### *Control Aids.*

Many aids to this scheme of general control exist. One, for example, is the scheme known as video mapping. This consists of a means of developing in the video the information necessary to write a map or any information needed on the off-center PPI. This is then kept as a facility which the controller or scope operator can fade into his whenever he wishes. In this way it is possible to marry-up radar targets with points on the ground.

A second aid is a beacon such as the AN/APN-19 which locates friendly or otherwise specialized targets at will.

A third and most important aid is the VHF direction-finding equipment which will locate an airplane, in direction only, to an accuracy of one degree. This enables particular planes to be sorted out.

When equipment is available for general control, the necessity for accurate control now arises. This can be achieved in several ways. Either one can extract maximum accuracy out of the general control radar, or one can design a specific radar intended for accurate control. Up to the present this latter has not been done, but a modification of a fire control radar, the SCR-584, has been used in which for accurate control of a single aircraft an accurate track is carried on a plotting board by means of the locking-on feature of the SCR-584, and this is used to give vectors to the plane. It is felt by many that it would be better to build a set which did not forego the ability to see everything else in the neighborhood while controlling, and this would involve essentially a rapidly rotating V-Beam set with rather small antennas perhaps set at X-band rather than S-band, and a number of these sets would be fixed up appropriately so as to permit accurate control. A preliminary specification of a possible set is given:

Wavelength, X-band

Dish size, 15 x 3 ft giving 0.5° beam for vertical and slant beams

Three feeds for each beam to give lower, middle, and upper coverage

Pulse width, 1 microsec

Power out, 300 kw

MTI on both lower beams

Scan rate, 6-12 rpm variable

Receiver sensitivity about 8 db below KTB

Skiatron general indicator

Up to six special control scopes of the off-center type with special tracking equipment similar to the APA-44. These would feed six controllers with the necessary data for precise bombing or close cooperation. The six controllers sit around the skiatron in the "soda fountain" technique proposed for C.I.C.

The use of radar offensively for a tactical air command follows, therefore, the following general pattern. First, the planes take off and are vectored by a tower search set; second, they report in to a V-Beam for general control; third, they are vectored by general control to accurate control, where they are controlled until their mission is completed; then they are returned to general control and finally are put in to the tower-search set which controls them for landing. It has proved necessary to construct for this purpose a special tower-search set. The complete design of this is not yet in. At the moment a modification of the SCR-584 is contemplated. This modification uses moving target indication, has provision for beacon reception for identification, and contemplates four indicators with a central indicator of an expanded type such as a skiatron or possibly a photoprojection tube. With this a survey of the aircraft interested in landing can be carried by each airport, and they can keep planes not interested in landing flying along a definite lane overhead and can bring the planes in with reasonably good control so that stacking is not necessary, or if necessary can be used for only a short time.

***Future Problems.***

Atmospheric reflections from clouds, i.e., from rain drops, are a very annoying feature when detailed control has to be carried on. In wartime one has to envisage the possibility of an aircraft flying through a storm area since it affords him a certain measure of protection from the radar and since, moreover, he has a certain degree of immunity there. In peacetime it is quite likely that a knowledge of the position of such rain storms could be a great asset and would help in controlling aircraft so that they would be able to fly in clear weather all the time even though flying at night. Microwave radar, and indeed any radar sees these rain storms quite definitely. When the performance of microwave radar is brought up close to theoretical, these rain storms will be still more apparent than they are at present. The development of circuitry to enable these to be eliminated is one of the important jobs that has to be done before radar can be considered to have arrived. In other words, it is necessary to see the aircraft where or when desired and to see the rain storms when desired. This has not yet been achieved although some palliatives are in existence. Considerable research should be put on this phase and possible directions of research lie along moving-target indication techniques with delay lines of variable length so that the variable motion of the clouds can be eliminated. Circuitry such as fast time constant and instantaneous automatic volume control have been proved to help a little. By very careful circuitry this assistance is such that it is quite appreciable at the present moment; however, much more and better remains to be done.

A second important problem that remains to be tackled is that of indication. We have never had any means of appraising instantly the situation of aircraft in the sky. The eye is not very good at this; the estimate of height and range of this is very slight and very inaccurate, and the ranges of detection are very low. Radar gives such a wealth of data that it far outstrips the eye, and therefore some means of using the data involves a considerably difficult psychological as well as material problem. Various things have been suggested, one of which is a continuous tracking mechanism on each aircraft, which by means of a servodrive moves (for example) small luminous dots up and down thin wires, and which therefore gives you a three-dimensional picture. Change in colors of the lights would indicate different aircraft. Such an indicator would be extremely elaborate and while perfectly possible would be something which would have to be embarked on only in an area of very high traffic. It would be a little difficult to build this unless one were sure of its ultimate success since the cost involved would be rather large. However, if the future of aircraft is such that aircraft becomes as common as automobiles, then something of this nature will be absolutely necessary. Otherwise the direction of flying from the ground will be extremely difficult.

One further thing remains unsettled. It has always been argued in the past that a pilot is one who likes to fly his own plane and to keep freedom of action. On the other hand, if he is controlled from the ground, his movements are much more certain and he is sure to get where he wishes to go more quickly and accurately. Moreover, he will be safer from enemy attack and he will get there in greater comfort since he will be vectored around the various cloud positions. It has been argued that this control from the ground will never be greatly liked by pilots. At this stage we do not have the answer to this problem. Many pilots who have flown missions closely controlled from the ground like it very much. Many pilots who fly navigational systems like those better; in this case they have, essentially, control in the aircraft. A period of extensive testing, lasting possibly as long as ten years, will remain to decide whether equipment will be procured and put in aircraft to enable the pilot to fly his own course using data fed in from the ground or whether he will merely listen to his radio and follow the instructions given to him.

A proposal has been made, by Griggs and the writer among others, for relaying back up to the aircraft the information from a ground radar set together with beacons and video mapping. If this were done, then the pilot could fly his own course and see where he was on a map instantly and would have no problems whatsoever. On the other hand, he would have one more thing to look at, one more thing to maintain in his aircraft and one more thing to learn to do without when it fails.

The other philosophy is that of control solely by radio, making sure, as is at present done on ATC aircraft, that enough radio is carried so that it can't possibly go out. Then by merely taking verbal instructions from the ground the plane, with no further equipment, can be vectored wherever he needs to go. This form of divine guidance, however, may not be psychologically satisfactory. Either way will achieve the necessary result of letting an aircraft reach his objective in bad weather or at night in complete safety.

Before such decisions can be made, however, we have to develop and make these systems absolutely reliable: (1) V-Beam, (2) tower search, (3) landing control, (4) beacons, (5) video mapping, (6) relay radar, (7) accurate control radar. After this equipment is as good as the ordinary human being for reliability, ground radar control can be said to have arrived.

## THE CONTROL SYSTEM

Communication links for a control system are shown in Fig. 12. All control except a few specialized functions is concentrated at a convenient location within the area. The main difference between this system and those now in use lies in the transmission of the radar data to indicators in the control center. Under present operational practice, data is transmitted to the control center by verbal relaying of coordinate positions. This step introduces delays and errors which make reliable control from the retold plots an impossibility. The alternate solution now in use is to pass control to the radar station. This is undesirable because the control is no longer centralized, resulting in difficulties in coordination between the operational planning group and the control group. The use of a relay link to transmit the radar data to the control center avoids these difficulties. It is probable that no advantage would be gained by bringing the control of traffic at an airport into the control center. Therefore, the airport control radars are indicated as operating with only voice and teletype communications to the control center. On the other hand, it may prove desirable to provide the over-all air picture to the airfield control tower by a relay transmissin from the control center.

Antiaircraft defenses must also operate as semi-independent units, because of the requirement that the gun-laying radar must be near the guns. These units will be alerted from the control center and will be kept informed of friendly aircraft movements.

Antirocket defenses will probably have to operate amost independently because of the very short time available for carrying out defensive measures. Time delays in alerting cannot be tolerated. Furthermore, the equipment used for this purpose will probably be highly specialized and may be of little use in aiding in the control of aircraft. Certainly the present types of aircraft-control equipment will contribute virtually nothing to rocket defenses.

The directional air-ground communications systems are placed at the radar sites in order to provide easy orientation of the antenna to correspond with the radar picture. This feature also provides an identification aid by using the communication equipment as a direction finder.

Since the equipment is merely a means to an end, the organizational command will be operational rather than technical. The two main lower echelons will be air-control and technical, with suitable subdivisions to cover the functions and to provide for proper units at the various stations. Regardless of the classification as control or technical, all men on the system should be administratively under the same chain of command. The Army practice of having the control personnel in the Air Corps and the technical personnel in the Signal Corps had resulted in considerable conflict at times, and had been detrimental to the proper functioning of the system. It should be possible for either the control or the technical personnel to rise to the commanding position in the organization. In either case, the man should have a good grasp of the over-all functioning of the system.

The control network, if used to handle civil as well as military aviation during peacetime, can be kept an alive and progressive organization. On the other hand, if only simulated missions are carried out, crews will become indifferent and improvements will lag. This does not mean that simulated interception and bombing missions should be omitted, but it does mean that the organization should function continuously between these maneuvers.

This system can and should be set up to cover the United States and its possessions. At this time, the main ground radar should be the AN/CPS-6 and the main air-ground communications should be VHF. Development of improved communications should be pushed and substituted for the VHF. Mark V IFF can be used as a temporary beacon system while a higher resolution sysem is being developed. To obtain coverage out to sea, a long-range airborne system is needed, although this function could be carried out by picket ships. During peace, the main function of this airborne system would be to provide navigation, traffic control and aid to planes and ships in distress. Further development of equipment and techniques of control would be indicated as operating problems developed.

In addition to the relatively fixed defense installations, there is a requirement for a highly mobile control system to be used with armies in the field. For air-ground cooperation, a control network must be available which includes provisions for precision navigation of aircraft and rockets from the ground. Although the ground-control system is limited by optical horizon, many targets are suitably located for attack by aircraft under ground control. Control at greater distances can be accomplished by augmenting the ground radar with long-range airborne radar which can effectively raise the antenna height. This radar must be capable of seeing aircraft in the presence of fixed echoes, and if possible should be capable of detecting moving vehicles. The actual control should probably be carried out on the ground because coordination with other radar equipment would be easier. The aim of this control system, together with airborne bombing and navigation equipment, should be to prevent all movement of the enemy's supplies, equipment and troops on an all-weather, 24-hour basis, and to make enemy air force, rockets and artillery completely inoperable by destruction of enemy equipment on the ground and in the air. Complete paralysis of enemy supply lines would eventually cause collapse, even if the destruction of weapons at the front could not be accomplished.

Strategic operations introduce one additional requirement. Because of the distances involved in attacking the enemy's manufacturing facilities, airborne control centers must accompany bombers on long-range missions. These centers should be capable of carrying out limited operations of the same types needed on the ground. In addition, there may be a requirement for precision control of rockets, the rockets being launched either from aircraft or from distant ground installations. These aircraft may act either as "shell spotters" or may actually control the rocket. Techniques to accomplish the latter should be developed. The strategic aim should be to wipe out all production facilities and storage depots. This too will cause collapse of the enemy, but the effects will take longer to show than the paralysis of the enemy's transport system.

