A PROPOSED SYSTEM FOR ALL WEATHER ATTACK ON MOVING VEHICLES

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SECTION I: INTRODUCTION

The following study was undertaken at the request of the AFDAF office of USAF to investigate, and perhaps forecast, the probability of providing an all weather attack system for the United States Air Forces by 1957. The USAF "Development Planning Objective--Phase I" states that the principal problem of these studies is "to establish a development planning objective for tactical air by determining preferred weapons systems as a guide to research and development activities."

A rather quick survey of the present state of the art of airborne moving target indication (AMTI) seems to indicate the possibility of extending this art to include a non-visual moving target attack. Since this is a new area for USAF operations, it was deemed a preferred use of the limited time allowed for this study to emphasize the all weather attack rather than to consider improvements in present methods of accomplishing the other tasks appropriate to a tactical air force. It is admitted here that engineering improvements can be sought for the present tactical systems but furthermore, it was understood that such improvements were not to be the burden of Phase II of the Development Planning Objective.

SECTION II: AIRBORNE MOVING TARGET INDICATION

The present forms of airborne indication of moving vehicles on the ground depend upon the amplitude modulation...
of the ground signals by the moving targets. This modulation has a frequency which is characteristic of the radial velocity of the target and the wave length of the radar used to illuminate the target. For X-band, this frequency is about 28 cycles per second per mile per hour; while for Ku-band, it is about 50 cycles per second per mile per hour. Any detection of such frequencies as would be appropriate for vehicles on the ground will necessarily require observation of several cycles for each target and will take appreciable fractions of a second. Therefore, moving target indication will require slow scanning.

Presently, there are two basic types of airborne moving target indication for pulsed radar. The first of these is "Aural Selection," as exemplified in the APS-58; and the second of these is "Pulse to Pulse Cancellation," as exemplified in the APS-27. The distinguishing characteristics of these are as follows:

"Aural Selection"

1. Aural presentation
2. Spot by spot search along the ground ahead of the plane
3. Area picture of movement available only after flight is completed
4. Range on trucks, etc., limited by terrain, or curvature of the earth
5. Lack of any navigational aid which the plane would have received from the radar aboard, and consequent requirement for some other navigational aid
6. Detectable radial velocities in excess of, or equal to, two miles per hour

"Pulse to Pulse Cancellation"

1. Visual presentation, with a scanning radar and PPI
2. An area picture of the enemy movement
3. Utility of the radar for navigational data
4. Ranges as well as moving target detection expected to be somewhat less than with the "Aural Detection" technique.
5. Velocities detected will be greater than, or equal to, approximately ten miles per hour.
6. False targets off only to the side of the ground track, leaving a forward sector which is reliable. The size of this sector is proportional to the velocity of the plane, and the beam width, but is independent of the wave length without added electronic complexity.

SECTION III: CLOSE SUPPORT

As far back as 1945, it was envisaged that the aural selection technique for AMTI could be used in the regions near the front where the enemy movements can be expected to be so slow that they would not be detected by pulse to pulse cancellation. This region corresponds to that presently referred to as a region of close support. The use of aural selection in the close support region must incorporate an external navigational aid. This can be provided, for example by a MSQ-1, especially with beaconry. Also, aural selection signals may be transmitted directly on VHF so that the controller at the MSQ-1 will know instantly when the plane picks up any movement, where it
is on the map from the radar following the plane, and the extent of the movement estimated from the length of time of detection. Also, since the region for slow movements is relatively near the front, destruction of the targets might well be undertaken by the artillery. This information would come to the artillery from the MSQ-1 cab, which could then either scramble the plane from the area, or withhold a bombardment until the plane has finished its reconnaissance. Such an operation would truly be a combined air force ground force armed reconnaissance, and would probably be as effective and important as any close support operation that the air force can provide.

Also, it is to be recognized that "aural selection" reconnaissance without immediate artillery might be the best way of detecting and following the build-up of suitable tactical A-bomb targets.

RECOMMENDATIONS

1. Immediate outfitting an armed reconnaissance contingent for AMTI close support

2. Development of a search radar having as options both of the existing forms of AMTI. ("Aural selection" and "pulse to pulse cancellation")

3. Push the research developments of "sinufly" and "delay line integration" AMTI techniques. (Also the magnetic storage possibilities)

While the future holds some hope of providing a PPI area presentation of low velocity movements, nothing is certain now, so the utilization of this belongs in the more distant future. Such a set as recommended above,
would not only provide all of the AMTI features called for in Phase-I, but would also aid close support. Also, it would fulfill all of the requirements for straight radar reconnaissance as well as AMTI reconnaissance. Incorporating "aural selection" would only add about ten pounds to such a set. In designing such a set, careful consideration should be given to Ku-band wave length and to miniaturized components, in order to keep its size within that appropriate for airplanes. It should consider presenting the AMTI as an option only in the center sector, and only for certain ranges (up to 25 miles). When longer ranges are used, as is necessary for radar reconnaissance, these would be without AMTI option and could have "fast scans". Finally, by building a new radar, one would not only take advantage of new radar techniques, but could, from the beginning, install the extra stabilities required by AMTI as well as avoid certain duplications inherent in any modification to existing radars.

Sинфл and delay line integration have potentially the possibility of reducing the minimum detectable velocity with visual presentation and area search, and of widening the sector of true target presentation as compared to the present pulse to pulse cancellation presentation. It is impossible at this time to accurately estimate the ultimate complexity, weights and success of these techniques.
SECTION IV: NON-VISUAL INTERDICTI0N

In essence, all weather interdiction is the sensing and attack of fixed stationary and fleeting targets. Non-visual interdiction is further restricted to either low altitude flying or high altitude flying (excluding altitudes between four and twenty thousand feet because of the effectiveness of enemy automatic anti-aircraft weapons).

Fixed targets could continue to be detected from recon data and attacked by conventional coordinate bombing or radar bombing. It is to be noted, however, that radar bombing has become more difficult with the higher speed planes due to the intermittent data received from the search radars. Rapid scans help to alleviate this.

It is to be noted that the proposed use of airborne "lock-on" systems for ground targets will not be nearly as seriously affected by specular reflection as the use of ground lock-on for air targets. In the latter case, the "lock-on" system occasionally follows the image of the air target as reflected from the ground. This image is as far below the ground plane as the air target is above. Similarly, airborne lock-on systems can be expected to follow images of the ground targets, but these will be contiguous to the ground target and so introduce an error no larger than the size of that target.
Wright Field has a project adapting LAB techniques to the moving target indication of the APS-27. This is not only made difficult by the high speed of the planes as referred to just above, but also by the inherent requirement in AMTI for slow scans.

SECTION V: MOVING TARGET LOCK-ON SYSTEM

Recent considerations indicate the feasibility of modifying or designing a conical scan radar system so that it will lock-on moving targets amongst the ground clutter. The advantage of this is that it will provide approximately continuous information, and therefore, overcome the limitations imposed by high speed planes and by slow scan for AMTI search. Essentially, the conical scan systems work by signal intensity control of servos. This does introduce a modulation from the conical scan so that, in the electronics sense, the data are not as continuous as they might be, i.e., about 30 bits per second.

Monopulse techniques give more continuous data than conical scan systems. Recent considerations also indicate that it might be possible to effect a monopulse lock-on with either a percentage modulation control of the servos, or by using a Butterfly phase-detection receiver for control of the servos. Under such conditions, there is no need for the receivers to have identical dynamic responses. Either of these would
give more continuous data than conical scan systems, but also, either requires more development than modifying a conical scan for moving target lock-on.

RECOMMENDATIONS

1. The necessary research and development of a conical scan moving target lock-on system should be pushed with top priority.

2. Research and development of monopulse moving target lock-on systems should be started.

SECTION VI: AIRBORNE MOVING TARGET ATTACK (AMTA)

The limiting features of an airborne moving target attack on moving vehicles are the desirability of a single pass over the enemy, of low altitude flying in the area and of minimizing chances of self destruction while maneuvering in a selected area. The following attack procedures have been designed to comply with these requirements.

In this description, it is assumed that there is a plane that can travel economically at about 400 knots at low altitude and that it is equipped with a radar system providing independently both a search radar feature with an optional AMTI sector, and a moving target lock-on feature.

The feasibility of an airborne moving target attack under non-visual conditions will now be explored by proceeding step by step through the maneuvers required to destroy the moving target.
NAVIGATION INTO AND OUT OF THE TARGET AREA

Presumably, any maps, inspecific or otherwise, of a present position of the enemy and the territory through which supply lines must come to support it leads to a plan to seek out and attack supplies and re-inforcements in transport across some more or less rolling areas behind the enemy lines. The attack procedure is not suitable for rough terrain. The pilot can then proceed from his base to this area by radar pilotage, as was used in the bombing raids of Europe, or upon perfection of one of the new navigation computers under development. The radar pilotage can be obtained from the search radar feature and will operate from high altitudes. Apparently, suitable navigational computers now under development are either the inertial North American MX1688A, or the doppler dead-reckoning APN-79.

NAVIGATION WITHIN THE TARGET AREA

After reaching the area, in order to increase the probability of hit and to reduce the warning to the enemy, the pilot would probably descend to within 4,000 feet of the ground. This was the basis for the desire to select an area that is not too rough. On the other hand, a completely smooth area cannot be expected, so the plane will need a search navigational radar for several reasons. One of these is just to avoid running out of the area into mountainous regions without warning. The second is to utilize villages, towns, and other radar
landmarks as navigational aids to be compared with a map. The third is that during the descent from the run into the area, the primary navigational aid may not have brought him to within the confines of the area and he may need a search radar to avoid hills, etc., bounding that area. Finally, he may find it desirable to avoid specific large towns, air fields, or regions in which the enemy would find it profitable to put up barrage balloons or other defenses against low flying aircraft.

It is felt that this navigational aid will be needed at all times and that the operation will require a second man, navigator-copilot.

TARGET ACQUISITION

While flying within the area, the pilot and co-pilot will be looking for suitable targets. For this area search, an AMTI of the pulse to pulse cancellation type is the only existing form suitable and only a forward looking sector of about thirty degrees width can be utilized to give moving target indication without false targets. It is probably just as well that a great deal larger section is not available because of the difficulty of high speed planes to maneuver far to the side of their course in short ranges. Further, with a forward looking sector scan of about 160 degrees, if the center 30 degrees alone has optional AMTI, there remain sectors of 65 degrees width to either side in which the regular radar signal
should be presented to assist with the navigational problem at such low altitudes. A 30 degree width sector is not insignificant. With ranges of pick-up of about twenty miles, a single pass of the plane will sweep a swath 10 miles wide.

Area search is needed in order that the plane spend its efforts on the most worthwhile targets. With a spot-to-spot pick-up, such as is obtained with the Butterfly system, no knowledge would be available with a signal as to whether or not it was a single vehicle or an extended movement without first having essentially passed over the target. This would violate the restriction of a single pass at the target. The sharing of duties between the pilot and co-pilot in the operation being described is not entirely decided yet. However, with a PPI presentation for the copilot-radar operator it seems as though the pilot must rely upon the co-pilot to select the principal targets in any given area for attack.

TARGET DESTRUCTION

The general procedure for making a destructive run on a target, which has been sensed by the AMTI radar, starts by having the co-pilot direct the lock-on feature to the target. This will provide continuously the data necessary for executing either a level or a closing run on the target attack. When the lock-on has centered on a target, bright traces will appear on the PPI presentation.
at the range and azimuth of lock-on and thus confirm that the proper target has been locked on. These traces further permit the co-pilot to follow the progress of the attack upon every presentation of the PPI picture. Also listening on ear phones to the "aural selection" of the lock-on will permit constant surveillance and insure that the data presented to the pilot or autopilot is valid.

If at any time the aural signal ceases, pull-out of the maneuver is in order. The lock-on system also feeds appropriate data for navigation and closing on the target to the pilot's scope.

Even with these continuous data, the timing requirements are quite stringent. For example, there is a minimum range and bearing of a sensed target that will permit turning toward target and a 20 second run in that direction, for rectifying the azimuth aim, before releasing ordnance or nosing down for a closing path. That is, the decision to make a run on a target, must be made and the turn toward it started, while the target is still at sufficient range for the 20 second run. These ranges for various needlewidth turns into the run are shown in Figure 1 for both, a level run of 20 seconds before bomb release and for glide attacks consisting of a level run of 20 seconds followed by a 10 second closing run. Of course, if the turn is made at ranges greater than those shown in Figure 1, this simply allows more time for rectifying any errors during the run.
If the target aspect, after turning toward it, is thought very unfavorable for a successful attack, then the procedure would be either to abort and look for a better target or to execute some procedure turns to a new approach and reacquire the target.

In the following paragraphs, two forms of attack are independently considered. The first is called "Level Bombing" and envisages bomb release from a low altitude level flight. The second is termed "Closing Path Attack" and envisages firing from a homing glide path corrected for super elevation.

**LEVEL BOMBING**

The level bombing attack has been studied quite thoroughly. From various sources, it seems that a dispersion of about 20 mils exists in present practice for all bombing under combat conditions. (The dispersion angle for fire in this paper and in the data presented with it, means the angle subtended by the radius of a circle at the target which would include 40 per cent of the projectiles fired at the target.) It seems feasible to design and make the radar computer system for moving targets so that it will not enlarge this 20 mil limit. The small size of the expected targets dictates close approach to these targets before fire, and hence, a low altitude approach. The effect of altitude on the probability of hit is shown in Figure 2. Assuming a
flight altitude of 1,000 feet and a speed of 400 knots, the range from the target at release is 5,300 feet and the target is at a depression angle of 10 degrees. It is to be noted that the lock-on radar provides all the data needed for solving the release point equation (R, dR/dt, and the depression angle θ). The accuracies expected for R, dR/dt are well within bounds for a 20 mil dispersion. The solution places least dependence upon θ, and tests can determine whether the lock-on systems will provide a sufficiently accurate θ. If not, other variables such as the plane speed or altitude can be used in the bombing equation. In any case, signals can be obtained from the computer and displayed so that the pilot can anticipate the release point.

Since supply and reinforcement transport are the envisioned principal targets, fragmentation bombs, or Napalm are considered the most likely ordnance. The probability for a single hit and the number of missiles to effect 85 per cent probability of a destructive hit on a point target versus the weight of the H.E. head are shown in Figure 3. A destructive hit has been assumed to mean one fragment that can penetrate 1/8 inch of steel per square foot of exposed area. ("Exposed area" herein means the projected area perpendicular to the line between the bomb and target.)
and all but armoured vehicles. Since the targets may be considered to be extended along a highway for distance greater than the base of a 20 mil cone (106 feet radius under the conditions cited) the probabilities were recomputed for such a target. These are shown in Figure 4.

There has been no evaluation for the destruction of enemy personnel since in the region of interdiction, motor transport of personnel is expected. Naturally, the probabilities for effective action against exposed personnel would be considerably higher.

Wright Field believes toss bombing from level flight can be instrumented. This would give the pilot the opportunity to pull out after release and would put him further from the target when it is struck by the missile. However, it would reduce the attack along a line of traffic to one missile and further be subject to increased errors due to the longer time of flight of the missile and any error in the angle of release.

Retro-bombing was also considered, but the conditions imposed upon it with the present high speed planes are not the same as when it was used in World War II. It would be extremely difficult to precisely annul the speed of the plane. Also AMTI would have to be aided by a computer after the depression angle of the target becomes 20 or 30 degrees.
Consideration has also been given to the use in level flight of depressed guns, vertical guns, and flexible guns. The hit probabilities of these suffer from the fact that the damage area for the missile is small and that the target is also small. However, the high rates of fire can offset these limitations within gun range. Guns depressed greater than the minimum angle of lock-on for level flight (so far undetermined but of the order of 20 degrees) would need a computer. At 20 degrees and 1,000 feet altitude, the range of fire is about 2,900 feet which may be excessive for accurate fire. Since a lock-on system can give the $dR/dt$ and $\theta$ between the plane and the target quite accurately, a computer to follow in after the target is lost is not out of the question. With such a computer, vertical fire could take place at a range of 1,000 feet (the assumed altitude of level flight) and therefore, be within normal gun ranges. A rough estimate of probable destruction shows the system comparable in accuracy to that of level bombing, especially if several guns are used and bore sighted six to ten mils from each other. Flexible guns servoed from the lock-on tend to eliminate platform errors. If this could be done, a 5 mil system might be feasible which would make gun fire a superior weapon. The extra weight for flexible guns and the steepest AMTI depression angle must be investigated further.
CLOSING PATH ATTACK

In order to affect shorter ranges of fire consideration shows the feasibility of glide approaches aimed at the target. These are the non-visual equivalent of dive attacks and similarly, would permit the use of rockets, toss-bombs, and guns, within limitations. The timing of the requirements of this in maneuver are even more stringent than for level bombing. However, full use can be made of the continuous nature of the data from the lock-on feature so that the pilot and copilot can see the time approaching for each activity and anticipate it, much as the timer at a race anticipates "clocking the finish." Also, automatizing the weapon fire and perhaps the auto-pilot, can materially relieve these demands. After the "nose down" the target is on the path of flight and the lock-on feature will be at optimum performance. The limiting features of a single pass over the enemy and of minimizing the chances of self-destruction dictate the angle of glide.

The attack procedure after acquiring a suitable target on the AMTI search feature is to turn toward the target, run at a constant level, nose down, glide, fire and pull out. An evaluation of the glide and pull out was made using charts from an F-89 manual to evaluate "squash". The features considered here, with a minimum distance from the ground during pull-out are the minimum
distance from the target, (throughout the maneuver which is during pull-out) $R_n$, the range at which pull-out must start, $R_0$, the altitude of the level flight, $h$, (sufficient to permit a glide of 10 seconds of time in which to rectify the elevation error), and the $G$ exerted in pull-out. A graphical summary of these as a function of the glide angle is shown in Figure 5 for 400 knots and a minimum distance of approach to the ground at any time of 750 feet, and $G$'s of 4 to 6. The data of Figure 5 shows that a plane with $G = 6$ capacity can get closer to the target before firing than a plane with $G = 4$, as well as remain further from the target during pull-out. However, in both cases, there are diminishing returns for increasing $\theta$ beyond 15 degrees. Thus, the detailed analysis to follow has been given to a glide attack of 15 degrees. This angle was incorporated in the data shown in Figure 1.

