retained as CO of the section but a number of new men who were "to turn the section on to real operational research" were added. The foremost of these was Major Michael Swann who left the infantry school to become 2 i/c of the section. The second addition, H.A. "Tony" Sargeaunt, had developed a detailed knowledge of the armoured corps while working with a tank brigade over a period of several months.[86] Schonland hoped to use his expertise to address broad operational issues in armoured warfare.

A third new appointment was a Canadian artillery officer, John F. Fairlie, a Royal Military College of Canada (1932) and University of Toronto graduate in mechanical engineering (1935). Fairlie had worked for Imperial Oil as a technical development engineer and operations manager from 1935 to 1942. After brief service in an artillery field regiment he was posted to the AORG gunnery section in December 1943.[87] His work on the accuracy of field artillery and pre-war experience convinced Schonland that Fairlie could approach the study of artillery doctrine in the desired manner. Schonland also recalled D.B. Pike from Italy where he was attached to No.1 ORS. Pike was initially assigned to assist the Special Air Service (SAS) with its plan to disrupt German communications on the eve of D-Day.[88]

Schonland soon added a signals expert and an administrative officer to the team. He also obtained Major D.K. Hill as his personal staff officer. After his return from service with First British Army in North Africa, David Hill had served as the Army OR liaison with Second Tactical Air Force as it prepared for the invasion on Northwest Europe.[89] Hill became Schonland's advisor on air matters, an area of great sensitivity. In his memoir Schonland emphasized that an army commander must have his own

advisor on air matters and that this was the one area of OR work which had to be directed personally by the Scientific Advisor.[90]

From March to late May 1944, Schonland and No.2 ORS were occupied with a wide variety of familiar technical matters. Lieutenant-Colonel Johnson was acting as radar advisor to the assault Anti-Aircraft Brigade. He spent the first three weeks of "Overlord" in the bridgehead watching over the "multiplicity of apparatus" that had been taken to Normandy. Major Fairlie was also detached from the section to join a Special Observer Party "formed at the last minute to study the different types of attacks on the coastal defences."[91]

Fairlie prepared the first two OR reports of the Northwest European campaign on the basis of these investigations. Report No.1, "Self-Propelled Artillery in the Assault on the Beaches, 3 Canadian Infantry Division Sector," produced some startling revelations. Although the Self-Propelled Artillery regiments performed in accordance with doctrine, it was evident that "no serious damage was done to any of the defences by SP fire." In an overall review of the battle for the Atlantic Wall, Fairlie wrote,

> The defences were overcome by D.D. Tanks, engineer and infantry assault. The degree of neutralization (by the Bombardment) actually achieved is difficult to assess because of the (German) method of siting guns to enfilade the beach area only. As few guns could fire to seaward it is difficult to say whether the delay of the enemy in opening fire was due to neutralization or to the fact that guns would not bear. In any event the defences were substantially intact when the infantry touched down and the enemy were able to deliver lethal fire in great quantity against our troops.[92]

This was not what the navy, air force or Royal Artillery expected or wished to hear, but it was of vital importance in the planning of future attempts to storm fortified positions. Fairlie's second report examined the "Employment of Royal Marine Artillery During Operation Neptune." This was written under great pressure as the Brigadier (Staff Duties)[93] at 21 Army Group Headquarters was anxious to learn about their role in the D-Day landings. The Royal Marine Artillery had come ashore on the three Anglo-Canadian beaches equipped with Centaur Armoured Fighting Vehicles mounting 95 mm guns. These were intended to provide close support to the infantry especially in reducing or neutralizing concrete gun positions. Fairlie found that the Centaurs had provided "very useful close support" at both Sword and Juno beaches suggesting the enormous value of aimed fire from a heavily gunned tank in infantry assaults against fortified positions.

In late June Fairlie and Johnson rejoined the OR team which had arrived in Normandy on June 24th. The section messed with the Weapons Technical staff "underneath an avenue of firs, which led down to the Chateau on the edge of Creully, round which Main Headquarters of Second British Army was scattered." But no one at Second Army was yet interested in OR and Schonland was still with 21 Army Group Main HQ back in England. It was up to the OR team members to find work for themselves. Two projects, mortar location and an analysis of the cases of tank losses were begun.[94]

These worthwhile endeavours were interrupted by the bombing of Caen on the night of July 7th. The awe-inspiring sight of Bomber Command's massive effort affected everyone in the bridgehead. But the battle of July 8th was as tough, costly and limited as any previous battle. Johnson, Swann and Sargeaunt set out to study the effect of the bombing on their own initiative, quite unaware that many others would be engaged in the same task.[95] Their report contained some diplomatic language about "the disorganization and morale effects" the attacks may have produced but it also demonstrated how slight the impact of the bombing had been on the battle.

Schonland was now in France and he was able to bring the report to the attention of de Guingand. No.2 ORS was ordered to study all subsequent heavy bomber operations so that the army would have its own independent assessment of such action. The OR group looked at the bombing in support of Operations "Goodwood" (July 18), "Bluecoat" (July 30th) and "Totalize" (August 7th/8th). Each of these reports provided 21 Army Group with important information which permitted army planners to develop a much more sophisticated approach to the use of heavy bombers on the battlefield.[96]

A further report, "Heavy Bombing in Support of the Army" provided a summary of what the OR team had learned about the subject in the summer of 1944. Bombing, they insisted, should be examined under three distinct categories, "obstruction, destruction and demoralization." Obstruction involved the blocking of enemy movement and, particularly in the context of Normandy, enemy withdrawals. The report noted that "the pattern on the ground of an attack by British bombers is much the same size (1000 yards diameter) whatever the weight of the attack." The fact that the centre of the pattern was "often wrongly placed," not the individual crew's wide shots, presented a safety problem to friendly troops. Given the wide dispersion throughout a 1000 yard circle (quite apart from incorrect aiming points) heavy bombing should, they wrote, "be confined to genuine area targets."[97]

