

## THE BEGINNINGS OF OPERATIONS RESEARCH: 1934-1941

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This paper, the first in a series on the history of operations research and management science, traces the scattered beginnings of operations research from World War I up to the activities in Britain before and during the early months of World War II.

Operations research was born of radar on the eve of World War II. But its advent was forecast before and during World War I in connection with three technologies introduced during that war: the dreadnought, the aeroplane and the submarine.

The dreadnought (a large battleship armed with heavy caliber guns in turrets) was the product of studies by Admiral John Fisher while he was superintendent of Britain's Portland naval base. With the Royal Navy finally divorced from wind and sail, Fisher and a small group of associates recognized the tendency to design warships in terms of the available technology rather than in terms of strategic and tactical requirements. This group designed a new navy, with far fewer ships in commission, with heavy reliance on reserve ships and personnel, and with vessels that met the requirements of war at sea. When Fisher became First Sea Lord in 1904, he was in position to move his "Grand Design" from plan to reality, and it was essentially Fisher's navy with which Britain fought World War I.<sup>1</sup>

The aeroplane interested F. W. Lanchester, a pioneer in the motor car industry who had also made fundamental contributions to aeronautical theory. He developed his  $N^2$  law to describe the outcome of military actions, relating victory to numerical superiority, superiority in firepower, and concentration of forces. He illustrated his theory by examples from

conflict on land and sea and predicted that, in future times, the outcome of great battles would be determined by the "efficiency of the aeronautical forces." Lanchester's work had no effect on operations in World War II, but it now occupies an honored place in operations research.<sup>2</sup>

In 1915, Lord Tiverton, who in 1921 was to succeed his father as the Earl of Halsbury, began a detailed study of strategic bombing. In September 1917, he submitted a report to the Air Board that dealt with target selection, methods of navigation, weather, and logistical problems. He argued in favor of daylight bombing because of the characteristics of available aircraft, the training of crews, and problems of maintenance. He also suggested that all available aircraft should concentrate on a single target on any single day, thus anticipating the rationale that led to 1,000 plane bombing raids during World War II.<sup>3</sup>

In the realm of anti-aircraft operations, A. V. Hill headed the experimental section of the Munitions Invention Department of the British Army, and his unit came to be known as "Hill's Brigands." They studied anti-aircraft gunnery and developed tactics and procedures that enhanced the effectiveness of anti-aircraft fire. We shall meet up with Hill and some of his Brigands later in this story.<sup>4</sup>

To complete this brief review of the World War I precursors of operations research, we look to the efforts of Thomas A. Edison as head of the U.S. Naval Consulting Board. He developed statistics to aid in evasion and destruction of submarines, used a "Tactical Game Board" for solving problems of evading submarine attack, and analyzed zigzagging as a method of protecting merchant shipping against

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submarines.<sup>5</sup> Ronald W. Clark credits Edison with a significant role and characterizes this aspect of his work as “nothing less than an early piece of operational research.” He points out that Edison studied sinkings by submarines and that “one startling discovery emerged: most ships were still following prewar routes and it was on these routes that most sinkings occurred. Another point was that, while only 6% of sinkings took place at night, most vessels were still traversing the danger zone in daylight.”<sup>6</sup>

During the interwar years, nothing of significance to the history of operations research was done in these areas; at least, nothing has come to light. And this despite continued progress in the development of aircraft and submarines, surface vessels, tanks and other vehicles of land warfare, and radio and telephone. The designers led, the tactics lagged, and effective countermeasures were virtually nonexistent.

As for countering aircraft, Stanley Baldwin, a former and again-to-be British Prime Minister, summed up the 1932 position succinctly: “The bombers will always get through.” That estimate was made somewhat more comfortable by the “official” assumption (as a basis for military budgets) that there would be no war for 10 years.

Work was under way on acoustic devices to provide early warning of the approach of aircraft, but the range of these devices was limited and they were sensitive to ground noises. Good work was being conducted on aircraft and on the tactics to be employed by fighter aircraft against intruding bombers, but there seemed to be no way around the requirement for standing patrols. The advantages of barrage balloons had also been recognized. Nevertheless, Britain’s position was becoming increasingly perilous.<sup>7</sup>

There were voices abroad in the land calling for action and specifically for greater reliance upon scientists. Foremost among them was Winston Churchill (not then a member of the Government), prompted no doubt by his friend and personal scientific adviser, Frederick A. Lindemann, later Lord Cherwell. Both wanted action in support of increased scientific endeavor before abandoning the field to the bomber.<sup>8</sup>

Their concern may have influenced A. P. Rowe, then assistant for armaments to H. E. Wimperis, Director of Scientific Research in the Air Ministry. He was certainly influenced by his own convictions about the value of civilian scientists to the military. In any event, after witnessing a demonstration of the acoustic mirrors then being installed on the south coast of England, Rowe, on his own initiative, went through all 53 files on activities within the Air Ministry relating to air defense. He found little to encour-

age him and so wrote a memorandum to his superior. He stated very bluntly that, unless the scientific community could come up with something new with which to counter the bomber, Britain would lose any war that started within the next 10 years. This was June 1934.<sup>9</sup>