After selecting the target, the copilot directs the lock-on feature toward it, and sets the lock-on. Again, bright traces appear on the scope, x-ing the target, and the lock-on system feeds appropriate data to the pilot's scope. The altimeter can give the data to put a range mark on the PPI scope indicating the range of the target when it is time for nose down and a second range mark can be put on for the range appropriate for pull-out. These marks permit the copilot to assist the pilot in anticipating these critical maneuvers.
The pilot's scope shows range, range rate, elevation azimuth, artificial horizon, and appropriate fixed markers for his maneuvers, and thus supplies sufficient intelligence for the necessary maneuvers so that he can anticipate nose down, fire, and pull-out. Anticipatory warnings can also be given with lights in the cockpit. With these data, the pilot turns into his run, corrects azimuth, and flies level until nose down is indicated by the range to the target coming up to the appropriate fixed marker. It is not implied in this procedure that the glide path be at a pre-set angle. The system operates at any angle of dive since there are no off-course clutters, to confuse the lock-on. The scope simply indicates to the pilot the homing course including the appropriate super elevation and lead angles as put in by the computer. The pilot chooses his own glide angle. The pilot will see the range to target come up to the firing fixed marker and then to the pull-out fixed marker. If the system is implemented for automatic fire, he simply concentrates on nullifying azimuth and elevation until the pull-out range is reached. A servo-controlled auto-pilot can let the pilot put his full attention on pull-out.

This tactic does not permit more than a single burst of fire at a target unless that target is aligned along the flight path. Then the tactic would permit fire during the first few degrees of the pull-out.
On the other hand, this tactic is good for a cloud cover higher than that suitable for low altitude bombing. In such cloud cover, the plane would remain obscure until it came out under the clouds at its 15 degree angle and be aimed at the target at the time of coming out from under the clouds.

The expected probabilities for this tactic are shown in Figure 4 and 7 for a 20 mil system with the appropriate ranges. These are independent of the altitude of the level flight. The data are suitable for rockets with fragmentation heads of the weight shown and also for toss bombing fragmentation bombs. A range of 3,500 feet is marginal for $G = 4$ at 15 degrees where the pull-out range is 3,500 feet as seen in Figure 4. However, if the minimum approach to the ground is reduced to 500 feet, then the pull-out ranges are 2,600 feet and 2,200 feet for $G = 4$ and 6 respectively. Also, the minimum ranges from the target now become 670 feet and 800 feet respectively.

Toss bombing probably provides the most efficient delivery of H.E. under these conditions. The total weight of a rocket is about 3 times the weight of its H.E. head, and thus the delivery factor is less for rockets than for bombs.

Rockets would have to have effective ranges of 3,500 feet to be used in this tactic. It is understood such are being developed. Of course, rockets with infra-red
homing heads such as "Sidewinder" would materially increase the accuracy of the system when attacking motor transport and locomotives.

The information obtained from Wright Field for guns indicates shorter ranges for effective fire than this tactic will provide. If and when guns with ammunition with effective fire for 20 mil system of 3,500 feet are available, they could also be used.

Finally, in summarizing, this form of attack has the following features. It needs a copilot. It has been kept within the prescribed minimum distance from the ground. It would be simplified with a servoed auto-pilot, which is quite feasible. However, at all times, the pilot has continuous information as to how the tactic is progressing, and he can anticipate the three maneuvers, nose-down, fire and pull-out. The copilot also has the same information as the pilot in the form of markers on his scope as well as the use of either side of the AMTI sector of the scope as a navigational aid at all times. He can assist the pilot in anticipating the critical maneuvers.

REQUIREMENTS

The tactics described above for airborne moving target attack (AMTA), level bombing or glide attack, impose several requirements on the radar systems, and the airplane.
A combined search-lock-on radar is needed. For the purposes of substantiating the feasibility of a tactic, a "wedding" can be made between a search radar with AMTI and a gun-laying system such as one of the E-series. However, the eventual manufactured product should be "the child of such a wedding" and engineered as such. For example, it should have a common trigger and at least a common modulator and common stabilization.

A study has been made to determine the geometries required. For AMTI search there must be a compromise between the beam-width and the scan rates. The narrower beamwidths reduce the probability of false targets. Narrow beamwidths, however, need relatively large antennas. The Ku band seems best for search despite its slight reduction in range with heavy rain. On the other hand, X-band is to be preferred for the lock-on because of blind speeds due to the cross modulation resulting from the conical scan. This cross modulation will introduce two slightly separated blind speeds near 1/2 the prf (pulse repetition frequency). On the other hand, these two blind speeds are only 1 mile an hour apart and they are very narrow. The prf for AMTI cannot be greater than 3,000 or the range for target acquisition at low altitude and for navigation would be too short. With a prf of 3,000, these new blind speeds would be around 30 miles per hour for Ku and 54 miles per hour for X-band. With military transport, 30 miles per hour seems rather
probable while 54 miles per hour would not be excessive for trains. Thus, a train would have to be going at exactly one of these blind speeds to escape detection. Furthermore, the lock-on beam does not need either to be particularly narrow, or to have excessive power.

So far, no range limit has been found for 50 K.W. AMTI Butterfly detection, which should be used in the lock-on feature, except that caused by curvature of the earth or excessive foreshortening at long distances. Monopulse lock-on would not have these blind speeds.

The data just cited led to considering a 40 inch antenna for the search feature, and an 18 inch antenna for the lock-on. The ground plane antenna developed at Convair for navigation and search for their APS-48 and DPS-2 systems is the only known type that would make it possible to mount a 40 inch (1.43° in Ku) search antenna and an 18 inch lock-on antenna so that it will not interfere within a 46 inch circle if both are mounted independently to the plane. If the lock-on is mounted on the search antenna as a platform, a "dummy-gun" gimbal analog computer would be required to rectify the data before presentation to the pilot. This is avoided if both are referenced individually to the plane. Such a mounting would limit the stabilization of the search radar to ± 30° in pitch and ± 70° in roll. It would also restrict the lock-on to ± 40° in azimuth and in elevation. These do not seem to be excessive
restrictions. Models have been made of such an assembly and the dimensions checked.

Since these data were developed, Convair has sent drawings of similar installations both with the B-57 and the Convair XB 1956 which confirm the findings at the Control Systems Laboratory. A feasible assembly is shown in Figure 8.

Very rough estimates have been made for the combined radar set, auxiliary sight, computer and stabilization. Without excessive miniaturization, the combined gear should not exceed 750 pounds.

The tactics put several requirements on the plane. In order to avoid protuberances, the antenna should be mounted in the nose. The size of antenna suggested would require a nose ring of about 50 inches. For the glide attack, the plane should be built to withstand a G of 6 or greater during pull-out. The plane should be able to carry the appropriate munitions. It should probably have such yaw stabilization as has recently been put on some F-89's. Finally, it should be capable of efficient operation at 400 knots or less, and also have a high speed capability for other operations. The slower speeds seem advisable for AMTI in order to minimize the chances for self-destruction and to raise the accuracies for the glide attack.
SECTION VII: OTHER USES FOR THE EQUIPMENT DESCRIBED

The search navigation facility of the radar just described could be used for high altitude bombing on fixed targets. For this use, the AMTI features would be switched off. It would need a high altitude bombing computer. High altitude bombing does not place such stringent requirements on the pilot and copilot since the target acquisition is from a greater distance.

The lock-on portion of the radar can be used for air attack on bombers and other planes within the speed capability of the AMTA plane to overtake them. There is a project at Hughes sponsored by Wright Field for converting one of the present gun-laying systems to AMTI for low level air-to-air interceptions. Ordinary gun-laying equipment will not track on a plane at low altitudes where the ground signals will interfere with the tracking. For higher targets, the lock-on system should have an optional non-AMTI operation.

The combined system would work with optional AMTI turned off for attacks on shipping on the high seas. It is to be noted that shipping on inland waterways will be detected and can be attacked because the shores provide the necessary ground clutter for detection. In 1945, the proposed use of AMTI for the detection of Japanese shipping that hung close to the shores was considered as one of its important applications.
SECTION VIII: RECOMMENDATIONS

1. Expediting a "lash-up" of a wedding of an AMTI search radar and a modified E-series gun-laying equipment, for confirmation of the tactics described and for determining the constants for the engineering of a combined radar.

2. The design and production of the described AMTA system with its associated computer.

3. Determination of the suitability of existing, in production and in design aircraft for AMTA use.

4. The introduction of AMTA to tactical planning.

5. The research and development of suitable ordnance--cluster bombs, rockets, and guns with appropriate ranges and war heads.

6. Accelerate the development of the North American inertial navigator MX1688A and/or the Doppler dead reckoning navigational radar APN-79.

SECTION IX: COUNTERMEASURES

Undoubtedly, a sufficient study of possible countermeasures has not been made. A cursory study indicates that electronic countermeasure and jamming will be very difficult. However, a liberal distribution of rotating arms with corner reflectors at the ends could present sufficient false targets to confuse the AMTI screen and perhaps prevent detection of a convoy or train. If non-visual attack is restricted to trains and convoys, a string of these false targets might induce attacks. On the other hand, no way is foreseen to camouflage a moving train or convoy to prevent detection.

Finally, trucks or convoys carrying a set of corner reflectors rotating at precisely the scan rotation
(i.e. 33 r.p.s.) would throw the lock-on off the target and prevent attack. Equipment of enemy vehicles with such "windmills" is well within the realm of feasibility. However, monopulse moving target lock-on would not be subject to this "throw-off." This reinforces the recommendation of Section V as well as indicating that "the child of the wedding" of "Requirements" of Section VI should employ a monopulse lock-on rather than a conical scan lock-on.

This report was prepared at the Control Systems Laboratory of the University of Illinois by Messrs. Buchta, Johnston, Knoebel, Kruger, Linford, and Longacre.
Figure 1

Plots the minimum distance from a target that a 400 knot plane must start its turn toward the target in order to have a straight run for a time, $T_A$, of 20 seconds after completing the turn for rectifying the azimuth before reaching the point for release or fire of an armament, as a function of the bearing off course of the target at the start of the turn. For a closing glide attack an additional time of glide, $T_g$, for rectifying the angle of elevation has been allowed. With a glide attack, this determines the altitude of flight. The altitude of a level bombing attack affects the release point. Each curve carries the corresponding needle width turn, $N$, the bank angle, $\Theta$, and the $G$ loading on the wings for the rate of turn toward the target.
MINIMUM RANGE TO START TURN

TURN AND APPROACH

\( V = 400 \) KNOTS

\( T_a = 20 \) SEC.

![Graph showing minimum range to start turn](image)

LEVEL BOMBING

- **Altitude**
  - 5000 F.T.
  - 2000 F.T.
  - 1000 F.T.
  - 1000 F.T.

- **N** = \( \frac{1}{2} \)
- **\( \theta \)** = 28°
- **G** = 1.13

- **Altitude**
  - 2640 F.T.
  - 2640 F.T.
  - 2640 F.T.

- **N** = 1
- **\( \theta \)** = 47°
- **G** = 1.46

CLOSING ON
TARGET
ATTACK
PULL OUT

G = 4

- **Altitude**
  - 4350 F.T.
  - 10 SEC.

- **N** = \( \frac{1}{2} \)
- **\( \theta \)** = 28°
- **G** = 1.13

- **Altitude**
  - 2640 F.T.
  - 10 SEC.

- **N** = 2
- **\( \theta \)** = 65°
- **G** = 2.36

**FIGURE 1**
Figure 2

Plots the probability of a hit by an average of one destructive fragment per square foot on a point target using a 100-pound fragmentation bomb exploded at optimum altitude with a 20 mil system as a function of the altitude of the level flight from which the bomb is released. The right edge also gives the number of missiles that would have to be released under independent identical conditions to effect an 85 per cent probability of a hit by an average of one destructive fragment per square foot.
LEVEL BOMBING
100LB. FRAG BOMB

20 MIL SYSTEM
ACROSS THE TARGET

PROBABILITY OF HIT USING SINGLE MISSILE

NUMBER OF MISSILES FOR 85% PROBABILITY OF ONE OR MORE HITS

ALTITUDE

5 $\times 10^8$ FEET

FIGURE 2
Figure 3

Shows the probability of a hit by an average of one fragment per square foot of exposed surface of essentially a point target from a fragmentation bomb or H.E. head, as a function of the weight of the head when fired or released at a range of 5,300 feet from the target. 5,300 feet is the range appropriate for release from a 400 knot plane flying at an altitude of 1,000 feet. The number of missiles independently released that are required to attain an 85 per cent probability of an average of one destructive fragment per square foot of exposed surface of the target is also shown. Points for napalm bombs and frag clusters are also plotted against the corresponding weight loadings.
SINGLE VEHICLE DESTRUCTION
R=5300 FEET

FIGURE 3
The probability of attaining an average of one hit per square foot of exposed surface on some portion of an extended target by a destructive fragment from a frag head is shown as a function of the weight of the frag head for various release or fire ranges with a 20 mil system. 5,300 feet is the range appropriate for level bombing with a 400 knot plane at 1,000 feet altitude. The number of missiles independently fired or released required for 85 per cent probability of a destructive fragment per square foot are also shown. The probability of hit for a single release or burst of fire is expected to be less for an attack along a target as compared to an attack across the target due to the glancing angles of the attack. This reduction may be more than off-set with rippled release or fire along a target. Rippled release or fire is impractical for an across-the-target attack.
CONVOY OR TRAIN DESTRUCTION

NAPALM
110 GAL. TANK AT 5300'

FRAG CLUSTER 350 LBS. (SIZE = 750 LB. FRAG BOMB) AT 5300'

ACROSS THE TARGET 20 MIL SYSTEM

NUMBER OF MISSES FOR 85% PROBABILITY OF DESTRUCTION

PROBABILITY OF Hitting ONE MISSILE

WEIGHT OF FRAG HEADS

FIGURE 4
Figure 5

The pertinent distance parameters of a glide attack are shown as a function of the glide angle for a 400 knot plane and a planned minimum distance from the ground of 750 feet during the pullout for pullouts of $G = 4$ and $G = 6$. The curves $R_0$ show the slant distance from the target at which the pullout must start for a 750 feet minimum. The curve $h_1'$ shows the minimum distance from the ground if the pullout is started one second late. The curves $h$ show the altitude of level flight before nose down into the glide to permit a 10 second glide before pullout to permit rectification of the glide angle. The curves $R_n$ show the minimum slant distance from the target during pullout.
FIGURE 5
GLIDE ATTACK
V = 400 KNOTS
h_n = 750 FEET

DISTANCE
FEET X 10^3

G = 4
G = 6

h_n
R_o

G = 4
G = 6

h_n' = (R_o + 1 Sec)

GLIDE ANGLE
5° 10° 15° 20° 25° 30° 35°
Figure 6

The total weights of frag heads to effect an 85 per cent probability of an average of one destructive fragment per square foot of exposed target surface are shown as a function of the size of the frag heads released or fired. These curves assumed independent releases with a 20 mil system from the proper aim point. With the exception of laterally spaced rocket fire, these probabilities are unlikely to be realized.
TOTAL WEIGHT OF FRAG HEAD
REQUIRED FOR 85% PROBABILITY
OF ONE HIT
VERSUS
TYPE OF FRAG HEAD

FIGURE 6
Figure 7

The probability of an average of one destructive fragment per square foot of exposed target for an extended target is shown as a function of the weight of the frag heads for salvos of from 1 to 8 missiles. The assumption has been made that the releases or fires from the correct aim point with a 20 mil system are essentially simultaneous and independent. These conditions are unlikely to be realized except with laterally spaced rockets.
SALVO ATTACK ON CONVOY OR TRAIN

ACROSS THE TARGET
R=3500 FEET
20 MIL SYSTEM

FIGURE 7
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ABSTRACT

An analysis is made of some problems in the design of an all-weather attack system. It is assumed that two radar sets are necessary, one for search and navigation and the other for precise lock-on.

Some characteristics of some possible parent radars are given and proposals made for their coordination into an integrated system.

Problems of physical placement of the antennas in an aircraft are discussed.

A general block diagram of the proposed system is given and various parts discussed.
I. INTRODUCTION

This report will deal primarily with certain problems concerned with combining two types of radar to form an effective all-weather attack system. The first type is a search radar for navigation and target acquisition, and a second is a gun-laying, or lock-on, type of radar for giving data to a pilot and/or computers during the latter portion of an all-weather attack. No attempt will be made to show that the two radars are necessary for the attack since that is not province of this report. That two are necessary is accepted as a premise and the following discussion concerns certain problems related to the choice of the systems, and primarily how the systems so chosen may be combined to produce a unified, all-weather attack system.

At first, the characteristics of the two proposed parent systems will be discussed as a background for the discussion of the problems of combining the two into a unified system. These latter problems will be divided roughly into a proposed method of mounting the two antenna systems in the nose of an aircraft, and a proposed block diagram of the combined system, with a discussion of some problems connected with making the lock-on system actually track a moving target.
II. CHARACTERISTICS OF THE PARENT SYSTEMS

The proposed search system is a modification of the AN/APS-48 much as proposed by Convair as their Sartack system.* The lock-on system proposed is one of the E-series. Most of the discussion is based on the E-1 system, since complete descriptions and many of the parts were available for study. The latter system consists of an A-1 gun sight and computer and an AN/APG-33 gun-laying radar. However, as will be mentioned below, some of the later members of the E-series will come more nearly being the desired parent system.

* "SARTACK: A System Design Proposed For Tactical Reconnaissance Ku-Band Radar"
Electronic and Guidance Section
Consolidated Vultee Aircraft Corporation
San Diego, California
Secret Report ZN-130, June, 1952

A. THE SEARCH SYSTEM

1. Tactical Purpose

The tactical purpose of the search system is two-fold: first, navigational aid, both in getting to the target area and also within the target area, and second, the acquisition or location of moving targets once in the area.

As a navigational aid into the area, one assumes that the plane flies at high altitude in order to reduce anti-aircraft danger, and for this type of flying, one needs a long-range search set capable of ranges of about 60 miles in essentially a forward semi-circle. Such a requirement dictates a pulse repetition frequency, PRF,
of about 800 pps. Furthermore, the pulses should be moderately long, that is of the order of 1 \( \mu \text{sec} \). Pulse lengths greater than 1.9 \( \mu \text{sec} \) must be reserved for beacon interrogation. The indication would probably be on an off-centered, plan position indicator, PPI.