The ultimate goal of all air-control systems should be to provide complete and usable position information on all aircraft in flight, and to provide for the use of this information to aid any aircraft in safely completing its mission in either peace or war. In war, there must be the additional aim of maximum damage to the enemy, with minimum losses from enemy actions.

## AIR BASED CONTROL OF AIR OPERATIONS

### THE PROBLEM

The existence of ground radar equipment, which has been used so successfully for fighter control since the Battle of Britain in 1940, and the existence of airborne radar, which has been employed for individual fighter contacts and interceptions, have inevitably led to the sugestion of mounting in an airplane a radar set which could be used for general surveillance of the air situation and control of friendly aircraft in accordance with the demands of enemy air dispositions. The origin of this suggestion is not known, but as early as 1942 the RAF, at the suggestion of Wing Commander Sidney Lugg, mounted in a Wellington a set derived from the CHL/GCI, with a rotating 200-megacycle antenna which made it very remarkable that the airplane was able to get off the ground. This equipment was on the face of it technically impracticable, and no particular operational experimentation with it was carried out. The notion of airborne aircraft control has been reinvented several times since, but it is interesting to observe that the equipment which is now under development for airborne tracking of distant aircraft is called AEW (standing for airborne early warning). While it may be thought that this is done in analogy with the set whose principal use is fighter control, but whose name in MEW (microwave early warning), the fact is that the AEW is essentially an equipment conceived to permit ship-based aircraft control. It happens to be installed in an airplane, but this is so only because a mast of the requisite height for the ranges demanded by the design would raise the center of gravity of the ship on which it was mounted to an intolerable degree.

It will be instructive in the present discussion to inquire as to the general conditions which make an airborne aircraft control system desirable. The basic circumstance, of course, is that the world is round. Only microwave radar has the property of permitting an antenna of a size which can be successfully carried by an operational airplane to give the performance necessary in a radar equipment which provides sufficiently detailed information for aircraft control. The beam of a microwave radar is propagated in a quasioptical fashion, and does not extend over the horizon to any substantial degree. This leaves two possibilities when control of air operations must be exercised in places over the horizon from friendly territory: Either an airborne control center, with the necessary radar and communications equipment, and personnel for plotting and control, must accompany the combat aircraft, or else such an airplane must carry with the combat aircraft the necessary radar equipment, and specialized communications equipment which permits the display of the radar to be relayed back to a control center located on a ship or a piece of friendly land. This, of course, assumes that the command communications are also so relayed; it is now commonplace that really satisfactory command radio can only be achieved at VHF and above, and this suffers from the same horizon limitation which affects the microwave radar.

The ultimate choice between these two possibilities has not been made, and can scarcely be made intelligently while neither has actually been tried out even under proof-test conditions, let alone in combat. It may be remarked in comparing them, however, that the chief disadvantages of the airborne control center is that the limited pay load and space afforded even by the largest aircraft now in use limits severely the layout and adequate manning of such a control airplane, especially considering the amount of electronic equipment which must be carried to look after the necessary information-gathering and control-communications services. A secondary drawback is the fact that the men operating as controllers in such an airplane are subjected to the same combat stress as the crews of the bombers and fighters they are controlling. While this may lead to a feeling of brotherhood between controllers and controlled which results in unquestioned obedience to directions, it will also lead to some deterioration in the performance of control personnel. The principal disadvantage of the scheme of relaying information is its cumbersome operational character. Successful control depends, in general, not alone upon the radar plane accompanying the combat aircraft staying in the air, but also upon a relay airplane near the control center staying in the air. The amount of electronic equipment which must all work at once to conduct an operation is considerably greater in this latter scheme. In so far as any *a priori* decision between these means is accessible, it will arise from the direction in which the development of combat aircraft is to proceed in the future. This matter is considered fully later in this paper, page 142.

There are two sorts of operation which require or benefit by over-the-horizon aircraft control; these are fighter control and bomber operations. The first is defensive, and has as its aim destruction of enemy aircraft bent on attack, at a sufficient distance from the target to provide plenty of room for friendly fighter maneuver. The second is primarily offensive, and any class of aircraft may be engaged. The bombers mentioned in the phrase "bomber operations" may be anything from very heavies to self-propelled bombs. The purpose of the control is partly navigational, partly to warn the bombers of imminent attack by enemy air units, and partly to control escort fighters, if any. It will be instructive to discuss the immediate future possibilities in these two types of operation.

The range at which fighter control can be successfully exercised by ground radar has always been marginal, because of the horizon limitation, and is now definitely too small. If the attacking aircraft fly at low altitude, the optimum detection range is very small and increasing speed of the attacking airplanes demands its increase not only because of the shorter time between radar pickup and hostile attack, but also because of the greatly increased difficulty of making an interception on a high-speed plane. A typical example which proved troublesome when this was written [May, 1945] was the problem of the Japanese suicide bombs. These had a range, from release at the mother plane, of some 50 miles, which made the interception and destruction of the loaded mother plane before it had released its bomb, almost impossible if the only radar information available must be obtained at the target with antennas no higher than the usual one of a ground or ship radar equipment. B-29's of the

Twentieth Air Force were used to bombard the airfields from which these aircraft operated; this was a somewhat inefficient use of the B-29, and suggests that greater returns might have been obtained by a contiuous picketing of these fields by radar-equipped B-29's capable of alerting friendly fighters when a raid takes off. It is conceivable that this could be done with the help of existing airborne radar, if it were skillfully used. In any case, it is clear that the only available answer to low-altitude attacks by fast aircraft is a warning service and aircraft-control facility whose coverage extends well beyond the optical horizon.

The problem, as it concerns bomber operations, is not nearly so clearly defined. This is so chiefly because the air offensive of the future is more difficult to predict than the defense. The backbone of the latter will always be destruction of the enemy's offensive machines, whatever shape they take, and this will always demand warning and information of position sufficient to permit control of the defensive agencies, whatever they may be. The design of offensive machines is something else again. There is an enormous range of choice, ranging from an extension of the escorted heavy-bomber attack familiar from European experience, through medium-bomber operations and the use of fighter-bombers, to an attack by entirely unmanned aircraft, which, in the extreme may themselves be projectiles. The usefulness of the detailed control which modern radar permits will be greatest for the escorted heavy bomber operation, and will decline through the list just given, with the important exception that unmanned aircraft may be controlled to their target entirely by means dependent on radar. This last is a somewhat speculative possibility. In the present war we have committed ourselves rather completely to the mass escorted heavy- or very-heavy-bomber operation as the chief weapon of long-range air attack, and further discussion of air-based control of offensive air operations will be made on the basis, principally, of this type of operation.

During the last months of operation of the Eighth Air Force, which was the cradle of the modern escorted heavy-bomber operation, control of escorting fighters and some degree of navigational facility to bomber formations were provided by a long-range high-definition radar set which was sited first in eastern England, and later on the Continent. Increasing reliance was placed on aircraft control exercised by this equipment, and it became clear that an extension of the facilities it provided to cover the entire area of operations of the Eighth Air Force could, in principle, cause a revolution in the character of the operations of that force. It was customary to lay out a proposed operation, down to the most minute detail, from 24 to 48 hours before it was actually to be carried out, and the numbers of aircraft involved were so huge that no enemy reaction, however unexpected or threatening, could be allowed to cause an alteration in the broad outlines of that operation. The ability of the MEW radar, within its range, to permit the fighter dispositions to be altered to deal with actual, not expected, enemy reaction suggested that the entire operation could, in principle, be controlled from such an installation if its range of coverage were sufficient. Such coverage can be provided, clearly, by air-based detection and control equipment.

### THE EQUIPMENT

It will be our purpose in this section to discuss only the principal performance features of existing and proposed equipment for air-based control of air operations.

It will not be our aim to discuss this equipment exhaustively, nor to indicate its limitations arising from the present state of our technical development. We must, of course, discuss the limitations which are fundamental and cannot be escaped. Perhaps it will make this distinction clearer to say that the horizon range of microwaves is a fundamental limitation, which, there is good reason to think, cannot be avoided. On the other hand, the fact that there is presently no adequate three-dimensional radar indicator, showing a scale map of the air space with aircraft positions and past courses displayed upon it, is simply a confession of the fact that insufficient technical effort has been put on the development of such a device, which has not yet appeared sufficiently urgent. There are two basic types of equipment to be discussed: radar and communications. Communications includes as subtypes voice radio, IFF, and radar-relay equipment.

So far as the radar is concerned, there is presently under development and nearly ready for operational use a set which has been informally called the AEW (AN/APS-20). This equipment operates at 9 cm and has several operational drawbacks which must still be cured in order to provide a really satisfactory radar for airborne aircraft control. The two chief objections to the AEW as it is presently designed are that it does not provide any means of giving accurate height information, and that it suffers excessively from ground returns. A less significant drawback is that the AEW will not, in its first embodiment, give full horizon coverage on a single aircraft of any type; its performance falls short of this. Improved receiver performance is in sight as a consequence of the discovery of a process for making very much better mixer crystals than used to be thought possible, and the range limitation is very clearly a transitory one. Height-finding from a platform as unstable as an airplane is a considerably more important difficulty, but there is no reason to think that this will not yield to development effort. Perhaps the most difficult of all is the elimination of ground returns, but this has been successfully achieved for stationary ground radar stations, and there is no basic reason for supposing that this technique cannot be improved and extended even to a radar station in a moving airplane. The situation with regard to radar equipment for air-based control of air operations can be summarized by saying that all the necessary techniques are either in hand or in sight.

The same remarks apply to the equipment for the relaying of radar information. Perhaps because this has never been seriously done in military operations, it seems that there are no difficulties in principle, and the work in hand on this subject gives great promise of success. It may be, and probably will be, that the first embodiments of this equipment will have faults, but these should prove to be correctible.

There is a basic difference between the two types of equipment just mentioned and the voice radio and IFF gear demanded by a flexible control setup. While the technical difficulties of the former are considerable, they seem capable of solution and (this is the important point) a very small number of equipments will do the complete operational job even for a very large air force. Large-scale policy decisions do not have to be made, and the influence of political considerations on the technical problem is at a minimum. This is not true of voice radio and IFF. Whatever equipment is installed in aircraft for use by the air-based control facility will be expected to serve as voice radio and IFF for all possible purposes, and the resulting political arguments will be very formidable. While it is not realistic to ignore this fact, which arises from the circumstance that all aircraft carry the equipment concerned, this will have to be done to permit us to get on with the discussion.