### The Tizard Committee and Radar

In November 1934, Wimperis acted. He recommended that a Committee for the Scientific Study of Air Defence be created to “consider how far recent advances in technical knowledge can be used to strengthen the present methods of defence against hostile aircraft.” Lord Londonderry, Secretary of State for Air, approved, and the committee was formed. Henry Tizard accepted the chairmanship. The other outside members were A. V. Hill and P. M. S. Blackett. Wimperis represented the Air Ministry, and Rowe served as secretary. Because of its accomplishments, this committee, usually identified by its chairman’s name rather than by its mission, must be rated as one of the most unusual and successful bodies of its kind that has ever existed.

Tizard was a chemist, Rector of the Imperial College of Science and Technology, and a World War I test pilot. Hill was a physiologist, a professor at University College and, at the time, the most distinguished and internationally best known of the members of the committee, having shared the Nobel Prize in physiology and medicine in 1923. I have already touched on his World War I service for the Army. Blackett, gaining recognition as one of the best of the younger men in physics, had served in the Royal Navy in World War I. His distinction in operations research and his Nobel Prize in physics were in the future.

Wimperis was an engineer and inventor. He is known for the Wimperis accelerometer and for the course-setting bombsight that he developed for the Air Service in 1917 (it remained in use until 1939). He had been appointed the first Director of Scientific Research in the Air Ministry in 1924. Rowe, at the time of his appointment as secretary of the committee, was a civil servant of no particular distinction. As with Blackett, his great contributions lay in the future, as superintendent of the Air Ministry Research Station at Bawdsey and of its successor (after several changes of name and location), the Telecommunications Research Establishment (TRE), from 1938 until the end of the war.

At Hill’s suggestion, and before the first meeting of the Tizard committee in January 1935, Wimperis approached Robert Watson-Watt, superintendent of

the Radio Department of the National Physical Laboratory, about the feasibility of “death rays,” a perennial favorite of amateur inventors. Watson-Watt and his assistant, A. F. Wilkins, made some calculations and concluded that there then existed no means of incapacitating a crew or disabling an aircraft by radiation. But Watson-Watt added a paragraph to his report to Wimperis suggesting that reflected radio waves might be used to *locate* aircraft.

At Wimperis’s request, Watson-Watt expanded on his idea and it became the principal item on the agenda of the first meeting of the Tizard committee. One month later, an experiment, conducted by Wilkins and witnessed by Watson-Watt and Rowe, was carried out, using a transmitter near Daventry as the source of radio waves. The crude receiver that had been assembled for the test detected a plane, whose pilot was unaware of the reasons for the course he was flying. Rowe’s report to the committee was favorable, and work on radar was pressed from that time on (as RDF, for radio direction finding, until adoption of the U.S. name).<sup>10</sup>

Watson-Watt was not a member of the Tizard committee, but his concept of radar gave the committee point and purpose. He had served in World War I primarily in meteorological posts. He had participated in the work that had gone on in the 1920s on the measurement of the Heaviside layer, and knew of other work with radio that laid the foundation for radar. There is some controversy about his contributions to radar and operations research,<sup>11</sup> but without his particular genius, the Tizard committee might have been just another committee. On the other hand, without the influence, access, and drive of the committee and especially of its chairman, Watson-Watt’s ideas might have suffocated in the machinery of bureaucracy (as had happened with earlier work on reflected radio waves, and particularly that of W. A. S. Butement and P. E. Pollard).<sup>12</sup> As it is, the Tizard committee and Watson-Watt, working together, deserve a significant share of the credit for Allied victory in World War II.

The path of the Tizard committee was not completely smooth, however. Shortly after it was formed, Churchill insisted that Lindemann be made a member. Lindemann felt very strongly that high priority should be given to developing aerial mines and infrared devices; he was also critical of the slowness with which the committee moved. Because the committee maintained its priority on radar, Lindemann became increasingly critical and shared his criticism with Churchill, who would then air Lindemann’s views about the committee and its workings in meetings of

the Subcommittee on Air Defence of the Committee of Imperial Defence, of which Tizard was also a member.

By September 1936, this situation reached the point where the public members resigned and the committee was dissolved—only to be reconstituted immediately with its original membership, plus Edward A. Appleton, Britain’s foremost authority on radio and a future Nobel laureate in physics (1947).<sup>13</sup> That Lindemann remained opposed to radar, as some have claimed,<sup>14</sup> is belied by his support of Watson-Watt and by his subsequent strong interest in Bomber Command of the Royal Air Force (R.A.F.) and its need for radar. I will have more to say on this subject.

