OPERATIONAL RESEARCH*

By P. M. S. Blackett

I am very honoured to be invited to be your guest at regular intervals and find these visits stimulating and valuable to me, and I hope I can be of some use to your country in building up your forces under the new conditions. I am particularly fortunate in this visit in being able to sit here and listen to two speeches, both of which I consider extraordinarily interesting and important. General Chaudhuri's[1] account of his view of future land battle which the Indian army is likely to encounter and Air Commodore Lal's[2] brilliant talk about aeronautical developments in Europe, have done, both in a different way, a great deal to clear my mind as to the sort of problems, which India is facing.

Now, the Defence Science Laboratory here really fulfils two different functions which have been fulfilled in U.K. by two different groups; the Operational Research aspect by one group and a good deal of the function of the study of Military weapons, aircraft and equipment usually done by another group in the Ministry of Supply. The detailed investigations of the performance of air craft, the functioning of engines of different types or range—load weight relation and the like is one aspect of it, and the other aspect is the actual study of the operations of war more on the tactical side. In both aspects of work, namely, the systematic and scientific investigations of the expected performance of different types of guns or aircrafts and the logical study of tactics in its relation to the history of war it is very essential that both should be kept, as far as possible, down to the ground of practical objectives. It is extremely easy to let these investigations run riot into theoretical investigations which, though some times of great academic interest, may fail to lead to conclusions of any practical importance. In both types of investigations, the object is to make a decision. For instance, in the very interesting analysis described by Air Commodore Lal[2] on the work done on the different types of aircrafts, in Europe, the object was to enable the executives of airlines to decide what to order so that the marginal differences of performance are probably not very important as compared to other considerations. This brings to my mind that in all this work, one must keep the practical objective in view, and that is a very good way of avoiding undue sophistication of analysis and undue accuracy for the data to bear. In the end, the result of both types of analysis is to help somebody to take decisions on the basis of these arguments, for ordering a certain item, say A rather than B.

If you look at it a little more broadly, the present situation of the world is relatively peaceful for the moment as compared to the rather warlike century we live in, and it is reasonable to assume that the Armed Services in this country, like those of any other can take up a fairly long range view. Let us say for the moment that the plan is that there would not be a war for the next five years. In that case, the main job, I think, of the Defence Science Laboratory must be to help their uniformed colleagues to decide what to make and what to buy. After these decisions of what aircraft, tanks, guns, radar and so on one wants to buy, have been made, the question naturally arises as to how to use them. It seems to me clearly to be the whole basis of Air Commodore

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Lal's[2] talk. The decision to be made is what aircraft does India want and to what extent General Chaudhuri's criteria of the suitability of that aircraft for air support to ground attack are satisfied by this particular type ? In my view, it is a clear-cut practical objective behind the work of the Defence Science Laboratory and the associated Service bodies dealing with it at the same time, i.e. what do you want in this country to fight or to have as fighting weapons?

If that practical objective is kept in mind it will be quite a good gauge of what work is particularly important and what is not so important and also to avoid undue stress on accuracy. It is extremely important in all these matters to keep orders of magnitude of quantities in view, more rather than the exact quantities. For the accuracy of weapons, it must always be remembered what they really do in practice as that will avoid a number of errors. For example, I remember the RAE finding a certain type of bombsight. The bombsight had special scales for bombs of different terminal velocities (TV). There was one scale for bombs of 1425 TV and another separate scale for bombs of 1435 TV which worked out to a difference of a few yards from a height of about 20,000 feet, but the bombing error itself was 200 yards. The calibration was obviously done in an instrument shop without any relation whatever to the real accuracy of bombing. Perhaps that is an example where instrument designers were hopelessly wrong. They do not keep in mind the actual facts of life in the field.

