Canadian Military History

Volume 4 | Issue 2

Article 8

1-23-2012

Some Personal Recollections of Army Operations Research on Radar in World War II

George Lindsey

Recommended Citation

Lindsey, George (1995) "Some Personal Recollections of Army Operations Research on Radar in World War II," *Canadian Military History*: Vol. 4: Iss. 2, Article 8.
Available at: http://scholars.wlu.ca/cmh/vol4/iss2/8

Some Personal Recollections of Army Operational Research on Radar in World War II

George Lindsey

Operational Research had its origin at the beginning of the Second World War, and made important early contributions to many aspects of the Air Defence of Great Britain, an activity of monumental significance in the war. Air defence depended for its success on the development of a command, control, communication and information system on a scale that had never been approached before. It also depended on other types of technology, such as high performance aircraft, air-to-air weapons and anti-aircraft artillery, and, most critically, on the new science of radar. All of these offered opportunities for applications of operational research, as did the study of tactics for individual engagements and of strategy for the optimum allocation of dangerously scarce resources.

Of the many technological developments that made advances throughout the course of World War II, radar was the one which saw the greatest improvement in capabilities and had the most significant influence on operations. The contributions of radar to fire control of weapons, and the direction and navigation of aircraft and ships, called for systematic studies of the technical design and performance of the radar, of the weapons depending on its information, of the capabilities of the human operators, and of the design and effectiveness of the entire system of which the radar was one vital part.

This provided a glorious opportunity for operational research. There was an atmosphere of extreme urgency. There were no worries about budgets. There was no time for extensive instrumented field trials or operational evaluation–new equipment was rushed into service. The data on effectiveness under field conditions was obtained from real operations.

In earlier years it was possible to find people who held senior positions in organizations conducting important military operations, and could therefore give a first hand account of the critical decisions and results as seen "top down" from the highest level. But if one wants to go back as far as World War II, where operational research was born, it is getting increasingly difficult to find survivors who held senior appointments in the early 1940s. I am not one of these. However, I was fortunate enough to have been able to participate in operational research during World War II at a junior level, and to have spent most of the half century since then in the study and practice of military OR.

I am going to describe a few incidents which occurred in the life of a junior army officer engaged in military operational research on the applications of radar to air defence, during an extremely active period. So what you are going to receive is a bottom-up worm's eye view of operational research during its interesting pioneer period fifty years ago.

* * * * *

As Britain mobilized for war, both the Royal Navy and the Royal Air Force foresaw the coming importance of radar and the need for personnel with the technical background that would be necessary to operate and maintain the succession of new types of equipment that would follow one another as the radically new technology progressed. Britain's

© Canadian Military History, Volume 4, Number 2, Autumn 1995, pp.69-74.

scientists were quickly directed into a variety of wartime activities, with the RAF getting most of those whose backgrounds were related to radar. A request was made to Canada to provide suitable people. Several Canadian universities identified students nearing graduation in physics, engineering, and mathematics, and organized a series of courses. The Navy recruited the first batch, and at one time every capital ship in the RN had a Canadian radar officer. Later the air force and the army had their turn.

Nobody really knew who would be in charge of radar in the Canadian army. The Royal Electrical and Mechanical Engineering Corps (REME) had not been invented. Signallers were believed to know something about electricity and wireless, but the army wanted to use their radars to direct gunfire. My badges were changed from University of Toronto Canadian Officers' Training Corps to Royal Canadian Corps of Signals, and then to Royal Canadian Artillery.

After I graduated from basic courses for coast defence and anti-aircraft artillery, and a very good course on army radar, I was listed as a Lieutenant (EMFC). The term stood for "Electrical Methods of Fire Control," a term that was intended to fool the enemy, but sometimes resulted in expectations that my job was to put out fires in the barracks. The word "radar" was secret, although we could talk about "radio location."

The magnetron was so secret that one of my early duties was to guard a magnetron with a pistol for every minute of its journey from Ottawa to a coastal defence battery in Halifax, where an experimental fire control radar, based on a new centimetric set designed for anti-aircraft use, was to be tested. The regular battery officers were absolutely confident of the infallible accuracy of their optical fire control, which was based on combining the bearings observed from two telescopes sited at the mouth of the harbour. They resented the intrusion of this crazy newfangled invention. The final test came when the guns fired 9.2-inch shells at a small towed target, using radar information. In the test, the fall of shot (easily visible both optically and by radar), straddled the target, but the battery declared the radar to be a failure since the target had not received a direct hit. We asked Halifax Fortress to show us their optical plot, so we could compare it with our radar plot. This was refused. Later a friendly spy revealed that one of their telescopes was reporting true bearings and the other magnetic bearings, with the resultant plot making its way over dry land. Fortunately no German battleship came to provide another test of the coastal defences of Canada.