Despite the problems within the committee, work was moving forward on radar. An “Ionospheric Research Station” had been established at Orfordness, on the east coast of Britain. It was staffed by Watson-Watt on a part-time basis, by Wilkins and E. G. Bowen, all transferred from the Radio Department, and by a few assistants. Within a few months, the organization was moved to Bawdsey Manor, nearby, and was renamed the Bawdsey Research Station, with Watson-Watt, now transferred to the Air Ministry, as superintendent. By this time, construction of a chain of radar stations to be located along the east and south coasts had been approved, with the first one to be located at Bawdsey.

### Radar and Fighter Control

As the possibilities of a radar-aided defense began to take shape, Tizard recognized that radar had created a whole new set of problems in fighter direction and control. Accordingly, he began a series of experiments at the R.A.F. Fighter Command station at Biggin Hill, starting in the latter part of 1936 and lasting for nearly 2 years. Inasmuch as the first radar station was not operational when these trials began, artificial information of the type that radar was expected to supply was passed to the control center at Biggin Hill so that new methods of interception could be devised. This work was under the immediate supervision of B. G. Dickins, an engineer from the Royal Aircraft Establishment at Farnborough.

The Biggin Hill experiments integrated radar into the early warning systems, which included the Observer Corps, and into fighter direction and control. They obviated the need for standard patrols of fighter aircraft and the coincident constant alert status of antiaircraft gun crews. *And they started operations research.*<sup>15</sup>

While the Biggin Hill experiments were in progress,

the radar station at Bawdsey was finished (1937) and the complete radar chain was ready by the summer of 1939. Meanwhile, early in 1938, Rowe was transferred to Bawdsey as assistant superintendent and, when Watson-Watt was transferred to the Air Ministry as Director of Telecommunications Research, Rowe became superintendent.

### The Recognition of "Operational Research"

One of Rowe's first acts after moving to Bawdsey was to assure the continuation of the work that was concluding at Biggin Hill. He assigned E. C. Williams and G. A. Roberts to do "operational researches" on the control room and the communication system, respectively. Williams was the first scientist from a university to join the Bawdsey staff. Roberts was a telephone engineer. Their assignments represent the first known use of the term "operational research."<sup>16</sup>

In a sense, the task assigned to Williams was the more significant in terms of the development of OR, for he analyzed and compared the performance of the several control centers that had been established in order to identify factors that could explain differences. Thus, there was no direct developmental objective in the work; rather it was a case of "doing the best you can with what you have." Roberts, on the other hand, became involved in development and created an electrical converter that simplified the transmission of radar data to the control centers.<sup>17</sup>

During this same period, Tizard interested John Cockcroft, a professor of physics at Cambridge, in what was going on at Bawdsey. Some visits involving scientists from Cambridge were arranged, but secrecy was a problem and nearly a year was to pass before the decision was made to reveal the secret of radar to scientists outside the government. By that time, scientists not only at Cambridge but also at Oxford, Manchester, Birmingham, and London had become involved. As a result, some 80 scientists reported to Bawdsey on September 1, 1939, to spend a long vacation on the radar sites.<sup>18</sup> For some, the vacation proved long indeed!

Shortly before the arrangements for the university scientists to spend time on the radar sites had been completed, Rowe took another step in his sponsorship of operations research. He entered into agreement with Raymund G. Hart, a Royal Air Force squadron leader, to assign some of his staff to Fighter Command headquarters at Stanmore immediately upon the outbreak of war. As it happened, Williams and Roberts were already there for the 1939 summer air exercises, continuing their work on the control room and on

communications. Harold Larnder was sent to Stanmore immediately after September 3, 1939, to head the group, to include Williams and Roberts as well as J. C. Bower, I. H. Cole, and W. E. Egner, all of whom were destined to head OR sections in various commands.<sup>19</sup>

Because this agreement between Rowe and Hart represents a milestone in the development of operations research, Rowe's observations are of interest:

By this agreement I hoped to give and to get. I hoped to give Fighter Command the services of men who had an intimate knowledge of the performance of the radar chain and who had, as scientists, been trained to use their analytical faculties; and I hoped to get from my detached members of staff the true facts concerning the operations against the enemy, and so enable the Bawdsey staff to be permeated with an intimate knowledge of the needs of Fighter Command.<sup>20</sup>

Larnder's group remained a part of Rowe's organization for nearly a year, operating as the Stanmore Research Section. During that time, the calls on its services began to move away from the original exclusive concern with radar and into different and more general problems. Thus, during the Battle of France, British and French losses in aircraft were heavy, but the French kept asking for more and more fighter support. The Stanmore Research Section was asked to evaluate the situation. The analysis showed that additional transfers would involve attrition that could not be made good and that Fighter Command would be weakened beyond recovery in the face of the likelihood of a German attempt to invade Britain.<sup>21</sup> Of this situation, Churchill has written:

The hard question of how much we could send from Britain without leaving ourselves defenceless and thus losing the power to continue the war pressed itself henceforward upon us. Our own natural promptings and many weighty military arguments lent force to the incessant, vehement French appeals. On the other hand, there was a limit, and that limit if transgressed would cost us our life.