With the foregoing remarks about the lack of realism involved in such a discussion, it is fair to say that the existing and proposed voice radio, operating at VHF and just above, is very nearly satisfactory (it can be somewhat improved by a system which has sufficient channels to provide a separate one for each aircraft; such a system has previously been described in detail). Existing and proposed schemes of IFF are entirely unsatisfactory. Not only is the directivity of the largest feasible antenna which can be carried on an airplane marginal for the precise separation of friend and foe needed for aircraft control, but also personal recognition is not provided by any system, not excepting the highly regarded Mark V, and personal recognition is the backbone and the basis of successful aircraft control. It is even likely that the height-finding on friendly aircraft could be done with the help of the IFF system, if one like that proposed in the foregoing article could be used. It is to be hoped that the very great advantages of such a system in all connections will result in its adoption. Its virtues from the standpoint of airborne control can scarcely be regarded as important enough alone to produce its adoption. It is important to recognize, however, that the lack of directivity and of personal recognition facilities in all IFF, including the Mark V, constitutes a fundamental limitation arising from the frequency range used, and is curable only by the adoption of a completely new system.

## THE FUTURE

As has already been indicated, the importance and the detailed design of equipment for the air-based control of air operations will depend upon the character of these very air operations. It is difficult to foresee just what this character will be. There are basically two directions in which offensive air operations can go. The first is toward a Navy task force sort of arrangement, in which the present-day escorted heavy-bomber operation is elaborated to whatever degree the square-cube law permits. This contemplates giant fleets of large airplanes, capable of long-range performance, and protected by specialized fighters (which may be manned or not, as the nature of the opposition demands), flying in formation from base to target and dropping great loads of bombs. On the assumption that long-range escort fighters can always be provided with the ability to engage defending fighters on reasonably equal terms (this has so far been the case), the chief hazard to such future aircraft can be expected to come from antiaircraft fire. Such fire, as the speed and the operating altitude of the bombers increase, will probably not be gunfire because of the large times of flight and the consequent difficulty of accurate prediction, but will be composed of homing or ground-directed self-propelled missiles, such as rockets. The problem of defense against this fire can be reduced to that of the problem of defense against fighters if the offensive aircraft fly high enough to permit such missiles to be engaged by their defending escort fighters before the missiles reach the bombardment aircraft. Such an eventuality places an extremely great premium on the development of a swift and adequate facility for the air-based plotting of such attacks, and the marshalling of escort fighters in detail to meet them.

The second direction in which offensive air operations can go is diametrically opposed, and seems at first glance to offer a far smaller field for the air-based control of air operations. This is the development of extremely fast bombers (or self-propelled unmanned bombs) which would proceed without escort from base to target. They would rely on their speed alone, and the difficulty of interception which is creates, for security against both fighter attack and ground antiaircraft fire, by whatever type of weapon. At first sight, this seems to remove the necessity for detailed control of air operations, but only at first sight. Not only is the guidance of unmanned bombs to their target of the greatest importance, but also there is a type of defense against such attack which makes radar location and fighter control as important as ever.

This arises from the circumstance that the laws of motion followed by a bomb are equally known to both sides in a war. Consequently, if a fleet of bombs or of bombers, flying at supersonic speeds, is detected by the enemy to be flying in a given direction, he can make a shrewd guess as to the target, and he can tell at precisely what point in space a bomb must be released from each altitude to hit the target. It will then be possible to deploy defensive air mines, which may be ground-controlled helicopters without crew, in a space lattice so placed that the offensive machines must run through it if the target is to be attacked at all. This will almost certainly be a more feasible form of defense than attempted fighter interception of very fast aircraft can ever be, and it demands the sweeping of the mine barrage before a successful attack can be carried out. This can only be done on the basis of the same sort of highly detailed aircraft control which has been contemplated throughout this article.

Since any other direction of development for offensive air tactics lies between the poles of the great air fleet and the supersonic unmanned bomb, and since both of these demand control of aircraft to be exercised over the horizon from friendly bases, we can conclude that:

(1) Air-based control of aircraft will be an important technique in future air warfare.

(2) The necessary radar equipment and equipment for relaying radar indication to a ground or ship base are being developed in a form which gives promise of being satisfactory.

(3) A decision between the control of air operations from an actual airplane, or such control from a ground or ship base, receiving relayed radar signals, cannot be made without extended experiment, which has so far not been undertaken.

(4) The voice communication and IFF techniques afforded by the use of microwaves are far more promising than those offered by existing or contemplated equipment, and will be very helpful to air-based control of aircraft if the political difficulties of introducing them can be overcome.

# LOCATION OF TARGETS

## EXACT TARGET LOCATION

It will do very little good to provide elaborate and precise means of navigating aircraft, and other elaborate and precise means of dropping bombs, unless we know where targets are to be found in enemy territory. The navigation and bombing problems may possibly be entirely solved by the means of automatic machinery involving no men in the aircraft, but the problem of determining precisely where the target is located in the first place requires the judgment which can only be supplied by men. It may be divided into two parts, namely, (a) reconnaissance, to locate the target in the enemy territory in order that plans for its attack may be formulated, and (b) recognition, to distinguish and recognize the target immediately prior to its attack. Reconnaissance is the process initiated after intelligence has determined that the target actually exists.

## RECONNAISSANCE

Unless accurate maps or geodetic surveys of the enemy's territory already exist, these must be provided by our own forces. One example in the present war has been the mapping of the Solomon Islands and other Pacific Islands rendered necessary by the inaccuracies of the charts which we had before the war. The prime purpose of such maps should be to give an accurate picture of the topography of the enemy territory. They may or may not show the actual location of all possible targets. They will, however, show the shape and location of cities, important rivers, coastlines, mountains and other natural features.

The most important method of finding out what the enemy territory looks like is by aerial photography. The methods of aerial photography have been highly developed, and there is no reason why they should not continue to be useful even if the speeds and flying altitudes of aircraft increase. For very high-altitude flying, however, it may often occur that photographic missions have to be carried out from such long distances that very few of them succeed in finding enemy territory unobscured by clouds. In such cases, useful maps can be made by photographing the indicator scope of an airborne radar set. It may be desirable to provide special reconnaissance radar whose express function is to provide large and clear map-like presentations of the terrain, suitable for photographing.

It will not, however, be desirable in all cases to furnish either the ordinary aerial photographs or the reconnaissance photographs taken of radar scopes to bombardiers and navigators for use during actual bombing missions. Rather, it may be desirable to make line-drawn maps from these photographs. Apparatus to assist in the preparation of detailed maps from aerial photographs is at present highly developed. The development of similar apparatus for reducing radar-scope or PPI photographs to maps should present no difficulties and would require only the initiation of a development program to get it under way.

Incidental to preparing maps from photographs it is necessary to know not only what the enemy territory looks like but where it is located with respect to our own territory. In order to provide this latter information, a means of geodetic survey must be provided. That is, we must know the exact latitude and longitude of prominent features of the enmy territory. In order to provide this information, it is necessary that there be some means of accurately locating the photographic aircraft with respect to our own territory while it is taking the photographs. Several methods may be used to furnish this information: (1) Astronomical navigation may be carried out by the photographic airplane. (2) Various types of electronic ground-based navigational equipment may be employed.

Because of the limited range of electronic equipment, the solution to this problem differs according to the distance which separates the nearest friendly base from the enemy territory. If the nearest friendly base is more than approximately 1000 miles from the enemy territory, we must rely upon astronomic navigational data in order to position accurately the photographing aircraft. At the present time astronomical methods of navigation are not as precise as several types of electronic methods. Therefore, if the enemy territory is not more than approximately 1000 miles from the nearest friendly base, the latter should be employed. For this purpose the Loran apparatus presents many attractive possibilities. By its use, position data may be continuously and automatically recorded and impressed directly upon the photographs. (The principles of the Loran system of navigation and its future possibilities are described in the section "The Future of Hyperbolic Navigation," pages 110 ff.).

Neither astronomical data nor even Loran data, with the possible exception of cycle-matching Loran, discussed on page 114, will be of sufficient accuracy to compare favorably with maps made according to the standard methods of geodetic survey. There is, however, another system of electronic navigation called Shoran which is capable of giving data for the location of the photographs which compares favorably in every way with standard methods. This system, however, possesses the disadvantage that it can only operate from bases which are on the order of 200 or 300 miles distant from the enemy territory. Therefore, it may not always be possible to use it, especially at the beginning of a war. This restriction on the range of our most accurate survey means is a fundamental one and is not likely to be greatly improved by future developments in the electronic art. It suggests that before wars are declared one should already be in possession of accurate maps of the enemy territory.

After we have provided ourselves with accurate and precise survey maps of the enemy territory, we must then spot on these mapsthe location of those enemy installations which we regard as targets. However, before we can spot the enemy's targets upon the map, we must first know that they exist. The first procedure will undoubtedly be to make factual surveys of the enemy industry to find out what targets and how many and approximately where they are likely to be. This can be done by the usual methods involving agents, the study of prewar economic data, and other studies such as are now carried out by the Board of Economic Warfare. This information can also be found from aerial photographs or even in some cases from photographs of the radar indicators of the reconnaissance aircraft. However, the enemy, knowing that we are desirous of locating his main factories and other installations may try to disguise their appearance either by camouflage or by providing simulated decoy targets, or he may try to jam our electronic equipment. We must, therefore, employ a variety of means to locate the targets, comparing the results of one against the others. There are also several electrical devices whereby the operation of our agents and the conveyance of their data may be expedited. Some of these will be discussed below.

In considering the use of each of the devices to be discussed, therefore, we must also consider what means the enemy may use in order to defeat them. We shall discuss here the provision of decoy targets and the concealment of the actual target, leaving the dicussion of jamming to another place. The means of concealment include natural cover (as by forests), camouflage, and the placing of major installations underground.

We shall first describe the means which may be used to locate accurately the position of cities and other targets which occpy a large area.

## AERIAL PHOTOGRAPHY

There is very little that the enemy can do to conceal his cities or major factories. Efforts had been made during the recent war, especially by the Germans, to disguise the appearance of parts of cities, for example, by covering over main roadways with roofs of camouflage material. In another case, the enemy provided a decoy, complete in many details, of an important oil field. Such methods are, however, of more importance to the enemy in his efforts to defeat the recognition of his enterprises by bombardiers prior to a bombing mission than they are in defeating our reconnaissance efforts. The reason is that the long period of time which is available for the study of reconnaissance data usually enables decoys to be detected as such, since the actual target also appears on the photographs.

The concealment by camouflage of any target against aerial photography can generally be defeated by one of two methods. First is the employment of colored photography. There are very few pigments useful for optical camouflage which so carefully match the colors of the surrounding territory that by the proper applications of color photography and the use of carefully selected color filters they cannot be made to stand out in considerable contrast from the surroundings. This is regardless of the fact that they may appear indistinguishable to the eye. The second method involves the use of stereoscopic photography which has also been highly developed. This method provides photographs which when viewed through suitable devices show the height of the subject to be greatly exaggerated. The method is powerful because the height of a target such as a factory building cannot be made smaller by the application of camouflage paint.