There were real possibilities in using the heavies to obstruct German withdrawals and the OR team provided specific guidance on the number of bombs required for various types of localities. However, the destructive effect of bombs, that is the actual physical impact on enemy troops and equipment, was so small that it "was the moral effect which must be utilized if heavy bombing is to prove really useful." Since morale was only affected for a brief time "no bombing attack with demoralization as its primary object should be arranged unless it can in fact be readily followed up."[98] Here were the elements of a new doctrine for the use of the heavy bombers in support of the land battle. Unfortunately, at the end of August General Eisenhower lost control of the strategic air forces which returned to their preferred task of bombing targets in Germany.

If the work on heavy bomber targets could not be immediately applied it nevertheless provided a foundation for other studies of the battlefield. Schonland had long been anxious to know something concrete about the effectiveness of fighter and fighter-bomber close support. This was an issue which was causing much difficulty between the army and air force and 21 Army Group badly wanted to know what was going on.

Major Pike had already studied one Typhoon attack on a German column near La Baleine in the American sector. Together with a young RAF Pilot Officer, Pike had surveyed the aftermath of the air attack and had noted that only one tank had actually been hit by a Typhoon rocket projectile. This report was not well received by Second Tactical Air Force (2 TAF) and the Pilot Officer was sent back to do the investigation again.[99]

On August 8th word came that the team was to proceed to the town of Mortain in the American zone. Here, the RAF proclaimed, the tactical air force had been "a decisive battle winning factor" in stopping the German counterattack to cut off the American troops south of Avranches. According to Air Marshal Coningham, the commander of Second Tactical Air Force, rocket-firing Typhoons claimed to have destroyed 89 tanks, probably destroyed another 56 tracked vehicles, set on fire 104 motor vehicles and saw 47 motor vehicles smoking. These claims do not include 56 enemy tanks damaged and 81 motor vehicles damaged.[100] It had been, the air force insisted, "The Day of the Typhoon."

The army OR section was not the only group interested in the Mortain battlefield. When Second Tactical Air Force was formed in 1943 it acquired operational research staff from Fighter and Army Co-operation Commands. Fighter Command had a good deal of experience with OR work and had amassed considerable information about attacks on ground targets. For example, in early 1943 a full- scale model of a German artillery division with 48 mock guns and 558 dummy soldiers was created. "Every effort was made to aid the fighters and fighter-bombers in their attack task, but neither Mustangs strafing, nor Typhoons firing their new rockets with 60 lb. warheads were able to inflict more than negligible damage on the position."[101] A second experiment with a mock-up troop of medium artillery produced equally dismal results.

A carefully controlled study of the ability of pilots to find specific positions on the ground produced even more startling information. Tactical Memorandum No.30, dated March 1943, reported that:

> fighters, given a six-figure map reference were unable to spot well camouflaged guns even when the guns were actually firing...attacks on gun positions give negligible results for a high wastage and should only be ordered in an emergency.[102]

After 2 TAF was established, OR studies continued to show that there were very real problems in attacking the kind of targets which were of interest to the army. Operations against a variety of targets were carefully examined in the pre-D-Day period. Typhoon rockets were found to hit a viaduct 500 yards long and 8 yards wide, one in 15 times. Bombs dropped from fighter-bombers scored hits one in 82 times. Rocket Projectile (RP) attacks on gun positions produced results varying from 110 rockets fired at a casement in Courseulles-sur-Mer with zero hits to two hits out of 127 at Fontenay. Second TAF found all this disappointing, particularly since none of the targets had been "well-defended."[103]

The Allied Expeditionary Air Force (AEAF) established a school for training fighter pilots in close support during 1944. Results were not encouraging, for while strafing was "outstandingly successful" for damaging or destroying soft-skin vehicles, bombs and rockets could not be delivered accurately by average pilots. Near misses, it was found, did little damage. Even worse, accurate target location and identification of friendly troops proved to be an art which was readily mastered by very few pilots.[104]

The AEAF operational research section concluded that the probability of pilot error in identifying friendly troops and the inaccuracy of rocket and bombing attacks meant that close support of army operations should be ordered only in an emergency.[105] This information confirmed 2 TAF's preference for missions involving armed reconnaissance, deep interdiction and the search for targets of opportunity well beyond the battle lines. Nothing in the first two months of the campaign had altered this view, but if the Typhoons had really stopped the German armour at Mortain the whole question of close support might need to be re-examined and 2 TAF ordered its OR section to the scene of the battle.

The two rival OR groups began work at Mortain as soon as the German retreat cleared the area. For eight days, August 12th to August 20th, a not entirely friendly competition to locate and examine German tanks, self-propelled guns and other vehicles was underway along the roads and lanes of the hilly countryside. Descriptive accounts of the battle, as well as air force claims, had prepared the investigators for scenes of devastation. A Panzer division, it was said, had been caught in a traffic jam caused by the crash of an Allied aircraft onto the lead tank in the column. Scores of panzers had been destroyed near St. Barthélemy, and this was just one among many stories that everyone had heard.