In 1943 I was posted to the British Army Operational Research Group, to work in the section responsible for air defence and radar. The activities included the operation of recording vans on Heavy Anti-Aircraft (HAA) gunsites deployed all over Britain. These vans made photographic records of data from the radar, predictor, and guns, taken during an engagement. The analysts then reconstructed the behaviour of these devices, and estimated where the target had been and where the shells had burst. Errors made during each engagement could be assessed. Data pooled from many engagements was analyzed to detect trends, including changes in enemy tactics.

The complicated process of the radar fire control of HAA contained errors in many steps. Electrical and mechanical calibrations were not perfect. Human operators, of whom there were many in the systems of those days, could not track the fluctuating radar echoes from moving targets or match the moving pointers on dials perfectly. The fuse setter added delays and made small errors. The predictor's output depended on an assumption regarding the motion of the target while the shell was in flight.

Many of the errors introduced by humans were reduced by increasing the degree of automation. Radar data could be fed directly into the predictor, and the motion of the guns and the setting of the fuse could be made automatic and slaved to the predictor commands.

A memorable incident occurred during the program to make the guns follow automatically. A demonstration was organized to display this wonder to a high-ranking group of visitors. On a clear day they gathered around the guns, observed the radar acquire a track, saw the target tow cross well within range and watched the guns move steadily and remorselessly in response to their automatic instructions. They continued to watch in surprise as all of the guns suddenly elevated to 90° and fired a vertical salvo. When the visitor's ears had stopped ringing they discussed this unexpected event for a few seconds, until one of them remembered that what goes up must come down, whereupon they abandoned their dignified demeanour and demonstrated remarkable abilities to sprint in all directions.

Automation introduced its own problems in many ways. For example, radar signals tend to fluctuate, so that their indications jitter about the correct values, while the predictor needs steady input or it will produce wildly changing estimates of future position. The input data can be smoothed by a human operator, which requires judgement, or it can be fed through an electrical filter, set to smooth over a selected time period. But what is the best time constant? Too short and there is the unwanted jitter. Too long and there will be a sluggish response to a real change in the course, height, or speed of the target. A compromise was attempted with "rate-aided laying," which caused the reading to change at a constant rate until the operator moved his control, at which time an immediate shift in position was combined with a small change in the rate. But what should be the proportion between Delta x and Delta x dot? A major step was to make the radar follow automatically, but this made it vulnerable to ejection of what is now called chaff from the target, which could seduce the radar to follow the strongest echo in the vicinity, quite likely to be a bundle of chaff.

I vividly remember one visit to a four-gun 3.7-inch HAA gunsite near London soon after the Luftwaffe had started to use chaff. We picked up an approaching bomber and followed it smoothly. I was watching the A-scope tracking the range. All of a sudden the radar blip started to multiply and leave replicas of itself behind. The operator continued to track the leading blip, which was reflected from the aircraft, whose bundles of chaff were soon left behind in the slipstream. Then the guns opened up, with a most peculiar tune in four-four time; three great

2nd Lieutenant George Lindsey, Royal Canadian Artillery, 1942 booms followed by a hollow bonk as if someone had struck a hollow drainpipe. This got my close attention, since I had just been reading a report about dangerous wear in barrel liners, causing premature explosions at the gunsite. New liners were in short supply, so that changes were made one gun at a time. Obviously, the number four gun in our battery was overdue for a liner change.

The Vickers and Sperry AA predictors were marvels of mechanical ingenuity. They were special purpose real-time analogue computers, long before digital technology or semiconductor chips had been invented. Their variables were processed in the form of shaft rotations, their memories were stored on three-dimensional cams whose shapes represented ballistic data and trigonometric functions, and their programs were embedded in the mechanical linkages. They were advertised as soldier-proof, a foolish boast which proved to be untrue. Their successors, the Bedford-Cossor and the Bell Telephone Labs BTL, were electrical analogue computers, whose data were recorded as voltages, memories were in potentiometers, and programs in hard-wired circuitry.