This long-range search radar is envisioned as only an aid to navigation and the aircraft should carry some other type of navigational aid in order to locate the target area more precisely.

Once the aircraft is in the target area, the proposed maneuver would be for the aircraft to descend rapidly to an altitude of approximately 4,000 feet and then begin searching within the area for moving targets. Under these conditions, the radar will be used for navigation within the area primarily to avoid flying into obstructions such as mountains. Reasons connected with the target acquisition function of this radar system dictate an increase in the PRF to about 3,000 pps with a corresponding reduction in maximum range to approximately 25 miles and a reduction in pulse length to approximately \( 1/2 \mu \text{sec} \).

In practically all cases, the normal video output of the system would be presented on the indicator at large angles from the airplane heading. It would also be possible to apply the normal video to the indicator at all angles in order to give the navigator the opportunity to survey for danger points in the line of flight of the
aircraft. The same search set would be equipped with AMTI in order to locate moving targets and present their signals on the PPI.

The apparent relative motion, with respect to the aircraft of two fixed ground targets in an off-axis position gives rise to fluctuating signals. Therefore, the AMTI presentation mistakenly shows these signals as moving targets. Thus, this system discriminates between moving and fixed targets only at angles moderately close to the flight vector of the aircraft. At 400 miles per hour, the angle is of the order of ±15 degrees from the aircraft heading.

Once a moving target is located, the next decisions to be made are whether or not to attack it, and then the angle of approach to the target. These considerations may allow a turn toward the target and then an attack run, or the geometry of the situation may require a series of procedure turns and a new acquisition of the target so as to approach the target from the proper direction.

2. The Indicator System

The indicator for the search system would be primarily for the navigator. Depending upon the military point of view, it may be necessary to place a repeater indicator in the pilot's cockpit, since it is on the basis of the search system indicator that the choice of target and choice of direction of approach will have to be made.
If military procedures would allow these choices to be made by the navigator, then a repeater PPI in the pilot's compartment would be unnecessary. If the pilot were going to have to make the above decisions, it would be necessary for him to be able to view a search-system indicator. The following discussion applies to the navigator's indicator, and would apply to a search indicator for the pilot if one is used.

Since only a forward-looking search radar is envisioned, the proposed radar could have a back-to-back antenna, giving two coverages of the forward area per revolution of the antenna. Because of the time required for r-f switching, the presentation would be limited to approximately the forward 160 degrees. With this type of coverage, an off-center PPI would give a larger picture on the same size tube.

At high altitudes, a long sweep, perhaps 60 miles, would be presented. When operating at high altitude, the AMTI unit would be inoperative and only the customary radar signals would show. When operating at low altitude, the AMTI unit could be in operation and the navigator would have several choices of presentation. He could present entirely normal video, or he could use video switching so that the AMTI would show in the sector near the aircraft heading where the AMTI is most useful, and the normal video show at larger deviations from the aircraft
heading. This video switch could be coupled to the azimuth-information data take-off in order that the switching would be automatic during scanning.

In addition to these presentations, when the lock-on system is in operation, the PPI would show the range gate of the lock-on system as a circle at the appropriate range and would intensify one trace at the azimuth of the axis of the lock-on set. This could also be accomplished by a mechanical courser. This would aid the navigator in locking the lock-on set to the target and in monitoring the lock-on set to be sure that it remains locked-on to the desired target during the entire approach maneuver.

3. The Antenna System

The antenna system of the proposed Convair Sartack is ideal for this application in that it is a "ground plane" antenna which consists essentially of a flat pill box, rotating about a vertical axis that is stabilized in space. This allows the installation of the lock-on antenna in the same radome without serious electrical or mechanical interference.

The system proposed is at the Ku-band (about 1.8 cm) and thus an antenna, which is a wheel about 40 inches in diameter by about 6 inches high, will have a beam width of about 1.3 degrees. The beam can be shaped in the vertical plane to cover the search area and the navigation area.
The antenna is stabilized for roll, pitch, and yaw. The roll stabilization, on an axis parallel with the long axis of the airplane, is the first stabilization. This is followed by a pitch stabilization about a transverse axis. These two stabilizations keep the plane of the antenna-beam vertical. The third stabilization, that for yaw, is introduced on the indicator. Convair indicates that roll accelerations of 2,800 degrees/sec$^2$ and roll velocities of 400 degrees/sec are followed with an error of less than 2 degrees. They feel that errors less than 0.5 degree are realizable without difficulty on the slower rolls that would be encountered in this attack system. The pitch stabilization will follow an acceleration of 280 degrees/sec$^2$, and a pitch velocity of 280 degrees/sec with an error of less than 0.5 degrees.

B. THE LOCK-ON SYSTEM

1. Tactical Purpose

The lock-on system is a radar that locks on and follows the movement of the target in azimuth, elevation, and range. These data are then fed to appropriate indicators and to appropriate computers. The data from this system then give first, information to the pilot so that he may guide the aircraft to the final attacking position and, second, information to the computer so that the time of firing weapons or the release of bombs will be given. One system under consideration has a
conical scan the output of which will be "Butterflied",
and the Butterfly output used to control the servos
determining range, elevation, and azimuth.

2. The Indicator System

The indicator system here described is essentially
that of the E-1 system. Mention is made of some modifi­
cation introduced because of the envisaged attack tactics
and some modifications are mentioned that constitute
part of the later members of the E-series.

The pilot's indicator presents, on a time sharing
basis, the following information:

1. The artificial horizon
2. The target range
3. The rate of closure on the target
4. The azimuth and elevation of target with
   respect to plane on a coarse scale as an
   error circle
5. Azimuth and elevation information on a fine
   scale as an error dot
6. Fiducial marker for indicating when weapons
   should be released or fired and when the
   attack should be broken off

The artificial horizon requires little discussion.
The central portion of the horizon line is blanked out
so as not to confuse other indications presented at the
center of the indicator.

The range scale to target is given as the radius
of a circle. In its present form, this range circle
does not start giving range until the target is very close. The range scale in the proposed system would necessarily have to be made appropriate to the tactics used in attack.

The rate of closure or range rate on the E-1 indicator is shown by blanking a certain segment of the range circle. If the target is moving away as fast as the pursuing plane, range rate of zero, the blanking occurs at the top of the circle. The blank moves to the right if the pursuing airplane is overtaking and to the left if falling back. This would have to be changed to coordinate with the different tactics. Since the ground targets are moving slowly compared with the speed of the airplane, the rate of closure would be almost the speed of the aircraft.

The error circle that gives the angle between the aircraft heading and the line of sight to the target would remain essentially unchanged.

Before the computer is turned on the error circle and the error dot will be displaced from the center by distances proportional to the angles of elevation and of azimuth of the target with respect to a set of axes in the plane. The longitudinal axis of the plane defining zero azimuth and the lines through the wing tips and an intersecting line parallel to the axis of the airplane define the plane from which angles of elevation are measured.
After the computer is in operation, the deflections of the error circle and error spot show the direction of the course to be flown with respect to the orientation of the plane, rather than the direction of the line of sight to the target.

In the later members of the E-series, the error circle changes to a smaller size when the computer is inserted in the system. The error circle reduces to wings when at the range to start firing or dropping weapons. Finally, the error circle and error dot disappear and a cross appears at the time when the attack should be broken off for the safety of the aircraft. These features probably should be incorporated in the final system.

3. The Antenna System

The antenna is an X-band antenna with a paraboloidal reflector 18 inches in diameter. In the E-l system, it is positioned first on a vertical axis and then on a horizontal axis which intersect at a common point about four inches behind the apex of the paraboloidal reflector.

In the E-l system, the conical scan is obtained by tilting the normal to the plane of the reflector 1.5 degrees from the line of the r-f feed, and rotating the reflector about the axis of the feed. In the later E-series, the reflector remains fixed, the r-f feed is carried around to the front of the reflector and a prismatic lens
is rotated so as to feed the reflector non-uniformly and thus give the desired conical scan.

As the lock-on system is usually mounted in the aircraft, and is aimed forward, both axes of motion are perpendicular to the axis of the airplane. The vertical axis is always perpendicular to the plane defined by the long axis of the airplane and a line parallel to the line between the wing tips, whereas the horizontal axis is always parallel to this plane.

III. HOW TO MOUNT THE ANTENNAS OF THE TWO SYSTEMS

Mounting the two antennas in an airplane poses some problems. The possibility of mounting the search antenna in a radome in the belly of the airplane was discarded because such radomes produce considerable drag at the speeds envisioned for the aircraft carrying this equipment. It then resolved itself into a problem of how to mount both antennas in a nose radome.

Two possibilities presented themselves immediately. An obvious one was to mount both antennas independently to the frame of the airplane. The other was to use the horizontally stabilized platform of the search antenna as a mounting base for the lock-on antenna. There are advantages and disadvantages to both systems. Briefly, there can be a better utilization of space if the lock-on antenna is mounted on the search antenna base; however, the computer problems involved in this case are deemed serious. A more detailed analysis follows.
A. ANTENNA OF THE LOCK-ON SYSTEM MOUNTED ON THE STABILIZED FRAME OF THE SEARCH ANTENNA

In the type of search system under consideration, the pitch stabilization is about a transverse axis on a roll stabilized fork. The pitch stabilized axis then carries the axis of rotation of the antenna itself together with the necessary driving motors and data take-off instruments. Stabilization keeps this section of the frame level as already described. If the support of the lock-on antenna were then rigidly attached to this stabilized frame, the azimuth and elevation data take-offs from the lock-on antenna would read the azimuth and the elevation of the target with respect to a horizontal plane.

1. Advantages

As previously mentioned, mounting the lock-on antenna on the stabilized frame of the search antenna allows for better utilization of space and the possibility of allowing large limits of roll and pitch stabilization. If the axis of roll stabilization is coincident with the axis of circular symmetry of the radome, then any arrangement of antennas within the radome, that will allow full motion of the lock-on antenna and motions connected with pitch of the search antenna when the search-antenna roll is zero, will give full clearance for all positions of roll stabilization.
One clearance problem does arise in that the lock-on antenna would have to be mounted some distance forward of the edge of the rotating search antenna disc, in order that it may look downward with the airplane in level flight. If the airplane were pitching downward or nosing downward, the lock-on antenna would be lifted toward the top of the radome, as shown in Figure 1. This would seriously limit the angle of glide allowable in a radome of reasonable size. Climb would be similarly limited as shown in the figure.

2. Disadvantages

In addition to the one clearance problem just mentioned, the problem of data take-off is a very serious one. As previously noted, the pilot's indicator in the E-1 system presents azimuth and elevation of the target with respect to the airplane as a frame of reference. Since, in an operational case, the antenna of the lock-on system will effectively have motions around four different axes, the interpretation of the data is complicated. By an appropriate choice of the order of the stabilizations in the lock-on antenna mount, two of these axis can be parallel, but the angle between the last axis in the lock-on mount and the first or roll axis of the search mount may vary over a wide range, and so the reduction of data is a complex problem.
Figure 1. Sketch to show interference between lock-on antenna and radome when lock-on antenna is mounted on stabilized platform of search antenna, and the airplane pitches.
The solution of this computing problem by means of potentiometers giving trigonometric functions seemed to be too complicated for a practical solution. Therefore, a set of gimbals were devised representing the two axes of the stabilization of the search antenna and two axes of motion of the lock-on antenna. Added to this was a rigid support from the outer frame to the center of the gimbal system. On this were set two more gimbals with axes vertical and horizontal with respect to the gimbal frame. The latter, of course, represents the airplane. The two systems of gimbals could then be joined together by a sleeve bearing along the axis of sight of the represented lock-on system. By repeaters from the four data take-offs on the two antenna systems, the motion of the sleeve can be made to follow precisely the motion of the axis of the lock-on set. Data takeoffs on the inner two gimbal rings would then read azimuth and elevation with respect to the aircraft. Such an analog computer could be built but it definitely represents a disadvantage to this system of mounting.

Before deciding on the gimbal type of analogue computer, a small scale model of an aircraft with a search antenna stabilized in roll and pitch was constructed by Mr. Longacre. An elastic thread from a point above the center of the stabilized platform could be made to point toward the target. It was then easy to see from the
Appendix I

geometry that the computation by trigonometric functions would be much too complicated, even neglecting second order terms. A rough model of the gimbal system was then constructed and it was evident that the direct mechanical analogue computer would be far superior in case the lock-on antenna were mounted on the stabilized base of the search antenna.

At about this stage of the investigation, P. G. Kruger, J. C. Buchta, and L. B. Linford, made a trip to Wright Field. In a conference, Mr. P. E. Koenig of Wright Field Armament Laboratory recommended very strongly that the lock-on antenna be mounted directly to the aircraft frame so that azimuth and elevation, with respect to the aircraft be read off directly. This recommendation received concurrence from members of the Computer Laboratory at M.I.T. during a visit there by the above persons and A. Longacre.

B. BOTH ANTENNAS INDEPENDENTLY MOUNTED TO AIRCRAFT

The study then was made to determine ways and means of mounting the two antennas independently to the aircraft frame and still giving as large amplitudes as possible for roll and pitch stabilization of the search antenna and as large deflections in azimuth and elevation as possible for the lock-on antenna.
1. Data Take-Off Problems

The data take-off problems in this case are reduced to a minimum since these problems have been solved for each of the parent sets, and thus, more or less standard, tested methods would be envisioned. The one computation that would be required in this particular case is the presentation of the azimuth line on the search PPI corresponding to the direction of aim of the lock-on antenna. This presents no problem at all when the aircraft is horizontal and the target essentially on the horizon. If, however, the target is at an angle downward, and the airplane rolls and pitches, the azimuth with respect to the horizontal search antenna will be a function of both the azimuth and elevation angles of the lock-on antenna. An appropriate computer of moderate accuracy needs to be designed for this purpose. It is recommended that this design be postponed until the computer for the ordnance is designed, since it is probable that the computation, necessary for the PPI, will be made in the ordnance computer itself. Then the necessary data could be brought out from the computer with little extra instrumentation.

2. Space Configuration of the Two Antennas

In order to determine possible arrangements of the search and lock-on antenna in a possible nose radome and also the size of the radome that would allow given
amounts of stabilization, scale models on a 1 to 4 scale of both antennas were constructed by Dr. Longacre. These were then supported independently in different relative positions in order to determine space interferences under varying conditions. A series of drawings were then constructed in order to determine the necessary radome size under different arrangements and placements of the two antennas. The search antenna was assumed to be a flat cylinder 40 inches in diameter by 6 inches high, rotating on a vertical stabilized axis. The top of this antenna proper was assumed to be 2 inches below the axis of pitch stabilization. The axis of pitch stabilization was set at varying distances below the axis of roll stabilization. The axis of roll stabilization which is parallel to the long axis of the aircraft was assumed to be the center of circular symmetry of all cross sections of the radome. The antenna was assumed to be stabilized for a dive of 30 degrees, a climb of 30 degrees and for a roll of ± 70 degrees. For each case, one drawing was made in a vertical section containing the long, or roll, axis of the airplane and a second showing a cross-section perpendicular to this roll axis. In the former drawings, the antenna is shown in the horizontal position, that is, parallel with the roll axis, and for both extremes of climb and dive. In the cross section, the antenna is shown for zero pitch in the position of no roll and then the extreme ± 70 degree roll.
In order to make the final check on clearance in this latter diagram, it is necessary to show the trace of the lower edge of the antenna when in one of the extreme positions of pitch stabilization. This is done for the case of zero roll. In order to do this, an ellipse was constructed with a major axis scaled to 40 inches and the minor axis scaled to 20 inches. The latter is the projection of the front to back diameter on a vertical plane, when the antenna is tilted 30 degrees. A minor axis intercept was then placed as far below the roll axis as the extreme depression of the bottom of the antenna showed on the longitudinal view. The ellipse was then drawn or traced onto the cross section. A portion of this ellipse made the extreme clearance requirement of a radius of 28 inches or a 56 inch circle for the inner diameter of the radome. This radius of clearance must be preserved to a point approximately 14 inches in front of the pitch axis. The diagram showed that there was a large region above the roll axis for carrying supports of the search antenna and the support for the lock-on antenna. In addition, many of the radar components could be placed in this region.

It was then observed that space could be saved by a change in design from the AN/APS-48. In this design, the pitch axis is supported out on arms that rotate about a roll axis at the rear of the antenna. The modification
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proposed involves carrying a rigid support high and making a two-bearing roll axis with a bearing separation of less than 40 inches. It then is possible, under conditions of pitch, to have the top of the antenna disc come up to, or even above, the roll axis. Using this technique, a second set of diagrams was made with the conditions the same as before except that the pitch axis was 8 inches rather than 12 inches below the roll axis. It was then possible to obtain the same limits of stabilization with a circle 51 inches inside diameter, 10 inches in front of pitch axis. The lock-on antenna could be set in such a position that the intersection of the axes of stabilization would be 8 inches above the roll axis and 52 inches in front of the bulkhead that the search antenna must clear. At this point, the radome would have to have a diameter of 34 inches.

The third and final set of drawings was constructed with the pitch axis 4 inches below the roll axis and the limits of roll and pitch the same as before. This configuration required a circle 46 inches in diameter, 5 inches in front of the pitch axis. As the pitch axis is raised, the free space in the upper part of the radome left free for supporting both antennas is reduced. However, it appears possible that the final configuration would allow sufficient space for everything required. In the latter case, however, there could not be a reduction in
the diameter of the radome until the plane of the
lock-on antenna is reached. The location of the lock-on
antenna is the same as for the previous case. The drawings
for this case are shown in Figure 2.

Reducing the size of the search antenna would not
save much space unless the size of the lock-on antenna
and its mount could be correspondingly decreased.

During a visit to the Control Systems Laboratory,
Mr. L. H. Orpin of Convair seemed to feel that the chosen
configuration was a good one, and he agreed to send
dimensions of a similar design they had under consideration.
When these arrive, the results of the three analyses can
be turned over to a draftsman for careful clearance drawings.