What the researchers saw was very different. Despite the most systematic search, very few wrecked tanks could be located. The army team borrowed an Auster aircraft to conduct a survey, but not a single additional vehicle was seen. In the end only 33 Panthers, 10 Mark IVs and 3 self-propelled guns were uncovered. If armoured troop carriers, armoured cars and tank recovery vehicles were added, the total for all armour left behind in the area was 78. Nor was it possible to find many of the motor vehicles which the air force had claimed to have destroyed. Only 30 German trucks were available to investigate. While this discrepancy was difficult enough to account for, the results of the individual examination of vehicles was even more problematic. Nineteen of the 43 tanks had definitely been destroyed by US Army units. Only seven tanks showed signs of being struck by rocket projectiles. Two had been disabled by US Army Air Force bombing, seven had been abandoned without a mark on them, and four had been destroyed by their crews. The fate of just three tanks was judged to be from unknown causes.[106]

The Army OR group was quite prepared to accept the argument that air power might be credited for some of the abandoned and crew-destroyed tanks. Their report, however, noted that these tanks could not be taken into consideration when comparing pilots' claims of having destroyed or damaged vehicles. Major Pike's dispassionate analysis of the evidence angered the RAF and provoked outrage at 2 TAF headquarters. An official air force review of the events was quickly developed. It is worth quoting at length:

Ground Investigation:

An attempt was made to examine the area on the ground within five days of the air attacks. However, at that time, fighting was still in progress and it was not until 20th August 1944 that the examination was completed. Nevertheless 39 tanks and 58 other vehicles, or the remains thereof, were examined. An analysis of the extent to which these were damaged is given below:

| | Destroyed | Damaged | Abandoned, Slightly damaged or untouched |
|---|---|---|---|
| Tanks | 24 | 10 | 5 |
| Other Veh. | 32 | 23 | 3 |

The German recovery service is remarkably efficient, and on this occasion there was very definite evidence that it had been as efficient as usual. Eye witnesses confirmed this fact. It can therefore be safely assumed that the vehicles found were only a small proportion of those actually destroyed and damaged, and probably an even smaller proportion of those which, although only slightly damaged, had been abandoned by their crews. To attribute destruction or damage to a particular arm or weapon is particularly difficult; however, taking into account the number of vehicles found, surrounded by rocket craters, and others with almost certain rocket or 20mm strikes, it appears that the claims were reasonable. It is inevitable that when a large number of aircraft are operating in a comparatively small area, that certain claims will be duplicated. There is no reason to believe, however, that on this occasion the duplication resulted in anything but a small over-statement of the damage inflicted.

Officers and other ranks who witnessed the attacks were effusive in their praise of their effectiveness. They freely admitted that had the counter-attack continued with the same determination as before the Typhoons had appeared, they would have been unable to repel it.[107]

This was a serious distortion of the evidence which the Army OR group could not let pass unchallenged. Major Pike, in his report, directly contradicted the RAF view:

> The efficiency of the German recovery system has been put forward as an explanation of the large discrepancy between the number of vehicles claimed to be destroyed and the actual number found. Tanks and lorries that are destroyed as a result of air attack are almost always burnt out and would not be worth salvaging unless time and labour were both very plentiful. Many prisoners have been questioned on the subject of the recovery of tanks and it has been established that burnt-out tanks are never salvaged. In addition it has been ascertained that, contrary to certain statements made about the Mortain battle, very little recovery was done in this part of Normandy at the time; in fact the repair and recovery teams were already pulling out of Normandy when the battle of Mortain was at its height.[108]

The Army OR group agreed that the Allied Air Forces had a "considerable effect" on the German attack at Mortain. But nothing remotely resembling the air force claims could be justified. Indeed, in many areas of the battlefield, no signs of the characteristic rocket crater could be found. The RAF ought to have accepted this view, for it knew from its own recent research that there were serious aiming problems with rocket (and bomb-equipped) Typhoons.

The most recent RAF study on the "accuracy of attacks" had been completed in June 1944. It showed that under the most favourable conditions average pilots were lucky to concentrate their rockets in a circle 150 yards in diameter. The report stated:

> In order to hit a small target with R.P. the pilot must be at the right height and dive angle, have the correct speed, have his sight on the target and the right angular depression on his sight, make the correct wind allowances and be free from skid or 'g'....
>
> All of these factors are important but it is very difficult for a pilot to have them all right at the same time.[109]

The report raised the question of what really happened in combat when the pilot was also being harassed by anti-aircraft fire. It concluded that previous views of the accuracy of RP attacks and of dive-bombing (which was even more subject to aiming error) were wrong. Such ideas must have been based on "the performance of a few very keen and experienced pilots who can hit small objects, such as tanks, with R.P.'s." Such men might be grouped into a "corps d'élite" capable of attacking special targets but only continual training and practice could improve the accuracy of most of the TAF pilots.[110]

The rival OR teams next raced north to examine the battlefield around Falaise and the roads leading to the Seine crossings. Here there were thousands of wrecked vehicles to investigate and a new round of argument over the role of air power to be waged. The army investigators would once again report that their three-week investigation established beyond dispute that the devastation of the German forces in the area known as the "Shambles" was not due to direct air attack. Only 11 of 171 armoured fighting vehicles examined had been hit by bombs or rockets. No doubt the air force had assisted in destroying German morale – strafing had accounted for a third of all soft-skinned vehicle losses – but, in the words of the OR report, the destruction of the German army had been achieved by "land action."[111]

The investigation of the Mortain battle continued to produce sparks. After one particularly nasty exchange, Brigadier Schonland suggested that "unless there were fairies in Normandy who could remove a large formation of tanks from the Mortain area,"[112] it was time to accept the evidence and act on the basis of fact, not fiction. But in the summer of 1944, 2 TAF was in no mood to discuss the issues raised by Army OR. In an official "Addenda" to the Army's *Report* the Air Force insisted that:

> It would be wrong to regard the data provided in this report as yielding information on which to make recommendations for changes in weapons, tactics or operational doctrine, although the factual side of the report can itself be accepted.[113]

If it was not permissible to use accepted data as the basis for recommendations about "changes in weapons, tactics or operational doctrine" then there was little point to further investigation of tactical air power. However, 21 Army Group was not about to give up its attempts to influence tactical air doctrine. A formal agreement was negotiated between Schonland and 2 TAF which provided for joint investigations of air operations against ground targets.