In many cases, cities and large industrial installations may be located with sufficient accuracy from a study of radar-scope photographs taken by photographing the indicator tube of an airborne reconnaissance radar set. The ordinary methods of camouflage which are suitable against aerial photography do not at all accomplish their purpose when radar is employed to look at the target. The reason targets are seen in radar sets is because of their gross characteristics and in particular because the target contains many reflecting surfaces which would have to be covered over by means of a camouflage material in order to make the target invisible. However, most camouflage materials, such as nets and pieces of cloth as they are now commonly employed, are quite transparent to the radar beam, which would therefore look through them and see the target underneath. Moreover, were the camouflage itself sufficient to hide the target beneath it, it would be in turn very difficult to prevent the camouflage from being detected as an object or region on the PPI or radar indicator tube different from the surrounding terrain, and this in turn would be almost as satisfactory as seeing the target.

The use of decoys to defeat radar detection of targets has been tried in some cases. However, the installations required to make a radar decoy are very expensive in comparison to those required to make an optical decoy. Furthermore, the same considerations apply here that apply to optical decoys, namely, that since the actual target will also appear and time is available to study the photographs, there is little hope that the Intelligence personnel would be fooled by this measure. It is, therefore, not regarded as being practical to attempt to hide either cities or area targets from reconnaissance aircraft either by camouflageing them or by providing decoys.

The building of cities underground is not regarded as practical from the point of view of the ventilation required if the city includes power plants and large, heavy industries. In this respect reference is made to "Heat and Television Guided Missiles," (G. A. Morton) page 42 ff., of the SAG report *Guidance and Homing of Missiles and Pilotless Aircraft* which discusses the problems of ventilating and getting rid of the heat generated in large installations when they are built underground. There are, however, many special types of large industrial installations, in particular aircraft assembly plants, which can be placed underground with practicability. These underground installations can be detected neither by aerial photography nor by radar-scope photography, and other means must be sought. We must therefore consider how we may detect these underground factories.

One must first remember that all the power consumed by a factory of any sort is eventually turned into heat. This process involves the friction in the machines, the resistive losses in electric motors, the heat generated by lighting fixtures, by air compressors, and so on. Now, if the factory is to be kept at sufficiently low temperature as to be endurable by the workers, some means must be provided for getting rid of this heat. As is shown in the above-noted paper on the thermal detectability of underground factories, this heat may be dissipated by a sufficiently elaborate but quite practical ventilating system; it will not dissipate of its own accord. In this respect an underground building resembles a thermos bottle. The hot air taken from the factory must be conveyed to the surface of the earth, and unless special and very expensive means are taken, the hot-air exhaust pipes may be detected by sufficiently sensitive equipment carried in reconnaissance airplanes. The reference mentioned shows that there are only a certain limited group of plants which may be so treated and that in any practical case there is always going to be a possibility that the exhaust pipes may be detected. Of course, the detection of such exhaust pipes is very nearly as good as the detection of the plant itself. Therefore, one should seriously consider the installation in reconnaissance aircraft of equipment especially devised to detect the heat given off by industrial installations. Apparatus for this purpose is understood to be now under development at the RCA laboratories.

In the event that underground installations are undetectable by heat-sensitive equipment carried in reconnaissance aircraft, other means may be partially effective in detecting them. The chief of these is the employment of sound detectors. Just as all industrial installations give off heat so do they give off a good deal of noise. The direct detection of this noise by microphones carried in reconnaissance aircraft is not regarded as practical because of the noise of the aircraft itself, which will very easily shield any noise from the ground. However, as is shown in the reference, it is possible to drop radio transmitters, carrying microphones, to the ground which may then pick up the noise on the surface of the ground and retransmit it to the reconnaissance aircraft. Devices suitable for this purpose, called sonobuoys, have been employed in the recent war against submarines. These sonobuoys are dropped in the water in vicinities suspected of harboring submarines, and they pick up the submarine noise and radio it to the aircraft above. It is entirely practicable to employ similar devices against underground targets. Of course, a great many of them would need to be employed, but fortunately they are not very expensive to construct. The tactic would be to fly a considerable number of aircraft over the enmy territory and drop such a sound detector say for every square mile of territory. By suitably coding these detectors and marking the position in which they were dropped it would be entirely possible in some cases to locate the underground factory with a fair degree of accuracy.

Radio transmitting equipment, although it may be constructed underground, necessarily requires an antenna above the surface. Highly developed and rather simple equipment is already available for detecting enemy radio transmitters.

Atomic power plants, should they be developed, may be detected not only by the heat which they give off in common with other industrial establishments, but also they may be expected to give off types of radiation peculiar to themselves, which are able to penetrate considerable thicknesses of earth. It may be feasible to provide suitable airborne equipment for the detection of such radiation.

In the present war, equipment has been employed to detect submerged submarines by virtue of the irregularities which they produce by virtue of their iron construction in the earth's magnetic field. In principle, such devices should also be applicable to the detection of underground factories. However, because of the short range of detection, these devices are not regarded as highly practicable for this purpose.

We may divide all industrial installations into three classes. These are: (1) heavy industrial establishments, such as steel plants or entire cities which can neither be economically placed underground nor can be dispersed; (2) manufacturing enterprises which cannot be dispersed but which may be placed underground with a certain amount of immunity to detection; (3) small establishments and potential targets dispersed on the surface. Small factory buildings isolated from any surrounding establishments may be effectively comouflaged or hidden by natural cover assuming that they are not underground. They may be camouflaged or hidden either from detection by aerial photography or from detection by airborne radar. However, the type of camouflage which is required in the first case is not particularly effective in the second, and the type of camouflage which is required against radar may be definitely harmful from the point of view of detection by aerial photography. Even targets which are hidden by natural cover like forests may in some cases be detected by airborne radar because the forests are often transparent to the radar beam. They will also be detectable by virtue of the heat which they give off as has been previously pointed out. The best way of locating such small establishments accurately is by a repeated series of reconnaissance missions each employing all of the useful techniques simultaneously. By a study of the successive photographs taken on successive days over a considerable period of time, it will often be possible to detect imperfectons in the camouflage or other unnatural phenomena which will serve to expose the position of the target. Objects which are surrounded on two or more sides by water are particularly easy to detect by radar beams. This applies particularly to bridges. In some cases, however, in the present war the Germans succeeded in constructing bridges which were entirely submerged, their roadways being about a foot beneath the surface of the river. Such bridges are of course quite undetectable by radar and also in most cases by photography, or indeed by any other means. Their presence may be again detected, however, if a sufficient number of photographs are taken over a long interval of time, due to changes in the river height, eddies, and other chance phenomena.

Materials exist which are sufficiently nonreflecting to radar beams as to render the covered objects undetectable thereby. A building covered with such material and located in a dense forest might be expected to be completely undetectable by radar. In such cases, recourse must be had to the subsidiary methods mentioned in connection with underground establishments; in particular, the possibility of dropping of small sound detectors must be considered.

## TACTICAL RECOGNITION

Tactical recognition is the procedure whereby the bombardier or gunner is enabled to find the target preparatory to aiming at it. In the case of large and extended targets, such as factories or major industrial installations which are located above ground, this presents no difficulty, the problem having already been solved by the reconnaissance. Small maneuvering targets (such as tanks) or targets which are stationary but of small size (such as small buildings) camouflaged or underground installations, gun batteries and the like may be marked by agents. This may be done by the use of beacons of various types which may be set up just prior to the raid. In a few restricted cases, the beacons may consist of flares. However, in most cases it would be preferable to use devices which are, temporarily at least, invisible to the enemy. In this category come portable radar beacons. Such beacons are being made, and in the future considerable effort should be made to make these devices smaller and lighter so that they may be more inconspicuously carried by a man. Use of such devices would require no special equipment to be attached to the sighting devices in the aircraft since radar bombsights are already equipped at the present time to detect corresponding beacons, and visual light flares would of course be detected in the usual manner.

A useful tactic for vehicle detection might also be to place small microphones and associated radio transmitters along the expected path of the enemy vehicles. Operational tests, however, would be required to tell whether such a procedure would be tactically successful. It might be more successful as a means of sentry duty available to ground troops than as a means of identification for air attack.

A number of special devices may be utilized in order to enable the attacking aircraft to recognize unmarked targets.

Special attachments are available to airborne radar sets which will enable them to detect small moving land targets such as motor cars and tanks. The development and application of such devices is highly recommended.

The use of airborne control information centers may be of importance in strategic bombing operations. A complete description of the operation of such airborne control centers has been given in "Air Based Control of Air Operations," page 138. Finally, the attacking airplane may be equipped with specific radiation detectors to detect radio and radar transmissions, and this apparatus may be used to identify targets. IFF equipment is a particular example of equipment which is widely used to identify enemy positions from friendly ones.

There are a number of devices, navigational in nature, which may be used on the ground in order to control aircraft to the exact vicinity of the target. These include the various types of ground-controlled radar (which had been previously discussed under bombsights), IFF equipment, and of course the various types of communication equipment.

## CONCLUSION

The problem of exact target location may be divided into two parts: (1) the strategic reconnaissance problem which accurately maps the enemy territory and locates on these maps the exact positions of all targets; and (2) the tactical recognition problem, the solution of which enables the attacking aircraft actually to sight upon the target. Different devices for the different types of these problems have been outlined. It is considered that no one device will solve all of the problems but that the devices employed must be chosen according to the need. The problem of training and briefing of all personnel concerned should not be neglected. In particular, the selection of suitable operational personnel is of the utmost importance; simplification of the intelligence material which is presented to the operational personnel must be achieved; and it is recommended that methods of presenting and preparing intelligence material should be studied continually.

# RADAR AIDS FOR THE ALL WEATHER AIR BASE

## INTRODUCTION

It is best to begin this discussion by listing the various steps which an all-weather air base would face in handling the take-off or return of large numbers of aircraft under instrument conditions. The problems vary from the emergency landing of a single airplane to handling several squadrons of airplanes many of which may be foreign to that particular field. The facilities for the most complex cases will be considered here although it is recognized that emergency landing of small numbers of planes may require only a part of the equipment required for the full job. In the proper sequence these various steps are:

(1) Clearance for taxiing aircraft and blind take-off.

(2) The marshalling of aircraft after take-off into squadron formation and the relinquishing of control of the aircraft to whatever navigational system may be used to aid the flights in their mission.

(3) The identification and control of aircraft returning to the field. It is probable that this will include the spacing, stacking or any other method of separation of planes into desired intervals for landing, and the initial contact of the plane with the landing aid.

(4) The final approach using the landing aid.

(5) Speedy clearance of runways after landing.

In normal weather the air-base control tower has little concern with functions except within a very small area (approximately 5 miles radius) around its field. The control tower gives taxiing instructions for take-off and landing, and functions to control planes entering the traffic circuit. The prime responsibility for the actual position of the plane is the pilot's. There are many who believe that in blind landing, the pilot can be given instruments by which he can function much as in good weather and with the very minimum of control by the tower. It appears to many others, however, that the functions listed above will all have to be the prime concern and responsibility of ground personnel and equipment, functioning very much as a control tower. In fact, the development of satisfactory facilities for handling large numbers of aircraft in blind approaches, should lead to the adoption of part of the same methods for good weather control. There is much to be said for each of these viewpoints to make it appear that both are correct, that the two systems of operation are complementary and that both will be of future use.