At this time all these issues were discussed by the whole War Cabinet, which met several times a day. Air Chief Marshal Dowding, at the head of our metropolitan fighter command, had declared to me that with twenty-five squadrons of fighters he could defend the island against the whole might of the German Air Force, but that with less he would be overpowered. This would have entailed not only the destruction of all our airfields and our air power, but of the aircraft factories on which our whole future hung. My colleagues and I were resolved to run all risks for the sake of the battle up to that limit—and those risks were very great—but not to go beyond it, no matter what the consequences might be.<sup>22</sup>

The support given to Dowding by Larnder and his people “was a notable milestone in the progress of the idea of operational research”<sup>23</sup> and led to the decision to transfer the group formally to Fighter Command and to designate it the Operational Research Section (ORS) Fighter Command. (It would appear that Rowe’s original use of the term operational research had dropped out of use and that it was revived by Larnder.<sup>24</sup>)

### Scientific Analysis in Warfare

While operations research was thus developing and finding a place within the structure of the Royal Air Force, other developments destined to have direct or indirect bearing on OR were taking place. Thus, in 1937, B. H. Liddell-Hart, one of Britain’s most influential military thinkers, submitted a memorandum to the Secretary of State for War that merits quotation at length:

The more one examines the course of past wars the more one is impressed by the frequency with which military policy and preparations have taken the wrong turning. And this abnormal percentage of error can be traced to the habit of basing policy and preparations on an assumption, without adequate verification. The way that decisions are reached on questions of strategy, tactics, organization, etc., is lamentably unscientific. It is due in part to the difficulty of developing a truly critical habit of mind under the conditions of military subordination, and in part to the lack of any staff organ devoted to research. . . . At present the investigation of problems is pushed onto officers who are occupied with current military business. That task ought to be given to a body of officers who can devote their whole time to exploring the data on record, collecting it from outside, and working out the conclusions in a free atmosphere. Such a body should be composed of the best intellects in the army with a good blend of practical experience, and in selecting them particular attention should be given to originality of thought or critical powers. It is also very desirable that they should be supplemented by a permanent nucleus consisting of some first-rate University men who have been trained in the processes of scientific enquiry; these might take Territorial commissions to give them an acquaintance with military practice.<sup>25</sup>

There is no indication that the army took any steps to implement Liddell-Hart’s ideas, but he certainly recognized the problem and recognized that scientific training would require reinforcement by an understanding of the military and of military operations.

Another approach to bringing scientific talent into the service of the nation was started in 1938 by G. T. R. Hill and Charles F. Goodeve, who wrote to

the secretaries of the Royal Society on “Peacetime Organization for Voluntary Training of Scientific Workers in the Event of a National Emergency.” At that time, A. V. Hill was Biological Secretary and A. C. Egerton was Physical Secretary of the Royal Society, which may account for the fact that the suggestion fell on fertile ground. The result was the establishment of a Central Registry of scientists, engineers, and other specialists.<sup>26</sup>

Events bore in on the nation before the Registry could be fully organized, however, and so much of the success in bringing the “right” people into radar, and from there into operations research, must go to Tizard, Watson-Watt, Cockcroft and Rowe. Additionally, many of those who found their way into operations research, whether for the Army, Navy, or Air Force, did so because of the efforts of Frederick Brundrett of the Admiralty.<sup>27</sup>

When war broke out, Rowe’s organization was moved from Bawdsey to Dundee in Scotland because of the former’s vulnerable position on Britain’s east coast. At Dundee, the group became the Air Ministry Research Establishment (AMRE), but the location proved unsatisfactory and so the organization was moved to Worth Matravers on the south coast in May 1940 and then expanded into the Swanage area. When the Ministry of Aircraft Production was formed, AMRE became MAPRE for a short time but in November 1940 it was renamed the Telecommunications Research Establishment (TRE), under which name it came to be recognized as one of the great laboratories of World War II. Finally, in May 1942, TRE was moved to Malvern, where it still exists as the Royal Radar Establishment.

Amid all these changes, it was at Worth Matravers that an institution conceived by Rowe reached fruition. These were meetings held in Rowe’s office on Sundays. They were open to anyone interested in radar (and with access to the secrets) whether governmental, civilian, or military, and regardless of rank. Thus Lindemann (Lord Cherwell), Tizard, Watson-Watt, members of the TRE staff, and serving officers of the Royal Air Force were welcome to air their views on ways in which the uses of radar could be improved and on requirements that might be filled by radar. These Sunday Soviets, as they came to be called, proved of great value to the operational research sections of the various commands of the Royal Air Force.<sup>28</sup>

At this point, we must clarify the chronology and terminology involved in the Battle of Britain and the Blitz. The former was Hitler’s effort to destroy the Royal Air Force, and specifically Fighter Command,

so that the invasion of Britain could go forward; it started in August and ended in September, 1940, and involved mostly daylight attacks. The latter was Hitler's revenge when he lost the Battle of Britain. It concentrated on the bombing of British cities, and especially London. It began in September 1940, peaked during the autumn months, and ended in May 1941. Most of the attacks were at night.