In setting up the clearance conditions and stabiliza-
tion limits the following considerations were applied.
The 70 degree roll would allow the pilot to make a turn
of approximately 2 needle widths at 600 miles per hour.
That is, he could turn 180 degrees in 30 seconds. This
would place a net force on the aircraft of approximately
3 G, and he would fly a circle about 3.2 miles in diameter.
Not all search radar information would be lost if the
aircraft banked an additional 10 degrees beyond the
stabilization limit and this would place a load of about
5 G on the aircraft which is probably as much as would
ever be used in a tactical maneuver. It was not possible
to be as liberal with the pitch stabilization limits.
(a) Longitudinal section showing extreme positions of pitch.

(b) Cross section showing extreme positions of roll, with trace of 30-degree pitch for the no-roll position.

FIGURE 2: Clearance drawings to show relative positions of antenna in nose radome showing clearances for the following cases. Search antenna 40 inches diameter, 4 inches high, stabilized for ± 30 degrees pitch and ± 70 degrees roll.
Military aircraft frequently climb and dive at angles much steeper than 30 degrees. If climbing at much in excess of 30 degrees, the radar beam would be lifted off the ground and most of the PPI presentation would be lost. However, in diving at angles steeper than 40 degrees, the beam would strike the ground and the picture of the area immediately ahead of the plane would still be presented. Dives at angles steeper than 30 degrees would probably be made only in coming from the high altitude to the altitude of approximately 4,000 feet. Below 4,000 feet, it is very doubtful that any dive in excess of 30 degrees would be made by a pilot.

For the lock-on antenna, it is assumed that a ± 45 degree travel is allowed both in azimuth and in elevation. It is felt that with greater deviations from ground track, it would be impossible from the electronic standpoint to maintain target lock-on.

The E-1 antenna available in the Control Systems Laboratory for inspection has an 18 inch paraboloidal reflector set with the apex about 5 inches in front of the intersection of the azimuth and elevation axes. The radial distance from the intersection of the axes to the edge of the parabola is approximately 12 inches, thus, in its possible motions, the rim of the parabola moves on the surface of a sphere 12 inches in radius or 24 inches in diameter. Maintaining the 1 to 4 scale,
a 6 inch rubber ball was procured and cut to conform with the limits of travel of the edge of the reflector of the lock-on antenna. This can then be mounted in a fixed position relative to the model of the search antenna and mechanical interference can be checked by moving just the search antenna model without the necessity of moving the model of the lock-on antenna.

It is recommended that future mechanical interference studies be made with a precise scale model of the search antenna to be constructed after the drawings have been received from Mr. L. H. Orpin of Convair.

One other form of interference should be investigated and watched in the final configuration. That is interference of one antenna with the radar beam of the other. No interference can be tolerated with the beam of the lock-on antenna and therefore, under no condition should the search antenna, or any part thereof, find itself in the cylinder in front of the lock-on antenna.

The converse interference problem is not as serious, but there are these cases that should be investigated.

The first case that must be considered is that when the airplane is diving downward, it will probably be impossible to keep the lock-on antenna completely out of the beam of the search antenna at the full dive angle of 30°. It is also probable that dives at the target from low altitude will occur at small angles, of the
order of 10 or 20 degrees, and under these conditions the lock-on antenna will be aimed approximately along the axis of the airplane. It should, therefore, be sufficient if the configuration is arranged so that when the lock-on antenna is aimed essentially along the axis of the airplane, it will not be below the plane of the search antenna for angles of depression less than 20 degrees.

The second case where interference might occur is during the approach for level bombing. In this case, the lock-on antenna may have a depression angle up to 40 degrees and the search antenna will be approximately level with respect to the plane, since the plane is assumed to be in level flight. In this configuration, there should be no interference with the beam of the search antenna.

The third condition that should be met is that when the lock-on antenna is not locked on the target or in the process of being locked on the target, its rest position should be up and straight ahead. In this position, there should be no interference with the beam of the search antenna, even when the aircraft is diving at the full 30 degrees.

If these three conditions are satisfied, there would appear to be little chance for the interference of one antenna with the beam of the other in any tactical situation.
Mr. Orpin, of Convair, pointed out that if the search antenna were to search on the ground at a distance of 25 miles from an elevation of about 4,000 feet, then the top edge of the beam must be almost in the plane of the antenna itself; this would require the curved reflectors to drop down more than 4 inches from the top of the antenna assembly. He reported, however, that these could be cut off at the end so as to clear the circles assumed in the clearance diagram.

IV. BLOCK DIAGRAM OF COMBINED SYSTEM

Figure 3 (at the end of Appendix I) is a block diagram of the combined systems. No attempt has been made to make the diagram sufficiently detailed to show the purpose of each tube, nor has there been an attempt to make the complexity of each block more or less uniform throughout. Rather the attempt has been to show in some detail the sections that are reasonably well defined and to show with less specific blocks, the portions of the system that as yet have not been completely worked out.

A. GENERAL FEATURES

In general, it is planned to have a common modulator, a common synchronizer, and common power supplies for those portions not requiring power supply isolation. When the two sets are operating simultaneously, the pulses will
be transmitted simultaneously. This should reduce intersystem interference to a minimum.

Nothing has been done toward deciding which blocks are to go into which package and where the packages are to be located. As a general philosophy, it is recommended that as much of the circuitry as possible be placed in the radome in the space above that used by the search antenna. Those circuits that need to be under close control of the navigator and those circuits concerned with generating range marks and sweeps should be close to the navigator's indicator.

B. THE SEARCH SYSTEM

1. Pulse And PRF Characteristics

There will be three sets of pulse characteristics and with them associated PRF characteristics. First, long range navigation or high altitude. For this, there should be a PRF of about 800 pps. The pulse length should be of the order of 1 μsec, although it might be increased to approximately 1.5 μsec. The sweep length should be 60 miles, and under these conditions, the lock-on transmitter will be off. The second set of conditions should be those for low altitude search and target acquisition. Under these conditions, the recommended characteristics should be a PRF of 3,000 pps, pulse length approximately 0.5 μsec, i-f bandwidth of receiver about 2 Mc, sweep length 25 miles and both transmitters should be on.
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The third operating condition should be beacon interrogation. Since one would not expect to find beacons in the area where one is flying at low altitude and searching, it is suggested that the beacon provision should be a modification of the first, or high altitude navigation position, which would change the pulse length to 2.35 ± 0.15 μsec and drop the PRF to 400 pps. The sweep range then could be set to 150 miles so as to make the beacon range greater.* Switch A, Figure 3, controls the operating conditions.

* It is assumed that beacons in the K_u-band will be available, and that their pulse and PRF characteristics will be the same as is now standard for X-band beacons. If K_u-band beacons are not available, either the beacon provision should be abandoned or it would have to be applied to the lock-on set. The latter would introduce additional complexity.

2. The AMTI Section

No particular comments need be made about the radar set as a whole, except that care must be taken to be sure there is no amplitude modulation on the transmitted pulses nor on the local oscillator. The receiver probably should be of the lin-log variety. The AGC, if used, must be slow enough that changes in its value between successive pulses are not great enough to prevent effective cancellation of the same size pulses. The type of AMTI
unit will certainly depend on the state of the art at the time the final set is engineered.*

* A limiting receiver with phase comparison between ground clutter from adjacent patches, suggested by Dr. S. N. Van Voorhis should also be considered. This would eliminate the undesirable scan frequency modulation on the ground clutter.

The simplest type of cancellation unit is to split the video, send one channel through a delay line whose delay time is equal to the pulse interval, then to amplify this video back to the original level, invert with respect to the unmodified video, and then feed the two into a cancellation unit. The disadvantage of this system is that the delay line and video amplifier will change the pulse-shape characteristics of the video unless the bandwidths of both are wide compared with the bandwidth of the video amplifier of the receiver. Two pulses, even though of the same amplitude, but of different shape, will not cancel completely. The block diagram of this is shown in Figure 4a.

An improvement of this system is made by introducing an attenuator and amplifier in the undelayed line as shown in Figure 4b. By this means, the band pass characteristics of the delayed and undelayed branches may be matched moderately well and more complete cancellation obtained.

Finally, instead of using a video delay line, the video may be applied as a modulation, either AM or FM
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on a carrier generated in a fixed oscillator. The output must be then detected before cancellation. This has the feature of preserving video characteristics even better for still better cancellation. The FM approach should be investigated because this obviates the need of accurate balancing of the two parallel channels, one delayed and the other not delayed. If the FM system is developed and is as good as it appears at the present time, it would probably be the best one to use in this system. This is shown in the AMTI section of Figure 3.

Figure 4a. Simple AMTI Circuit

Figure 4b. An AMTI Circuit With Matched Channels
3. The Synchronizer

When the AMTI is being used, the delay line must determine the PRF of the system. When the AMTI is not being used, as for high altitude search and navigation, the delay line should not be the trigger generator, and so it is necessary to switch in an 800-pps trigger generator. The 400 pps for beacon interrogation can be derived by a 2 to 1 count down. The latter is purely conventional. The former requires some discussion.

Since there is some delay in the synchronizer and modulator, the trigger delay between the time one trigger is generated and the time the synchronizer is triggered to generate the next succeeding trigger must be somewhat less than the video delay. Further, there must be a variable fine adjustment in this delay to take care of small circuit differences and differences introduced by replacement of tubes, in this circuit. Several methods can be used to fulfill these conditions.

One method is to use the same delay line for both purposes and then add a variable video delay. This has the very definite disadvantage that one may have spent considerable effort to balance the wave shapes of the delayed and undelayed video, and then an additional video delay would introduce an additional change in shape prior to the time of cancellation. It is, therefore, recommended that this method be used only as a last resort. This arrangement is shown in Figure 5a.
An alternative is to have a fixed video delay after the delay line, greater in value than the delay in the synchronizer circuit. Then place a small variable delay in the synchronizer circuit to give best cancellation. This is shown in Figure 5b. This has some of the same disadvantages as the previous scheme. However, high quality fixed delay lines are smaller than variable lines of the same quality.

It is recommended that video delays in addition to the delay line be avoided by one of the two following circuits.

If it is possible to obtain a delay line with two outputs separated by the order of 1 or 2 µsec in delay, then the trigger circuit can be taken out on the shorter delay path and the video on the longer delay path. It would then be possible to introduce a small variable in the trigger circuit to make the final fine adjustment in the delay.

If such a delay line is not feasible, then one should investigate the advisability of two delay lines of slightly different delay, the shorter to handle the trigger circuit, and the other to handle the video circuit. If this is done, it would be necessary to investigate possible relative drift in delay time between the two delay lines. This latter circuit is shown in Figure 3. Two taps on one delay line would be equivalent to making
Figure 5a: AMTI SYNCHRONIZER WITH VARIABLE VIDEO DELAY

Figure 5b: AMTI SYNCHRONIZER WITH FIXED VIDEO DELAY
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the delay lines in Figure 3 into a single block with two inputs and two outputs.

The choice between liquid and solid delay lines must be made on the basis of availability, state of development, and the possibility of the two outputs as previously mentioned.

4. The Indicator

It is proposed to use an off-center PPI as the navigator's indicator. The indicator central should prepare the three sweep lengths, 150, 60, and 25 miles, with range mark intervals of 20, 20, and 5 miles respectively. A video switching arrangement must be available so that in the high-altitude, long-range condition, only normal video can be shown. When the main switch (SwA) is thrown to position (3) for short range, that is for target search, then the operator should have three possible combinations available to him (on SwB): 1) normal video for the entire scan, 2) AMTI for $\pm \varphi$ degrees from the airplane heading and normal video for all other azimuths automatically controlled by azimuth data from the search antenna, and 3) AMTI for the entire scan. Thus, this unit must have azimuth information fed to it to control the video switching. This video output as selected must be fed to a video mixer to mix the video with the range marks and with information showing the range of the range gate and azimuth of the line of sight of the lock-on system.
The possibility of using a two-color tube should be kept in mind. If a satisfactory two-color tube is developed, then the AMTI could be presented in one color and the normal video in the other. This would make it possible to watch both fixed and moving targets in the sector ahead.

Finally, this presentation must be stabilized for small, rapid, yawing motions of the aircraft. This is necessary to avoid a blurred picture. This yaw stabilization must have a relatively short time constant so that when the plane is making an intentional turn, the picture on the PPI will follow the purposeful change of heading of the plane, with moderate delay.

5. Stabilization

Stabilization of the search system will be that discussed earlier. That is, the antenna will rotate about an axis vertical in space as long as pitch does not exceed $\pm 30$ degrees and roll does not exceed $\pm 70$ degrees. The motion of the aircraft can be followed so that the error will be certainly less than 0.5 degrees.

C. THE LOCK-ON SYSTEM

1. Pulse And PRF Characteristics

The lock-on system will operate only when the search system is set for low altitude search and target acquisition. In the high altitude position, the high voltage on the transmitter will not be applied. However, other
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circuits will be on so that they will be warmed up, ready for instantaneous operation. When the search set is switched from high altitude to low altitude position, the lock-on system transmitter will be activated at the general system PRF of 3,000 pps.

2. The Boxcar Generator

As before, a general system of high quality must be used in order that there be no amplitude modulation arising in either the transmitter, the local oscillator, receiver, or due to AFC action. In this system, the i-f amplifier must be linear. The video should be divided into two channels and boxcars generated in each channel. One channel, called the early boxcar generator should lock on the early part of the Butterfly signal and the late boxcar generator lock on the latter part of the same signal. Unless a single-stage boxcar generator of good quality is developed, two-stage boxcar generators would be used. The latter type would use a short gate in the first stage and a long gate in the second. The early boxcar generator is triggered by the range-gate trigger and the late boxcar generator is triggered by the same trigger delayed by a variable delay, tentatively set at 0.2 - 0.6 μsec. Each boxcar output should be filtered by a high-pass filter to remove the conical scan frequency and low modulation frequencies, due to very slow targets, that might interfere with the conical scan frequency. The output of this filter should be full-wave
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rectified, and a filter with a time constant of approximately 0.005 seconds should probably be inserted.* The output of the early and late channels should then be fed to sum and difference mixers. The output of the sum mixer can be used to give information about azimuth and elevation errors. The DC difference output should give a discriminator type of curve obtained by proportioning pulse length and late gate delay that will allow range tracking. The output of this range tracking circuit should be a voltage depending on the range of the target. When the system is locked on, this voltage applied to the range-gate generator, and that in turn generates the gate for the early and late boxcars. When not locked on, a manual range-voltage generator feeds a voltage into this same range-gate trigger generator to bring the boxcar gate onto the Butterfly signal.

* It is to be noted that this filter will introduce unwanted phase shifts that may cause an objectional spiral motion when correcting an error signal.

3. PRF Problems, Unwanted Frequencies

The effective target cross-section, when a moving target is viewed against a fixed background, is a function that consists of a constant plus a sinusoidal fluctuation. It is this sinusoidal fluctuation that is desired. At X-band, this sinusoidal fluctuation has a frequency of about 28 cps for each mile per hour the target is moving. It is to be understood that the "speed" of the moving target is the radial component of the target's velocity.
A radar system samples this cross sectional area at intervals. The number of samples per second is the PRF of the radar system. The series of pulse returns contains the following frequencies: 1) The PRF and all multiples thereof, 2) the frequency due to the moving target, which will be referred to as the modulation frequency, 3) the PRF + the modulation frequency, 4) twice the PRF + the modulation frequency, and so on. For modulation frequencies in excess of the PRF, there will also be frequencies for positive values of the modulation frequency minus integral multiples of the PRF.

The boxcar generator acts both as a power amplifier for the modulation frequency and as a filter that removes the repetition frequency and its harmonics. As a power amplifier, the factor is equal to the product of the ratio of the repetition interval to the pulse length and the sine squared of \( \pi \) times the ratio of the modulation frequency to the PRF. This is a maximum when the modulation frequency is one-half the PRF and zero when the modulation frequency is equal to the PRF. Thus, targets with radial speeds providing a modulation frequency equal to the PRF or any of its harmonics cannot be detected. These speeds are called blind speeds.

Because of the relationships just mentioned, all modulation frequencies (save those of the blind speeds), no matter how large, will always produce an output in the frequency range from zero to one-half of the PRF.
In order to lock on the target in azimuth, the proposed system uses a conical scan. The E-1 system scans conically 35 times per second, thus, if the lock-on system is not directed toward the target, there is introduced, a 35-cps envelope in the amplitude of the signal from the target. In the case of an isolated target, it is the total amplitude of the signal. In the case of a moving target against a fixed target background, if the antenna is not pointed toward the moving target, then there would be not only a 35-cycle modulation of the fixed target signals but also a 35-cycle fluctuation in the amplitude of the modulation due to moving targets. This 35-cycle fluctuation in amplitude must be preserved and that must be fed to the direction correcting circuits.

A target moving at about 1.25 miles per hour would produce a signal with a 35-cycle modulation. This would, of course, be a fictitious error signal and would throw the antenna off target and thus a 35-cycle modulation on the boxcar output must also be rejected by filtering. For these reasons, it is suggested that a band pass filter be applied immediately after the boxcar generator. The filter to have the following characteristics:

1. The filter should cut off below 35 cycles per second, or perhaps 70 or even 105 cps to eliminate harmonics, and should have good transmission above 200 cycles per second to handle speeds above 8 miles per hour with X-band.
2. The attenuation should remain zero to approximately one-half the PRF and cut off at the PRF.

It is recommended that the PRF be high, probably 3,000 pps. This PRF would set the first blind speed just above 100 miles per hour. Few expected targets would have radial speeds this high.

There is one other difficulty to be expected about which it appears little can be done. This is the generation within the circuitry of a self-jamming frequency when the modulation frequency is very close to one-half the PRF. If the modulation frequency is 17.5 cps less than one-half the PRF, then there will be generated another frequency that is 17.5 cps plus one-half the PRF. During subsequent detection, these two frequencies will give rise to a 35-cps envelope on the modulation signal and this cannot be filtered out by the original filter that removed 35 cps modulation. This 35-cps envelope will become a 35-cps signal after full-wave rectification. This will be identical with an error signal resulting from an off-axis target. Thus a target at this speed will not be tracked.

The same result will occur if the modulation frequency due to the moving target is 17.5 cps plus one-half the PRF since it will also produce the one-half the PRF minus 17.5 and then later the difference frequency of 35 cps.
These modulation envelopes, superimposed on the modulation resulting from a moderately high-speed moving target, were observed on films made from tape recordings.