Air Force and Army OR researchers prepared four Joint Reports in the fall and winter of 1944-1945.[114] Again there was no disagreement about the evidence. For example, in Joint Report No.3 titled "Rocket-Firing Typhoons in Close Support of Military Operations," it was found that 350 rockets, involving 44 sorties, would have to be fired at a small gun position to obtain a fifty percent chance of a hit.[115] Typhoons were clearly weapons which were best used to reduce enemy morale and raise the morale of Allied infantry. Both doctrine and the manner of planning operations needed to be revised to take account of this new information as had been done in the US Ninth Air Force.[116] The RAF, however, would not budge. The German offensive in the Ardennes provided the section with another opportunity to study the hard evidence on the role of tactical air power and once again their findings challenged the accepted interpretation. Almost the entire section was involved in the ground search while D.N. Royce worked his way down the line of communications interviewing prisoners of war.[117]

If work with the tactical air force had limited operational value the same could not be said for the OR approach to mortar location. Michael Swann had developed a detailed knowledge of German mortars and his analysis of the methods used to locate enemy mortars was a classical example of operational research in the field. Swann's proposals are outlined in Report No.11 (Chapter 12) but the results of his inquiry, which had an immediate impact on the battlefield also need to be understood.

No.2 ORS's "Report on the Location of Enemy Mortars" was delayed by orders that the section give priority to a study of the effectiveness of heavy bombers in the land battle, so it did not reach the Counter-Mortar Committee of Second British Army until early August.[118] Brigadier Schonland was present to argue the case Swann had made and to add his own views about the role of radar on the battlefield. He

noted that the American SCR 584 was vastly preferable to the British or Canadian GL IIIs but none were available. The new British 10 cm equipment, the FA 3 which was mounted on a half-track, was well suited for employment in the field but the first three would not be delivered until mid-October. In the meantime it was important to organize counter-mortar units with a staff at divisional H.Q. and an officer with a small staff at each brigade. The Canadians had already added personnel to man specific counter-mortar listening posts and this system was adopted in Second British Army. The Corps Survey Regiment was to receive extra personnel and equipment to operate additional Four-Pen Recorder teams across the front. The Committee also decided to recommend the creation of a "Radar Battery" for each army "organized into 3 sections of 3 GL IIIs plus 1 spare." It was agreed that "in view of the extreme urgency of the problem there must be no lengthy haggling over details."[119]

By late September both 1 Canadian Radar Battery and 100 British Radar Battery were organized and a ten-day training course "in the theory and drill of locating mortars" was underway. At the divisional level, organizational changes were implemented in time to assist the British in the Arnhem salient and the Canadians in the battle of the Scheldt, but the two Radar Batteries were not ready for an operational role until January 1945.

The Canadian Radar Battery was deployed in the Nijmegen area in support of British and Canadian units of First Canadian Army. A scheme, Operation "Trojan," was devised to draw enemy fire and the radar sections pinpointed 19 locations in a three-hour period. Three weeks later they played an important role in Operation "Elephant," an attack on a small but well-defended German position at Kapelsche Veer. Two GL IIIs were deployed to cover the area across the River Maas and almost complete success was obtained in locating and relocating enemy mortars.[120]

The enemy quickly reacted to these and other examples of improved mortar location techniques by waiting for long intervals between rounds, or firing a few rounds before moving some distance away. Both of these counter-measures "worked" in the sense that locations were more difficult to obtain, but escaping detection is not the main task assigned to mortar crews.[121]

The real test of the new counter-mortar methods came in Operation "Veritable," the Anglo-Canadian attack down the west bank of the Rhine. Both the Canadian and British Radar Batteries were deployed to provide counter-mortar information and near complete success was obtained. The attacking infantry reached their initial objectives, consolidated and moved forward to the next phase without any interference from enemy mortars.[122] As the troops advanced south they moved out of range and the radar sets had to be moved forward quickly. One section working with 2nd Canadian Infantry Division came under heavy shellfire and two men were killed, though the set was not damaged and continued to report hostile mortar locations.

The Germans used enormous quantities of artillery, Nebelwerfer and mortar fire in resisting the Allied advance and there was constant pressure on all radar detachments until the battle ended in early March. Ten ton radar sets had limited mobility in the flooded Rhineland landscape but they were relocated in forward areas and made a significant contribution to reducing casualties and speeding the advance.

The relative success of post-Normandy counter-mortar techniques inevitably raises the question of why such a system was not in place earlier. All of the equipment actually used in 1945 was available in 1943 but the Army Operational Group was unable to persuade the Royal Artillery that the available radar equipment should be employed in the land battle. The Mk.III Gun Laying sets were in short supply and most of the available ones went to Anti-Aircraft Command and the Anti-Aircraft batteries for the defence of the Allied bridgehead in Normandy.

There were other reasons for the slow recognition of the part radar might play in artillery support of land operations. When scientists of the Army Operational Research Group began to investigate the accuracy of predicted artillery fire they found that the gunners, who saw themselves as the scientists of

the battlefield, had developed their techniques using a set of assumptions which rarely turned out to be as accurate as battle conditions demanded. The OR group fought a struggle, parallel to the one described here, to persuade the gunners to examine the results of predicted fire and to make use of radar in a number of ways including checking the RAF's "Meteor" messages which provided the essential information on air pressure, wind strength and direction. Members of No.2 ORS played a major role in converting the artillery to an operational research approach to gunnery but they could not accomplish this until the gunners themselves recognized the problem.