All predictors had to be provided with an assumption (which would now be called an algorithm) regarding the future motion of the moving target. The simplest hypothesis was that the target would maintain the same course, speed, and height that it had at the moment that the fuse was set. But the pilot could falsify that assumption by taking evasive action, although this might spoil an accurate bomb run. Prediction along the tangent to the track would cope with a steady descent on a constant bearing, but would produce a future position that would oscillate wildly ahead of a snaked track, and would never be correct against a helical track. It could predict along a chord, but what chord? Today such problems would be classified as artificial intelligence.

A solution to this problem of evasive action was offered by the Crabtree predictor, which allowed a human operator to place his personal estimate of the future position on a plot, and then direct the guns to hit that spot. An experimental mockup was built, and an RAF pilot, who it was hoped might have psychic powers regarding the habits of his Luftwaffe counterparts, practised his skills against British bomber pilots, and predicted their manoeuvres with remarkable success. The equipment was installed on a gunsight in London, with the latest twin 5.25-inch naval AA guns, and the next real air raid eagerly awaited. Alas, the Luftwaffe did not oblige for a long time. Finally the sirens went, a detection was made on the radar, and a hostile target approached the gunsite. The psychic pilot commenced his duties, concentrating with extraordinary skill, oblivious to the excitement of the rest of the team, and successfully forecast every manoeuvre of the German bomber. Finally the bomber disappeared from the display, the pilot looked up, exhausted but elated and inquired "How did I do?" The answer was "You never gave us the order to fire!"

The cumulative results of experience, and technical improvements, aided by operational research, increased the effectiveness of AA Command against German bomber aircraft between 1941 and 1944 by a factor estimated to be between four and five.

The Air Defence of Great Britain encountered a new challenge in 1944, just after the launching of the D-Day cross-channel invasion of France. The V1 unmanned pulse-jet flying bomb, in today's terminology a Ground-Launched Cruise Missile, provided a target for air defence that was easier in one respect, in that it took no evasive action, but more difficult in several others, in that it was smaller and faster than the bombers of the day, flew at an altitude that was too low for easy engagement by HAA but too high for Light Anti-Aircraft (LAA), and was likely to inflict serious damage even if brought down by AA fire unless its warhead was detonated in the air.

The new threat caused AA Command to make major redeployments of the forces which had been stationed in static sites for the defence of British cities. Only cities in the south of England were within range of the V1 launch sites in France, and of these by far the most important target was London. Once a V1 reached London it was not useful to shoot it down and have its bomb detonate in the city; it was better to leave it alone in the hope that it would keep on going and land in the open country to the north of the city.

The first strategy was to move the guns from all over Britain to the North Downs, between London and the Channel, with fighter aircraft operating to the south and barrage balloons to the north of the gun belt. An immediate difficulty arose due to the rolling hills in the area and the low altitude of the approaching V1s, which did not enter the lowest radar beams and clear the ground clutter until they had penetrated to very close range. An improvement was obtained by installing a large horizontal wire screen around the radar site, a practice that had been adopted earlier for fixed sites around cities, and adding a low vertical wire fence at the perimeter of the screen. The resulting diffraction pattern of the radar energy allowed a concentrated lower beam to escape the ground clutter but achieve early detection of the small approaching target. Nevertheless, the results were disappointing, and other difficulties of an operational nature were encountered in demarcation of the boundaries of operating zones for guns and for fighters. Overall, the fighters obtained better results than the guns.

I remember receiving a decidedly chilly welcome in a town in Sussex, whose inhabitants disapproved of the attempts of the gunners to bring the V1s down into their town, instead of letting them proceed on to London. I also remember watching a V1 land in London about a mile away from where I was standing, saw a dark spherical shock wave expanding into the sky from the point of impact, then felt the shock wave coming through the ground, with my feet, and later heard and felt the blast propagated through the air.

As well as attempting to make HAA operate at altitudes below those for which it was most effective, efforts were made to improve the capabilities of LAA at altitudes higher than those for which it had been designed. The 40 mm shells for the Bofors guns were contact-fused, so that there was no time fuse to set, but to damage the target a direct hit was necessary. Ranges and times of flight were short, and optical tracking in bearing and angle of sight was quite accurate. The Kerrison LAA predictor would work reasonably well if fed with accurate range data, but the various optical methods of estimating range were crude and notoriously inaccurate. As a solution it was suggested that a simple radar range-only set designed for the tail gun turret of Lancaster bombers, whose gunners could also track direction optically but required accurate range data, should be mounted on the Kerrison predictor. I participated in the work at Telecommunications Research Establishment (TRE), which had designed the aircraft radar, and were preparing to modify the equipment for the AA predictors in their own model shop. I then went to LAA sites to observe their operations. I remember one night watching a V1 make a low approach directly over our gunsite, and being engaged with very visible tracer-equipped shells. I also remember eagerly anticipating a hit, and then suddenly wondering what would happen after we hit the target. I never found out.