## GENERAL MILITARY REQUIREMENTS

It would be well to set down a summary of the military requirements of the problem outlined above. Some of these are general requirements for all instrument flying, and are doubly important here.

(1) The system must give satisfactory results with all types of pilots, with the inexperienced as well as the veterans, even when tired or wounded.

(2) It is desirable that the systems require as a maximum but a few hours of pilot training and but little long-term practice to enable satisfactory emergency use.

(3) Both ground and airborne equipment must give 100% reliability. This is not only necessary for safety but is required to hold the pilot's confidence. This means that constant monitoring facilities for presentation to the pilot should be provided on airborne receivers. If beam-approach systems are used, the beams must hold their position over long periods of time.

(4) The system must be capable of handling planes approaching at various speeds up to 1000 mph, and whose top landing speed may be of the order of 250 mph; landing speeds range from 70 to 250 mph.

(5) The system must handle nonscheduled emergencies such as disabled planes, crack-ups on the runways, etc.

(6) Provisions must be made for preventing collisions.

(7) The equipment must provide security against enemy intruders.

(8) The equipment must provide protection against jamming.

(9) The weight and bulk of the airborne equipment must be kept at a minimum.

(10) The ground equipment must not present a hazard to flying aircraft.

(11) Ground equipment on the airfield itself must be mobile. If possible, all equipment should be air-transportable.

(12) The equipment must indicate to the pilot how to clear any flight obstacles which may be required around the airfield.

(13) The final landing aid must give the pilot an accurate sense of position in both the horizontal and vertical planes. It is desirable that the heading of the aircraft with respect to the runway should be indicated.

(14) The equipment must be capable of handling successive planes of very different landing characteristics.

(15) Provision must be made for positive identification of all aircraft to be landed.

(16) If landing beams, homing beacons, etc., are used, positive identification of a particular field in congested areas is required.

(17) Interference between ground stations cannot be tolerated.

(18) In multiposition ships, the system should allow for another member of the crew (copilot, navigator, or radio or radar operator) to take some part in the landing operation.

(19) Provision should be made for landing on parallel runways. Landing aids for the two runways must not interfere.

(20) Adequate radio communication must be available in the plane.

(21) At every all-weather airport, there must be at least an emergency system, of sufficient flexibility to handle any type of aircraft or military pilot. This requires that

every plane to be used in all-weather operation be equipped with some emergency landing aid, or that the system used require only radio communications in the aircraft.

(22) The over-all system should be capable of handling planes on single runways at approximately the speed at which these planes can be landed under good visibility conditions. The minimum requirement is 60 planes per hour, the maximum not more than double this.

(23) The pilot's indication or presentation device must be as simple as possible and such that little or no mental computation or interpretation is needed.

(24) Last and perhaps most important is that the equipment must gain and hold pilot's confidence. The pilot is a human being who likes to stay alive; pilot apprehension and distrust have killed about as many landing systems as pilots. The psychological attitude of the pilot is of prime importance in bad-weather flying and landing. In order to convince him, the data presented to him has to be of highly reproducible accuracy. He should be able to make check flights in good weather to convince himself of their accuracy.

The preceding list of requirements hold for the most rigorous conditions; no one existing equipment, radio or radar, completely satisfies this list. Combinations of existing equipments can be made, however, which will approximately satisfy all the operational requirements.

The question is asked, "How do the requirements for permanent bases differ from temporary ones?" In the above list only item (11) seems to be affected if permanent installations are desired. At permanent bases it will be possible to make a much more elaborate installation of the ground equipment; the mobile features of the airport gear may be removed and duplicate landing equipments established for various runways. It is possible to lay down permanent connecting cables from tower to field installation, etc. The need for extremely rapid shifting of landing equipment from one runway to another is not generally considered a necessity.

## EXISTING LANDING AIDS

The following is a list of the navigational and landing aids that are in operational use by USAAF, USN, or RAF; are in development by the services; are developed but not in operational use; or are obsolete.

1. Navigational aids to help aircraft back to base or systems that can function as such

   a. radio ranges
      direction-finding chains
      Loran
      Gee, H, etc.
      radio-homing beacons with coded sectors
      *racons (used with AI or ASV radars)
      *airborne radars such as $H_2S$, ASV
      *AN/CPS-1
      *GCL, etc.

   b. *AN/CPS-6

*Indicates microwave systems.

2. Traffic control systems

   a. radio ranges, direction-finding chains, etc.
      *AN/MPN-1 (partially effective)

   b. *British ACR systems
      *AN/CPN-18 (AAF, NDRC development)

3. Approach systems

   a. Beam approach (localizers and glide paths)

      (1) SCS-51
          VHF-BA (British)

      (2) *PGP (X-band pulsed glide path NDRC)
          *Sperry (S-band CW localizer and glide path)

      (3) SBA (British Lorenz), Air Track (YB and YO), Bendix (93 mc), Lorenz (10 mc), CAA-MIT (600 mc) — all constant-intensity glide paths

   b. Beacon-beam approach system

      (1) Radar BA (BABS) or Lucero BA (British)

      (2) BUPS
          AN/CPN-7

      (3) AI-BABS, ASV-BABS

   c. Ground control of approach

      (1) AN/MPN-1

      (2) AN/MPN-3
          AN/CPN-4
          AN/GPN-2

      (3) Modified SCR-517 or SCR-717, or AN/APS-15

*Indicates microwave systems.

## TRAFFIC CONTROL

Let us now examine in more detail some of the landing functions required for an all-weather air base.

The problem of handling large numbers of planes (say 60 to 80 per hour) returning to the field under conditions of poor visibility is a rather hopeless one without radar facilities. Neither the planes nor the towers however, now possess the radar facilities to locate the planes individually in azimuth, elevation, and range with respect to the landing strip, nor to identify, space or stack them, nor to give proper order of landing, nor to feed them into a given final approach system.

The first and foremost requirement for the all-weather base is a ground search radar that is capable of giving to the control tower the necessary positional information of all the aircraft in space about it, including traffic passing through the control area, as well as that desiring to land. Ground radar can supply all the necessary information and control such planes if the necessary communication and personal idenitfication schemes are available to identify each individual plane, i.e., to identify positively, the plane desiring information or to be controlled, and to give instructions.

The GCA equipment developed at the Radiation Laboratory and now in operational use by the AAF, Navy, and RAF, although primarily an approach system, contains the first elements of traffic control in its S-band search radar. It has been used in a limited way to study some of the problems of aircraft traffic control on a PPI of 15- or 30-mile radius. Experiments were performed on stacking methods about the airport itself, stacking in angle, range, dog-leg path, etc., and the correlation of an approach system with blind vertical stack by the tower itself. These have led to the conclusion that in general a separate equipment must be made available with greater range, elevation coverage, indicator facilities, etc., than the present GCA to serve adequately the desired function. It has not been found possible for the one PPI operator available for traffic control to keep more than four or five single planes completely under his control at one time. Control schemes are now under study and test by the Air Forces whereby groups of planes such as fighter-bombers which can fly formations of two to four planes through cloud may be controlled by such facilities as are available in GCA itself. However, such procedures will be limited to highly maneuverable aircraft and must be looked on as only interim solutions.

The Army Air Forces together with the Radiation Laboratory began experimental studies of the equipment, operator, and operational requirements for such a separate ground radar set under the AN/CPN–18 development program for an airport search set.

This program proposes to study the following problems:

(1) The control of the spacing, course, and altitude of single or formation flights of planes over sufficient range so that the planes arrive over a marshalling point or "gate" at the proper interval be immediately handled by the final approach system. From the early experiments mentioned above it is believed possible to control the returning courses of a large number of planes with sufficient skill if planes are brought under control early enough, i.e., at sufficient range. Thus the aircraft will be stacked in a horizontal plane as they progress through the control area toward their field. It is realized that in a dense population of airfields it may be necessary to have such a system act as an area control, feeding planes into a number of fields; hence more than one such gate may be required.

(2) The control of these planes about such a gate, which may be a homing beacon, radio range station, etc., may be required since it may be found impossible to adjust arrival of planes at such gates with sufficient fineness in time as just to match the landing interval which the landing aid, whatever it might be, can handle. The gate, of course, can be the airfield itself, although it is generally felt that points eight to ten miles distant are more desirable. Provision must be made then for surveillance by radar of the control point so that planes may be stacked horizontally or vertically about them and their position in such a stack known at all times. It will then be possible to call the planes into the approach aid at the desired time so the desired landing rate can be maintained.

(3) The control of the descent of planes through overcast under sufficient ceiling (200 to 500 ft possibly) so that they may be brought in by the search radar itself. It has been found possible with the GCA search to bring airplanes in on the PPI alone so that singly or in small formations, they break out below the overcast and make their final approach visually.

(4) The final function of such a set is to feed planes into a final approach system so that, if a ground control system such as GCA is used, the plane is in proper position to be handled quickly and easily on the narrow sectors of vision of the approach system, or if other types of landing systems are used, so that time is not wasted in hunting localizer beams, etc.

It is recognized that the above aids fail unless proper facilities for communications with the planes and positive personal target identification methods are available.

In the experimental program outlined above, eight-channel HF and VHF communication facilities will be provided. It is hoped that communication channels necessary for the traffic control function will be found to be a maximum of two or three. Transmitting to any one plane under control need not be long, only a few seconds, so that many planes may be controlled in a short time. It may be required to separate the different functions into different channels.

The identification problem is recognized as perhaps the most difficult of all. It is recognized that, on a long-range program, a solution such as the proposed microwave communication system must be found to provide a very large number of communication frequencies and to provide personal recognition of aircraft. It is felt, however, that considerable success can be achieved by a combination of the several identification aids now available, namely, communication direction-finding, particularly if the direction-finding bearing can be added to cathode-ray tube presentation, height information, and beacon facility such as Rosebud. The combination of such information with maneuvering, such as the sending of a given plane out on a given heading from a given point, should be studied thoroughly.

Schemes will be devised in the future by which the information as to an airplane's range, azimuth, and elevation relative to a given control point may be fed to the plane's automatic pilot so that planes may be automatically controlled in the stack. In this vein, one should mention the experiments being conducted in England on orbiting control using Radar BA. The range indication from the interrogated ground beacon is used to feed voltages into the autopilot so as to hold the plane on a circular course around the beacon at constant range from it. Planes could be fed into such a system and given different ranges, say at half-mile intervals, in which to stay until called out to land. The spacing of such planes to obtain very high landing rates does not at the moment look too promising. These experiments are in their infancy and will be watched with a great deal of interest.

## LANDING AIDS

The development of usable radio aids to landing has been along three general lines. The first, beam-approach devices (localizers for azimuth and glide paths for elevation), is the field in which most of the development has been concentrated. These systems are called air-indicated systems, i.e., airborne receiver systems and indicators such as cross-pointer meters or cathode-ray tubes. These are used to detect and indicate single or multilobe beams generated on the ground and pointed in the desired directions in azimuth and elevation out from the runway. The second general class, beacon-beam approach systems, involves the use of airborne interrogators in addition to the airborne receiving and indicating gear. The ground equipments are essentially beacons which only radiate their beams when interrogated by the airborne equipment; the positional information furnished by the plane's interception of the beam is presented to the pilot or navigator on CRT's or on meters. The third general class is ground-controlled approach systems which in general are ground installations of scanning systems that obtain on the ground all the information as to a plane's position relative to a desired glide path in azimuth, elevation and range from the runway and then relay such information by voice or aural tone to the plane through normal radio communications.