The section's artillery expert, John Fairlie, had to be hospitalized in England in September 1944. He was replaced by Major J.G. Wallace and Captain G. Mathieson, two Royal Artillery officers with AORG experience.[123] Their first investigation, which looked at the accuracy of a large predicted shoot in the Canadian battle to clear the Breskens Pocket, "proved nothing short of a bombshell." The report "showed the grossest of inaccuracies in many of the concentrations, far greater than ever had been suspected.[124] Fortunately the senior artillery officer at First Canadian Army Headquarters, Brigadier H.O.N. Brownfield, was anxious to make use of operational research and a good deal of attention was directed at improving accuracy.

The involvement of the OR team in the planning phase of "Veritable," the next major Canadian-British operation, was evidence of the growing reputation of the section. A major effort in battle research was planned in close co-operation with the staff of First Canadian Army. Work continued to the end of the war. When the section was disbanded in July 1945 it had completed more than 40 reports. Michael Swann, reflecting on what had been accomplished, was convinced that Operational Research had much to contribute to clearing up the uncertainties of war. He was equally convinced that the team's work had slight impact on military operations. Schonland, who was in a better position to judge, disagreed. He insisted that OR had influenced many aspects of 21 Army Group planning. Both men agreed that:

> the great thing that the ORS did was to show that an operational research section have as their first duty the rapid application of lessons learned from operations and they are able to derive such lessons in a form which will carry conviction. Every C-in-C and his Chief of Staff in a future campaign should be given a copy of *Operational Research in Northwest Europe*...[125]

Whether future C-in-Cs read the report or not, Schonland was right about the success of OR. A new discipline had been created and henceforth no modern military force would try to function without the aid of a large operational research team. Scientists had won the right to bring their methodologies to bear on the art of war.

## Notes

1. For an account of the origins of operational research see Joseph F. McCloskey, "The Beginnings of Operations Research 1939-1941" in *Operations Research*, Vol.35, pp.143-152; Air Ministry, United Kingdom, *The Origins and Development of Operational Research in the Royal Air Force* (London HMSO 1963), and C.H. Waddington, *OR in World War 2 Operational Research Against the U-Boat*, (London 1973).
2. Joseph F. McCloskey, "British Operational Research in World War II," *Operations Research* Vol.35, pp.453-470.
3. Ivor Evans, "The Beginnings of Operational Research," Unpublished Paper, 13 pages, Ivor Evans Papers, Imperial War Museum.
4. L.E. Bayliss, "The Origins of Operational Research in the Army," AORG Memorandum No.615, October 1945. Ivor Evans Papers, Imperial War Museum, p.2.
5. *Ibid.*, p.2.
6. Transcript of an Interview Terry Copp with D.K. Hill, 8 October 1990, 31 pages, p.2.
7. Bayless, p.3.
8. Evans, p.2.

9. Bayliss, p.3.
10. *Ibid.*, p.6.
11. R.B. Weber "The History of ORS 1(b)," in R.W. Shephard, *Readings in Early Military Operational Research*, (The Royal Military College of Science, 1984), p.111.
12. Solly Zuckerman, *From Apes to Warlords,* (London, 1988), p.398.
13. No author listed, "Operational Research in the British Army 1939-45," PRO WO 291/1301.
14. J.D. Cockcroft, "General Account of Army Radar," Cockcroft Papers 25/4, Churchill College Archives.
15. *Dictionary of National Biography 1961-1970*, p.761.
16. Biographical Memoirs of Fellows of the Royal Society "B.J. Schonland," 1973 Vol.19, p.269.
17. Interview with D.K. Hill. Interviews with others who worked with Schonland confirm this view.
18. "A Review of A.O.R.G. Sections and Their Work," July 1944. Ivor Evans Papers.
19. C.C. Varley, "Notes on the Work of A.O.R.S.2 of A.O.R.G. 1941-44," PRO WO 291/1290.
20. *Ibid.*, p.2.
21. *Ibid.*, p.6.
22. See for example, P.C. Varley, "Report on the Coast Artillery Action of September 3-4 1943," PRO WO 291/576.
23. P.M.S. Blackett, "Operational Research," p.26. Imperial War Museum.
24. *Ibid.*, p.29.
25. Sir Charles Darwin (1887-1962). Physicist, associated with Ernest Rutherford at Manchester University, 1910-1914. Officer, Royal Engineers WWI, specializing in detection of enemy guns by sound ranging. He held various scientific positions, 1914-1938 when he was appointed Director of the National Physical Laboratory. "He successfully reorganized the NPL for urgent war work and in 1941 was seconded to Washington for a year as first director of the British Office set up to improve Anglo-American scientific war co-operation...Involved in liaison over the Atomic Bomb... On returning to Britain he became Scientific Advisor to the War Office." He returned to the NPL in 1943 and was instrumental in the development of the first electronic digital computer available in Britain. He retired in 1947. *Dictionary of National Biography 1961-1970*, p.272.
26. Scientific Advisor to the Army Council [SA/AC], "Operational Research," WO291/1301.
27. The minutes of the Control Meetings, Army Operational Research Group are in PRO WO 233/22. It is evident that Darwin and Schonland had to tread very carefully.
28. Minutes of Control Meeting, AORG, 20 May 1943, PRO WO 233/22.
29. *Ibid.*, p.96.
30. Letter O.M. Solandt to B.J. Schonland October 1944. Solandt Papers, University of Toronto. Copies of the Solandt Papers related to war-time OR are in the author's possession courtesy of Dr. Solandt.
31. SA/AC "Operational Research...", 5. Reports include C. Powell, "Army-air Co-operation in the Western Desert," November 1942 PRO WO 291/1369; J.M. Whitaker, "Penetration of Minefields," January 1943, PRO WO 291/1298 and author unknown, "The Comparative Accuracy for Range and Line of the British 3" and German 81 mm mortars under field conditions," PRO WO 291/1370.
32. Hill Interview, p.15.
33. Omond M. Solandt (1909-1992) B.A. and M.D., University of Toronto, 1936. Research in physiology University of Toronto and University of Cambridge. Lecturer, University of Cambridge, 1939. Established and directed Medical Research Council (U.K.) Physiology Lab, Armoured Fighting Vehicle School, Lulworth, England. Armoured Fighting Vehicle Section AORG, 1943. Deputy Superintendent, AORG, 1943-44. Superintendent AORG, 1944-45. Colonel Canadian Army, 1944-45. Chairman, Defence Research Board, 1947-56. *Who's Who in Canada 1988*.
34. O.M. Solandt, "Analysis of AFV Casualties – 'I' Tanks Mk III 23rd Armoured Brigade, 22 July 1942," 19 December 1942, PRO WO 291/73.
35. O.M. Solandt, "Operations Research," unpublished address 1956, 6 pages Solandt Papers, p.3.
36. *Ibid.*, p.3
37. F.H. Hinsley, *History of British Intelligence,* Vol.2, Appendix 14.
38. J.G. Wallace, "Comparison of Methods for Tank Gunnery..." WO 291/78. H.A. Sargeaunt, "Errors in Visual Estimation of Range...and the Learning Curve with Practice and Training." WO 291/130.
39. "Lecture on Tank Operational Research," Solandt Papers.
40. No.1 Medical Research Section, Lieutenant-Colonel W.C. Wilson, Major E.T.C. Spooner and Major A.L. Chute arrived in Cairo on 31 May 1942 with a directive from the Army Council giving them facilities for entering battle zones and reporting directly to the Army Council and the MRC on urgent matters. The reports of No.1 MRS are in PRO WO 222/72 and 222/111. See also R. Shephard and E. Visco, "Injuries to Tank Crews: A New Collection of U.K. Data from WWII. "Shephard Military Operational Research Archives, Laurier Centre for Military Strategic and