There is also a danger of elaborating a simple problem unnecessarily. There is a story that amuses me very much. There was a very good Air Force Scientist working in isolation during the war who was asked by the Air Force as to the best way of bombing German battle cruiser Scharanhost in Brest harbour sometime in 1942. He was asked how many bombs they would have to drop from an aircraft in order to have a fifty-fifty chance of disabling this ship. Having come from a good school of Applied Mathematics he tackled the problem like this: Having found from intelligence photographs the location of the ship, he approximated it by two ellipses of given eccentricities. He assumed the mean point of aim of the aircraft as the centre of gravity of the ship and on the basis of Gaussian error law of distribution, he worked out the probability of hitting the ship within bombs. He worked out five pages of mathematics using double integrals involving complicated exponential functions and came to the conclusion that if 1000 bombs were dropped, the probability of hitting the ship would be only 0·24. Then in a line underneath he wrote, "From considerations of the areas we get 0·2". When he was asked as to why he used the complicated double integrals when the results followed from simpler area considerations, he said, "Oh, to impress the Air Marshall". In all my work in operational research I fought shy of mathematics and used to keep it very much in the background and in appendices, and in general found it possible to avoid the use of it. Of course, often it is not possible to avoid it for detailed assessment of performance of weapons, in calculation of trajectories in ballistics and of the performance of aircraft. One may have it but it must not be exaggerated. Exaggeration is very out-of-place in all operational problems of this sort where inaccuracy is inevitable and where the whole idea is to get the right order of magnitude rather than to get detailed figures.

In the same way I look on statistics. What I want to say is that statistics is a thing that you should know about, in order never to have to use it, and whenever any of my workers during the war started to use χ^2 test or something like that, I used to say that he had gone off the rails for the reason that it was not quite right to use it. Whenever an answer is in doubt you have to use the sophisticated statistics to discover what it is about. It is of no use for executive action and for this particular purpose it can be ignored. For instance, the correlation co-efficient is almost never useful in operational research.

The criterion of thinking about one's work in terms of possible actions by somebody else is in fact a very important one. It is extremely important that when the work is being done it may be quite sophisticated but its final presentation must be made absolutely crystal clear and simple, because not only it is very difficult for the scientist to follow a work in a different field, but this has got to be understood by a non-scientist as well. And in the art of making perfectly clear in a paper or a lecture what really has been assumed and concluded is very important. Very often the machinery of calculation is allowed to outweigh the results or the assumptions. There is a story of one of the Presidents of the Royal Society. There was extreme boredom when some biologist was giving an utterly unintelligible account of some work on biology for half an hour, and in the end the President got up and asked that lecturer "Could you please stand up another five minutes and tell us (*a*) What you have done, (*b*) Why you have done it, and (*c*) What you have found out ?" The man got up and did it, then the whole audience understood what he wanted to say.

It is also important to keep our eyes open for conclusions in quite different fields. I was very impressed by the account of the work started here in the Laboratory on the properties of soils. It is obviously very important for all Army work, and incidentally it turned up as a technical development in Australia which is entirely novel to me and to our people. That shows the value of having scientists roaming round literature. If this is really a cheap way of making roads, nothing could be more valuable in this country. And of course, it is to Australia that you will look increasingly, rather than to Western countries for tactical solutions of some of the problems because they do have similar conditions. I think other examples will be found where Australian experience will be stimulating and valuable to this country.