A fourth classification which is in its early experimental stages might be added. This involves the use of the information available in the plane from any one of the other three general types as data to be fed into an automatic pilot to accomplish automatic approaches and landings.

Radar, particularly microwave, equipment has made valuable contributions in all three of the general types. Some of its peculiar properties such as the ability to produce very narrow beams (less than one degree half-widths) with reasonably sized antennas, the relative freedom from atmospheric effects, etc., over the short distances involved, the relative security from jamming and interference afforded by such narrow beams can materially aid in the elimination of many of the faults experienced with the lower frequency CW systems.

In discussing landing aids it is generally admitted that the systems in existence today are primarily approach systems. They are, in general, designed to handle a plane to within a certain altitude above the runway from which point the pilot lands his plane visually.

This does not mean that they cannot be used all the way to the ground and blind landings made on them. Practically all the systems that have been devised (those that have died as well as those adopted for general use) have recorded numerous "hooded" or blind touchdowns with expert instrument pilots; most of these systems are, however, incapable of achieving such results time after time under zero-zero emergency conditions with the ordinary AAF pilot and hence are not entitled to be considered as truly blind-landing devices. A true blind-landing device must provide for guiding the plane straight down the runway after touchdown until the plane has rolled to a stop. It must solve the problem of the change in the plane's direction after touchdown from its direction of flight while crabbing in the approach due to the cross wind.

Although conditions of ceiling and visibility which necessitate using instrument landing aids vary widely and hence require varying degrees of proficiency of the aid, a satisfactory definition of an approach aid may be the following: A satisfactory approach aid is one which is capable of repeatedly bringing the plane to within an elevation of 50 ft above the runway over its end, in azimuth to within the center half of a narrow runway of 150-ft width, and on such a heading, in such an altitude, forward speed, and rate of descent as to be able to make a visual landing from that point. The fulfillment of such conditions will take care of the vast majority of instrument landings. Since worse conditions down to zero-zero emergencies do arise and since pilots will attempt by necessity to fly an approach system all the way to the ground, a successful approach system will find itself used in zero-zero, and may, if a sufficient number of such emergency landings are made, become to be regarded by pilots as actual blind-landing devices.

The development of the intensity-type system involving radio-beam localizer and glide path has followed along natural lines in first the use of single-lobe beams and then multilobe (two to eight in azimuth and dual lobe in elevation). Most of the early type 1929-1939 glide paths were single-lobe constant intensity paths. All such systems, such as the Air Track and British SBA Lorenz, have now been abandoned in favor of the dual-lobe, straight-line glide path such as utilized in the IT&T development, now a part of the SCS-51 equipment. The constant-intensity systems, besides requiring the airplane to fly a curved path in the elevation plane, suffered severely from false and bent courses with bad bumps due to reflections from buildings, etc., and, since they involved ground reflections, were susceptible to ground, moisture conditions, and roughness of terrain immediately in front of them and other difficult sighting problems. They failed to meet almost all the requirements listed and hence died.

The surviving CW system, which the Army has adopted as its standard beam-approach device, is the SCS-51. This is considered by all service, including the British, to be the best CW beam system yet devised. The decision to adopt this was made in 1943 after some trials in conjunction with two microwave glide paths, the PGP, an X-band pulsed glide-path system developed by NDRC, and the S-band CW system developed by Sperry. This decision was based partly on the feeling that greater reliability would be realized with the standard type tubes, receivers, and antennas that were used in the 110-megacycle localizer and the 330-megacycle glide path than with the untried specialized gear of the microwave equipment. A development contract, later cancelled, was let to continue the improvement of the pulsed glide path and to devise a pulsed microwave localizer.

The difficulties now being experienced with many of the SCS-51 installations suggest that it might be well for the proponents of the intensity-type beam systems to reconsider carefully the advantages which microwave equipment have to offer. These troubles involve maintenance of the ground gear, problems of sighting both localizer and glide path (where normal obstructions on the airfield or hills, etc., have to be carefully balanced out by screens or shields), effects of moisture both on the ground and on the antennas on beam position, and unreliability of the airborne gear. The glide path uses the perpendicular-type aerial system which necessitates the use of ground reflections in order to be produced.

Both the microwave systems are tiltable glide paths which do not require ground reflections to form their beams and which in fact attempt to adjust their beams above such ground objects. The state of the radar art is now sufficiently advanced that an X-band glide path such as PGP can reliably reach out to ranges of 15 miles or more and can be built into compact airborne installations and fairly reliable ground gear. The pulsed glide path is favored over the CW microwave system in the much simpler, less bulky and weighty, airborne and ground installations. It is felt that an adequate microwave localizer could likewise be developed. Considerable work in the airborne instrument-presentation problem might likewise produce more satisfactory results.

This general approach to the problem, however, when examined in the light of the conditions set forth in the section on "General Military Requirements," page 151 is incapable of meeting the majority of them and appears to be ultimately hopeless in providing a general, flexible system sufficiently accurate and reliable for emergency use by all pilots to be considered as the required all-weather aid. All such systems require long and careful pilot instrument training and continued practice. They do not provide sufficient safety factors in the lack of pilot warning of danger of collision with other planes or ground objects, etc. Such systems will no doubt prove useful in certain limited installations, in carefully chosen sites, with careful maintenance and continuous human monitoring of both ground and airborne gear, and with long and continuous practice by expert pilots. However, their use is restricted to those planes which presumably can afford to carry the weight of the airborne components and hence offers no general solution. Past and present experience suggest that all systems which depend for their positional information on the relative intensities of two or more lobes will fail ultimately in achieving wide-spread pilot confidence and will eventually meet the fate of their predecessors.

The case for the beacon-beam approach system has been presented primarily by the British who contemplate using the Radar BA system in Bomber Command. Only the localizer system has reached experimentation. Its chief advantages over the type just discussed are: greater security, because the ground gear is not continuously radiating but only when interrogated by the correct frequencies; less subject to interference unreliability; much more stable in beam position; more readable presentation (at present presented to navigator who talks pilot in); narrow azimuth pattern to minimize sighting difficulties; and continuous range information.

The 200-300 megacycle BABS system, however, will suffer from some airport sighting problems as the beams are subject to reflections from hangars, etc.; higher frequency equipment would be less susceptible to such effects although they are not completely eliminated on S- or X-band. The present Radar BA airborne equipment is very heavy (150 pounds, although it is thought that 60-pound equipment can be attained). The present equipment is designed to be used with the Eureka or Lucero interrogator and later with SCR-720, etc.; thus it is limited in application to those planes so equipped.

The use of microwave ground beacons such as BUPS or BUPX has been tried as a localizer facility with the plane carrying the appropriate S- or X-band radar to interrogate. Skilled pilots or navigators observing PPI presentation can achieve moderate success in aligning themselves with the runway under conditions of small cross wind and when the terrain surrounding the airport is completely familiar to the pilot. The problem of finding the correct heading to counter cross-wind appears a fairly difficult task.

It is extremely doubtful that such systems can hope for any widespread use; certainly those planes without the necessary interrogating radars will not add them specifically for this use.

Suggestions have been made that there might be a possibility in the future of utilizing time-measuring schemes. The time difference between the reception by the plane of beacon responses from two interrogated beacons placed on a base line perpendicular to the runway could be used in indicating the azimuthal error left or right of the extended runway line. The time intervals for practical base-line distances between the two beacons are so small, however, that a considerable advance in interval measuring methods and steepness of transmitted pulses will have to be made before such a possibility could be considered. For example, for beacons one-half mile apart, differences of 0.1 microsec would occur for an airplane 50 ft off course at one mile range and approximately 0.01 microsec for same error at ten miles range.

The development of the ground control of approach (GCA) equipment by NDRC and the operational use of the gear (AN/MPN-1) in the past few months by the services has made available an entirely different approach to the instrument-landing problem. For a number of years attempts have been made to talk a pilot down first by listening for him over the airport and attempting to direct him from such meager data as could be obtained from the sound of his motors and later by the use of direction-finding fixes on his radio transmission.

The success of the GCA equipment during the first few months of its operational use in achieving numerous emergency landings under operational conditions and with pilots who have never previously made an approach on the equipment suggests that the system possesses a number of desirable attributes.

(1) First and foremost, since it feeds information to the pilot over his normal radio communications, the system requires no additional specialized gear in the plane. It, therefore, can be considered a universal system if the proper communication channels are made available for use.

(2) The radar information obtained by the narrow-beam scanning antennas covering the plane's position continuously in range, azimuth, and elevation is of very high accuracy (order of two mils in elevation and four mils in azimuth) and is not subject to error because of reflection of the beams from the ground, hangars, other aircraft, etc. Likewise such microwave beams suffer very little distortion from atmospheric effects over the short distances used in the system. Sighting difficulties in relation to the equipment's position to other airport objects are therefore minimized.

(3) Reflections from objects close to the desired azimuth or elevation landing path instead of being harmful provide positional information to the ground crew of the proximity of the plane to these objects so that the plane can be warned when it is too close and can be given direction of course to fly to avoid them. This includes other planes in or crossing the approach path.

(4) The verbal information presented to the pilot is in such form that the amount of data interpretation is greatly minimized. It is fed to him through the sense least in use by him during the approach, his ears. Thus the pilot is relieved of part of the additional burden placed upon him by the instrument-flying condition instead of having the strain increased by requiring his close attention to additional meters or CRT's as is necessary in most other systems. Some of this strain is shifted to the ground crew

who are, for the moment, better equipped to accept the responsibility for the plane's safety.

(5) It has shown itself capable of handling all types of aircraft. In general it has been found possible to use glide paths of approximately 3° angle with all types although the desired glide angle can be changed quickly from one angle to another within the range 2° to 5°.

(6) The radar-scope presentations allow the operators themselves constantly to monitor the system so that they are immediately aware of any shift in the radar picture due to instability in electronic circuitry, etc., which may cause the positional data given to the pilot to be incorrect. This constant human monitoring is a tremendous safety factor which cannot help but increase pilot confidence if demonstrated to him.

(7) Its mobility about the airport from runway to runway is unusual for such ground equipment.

(8) It has demonstrated that it can be used by tired and inexperienced pilots with little or no previous contact with the equipment although it is recognized that pilot indoctrination and a few training flights are useful in dispelling fears and increasing the willingness to use the equipment when the necessity demands it.

(9) It is felt that a strong virtue of the ground-control approach system is its great versatility in handling the many unforeseen emergencies that arise in instrument weather flying.