With the help of Mr. Jack Ritt, tape recordings of the Butterfly signal, transmitted over a communication channel from an airborne Butterfly radar set, were amplified, placed on an oscilloscope as a horizontal deflection, and then photographed by means of a continuously moving film camera. Thus, the output of the boxcars could be viewed visually. In several places, on the short length of film exposed, the high-frequency modulation was shown, and superimposed upon this modulation was an envelope with a frequency varying from below 30 to the order of 100 cps.

A careful study was made of the results of this effect. It was felt that the effect could not be eliminated, but that it would not be serious for the following reason. There would be two speeds that would cause this jamming effect. They are separated by 2.5 miles per hour, one above and the other below one-half of the first blind speed. If, however, we assume that the input to the azimuth and elevation servos, will carry a time constant of about 0.1 seconds, or longer, then frequencies differing from 35 cps by 10 cps or more, should not cause serious disturbances, in the antenna control. This corresponds to a speed range of approximately one-third mile per hour.
Thus, under the conditions postulated, that is a scanning rate of 35 scans per second, a PRF of 3,000 pps, and a time constant in the directional servos of the antenna of the order of 0.1 seconds, there would be two jamming speed bands each about one-third mile per hour wide separated by 2.5 miles per hour in the speed range somewhat above 50 miles per hour. The probability of finding a moving target with just this radial component of speed is very small and therefore, this effect is felt not to be a serious handicap to the set.

Pilots and navigators using the set, however, should be warned of the presence of this effect so that if observed, they will know that it is inherent in the system and not indicative of poor operation of the set. If the effect is noted, the attack should be broken off and the crew could choose to try another target or they could try the same target at a different azimuth of approach. This latter tactic would give a different radial component of speed and thus a high probability of success.

4. Range Information

The difference in the output of the early and late boxcars will give a discriminator type of output, and this output can be used to correct a range voltage. This voltage fed into the range circuit will give a range gate at the proper time. In the course of searching for a target in range, the range gate can be moved out or in
by a manual range control which is then thrown over to automatic once the antenna is locked on the target.

From this range voltage, a differentiating circuit can give the rate of change of the range voltage or the rate of change in range. This information may be desired for the computers provided it is smooth enough. Both the range and range-rate data should appear on the pilot's indicator.

5. Elevation And Azimuth From Boxcars

The AC output of the circuit summing the early and late boxcar outputs should carry angle correction information, that is, if the antenna is not pointing precisely toward the target, the phase of this AC summed boxcar output will be indicative of the direction of the antenna error while the amplitude of this AC output is a measure of the size of the error. By feeding this output into a bridge circuit together with the output of a reference generator on the scanning mechanism itself, one circuit can give azimuth error information and an identical circuit can give elevation error information. These circuits can be essentially identical with those in the E-1 system.

There is, however, one problem in operating against ground targets not present against isolated airborne targets, and that is one that leads to an automatic gain control, AGC, problem.
6. The AGC Problem

Since the receiver is linear, it has a very limited dynamic range. It may well be that when the antenna is looking in one direction, that is, right, left, up or down, the background target may be very much larger in effective cross-section than in other directions in the course of a single scan. This difference may well exceed the dynamic range of the receiver, in which case there would be saturation on one side and probably loss of signal in noise in the other. Such a condition will make accurate azimuth information impossible.

In order that the direction information be not lost, it is necessary to have a fast acting AGC on the i-f amplifier and it must operate on tubes early enough in the amplifier that there will be no saturation under any ordinary circumstances. This AGC must operate rapidly enough that it can change in value to accommodate different target cross sections in different parts of the scan. Thus, its time constant should be less than $1/k$ of the scanning cycle or of the order of 0.007 seconds.

Such a rapidly acting automatic gain control will affect target direction information because in the presence of a large background target, the gain of the receiver will be reduced and the amplitude of modulation resulting from the moving target will be correspondingly reduced. Where the cross section of the background target is small, the gain of the receiver will be large and the modulation
correspondingly large. Thus the antenna would tend to be pulled away from a large fixed target in the neighborhood of the moving target.

In order that the AGC may be sufficiently rapid, it will have to be derived from the sum of the boxcars before filtering, and this same AGC voltage can be fed into the output of the sum of the filtered boxcar outputs as a gain control factor. If done properly, it should approximately restore the original relationship in the modulation amplitude, regardless of the direction of the scanning beam, and thus, it should be possible to derive moderately good directional information.

7. Elevation Information From Total Signal

There is some question as to whether good elevation error information can be derived from the boxcar output. When the scanning beam is in its maximum upward position, the major portion of the beam is looking up into the air, and when it is in a downward position, it is looking into the ground. If the range gates can be moderately short, the difference in total background signal may not be too great. There is some indication that better lock-on in elevation might be obtained by using total signal, rather than the boxcar signal. As long as the range gate remains on the moving target, the elevation information obtained from total signal would hold the antenna on the strongest ground target within the range gate. This would not be
far different in elevation angle than the moving target itself provided the range gate is short. It is, therefore, recommended that the circuits be arranged so that the navigator may choose to use either elevation information from the total signal, or from the boxcar signal. In this way, he could choose the signal that gave the best lock-on.

The availability of this circuit may aid greatly in the original target lock-on as will be explained later.

8. The Pilot's Indicator

The indicator of the lock-on system should be essentially like the pilot's indicators of the E-1 system and later systems of that series. Whether or not the navigator should have a repeating indicator can only be determined by field tests. As modified for this purpose, the indicator would show:

1. The artificial horizon. The center part of the trace should be blanked out.

2. The target range. In this case, the target range should be presented from 15 miles to 0 with the range dependent on the radius of the range circle. However, it is recommended that the range scale be nonlinear so that the last five miles should cover at least half of the radius available on the tube, and that the range extend out to about 15 miles.

3. Rate of closure blanking. The range circle should contain a gap showing rate of closure. The scale must be entirely different than that on the E systems because of the difference in target. A suggested scale would have rate of closure of 300 miles per hour at 9 o'clock, and 400 miles per hour at
12 o'clock, 500 miles per hour at
3 o'clock, and 600 miles per hour at
6 o'clock.

4. An error circle. In the early stages of
target lock-on. The error circle should
appear on the oscilloscope to show the target
azimuth and elevation with respect to the
plane of the aircraft.

5. Error dot. When the error circle gets almost
centered, an error dot magnifying the error
should appear along the same radius. When
the error dot is centered within the error
circle, the aircraft is then lined on the
target.

In the early stages of the attack, the error dot
and error circle show the difference between line of
sight of the target and the aircraft heading.

During the attack run, the proper computer must
be activated by the pilot (SwE of Figure 3). The
computer must be designed for the type of ordnance to
be used in the attack. As soon as the chosen computer
is set into operation, the error dot and error circle
show the correction in aircraft heading required for a
proper approach as set by the computer.

In the final construction, modifications used in
the later E-series should be investigated and used if
desirable. Among these are changes in the size of the
error circle when the computer is put into operation,
and particularly, the change that makes the error dot
and error circle disappear and a large cross appear
when the attack must be broken off for the safety of
the airplane.
9. Antenna Motions

It is suggested that the lock-on set be capable of moving 45 degrees right and left and also 45 degrees up and down. If space considerations dictate a smaller limit of travel, then these figures might be reduced if early flight tests indicate that tracking at such large angles from ground track is impossible.

One other feature is recommended for the lock-on system, namely, an automatic control that will set the antenna at zero azimuth and maximum elevation when the lock-on set is not being used. This would help keep the lock-on antenna from interfering with the search system beam at maximum dive angle. This is shown as SwC in Figure 3.

D. COORDINATION AND OPERATION OF THE COMBINED SYSTEM

1. Long Range Navigation Aid

Regardless of other navigational aids, the picture given on the PPI by the search set with long sweep will aid in navigation to the target area. A single switch, SwA position (2), should set the search system for long range navigation and turn off the transmitter of the lock-on system. The search set would then have PRF of about 800 pps, a pulse length of 1.0 to 1.5 microseconds, and the PPI show only the normal video on a 60-mile sweep.
2. Short Range Navigation Aid And Target Search

As soon as the aircraft is in the target area and is descending to low altitude in order to search for moving targets, the above mentioned switch should be thrown to search position, position (3), in which case the lock-on system transmitter will go into operation. The antenna of this system would still be pointing ahead and up. Both systems would go to a PRF of 3,000 pps, with a shorter pulse, approximately 0.5 µsec long. The indicator would show a shorter sweep, about 20 miles, and the operator would have the choice of showing ordinary video, ordinary video at large angles from straight ahead, and AMTI straight ahead and for a small angle to either side. This latter switching can be handled automatically from the data information giving the azimuth position of the search antenna.

Under these conditions, the navigator would search for moving targets.

3. Navigation To Obtain Correct Approach To Target

Once the desired moving target is chosen, the navigator or pilot, or both would have to determine quickly whether it would be possible to turn and line up on the target with a relatively small turn, or whether a more elaborate procedure is indicated. A more elaborate procedure would probably be required most of the time if it were desired to make the attack run parallel with,
or almost parallel with the road or railroad track, as
the case may be. In such a case, the navigator and pilot
would have to observe the position of the desired target
and then try by means of a series of procedure turns to
get into a position so that they line up with the target
at the proper angle of approach.
4. Target Lock-On

As soon as the target is seen, and the approach can
be made without large changes in heading, the lock-on
system should be locked on the target by the navigator.
Pressing the button (SwC) Figure 3 for manual lock-on,
should bring the position of the lock-on antenna under
control of a small "joy stick" similar to that used
on the E-1 system. As soon as this is done, the azimuth
of the lock-on target beam should appear as a bright
trace on the search PPI. The range of the range gate
should appear as a circular trace at the proper range on the
same PPI. By adjusting the azimuth and range of the
lock-on system, the intersecting light traces on the
PPI should be brought into coincidence with the desired
moving target. The only unknown left is the angle of
elevation.

In most cases, the angle of elevation would be a
slight downward angle and all that would be necessary
might be that the neutral elevation of the "joy stick"
could be set a few degrees below the horizontal. This
might be sufficient, but if not, either of the following two would probably be much better.

In the first method, the navigator from his ground clearance indicator should know his approximate elevation above the ground over which he is flying, and therefore, with some precision, his elevation above the target. This height could then be set into a very simple computer to which also the range information from the range-gate setting could be fed. The angle of depression fed to the lock-on antenna would then be the angle whose sine is the ratio of the estimated and set in height to the manually determined range.

The second, and probably better method could be used if the circuitry were included in the system so that the elevation error information could be derived from the total signal. The lock-on procedure would then be to have SwD in position (1) and then set the antenna in azimuth and the range gate in range by observing the bright traces on the PPI. The antenna would automatically be set to -5 degrees elevation. By turning to position (2) and adjusting the manual control, the lock-on antenna would be set on automatic elevation lock-on based on total signal. In this way, the lock-on antenna would lock on the ground at the range of the moving target, and would, therefore, be nearly at the elevation of the moving target itself. The switch would then be thrown to lock
Appendix I

the antenna on the target in azimuth and range gate on the proper range.

In position (3), the vertical control is derived from the total signal; in position (4), from the Butterfly signal. This second arrangement is the one shown in Figure 3.

5. Target Approach

As soon as the lock-on system was locked on the moving target, the range, the range rate, and the azimuth and elevation error signals would appear on the pilot's indicator. The pilot would then take over and follow the directions given by his indicator. The navigator could see that the lock-on system was locked on the correct target by following the range and azimuth traces, and see that they followed the desired target on the search PPI, besides "double checking" the pilot for "slips". He would also monitor the lock-on with head­phones in order to have immediate knowledge of tracking failure.

6. Computers

The last part of the target approach would be determined by the ordnance to be used. This would determine the computer to be used and the particular tactics to be followed by the pilot. At the present stage of the development, it is felt to be unwise to try to design computers. However, the following comments
might be made. If the armament to be used consists of guns firing straight ahead, or rockets, then the aircraft would fly level to that point where the target was depressed by an angle of, say, 15 degrees. The pilot would then set the plane into a glide aimed almost directly at the target. The computer would then make the appropriate correction in super-elevation required for the armament ballistics and for any required lead angle. Indication would have to appear on the pilot's indicator as to when the ordnance has to be fired and also when the pilot must pull out in order to avoid disaster.

A similar flight pattern might be used for toss bombing except that after the glide has progressed to the proper point, the pilot would start a vertical pull-out and the toss bomb computer would release the bomb when the path of the airplane followed the correct trajectory.

Another alternative would be bombing from level flight. In this case, a level bombing computer would be required and when this was in operation, the pilot error signal would show zero elevation error when flying level. The computer would then have to indicate when the bomb should be dropped. The position would depend on whether ordinary bombs, aero-dynamic high-drag bombs, retrobombs, or other types are being used.
Finally, consideration should be given to guns firing directly downward, slightly ahead, or slightly to the rear of the aircraft. In all cases, the computer must be designed after the type of ordnance is selected.

7. Computer For Placing Azimuth Line On The PPI

The details of this computer are not worked out at present. Since the information may well be derived in some of the ordnance computers, it may be unnecessary to derive it again. If the aircraft is in level flight, the azimuth data takeoff of the lock-on system will give true azimuth with respect to the aircraft. If the aircraft is not in level flight then corrections must be made for the roll and pitch of the airplane. The search antenna is stabilized against roll, and thus, azimuth presented on the PPI are all true azimuths with respect to a stabilized horizontal plane. The lock-on set is not operated on a stable base, and thus, when the aircraft is banked, and the lock-on set is not looking straight ahead, the azimuth in a horizontal plane of the line of sight of the target is a function of the roll and pitch of the plane and of the azimuth and elevation of the lock-on system.

As pointed out before, a special computer for this purpose should not be considered until it is determined that the necessary data are not available in the ordnance computer.
If the azimuth of the lock-on set in the horizontal plane is computed either in the ordnance computer or in a special computer, it need not be corrected for yaw. If the bright trace generator for the PPI is activated by a coincidence between the computed lock-on azimuth of the search set before the latter is corrected for yaw, the bright trace will be independent of the yaw correction.

V. CONCLUSIONS

This preliminary analysis was prepared in order to point out some of the problems of design that would be encountered in an all-weather attack system. It also points out possible solutions to some of these problems. Future experimental research and design studies must decide whether the proposed solutions of some of the problems are feasible, or whether a new approach must be made. Further, there are undoubtedly problems that will not become apparent until development has progressed beyond the present stage.

It is felt by the writer, however, that the outlook for an effective all-weather attack system is good and that research and development should continue as rapidly as possible.

VI. ACKNOWLEDGMENTS

The writer wishes to point out that the ideas and recommendations in the foregoing report are not original with him, but are collected by him as a result of many
helpful discussions with Dr. Andrew Longacre, Dr. P. Gerald Kruger, and Messrs. John Buchta, Howard Knoebel, I. W. Janney, and Jack Ritt. He also wishes to express his appreciation to Mrs. Virginia Hartshorne for transcribing this report, and to all others who made this report possible.
Appendix J

EXPLANATION OF ANGLE SYMBOLS

- Azimuth of search antenna, with respect to aircraft azimuth (measured in horizontal plane)
- Yaw correction of search set
- All angles of search antenna corrected for yaw
- Azimuth of search antenna, measured in vertical plane
- Yaw correction of search set
- Azimuth of lock-on antenna, with respect to aircraft azimuth (measured in plane of aircraft)
- Elevation of lock-on antenna (measured in plane of aircraft)
- Elevation of lock-on antenna, measured in plane of aircraft
- Azimuth of lock-on antenna, measured in vertical plane
- Elevation of lock-on antenna, measured in vertical plane
- Azimuth of lock-on antenna, measured in horizontal plane
- Elevation of lock-on antenna, measured in horizontal plane
- Azimuth of lock-on antenna, measured in vertical plane
- Elevation of lock-on antenna, measured in vertical plane

Switch A selects radar pso, range, etc.

Switch B selects between normal and static video.

Switch C activates look-on antenna signal on control error circle and dot.

Switch D selects control of lock-on antenna.

Switch E selects control of look-on antenna.

Switch F selects control of look-on antenna.

Switch G selects control of look-on antenna.

Switch H selects control of look-on antenna.

Switch I selects control of look-on antenna.

Switch J selects control of look-on antenna.

Switch K selects control of look-on antenna.

Switch L selects control of look-on antenna.

Switch M selects control of look-on antenna.

Switch N selects control of look-on antenna.

Switch O selects control of look-on antenna.

Switch P selects control of look-on antenna.

Switch Q selects control of look-on antenna.

Switch R selects control of look-on antenna.

Switch S selects control of look-on antenna.

Switch T selects control of look-on antenna.

Switch U selects control of look-on antenna.

Switch V selects control of look-on antenna.

Switch W selects control of look-on antenna.

Switch X selects control of look-on antenna.

Switch Y selects control of look-on antenna.

Switch Z selects control of look-on antenna.
CONSIDERATIONS ON ARMAMENT FOR AN ALL WEATHER ATTACK (AWA) SYSTEM

Report Number R-28
Appendix II
December 1952

Prepared by:

[Signatures]

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Contract DA-11-022-ORD-721

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ABSTRACT

The use of bombs, rockets and guns; the mode of attack, and delivery of armament on moving ground targets from the air is considered. Hit probabilities, under certain feasible conditions, for systems with an overall accuracy of 20, 10 and 5 mils, are included.
INTRODUCTION

The overall accuracy of the better present day air-to-ground attack systems is about 20 to 25 mils, including the errors introduced by pilot, aircraft, armament, and the sighting and computing elements. Since bombs and rockets have errors of about 5 mils, and guns have even smaller errors, the main source of error would seem to be in the airframe and sighting system.

It is anticipated that the moving-ground-target tracking-radar being developed by the Control Systems Laboratory may operate with errors of the order of 10 mils; in such case, the overall attack system would have errors comparable to those of existing systems.

This report will consider systems with overall accuracy of 20, 10, and 5 mils; the 20 mil system representing present practice, the higher accuracies show the results which might accrue from better system performance. The weapons studied include bombs, rockets (Sidewinder) and guns.

The calculations on ranges, hit probabilities and other considerations presented in this report are based on very simple assumptions and are intended only to give values of the correct order of magnitude. No correction for the velocity of the moving target has been taken into
consideration, though in most cases, if $V_p$ is replaced by the closing range-rate along the ground, the calculated values will be correct under the assumptions given. In any case, the velocity of the moving target is expected to be approximately $30 + 20$ mph and this is less than 10 per cent of $V_p$.