In the absence of a great deal of field material about which to think considerably, sometimes it is quite profitable to think about analytically by reading the instructional manuals of the Armed Services and to look at the self-consistency of the orders in it. Now the orders of the Artillery Manual or the Infantry Manual or the anti-Submarine Manual of the Navy are the re ults of skilled experience of decades of field or sea operations. And, there it is w itten in more or less details, what the Military authorities think best tactics or strategic behaviours as a result of all their experience. They are the end results of all the Manuals, analysis, reports, and trials, and usually, they are pretty sound and well established too, but every now and then we find inconsistencies due often to different origins and from the different bits of information received at the command. For example, a simple reading of instruction with no field knowledge at all may show that there was something wrong. As an illustration, let us take the fairly well known story of big and small convoys. When we tackled this problem, one of the things we spotted was this : when we went to the Navy and asked as to the theory or ideas about the size of convoys, we got two answers. The first answer was that a small convoy was the best, and then in order to be a little more precise we asked, "If you have a convoy of N ships, how many escorts do you think it is necessary to get equal safety?" A rough and ready guide was provided by the long-standing rule, $n=3+N/10$, where N denotes the number of ships and n the number of escorts. At first sight it is a very simple rule. You have for one ship three escorts to cover the ground reasonably. When N is 10, i.e., with 10 ships, the number of escorts is 4. If N is 100 then the number of escorts is 13. Now that seems at first fairly sensible, clearly using minimum number of escorts. We could not have discovered the origin of it. I think it is not out of any trial, but probably is a good guess made by some able officer during the battle. You had to have a rule and that was it. The implication of the rule was that this number of escort vessels would make convoys of different sizes equally safe, that is same percentage loss would be expected. But the point was that these two statements were mutually inconsistent as the Admiralty "3+N/10" rule could be shown to be inconsistent with the view that small convoys were safer than larger ones. Consider the alternative running of (*a*) 10 convoys of 10 ships each, all sailing independently with 4 escorts for each as provided by the rule, then you need 40 escorts in all and (*b*) one convoy of 100 ships with all the available 13 escorts. By the assumption of this rule the results are the same. Of course, this cannot be; as clearly the large convoy would be much safer, and that is in fact one of the basis of the big convoy theory. This does not prove that the big convoys are better. It shows therefore that orders were inconsistent without ever going into any field data.

The other very famous case was about the depth at which the depth charges should be exploded to disable a submarine. The practice was to set the charges to explode at a depth of 100 feet. A simple analysis revealed that this depth was too great and when the depth was reduced to 25 feet the results obtained were very striking.

I hope that Service people will get interested in the critical examination of field orders and manuals and look through them to discover whether there are any logical inconsistencies of any sort in the instructions. I do not mean that all orders can be perfectly consistent. At any rate, analytical study of field orders is extremely valuable particularly in relation to the use of weapons. To the young scientists it would be good discipline to read through these instructions critically and look into them numerically and scientifically.

It will be profitable to check numerically some of the intrinsic assumptions made while planning operations. I shall just cite one instance to illustrate this point. The landing on the Normandy coast was planned by the Admiralty and as we all know it was extremely well planned and was executed successfully. As I came a Scientific Adviser to the Admiralty at a rather late stage there was not much that I could do very concretely in planning this operation. We found, however, one point of interest in our analysis of some of the intrinsic assumptions made.

The Navy believing in big guns was also fighting with big guns. From photographs the Admiralty knew all about German big guns mounted all around the Normandy coast. Our Navy was rather frightened of these big guns. So, we looked into the question of what damage these guns could do. It turned out that the big guns were incomparably less dangerous then the little ones. This was due to the fact that the barrel life of these big guns was very short. Their barrels had to be charged after firing 80 rounds. This could not be done often during the heat of the battle. If one works out what these big guns can hit at a range of 10 miles it will be found what the damage they can inflict with 80 rounds is very small. As it turned out the German 88 mm guns were more deadly than the big guns. Owing to a high rate of fire and long barrel life they inflicted more damage than the big guns. Had the Germans put in the same effort on their 88 mm guns as on their big guns the Normandy landing could not have been so very successful.

I made some formulation many years ago during the war about the operational theory of small changes. The theory is this : Man is not clever enough to calculate what will happen in any big operation. It can be calculated with some success what will happen if some small changes are made in the existing arrangements. This rather pompous formulation of mine forms what may be termed as operational calculus. I think it is extremely useful and is used implicitly in great many fields of calculation, but, of course it does ignore the fact that the object of war is to make a big change. The object of military operations is to make the enemy do something different to what he was doing before with the ultimate object of making him surrender entirely. Now that cannot be calculated by any form of variational calculus and I do want to draw your attention to this point which does have some rather wide tactical, strategical and even political reaction. We want to make the probability that the enemy will do something we want him to do, e.g., ultimately to capitulate, or in a smaller scale of tactics, surrender some armed post which he may be holding or tentatively retire from that armed post as large as possible. He may be staying in an armed village or something like that and doing a useful military job. From his command and personal point of view it is worth-while staying there for the time being, but we want him to do something else. We want to raise the probability of his doing that by putting pressure on him and that is a military operation. Now the probability from the enemy's point of view that he will make such a change of policy will be written as a function of "worthwhileness"—a new term I want to introduce. An interesting point is that this probability is much more like a wave function, a function of two variables in which the end state and the initial state come in.