### **Blackett's Circus**

At the height of the Battle of Britain, Tizard and Rowe both urged General Frederick Pile, the Army's Anti-aircraft Commander, to use scientists. This was a quite natural crossing of service lines inasmuch as AA Command was under the operational control of Fighter Command. Hill introduced Pile to the physicist P. M. S. Blackett who, when asked, became Pile's scientific adviser. Blackett's first recommendation was that technicians be trained to put and keep the gun-laying radars in order and that they live on the sites. By November 1940, a school for radar technicians had been established at Petersham under J. A. Ratcliffe.

Blackett next proceeded to recruit scientists who had no particular background in radio or radar; he had seen that much more than radar was involved in the problems of AA Command, especially since there had been no equivalent of the Biggin Hill experiments to integrate radar into the overall operations of the command. He called this new unit the Anti-aircraft Command Research Group, but it soon became known as Blackett's Circus.<sup>29</sup>

I shall discuss some of the work of the Circus in the next installment, on wartime OR in Britain. But before we leave it, it is interesting to speculate on the reasons for its composition, which gave OR the concept of the mixed team. Blackett may have been influenced in the direction of physiologists by his friendship and respect for Hill, whose son, D. K. Hill, also a physiologist, became a member of the Circus. Or Blackett may have recognized that the man-centered problems of an army are quite different from the ship-centered problems of a navy or the plane-centered problems of an air force and that scientists accustomed to working with individual differences involving statistics and probability might have a special contribution to make. Or it may be merely that Blackett entered the market for scientists too late and that most of the "hard" scientists had been absorbed into the war effort elsewhere. Whatever the reasons, the Circus consisted of Blackett, a physicist, then of two physiologists, two mathematical physicists, an astrophysicist, a surveyor with a background in anti-

aircraft, and later added another physiologist and two mathematicians.<sup>30</sup>

### **The Spread of OR Work**

The next milestone in the development of OR also involves Blackett—and Rowe. One of Rowe's great concerns was that, given a successful outcome in the Battle of Britain, the U.K. still could not hope to win the war unless the submarine menace to its lifelines could be countered. This meant not only a need for radar equipment, but also the kind of scientific support Larnder and his group were giving to Fighter Command. As Rowe puts it:

... we did not know what was happening in the battles against the submarines, largely because there was nothing at Coastal Command corresponding to the Operational Research Section at Fighter Command. We wanted to know the hours flown per submarine sighting by day and by night, the average ranges of radar locations and, less obviously our business, the results of attacks on submarines. I therefore went to Air Marshall Sir Wilfred Freeman, Vice-Chief of the Air Staff, who was ever ready to listen, and urged that P. M. S. Blackett should be asked to form an Operational Research Section at Coastal Command. This was arranged within a few days.<sup>31</sup>

Thus, after little more than six eventful months at Anti-aircraft Command, Blackett moved to Coastal Command in March 1941. C. E. Bayliss replaced Blackett, but the Circus was soon merged into an Air Defence Research and Development Operational Research Group under Ratcliffe. Ratcliffe in turn was lured away by Rowe to head up the Post-Design Service as part of TRE that Rowe felt was needed to fill the gap created both by the growth of radar and by the broadening of operations research away from its initial association with radar. Ratcliffe was ideal for the assignment because of the experience he had gained in training radar technicians for AA Command. His place there was taken by B. F. J. Schonland, a physicist from South Africa, who expanded the organization into the Army Operational Research Group (AORG), serving the whole Army rather than just Anti-aircraft Command.

When Blackett arrived at Coastal Command, he found there a Radio Operational Research Officer named John C. Kendrew. His title was one that Rowe used when he assigned TRE staff members to an organization that did not yet have a formal operations research group to serve as liaison between the command and TRE. Although he was in a sense displaced by Blackett, Kendrew was destined to make unique contributions to wartime operations research and was

then to join the impressively long list of wartime OR personnel who won Nobel Prizes (chemistry, 1962).<sup>32</sup>

After some 9 months at Coastal Command, Blackett moved again, this time to his first love, the Admiralty. He became Scientific Adviser and Director of Naval Operational Research. There he established a small centralized group, and he remained at this post until the end of the war. This move represented little break in continuity for Blackett inasmuch as Coastal Command was under the operational control of the Admiralty. Thus, his efforts continued to be focused on the problem of ridding the sea lanes of the submarine menace so that the supplies needed for the prosecution of the war could reach Britain.