The unsatisfactory deployment of the AA gun zone south of London was radically corrected, by moving all calibers down to a narrow belt right at the channel coast, from where they could have an unobstructed line of sight over the water with no obstacles, and on a clear night even see the V1s almost as soon as they were launched from France. V1s damaged by AA fire usually fell into the sea. Two other factors were also changed for the better. American SCR-584 radars with fully automatic tracking and data transmission were deployed in large numbers, and the guns were armed with the new and very secret proximity fuses. It was an AA gunners' paradise. (Lesser branches of the army, and all branches of the air force, maintain that anti-aircraft gunners never go to Paradise, but I now know that this is not true.) I remember looking along the channel coast on a clear night and seeing seven V1s in flight at the same time, greeted by a spectacular display of fireworks, including 20 mm shells landing in the water at about 1/3 of the range to their target, 40 mm tracer passing very close to their targets, 90 mm and 3.7-inch proximity-fused shells detonating about 50 feet above the water well beyond their targets, other HAA shells bursting very close to the targets, and occasionally a wonderful giant explosion when a V1 warhead was detonated. After that Guy Fawkes and the 24th of May have never seemed very impressive.

In addition to its investigations of air defence, Army Operational Research Section 1 (AORS1) made some studies of the use of radar in support of field artillery. It was suggested that mortar bombs, which were causing severe casualties to infantry in the Far East, might be tracked in their slow high parabolic trajectories, and the launcher located for counter fire. But the mortar bombs were very small and the polar diagram of the radar reflections would depend on the precise shape and angle of observation. We needed to measure the reflections from a real Japanese mortar bomb. One which had been captured in Burma was available in an ordnance establishment near London, and I was provided with a jeep and told to go and get it. It had a rather sinister appearance, with Japanese stencils on it, and the explosives expert who was about to give it to me seemed to treat it with considerable caution. I explained that we were only interested in its outer casing, nose, and fins, and had no interest in its interior. He asked me if I planned to remove the fuse, detonator, and high explosive. This was not the way I had planned my day, and I explained that our laboratory was lacking some of the necessary equipment and asked him if he could possibly save us some time and do this for me. This he did, with me as a very attentive and alert bystander. I noticed that he held the fuse between his thumb and little finger, which seemed an odd grip for something not to be dropped. He explained that if it went off he might save one or two fingers that way. I was content to bring the bomb back to Ibstock Place without its innards.

When the Canadian Army decided to establish its own Army Operational Research Group and prepare to move its operations to the Pacific Theatre, I was posted back to Canada.

This account has focused on the type of operational research that is closely associated with the technical performance of equipment forming an element of a complicated system. At the time, many functions which had been performed by humans, with inevitable inaccuracy, were being converted to automatic operation, which removed errors, but sometimes introduced new problems involving the need for human judgment.

The type of problems with command, control, communication, and information systems being discussed fifty years later have some of the same elements. Operational Research will be needed, and the practitioners may have to become very knowledgeable regarding the technical performance of the various types of equipment involved in the systems. Exercises must approximate the operational situation as closely as is possible in peacetime. But the studies may not be as exciting as they were in AORG in 1944.

This paper was first presented at the Eleventh International Symposium on Military Operational Research, Royal Military College of Science, Shrivenham, England in September 1994.

George Lindsey holds degrees in mathematics and physics from the Universities of Toronto and Queen's, a PhD in nuclear physics from Cambridge, and is a graduate of the National Defence College. He served in the Royal Canadian Artillery in World War II and with the British Army Operational Research Group and the Canadian Army Operational Research Group. After the war he held various appointments with the Department of National Defence. Following his retirement he has carried out studies for the International Institute for Strategic Studies in London, the Canadian Institute of Strategic Studies in Toronto, the Canadian Institute for International Peace and Security, and the Verification Research Unit of External Affairs and International Trade, Canada.