Let us now turn to some practical points, particularly the thoughts of mine after listening to General Chaudhury's and Air Commodore Lal's talk. I was particularly glad to hear General Chaudhury's authoritative statements and take note of how he think India's tactical problems should be faced. He took a very simplified view of the wars likely to be fought along the narrow airline communications with rather strong, hard-hitting forces using heavy to medium-heavy tank. This close up of logistic air support does seem to me extremely interesting one that has also very big civil usefulness in this country because a good aircraft, of good carrying capacity, load performance, hedge hopping capacity would be extraordinarily useful for military as well as for civil operations such as air supply in Assam and Himalayas. If one could make sure of the future conditions of this country I should have thought that with an aircraft of the Krische type, you could become self supporting in air craft for both civil and military operations. It would be very interesting to undertake a study of the performance, sizes, ranges etc. of aircraft of that general type and examine whether India could perhaps later on add to her national programme manufacture of aircraft of that type. I think, probably to the civil and the military requirements it would be very closely matched.

The next question which is of great interest to me is what air power can and cannot do in modern battle in the front lines. Let us leave aside for the moment the aspect of the logistic air supply behind the lines. I have not read all the possible literature on the subject. Anyway, we can look at it certainly from a very broad point of view. The western allies had complete air superiority in their campaign against Germany in France in 1944. Yet the German army fought extremely well in general and inflicted very heavy casualties. So the complete air superiority, though extremely valuable, is not quite capable of doing everything. In the same way, later on in Korea, the allies had almost complete air superiority and yet the North Koreans and Chinese had fought extremely efficiently and inflicted casualties. I was asking somebody having sufficient experience whether he could put this factor of complete air superiority into military terms to which he said, "No" but I had heard somebody say "An army with complete air superiority is about equivalent to an army twice the size without any air support". Now, I think it is only a pure guess, but it is an interesting guess because I am quite convinced that, that factor two should not be ten. It is not ten; whether it is three or five I do not know but its order of magnitude and some planning figure of that sort must be in the minds of the military planners because obviously nobody believes, though often it is said that if you win air superiority the battle is won. I think a knowledge of these factors is all important. The question is how much you have to pay for air superiority. Further, air superiority on an extended frontier is an extremely difficult thing to achieve.

Incidentally this factor two reminds me of the earliest bit of operational research, 150 years before the name was invented, carried out by the famous Clausewitz in which he tried to investigate in military terms the advantage of having a really good general. Now, of course, Clausewitz was a complete Napoleon fan, Napoleon being his ideal of a general, though he was fighting on the other side. He analysed all the battles that Napoleon had fought, made tables of the relative numbers of the army and whether they won or lost and he came to the conclusion that even the best general imaginable and as great as Napoleon, could not win a battle unless his forces were more then half that of the enemy. So he reckoned the difference between the average general and a genius as a factor of two. But here again, reading the story books one might think that the factor is 100 or 1000.

Coming back to air power the thing that I would like to know is what air power really did in Korea. What its effect was, did it successfully attack heavy, hard vehicle or only soft? Was it really effective against troops with napalm bombs or things like that? Was it high level bombing? Was it low attack mainly and if so whether it was by Sabres F 86, Meteors or Mustangs. How did the question of the limited range of the high performance, high altitude-rated fighter like Sabres F 86 come in limiting its role near the ground ? These things seem to me absolutely vital for this country to get a clear idea. After hearing Air Commodore Lal's talk it seems to me that his ideas carry extremely good potentialities for your country, and no doubt, the target will be to have a good, a reasonably good ground attack aircraft. But no aircraft rated for fifty thousand feet can be ideal at the tree-top level. So the question is, "Is there something else that could be achieved to serve the purpose of the army?" I was very much interested in Commodore Lal's reference to the French Potez aircraft which I gathered from him, is a light aircraft under ten thousand pounds, with engine behind, pilot in the nose and presumably with a bunch of rockets and armour piercing guns or something like that in front of him, which will take off from any field, which is supposed to have only a tree-top altitude of operation and would not be shot down from the air. Such an aircraft seems extremely useful and relatively cheap to make.