Perhaps more important to the history of operations research than his pioneering work in AA Command, Coastal Command, and the Navy was the note Blackett prepared on the occasion of his move to the Admiralty. This was his "Scientists at the Operational Level," "written in December 1941 in order to inform the Admiralty of some of the developments which had occurred in the Operational Research Sections already established at Fighter, Anti-Aircraft and Coastal Commands." This note was accompanied by a second document, "A Note on Certain Aspects of the Methodology of Operational Research," "originated in 1941 as an attempt to set out, for the benefit of new scientific recruits to the operational research sections, some of the principles that had been found to underlie the work of the first two years of the war."<sup>33</sup>

In "Scientists at the Operational Level," Blackett crystallized the ideas that led him to develop his Circus as something more than a group dedicated to making radar work. He makes a case for operations research as a distinct and identifiable activity requiring the efforts of highly competent, scientifically trained individuals, working at the operational level, and providing commanders with analyses of problems while serving as a communication link between the technical establishments and the operating commands. As he put it, the use of operation research "can help avoid running the war by gusts of emotion." It could also serve as a corrective to his conclusion "that relatively too much scientific effort has been expended hitherto in the production of new devices and too little in the proper use of what we have got." Together with his introduction of operations research into Antiaircraft Command, Coastal Command, and the Admiralty, "Scientists at the Operational Level" provides ample support for those who regard P. M. S. Blackett as the "father" of operations research.

Blackett's move to the Admiralty completed the introduction of OR into Britain's major commands

inasmuch as a Bomber Command group had been set up in September 1941. There, bomber-loss studies had been initiated under A. E. Woodward-Nutt about June 1940. After a few months, B. G. Dickins, then with the Ministry of Aircraft Production, took over these studies. Later, Lindemann initiated studies of bomber accuracy. These showed that Bomber Command, relying on sextant navigation, was achieving accuracies one-third to one-fourth of what had been expected. Crews that claimed to have found the target were, two-thirds of the time, not within 5 miles of it.<sup>34</sup>

During the summer of 1941, A. O. Rankine was assigned from TRE as a Radio Operational Research Officer and was succeeded by G. A. Roberts from ORS Fighter Command. Finally, the decision was made to establish an Operational Research Section with Dickins as its head and Roberts as his principal assistant.<sup>35</sup>

In addition to the military OR groups, there was one very significant nonmilitary effort. The Ministry of Home Security established a research unit at Princes Risborough, Buckinghamshire, shortly after the outbreak of war, with two principal objectives: The design of equipment and procedures for air raid protection and analysis of the effects of enemy bombing. This work was under the direction of Reginald Stradling and provided the channel through which J. D. Bernal, Solly Zuckerman, and John Baker, among others, became involved in operations research.<sup>36</sup>

In the next installment, I shall review the work of all of these groups. But first, some recapitulation is in order.

### The Actors

Inasmuch as my primary concern at this point is with the people involved rather than with specific technical accomplishments, I shall divide those whom we have met so far into a cast of leading and supporting players in the unfolding drama of operations research.

The supporting players include Wimperis, who has not been given adequate credit in these pages, primarily because he retired in 1937. He had played a most significant role in advancing radar, but he left the stage just as operations research was making its appearance.

Tizard's awareness of operational requirements and particularly his initiation of the Biggin Hill experiments generated an atmosphere in which OR, once born, could thrive. Cockcroft, another of the postwar Nobel laureates (physics, 1951), was a major catalyst in bringing civilian scientists into effective working relationship with service scientists. Watson-Watt's

perception of the potential of reflected radio waves earns him a respected place in the history of OR, as does his presumably approving, as superintendent at Bawdsey, of the “operational researches” assigned by Rowe to Williams and Roberts.

Cherwell must be recognized for his interest in Bomber Command and his support of OR activities there. Moreover, because of his key position as scientific adviser to Churchill, he was in position to advance—or obstruct—this use of scientific talent.

Hill and Rowe proved so influential in so many ways that one is strongly tempted to classify them as foreground characters in the OR drama. Both appear to have had the knack of being in the right place at the right time—and doing the right thing—to advance the development of OR.

Of the leading players, the scientists and engineers directly involved with OR in the formative days, the numbers grow large very quickly. In our story so far, full recognition must go to Larnder, E. C. Williams, and Roberts as the pioneers at Fighter Command; to Dickins for his work at Biggin Hill and then at Bomber Command; and, above all, to Blackett for his perception of operations research as a new and potentially powerful scientific activity in its own right and not only as an adjunct of radar, as well for his pioneering work at AA Command, Coastal Command, and the Admiralty. And we will hear more of Bernal, Zuckerman, and Baker in connection with civil defense, and of Bernal and Zuckerman in military OR.

And to whom do we credit origins? Watson-Watt married radio to the military usage we call radar. Tizard saw that radar changed fighter direction and control and so laid on the Biggin Hill experiments. Rowe saw continuing value in having scientists study operations. Larnder headed the first formal OR group and set standards of organization and reporting.<sup>37</sup> Blackett “universalized” OR in the British services and defined the function and scientific credentials of OR.