Disarmament Studies [LCMSDS], Wilfrid Laurier University [WLU].

41. O.M. Solandt, "Tank Design," 27 March 1943. Solandt Papers.
42. O.M. Solandt, "Known Defects in British AFVs." This memo of November 1942 was sent to the Scientific Advisor with the March 1943 paper on "Tank Design." Solandt Papers.
43. Colonel Ross was Assistant Superintendent of Design, Woolwich Arsenal 1940-42 and British Chief Technical Liaison Officer with the US Army Ordnance Dept. 1943-45. Ross and Solandt maintained close contact. See G. Macleod Ross, *The Business of Tanks 1933-43,* (London, 1945).
44. Solandt, "Tank Design."
45. L.F. Ellis, *Victory in the West,* (London: HMSO, 1962). Vol.1 Appendix IV.
46. Henry Anthony Sargeaunt, b.1907. University College, Reading and Cambridge. After No.2 ORS was disbanded Sargeaunt enjoyed a lengthy post-war career in operational research. He became Superintendent of AORG 1947-1950 and Scientific Advisor to the Army Council in 1952. He subsequently served in a variety of posts including Chief Scientific Advisor to the Home Office 1962-1967. *Who's Who 1990.*
47. Interview, Terry Copp with Tony Sargeaunt, May 1990. Solandt Interviews.
48. See for example R.S. Whitney, "The Accuracy of Anti-Tank Gunnery..." PRO WO 291/213.
49. "History of ORS5." PRO WO 291/1287.
50. The quotations in the above paragraph are from the transcript of an interview Terry Copp with Lord Swann. Coln St. Denys, October 1989.
51. PRO WO 291/434 and 436.
52. Interview Terry Copp with David Bayly Pike, May 1990.
53. PRO WO 291/347.
54. J.W.S. Pringle, "The Work of TRE in the Invasion of Europe," *IEE Proceedings,* Vol.132, No.6, October 1985, p.351.
55. "History of ORS 5."
56. Swann Interview.
57. AORG Memorandum No.32, "Equipment-Miscellaneous," February 1943, Swann Papers. Copy in possession of author. Lord Swann permitted me to xerox relevant material from his papers in 1990. Copies may be found in the Shephard Archives LCMSDS. The AORG Memos are not included in PRO WO 291.
58. AORS6 Memo No.6. Swann Papers.
59. "LMG Fire Against Groups of Attackers in the Defence." Swann Papers. See also AORG Memorandum No.128 PRO WO 291/128.
60. "Note on Bombardment," April 1943. Swann Papers.
61. "The 3" Mortar White Phosphorus Bomb," AORG Memorandum No.42, April 1943. Swann Papers. See also AORG Report No.161 PRO WO 291/150.
62. Swann Interview.
63. "The Tactical Handling of the PIAT in the A/TK role." November 1943. Swann Papers. See also PRO WO 291/153.
64. "A Comparison of British and German 3" Mortars." Swann Papers.
65. "The Infantry Battle," 1943, Swann Papers.
66. "Reverse Slope Positions," 1943, Swann Papers.
67. "A Scientific Study of the Fire-Power of the Infantry Section," 1943, Swann Papers.
68. Swann interview.
69. PRO WO 291/371.
71. PRO WO 291/373 and 376.
72. AORG Unumbered Paper, printed in R.W. Shephard, *Readings in Early Military Operational Research*, (Shrivenham, 1984), p.223.
73. PRO WO 291/833.
74. I. Evans, "The History of AORS10 from July to October 1945," typescript 12 pages. Evans Papers, Imperial War Museum, p.1. Sir Charles Drummond Ellis, 1885-1980, Physicist. Graduate of the Royal Military Academy, Woolwich, Trinity College Cambridge. Cavendish Labratory 1920-1936, Deputy Scientific Advisor to the War Office 1940-1943, Scientific Advisor 1943-1945. Scientific Member National Coal Board 1945-1955.
75. PRO WO 291/737,738,739.
76. "Operational Research in the Army," p. 3.
77. *Ibid.*, p.14.