The traffic handling capacity of GCA was overemphasized in the early experimental period. The proponents of the system are fully aware that it cannot serve as a traffic-control set in itself. It, however, has been repeatedly demonstrated that if planes are fed into it at proper intervals it can handle planes in the approach at two- to three-minute intervals which is better than any other existing system can do. It has in addition a partial traffic handling capacity of four or five single planes or groups at a time, which is a feature no other system can at present claim. The potentialities of high-density traffic handling on the approach are only now being considered with multi-positional-approach indicators, etc. A rate of 60 planes per hour is being aimed at in new Army-developed GCA's.

## OTHER PROBLEMS

The question of aids to instrument take-off should perhaps be mentioned. It would be perfectly feasible to provide any of the discussed landing aids to view the take-off and give the pilot positional information. Inasmuch as hooded take-offs are common practice in service flying experiments, it is felt that the chief problem comes after take-off in maneuvering away from the field. Obviously the traffic control radar search set or the GCA search could aid materially in marshalling after take-off, in avoiding collisions with planes and hills, etc.

Finally there is the problem of clearing the runway after landing. The control tower of the future will no doubt wish to have accurate information as to where his taxiing planes are, and the planes will want information as to how to taxi. The British have experimented with a short-range high-resolution X-band set to show the position of ground objects on the field with indicator presentation in the tower. Such aids could certainly be provided although it is hoped that the use of high-powered light or infrared systems might be easier solutions.

## CONCLUSION

The all-weather air-base problem has two important aspects, traffic control and blind landing. Related subjects of less importance include blind take-off and ground-traffic control of aircraft taxiing along the runways. A complete system should solve all of these.

Air-traffic control may best be achieved by means of microwave radar, based on the ground and used by the control-tower officials together with the requisite communicating facilities, etc.

Two types of blind-landing equipment are outstanding, namely: the talk-down system as typified by GCA, and the glide path localizer system typified by SCS–51, and systems designed by the Sperry Corporation and by NDRC (PGP system).

The former of these types is noted for its operational flexibility and ability to cope with emergencies. The latter type is regarded as being particularly suited for heavy traffic. It would appear that this type of equipment is desirable under such conditions but that an airport equipped with it should also possess GCA. However, there will be some airports where only GCA is needed.

When assessing the relative ease of training and maintenance of these two types of equipment it should not be overlooked that one of them requires a good deal of equipment to be operated and maintained in the airplanes.

# RADAR COUNTERMEASURES

In this section we shall try to estimate the influence of countermeasures upon the future usefulness of radar. One occasionally hears the view expressed that every radar system has its counterpart in a jamming device to which it will sooner or later fall victim. The picture suggested is one of an eventual undeclared truce in radar warfare, in which neither side can profitably use radar, because the other side could promptly annul its effectiveness. This view is not supported by a critical study of the problem and of the trends in radar development.

Action which can be taken against a radar-equipped enemy may be, roughly speaking, of three sorts:

(1) Jamming, that is, causing extraneous signals to appear in his radar set which confuses, obliterates, or falsifies the information he seeks.

(2) Concealment, that is, reducing the visibility to radar of his targets (for example, the Germans at last succeeded in rather effectively hiding their submarines from radar by submerging everything but the "Schnorkel," and by applying to the top of that a special coating of low-reflecting power).

(3) Listening or detection of radar transmission leading either to early avoiding action or to direct offensive action against the radar station itself.

## JAMMING

The radar-jamming methods which have been used or at least developed in this war can be conveniently classified in four categories.

(1) Electronic Blanket Jamming. In this type of jamming, the aim is to obliterate the radar echo by jamming signals. The most effective type of jamming signal so far devised has been a CW carrier which has been either amplitude- or frequency-modulated by resistor noise. Two cases must be distinguished, however, one in which the main jamming signal energy is confined to a frequency range about equal to the radar receiver bandwidth (to be called "spot-frequency jamming"), and the other in which the jamming energy is distributed over a broad band (to be called "barrage jamming").

(2) Electronic Spoof Jamming. In this form of electronic jamming the idea is not to obliterate the radar echo, but to provide several additional synthetic echoes which will confuse the radar operator so that he will not know the exact position of the true echo.

(3) Reflector Jamming (Window, Angels, etc.). In this form of jamming, material is disseminated whose radar reflection is made either to cover up the target signal or to provide many similar echoes for confusion purposes. This form of jamming has been very widely used because it is inherently broad band.

(4) Special Forms of Jamming. In this category fall many special jamming tricks, generally utilizing some vulnerable feature of the radar set. As an example,

"Peter" may be mentioned; this is a jamming scheme utilizing the lobe switching rates of automatic tracking radar sets.

Certain problems are common to all methods. In the first place, one must know something about the particular enemy equipment to be jammed. If the jammer is electronic, it must be set on the proper frequency. In many cases this requires continual monitoring of the enemy transmissions in order that any changes in frequency may be followed. The problem is made more difficult when there are many enemy stations in the vicinity and more difficult still when these sets scan with narrow beams, so that the transmission is heard only during brief, widely separated intervals. Uniformity of jamming cover must be sought, for complete protection, and it is usually harder to protect many targets than to protect a single target.

The above requirement can be discussed quantitatively only in particular cases. The important question of the power required for jamming, however, deserves to be examined quantitatively. Suppose we are required to jam a radar set operating at a single known frequency. If the jammer is located at the target to be protected, and if the jamming power is radiated from a nondirectional antenna, the power required is at least equal to the radar-scattering cross section, $\sigma$, of the target. Using the same symbols which we used in writing the radar equations, page 42, with $P_j$ meaning minimum jamming power,

$$P_j = \frac{P_t G \, \sigma}{4 \, \pi \, R^2} \qquad (4)$$

For example, consider a target of radar cross-section 1000 sq ft (about that of a large bomber) 20 miles from an MEW (AN/CPS–1) set. $P_j$ in this case is about 60 w, for a nondirectional jammer located at the target.

The power output of present jamming transmitters is indicated below. The numbers in the last column suggest what might be done with present techniques, and are, of course, only guessed. The important trend to note is the decrease of available power with decreasing wavelength. This can be traced to causes closely related to those responsible for the decrease at shorter wavelengths of the peak power of radar transmitters, already mentioned in the section on "Pulsed Radar". Thus in respect to power output alone, the jammer and the radar compete on more or less even terms at different wavelengths. However, at shorter wavelengths, with a given antenna size, the radar beam is concentrated more strongly on the target, G, equation (4), being proportional to $1/\lambda^2$. This factor tips the balance heavily in favor of the radar. The disadvantage to the jammer can only be overcome by providing the jammer itself with a highly-directional antenna. But this drastically limits the usefulness of the jammer. If either the jammer or the radar is moving, the jamming beam must accurately track on the radar at all times.

The following is a comparison of the present and possible power outputs for jamming transmitters.

| *Wavelength* | *Present Power Output* | *Possible with Further Improvement* |
|---|---|---|
| 50 cm | 20 kw | 100 kw |
| 10 cm | 1 kw | 10 kw |
| 3 cm | 250 w | 1 kw |

The jamming operation implied in the preceding discussion conceals targets only near a line through radar and jammer. It is self-screening jamming. When the radar is looking in some other direction, to mask its signals, much more power is required, by a factor of the order of the gain of the radar antenna. This gives an additional and enormous advantage to short-wavelength, high-gain radar.

Spot-frequency jamming requires that the jammer monitor the frequency of the radar transmitter in order to be able to set the jamming transmitter on the right frequency and to follow any changes in radar transmitter frequency. Now the bandwidth of the radar receiver is determined essentially by the pulse length and in most applications is of the same order (a few megacycles) independent of the carrier frequency. But the band over which a given type of radar can operate is usually limited to some fraction of the carrier frequency, which fraction includes more megacycles the higher the frequency. Thus it is usually more difficult to discover the exact frequency of a high-frequency transmitter, and to follow arbitrary changes in frequency.

In barrage jamming, the monitoring problem is avoided by causing the jamming transmitter to emit radiation over a broad frequency band. This is much more expensive in power by just the ratio of barrage bandwidth to radar receiver bandwidth, a ratio which in general is larger the higher the radar frequency, as explained in the previous paragraph.

Electronic spoof jamming, which seeks to create confusing artificial echoes is less effective against short-wave radar because of the higher resolving power of which such equipment is capable. It is hard to inject spoofs which cannot be recognized as such.

Because of its broad band, window jamming has been most successful. Microwaves have not been the answer to it, although it is still true that they are by far the hardest frequencies to jam with window. The actual weight of window material needed to give an echo approximately that of a bomber is not critically dependent on $\lambda$, but depends on cutting methods, packing, materials, etc. At present about four ounces of material will give one B-17 echo although at X-band slightly more than this is required. However, to lay a lane of window to cover a flight of bombers requires one such bundle dropped in every radar "pulse packet." This will last only a given time (usually about five minutes), then needs replacing. Thus the amount needed per hour for the lane will be approximately inversely proportional to pulse length and to $\theta$ (beam width). Since both of these quantities go down with $\lambda$, the microwaves are far more difficult to jam with window. As an example the new 584-X set, designed to withstand window at X-band has a pulse length of $0.1 \times 10^{-6}$ sec and a beam width of about 2°. It has successfully tracked an aircraft through window laid by a preceding aircraft at the rate of 600,000 dipoles per sec.

It will be possible, however, to devise new materials and reflection methods so that even our best microwave sets will be greatly hampered. Our best technical answer to it appears to be MTI which should virtually remove the threat of window.

## ANTIJAMMING DEVICES

It will never be possible to claim that a given radar set is jamproof. However, it may be uneconomical to carry out effective jamming tactics. As we have seen, microwave sets are generally much more difficult to jam for several fundamental reasons. In spite of this it is believed that an active antijamming program is an essential part of future radar development. The most important lines of research appear to be (1) the development of tunable systems, (2) moving target indication (also tunable), and (3) further improvement in discrimination. If this research is coordinated with systems design and development, there is every reason to believe that the jamming of future sets will never be as successful as the early jamming of both our own and the enemy's long-wave radar.

## CONCEALMENT AND CAMOUFLAGE

If a target exposed to radar beam is to be hidden from detection, it must be prevented from reflecting radiation, or it must be located in the midst of other objects which return similar signals. The problem of reflection elimination has been discussed previously. It is possible, with existing means to reduce the reflection coefficient of a large, smooth metal surface to a few percent of its normal value. It is much more difficult to do this for an object of complicated shape. The blacking-out of aircraft by this means is not practical with present techniques, since the coating required would be prohibitively heavy. In any case, the external shape of the aircraft would not permit a very great reduction in scattering cross section. For submarines, for small vessels, perhaps also for long-range rockets, antireflection coatings may prove to have some value.

The best concealment for objects on the ground is natural cover, in the form of rough terrain, trees, or other highly reflective objects. This may not suffice to conceal a moving target, if the radar uses MTI. In general, the higher the resolution of the radar the more densely distributed the cover must be.

A countermeasure which can be classed either as deception or camouflage consists of making a fake target or otherwise altering the picture seen by the radar, by man-made reflectors. This was tried by the Germans in some cities with little success. A more economical and effective measure was the use of single reflectors to confuse sea-search radar.