Perhaps the best judgment is that of E. G. Bowen, who became known as the “father of Airborne Radar,” when asked about credit: “. . . the point is that this is the way *many* of us were thinking at that time, . . . taking a hard quantitative look at an established service procedure and suggesting new methods and in some cases developing new equipment to carry it out. This is one reason why the real origins are hard to pinpoint.”<sup>38</sup>

## Notes

1. John E. Tashjean, Arlington, Virginia, opened his files on Fisher to me. Included were extracts from

P. K. Kemp (ed.), *The Papers of Admiral Sir John Fisher* (London: Navy Records Society, 1960). He also made available a manuscript copy of his paper, “Admiral Fisher, Professor Pareto, and Social Systems Theory,” since published as “Contributi allo sviluppo della teoria dei sistemi sociali: l’ammiraglio Fisher e il prof. Pareto,” in Charles R. Dechert (ed.), *Sistemi Paradigmi Societa* (Milan: Franco Angeli Editore, 1978), pp. 171–183.

2. Frederick William Lanchester, *Aircraft in Warfare, the Dawn of the Fourth Arm* (London: Constable & Co., 1916). The section on the development of the  $N^2$  law is available as “Mathematics in Warfare” in James R. Newman (ed.), *The World of Mathematics* (New York: Simon & Schuster, 1956), Vol. 4, pp. 2138–2157. See also Joseph F. McCloskey, “Of Horseless Carriages, Flying Machines, and Operations Research: A Tribute to Frederick William Lanchester (1868–1948),” *Opns. Res.*, **4**, 141–147 (1956).
3. Neville Jones, *The Origins of Strategic Bombing: A Study of the Development of British Air Strategic Thought and Practice up to 1918* (London: William Kimber, 1973). (Excerpts supplied by Ronald W. Shephard.)  
Lee Kennett, *A History of Strategic Bombing* (New York: Charles Scribner’s Sons, 1982), p. 87, after commenting on visits by Billy Mitchell, states that “other American air officers worked with the RNAS [Royal Naval Air Service] and so became familiar with the ideas of Viscount Tiverton . . . on the value of precise strikes on critical industrial objectives.”
4. Noel Falconer, University of Manchester, brought to my attention the seminal role played by Hill (letter to author, August 17, 1976). See also C. P. Snow, *Science and Government* (Cambridge: University Press, 1960) p. 86, note 20.
5. William F. Whitmore, “Edison and Operations Research,” *Opns. Res.* **1**, 83–85 (1953).
6. Ronald W. Clark, *Edison* (New York: G. P. Putnam’s Sons, 1977), p. 227, and letter, Edison to Sir Eric Geddes, November 21, 1917.
7. A. P. Rowe, *One Story of Radar* (Cambridge: University Press, 1948), pp. 3–4.
8. Ronald W. Clark, *Tizard* (Cambridge: MIT Press, 1965), pp. 107–108, and The Earl of Birkenhead, *The Professor and the Prime Minister* (Boston: Houghton Mifflin Co., 1961), p. 110.
9. Rowe, *One Story*, pp. 4–5.
10. Clark, *Tizard*, pp. 108–18; Rowe, *One Story*, pp. 5–9; Robert A. Watson-Watt, *Three Steps to Victory* (London: Oldhams Press Limited, 1957), pp. 78–83, 107–112, and, for the memorandum to the Tizard Committee, pp. 470–74.
11. Part of the controversy over Watson-Watt’s role in the development of radar stems from his less than generous attitude toward the contributions of his predecessors and contemporaries. So far as his role