78. J.W. Mayne, *Operational Research in the Canadian Armed Forces During the Second World War*, DND, ORAE Report No.R68 1978 Vol. II. Directorate of History & Heritage [DHH], Department of National Defence, 79/558.

79. B.F.J. Schonland, "Some Recollections of My Time with 21 Army Group," typescript 2 pages, Schonland Papers, Imperial War Museum.

80. Evans, p.2.

81. Quoted in Schonland, "Some Recollections."

82. B.F.J. Schonland, "Operational Research with the 21st Army Group, British Liberation Army before and after the invasion of the Continent, June 6th, 1944," handwritten draft 6 pages. Schonland Papers, p.4.

83. B.F.J. Schonland, "On Being a Scientific Advisor to a Commander-in-Chief," typescript 18 pages, Montgomery Papers, BLM 140/6 Imperial War Museum.

84. *Ibid.*, p.12.

85. Patrick Johnson, 1904-1996. Physicist. Graduate of Magdelen College, Oxford 1928. Fellow Magdelen College 1928-1940. AORG 1940-1943. Officer Commanding (LCol) No.2 ORS 1943-1945. Director of Studies, RAF College Cranwell 1947-1948. Obituary, *The Independent*, November 1996.

86. Interviews, Sargeaunt and Solandt.

87. Personnel File, Major John F. Fairlie, National Personnel Record Centre. National Archives Canada [NAC].

88. Pike Interview.

89. Hill Interview.

90. Schonland, "On Being a Scientific Advisor..."

91. Terry Copp, ed., *Montgomery's Scientists: Operational Research in Northwest Europe - The Work of No.2 Operational Research Section with 21 Army Group June 1944-July 1945* (Waterloo, Laurier Centre for Military Strategic and Disarmament Studies, 2000), p.41.

92. Copp, ed., *Montgomery's Scientists*. The reports are reproduced in Chapter 9.

93. The Brigadier (SD) was responsible for reinforcements, establishments, the provision of equipment of every kind, and controlled the Weapons Technical Staff and the OR group except on matters related to air questions. Schonland, "Operational Research," p.6.

94. Copp, ed., *Montgomery's Scientists*, Introduction, p.42.

95. See Zuckerman, p. 272 for an account of the high-level investigation of the bombing in which Zuckerman, as Scientific Advisor to the Allied Expeditionary Force, took part. See also David A. Barnhill, *RAF Bomber Command and Tactical Air Support – Normandy 1944* M.A. Cognate Essay, Department of History, Wilfrid Laurier University, 1988.

96. Copp, ed., *Montgomery's Scientists*, Introduction, p.43.

97. Copp, ed., *Montgomery's Scientists*, Report No.14, "Heavy Bombing in Support of the Army," is a synthesis of knowledge obtained in July-August 1944. The Report is reproduced in Chapter 1.

98. Copp, ed., *Montgomery's Scientists*, The quotations in this and the following paragraph are from Report No.14.

99. Interview, Terry Copp with D.B. Pike, May 1990.

100. Air Marshal Sir Arthur Coningham, *Report Concerning Operations Carried out by Second Tactical Air Force between June 6, 1944 and May 9, 1945*. p. 11. PRO AIR 37/876.

101. Fighter Command Tactical Memorandum #30, March 1943, DHH 79/32.

102. *Ibid.*

103. Operational Research Section, Allied Expeditionary Force Report No.16, DHH 181/003 (D 342).

104. ORS, Allied Expeditionary Force (AEAF), "The Accuracy of Attacks on Small Targets by Fighter Bombers and R.P. Fighters," PRO AIR 37/653.

105. *Ibid.*

106. Copp, ed., *Montgomery's Scientists*, Report No.4. Chapter 3.

107. 2 TAF OPS, Appendix A to Tactical Bulletin No.45, "Tactical Equipment of Rocket Projectiles." PRO AIR 37/653.

108. Copp, ed., *Montgomery's Scientists*, Report No.4.

109. ORS (AEAF), "The Accuracy," p.2.

100. *Ibid.*, p.5.

111. Copp, ed., *Montgomery's Scientists*, Report No.15. Chapter 4.

112. B.S.J. Schonland to G.C. Oxborrow, 28 Oct. 1944, PRO WO 205/556.

113. Copp, ed., *Montgomery's Scientists*, Report No.15.

114. Copp, ed., *Montgomery's Scientists*, Chapter 4.

115. Copp, ed., *Montgomery's Scientists*, Joint Report No.3. Chapter 4.

116. There are many references to introduce Quesada's close co-operations with army units. See for example, R. Weigley, *Eisenhower's Lieutenants*, (Bloomington, 1981), pp.165, 166. See also Michael Bechthold "Close Air Support in Normandy: The Case of First US Army and IX Tactical Air Command, A Question of Doctrine, Training and Experience." WLU MA Thesis, 1993.

117. Copp, ed., *Montgomery's Scientists*, Chapter 2, Memo No.6 and Chapter 3, Joint Report No.3; interview, Terry Copp with D.N. Royce, London, 1988.

118. "Counter-Mortar," Minutes of Second Meeting, 21 August 1944, NAC RG 24 Vol. 10,464.