Complicated assumptions, leading to more accurate equations and correspondingly accurately calculated values are not justified in this planning stage.

SECTION I: THE AWA BOMBING SYSTEM

From an examination of bomb characteristics, it appears that the following types of bombs need to be considered for the reduction of railroad stock, trucks in convoy, and tanks.

1) 750 pound size fragmentation bomb
2) 750 pound size (110 gallon) Napalm
3) 750 pound size "fragmentation cluster" bomb (Contains 14 - 20 pound bombs; total weight approximately 350 pounds)
4) 750 pound size "Shaped charge cluster" bomb (Contains 24 - 14 pound bombs; total weight approximately 400 pounds)
5) Lazy dog (hail, dart, etc.)

The first two, in the above list, would be useful against railroad stock and trucks, and are available now. Number three is in development and has the desirable property of having a larger damage area than one and two. Number four, also in development, should be good against
tanks, since it is alleged that the "shaped charge" will penetrate four inches of mild steel. Number five is mainly anti-personnel, though may do some damage to trucks. In all cases (except Number 4) an air burst (30 to 40 feet for bombs--higher for Lazy dog) seems desirable.

In attempting to evaluate the usefulness of these bombs, the following considerations have been made. A number, $E$, is defined as the effective number of bomb fragments per foot$^2$ of area perpendicular to the line connecting the explosion point and the target, each fragment having an energy such that it will penetrate 1/8 inch of mild steel.

The following empirical relation for the effectiveness, $E$, has been found:

$$ E = \frac{E_0}{(\bar{x})^{2.5}} $$

where $\bar{x}$ is the damage radius.

$E_0$ is a function of the weight of the bomb and empirically has been found to be equal to $41.8 \ W^{0.9}$ for fragmentation bombs of 20-pound to 750-pound size.

Thus

$$ E = \frac{41.8 \ W^{0.9}}{(\bar{x})^{2.5}} $$

or

$$ \bar{x} = 4.45 \ \frac{W^{0.36}}{E^{0.4}} $$

and if one lets $E = 1$

$$ \bar{x} \ (\text{for } E = 1) = 4.45 \ W^{0.36} $$
This relation can now be used to calculate the damage radius for \( E = 1 \) and then the hit probabilities which give \( E = 1 \) for any weight of bomb.

Values for the damage radius and damage area for \( E = 1 \) are given in Table I for several bombs.

The effective radius against personnel is roughly four times greater than that defined for \( E = 1 \) above.

These figures seem to indicate that for AWA the 750 pound "Frag Cluster" and Napalm are the best suited though many small bombs (20 and 100 pound size) give as good or better hit probabilities for the total weight carried. It should be remembered, however, that most consensus indicate that one can prove any desired point from bomb figures!

There are several possible modes of bomb delivery for the AWA system:

1) Level bombing
2) Toss bombing
3) Retro-bombing

The relative merits of these will now be considered. Assume that the altitude of attack above the terrain will be 1,000 feet. This is thought to be a "safe" altitude, from the standpoint of enemy fire since the AWA plane presents a target of high angular velocity when the plane's speed is 660 feet per second. At the same time, the altitude cannot be too low because of the all weather feature of the system.
<table>
<thead>
<tr>
<th>Size and Kind of Bomb</th>
<th>Damage Radius for $E = 1$</th>
<th>Damage Area for $E = 1$</th>
<th>Probability of hit on a point target for a single missile, having a given damage area, and for systems of 20, 10 and 5 mil error.</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 lb. Frag</td>
<td>13 ft.</td>
<td>530 ft.$^2$</td>
<td>0.0075, 0.030, 0.11</td>
</tr>
<tr>
<td>100 lb. Frag</td>
<td>25.5 ft.</td>
<td>2,050 ft.$^2$</td>
<td>0.029, 0.11, 0.37</td>
</tr>
<tr>
<td>260 lb. Frag</td>
<td>29.5 ft.</td>
<td>2,750 ft.$^2$</td>
<td>0.037, 0.14, 0.55</td>
</tr>
<tr>
<td>500 lb. Frag</td>
<td>43.0 ft.</td>
<td>5,800 ft.$^2$</td>
<td>0.078, 0.28, 0.74</td>
</tr>
<tr>
<td>750 lb. Frag</td>
<td>48 ft.</td>
<td>7,250 ft.$^2$</td>
<td>0.097, 0.34, 0.81</td>
</tr>
<tr>
<td>750 lb. Frag-Cluster</td>
<td>43.5 ft.</td>
<td>7,400 ft.$^2$</td>
<td>0.10, 0.35, 0.82</td>
</tr>
<tr>
<td>750 lb. Napalm</td>
<td>---</td>
<td>(13,000) ft.$^2$*</td>
<td>0.17, 0.52, 0.95</td>
</tr>
</tbody>
</table>

* Napalm has no $E$ value, as defined.
Appendix II

Conditions of Level Bombing

The simple expression for the position of the target, ahead of the bomb release point, is

\[ x = \sqrt{\frac{2h v^2}{g}} \]

for our case \( x = \sqrt{\frac{2000 (660)^2}{32}} = 5,210 \) feet or 0.862 nautical mile

This provides a bomb flight path of approximately 5,300 feet from the bomb release point to the target.

Hit Probability Considerations: Assuming that the errors are gaussian in two dimensions around the target, it can be shown that the probability of a projectile falling within a circle of radius \( \bar{x} \) is

\[ P = \frac{1}{\pi^2} \int_0^\infty r e^{-\frac{r^2}{2\sigma^2}} dr = 1 - e^{-\frac{\bar{x}^2}{2\sigma^2}} \]

This can be written \( P = 1 - e^{-B} \)

where \( B = \frac{(\bar{x})^2 \times 10^6}{2R^2 M^2} = \frac{\text{A} \times 10^6}{2\pi R^2} = 9.9 \times 10^6 \)

and \( A \) is the target area (or projectile-damage area, whichever is larger) in feet\(^2\).

\( R \) is the range to the target in feet and \( M \) is the dispersion of the system in mils, defined so that 40 per cent of the missiles fall inside a circle of radius \( \bar{\sigma} = MR \) centered at the aiming point.

\( P \) then gives the probability of a projectile hitting within a circle of area \( A \).
For the above case, the following data apply:

\[
\begin{align*}
R &= 5,300 \text{ feet} \\
M &= 20,10,5 \text{ mils} \\
A &= 1.3 \times 10^4; 7,400; 7,250 \text{ feet}^2
\end{align*}
\]

respectively for Napalm, "Frag Cluster" and Frag bombs and for \( E = 1 \).

Table I gives values of \( P \) for these data.

The probability of one or more hits from \( N \) missiles is

\[
P_{1+} = 1 - e^{-NB}
\]

where \( B \) is defined as above. From this expression, one can calculate \( N \) for \( P_{1+} = 0.5 \) and 0.85 and the weight of bombs corresponding to \( N \). These data are given in Table IIA and IIB.

For an extended target, such as a train or a long convoy, (i.e. \( 1 \pm 1/2 \) miles) the hit probabilities are appreciably larger. Consider the probability of a hit with one missile:

\[
P_{1/1} = \frac{2}{\pi} \int_{0}^{Y} e^{-\frac{y^2}{2\rho^2}} dy \int_{0}^{W} e^{-\frac{w^2}{2\rho^2}} dw
\]

where \( Y \) and \( W \) are rectangular coordinates, and \( \rho \) is the radius of a circle enclosing 40 per cent of the hits centered about the aiming point. Here \( W \) can be considered to be along the target and any train or convoy over 1,000 feet long is essentially infinite.
TABLE II A

Number of missiles, and corresponding total weight, necessary to give a 0.5 probability of hit by one or more of the N missiles.

<table>
<thead>
<tr>
<th>Size and Kind of Bomb</th>
<th>( \frac{P_{1+}}{N} = 0.5 ) and ( E = 1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 mil system</td>
</tr>
<tr>
<td>No. of Bombs</td>
<td>Total wt. of Bombs</td>
</tr>
<tr>
<td>20 lb. Frag</td>
<td>92</td>
</tr>
<tr>
<td>100 lb. Frag</td>
<td>23</td>
</tr>
<tr>
<td>260 lb. Frag</td>
<td>18.5</td>
</tr>
<tr>
<td>500 lb. Frag</td>
<td>8.5</td>
</tr>
<tr>
<td>750 lb. Frag</td>
<td>6.7</td>
</tr>
<tr>
<td>750 lb. Frag Cluster</td>
<td>6.5</td>
</tr>
<tr>
<td>750 lb. Napalm</td>
<td>3.8</td>
</tr>
</tbody>
</table>

TABLE II B

Number of missiles, and corresponding weight, necessary to give 0.85 probability of hit by one or more of the N missiles.

<table>
<thead>
<tr>
<th>Size and Kind of Bomb</th>
<th>( \frac{P_{1+}}{N} = 0.85 ) and ( E = 1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 mil system</td>
</tr>
<tr>
<td>No. of Bombs</td>
<td>Total wt. of Bombs</td>
</tr>
<tr>
<td>20 lb. Frag</td>
<td>254</td>
</tr>
<tr>
<td>100 lb. Frag</td>
<td>65</td>
</tr>
<tr>
<td>260 lb. Frag</td>
<td>50</td>
</tr>
<tr>
<td>500 lb. Frag</td>
<td>23</td>
</tr>
<tr>
<td>750 lb. Frag</td>
<td>18.6</td>
</tr>
<tr>
<td>750 lb. Frag Cluster</td>
<td>18</td>
</tr>
<tr>
<td>750 lb. Napalm</td>
<td>10.5</td>
</tr>
</tbody>
</table>
Integrating \( W \) from \(- \infty \) to \( + \infty \) gives:

\[
P_{1/1} = \frac{\sqrt{2}}{2 \sqrt{\pi}} \int_{0}^{\infty} e^{-y^2} \, dy = \frac{2}{\sqrt{\pi}} \int_{0}^{\infty} e^{-z^2} \, dz
\]

where

\[
z = \frac{y}{\sqrt{2} \sigma} = \frac{1 \times 10^3}{\sqrt{2} \, RM} \quad \frac{3.16 \ (10^3) \ W^{0.36}}{\ RM \ E^{0.4}}
\]

This follows from the fact that \( \rho = RM \) and \( y = \bar{y} \) as defined above.

One may now calculate \( z \) and look up \( P_{1/1} \) in appropriate tables.

Moreover, for \( N \) missiles

\[
P_0/1 = 1 - P_{1/1}
\]

and

\[
P_0/N = 1 - P_{1+/N} = (1 - P_{1/1})^N
\]

so

\[
N = \frac{\log (1 - P_{1+/N})}{\log (1 - P_{1/1})}
\]

Data calculated in this way is shown graphically in Figures 4 and 6 and "All Weather Tactical Operations" by Dr. Andrew Longacre.

**Conditions For Toss Bombing**

It is considered here that toss bombing will take place on "pull out" from a level bombing run.
Then \( x = \frac{v^2}{g} \cos \alpha \left[ \sin \alpha + \sqrt{\sin^2 \alpha + \frac{2gh}{v^2}} \right] \)

and \( \frac{dx}{d\alpha} = \frac{v^2}{g} \left\{ \cos 2\alpha + \sin \alpha \left[ \frac{\cos 2\alpha - \frac{2gh}{v^2}}{\sqrt{\sin^2 \alpha + \frac{2gh}{v^2}}} \right] \right\} \)

or \( \frac{dx}{d\alpha} = \frac{v^2}{g} A \)

for \( \alpha = 0 \) \( x = \sqrt{\frac{2h}{g} v^2} \)

and \( \frac{dx}{d\alpha} = \frac{v^2}{g} A \)

This means that the dispersion increases with \( v^2 \) (for level or toss bombing) so that the bombing plane should not have too high a speed during the bombing run.

Furthermore:

\[ h = h_0 + \bar{F} (1 - \cos \alpha) \]

Table III gives values of \( x, h, \) and \( A \) calculated from

\[ \frac{dx}{d\alpha} = A \frac{v^2}{g} = A (1.36 \times 10^4) \text{ feet per radian}. \]
TABLE III

\[ \frac{v^2}{g} = 1.36 \times 10^4 \text{ ft.} \]

\[ h_0 = 1,000 \text{ ft.} \]

\[ \frac{v^2}{2} = 43.5 \times 10^4 \text{ ft}^2/\text{sec}^2 \]

\[ \bar{f} = 12,700 \text{ ft. for } G = 2 \]

\[ \frac{dx}{da} = A \times 1.36 \times 10^4 \]

where \( A \) is given in column below.

<table>
<thead>
<tr>
<th>( \alpha )</th>
<th>( h )</th>
<th>( \frac{2gh}{v^2} )</th>
<th>( X )</th>
<th>( L = \bar{f} \sin \alpha )</th>
<th>( X + L )</th>
<th>( A )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>1,000 ft.</td>
<td>.147</td>
<td>5,210 ft.</td>
<td>0 ft.</td>
<td>5,210 ft.</td>
<td>1.0</td>
</tr>
<tr>
<td>1°</td>
<td>1,002.5 ft.</td>
<td>.147</td>
<td>5,445 ft.</td>
<td>222 ft.</td>
<td>5,667 ft.</td>
<td>1.0275</td>
</tr>
<tr>
<td>2°</td>
<td>1,007.6 ft.</td>
<td>.148</td>
<td>5,715 ft.</td>
<td>443 ft.</td>
<td>6,158 ft.</td>
<td>1.0736</td>
</tr>
<tr>
<td>3°</td>
<td>1,017.8 ft.</td>
<td>.150</td>
<td>6,012 ft.</td>
<td>664 ft.</td>
<td>6,676 ft.</td>
<td>1.107</td>
</tr>
<tr>
<td>4°</td>
<td>1,030.5 ft.</td>
<td>.152</td>
<td>6,325 ft.</td>
<td>887 ft.</td>
<td>7,212 ft.</td>
<td>1.138</td>
</tr>
<tr>
<td>5°</td>
<td>1,048.3 ft.</td>
<td>.154</td>
<td>6,630 ft.</td>
<td>1,107 ft.</td>
<td>7,737 ft.</td>
<td>1.170</td>
</tr>
<tr>
<td>6°</td>
<td>1,070 ft.</td>
<td>.157</td>
<td>6,960 ft.</td>
<td>1,327 ft.</td>
<td>8,287 ft.</td>
<td>1.187</td>
</tr>
<tr>
<td>7°</td>
<td>1,095 ft.</td>
<td>.161</td>
<td>7,300 ft.</td>
<td>1,548 ft.</td>
<td>8,848 ft.</td>
<td>1.204</td>
</tr>
<tr>
<td>8°</td>
<td>1,123 ft.</td>
<td>.165</td>
<td>7,660 ft.</td>
<td>1,766 ft.</td>
<td>9,426 ft.</td>
<td>1.218</td>
</tr>
<tr>
<td>9°</td>
<td>1,156 ft.</td>
<td>.170</td>
<td>8,025 ft.</td>
<td>1,986 ft.</td>
<td>10,011 ft.</td>
<td>1.229</td>
</tr>
<tr>
<td>10°</td>
<td>1,193 ft.</td>
<td>.175</td>
<td>8,390 ft.</td>
<td>2,205 ft.</td>
<td>10,595 ft.</td>
<td>1.232</td>
</tr>
<tr>
<td>45°</td>
<td>10,000 ft.</td>
<td>1.472</td>
<td>20,300 ft.</td>
<td>8,980 ft.</td>
<td>29,280 ft.</td>
<td>.738</td>
</tr>
<tr>
<td>90°</td>
<td>13,700 ft.</td>
<td>1.945</td>
<td>0 ft.</td>
<td>12,700 ft.</td>
<td>12,700 ft.</td>
<td>0.715</td>
</tr>
</tbody>
</table>
Appendix II

Figure 1 gives a plot of $x$ and $A$ versus $\alpha$.

$r$, the radius of "pull-out" has been taken as 12,700 feet. This is the average $r$ for $G = 2$ and for $V = \text{constant} = 660$ feet per second. It is based on the following simple derivation.

Assume $V$ constant

Then $F = \frac{mv^2}{r} + mg \cos \omega$

Let $G = \frac{F}{mg} = \frac{v^2}{gr} + \cos \omega$

Then $r = \frac{v^2}{g(G - \cos \omega)}$

Thus $r$ varies with $G$ and $\omega$. Since "pull-out," in general, will occur between $\omega = \pm 30$ degrees an average value of $r$, over this region will be accurate enough.

Table IV gives values of the "pull-out" radius, in units of $\frac{v^2}{g}$. Figure 2 shows a plot of these data. Values for $r$ were taken from the data given by the graph in Figure 2.

**TABLE IV**

Values of the "Pull-Out" Radius in Units of $\frac{v^2}{g}$

<table>
<thead>
<tr>
<th>$G$</th>
<th>1.5</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>2.000</td>
<td>1.000</td>
<td>.500</td>
<td>.333</td>
</tr>
<tr>
<td>30°</td>
<td>1.36</td>
<td>.882</td>
<td>.468</td>
<td>.319</td>
</tr>
<tr>
<td>60°</td>
<td>1.00</td>
<td>.666</td>
<td>.400</td>
<td>.285</td>
</tr>
<tr>
<td>90°</td>
<td>.666</td>
<td>.500</td>
<td>.333</td>
<td>.250</td>
</tr>
<tr>
<td>120°</td>
<td>.500</td>
<td>.400</td>
<td>.286</td>
<td>.222</td>
</tr>
<tr>
<td>150°</td>
<td>.413</td>
<td>.348</td>
<td>.258</td>
<td>.206</td>
</tr>
<tr>
<td>180°</td>
<td>.400</td>
<td>.333</td>
<td>.250</td>
<td>.200</td>
</tr>
</tbody>
</table>
Conclusions On Toss-Bombing

From the data in Table III and Figure 1, it is seen that toss bombing, as here described, will be less accurate than level bombing. There are two reasons, 1) the range is greater, 2) the angular dispersion increases with angle. The only advantage to toss bombing is the increased time it allows the pilot in which to get away from the bomb explosion or explosion set off by the bomb.

Moreover, any accidental up or down draft will give a vertical component to the plane's velocity which will increase da materially. This will apply both to level and toss bombing.