If General Chaudhury is right, your planning is going to be on the basis of medium heavy tanks and if the enemy have medium heavy tanks, you must, in fact, be able to compete with them. Now, tanks having mobility may turn up in unexpected places and it is very hard to run your tanks or anti-tank guns specially there. Hence a really effective air attack on tanks is extremely valuable. One of the interesting things to me would be for India to order one or two of these Potez planes and make really big field trials of accuracy. It is an extremely cheap experiment to readily discover whether they can in fact, do their job, because, the alternative is to rely for all the hitting power down at sea level at something which is primarily designed to climb to fifty thousand feet in five minutes. Now, commonsense says you may get an answer but it cannot be the best answer. It may be a very good aircraft, but it cannot possibly be produced so as to be the best aircraft for all these jobs. And I think it is extremely good experiment for India to buy quickly one or two Potez or similar types. Those are also the types which India could reasonably manufacture and service quickly or even redesign for her purpose, and thereby become indigenously self-supporting in aircrafts within a short period.

These things I am talking about do not touch exactly operational research, and also they go right outside the responsibility of Defence Science Laboratory, but these show the conclusions I have come to after listening to these discussions. It seems to me that it is in the air arm where there is the greatest difficulty in deciding what you are going to have because there is so much you could have and so expensive. But in the army there is not much to choose. If it is a question of tanks, it can be settled by the army staff and after that there is no so much question of choice. You got to have your field guns and anti-tank guns, where though there may be variety of choice, it's not much. You can go round and see the Farn-borough air shows and see the fantastic choice and ways of wasting money if you make the wrong choice, and I have for long tried to see a sort of pattern at which the Indian Air Force might get into. Following Air Commodore Lal's and General Chaudhury's views, one can easily leave long range bombing out. The only role in my view for long range aircraft is overseas recce where our Liberators are admirable and take a large part of the Navy's function there. There is enormous belief in Liberators and if you want to know where anything is in the Indian Ocean, or search for a raider, a Liberator with good radar is the ideal thing.

As to the high altitude fighters, admittedly you must have a few, though you may not have to use them at fifty thousand feet. The 'Gnat' or a similar type seems to me to be the ideal. Nobody seems to have made a good case in between the first line trainer HT2 and the medium bomber of the Canberra type. I think, one or two Canberras which seems to me not very expensive would be extremely valuable for P.R.U. purposes—these are big enough to carry big cameras and can outdistance anything but fighters. So you could recce the whole enemy area. I gather you have 'Harvard.' If the logistic question is really important and if this anti-tank, low performance, tree-hedge hopping aircraft is really useful, it seems to me, it might almost be a revolution because it is extremely cheap. You might have to risk one of its advantages viz., of getting anti-tank fire power. Anyway, studies may be undertaken at the Defence Science Laboratory on its comparative performance with 'Gnat' regarding its range, fuel consumption, number of sorties per day, aerodrome characteristics etc. So far as aerodrome is concerned, with a runway of 2000 yds, with Harvard you can perhaps make ten sorties more a day and also stay a longer period in the air than with 'Gnat.'

In conclusion, I would like to mention that many of the issues which have been raised during the discussion of last one hour or so, seem to me to offer chances in operational research study which might lead to results of extreme importance and should be pursued by the Scientists in the Defence Science Laboratory in collaboration with their uniformed colleagues.

REFERENCES

1. Chaudhuri, J.N. : Weapons and Equipment for Eastern Theatres. Ibid, *5*, 103, (1955).

2. Lal, P.C. : Some Aspects of Air Operations, Ibid, *5*, 283, (1955).