It is occasionally suggested that the radar echo could be eliminated by a device on the target which would receive, amplify, and retransmit with suitable phase and amplitude, the incident wave, so as precisely to cancel the reflected wave. This might be possible in certain very special cases, but an extended target such as an airplane reflects short radar waves in a complicated way. The net amount of reflection depends critically on the direction from which the incident wave arrives. The cancelling device would have to measure this angle instantaneously with a precision which could be achieved only by the use of an antenna as large as the airplane. On many other grounds, as well, such a scheme is utterly impractical in the microwave region.

In general one must conclude that *we cannot foresee any means by which aircraft can be made invisible to radar.*

## LISTENING

The detection of radar transmissions is an extremely simple problem technically. If a target is to be detected by radar, there is no way of preventing an observer at the target from detecting the incident.

The radiation arriving at the target is necessarily intense, and the most rudimentary equipment suffices to detect it. Because of this advantage in power, it is not difficult to make the detection device sensitive over a very broad band of frequencies. The assumption that the enemy does not know that he is being looked at with radar will never again be justified. It can almost be said that one temporary advantage of radar over the searchlight, its invisibility, has vanished.

# DEFENSE AGAINST THE ATOMIC BOMB

(Supplement to Radiation Laboratory Contribution to the AAF SAG Report)

*By*

G. E. VALLEY

## FOREWORD

The effect of the atomic bomb on military tactics and weapons will be far-reaching. At the present time, detailed analyses of what all of these effects may be cannot be given. The following notes seek only, therefore, to present some thoughts and speculations on this subject by members of the Radiation Laboratory. They are presented here more as a basis for discussion of the necessary research policies, than as definite suggestions of what those policies should indeed be.

# DEFENSE AGAINST THE ATOMIC BOMB

## INTRODUCTION

The atomic bomb renders obsolete a number of tactics and weapons newly developed during the war. Among these are even some which were so new as not yet to have been put into operation. Since it would be folly to continue to develop outmoded weapons, this supplementary note is written to indicate what some of these may be.

The atomic bomb is fantastic; its advent means that we must think boldly if our future efforts are indeed to be aimed at future needs. We must not hesitate to scrap our present weapons regardless of their novelty, it they cannot be employed in a war of atomic bombs. It would be better to have no weapons at all, and to know it, than to place our faith in obsolete devices of imposing size and number.

We should not let the fact that such outlawed weapons as poison gas and bacteria were not used during the past few years convince us that the atomic bomb can similarly be outlawed. The ease by which enemy material can be destroyed by this weapon and the simplicity of its associated tactics indicate forcefully that it will be used.

## LESSONS FROM THE WAR

It has been demonstrated that bomber fleets of at least 1000 aircraft can be produced and operated at one time. It has also been shown that one atomic bomb can wipe out a city of 300,000 inhabitants. Therefore, in one raid, it is in principle possible according to present conditions to wipe out a city of 300,000,000 inhabitants or its equivalent. If we assume that half the pouplation of this country inhabits the cities, it has an urban population of 70,000,000. Assuming that a fleet of 1000 aircraft were to be individually directed against the different cities inhabited by these 70,000,000, they and their works could be wiped out four times over.

We must assume that this possibility will dominate the offensive plans of any power contemplating war.

From this, one must conclude that massive multiplane raids against individual targets are things of the past. This means that formation flying and everything that it connotes to the aircraft and radar designer must be most carefully considered to determine whether or not it is obsolete. If this tactic is found to be obsolete, then it follows that the tactic of saturating the enemy's antibomber defenses is also obsolete, for all practical purposes.

The situation then becomes tactically very like the Battle of the Buzz Bombs, in that individual bombers (manned or pilotless, airborne or rocket) will seek individually to penetrate a massive defense. This battle is also of interest because it represents a nearly automatic defense (SCR-584 plus the M-9 director, plus the servo-driven 90-

mm guns) against robot-controlled aircraft. It may, therefore, be regarded as setting the pattern for the future.

We are informed in the Radar Press Release that "one Sunday late in August, 105 buzz bombs crossed the British Coast, headed for London. Only three of them arrived." Now this was the best figure attained; London would certainly have been wiped out had the V-1's carried atomic bombs even against such superlative defense measures.

But the fact that a defense which let through as few as 3% of the attacking aircraft would be inadequate if these carried atomic bombs is not the most important lesson to be derived. What is most important to realize is that this defense required at least six weeks to reach its maximum efficiency, and this in spite of the fact that all the defense weapons were at hand, all the operators trained, and the whole country experienced and forewarned in war of this particular means of attack. In spite of all the training and availability of weapons and military experience the first attackers suffered little loss.

This is not an indictment, therefore, of the defensive instruments, since after all 97% of the attackers were eventually shot down; what it means is that the people who manned the defense were incapable of instantaneous reaction. Therefore, the pre-eminent problem of defense with which we are now faced is: "How can the defense be made to react to the first blow with all its potential efficiency?"

Combining the known capabilities of the atomic bomb with the experience of the past war, we can state three requirements for any defense against it:

(1) The defense must be capable of defending all our potential targets simultaneously.

(2) The defense must closely approximate 100% efficiency.

(3) The defense must function with its maximum efficiency against the first raid.

## POSSIBLE METHODS OF DEFENSE

There are three general classes of defensive measures which may be considered:

(1) Prevent any potential enemy from setting an atomic bomb attack in motion.

(2) Destroy the bombs before they reach their targets.

(3) Render all our potential targets impregnable to the atomic bomb.

The most general remark about these possibilities is that we should not try them all if this means that no one of them is developed to perfection. Three methods of defense, each 50% effective, when used together do not necessarily yield a defense which is 150% effective.

### *Class 1.*

In order to prevent anyone from setting off an atomic-bomb raid against us we need to police the world, either as a member of an international organization or independently thereof. It means that we must prevent anyone else from manufacturing atomic bombs. Since the manufacture of these bombs is intimately connected with the peaceful utilization of atomic energy, this may mean that we must be prepared to use forceful measures to restrain anyone else from manufacturing atomic fuel. This might mean that the world-wide utilization of atomic energy must be placed under our control, the fuel being prepared here and carefully rationed to the rest of the world, to be used under our surveillance or that of an international organization.

Barring such an arrangement we must be prepared immediately to start reconnoitering all places where atomic fuel can be manufactured, and be prepared to destroy such manufacturing establishments.

Aircraft such as the B-36 should be equipped for reconnaissance with neutron and heat detectors since large amounts of either or both of these types of radiation are known to be emitted by the most important method of manufacturing atomic fuel (the uranium-pile method for manufacturing element 94). Such aircraft must also take aerial photographs. The use of radar photography should not be omitted; since great range is not nearly as important as high resolution and 360° "looking," 1-cm PPI equipment should be used. It is recommended that an effort be made to equip a B-36 with at least a 12-foot antenna suitable for PPI use, and operating in the 1-cm region of wavelength. A special modification of AN/APQ–34 or AN/APS–30 could probably be prepared in six months time.

Since none of the detecting devices mentioned can be regarded as infallible, we must depend upon repeated reconnaissance and constant interpretation and comparison of the results for certainty.

In order to destroy any atomic-fuel factories we discover, the atomic bomb used in conjunction with the present bombsights will be sufficient. It does not seem very worth while to improve the accuracy of bombsights over that now attainable; on the other hand, considerable bombsight research will be needed to make instruments at all suitable for supersonic aircraft. However, in comparison with other technical problems posed by the atomic bomb, it might be unwise to continue an elaborate bombsight development program. The development of guided bombs probably falls in the same category.

The above police measures are useful right now; they will only remain useful if we retain control of the situation. If we lose control of the international atomic-energy situation, then fairly fantastic measures must be adopted.

Suppose we are denied reconnaissance by aircraft. We may then try the German suggestion of an observation post established in a free orbit beyond the atmosphere. Corresponding to this, the development of V-2 missiles with ranges of several thousands of miles is also important. Probably the easiest way to start such developments is to try to send a remote-controlled rocket to the moon, since the direct line-of-sight control problem is simplest.

If one discards the suicide-pilot method of control, two methods of control suitable for distances reaching far beyond the horizon are available: (1) automatic celestial navigation such as was worked on by the Eastman Kodak Co., and (2) radio control. It will be difficult to get the required accuracy with either of these methods and in addition the second may be easily jammed.

The missiles may in addition be fitted with homing devices sensitive to light, heat, electrical and nuclear radiation. Their use would relax the accuracy requirements placed upon the control system considerably; unfortunately, the high speeds likely to be attained by such rockets may require the homing devices to have impossibly long ranges of action in order to be effectual. The ideal solution would thus seem to be to control the rocket for somewhat more than half its journey by microwave radio (governed by an elaborate ground-based computer) and to have a homing device in the rocket guide it the rest of the way. The development of the ground-based control radio is relatively straightforward; the development of suitable homing devices cannot be regarded so optimistically.

### *Class 2.*

If we elect to defend ourselves by destroying all the missiles launched against us, the defensive measures must be as nearly automatic as can be conceived. They must locate, recognize, load and fire their missiles automatically. Regardless of the size and excellence of training of our forces, there are enough equivalents of the Pearl Harbor attack in history to teach us that the human part of the defense force is not likely to be ready. Since only one attack will be necessary we cannot take the chance that the lessons of the past plus future good intentions will preserve us.

The defense will almost certainly employ radar-guided missiles. Probably these will be launched from the air, since the attackers, if airborne, will likely fly low; if the attack is by long-range rocket; then either air- or ground-launched counter rockets may be employed.

Since it will be desirable to destroy the attackers some distance away from the target, a combination of guided and homing missile will be likely to be employed. It would be sensible to coordinate the Army and Navy antiaircraft guided-missiles programs, in order to use the available effort more efficiently. Only one problem should be attacked; there is now sufficient technical knowledge to choose the correct method of attack. In order to get warning of attack, radar of much longer range than is now available should be designed. A free-space range of several thousands of miles is attainable and would be useful. Possibly long-wavelength nondirective sets such as the British CH Stations which were so useful in tracking V-2 will be needed. In any event, a chain of such stations should be set up on the far sides of both oceans.

The possibility of the previously mentioned space-ship observation post should not be neglected.

### *Class 3.*

In order to render all our installations impregnable to atomic-bomb attack, they must either be placed underground or be dispersed in units so small as to make prohibitive the price of knocking out any sizeable number of them.

The technological problems associated with a thing like an underground steel mill are probably as difficult to solve as those associated with building a space ship or any of the other defensive measures.

The economic and social consequences of such a program would certainly reduce our standard of living and thus weaken us militarily in an indirect way. This is particularly true since one cannot single out any particular industry for such treatment: all are interconnected. However, the continuing popular use of automobiles and air transport will cause, according to many, a certain amount of natural decentralization of the economy. This process can be aided by a wise tax program, and should be viewed with satisfaction as long as adequate transportation is available.

## CONCLUSION

The foregoing indicates that technologically, economically, and sociologically the simplest defense against atomic bombing is a world-wide police system whose purpose would be to prevent the manufacture of atomic bombs.