Tables V and VI give the hit probability, P, for $a = 5^\circ$ and $a = 10^\circ$. Comparing these values with those in Table I, shows that (at least in a relative way) the accuracy for toss bombing is considerably less than that for level bombing. For $a = 5^\circ$, the probabilities are roughly $1/2$ of those for level bombing and for $a = 10^\circ$ about $1/3$ of those for level bombing.

In making the calculations given in Tables V and VI, R was taken $= \sqrt{h^2 + x^2}$ from Table III. The bomb flight path is somewhat larger than this and thus these represent the maximum probabilities under these conditions.
Appendix II

Data for Table V

Range (for \( \alpha = 5^\circ \)) = 6,720 ft.
\[ M \text{ (for } \alpha = 5^\circ ) = 20 \text{A} = 23.4 \text{ mils} \]
\[ 10 \text{A} = 11.7 \text{ mils} \]
\[ 5 \text{A} = 5.85 \text{ mils} \]
\[ \alpha = 1.17 \]

Data for Table VI

\[ R \text{ (for } \alpha = 10^\circ ) = 8,470 \text{ ft.} \]
\[ M \text{ (for } \alpha = 10^\circ ) = 20 \text{A} = 24.6 \text{ mils} \]
\[ 10 \text{A} = 12.3 \text{ mils} \]
\[ 5 \text{A} = 6.2 \text{ mils} \]
\[ \alpha = 1.23 \]

### TABLE V

Hit Probabilities for Toss-Bombing with \( \alpha = 5^\circ \)

<table>
<thead>
<tr>
<th>Size and Kind of Bomb</th>
<th>Bomb Damage Area</th>
<th>Values of ( P (\alpha = 5^\circ) )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>23.4</td>
</tr>
<tr>
<td>Napalm</td>
<td>13,000 ft.(^2)</td>
<td>.081</td>
</tr>
<tr>
<td>750 lb. Frag</td>
<td>7,400 ft.(^2)</td>
<td>.044</td>
</tr>
<tr>
<td>Clusters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 lb. Frag</td>
<td>5,800 ft.(^2)</td>
<td>.037</td>
</tr>
</tbody>
</table>

### TABLE VI

Hit Probabilities for Toss-Bombing with \( \alpha = 10^\circ \)

<table>
<thead>
<tr>
<th>Size and Kind of Bomb</th>
<th>Bomb Damage Area</th>
<th>Values of ( P (\alpha = 10^\circ) )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>24.6</td>
</tr>
<tr>
<td>Napalm</td>
<td>13,000 ft.(^2)</td>
<td>.046</td>
</tr>
<tr>
<td>750 lb. Frag</td>
<td>7,400 ft.(^2)</td>
<td>.027</td>
</tr>
<tr>
<td>Clusters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 lb. Frag</td>
<td>5,800 ft.(^2)</td>
<td>.021</td>
</tr>
</tbody>
</table>
Retro-Bombing

This is a system where the bomb or rocket is fired in a direction opposite to that of the plane's motion when the plane is vertically over the target. Then, ideally, if the rocket or bomb, instantaneously receives a velocity \( -V_p \), the bomb will drop vertically to the target. Allegedly, this gave good results against submarines in War II from altitudes 100 to 200 feet and plane velocities of approximately 100 miles per hour. (146.5 ft/sec.)

Consider what happens at \( V_p = 660 \) feet per second and \( h_0 = 1,000 \) feet.

Let \( a \) = acceleration of bomb during firing (or rocket during burning),

\[ t_b = \text{burning time (or firing time)} \]

\[ t_f = \text{time of fall after burning} \]

\[ D = \text{distance plane goes in } t_b \]

\[ D_b = \text{distance rocket goes in } t_b \]
Appendix II

\[ \Delta D = \text{distance between firing point and bomb after } t_b \]

\[ t = t_b + t_f = \text{total time of fall} \]

Then:

\[ x = D - D_b - \Delta D \]

\[ = V_p t_b - \frac{1}{2} (at_b^2) - (at_b - V_p) t_f \]

= horizontal distance of the bomb from target, assuming ejection, or firing, when vertically over the target.

We wish \( x = 0 \).

This will occur for \( (at_b - V_p) \approx 0 \) but nearly = 0 since \( t_b \neq 0 \).

It follows that

\[ \frac{t_b + t_f}{t_b + 2t_f} = \frac{2t}{2t - t_b} = \frac{V_b}{V_p} \approx 1 \]

Thus \( t_b \) must \( \to 0 \)

i.e. as \( \frac{V_b}{V_p} \to 1 \)

For our conditions \( t = \sqrt{\frac{2h}{g}} = 7.9 \) sec.

Table VII gives the several important constants for various values of \( t_b \).

also

\[ \frac{dx}{dt_b} = V_p - a(t_b + t_f) \] \hspace{1cm} (a)

\[ \frac{dx}{dt_f} = t_b + t_f \] \hspace{1cm} (b)

\[ \frac{dx}{dV_p} = (V_p - at_b) \] \hspace{1cm} (c)

Thus, the accuracy will depend on the constancy of \( V_p, t_b, \) and \( t_f \).
TABLE VII

Pertinent constants for retro-bombing and for various assumed values of \( t_b \)

<table>
<thead>
<tr>
<th>( t_b ) sec</th>
<th>Burnt Vel. ( V_b )</th>
<th>Acceleration During Burning ( a )</th>
<th>Distance Plane Goes in ( t_b ) ( D )</th>
<th>Distance Projectile Goes in ( t_b ) ( D_b )</th>
<th>( \Delta D=D-D_b )</th>
<th>( \frac{V_b}{V_p} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/32</td>
<td>661 ft/sec.</td>
<td>21,150 ft/sec(^2)</td>
<td>20.62 ft.</td>
<td>10.33 ft.</td>
<td>10.3 ft.</td>
<td>1.002</td>
</tr>
<tr>
<td>1/16</td>
<td>662.5</td>
<td>10,580</td>
<td>41.25</td>
<td>20.7</td>
<td>20.55</td>
<td>1.0045</td>
</tr>
<tr>
<td>1/8</td>
<td>664.5</td>
<td>5,315</td>
<td>82.5</td>
<td>41.5</td>
<td>41</td>
<td>1.0075</td>
</tr>
<tr>
<td>1/4</td>
<td>671</td>
<td>2,682</td>
<td>165</td>
<td>83.8</td>
<td>81.2</td>
<td>1.017</td>
</tr>
<tr>
<td>1/2</td>
<td>682</td>
<td>1,364</td>
<td>330</td>
<td>170.5</td>
<td>159.5</td>
<td>1.033</td>
</tr>
<tr>
<td>1</td>
<td>705</td>
<td>705</td>
<td>660</td>
<td>352</td>
<td>308</td>
<td>1.068</td>
</tr>
<tr>
<td>2</td>
<td>757</td>
<td>378.5</td>
<td>1,320</td>
<td>757</td>
<td>563</td>
<td>1.146</td>
</tr>
<tr>
<td>4</td>
<td>883</td>
<td>221</td>
<td>2,640</td>
<td>1,768</td>
<td>872</td>
<td>1.338</td>
</tr>
</tbody>
</table>
At present, all of these quantities are not very constant or reproducible. Also, present rocket burning-times are of the order of 1/2 second or longer. Moreover, there may be serious stability problems in this kind of rocket or bomb. So, to make a suitable retro-rocket or retro-bomb at present would demand a long time development program. It would be excellent if it existed!

In any case, if and when a suitable retro-bomb or rocket is available, one will need an inertial navigator (or something equivalent) like the North American Aviation MX1688A which is under development and allegedly will give true plane velocities with respect to the ground. This navigator then could control the plane to fly at a constant $V_p$, such that the closing speed to the target appropriately matches $V_b$.

A comparison of the relative errors for low velocity, low altitudes versus high velocity, high altitudes retro-bombing operations can be obtained from the above equations. From these, one can understand the success of the low velocity, low altitude attack or submarines in World War II and the increased difficulty with this kind of operation using high velocity planes.

General Conclusions on Bombing

1) Level bombing seems to be the most accurate and most desirable for the A.W.A.
2) Retro-bombing would be good if a suitable missile were developed.

3) The bombing should be done at approximately an altitude of 1,000 feet above the terrain.

4) The following types of bombs would be expected to be effective against trucks and railroad stock.*
   (a) 750 pound size "Frag Cluster"
   (b) 750 pound Napalm
   (c) 500 pound Frag Bomb

* A similar conclusion is reached in Ballistics Research Laboratory, Report Number 754, May, 1951, "The Effectiveness of Various Weapons Used in Air Attack on Ground Troops".

5) If a method exists or can be developed for dropping many (50 to 100) small bombs at the same time, the armament load of the plane can be reduced and still maintain good hit probabilities (see Table IIA). However, the logistics for large numbers of small bombs may be more difficult than for a smaller number of large bombs. Also loading the aircraft with many small bombs may be more costly in time and manpower.
SECTION II: THE ALL WEATHER ATTACK ROCKET FIRING SYSTEM

For this system, the following approach to the target has been considered.

The plane is flown level at some altitude $H$, until the target appears at some depression angle $\theta_o$, $(\theta_o \approx 10^\circ)$. Then the plane goes into a dive at angle $\theta_o$ until the range, $R_o$, of rocket fire is reached. Thereafter, the plane pulls out on an assumed circular path.

The range, $R$, to the M.T., at any time after firing the rocket and assuming a circular turn out is:

$$R^2 = R_o^2 - 2\bar{r} R_o \sin \omega + 2(\bar{r})^2 (1 - \cos \omega)$$

$$R_{\min} = \sqrt{(\bar{r})^2 + R_o^2 - \bar{r}}$$

and

$$\sin^2 \omega = \frac{R_o^2}{R_o^2 - (\bar{r})^2} \left[ 1 - \frac{\bar{r}}{R_o} \sin 2\omega \right]$$

In general

$$h = h_o + 2 \bar{r} \left[ \sin \omega/2 \right] \left[ \sin \left( \frac{\omega}{2} - \theta_o \right) \right]$$

and for $h_{\min}$, $\omega = \theta_o$

so $h_{\min} = h_o - \bar{r} (1 - \cos \theta_o)$

$$= R_o \sin \theta_o - \bar{r} (1 - \cos \theta_o)$$
Then \( \frac{dh_{\text{min}}}{dt} = -V \sin \theta_0 = \text{constant} = 114.5 \text{ feet/sec} \)
under the conditions given below. This means that for each second delayed reaction time of the pilot on pull out, 115 feet should be subtracted from the \( h_{\text{min}} \) values in Table IX.

From the above equations and with the following assumptions, one calculates the data in Table IX.

Assume \( \theta = 10^\circ \)

\( V_p = 660 \text{ ft/sec} \)

\( R_0 = \text{Range at firing} \)

\( G = \text{Number of g's on pull-out} \)

\( R_0 \sin \theta = h_0 \)

The "squash" included in \( h_{\text{min}} \) in Table IX is that for an F-89-C plane.

**TABLE IX**

Minimum Heights On Pull-Out After Firing At Range

\( R_0, \) and \( \theta_0 = 10^\circ \)

<table>
<thead>
<tr>
<th>( G )</th>
<th>( r ) Average ( R_0 = ) 6000 ft. ( h_0 = 1042 ) ft.</th>
<th>( R_0 = ) 5000 ft. ( h_0 = 870 ) ft.</th>
<th>( R_0 = ) 4000 ft. ( h_0 = 695 ) ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>calc. ( h_{\text{min}} )</td>
<td>( h_{\text{min}} ) including &quot;squash&quot;</td>
<td>calc. ( h_{\text{min}} )</td>
</tr>
<tr>
<td>1.5</td>
<td>21,900 ft.</td>
<td>709 ft.</td>
<td>625 ft.</td>
</tr>
<tr>
<td>2</td>
<td>12,700 ft.</td>
<td>849 ft.</td>
<td>780 ft.</td>
</tr>
<tr>
<td>3</td>
<td>6,520 ft.</td>
<td>943 ft.</td>
<td>910 ft.</td>
</tr>
<tr>
<td>4</td>
<td>4,380 ft.</td>
<td>975 ft.</td>
<td>935 ft.</td>
</tr>
</tbody>
</table>
The calculations indicate that, for safety of plane and crew (blind flying), if 500 feet is the minimum altitude deemed safe and if one second delayed reaction at pull-out is allowed:

\[
R_0 = 5,000 \text{ feet is permissible at } G \geq 2
\]

\[
R_0 = 4,000 \text{ feet is permissible at } G \geq 4
\]

Therefore, \( R_0 = 5,000 \) feet will be assumed (unless another value is indicated) in the following calculations.

**Hit Probability Considerations For Rockets**

System errors (20, 10, 5 mils) the same as for bombs will be used. It will also be assumed that the rocket will be capable of carrying a 50 pound war head. The \( E \) value will be assumed to be \( E = .17 \) at 40 feet radius. Then the damage area \( = \pi R^2 = \pi 40^2 = 5,000 \) feet\(^2\).

Data for rockets, calculated by the same method as for bombs above are given in Table X.

**TABLE X**

| Hit Probabilities for rockets fired from Ranges \( R_0 \) = 5,000 feet and 3,000 feet. |
|------------------|------------------|------------------|------------------|
| \( A \)          | \( M \)          | \( P_{1/1} \) for \( R_0 = 5,000 \) feet | \( P_{1/1} \) for \( R_0 = 3,000 \) feet |
| 5,000 ft.\(^2\) | 20 mils          | .08              | .2               |
|                  | 10 mils          | .27              | .6               |
|                  | 5 mils           | .72              | .97              |
| 5,000 ft.\(^2\) |                  |                   |                   |
As is seen from the data in Table X, a (50 pound war head) HVAR or sidewinder rocket has probabilities of .08; .27 and .72 for a hit with systems of 20, 10, and 5 mil accuracy at a range of 5,000 feet. These are about the same as for one Frag bomb of 500 or 750 pound size except that $E = 0.17$ instead of $E = 1$. But at 3,000 feet range, the probabilities are 0.2, 0.6 and 0.97. Thus rockets like HVAR and Sidewinder at ranges between 3,000 and 4,000 feet can be effective.

However, this does not take into account the IR homing properties of Sidewinder. These, at present, are unknown when homing on railroad engines or trucks is concerned. Inyokern plans (by January, 1953) to make tests of homing by Sidewinders on railroad engines, tanks and trucks.

One Sidewinder weighs about 163 pounds including a 50-pound war head. Thus about three times the weight of rockets needs to be carried by the plane to deliver the same amount of H.E. as for bombs, assuming the system to have the same dispersion.

Calculations show that, if, after launching, Sidewinder picks up a "hot" target at 1,500 to 2,000 feet range, it can maneuver (10 to 20g) to the target. It seems reasonable that even if Sidewinder or a modification of Sidewinder is launched above clouds and later comes out below clouds, it might home on railroad engines and trucks. It is thought
that railroad engines (possibly from a tail approach along the length of the train) would make the "best" target. One must wait for the completion of the tests at Inyokern before one can decide on the desirability of this rocket, i.e., before one knows how much the IR homing will help to correct the errors of a 20 mil system and achieve, hopefully, a 5 mil system.

It must be remembered that the 10° dive approach to the target has the disadvantage of being able to attack only one target (out of a convoy or train) unless one can fire successively along the length of the target on pull out, whereas the level approach allows dropping bombs or firing guns all along the train or convoy.

Glide bombs should be mentioned as a possible type of armament, though at present no suitable armament of this type is known to exist. If they are developed and are suitable for air force tactics, they can be used with this AWA system. Preferably, they should have guidance or homing features in them.

Another mode of rocket delivery, which may be effective and should be mentioned is the possibility of beam riding rockets. Since in this system the radar is locked on the moving target during the attack, a beam riding rocket would follow the radar beam to the target. Very likely, beam riding systems for conical scan beams exist and could be adapted to this system. However,
the accuracy and reliability of such guidance systems has not been investigated.

Likely, a beam-riding-guidance-system for monopulse beams does not exist, and if feasible, would necessitate considerable thought and development.

A final suggestion, is to put a moving-target-homing-guidance-system into the rocket (or bomb). This could be of the same form as that used with the conical scan or the monopulse system. If sub-miniturized, a modification of existing radar-homing-systems for missiles might be made small enough to fit into a 5-inch rocket. Again, such guidance systems have not been examined and little thought has been given to this possibility. It is mentioned only as a suggestion.

SECTION III: THE AWA GUN FIRING SYSTEM

The system here considered is that of flying the plane level at approximately 1,000 feet above the terrain, and firing guns vertically downward or at a fixed depression angle of $\theta_f$. 
Appendix II

Firing guns in this manner at trucks or railroad stock has the advantages of close range and all inherent advantages of gun fire.

To consider this system, make the following assumptions:

a) \( V_p = 660 \text{ ft/sec} \)

b) \( V_b = 3,500 \text{ ft/sec} \)

c) \( \theta_o = 20^\circ (30^\circ) \) (\( \theta_o \) is limited by false moving targets which appear when \( \theta_o \) is too large).

d) \( h = 1,000 \text{ feet} \)

e) The target is a railroad train or a convoy on a straight road and the plane can fly accurately over the target.

The time for the bullet to cover \( h \) is \( t_\perp \)

\[
t_\perp = \frac{h}{V_b \sin \theta_f + \frac{gt_\perp}{2}}
\]

Since \( t_\perp = .4 \text{ sec.} \) and \( V_b \sin \theta_f \approx 1,800 \text{ feet/sec} \) for \( \theta_f \geq 30^\circ \), neglecting \( \frac{gt_\perp}{2} \) will introduce an error of less than 0.5 per cent. For simplicity, this will be done.

Then \( t_\perp = \frac{h}{V_b \sin \theta_f} \)

Also during this time, the projectile goes horizontally a distance = \( d \).

\[
d = (V_p + V_b \cos \theta_f) t_\perp
\]

The horizontal distance, \( x \), to the target at Range \( R_o \) is

\[
x = R_o \cos \theta_o = h \cot \theta_o
\]
Then, \( \Delta t \) (the delay time between the radar signal for "on target" and the firing of the gun) is

\[
\Delta t = \frac{x - d}{V_p} = \frac{h}{V_p} \left[ \cot \theta_o - \cot \theta_f - \frac{V_p}{V_b \sin \theta_f} \right]
\]

For \( \theta_f = 90^\circ \) (vertical firing) this reduces to

\[
\Delta t = \frac{h}{V_p} \left[ \cot \theta_o - \frac{V_p}{V_b} \right]
\]

For this case

\[
t_\perp = \frac{h}{V_b} = .286 \text{ sec.}
\]

\[
R_o = \frac{h}{\sin \theta_o} = 2,925 \text{ feet} \left[ \approx 1,000 \text{ yards} \right]
\]

\[
\Delta t = 3.89 \text{ seconds}
\]

\[
t = t_\perp + \Delta t = 4.17 \text{ seconds}
\]

Thus a computer must keep the plane on the correct course for a time \( \Delta t \) and must fire the guns at proper time.