- in the development of OR is concerned, there is no question but that he was superintendent of the Bawdsey Research Station when the Biggin Hill experiments and the first “operational researches” were conducted. Beyond that, there is little support, especially among his contemporaries at Bawdsey, for his statement that “If I was not *the* first and true inventor of Operational Research . . . I was at the very least *a* first and true inventor with one or two of my early staff at Bawdsey.” (*Three Steps*, p. 200). Similarly, support is lacking for his claim that “In 1940 I coined for the subject and for the groups the specific names ‘Operational Research’ and ‘Operational Research Section’” (*Three Steps*, p. 203).
12. Clark, *Tizard*, pp. 114–115. These two patented a device that was intended to be used for the detection of ships, from shore or from another ship; neither the War Office nor the Admiralty was interested. This was in 1931. During the 1920s and 1930s, most clues to what eventually became radar were regarded as annoying interference by scientists conducting radio experiments.
  13. Clark, *Tizard*, pp. 128–148; Birkenhead, *Professor*, pp. 188–216. See also Ronald W. Clark, *Sir Edward Appleton* (Oxford: Pergamon Press, 1971), pp. 96–103.
  14. Birkenhead, *Professor*, pp. 202–14.
  15. Clark, *Tizard*, pp. 149–56; see also Birkenhead, *Professor*, p. 201, quoting R. V. Jones, wartime head of scientific intelligence in the Air Ministry, on Tizard’s contribution.
  16. E. C. Williams, “Reflections on Operational Research,” *Opns. Res.* 2, 441–443 (1954), states, “The term *Operational Research* was specifically coined, by A. P. Rowe, to describe the activities of a small section of the Air Ministry Research Station at Bawdsey in the years 1937–39.”
  17. Rowe, *One Story*, p. 26.
  18. Clark, *Tizard*, pp. 171–172; Watson-Watt, *Three Steps*, pp. 211–212.
  19. Rowe, *One Story*, p. 52. Hart had been assigned to Bawdsey in February 1937 to establish a training school for R.A.F. personnel. He “soon demonstrated that radar was not merely a toy for scientists but could be operated by Service personnel” (p. 23). See also Air Ministry, *The Origins and Development of Operational Research in the Royal Air Force* (London: HMSO, 1963), pp. 7–8.
  20. Rowe, *One Story*, p. 52.
  21. Air Ministry, *Origins*, p. 24. Larnder credits E. C. Williams with making the calculations and, much later, admitted that it was he, Larnder, who translated the columns of figures to graphic form. Dowding’s biographer, in his turn, credits the graphs with “turning the trick” in convincing Churchill to deny the French request. See Harold Larnder, “The Origin of Operational Research,” *Opns. Res.*, 32, 465–475 (1984). For more on Rowe’s early role, see W. Peyton Cunningham, Denys Freeman and Joseph F. McCloskey, “Of Radar and Operations Research: An Appreciation of A. P. Rowe (1898–1976),” *Opns. Res.*, 32, 958–967 (1984).
  22. Winston S. Churchill, *The Second World War*, Vol. 2, *Their Finest Hour* (Boston: Houghton Mifflin Co., 1949), pp. 41–42.
  23. Air Ministry, *Origins*, p. 24.
  24. John W. Abrams, “The Crystallization of Military Operational Research into an Accepted Role—1939–45,” paper delivered at the TIMS/ORSA Joint National Meeting, San Francisco, May 10, 1977.
  25. Basil Henry Liddell-Hart, *The Defense of Britain* (New York: Random House, 1939), pp. 346–347.
  26. Ronald W. Clark, *The Rise of the Boffins* (London: Phoenix House Ltd., 1962), pp. 56–57.
  27. Clark, *Boffins*, pp. 72–73.
  28. Rowe, *One Story*, pp. 83–86; Air Ministry, *Origins*, p. 39.
  29. J. G. Crowther and R. Whiddington, *Science at War* (New York: Philosophical Library, 1948), pp. 95–96.
  30. Clark, *Boffins*, pp. 142–145. One of the other physiologists was A. F. Huxley, who shared the Nobel Prize for physiology and medicine in 1963.
  31. Rowe, *One Story*, p. 105.
  32. Air Ministry, *Origins*, p. 105.
  33. P. M. S. Blackett, *Studies of War, Nuclear and Conventional* (New York: Hill & Wang, 1962), pp. 171–198. Blackett’s two papers, while very influential in the development of operations research, were not the first publication on the subject. That honor goes to a Penguin Special, published anonymously in the summer of 1940, under the title, *Science in War*. Solly Zuckerman was the principal author, along with J. D. Bernal and J. G. Crowther, with “snippets” from many others, including C. H. Waddington, all of whom were members of an informal dinner club that met once a month. At a meeting during the Battle of France, Allen Lane, founder of Penguin Books, a guest, suggested that the dinner discussion would make a good Penguin book. The anonymous authors had copy ready in less than 2 weeks, and copies of the finished product were available in another 2 weeks. According to Zuckerman, the book “dealt with the problems of speeding the translation of scientific discovery into matters of practical value for the war.” See Solly Zuckerman, *Scientists and War* (New York: Harper & Row, 1967), pp. 147–148, and *From Apes to Warlords* (New York: Harper & Row, 1978), pp. 111–112 and 398–399.
  34. Clark, *Boffins*, pp. 220–21; Birkenhead, *Professor*, pp. 231–232. The terminology used here is a paraphrase from the report on these studies, as quoted by Birkenhead (p. 232), and presumably refers to

the percentage of bombs on target, but may refer to the frequency with which any bombs hit the target.

35. Air Ministry, *Origins*, p. 44. Of interest is the fact that two of the original members of ORS Bomber Command were the Misses K. M. M. Goggin and Hilary Lang-Brown, the latter of whom had been with Roberts from the early days of the Stanmore Research Section. No woman achieved the status of analyst in the various U.S. operations research units during World War II.
36. Air Ministry, *Origins*, pp. 41–2; Lord Baker of Windrush, *Enterprise versus Bureaucracy* (Oxford: Pergamon Press, 1978), pp. 1–8.
37. Air Ministry, *Origins*, pp. 194–198, reprints a paper on “O.R.S. Reports” prepared by Larnder in June 1943.
38. Letter, Bowen to author, July 18, 1977.