119. *Ibid.*

120. War Diary, 1st Canadian Radar Battery, NAC, p.12.

121. *Ibid.*, p.14.

122. *Ibid.*, p.17.

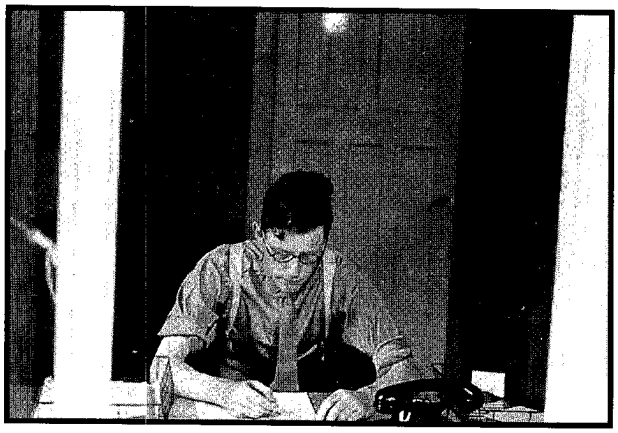
123. Swann Interview.

124. Copp, ed., *Montgomery's Scientists*, Report No.24. Chapter 6.

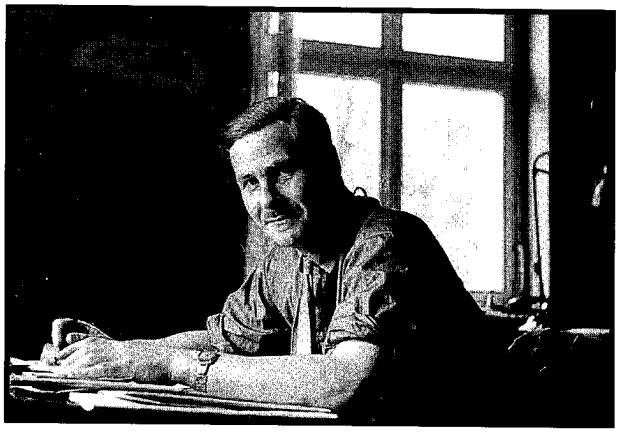
125. Schonland, "On Being a Scientific Advisor," p. 10.

| Army Operational Research Group Sections | | |
|---|---|---|
| **Section** | **Sub-Section** | **Function** |
| **AORS 1 Air Defence Radar** | AORS 1a HQ AORG, AA Command & School of Artillery | Performance of a modification to standard service Radar Equipment in AA & FA Roles. |
| | AORS 1b HQ AORG & AA Command | AA & SL Operations and Equipment trials |
| | AORS 1c Air Defence Division, SHAEF | Analysis of Continental V-operations |
| **AORS 2 Coastal Radar & Gunnery** | AORS 2A HQ AORG & Coast Defences | Performance of CD & CA Sets; Study of Anomalous Propagation |
| | AORS 2B HQ AORG & with CA Units | Analysis of CA Shoots and Trials |
| **AORS 3 Signals** | AORS 3 HQ AORG | Signals problems & performance of signals equipment in the field |
| **AORS 4 AFV FIELD A/Tk Artillery** | AORS 4A HQ AORG & Gunnery Wing; AFV School, Lulworth | AFV Gunnery, Tank Mobility & Tactical Problems |
| | AORS 4B School of Artillery, Larkhill | A/Tk & FA trials and problems |
| **AORS 5 Airborne Forces** | AORS 5 AATDC, Amesbury | Equipment & Exercises of A/B Forces |
| **AORS 6 Infantry** | AORS 6 Infantry Battle School, Warminster | Infantry Weapons and Tactics |
| **AORS 7 Lethality of Weapons** | AORS 7A HQ AORG | General mathematical problems, Fragmentation and Fuzes |
| | AORS 7B HQ AORG | Accuracy & Lethality of Artillery Fire, Field Trials & Exercises |
| **AORS 8 Problems of New Equipment** | AORS 8a HQ AORG & LAW AT & DC | Mines and Obstacles |
| | AORS 8c HQ AORG | Special optical aids & visual problems |
| | AORS 8d HQ AORG | Flame Throwers & Smoke |
| **AORS 9 Time & Motion Studies** | AORS 9 Whitehall Court | Time & Motion Studies of drill and uses of equipment |
| **AORS 10 Battle Analysis** | AORS 10 Whitehall Court | Analysis of Battle Records |
| **Library Publication, Photographic Liaison Section** | P & L HQ AORG | Publication of Reports & Memoranda; Circulation of information. |

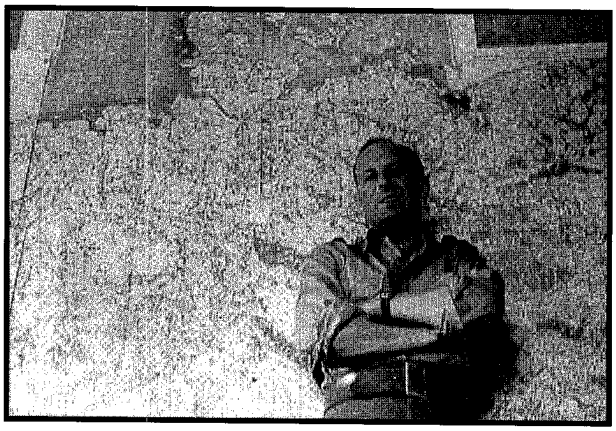
Adapted from R.W. Shephard, ed. *Readings on Early Military Operational Research (With Particular Reference to Army OR)* (Shrivenham, England: Royal Military College of Science 1984), p.97.



*D.K. Hill*



*D.B. Pike*



*Tony Sargeaunt*

*Mike Swann*

*John Fairlie*