Some gun characteristics for this system are:

1) High firing rate approximately 100 to 150 rounds per second.

2) High velocity bullet: 3,500 feet per second.

3) Caliber 30 to 40 m.m.

4) Explosive head (.1 to .2 pounds H.E.)

For the immediate future, guns like T45, T171, 302RK or the T110E probably would do.

During the approach to the target, it will be necessary to know \( R \) and \( dR/dt \) so as to get \( V_p \) with respect to the M.T.
Then a suitable computer can automatically fire the guns after the proper delay time $\Delta t$.

**Hit Probability Consideration For Guns**

The same system errors will be assumed as for bombs and rockets. However, now the target area will be the controlling factor since the damage area from bullets is small.

Then, for the case of $\theta_f = 45^\circ$

$$\Delta t = 2.24 \text{ seconds}$$

The Range now is

$$R = h \sqrt{1 + \left[ \frac{v_p}{v_b \sin \theta_f + \cot \theta_f} \right]^2} = 1,615 \text{ feet}$$

Assume

- $h = 1,000 \text{ feet}$
- $A = \text{Area} = 10 \times 20 = 200 \text{ feet}^2$

Calculations give

- $R = 1,018 \text{ feet for } \theta_f = 90^\circ$
- $R = 1,615 \text{ feet for } \theta_f = 45^\circ$
- $R = 1,476 \text{ feet for } \theta_f = 50^\circ$

Table XI gives $P_1/1$ for a single gun under the various conditions given in the table. Most of the guns under consideration will fire three rounds in the length of a vehicle. Table XI also lists the probability of one or more hits out of three shots.
TABLE XI

The probability of a hit from a single shot and for one or more hits from three shots for various values of $\theta_f$ and $R$ are given. The target area is assumed to be 200 square feet.

<table>
<thead>
<tr>
<th>$\theta_f$</th>
<th>Altitude</th>
<th>$R$</th>
<th>mils 20</th>
<th>10</th>
<th>5</th>
<th>20</th>
<th>10</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$P_{1/1}$</td>
<td>$P_{1/1}$</td>
<td>$P_{1/1}$</td>
<td>$P_{1+/3}$</td>
<td>$P_{1+/3}$</td>
<td>$P_{1+/3}$</td>
</tr>
<tr>
<td>45°</td>
<td>1,000 ft.</td>
<td>1,615 ft.</td>
<td>.030</td>
<td>.11</td>
<td>.38</td>
<td>.087</td>
<td>.31</td>
<td>.77</td>
</tr>
<tr>
<td>50°</td>
<td>1,000 ft.</td>
<td>1,475 ft.</td>
<td>.036</td>
<td>.14</td>
<td>.44</td>
<td>.10</td>
<td>.36</td>
<td>.83</td>
</tr>
<tr>
<td>90°</td>
<td>1,000 ft.</td>
<td>1,020 ft.</td>
<td>.074</td>
<td>.26</td>
<td>.70</td>
<td>.20</td>
<td>.60</td>
<td>.97</td>
</tr>
<tr>
<td>90°</td>
<td>500 ft.</td>
<td>509 ft.</td>
<td>.27</td>
<td>.72</td>
<td>.99</td>
<td>.62</td>
<td>.97</td>
<td>.99+</td>
</tr>
</tbody>
</table>
These probabilities for guns are smaller than those in Table I for bombs (500 and 750 pound frag bombs), but not more than a factor of two or so. This is readily compensated by the rapid fire of the guns and thus the gun system should be effective with vertical fire. The system with \( \Theta_f = 45^\circ \) has a smaller probability than the system with \( \Theta_f = 90^\circ \) by about a factor of two and thus is less desirable than the vertical firing system.

Flying at an altitude of 500 feet would materially improve the hit probabilities of this system. See Table XI.

There will be some difficulty in flying the plane exactly over the target, i.e., the road. To minimize this error, four (or more) guns can be hung in the plane with angles between the bore sight lines of the guns of approximately six to ten mils and placed perpendicular to the flight axis. This assures that with reasonable stability of the plane and reasonably accurate navigation at least one gun will point at the target on the road.

**Flexible Gun System**

Next consider a system of flexible guns. Servo the guns to the radar antenna through a computer and aim by tracking the M.T. to about \( \Theta_o = 30^\circ \). Under these circumstances \( R = R_o \) in the figure on page 26 and

\[
w = Q \cos \Theta_f = h \cot \Theta_f
\]
\[ y = \frac{V_p h}{V_b \sin \theta_f} \]
\[ D = w + y = h \left( \cot \theta_f + \frac{V_p}{V_b \sin \theta_f} \right) \]
\[ R = R_0 = \sqrt{h^2 + D^2} \]

and from the law of sines
\[ \frac{R_0}{\sin \theta_f} = \frac{h V_p}{[V_b \sin \theta_f] \sin (\theta_f - \theta_o)} \]

Calculations give:

\[
\begin{array}{ccc}
\theta_f & \theta_o & R_0 = R \\
35^\circ & 28^\circ 30' & 1664 \\
45^\circ & 38^\circ 17' & 1615 \\
\end{array}
\]

Next, ask what M is necessary for range tracking to \( \theta_o \approx 30^\circ \) incorporating gun servos to follow the target with radar (i.e. flexible guns) to get the same accuracy as given by vertical firing from 1,000 feet altitude and a 20 mil system. Assume the same target area (200 feet²).

Then:
\[ R_1^2 M_1^2 = R_2^2 M_2^2 \]

So
\[ 1000^2 (20)^2 = 1660^2 M_2^2 \]

and
\[ M_2 = 12 \text{ mils} \]

For comparison with other data see Table XI.

Thus, if a 20 mil system can be improved to a 12 mil system by servoing the guns to the radar tracking antenna, this will be at least as effective as the vertical firing system. One might conceivably get a
5 mil system. What the cost would be, in additional weight necessary for the installations of a flexible gun mount and servos, and how feasible this is, is not known at present. It should be considered in more detail.

**Comments On Armament Load For AWA Plane**

**Bombs:** Carry at least 2 bombs of the Frag Bomb, Frag Cluster or Napalm type. Weight 700 to 1,500 pounds.

**Rockets:** 2 HVAR or Sidewinders (approximately 165 pounds each) 330 pounds.

**Guns:** 2 or 4 guns of something like the following types (See Gun-Val)

<table>
<thead>
<tr>
<th>Type of Gun</th>
<th>Number of Rounds/Gun</th>
<th>Total Installed Weight Of Gun And Ammunition</th>
</tr>
</thead>
<tbody>
<tr>
<td>T45</td>
<td>1000</td>
<td>2588/2 guns (5176 lbs./4 guns)</td>
</tr>
<tr>
<td>T171</td>
<td>1000</td>
<td>2720/2 guns (5440 lbs./4 guns)</td>
</tr>
<tr>
<td>T110E</td>
<td>25</td>
<td>1880/2 guns (3760 lbs./4 guns)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1400/2 guns--Future)</td>
</tr>
<tr>
<td>302RK</td>
<td>100</td>
<td>1400/2 guns (2800 lbs./4 guns)</td>
</tr>
</tbody>
</table>

Average total estimated weight of guns and ammunition =
3000 to 5000 lbs./4 guns
1500 to 2500 lbs./2 guns

With 2 bombs, 2 rockets and 2 guns, one could attack three targets (trains or convoys) per mission and the total weight of armament could be:
Possible Minimum Maximum Weight

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>One Napalm or Frag Bomb</td>
<td>750 lbs.</td>
<td>One Napalm</td>
<td>750 lbs.</td>
</tr>
<tr>
<td>One Frag Cluster</td>
<td>350 lbs.</td>
<td>Two Frag Clusters</td>
<td>700 lbs.</td>
</tr>
<tr>
<td>Two HVAR or Sidewinder Rockets</td>
<td>330 lbs.</td>
<td>Four HVAR</td>
<td>600 lbs.</td>
</tr>
<tr>
<td>Two guns with ammunition</td>
<td>1400 lbs.</td>
<td>Four guns</td>
<td>5200 lbs.</td>
</tr>
<tr>
<td>installed</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total typical armament load 3000 pounds to 7000 pounds.

Comments On AWA Plane Characteristics

(1) Speed: The plane should be capable of high speed (about 600 knots) at high altitude (altitude ≥ 30,000 feet) to get into the area where M.T. search is desired.

The plane should be capable of low to medium speed (300 to 400 knots) at low altitude (500 to 4,000 feet) which will be used for searching for M.T. in the area.

(2) Flight Time: Estimated three to four hours for a complete mission.

(3) Stability: All possible means and devices should be used to make the plane a stable platform at low altitudes, e.g., Yaw dampers or synthetic Yaw damping to improve Yaw stability are necessary.
(4) A two engine, two man plane is recommended so that the nose is available for electronic gear and so that adequate man power for the operation of electronic gear is available.

Comments On Estimated Load and Plane Size:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic gear:</td>
<td>800 pounds</td>
<td>900 pounds</td>
</tr>
<tr>
<td>Armament:</td>
<td>3,000 pounds</td>
<td>5,000 pounds</td>
</tr>
<tr>
<td>2 Men:</td>
<td>1,200 pounds</td>
<td>1,200 pounds</td>
</tr>
<tr>
<td>Total Useful Load</td>
<td>5,000 pounds</td>
<td>7,100 pounds</td>
</tr>
</tbody>
</table>

Assuming Shatz's figure of 7 pounds of airplane/pound of useful load at velocity = .6M (which \( \approx \) 660 ft./sec.), one gets the weight of the plane to be between 40,000 and 50,000 pounds. However, it is understood that the F2H3 has a weight of 17,000 pounds, carries 7,000 pounds of armament, and has a range of 650 miles radius with a speed of 0.9M. Thus, it seems feasible that a plane similar to the F2H3 would be suitable if the permissible G were approximately 6 and if the required space for electronic gear and armament load were available.

Acknowledgments

In addition to those sources of information given in Appendix IV, we wish to acknowledge the helpful discussions of others in the Butterfly Group of the Control Systems Laboratory and especially those of Dr. Andrew Longacre.
## Comments on Electronic Gear for AWA Plane

<table>
<thead>
<tr>
<th>Component</th>
<th>Present Weight</th>
<th>Volume Cubic Feet</th>
<th>Estimated Future Weight</th>
<th>Estimated Future Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Navigation and Search Radar</td>
<td>500 lbs.</td>
<td>45</td>
<td>500 - 600 lbs.</td>
<td>50</td>
</tr>
<tr>
<td>(b) Fire Control Computer</td>
<td>90 lbs.</td>
<td>25</td>
<td>500 - 600 lbs.</td>
<td>50</td>
</tr>
<tr>
<td>(c) Fire Control Radar</td>
<td>365 lbs.</td>
<td>25</td>
<td>500 - 600 lbs.</td>
<td>50</td>
</tr>
<tr>
<td>(d) Autonavigator*</td>
<td>300 lbs.</td>
<td>5 - 10</td>
<td>150 - 200 lbs.</td>
<td>5</td>
</tr>
<tr>
<td>(e) Radio Altimeter</td>
<td>25 lbs.</td>
<td>1.5</td>
<td>130 lbs.</td>
<td>5</td>
</tr>
<tr>
<td>(f) UHF Radio</td>
<td>90 lbs.</td>
<td>2</td>
<td>130 lbs.</td>
<td>5</td>
</tr>
<tr>
<td>(g) IFF</td>
<td>45 lbs.</td>
<td>2</td>
<td>130 lbs.</td>
<td>5</td>
</tr>
<tr>
<td>(h) Alternator</td>
<td>70 lbs.</td>
<td>4</td>
<td>50 lbs.</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>1,485 lbs.</td>
<td>84 - 89</td>
<td>830 - 980 lbs.</td>
<td></td>
</tr>
</tbody>
</table>

* At this time, the North American Aviation autonavigator equipment seems to be the only good equipment (from the standpoint of low weight, passive operation and accuracy) likely to be available in two or three years. Its development and production should be accelerated!
Figure 1 shows $x$, the horizontal distance from the point of release of the bomb to the moving target, plotted against $\alpha$, where $\alpha$ is the angle which the plane's axis makes with horizontal at the time of the release of the toss-bomb. On the right side of Figure 1 is given the scale for values of $A$ from the equation

$$\frac{dx}{d\alpha} = A \times 1.36 \times 10^4 \text{ feet/radian}. $$

The curve showing $A$ versus $\alpha$ indicates the increased error for toss bombing as $\alpha$ increases.
Figure 1

$\frac{dx}{d\alpha} = A \times 1.36 \times 10^4$

$\alpha$, the angle between the horizontal & the planes axis at time of release of the toss bomb
Figure 2 shows curves giving the "pull out" radius for values of $\omega$ from $-120^\circ$ to $+120^\circ$ and for $G = 1.5$, 2, 3, and 4. These are calculated from the simple assumptions given in the text. The average values of the radius, $\bar{r}$, over $\omega = \pm 30^\circ$ are indicated. These values of $\bar{r}$ are used in later calculations.
Average Radius over $\theta = \pm 30^\circ$ for $G = 1.5 = 1.6 \frac{V^2}{g}$

- $G = 2 = 0.925 \frac{V^2}{g}$
- $G = 3 = 0.475 \frac{V^2}{g}$
- $G = 4 = 0.320 \frac{V^2}{g}$

**Figure 2**

Radius on circular, vertical plane pull out

- $0.25$
- $0.50$
- $1.0$
- $1.5$
- $1.75$

The angle between the horizontal & the planes axis at start of pull out.
The purpose of this trip was to get recent information on navigational devices suitable for the Night Interdiction Airplane. I first talked to John Keto, Technical Director of the Division, to see what equipment he had under development to satisfy our requirements, which were stated as:

1) accuracy, 2 per cent of distance traveled
2) range, at least 500 miles
3) altitude, 60,000 down to 5,000 feet (below line of sight from friendly territory)
4) weight, less than 250 pounds

Mr. Keto had no suggestions beyond the two that had occurred to us already, namely, inertial systems and Doppler radar. A couple of other ideas emerged in talking to C and N people, however.

To investigate inertial systems, I saw Dr. S. M. Burka, who is their specialist on the subject. Their most hopeful development is a development contract with North American Aviation Company, MX 1688A. This is an inertial navigator designed for fighters, having an operating circle of 750 miles radius (maximum range 1,500 miles if "home" is at one edge of the chosen circle). The expected accuracy is stated as:

<table>
<thead>
<tr>
<th>hours</th>
<th>1</th>
<th>2</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>miles accuracy</td>
<td>2</td>
<td>5</td>
<td>15</td>
</tr>
</tbody>
</table>
The equipment gives present position indication and also provides error signals to an autopilot, to fly the airplane to a given destination. The weight is about 200 pounds, and the volume is about a 30-inch diameter sphere. Sufficient redundant gyros are used that there is no limit to the plane’s maneuvers.

Technically, this system operates as follows: two linear integrating accelerometers are mounted at right angles to each other on a gyro-stabilized table; their outputs giving directly the x- and y- components of distance traveled. Small corrections are made for the error introduced by using a table whose axes remain fixed in space, instead of tilting as one follows the curved surface of the earth. This latter feature is what limits the range of the system.

The time scale they hope for is as follows: Engineering Model to be finished in 1953, Production Prototype in 1957. Neither Burka nor Keto were willing to recommend this set to be used in a plane to be in production in 1957.

The Spire system being developed by Draper operates by sensing the local direction of gravity, and comparing this to a gyro whose axes are fixed in space. This tells how far around the earth you have gone. It uses no accelerometers. This is a very bulky system suitable only
for heavy bombers. Draper has made a "paper study" of a system adapting his components to a fighter, but it does not look hopeful. (Burka) There is no such development being carried out.

For the Doppler Radar Systems, I then saw H. J. Rosenberg in the "Advanced Development" branch of the C and N Laboratory. The APN-66 Doppler navigator is scheduled to have 12 production prototype models in November, 1952. Engineering models are actually showing an accuracy of one mile plus 0.9 per cent of distance traveled. This equipment is for bombers only.

The APN-82 is considered only to be an interim solution to the problem for a fighter navigator; it uses the radar component from the APN-66 plus a simplified computer which gives present position only to 2 per cent (but not referenced to a target). It has restrictions on the plane's maneuvers, which for a fighter are serious.

The APN-79 is their ultimate fighter navigator, which is in a study phase at present. It is supposed to give 2 per cent accuracy and weigh 150 pounds, using a smaller antenna system than APN-66, and allowing more freedom to maneuver. They hope for a production prototype in early 1955, and they are willing to recommend its incorporation into a plane to be produced in 1957. (It seems to me that they have a good basis for planning this equipment, in view
of the advanced state of the similar APN-66.) This equipment is being built specifically for the F-84 and RF-84 airplanes.

Mr. Rosenberg told me of an equipment, the APA-58, which would be an attachment to the search radar. It is principally a "dead reckoning" computer for present position based on air speed and compass heading, but it gets wind velocities by having the operator track ground targets on the radar and uses this as a correction. The accuracy is probably not better than 5 per cent, and depends very much on the quality of air speed information. The equipment weighs 60 pounds, and engineering models exist. (Probably not worth our serious consideration).

EVALUATION

Both the North American inertial system and the APN-79 seem hopeful to meet our requirements. The former would be especially useful since its accuracy is high and it uses a completely passive system (undetectable by the enemy). It would be worthwhile to investigate the possibility of accelerating this development for our use.
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SOURCES OF INFORMATION FOR THE AWA SYSTEM

Report Number R-28
Appendix IV

December 1952

CONTROL SYSTEMS LABORATORY
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS
Contract DA-11-022-ORD-721

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SECURITY INFORMATION

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University of California
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